Sea-fastening of Wind Turbine Generators for assembled tower Transportation and Installation

MSc Thesis

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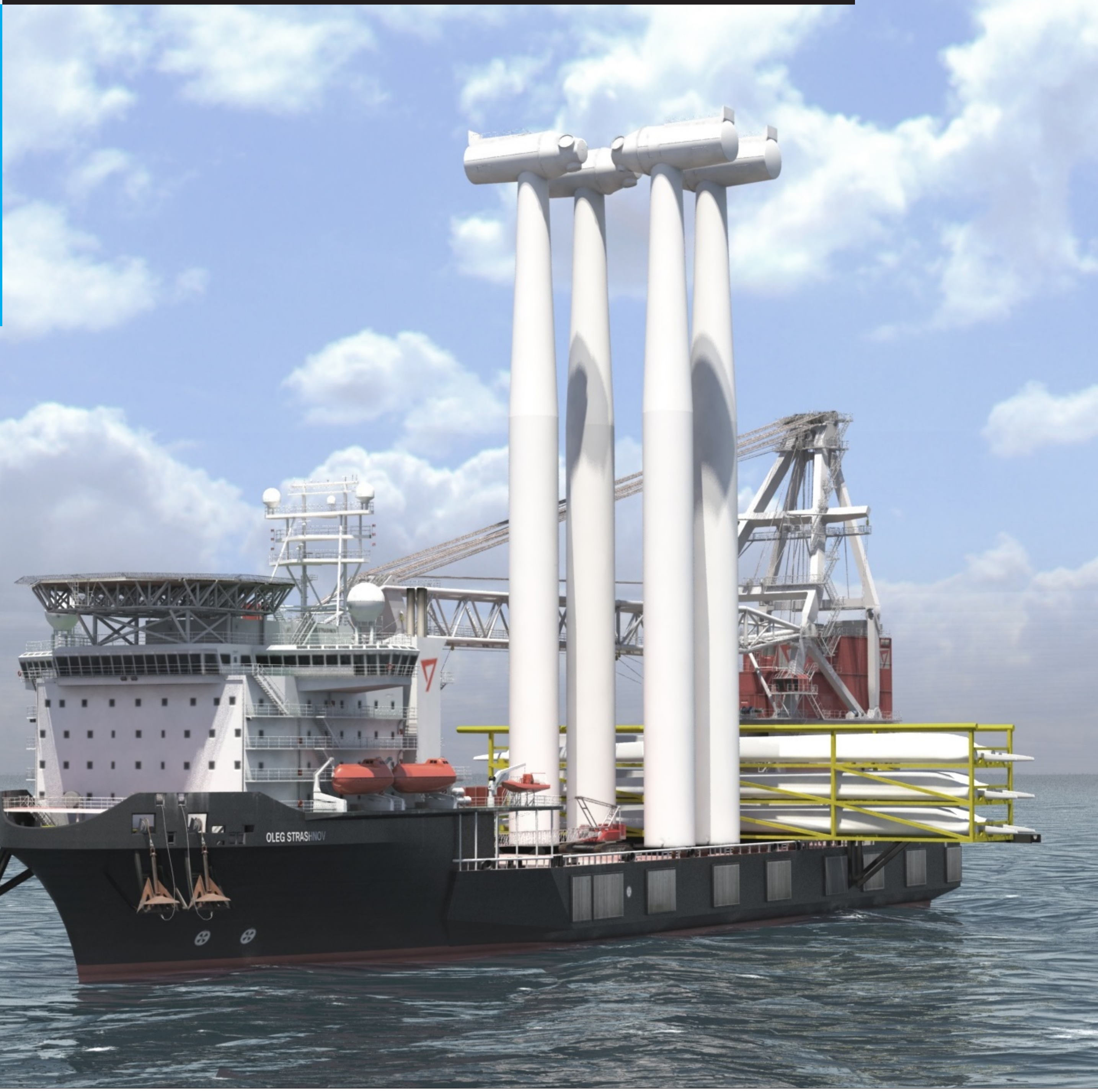

TU Delft Delft University of Technology

Seaway Heavy Lifting

Challenge the future

Sea-fastening of Wind Turbine Generators for assembled tower Transportation and Installation

MSc Thesis

by

Giuseppe Izzo

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Giuseppe Izzo
Delft, October 2014

One day, machines will be able to solve problems, but none of them will be able to set one

Albert Einstein (1879 - 1955)

Abstract

Seaway Heavy Lifting is an offshore contractor, involved in the wind energy market. Nowadays SHL is preparing on expanding T&I capabilities to include WTGs, after the experiences with foundations, platforms and met-masts. The company desires to enter in this market with innovative and highly efficient solutions. In order to achieve this goal, Oleg Strashnov HLV, SHL's flagship, has been selected as the ideal means for this path. Indeed, the potential of such a vessel is seen, by the offshore experts, as possibly being applied to the T&I of WTGs in single pieces, including the nacelle. Current practice is to perform the scope in parts, by means of jack-up vessels, addressing a great amount of the work offshore. Offering an integrated solution would definitely mark a turning point for the market, providing that this new proposal has the economical and efficiency characteristics required. The main challenge for such a proposal, from the structural point of view, is to provide a proper sea-fastening for safe and stable logistical procedures, ensuring structural integrity of both vessel and transported elements. The goal of this thesis is to propose a sea-fastening solution able to meet such requirements.

An articulated and detailed path has been followed, from general to more detailed analyses, in order to reach the proposed objectives. Firstly, the definition of the boundary conditions and company's choices took place, according to the specific needs of the chosen vessel and the solution effectiveness requirements. Current offshore wind energy market situation and trends have been investigated and analysed, in order to find specific WTG designs to use for the study. After the definition of sea state conditions, vessel accelerations have been quantified and the most critical load combination for the WTGs was found. Then, possibilities of sea-fastening arrangements have been analysed, through a conceptual study. In order to deal with the destructive bending moment effects on the WTGs, the concept providing a free moment connection at foundation level has been selected. It was required to provide additional external structures, clamping the WTGs at a certain height, in order to doubly support the transported elements. A parametric study has been carried out to compare the best achievable solution using such a hinged bottom connection, against the best achievable solution adopting a fixed connection. Higher requirements in stiffness, for the external supporting structures, have been found in the case of fixed connection. Among other advantages, important steel savings resulted and it was ensured that final solution did not exceed them. Detailed design has been provided for bottom support, due to its challenges from a structural point of view. Besides rotation, main requirements were vertical and horizontal loads constraint. After a dedicated conceptual analysis, a combination of rubber and steel elements was found to be most effective for the purpose. Linear structural analysis have been carried out, supported by parametric studies. The unusual utilization of rubber for sea-fastening has been analysed and proven to be feasible. Starting from the defined model, additional studies for linear buckling and free vibration analyses followed. Subsequently, focus moved to the intermediate support connection. Where design was less detailed, because of the presence of features more related to mechanical engineering, considerations and suggestions have been proposed. An innovative flexible clamping connection has been designed and proven to be effective; this involved rubber fenders, steel rings and bracings. Finally, the design was carried out for the bottom grillage system, connecting the above sea-fastening to the vessel deck. Practical considerations led to a conservative solution, able to meet the structural integrity requirements and available for further optimisations. Once all the individual parts were designed, adaptation of initial assumptions and solution final assessment were proposed.

With its 8050 tonnes of total weight, such a system is proven to provide safe and efficient T&I activities for six WTGs per voyage. Among the selected models, the ALSTOM 6MW is chosen for the analysis, because of its most onerous configuration. Structural feasibility and integrity are assessed through hand calculations and FEAs. Boundary conditions are all met and effective features are finally pointed out. Because of the choice of taking advantage of flexibility and the unusual application of rubber elements, the final solution demonstrates clear innovative features. According to the initial conditions, such a sea-fastening system provides a solution for extremely critical sea-states, probably unlikely to appear in real operations.

Contents

List of Figures

List of Tables

List of Abbreviations

CHS	-	Circular hollow section
CoA	-	Center of Area
CoG	-	Center of Gravity
DP	-	Dynamic Positioning
FEA	-	Finite Element analysis
FEM	-	Finite Element model
HLV	-	Heavy Lift Vessel
Hs	-	Significant wave height
HSS	-	High strength steel
LCoE	-	Levelized Cost of Energy
MoI	-	Moment of Inertia
OS	-	Oleg Strashnov
OWF	-	Offshore Wind Farm
SHL	-	Seaway Heavy Lifting
T&I	-	Transportation and Installation
TP	-	Transition Piece
WoW	-	Waiting on Weather
WTG	-	Wind Turbine Generator

1
Introduction

Many are stubborn in pursuit of the path
they have chosen, few in pursuit of the goal

Friedrich Nietzsche (1844 - 1900)

Offshore wind market is still at its early stages; the first offshore wind farm was completed in 1991 and from that time the growth has been rapid and constant. Nowadays this situation holds, but a lot of improvements can be done to ensure a positive future trend. The offshore environment is well-known for its critical working features, mainly dependent on the hard and rapidly changeable weather conditions. For this reason, among the total system costs for an offshore wind farm, a significant percentage is occupied by transportation and installation of its main parts. Seeking optimisation is critical in every project execution, therefore logistics appears as a fundamental aspect to be focused on.

Actual practice is to perform the transportation of WTGs in parts, by means of jack-up vessels, addressing a great amount of the work offshore. Offering an integrated tower transportation and installation would definitely mark a turning point for the market, providing that this new proposal has the economical and efficiency characteristic required. Most of the work would be performed onshore, in a safer and more controlled environment. Then assembling of integrated towers would follow on the quay side. Only at this stage offshore activities would start, from the load-out and transportation on the vessel to the installation on site. Time spent offshore would be dramatically decreased and become mainly dependent on travel distance. Of course, the reason why so far none of the actual contractors has ever provided a solution like this can already represents an explication of the many related issues that seem to make it completely unfeasible. To perform this kind of practice, the construction of new and "ad hoc" vessel would be required with consequent re-evaluation of investment cost-benefits.
Eventually, the potentials of current huge HLV, like Oleg Strashnov, have been seen as possibly being addressed to the mentioned scope by offshore experts. The main challenge for such a solution, from the structural point of view, is to provide a proper sea-fastening for safe and stable logistic procedures, ensuring structural integrity of both vessel and transported elements.

This thesis will analyse the problem from its general features to the definition of several possibilities capable to achieve the scope. Then, among all the individuated concepts, one will be selected and studied in detail, in order to inspect his structural feasibility. Calculations according to the offshore design codes will be carried out, helped by the developing of a FE models which will study in depth the structural issues.

1.1. Thesis Goal

The goal of this thesis is to propose a structural solution for sea-fastening of integrated Wind Turbine Generators, over the Oleg Strashnov heavy lift vessel. Such a system has to provide for safe and efficient transportation and installation activities.
The sea-fastening method is not meant to be general but specifically designed and tailored for the mentioned vessel. Then specific boundary conditions arise due to this choice.Furthermore, this solution needs to be economically competitive and applicable to real practical situations.
Therefore background and current practice analysis are fundamental to produce a convenient and innovative alternative. Even though cost investigation is outside the scope, the cost-effectiveness of each choice is always considered, in terms of both material used and involved procedures.
However, all these aspects need to be combined and addressed to the main focus of the study, namely the structural engineering. Dealing with large forces and bending moments, produced by the combination of incredibly high structures and sea-motion, is the challenge, according to this view.

1.2. Thesis Approach

An articulated and detailed path is followed in order to reach the proposed objectives. Firstly, the definition of the boundary conditions, Chapter 1.3. They are mainly due to the specific needs of the chosen vessel and to the solution effectiveness features, required by the company SHL. Then, according to the grade of optimization desired, further boundaries can be applied. Indeed, such a solution needs to be economically competitive and applicable to real practical situations. A possible Offshore Wind Farm location is decided, within the North Sea, together with potential manufacturer's designs for the coming years.

Subsequently, in order to propose any innovative solution, current practice has to be investigated and critically assessed, finding the weak points to work on. Therefore offshore wind energy background is analysed, with focus on common issues and challenges, their field of application and the stakeholders involved in their processes, Chapter 2.

Once the situation is known and the limits are determined, it is possible to proceed with the generation of concepts, Chapter 3. Fundamental at this step is the definition of all the functions involved in the processes, differentiating among the required, desirable or undesirable ones. Through a morphological chart, several options are identified and then combined to produce several conceptual ideas. The main aim is to provide a solution able to transport as more as possible WTGs at the same time. Among them, six concepts are analysed in depth and proposed in detail as possible solutions. Their strengths and weaknesses are underlined to make a clear and understandable comparison for the final selection. A final conceptual solution is selected. It provides a grillage system, covering a large are on the deck, some vertical steel braced structures for external sea-fastening and two flexible connections between them and the WTGs, namely at the bottom level and at an intermediate position below the CoG. These components represent the focus for the next phases.

Then, further phases of work provides the starting of calculation procedures. Firstly, all the general data is gathered and arranged for the defined design situation, Chapter 4. Amongst the data, the vessel accelerations through the analysis of the Naval Department appear to be fundamental information for the study. Choices are made at this stage to define the reference wave height (Hs), mostly affecting parameter for the final induced accelerations. They are applied at the calculated CoG levels of the transported elements. One specific WTG product, among the three selected, gives the most critical scenario and is kept as reference for the calculations. Design actions and governing directions are defined, through combinations of motions.

From the previous qualitative selection, further analyses are provided to precisely define the position of this intermediate support and the structural capacity requirements for the vertical sea-fastening structures, Chapter 5. In order to deal with the destructive bending moment effects on the transported structures, possibility of a free moment connection at WTG foundation level. A parametric study is

carried out to compare the best achievable solution, using such a connection, with the best achievable solution adopting a traditional fixed connection. Indeed, different trends are found to be applicable for the two situations; higher requirements in stiffness are expected in case of fixed connection. It increases by considering lower height for the intermediate support application.
Such analysis provides the stiffness assessment of several steel frame arrangements. Since the requirement is flexibility, a limit for WTGs rotation at the bottom is defined. A comparison is provided between the two lightest and smallest solutions, achievable respectively with a hinged and a fixed connection at the WTG bottom. The advantages in terms of steel savings are kept as limits for the cost effectiveness assessment of the next specific connection designs.

Bottom support appears to be the most challenging component, from a structural engineering point of view. Its analysis is therefore more articulated and carried out through both conceptual and detailed design phases, Chapter 6. Conceptual ideas come from adaptation of already existing support systems, applied onshore. Different material combinations are considered. Main issue is the provision of a certain rotation along the design direction to meet the flexibility requirements previously found. Dimensioning and general structural design is carried out for all the concepts; comparison and selection is made again according to the amount of structural material and special equipment involved. Out of them, the most promising solution is selected and kept for a further analyses.

Detailed design is therefore provided for such a solution, Chapter 7. FEM linear structural analysis is carried out, supported by parametric hand calculations. Besides rotation, main requirements are vertical load bearing and horizontal force constraint. Proper supporting elements are defined. Unusual material for sea-fastening is provided in an innovative arrangement. Therefore detailed analysis are performed to assess its feasibility. Due to the large number of involved parameters, several design steps are involved, to increase the effectiveness of the solution. The procedure firstly focuses on stiffness requirements and then on strength issues.
Starting from the defined model, additional studies are provided. Linear buckling analysis is carried out, both by FEM and hand calculations. Subsequently, free vibration analysis is provided, in order to assess the solution response with respect to the natural frequencies of the vessel during motion, respectively in pitch, roll and heave situations.

Then, the focus moves to the intermediate support connection, Chapter 8. Again, requirements in terms of flexibility are firstly analysed. Only conceptual design is provided, to assess the structural engineering features. The concept defines a steel ring element, to be placed at the external sea-fastening structures height, responsible for the WTG clamping and the load transfer to the external structures themselves. Deformable elements are attached, in order to provide the required deformation Initial dimensioning phase and FEM analysis lead to the selection of the final layout. Starting from these results, transmissions to the vertical structures are studied. They are compared with the assumptions made at the beginning of the analsys and adaptations to the whole model are made in case of different behaviour.

By adopting a new load path, all the sea-fastening elements have to be checked again, in order to have a final proposal for the solution, Chapter 9. Modifications are applied, together with considerations and suggestions. Final solution advantages are adapted and comparison is made for effectiveness considerations. After that, final analyses are made for the grillage, responsible for the load transfer between the complete designed system and the strong positions on the vessel deck. Several considerations are made for the grillage, since its design is provided at a conceptual stage. Structural integrity requirements are checked and suggestions for further optimizations are given. Finally, the total weight of the complete sea-fastening system is computed and compared with the main boundary condition, given by the vessel capacity.

Conclusions, Chapter 10, and recommendations, Chapter 11, complete the design proposal, by giving numerical results, effectiveness assessments and suggestions for further studies.

1.3. Boundary conditions

One of the aims of this thesis is defining a new and optimized structural system for sea-fastening. Optimized means also cost-effective. This can be immediately translated in the necessity of reducing offshore activities. It leads to the first three main demands:

- Limiting offshore labour, in terms of time and difficulty;
- Limiting vessel voyages;
- Carrying as many WTGs as possible per voyage.

As previously mentioned, these features are strictly related to the costs for daily usage of the vessel, which the system is designed for: Oleg Strashnov. Its high capacities, tremendous potential and possible time savings move together with a daily cost for the contractor of about half million Euro and subsequently higher for the client. It is clear now that the just proposed demands are “condicio sine qua non” for any proposal that involves Oleg Strashnov and which wants to be competitive on the market. The boundary conditions to narrow down the project can now be defined. These are independent on external choices and based on vessel limitations and practical requirements. They are first proposed and then explained:

- ability to withstand high forces;
- abiding by the deck footprint;
- abiding by the crane operation radii;
- not exceeding weight limit on deck;
- no welding on WTG;
- necessity of re-utilization.

High force capacity is the key boundary condition from a structural point of view. This main issue comes out from the dimension, weight and position of CoG of the objects to be transported. This is combined to the strong vessel accelerations during T&I phases. From the definition of these actions, the sea-fastening features are defined and then all the other related conditions of the system. At this stage it is required to be conservative and to adopt a certain degree of redundancy. But at the same time it is wise to think about possible reasonable adaptation to the current practice. A right combination between the severe situations expected during navigation and time spent in the process itself has to be taken into account. Due to the high forces acting, in order to limit the sea-fastening oversizing, some expedients from the usual T&I parameters are decided and defined in the final choices.

For WTG transportation the complete deck can be available since no other structures are provided except from sea-fastening. Moreover, the related equipment for installation is limited and does not interfere with the available space on deck. On the other hand, a most important limit is represented by the crane position at rest. This deeply restricts the possible footprint for the WTGs due to their high heights. Then, cradle and main boom rest structures are a further boundary for a possible skidding system running through the deck. Finally, the main requirement for a sea-fastening is to transfer the load from the structure to the strong point of the vessel, identified in the crossings among frames and bulk-heads. Then, a smart disposition on the deck is required to match this demand.

Crane operation radii are defined by capacity and elevation of the auxiliary host number 1, the one selected for this operation. These features change with the operation radius. The operation capacity is chosen according to the WTG weights: then at least 840 tonnes are required. To perform it, crane radii range from 43 m to 72 m. The first is limited due to the required crane clearance. The second is due to the weight capacity required. Finally, the working area for WTG lifting is defined.

The maximum amount of weight the deck can carry is 8500 tonnes. This can be taken in large part by the WTGs but a certain percentage is expected for sea-fastening structures and lifting equipment. It follows that, depending on the nature of sea-fastening system, the number of WTGs can vary. According to their average weight of 800 tonnes, a maximum of 6 WTGs can be defined to assure adequate capacity for the mentioned extra materials. Further specifications are provided in the different concept solutions.

The nature of connections to be made represents another possible limitation. According to the manufacturers' requirements it is not possible to realize welding over the WTGs. Then, for the bottom part of the structure, only bolting or clamping are available, through the thin flange at the basement designed for the connection to the Transition Piece on site. Welding can be done only for connections that do not directly involve the WTGs, e.g. sea-fastening-deck connection.

Re-utilization requirement means that the structures for sea-fastening have to be designed for a long term period. Many voyages need to be executed with the same structures. Fatigue issues have to be investigated in this view, in order to provide sufficient capacity for duration during time. Bolted connections do not completely fit these purposes, since preloaded bolts, once used, are thrown and changed. On the other hand they are more effective then welding in fatigue behaviour. Anyway, even other alternatives will be investigated.

After the definition of these boundary conditions, several further choices are made in order to finally confine the field of study. These have been selected after discussions within the company (SHL) for finding the best solution that can be feasible and realistically competitive for the next years. They are so listed:

- no design changes on WTGs;
- rotor blade involved in a different T&I process;
- focus on actual projects and manufacturers' designs;
- no internal sea-fastening;
- lifting from the top;
- utilization of a new auxiliary hoist.

The first choice refers to the manifested trend for the future of changing the design according to the logistic issues pointed out by offshore contractors. After having been so reluctant towards this view, manufacturers are now starting to change their convictions. But this will be a process developing in long time period and still the actual changes will happen are not clear. Then it is decided to keep the actual practice.

The topic of blade installation is delicate and wide itself. First ideas have been to go for a solution which provided the complete WTG including the rotor. Here the advantages were less than the issues linked to the logistic for these 70 m blade lengths. Moreover, an analysis of an optimal storage within the vessel and a further installation on site would have been outside the topic of this thesis. Then, blade transportation is decided to be provided by a different and cheaper feeder vessel and the installation procedure to be made on site. This choice can still be seen as optimized for the current practice, since for the future the forecast sees the utilization of two-blade rotors, which will completely revolutionises the procedures in this field.

Focusing on actual projects is justified by the necessity of environmental and site data for the system and model set-up. Probably, if positive, this solution will not be proposed for these projects because too late for the tender phases, but represents a starting point to be adapted for the new ones. Same reasons are behind the current manufacturer's design choice. Here, moreover, the decision is validated by the future trends, that sees a settlement of the recent design nowadays proposed, with just few optimizations and without large evolutions.

According to the latter, many designs feature the inner part of the bottom tower element partially occupied by electronic devices and maintenance structures. This implies that no internal sea-fastening is possible or it would be so only if the sea-fastening were specifically adapted to each designer model. Since a solution like that would not be flexible for a large number of possibilities in the market and since the future developments in this term are not known yet, no internal sea-fastening is kept as design choice.

The lifting point is chosen at the top of the structure, located so at the nacelle position. This assumption is relevant since no issues due to vertical space occupation are implied. Indeed, with a lifting procedure from the bottom, external device would be required and they would affect the grillages and other sea-fastening localization. A disadvantage of this choice is the manufacturers' reluctance towards lifting activities around the nacelle. For this reason no calculations have been provided so far to assess the feasibility. On the other hand, lifting from the bottom would require external elements attached to the tower by welding: this would go against one of the boundary conditions as well.

Finally, the utilization of the new auxiliary host for Oleg Strashnov is decided. Even though this upgrade has not been performed yet, it is in the company planning and will be done for sure once the T&I for WTGs start. Its main feature is the maximum capacity of 910 tonnes, reachable at a radius from 40 m to 60 m. Then the load curve changes as well, providing a larger area for the minimum defined boundary of 840 tonnes capacity.

2
Background

The journey is the thing

Homer (800 BC - 701 BC)

2.1. Company Description

Seaway Heavy Lifting (SHL) is a leading offshore contractor in the global Oil & Gas and Renewables industry, offering tailored T&I and EPCI solutions. The client portfolio includes the major operators in the offshore Oil & Gas and offshore Renewables industry. SHL operates globally, focusing on the North Sea, Mediterranean, America's, Africa, Asia Pacific and Middle East. The company's goal is to provide their clients with the most effective and added value solutions. This is reached together with high standards for safety and environmental protections, tailored solutions for the clients and modern crane vessels with large lifting capacities.
The acquired know how over the years in heavy lift crane operations has led the company to apply its capabilities into a new and different market within offshore operation field, the Renewable energy sector. Here, great effort has been directed towards the Offshore Wind Market. So far, SHL has been focusing on foundations (monopiles, jackets and transition pieces), platforms (substations, transformer stations) and met-masts.

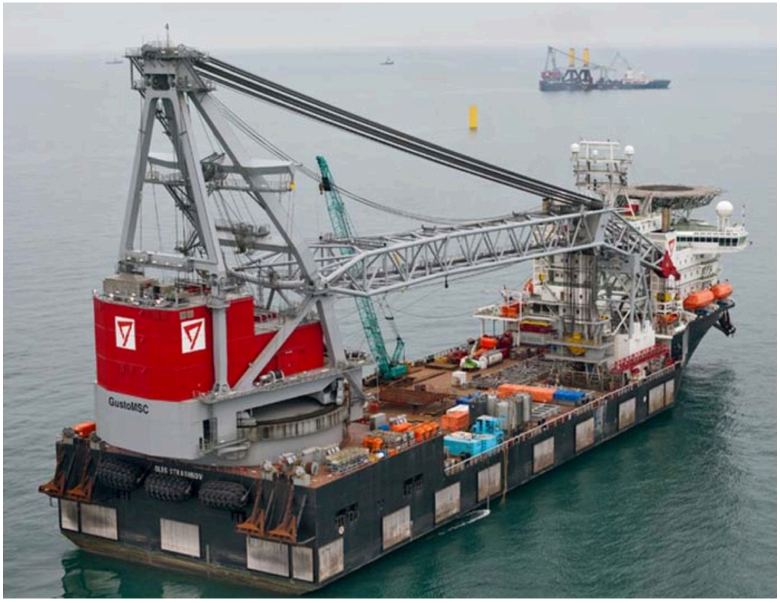


Figure 2.1: SHL's Oleg Strashnov crane vessel

Nowadays SHL is preparing on expanding T&I capabilities to include wind turbine generators (WTGs). This would be a complete new experience for the company and the willing is to enter in this market with innovative and highly efficient solutions. In order to do achieve this goal, the heavy lift vessel Oleg Strashnov, SHL's flagship, has been selected as the perfect means for this path. Project locations in this field are mainly spread across the North Sea, where SHL's senior personnel played an important role in its first offshore installation projects around the early 1980s, when the company activities basically started.

A strong engineering presence at Seaway is required to provide and support all the activities of the two main vessels. The importance for research and the aim to provide innovative results is suggested by the presence of a continuously growing R&D department, where research can be applied to the current practice to find more effective solutions for the future. Among all the prerogatives of efficiency and optimized solutions for the clients, safety is of paramount importance to SHL. An Incident and Injury Free (IIF) programme has been established and governs the activities of all the parties involved in the company works.

2.2. Offshore Wind Energy

> *2013 was a record year for offshore installations, with 1,567 MW of new capacity grid connected. Offshore wind power installations represent over 14% of the annual EU wind energy market, up from 10% in 2012. During 2013, work was carried out on 21 offshore wind farms in Europe. Seven large-scale wind farms were completed and three demonstration projects went online. [3]*

In 1991 the first offshore wind farm took place in Denmark. From that time, the market has been growing tremendously in terms of installations, number of sites and WTG capacities. It is acquiring more importance within the Renewable Energy market, especially in the forecasts for future situations. Targets for 2020 have been already defined and nowadays trends towards 2030 are being prepared. What appears clear is the great relevance given to the Wind Energy and especially to its offshore applications, that the appear to have the highest potentials. (Figure 2.2)

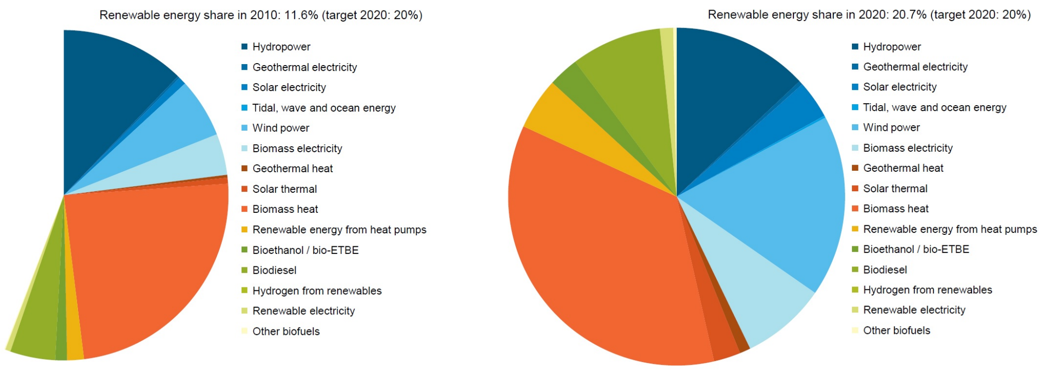


Figure 2.2: Renewable energy share: actual situation and 2020 forecasts [1]

As shown by the predicted share, Wind Energy is acquiring tremendous relevance among the renewable energy sources. The forecast underlines a further target for governments and public organizations to invest in this market. Both onshore and offshore share this positive trend. It is commonly believed that the latter will affect in larger part the future Wind Energy Market.
Europe has been showing an deep understanding of these potentials, becoming nowadays the front-runner in application and commercialization of offshore wind technologies. Other continents are looking to the European developments, ready to apply their mature knowledge, going out from research and experimental phases.
For US, onshore wind resources have had the potential to fulfil the energy needs without looking for different solutions. Nowadays situations have changed but the deep seabed levels appeared as limiting

conditions, since technology developments are needed for finding optimal foundation systems for those situations. Then, lack of experience and proprietary technology combined with long and complicated permitting processes have delayed the development of offshore practices for wind applications. [9] [10]
Offshore in China has proven huge potentials and the last years have represented fundamental turning points toward this path. Indeed the transition from research and pilot project to commercialization took place and rapid developments are expected for the coming decade. [11]

Focusing on European market only, number of facility installations within this market have been continuously incremented over the years and, according to the already signed project for the imminent future and the forecasts for longer period, this trend will be confirmed. Several factors are leading this growth and mainly refer to water depths, distance to shore, manufacturers' technologies, turbine capacities and wind farm sizes. From the 0.5 MW proposed in the very first OWF, 4 MW turbines represent the standard nowadays, with the manufacturers already preparing and testing new designs able to reach up to 10 MW in a few years.
Current technologies assure efficient installations for limited water depth, up to 30-40 m. According to that, European seas appear to have the best conditions to host OWF. The most used foundation type is the monopole, followed by gravity based, tripod and jacket technologies. Tests and studies on floating foundations are being carried out nowadays, in order to extend, for the future, the range of application towards deeper seas of more than 50 m depth. Distance to shore is very often linked to the water depth. Environmental laws and limited space close to shore are driver factors for its trend.
Increments in turbine capacities have led to enlargements in the whole structure dimensions. Tower heights have reached 90 m with a rotor diameter about 120 m. Subsequently, the increase of dimensions induces even necessary sophistications in designs, in order to limit the weights on the table.
The choice of Wind Farms offshore rather than onshore can found its strong motivations among several arguments, such as the possibility to have an better wind resource, a theoretical room to scale up until large limits and lower impacts on the environment. Although offshore and onshore turbines operate in a similar manner, sea installation can provide less visual and noise problems as well. Furthermore wind forces are stronger there and turbines can work at their maximum capacity for more frequent periods. Even the high demographical and economical concentration along coastal regions make offshore solution very convenient in term of distance from power supply. [12]

Of course many disadvantages have been pointed out, like the difficult weather conditions these constructions have to withstand, environmental boundary conditions linked to technologies and designs just at an early stage and high costs for these kind of solutions. Despite that, as mentioned, the future of Wind Energy is moving towards offshore sites, as underlined by the past trend and future forecasts which provide the overcoming of these limits by the technology progresses will happen in this field. (Figure 2.3)

Onshore practice addresses minimal importance towards transportation and installation issues, since they do not have huge impacts on the involved projects. A similar approach has been used from the beginning towards the offshore application, driving the focus almost completely on the optimal design for the structure itself, taking minimally into account logistic considerations. On the other hand, according to the contractor's view, Offshore Wind Energy market was approached by adapting the already present knowledge, vessels and technologies from their experienced oil & gas tradition. These attitudes have led to a lack in standardization and optimization for T&I procedures with consequent maintenance of high costs for offshore wind projects. This is the reason why the actual situation is ready for great improvements and seeks for new directions to abate costs. Indeed working offshore appears to be more complicated than onshore, due to the already mentioned limits. Then a logical goal would be keeping the work to be done offshore at minimum.

Among the several factors within the Wind Turbine installation, time is the key-factor which mostly affects the final cost of a OWF construction. According to that, logistics and installation have acquired more importance and even the manufacturers are now starting to adapt their designs in order to facilitate these procedures. The time range in such projects is about 7-10 years, from the initial planning to the actual installation and commissioning. Great investments are required to guarantee the development of a project over such a large period. Therefore, finding solutions to improve offshore

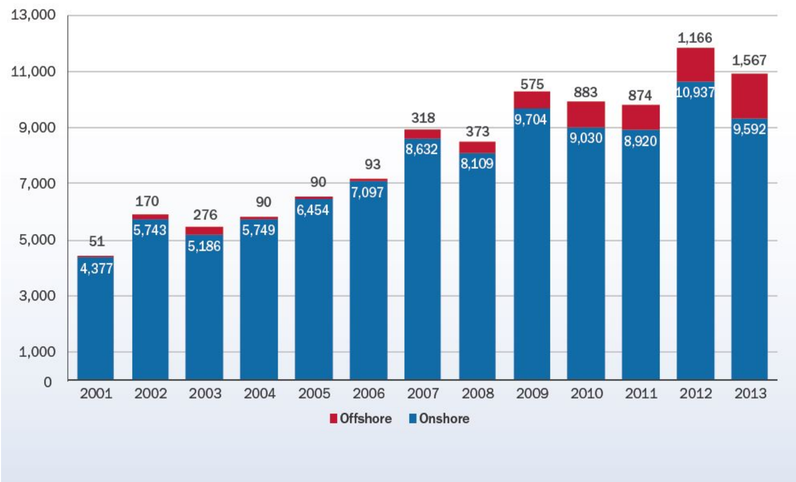


Figure 2.3: Annual Onshore and Offshore installations (MW) [2]

efficiencies the current practice for each stakeholder involved in this work. Investments, despite these issues, have seen a constant increase over the years and the same can be confirmed for the future trends. (Figure 2.4)

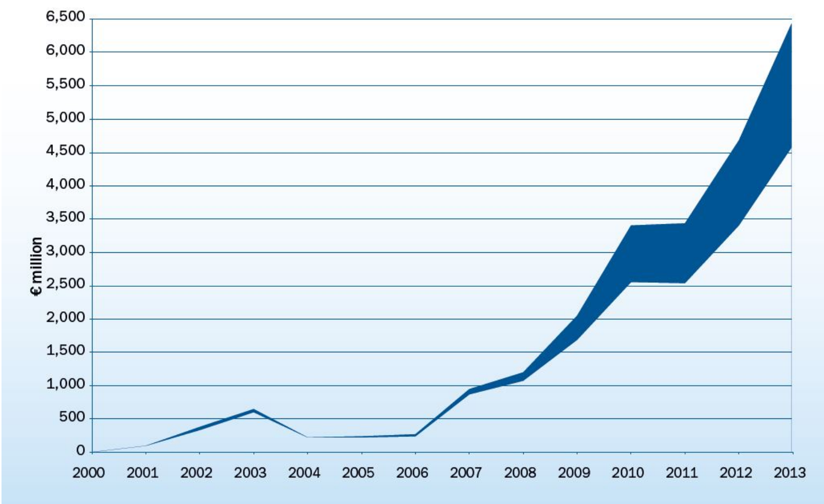


Figure 2.4: Annual Investements in Offshore Wind Farms [3]

Offshore contractors themselves have been trying to find new practices in order to create competitive solutions for carrying out these jobs. Their experience in Oil & gas market represents a starting point but could be also a huge limit if no improvements are added from that situation. Nowadays a simple adaptation of technologies, vessels and procedures from that field to the Wind Farm market cannot be a solution anymore. New generation vessels, for example, larger in size and storage capacity, with the ability to work in deeper waters and with higher navigation speeds are now designed and will be available in the next years.

Due to its development over long period, any OWF has to be planned carefully and requires large amount of investments. Then, in order to justify any initial fund, economic benefits at the end of the process have to be guaranteed. A feasible economic for the project is determined by electricity cost per kWh, operational and maintenance cost, and capital cost. Among the all factors involved, the capital cost of wind energy has progressively decreased, giving a good momentum for its application offshore. [13] (Figure 2.5)

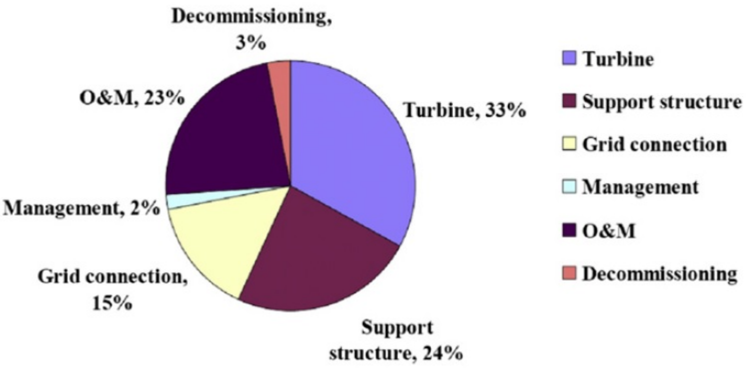


Figure 2.5: Composition of total system costs for an offshore wind farm in shallow water [4]

At present offshore wind power is still less competitive than onshore and other sources, due to the relatively high final cost for electricity generated. Among the several components in this system, operation, installation and maintenance play an important role. R&D efforts in these fields can lead to cost efficient solutions for the future. [14] The common goal to further enhance the Offshore wind industry is to abate the LCoE in order to better compete with the other energy possibilities and to become independent of public mechanisms which are supporting now its development. The actual cost level of 15 ct/kWh is too far from the competitive cost level of 4.9 ct/kWh defined by natural gas, lignite and nuclear power. [5] (Figure 2.6)

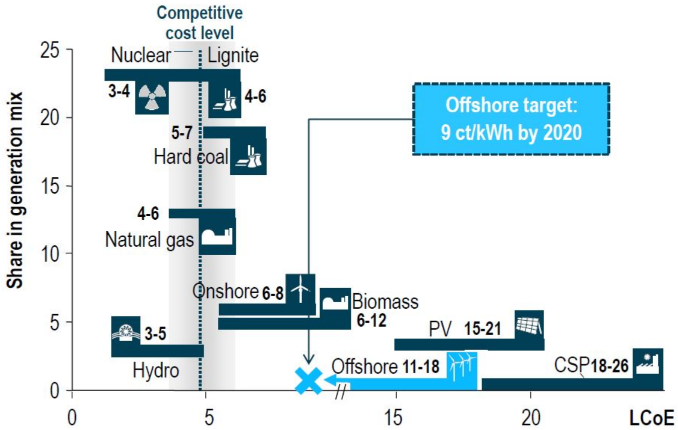


Figure 2.6: Comparison of LCoE costs, Europe 2012 [5]

The interest around the OWF market is underlined by the enormous number of stakeholders involved, from clients to contractors, public and public organizations, governments, producers and final consumers, who are involved just at the end of these processes but without whom all the efforts would be vane. Thus, although a lot of improvements and probably drastic changes have to be made, the path appears the right one to make Offshore Wind Energy a fundamental supply source.

2.3. WTGs: Definition and Transportation & Installation

The Wind Turbine Generator represents the final part of an OWF construction. Here all the electrical equipment take place and the wind source is converted into profitable energy to be sent to the grid. Nowadays WTGs are basically composed by the main tower, nacelle and hub, attached to a rotor with blades. The tower can have variable height according to the site requirements but usually is over 80 m. The nacelle, where all mechanical and electrical are found, is positioned at the top of the tower. Then the rotor, composed by three blades, is linked to the nacelle by the so called hub. The tower is connected by the foundation parts through the so called Transition Piece.
An example of wind farm is proposed in Figure 2.7. Foundation limits are shown, here in monopile according to the most common practice, and the transition piece element. These two structures are usually built up in close sequence, sometimes at the same time, while the WTG installation takes place during a further step. Logistical optimisation of the process has lead to the monopile and transition piece both being installed from the same vessel. Thus, several wind turbines can be completed up to the platform level with just one vessel travel. WTG logistic provides specific T&I processes.

Figure 2.7: Offshore Wind Farm main components

Transportation and Installation procedures, as briefly anticipated, represent a field for large improvements in terms of optimization, time saving and subsequently cost efficiency. The current practice involves jack-up vessels which carry out this job by dividing the single WTG structure into parts . This has advantages in material loadings and transportation requirements, since the amount and required technology for sea-fastening is limited. However most of the required work, such as the assembling of all these parts, is addressed offshore, where environmental conditions are critical, time elapsed and costs subsequently increased. Furthermore, due to the very slender nature of the structures involved, even manufacturers have been promoting the transportation in parts. The structure of WTGs has not been designed for transportation and installation as single piece. That implies even further complications for the logistic in this eventual new way. Moreover WTG manufacturers have shown a negative feeling towards possible adaptation in design to facilitate T&I needs, and this situation will hold for the imminent future projects. It is most likely that this trend will be changed in long term considerations, due to the further complexities which will arise together with new technologies and larger dimensions.

Currently, analysis can be solely carried out with regards to sea-fastening and any external system able to keep the WTGs stable during offshore transportation and to provide feasible unloading and installation procedures once on site.
Current practice transportation for WTG is to divide it in pieces. The tower is basically divided into its two or three fundamental elements which are sea-fastened over the vessel deck together with the nacelle and the hub, fastened apart. Blades are arranged in specific frames, sea-fastened and transported

within the same barge or with a specific one. Once arrived on site, the pieces are sequentially unloaded, lifted and installed from the transition piece to the top. The only type of connection allowed for offshore WTG is a bolting connection, throughout steel flanges. Jack-up vessels have been identified so far as the only means for T&I of wind turbine generators. Sometimes feeder vessels are used in cooperation with them. Floating installation is the alternative solution that nowadays is being analysed and tested through numerous demonstrators for new OWF projects.

This could overcome the jack-up disadvantages, especially in terms of time and cost saving. Generally onshore work is always seen as less expensive, lower risky, quicker and safer with respect to the same kind of work to be carried offshore. Other advantages are:

- No seabed disturbance and residual footprint or time spent for jacking operations;
- Higher navigation velocities for single hull vessels;
- No dependency on water depth;
- Excellent manoeuvrability during installation;
- WTG can be assembled, for a large part tested and commissioned onshore;
- Minimization of the hook-up offshore in terms of both mechanical and electrical connections;

On the other hand, several disadvantages could arise due to the different T&I approach and vessel used. Relatively high costs are required for operations with floating crane vessels, and even more for those able to provide Dynamic Positioning installations. Furthermore, the transportation forces on the turbine appear different to those seen in current installation methods. Current design suggest that such new lifting procedures would require a design improvement for the tower and potentially an upgrade to the internal sea-fastening of turbine components. Nevertheless, working onshore requires appropriate investments for facilities and logistics at the quay side.

A final but important aspect to underline is the current lack of vessels able to perform this kind of T&I procedure. Even though a certain vessel could provide an innovative solution for this scope (e.g. Oleg Strashnov of SHL), questions have arisen about how the uniqueness of it over the world would affect the whole project in case of a single point failure.
Despite these negative tendencies, most contractors are looking for finding a solution in this way and clients seem ready to invest in such a T&I solution for the mentioned cost and time advantages. Nowadays floating installation can be provided by Semi-submersible vessels or mono-hull crane vessels. The first were applied in the 1990s and appeared to be too expensive in operation and maintenance. New models are being developed now but their limited transportation capacities would increase the number of voyages and subsequently decrease the time-cost efficiency.

Mono-hull vessels are the most promising options and therefore nowadays strongly under development. Contractors are studying new solutions to be adapted specifically to the OWF market. Only Oleg Strashnov (SHL) seems to already have the potential to carry out such a task with its current features. This is one on the main reasons why this paper applies its design concepts and calculations to that specific vessel, in order to provide a practical and really feasible solution.
From a structural point of view, sea-fastening is the field which requires more focus and analysis. By this term are identified all the structural components able to make carry out the external actions due to combined sea and vessel motions, during offshore transportation and installation phases. To achieve that, it is fundamental to have a proper and effective transmission of all the forces between the structure transported to the strong points of the vessel (frames and bulk heads). Examples of grillage utilized for sea-fastening is proposed in Pictures 2.8 and 2.9. They do not refer to WTG grillages since they are never been developed and used in real projects; indeed they show grillages for Transition Pieces and Topsides.

Figure 2.8: Topside grillage prefabrication – WindMW Meerwind Project (SHL)

Figure 2.9: Transition Piece grillage over Oleg Strashnov (SHL)

2.4. Future developments

According to the OWF definition and construction times, fundamental aspects to be considered are the future developments of technologies and procedures, in order to orientate the current choices to a long term view. Analysis for 2020 and 2030 targets set the future requirements and the necessary technology to be developed for achieving them. One main aspect that seems to be shared by all the analysts is the definition of 8 MW as average limit for single WTG capacity. Even though several manufacturers are providing analysis and tests on 10 MW designs, these are not likely to be applied in the upcoming years. Two blade solution are already being designed (e.g. Aerodyn) and will be commercialized in the next decade, but this will not became the standard solution up to 2030.

The average OWF size will continue to increase, thanks to the fact that larger farms allow improved fixed cost allocation. Power and size amplifications are linked to the continuous increase of energy supply request by the world community, that will put more trust into the wind energy market. These requirements will lead to more specified design for the different offshore locations, in order to maximise the outputs in terms of energy production. Therefore, the cumulative number of WTGs all over the world will dramatically rise up to 2030.

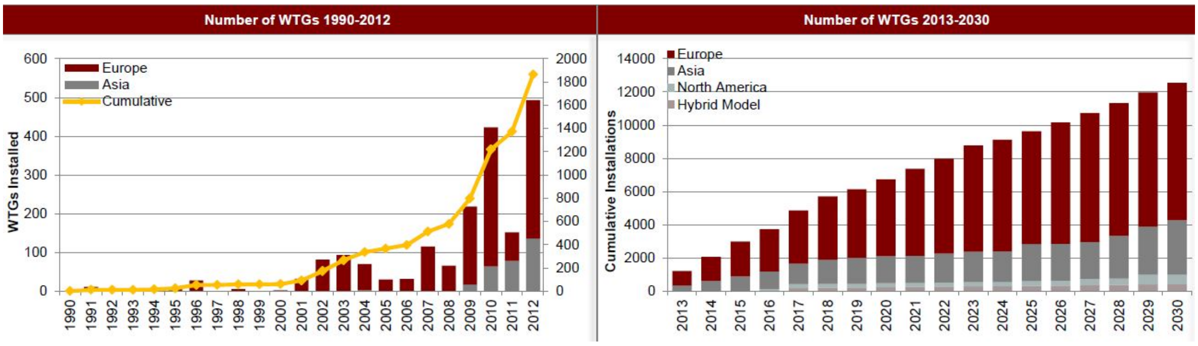


Figure 2.10: Number of WTG installations for OWFs [6]

This set of data is important for contractor choices towards their directions in technologies and equipment to be focused on. Despite the great influence that floating foundations are generating nowadays (due to their first offshore tests, e.g. Hywind), up to 2030 they will not become the leading solution and monopile foundations will still maintain the primacy among the others. That is because water depths will settle around the 30 m, with possibilities to go further. Even jacket installations will find more applications. [5] [6]

Another aspect, linked to the water depth, is the distance from shore. Generally the higher the distance, the deeper the sea. Moreover, the capabilities of wind sources could be greater, with subsequent more difficult environmental conditions for the placement and activity of the OWF. Higher turbulences and foundation limits will move the focus on different possibilities, such as vertical axes wind turbines which would be able to use smaller flotation systems. Despite this trend that leads to higher revenues in terms of energy produced, other functional costs could increase, such as the grid connection that will be more complicated and extensive. And, of course, Operation and Maintenance will become more costly due to higher distances and more severe environmental conditions.

Further researches are going to focus on different materials for offshore constructions instead of steel. Concrete or composite solutions seem to be really competitive and to match with the future dimensional and performance requirements of OWF. Moreover, advanced carbon fiber solutions for blades and other components will play an important role in future developments. [12]
At this stage, defining boundary conditions, according to the actual situation but keeping in mind the future ones, can lead to the best choices able to be competitive for a longer period of time.

2.5. T&I Sequence

The period of analysis, which the structures have to be designed for, covers several subsequent steps. From the preparation and assembly on shore, to the load-out and sea-fastening, transportation, release of sea-fastening, hooking-up, positioning on site and final installation procedures. Even though this thesis is focusing on the sea-fastening related processes, knowing the external related phase features and keeping in mind their practical issues are fundamental requirements to provide an effective and feasible solution.

Proceeding more in detail, four main phases have to be analysed in order to define external actions and precautions to be taken into account:

- Sea-fastening structure loading (harbour);
- Load-out (harbour);
- Transportation (sea);
- Unfastening and hooking-up (sea).

At the beginning, once the onshore yard is prepared, the vessel arrives at the harbour and loading procedures can start. Firstly the supporting structures have to be loaded and arranged on the deck. Generally grillage systems are installed at this time, by direct welding on the deck, while more sophisticated equipment (e.g. prestressed cables) later, once the WTG are placed on board. If external structures are provided, they are installed now. At this stage external actions go from zero to minimum, since vessel accelerations are still present but definitively lower with respect the sea situation. Wind effects are present and need to be considered. Static loads are minimal as well, since the supporting structures are designed to weight much less than the elements to be supported. A good planning of installing activities has to be followed, in order to avoid any kind of problems for the following phases (e.g. logistic delays due to not optimized space utilization on deck). Small cranes are generally used for these installation procedures.

Once the deck layout is ready to accommodate the main structures, the load-out phase can begin. WTGs have been already built up onshore, from the bottom element to the nacelle, and now are hooked-in and lifted-up onto the vessel. This procedure involves one WTG at time. Again, the vessel accelerations are present but minimal (small pitch and roll angles). Static loads play an important load now since the vessel is going to reach his full capacity at the end of the process. Wind loads need to be accounted for. Attention has to be paid towards the stability of the vessel during the loading path. Repetition of standardized procedures is fundamental for time saving and optimization. Once the WTG are placed on deck, they are fastened while the crane is still hooked up to the structure. In order to optimize the process, temporary sea-fastening should be provide in order to quickly free the crane and move that to the next WTG to be loaded-out. If skidding system is provided, after the fastening completion, the structure can be moved to a different position to make space available for the next load out. The crane involved in these operations is the main one.

The vessel is completely loaded, WTGs are finally sea-fastened, crane is at rest position. Transportation begins and the worst external actions can take place. Pitch, roll, heave, wind are combined with the static forces and considered in their cumulative effects. The whole sea-fastening design is focused on this phase and all its governing conditions. Eventual redundancy provisions have to be investigated in order to prevent system failures and to face unexpected conditions.

When the vessel reaches the offshore site, installation procedures start. The structures are hooked-in again from the top. How to make this happen in safe conditions and with and efficient work has to be investigated. Then unfastening can take place and subsequently loading out of the structures onto the transition piece. Here each WTG is installed per time, then the vessel moves to another close location for the next installation. Stability of the vessel has to be verified for each combination of WTGs present on the deck.

2.6. Selected manufacturers' designs

As already pointed out, three specific designs are selected, in order to give a real field of application for the solutions of this study. All of them are already present on the market. Their dimensions are comparable and perfectly match the target trends for the future. They are proposed without considering the rotor presence. Differences in heights are due to the diverse project applications. Differences in detailed design are related to manufacturers' choices and analysis.
From Table 2.1 it can be seen how Alstom solution will give the most critical scenario since the weight of the nacelle is higher and will affect the total weight and CoG position. Moreover, Siemens solution has the highest tower height, producing issues for crane operations and buckling of the structure. The goal of this study is to provide a solution applicable for all these three cases. Adaptations and considerations will be applied where necessary but always maintaining the main idea of providing a flexible and relative wide range solution.

Table 2.1: Selected manufacturers' designs

			Areva	**Alstom**	**Siemens**
			M5000-135	*Haliade 150-6MW*	*SWT-6.0-154*
	Capacity	*Power [MW]*	5	6	6
Tower	Bottom	*D [m]*	6	6	6.5
		Height [m]	13.5	20.0	14.1
		Weight [t]	190.0	173.0	94.0
	Middle	*Height [m]*	28.4	24.5	37.7
		Weight [t]	88.8	124.0	158.7
	Top	*Height [m]*	30.7	28.8	36.0
		Weight [t]	87.5	103.0	113.7
	Total	*Heigth [m]*	72.6	73.3	87.8
		Weight [t]	366.3	400.0	366.4
Nacelle+hub	Total	*Height [m]*	10.5	8.4	8.4
		Weight [t]	296.7	363.0	308.0
WTG	Total	*Weight [t]*	663.0	763.0	674.4

2.6.1. ALSTOM Haliade 150-6MW

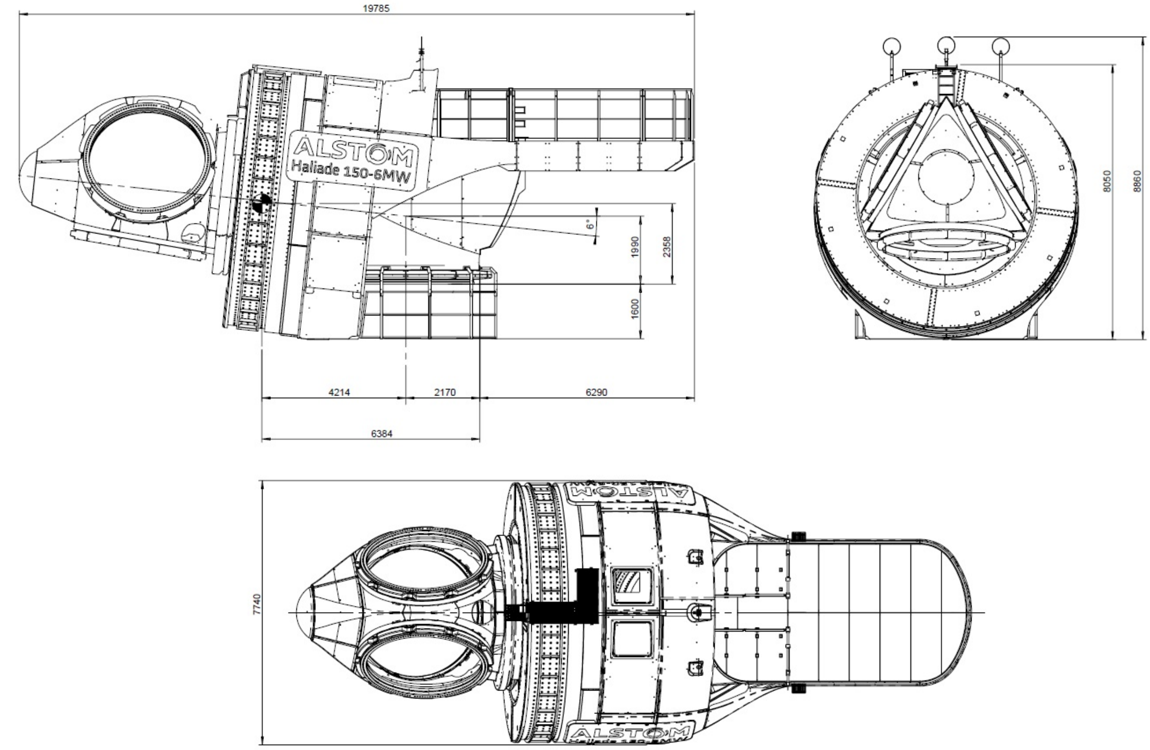


Figure 2.11: Nacelle + hub configuration, Alstom

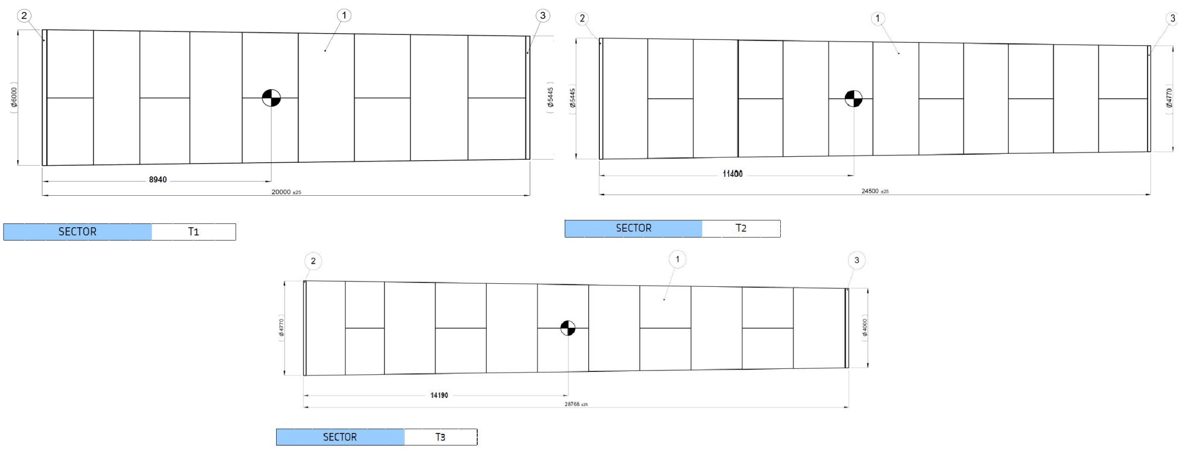


Figure 2.12: Tower segments, Alstom

2.6.2. AREVA M5000-135

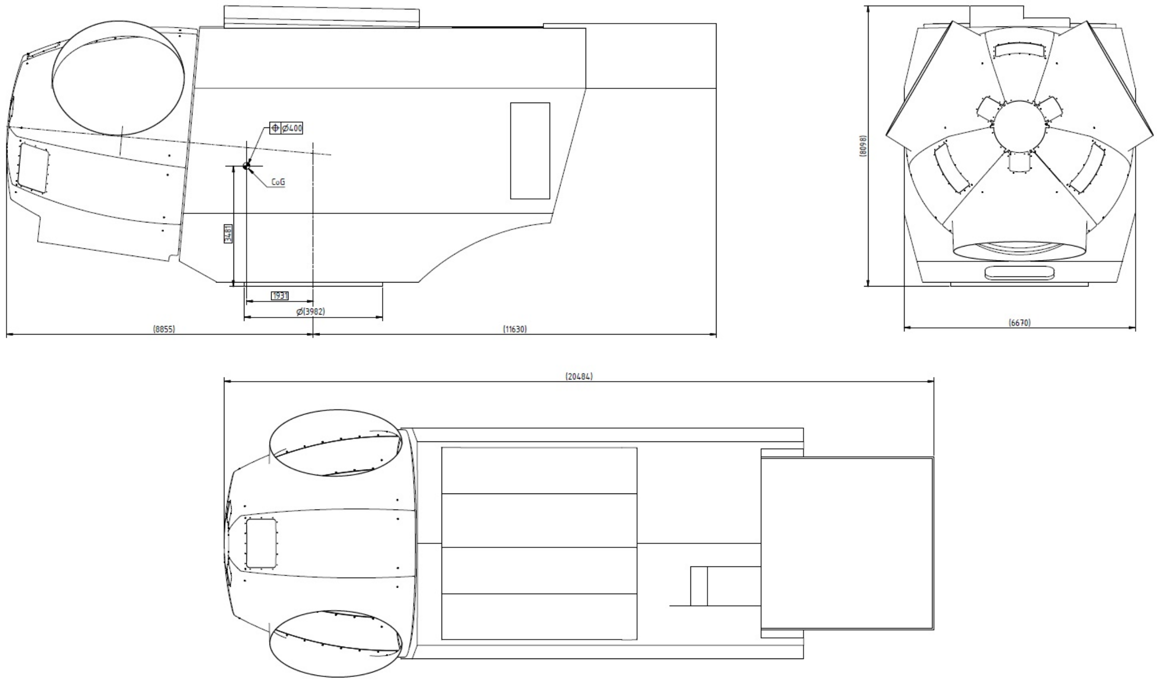


Figure 2.13: Nacelle + hub configuration, Areva

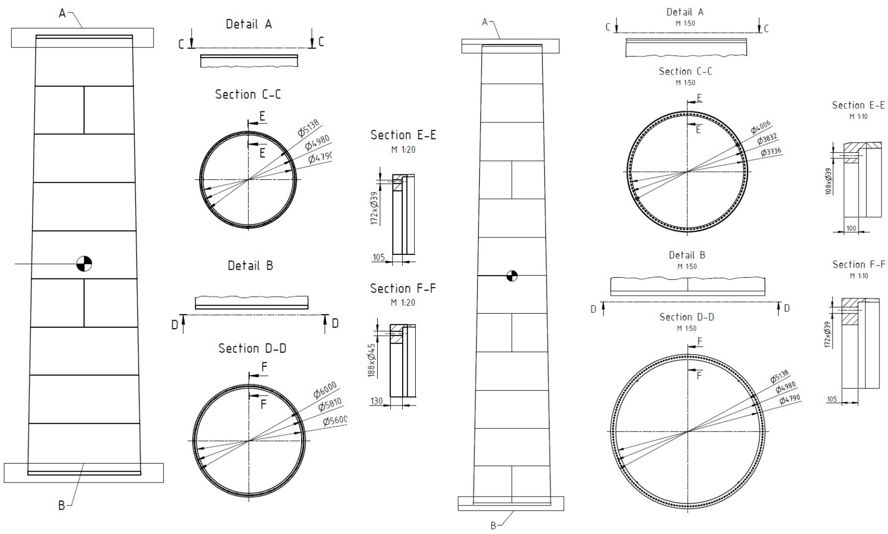


Figure 2.14: Tower segments, Areva

2.6.3. SIEMENS SWT-6.0-154

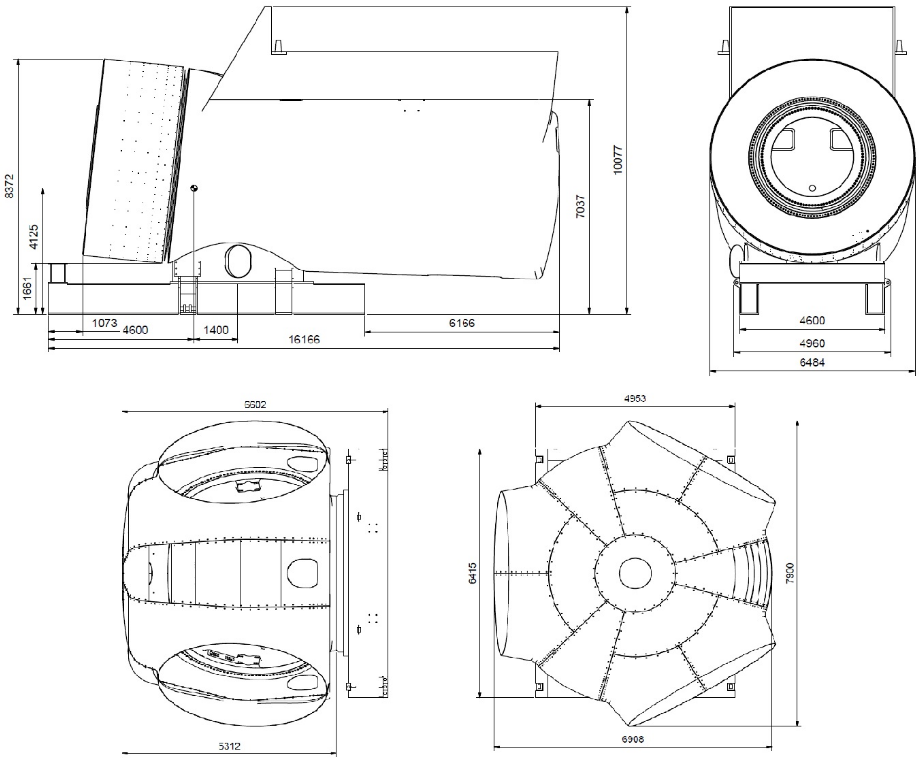


Figure 2.15: Nacelle + hub configuration, Siemens

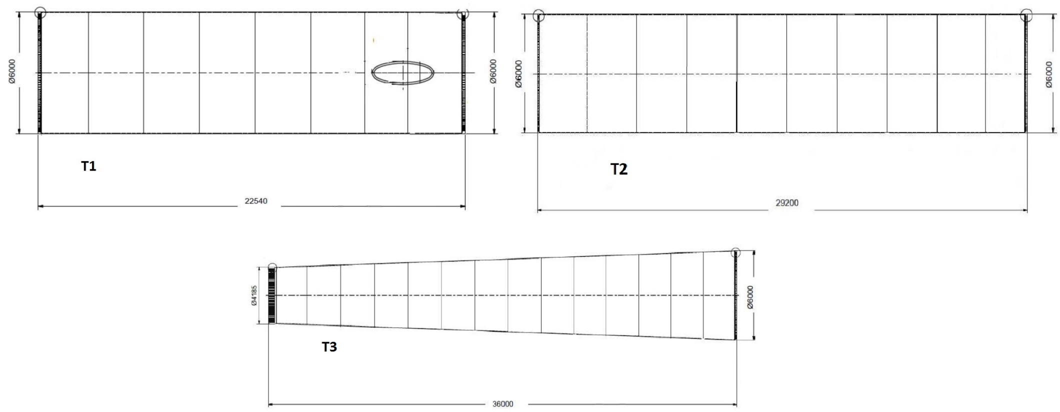


Figure 2.16: Tower segments, Siemens

3

Conceptual Analysis

Thoughts without content are empty,
intuitions without concepts are blind

Immanuel Kant (1724 - 1804)

Concept definition phase is definitively a delicate and important step, since all the information and ideas gathered so far are addressed and focalized into practical solutions. What leads every kind of choice at any step is the pursuing of cost/time efficiency and safety. The first could be more generally translated into the requirement of loading as many WTGs as possible per single voyage. Then, finding the most optimized procedures for every construction step can increase the time saving and subsequently reduce costs. Importance for practical procedures finds also strong relations with safety issues. This can be achieved by analysing practical consequences of each design choice, trying to provide the best conditions for the workers, avoiding handling compliances. Then the focus goes to the main aspects of the structures to be transported, together with the related potential critical aspects during T&I.

At this stage a precise and wise assessment of advantages and disadvantages is required, in order to have a complete scenario of possibilities from which the best one can be chosen. Since the boundary conditions have been already defined, conceptual analysis strictly abides by these requirements. Only potential critical points in respecting them are pointed out and represent part of the evaluation assessment.

Among the several WTGs available on the market, only three models have been selected, in accordance with the already mentioned requirements of current feasibility and future forecast applicability. The solution will try to be as general as possible in order to accommodate each of these three designs with just slight design adaptations. To achieve that, the design will be made with respect to the one which shows the highest induced transportation actions (i.e. Alstom model).

For extricating among the possible design combinations and coming up with solutions in an organized way, slightly modified morphological chart technique is adopted. "Modified" refers to that the first parameter of each concept is selected by a predefined static scheme. Therefore the several static schemes are proposed to face this problem and then all the further functions are investigated. Moreover, once defined all the options for each function, another important parameter to be taken into consideration is the application of a skidding system. This choice, for its importance, is kept again outside the morphological chart and treated when all the concept will be generated for the first time. Thus, each concept will have at the end its definition both with and without skidding system, in order to give a wider scenario for selection.

Once all the concepts are listed and depicted in their distinguish features, comparison and selection can follow. Since most of these characteristics have very different nature among each other, several main behaviour are investigated and grades are given for each concept according to the influence of its components for that behaviour. Thus at the end, the combination of these results with general considerations, out of three best options the final concept to be analysed is selected.

Finally, some detailing are proposed, only regarding the chosen solution, in order to narrow the analysis to a specified case of study.

3.1. Concept Definition

Cost efficiency, time efficiency and safety are the goals which orientate all the choices and will determine advantage and disadvantage analysis. Of course the attributes of stable and sufficiently resistant are implicit meanings for the feasible structural system of this study.
The following important issues immediately arise, due to the nature of WTG structures:

- Considerable height;
- Considerable weight;
- Very high CoG for the total system;
- Thin bottom flange and tower walls, compared to the height dimension.

These features suggest the appearance of critical situations, once the vessel motion conditions are induced to the structure. If it is just connected at the bottom without intermediate supports, the possible bending moments at the base will be tremendously high. This can affect connections and flange failure due to high stress concentrations. Moreover, depending on the solution chosen, buckling in the tower could appear. Stress distribution through the wall has also to be investigated since could lead to unexpected material failures.

The conceptual ideas are basically meant to face these initial problems. To treat the WTG, a stick model is chosen for the initial step, when the static schemes are defined. This is the most general simplification possible for such a slender system which can still give some feedbacks about its general behaviour. The actions induced to the structure by the vessel motions are simplified into horizontal and a vertical forces, both acting at the CoG. Only the horizontal force is considered at this step, since the bending and shear diagrams are the focus of this investigation. By choosing different positions and nature of supports is possible to define the general actions applied on the related sea-fastening positions. They are here listed and depicted, together with their bending moments and shear diagrams.

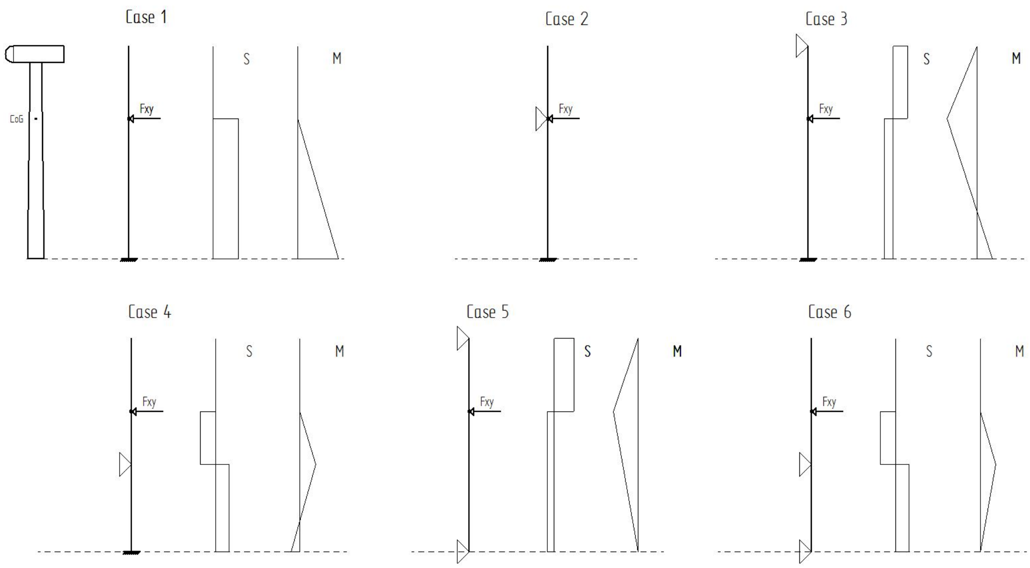


Figure 3.1: Static schemes for Concept definition

- Case 1: simply cantilever. High bending moment appears at the bottom;
- Case 2: fixed support at the bottom plus semi-rigid support at the CoG: Shear force is critical at the CoG position;
- Case 3: fixed support at the bottom plus support at the top: depending on the torsional stiffness of the supports, bending moments can be critical at the bottom, CoG or top;
- Case 4: simply supported at bottom and at an height above the CoG: bending moment is critical at the CoG position;
- Case 5: fixed support at the bottom plus support at an height below the CoG: bending moment is critical at the support position;
- Case 6: simply supported at bottom and at an height below the CoG: bending moment is critical at support.

Depending on the torsional stiffness of the supports, slightly different stress distributions can appear. Once that five static scheme are defined, morphological chart analysis can start.
Basically only general aspects are treated at this step, while more specified definitions are given for each concept generation. The functions are proposed in the table, where the related several options are shown. These functions are strictly dependent on the previous schemes.

Table 3.1: Morphological Chart

	Functions	**Options**				
		a	*b*	*c*	*d*	*e*
1	*Critical Actions*	bottom	CoG	in between	top	combination
2	*Structural Elements*	steel beams	cables	steel beams + cables	none	/
3	*Bottom Connection*	rigid	semi-rigid	hinged	none	/
4	*Bottom Equipment*	bolts	clamps	rotational equipment	none	/
5	*Mid/Top Connection*	rigid	semi-rigid	hinged	none	/
6	*Mid/Top Equipment*	ring or pads	hook	ring + hook	none	/
7	*Structural System transversal position*	in between	over grillage	external grillage	combined	none

According to the chart, a grillage solution at the WTG foundations is always required. The detailed quantification of its dimensions and features is going to be done later since basically represents the scope of this study. But, in order to assess when it is required a smaller or bigger solution of this kind, it is assumed a starting grillage dimensioning of 20x18 m. It is built up by I-beams, arranged in different layout, with an initial height of 2.5 m. In the concept definition all the comparison will be made with respect to these starting dimensions.

Now the concepts can be defined by selecting different combinations of available options. A last important possibility can be investigated. It consists in the application of a skidding system. Then, for each concept two possibilities are proposed, providing the presence or not of this additional function. It results in further considerations about how arrange the overall system and which changes are necessary to make it feasible, according to the already mentioned requirements. The presence or not of such a system affects the number of WTGs can be transported in a single voyage for each conceptual solution. The idea of skidding system application comes from the necessity of carrying as many WTGs as possible.

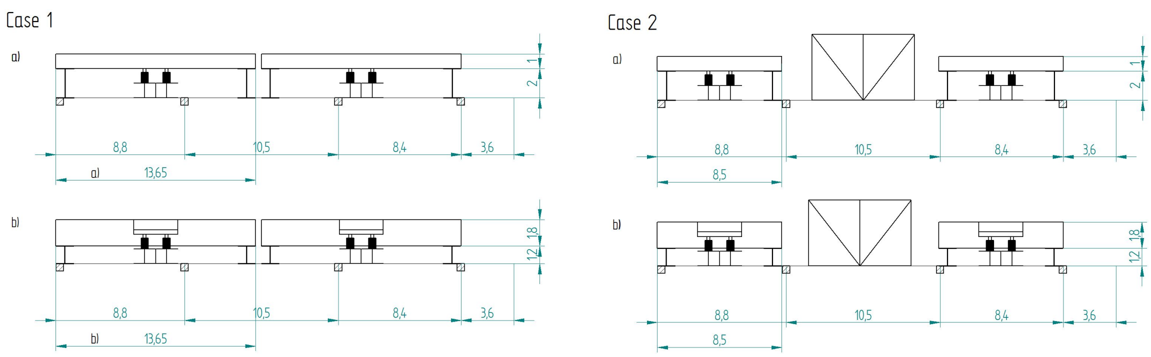
Even though it represents a special and probably costly device, can make the overall solution still optimized and cost effective. Due to the tailor-made nature of this kind of equipment, solutions available on the market are just an input idea, since even deep adaptation can be applied, depending on the project applications.
Its main features are the presence of skid shoes with integrated load carrying cylinders and hydraulic push-pull units, acting on skidding tracks. Firstly it is assumed to carry a maximum of six WTGs, arranged into two rows running through the longitudinal vessel dimension. In order to withstand the static load of WTGs and grillages, eight skid shoes are required, arranged in two parallel lines per longitudinal row.

Then two main solutions can be defined, such that carrying the load from the bottom of the grillages or from external points. In the first case really low rails are required and each three-grillage system can be jacked up from different positions. In the second case specific bracket structures need to be added to allow the procedure and are inevitably placed only at the grillage ends. Skidding rails are placed over three lines of I-beams that spread parallel to the longitudinal length of the track.
According to the needs of different concept layouts, four solutions are provided to better match with their needs. Basically they differ in the jacking positions, from the bottom or mid-height of the grillages, and in the track arrangement over the deck. The following picture can give an overall appearance of these systems, applied on the OS' deck. The dimensions are just assumed, based on practice on similar order of magnitude projects. In these sections, the main boundary conditions are represented by the bulkheads – frame crossing positions and the location of the cradle.

Once the general features of this system are defined, it is possible to proceed with its application on the different concepts. Even if this kind of solution could have large possibilities for adaptations to each concept needs, it is chosen to maintain the general proposed design. Practice has shown that skidding rails could be placed either directly on the deck or over further beams.

Finally, for each Concept two pictures are proposed: one for overall appearance and main equipment schematisation and another for footprint over the deck. In the latter crane at rest, frames, bulkheads and crane operation ready are underlined in order to immediately show these boundary conditions.

In Appendix A.1 all the calculations behind each concept definition are proposed. Their detail is limited since the purpose at this stage is to verify if the hypothetical solution can be applied to the OS's during the considered motion condition.



(a) (b)

Figure 3.2: Skidding system sections - close parallel skid lines (a), skid lines with external structure in between (b)

3.1.1. Concept 1

The first concept is based on the static scheme n. 1 and has the following features:

- Critical actions: bottom;
- Structural element: none;
- Connection (bottom): rigid;
- Equipment (bottom): bolts;
- Connection (Middle/Top): none;
- Equipment (Middle/Top): none;
- System positioning: none;

This concept provides a sea-fastening made just by bottom grillages, connected to the WTGs by bolting the flanges. No further supporting structures are included. High stresses develop along the whole structure, affecting its integrity and capacity. High bending moment are expected at the foundation level, generating possible issues for the flange and the connection itself. The grillage should be strong enough to withstand these actions: an eventual over dimensioned system would be required.
The general grillage dimension assumed is not enough for this concept, implying different arrangement and large space occupation over the deck. The increment in weight is not an issue since is limited with respect to the total capacity. Furthermore, due to the long unsupported length of the structure, buckling can became critical in further calculations.

Positive aspects, on the other hand, are the relatively simple system technique and the non-occupation of vertical space, excluding the WTGs.

Time spent for installation on vessel is limited to the grillage welding on deck and bolt fastening of the flanges. To optimize the sea-fastening time, temporary clamps are used in order to allow a fast hooking out of the crane. They can then be replaced by full preloaded bolts for sea transportation.
According to the space occupation for this concept, just three WTGs may be placed on deck.

Application of the skidding system to this solution appears not feasible. Due to the wide grillage dimensions, skid tracks as conceptually proposed would be not effective and therfore this possibility is discarded. Indeed, only one track could be installed. In this case the system would be highly non-symmetric and the advantages would not be sufficient to justify the implementation, since the grillage limit would be of four elements as maximum.

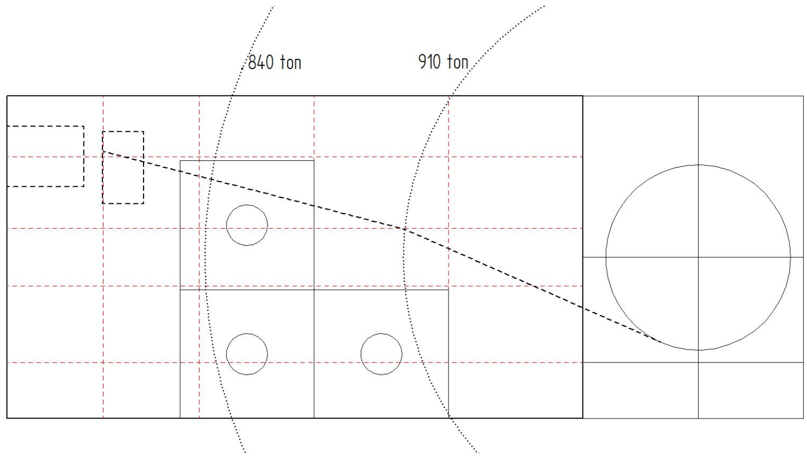


Figure 3.3: Footprint over OS deck, Concept 1

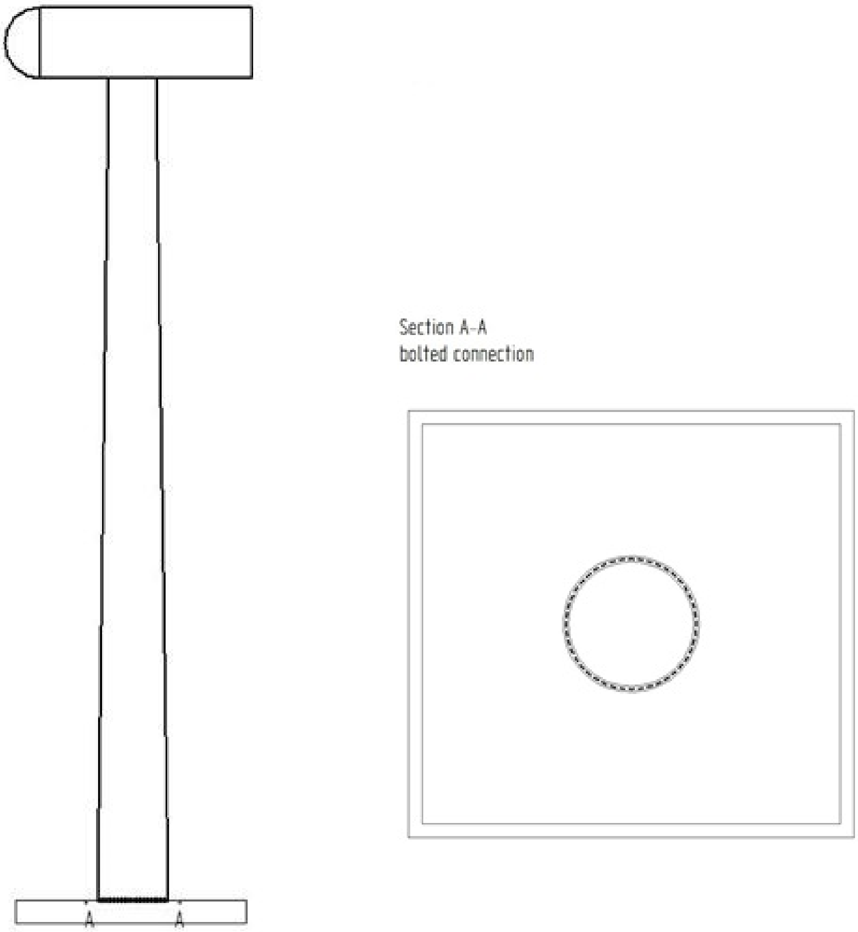


Figure 3.4: Vertical and section WTG views, Concept 1

3.1.2. Concept 2

The second concept is based on the static scheme n. 2 and has the following features:

- Critical actions: CoG;
- Structural element: cables;
- Connection (bottom): rigid;
- Equipment (bottom): bolts;
- Connection (Middle/Top): semi-rigid;
- Equipment (Middle/Top): ring + hook;
- System positioning: over grillage;

This is the first concept which applies cable system for sea-fastening. Principal issue is to provide a sufficient pre-tensioning in the cables to withstand the horizontal force applied at the height of CoG. Here cable anchorage position at the bottom plays an important role, since define its slope and then the amount of force carried. To increase the slope, crossing cable solution is preferred. In order to provide a stable connection for cables at the required height, in this case at CoG, specific equipment is required.
Firstly a ring element that encases the tubular structure is chosen. This is attached by a wide and slender steel frame with the nacelle length main dimensions. The cables are anchored there to transmit the load to the bottom grillage. Proper material is provided between the ring-tower wall interface to give a certain stiffness and homogeneously spread the stresses.
Since it is not possible to connect anything directly to the tower walls, a combination with an hooking system is selected. Ring is kept at the required height by the hooking device, placed at the top, around the nacelle. This is the same will be used for the lifting procedures.
A grillage system is required, in order to spread the vertical loads to the strong points of the vessel. Since bending moment at the foundation is not expected, grillage dimension can be lower than what expected at the beginning. Anyway, high forces are still acting thanks to the reaction components due to the cable stresses. Furthermore, high compression forces through the tower height arise, affecting the stability and structural integrity.

Advantages of this concept are the relatively light weight of the system, with cables and smaller grillages. The vertical occupated amount of space is not an issue, due to the very thin nature of the cables. Less design for bending moment connection is required, both at bottom and at the intermediate support.

A first critical aspect is the positioning of the ring in combination with the hooking system. Specific devices should be designed and their feasibility assessed. Then, at this connection point the highest shear stress arises. Wall high stress concentration could be an issue. Furthermore, installation time on the vessel can definitely increase. Several procedures have to be followed, and their path is fundamental for time optimization. Cable tensioning and un-tensioning can be performed only when the ring is at its final position. To permit the hooking out of the crane as early as possible, temporary sea-fastening at the bottom is done first.
According to these features, four WTGs may be placed on deck.

Application of skidding system can be very complicated due to the presence of cables. Skidding can be provided only when the WTGs are sufficiently supported, so after the cable pre-stressing. Then, best solution would be for cable anchorages over the respective grillage system. Combination of crossing cables between the two lines of grillages can create problems during skidding. Here, skidding design can follow the first case, with jacking up from the bottom.
Thanks to this skidding system adoption, six WTGs may be placed on deck.

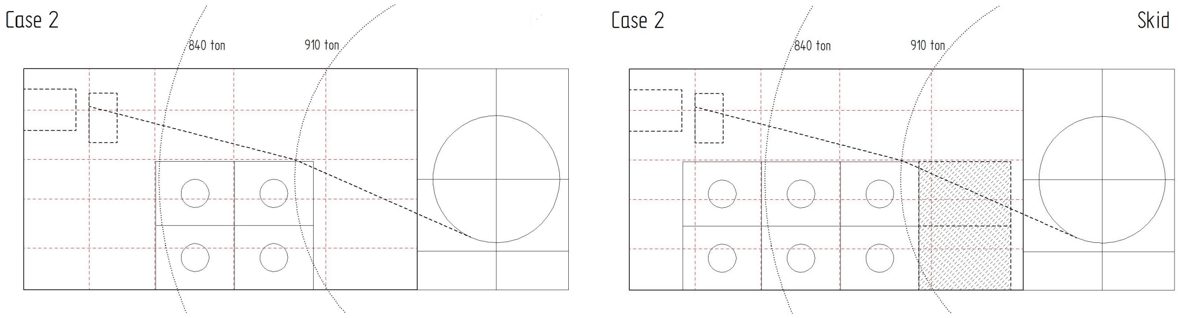


Figure 3.5: Footprint over OS deck, Concept 2

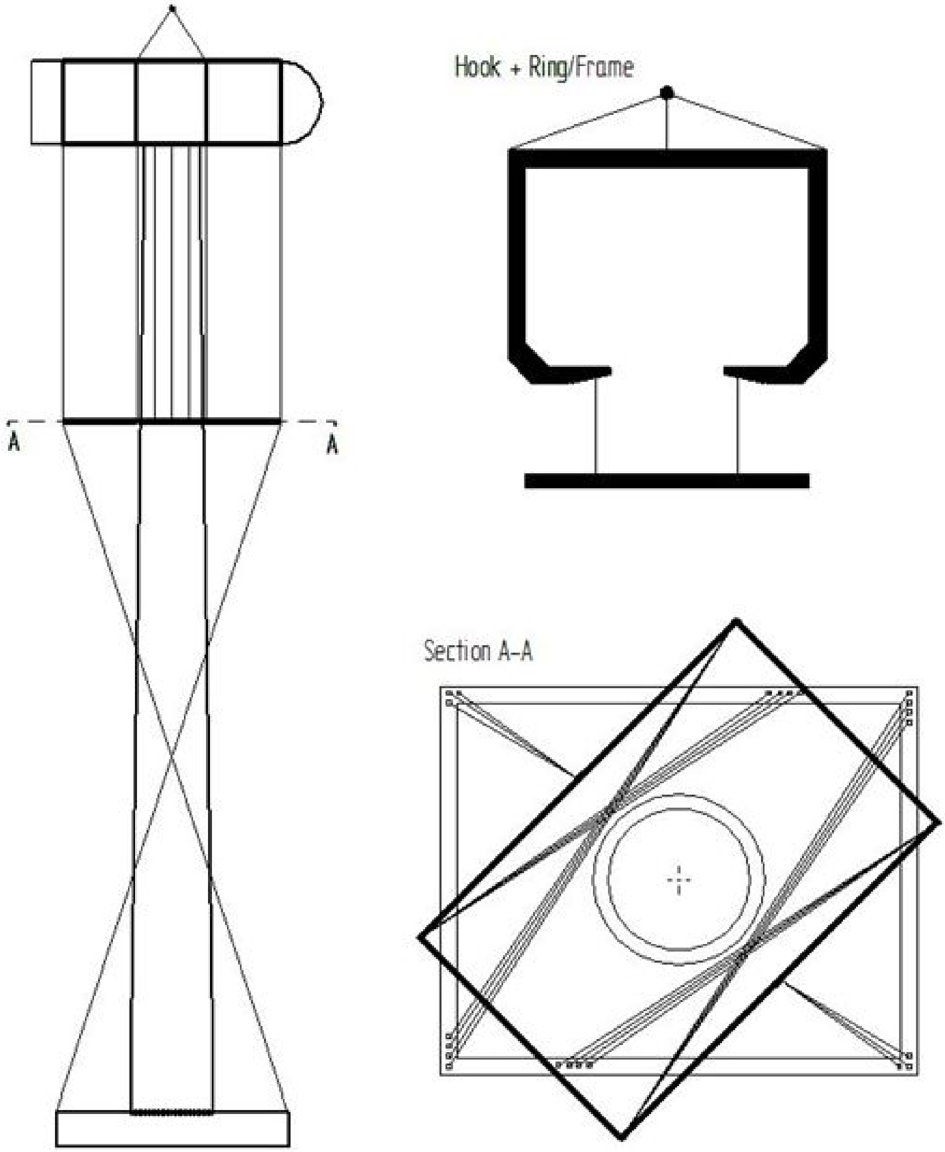


Figure 3.6: Vertical and section WTG views, Concept 2

3.1.3. Concept 3

The third concept is based on the static scheme n. 3 and has the following features:

- Critical actions: CoG and bottom;
- Structural element: cables;
- Connection (bottom): rigid;
- Equipment (bottom): bolts;
- Connection (Middle/Top): semi-rigid;
- Equipment (Middle/Top): ring + hook;
- System positioning: combined;

The idea behind this concept is to provide a support at the top of the structure. Again, it can be only done by cables, due to the required height. Sufficient pre-tensioning is still an issue as well as cable slopes. Anchoring positions are more critical than in the previous concept. Crossing cables are chosen in order to try to decrease the slope.

For the connection with the tower, again a ring element is chosen, attached by an external steel frame with the dimension of the nacelle main length. This time, due to its proximity with the nacelle, a less complex equipment would be required. Just a combination of an hooking system which ends with a ring at the top of the tower, without movement tools. Same features as before are here required for the ring element. Lower shear stresses are expected, while, depending on the rotational stiffness of the connection, a certain bending moment could arise. Another critical position is the CoG, where maximum bending moment is expected. Tower wall capacity has to be checked against these actions. Furthermore, high compression forces through the tower height arise, affecting the stability and structural integrity.

A grillage system is required, in order to spread the vertical loads to the strong points of the vessel. This time a certain bending moment is expected at the foundation, then the grillage and bolted connection should be properly designed to accommodate that. Grillage dimensions are the same as in Concept 2 and still smaller than the general ones.

Handling procedures can affect time efficiency, since the solution appears potentially complex and requires sophisticated equipment. During the load-out the hook-ring system remains over the nacelle, together with the cables. An additional link at the bottom of the tower should be added to avoid free movements during lifting. Once the positioning over the grillage is performed, temporary sea-fastening can be applied, crane released and cable stressed. During installation offshore, similar and inverse activities shall be performed. At this stage, when hooking-in starts, cables have to be released both at bottom and frame positions.
According to these features, four WTGs may be placed on deck.

Application of skidding system, as before, can be challenging. Again, anchorages over each grillage are required to allow a time efficient skidding procedure. System design can follow the first case, with jacking up from the bottom. Thanks to this skidding adoption, six WTGs may be placed on deck.

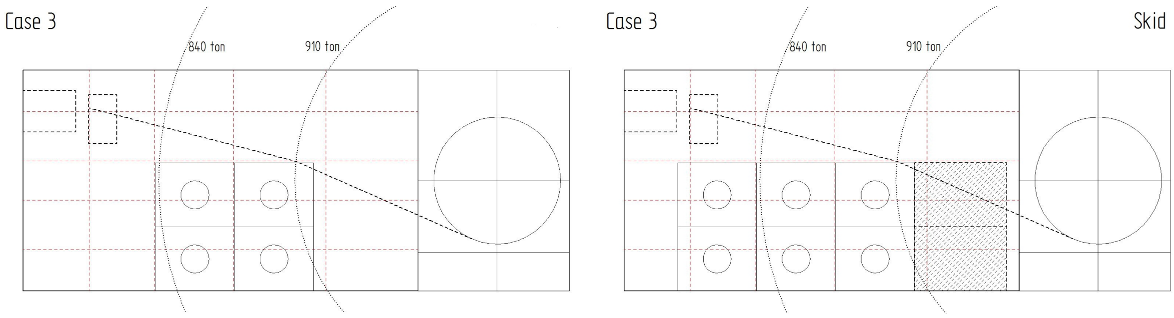


Figure 3.7: Footprint over OS deck, Concept 3

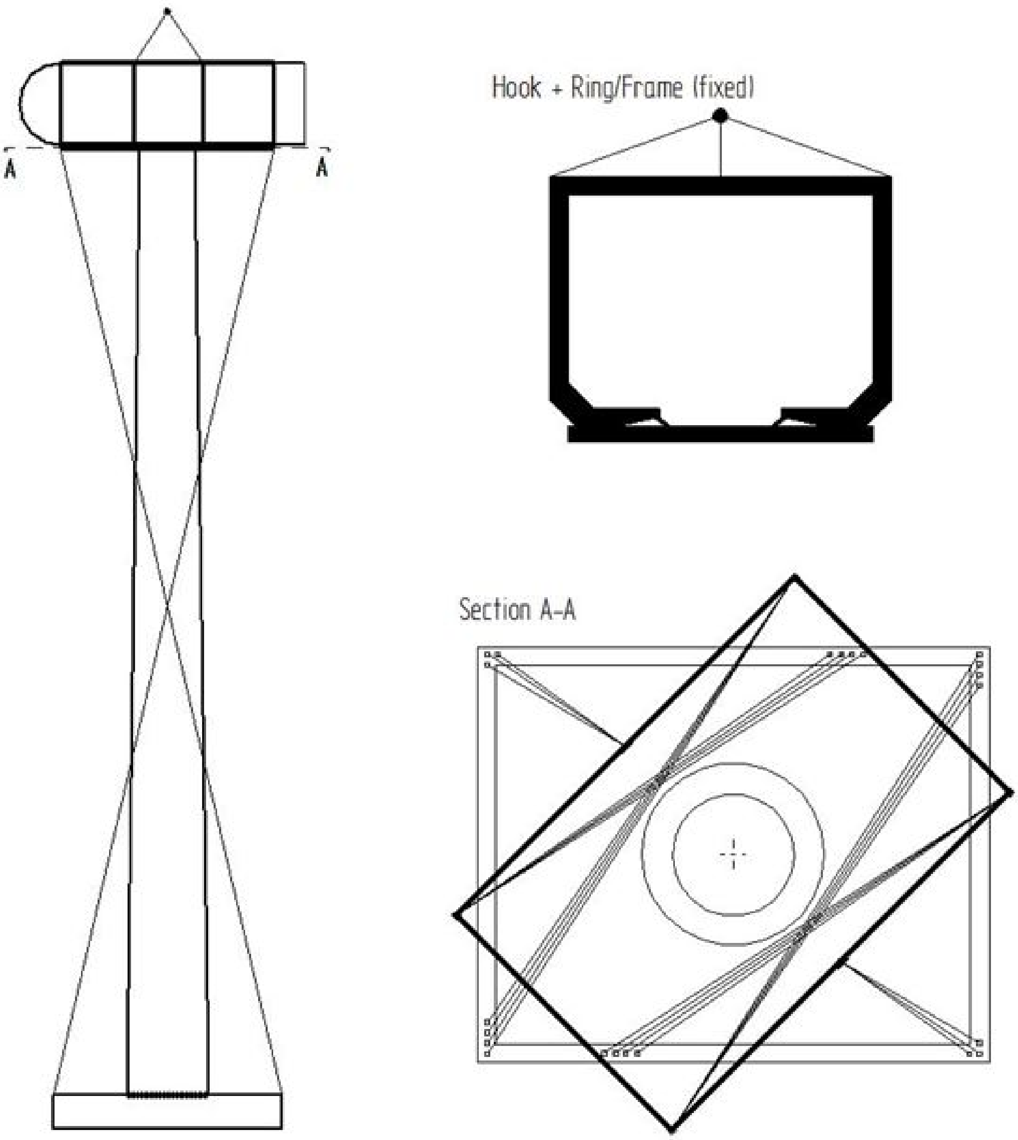


Figure 3.8: Vertical and section WTG views, Concept 3

3.1.4. Concept 4

The fourth concept is based on the static scheme n. 4 and has the following features:

- Critical actions: between CoG and top;
- Structural element: cables;
- Connection (bottom): hinged;
- Equipment (bottom): rotational bearing;
- Connection (Middle/Top): semi-rigid;
- Equipment (Middle/Top): ring + hook;
- System positioning: combined;

This concept has been developed from the idea of treating the actions on WTG as on double simply supported system. Started form Concept 3, its adaptation provides a pinned connection at the bottom to avoid the bending moment appearance and to allow rotations. This can be done by using specific and special systems. They may be really simple (e.g. rocker steel plates) or more sophisticated (e.g. elastomeric materials, sophisticated spherical-sliding steel plates).

Again, tensioning cables are present, together with their advantages and issues. The lower bending moment developed at the foundation level allow for a smaller grillage dimensioning. On the other hand, cable slope and vertical reactions still remain a problem. Moreover, thanks to the bearing device, the system acquires more complexity. That affects handling and therefore safety matters. Furthermore, high compression forces through the tower height arise, together with bending moments, affecting the stability and structural integrity.

Indeed, during installation the crane cannot be released since all the cable are positioned and adequately tensioned. A temporary bolting at the flange level would not be useful. The result is relevant decrease in time efficiency for the overall load out and installation procedure.
Despite the savings in grillage dimensioning, the number of transportable WTGs per single voyage would remain four.

By applying a skidding system it could be increased to six. Similar to Concept 2, it would be applied by jacking up from the bottom. Again, skidding can be performed only when all the cables are properly tensioned.

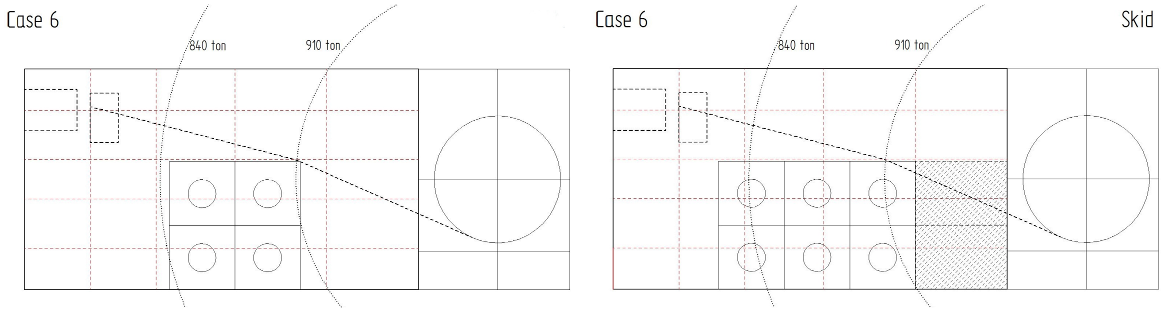


Figure 3.9: Footprint over OS deck, Concept 4

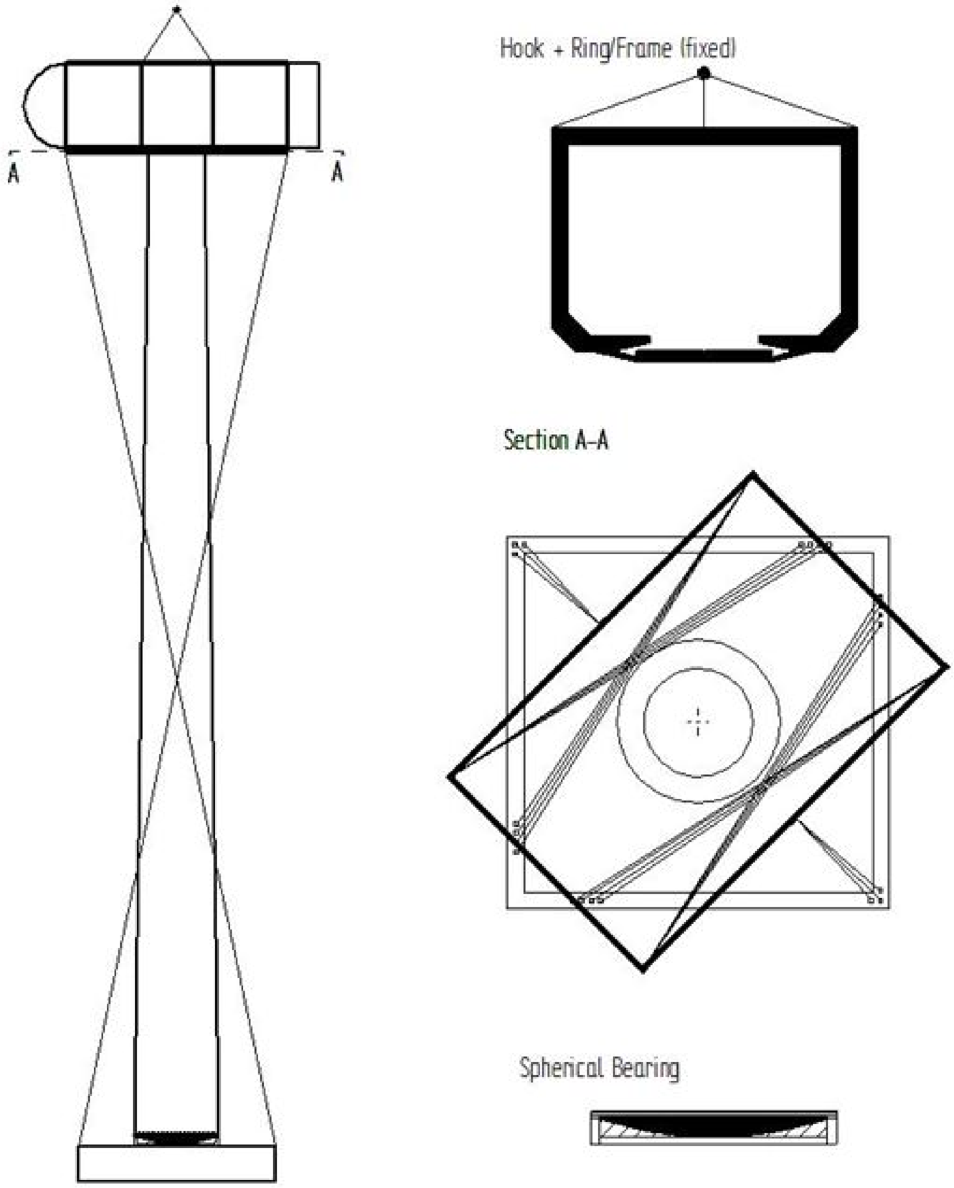


Figure 3.10: Vertical and section WTG views, Concept 4

3.1.5. Concept 5

The fifth concept is based on the static scheme n. 5 and has the following features:

- Critical actions: between CoG and bottom;
- Structural element: steel beams;
- Connection (bottom): rigid;
- Equipment (bottom): bolts;
- Connection (Middle/Top): semi-rigid;
- Equipment (Middle/Top): pads;
- System positioning: over grillage;

The aim of this concept is to use an external structure to keep part of the stresses acting on the tower, by being as less invasive as possible. This suggests the utilization of sliding steel elements able to perform a cladding system by their attached pads. In order to be an effective solution, the height of this system has to be limited, from 5 to 10 m over the grillage. Here shear and bending moment on the tower are still really high and represent an issue for the system design and feasibility. In order to give an appropriate slope, the grillage dimension is kept as the one of cable solutions, so smaller than the initial concept. Appropriate material should be applied at the pad-tower connection to avoid external structure damages and proper distribution of stresses. High bending moment would develop through the tower height, affecting structural integrity of the thin wall elements.

Installation procedure can be really effective, since all the sea-fastening is incorporated into the grillage volume. Once the load-out is performed, both the temporary sea-fastening and clamping can be applied and the hooking out rapidly may take place. Another advantage is that just moderate special equipment is required. It refers to the jacking system able to clamp the bottom tower trough circular pads.

Challenges can be found in the spreading of high induced actions on the grillage itself. These should be spread on the deck according to its capacity and the grillage footprint could not be enough for that. Moreover, this solution would be pretty similar to the first concept, in terms of acting stresses on the tower. At clamping position and bottom flange these could be critical.
According to deck and crane boundaries, up to four WTGs may be placed on deck.

The application of a skidding system could be really effective for this solution. Case 1 is therefore here considered, with both the carrying load possibilities from bottom and external brackets. The longitudinal direction of this system would allow up to six WTGs to be transported simultaneously.

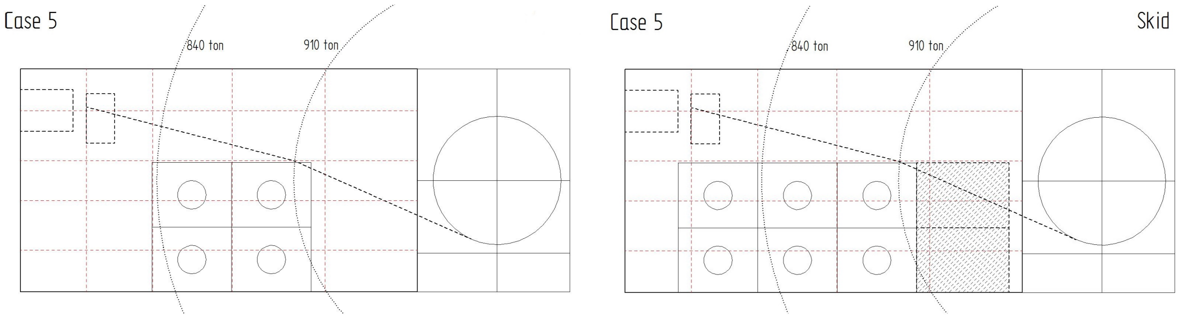


Figure 3.11: Footprint over OS deck, Concept 5

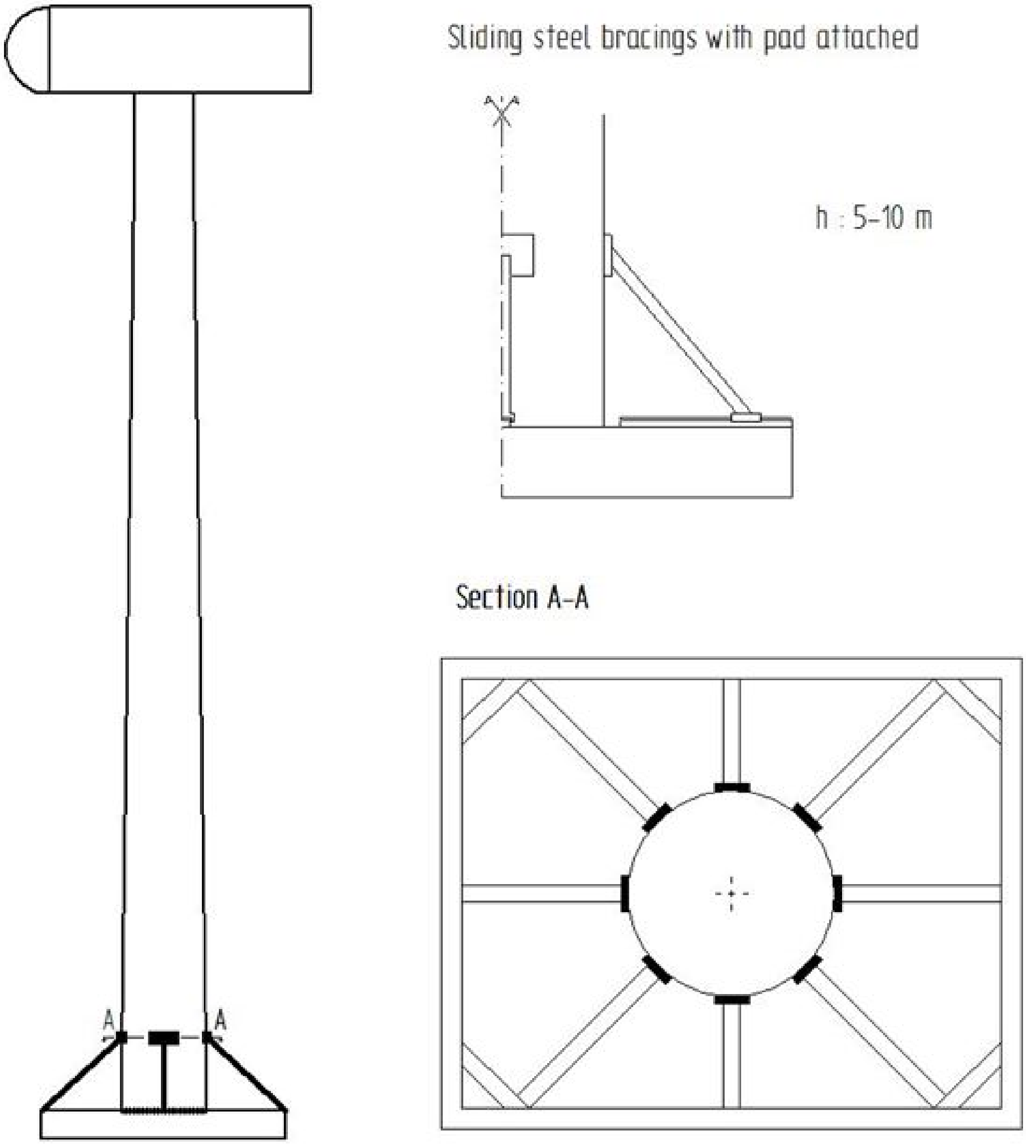


Figure 3.12: Vertical and section WTG views, Concept 5

3.1.6. Concept 6

The sixth concept is based on the static scheme n. 6 and has the following features:

- Critical actions: between CoG and bottom;
- Structural element: steel beams;
- Connection (bottom): hinged;
- Equipment (bottom): rotational equipment;
- Connection (Middle/Top): semi-rigid;
- Equipment (Middle/Top): ring or pads;
- System positioning: in between;

The concept provides a combination of bottom sea-fastening together with middle height clamping by means of an external structure. In order to make it less invasive and to not affect the weight increase over the deck, steel bracing system is chosen. Here, the higher the height, the lesser the reactions and bending moment at the bottom. Of course a balance is required, since too high external structure would affect logistic procedures and solution effectiveness. Thus, a range from 25 of 35 m is chosen for this solution, to be used for possible further analysis.

The idea is to apply a main steel vertical structures that balances two rows of WTGs. Since the loads are anti-symmetric, even despite different nacelle orientation, optimization is necessary to avoid high stress concentration on just one edge. Thanks to the potential reduced bending moment at the bottom a reduced grillage dimension is chosen. This fit with the requirement of reduced foot print to have available space for external structure. For the solution without skidding, both longitudinal or transversal vertical steel structures are possible. Integrated solutions between grillages and external structure can be applied.

As in Concept 4, an hinged connection is provided at the bottom of the tower. This may come from the adaptation from bridge engineering practice; here a rotational system is seen here as the most suitable choice for the purpose, due to its delicate nature and the already well proved technology for this kind equipment. common solutions are elastomeric, pot and spherical bearings. All the specifications and selections are proposed further, when the specific design is proposed.

Advantages are found in the low requirement of special equipment. A clamping connection, by means of ring elements, should be designed to transfer the loads to the external structures. Even though that may be enough, differences in stiffness between bottom and support could affect the whole sea-fastening system behaviour. Nevertheless, too high stress concentration may arise in the low tower part. For these reasons, a hinge connection is chosen to avoid these potential problems. Time spending can be reduced, since the construction of the steel structure is carried out onshore and can be loaded out in one stage. Welding on the deck can be a time spending procedure, so proper organization is required to optimize it by its overlapping with other parallel activities. Load out of the tower can be performed in sequence and temporary sea-fastening can be done at bottom and through the clamping at middle height. This shall speed up crane activities, related to hooking in and out of WTGs in series. Possible issues regard the high concentration of stresses at the clamp position and vertical and plane space occupancy of the massive steel structure, which could limit crane operations during installation.
According to these features, up to six WTGs may be placed on deck.

The application of a skidding system would limit the steel structure development only through the longitudinal direction. Grillages are not incorporated but free to move over the skidding rails. Case 2 is the one considered here, with the possibility of carrying the load from external brackets positioned at the grillage ends. Thanks to this skidding system adoption, six WTGs may be placed on deck.

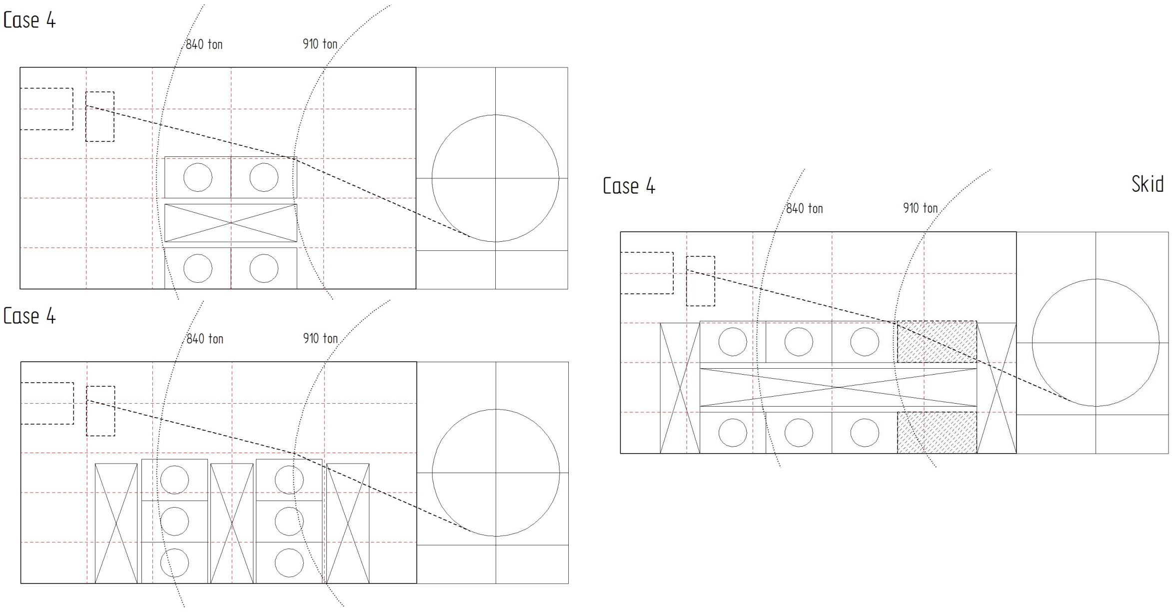


Figure 3.13: Footprint over OS deck, Concept 6

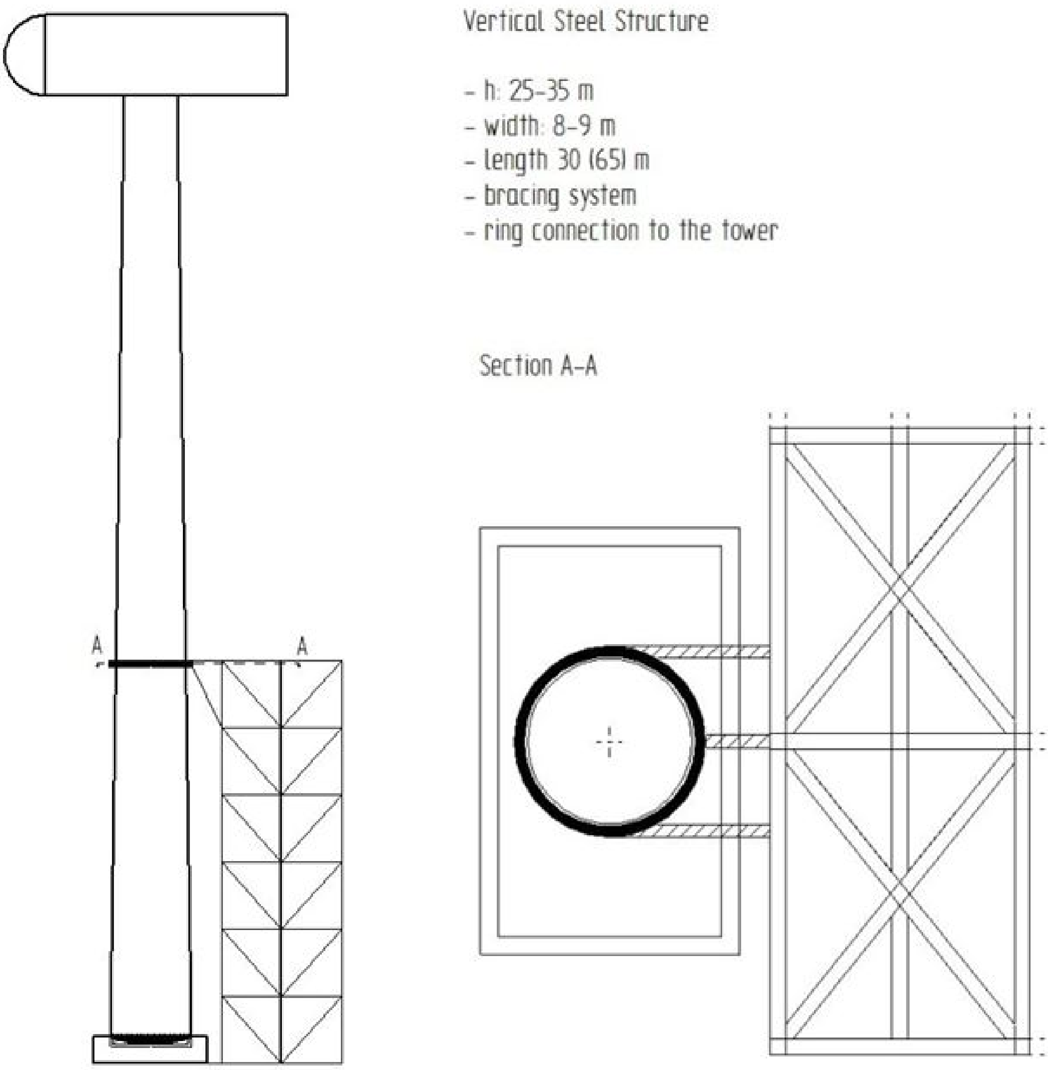


Figure 3.14: Vertical and section WTG views, Concept 6

3.2. Comparison and Selection

After having pointed out main features and installation techniques of selected concepts, a comparison is made in order to assess the goodness of choices by investigating their response towards some relevant functions. The following procedure provides a rather simple evaluation of the argument relation with respect to each concept. It is done through the definition of a weighted evaluation matrix. This tool allows to compare alternatives with different level of importance and field of application by defining a "weight" for each alternative involved. Here the alternatives are arranged in main indexes. Each index presents the description of the different concept behaviours with respect to that issue. Grades are given, in a scale from one to ten, and then weighted according to the index importance towards the overall assessment. The evaluation procedure is described for each index.
A total of seven indexes are considered for this purpose. The final decision takes into account these results but do not consider them as binding but just as a useful tool to which base the effectiveness of the conclusive choice. Therefore considerations are provided for the explanation of each decision. According to the described procedure, the best solutions to be discussed are the ones with the lower final grades. Index weights are defined according to their importance towards the concept realization and application. Number of WTGs is the most relevant one. Then handling complexity plays a decisive role, together with structural feasibility. Time spent for both load-out and installation are ranked with the same weight. Finally solution complexity takes place. These weights are defined starting from the average value of 14% (seven options with the same weight) and adapted according to the just mentioned considerations. Their values are proposed in the last Table 3.9, where the analysis results are shown as well.

First index refers to solution complexity. Base reference is given by Concept 1 that does not have any complex device, since just limited to bolted bottom flange. Other situations take into account the complexity by considering the number of equipment and their grade of sophistication, Table 3.2. The higher the complexity, the higher the grade.

Table 3.2: Ranking for index 1: solution complexity

1. Solution Complexity		
Concept	*Description*	*grade*
1	/	0
2	hook, moving ring, cables, anchorages, tfc	5
3	hook, fixed ring, cables, anchorages, tfc	4.5
4	hook, fixed ring, cables, anchorages, tfc, rotational system	5.5
5	small steel, pads, tfc	3
6	massive steel, ring elements, tfc, rotational system	3.5

Time saving is divided into two steps, at load-out and installation phases. The flange bolting is present in all the situations but considered more incisive for the first concept. Cable tensioning has more influence in the first phase than during installation offshore, since the proper arrangement can be done there while the vessel is sailing away. The higher the time spent, the higher the grade (Tables 3.3 and 3.4).

Table 3.3: Ranking for index 2: time saving – load-out

2. Time saving – Load-out		
Concept	*Description*	*grade*
1	flange bolting	0.5
2	ring movement, cable tensioning	3.5
3	cable tensioning	2.5
4	cable tensioning	2.5
5	pads alignment	1.0
6	steel welding, ring alignment	2.0

Table 3.4: Ranking for index 3: time saving – Installation

3. Time saving – Installation		
Concept	*Description*	*grade*
1	flange bolting	0.5
2	ring movement, cable tensioning	2.5
3	cable tensioning	1.5
4	cable tensioning	1.5
5	pads alignment	1.0
6	ring alignment	1.0

Structural feasibility assesses the number of critical positions that could be overstressed or becoming an issue for the design. These are related to the static scheme chosen and the special equipment limitations. Only hypotheses are made at this stage since the structural behaviour is not known yet. The higher the feasibility issues, the higher the grade (Table 3.5).

Table 3.5: Ranking for index 4: structural feasibility

4. Structural feasibility		
Concept	*Description*	*grade*
1	flange, wall, connection, buckling	7.0
2	top, support	3.0
3	wall, top, buckling	4.0
4	buckling, wall, hook	5.0
5	support, flange, connection, buckling	5.0
6	wall, support	2.0

Cost optimization is related to the material involved for making the required sea-fastening. Steel for grillage is considered with an unitary coefficient while acquires a slightly higher value for external structure. They are considered according to the assumed dimensions. Equipment is accounted per units. The coefficient is about one hundred time the one adopted per meter of steel assumed to be used. The higher the hypothetical costs, the higher the grade (Table 3.6).

Table 3.6: Ranking for index 5: cost optimization

5. Cost optimization		
Concept	*Description*	*grade*
1	Grillage	0.9
2	Grillage + equipment	6.1
3	Grillage + equipment	5.6
4	Grillage + equipment	7.0
5	Grillage + equipment + external small structure	2.1
6	Grillage + equipment + external massive structure	8.3

Handling complexity refers to the issues and procedures in dealing with the several selected structural systems. As already underlined in the concept overview, they are strongly dependent on the external equipment chosen and their position. This is one of the most relevant parameter able to affect safety matters for the procedures. The higher the complexity, the higher the grade (Table 3.7).

Table 3.7: Ranking for index 6: handling complexity

6. Handling complexity		
Concept	*Description*	*grade*
1	/	0.0
2	hook fixation, bottom cable anchoring	2.0
3	hook fixation, ring fixation, bottom cable anchoring, free cables	3.5
4	hook fixation, ring fixation, bottom cable anchoring, free cables, rotational system	4.0
5	pad fixation	0.5
6	ring fixation, rotational system	1.5

Number of WTGs represents the most important parameter for the consideration and the selection of the choice. It is fundamental for the application of the conceptual design in real projects. To make this study competitive, a large number of WTGs needs to be carried on board. Since the maximum number of WTGs is set at six, for deck and crane dimensional limits, this value is considered as reference. Necessity of skidding system gives a negative contribution in the grade. The lower the number of WTGs possibly carried, the higher the grade (Table 3.8).

Table 3.8: Ranking for index 7: number of WTGs

7. Number of WTGs		
Concept	*Description*	*grade*
1	No skid 3 – skid 3	3.0
2	No skid 4 – skid 6	1.0
3	No skid 4 – skid 6	1.0
4	No skid 4 – skid 6	1.0
5	No skid 4 – skid 6	1.0
6	No skid 6 – skid 6	0.0

The final matrix, without the specific descriptions, is provided in Table 3.9. The analysis points out that the three most promising solutions, in order of relevance, are Concepts 5, 6 and 1.

Table 3.9: Final Concept ranking - Weighted evaluation matrix

Index	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**TOTAL**
Weight	**7.00%**	**12.00%**	**12.00%**	**16.00%**	**14.00%**	**18.00%**	**21.00%**	
Concept				*weighted grades*				
1	0.00	0.06	0.06	1.12	0.13	0.00	0.63	***2.00***
2	0.35	0.42	0.30	0.48	0.85	0.36	0.21	*2.97*
3	0.32	0.30	0.18	0.64	0.78	0.63	0.21	*3.06*
4	0.39	0.30	0.18	0.80	0.98	0.63	0.21	*3.49*
5	0.21	0.12	0.12	0.80	0.29	0.09	0.21	***1.84***
6	0.25	0.24	0.12	0.32	1.02	0.18	0.00	***2.13***

The high advantages of Concept 1 are clearly due to its simplicity, even though over-dimensioned grillages would be required. On the other hand, structural feasibility and number of WTGs show how this solution is the less competitive for the critical parts involved and the limited number of WTGs transported.
Concepts 6 and 5 good grades underline their positive responses with respect to basically all the requirements. Still, concept 5 seems to have more potential issues in structural feasibility. Concept 6 compensates the disadvantages of massive external structure presence with the possibility to transport up to six WTGs both with and without skidding system.

Some calculations are carried out and proposed in Appendix A.1, to check the feasibility of the solutions with respect to reaction forces allowed on board of OS.

For the reason mentioned so far, according to description, conceptual design calculations, advantages and disadvantages and potential issues, Concept 6 is chosen as the solution to be investigated for this case of study. It is applied without skidding system, since one configuration has been found that makes possible the same amount of WTGs, such as six per voyage. For this choice, skidding system is not further mentioned or taken into account.

3.3. Preliminary detailing considerations

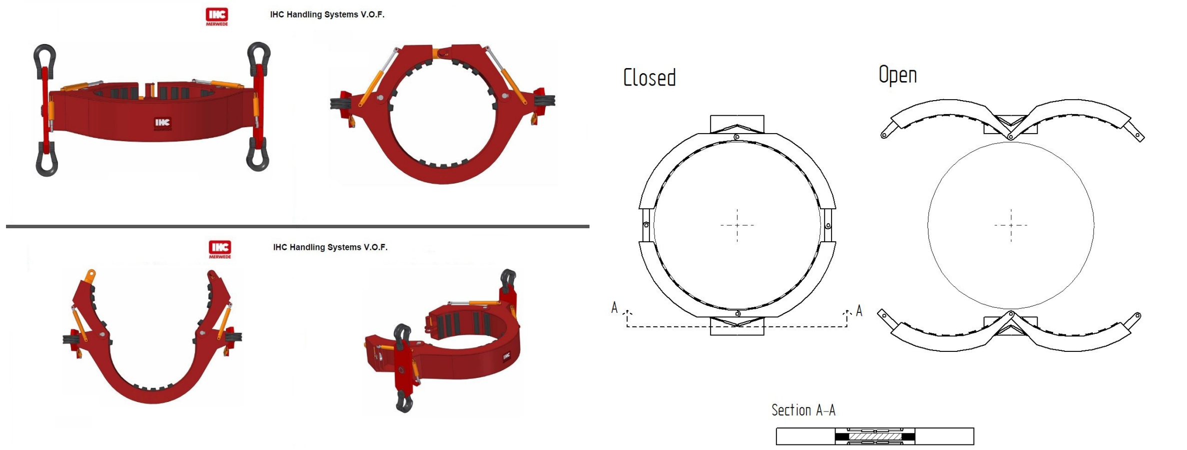
Now that the concept is defined, its proper definition is required. Since the possibilities of applications could be definitely wide, this stage is important to further narrow the application field of this case of study.
The main playing characters to be focused on are the steel bracing structure, clamping ring, hooking system, rotational system and bottom flange connection (bolted and with TFC). Required performances, order of magnitude for dimensions and already available designs are proposed. It represents the starting for the complete detailing to be developed, main goal of calculations and structural analysis.

3.3.1. Steel bracing structure

The purpose of the external steel structure is to provide a sufficient stiff support for the tower against external actions. After the stresses are taken over by proper clamps, this structure needs to transfer all the resultants to the deck strong points. Its dimension has still to be evaluated. Only the height is chosen, at 30 m, where clamping system are attached and connected to the towers.
Since the bending moment resultants at the foundation are really high, due to the level arm length, a distribution of supports over a large deck footprint is required, in order to match with the vessel capacity. At deck level another boundary is given by the crane position at rest. On height, dimension requirements are just related to tower occupancy and tolerances for clamping system movements. Because of the goal is to optimize the structure to avoid high weights and accelerate welding and handling works, steel frame system is chosen. Moreover, to save important deck footprint, grillages are incorporated in this structure.
At the end, each transversal row of towers is clamped and supported at both sides. Thus, a symmetrical structure is proposed, even though the presumable rolling action would require higher dimensioning for one of the two sides.
The final appearance follows the idea proposed in the concept final overview (Figure 3.19 and 3.20), where the mentioned parameters are put together to create a starting concept. Steel bracings are made by wide and compact flange beams, according to the grillage structures. Further improvements and changes are provided after calculation checks.

3.3.2. Clamping system

According to the concept chosen, a main requirement is to transmit actions from the tower to the external supporting steel structure. Clamping system is defined as the most suitable choice, even with regards to the boundary of no welds on the tower. Symmetry and necessity to involve as more surface as possible (for a better stress spreading over the structure) are fundamental requirements. Furthermore, this device needs to withstand high horizontal forces and bending moments induced by the vessel movements. This scope has to be carried out through a sufficient stiff connection, in order to avoid stress distribution over different parts of the tower. At the same time, this system should provide efficient and fast handling procedures for load-out and installation offshore. For these reasons, ring solution appears the most appropriate for the purpose.
In the following pictures, first an input design is provided. It comes from IHC and refers to a movable ring elements, thought basically for lifting activities. (Figure 3.15(a)) A second picture shows the general appearance of the desired one, able to clamp the tower around the whole diameter and free it when required. (Figure 3.15(b))

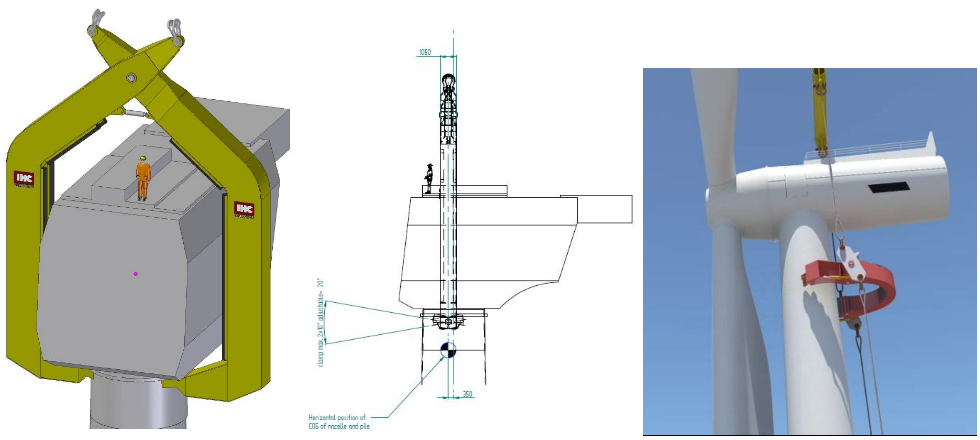


(a) IHC handling system design (b) Conceptual design

Figure 3.15: Clamping system: ring element

3.3.3. Lifting system

A lifting system is required to allow load-out and installation activities. Its design is not the focus of this study but considering its possible applications and issues acquires fundamental importance for a complete view of the work. Thus, some possibilities may be investigated. The first one is based on the utilization of a large hook over the nacelle, connected to the crane and acting directly at the top of the tower, Figure 3.16. Critical features of this choice may arise about the high stress developments at the clamping surface, localized at the bottom of the nacelle, over the flange connecting the latter with highest tower element. Moreover, with this method no links to the bottom of the tower are provided. That may induce unexpected movements during lifting and difficulties in alignment during installation. In order to avoid these problems, trunnions at the bottom should be installed and connected in a certain way at the lifting point. It may be performed by using the clamping ring itself as lifting mean: once required, it would be disconnected form the external steel structure and linked to the crane with appropriated rigging, running from the top to the trunnions at the bottom of the tower. With this solution, the ring is used to withstand horizontal actions while the rigging to carry the high vertical forces directly from the bottom.
As already mentioned in the boundary conditions and initial choices, Chapter 1, the possibility of welding elements like trunnions on the main structure has to be avoided. Thus, the first choice, a massive hook, is selected as preferred one. According to the purpose of this study, this selection is assumed as not able to affect next calculations and choices.



(a) Hooking system (c) Ring connected at the bottom

Figure 3.16: Lifting system, IHC draft design (IHC)

3.3.4. Tower-flange bolted connection

A bolted connection is provided at the tower bottom flange level, in order to finally sea-fasten this part with the grillages on deck. Depending on the choices around he spherical bearing, this connection is made by the internal circular flange at the bottom of the tower. This part is usually really thin and potentially brittle. Bolt dimensions are in the order of M50, and number of holes along the circumference may vary, even with same section diameter.
Apart from flange failure, another critical aspect is the tension in the bolts. For Concept 1 this represents one of the main limits, since the tension capacity of the strongest preloaded bolts on the market cannot withstand the bending moment for the worst motion conditions. The selected concept does not have this issue. The focus move to the flange integrity and the kind of connection in case of structural bearing. Depending on the latter dimension, proper considerations on this connection has to be made.

3.3.5. Tower-flange clamp

This device provides a quick way of connection through an hydraulic system. It is meant for tower – foundation flange connection, originally just for temporary activities during the offshore installation. Its design is from IHC Merwede. Due to its potential of increase in time saving and reutilization, it can be transposed to sea-fastening applications. Fundamental features are the compact dimensions and weight that make it able to be handled by one person. This tool uses three adjacent holes of the flange. In the middle one an hydraulic puling device acts while the external two provide the required support. The pulling force capacity is set up at 25 tonnes, with possible improvements without deep changes in the actual design. The capacity is currently the most strict boundary condition that do not allow this devices to substitute all the bolted connections present in the conceptual ideas. Since this force has to compensate the tensile resistance offered by three bolts, it could be feasible only where bending moment are not too high at the foundation level. Despite the investment costs for this tool can be high (ca 12000 € per piece), the advantages given are enormous, in terms of speeding up the unfastening procedures offshore and reutilization of elements.
For the purposes of this study, it appears an useful tool for providing a temporary sea-fastening during load-out phases at the harbour. Once the WTG is placed over the grillage, a sufficient amount of TFC can be placed to clamp the structure and to withstand the limited vessel motions and wind acceleration due to the harbour conditions. At the same time clamping system at height can be applied, while the crane can be hooked out from the WTG and move to the next tower load-out. Since hooking-out time is much longer than the one for hooking-in, being able to start this procedure early can positive affect the overall time saving. Once the tower is clamped, another team can substitute the TFC with traditional bolting and move to the next structure to be temporary sea-fastened. Even though in this way a double fastening is provided, the advantages in time saving are enormous since do not constrain the crane operation for long lapses of time. Moreover this equipment would be already present on board for its utilization during offshore installation: then no added cost would be induced. In Appendix A some calculations are provided to show the feasibility of this choice.

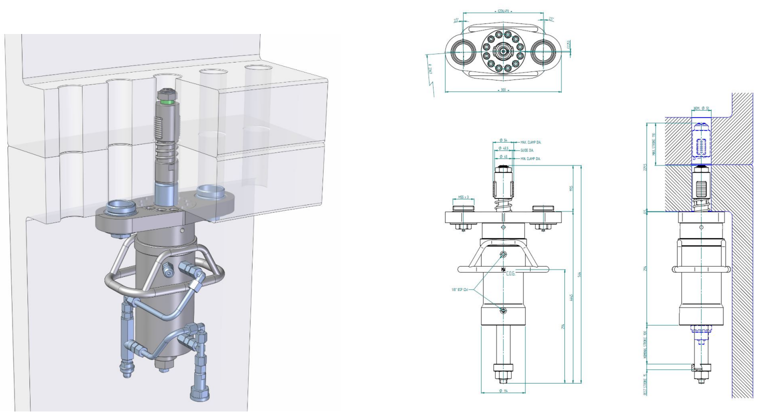


Figure 3.17: Tower Flange Clamp: mechanical sections and application view (IHC)

3.3.6. Rotational system

The idea of structural bearing acquires more importance foreseeing a critical behavior of the tower under the worst transportation conditions. Indeed, providing a moment-free connection at the bottom, even for the selected concept, could not be seen fundamental for withstanding peak forces. On the other hand, it might appear really useful for avoiding stress developments through potentially critical parts. Moreover, less complicated calculations are required, to take into account difference in stiffness between the two support connections, once a proper hinged connection is guaranteed at the bottom. Then, the focus is moved to the clamping stiffness, where the great amount of shear force needs to be transferred to the external system.
Several possibilities could arise, based on already present solutions or on new and tailor made concepts. Since similar devices are commonly used in civil engineering practice for bridge applications, the initial choices move to them. Even though the field of application seems completely different, some analogies support this conceptual decision. High vertical forces involved, possibility of up-lift constraints, relatively large range of rotations, necessity of high durability with limited maintenance, suitability for low degree of temperatures. According to that, various possibilities are present among structural bearings for bridges, such as rocker, pot, elastomeric and spherical bearings. Their different features are treated and investigated according to their response in terms of:

- Vertical reactions due to self-weight and heave actions (both positive and negative);
- Range of angular rotation provided (it is calculated according the bending moment would arise if the hinge were not present);
- Fixed support, since no translations are required for this purpose.

Some of them may be very complex and subsequent highly expensive; however they already find application in the most critical bridge situations and are largely tested and checked. Durability is one aspect to be further considered during analysis. Another issue regards the different dimensions between usual bridge bearings, about one square meter, and the higher dimensions involved at the bottom of the WTG, for a diameter of 6 meters. Further adaptations and considerations are provided in detail after the structural analysis, during conceptual and design phases. At this stage some examples from bridge engineering practice are proposed.

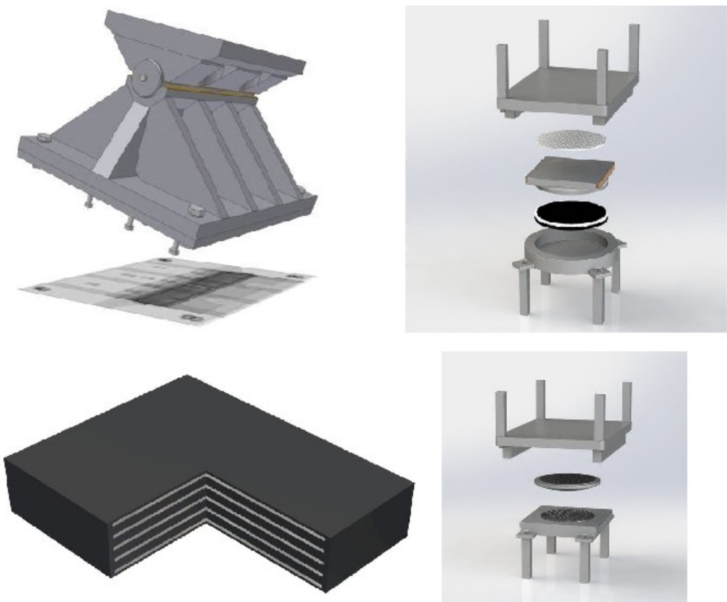


Figure 3.18: Bearing examples: rocker (a), pot (b), elastomeric (c) and spherical (d) bearings, Mageba and CCL designs

3.4. Summary and results

All the parameters of the selected solution are now defined. The overall appearance is therefore proposed. In the further chapters analysis is carried out regarding the external system and its interaction with the main structure involved, i.e. the integrated towers. The system is then divided into its four main parts, which represent the focus points of this study. They are so classified, together with their required calculations:

- Grillages and bottom steel structures;
- Rotational system;
- Steel bracing structure;
- Clamping system.

Grillages are common practice in offshore transportation. As already underlined, their main requirement is to properly transfer loads from limited areas to specific strong supports on the deck. Wide flange beams are normally used for this purpose, radially arranged in case of central load position. Therefore, the analysis about this part focuses on unity checks for each steel beam and buckling calculations. A limited fatigue analysis is proposed to determine the system quality in this field and the number of voyages can be provided before fatigue failure. It is chosen to apply a grillage system to the whole footprint area over the deck, as shown in Figure 3.19.

Rotational system is applied. It is chosen to avoid bending moment at the tower bottom by allowing rotations about longitudinal and transversal axis. Among all the possibilities, structural bearings are defined as possible solutions. They represent something new in terms of their application for offshore transportation, especially if the solution comes from bridge engineering common practice. Therefore a careful definition of the most suitable materials and available structural possibilities is provided. Then, calculation and dimensiong regard bearing and rotation capacity of the device, to be checked against the defined working conditions.

Two main requirements govern the vertical structure design. Firstly being able to withstand external actions providing necessary support for the WTGs and secondly being as lightest as possible. Lightness is intended in terms of weight, which directly affects features of fabrication cost, handling complexity and installation time. Therefore the design is based on compact or wide flange steel beams, arranged in a bracing system as proposed in the overview, Figure 3.20. Similar to grillages, calculations at this step regard unity checks and reaction forces, for the interested steel elements.

Clamping system represents a critical part, since it is the first place where sea-fastening act on the integrated towers. Definition of a proper connection acquires tremendous importance because of has to maintain tower integrity and not create issues for its service life after transportation. Furthermore it needs to have a smart design, in order to improve handling and speed in working procedures. Similar to rotational bearings, at this stage a careful research about available materials and solutions practice is required, to provide an effective design. Stiffness is one of the main focus points and is treated with some assumptions to be proved by models and FE analysis.

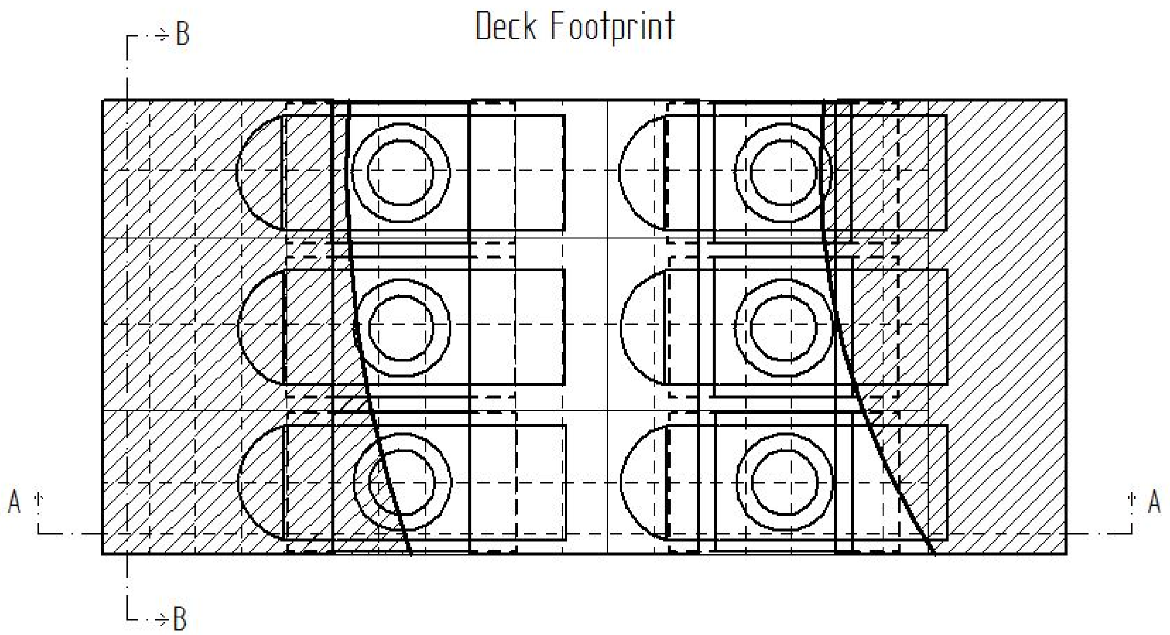


Figure 3.19: Top view, final conceptual solution over the deck

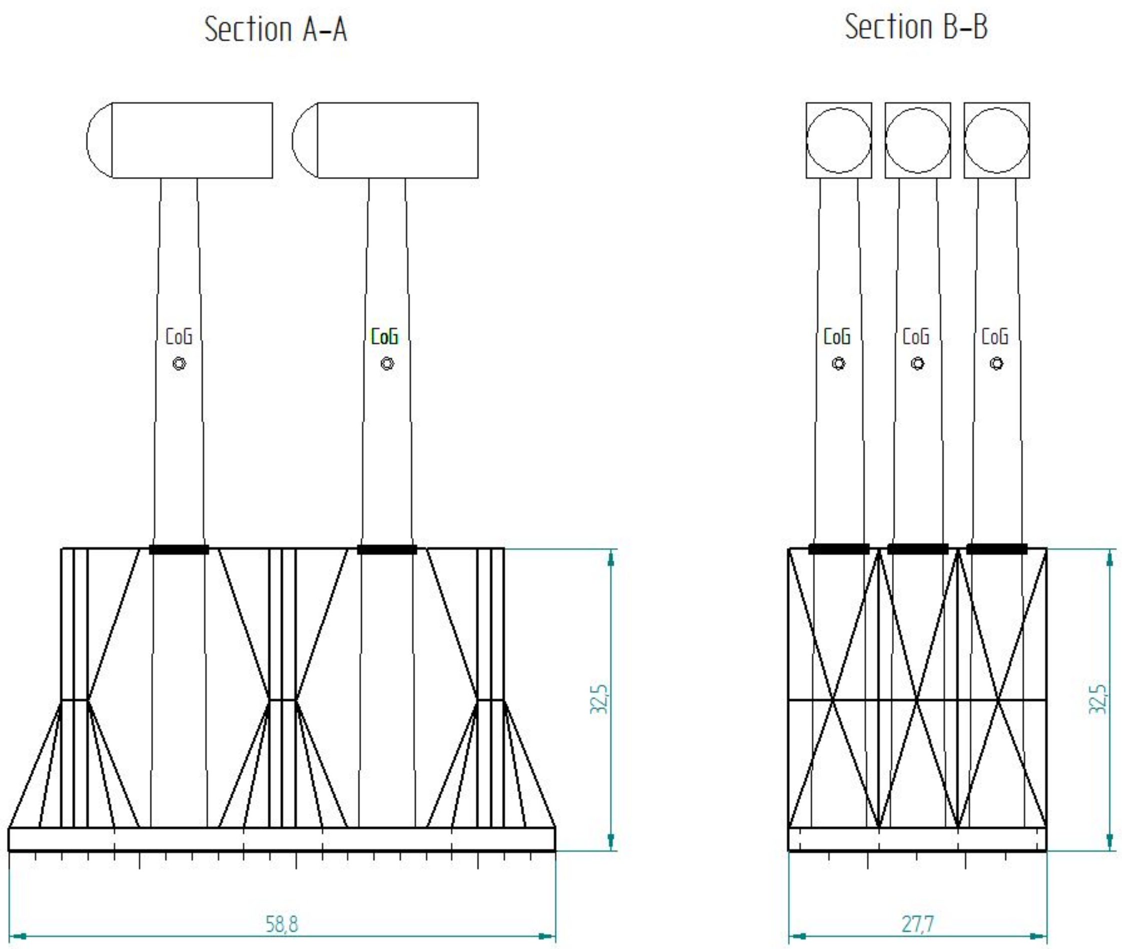


Figure 3.20: Side views, final conceptual solution over the deck

4

Design data

Land is the secure ground of home, the sea is like life, the outside, the unknown

Stephen Gardiner (1497 - 1555)

Calculation of involved actions is the aim of this chapter. The procedure just follows the natural order of analysis. From manufacturers' information, main dimensions and quantities are extracted. Then CoGs calculation follows, since constitutes one of the governing parameters for the final sea-fastening solution definition.
The assembled towers and sea-fastening structures are treated separately, with slightly different initial assumptions but same calculation procedure. Then, environmental data and vessel motions are provided, directly from SHL's Naval Department. They refer to specific sea-motion conditions in the North Sea, Appendix A.2. With reference to that, wind actions are evaluated, based on DNV guidelines [15]. Then, accelerations due to vessel motion are applied, in order to find pitch, roll and heave resultant actions.
Once the entire scenario is completed, load combinations are provided and the worst case situation is selected and kept for the study.

4.1. Input data definition

The first data to be used are the tower characteristics from manufacturers. A more precise analysis is now required for mass and CoG definition. There is an uncompleted data specification for Alstom and Siemens products, while Areva provides more detailed information about their WTGs. Anyway, since Alstom tower is going to be the one selected for further analysis, all the calculation passages are based on that product. For Areva and Siemens products, procedures are the same and final results are proposed at the end of this section. The main idea considers the division of the tower in three pieces, calculation of each CoG and CoA, addition of nacelle and hub contributes and final evaluation of integrated tower data. Orientation convention holds the x-axis along the longitudinal direction of the vessel, y-axis along the transversal one and z-axis along the vertical direction, upward positive.
The procedure is now proposed, just for the Alstom product, starting from the manufacturer input data. For the Tower it holds:

$$D_{bot,1} = 6.00m \qquad D_{top,1} = 5.45m \qquad H_1 = 20.00m \qquad Mass_1 = 173.00t \tag{4.1}$$

$$D_{bot,2} = 5.45m \qquad D_{top,2} = 4.77m \qquad H_2 = 24.50m \qquad Mass_2 = 124.00t \tag{4.2}$$

$$D_{bot,3} = 4.77m \qquad D_{top,3} = 4.00m \qquad H_3 = 28.77m \qquad Mass_3 = 103.00t \tag{4.3}$$

$$D_{bot} = 6.00 \qquad D_{top} = 4.00 \qquad H_T = 73.27m \qquad Mass_T = 400.00ton \tag{4.4}$$

then for Nacelle and Hub (considered together from manufacturer data):

$$H_N = 8.05m \qquad Mass_N = 363.00t \tag{4.5}$$

The centre of area (CoA) needs to be quantified for further wind action analysis. Tower, Nacelle and Hub CoAs are quantified from the deck height.

$$z_{T,CoA} = \frac{\left[\left(\frac{H_T}{3}\right)\left[\left(D_{bot} - D_{top}\right)\frac{H_T}{2}\right] + \left(\frac{H_T}{2}\right)\left(D_{bot}H_T\right)\right]}{\left(D_{bot} - D_{top}\right)\frac{H_T}{2} + \left(D_{bot}H_T\right)} = 34.19m \tag{4.6}$$

$$z_{N,CoA} = H_T + \frac{H_N}{2} = 77.29m \tag{4.7}$$

The centre of gravity (CoG) of each element is provided by the manufacturer:

$$x_{T,CoG} = 0.00m \qquad x_{N,CoG} = 4.21m \tag{4.8}$$

$$y_{T,CoG} = 0.00m \qquad y_{N,CoG} = 0.00m \tag{4.9}$$

$$z_{T,CoG} = 28.71m \qquad z_{N,CoG} = 77.23m \tag{4.10}$$

Then the results for the complete WTG to be transported holds:

$$x_{WTG} = \frac{Mass_T x_{T,CoG} + Mass_N x_{N,CoG}}{M_T + M_N} = 2.00m \tag{4.11}$$

$$y_{WTG} = \frac{Mass_T y_{T,CoG} + Mass_N y_{N,CoG}}{M_T + M_N} = 0.00m \tag{4.12}$$

$$z_{WTG} = \frac{Mass_T z_{T,CoG} + Mass_N z_{N,CoG}}{M_T + M_N} = 51.33m \tag{4.13}$$

Finally, the last data to be underlined is the total mass of the WTG. From table 4.1 the weights of each component are summed up and multiplied by a conservative coefficient, as suggested by SHL. This takes into account imperfections and external inaccuracies by considering a total mass increased of its **10%**.

$$Mass_{WTG} = \left(Mass_T + Mass_N\right) coeff_{SHL} = 839.30t \tag{4.14}$$

The same approach is applied for Alstom and Siemens WTG models. The final results are proposed in Table 4.1. As already mentioned, Alstom WTG is taken as reference one for most of the calculations, since it gives clearly the most onerous situation out of the three, from mass and dimension points of view.

So far only WTGs have been considered. External sea-fastening structures are now taken into account. Since their designs still has to be done, conservative dimensions and certain assumptions are made at this stage, further checked at the end of this chapter. A first choice is to consider the structures acting all together, defining a single CoG for the integrated system. This simplifies the calculations, since, as proposed in Figure 4.1, the structure results symmetrical about both x-z and y-z planes. Thus, inspection is required for the only vertical CoG position. Again, the grillage system should have thicker concentration per unit height with respect the bracing system, for the same longitudinal and transversal footprint. Since this difference could be difficultly calculated at this stage, it is not considered. This choice stays on the conservative side, because of results in an higher position of CoG. Thus, it can be simply calculated by considering the centroid of a rectangular area:

$$H_{grillage} = 2.5m \qquad H_{bracing} = 30m \tag{4.15}$$

$$z_{ext,CoG} = \frac{H_{grillage} + H_{bracing}}{2} = 16.25m \tag{4.16}$$

Table 4.1: Input Data - WTGs

ALSTOM Haliade 150-6MW							
From foundation	Part 1	Part 2	Part 3	**Tower**	Hub	Nacelle	**Complete WTG**
D_max [m]	6.00	5.45	4.77	6.00			
D_min [m]	5.45	4.77	4.00	4.00			
Height [m]	20.00	24.50	28.77	73.27		8.05	
x_L [m]						19.79	
y_L [m]						7.74	
Mass [t]	173.00	124.00	103.00	400.00		363.00	**839.30**
x_CoG [m]						4.21	**2.00**
y_CoG [m]							**0.00**
z_CoG [m]				27.82		77.23	**51.33**
x_CoA [m]						4.21	
y_CoA [m]							
z_CoA [m]				34.19	73.27	77.29	

AREVA M5000-135							
From foundation	Part 1	Part 2	Part 3	**Tower**	Hub	Nacelle	**Complete WTG**
D_max [m]	6.00	6.00	5.14	6.00			
D_min [m]	6.00	5.14	4.01	4.01			
Height [m]	13.50	28.40	30.67	72.57	7.51	6.75	
x_L [m]					5.17	16.10	
y_L [m]					7.50	10.50	
Mass [t]	190.0	88.80	87.50	366.30	75.00	221.65	**729.25**
x_CoG [m]					5.57	0.87	**0.92**
y_CoG [m]							**0.00**
z_CoG [m]				27.82	76.90	75.85	**49.43**
x_CoA [m]					5.57	0.87	
y_CoA [m]							
z_CoA [m]				33.88	76.33	75.95	

SIEMENS SWT-6.0-154							
From foundation	Part 1	Part 2	Part 3	**Tower**	Hub	Nacelle	**Complete WTG**
D_max [m]	6.50	6.50	6.50	6.50			
D_min [m]	6.50	6.50	4.15	4.15			
Height [m]	14.10	37.70	36.00	87.80	8.00	7.40	
x_L [m]					5.50	15.08	
y_L [m]					8.00	6.50	
Mass [t]	94.00	158.70	113.70	366.40	90.00	218.00	**741.84**
x_CoG [m]					7.68	1.40	**1.48**
y_CoG [m]							**0.00**
z_CoG [m]				37.74	93.46	91.93	**62.70**
x_CoA [m]					7.68	1.40	
y_CoA [m]							
z_CoA [m]				40.67	91.80	91.50	

Finally the Moment of Inertia for the WTGs can be computed, with respect to their CoG positions. To treat the truncated cone geometry, the average external radius is considered, for each of the three tower elements, in order assume them as solid cylinders. Then, the contribution of hub and nacelle are added up, considering them as a cuboid, [16].

$$Ix_{T,1} = \frac{1}{12} Mass_T \left(3R_{av,1}^2 + H_1^2\right) + Mass_T \left(z_{WTG} - 0.5H_1\right)^2 = 3.02 \cdot 10^8 kgm^2 \tag{4.17}$$

$$Ix_{T,2} = 1.96 \cdot 10^8 kgm^2 \tag{4.18}$$

$$Ix_{T,3} = 1.48 \cdot 10^8 kgm^2 \tag{4.19}$$

$$Ix_T = Ix_{T,1} + Ix_{T,2} + Ix_{T,3} = 6.45 \cdot 10^8 kgm^2 \tag{4.20}$$

$$Iy_T = Ix_T = 6.45 \cdot 10^8 kgm^2 \tag{4.21}$$

$$Ix_N = \frac{1}{12} Mass_N \left(L_{y,N}^2 + H_N^2\right) + Mass_N \left(z_{N,CoG} - z_{Cog}\right)^2 = 2.47 \cdot 10^8 kgm^2 \tag{4.22}$$

$$Iy_N = \frac{1}{12} Mass_N \left(L_{x,N}^2 + H_N^2\right) + Mass_N \left[\left(z_{N,CoG} - z_{Cog}\right)^2 + y_{N,CoG}^2\right] = 2.64 \cdot 10^8 kgm^2 \tag{4.23}$$

A summary table proposes the results for the three designs. (Table 4.2)

Table 4.2: Moments of Inertia - WTGs

		Tower	Hub	Nacelle	***Total***
Alstom	$Ix\ [kgm^2]$	6.45E+08	-	2.47E+08	**8.92E+08**
	$Iy\ [kgm^2]$	6.45E+08	-	2.64E+08	**9.09E+08**
Areva	$Ix\ [kgm^2]$	5.75E+08	5.73E+07	1.58E+08	**7.89E+08**
	$Iy\ [kgm^2]$	5.75E+08	5.94E+07	1.61E+08	**7.94E+08**
Siemens	$Ix\ [kgm^2]$	8.57E+08	8.62E+07	1.88E+08	**1.13E+09**
	$Iy\ [kgm^2]$	8.57E+08	9.12E+07	1.92E+08	**1.14E+09**

In accordance with WTG calculations, a similar procedure is applied for the sea-fastening structures. A first assumption is to divide them into four main parts: the grillage, the central vertical structure and the two external ones. They are treated symmetrically with respect x-z and y-z planes, passing through the CoG of the central vertical structure. To make it possible, more hypothesis are made, regarding cross section steel beams for grillages and bracings. A more detailed calculation for the beam distribution is required to define the total mass of the system. It is proposed in Appendix A.3, where the output from software SACS provides the general overview and the mass definition, for the chosen cross sections. In the analysis they may be modified and this initial assumption be revisited. The result is a total mass of 2600 tonnes, with 1200 tonnes just referred to the bottom grillage. In Table 4.3 all the properties are proposed.

Regarding MoI definition, these elements are treated as parallelepipeds thanks to their symmetric nature. For the vertical structures, the maximum longitudinal dimensions (i.e. at the bottom) are considered, in order to be more conservative. Since the calculation procedure is comparable to the one provided for the WTGs, just the results are showed in Table 4.4.

Table 4.3: Input data - External sea-fastening structure

From foundation	***Grillage***	***Vertical 1***	***Vertical 2***	***Vertical 3***
Height $[m]$	2.50	32.50	32.50	32.50
x_L $[m]$	58.80	14.00	16.80	14.00
y_L $[m]$	27.70	27.70	27.70	27.70
Mass $[t]$	1200.00	350.00	700.00	350.00
x_A $[m^2]$	147.00	79.62	67.41	79.62
y_A $[m^2]$	69.25	263.50	263.50	263.50
x_CoG $[m]$	0.00	22.40	0.00	-22.40
y_CoG $[m]$	0.00	9.10	0.00	-9.10
z_CoG $[m]$	1.25	17.50	17.50	17.50
x_CoA $[m]$	0.00	22.40	0.00	-22.40
y_CoA $[m]$	0.00	9.10	0.00	-9.10
z_CoA $[m]$	1.25	17.50	17.50	17.50

Table 4.4: Moments of Inertia - External sea-fastening structure

Moments of Inertia	***Grillage***	***Vertical 1***	***Vertical 2***	***Vertical 3***
Ix $[kgm^2]$	3.46E+08	3.20E+07	6.90E+07	3.20E+07
Iy $[kgm^2]$	7.74E+07	4.86E+07	9.73E+07	4.86E+07

4.2. Motion analysis reference

In Appendix A.2, results form Naval Department show accelerations of WTGs placed on the Oleg Strashnov vessel, for the selected environmental and working conditions.
Translational accelerations:

$$a_x = 2.4\frac{m}{s^2} \qquad a_y = 3.0\frac{m}{s^2} \qquad a_z = 11.3\frac{m}{s^2} \tag{4.24}$$

Angular accelerations:

$$Roll \qquad \alpha_x = 1.343\frac{deg}{s^2} \qquad Pitch \qquad \alpha_y = 1.430\frac{deg}{s^2} \tag{4.25}$$

Project location for the hypothetical wind-farm is chosen in the North Sea, specifically at Borkum West II, *54.0417° N, 6.4667° E*. Even though accelerations vary along different positions on the vessel, the results refer to a unique Tower CoG. This assumption seems to be not conservative but allows to speed up output data from Naval Department. Considerations about that are underlined at the end of the study, in Chapter 11. To increment the possible working periods during the year, according to 10 years of wave spectra for the selected position and vessel heading, a significant wave height of 5.0 m is chosen. This parameter has a fundamental influence on the whole analysis, since if reduced, would decrease external actions on the WTGs and limit the working period at the same time. Therefore, a minimum value to maintain a certain competitiveness for the clients would be 4.0 m. Heading control is another parameter which affects roll and pitch actions on the vessel. It is chosen to consider for this study a fixed heading of 180 deg.

For Wind Load analysis, calculations are based on DNV guidelines [15]. Input data, again from Naval Department, provides the mean Wind speed, for 10 min at reference wind Height of 10 m:

$$U_0 = 40knots \qquad H_{ref,LAT} = 10m \tag{4.26}$$

4.3. Design actions

In this section, forces induced by wind and vessel motion are determined, according to all the possible situations. They result in terms of bending moments at the foundation level. Then, a combination of them proposes the different scenarios and the related cumulative actions. The worst is chosen as design data for the further calculations. Even though actions at CoG and not at foundation level are the goal of this section, this procedure provides a simple way of comparison for the several action combinations; then the selected one is translated into design loads at the required position. Again, the same process holds for both WTGs and sea-fastening structures. Therefore, for the first the main calculation steps are proposed together with final results. For the latter, just final design actions are summarised in the related tables. For both of them, further details are provided in Appendix A.3.

4.3.1. WTGs

First step is the definition of the several areas, influenced by the wind action. Due to its truncated conical geometry, tower's area for both x and y directions appears as follows. Then, hub and nacelle are treated, assuming respectively an hemisphere and a parallelepiped. Since no information is provided for Alstom hub dimensions and weight, it is considered together with the nacelle. This assumption gives results on the safe side.

$$A_{T,x} = D_{bot,1} \cdot H_1 + \left(D_{bot,2} + D_{top,3}\right) \cdot (H_2 + H_3) \cdot 0.5 = 371.56m^2 \qquad A_{T,y} = A_{T,x} = 371.56m^2 \tag{4.27}$$

$$A_{N,x} = L_{N,x} \cdot H_N = 159.27m^2 \qquad A_{N,y} = L_{N,y} \cdot H_N = 62.31m^2 \tag{4.28}$$

The distance from the L.A.T. and the actual position of WTGs CoG is treated by defining the deck height and assuming the grillage height (as previously proposed).

$$H_{deck} = 5m \qquad H_{grill} = 2.5m \tag{4.29}$$

Then, all the CoG positions may be adapted:

$$z_{T,CoG,LAT} = z_{T,CoG} + H_{deck} + H_{grill} = 35.32m \tag{4.30}$$

$$z_{N,CoG,LAT} = z_{N,CoG} + H_{deck} + H_{grill} = 84.73m \tag{4.31}$$

The mean wind speed actions on each WTG component, for an average period T of 10 minutes, are calculated according to the related offshore guidelines DNV-RP-205 [15]. Furthermore, from the same guidelines shape factors are defined.

$$U_{T,10} = U_0 \cdot \left[1 + 0.137 \cdot ln\left(\frac{z_{T,CoG,LAT}}{H_{ref}}\right) - 0.047 \cdot ln\left(\frac{T_1}{T_0}\right)\right] = 26.36\frac{m}{s} \tag{4.32}$$

$$U_{N,10} = U_0 \cdot \left[1 + 0.137 \cdot ln\left(\frac{z_{N,CoG,LAT}}{H_{ref}}\right) - 0.047 \cdot ln\left(\frac{T_1}{T_0}\right)\right] = 28.83\frac{m}{s} \tag{4.33}$$

$$C_{T,x} = 0.5 \qquad C_{T,y} = 0.5 \tag{4.34}$$

$$C_{N,x} = 0.5 \qquad C_{N,y} = 0.5 \tag{4.35}$$

Finally wind load actions on each part of the WTG can be evaluated. The results show that along x-direction their magnitude is higher than in y-direction.

$$F_{T,w,x} = 0.5\rho_a \cdot U_{T,10}^2 \cdot A_{T,x} \cdot C_{T,x} = +79.16kN \quad F_{T,w,y} = F_{T,w,x} = +79.16kN \tag{4.36}$$

$$F_{N,w,x} = 0.5\rho_a \cdot U_{T,10}^2 \cdot A_{N,x} \cdot C_{N,x} = +40.58kN \quad F_{N,w,y} = 0.5\rho_a \cdot U_{T,10}^2 \cdot A_{N,y} \cdot C_{N,y} = +15.88kN \tag{4.37}$$

These forces are translated in bending moments at the WTG foundation level, to provide useful data for further calculations and load combinations. Due to the wind nature, these bending moments can be positive or negative according to their direction.

$$M_{w,+,x} = F_{T,w,y} \cdot z_{T,CoA} + F_{N,w,y} \cdot z_{N,CoA} = +3933.7kNm \qquad M_{w,-,x} = -3933.7kNm \tag{4.38}$$
$$M_{w,+,y} = F_{T,w,y} \cdot z_{T,CoA} + F_{N,w,y} \cdot z_{N,CoA} = +5843.2kNm \qquad M_{w,-,y} = -5843.2kNm \tag{4.39}$$
$$M_{w,+,z} = F_{N,w,y} \cdot x_{N,CoA} = +66.9kNm \qquad M_{w,-,z} = -66.9kNm \tag{4.40}$$

Moreover, the horizontal wind loads are given in their combined effects.

$$F_{w,x,+} = F_{T,w,x} + F_{N,w,x} = 119.7kN \qquad F_{w,x,-} = -F_{T,w,x} - F_{N,w,x} = -119.7kN \tag{4.41}$$
$$F_{w,y,+} = F_{T,w,y} + F_{N,w,y} = 95.0kN \qquad F_{w,y,-} = -F_{T,w,y} - F_{N,w,y} = -95.0kN \tag{4.42}$$

Now the focus moves to the dynamic actions due to vessel motion accelerations. The latter has been already defined, together with the Moment of Inertias. At this stage, combinations of roll and pitch actions are determined for upward and downward heave, in order to investigate all the possible situations to be combined later on. Firstly, general dynamic loads are evaluated, by considering the total mass and the vessel accelerations.

$$F_{CoG,x} = M_{WTG}a_x = +2014.3kN \quad F_{CoG,y} = M_{WTG}a_y = +2517.9kN \quad F_{CoG,z} = M_{WTG}a_z = +9484.1kN \tag{4.43}$$

$$M_{roll,x} = I_x\alpha_x = +20917.1kNm \qquad M_{pitch,y} = I_y\alpha_y = +22683.3kNm \tag{4.44}$$

$$F_{static} = -M_{WTG} \cdot g = -8233.5kN \tag{4.45}$$

Actions at foundation level are so found along the three directions.

x-direction

Positive roll, upward heave

$$M_{dyn,y,up,+} = M_{roll,x} + F_{CoG,y} \cdot z_{CoG} = +150148.5kNm \tag{4.46}$$

Positive roll, downward heave

$$M_{dyn,y,dw,+} = M_{roll,x} - F_{CoG,y} \cdot z_{CoG} = -108314.2kNm \tag{4.47}$$

Negative roll, upward heave

$$M_{dyn,y,up,-} = -M_{roll,x} - F_{CoG,y} \cdot z_{CoG} = -150148.5kNm \tag{4.48}$$

Negative roll, downward heave

$$M_{dyn,y,dw,-} = -M_{roll,x} + F_{CoG,y} \cdot z_{CoG} = +108314.2kNm \tag{4.49}$$

y-direction

Positive pitch, upward heave

$$M_{dyn,y,up,+} = -M_{pitch,y} - F_{CoG,x}z_{CoG} + \left(F_{static} + F_{dyn,z,up}\right)x_{CoG} = -140068.1kNm \tag{4.50}$$

Positive pitch, downward heave

$$M_{dyn,y,dw,+} = -M_{pitch,y} - F_{CoG,x} z_{CoG} + \left(F_{static} + F_{dyn,z,down}\right) x_{CoG} = -145082.4 kNm \tag{4.51}$$

Positive pitch, upward heave

$$M_{dyn,y,up,-} = M_{pitch,y} + F_{CoG,x} z_{CoG} + \left(F_{static} + F_{dyn,z,up}\right) x_{CoG} = +112068.8 kNm \tag{4.52}$$

Positive pitch, downward heave

$$M_{dyn,y,dw,-} = M_{pitch,y} + F_{CoG,x} z_{CoG} + \left(F_{static} + F_{dyn,z,down}\right) x_{CoG} = +107054.5 kNm \tag{4.53}$$

z-direction

$$F_{dyn,z,up} = \left(F_{static} + F_{CoG,z}\right) = 1250,56 kN \qquad upwardheave \tag{4.54}$$

$$F_{dyn,z,down} = -\left(F_{static} + F_{CoG,z}\right) = -1250,56 kN \qquad downwardheave \tag{4.55}$$

$$M_{dyn,z,+} = -F_{CoG,y} x_{CoG} = -5047.9 \qquad positivepitch \tag{4.56}$$

$$M_{dyn,z,-} = F_{CoG,y} x_{CoG} = 5047.9 \qquad negativepitch \tag{4.57}$$

All the possible actions are now defined along the three directions. At this stage, the analysis of load combinations can start. There are eight cases to be considered, according to SHL design practice, in order to investigate the worst possible scenario. Basically, for each situation, one vertical force and three bending moments are computed. Conditions which make the cases differ each others are positive and negative heave, pitch, roll and wind (acting both in x and y directions). In Table 4.5 the features of these cases are provided.

Table 4.5: Load Combination features

	Heave	Pitch	Roll	Wind
Case 1	up	+	+	+ x-direction
Case 2	down	+	+	+ x-direction
Case 3	up	-	+	- x-direction
Case 4	down	-	-	- x-direction
Case 5	up	+	+	+ y-direction
Case 6	down	+	+	+ y-direction
Case 7	up	-	+	+ y-direction
Case 8	down	-	-	- y-direction

The complete overview of load cases, in terms of calculation and resulted actions, is shown in Appendix A.3. Here the case which provides the worst situation is proposed. It is found by considering the maximum bending moment result due to combination of Mx and My values.

Load case 4

Downward Heave, Negative Pitch, Positive Roll, Negative Wind in y direction
Vertical Load

$$F_z = F_{static} + F_{dyn,z,up} = -9484.1 kN \tag{4.58}$$

Bending Moment, x-direction

$$M_x = M_{dyn,y,dw,+} = +150148.5 kNm \tag{4.59}$$

Bending Moment, y-direction

$$M_y = M_{dyn,y,dw,+} + M_{w,-,y} = -150925.6 kNm \tag{4.60}$$

Bending Moment, z-direction

$$M_z = M_{dyn,z,-} = +5047.9kNm \quad (4.61)$$

With reference again to appendix A.3 , these actions result in a combined bending moment, oriented with a certain angle on the deck. From that value, dividing by the CoG height, the design force for each WTG is finally defined. Then, dividing the last result into its components along x and y directions, it is possible to get useful output for further stage calculations (Fig. 4.1). It is underlined that bending moment around z-direction in not considered at this stage, due to its really low order of magnitude with respect to the others.

At foundation level

$$M_{xy} = 212129.3kNm \qquad \theta = 320° \quad (4.62)$$

At CoG position

$$F_{xy} = 4133.1kN \quad (4.63)$$

$$F_x = cos\,(50) \cdot F_{xy} = 2656.7kN \qquad F_y = -sin\,(50) \cdot F_{xy} = -3166.1kN \quad (4.64)$$

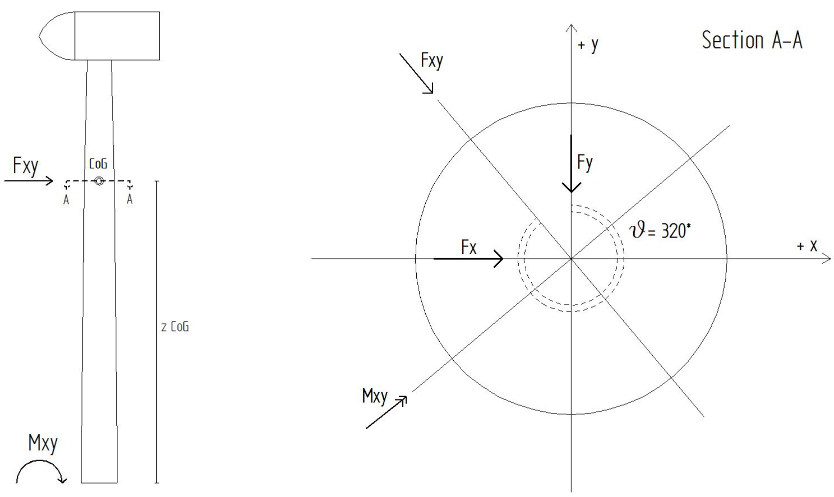


Figure 4.1: Overview of action application and orientation

A summary of the resulting design loads is hereby proposed, Table 4.6, for the three different manufacturer designs. Again, reference is given in Appendix A.3 for the calculations referred to Areva and Siemens products.

Table 4.6: Overview of design loads

	Design Situation		
	Alstom	*Areva*	*Siemens*
Mxy [kNm]	**212129.27**	**174049.20**	**230737.00**
θ [°]	320.00	310.00	310.00
H_CoG [m]	51.33	49.43	62.69
Fxy [kN]	**4133.05**	**3521.00**	**3680.50**
Fx [kN]	2656.68	2697.24	2819.43
Fy [kN]	-3166.10	-2263.26	-2365.78

4.3.2. Sea-fastening structures

A similar procedure is performed to find the design forces and moments acting on the external sea-fastening structures. In the same way, the final results are in terms of horizontal forces along x and y directions, at the respective CoG levels. Due to the presence of similar calculation passages, in this section only a final table with cumulative results is provided. Full calculations are provided in Appendix A.3.

From wind analysis, the following Table 4.7 summarises the quantities involved and the partial actions computed.

Then, using the same vessel accelerations as before, calculation of dynamic loads due to pitch, roll and heave is provided, Table 4.8.

Table 4.7: Wind load calculation results

	Grillages	***Vertical 1***	***Vertical 2***	***Vertical 3***
z_CoG_LAT [m]	6.25	22.50	22.50	22.50
Mean wind speed at 10 min				
U_z,10 [m/s]	21.48	25.09	25.09	25.09
Shape Coefficient				
C_x	0.50	0.50	0.50	0.50
C_y	0.50	0.50	0.50	0.50
Area				
x $[m^2]$	88.20	109.80	97.90	109.80
y $[m^2]$	41.55	402.29	402.29	402.29
Forces				
F_w_x [kN]	12.48	21.19	18.89	21.19
F_w_y [kN]	5.88	77.64	77.64	77.64
Moments at foundation				
M_w_+_x [kNm]	36.73	1746.93	1746.93	1746.93
M_w_+_y [kNm]	77.97	476.80	425.13	476.80
M_w_-_x [kNm]	-36.73	-1746.93	-1746.93	-1746.93
M_w_-_y [kNm]	-77.97	-476.80	-425.13	-476.80

Table 4.8: Vessel motion calculation results

	Grillage	***Vertical 1***	***Vertical 2***	***Vertical 3***
Dynamic Loads				
F_x_CoG [kN]	2880	840	1680	840
F_y_CoG [kN]	3600	1050	2100	1050
F_z_CoG [kN]	13560	3955	7910	3955
M_x_roll [kNm]	8109.40	790.99	1699.90	790.99
M_y_pitch [kNm]	1920.63	1258.10	2516.20	1258.10

Finally, combining the actions in eight load cases, the worst scenario is found and the design actions are defined and proposed as follows. Extensive passages are provided in Appendix A.3. Figure 4.2 shows the action positions and orientations.

At foundation level

$$M_{xy,grl} = 13771.6kNm \qquad \theta = 230° \tag{4.65}$$

$$M_{xy,v1} = 26263.1kNm \qquad \theta = 150° \tag{4.66}$$

$$M_{xy,v2} = 51307.9kNm \qquad \theta = 230° \tag{4.67}$$

$$M_{xy,v3} = 26263.1kNm \qquad \theta = 150° \tag{4.68}$$

At CoG position

$$F_{xy,grl} = 11017.3kN \qquad F_{x,grl} = 8439.3kN \qquad F_{y,grl} = 7084.1kN \tag{4.69}$$

$$F_{xy,v1} = 1500.7kN \qquad F_{x,v1} = -750.4kN \qquad F_{y,v1} = 1299.6kN \tag{4.70}$$

$$F_{xy,v2} = 2931.9kN \qquad F_{x,v2} = 2245.8kN \qquad F_{y,v2} = 1885.2kN \tag{4.71}$$

$$F_{xy,v3} = 1500.7kN \qquad F_{x,v3} = -750.4kN \qquad F_{y,v3} = 1299.6kN \tag{4.72}$$

A summary of the resulting design loads is hereby proposed, Table 4.9, for the four different involved

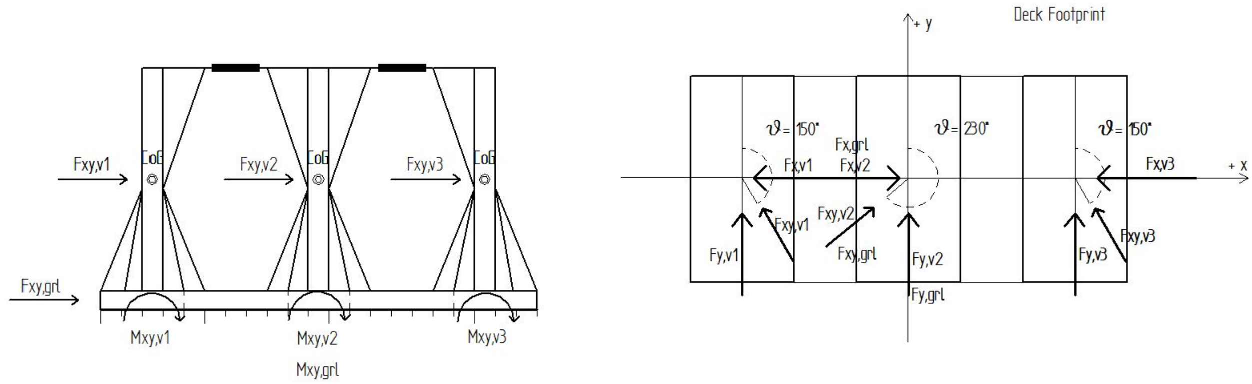


Figure 4.2: Overview of action application and orientation, external structures

structures. Again, reference is given in Appendix A.3 for the detailed calculation passages.

Table 4.9: Overview of design loads - Sea-fastening structures

	Design Situation			
	Grillage	*Vertical 1*	*Vertical 2*	*Vertical 3*
Mxy [kNm]	**13771.64**	**26263.11**	**51307.90**	**26263.11**
θ [°]	250.00	150.00	230.00	150.00
H_CoG [m]	1.25	17.50	17.50	17.50
Fxy [kN]	**11017.32**	**1500.75**	**2931.88**	**1500.75**
Fx [kN]	10352.89	-750.37	2245.95	-750.37
Fy [kN]	3768.14	1299.69	1884.58	1299.69

4.4. Summary and results

As it is pointed out, the final force magnitude acting at the CoG of the WTG is quite relevant and needs to be treated in a proper way. The conceptual phase assumptions are therefore validated and the analysis may continue with the chosen sea-fastening system. Furthermore, it clearly appears from the results that Alstom product gives the worst scenario for calculation: then the assumption to use it as reference happens to be correct and it is kept for the next steps. Focusing on the force orientation, the results show how roll is governing, thanks to an angle of 320 degrees with respect to the reference system origin. On the other hand, pitch is still considerably present and a certain sea-fastening needs to be provided also along that direction. The initial choice of a symmetric sea-fastening system about the transversal direction still may still hold, since is due to the mass disposition over the deck. However, specific improvements are required in order to face the resulting actions in their new symmetry direction.

Regarding the external structures themselves, wind and vessel motion applied to them produce actions of a certain magnitude that require to be considered. Nevertheless, compared to WTG actions and the related height of applications, they do not produce the governing situation for the design.
Of course, since they are evaluated by assuming certain dimensions and weights, they can be adapted according to the modifications in their design proposed in the next chapters. The idea is to give more conservative, but still realistic, input data at this stage in order to propose more effective solution during the analysis progress.

5

Stiffness Analysis

Never was anything great achieved without danger

Niccoló Machiavelli (1469 - 1527)

In this chapter stiffness analysis of the selected system is pursed. Analysis of the combined system behavior with respect to stiffness appears to be of fundamental importance for the whole solution feasibility assessment. This is due to the fact that the six towers are surrounded by three main vertical external structures and supported at the bottom by a wide grillage.
Furthermore, the possibility to use an hinged connection at the bottom of each tower is chosen at the conceptual phase. This assumption has to be verified and judged in terms of efficiency given to the overall system itself.
Stiffness is a very interesting aspect towards this goal. Indeed, providing rotational capacity at the bottom would reduce the stiffness requirement at the support position, with a magnitude depending on its height. Therefore the two possible situations, with an hinged and fixed connection at the bottom of WTGs, are studied in order to show the different requirements in stiffness at support locations. In order to avoid misunderstandings from now on, when the description mentions these two possibilities, they always refer to the kind of bottom connection for WTGs and never for the sea-fastening structures. The latter are meant to be fixed.
Then several layouts for the external supporting structures are provided and analyzed, in order to asses their efficiency and the response in terms of stiffness. Some assumptions and specific choices are made in order to narrow the field of analysis, potentially very wide in terms of possible layouts for the structures. These selections are carried out after discussion and comparison with SHL engineers' expertise.

5.1. Procedure

In order to carry out such an analysis, several steps have to be performed. Hand calculations need to support software analysis to avoid unexpected and cryptic results from the latter. The structural analysis software adopted for this purpose is *Oasys GSA 8.7*, [17]. For the hand calculations *Maplesoft MAPLE17* supports the results in terms of analytic equations, [18].
Firstly, the tower modelling is provided in order to answer the question of what the required stiffness is. Then, the second phase is about the sea-fastening structure modelling. Since the design possibilities may be really wide, some additional considerations, company choices and boundary conditions are set-up. Here the analysis goes from general to more detailed arrangements. They are studied and selected according to analysis from similar structure, applied for different situations, [19] and [20]. All the assumptions, used for hand calculations, are verified at the end and supported by software results (and vice-versa). Hand calculations are supported by theory of structural mechanics, [16]. Due to the elevated number of variables involved, analytical equations are not always provided and some

parameters are let fluctuate between reasonable limits, in order to show the result dependency on the main variables. Then, among the resulting solutions, a comparison is carried out to define the most effective ones. Advantages in terms of steel saving are provided for the solution which requires an hinged connection at WTG foundations. Some strength considerations are provided as well, since the structure is designed to fulfil these requirements too.

5.2. Tower modelling

The first step is about the calculation of the maximum allowed bending moment for the WTG tower. Since very few information is given by the manufacturer towards this aspect, the analysis is merely based on the steel cross section capacity. Since the external sea-fastening will be placed within a maximum height of 30 m, the tower properties are evaluated for this dimensional range. With a variable wall thickness from 30 to 23 mm along this tower length, a reference value of *26.15 mm* is chosen as average result. In a similar way, the average radius is found equal to *5.38 m*. It is underlined that at the connection positions between the tower composing elements, steel flanges are provided and the wall thickness increases for limited areas up to 50 mm. This positively affects the elastic modulus of the tubular section. In order to be on the safe side, this aspect is not considered for the calculations. Therefore, assuming the steel grade of S355, the bending moment capacity of the tower comes out from an elastic analysis. This domain is chosen, in order to avoid plastic hinge developments during T&I procedures, which may affect the further service life capacity of the structure. Reduction coefficients are chosen in accordance with AISC 13th edition guidelines, [21], by using allowable stress distribution.

$$t_{mean} = 26.15mm \qquad\qquad D_{mean} = 5380mm \tag{5.1}$$

$$W_{el} = \frac{\pi \cdot \left[D_{mean}^4 - (D_{mean} - 2 \cdot t_{mean})^4\right]}{32 \cdot D_{mean}} = 5.87 \cdot 10^8 mm^3 \tag{5.2}$$

$$\gamma_F = 0.6 \qquad\qquad F_y = 345\frac{N}{mm^2} \tag{5.3}$$

$$M_{el,max} = F_y \cdot \gamma_F \cdot W_{el} = 121488kNm \tag{5.4}$$

Assuming a linear distribution of bending moment from the point of maximum force application, CoG, the minimum height for which $M = M_{el,max}$ is found.

$$F_{xy} \cdot (z_{CoG} - H_{min}) = M_{el,max} \tag{5.5}$$

$$H_{min} = 22m \tag{5.6}$$

For both the situations, with hinged and fixed connection at bottom, this limit holds.

5.2.1. Required stiffness

Firstly the case of fixed connection at WTG bottom is considered. This situation can be translated into a simple structural scheme where a cantilever beam is loaded with a force in shear direction, at CoG height, and supported by a spring in between. The bending moment at the fixed end support is known and set as M_{el}. The final unknown is the spring stiffness. For variable support position, the following three equations hold and stiffness values are found.

$$F_s = \frac{(F_{xy} \cdot z_{CoG}) - M_{el,max}}{H_{supp}} \tag{5.7}$$

$$u_{supp} = \frac{F_s \cdot H_{supp}^3}{3EI} \tag{5.8}$$

$$k_s = \frac{F_s}{u_{supp}} \tag{5.9}$$

Then, hinged connection situation is studied. A similar static scheme is here applied, with a hinge providing null bending moment at the end support. In order to find the required degree of freedom,

maximum displacement at spring position needs to be set. This value can be found by making practical considerations and checking specific element limits. The latter implies a maximum nacelle acceleration of *0.4 g* from the manufacturer, limited by SHL at *0.2 g* [22]. It holds that $a_{max} = 1.96 m/s^2$.
According to data from SHL's Naval Department, Appendix A.2, time period is imposed ($T = 10s$). Angular acceleration is translated into transversal acceleration and finally into maximum linear displacement at the nacelle level. The assumption behind the calculation, agreed by SHL, is a rigid body motion between the vessel and all the components attached to it. Since roll is governing, it follows:

$$a_{roll} = 8 \cdot \alpha_{roll} \cdot \frac{\pi^3}{360 \cdot T^2} \; [rad/sec^2] \tag{5.10}$$

$$a_{max} = \frac{a_{roll}}{H_{tot} + z_{LAT}} \; [m/sec^2] \tag{5.11}$$

$$u_{top} = (H_{tot} + z_{LAT}) \cdot sin\alpha_{roll} = 4.97m \tag{5.12}$$

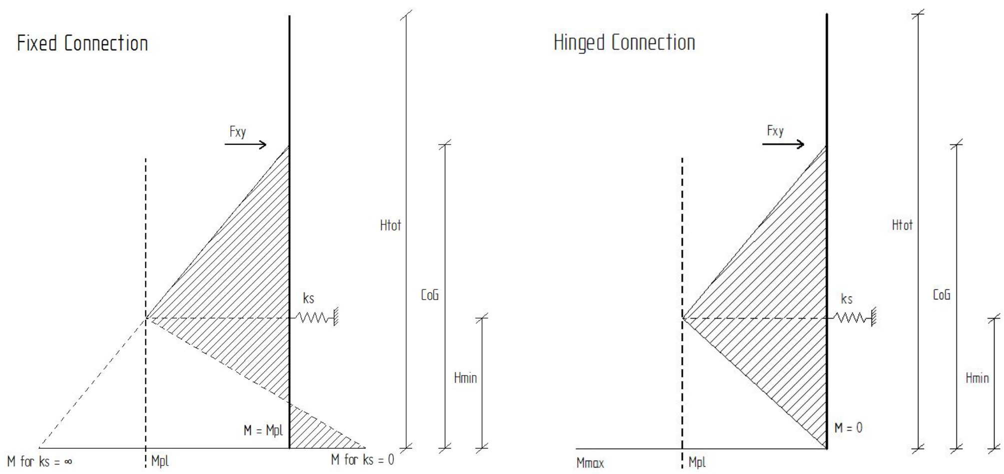
Since u_{top} value seems to be quite large, this conditions is not governing and practical considerations are adopted. The limit is therefore set up at *1.25 m* for the nacelle position. This because of deck footprint boundaries, that do not allow further displacement without collision between two adjacent WTGs (considering asynchronous oscillations). A specific analysis may be provided about the relative motion of two adjacent WTGs, which could lead to an upper limit for this maximum displacement. In order to be on the safe side, this value is kept and discussed in further considerations.
Again, for variable support position, the following three equations hold and stiffness values are found.

$$F_s = \frac{M_{el,max} \cdot z_{CoG}}{H_{supp}} \tag{5.13}$$

$$u_{supp} = \frac{u_{top} \cdot H_{supp}}{z_{N,CoG}} \tag{5.14}$$

$$k_s = \frac{F_s}{u_{supp}} \tag{5.15}$$

The two possible static schemes are proposed in Figure 5.1. For the fixed situation, 5.1(a), a limit situation is considered. It happens when the bending moment below the support is opposite, with respect its normal distribution, and limited by the plastic moment capacity of the cross-section. On the other hand, hinged situation is simply proposed by avoiding any bending moment appearance at the bottom connection, Figure 5.1(b).



(a) (b)

Figure 5.1: Bending moment diagrams - Fixed (a) and Hinged (b) situations

5.2.2. Considerations

Extensive calculations are proposed in Appendix A.4, where graphical results from *Oasys GSA* analysis are shown as well. An interesting output is the derived graph, Figure 5.2, which shows the stiffness trend for the two solutions, for intermediate support height variation. It is immediately clear how the advantage in terms of stiffness are already present at the maximum height, *30 m*, and becomes really consistent at the minimum height, *22 m*. Here the ratio in stiffness requirement between fixed and stiffness solution reaches a considerable value of *2.11*.
Therefore, the design aim of keeping the sea-fastening structures as small as possible seems to be validated by the hinged solution, which requires much less stiffness than the other. Next step is to check whether such a stiffness value may be really provided by a vertical sea-fastening structure, for different heights.

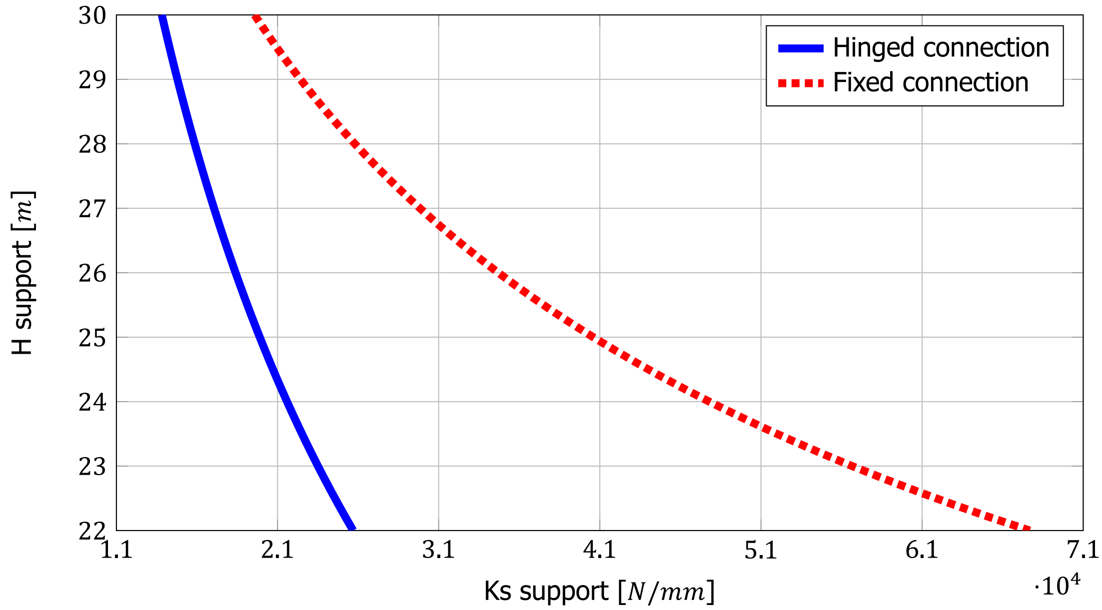


Figure 5.2: Support requirement, based on tower max allowable bending moment: lateral stiffness versus height

5.3. Sea-fastening structure modelling

Deck footprint is recalled from Figure 3.19. As computed for design data in Chapter 4, sea-fastening structures are composed by four main vertical elements and a grillage directly above the deck. At this stage only the vertical parts are considered. Furthermore, since these are arranged as two individuals at the edges and two combined between the two rows of WTGs, only one vertical element is considered as reference. Some assumptions are then required. As briefly mentioned at the conceptual stage, the WTGs are meant to be clamped with a specific clamping system, acting as a ring element around the tower cross section. This system is attached to the external vertical structures by both the sides, involving therefore two of them. The vertical elements are meant to be built up by an arrangement of steel frames, with a certain amount of bracings. Four contact points are assumed for each clamping ring. For each direction, two frames of the whole structure are assumed to withstand the actions of each WTG. Then, since the cumulative force *Fxy* is split in two direction components, it is assumed that for each frame takes over only one fourth of the related component action. This assumption needs to be verified or adapted at the end of the study. Figure 5.3 clarifies this reasoning.
Since the aim is to look for stiffness quantities, frames in each direction are modelled and presented as translational springs. At this stage, clamping system is assumed to be infinitively stiff. The arrangement is the kind of springs in series, therefore the stiffness provision is completely up to the vertical elements, made by steel frames.
Finally, from design data is clear that design actions from WTGs motions are more critical than the ones from the sea-fastening structures themselves. Moreover, the latter are acting with a different

orientation angle. This would affect stiffness analysis by increasing the overall stiffness in that direction. Therefore, in order to be conservative, it is reasonable to consider as external actions only the forces and bending moments from WTGs motions. In further stages, when grillage design and load over the deck are checked, sea-fastening structure induced actions are considered again.

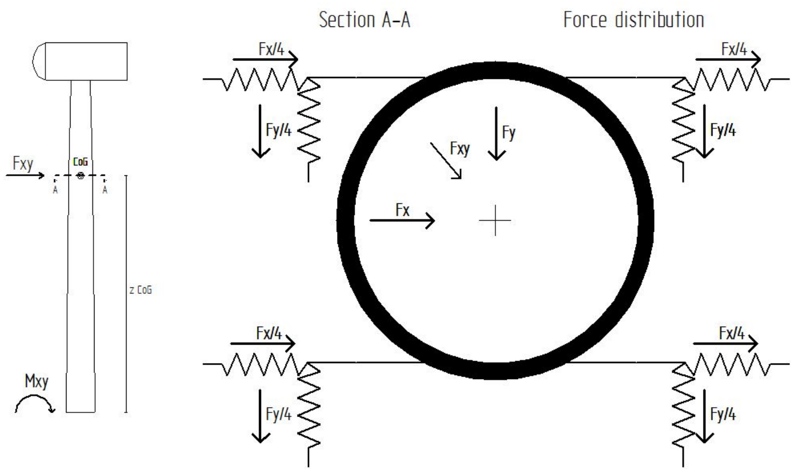


Figure 5.3: Forces distribution between ring and external structures

5.3.1. Provided stiffness

The analysis at this stage provides a large number of variables to deal with. Furthermore, in order to make the design proposal clear for comparisons, it needs to show results for the combinations of all these involved parameters. They can be grouped as follows:

- H_i, single floor height;
- H_{tot}, total frame height;
- EI, EA, column, beam and bracing cross-section properties;
- Arrangement of bracings and floor heights.

Goals for this "design for stiffness" of the sea-fastening structures are already set up. They are implied by the cost-effectiveness features of the design itself, and basically refer to:

- Limit total height;
- Limit the amount of welding (reduce the number of members);
- Limit total weight.

Some assumptions are made to limit the possibility in design choices and to make the analysis and comparison more effective. The required amount of stiffness has been pointed out in the previous section, about tower modelling. Furthermore, strength needs to be considered as well, even at this stage, due to the high forces involved. For these reasons, among the all possible cross sections, a selection is made. Circular sections for columns and bracings (*CHS 400-660*), compact flanges for beams (*HEB 700-900*). It is expected that maximum dimensions for these sections are being used, to better deal with strength issues.
Then, four possible floor heights are defined, respectively *5.0 m*, *5.5 m*, *6.0 m* and *6.5 m*. Finally four main possibilities are selected for the external layout of the structures. Indeed, they are meant to be both internally and externally braced. The division depends on the number of externally unbraced floors and the total height, as shown in the two layouts solution of Figure 5.4. As it can be seen, the main differences are in the number of externally unbraced floors.

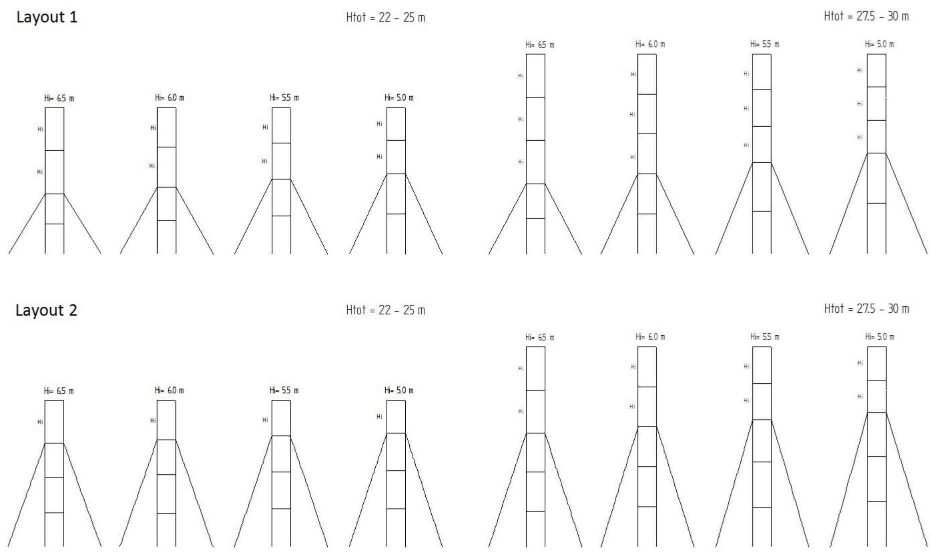


Figure 5.4: Layout solutions - 1 (short external bracings) and 2 (long external bracings)

5.3.2. Calculation

The analysis now is divided into the two directions, since a different arrangement of frame is defined. The situations to be investigated are single-floor frames: unbraced, internally braced and externally braced. Then, assemblies of these simple layouts are provided to create the previously shown complete layouts. The output at each intermediate step is the lateral displacement of the frame. It is computed by means of analysis with stiffness matrices, [16]. Some assumptions are made in order to get reliable results by just using stiffness matrices. Partial combinations and assembly situations are also validated by displacement results from *Oasys GSA* software outputs. Then, once each vertical sea-fastening structure is completely modelled, stiffness is calculated from displacements and comparison with the tower requirements can take place. In order to be consistent with the procedure, this comparison is still given separately for *x* and *y* directions. Complete results are proposed in Appendix A.5, where solution effectiveness can be clearly seen from table results. Here the most interesting outputs form this analysis are combined to create several design proposals. They are selected, discussed and finally assessed, even considering strength issues. In this way, combined unity checks for the selected designs are provided by *SACS* model results. They are extensively proposed in Appendix A.5.

The actions on the sea-fastening structures, for both the directions, come from the reaction forces at the several support heights, evaluated during the Tower modelling phase. According to the different static schemes adopted, higher reactions are expected for the hinged than for the fixed case. Only shear forces are transmitted since the clamping system is assumed to transfer no bending moment. Results from reaction forces are proposed in the following Table 5.1. These values, already derived for both the directions and considered for one fourth of their contribution, are being used in the further calculations of this chapter.

$$\theta = 320.0deg \qquad x - direction = 0.643 \qquad y - direction = 0.766 \tag{5.16}$$

Table 5.1: Acting forces on sea-fastening structures

Case	*Direction*	*Support position*			
		22.0 m	*25.0 m*	*27.5 m*	*30.0 m*
Hinged	x [kN]	1549.63	1363.67	1244.23	1136.39
	y [kN]	1846.77	1625.16	1482.81	1354.30
Fixed	x [kN]	663.59	583.96	532.81	486.63
	y [kN]	790.83	695.93	634.98	579.94

X-direction

Along this direction the frame is composed by two columns with variable *H* and one beam with fixed length, *L = 2.8 m*. This comes from to practical considerations about vessel deck and its strong points for load transfer; Appendix A.8 for reference. The dimension selected is therefore consistent with them. Three arrangements are studied, respectively a simple frame, 5.5(a), an internally single-braced frame, 5.5(b), and an externally braced frame, 5.5(c). Actions at the top of each frame are taken from Table 5.1 and here proposed again.

$$F_x = \frac{F \cdot x_{direction}}{4} [kN] \tag{5.17}$$

Table 5.2: Acting force for different support height, x-direction, hinged situation

H tot [m]	22.0	25.0	27.5	30.0
HINGED: ***Fx [kN]***	1549.63	1363.67	1244.23	1136.39
FIXED: ***Fx [kN]***	663.59	583.96	532.81	486.63

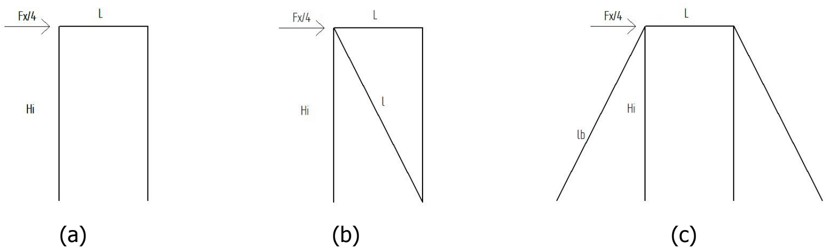


Figure 5.5: Frames in x- direction for analysis

Stiffness matrix for the simplest frame, 5.5(a), with the related loading pattern gives the results in terms of lateral displacement at the top.

$$\mathbf{K}_u = \begin{bmatrix} \frac{24EI_c}{H_i^3} & \frac{6EI_c}{H_i^2} & \frac{6EI_c}{H_i^2} \\ \frac{6EI_c}{H_i^2} & \frac{4EI_c}{H_i} + \frac{4EI_b}{L} & \frac{2EI_b}{L} \\ \frac{6EI_c}{H_i^2} & \frac{2EI_b}{L} & \frac{4EI_c}{H_i} + \frac{4EI_b}{L} \end{bmatrix} \tag{5.18}$$

$$\mathbf{u} = \begin{bmatrix} u_{top} \\ \theta_1 \\ \theta_2 \end{bmatrix} \qquad \mathbf{F} = \begin{bmatrix} f_{top} \\ 0 \\ 0 \end{bmatrix} \tag{5.19}$$

Considering the case of a braced frame, 5.5(b), stiffness matrix changes and contribution of this element is added, from both its rotational and axial rigidity. Force and displacement vectors remain the same.

$$\mathbf{K}_b = \begin{bmatrix} \frac{24EI_c}{H_i^3} + \frac{12EI_c sin(\alpha)^2}{l^3} + \frac{EAcos(\alpha)^2}{l} & \frac{6EI_c}{H_i^2} + \frac{6EI_c sin(\alpha)}{l^2} & \frac{6EI_c}{H_i^2} \\ \frac{6EI_c}{H_i^2} + \frac{6EI_c sin(\alpha)}{l^2} & \frac{4EI_c}{H_i} + \frac{4EI_b}{L} + \frac{4EI_c}{l} & \frac{2EI_b}{L} \\ \frac{6EI_c}{H_i^2} & \frac{2EI_b}{L} & \frac{4EI_c}{H_i} + \frac{4EI_b}{L} + \frac{4EI_c}{l} \end{bmatrix} \tag{5.20}$$

Then, the already mentioned expression holds, and displacement u_{top} can be found.

$$\mathbf{K} \cdot \mathbf{u} = \mathbf{F} \tag{5.21}$$

$$\mathbf{u} = \mathbf{K}^{-1} \cdot \mathbf{F} \tag{5.22}$$

The total displacement in x-direction can be given by an individual or a combination of floors, up to three, according to the previously exposed layout solutions. This is because it is assumed that the externally braced parts of the structure are not affected by lateral displacement or, at least, they are really small compared to the upper floor ones, 5.5(c). The assumption is due to the amplitude of actions applied to these systems and is validated by software solutions. Anyway, to be on the safe side, an addition of 10% of the already evaluated displacement is considered in order to take these effects into account. These considerations are valid only for x-direction. It will be shown how for y-direction the externally braced frames affect in a different manner the overall results.

At this stage just the selected situations are shown. They are about *CHS660* columns with thickness of 32 mm and *HEB900* beams. Bracings have the same column cross section. The focus here is on total structure heights H_{tot} of *22* and *25 m*. Tables 5.3 and 5.4 propose the results in terms of displacements, for both the situations. In Appendix A.5 extensive results are proposed, for all the parameters and their possible ranges. Moreover, analytical equations and solutions for stiffness matrices are provided as *Maple* calculation sheets and results.

Table 5.3: Total lateral displacement assembly - x-direction, HINGED situation

H [m]	***Layout***	***H_i [mm]***							
		Top floor Braced				*Top floor Unbraced*			
		6500	6000	5500	5000	6500	6000	5500	5000
		Displacement [mm]							
22.0	1	64.8	51.5	40.2	30.7	115.8	91.9	71.5	54.4
	2	19.2	15.6	12.5	9.9	63.4	50.3	39.2	29.8
25.0	1	57.0	45.3	35.4	27.0	101.9	80.9	63.0	47.9
	2	21.8	13.8	11.0	8.7	55.8	44.3	34.5	26.2

Table 5.4: Total lateral displacement assembly - x-direction, FIXED situation

H [m]	***Layout***	***H_i [mm]***							
		Top floor Braced				*Top floor Unbraced*			
		6500	6000	5500	5000	6500	6000	5500	5000
		Displacement [mm]							
22.0	1	27.7	22.1	17.2	13.1	49.6	39.4	30.6	23.3
	2	8.2	6.7	5.4	4.3	27.2	21.6	16.8	12.8
25.0	1	24.4	19.4	15.1	11.6	43.6	34.6	27.0	20.5
	2	9.3	5.9	4.7	3.7	23.9	19.0	14.8	11.2

Comparison with results from software *Oasys GSA* is provided in the next section, when the complete solutions are defined. Validation of the just proposed results follows from those considerations.
Finally it is possible to define the stiffness of each solution and compare them with the required quantities resulting from tower modelling. They result by dividing the acting forces from Table 5.2 by the displacements just found in Tables 5.3 and 5.4.

Graphical results, from table proposed in Appendix A.5, show the solution feasibilities for each combination of parameters. From these results it is already clear where the requirements of stiffness are met, for both the *fixed* and *hinged* connection situations. Text colours describe this differentiation: in *green*, values for which the hinged solution becomes profitable. In *red* the stiffness already meets the requirements of the fixed situation. Lower values of stiffness are kept in *black* colour text.

To validate the hand calculation results, several solution arrangements are modelled in *Oasys GSA* and displacement outputs are compared. In Figure 5.6 an example of possible arrangement along x-direction is proposed. Table 5.7 shows the comparison in terms of lateral displacements at the top, from

Table 5.5: Total lateral stiffness assembly- x-direction

H [m]	***Layout***	***H_i [mm]***							
		Top floor Braced				*Top floor Unbraced*			
		6500	6000	5500	5000	6500	6000	5500	5000
		Stiffness $\cdot 10^4$ ***[N/mm]***							
22	1	2.39	3.01	3.86	5.05	1.34	1.69	2.17	2.85
	2	8.06	9.91	12.40	15.60	2.44	3.08	3.96	5.20
25	1	2.72	3.42	4.38	5.74	1.52	1.92	2.46	3.24
	2	7.12	11.30	14.00	17.70	27.80	35.00	44.90	59.10

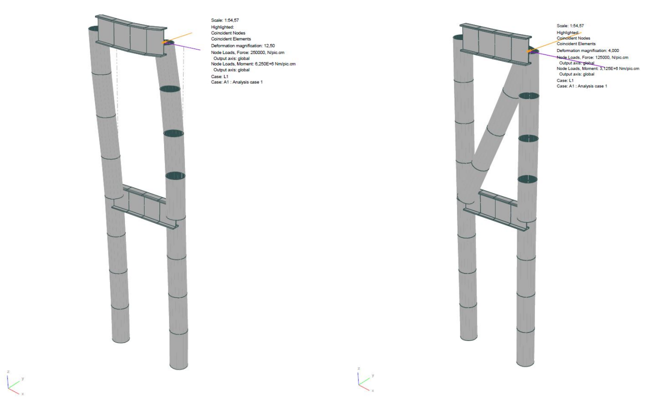
Table 5.6: Required stiffness - x-direction

H [m]	***Situation***	***Stiffness [N/mm]***
22	Fixed	*4.35E+04*
	Hinged	*1.65E+04*
25	Fixed	*2.61E+04*
	Hinged	*1.28E+04*

both the ways of analysis, for one of the possible arrangements. Discrepancies are below the value of 10 %, therefore calculations can be validated. Small differences in results may depend on the assumption of small contributions for externally framed floors. In Appendix A.5 more extensive reference are proposed, with the complete software numerical outputs for all the solutions to be selected in the next section. Before the selection, a similar analysis for y-direction has to be carried out. Indeed, certain cross sections, columns dimensions and frame arrangements may be applied only if they are working in the other direction too.

Table 5.7: Comparison with software results - X-direction

	Displacement [mm]		Situation (hinged)	
X-direction	**Unbraced**	**Braced**	Htot [m]	22
Hand calculation	91.9	51.5	Hi [m]	6
GSA	90.5	48.4	Layout	1
Difference	**2.0 %**	**6.0 %**		



(a) (b)

Figure 5.6: GSA output - Deflected configurations, Htot 25m, Hi 6 m, Layout 1, x-direction

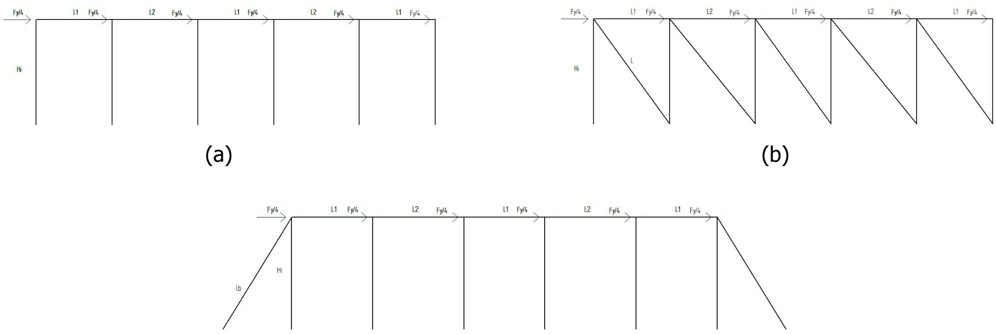
Y-direction

Along this direction, the number of frames is equal to five, then the value *n* results equal to six. They have variable length beams between *4* and *4.5 m*. For calculation, the average value is used, *L = 4.2 m*. This is due to practical considerations about vessel deck and its strong points for load transfer; Appendix A.8 for reference. The dimension selected is therefore consistent with them.
Three arrangements are studied, respectively a simple frame, 5.7(a), an internally single-braced frame, 5.7(b), and an externally braced frame, 5.7(c). Actions at the top of each frame are taken from Table 5.1 and here proposed again.

$$F_y = \frac{F \cdot y_{direction}}{4} [kN] \tag{5.23}$$

Table 5.8: Bending moments for different support height, y-direction

H tot [m]	22.0	25.0	27.5	30.0
HINGED: ***Fx [kN]***	1846.77	1625.16	1482.81	1354.3
FIXED: ***Fx [kN]***	790.83	695.93	634.98	579.94



(a) (b) (c)

Figure 5.7: Frames in y-direction for analysis

Stiffness matrix for the simplest frame, 5.7(a), with the related loading pattern gives the results in terms of lateral displacement at the top.

$$\mathbf{K}_u = \begin{bmatrix} \frac{12EI_c}{H_i^3} \cdot n & \frac{6EI_c}{H_i^2} & \frac{6EI_c}{H_i^2} \\ \frac{6EI_c}{H_i^2} & \frac{4EI_c}{H_i} + \frac{4EI_b}{L} & \frac{2EI_b}{L} \\ \frac{6EI_c}{H_i^2} & \frac{2EI_b}{L} & \frac{4EI_c}{H_i} + \frac{4EI_b}{L} \end{bmatrix} \tag{5.24}$$

$$\mathbf{u} = \begin{bmatrix} u_{top} \\ \theta_1 \\ \theta_2 \end{bmatrix} \qquad \mathbf{F} = \begin{bmatrix} 6 \cdot f_{top} \\ 0 \\ 0 \end{bmatrix} \tag{5.25}$$

Considering the case of a braced frame, 5.7(b), stiffness matrix changes and contribution of this element is added, from both its rotational and axial rigidity. Force and displacement vectors remain the same.

$$\mathbf{K}_b = \begin{bmatrix} \frac{12EI_c}{H_i^3} \cdot n + \frac{12EI_c sin(\alpha)^2}{l^3} \cdot n + \frac{EAcos(\alpha)^2}{l} \cdot n & \frac{6EI_c}{H_i^2} + \frac{6EI_c sin(\alpha)}{l^2} & \frac{6EI_c}{H_i^2} \\ \frac{6EI_c}{H_i^2} + \frac{6EI_c sin(\alpha)}{l^2} & \frac{4EI_c}{H_i} + \frac{4EI_b}{L} + \frac{4EI_c}{l} & \frac{2EI_b}{L} \\ \frac{6EI_c}{H_i^2} & \frac{2EI_b}{L} & \frac{4EI_c}{H_i} + \frac{4EI_b}{L} + \frac{4EI_c}{l} \end{bmatrix} \tag{5.26}$$

For this direction, the externally braced frames give an important contribution and are proposed too. Again, force and displacement vectors do not vary while the stiffness tensor aquires the contribution of the external bracings, acting on both sides of the whole frame.

$$\mathbf{K}_b = \begin{bmatrix} \frac{12EI_c}{H_i^3}\cdot n + \frac{24EI_c sin(\beta)^2}{l_b^3}\cdot n & \frac{6EI_c}{H_i^2} + \frac{6EI_c sin(\beta)}{l_b^2} & \frac{6EI_c}{H_i^2} \\ \frac{6EI_c}{H_i^2} + \frac{6EI_c sin(\beta)}{l_b^2} & \frac{4EI_c}{H_i} + \frac{4EI_b}{L} + \frac{4EI_c}{l_b} & \frac{2EI_b}{L} \\ \frac{6EI_c}{H_i^2} & \frac{2EI_b}{L} & \frac{4EI_c}{H_i} + \frac{4EI_b}{L} + \frac{4EI_c}{l_b} \end{bmatrix} \tag{5.27}$$

Then, the already mentioned expression holds, and displacement u_{top} can be found. The total displacement in y-direction is given by combining each floor displacement, according to their related stiffness matrices and the previously exposed layout solutions. For this direction, as previously anticipated, externally braced frames play an important role. They tremendously affect the total structure stiffness, therefore their modelling is required. The assumption of just adding a contribution of 10 % of displacement (as for x-direction) is not applicable here. Furthermore, arrangements from layout number 2, Figure 5.4, result in really high displacements. Therefore only layout 1 is considered; different possibilities for comparison are given by one or two rows of top framed floors. This reasoning is due to a different external bracing dimensions and number of applied forces along the y-direction; again, it is validated by software solutions at the end of the section.

In Appendix A.5 extensive results are proposed, for all the parameters and their possible range. Moreover, analytical equations and solutions for stiffness matrices are provided as *Maple* calculation sheets and results. Here just the selected situations are shown. They are about *CHS660* columns, with thickness of 32 mm, and *HEB900* beams. Bracings have the same column cross section. The focus is on total structure heights H_{tot} of *25* and *27.5 m*. Differently from x-direction, at height of *22 m* no arrangements make the fixed solution feasible, therefore higher total heights need to be studied.
Tables 5.9 and 5.10 propose the results in terms of displacements, for both the situations.

Table 5.9: Total lateral displacement assembly - y-direction, HINGED situation

H [m]	***Layout***	***H_i [mm]***							
		2 Top floors Braced				*1 Top floor Braced*			
		6500	6000	5500	5000	6500	6000	5500	5000
		Displacement [mm]							
25	1	58.2	67.9	80.8	97.6	125.9	121.1	121.6	128.0
27.5	1	57.8	67.9	81.1	98.3	119.1	116.0	118.1	125.9

Table 5.10: Total lateral displacement assembly - y-direction, FIXED situation

H [m]	***Layout***	***H_i [mm]***							
		2 Top floors Braced				*1 Top floor Braced*			
		6500	6000	5500	5000	6500	6000	5500	5000
		Displacement [mm]							
25	1	24.9	29.1	34.6	41.8	53.9	51.8	52.1	54.8
27.5	1	24.8	29.1	34.7	42.1	51.0	49.7	50.6	53.9

Comparison with results from software *Oasys GSA* is provided in the next section, when the complete solutions are defined. Validation of the just proposed results follows from those considerations.
Finally it is possible to define the stiffness of each solution and compare them with the required quantities resulting from tower modelling. They result by dividing the acting forces from Table 5.8 by the displacements just found in Tables 5.9 and 5.10.

Graphical results, from table proposed in Appendix A.5, show the solution feasibilities for each combination of parameters. Form these results it is already clear where the requirements of stiffness are met, for both the *fixed* and *hinged* connection situations. Now that the values are found for both

Table 5.11: Total lateral stiffness assembly- y-direction

H [m]	***Layout***	***H_i [mm]***							
		2 Top floors Braced				*1 Top floor Braced*			
		6500	6000	5500	5000	6500	6000	5500	5000
		Stiffness $\cdot 10^4$ ***[N/mm]***							
25	1	2.79	2.39	2.01	1.67	1.29	1.34	1.34	1.27
27.5	1	2.55	2.17	1.81	1.50	1.24	1.27	1.25	1.17

Table 5.12: Required stiffness - y-direction

H [m]	***Layout***	***Stiffness [N/mm]***
25	Fixed	*3.11E+04*
	Hinged	*1.52E+04*
27.5	Fixed	*2.15E+04*
	Hinged	*1.27E+04*

directions, combinations of possible arrangements can be made and some solutions may be proposed for further comparisons.
To validate the hand calculation results, several solution arrangements are modelled in *Oasys GSA* and displacement outputs are compared. In Figure 5.8 an example of possible arrangement along y-direction is proposed. Table 5.13 shows the comparison in terms of lateral displacements at the top from both the way of analysis. Discrepancies are below the value of 10 %, therefore calculations may be validated. Small differences in results may depend on the different beam lengths considered between the hand calculation (mean value) and software (actual values). In Appendix A.5 more extensive reference are proposed, with the complete software numerical outputs for all the solutions to be selected in the next section.

Table 5.13: Comparison with software results - Y-direction

	Displacement [mm]		Situation (hinged)	
Y-direction	**1 Braced**	**2 Braced**	Htot [m]	25
Hand calculation	125.9	58.2	Hi [m]	6.5
GSA	130.5	56.5	Layout	1
Difference	**4 %**	**3 %**		

(a) (b)

Figure 5.8: GSA output - Deflected configurations, Htot 25m, Hi 6 m, Layout 1, y-direction

5.3.3. Definition of most promising solutions

The criteria behind this selection is implied by the initial purposes of such a stiffness analysis. Providing both qualitative and quantitative considerations about the stiffness importance in this design situation is one main goal. Then assessment of solution effectiveness becomes another important focus point. Therefore, the comparison is between the two best system solutions, achievable with both the situations of fixed and hinged connection for the WTG tower. The attribute "best" refers to the solution's ability to meet the already mentioned design goals of total weight, total height and number of frame limitation. All of that is performed, of course, abiding by the just evaluated results in terms of stiffness.

Both the two layouts with different external bracing lengths are considered. The selection focus on the total height; in particular the minimum of *22 m* is looked for. This structure dimension is achievable only for the hinged situation, in a limited number of cases, while for the fixed one the minimum possible height holds at *27.5 m*. Then, frame height is analysed. As already shown in previous results, different trends govern x and y directions. In the first case, the advantages in weight for having smaller upper top frames follows the higher values in terms of stiffness. On the other hand, in y- direction, the higher the top floor height the higher the stiffness. This because the externally framed floors become smaller and then affect less the overall stiffness. As already underlined, their contribution appears decisive along this direction.
Therefore the aim is to have the highest possible value of column lengths in order to limit the number of floors is just theoretical. It needs to be applied differently along the two directions. In Figure 5.9 is shown how this trend is different, for the case at total height of *22 m*; curves are referring to different column cross sections while vertical lines individuate the limits given by fixed and hinged situations. Other similar results are proposed in Appendix A.5.

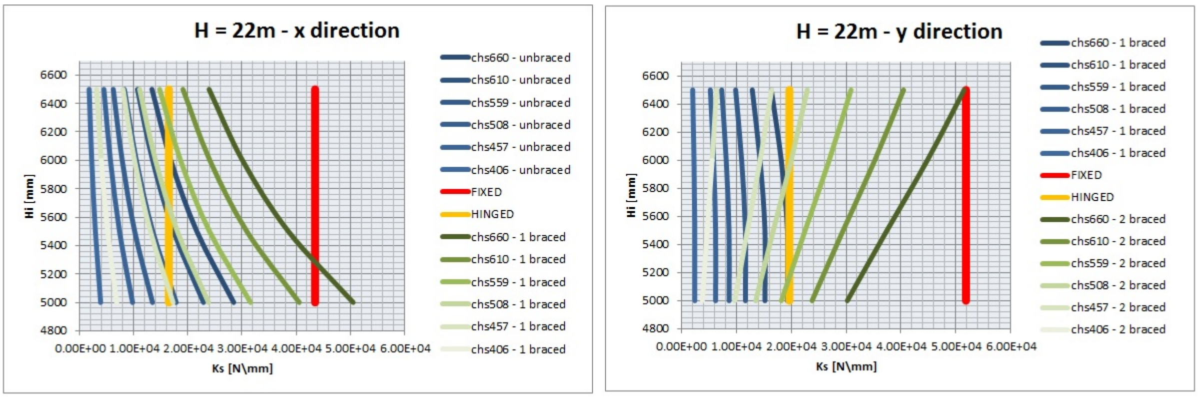


Figure 5.9: Stiffness vs frame height - comparison x and y directions

Then selection goes to the possible layout situations. At this stage also the amount of bracing plays an important role. As calculated before, different stiffness results are found indeed for *braced* and *unbraced* cases (x- direction), *2 braced* and *1 braced* cases (y-direction).
Finally, once all the parameters are defined, total weight can be computed and differences between the solutions coming out from the situations *fixed* and *hinged* are pointed out. The comparison is made by assuming the whole sea-fastening system weight; it means that the partial result has to be multiplied by a factor in order to consider the number of sea-fastening structures over the deck. According to the arrangement proposed in Figure 5.14, a reasonable factor that takes into account for main structures with some external bracings and columns shared is *3.8*.

Now the requirements of maximum total weight over the deck, as proposed in the boundary conditions, Chapter 1.3, may be checked. Indeed, with a theoretical deck capacity of 8500 tonnes, 5000 tonnes taken by the WTGs and 1000 tonnes assumed for the grillage, 2500 tonnes are left for the sea-fastening structure. Theoretical because the high CoG's of transported structures decrease the vessel capacity. Since a certain amount of extra equipment has to be loaded as well, the limit for the sea-fastening structure weight is reasonably imposed to 1500 tonnes.

As already anticipated, strength considerations have to be made as well at this stage of the analysis. This is the reason why a number of two promising solutions is proposed. Minimum total height for strength purposes is the main criteria behind this selection. External bracing lengths and therefore general layouts are not compared since layout *2*, along y-direction, does not give any advantage in terms of weight and stiffness either. The solutions are proposed in the following Table 5.14 and presented as follows:

- **a**, minimum possible total height for both hinged and fixed situation;

- **b**, 25 m as minimum total height for both hinged and fixed situation;

As it can be seen, the situation of partially braced frame appears in the comparison. It is due to the fact that stiffness requirements are very close for the unbraced floors, in the hinged situation, but still not met. The application of fully braced systems would increase the stiffness in order to largely meet these requirements, being still far from the fixed situation requirements. So an adaptation is provided by bracing just the external frames of the structure. This bracing optimization, [19], is shown in Figure 5.10. The behaviour of the system is then modelled and verified, only through *Oasys GSA* software. The displacement results validate the initial assumption and this solution is applied for hinged solutions, during this final selection. It is also tested for fixed situation, but stiffness requirements are not met, resulting in a not applicable arrangement.

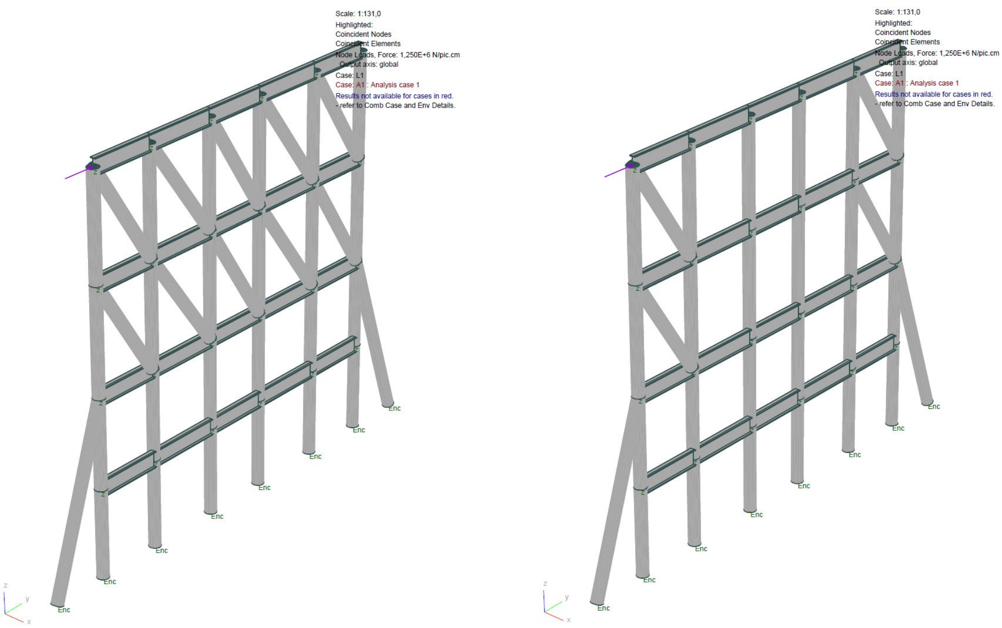


Figure 5.10: Comparison between braced floors (a) and partially braced floors (b)

The most interesting results for comparisons are given by **Δvalues**, expressed in weight saving and percentage difference between the two conditions for WTG connection. Average savings in terms of steel weight, from comparison of each solution combination, are above *20%*. These solutions need to be consistent with strength considerations too. This is the reason why a limit of *25 m* of total height is studied (case **b**). Indeed, the higher the height the lower the horizontal forces acting on the structure, with related less critical stress conditions for its elements. Another aspect is the total weight. The previously mentioned limit of 1500 tonnes for sea-fastening structure is critical for fixed solutions.

Table 5.14: Defined cases - Layout 1

Case a	Hinged	Fixed
Htot [m]	22.00	27.50
Hi [m]	6.0	6.0
x-dir	unbraced	unbraced
y-dir	2 part. braced	2 braced
single [t]	315.47	449.31
TOTAL [t]	1198.80	1707.37
Δ	**508.6 t**	**29.8%**

Case b	Hinged	Fixed
Htot [m]	25.00	27.50
Hi [m]	6.5	6.0
x-dir	unbraced	braced
y-dir	2 part. braced	2 braced
single [t]	349.35	449.31
TOTAL [t]	1327.52	1707.37
Δ	**379.8 t**	**22.2%**

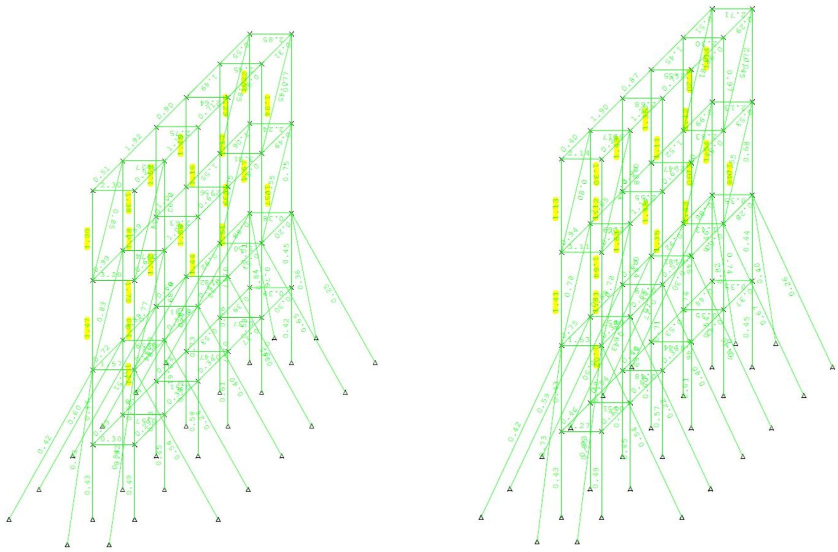
Results from Table 5.14 show an average saving of *26%* between the two possible solutions.
As a rough analysis, SHL estimated *25%* to be the minimum value for taking this solution under consideration, with respect to the cheapest and lightest solution possible in case of fixed WTG connection. This because further and new equipment would be required in order to provide the hinged connection at the WTGs foundation levels.

5.3.4. Strength considerations

In order to apply strength considerations, the previously proposed solutions are modelled on *SACS* in their complete 3D arrangements. Here analysis criteria from AISC 13th edition, [21], are applied and the structures are verified with combined unity checks. The results involve therefore the critical combination of shear, compression with bending, tension with bending, web shear, flange shear, buckling and torsion. This rough verification is meant to see whether the structure can withstand the load cases or not and if the stiffness reasoning are still applicable with general strength requirements. So, the structure is assumed acceptable and feasible if the combined unity checks outputs are equal or less then unity.
In particular, vertical elements (i.e. columns and bracings) are the critical ones to be assessed. Horizontal elements (i.e. beams) do not represent the focus of the analysis since their contribution for lateral stiffness is much lower. Therefore, unity checks that are not met for these elements do not represent a constraint for the design. Indeed, additional stiffening applications in this directions may be added without influencing the lateral stiffness of the whole structure.

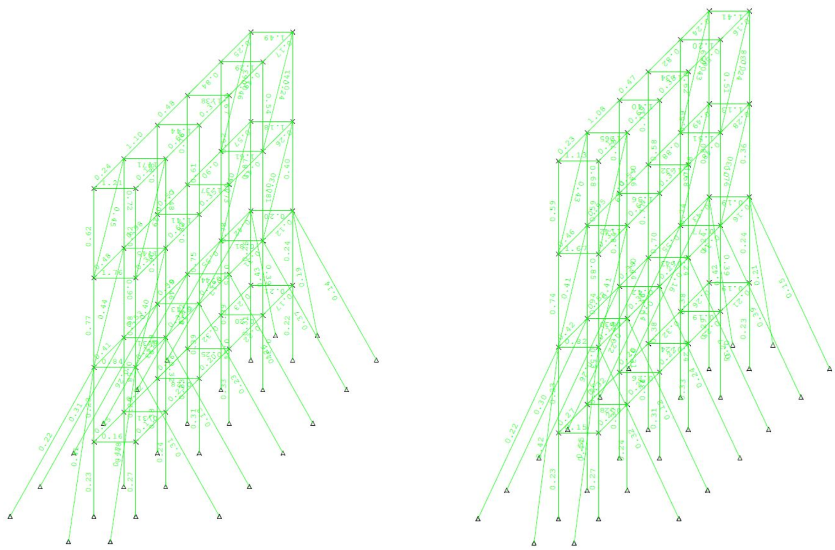
SACS model outputs are proposed in Figures 5.11(a) and 5.11(b), referring respectively to case **a** and case **b**, for hinged connection solution only. Indeed, fixed situation has an higher total height, more steel members and less applied forces: it reasonably behaves better than the other one and therefore its results are not interesting at this stage. They are proposed in Appendix A.5, together with all the other complete results, with graphical and numerical software outputs. A common trend is that critical elements remain in the top floors, where loads are applied, and in the external parts along y-direction, where the roll effect governs. Indeed forces are modelled as applied the top nodes of the structure. An optimization of load application may be provided by spread the load through more nodes, also to one lower floor, in order to have a more even stress distribution. This would mitigate the unity checks results but would not completely change the order of magnitude of the already obtained results.

Besides these considerations, critical elements are shown and highlighted for each graphical output. They have combined unity checks which exceeds the limits. Already from their values is possible to guess if the structural solution can be feasible or not. Figure 5.11 shows issues in unity check members for both the cases, slightly less critical for case b.
It so decided to apply the same cross sections but with high strength steel (S690) instead of the regular one (S355). The results are satisfactory and the number of critical elements is limited, with no peak values in unity checks. The outputs for both cases are proposed in Figure 5.12, while again Appendix A.5 accommodates extensive results for all the cases.



(a) (b)

Figure 5.11: SACS output - Maximum combined unity checks, case a and b, S355 , (overstressed in yellow)



(a) (b)

Figure 5.12: SACS output - Maximum combined unity checks, case a and b, S690 , (overstressed in yellow)

5.4. Summary and results

The analysis provided in this chapter shows how an optimal design for stiffness may lead to effective structural solutions. In this case, it is possible by providing hinged connections at the bottom of WTGs and supporting them at a certain height, below their CoG positions. Some lateral displacements need to be allowed here, in order to make the stiffness reasoning effective. The displacement limit is a delicate aspect to be analysed. A value of *1.25 m* at the top is chosen, after practical reasoning and dimensional boundary conditions. They refer to maximum available space at the nacelle level between two adjacent WTGs, in order to avoid their collision during motions. This value corresponds to maximum *37 cm* of lateral displacement at the intermediate clamp position.

Calculations are carried out starting from the most basic expected situations, for the single frame to the final complete arrangements of the whole structure. Comparisons are made between results from stiffness matrices and softwares; model validation is provided, assumptions are shown to be consistent with the actual behaviour. Different trends are underlined along the two main directions, according to different forces and number of elements involved. Several frame arrangements are investigated, in order to find optimal solutions for the discussion. Cross section selection goes, from the beginning, to the highest dimensions, both for strength and stiffness purposes.

An optimal solution is defined, with the lowest weight and at the lowest possible height, among the several possible arrangements taken into account. It is **case a** from the previous reasoning, with the application of HSS S690. Individual structure layout, together with combined unity checks for strength purposes, are proposed in Figure 5.13. All the choices so far have been shown to work even in terms of strength, by using high strength steel columns and beams. By doing that, a lower total height for the structure is reached, with related lower weight involved. Furthermore, after the comparison with the optimal solution achievable by adopting fixed bottom connection for WTGs, a *29.8%* of advantage in terms of weight saving is pointed out. This value corresponds to about *500 tonnes* of structural steel.

Besides its potentials and advantages, a solution with hinged bottom connections may lead to further unexpected issues. Indeed, it has never been applied for this kind of purposes. Moreover, the required equipment could be largely expensive and that would kill the whole solution cost-effectiveness. Therefore, in the further chapters, analysis is focusing on a clever design for these hinged connections, considering the load and set up condition just defined. It follows that a final term of comparison, besides structural reasoning, will be between the total cost implied by this choice and the utilization of 500 tonnes of steel with a more standard fixed connection solution.

Figure 5.14 shows the selected sea-fastening structure design in combination with the six WTGs over the deck. This is the solution appearance as it results after a design for both stiffness and strength. It is ready for further detailed analysis. The modelled structures for WTGs are meant to give an idea of the overall dimensions; together with the sea-fastening structures, they do not represent the final design (e.g. clamping system at intermediate support are not modelled).

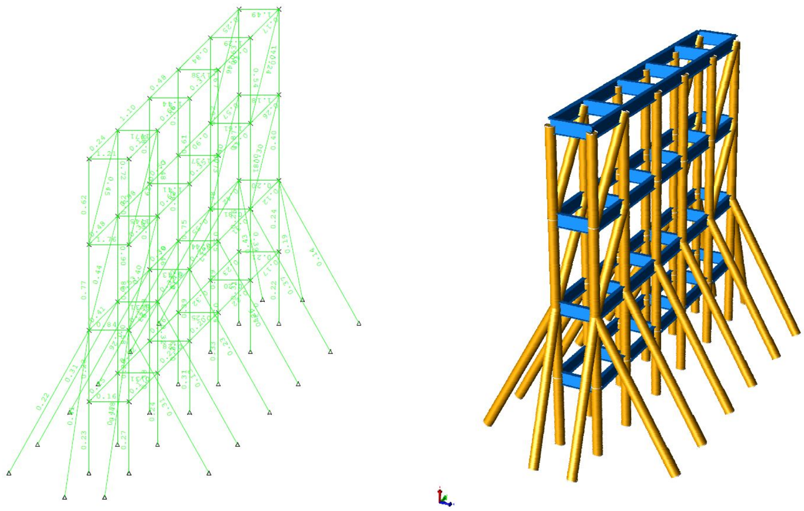


Figure 5.13: SACS output - Maximum combined unity checks and structure overview, final solution

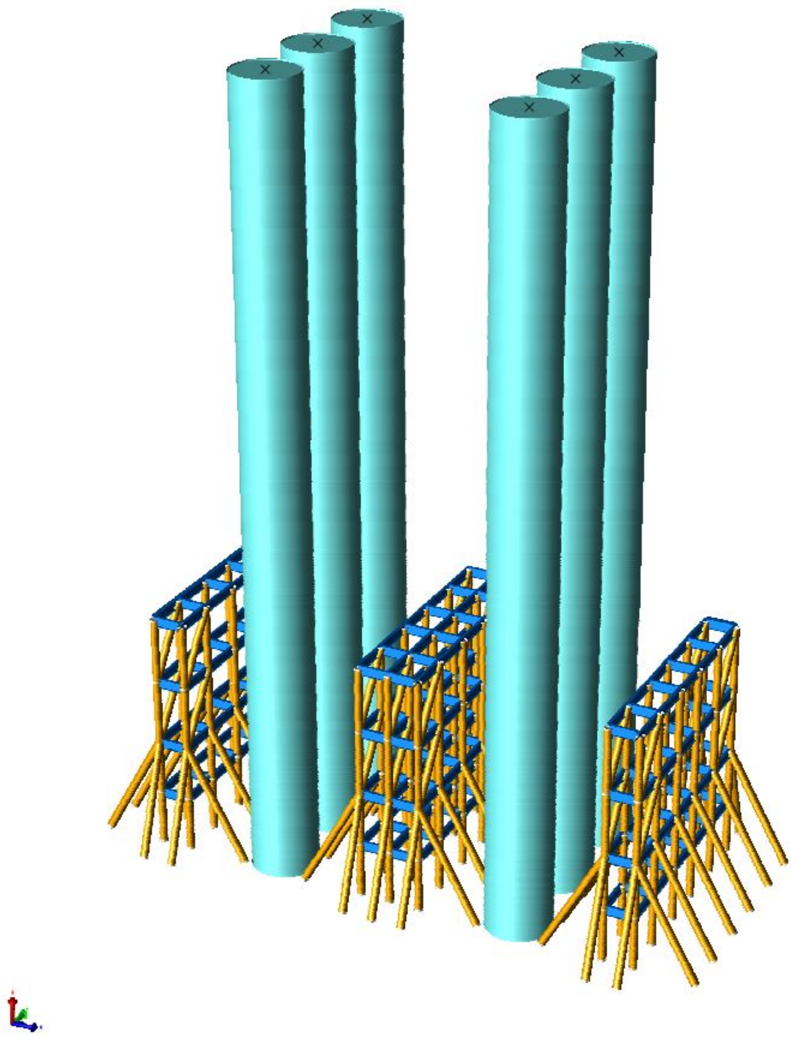


Figure 5.14: SACS output - Final appearence of complete solution over the deck

6

Bottom support - Conceptual phase

Any man may make a mistake; none but a fool will stick to it. Second thoughts are best as the proverb says

Cicero (106 BC - 46 BC)

The connection at the bottom of WTGs is decided to be performed with an hinge. It should be able to provide rotations and to not transmit bending moment at the foundation level. This initial idea needs to be designed and verified, abiding by system boundaries and according to practical considerations, Chapter 1.3. Furthermore, cost-effectiveness of this kind of connection is fundamental for a positive assessment of the whole structural solution. It has been already pointed out how this comparison is made to other comparable structural systems, with respect to material savings, Chapter 5.
Rotation and high flexibility requirements are not usually faced by offshore transportation and installation designs. Sea-motion compensators and dampers are commonly applied, but no references are available for such elevated dimensions and weights, as the ones involved in this study.

The procedure for such an analysis provides a first selection of applicable solutions. Design actions are defined. Ideas, which lead the preliminary design phase, are again related to the main aim of a cost-effective solution. This may be translated into features of lightness, enough strength capacity, cheapness (simple manufacturing) and easy/fast related handling procedures. For these reasons, preliminary thoughts move the focus towards onshore civil engineering practice, especially to the bridge engineering field. Here, structural bearings are largely used for the connection between superstructures (e.g. girders, deck) and substructures (e.g. piers, abutments). Their function is to transfer vertical actions and bending moments, providing certain constraints along translational and rotational directions at the same time.
This general idea seems to be applicable for this case of study. Of course, adaptations are necessary due to the different set up of the problem, field of application and involved parameters.

Then, a preliminary design is provided for each considered solution, in order to assess the feasibility and discuss about advantages and disadvantages. Once the selection is made, a second and more detailed design phase begins, just for the selected optimum case. FEM analysis is provided to evaluate stress distributions and assess the quality of design with respect to service life conditions.

It is pointed out that design calculations are carried out according to European regulations for steel structures, [23]. This is done, in order to be consistent with other European standards, adopted for structural bearings design, [24]. The choice may lead to objection since, so far, mainly American standards, [21] have been used. With proper accuracies in calculation phases, the problem does not arise. As long as the design procedure at each stage is clear and consistent with the related regulation, starting from characteristic values and applying design coefficients only in a second time, even different guidelines can be applied.

6.1. Design data

Design situation for this specific analysis comes out from previous calculations. Firstly, the WTG is still modelled as a stick element: results from motion analysis are still valid and do not need to be adapted, Chapter 4. Vertical force acting above the connection is therefore defined. Horizontal actions are evaluated from Chapter 5: here, according to the choice of hinge-connected system and the related static scheme, reaction horizontal forces at the bottom of WTG are defined. Required rotation immediately follows, again from stiffness analysis considerations. Indeed, the allowed displacements, at WTG top or intermediate support, define the rotation angle to be taken during the worst design condition.
Figure 6.1 explains the static scheme arrangements with the resulting diagrams. In Table 6.1 resulting values are proposed and adopted for further analysis.

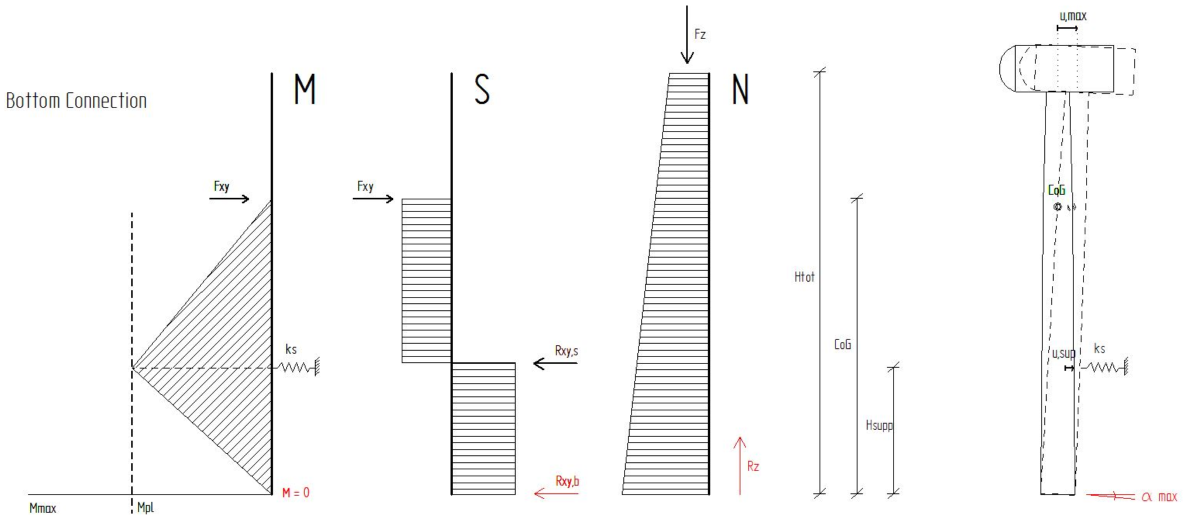


Figure 6.1: Bottom connection - static schemes and design situation

Table 6.1: Bottom connection - Input data

Design data	
Vertical Force [kN]	-9484.1
Horizontal Force [kN]	5510.1
Rotation [deg]	0.98
Rotation [rad]	0.0171

6.2. Possible solutions

As already mentioned, first inputs come from bridge engineering practice. Within this field, several structural bearings have been applied over the years. The technologies behind them are continuously changing and developing to meet the increasing in design action requirements. Large use of structural steel has been characterizing most of the solutions. Then, combination with rubber (elastomer) layers is another possibility. This grants higher flexibility for the bearing, less complicated arrangements for the shear and rotation capacities provided by the material itself.
This design situation provides a bearing connection to be placed underneath the circular hollow section of the WTG tower. Even though a bottom flange is provided, the possible contact surface is still limited and anyway located at the sides. Therefore, in order to use relatively simple connection systems, first ideas are to place steel plates in order to apply the bearing at the centre of the cross section. Rotation capacity is the first requirement, then vertical and horizontal actions constraints. Since it appears to be potentially too expensive, in terms of used material, alternative solution should be the application of bearing directly at the sides. Here rotation capacity becomes an issue.

The following sections describes this initial conceptual phase, by providing several possible solutions. Initial structural design is provided for each of them, according to comparable and related guidelines, in order to give a good idea of possible dimensions and weights.

6.3. Steel rocker system

The main idea is to provide a connection by using just steel material. This is for aim of simplicity and low maintenance requirements. The theoretical hinged connection is translated into rotations about the two main axis. It is made by two overlapped rocker steel lines. Contact surface for the rocker is steel-on-steel, without any other sliding material. The load transfer among them, the WTG flange and the bottom grillage is realized through steel plates. Load transfer through this system, from the WTG to the grillage, determines the structural design. Governing action is the vertical load, which is spread from the WTG walls to the first rocker, then from the latter to the rocker oriented along the other direction. High bending moments arise; really thick plates are required to withstand them.

6.3.1. Design

Design coefficients are applied to actions and materials, as suggested by related guidelines, [25]. Figure 6.2 shows the bending moment diagram for the two main situations.

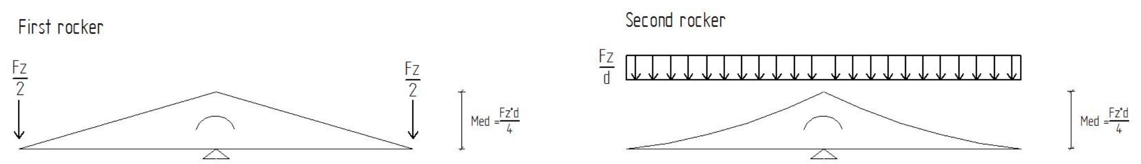


Figure 6.2: Bending moment distribution for first (a) and second (b) rocker

First step is to determine the main plate thickness; for material optimization, due to high expected thickness, the main plate is split in several smaller plates, with increasing dimensions. Governing condition is clearly at WTG centre. Maximum thickness is therefore designed for this position. Design action is the vertical force, from Table 6.1; steel S355 is considered. Thickness of some plates could be higher than 40 mm, therefore the following values are applied, according to guidelines, [23].

$$f_y = 335\frac{N}{mm^2} \qquad f_u = 510\frac{N}{mm^2} \tag{6.1}$$

$$d = 6000mm \qquad F_z = 9.48 \cdot 10^6 N \tag{6.2}$$

$$\gamma_0 = 1 \qquad \gamma_1 = 1.5 \tag{6.3}$$

Assuming steel plastic design, it follows:

$$M_{Rd} = \frac{f_y \cdot d \cdot t_{max}^2}{\gamma_0} \tag{6.4}$$

$$M_{Ed} = \gamma_1 \cdot \frac{F_z \cdot d}{4} \tag{6.5}$$

$$t_{max} = \sqrt{\frac{M_{Ed} \cdot 4 \cdot \gamma_0}{d \cdot f_y}} = 206.1 = 210mm \tag{6.6}$$

Minimum thickness is designed where bending moment is not critical; only shear and axial forces are acting. It happens at the position of WTG flange. Actual force comes from the horizontal reaction force at the bottom of WTG, Table 6.1.

$$F_n = \frac{H}{2} = 2.76 \cdot 10^6 N \tag{6.7}$$

$$N_{Ed} = \gamma_1 \cdot F_n \qquad N_{Rd} = f_y \cdot \gamma_0 \cdot d \cdot t_{min,1} \tag{6.8}$$

$$V_{Ed} = \gamma_1 \cdot \frac{F_z}{2} \qquad V_{Rd} = \frac{d \cdot t_{min,2}}{\sqrt{3}} \tag{6.9}$$

$$t_{min,1} = \frac{N_{Ed}}{f_y \cdot \gamma_0 \cdot d} = 2.1mm \tag{6.10}$$

$$t_{min,2} = \frac{\sqrt{3} \cdot V_{Ed}}{f_y \cdot \gamma_0 \cdot d} = 6.1mm \tag{6.11}$$

$$t_{min} = MAX\left[t_{min,1}; t_{min,2}\right] = 6.1mm \tag{6.12}$$

According to bending moment distribution, three layers of plates are chosen to be applied, with different lengths in order to satisfy the requirements. They are connected by fillet welding, that is just assumed and not checked at this design stage. After an iterative process, they are defined as follows:

$$t_1 = 100mm \qquad L_1 = 6000mm \tag{6.13}$$

$$t_2 = 60mm \qquad L_2 = 4600mm \tag{6.14}$$

$$t_3 = 50mm \qquad L_3 = 2200mm \tag{6.15}$$

Now rocker dimensions can be designed. Specific guidelines procedures are used at this stage, coming from bridge engineering and referred to similar rocker bearings, [25]. Since the application is different but the general ideas are the same, these procedures are not used as prescriptive but just as useful reference. Anyway, they are still strictly dependent on the general guidelines of European standards, [23]. Since a line rocker over the diameter length is chosen, the dimensioning requirements are then proposed. Contact surface for the rocker is assumed flat and minimum radius R is calculated.

$$N'_{Ed} = \frac{N_{Ed}}{d} = 2.37 \cdot 10^3 \frac{N}{mm} \qquad N'_{Rd} = \frac{N'_{Rk}}{\gamma_0^2} \tag{6.16}$$

$$N'_{Rk} = 23 \cdot R \cdot \frac{f_u^2}{E_d} \qquad E_d = 210000 \frac{N}{mm^2} \tag{6.17}$$

$$N'_{Ed} = N'_{Rd} \tag{6.18}$$

$$R = \frac{N'_{Ed} \cdot E_d}{23 \cdot f_u^2} = 24.5 = 30mm \tag{6.19}$$

Then the focus goes to the eccentricities due to the design rotations and horizontal loads. Their combination has to be compared to the thickness of the plate in contact; certain limits are required. In Table 6.1 maximum rotation is considered, acting on the worst direction. Assuming to apply rockers along x and y directions, the maximum of the two component is taken as design value. Gap between the rocker and steel restraint lines, l_1, is chosen of *10 mm*; minimum required value is set at *5 mm*.

$$\theta_x = 0.643 \cdot \theta \theta_y = 0.766 \cdot \theta \tag{6.20}$$

$$\theta_d = MAX\left[\theta_x; \theta y\right] = 0.0131rad \tag{6.21}$$

$$e_{2,d} = 2 \cdot \theta_d \cdot R = 2.35mm \qquad e_{3,d} = \frac{F_h \cdot l_1}{F_z} = 5.81mm \tag{6.22}$$

$$e_d = e_{2,d} + e_{3,d} = 8.16mm \qquad e_d \leq \frac{1}{6} \cdot t_3 = 8.33mm \tag{6.23}$$

$$8.16 < 8.33 \qquad verified \tag{6.24}$$

Other dimensional requirements are defined. At maximum rotation, the dimension of the curved surface needs to be such that the contact line is at least *25 mm* from any discontinuity in the curved surface.

$$R - e_2 = 27.7 \geq 25mm \qquad verified \tag{6.25}$$

A last requirement is defined for line steel restraints. They shall withstand horizontal actions diminished by frictional effects. Static friction coefficient for steel vs steel contact is set as *0.4*. Therefore, the resulting horizontal design action is found. Both line restraints are dimensioned for this design load.

So, minimum thickness, t_r, is here evaluated, according to the guidelines, [24]. For practical reasons and tolerances it is kept at *10 mm*.

$$\mu_k = 0.4 \qquad \gamma_\mu = 2 \tag{6.26}$$

$$F_{Rd} = \frac{\mu_k}{\gamma_\mu} \cdot N_{Ed} + d \cdot t_r \cdot fy_d \qquad F_{Ed} = \gamma_1 \cdot F_h \tag{6.27}$$

$$t_r = \frac{F_{Ed} - \frac{\mu_k}{\gamma_\mu} \cdot N_{Ed}}{d \cdot fy_d} = 1.25mm \tag{6.28}$$

6.3.2. Results

Due to symmetry reasons and to the similarity of main design actions, already expressed in Figure 6.2, this calculation is valid for both the rockers along the two dimensions. The same holds for the steel plates. Final arrangement is proposed in Figure 6.3, where sections and detailing are shown. It is mentioned that connection between main plate and WTG flange is made by bolts. All the other connections between adjacent steel elements are realized by welding.
A simple calculation of involved weights is now carried out, Table 6.2. This is useful for further comparison with other solutions. All the plate elements are grouped according to their thicknesses and areas. Line rocker are not considered, due to their small influence with respect to the other components. Finally, no further equipment is part of the solution.

Table 6.2: Weight calculation (single WTG) - Steel rocker system

Plate element	*t [mm]*	*n*	*Area [m^2]*	*Volume [m^3]*	*Weight [t]*
1	100	2	56.55	5.65	44.22
2	60	2	55.20	3.31	25.90
3	50	4	52.80	2.64	20.64
			164.55	**11.6**	**90.8**

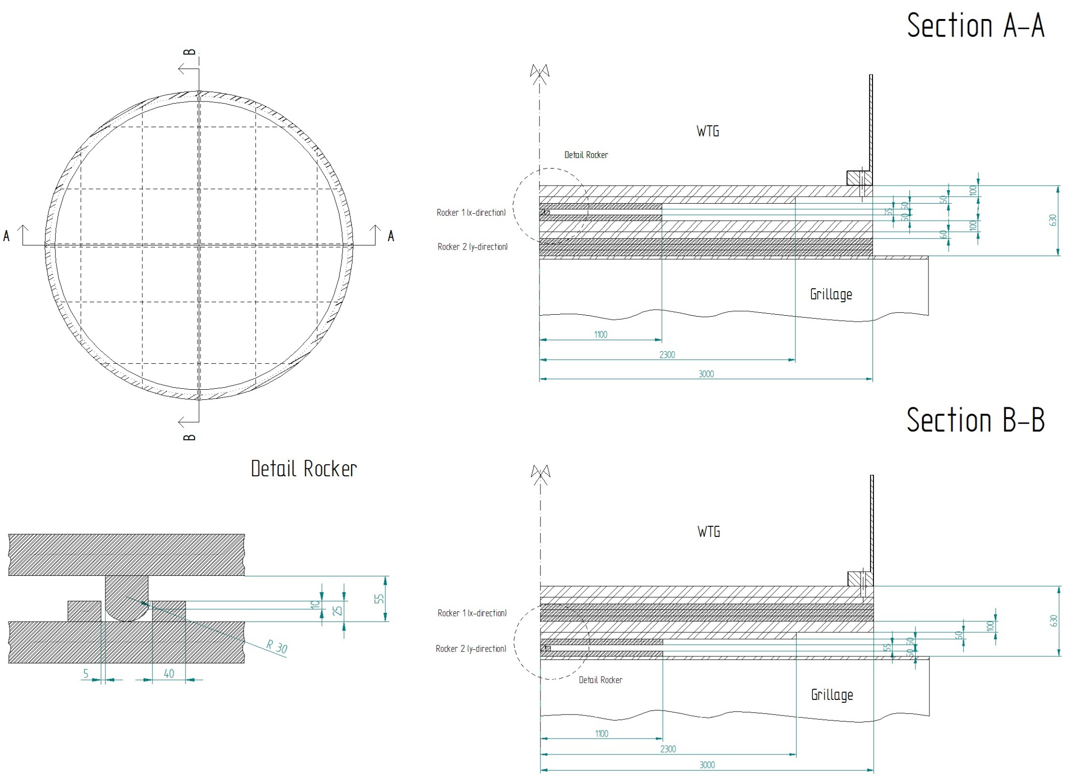


Figure 6.3: Steel rocker system design - Sections and detailing

6.4. Pot bearing system

Massive amount of steel is required for the rocker system. Therefore a more effective solution is investigated. Still providing support at the centre of the WTG section, a pot bearing system is analysed. It comes from bridge engineering and is chosen for its good behavior with respect to high vertical forces and allowed rotations, in every direction. This equipment is made by a steel container, filled by elastomer and covered by a steel plate acting as a piston. Therefore a combination of two different materials is applied in this solution, potentially increasing service-life issues and maintenance requirements. Environmental condition requirements do not seem critical. Elastomer confined in such a way does not decrease its performance within a range from *- 40 deg C* and *+ 50 deg C*. These conditions are in the range of offshore situation within the North Sea operations, defined at the beginning.
Then, since the position is still close to the centre of the WTG section, thick steel plate or several connected steel plates are required to transfer the load properly.

6.4.1. Design

Same design coefficients are applied to actions and materials. Figure 6.4 shows the bending moment diagram for this case. It depends on the length of the piston and therefore the bearing. Limitations are given in pot bearings guidelines, [26]; a maximum length l_{pb} of *2000 mm* is considered as design condition. It results in basic preliminary dimensions. Then, it can be easily translated into maximum design bending moment.

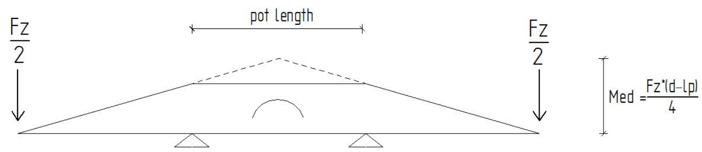


Figure 6.4: Bending moment distribution for pot bearing

Similarly to the previous procedure, thicknesses for the connected plates are found. Again, fillet welding is assumed and connection verification is not provided at this design stage. Since the maximum bending moment is slightly lower, thicknesses result in thinner dimensions. Just final results are provided, because of the same reasoning and formulas hold.

$$M_{Rd} = \frac{f_y \cdot \left(d - \frac{l_{pb}}{2}\right) \cdot t_{max}^2}{\gamma_0} \tag{6.29}$$

$$M_{Ed} = \gamma_1 \cdot \frac{F_z \cdot d}{4} \tag{6.30}$$

$$t_{max} = \sqrt{\frac{M_{Ed} \cdot 4 \cdot \gamma_0}{d \cdot f_y}} = 168.3 = 170mm \tag{6.31}$$

$$t_1 = 70mm \qquad L_1 = 6000mm \tag{6.32}$$

$$t_2 = 50mm \qquad L_2 = 5100mm \tag{6.33}$$

$$t_3 = 40mm \qquad L_3 = 3500mm \tag{6.34}$$

Now the focus can go to the specific equipment itself. On the market, several products are available, ranked for their capacities and dimensions. A preliminary design of a similar solution is provided here, according to the boundaries given by the related guidelines [26]. First rotation limitations are checked.

$$\alpha_{d,max} = 0.03rad \qquad \alpha_d = 0.017rad \qquad \alpha_d < \alpha_{d,max} \tag{6.35}$$

According to the initial decision of equipment length maximization, some dimension constraints are implied. Also, material limitations are required by the guidelines; they are proposed through the following calculation steps. Figure 6.5 simply shows a general pot arrangement and the involved dimension classification.

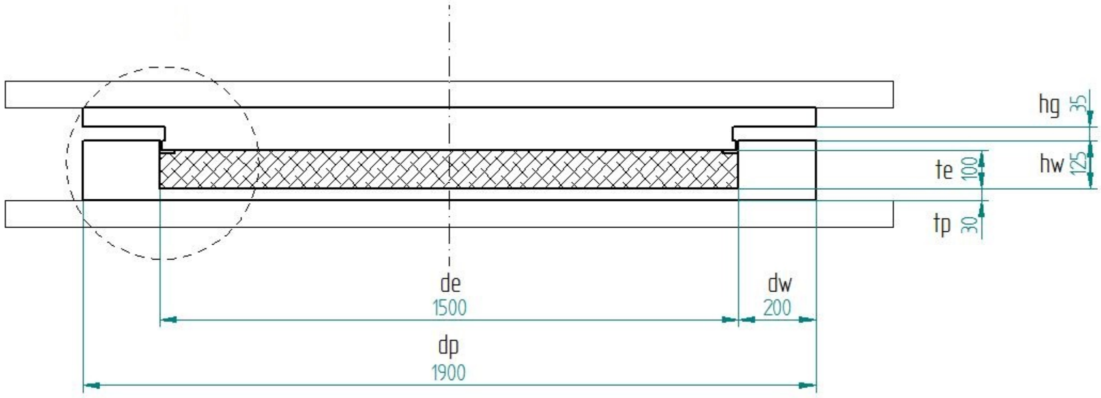


Figure 6.5: Pot bearing dimensions - overall arrangement

Pad verification is the first design check. The maximum allowed dimension d_e according to the guidelines is *1500 mm*. Therefore this value is chosen. Main action is the vertical force, which the pad is subjected to. Therefore it follows:

$$N_{Rd} = \frac{N_{Rk}}{\gamma_m} \qquad N_{Rk} = \frac{\pi}{4} \cdot d_e^2 \cdot f_{ck} \tag{6.36}$$

$$\gamma_m = 1.3 \qquad f_{ck} = 60\frac{N}{mm^2} \tag{6.37}$$

$$N_{Rd} = 8.15 \cdot 10^7 N \tag{6.38}$$

$$N_{Ed} = \gamma_1 \cdot F_z = 1.42 \cdot 10^7 N \tag{6.39}$$

$$\frac{N_{Ed}}{N_{Rd}} = 0.17 \tag{6.40}$$

For this first criterion, the elastomeric pad seems to be over-sized; it is important to remember that in this way steel is saved (e.g. connection plate) since bending moment is lower. Then, further design criteria depend on this dimension, leading to smaller requirements for other parameters.
Now the design moves to the steel pot. Firstly, limits in base plate thickness are provided:

$$t_{p,min,1} = 3.33 \cdot \alpha_d \cdot d_e = 85.2mm \qquad t_{p,min,2} = 12mm \tag{6.41}$$

$$t_{p,min} \geq \frac{\alpha_d \cdot \frac{d_e}{2}}{0.15} = 85.3mm \qquad t_{p,min} \geq \frac{d_e}{15} = 100mm \tag{6.42}$$

$$t_p = 100mm \tag{6.43}$$

Tension in pot walls is now investigated. A further dimension that here appears is the wall height h_w. Following equations are applied and this minimum value is found.

$$V_{Fxy,Ed} = F_h \cdot \gamma_1 = 8.27 \cdot 10^6 N \tag{6.44}$$

$$V_{Ed} = \frac{4 \cdot N_{Ed} \cdot t_p}{\pi \cdot d_e} + \sqrt{2} \cdot V_{Fxy,Ed} = 9.47 \cdot 10^6 N \tag{6.45}$$

$$V_{Rd} = \frac{f_{yd} \cdot (d_0 - d_e) \cdot h_w}{\gamma_m} \tag{6.46}$$

$$V_{Rd} \geq V_{Ed} \qquad h_{w,min1} = \frac{V_{Ed} \cdot \gamma_m}{f_{yd} \cdot (d_0 - d_e)} = 86.74mm \tag{6.47}$$

From additional geometric conditions, related to the requirement of not falling out of elastomer during maximum rotation, another minimum value for h_w is defined. Then the design value is proposed.

$$h_{w,min2} = t_p + \alpha_d + 0.5 \cdot d_e + 10 = 122.8mm \tag{6.48}$$

$$h_w = MAX\left(h_{w,min1}; h_{w,min2}\right) = 122.8 = 125mm \tag{6.49}$$

Similar procedure is applied for shear verifications in pot walls. All the required parameters are already defined, thus unity check follows.

$$V'_{Ed} = \frac{V_{Ed} + 1.5 \cdot \sqrt{2} \cdot V_{Fxy,Ed}}{d_e} = 9.10 \cdot 10^3 N \tag{6.50}$$

$$V'_{Rd} = \frac{f_{yd} \cdot (d_0 - d_e) \cdot h_p}{2 \cdot \gamma_m \cdot \sqrt{3}} = 3.15 \cdot 10^4 N \tag{6.51}$$

$$\frac{V'_{Ed}}{V'_{Rd}} = 0.29 \tag{6.52}$$

Even this requirement is largely verified. Now tension in pot base is evaluated and checked. Among all the design requirements, this appears to be one of the most strict.

$$V''_{Ed} = V_{Ed} + V_{Fxy,Ed} = 9.47 \cdot 10^6 N \tag{6.53}$$

$$V''_{Rd} = \frac{f_{yd} \cdot d_0 \cdot t_p}{\gamma_m} = 1.23 \cdot 10^7 N \tag{6.54}$$

$$\frac{V''_{Ed}}{V''_{Rd}} = 0.77 \tag{6.55}$$

Now both steel and elastomeric material are designed for the worst load condition at ultimate limit state. Attention needs to be paid on contact surfaces between pot walls and piston. In case of horizontal action, a constraint is generated in this direction. A proper pot dimension, w_p at this contact surface has to be designed. This requirement arrangement is shown in Figure 6.6(a).

$$V'''_{Ed} = V_{Fxy,Ed} = 8.27 \cdot 10^6 N \tag{6.56}$$

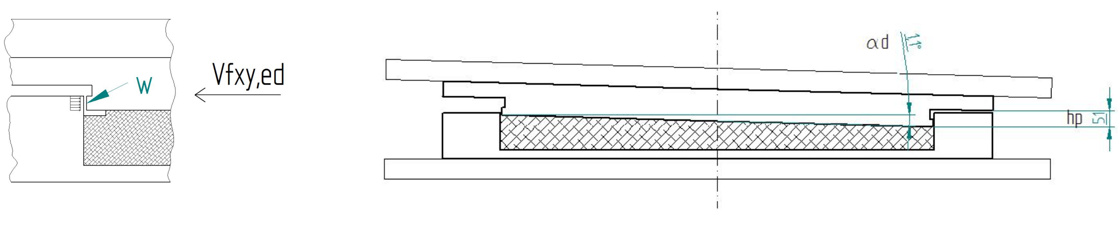
$$V'''_{Rd} = \frac{f_{yd} \cdot d_e \cdot w_p}{\gamma_{m2}} \qquad \gamma_{m2} = 1 \tag{6.57}$$

$$\frac{V'''_{Ed}}{V'''_{Rd}} \geq 1 \qquad w_p = 23.28 = 25mm \tag{6.58}$$

Finally, an additional geometrical condition needs to be applied. This is meant in order to avoid contact between the top of the pot wall and any other metallic component, once the maximum design rotation is expressed. Figure 6.6(b) proposes this situation, where a minimum height h_p is found and the final value for the gap h_g may be designed.

$$h_p = h_w - t_e + 10 + \alpha_d \cdot 0.5 \cdot d_0 = 51.21mm \tag{6.59}$$

$$h_g = h_p + t_e - h_w = 26.3mm = 35mm \tag{6.60}$$



(a) (b)

Figure 6.6: Pot bearing configuration - detail (a) and rotated situation (b)

A further interesting calculation would be about the determination of restrain bending moment. According to the related standard, [26], this calculation should come from test results with representative load applied. It is therefore difficult to assess whether the system is well designed or not with respect to this requirement. However, some assumptions should be made in order to define a design value, to be used for further grillage calculations. Indeed, this restraint moment would be applied as reaction forces at the pot bearing bottom connection. It is proposed only if this solution is selected as the design one.

6.4.2. Results

Final appearance is proposed in Figure 6.7. Again, connection between the main plate and the flange is realized by bolts, while the several plates are welded together by fillet welding.

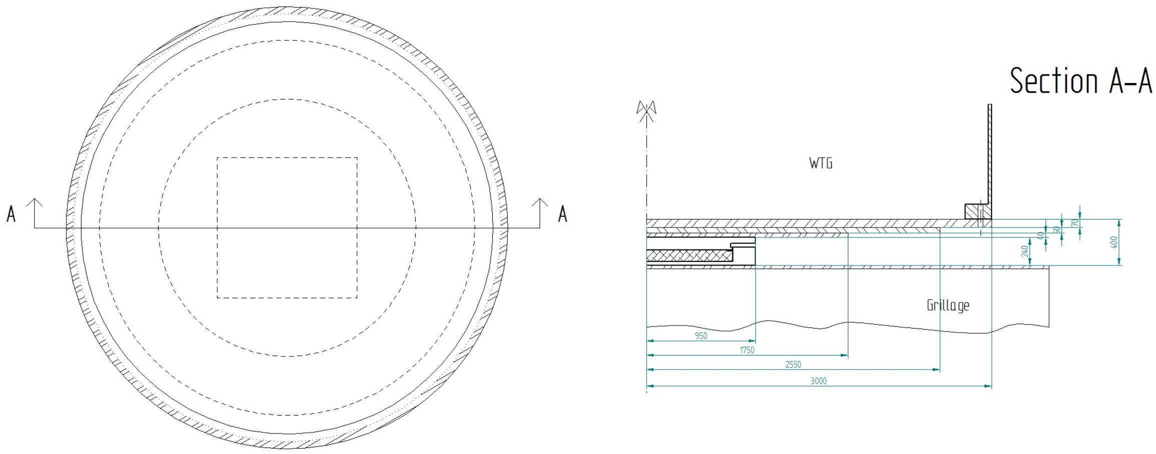


Figure 6.7: Pot bearing system - final appearance

Similar to steel rocker system, an evaluation of involved weights is proposed in Table 6.3. They consist of just steel plates, necessary for the connection between the bottom flange and the pot bearing. The latter is considered as special equipment and treated separately in the final solution considerations and selection, Chapter 6.6.

Table 6.3: Weight calculation (single WTG) - Pot bearing system

Plate	*t [mm]*	*n*	*Area* $[m^2]$	*Volume* $[m^3]$	*Weight [t]*
1	70	1	28.27	1.98	15.48
2	50	1	20.43	1.02	7.99
3	40	1	9.62	0.38	3.01
			58.32	**3.39**	**26.47**

6.5. Rubber system

Solutions with large amount of steel have been analyzed. In order to have an effective alternative, rubber material is considered. The idea is to perform the support at the sides of WTG cross section, in order to avoid thick steel plates to transfer the loads to the centre. Rubber can provide the required bearing performances, if properly designed. Really high load bearing capacity is achieved by small solutions, when combined with thin steel plates. Rotation capacity is provided, thanks to the high deformation capacity in shear direction.
On the other hand, the high compression loads affect the potential behaviour at the sides. Indeed, in order to provide the required rotation at the bottom of the WTG, three different situations should be considered: bearing of vertical load, differential vertical deflection between the two sides and relative rotation at each support. Therefore at the sides and along the design direction, some elements should considerably deflect in compression, and this represents the main limit for such a material, which is almost incompressible. Figure 6.8 shows the assumed arrangement while Figure 6.9 explains the critical situation. The actual deformation shape is not the one depicted and the amplitude is exaggerated; it is

just proposed to give an idea about the behaviour of this material under compression and the required deformation under such an action.

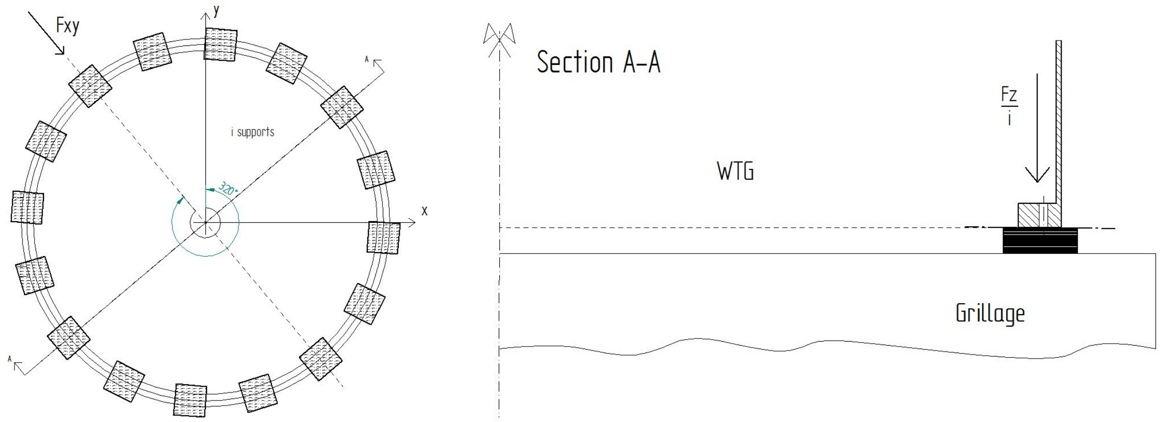


Figure 6.8: Rubber system, initial configuration - overall arrangement

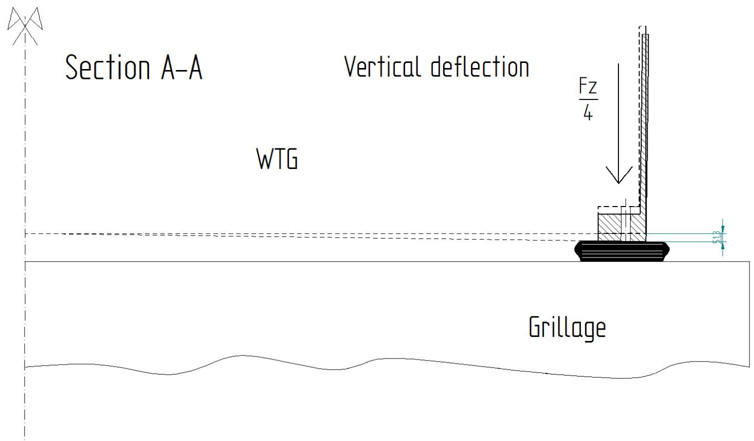


Figure 6.9: Rubber system, initial configuration - critical aspect

Some dimensioning tests are calculated, with resulting over dimensioned elements in height leading to further stability issues. In this way the solution would be probably still comparable or cheaper than the previous two, but the efficiency would decrease since the rubber material would not be used in a clever way.
By reasoning about the actual features of rubber and their consequent high potentials, shear behaviour comes out to be the key aspect for the further analysis.

It is therefore proposed to use the same concept of rubber elements, applied at the WTG sides, but this time rotated of *90 deg*. In this way the differential vertical deflection between two sides would not be critical anymore, due to the rubber high deformation capacity in shear direction. Furthermore, horizontal reaction force at the bottom would act as compressive load on the rubber surface, without representing a critical situation thanks to its already mentioned incompressible nature.
On the other hand, the amount of vertical load transferred through shear could be a critical and lead the design phase. Massive rubber elements are assumed at the beginning, arranged in layers and supported by steel structures. Exactly the contact surface between rubber and steel is investigated, and its stress capacity assessed.
Figure 6.10 shows the initial arrangement and the single supporting element. Figure 6.11 explains the reasoning behind it by the consideration of the actual applied actions and related deformations. Since high potentials are seen for this solution, it is selected as the one to be adopted for the study and

its design is provided in the next Chapter 7. Next sections summarize the choices and the reasoning behind the selection, through the comparison with previous possibilities.

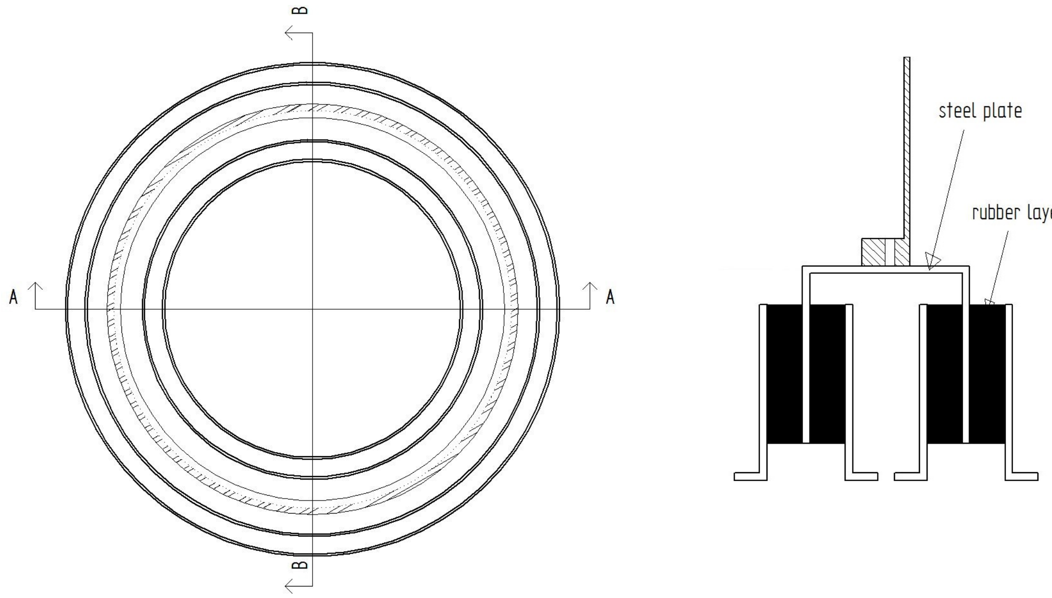


Figure 6.10: Elastomeric system, final configuration - overall arrangement and supporting element overview

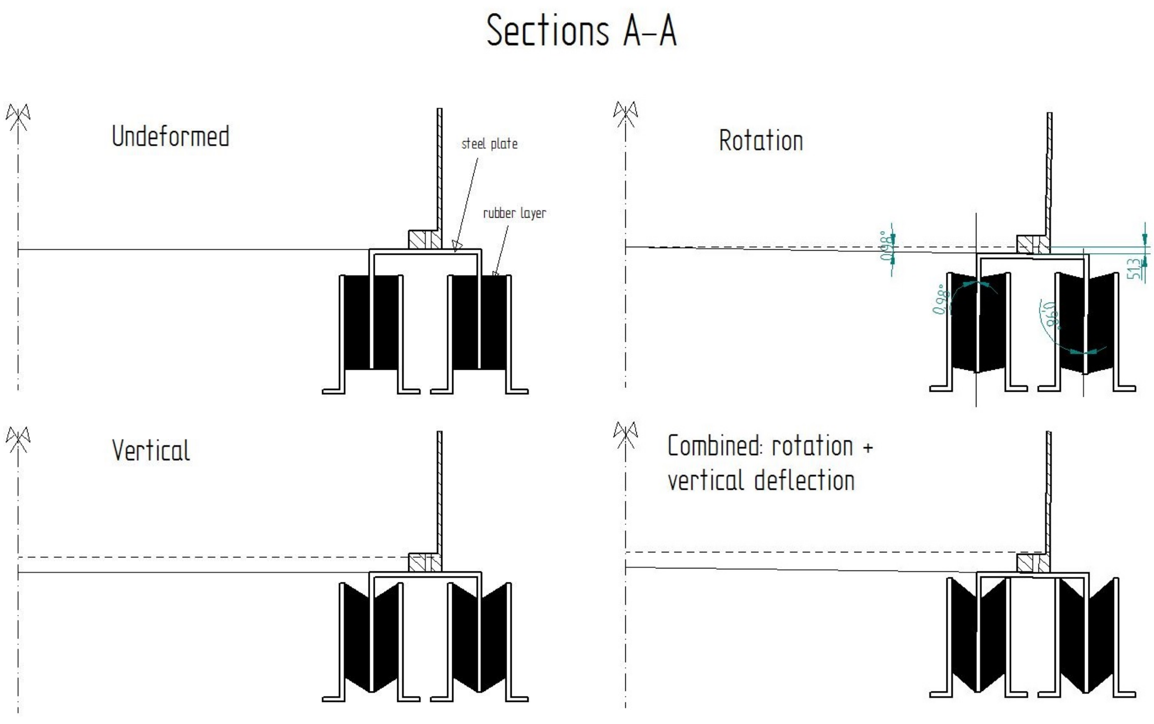


Figure 6.11: Elastomeric system, final configuration - actions and related deformation phases

6.6. Comparison of solutions

In the last section, three main proposals have been described. For all of them, it is decided to keep the solution complexity as low as possible. Therefore, a possible objective comparison may arise about the amount of structural steel, required for each solution. More detailed data are provided for the first two solutions while for the last one specific results still need to be designed. They are therefore proposed at the end of the next chapter.
Then, results may be easily compared to the advantages deriving from the stiffness reasonings behind this kind of bottom connection, already explained in Chapter 5. There, a value of **500 tonnes** of structural steel is set as design cost-limit. It represents the material saving of this solution with respect to the most effective achievable sea-fastening solution with a completely fixed bottom connection for WTG. Therefore this is kept as a fundamental criterion for the selection. Table 6.4 shows the summary of weight results, together with extra equipment involvement (*tbd=to be determined*).

Table 6.4: Bottom connection solutions - Material quantification

	Steel rocker		**Pot bearing**		**Elastomeric bearing**	
Material	*Single WTG*	*Total*	*Single WTG*	*Total*	*Single WTG*	*Total*
Steel (plate) [t]	91	**545**	26	**159**	0	**0**
Steel (additional) [t]	-	**-**	-	**-**	tbd	**tbd**
Equipment	-	**-**	1 elem	**6 elem**	n elem	$6 \cdot nelem$

6.7. Summary and results

In this Chapter, a preliminary design is made for the selection of the most promising solution, for the bottom connection of WTGs on OS vessel. The input requirements are analysed and treated from different point of views. It has resulted in three different conceptual designs. The last one is not designed in detail or at least these details are not proposed here, since resulted in unfeasible design solutions. On the other hand, huge potentials are seen for a different arrangement of this same design. Moreover it shows innovative features that would be worth it if further investigated. This is a governing aspect, taken into account for the conceptual selection.

From the last Table 6.4, it appears clear how the extreme simplicity of rocker bearing system gives back a tremendous amount of required steel. There may be still possibilities of cross section optimizations but, as the design phases have shown, a great boundary is the high bending moment at the centre of WTG bottom cross section. With a final weight of *545 tonnes* of structural steel, the limit is exceeded. At the end, this bottom connection solution nullifies the cost effectiveness of the whole sea-fastening system, even though is simple and feasible.

Pot bearing system shows a decisive saving in structural steel, about *70%* less than the rocker solution. On the other hand, a more complicated equipment is introduced, the pot bearing itself, which may have related high expenses, due to its construction procedures. The material involved are just steel and elastomer, but procedures to combine them may be potentially costly. Firstly because of dimensions, larger than standard pot bearings available on the market. Secondly for the new required set of tests, in order to apply this system offshore instead of onshore, for bridges, where it is traditionally installed.

Finally, rubber bearing solution has the advantages of no extra structural steel involved, since no thick and wide plates are required. Indeed, by placing the elements right below the bottom of WTG flange, they act as supports directly there. Two tentative designs are proposed and the second and most complex one is selected, due to the final inefficiency of the first. On the other hand, disadvantages arise as additional steel requirements, to provide such a relative complex supporting system, Figure 6.11. From this first conceptual design, amount of material involved is really high and need to be optimized through the analysis of Chapter 7.
This solution seems challenging and potentially innovative at the same time. Furthermore, the rubber material would be used in its most efficient way, increasing the effectiveness of the solution. Connection between rubber and steel is provided by vulcanization processes. Since this practice has been tested and applied for many years, results also in relative low production costs (at least compared to pot bearings). The different application in a *90 deg* rotated layout would require more validation tests. Then, other tests would be required for their application offshore. Finally, horizontal constraint is provided by combination of rubber compressive capacity and supporting vertical steel plates.

For the considerations exposed so far and for the potential advantages shown, solution with rotated rubber elements is selected for further design phases.

7

Bottom support - Design phase

Take care of small things if you want to obtain the greatest results

Federico Cesi (1585 - 1630)

In this chapter, the defined connection solution, Chapter 6, is further investigated and designed. Starting from initial conceptual ideas, the design procedure is carried out with both hand calculations and FEM analyses. Firstly, some choices are made by means of hand calculations. Then related models are generated to check the assumptions and find more accurate results. Due to the many parameters involved, this procedure becomes really useful during the optimization phases.

The first stage of analysis is depicted as **Design for Stiffness**. Major attention here is given on the deformation behavior of the rubber elements and all the structural boundaries related to this material. Then, **Design for Strength** is performed. Here the defined shape of rubber bearings is the starting point for the optimization process, mainly focused on the attached steel plates. Elastic beahviour is considered for the steel. Stiffeners and additional plates are discussed and provided, where necessary.

Some intermediate results are provided in order to show the steps of the design process. These are proposed in the text, while extensive results are provided just for the final solution. Excel sheets for hand calculations are attached in the Appendix A.6. Here, the parameters involved are shown, together with the main safety checks. ANSYS model results are proposed as well and compared with the hand calculation assumptions. The two procedures are briefly explained and shown to be consistent.

Finally, specific analysis are carried out, in order to completely investigate the structural effectiveness and quality of this solution. It is underlined again that one of the main aim of sea-fastening is to not ruin or negatively affect the structures to be transported, e. g. the WTGs. Therefore, a buckling analysis is provided, since several supports are placed at the tower base. ANSYS analysis is opposed to hand calculations, based on related theories and practical studies, [27] and [28].
Then, the free vibrations of the system are investigated. Natural frequencies of the first three modes of shape are compared with the related frequencies of the vessel motion. Related considerations and final conclusions close the section.

7.1. Design for stiffness

Starting point is the output of conceptual selection. Using rubber mainly acting in shear can cope with the requirements of differential deformation in vertical direction, between two cross sections at opposite sides (e.g. rotation about x and y axis). The required angle along the worst direction, which is the governing one, is $0.98deg$. It is translated, due to a radius of $3000mm$, into a differential displacement $\delta_{diff}$of $51.3mm$.
On the other hand, strict boundaries are implied, due to strength and deformation capacities of the rubber material itself. As already briefly mentioned in chapter 6, they are:

- Adhesion strength between steel and rubber contact surface;
- Rubber strength capacity;
- Maximum rubber shear deformation;
- Temperature affection on rubber shear modulus;
- Stability, relative rotation and compressive capacity of rubber.

For the first two issues about strength, it is known from rubber mechanical properties that the capacities in compression and shear are relatively high. Tension capacity may be a critical part and potentially a governing situation; id does not apply for this loading case.
General practice and extensive tests have shown that governing failure condition is most of the times the loss of the adhesion between the two materials. Bonding capacity is therefore investigated and becomes one of the main boundary conditions for this design. It is tested and assessed in standardized ways. For this study, reference comes from the American tests *ASTM D429*, where all the possible arrangements and resulting properties are defined, for different types of rubber materials, [29]. According to these studies, a realistic and rather conservative value for bonding strength is taken, considering adhesion by vulcanization of rubber *SHORE A* to metal:

$$\sigma_{ad} = 300psi = 2.065MPa \tag{7.1}$$

The choice of *SHORE A* material is consistent with its application bridge engineering practice, where this hardness value is the most common used for bearings.

Maximum rubber deformation under shear loading is then analysed. It is still related to the adhesion capacity: the higher the shear deformation the higher the probability of occurrence for bonding failure. Thanks to the vulcanization techniques available nowadays, it is allowed to consider as maximum shear deformation value the thickness of the rubber element itself:

$$\delta_{shear,max} = t_{rubb} \tag{7.2}$$

Below this limit, no negative effects on adhesion capacity are experienced and therefore the previously proposed value can be kept.

Temperature has an important effect on the rubber structural response. Non linearities describe this kind of behaviour and it would be difficult to take them into account for the wide range of temperatures available in offshore conditions. It is therefore decided to follow bridge engineering guidelines, [30]. The criterion basically consists on the shear modulus *G* adaptation. At very low temperatures, up to *-40 deg*, a shear modulus three times higher than room-temperatures, *+ 23 deg*, has to be considered. Normal practice allows to use a rubber material with a initial modulus $G = 0.75MPa$, [30]. It follows:

$$G_{T,23} = 0.75MPa \qquad G_{T,-40} = 2.25MPa \tag{7.3}$$

For this design, these two values are used. Calculations are performed for both the situations. They are going to govern alternatively the design phases and requirements.

Finally, the last requirements for the rubber material are investigated, such as stability, relative rotation and compression capacity. Since an horizontal reaction force is present at the bottom of the

WTGs, rubber elements are indeed loaded in compression. Moreover they also experience a relative rotation about their symmetry axis, which has to be considered and checked as well. Again, guidelines for these kind of analysis come from bridge engineering practice. Related European normative is used, [30], which provides several checks for stability, compression and rotation capacity. All the calculation procedures are of course adapted from the common practice to this particular case arrangement.

7.1.1. Rotational stiffness consideration

All the just mentioned features are the governing parameters of this design stage. Again, it is called **Design for Stiffness** since rotational flexibility of the whole connection is the final aim of this analysis step.
Due to different behaviours, according to temperature range, the rotational stiffness response will be different as well. Indeed, in order to have the required flexibility in all conditions, the governing situation would be the one at low temperatures, with a stiffer rubber *G=2.25 MPa*. To cope with these high rigidity conditions, rubber would be over-dimensioned. Then, with this design the situation at room-temperature would be very flexible, with really high related shear deformation. Some design tentatives are carried out to prove these already reasonable considerations.

Therefore it is decided to keep the room-temperature condition as governing situation for the design, keeping in mind the effects at low temperatures. In the meanwhile, a certain rotational stiffness limit for the complete bottom connection has to be identified.
It comes from initial reasonings, at the selection stage of these kind of moment-free connection and the related vertical structures at the intermediate support positions, Chapter 5. Figure 6.1 graphically shows the situation. Allowing a certain rotational stiffness means indeed allowing a certain bending moment at the bottom of the tower. As already shown, if it is low it does not affect the WTG integrity. A most important effect has to be checked with respect to the horizontal action transmitted to the vertical supporting structures. They have been dimensioned and selected starting from stiffness considerations and their comparisons with alternative less flexible systems.
Therefore, a limit in reduction of horizontal force at the intermediate support positions is set, by considering the capacity of the already designed structures. Then, this reduction is translated into bending moment allowed at the bottom and finally into minimum differential deflection, required at the rubber level. This is the design situation for the low temperature situation.

$$R_{H,top} = 9643.16kN \qquad R_{H,top,min} = 8680kN \tag{7.4}$$

$$\%Reduction = 10\% \tag{7.5}$$

$$M_{bott,max} = z_{CoG} \cdot F_{xy} - h_{supp} \cdot R_{H,top,min} = 51.33 \cdot 4133 - 22 \cdot 8680 = 21187kNm \tag{7.6}$$

$$F_{s,rubber} = \frac{M_{bott,max}}{r \cdot \gamma_{dir}} = \frac{21187}{6 \cdot 1.2} = 3050kN \tag{7.7}$$

$$\delta_{diff,min} = \delta_{diff} - \frac{t_{rubber} \cdot F_{s,rubber}}{G_{T,-40} \cdot A_{rubber} \cdot 4} = 17mm \tag{7.8}$$

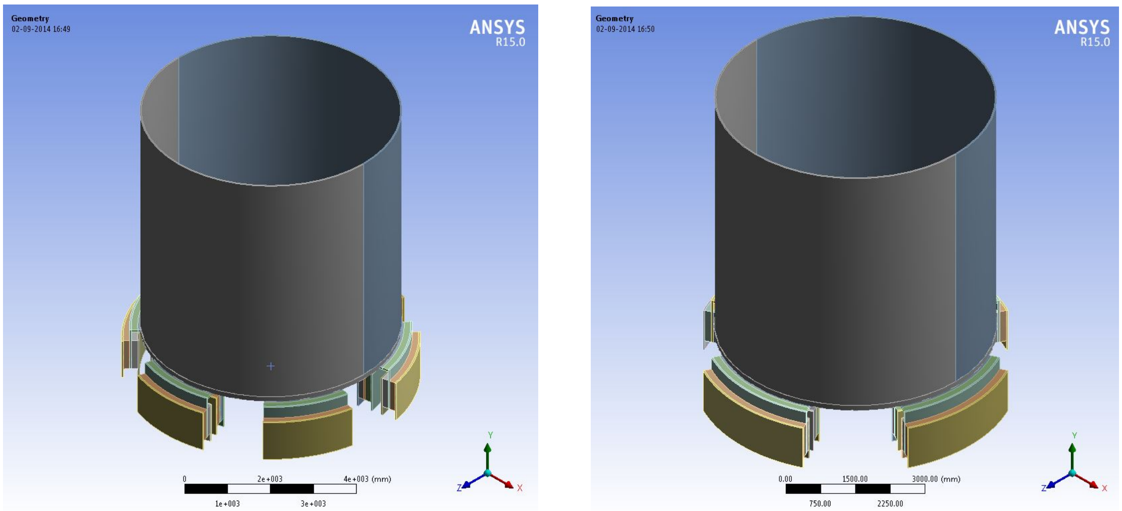
The same reasoning may be adopted for *T = 23 deg* as well. As already said, the design procedure abides by the initial $\delta_{diff} = 51.3mm$. At the end of the process, after strength optimizations, small differences in displacements and so generation of small bending moments will be considered as well, with the same procedure just proposed. Due to the lower *G* value, the effect will not be critical.

7.1.2. Procedure

Now that the boundaries are defined, the design procedure can be explained. An Excel spreadsheet is built up and used for the calculation, due to the large number of sub parameters involved. It is proposed in Appendix A.6, in several iteration outputs. Input values are defined for each design optimization step, then through iterations the responses are given in terms of unity checks for the several conditions and produced displacements for stiffness considerations (e.g. boundary conditions from Chapter 5). If they are positive, resulting parameters (e.g. elements dimensions) are taken and used for the creation of FEM model on ANSYS. Stress and deformation results for the rubber and deformation results for

the whole system are found and checked with the rough estimations from hand calculations. Then, if consistent, a second optimization step follows; otherwise adaptation on the excel calculations are performed and the procedure is started again.
The final result is the smallest and potentially less expensive (in terms of material volumes) possible solution, for the boundary and load conditions considered. This is the starting point for the further optimization process for strength requirements on the steel elements.

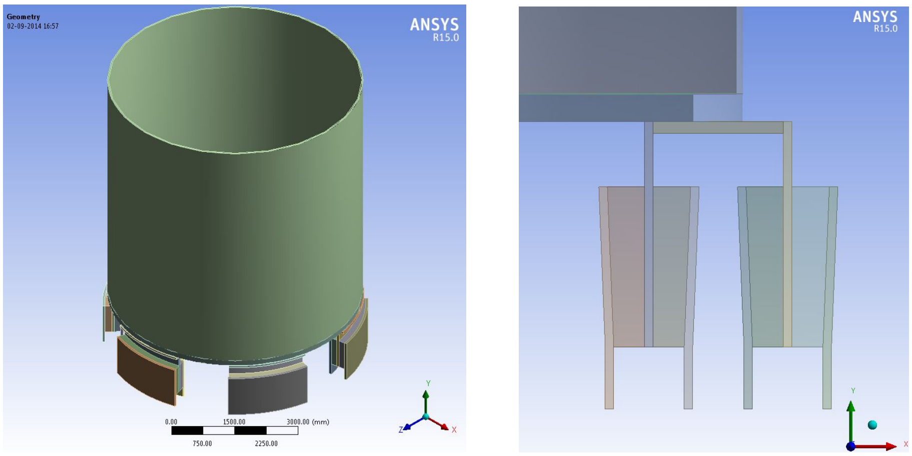
At the beginning of the procedure, starting arrangement is the one proposed during the conceptual phase, Figure 6.10, where it is meant to support the WTG along its all perimeter. It appears as a really expensive and complicated solution, due to the element shape and the high material volumes involved. Moreover, some access zones would be necessary at the bottom level, in order to practically connect the WTG with the structure. Therefore the first step is to split the complete ring into two main parts. For hand calculations, the circular shape is considered straight and the difference is taken into account by considerations on FEM outputs. In order to deal with total perimeter length decrement, other dimensions are increased, such as height and thickness of the rubber parts. However, their relationships are not linear, as further explained in the detailed design steps. Finally, an optimum minimum number of supports is found. From circular shapes they are adapted to straight ones in order to decrease manufacturing issues, up to the final selected arrangement. A brief overview of the main optimization process steps is proposed in Figure 7.1, with the main tested solutions, before the definition of the final one.



(a) (b)

Figure 7.1: Optimization steps - several small circular elements (a) and six large circular elements (b)

Other possible layouts, such as a solution with just two rubber elements or an arrangement with vertical plates, inclined of a small angle, are tested and immediately discarded since the resulting minimum dimensions are dramatically and negatively affected, Figure 7.2.



(a) (b)

Figure 7.2: Discarded solutions - two rubber elements support (a) and inclined vertical plates (b)

7.1.3. Hand calculations

Initial input parameters are basically the tentative dimensions to be assigned to the supporting elements. The aim of the optimization process is to save material and decrease solution complexities, to facilitate the manufacturing. It can be achieved by acting on the total support length (total number of supports, dimension of each one) and the number of rubber elements, together with their dimensions. Starting reasonings for the calculations are to consider all the elements straight. It creates some discrepancies in the results, especially during initial optimization phases, when the shape of the elements was still considered circular. Anyway, these effects appears on the safe side, since they under-estimate the stresses and displacement of the rubber.
In this section the main calculation expressions, to meet the stiffness requirements, are proposed. The results are shown in Appendix A.6 for the final solution arrangement. Main input data from loading situation are proposed in Table 7.1. The analysis is made considering half of the structure, therefore the resulting Vz, d comes from respectively from the shear load divided by two. The design attribute "$_d$" is adopted to produce a rather conservative design, due to its innovative attributes. It is not referred to a specific Ultimate Limit State condition. Indeed sea-fastening structures are designed, in general, for Serviceability Limit States. Then, in Table 7.2 the parameters for user input at each optimization design stage are proposed. They are referred to rubber and support dimensions. The analysis is made by considering half of the structure, therefore the number of supports in the table is 3 instead of 6. From

Table 7.1: Actions and main fixed parameters

Compressive load [kN]	5510.11
Shear Load [kN]	9484.09
Fxy,d [N]	8265.17
Vz,d [N]	7113.07
G [MPa]	0.75 2.25
fy [MPa]	355.00
α *[rad]*	0.01706

Table 7.2: Involved parameters - description

n_{elem} - *rubber elements*
n_{supp} - *bearing supports*
t_{rub} - *rubber thickness [mm]*
a_{rub} - *width [mm]*
b_{rub} - *length [mm]*

these parameters, simple calculations for geometry are carried out and only proposed in the Appendix A.6. Then, stress and strain in rubber is the focus point. Again, they are provided for both the G values. As already proposed in Figure 6.11, the complete load situation may be split into rotation and vertical actions. The first is due to horizontal force, while the latter to the self weight and heave action. Since shear stresses in rubber due to compressive force application would depend on the stiffness of the steel plate elements, they are not considered at this stage. Only shear stresses from shear load application is taken into account. Action stress and shear are so evaluated.

$$\tau_{ed} = \frac{V_{z.d} \cdot cos\alpha}{a_{rub} \cdot b_{rub} \cdot n_{supp} \cdot n_{elem}} \tag{7.9}$$

$$\delta_{tot} = \frac{\tau_{ed}}{G} \tag{7.10}$$

They are compared with the resulting capacities coming from the boundary conditions. The governing requirement is given by $\tau_{rd,1}$ referring to bond adhesion, since the shear capacity of the rubber itself $\tau_{rd,2}$ is usually much higher.

$$\tau_{rd,1} = \sigma_{ad} = 300psi = 2.065MPa \tag{7.11}$$

$$\tau_{rd,2} = \frac{V_{z.d} \cdot cos\alpha \cdot t_{rub}}{a_{rub} \cdot b_{rub} \cdot G \cdot n_{elem}} \tag{7.12}$$

$$\delta_{rd} = t_{rubb} \tag{7.13}$$

After these main requirements, some checks are performed to assess stability, relative rotation and compressive capacity of rubber. Calculation procedure comes from related European guidelines, applied for bridge engineering equipment (plain elastomeric bearings), [30]. Firstly compression verification, which is usually never critical due to the high volume of rubber adopted.

$$\sigma_{cd} = \frac{F_{xy,d} + V_{z,d} \cdot sin\alpha}{n_{rubb} \cdot n_{elem} \cdot a_{rub} \cdot b_{rub}} \tag{7.14}$$

$$\sigma_{rd} = 1.4 \cdot 7 \cdot G \tag{7.15}$$

$$uc = \frac{\sigma_{cd}}{\sigma rd} \tag{7.16}$$

Then rotational limit is investigated. The new parameter S refers to the shape factor of the rubber element; it is the ratio between the rubber area and its perimeter times the thickness.

$$v_{c,d} = \frac{G \cdot S \cdot V_{z,d} \cdot sin\alpha}{n_{rubb} \cdot n_{elem} \cdot a_{rub} \cdot b_{rub}} \cdot \frac{1}{5\dot{F}_{xy,d} \cdot S} \tag{7.17}$$

$$v_{rd} = \frac{a_{rubb} \cdot \alpha}{3} \tag{7.18}$$

$$uc = \frac{v_{c,d}}{v_{rd}} \tag{7.19}$$

Finally buckling stability is assessed. Guidelines provide a very rough calculation which appears really conservative. If this is not met, extra considerations could be applied, [30].

$$F_{rd} = min\,(b_{rubb} - a_{rubb}) \tag{7.20}$$

$$F_{zd} = t_{rubb} \tag{7.21}$$

$$uc = \frac{F_{zd}}{F_{rd}} \tag{7.22}$$

Now that all the parameter relationships are proposed, the final stage setup is provided. Dimension parameters are shown together with the first main checks. Extensive results are provided in Appendix A.6.

7.1.4. FE model with partial results

The software used for this analysis is ANSYS Workbench. From a 3D modelling of the elements geometry, the properties are assigned. WTG is modelled as a cylindrical shell element, with higher wall

Table 7.3: Involved parameters - results

n_{elem} - *rubber elements*	2
n_{supp} - *bearing supports*	3
t_{rub} - *rubber thickness [mm]*	165
a_{rub} - *width [mm]*	840
b_{rub} - *length [mm]*	1940

Table 7.4: Hand calculations - dimensioning results

Connection verification					
		G = 0.75 MPa		**G = 2.25 MPa**	
		Actions			
Shear total	τ,ed [MPa]	0.73		0.73	
Def	δ,tot [mm]	160.01		53.34	
		Reactions			
Bond adhesion	τ,rd1 [MPa]	2.06	**verified**	2.06	**verified**
Max shear	τ,rd2 [MPa]	480.04	**verified**	160.01	**verified**
Def max	δ,max [mm]	165.00	**verified**	165.00	**verified**

thickness at the bottom, according to the actual design from manufacturers. Property assigned is structural steel. The length considered is not the total one. It is chosen to use 6 m length, since ,from De Saint-Venant's theory, this is the minimum distance which provides a an eve stress distribution from the side of force application to another one, with width of 6 m (WTG diameter), [16]. Other steel elements are designed in a similar way: shells made by structural steel. This material property is well defined in all its features.
Different considerations are required for the rubber elements. These parts are designed as solid elements with property of *"Rubber 1"* from ANSYS *Engineering Data Catalogue*. The assigned properties and stress-strain relationships are not linear and defined from experimental data. Reference is from the studies of *L.R.G. Treloar* on vulcanized rubber under various type of deformations, [31]. These considerations are verified and confirmed as consistent for the analysis of this thesis. Main information, coming from these non-linear features, is the stress-strain diagram. It follows the *Odgen 3rd order curve* and is proposed for the two different shear modulus situations, Figures 7.3 and 7.4. Here, green curves describe the shear modulus behaviour. It reaches the design values of 0.75 and 2.25 MPa when the strain is about 100 %.

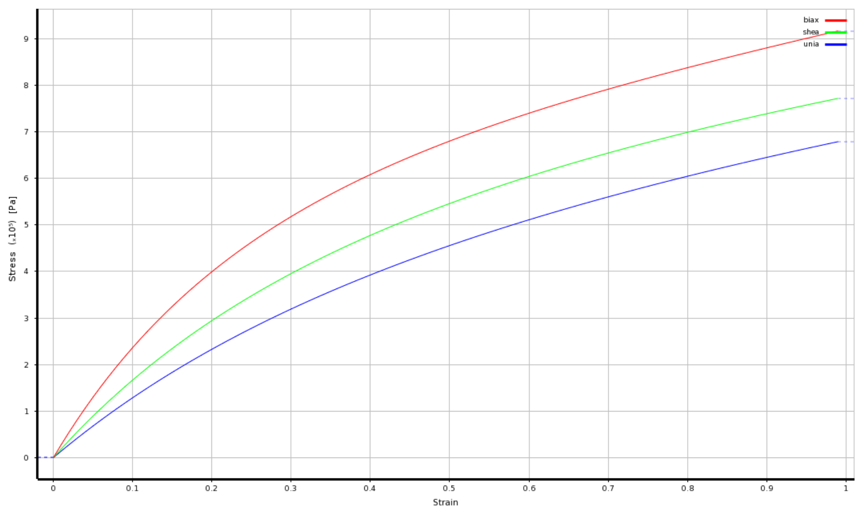


Figure 7.3: Stress - strain diagram: room T = + 23 deg

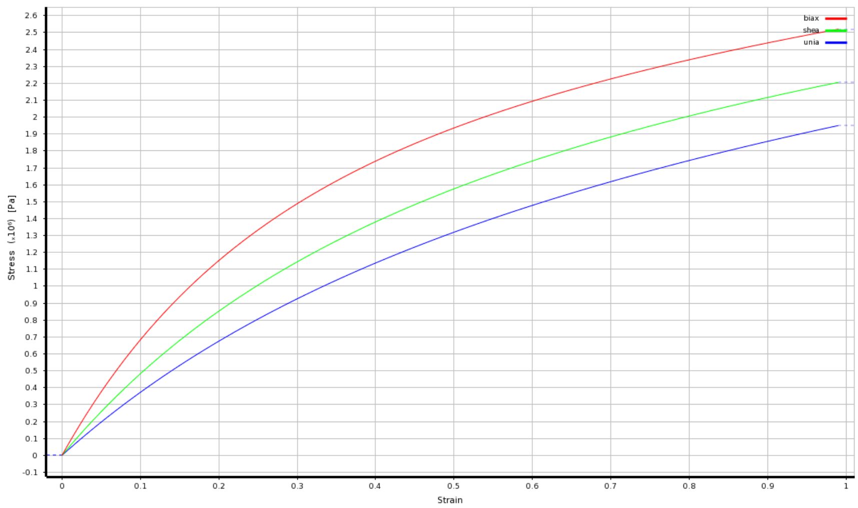
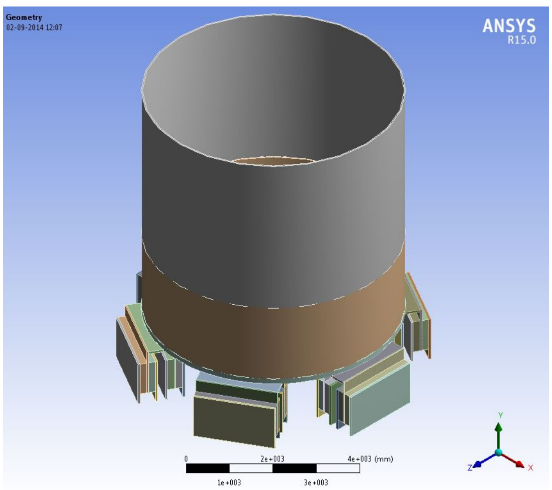


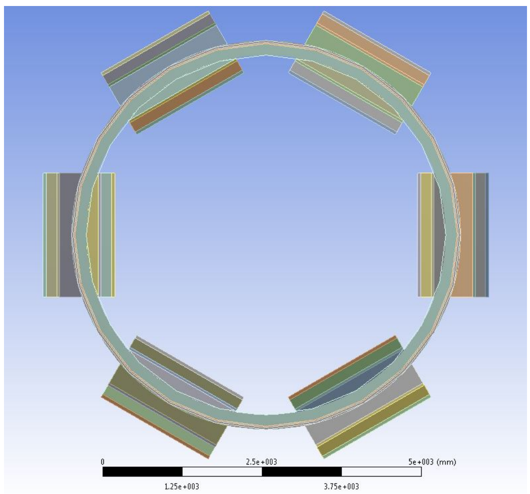
Figure 7.4: Stress - strain diagram: very low T = - 40 deg

The particular behaviour of rubber, achieved by using non linear properties, requires the analysis with allowed large deflections. For this design situation and the next in Section 7.2, *Static Structural Analysis* is carried out. For *Buckling* and *Free Vibration* analysis, non linearities of rubber generate solving problems. Different approaches are used and material properties are adapted to linear. Choices and features of these modifications are described later, in the related sections.

Only the final arrangement is proposed here. Dimensional values are the ones proposed in Table 7.3. Steel elements dimensions are related to them. Moreover, different positions for cross section connection over the top plate are tested. At this stage, since steel strength considerations are not applied yet, WTG flange is decided to lay at the middle of the transverse dimension, at mid longitudinal length position, Figure 7.5.



(a)



(b)

Figure 7.5: Overall arrangement (a) and top view detail for WTG positioning on the supporting plates (b)

Once geometry and material properties are defined, analysis is moved to mesh modelling. Program controlled meshing is provided by ANSYS, with some possible adaptations from the user. They are about mesh refinement at the connection points and where the highest stress concentration is presumable to appear. It happens at the connection between WTG walls and flange and WTG flange and steel plates, Figure 7.6. A coarse mesh is provided for the intermediate part of the WTG element.

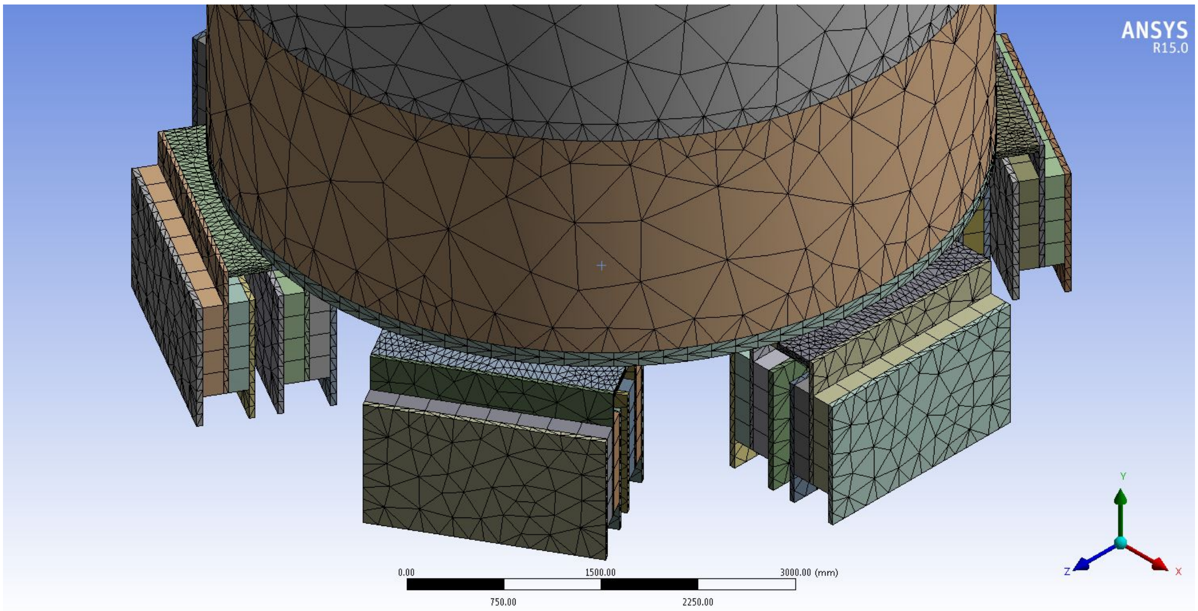


Figure 7.6: Meshing Detail - Supports and stiffened bottom WTG shell

Then, loads and supporting conditions are applied. Vertical compressive load is applied at the top of the WTG, through the wall thickness. Horizontal force from overall system reaction is applied at the bottom inner WTG surface. Fixed support constraints are placed at the bottom surface of the lowest vertical steel plates, 4 constraints per supporting element. Figure 7.7 shows the so mentioned situation.
Finite Element Model results are finally proposed, just for the final arrangement of **Design for Stiffness** analysis. Further considerations are provided during the processes about the design for strength, Section 7.2. Results in terms of maximum stresses in rubber elements and rotations in the worst direction are provided respectively in Figures 7.8 and 7.9. These are the results for G=0.75 MPa condition. For G=2.25 MPa, see Appendix A.6.

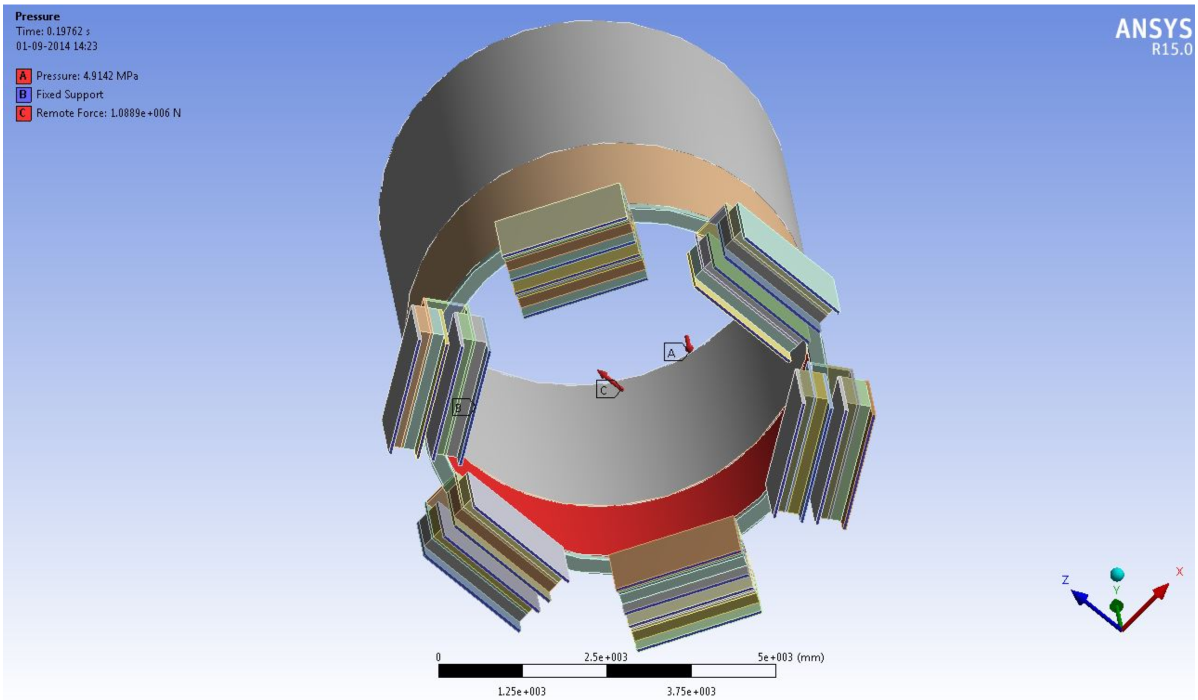


Figure 7.7: Load and support application

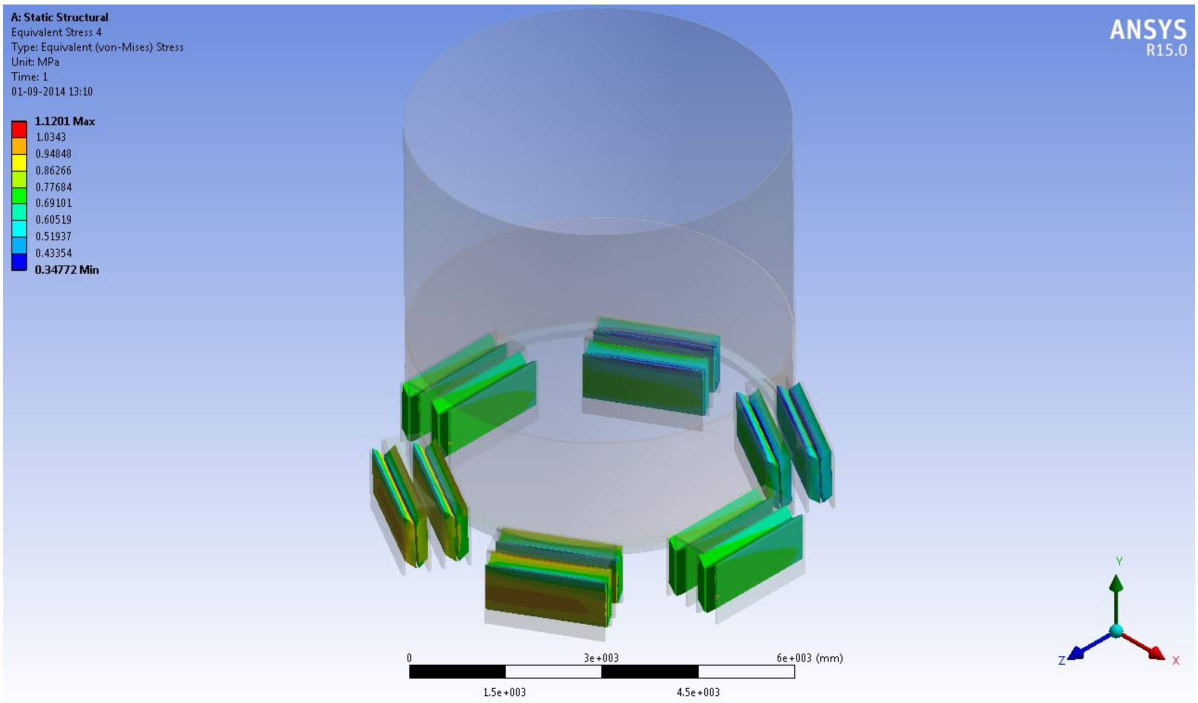


Figure 7.8: Rubber stress results

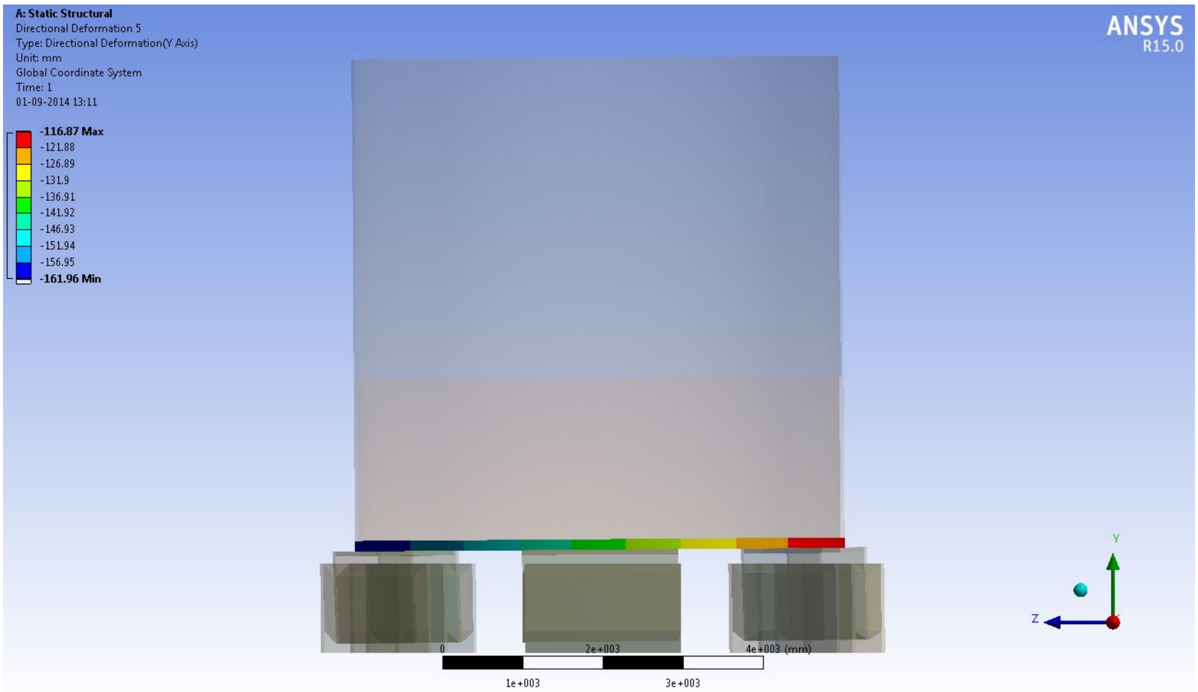


Figure 7.9: Vertical deformation partial results - Rotation in the design direction

Important outputs are the differential vertical deformation between the two sides and the maximum local stress in the rubber:

$$\delta_{diff,FEM} = 161.96 - 116.97 = 45.1mm \qquad \delta_{diff,HC} = 53.34mm \tag{7.23}$$
$$\tau_{ed,FEM} = 1.12MPa \qquad \tau_{ed,HC} = 0.73MPa \tag{7.24}$$

There are some small differences between the hand calculations and FEM model, as it is expect. However the results are pretty close so the procedure is proven to be consistent. Maximum bonding strength limit is not exceeded while the required vertical deflection is actually not reached. This implies a generation of a small bending moment. This is evaluated, using the same procedures proposed before:

$$\delta diff - \delta_{diff,FEM} = 51.3 - 45.1 = 6.2mm \tag{7.25}$$
$$M_{bott,generated} = 3854.2kNm \tag{7.26}$$
$$R_{H,top,generated} = 9467.8kN \tag{7.27}$$
$$\%Reduction = 1.82\% \tag{7.28}$$

It does not overcome the limit of 10 % reduction, therefore the solution is still valid and design for strength can start from this arrangement.

7.2. Design for strength

At this stage, the main system is already designed. Improvements have to be performed with respect to strength resistance of steel supporting members and structural integrity of the WTG. Therefore, considerations about plate thicknesses are applied, together with possibility of stiffeners application. Indeed, the overall geometry of the connection can not be deeply modified, otherwise stiffness achievements would be dramatically compromised. Moreover, practical and installation considerations are now applied.
No hand calculations are performed to check the FEM results but several considerations are made to manage the modelling phases.

Firstly, main requirement is to guarantee the even reaction force distribution among the four support positions at the bottom, for each element. Due to symmetry with respect to vertical force, this is only possible if the inner supports are not too close to the plane of force application. Considering only vertical action, it can be considered as a beam over four supports with a point load at mid span. Adding additional vertical elements and connections with them leads to the simple static situation proposed in Figure 7.10.

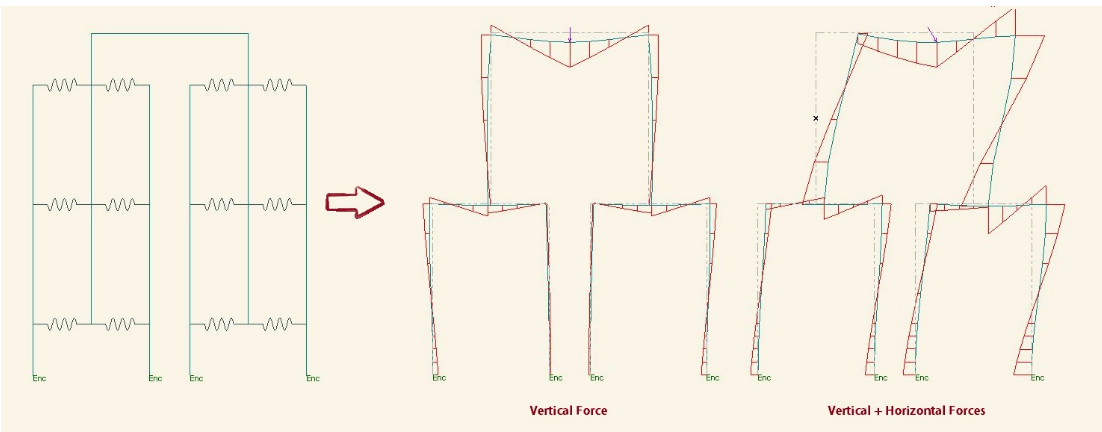


Figure 7.10: Simplified static behaviour - supporting element

Uniform reaction force distribution means uniform stress distribution among the rubber elements. These considerations are initially kept for the dimensioning of the top plate and flange connection

position. Then, since also horizontal force is applied, symmetry does not hold anymore and uneven stress distributions, among the elements and the rubber layers within each element, appear.
In order to avoid large affections from these effect, top plates need to be adequately stiff in their axial direction. Vertical plates need to be stiff as well in order to avoid bending moment deflection, which would affect the overall rotational stiffness of the connection.

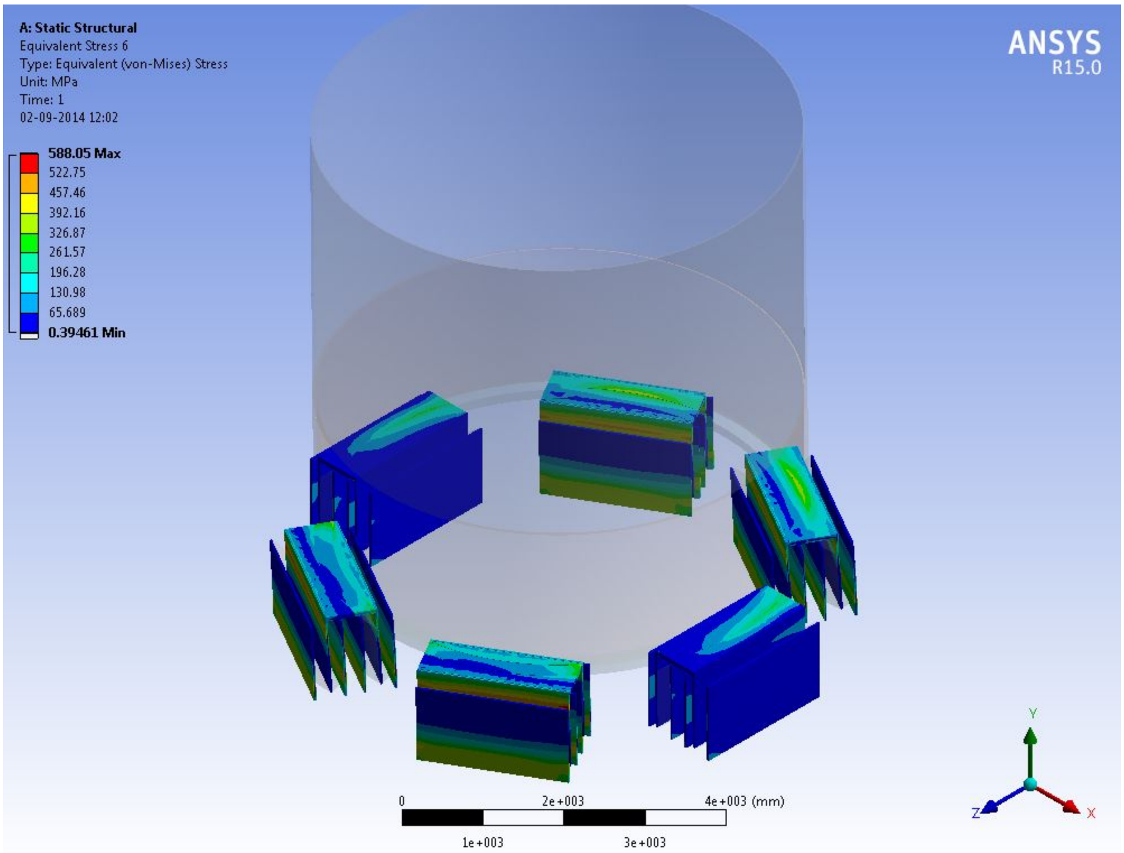
Initial input for steel plates during stiffness analysis is uniform thickness for all the elements, $t = 30mm$. It produces maximum stresses up to *588 MPa* in steel elements, Figure 7.11(a). This situation represents the starting point of the **Design for strength** optimization procedure. Section of the main supporting element is proposed in Figure 7.11(b), to be compared with the one at the final design stage. A part from thicknesses, dimensions are based on the ones already used for the previous analysis, proposed in Table 7.3.
Magnitude of stresses is limited by the minimum yielding of steel material. Given the property of S355, different values are defined, according to element thickness. They are shown in Table 7.5 and come from related European standards for steel, [32]. First optimization step is then to increase plate

Table 7.5: Steel material - Design yield stress

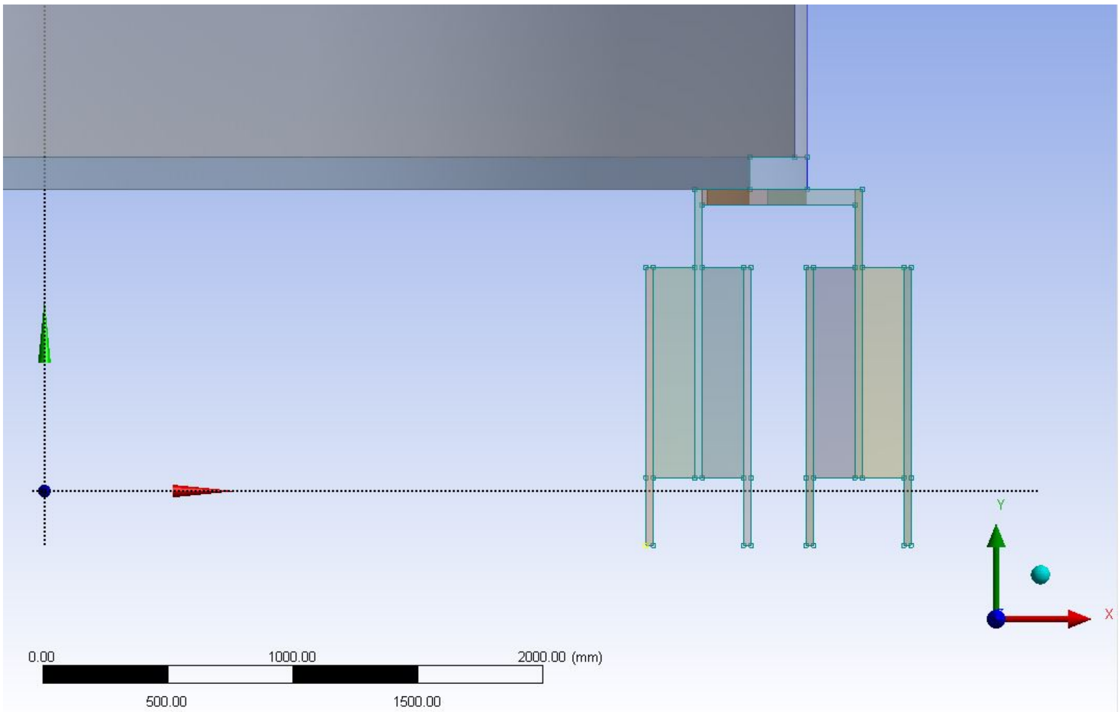
Min. Yield Stress [N/mm^2]	*Thickness range [mm]*
355	t ≤ 16
345	16 ≤ t ≤ 40
335	40 ≤ t ≤ 63
325	63 ≤ t ≤ 80

thicknesses. From results of Figure 7.11(a), high local stresses are found on the top plates. To deal with that, high thicknesses are so required.
Installation considerations perfectly fit at this moment. Fabrication and connection of these elements is meant to be carried out at the factory. Welding on the OS' vessel deck is done at the harbour. It is meant to use a small grillage, even in these supporting positions, to better spread the load through the strong points of the deck. Therefore, vertical steel plates are welded at the bottom on the wide flange beams of the grillage. Then, load-out of the WTG structures can take place.

The connection between the flange and the support is meant to be provided through pins. Indeed, due to the high self-weight on the WTGs, no uplift will appear and the only required constraint is along shear direction. Pins fit with the bolt holes, with a diameter range of *45-55 mm*, according to selected manufacturers, Chapter 2.6.
In order to deal with the possible small differences in bolt diameters, tolerances during welding and installation of WTGs on the supports, it is chosen to split the top plate of the support into two different element. A bottom one, already welded at the factory and jointed with the support itself. A second one, with the pins attached on it, to be connected once the support installation is completed, Figure 7.12.In this way small adaptations can be made before the load-out. Furthermore, this plate can be changed, according to the different WTG manufacturer designs, without deeply affect the layout of the complete. Finally, two plates with considerable thicknesses can withstand the high stresses expected by the model.



(a)



(b)

Figure 7.11: Initial setup - stresses in steel plates (a) and section of supporting element (b)

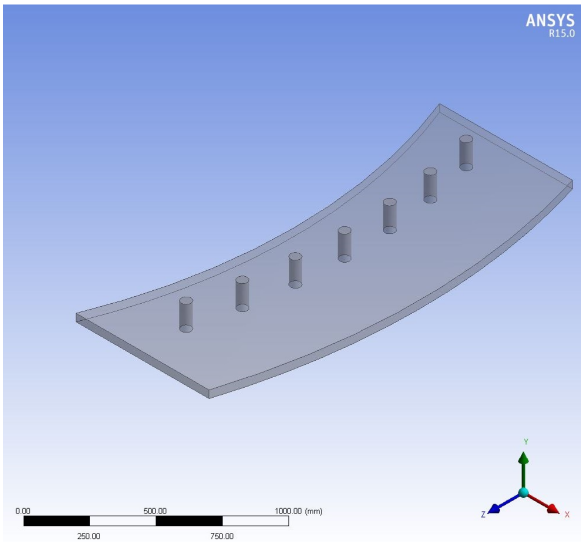


Figure 7.12: Top plate with pins - overview

Second optimization phase is carried out after considerations of stress transfer from top plate horizontal to vertical plates. As suggested by Figure 7.10 and indeed showed in the actual stress outputs, Figure 7.11(a), bending moment is generated. Therefore diagonal stiffeners are designed to increase the vertical elements stiffness. They basically consist of diagonal plates with similar thickness, welded both on the vertical and top attached elements. Due to the presence of two top plates, this procedure is simpler since can be done directly on fabrication site and not on the vessel.

Finally, element thickness is adapted from initial situation and the final appearance results as the one proposed in Figure 7.13, with final dimensions described in the following Table 7.6.

Table 7.6: Supporting element dimensions

lengths		**thicknesses**	
Reference	*Dimension [mm]*	*Reference*	*Dimension [mm]*
h_1	270	t_h1	40
h_2	250	t_h2	40
h_st	198	t_st	40
h_rubb	840	t_vi	40
l_1	640	t_vo	50
l_2	1115	t_rubb	165
l_3	670		
l_st	157		
t_fl	130		

7.2.1. FE model with final results

From the setup defined in the previous section, maximum stresses are checked for the different thickness ranges and the final solution is validated, Figure 7.14. Their peak values are *343.95 MPa* and *250.45 MPa* respectively for thicknesses below *40 mm* and below *63 mm*. Therefore structural requirements are met.
As extensively shown in Appendix A.6, the WTG structure itself does not experience peak stresses above its yielding limit, with a maximum local values at the supports up to *225 MPa*.

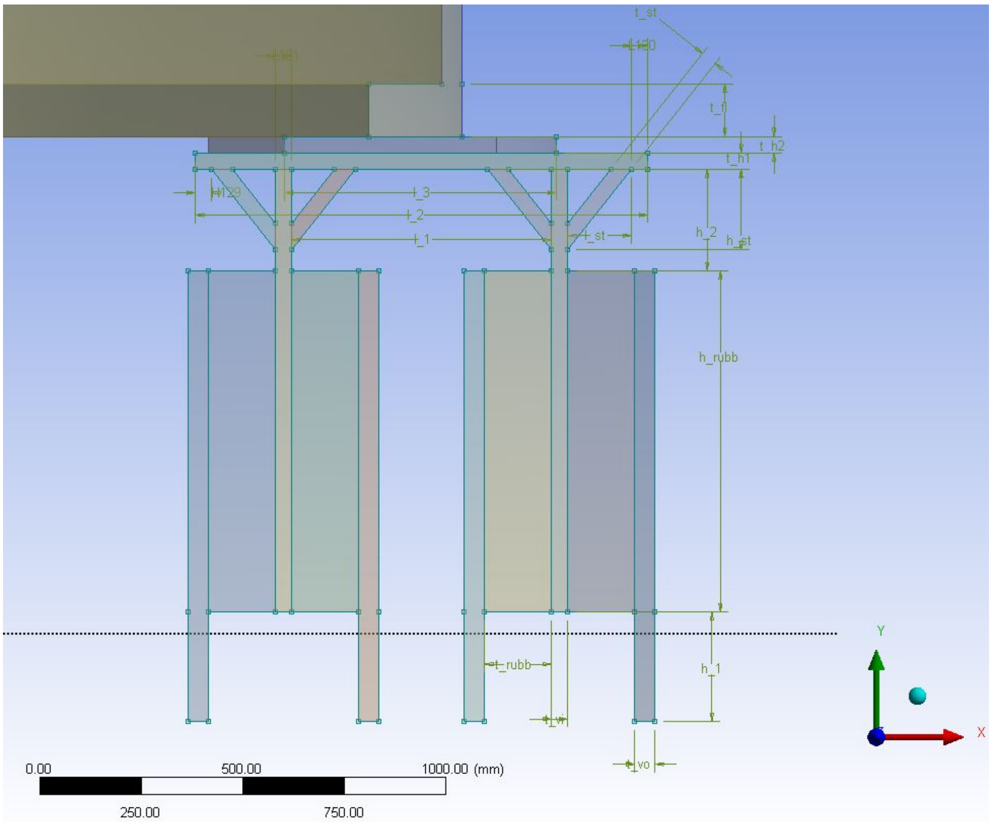


Figure 7.13: Final setup - section of supporting element

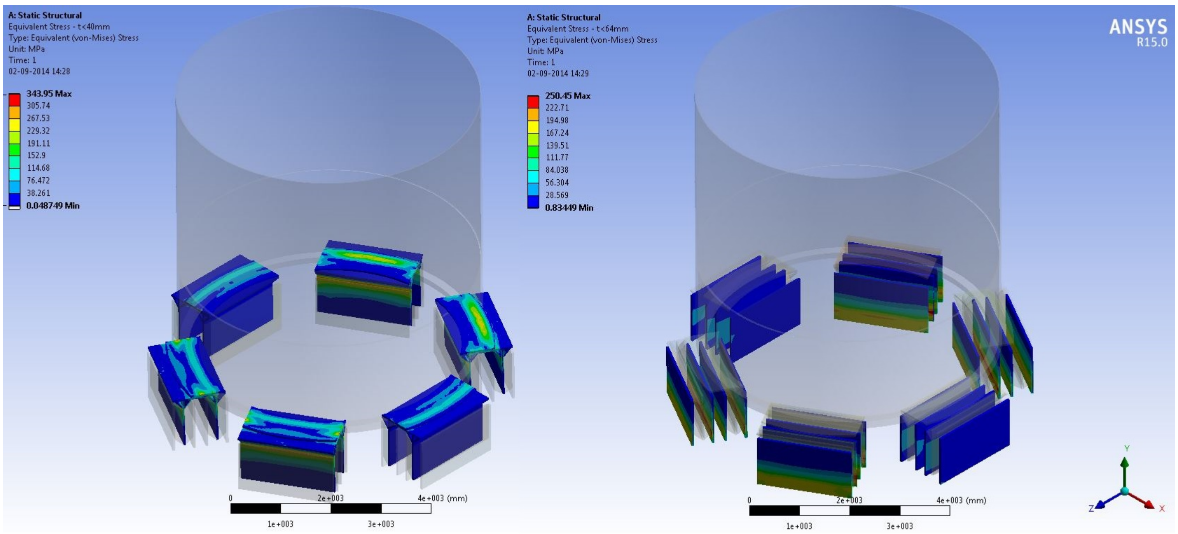


Figure 7.14: Final setup - stresses in steel plates with t < 40 mm and with 40 < t < 63 mm

Then, rubber stresses and stiffness deformations are checked as well, in order to show the effectiveness of the solution. All the requirements are met, with slightly different outputs from the **Design for stiffness** analysis. Extensive results are proposed in Appendix A.6, where all the solution information of the bottom connection are proposed. Here, similar to the results proposed in Figures 7.15 and 7.16, rotational stiffness of the complete solution is checked, for both the situations *G=0.75* and *G=2.25 MPa*. Then, generated bending moment is calculated and compared with the imposed limits, by using the same procedures applied in Section 7.1.4.

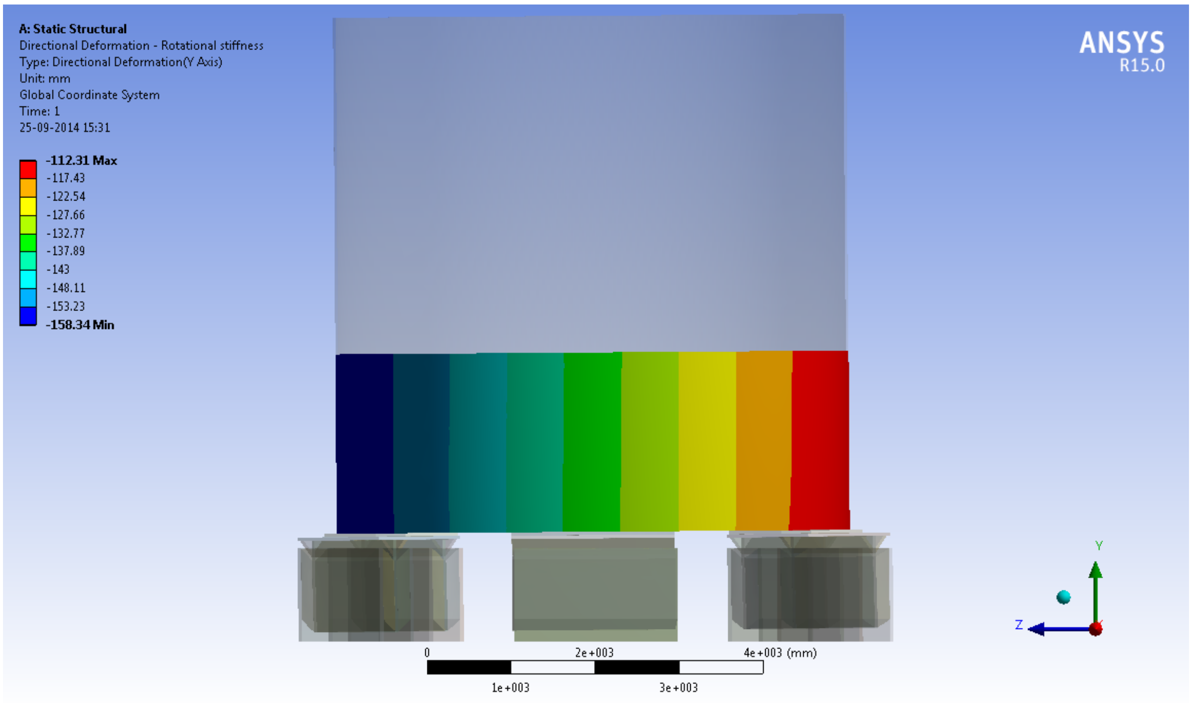


Figure 7.15: Vertical deformation final results - Rotation in the design direction, G=0.75 MPa

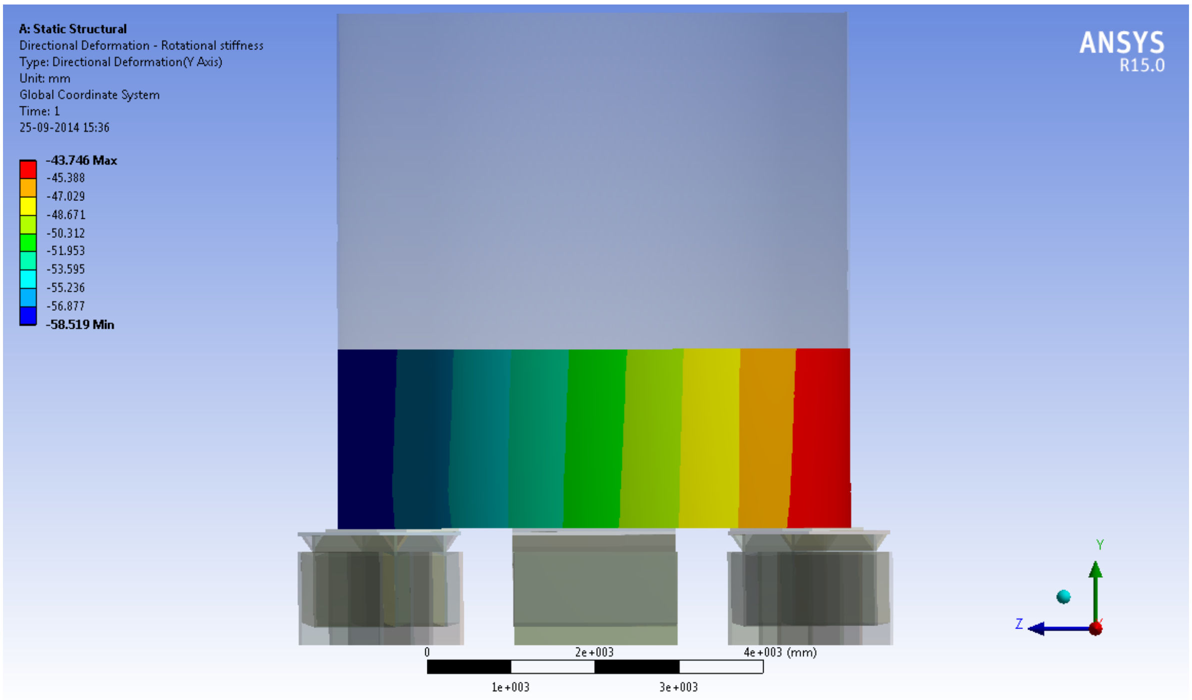


Figure 7.16: Vertical deformation final results - Rotation in the design direction, G=2.25 MPa

$$\delta_{diff,FEM,075} = 158.34 - 112.31 = 46.0mm \qquad \delta_{diff,FEM,225} = 58.52 - 43.74 = 14.8mm \tag{7.29}$$

$$\delta_{diff} = 51.3mm \tag{7.30}$$

Again, the required vertical deflection is actually not reached. This implies a generation of a small bending moment. This is evaluated, using the same procedures proposed in Section 7.1.4, for both the design situations :

$$\delta diff - \delta_{diff,FEM,075} = 5.3mm \qquad \delta diff - \delta_{diff,FEM,225} = 36.5mm \tag{7.31}$$

$$M_{bott,generated,075} = 1152.0kNm \qquad M_{bott,generated,225} = 22386.3kNm \tag{7.32}$$

$$R_{H,top,generated,075} = 9590.7kN \qquad R_{H,top,generated,225} = 8625.5kN \tag{7.33}$$

$$\%Reduction_{075} = 0.54\% \qquad \%Reduction_{225} = 10.55\% \tag{7.34}$$

Finally, a volume quantification is performed. The aim is to compare the involved weights with the ones of previous conceptual solutions, Chapter 6, and the initial effectiveness limit found at the overall stiffness analysis phase, Chapter 5. Given the final geometry proposed in Figure 7.13, complete dimensions are proposed in the following Table 7.7.

Table 7.7: Weight calculation (single WTG) - Rubber supporting system

Plate	*n (1 support)*	*Area [mm^2]*	*Volume [m^3]*	*Weight [t]*
h1	1.00	25600	0.05	2.32
h2	1.00	44600	0.09	4.05
st	4.00	10108	0.02	3.67
vi	2.00	43600	0.08	7.92
vo	4.00	55500	0.11	20.16
		179408	**0.35**	**38.12**

Multiplying this weight times the 6 WTGs, a total amount of 229 tonnes is found. This value is within the limit initially imposed of 500 tonnes. Compared to other conceptual solutions seems more convenient than the rocker bearing system, 545 tonnes, but less convenient than the pot bearing system, 159 tonnes. Of course this comparison is only made by considering volumes of structural steel. For a more detailed quantification, extra materials, such as pot bearing equipment itself and rubber layers, should be taken into account.
Such a quantification is not required at the moment, since the main limit of 500 tonnes steel would be reasonably met anyway; therefore more general considerations are applied.

7.3. Buckling analysis

Once the complete appearance of the connection solution is finalized, linear buckling behaviour can be investigated. Input data are the tower element, with its radius R and wall thickness t, and the kind of supports, number n and length d. In order to be consistent with the design rules provided by studies on buckling behaviour of thin metal shells, [27], the initial case of unstiffened plate is considered. It means that the wall thickness t is kept as $30mm$, the mean value along the complete tower length, without considering the actual increased thickness t_1 at the bottom level of $50mm$. Therefore a FEM model is provided for the first situation, then compared with hand calculations and finally assessed. Once consistency between results is proven, actual situation with increased wall thickness at the bottom course is analyzed, with an adapted FEM model.

7.3.1. Unstiffened shell

The design procedure follows the proposal of *J.G. Teng and J.M. Rotter*, thanks to their extensive studies of thin metal shells. Equations are supported by parametric analysis on a wide range of samples. Main parameter is the ratio $\frac{R}{t}$, called *slenderness ratio*. In this case it has a value of 100. The design procedure is verified for a limited range of $200 \geq \frac{R}{t} \geq 750$.
This aspect should not be critical as long as appropriate considerations are used for steel strength adaptation. Modifying factors are used for this purpose, [27].

First of all, the main parameters involved it the equations are proposed. Goal of the analysis is to find the critical force value for which linear buckling locally appears, F_u.

$$F_u = \kappa_{2,local} \cdot f_y \cdot d \cdot t \tag{7.35}$$

$$\lambda = \sqrt{\frac{f_y}{\sigma_{cl}}} \tag{7.36}$$

$$\sigma_{cl} = \frac{E}{\sqrt{3\,(1-\nu^2)}} \cdot \frac{t}{R} \simeq 0.65 \cdot E \cdot \frac{t}{R} \tag{7.37}$$

According to notations, f_y is the yielding strength of the steel element, λ is the dimensionless slenderness of the element, σ_{cl} is the elastic critical stress for a perfect cylinder under uniform compression and $\kappa_{2,local}$ is the buckling strength reduction factor for axial loading conditions. The critical force may be then evaluated by investigating the equation of $\kappa_{2,local}$; here modifying factors c_c and c_e are used to account for yield stress difference:

$$\kappa_{2,local} = 0.19 + \left(\frac{0.0283 \cdot c_c}{\eta \cdot \lambda^{0.77 c_e}}\right) - 1.04 \cdot log\lambda \tag{7.38}$$

$$c_c = -0.43 + 5\epsilon - 3.57\epsilon^2 \tag{7.39}$$

$$c_e = -0.87 + 6.38\epsilon - 4.51\epsilon^2 \tag{7.40}$$

$$\epsilon = \sqrt{\frac{235}{f_y}} \tag{7.41}$$

$$\eta = \frac{d}{R} \tag{7.42}$$

Using the material properties, $f_y = 355N/mm^2$, $E = 210000N/mm^2$, $R = 3000mm$, $t = 30mm$, and the defined dimension of the bottom supporting element,$d = 1940mm$, the equations can be solved.

$$\sigma_{cl} = 1365N/mm^2 \qquad \epsilon = 0.814 \tag{7.43}$$

$$c_c = 1.275 \qquad c_e = 1.335 \tag{7.44}$$

$$\lambda = 0.510 \qquad \kappa_{2,local} = 0.606 \tag{7.45}$$

Finally, the ultimate force value F_u is found.

$$F_u = 0.606 \cdot 355 \cdot 1940 \cdot 30 = 12513.30kN \tag{7.46}$$

This force value refers to the magnitude at which linear buckling failure occurs over one of the support, locally. In order to be compared with the actual acting forces over the support, results from ANSYS model are used. At the level of the most critical support, the acting force is $F_{Ed} = 2735.10kN$. Appendix A.6 provides extensive calculations and procedures for the description of what is behind this result. It is much lower then the buckling force, by a factor of :

$$\Lambda_{hc} = \frac{F_{cr}}{F_{Ed}} = 4.58 \tag{7.47}$$

Therefore, buckling of the WTG is not going to occur with the supporting solution provided. This Λ_{hc} value is compared with the one resulting from FEM analysis, Λ_{FEM}, to be proposed now.

The Finite Element Model for this analysis has been adapted, with respect to the one used for the Chapters 7.1 and 7.2. Indeed, due to non-linearity properties of rubber materials, linear buckling analysis on ANSYS cannot be solved.
To deal with this problem, it is chosen to consider a simplified situation, with the boundary conditions externally imposed. Supporting elements just as steel plates. Reaction forces are applied on them, to substitute the behaviour of the underlying suppressed elements (e.g. rubber, vertical steel plates, stiffeners). Tower structure, rotated about x and y axis, as result of the external applied forces and the rotational stiffness of the connection. Tower length is again limited by the diameter dimension, for the same reasons discussed in Section 7.1.4. Finally, in order to investigate the behaviour right above the supports, pressures come from the reaction forces at the bottom and fixed supports are applied on the wall thickness at the top of the tower. Figure 7.17 shows this arrangement, together with the mesh utilized for the analysis. The analysis is carried out for the first 6 buckling modes. Target results are the load multipliers. The first one is relevant and is the one to be compared with the hand calculation results. Appendix A.6 proposes results for all the modes. Here, just the governing *Mode 1* is considered. Figure 7.18 shows the deformation output of the first mode, amplified of a factor of $2.8e + 002$ to ba able to appreciate deformed shapes.

$$\Lambda_{FEM,glob} = 29.177 \tag{7.48}$$

It is underlined that this value does not consider local effects and imperfections. Previously proposed design procedure takes into account local effect and material imperfections, since comes from practical tests and parametric analyses. Therefore, it is required to make some considerations in order to get comparable FEM results.
A so called *knock-down* factor is adopted, coming from experimental determination. It is selected with a value of $C = 0.166$, as suggested by literature and tests reagrding axially loaded cylindrical shells, in which results showed a ratio between ultimate and critical load equal to this reduction factor, [28], [33], [34].
It follows:

$$\Lambda_{FEM} = 29.177 \cdot 0.166 = 4.86 \tag{7.49}$$

This result is definitely comparable with the theoretical output $\Lambda_{hc} = 4.58$. Once again, it is confirmed that buckling of the WTG is not going to occur with such a designed supporting solution. Furthermore the procedure has been proved to be consistent and reliable. However, it is underlined that a more detailed FE model for buckling analysis should be defined. Indeed, hand calculations give immediately realistic results, while FE results propose initial outputs too different from reality. Even though these high differences are taken into account by applying conservative knock down factors, for imperfections and local effects, there are still possibilities for FE model improvements. Since the hand calculation procedure is considered sufficiently reliable, it is chosen to not go further with analyses on FE models.
Final analysis of the actual situation, stiffened cylinder, could now take place. Since it has been already shown that buckling response is not critical, there is no point to further investigate the behaviour of a stiffer situation. Load multiplier will be higher than the ones just found and so the critical force required to make the buckling failure appear.

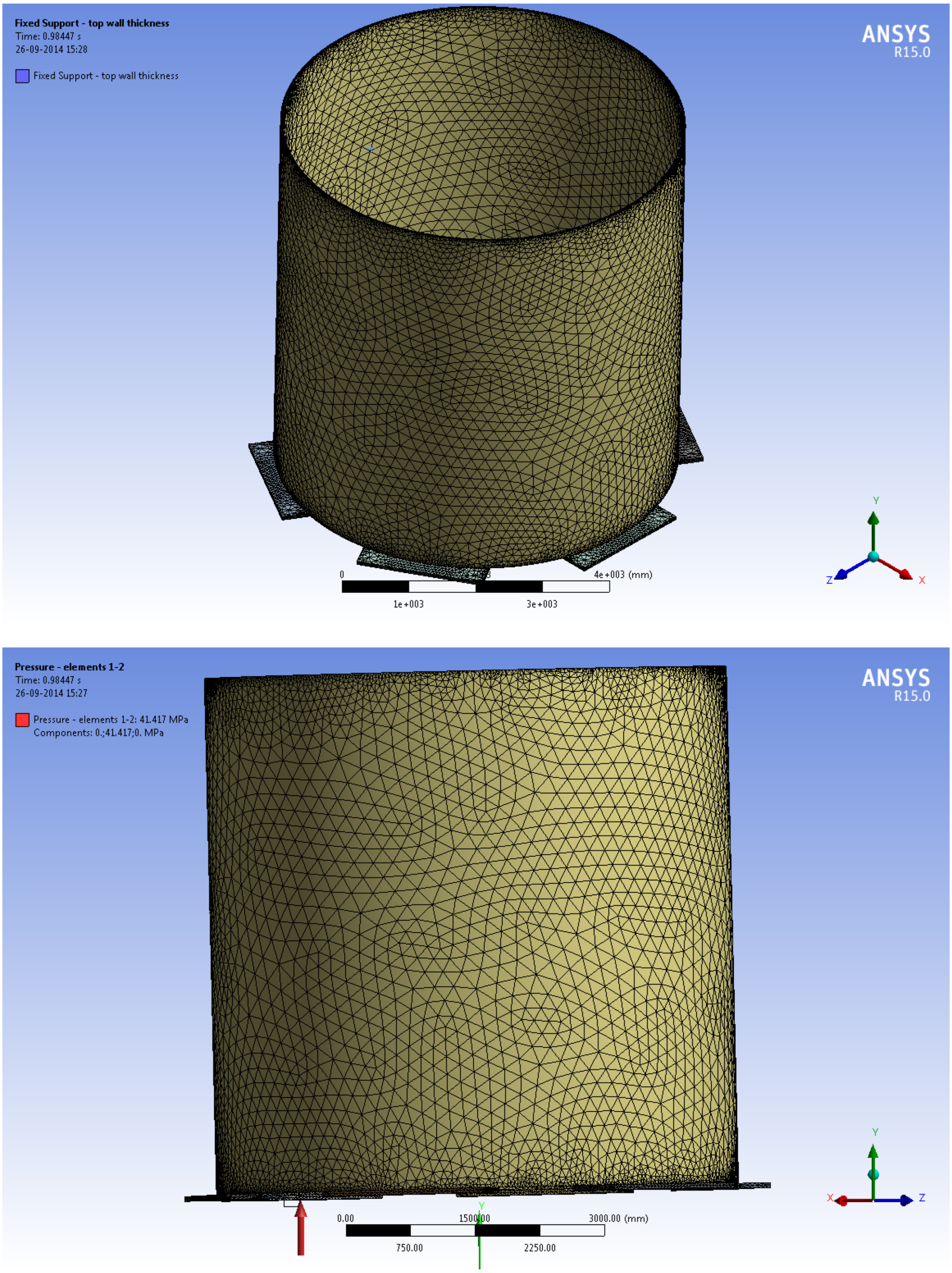


Figure 7.17: ANSYS model - Mesh, applied pressures and support conditions: general overview (a) and focus on rotated situation (b)

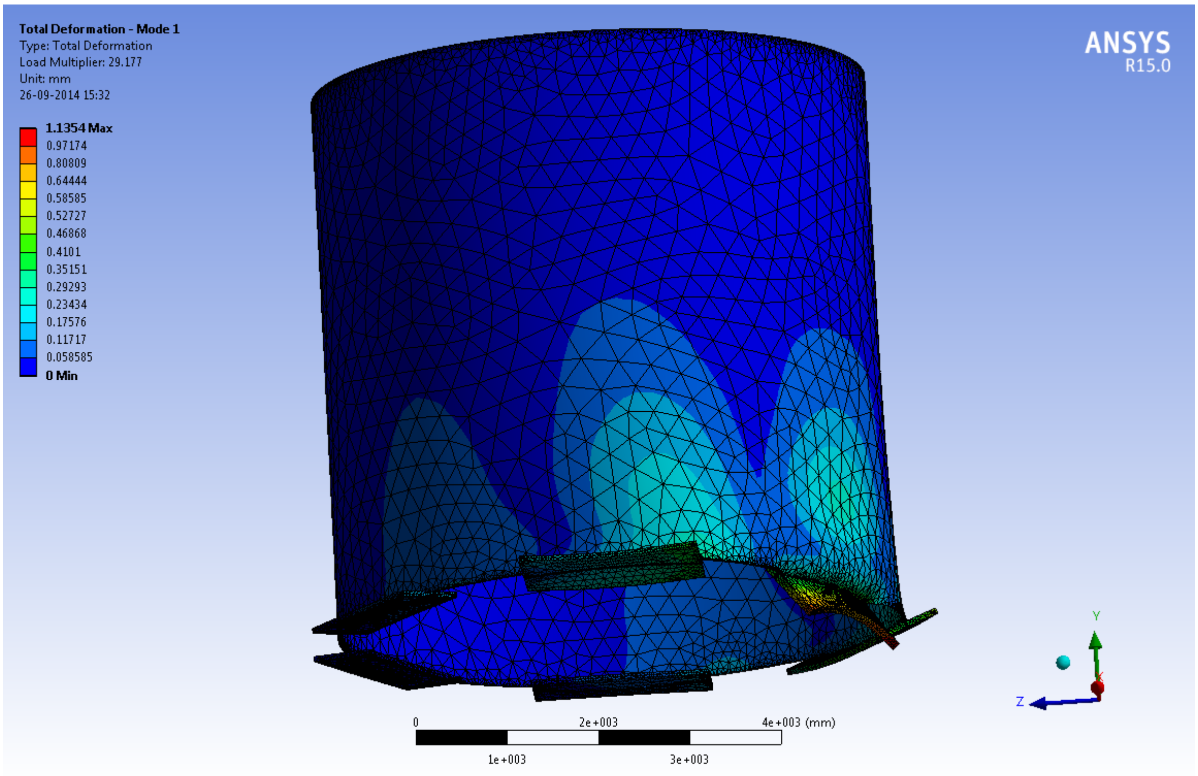


Figure 7.18: ANSYS model - Deformed situation, first linear buckling mode

7.4. Free vibration analysis

During free vibration analysis, natural frequencies and mode shapes of the system are investigated. The starting model is the one already used for the *Static Structural Analysis*, with the complete load and support condition. Adopted set-up is the one at room-temperature, with nominal *G=0.75 MPa*. This is the condition with more flexibility for the system and so with more potential issues from a dynamic point of view.
The main relationship for the involved variables is explained by the following equation:

$$\left([K] - \omega_i^2 [M]\right) \phi_i = 0 \tag{7.50}$$

where $[K]$ and $[M]$ are matrices for stiffness and mass, constant properties coming from the model, ω_i are the natural frequencies and ϕ_i the related mode of shapes. No damping or forces actions are included in this analysis. In order to apply this analysis to the designed solution, some adaptations are made for effective and realistic results.
First of all, point mass is added to the system. It substitutes the pressure at the top of the WTG cross section from linear static analysis. In this way mass parameter $[M]$ has its actual value. Since it is not a force anymore, stiffness $[K]$ is not affected. To consider the effect of lateral forces, pre-stress condition is applied. The analysis becomes therefore **Free vibration with pre-stress** and the equation is affected as follows:

$$\left([K+S] - \omega_i^2 [M]\right) \phi_i = 0 \tag{7.51}$$

where $[S]$ is the stress stiffness matrix coming from an initial linear static analysis. Then, horizontal and vertical forces are considered, fixed constraints are applied without specific considerations. The last adaptation to let the analysis start is about non linearities and large deflections.
The material behaviour proposed in Chapter 7.1.4 can not be applied here. Modifications of *Ogden 3rd order* stress-strain diagram need to be applied. From curve in Figure 7.3, the average weighted value is considered for constant shear modulus. It is, for the normal temperature situation $T, 23deg$, equal to *G=0.62 MPa*. It is smaller than the nominal value *G=0.75 MPa*in order to take into account the non linearities and the different response according to strain level. The goodness of this value is tested

by the static analysis, which provides comparable results with respect the same kind of analysis with non-linear rubber behaviour, Appendix A.6.

Vibration analysis is carried out for the first 4 modes. By investigating the results, it appears clear that only the first 3 are relevant since represent respectively rotation about x axis, y axis and vertical deformation along z axis. They are chosen because can be compared respectively with roll, pitch and heave vessel motions. Results are provided in terms of displacements, Figures 7.19, 7.20 and 7.21. They are amplified by a factor of $9e+003$, in order to underline the effect directions. As it is shown by the displacement output values, they are very small.
Most important results are here the evaluated frequencies. They are already shown in the just proposed figures and summarized in Table 7.8. Their values immediately appear considerably high, but need to be compared with the vessel frequencies during motion.

Table 7.8: Free vibration results - Frequencies and mode shapes

Mode		Frequency [Hz]
1	*roll*	**0.739**
2	*pitch*	**0.744**
3	*heave*	**1.703**

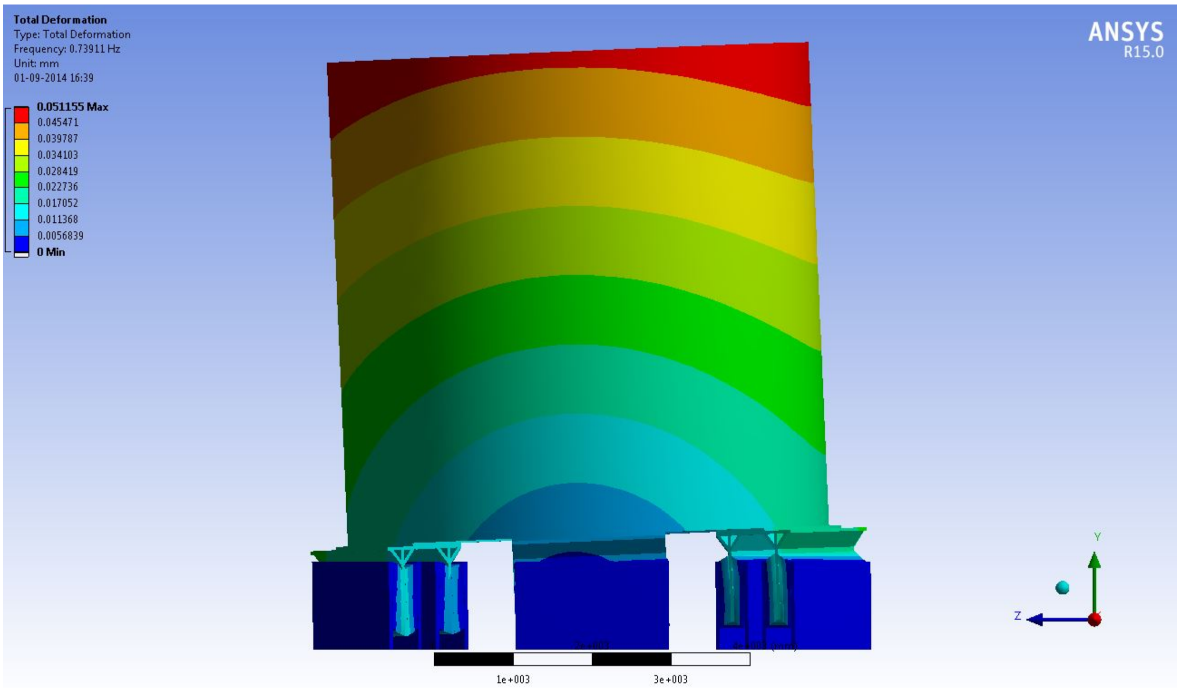


Figure 7.19: ANSYS model - free vibration analysis, mode 1

The aim of the analysis is to assess whether the bottom connection system, combined with the vessel motion, may generate resonance frequencies or not. This situation appears when the system natural frequency and vessel motion frequency have close values. Resonance behaviour needs to be avoided, since large amplitude oscillations are produced and the effect on vessel stability and structural integrity would be dramatically affected.
Figure 7.22 shows the situation. Basically, along x-axis frequency ratio takes place while y-axis values describes the dynamic amplification factor, still related to the frequencies involved and the possible damping effect. The latter is described by γ value.
For this analysis it is considered to have no viscous damping contributions. It is of course a conservative consideration, since rubber response gives a certain damped effect after time. If the response is not sufficiently satisfactory, more analysis are required to investigate this topic.

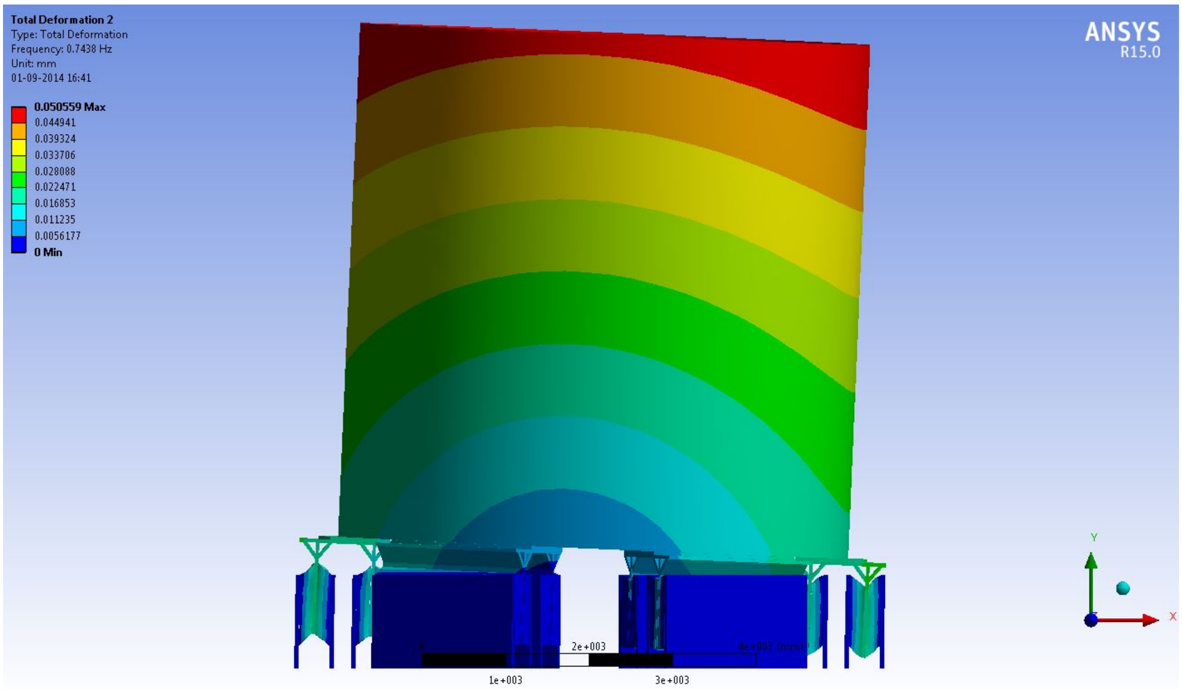


Figure 7.20: ANSYS model - free vibration analysis, mode 2

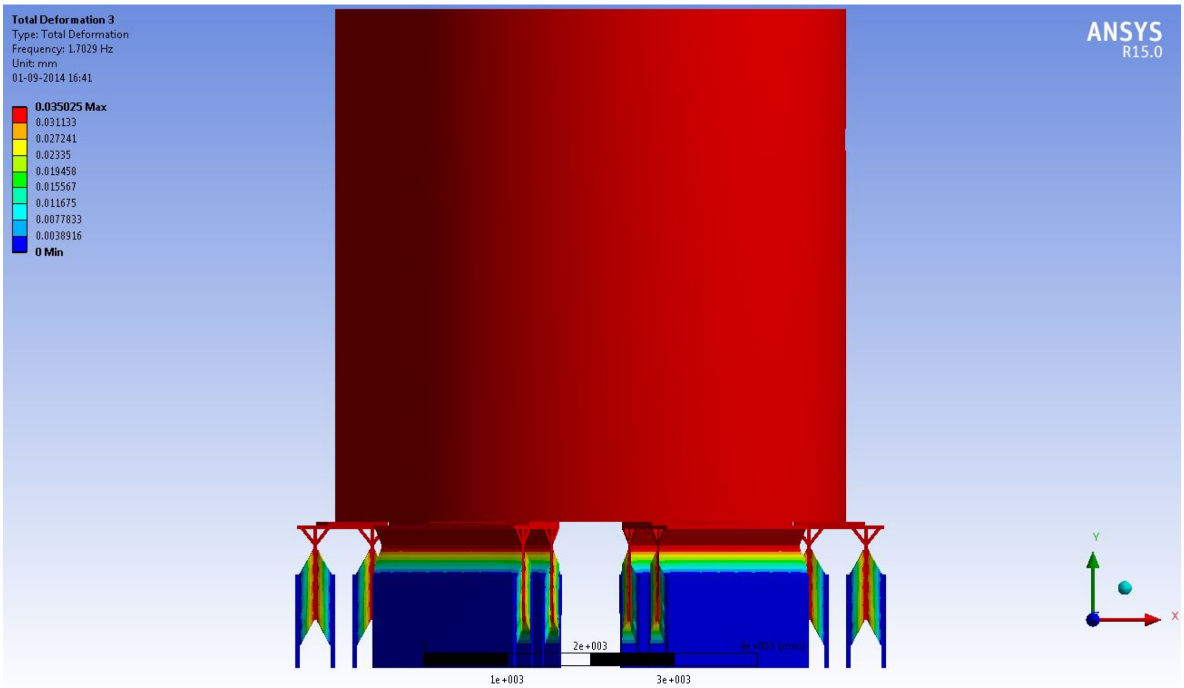


Figure 7.21: ANSYS model - free vibration analysis, mode 3

Therefore, curve for $\gamma = 0$ is chosen. It is clear that destructive effects appears for frequency ratios equal or really close to 1.
From the outputs, definitely far from unity frequency ratios, resonance does not appear as a critical situation for the system and further analysis for damping effects are not required.

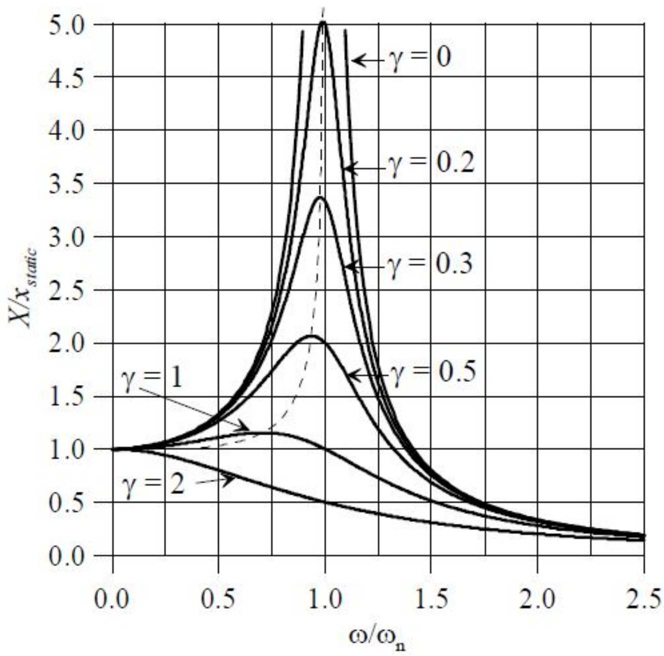


Figure 7.22: Frequency ratio behaviour with respect to resonance

From SHL's Naval Department analysis, the following frequency values are defined for OS' motion respectively along roll, pitch and heave directions.

In Table 7.9 they are proposed and compared with bottom connection natural frequencies. They result from motion periods of respectively 10, 10 and 5 seconds.

Table 7.9: Free vibration results - Frequencies and mode shapes compared with vessel motions

Mode		ω_n - Natural Frequency [Hz]	ω - Vessel Frequency [Hz]	$\frac{\omega}{\omega_n}$ - Frequency ratio
1	*roll*	0.739	0.100	**0.135**
2	*pitch*	0.744	0.100	**0.134**
3	*heave*	1.703	0.500	**0.294**

7.5. Summary and results

Through several design phases, the bottom connection system is finally defined. The solution is tested through static structural, linear buckling and free vibration analysis. Both hand calculations and Finite Element models support the output results. Environmental considerations are applied to take into account the potential issues offshore. Governing parameter is the temperature, which could reach really low values, especially for the North Sea applications. Therefore the two limit situations are investigated, with different input setups for material behaviour. Rubber is the most affected one, by means of its shear modulus. Two limit values of 0.75 and 2.25 MPa are considered and connection solution is designed for both of them.

Static structural analysis governs the overall arrangement of the system. Minimum number of required elements is found, in order to abide by the initial boundary conditions and perform the rotational and vertical requirements in stiffness. Considerations are applied for installation on the vessel and handling procedures; designed is so adapted for these requirements. Time efficiency remains the main aim of such reasonings.
A quantification of involved total weight is carried out and compared with the effectiveness limit imposed during the stiffness analysis, Chapter 5. The resulting 229 tonnes of structural steel and the 144 rubber elements are within the limit of 500 tonnes of structural steel saved by adopting a flexible sea-fastening solution.

Buckling and free vibration analysis are performed in order to assess the damages for the WTGs to be transported and the stability of the vessel itself. Due to the number of supports per WTG and their lengths, buckling is proven to be not a critical issue for this design. Free vibration analysis studies the natural frequencies of the single WTG together with its bottom connection. They are compared with the vessel motion frequencies, for the most critical modes of shape. Heave is found to be potentially the most critical situation, but results show that resonance phenomena are far form a possible options for this system behaviour.

Further analysis could be done with respect to fatigue response. The focus should go on the effects on WTGs, since limited fatigue life affection is allowed for T&I procedures. This aspect is not covered in this thesis, since would require extra information from WTG manufacturers and dedicated analysis, with in deep detailing. However it is suggested for next studies, in order to completely assess the effectiveness of this solution.

8

Intermediate support - Conceptual design

It is not good to be too free

Blaise Pascal (1623 - 1662)

Besides the foundation level, another position is responsible for the support of WTGs. This choice has been already defined during the stiffness analysis, Chapter 5 and set at *22 m* from the deck level. Now, the delicate load transfer behaviour between the WTGs and the external vertical structures is studied. Furthermore, displacement requirements need to be taken into account, since the design choice provides specific flexibility consideration at this support level. Indeed, since the complete WTG is allowed to rotate at the foundation level around its z-axis, the required displacement at the intermediate height is about *375 mm* along the direction of the most critical action, in the x-y plane.

Requirements for this analysis are therefore connection flexibility and strength capacity. The latter is of particular importance since the load has to be transferred to the vertical structures, placed at the both sides of the WTGs, in a non symmetrical arrangement with respect the direction of worst action. In the previous stiffness analysis, this force spreading has been supposed to be evenly distributed along the two sides. It means that specific considerations are required to make this assumption possible. If this situation is not applicable, adaptation for the overall design is suggested, after appropriate comparisons and considerations.

Design procedure starts with the input data and boundary conditions definition, coming from previous analysis. Then, initial considerations lead to the conceptual design. This thesis has the main aim to focus on structural engineering features and issues. These are found more applicable for the design of bottom support than for the intermediate one. Therefore, the design at this stage is limited and more general than for the one already extensively provided in Chapters 6 and 7. A FEM analysis is carried out only to investigate the effect of this connection with respect to the WTG element, since the main goal is to avoid any kind of damage for the structure to be transported.

Besides the structural point of view, installation and handling procedures are considered in this section as well. They are fundamental aspects, since may deeply affect the goodness and effectiveness of the overall sea-fastening solution. Priorities for this analysis are again safety and speed (together with the assumed already provided structural integrity). Practical considerations are provided to conclude this design. Since for this thesis the analysis is limited to a conceptual phase, recommendations are given to address for further possible studies about this specific part of the system.

8.1. Input data

With reference to previous calculations, design situation at intermediate support is found. Figure 8.1 shows the arrangement with the structural requirements at this position. They refer to horizontal force transfer towards the external vertical structures and flexibility in x-y plane (horizontal direction).

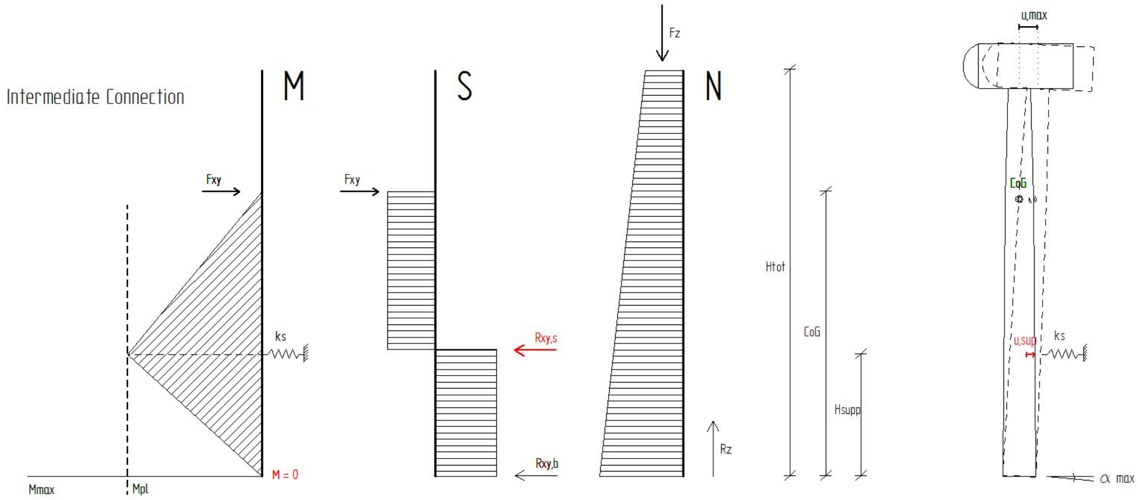


Figure 8.1: Intermediate connection - static schemes and design situation

The connection to be performed is basically a clamping system which does not contribute in bending moment and vertical force reactions. Due to rotation of the WTG at the bottom, horizontal deformation at intermediate position is generated, together with a small differential vertical displacement between two opposite sides of the cross section. This latter aspect is considered to have minor importance as long as a certain flexibility is allowed by the system, even in vertical direction.
Since each WTG is surrounded by external sea-fastening structures at two opposite sides, the connection should be provided such that each structure receives the same contribution. This requirement comes from the assumptions made at the stiffness analysis, where all the external sea-fastening structures are considered equally and symmetrically loaded, Chapter 5.3.
The values of the two most important input data are proposed in the following Table 8.1.

Table 8.1: Intermediate support connection - Input data

Design data	
Horizontal force - xy [kN]	9643.2
δ required - xy [mm]	375.3

8.2. Conceptual analysis

Using the just defined input data, initial considerations are made for the kind of connection to be adopted. Force capacity alone is not the main issue here, since several possibilities could be used and checked just according to their strength capacity. The combination with high directional flexibility makes the analysis more complicated. It is underlined again the necessity to keep the WTG structure undamaged during T&I procedures. Therefore, due to the large forces to be transferred, the connection needs to be performed through a large surface on the WTG wall.

Having that in mind, two possibilities are initially found to clamp the structure at this intermediate height:

- Hydraulic jacking system;
- Flexible elements.

The first solution would require the utilization of several jacks, placed around the WTG external surface. They may then be attached to additional external structures, in order to properly direct the reaction forces to the two main external vertical structures. The rotation of WTG, and so the horizontal displacement, has not to be applied by an external user but should be granted as soon as the sea-motion applied on the vessel acts.
Therefore, the hydraulic system should be passive and not active. To achieve that, a closed fluid circuit among jacks could be the solution. The basic principle is that once the jack is pushed on one side, the compressed fluid moves directly to the opposite side where another jack is pulled. Then the required horizontal displacements are performed and WTG shows a certain rotation about its main x and y axis. Limitation in maximum displacement is set by imposing a constraint in maximum piston stroke.
The apparent simplicity of the system hides several potential disadvantages, together with the elevated number of jacking elements required. Indeed, main potential issue is related to possible leakage and redundancy requirements. Furthermore, a governing problem is about the creation of such a closed circuit. A hose web should be provide to connect all the hydraulic elements. In order to limit their length and decrease the potential leakage points and pressure differences, this web should be placed at the same level of the intermediate support. It would mean a creation of a fixed connection between the two external sea-fastening structures; WTG load-out operations would be so dramatically compromised. Indeed, due to the lack of available space on deck, combined with the operational radii of the crane, 1.3, WTGs should be loaded out and moved along the passage available between the vertical sea-fastening structures. Anyway, a possible layout is proposed in Figure8.2, where the concept of supporting ring attached to jacks and external structures is explained. The same main idea is applied for the flexible material proposal.

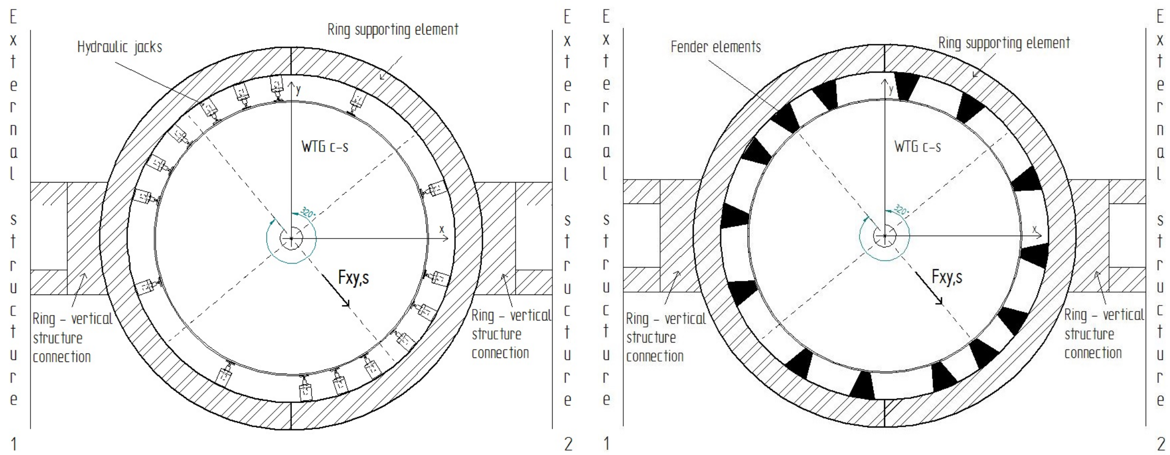


Figure 8.2: Conceptual design, intermediate support - jacks (left) and fender (right) application

So, utilization of flexible elements is the second focus point of the analysis. At the general conceptual phase, Chapter 3, it is assumed to use a clamping ring, acting around the WTG external surface. Starting from this idea, flexible material is analyzed to carry the deformation requirements. Rubber is seen as a potential one, for its known flexible nature.
Again, main issue is due to the elevated requirements in displacements, which should be provided in the compressive direction. Similar reasonings as the ones proposed for the bottom support connection may be applied here. Standard plain rubber elements are almost incompressible along this direction while show better flexibility in shear.
Useful inputs come from rubber applications in marine environment. They refer to the so called rubber *"fenders"*, used for the absorption of kinetic energy from the contact of boats with other fixed or movable solids (e.g. jetty, quay wall or other boat). According to their particular design, they act as bumpers and provides high deformations together with relatively high reaction forces. However, their primary feature remains the elevated energy absorption capacity. Several layouts are nowadays available on the market, with different shapes able to affect even deeply the structural response.

Average values of 50% of deflection, with respect to the initial dimension, are reached for most of them. Figure 8.3 shows some of the possible available designs.

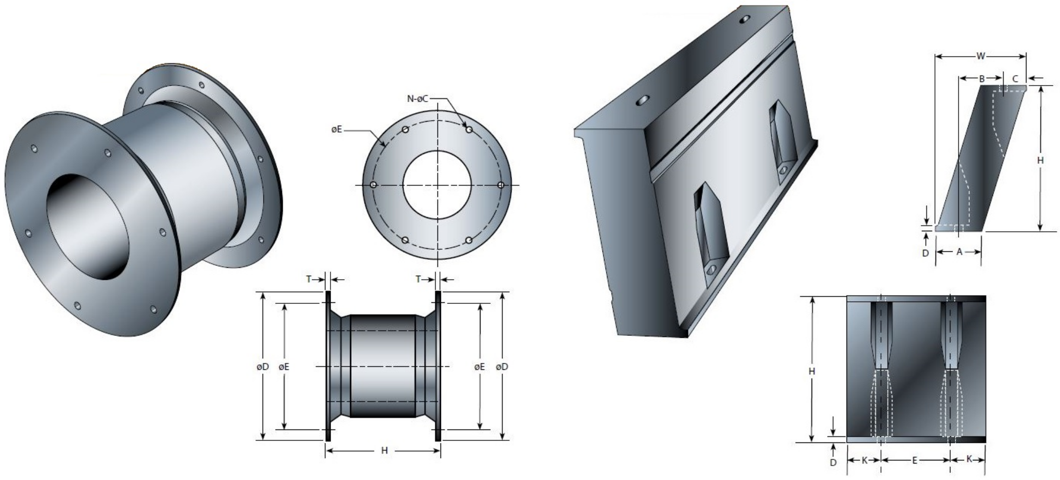


Figure 8.3: Fender products - examples available on the market [7]

The analysis now moves to the selection among already existent products, to be used at the intermediate support for an innovative fender application.

8.2.1. Selection phase

In order to provide an appropriate dimensioning calculation, one last consideration needs to be made about the expected behaviour of the system. Indeed, once the most onerous actions are applied along the design direction, the clamped WTG deforms the attached rubber elements. If no initial prestressing is assumed, there would be a loss of contact between the WTG and the fenders placed in one of the two sides. Therefore, the complete load would be carried only by the fenders on the opposite side, which would be more compressed with related oversizing requirements. Figure 8.4 explains this last situation, when only half of the elements are reacting along the worst direction.

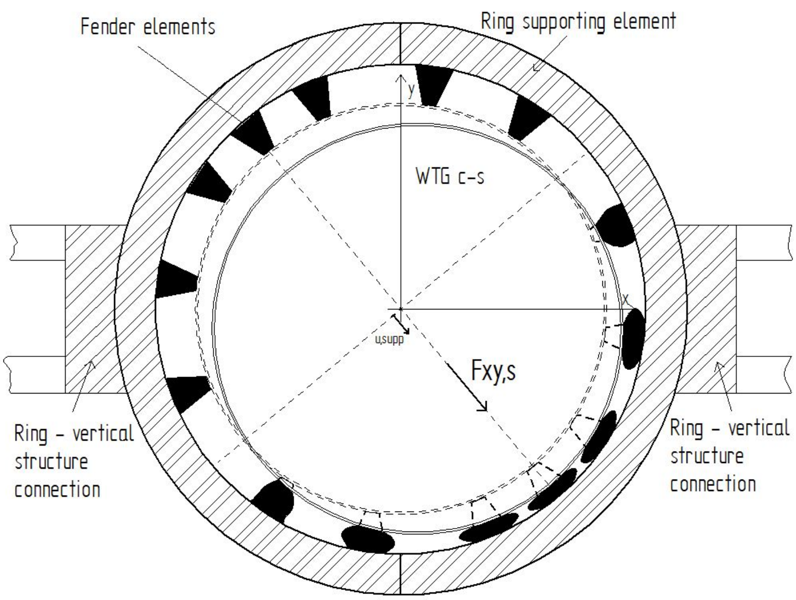


Figure 8.4: Solution with fenders, no prestressing - deformed situation overview

If prestressing is applied, all the elements reacts (in different ways, depending on their position along the perimeter) and contact is kept among all of them and the connected WTG. In order to achieve that, the elements should be initially compressed and part of the available deflection would be already applied. Again, a certain oversizing of the most compressed elements should be provided to take into account this initial compression. Moreover, to actually generate prestressing, additional hydraulic jacking equipment would be required.

On the other hand, as already mentioned, separation between some fenders and the WTG would appear without prestressing. Reactions forces would be provided by the elements still attached and uneven stress distribution would be generated along the hypothetical supporting ring. However, energy dissipation would be guarantee thanks to the nature of fender element itself. Over dimensioning would be still required since only half of the installed fenders would act during the most critical situation.

Since the two setup situations are different in concept but pretty similar in final results, the second one without prestressing is chosen, in order to avoid the installation of additional jacking system. According to the requirements mentioned so far, the aim of the selection is to find the best compromise among deformation capacity, bearing capacity and minimum dimensions. Several different products are available on the market. Fender elements with conical shape are selected for this design, because of their high flexibility, with deflection up to *70 %* of the initial height. Dimensioning is then carried out, according the several available sizes found for a specific manufacturer, [7]. Detailed information are provided in Appendix A.7.

8.2.2. Dimensioning phase

Fundamental data at this stage is the behaviour of the single fender element. From Figure 8.5(a), it is shown how this behaviour is almost linear for the energy development curve, while is not for the reaction force one. Since the latter is more relevant for the design, assumption of bilinear diagram is applied, Figure 8.5(b). It is conservative for the first part, where the *100 %* of the reaction force is reached, but it does not take into account the small fluctuations before the ultimate deflection limit. Given the behaviouir, it is assumed this exact limit of 70% as the design value for the analysis.

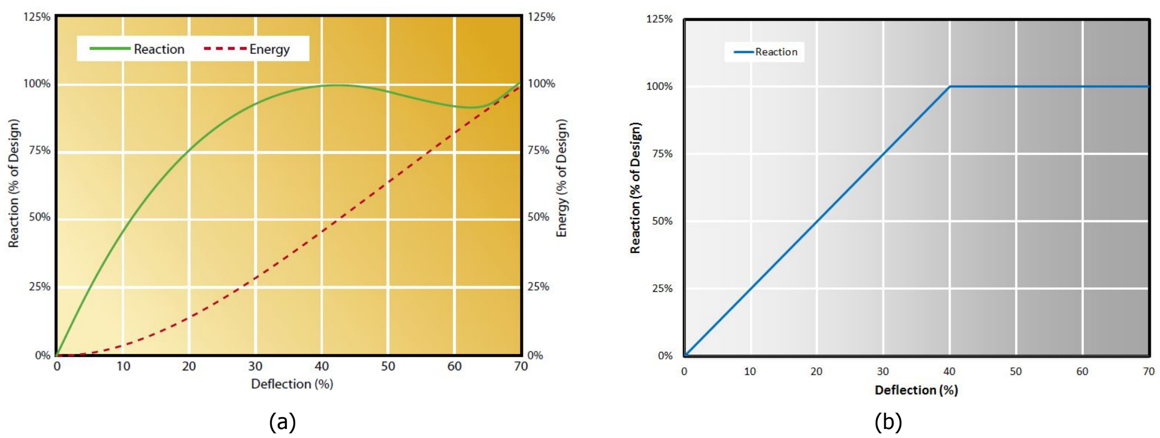


Figure 8.5: Conical fender performance curve: actual curve for MCN product (a) and adapted curve (b), [7]

Different response is expected for the fenders according to their positions around the WTG cross section. This is due to the action direction, oriented *140 - 320 deg* with respect to the global reference system on the deck, Figure 8.6. Considering the worst situation, when loss of contact appears on one semi circumference, Figure 8.4, reaction force distribution on the other one is calculated. Starting from global reference system, a local one is considered, to focus on the effects of the potentially supported WTG part. Figure 8.6 shows the described arrangement. A linear distribution is along the half circumference is assumed. Reasoning starts from maximum displacement along the direction of $F_{xy,s}$ action, *375.3 mm*. $Sin\alpha$ trend is used to describe the displacement distribution requirements along the half circumference, δ_{α}. Introducing an initial height for the fender element, % of deflection

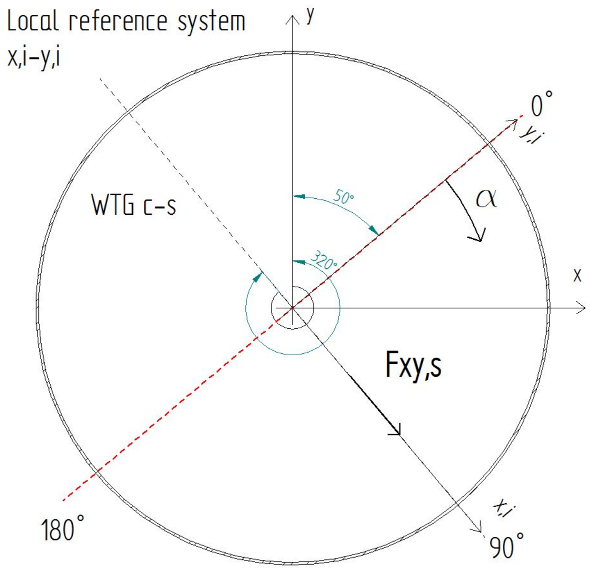


Figure 8.6: Local reference system - Supported WTG half circumference

is then found. It is imposed a maximum deflection of *70 %* along the direction of the acting force. Finally, actual deflections for the selected fenders, $\delta_{f,\alpha}$ are evaluated, starting from the requirements along the surface.

$$\delta_{max} = \delta_{90} = 375.3mm \tag{8.1}$$

$$\delta_{\alpha} = \delta_{max} \cdot sin\alpha \tag{8.2}$$

$$\delta_{\%} = \frac{0.7 \cdot \delta_{\alpha}}{\delta_{max}} \tag{8.3}$$

$$\delta_{f,\alpha} = h_f \cdot \delta_{\alpha} \tag{8.4}$$

Then, fender reaction force may be easily calculated by considering the biaxial diagram of, Figure 8.5(b). Finally, reaction components in fender axial direction are evaluated.

$$R_{axial,\alpha,\%} = \delta_{\%} \cdot 2.5, | \ \delta_{\%} < 40\% \qquad R_{axial,\alpha,\%} = 100\%, | \ \delta_{\%} \geq 40\% \tag{8.5}$$

$$R_{fender,max} = 993kN \tag{8.6}$$

$$R_{axial,\alpha} = R_{axial,\alpha,\%} \cdot R_{fender,max} \tag{8.7}$$

In Appendix A.7 extensive results are provided, showing in detail the distribution. As expected, for a large surface (in terms of angle α) the fenders can react at their maximum capacity since the deflection is in the range between 40% and 70%. The angular area goes from $35deg$ to $145deg$ in the local system. To optimize the design, fenders should be placed within these limits along the perimeter.
Now, considerations with actual value of the force $F_{xy,s}$ are required.

$$R_{Fxydir,\alpha} = R_{axial,\alpha} \cdot sin\alpha \tag{8.8}$$

Geometry possibilities are provided by the manufacturer, [7], and proposed in Appendix A.7. Since the force is pretty high, large dimensions are likable to be required as well as large number of elements. Therefore, considerations about available surface are necessary at this point. According to the half circumference perimeter of $\pi \cdot R = 9420mm$, some combinations of elements are tested, with respect to the generating reaction force.
In Tables 8.2 and 8.3 available elements dimensions are proposed and the position along the perimeter for the selected one is defined. In Appendix A.7 complete data and additional element geometries are proposed.

Table 8.2: Fenders MCN products - Maritime International Inc., [7]

Fender MCN features			
R [kN]	*H [mm]*	*D [mm]*	*F [mm]*
1483	1100	1650	935
1226	1000	1500	850
993	900	1350	765
785	800	1200	680
601	700	1050	595

Table 8.3: Design choice - Fender MCN 900, perimeter positioning

Design choice					
Position	*α local [deg]*	*α global [deg]*	*R - Fxy direction [kN]*	*σ,WTG [Mpa]*	*σ,ring [Mpa]*
a1	37.50	87.50	597.60	0.93	0.28
a2	58.50	108.50	842.11	1.31	0.39
a3	79.50	129.50	974.76	1.52	0.45
a4	100.50	150.50	974.76	1.52	0.45
a5	121.50	171.50	842.11	1.31	0.39
a6	142.50	192.50	597.60	0.93	0.28

In order to withstand $F_{xy,s} = 9643.2kN$, a solution with two rows of fenders is applied. This choice is mainly due to the lack of space along the perimeter. The only possibility to place enough elements is to split them into two rows. Indeed, an additional minimum spacing among elements needs to be provided, due to the kind of expected lateral deformation. Contact surfaces are considered for the connection of the a single fender with respectively the WTG and the supporting ring. Due to a conical shape of the element, the first is considered to be *800 x 800 mm* and the latter *1450 x 1450 mm*. They refer to transition plates made by flexible material, with additional PTFE layers at the contact WTG surface contact. It generates very low friction values, imposing no constraint for the clamping in vertical direction. Contact surfaces produce the σ values, proposed in the previous Table 8.3. Final element arrangement is depicted in Figure 8.7.

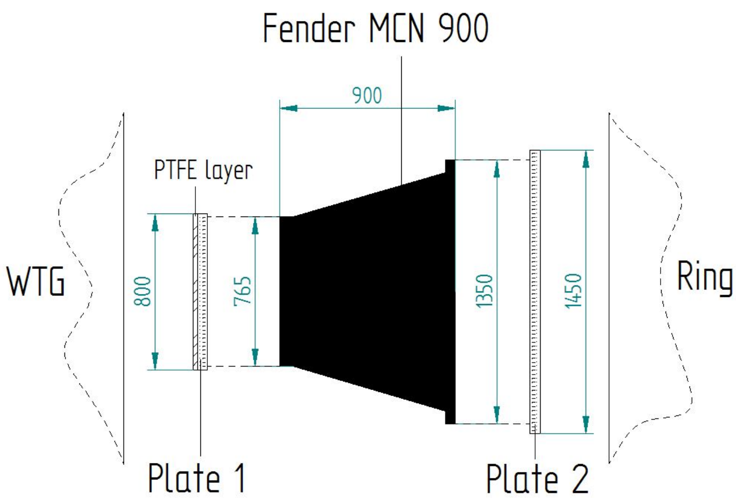


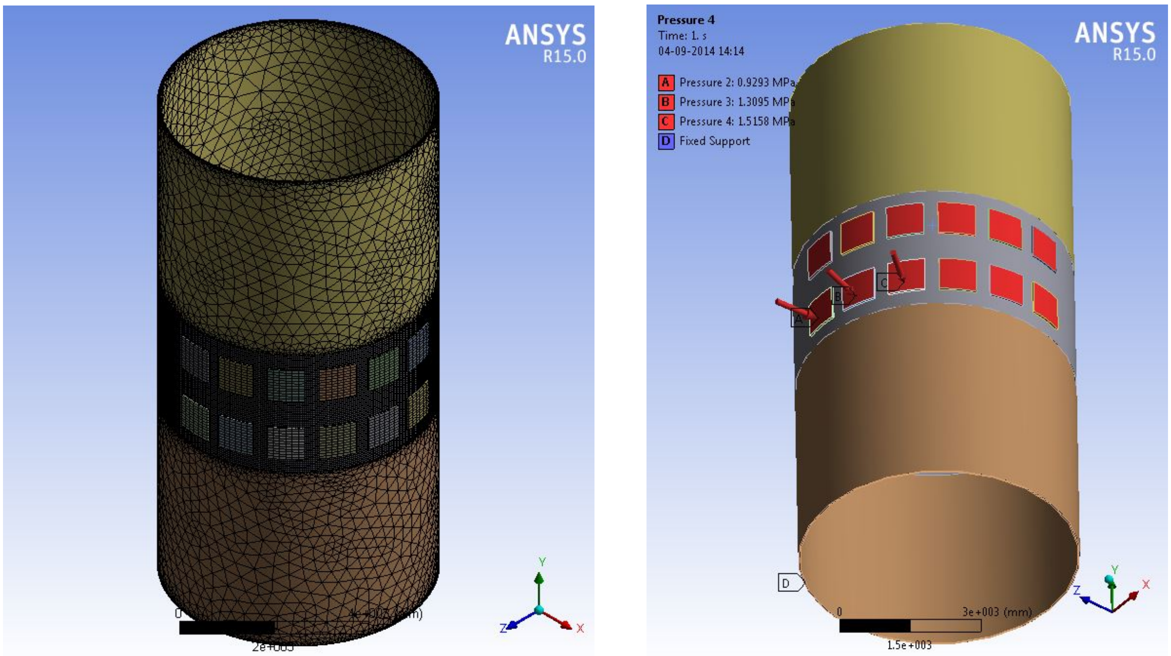
Figure 8.7: Fender MCN 900 - dimensions and contact surfaces

Now that all the input parameters are defined and a general response behaviour is calculated, FE modelling can follow. It will assess the effects of these supports in terms of stresses through the WTG element and produced reaction forces on the vertical sea-fastening structures.

8.2.3. FEM - effects on WTG

The software used for this analysis is ANSYS Workbench. From a 3D modelling of the elements geometry, properties are assigned. WTG is modelled as a cylindrical shell element, with constant thickness (30 mm), as suggested by manufacturers, Section 2.6. Support plates have a nominal thickness of *50 mm*, which is just assumed since not aspect fundamental for this kind of analysis. Assigned property for both of them is structural steel. The considered length is not the total one. It is chosen to use 12 m length, since for De Saint-Venant theories this is the minimum distance which provides an even stress distribution, for a force applied at mid length, through a cross section diameter of 6 m (WTG), [16]. Other steel elements are designed in a similar way: shells made by structural steel.

Once geometry and material properties are defined, analysis is moved to mesh modelling. Program controlled meshing is provided by ANSYS, with some possible adaptations from the user. They are basically about mesh refinement at the connection points and where the highest stress concentration is presumable to appear. The surface around the connection with plates has a more defined mesh as well as for the plates themselves, Figure 8.8(a). A coarse mesh is provided for the rest of the WTG element surfaces. It is applied in order to optimize the program calculation process.
Then, loads and supporting conditions are applied. Horizontal load from the tower to the reacting fenders is applied as pressure on the connection surfaces. Three different pressures are defined, according to the positions and related σ values, as proposed in Table 8.3. Fixed support constraints are applied at the bottom and top of WTG wall thickness. Figure 8.8(b) shows the so mentioned situation.



(a) (b)

Figure 8.8: FEM detail - mesh (a), load and constraint conditions (b)

Finite Element Model results are finally proposed. Outputs are in terms of maximum stresses (Equivalent Von-Mises stresses) for the WTG element. The main check is about the yielding limit of the S355 steel material. With maximum peak values of *226.7 MPa*, the requirements are met and the designed connection system does not appear critical for the WTG structural integrity, Figure 8.9.

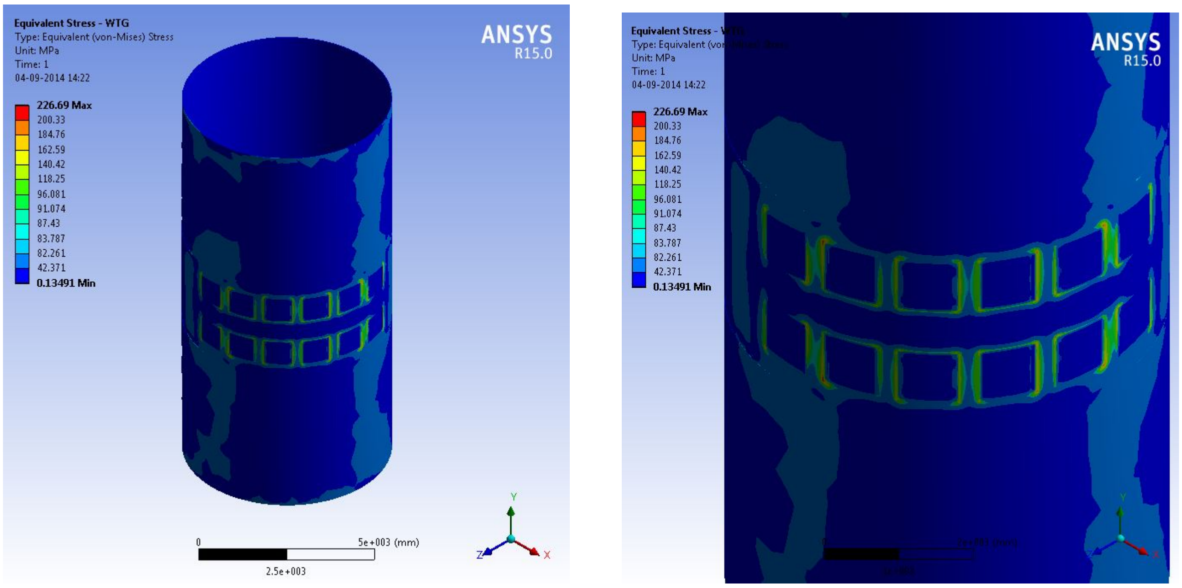


Figure 8.9: FEM contact WTG-fenders - stress results

8.2.4. FEM - effects on external vertical structures

Second main requirement of the intermediate support connection is to actually transfer the forces acting on WTG to the external vertical sea-fastening structures. Assumptions are made in the previous chapters about an equal distribution of the reaction between the two opposite supporting structures. Reference is made in particular with Chapter 5; here Figure 5.3 shows the main assumption which governed the beginning of the stiffness analysis. Here this assumption is checked, in a qualitative way. Indeed, a proper and more detailed analysis would require a specific design for the intermediate element, the ring. It is responsible to transfer the loads from the fenders to the supports. Choice is made at the beginning of this work, to not focus on the design of such an element, since it seems to have more challenges from mechanical than structural points of view. Indeed, such a system should to be opened and closed, in order to let the WTGs move during load-out. This can be achieved only by designing in detail specific jacking systems and mechanical parts, which are outside the purposes of this thesis.
Therefore, plausible assumptions are adopted for the ring design and further considerations are provided for handling procedures. The necessity of a more detailed design for such an element is however reminded in Chapter 11, where recommendations are proposed to conclude this thesis work. Main boundary condition is the space limitation for the installation of this element. Figure 8.10 shows the specific situation from the top view of the deck, where WTGs are placed and vertical supporting structures already installed. No issues come from the distance between a single WTG and two opposite sea-fastening structures. More critical is the available space between two consecutive WTGs, which is limited by initial design boundaries to *3.5 m*.
Therefore, by applying the previously designed fender elements, the gap is reduced to *1.7 m*. Proposed arrangement in the previous Figure 8.10 assigns a minimum gap of *0.7 m* between two consecutive rings. This value can be kept as final boundary, for practical reasons. Indeed, a minimum space needs to remain available for possible maintenance activities or unexpected handling procedures. In this way, the ring element would have a main thickness of *500 mm*. Then, extra elements are proposed with dashed lines. They are meant to transfer the loads to the vertical structures, resulting in four main locations for reaction forces.
For both the ring and extra bracing elements, no specific information are provided, since detailed calculations should be required. However, general considerations are applied and recommendations come out from results of qualitative FEM analysis.

Due to the a-symmetric loading with respect to the support positions, stress distribution through the ring needs to be investigated. In order to avoid high deformations, the ring should be adequately stiff.

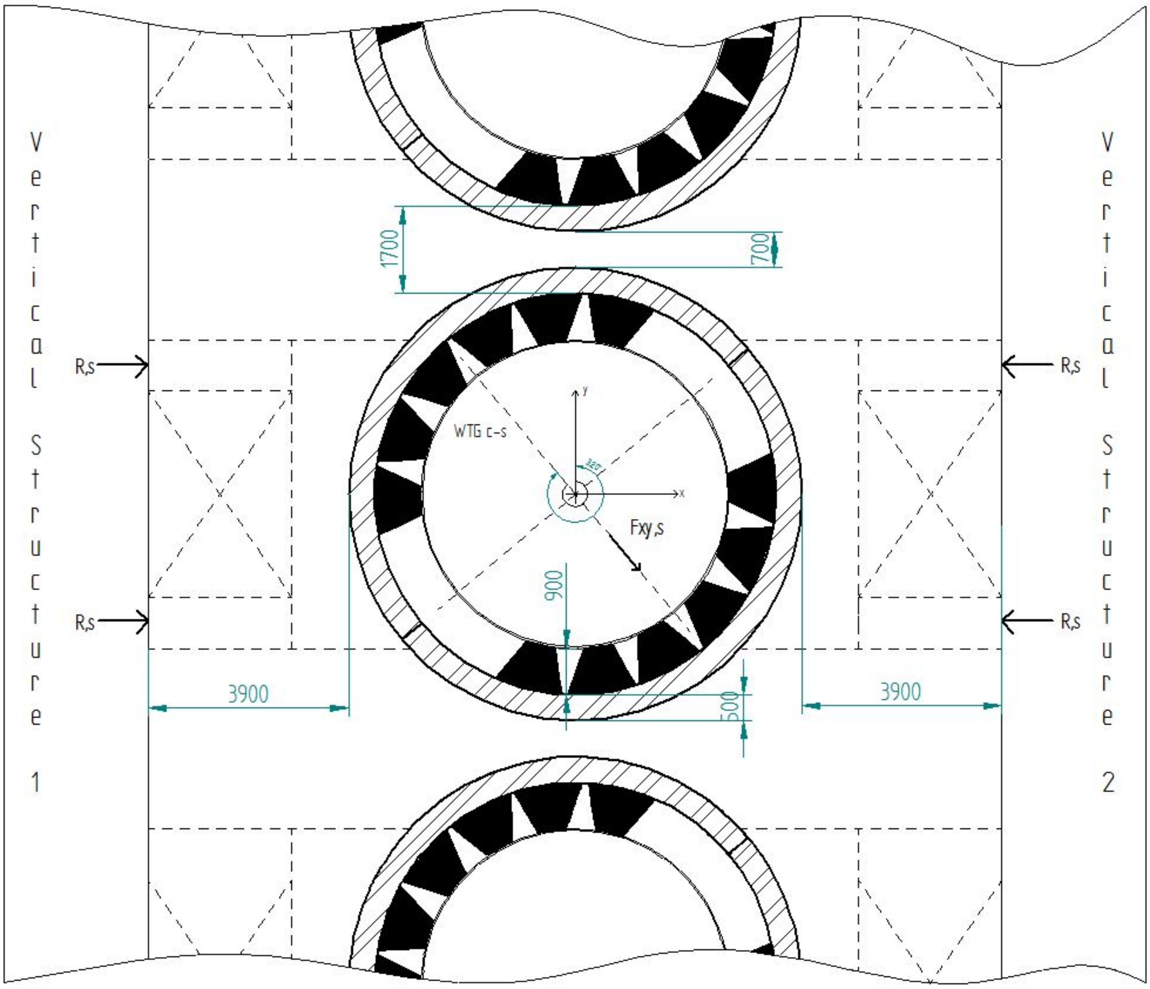


Figure 8.10: Ring-external structures connection - topview

Indeed, if the ring were too flexible, the stresses would be transferred from load application surfaces to the nearest constrained points. It would imply highly uneven stress distributions and deformations within the ring, with related unequal responses in terms of reaction forces at the supports.
FEM is provided by considering a still shell element with thickness equal to the maximum possible one, *500 mm*. This choice is unlikely to be used, due to the massive amount of steel required. Element modelling follows the rules already described in the previous section. Here, basically, the fenders' contribution is given by pressure on the external plate surfaces. Figure 8.11 shows the arrangement for the final situation, with applied forces and fixed constraints at the external support positions.

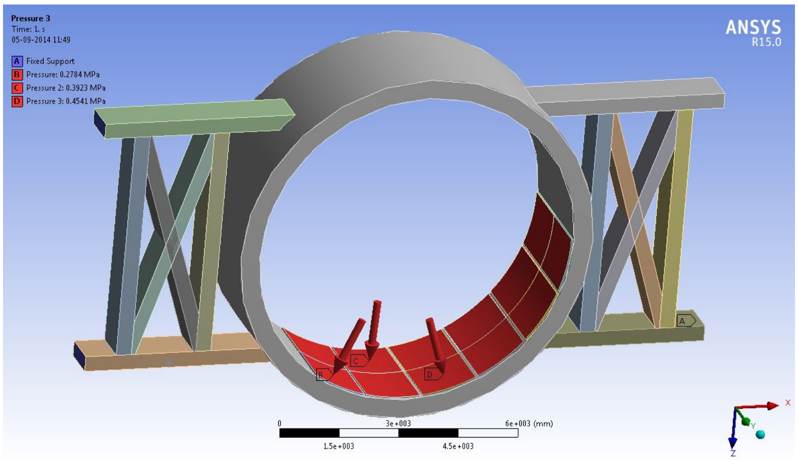


Figure 8.11: FEM detail - load and constraint conditions

Then, several possible arrangements are provided for the bridge connection to the external vertical structures. Even here, stiff considerations are necessary. What is found at the end of the analysis is that, even with an infinitely stiff construction, the stress distribution and so the reaction forces at supports would be uneven. Figure 8.12 graphically explains this situation. Several design steps are

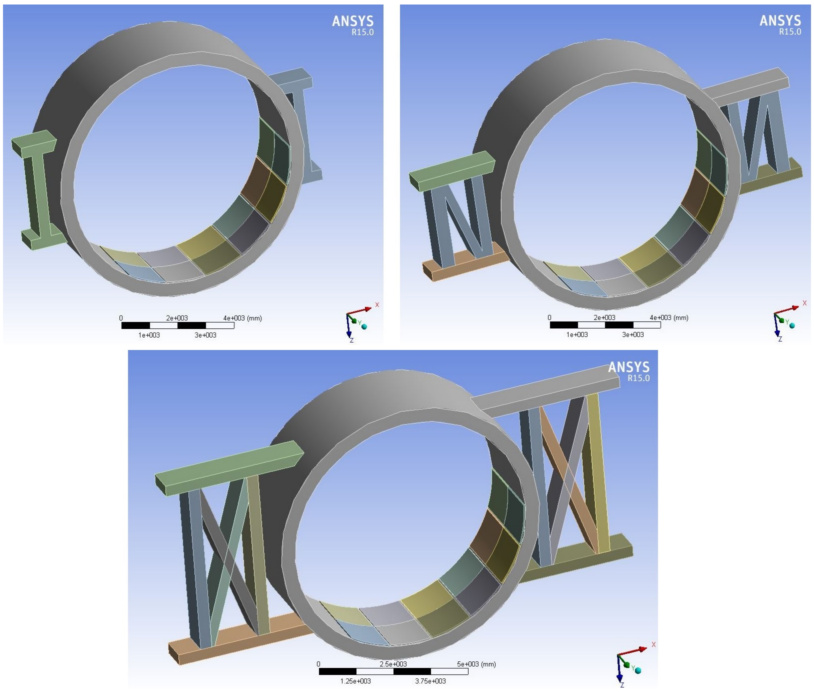


Figure 8.12: FEM layout - several design steps

made; the aim is to increase the stiffness of the connection, in order to see the advantages in terms of reaction force distribution at supports. As it can be seen from the last layout, highly braced connection is provided for the bridge. Even if cross sections are not defined and members are dimensioned in a qualitative way, the structural response can give good approximations for the presumable actual behaviour.

What basically happens is that one external support is going to be inevitably more loaded than the other one. The influence differences can be split along the two main directions.
Along y-direction (showed as z-direction in ANSYS model), similar values are present at the two sides, with opposite directions each other. This goes against the initial assumption of Chapter 5. But, in absolute values, the same amount force is transferred between the two external sides. It is underlined that the action component along this direction has the highest contribution.
Along x-direction, the results are such that one side is definitely more loaded than the other one. It is of course strictly related to the particular behaviour in y-direction. Therefore, initial assumptions are not checked. According to numerical results, it can be considered that the maximum reaction force along x-direction, on one external structure, is two times bigger than the one assumed. It implies that, in the worst condition, basically only one external structure is reacting.
Figures 8.13 and 8.14 summarize these considerations and compare the results with the assumptions from Chapter 5.

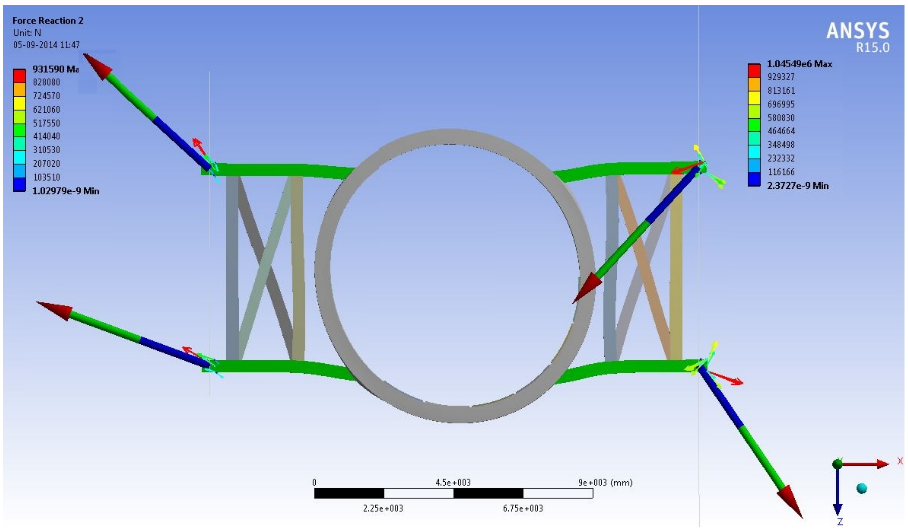


Figure 8.13: FEM results - reaction force distribution

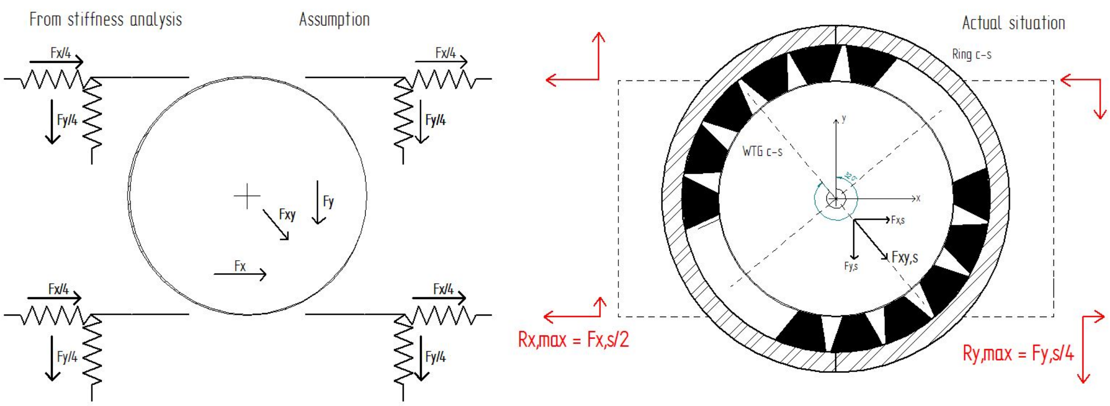


Figure 8.14: Maximum reaction forces - comparison with previous assumptions

8.3. Handling procedures

Installation procedures are now considered. Since three WTGs have to be placed per transversal row, no fixed space occupancy can take place in this direction. Therefore, a movable system should be applied in order to provide a connection between the two sides, once the installation procedures are concluded and sea-fastening is completed. Main boundaries are therefore WTGs diameter and space between two rows of vertical supports. During conceptual phase, a mechanical ring is assumed, chapter 3.3.2. It is split into two parts which can be further opened in order to let the WTGs move, Figure 3.15. This could still be a possible solution but probably too complex.

At this stage another kind of movable system is suggested. It is shown in Figure 8.15. It basically

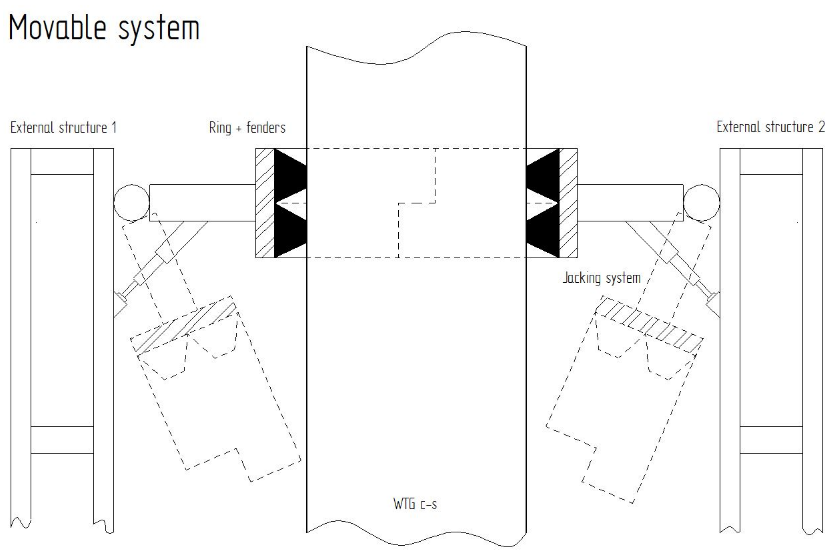


Figure 8.15: Intermediate support layout - movable system side view

consists in dividing the ring into two main parts. It is attached on one side to the bridge structure. This rigid body rotates about an hinged system, placed at the external support connection. Rotation is granted by appropriate jacking system installed right below the bridge and connected to the side structure. Required rotation is given by the WTG diameter plus appropriate space tolerances.

Once the two ring parts are connected again after WTG installation, the generated joint has to withstand high forces. Furthermore, it would be preferable to have an automatic coupling, in order to avoid the manual connection at such a delicate position (22 m height).

Possible design ideas come from railway practice, where automatic couplers are commonly used for vehicles connection. Here transferred forces, due to the train induced motion of considerable masses, are definitely pretty high. Concepts similar to *Buckeye coupler* can be applied, with the required adaptations. In the following Figure 8.16 this solution is proposed.

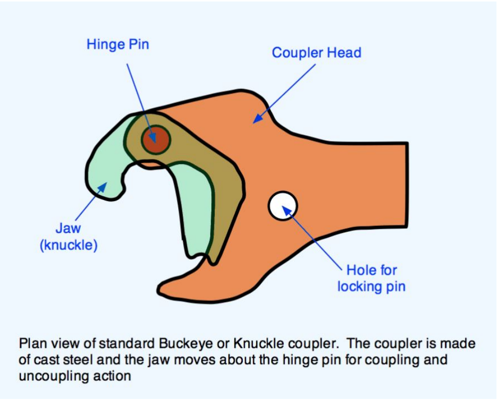


Figure 8.16: Coupler example from railway practice - Buckeye coupler, [8]

8.4. Summary and results

Intermediate support features are analysed. Starting from requirements in terms of flexibility, main elements are designed and suggestions are given for further and more detailed analysis. The clamping system is provided through a rigid element, steel ring, attached to flexible parts, rubber fenders. The ring is then connected to the external vertical structures through a steel braced bridge. Innovative nature of this design is given by the presence of fenders. They are chosen since able to provide high axial deformations under relatively high compressive loads. From products available on the market, 70 % deflection capacity elements are considered.

Fenders are arranged and designed in order to firstly allow WTG translation along the most critical direction. Transversal displacement here is about *375 mm*, which is translated into *1 deg* of rotation at the foundation level. A specific fender arrangement is defined along the ring perimeter. Stress distribution is generated by the number of fenders and their positions. This development is checked for the WTG cross section, in order to avoid high peak stress generation and yielding phenomena in the steel material.

Then, focus moves to the stress distribution along the ring itself and the generation of reaction forces at the external structure positions. At this stage, general considerations are provided, since the design of the connection bridge and the ring itself are given at a qualitative level. Comparison is provided with initial assumptions, made during Stiffness Analysis, Chapter 5. It is shown that the actual reaction force distribution among the supports is slightly different. This does not affect the main results of stiffness design for external sea-fastening structures and the already discussed advantages are still valid from the flexibility point of view.
However, different load path for the external structures has to be applied and could lead to different conclusions in terms of strength capacity. Moreover, these new results are used for the last considerations about grillage design, provided in the next Chapter 9.

Finally, some considerations are made for the installation procedures. Since really strict boundary conditions apply for the overall design, movable clamping system is necessary. Main requirements and coupling connection are suggested in qualitative way.

9

General design

You cannot cross the sea merely by standing and staring at the water

Rabindranath Tagore (1861 - 1941)

All the partial structural systems, designed so far, need to merge now in a grillage system. Adapted load paths are applied to the supporting structures, according to the results of the previous specific analysis. Structural integrity is checked again and considerations are provided for further improvements. This analysis is mainly focused on the external vertical structures, already designed and verified for both stiffness and strength in Chapter 5, and now adapted for the complete sea-fastening situation.

Then, final aim of any sea-fastening is to transfer the loads from the transported structures to the strong points of the vessel deck. Main grillage requirements are here proposed. Very basic indications have been provided during the conceptual phase, Chapter 3. Now, a more specific structural dimensioning is carried out. Leading procedure is the consideration of several planes of symmetry. It facilitates the design, which could be very complicated, due to the large area to be considered. However, this assumption needs to be adapted in some local points, where the actual anti-symmetric behaviour of the system mainly affects the structural response. Here, adaptations and considerations about possible improvements are provided, in order to preserve the effectiveness of the solution and its structural integrity.

9.1. External vertical structures

Starting situation is the one already proposed at the end of Chapter 5. After stiffness analysis, this frame structure is designed and then optimized for strength, in order to withstand the assumed load path. CHS elements are used for the vertical and diagonal parts, while I-section beams are adopted along horizontal directions. High strength steel S690 is chosen at the end, to meet strength requirements without oversizing the cross sections. Structural integrity is proven, according to the assumptions for the loading conditions defined in Chapter 5. After the general design of the intermediate support connection, Chapter 8, a slightly different behaviour is shown in terms of exerted forces on the external vertical structures. Therefore, a new load path has to be applied and structural integrity needs to be verified once more. As already proven, this different load path does not interfere with stiffness assumptions.

9.1.1. Final situation

For the design overview, reference is Figure 5.14. Here, load assumptions are that force components along x and y axis are equally distributed between four points, two per external vertical structure. These loads are applied at the top level. Section 8.2.4 shows that this assumption is not exactly applicable with the just designed clamping ring. Indeed, it defines a new load condition, which provides an even distribution between the two structures along y direction and an highly uneven distribution along the pitch direction. Indeed, only one braced structure can be considered to contribute now. Figures 9.1 and 9.2 show respectively previous and actual situations, by proposing input data analysis from the built up model on SACS. It is underlined that only one critical direction is proposed: because of symmetry, same considerations are valid in the opposite direction.

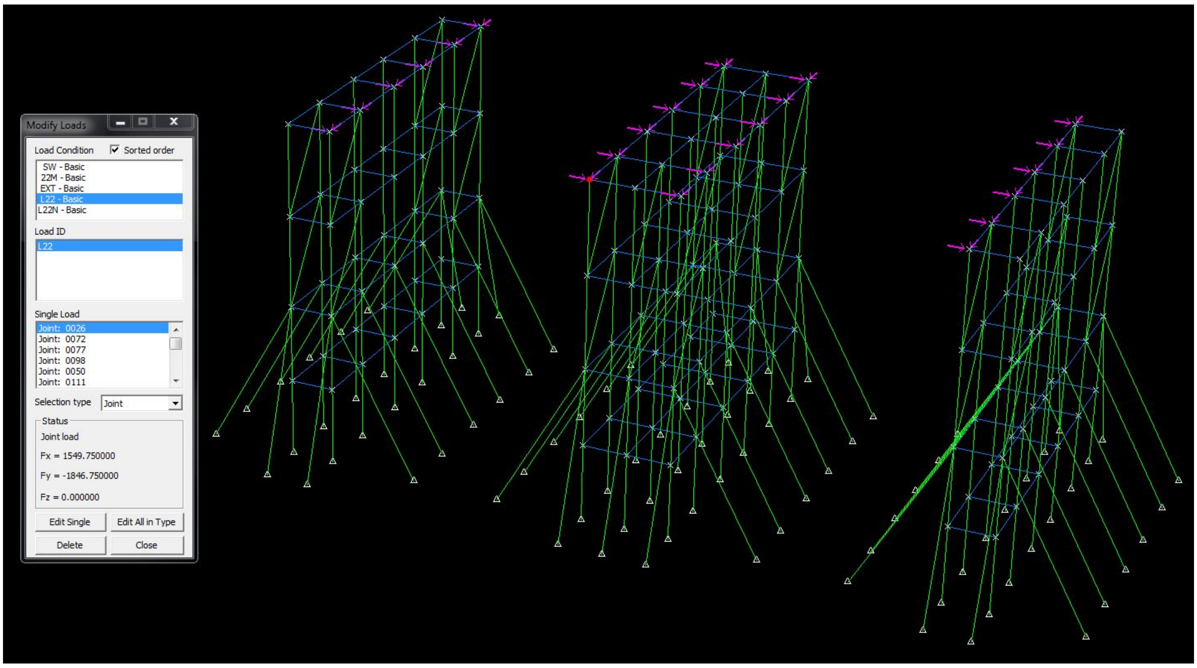


Figure 9.1: SACS model - Design action, old assumptions

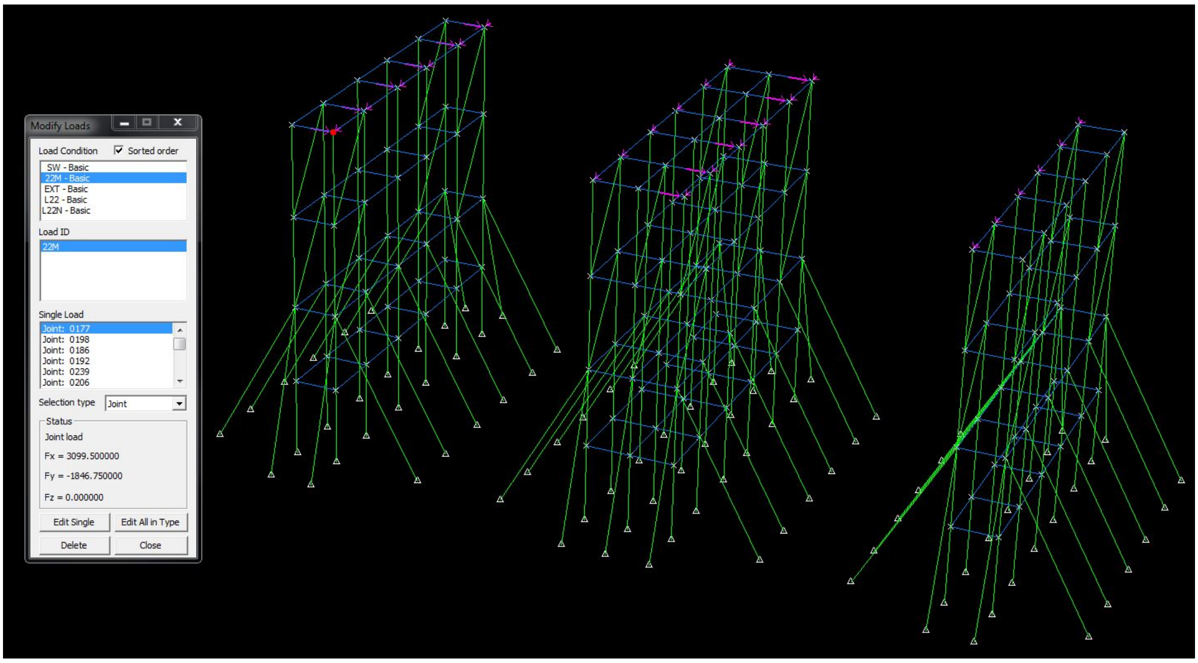


Figure 9.2: SACS model - Design action, actual situation

Once the input data has been proposed, structural analysis is carried out. Results are provided in terms of combined unity checks for structural elements. They involve the critical combination of shear, compression with bending, tension with bending, web shear, flange shear, buckling and torsion.
In the assumed situation, no issues were found, with all the resulting unity checks smaller that the unit

(from Figure 5.12). Here, only one frame is analysed, since the loads are assumed the same for all the vertical structures.
For the new situation, this condition does not apply anymore. Combined situation with all the elements is assessed, since behaviour can be different among different vertical structures. Output values for the new situation are proposed in Figure 9.3. Critical parts are underlined in yellow. As expected, higher

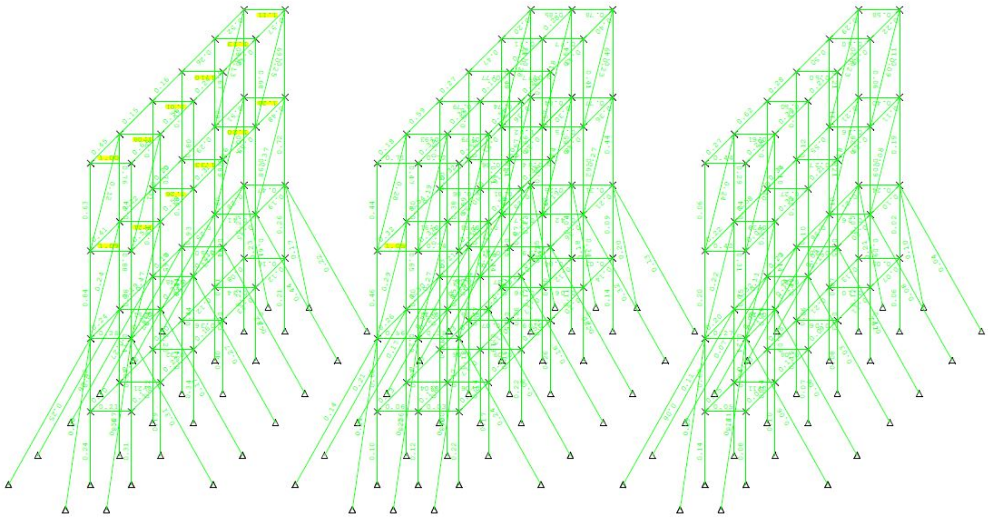


Figure 9.3: SACS output - Combined unity check

stress distributions appear in the more loaded structural parts. They belong to the external structure on the left side, with respect to the empty rows for WTGs positioning. On the other hand, element on the right hand side are less stressed. A counterbalanced behaviour is shown in the middle structure, since both effects are present.
Main requirement is to analyse the response of vertical members. Indeed, they are mostly responsible for the overall stiffness response. From Figure 9.3 it is shown that the new load path lead some columns, especially in the upper floors, to enter in a critical behaviour. It is expectable, since results from previous analysis, with less critical load path, were already close to the design limits. It is therefore required to add some bracings along x direction. This positively affects the stiffness in that direction and increase the total weight. Adaptations to solution effectiveness from stiffness analysis (Table 5.14) are required later.

Then the focus goes to horizontal members. Already from previous analysis they were showing a critical behaviour; but since this did not effect the stiffness response, no more adaptations were applied. Now these critical effects are amplified by the increased stresses in some members. Main contribution in combined unity checks, for this members, is given by bending moment about y load directions. Therefore, useful measures are the adoption of additional rows of beams and-or local stiffeners. Horizontal members, made by I section, are so applied while stiffeners are just considered as a further option. Again, since the total weight of the system is further increased, adaptations to solution effectiveness from stiffness analysis, Table 5.14, are required later.

9.1.2. Improvements

Figure 9.4 shows the new model in SACS, while 9.5 the outputs for combined unity checks. As it can be seen, diagonal bracings are adopted only for the external structures, and just in some frames at the third floor. In this way, increase in stiffness is limited. On the other hand, horizontal elements are placed for the two upper floors. A more dense arrangement appears now. As the underlined critical elements suggest, this is still not enough. Application of local plate stiffeners is suggested, in order to meet the integrity requirements. Further analysis about that are not provided in this work.

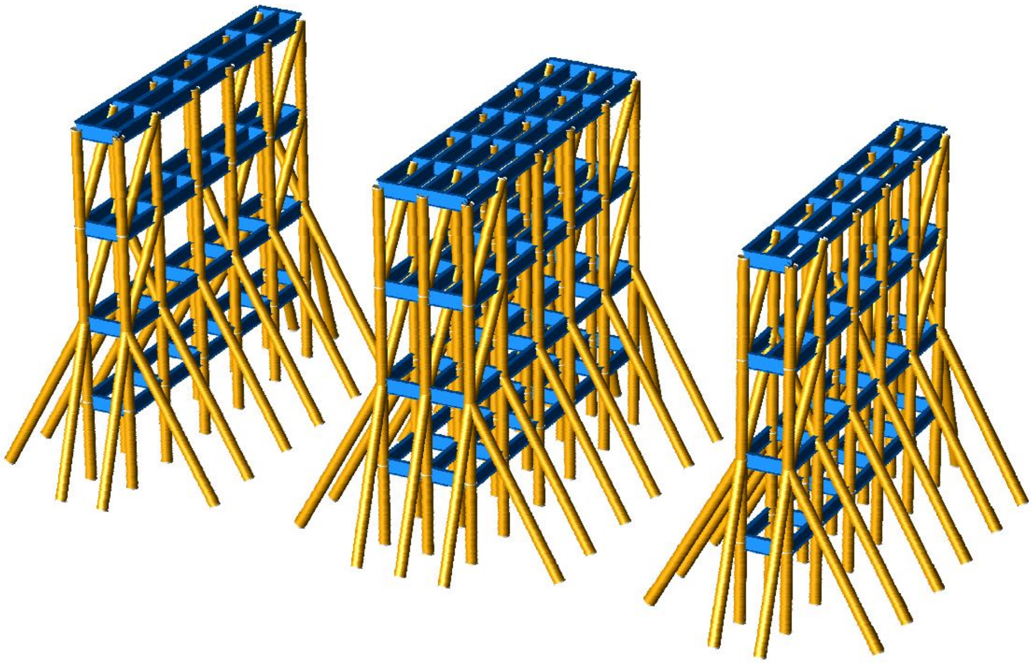


Figure 9.4: SACS model - New arrangement

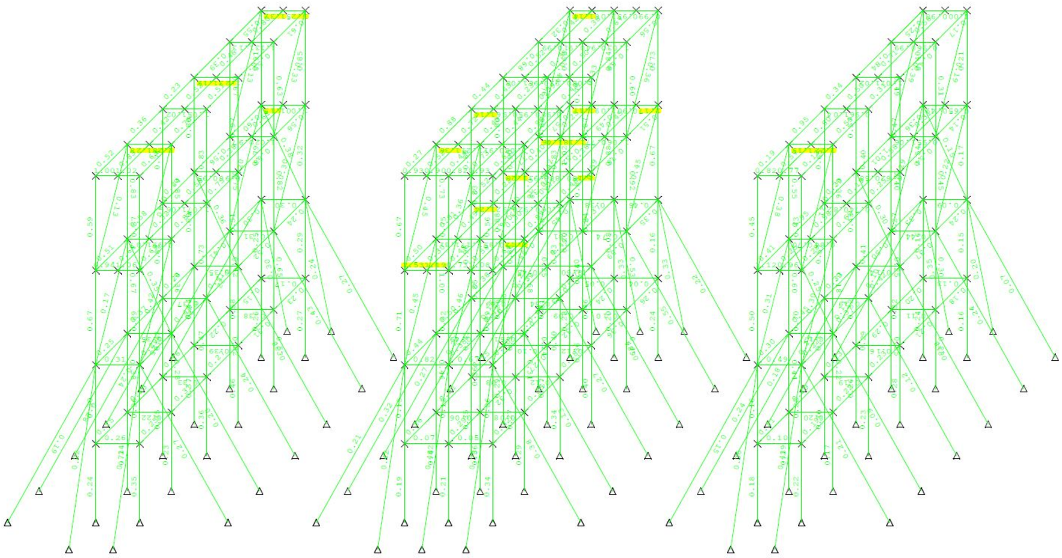


Figure 9.5: SACS output - Combined unity check, adapted solution

Now that the solution have been adapted according the the modified load situation, weight advantages are compared again. Table 9.1 shows the previous results from stiffness analysis, Table 5.14, and the new situation with the actual structure. Comparison is still made with the smallest and lightest solution achievable by using a fixed bottom connection for WTGs (reference to Chapter 5 for extensive explanation of the procedure).
Therefore, the new limit for overall solution effectiveness is set by **420 tonnes** of structural steel saving.

Table 9.1: Solution comparison with fixed WTG's bottom connection - assumed and actual

Assumed	**Hinged**	**Fixed**
Htot [m]	22.00	27.50
Hi [m]	6.0	6.0
x-dir	unbraced	unbraced
y-dir	2 part. braced	2 braced
single [t]	315.47	449.31
TOTAL [t]	1198.80	1707.37
Δ	**508.6 t**	**29.8%**

Actual	**Hinged**	**Fixed**
Htot [m]	22.00	27.50
Hi [m]	6.0	6.0
x-dir	part. braced	braced
y-dir	2 part. braced	2 braced
single [t]	337.00	449.31
TOTAL [t]	1280.60	1707.37
Δ	**426.8 t**	**25.0%**

9.2. Grillage

Grillage structure is meant to provide an optimized load spread over the vessel deck. Indeed the latter is supported by frames and bulkheads which form the skeleton structure of the vessel itself. The grillage is then only connected to these strong points, by welding. Initial considerations about grillage possibilities are provided during preliminary conceptual phase, Chapter 3, in order to qualitatively check the limits of the vessel capacity and the sea-fastening solution feasibility.
Now that all the above structures have been defined, general grillage design can be provided and further considerations applied. In Appendix A.8, definition of allowable concentrated loads on main deck for OS is proposed. These limits are basically *135*, *350* and *450 tonnes* capacity, according to different positions along the deck's length and width.
A model is built up on SACS, to consider these positions and the already designed sea-fastening structures.

9.2.1. Design criteria

Sea-fastening structures have been already designed by keeping in mind the possible supporting positions on the deck. Dimensioning processes already explained these choices, during the previous chapters.
Main design criterion for grillage elements is to take the load from an above structure and spread it to more than one support. The higher the load, the higher the number of required supports. By "load" it is meant vertical action, since it is the most critical one. Both directions are considered, since uplift has even more strict limitations than opposite dead load. However, in this analysis they are considered with the same weight, and equal limitations from Appendix A.8 are applied.

Having that in mind, simple symmetry design considerations are applied. Every lower element of the vertical sea-fastening structures is connected to a grillage beam, which is at least simply supported. The beam, from offshore standard practice, has an I-section layout with wide top flanges and variable web height. From rule of thumb considerations, comparison with similar projects already carried out and several specific tentative tests, maximum dimensions are chosen. It is decided to use an unique cross section for the whole grillage, in order to save manufacturing costs and decrease complexity. However, some elements could result over-sized. These dimensioning considerations are useful for structural integrity checks of grillage elements.

Slightly different approach is adopted for the grillage right below the WTG elements. Here, loads are transferred from the six supporting elements, Chapter 7. Their position is located around the WTG perimeter. It results in the creation of high stress concentrations within a pretty small area. Moreover, WTG positions are not symmetrical with respect to the deck strong points grid.
Indeed, governing criterion to arrange the WTGs over the deck has been the available space, given by the crane operation radii and its position at rest, Section 1.3. Therefore, a pretty dense and irregular deployment of grillage beams is expected at these locations. Common offshore practice for sea-fastening, in the specific case of circular cross section in vertical positions (e.g. Transition pieces), provides the installation of radial beams, going from a circumference projection to a bigger rectangular perimeter. Figure 2.9, from initial reasonings, shows an example of this kind of arrangement. Even

though it is valid for smaller scale sea-fastening (e.g. Transition pieces), the main idea holds for this situation.

The final solution provides a main general grillage, valid for the support of the vertical structures, combined with smaller local grillages, adapted for the WTG requirements.

Main grillage

As already mentioned, symmetry, simplicity and elevated number of strong supports on the deck are the main criteria behind this design proposal. The total area to be covered is $1630m^2$ (58.8 m length, 27.7 m width). Load application is almost every 3 m, due to the dimensions of vertical sea-fastening structures. Unique cross section is adopted. After the execution of several analysis tests, maximum shear resistance is resulted as the governing condition for beam integrity. Therefore, a beam with large web thickness is chosen. Height limit is set at 1.5 m, as assumed in the conceptual calculations, Section 4.3.2.

Since this is just an initial design, suggestions for further optimizations are, for instance, the installation of additional web stiffeners. It would reduce the requirement of web thickness, leading to more slender and cheaper beam elements. Furthermore, since the stress pattern within the grillage is not uniform, some beams result to be over-sized. Introduction of different cross sections could lead to material savings but, at the same time, more costs for manufacturing.

WTG grillage

For this specific situation, load application is different from the one proposed before. Here, high load concentration appear in the area defined by the WTG bottom connection, of about 6 m diameter. It means that these stresses have to be spread through several further elements, before reaching the supports. Furthermore, stresses from the main grillage contribute to the total transmitted loads to the supports.
After the execution of several analysis tests, based on existent similar grillage dimensions, governing design condition has appeared to be the bending moment capacity. Indeed, connection beams are placed inside the theoretical circumference, in order to equilibrate the loads coming from the WTG bottom connection positions and to generally stiffen the system. To improve the bending capacity, total height and beam flanges are increased. On the other hand, web thickness is decreased.
Table 9.2 shows the chosen dimensions for WTG grillage cross section and main grillage cross section.

Table 9.2: Grillage beams - Cross section dimensions

	Main grillage	*WTG grillage*
Width $[mm]$	450.00	500.00
Flange thickness $[mm]$	60.00	50.00
Height $[mm]$	900.00	1100.00
Web thickness $[mm]$	55.00	35.00
Area $[mm^2]$	9.69E+06	8.50E+06

Again, further optimizations can be applied. Application of local stiffeners, for example, could lead to less expensive beam cross sections. Figure 9.6 shows the final appearance of this specific grillage. Several beams are placed side by side, where the load application from WTG bottom connection is realized. Proposed nodal constraints are already the actual ones, coming from deck layout.

9.2.2. Final proposal

Final grillage layout comes out from the combination of the just discussed beam arrangements. It is underlined again that this design can be further optimized. Indeed, in order to meet strength requirements, it results over-sized in some parts. Strength analysis is carried out only through SACS software, by considering the design recommendations from American Standards, [21]. As for previous analyses, combined unity checks are evaluated. Load path is the final one, composed by design actions from vertical sea-fastening structures, WTG bottom connection and elements self-weight. All the sections

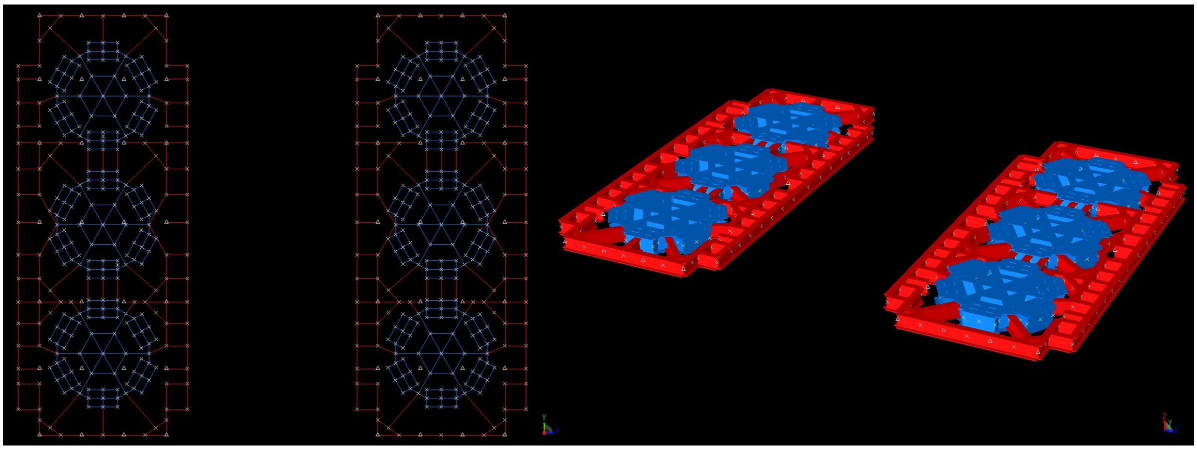


Figure 9.6: SACS model - WTG grillage, top and solid views

are verified and detailed results are provided in Appendix A.8. Following Table 9.3 summarizes the considered loads for the analysis. Application positions for vertical sea-fastening structures comes from the reasonings already proposed in Figure 9.2. Loads from the bottom connections are evaluated by considering reaction forces in ANSYS model. Detailed analysis is shown in Appendix A.8.

Table 9.3: Grillage design check - applied loads

		Loads (per node position) [kN]		
	element	*Fx*	*Fy*	*Fz*
Vertical sea-fastening	1	3099.50	-1846.75	-
	2	1549.75	-1846.75	-
	3	3099.50	-1846.75	-
	4	1549.75	-1846.75	-
WTG bottom connection	1	-	-	-1823.40
	2	-	-	-1823.00
	3	-	-	-1575.00
	4	-	-	-1344.20
	5	-	-	-1343.80
	6	-	-	-1575.20
Self weight (TOT)	-	-	-	-25560.00

Total loads are relevant at this final stage. They consist of the self weight of all the structural steel and rubber elements used for sea-fastening. The value of *25560 kN* corresponds to *2600 tonnes*. It meets the requirements imposed at the boundary condition definition stage, Chapter 1.3. Indeed, by adding the contribution in weight of the specific connections, maximum *400 tonnes* and the six WTGs, *840 tonnes* each, a total amount of **8050 tonnes** is found. It does not overcome the deck capacity of **8500 tonnes**.

Figure 9.7 shows the final layout of the grillage while Figure 9.8 the complete arrangement, in combination with the vertical structures. Bottom and intermediate support connections are not physically modelled; only their resulting actions are considered.

Analysis results are proposed in Appendix A.8. As mentioned at the beginning of this chapter, two main requirements hold: structural integrity of the elements and reaction forces at support positions on the deck. The first one is met, since the cross section design mainly focused on those strength requirements. According to deck reactions on its strong positions, some local peak loads appear in the final results. Even though the load is almost homogeneously spread among all the supports, local

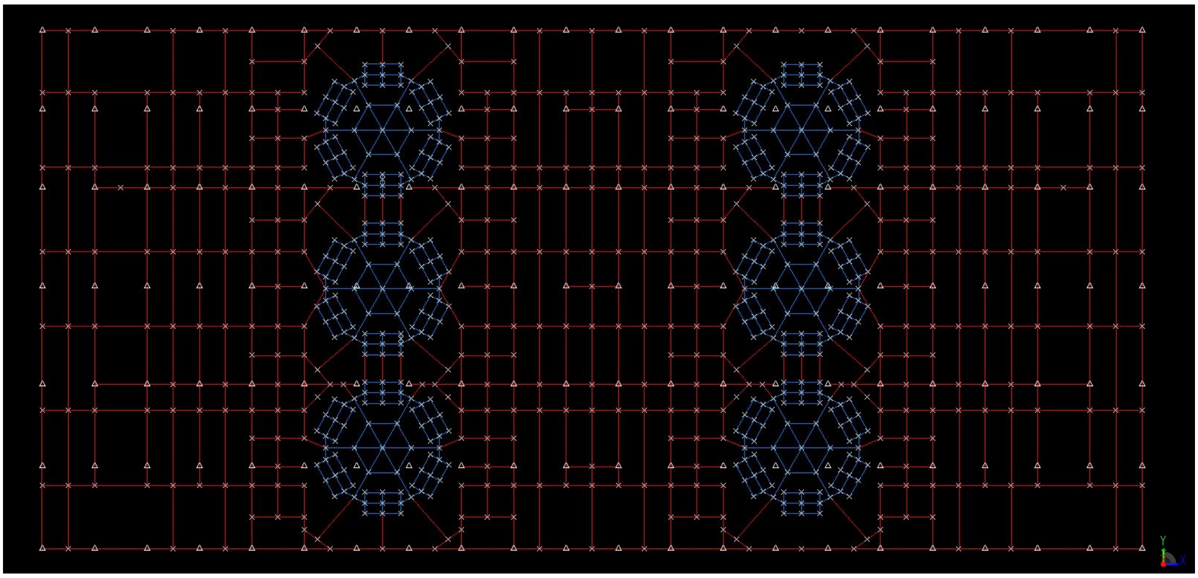


Figure 9.7: SACS model - Complete grillage, top view

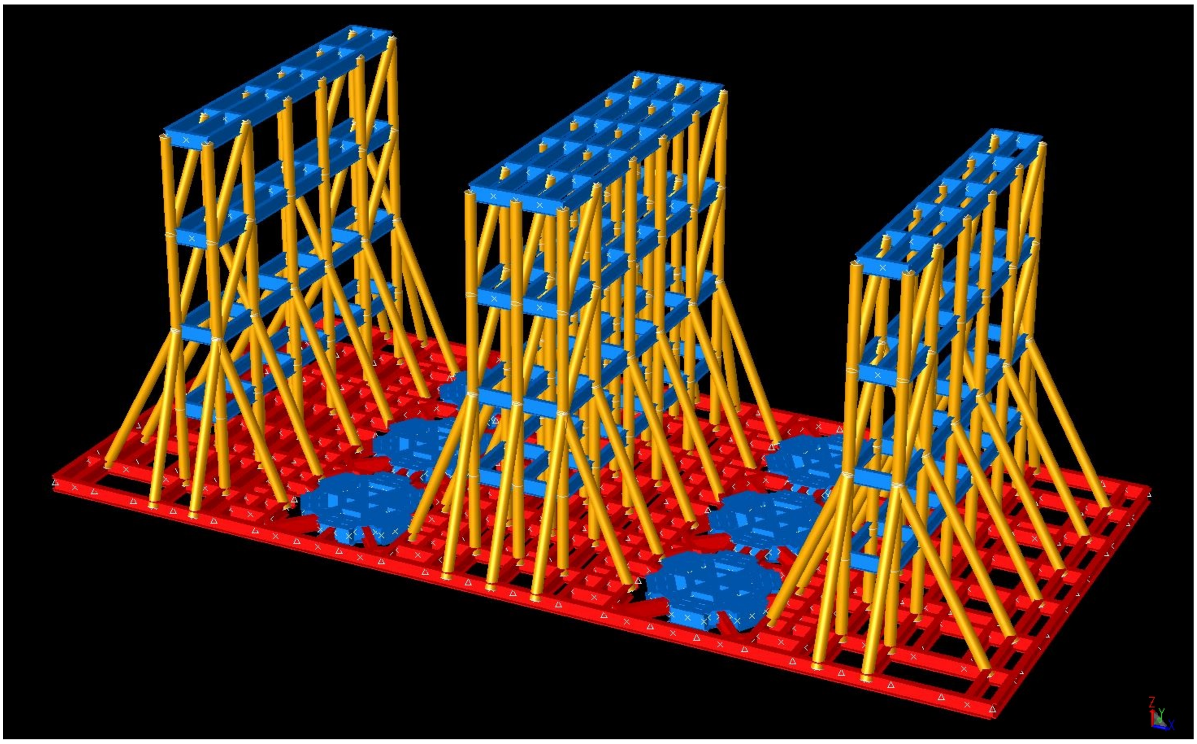


Figure 9.8: SACS model - Complete grillage, solid view combined with vertical structures

discrepancies appear in some heavy loaded parts. Improvements are therefore required with respect to this design goal. Suggestion is to create more connections among beams, in order to spread the stresses event to more distant supports. Moreover, increasing the total area of grillage would allow more available supports on the deck and so less reaction contribution for each of them. Besides that, reactions in other directions should be properly checked, even though they are not representing the governing situation. Furthermore, all the considerations about the creation of supports several specific points are guaranteed once the maximum beam deflections are verified as well. Indeed, if the deflection were too high, unexpected contact between the grillage and the deck would be generated. It would so imply force transmission, not allowed because outside the defined and allowed strong points of the deck.

9.3. Summary and results

Conclusive design aspects are considered in this chapter. Adaptations on the vertical sea-fastening structures are provided. Main differences between the actual situation and the initial assumptions come from the final intermediate support connection design. Results are that vertical structures are more loaded than expected. Thus, adaptations in frame beams and columns are applied. The final layout is checked with the requirements in stiffness and total amount of structural steel involved. Suggestions are proposed for further improvements, to solve local peak stresses in beam elements.
Advantages of the final solution, with respect to the smallest one achievable with fixed WTG bottom connections, are slightly decreased but still present. From comparison, the advantage is quantified in *420 tonnes* of structural steel.

Subsequently, general design for grillage system is carried out. Starting from initial conceptual design assumptions, Chapter 3, main boundary conditions are applied, Chapter 1.3. Besides that, structural elements are designed too meet structural integrity requirements. Overall system is divided into two parts. First the main grillage is analysed, where actions are transferred only by vertical sea-fastening structures. Then, smaller grillage parts, placed right below the WTGs, are considered. Different governing conditions are found and a final selection of design cross sections is provided.

A model on SACS is provided and calculations of maximum combined unity checks and vertical reaction forces are performed. Considerations and suggestions are produced as well, about critical parts and local peak force locations. Total weight of the system is finally computed and checked with initial boundary condition; with a final self weight of *8050 tonnes* for combination of WTGs and sea-fastening, the limit of deck capacity, *8500 tonnes*, is fulfilled.

10

Conclusion

Let your plans be dark and impenetrable as night, and when you move, fall like a thunderbolt

Sun Tzu (544 BC - 470 BC)

The goal of this thesis is to propose a structural solution for sea-fastening of integrated Wind Turbine Generators, to be applied on the Oleg Strashnov heavy lift vessel. Such a system has to provide for safe and efficient transportation and installation activities. Results for the main analysis steps are here assessed and commented, with respect to the above mentioned targets. Furthermore, the definitions of boundary conditions, company preferences and future market requirements, Chapters 1.3 and 2, represent additional terms of comparison for the design proposal effectiveness.

The first main study involves the conceptual analysis of the general system, Chapter 3. Basic calculations are provided at this stage and choices are made to further narrow the design possibilities, by focusing on specific structural systems. Comparison and selection finally provide a concept which abides by the boundary conditions. Furthermore, by assuming a doubly supporting sea-fastening with no theoretical bending moment development to the bottom of the WTG, structural integrity of the transported elements is carefully preserved. Therefore the results of this partial analysis are consistent with the main objectives.

During design data definition, the most critical situation is selected, by combining the possible acceleration paths along different directions, Chapter 4. From SHL's naval department, vessel motion accelerations are calculated, by considering possible sea-state conditions. A conservative decision is made by SHL, such as to consider transportation with significant **wave height** of **5 m**. According to the resulting acceleration values, it can be immediately concluded that this decision largely affects the design requirements and the overall sea-fastening solution. Indeed, they refer to a very severe condition, presumably not applicable in real WTG T&I procedures.

High resulting forces are found at the CoG levels of the three considered WTG manufacturers' designs. One specific product, **ALSTOM 6MW**, gives the most critical scenario and is kept as reference for the calculations. Acting horizontal force is $4130kN$ and related design direction is at **140 - 320 deg**, with respect to the initial reference system. It means that roll motion is governing, with a considerable contribution in pitch direction. This leads to specific requirements for sea-fastening structures positioning. Symmetry considerations are therefore still applied, with local adaptations where a-symmetric conditions are mostly expressed. It is so concluded that some advantages result from this choice, in terms of lower complexity and process optimization for the next design phases. On the other hand, it could necessitate to make several assumptions, based on symmetry, to be verified at the end of the design stage, when the actual asymmetrical situation applies.

During the stiffness analysis, Chapter 5, the first dimensioned sea-fastening structures are provided. The focus is mainly on the vertical framed structures. A first conclusion, from basic stiffness analyses, is that hinged connection at WTG foundation results in very low requirements of lateral stiffness, for the external supporting structures. The lower their height, the higher the advantages. The term of comparison is the beheviour obtained by adopting a fixed connection at the WTG bottom level. To enable such advantageous trend, maximum horizontal movement at the WTG top is pushed up to **1.25 m**. It implies, on the other hand, more challenges for the WTG connections at supports. The aim of the analysis is therefore to capitalise on the stiffness potentials. The end of the calculation procedure confirms, indeed, the initial assumption: **22 m** and **27 m** are the two minimum heights for comparable frame structures, respectively with an hinged and a fixed WTG bottom connection. It is found that less bracings are required for the first case. The conclusion is about the quantification of structural material saving, calculated at **500 tonnes** of steel, for the complete situation. This sets the limit for the whole sea-fastening solution effectiveness.

Design of the bottom connection is firstly performed through a conceptual study, Chapter 6. Challenges, at this stage, involve the provision of proper rotation and bearing capacities. It is concluded from the analysis that such a connection requires a massive deployment of structural material, especially if placed at the centre of the cross section. The total deployment of steel overcomes, or is pretty close to, the reference value of *500 tonnes*, previously set. Main limit is the high thickness requirements for the plate, which transfers the load from the bottom flange to the bearing position. **Rocker** and **pot bearing** systems belong to this group and are therefore not suitable.

Solution potentials are seen in a connection system with rubber elements, mainly acting in shear. It is designed in detail in Chapter 7. Through several optimization stages, a final solution is provided, composed by **6 supporting elements**, including **4 rubber pads** each and several steel plates. Such a system is able to provide the required rotations and directional constraints, both in vertical and horizontal directions. Furthermore, it is effective for a wide range of temperatures, since rubber is designed to withstand up to **-40 deg**. It is also concluded that the supporting system does not generate negative **buckling** effects on WTG element. Moreover, **free vibration** analysis results in a range frequencies far from the vessel ones and therefore no resonance phenomena are expected.

The design proposal provides fender elements attached to a steel ring, in order to deal with flexibility and load carrying requirements. This system clamps the tower along the external perimeter cross section and transfers the actions to the vertical sea-fastening elements, by means of steel bridge structures. Proper fender dimensions are provided, resulting in two rows of six main elements, per design direction. Regarding the steel ring and the steel connection to the frame, it is concluded that design loads can be carried but they result in an uneven reaction forces distribution a the external structures position. This affects the initial assumptions.

Addition of several bracing elements, in vertical direction, and more beams and stiffeners, in the horizontal one is provided, due to the application of the new actual load path, Chapter 9. With such adaptations, it is concluded that the structural integrity requirements are still met and solution effectiveness is still valid. Scaled down advantages, from comparison to fixed WTG bottom connection, are **420 tonnes** of structural steel saving. Conclusions about the grillage system design are that structural integrity requirements for beam elements are met, but more adaptations are necessary for the connection to the vessel deck. Indeed, deck capacity, according to the grid of vessel strong positions, is locally exceeded. The issues arise in limited locations but, by small load percentage.

With a total weight of **8050 tonnes** of steel, the strict limit of maximum vessel's deck capacity is not exceeded. All the other boundary requirements are met during each partial design selection phase.

According to overall efficiency, the solution is shown to be feasible and safe in all its crucial parts. Furthermore, the selection of rubber elements in different applications and arrangements, gives innovative features to the solution proposal. Relative efficiency is underlined, through the comparison with a potential comparable sea-fastening having fixed bottom connections for the WTGs. However, from an absolute point of view, the ratio between the six transported elements, *5050 tonnes*, and the resulting sea-fastening requirement, *3000 tonnes*, does not appear cost-effective for SHL. It is underlined that such sea-fastening would be used for more than one voyage and would become definitely more effective if the total number of WTGs to be installed were high (e.g. a complete OWF).

Therefore, it is finally concluded that the designed sea-fastening solution provides for safe and efficient transportation and installation activities of single-piece Wind Turbine Generators, for design situations worse than the ones can be expected in real offshore practice. By considering more realistic sea-motion situations, the solution would even provide higher advantages in terms of cost-effectiveness.

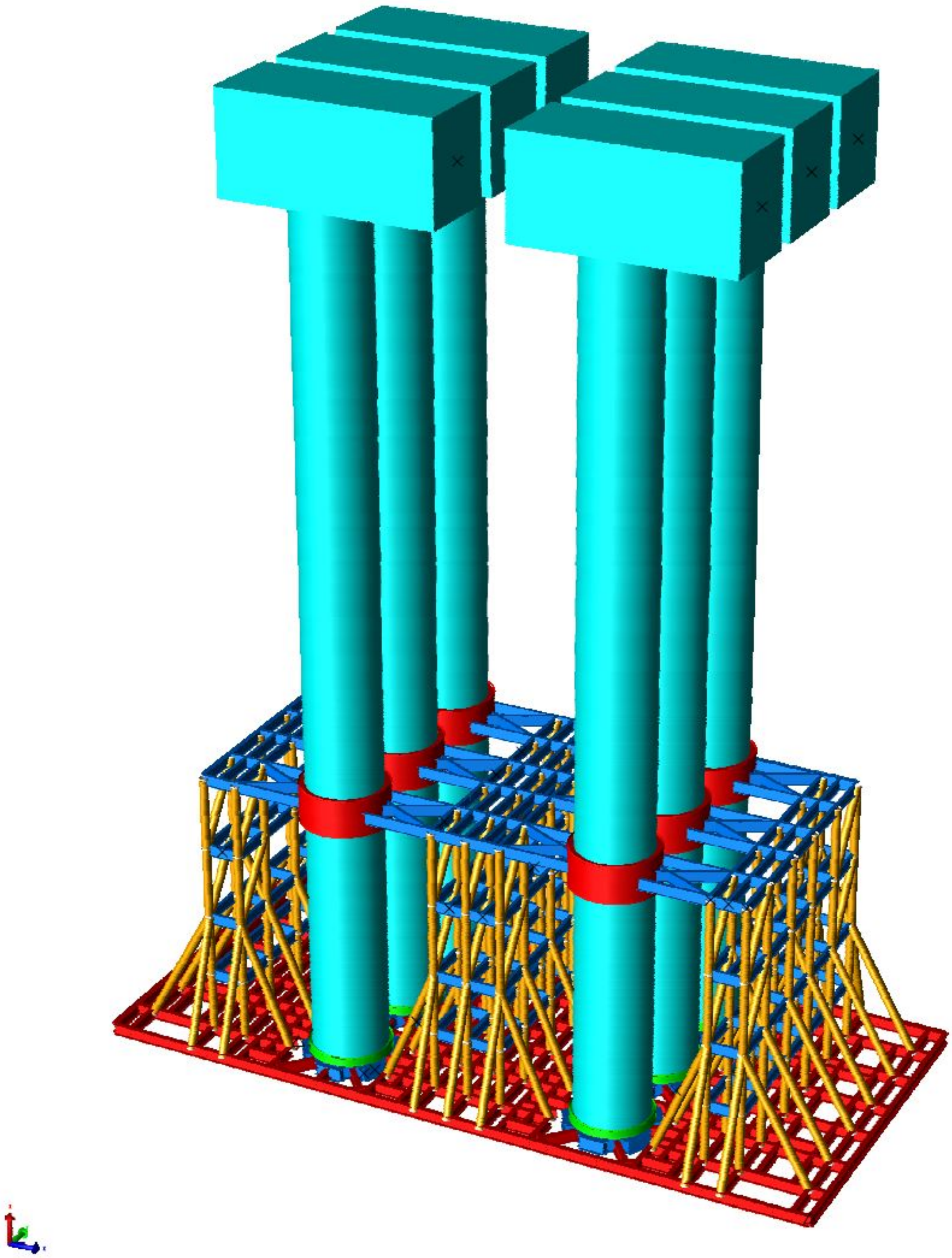


Figure 10.1: Final sea-fastening solution - overall appearence

11

Recommendations

I promise nothing complete; because any human thing supposed to be complete, must for that very reason infallibly be faulty

Herman Melville (1819 - 1891)

During the design process, several choices are made, in order to give, at the end, a complete and detailed solution proposal. Due to the large number of parameters involved and different aspects covered, analyses in depth are provided only for specific arguments. Partial results and final considerations enable to recommend additional studies, in order to cover further potential critical aspects, to optimize the current conceptual design parts and apply the solution flexibility features to different offshore situations. A brief list of them is therefore proposed:

- *Design sea-state*. Company choice is to design such a sea-fastening system, able to withstand a sea-motion up to *5 m* of significant wave height, Hs, in the North Sea. This choice appears way too conservative, if current practice is taken into account. Nowadays, T&I procedures for WTGs are carried out by jack up vessels. Even though their prerogatives and features are completely different from the ones of mono-hull vessels (e.g. Oleg Strashnov), they provide sea-fastening for WTGs able to withstand maximum *3 m* of Hs. SHL's choice, *5 m* of Hs, implies a tremendous increase of workability. On the other hand, although the procedures offshore would be limited, thanks to the single piece transportation, the installation procedures on site would be impossible during such a sea-condition. Therefore, a more reasonable Hs value would be around *3.5 - 4 m*. It would decrease the induced accelerations and so the design acting forces on WTGs, together with the sea-fastening requirements.
  Thus, starting from the conclusions of this study, resulting from the worst case situation, new analysis can be carried out by considering more realistic working sea-sate conditions. They are likely to result in reduced sea-fastening structural parts. Generally, the total height of the external supporting structures would be reduced, together with number of bracings and element cross sections. The number of maximum transportable WTGs would remain the same, since other boundary conditions apply (e.g. crane operation radii).

- *OS-WTGs combined motion*. From Naval Department, input motion data are provided for one WTG element, placed on the deck of OS, at a certain position and with a certain CoG height, A.2. Further analysis are required, in order to calculate the actual accelerations once *6* elements are placed on the deck, at different positions and with different CoG levels. This would largely affect the results. It is presumable to assume that the stability of the vessel could be compromised with high masses placed far from its own CoG. This is the situation of the proposed solution, where crane operation clearances and rest positions force the WTGs to be placed near the port side. Thus, possible negative effects should be a decreased deck capacity and so a maximum number of transportable WTGs scaled down to *4* elements.

- *Design load path*. From vessel motion analysis, by considering the WTG dimensions and weights, combination of action is carried out and the most critical situation is defined. Almost in between pitch and roll direction, this is assumed as the design situation for further calculations. However, recommendations are given in order to consider proper sea-fastening even along other directions. They do not represent the governing situation but could be still present. Therefore, a further analyses should be provided, in order to check the structural response in other less onerous directions, for the complete solution.

- *Vertical sea-fastening structures*. Their design is carried out for both stiffness and strength. Results are provided for combined unity checks, according to the relative standards for steel structures, [21]. Connection design is required, together with local application of stiffeners, where necessary. Indeed, structural integrity is checked for vertical and diagonal members, while for the horizontal ones some issues appear, especially in the highest frames, close to clamping ring load application. Main issue is the bending moment capacity. Therefore, application of additional stiffeners is suggested; if the requirements are not satisfied yet, increase of beam cross section height is recommended. Additional studies are required, in order to apply these adaptations only on local parts, without deeply affecting the final advantages of the overall solution.

- *Bottom support connection*. This system represents one of the innovative components of the proposed sea-fastening solution. According to that, several assumptions are made from the beginning, by using comparable guidelines from onshore practice, [24]. Rubber elements are the crucial components and therefore conservative considerations are applied. The main one is the material behaviour at different temperatures. Minimum limit is considered, *-40 deg*, at which a three time higher shear modulus is applied, with respect to room temperature condition. This choice is made in accordance to bridge engineering practice, where rubber elements are used for bearing purposes. In order to assess the degree of conservativeness of such a condition, small and large scale tests would be required.

- *Intermediate support connection*. This system has a less detailed design than the bottom connection one. The main reason is that more mechanical engineering challenges are present here. Therefore conceptual design and dimensional considerations are provided, especially for the steel structures. Further studies are therefore required to actually apply the stress distribution assumptions on the steel ring. After that, detailed braced system should be designed, again to check the assumption of force transfer to the vertical sea-fastening. Since rubber elements are involved, in a conical fender shape, tests would be required to certify their application in such an innovative arrangement.
  The choice of a non-prestressed connection leads to a loss of contact, between the WTG and some supporting fender elements, once the maximum action is produced. This selection abides by static requirements for fender optimised dimensioning and does not take into account dynamic effects. Further studies are required towards dynamic aspects, in order to investigate the bumping effects on the WTG external surface and the support itself. Different choices and design requirements could arise from such analyses.

- *Grillage system*. Symmetry considerations are adopted for this design. Structural integrity is checked and satisfies the related standard regulations for steel structures, [21]. It results in over-dimensioned elements for the less stressed parts, since only one cross section is considered. Therefore, optimizations in design would lead to less structural material involved. Moreover, the connection with the deck does not satisfy locally its strong positions capacity. It is required a further and dedicated study, in order to solve this problem. Grillage layout could deeply change and number of required elements would increase. Anyway, the total system weight would remain the same if the previously mentioned cross section optimization were applied as well.

- *Fatigue Analysis*. Specific recommendations are proposed for fatigue. Indeed none of such analyses are provided, during this study, since sea-fastening structures generally have simple arrangements, are relatively stiff and are meant to be applied for limited number of cycles. The proposed solution allows significant movements for the transported elements and therefore amplitude of stress ranges could incredibly increase. Furthermore, rubber is present and, according to its arrangement, is subjected to repetitive stress patterns. Although rubber fatigue failure should

not be the governing situation, [35], detailed studies are required to analysis its behaviour and predict the response.
Finally, fatigue capacity of the transported elements, the WTGs, should not be affected during T&I processes. Indeed, manufacturers usually limit to 5% the percentage of "expendable" cycles for transportation with respect to the total capacity, meant for offshore service life application. The flexible nature of this sea-fastening system could produce too high stress ranges for the WTG walls. Therefore, proper fatigue analysis is required to cover this last requirement, before a potential real application.

- *Handling procedures*. Even though installation and handling considerations are integral parts of the conceptual and design choices of this thesis, further dedicated studies would be required. Especially for intermediate support connection, proper clamping system design should be required, in order to limit man work at such an height. Suggestion is to use automatic coupler, adapted from railway practice, Chapter 8. However, further considerations would be required to optimize the clamp movements. Hooking system, for WTG, is treated at the initial conceptual phase, but not covered anymore during the next analyses. Proper design and schedule of installation phases should be further provided. This is another really important aspect, able to affect the time efficiency of the overall procedure.

- *Tower displacement at nacelle level*. During the stiffness analysis for the vertical sea-fastening structures, considerations are applied with respect to this aspect. A maximum value of *1.25 m* is set, abiding by the boundary condition of avoiding impact among WTGs, during asynchronous oscillations. This decision is valid according to static considerations. Increments in nacelle accelerations, due to this additional movement, are carefully checked and resulting in not critical situations. However, additional studies should be required in order to investigate potential critical effects from such high movements, from dynamical points of view. They may lead to higher limitations and lower maximum values for the tower displacement at the top. The effects would be translated into different and lower rotation and displacement requirements for the support connections.

- *Further applications*. A part from WTGs, other structures could be transported by adopting this sea-fastening principle. Main aspects, to make it effective, are the element weight and lengths. Regarding offshore wind farm components, monopile and transition piece transportation is investigated. Indeed, transition pieces could be an alternative, but are smaller and lighter than WTGs. Current practice already provides their transportation with less invasive sea-fastening systems. Monopiles, on the other hand, can be longer and heavier than WTGs, but the cross section thickness is usually higher. Nowadays they are transported horizontally and in a limited number of elements, because of the allowable space on deck. By transporting them vertically, higher forces would be generated, due to the higher weights, cross section capacity would be increased, due to the thickness, and critical bending moment would appear at lower height, due to a lower CoG (no nacelle on top). Therefore, the proposed sea-fastening system could be adapted to this situation, with potentially lower intermediate support height.
  Higher limits in horizontal displacements could be granted, allowing for more flexible sea-fastening structures and less rigid rotational connection at the bottom; this because no nacelle is placed at the top. It would grant the transportation of 6 elements and even more, if reduction in sea-fastening structure weight were significant. Anyway, boundary conditions of crane operation radii would be the same and even more strict. Indeed, due to the increased element length, maximum hook height could be critical for such a vertical transportation.

Bibliography

[1] L. Beurskens, M. Hekkenberg, and P. Vethman, *Renewable energy projections as published in the national renewable energy action plans of the european member states,* European Research Centre of the Netherlands (ECN) and European Environmental Agency (EEA), Petten (2011).

[2] EWEA, *Wind in power: 2013 european statistics,* A r (2014).

[3] EWEA, *The european offshore industry: key trends and statics 2013,* A report by the European Wind Energy Association (2014).

[4] M. Junginger, A. Faaij, and W. C. Turkenburg, *Cost reduction prospects for offshore wind farms,* Wind engineering **28**, 97 (2004).

[5] R. B. strategy Consultants, *Offshore wind toward 2020: on the pathway to cost competitiveness,* (2013).

[6] Douglas-Westwood, *World offshore wind market forecast 2013-2022,* (2013).

[7] Maritime-International-Inc., *Maritime fenders, technical data,* .

[8] R-T.com, *Railway technical design,* .

[9] U. D. of Energy, *Creating an offshore wind industry in the united states: a strategic work plan for the united states,* Predecisional Draft (2010).

[10] W. Musial, S. Butterfield, B. Ram, *et al.*, *Energy from offshore wind, Offshore technology conference,* , 1888 (2006).

[11] R. Enslow, *China, norway and offshore wind development. a win-win wind relationship?* (2010).

[12] X. Sun, D. Huang, and G. Wu, *The current state of offshore wind energy technology development,* Energy **41**, 298 (2012).

[13] B. Snyder and M. J. Kaiser, *Ecological and economic cost-benefit analysis of offshore wind energy,* Renewable Energy **34**, 1567 (2009).

[14] M. I. Blanco, *The economics of wind energy,* Renewable and Sustainable Energy Reviews **13**, 1372 (2009).

[15] DetNorskeVeritas, *Dnv-rp-c205 environmental conditions and environmental loads,* (2010).

[16] J. Gere and S. Timoshenko, *Mechanics of materials, 1997*.

[17] OasysLtd, *Oasys GSA 8.6 User Manual* (2012).

[18] Maplesoft, *Maple User Manual*, Waterloo Maple Inc. (2014).

[19] T. Ji and B. Ellis, *Effective bracing systems for temporary grandstands,* Structural Engineer **75**, 95 (1997).

[20] T. Ji, *Concepts for designing stiffer structures,* Structural Engineer **81**, 36 (2003).

[21] ANSI, *Aisc - specifications for structural steel buildings - 13th edition,* (2010).

[22] GLGH, *Cost comparison of a single-lift installation to a conventional method,* Client: Seaway Heavy Lifting (2013).

[23] EN, *En 1993-1-1, eurocode 3: Design of steel structures,* (2001).

[24] BS, *En 1337-1, structural bearings - part.1: general design rules,* (2000).

[25] BS, *En 1337-6, structural bearings - part.6: rocker bearings,* (2004).

[26] BS, *En 1337-5, structural bearings - part.5: pot bearings,* (2005).

[27] J. G. Teng and J. M. Rotter, *Buckling of thin metal shells* (CRC Press, 2006).

[28] M. Farshad, M. Farshad, and M. Farshad, *Design and analysis of shell structures* (Kluwer Academic Boston, 1992).

[29] ASTM, *Astmd429-14, standard test methods for rubber property adhesion to rigid substrates,* (2002).

[30] BS, *En 1337-3, structural bearings - part.3: elastomeric bearings,* (2005).

[31] L. Treloar, *Stress-strain data for vulcanised rubber under various types of deformation,* Transactions of the Faraday Society **40**, 59 (1944).

[32] BS, *Bs 7191 gr 355d - 355e,* (1989).

[33] J. W. Hutchinson, *Knockdown factors for buckling of cylindrical and spherical shells subject to reduced biaxial membrane stress,* International Journal of Solids and Structures **47**, 1443 (2010).

[34] E. MORGAN, P. Seide, and V. WEINGARTEN, *Elastic stability of thin-walled cylindrical and conical shells under combined internal pressure and axial compression,* AIAA Journal **3**, 1118 (1965).

[35] ASTM, *Astm d 4014-12, standard specification for plain and steel-laminated elastomeric bearings for bridges,* (2012).

A

A.1. Concept Calculations

Concept 2

Grillage considerations:

- Grillage 16.8x13.65m;
- Most critical situation considered: ALSTOM WTG;
- Load applied at the position of main stays: 6 + 6 point loads;
- Low unity checks suggest possible decrease in plate girder dimensions;
- Reaction forces fulfil the deck capacity.

Calculation procedure

Acting force at 180+α = 240°;

	Reaction Force [kN]	
Case 2	support	bottom
Alstom	6600.0	0.0
Areva	3700.0	0.0
Siemens	3780.0	0.0

Plane x-y			
	α	60	
	Total	*x-dir*	*y-dir*
Ft [kN]	6600.0	3300.0	5715.8

h	50	m	grillage
width	16.80	m	
length	13.65	m	
diagonal	21.65	m	
radius	7.6	m	ring

Actions

Cable group	Crossing assumption			
5	F5 [kN]	2757	1379	2388
6	F6 [kN]	2757	1950	1950
7	F7 [kN]	2757	2388	1379

length	7.6
diagonal	10.8
width	7.6

Reactions

cable	5	6	7
F	2757.24	2757.24	2757.24

F1	2692.71	2668.37	2683.53	
F4	593.07	694.39	633.31	
R2	**2692.71**	**2668.37**	**2683.53**	**8044.605**

beta	1.4	1.3	1.3	rad
	77.6	75.5	76.8	deg

Concept 3

Grillage considerations:

- Grillage 16.8x13.65m;
- Most critical situation considered: ALSTOM WTG;
- Load applied at the position of main stays: 6 + 6 point loads;
- High unity checks suggest increases in plate girder dimensions are necessary;
- Reaction forces fulfil the deck capacity.

Calculation Procedure

Acting force at 180+α = 240°;

	Reaction Force [kN]	
Case 3	support	bottom
Alstom	3100.0	3400.0
Areva	1700.0	2000.0
Siemens	1900.0	1860.0

Plane x-y			
	α	60	
	Total	*x-dir*	*y-dir*
Ft [kN]	3100.0	1550.0	2684.7

h	81.3	m	grillage
width	16.80	m	grillage
length	13.65	m	grillage
diagonal	21.65	m	grillage
radius	7.6	m	ring

Actions

Cable	Crossing assumption			
5	F5 [kN]	1295	648	1122
6	F6 [kN]	1295	916	916
7	F7 [kN]	1295	1122	648

length	7.6
diagonal	10.8
width	7.6

Reactions

cable	5	6	7
F	1295.07	1295.07	1295.07

F1	1283.35	1278.80	1281.64	
F4	173.84	204.66	186.02	
R2	**1283.35**	**1278.80**	**1281.64**	**3843.785**

beta	1.4	1.4	1.4	rad
	82.3	80.9	81.8	deg

Concept 4

Grillage considerations:

- Grillage 14x13.65m;
- Most critical situation considered: ALSTOM WTG;
- Load applied at the position of main stays: 6 + 6 point loads;
- High unity checks suggest possible decrease in plate girder dimensions;
- Reaction forces fulfil the deck capacity.

Calculation Procedure

Acting force at 180+α = 240°;

	Reaction Force [kN]	
Case 6	support	bottom
Alstom	4150.0	2400.0
Areva	2300.0	1400.0
Siemens	2500.0	1300.0

Plane x-y			
	α	60	
	Total	*x-dir*	*y-dir*
Ft [kN]	4150.0	2075.0	3594.0

h	81.3	m	grillage
width	14.00	m	grillage
length	13.65	m	grillage
diagonal	19.55	m	grillage
radius	7.6	m	ring

Actions

cable	Crossing assumption			
5	F5 [kN]	1734	867	1501
6	F6 [kN]	1734	1226	1226
7	F7 [kN]	1734	1501	867

length	6.9
diagonal	9.8
width	6.9

Reactions

cable	5	6	7
F	1733.72	1733.72	1733.72

F1	1718.03	1713.62	1717.79	
F4	232.72	263.22	234.53	
R2	**1718.03**	**1713.62**	**1717.79**	**5149.441**

beta	1.4	1.4	1.4	rad
	82.3	81.3	82.3	deg

Concept 5

Grillage considerations:

- Grillage 16.8x13.65m;
- Most critical situation considered: ALSTOM WTG;
- Load applied at the position of `main steel structures: 6 + 6 point loads;
- High unity checks suggest increases in plate girder dimensions are necessary;
- Reaction forces do not fulfil the deck capacity;
- Optimization both in grillage and steel system is required.

Calculation Procedure

Acting force at 180+α = 240°;

	Reaction Force [kN]	
Case 5a	support	bottom
Alstom	98270.0	91674.0
Areva	53000.0	49300.0
Siemens	69200.0	65400.0

	Reaction Force [kN]	
Case 5b	support	bottom
Alstom	47500.0	41000.0
Areva	26000.0	22000.0
Siemens	33700.0	30000.0

Plane x-y	
α	60

	Total	*x-dir*	*y-dir*
Ft	47500.0	23750.0	41136.2
Mxy	-136290.0	-68145.0	118030.6

h	10	m	grillage
width	16.80	m	
length	8.50	m	
diagonal	18.83	m	

Actions

Steel braces				
5	F5	19843.8	9921.902	17185.2
6	F6	19843.8	14031.69	14031.7
7	F7	19843.8	17185.24	9921.9

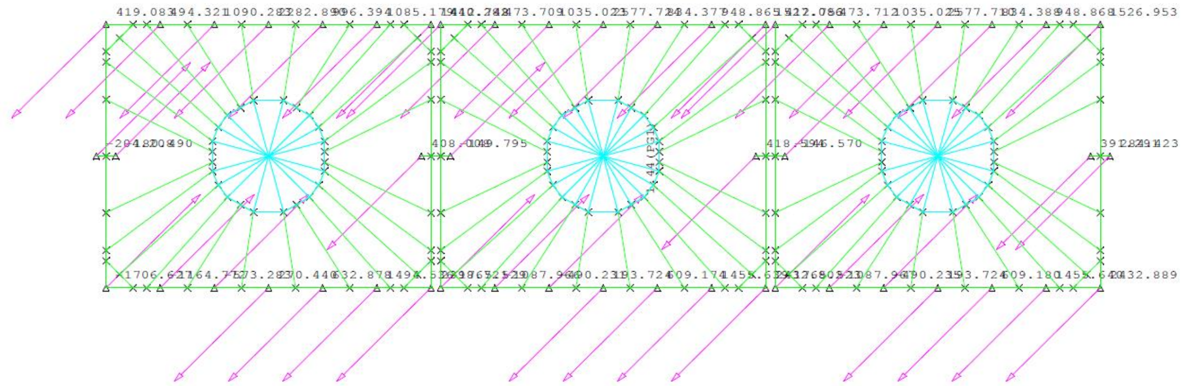
length	6.3
diagonal	9.4
width	6.3

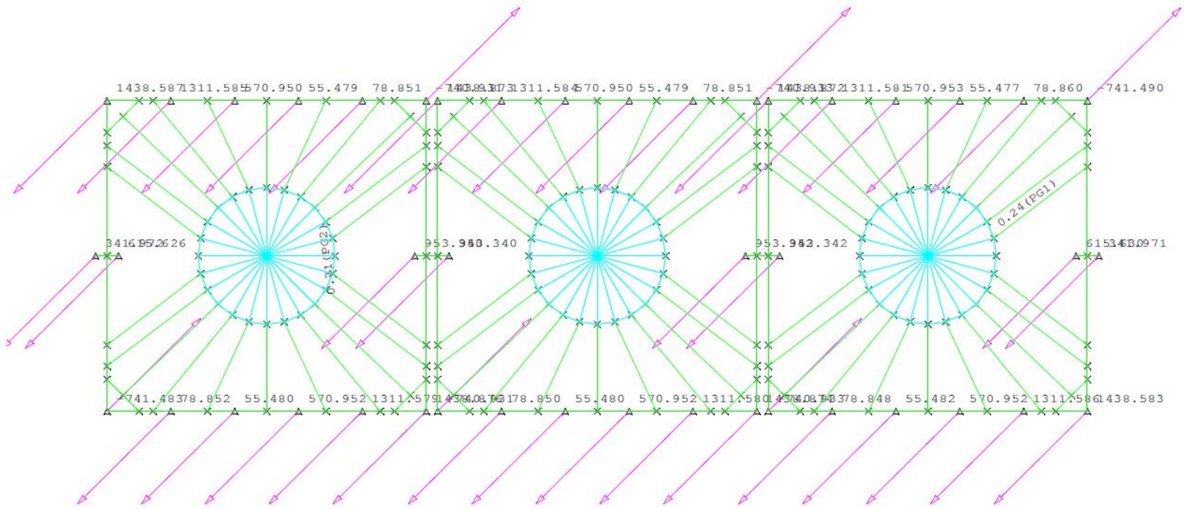
Reactions

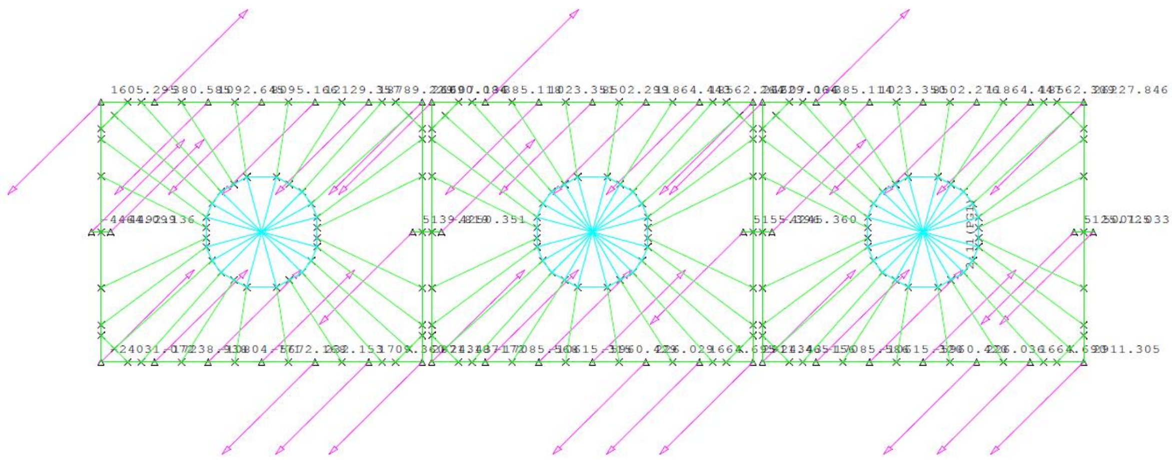
Steel braces	5	6	7
F	19843.80	19843.80	19843.80
F1	14279.35	16770.74	14448.68
F4	13779.57	10607.49	13601.92
R2	**14279.35**	**16770.74**	**14448.68**

beta	0.8	0.8	1.0	rad
	46.0	46.8	57.7	deg

SACS grillage results - Reaction forces, Concepts 3, 4, 5







Concept 6

Grillage considerations:

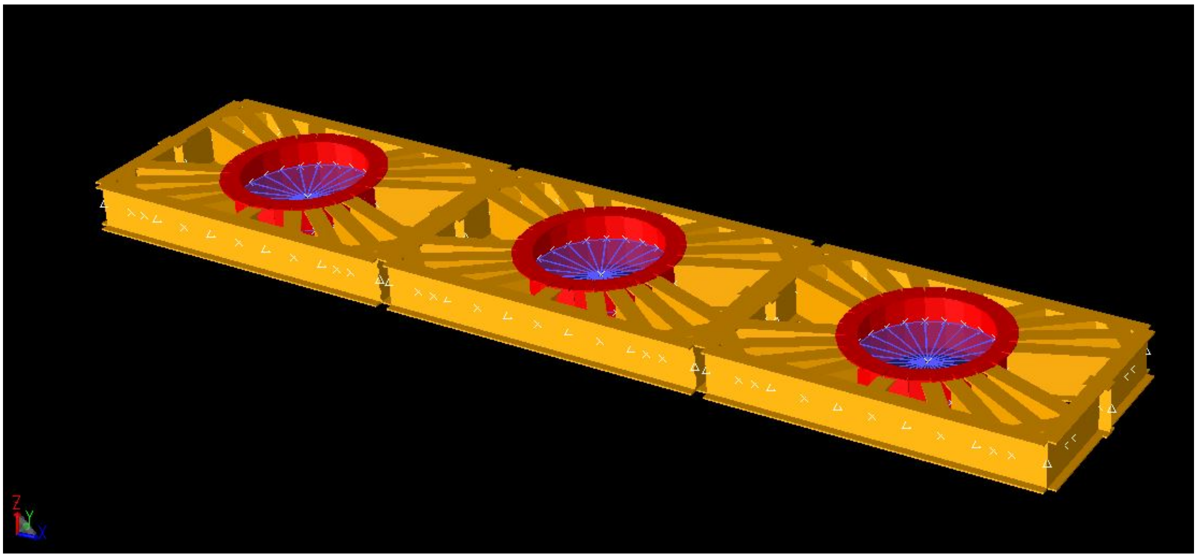
- Grillage 14x8.5m;
- Most critical situation considered: ALSTOM WTG;
- Anti-symmetric loading for the steel braced frame;
- Reaction forces do not fulfil the deck capacity, high vertical concentrations, order of magnitude x10;

Necessity to study the actual accelerations for different positions on the deck.
Loads are close to the limits of the deck and higher in some points; better load distribution is required.
Possibility to enlarge the steel frame foundation by including the grillages themselves.

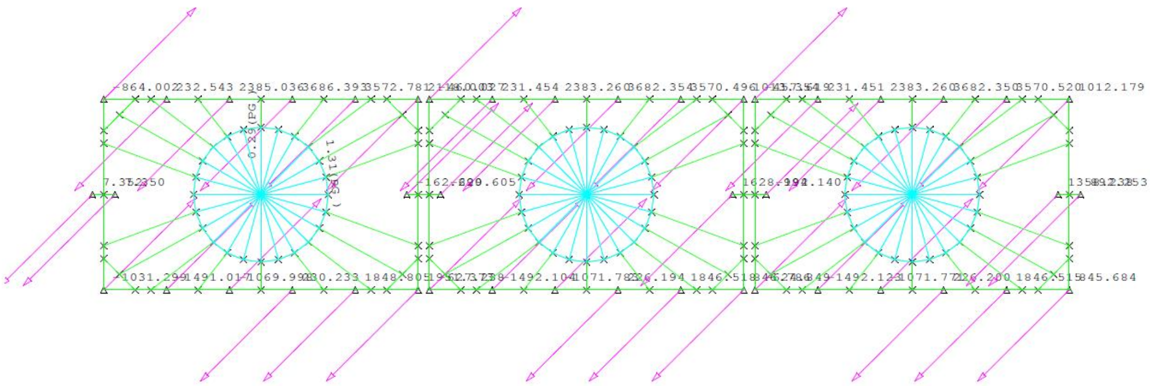
Load definition

	Bending [kNm]		Reaction Force [kN]		Support components	
	bottom	support	support	bottom	*α*	*60*
			(acting force pos)		Fx	Fy
Case 4a		**25 m**				
Alstom	**0**	**173580**	17014	10414	***8507***	***14735***
Areva	0	90280	9116	5416	4558	7895
Siemens	0	142506	12330	8550	6165	10678
Case 4b		**35 m**				
Alstom	**0**	**107580**	11210	4610	***5605***	***9708***
Areva	0	53280	5983	2283	2992	5181
Siemens	0	104706	8267	4487	4134	7159
Case 4c		**30 m**				
Alstom	**0**	**140580**	13630	7029	***6815***	***11804***
Areva	0	71780	7300	3589	3650	6322
Siemens	0	123606	9960	6180	4980	8626

SACS grillage model - Concept 6



SACS grillage results - Reaction forces, Concept 6



A.2. Motion Analysis reference data

Confidential

A.3. Design calculation reference

Wind and Vessel motion resulted actions and combinations – WTG's

ALSTOM				
At CoG	*Heave*			
Dynamic Loads at CoG	no diff	up	down	*Description*
F_x_CoG [kN]	2014.32			
F_y_CoG [kN]	2517.90			
F_z_CoG [kN]	9484.09			
M_x_roll [kNm]	20917.07			
M_y_pitch [kNm]	22683.28			

At Foundation center				
Static Loads				
F_z_static [kN]	-8233.53			
Dynamic vertical load				
F_z_dyn_up [kN]	1250.56			
F_z_dyn_dw [kN]	-1250.56			
Pitch				
M_y_dyn_+_h [kNm]		-140068.07	-145082.36	positive pitch direction
M_y_dyn_-_h [kNm]		112068.77	107054.47	negative pitch direction
Roll				
M_x_dyn_+_h [kNm]		150148.50	150148.50	positive roll direction
M_x_dyn_-_h [kNm]		-150148.50	-150148.50	negative roll direction
z-axis				
M_z_dyn_+_h [kNm]	-5047.95			positive pitch direction
M_z_dyn_-_h [kNm]	5047.95			negative pitch direction
Wind				
M_w_pos_x [kNm]	3933.68			positive roll direction
M_w_pos_y [kNm]	-5843.19			positive pitch direction
M_w_pos_z [kNm]	-66.90			positive wind direction y
M_w_neg_x [kNm]	-3933.68			negative roll direction
M_w_neg_y [kNm]	5843.19			negative pitch direction
M_w_neg_z [kNm]	66.90			negative wind direction y
F_w_pos_x [kN]	119.74			positive wind direction x
F_w_pos_y [kN]	95.04			positive wind direction y
F_w_neg_x [kN]	-119.74			negative wind direction x
F_w_neg_y [kN]	-95.04			negative wind direction y

Combinations		
Case	**1**	
	p/n	axis
Heave	p	
Pitch	p	
Roll	p	
Wind	p	x

Fx [kN]	2134.06
Fy [kN]	2517.90
Fz [kN]	-6982.98
Mx [kNm]	150148.50
My [kNm]	117911.96
Mz [kNm]	5047.95

	Mx [kNm]	150148.498
	My [kNm]	117911.955
Points	*Fz [kN]*	-6982.98
1	*Fz [kN]*	-12512.4
2	*Fz [kN]*	-9826.0
3	*Fz [kN]*	12512.4
4	*Fz [kN]*	9826.0

Case	**2**	
	p/n	axis
Heave	n	

Fx [kN]	2134.06
Fy [kN]	2517.90
Fz [kN]	-9484.09

	Mx [kNm]	150148.498
	My [kNm]	112897.658
Points	*Fz [kN]*	-9484.09
1	*Fz [kN]*	-12512.4

Pitch	p	
Roll	p	
Wind	p	x

Mx [kNm]	150148.50
My [kNm]	112897.66
Mz [kNm]	5047.95

2	*Fz [kN]*	-9408.1
3	*Fz [kN]*	12512.4
4	*Fz [kN]*	9408.1

Case	**3**	
	p/n	axis
Heave	p	
Pitch	n	
Roll	p	
Wind	n	x

Fx [kN]	-2134.06
Fy [kN]	2517.90
Fz [kN]	-6982.98
Mx [kNm]	150148.50
My [kNm]	-145911.25
Mz [kNm]	5047.95

	Mx [kNm]	150148.498
	My [kNm]	-145911.25
Points	*Fz [kN]*	-6982.98
1	*Fz [kN]*	-12512.4
2	*Fz [kN]*	12159.3
3	*Fz [kN]*	12512.4
4	*Fz [kN]*	-12159.3

Case	**4**	
	p/n	axis
Heave	n	
Pitch	n	
Roll	p	
Wind	n	x

Fx [kN]	-2134.06
Fy [kN]	2517.90
Fz [kN]	-9484.09
Mx [kNm]	150148.50
My [kNm]	-150925.55
Mz [kNm]	5047.95

	Mx [kNm]	150148.498
	My [kNm]	-150925.55
Points	*Fz [kN]*	-9484.09
1	*Fz [kN]*	-12512.4
2	*Fz [kN]*	12577.1
3	*Fz [kN]*	12512.4
4	*Fz [kN]*	-12577.1

Case	**5**	
	p/n	axis
Heave	p	
Pitch	p	
Roll	p	
Wind	p	y

Fx [kN]	2014.32
Fy [kN]	2612.94
Fz [kN]	-6982.98
Mx [kNm]	154082.18
My [kNm]	112068.77
Mz [kNm]	5114.85

	Mx [kNm]	154082.183
	My [kNm]	112068.766
Points	*Fz [kN]*	-6982.98
1	*Fz [kN]*	-12840.2
2	*Fz [kN]*	-9339.1
3	*Fz [kN]*	12840.2
4	*Fz [kN]*	9339.1

Case	**6**	
	p/n	axis
Heave	n	
Pitch	p	
Roll	p	
Wind	p	y

Fx [kN]	2014.32
Fy [kN]	2612.94
Fz [kN]	-9484.09
Mx [kNm]	154082.18
My [kNm]	107054.47
Mz [kNm]	5114.85

	Mx [kNm]	154082.183
	My [kNm]	107054.468
Points	*Fz [kN]*	-9484.09
1	*Fz [kN]*	-12840.2
2	*Fz [kN]*	-8921.2
3	*Fz [kN]*	12840.2
4	*Fz [kN]*	8921.2

Case	**7**	
	p/n	axis
Heave	p	
Pitch	n	
Roll	p	
Wind	p	y

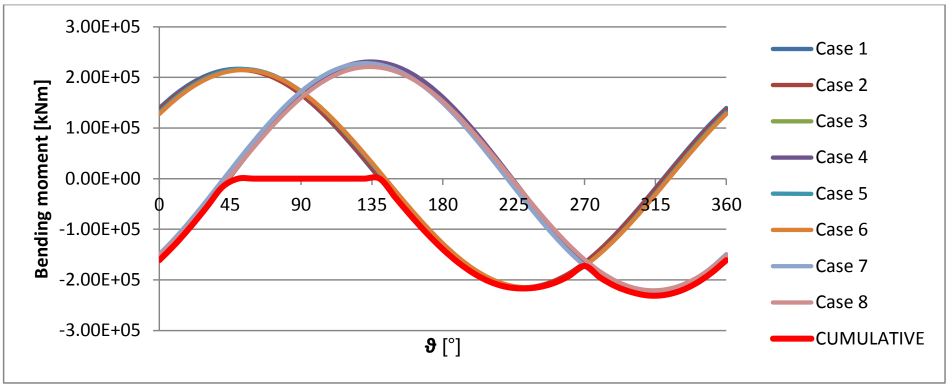
Fx [kN]	-2014.32
Fy [kN]	2612.94
Fz [kN]	-6982.98
Mx [kNm]	154082.18
My [kNm]	-140068.07
Mz [kNm]	5114.85

	Mx [kNm]	154082.183
	My [kNm]	-140068.07
Points	*Fz [kN]*	-6982.98
1	*Fz [kN]*	-12840.2
2	*Fz [kN]*	11672.3
3	*Fz [kN]*	12840.2
4	*Fz [kN]*	-11672.3

Case	**8**	
	p/n	axis
Heave	n	
Pitch	n	
Roll	n	
Wind	n	y

Fx [kN]	-2014.32
Fy [kN]	-2612.94
Fz [kN]	-9484.09
Mx [kNm]	146214.81
My [kNm]	-145082.36
Mz [kNm]	-5114.85

	Mx [kNm]	146214.813
	My [kNm]	-145082.36
Points	*Fz [kN]*	-9484.09
1	*Fz [kN]*	-12184.6
2	*Fz [kN]*	12090.2
3	*Fz [kN]*	12184.6
4	*Fz [kN]*	-12090.2



θ	*0*	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*
Cumulative	**-150926**	**-122560**	**-90470**	**-55631**	**-19102**	**0**	**0**	**0**	**0**	**0**

100	*110*	*120*	*130*	*140*	*150*	*160*	*170*	*180*	*190*	*200*
0	**0**	**0**	**0**	**0**	**-27041**	**-59447**	**-90048**	**-117912**	**-142194**	**-162155**

210	*220*	*230*	*240*	*250*	*260*	*270*	*280*	*290*
-177189	**-186839**	**-190813**	**-189473**	**-183120**	**-171202**	**-154082**	**-176064**	**-192713**

300	*310*	*320*	*330*	*340*	*350*	*360*
-205495	**-212033**	**-212129**	**-205780**	**-193177**	**-174706**	**-150926**

	kNm	*ϑ*
MAX	-212129.274	320

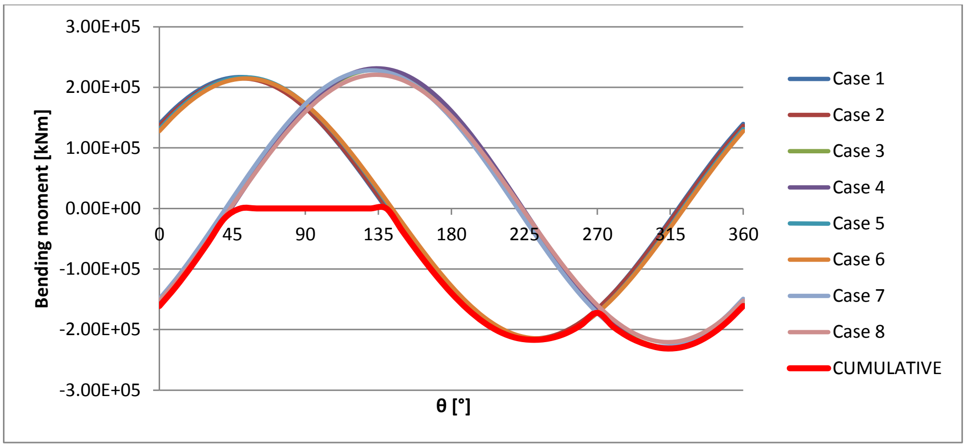
	Design Situation	
at CoG	Mxy [kNm]	**212129.3**
	Fxy [kN]	**4133.1**

AREVA				
At CoG	*Heave*			
Dynamic Loads at CoG	no diff	up	down	*Description*
F_x_CoG [kN]	1750.19			
F_y_CoG [kN]	2187.74			
F_z_CoG [kN]	8240.47			
M_x_roll [kNm]	18503.60			
M_y_pitch [kNm]	19828.54			

At Foundation center				
Static Loads				
F_z_static [kN]	-7153.89			
Dynamic vertical load				
F_z_dyn_up [kN]	1086.58			
F_z_dyn_dw [kN]	-1086.58			
Pitch				
M_y_dyn_+_h [kNm]		-111930.01	-113930.77	positive pitch direction
M_y_dyn_-_h [kNm]		100757.97	98757.21	negative pitch direction
Roll				
M_x_dyn_+_h [kNm]		126647.92	126647.92	positive roll direction
M_x_dyn_-_h [kNm]		-126647.92	-126647.92	negative roll direction
z-axis				
M_z_dyn_+_h [kNm]	-2014.19			positive pitch direction
M_z_dyn_-_h [kNm]	2014.19			negative pitch direction
Wind				
M_w_pos_x [kNm]	4688.45			positive roll direction
M_w_pos_y [kNm]	-5908.52			positive pitch direction
M_w_pos_z [kNm]	-95.49			positive wind direction y
M_w_neg_x [kNm]	-4688.45			negative roll direction
M_w_neg_y [kNm]	5908.52			negative pitch direction
M_w_neg_z [kNm]	95.49			negative wind direction y
F_w_pos_x [kN]	115.73			positive wind direction x
F_w_pos_y [kN]	112.56			positive wind direction y
F_w_neg_x [kN]	-115.73			negative wind direction x
F_w_neg_y [kN]	-112.56			negative wind direction y

Combinations						*Mx [kNm]*	126647.921
Case	**1**		*Fx [kN]*	1865.92		*My [kNm]*	106666.495
	p/n	axis	*Fy [kN]*	2187.74	*Points*	*Fz [kN]*	-6067.32
Heave	p		*Fz [kN]*	-6067.32	1	*Fz [kN]*	-10554.0
Pitch	p		*Mx [kNm]*	126647.92	2	*Fz [kN]*	-8888.9
Roll	p		*My [kNm]*	106666.49	3	*Fz [kN]*	10554.0
Wind	p	x	*Mz [kNm]*	2014.19	4	*Fz [kN]*	8888.9
						Mx [kNm]	126647.921
Case	**2**		*Fx [kN]*	1865.92		*My [kNm]*	104665.733
	p/n	axis	*Fy [kN]*	2187.74	*Points*	*Fz [kN]*	-8240.47
Heave	n		*Fz [kN]*	-8240.47	1	*Fz [kN]*	-10554.0
Pitch	p		*Mx [kNm]*	126647.92	2	*Fz [kN]*	-8722.1
Roll	p		*My [kNm]*	104665.73	3	*Fz [kN]*	10554.0

Wind	p	x	*Mz [kNm]*	2014.19	4	*Fz [kN]*	8722.1
						Mx [kNm]	126647.921
Case	**3**		*Fx [kN]*	-1865.92		*My [kNm]*	-117838.53
	p/n	axis	*Fy [kN]*	2187.74	*Points*	*Fz [kN]*	-6067.32
Heave	p		*Fz [kN]*	-6067.32	1	*Fz [kN]*	-10554.0
Pitch	n		*Mx [kNm]*	126647.92	2	*Fz [kN]*	9819.9
Roll	p		*My [kNm]*	-117838.53	3	*Fz [kN]*	10554.0
Wind	n	x	*Mz [kNm]*	2014.19	4	*Fz [kN]*	-9819.9
						Mx [kNm]	126647.921
Case	**4**		*Fx [kN]*	-1865.92		*My [kNm]*	-119839.3
	p/n	axis	*Fy [kN]*	2187.74	*Points*	*Fz [kN]*	-8240.47
Heave	n		*Fz [kN]*	-8240.47	1	*Fz [kN]*	-10554.0
Pitch	n		*Mx [kNm]*	126647.92	2	*Fz [kN]*	9986.6
Roll	p		*My [kNm]*	-119839.30	3	*Fz [kN]*	10554.0
Wind	n	x	*Mz [kNm]*	2014.19	4	*Fz [kN]*	-9986.6
						Mx [kNm]	131336.367
Case	**5**		*Fx [kN]*	1750.19		*My [kNm]*	100757.972
	p/n	axis	*Fy [kN]*	2300.30	*Points*	*Fz [kN]*	-6067.32
Heave	p		*Fz [kN]*	-6067.32	1	*Fz [kN]*	-10944.7
Pitch	p		*Mx [kNm]*	131336.37	2	*Fz [kN]*	-8396.5
Roll	p		*My [kNm]*	100757.97	3	*Fz [kN]*	10944.7
Wind	p	y	*Mz [kNm]*	2109.68	4	*Fz [kN]*	8396.5
						Mx [kNm]	131336.367
Case	**6**		*Fx [kN]*	1750.19		*My [kNm]*	98757.21
	p/n	axis	*Fy [kN]*	2300.30	*Points*	*Fz [kN]*	-8240.47
Heave	n		*Fz [kN]*	-8240.47	1	*Fz [kN]*	-10944.7
Pitch	p		*Mx [kNm]*	131336.37	2	*Fz [kN]*	-8229.8
Roll	p		*My [kNm]*	98757.21	3	*Fz [kN]*	10944.7
Wind	p	y	*Mz [kNm]*	2109.68	4	*Fz [kN]*	8229.8
						Mx [kNm]	131336.367
Case	**7**		*Fx [kN]*	-1750.19		*My [kNm]*	-111930.01
	p/n	axis	*Fy [kN]*	2300.30	*Points*	*Fz [kN]*	-6067.32
Heave	p		*Fz [kN]*	-6067.32	1	*Fz [kN]*	-10944.7
Pitch	n		*Mx [kNm]*	131336.37	2	*Fz [kN]*	9327.5
Roll	p		*My [kNm]*	-111930.01	3	*Fz [kN]*	10944.7
Wind	p	y	*Mz [kNm]*	2109.68	4	*Fz [kN]*	-9327.5
						Mx [kNm]	121959.474
Case	**8**		*Fx [kN]*	-1750.19		*My [kNm]*	-113930.77
	p/n	axis	*Fy [kN]*	-2300.30	*Points*	*Fz [kN]*	-8240.47
Heave	n		*Fz [kN]*	-8240.47	1	*Fz [kN]*	-10163.3
Pitch	n		*Mx [kNm]*	121959.47	2	*Fz [kN]*	9494.2
Roll	n		*My [kNm]*	-113930.77	3	*Fz [kN]*	10163.3
Wind	n	y	*Mz [kNm]*	-2109.68	4	*Fz [kN]*	-9494.2



θ	0	10	20	30	40	50	60	70	80	90
Cumulative	**-119839**	**-96026**	**-69296**	**-40460**	**-10395**	**0**	**0**	**0**	**0**	**0**

100	110	120	130	140	150	160	170	180	190	200
0	**0**	**0**	**0**	**-304**	**-29052**	**-56918**	**-83054**	**-106666**	**-127038**	**-143550**

210	220	230	240	250	260	270	280	290
-155700	**-163119**	**-165582**	**-164120**	**-157877**	**-146838**	**-131336**	**-148778**	**-161698**

300	310	320	330	340	350	360
-169706	**-174049**	**-173210**	**-167108**	**-155928**	**-140011**	**-119839**

	kNm	*ϑ*
MAX	-174049.15	310

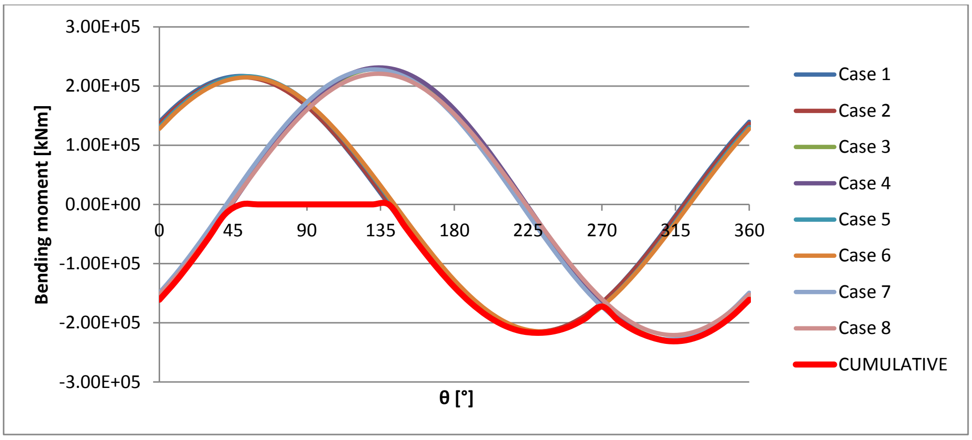
	Design Situation	
	Mxy [kNm]	**174049.2**
at CoG	Fxy [kN]	**3521.0**

SIEMENS				
At CoG	*Heave*			
Dynamic Loads at CoG	no diff	up	down	*Description*
F_x_CoG [kN]	1780.42			
F_y_CoG [kN]	2225.52			
F_z_CoG [kN]	8382.79			
M_x_roll [kNm]	26507.71			
M_y_pitch [kNm]	28445.58			

At Foundation center				
Static Loads				
F_z_static [kN]	-7277.45			
Dynamic vertical load				
F_z_dyn_up [kN]	1105.34			
F_z_dyn_dw [kN]	-1105.34			
Pitch				
M_y_dyn_+_h [kNm]		-149179.42	-152444.74	positive pitch direction
M_y_dyn_-_h [kNm]		130946.26	127680.94	negative pitch direction
Roll				
M_x_dyn_+_h [kNm]		166029.28	166029.28	positive roll direction
M_x_dyn_-_h [kNm]		-166029.28	-166029.28	negative roll direction
z-axis				
M_z_dyn_+_h [kNm]	-3287.23			positive pitch direction
M_z_dyn_-_h [kNm]	3287.23			negative pitch direction
Wind				
M_w_pos_x [kNm]	6428.29			positive roll direction
M_w_pos_y [kNm]	-8652.25			positive pitch direction
M_w_pos_z [kNm]	-147.21			positive wind direction y
M_w_neg_x [kNm]	-6428.29			negative roll direction
M_w_neg_y [kNm]	8652.25			negative pitch direction
M_w_neg_z [kNm]	147.21			negative wind direction y
F_w_pos_x [kN]	147.28			positive wind direction x
F_w_pos_y [kN]	138.18			positive wind direction y
F_w_neg_x [kN]	-147.28			negative wind direction x
F_w_neg_y [kN]	-138.18			negative wind direction y

Combinations						*Mx [kNm]*	166029.281
Case	**1**		*Fx [kN]*	1927.70		*My [kNm]*	139598.51
	p/n	axis	*Fy [kN]*	2225.52	*Points*	*Fz [kN]*	-6172.11
Heave	p		*Fz [kN]*	-6172.11	1	*Fz [kN]*	-12771.5
Pitch	p		*Mx [kNm]*	166029.28	2	*Fz [kN]*	-10738.3
Roll	p		*My [kNm]*	139598.51	3	*Fz [kN]*	12771.5
Wind	p	x	*Mz [kNm]*	3287.23	4	*Fz [kN]*	10738.3
						Mx [kNm]	166029.281
Case	**2**		*Fx [kN]*	1927.70		*My [kNm]*	136333.195
	p/n	axis	*Fy [kN]*	2225.52	*Points*	*Fz [kN]*	-8382.79
Heave	n		*Fz [kN]*	-8382.79	1	*Fz [kN]*	-12771.5
Pitch	p		*Mx [kNm]*	166029.28	2	*Fz [kN]*	-10487.2
Roll	p		*My [kNm]*	136333.20	3	*Fz [kN]*	12771.5

Wind	p	x	*Mz [kNm]*	3287.23	4	*Fz [kN]*	10487.2
						Mx [kNm]	166029.281
Case	**3**		*Fx [kN]*	-1927.70		*My [kNm]*	-157831.67
	p/n	axis	*Fy [kN]*	2225.52	Points	*Fz [kN]*	-6172.11
Heave	p		*Fz [kN]*	-6172.11	1	*Fz [kN]*	-12771.5
Pitch	n		*Mx [kNm]*	166029.28	2	*Fz [kN]*	12140.9
Roll	p		*My [kNm]*	-157831.67	3	*Fz [kN]*	12771.5
Wind	n	x	*Mz [kNm]*	3287.23	4	*Fz [kN]*	-12140.9
						Mx [kNm]	166029.281
Case	**4**		*Fx [kN]*	-1927.70		*My [kNm]*	-161096.99
	p/n	axis	*Fy [kN]*	2225.52	Points	*Fz [kN]*	-8382.79
Heave	n		*Fz [kN]*	-8382.79	1	*Fz [kN]*	-12771.5
Pitch	n		*Mx [kNm]*	166029.28	2	*Fz [kN]*	12392.1
Roll	p		*My [kNm]*	-161096.99	3	*Fz [kN]*	12771.5
Wind	n	x	*Mz [kNm]*	3287.23	4	*Fz [kN]*	-12392.1
						Mx [kNm]	172457.576
Case	**5**		*Fx [kN]*	1780.42		*My [kNm]*	130946.258
	p/n	axis	*Fy [kN]*	2363.70	Points	*Fz [kN]*	-6172.11
Heave	p		*Fz [kN]*	-6172.11	1	*Fz [kN]*	-13266.0
Pitch	p		*Mx [kNm]*	172457.58	2	*Fz [kN]*	-10072.8
Roll	p		*My [kNm]*	130946.26	3	*Fz [kN]*	13266.0
Wind	p	y	*Mz [kNm]*	3434.44	4	*Fz [kN]*	10072.8
						Mx [kNm]	172457.576
Case	**6**		*Fx [kN]*	1780.42		*My [kNm]*	127680.944
	p/n	axis	*Fy [kN]*	2363.70	Points	*Fz [kN]*	-8382.79
Heave	n		*Fz [kN]*	-8382.79	1	*Fz [kN]*	-13266.0
Pitch	p		*Mx [kNm]*	172457.58	2	*Fz [kN]*	-9821.6
Roll	p		*My [kNm]*	127680.94	3	*Fz [kN]*	13266.0
Wind	p	y	*Mz [kNm]*	3434.44	4	*Fz [kN]*	9821.6
						Mx [kNm]	172457.576
Case	**7**		*Fx [kN]*	-1780.42		*My [kNm]*	-149179.42
	p/n	axis	*Fy [kN]*	2363.70	Points	*Fz [kN]*	-6172.11
Heave	p		*Fz [kN]*	-6172.11	1	*Fz [kN]*	-13266.0
Pitch	n		*Mx [kNm]*	172457.58	2	*Fz [kN]*	11475.3
Roll	p		*My [kNm]*	-149179.42	3	*Fz [kN]*	13266.0
Wind	p	y	*Mz [kNm]*	3434.44	4	*Fz [kN]*	-11475.3
						Mx [kNm]	159600.986
Case	**8**		*Fx [kN]*	-1780.42		*My [kNm]*	-152444.74
	p/n	axis	*Fy [kN]*	-2363.70	Points	*Fz [kN]*	-8382.79
Heave	n		*Fz [kN]*	-8382.79	1	*Fz [kN]*	-12277.0
Pitch	n		*Mx [kNm]*	159600.99	2	*Fz [kN]*	11726.5
Roll	n		*My [kNm]*	-152444.74	3	*Fz [kN]*	12277.0
Wind	n	y	*Mz [kNm]*	-3434.44	4	*Fz [kN]*	-11726.5



θ	0	10	20	30	40	50	60	70	80	90
Cumulative	**-161097**	**-129819**	**-94596**	**-56499**	**-16686**	**0**	**0**	**0**	**0**	**0**

100	110	120	130	140	150	160	170	180	190	200
0	**0**	**0**	**0**	**-217**	**-37881**	**-74394**	**-108647**	**-139599**	**-166308**	**-187965**

210	220	230	240	250	260	270	280	290
-203910	**-213660**	**-216918**	**-214826**	**-206843**	**-192576**	**-172458**	**-195742**	**-213079**

300	310	320	330	340	350	360
-224334	**-230737**	**-230129**	**-222529**	**-208167**	**-187480**	**-161097**

	kNm	*ϑ*
MAX	-230736.955	310

	Design Situation	
at CoG	Mxy [kNm]	**230737.0**
	Fxy [kN]	**3680.5**

Wind and Vessel motion resulted actions and combinations – External structures

EXTERNAL STRCTURES										
	grillage			vertical 2			vertical 1-3			
At CoG	*Heave*			*Heave*			*Heave*			
Dynamic Loads at CoG	no diff	up	down							*Description*
F_x_CoG [kN]	2880.0			1680.0			840.0			
F_y_CoG [kN]	3600.0			2100.0			1050.0			
F_z_CoG [kN]	13560.0			7910.0			3955.0			
M_x_roll [kNm]	8109.4			1699.9			791.0			
M_y_pitch [kNm]	1920.6			2516.2			1258.1			
At Foundation center										
Static Loads										
F_z_static [kN]	-11772.0			-6867.0			-3433.5			
Dynamic vertical load										
F_z_dyn_up [kN]	1788.0			1043.0			521.5			
F_z_dyn_dw [kN]	-1788.0			-1043.0			-521.5			
Pitch										
M_y_dyn_+_h [kNm]		-5520.6	-5520.6		-31916.2	-31916.2		-15958.1	-15958.1	positive pitch direction
M_y_dyn_-_h [kNm]		5520.6	5520.6		31916.2	31916.2		15958.1	15958.1	negative pitch direction
Roll										
M_x_dyn_+_h [kNm]		12609.4	12609.4		38449.9	38449.9		19166.0	19166.0	positive roll direction
M_x_dyn_-_h [kNm]		-12609.4	-12609.4		-38449.9	-38449.9		-19166.0	-19166.0	negative roll direction
z-axis										
M_z_dyn_+_h [kNm]	0.0									positive pitch direction
M_z_dyn_-_h [kNm]	0.0									negative pitch direction
Wind										
M_w_pos_x [kNm]	36.7			1746.9			1746.9			positive roll direction
M_w_pos_y [kNm]	78.0			425.1			476.8			positive pitch direction
M_w_pos_z [kNm]	0.0			2.0			1.0			positive wind direction y
M_w_neg_x [kNm]	-36.7			-1746.9			-1746.9			negative roll direction
M_w_neg_y [kNm]	-78.0			-425.1			-476.8			negative pitch direction
M_w_neg_z [kNm]	0.0			2.0			1.0			negative wind direction y
F_w_pos_x [kN]	12.5			18.9			21.2			positive wind direction x
F_w_pos_y [kN]	5.9			77.6			77.6			positive wind direction y
F_w_neg_x [kN]	-12.5			-18.9			-21.2			negative wind direction x
F_w_neg_y [kN]	-5.9			-77.6			-77.6			negative wind direction y

Combinations		
Case	**1**	
	p/n	axis

	grl	**v2**	**v1-v3**
Fx [kN]	2892	1699	861
Fy [kN]	3600	2100	1050

	grl	**v2**	**v1-v3**
Mx [kNm]	12609	38450	19166
My [kNm]	5443	31491	15481

Heave	p	
Pitch	p	
Roll	p	
Wind	p	x

Fz [kN]	-9984	-5824	-2912
Mx [kNm]	12609	38450	19166
My [kNm]	5443	31491	15481
Mz [kNm]	0	0	0

Fz [kN]	-9984	-5824	-2912

Case	**2**	
	p/n	axis
Heave	n	
Pitch	p	
Roll	p	
Wind	p	x

Fx [kN]	2892	1699	861
Fy [kN]	3600	2100	1050
Fz [kN]	-13560	-7910	-3955
Mx [kNm]	12609	38450	19166
My [kNm]	5443	31491	15481
Mz [kNm]	0	0	0

Mx [kNm]	12609	38450	19166
My [kNm]	5443	31491	15481
Fz [kN]	-13560	-7910	-3955

Case	**3**	
	p/n	axis
Heave	p	
Pitch	n	
Roll	p	
Wind	n	x

Fx [kN]	-2892	-1699	-861
Fy [kN]	3600	2100	1050
Fz [kN]	-9984	-5824	-2912
Mx [kNm]	12609	38450	19166
My [kNm]	-5443	-31491	-15481
Mz [kNm]	0	0	0

Mx [kNm]	12609	38450	19166
My [kNm]	-5443	-31491	-15481
Fz [kN]	-9984	-5824	-2912

Case	**4**	
	p/n	axis
Heave	n	
Pitch	n	
Roll	p	
Wind	n	x

Fx [kN]	-2892	-1699	-861
Fy [kN]	3600	2100	1050
Fz [kN]	-13560	-7910	-3955
Mx [kNm]	12609	38450	19166
My [kNm]	-5443	-31491	-15481
Mz [kNm]	0	0	0

Mx [kNm]	12609	38450	19166
My [kNm]	-5443	-31491	-15481
Fz [kN]	-13560	-7910	-3955

Case	**5**	
	p/n	axis
Heave	p	
Pitch	p	
Roll	p	
Wind	p	y

Fx [kN]	2880	1680	840
Fy [kN]	3606	2178	1128
Fz [kN]	-9984	-5824	-2912
Mx [kNm]	12646	40197	20913
My [kNm]	5521	31916	15958
Mz [kNm]	0	0	0

Mx [kNm]	12646	40197	20913
My [kNm]	5521	31916	15958
Fz [kN]	-9984	-5824	-2912

Case	**6**	
	p/n	axis
Heave	n	
Pitch	p	
Roll	p	
Wind	p	y

Fx [kN]	2880	1680	840
Fy [kN]	3606	2178	1128
Fz [kN]	-13560	-7910	-3955
Mx [kNm]	12646	40197	20913
My [kNm]	5521	31916	15958
Mz [kNm]	0	0	0

Mx [kNm]	12646	40197	20913
My [kNm]	5521	31916	15958
Fz [kN]	-13560	-7910	-3955

Case	**7**	
	p/n	axis
Heave	p	
Pitch	n	
Roll	p	
Wind	p	y

Fx [kN]	-2880	-1680	-840
Fy [kN]	3606	2178	1128
Fz [kN]	-9984	-5824	-2912
Mx [kNm]	12646	40197	20913
My [kNm]	-5521	-31916	-15958
Mz [kNm]	0	0	0

Mx [kNm]	12646	40197	20913
My [kNm]	-5521	-31916	-15958
Fz [kN]	-9984	-5824	-2912

Case	**8**

Fx [kN]	-2880	-1680	-840

Mx [kNm]	12573	36703	17419

	p/n	axis
Heave	n	
Pitch	n	
Roll	n	
Wind	n	y

Fy [kN]	-3606	-2178	-1128
Fz [kN]	-13560	-7910	-3955
Mx [kNm]	12573	36703	17419
My [kNm]	-5521	-31916	-15958
Mz [kNm]	0	0	0

My [kNm]	-5521	-31916	-15958
Fz [kN]	-13560	-7910	-3955

θ		0	10	20	30	40	50	60	70	80	90	100
Cumulative	grl	**-5521**	**-3254**	**-888**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	v2	**-31916**	**-25058**	**-17438**	**-9289**	**-857**	**0**	**0**	**0**	**0**	**0**	**0**
	v1-v3	**-24372**	**-19591**	**-21188**	**-24017**	**-26074**	**-23255**	**-21340**	**-22301**	**-24583**	**-22174**	**-8919**

110	120	130	140	150	160	170	180	190	200	210	220	230
0	**0**	**0**	**0**	**0**	**-862**	**-3241**	**-5521**	**-7633**	**-9513**	**-11104**	**-12358**	**-13236**
0	**0**	**0**	**0**	**-8047**	**-16441**	**-24451**	**-31916**	**-38411**	**-43740**	**-47739**	**-50287**	**-51308**
-19832	**-24057**	**-22488**	**-10245**	**-26263**	**-25396**	**-18695**	**-26125**	**-23356**	**-23728**	**-22490**	**-25944**	**-24250**

240	250	260	270	280	290	300	310	320	330	340	350	360
-13712	**-13772**	**-13413**	**-12646**	**-13413**	**-13772**	**-13712**	**-13236**	**-12358**	**-11104**	**-9513**	**-7633**	**-5521**
-50770	**-48689**	**-45128**	**-40197**	**-45128**	**-48689**	**-50770**	**-51308**	**-50287**	**-47739**	**-43740**	**-38411**	**-31916**
0	**-21362**	**-21630**	**-26136**	**-24390**	**-23061**	**-24645**	**-843**	**-23612**	**-23786**	**-23680**	**-24707**	**-24372**

	grillage		vertical 2		vertical 1-3	
	kNm	*ϑ*	*kNm*	*ϑ*	*kNm*	*ϑ*
MAX	-13771.644	250	-51307.895	230	-26263.1	150

		Design Situation		
		grl	**v2**	**v1-v3**
	Mxy [kNm]	**13771.6**	**51307.9**	**26263.1**
at CoG	Fxy [kN]	**11017.3**	**2931.9**	**1500.7**

A.4. Tower modelling

Iy [mm^3]	1.145E+12
l [m]	51.33
ltot [m]	73.27
Fxy [kN]	4133.1
h [m]	22.0
Mmax [kNm]	121302
Umax [m]	1.2

Force	*orientation*	320			
	X dir	*0.643*	**Fx**	***2657***	kN
	Y dir	*0.766*	**Fy**	***3166***	kN

FIXED

Limit Mbott=Mmax

h [m]	**30.0**	**29.8**	**29.6**	**29.4**	**29.2**	**29.0**	**28.8**	**28.6**	**28.4**
Fsupp [kN]	3028.25	3048.58	3069.18	3090.05	3111.22	3132.68	3154.43	3176.49	3198.86
usupp [mm]	154.70	151.63	148.59	145.60	142.65	139.74	136.87	134.04	131.24
ks [N/mm]	1.96E+04	2.01E+04	2.07E+04	2.12E+04	2.18E+04	2.24E+04	2.30E+04	2.37E+04	2.44E+04

28.2	**28.0**	**27.8**	**27.6**	**27.4**	**27.2**	**27.0**	**26.8**	**26.6**
3221.55	3244.56	3267.90	3291.58	3315.61	3339.99	3364.73	3389.84	3415.32
128.49	125.78	123.10	120.46	117.86	115.30	112.78	110.29	107.84
2.51E+04	2.58E+04	2.65E+04	2.73E+04	2.81E+04	2.90E+04	2.98E+04	3.07E+04	3.17E+04

26.4	**26.2**	**26.0**	**25.8**	**25.6**	**25.4**	**25.2**	**25.0**	**24.8**
3441.20	3467.47	3494.14	3521.22	3548.73	3576.68	3605.06	3633.90	3663.21
105.42	103.05	100.70	98.40	96.13	93.89	91.69	89.53	87.39
3.26E+04	3.36E+04	3.47E+04	3.58E+04	3.69E+04	3.81E+04	3.93E+04	4.06E+04	4.19E+04

24.6	**24.4**	**24.2**	**24.0**	**23.8**	**23.6**	**23.4**	**23.2**	**23.0**
3692.99	3723.26	3754.03	3785.32	3817.13	3849.47	3882.38	3915.84	3949.90
85.30	83.23	81.20	79.21	77.24	75.31	73.41	71.55	69.71
4.33E+04	4.47E+04	4.62E+04	4.78E+04	4.94E+04	5.11E+04	5.29E+04	5.47E+04	5.67E+04

22.8	**22.6**	**22.4**	**22.2**	**22.0**	**21.8**	**21.6**	**...**	**0.0**
3984.54	4019.81	4055.70	4092.23	4129.44	0.00	0.00	0.00	0.00
67.91	66.14	64.40	62.69	61.01	0.00	0.00	0.00	0.00
5.87E+04	6.08E+04	6.30E+04	6.53E+04	6.77E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00

HINGED

Limit utop=1.2 m

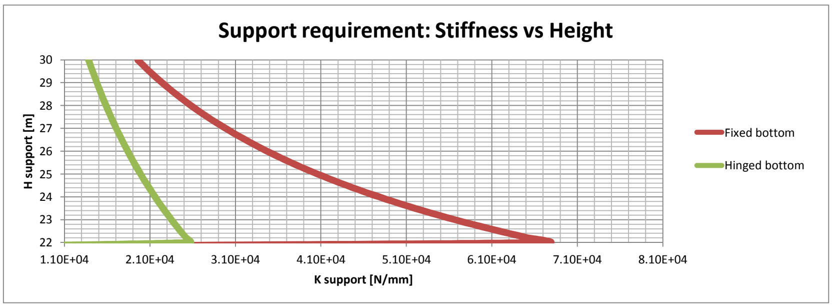
h [m]	**30.0**	**29.8**	**29.6**	**29.4**	**29.2**	**29.0**	**28.8**	**28.6**	**28.4**
Fsupp [kN]	7071.65	7119.11	7167.22	7215.97	7265.40	7315.50	7366.31	7417.82	7470.06
usupp [mm]	511.81	508.39	504.98	501.57	498.16	494.75	491.33	487.92	484.51
ks [N/mm]	1.38E+04	1.40E+04	1.42E+04	1.44E+04	1.46E+04	1.48E+04	1.50E+04	1.52E+04	1.54E+04

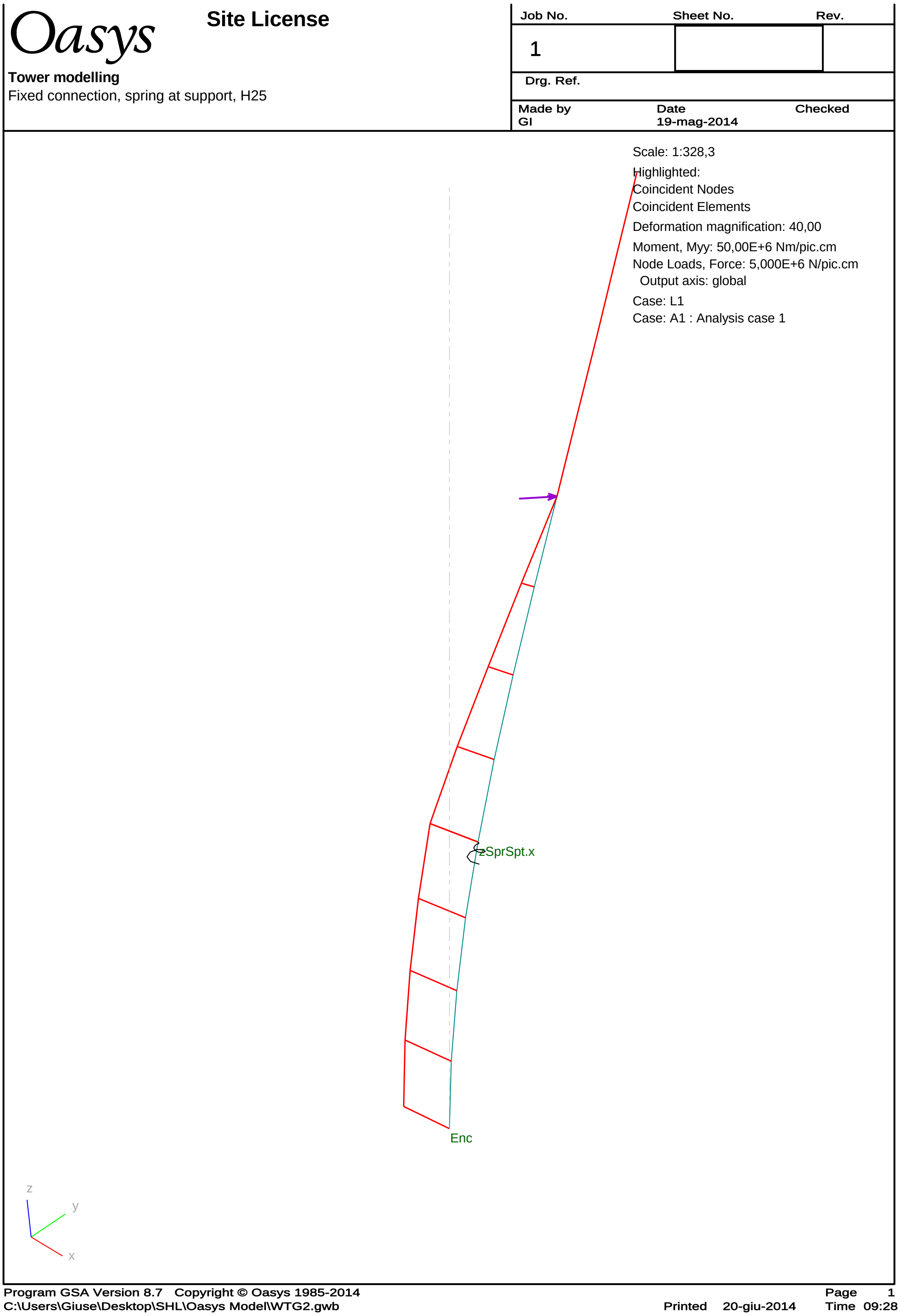
28.2	**28.0**	**27.8**	**27.6**	**27.4**	**27.2**	**27.0**	**26.8**	**26.6**
7523.04	7576.77	7631.28	7686.58	7742.69	7799.62	7857.39	7916.03	7975.55
481.10	477.69	474.27	470.86	467.45	464.04	460.63	457.21	453.80
1.56E+04	1.59E+04	1.61E+04	1.63E+04	1.66E+04	1.68E+04	1.71E+04	1.73E+04	1.76E+04

26.4	**26.2**	**26.0**	**25.8**	**25.6**	**25.4**	**25.2**	**25.0**	**24.8**
8035.97	8097.31	8159.60	8222.85	8287.09	8352.35	8418.63	8485.98	8554.42
450.39	446.98	443.56	440.15	436.74	433.33	429.92	426.50	423.09
1.78E+04	1.81E+04	1.84E+04	1.87E+04	1.90E+04	1.93E+04	1.96E+04	1.99E+04	2.02E+04

24.6	**24.4**	**24.2**	**24.0**	**23.8**	**23.6**	**23.4**	**23.2**	**23.0**
8623.97	8694.66	8766.51	8839.57	8913.85	8989.39	9066.22	9144.38	9223.90
419.68	416.27	412.86	409.44	406.03	402.62	399.21	395.80	392.38
2.05E+04	2.09E+04	2.12E+04	2.16E+04	2.20E+04	2.23E+04	2.27E+04	2.31E+04	2.35E+04

22.8	**22.6**	**22.4**	**22.2**	**22.0**	**21.8**	**21.6**	**..**	**0.0**
9304.81	9387.15	9470.96	9556.29	9643.16	0.00	0.00	0.00	0.00
388.97	385.56	382.15	378.74	375.32	0.00	0.00	0.00	0.00
2.39E+04	2.43E+04	2.48E+04	2.52E+04	2.57E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00

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Tower modelling
Fixed connection, spring at support, H25
Job No.
Sheet No.
Rev.
1
Drg. Ref.
Made by
GI
Date
19-mag-2014
Checked
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Highlighted:
Coincident Nodes
Coincident Elements
Deformation magnification: 40,00
Moment, Myy: 50,00E+6 Nm/pic.cm
Node Loads, Force: 5,000E+6 N/pic.cm
Output axis: global
Case: L1
Case: A1 : Analysis case 1
zSprSpt.x
Enc
z
y
x
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Tower modelling

Fixed connection, spring at support, H25

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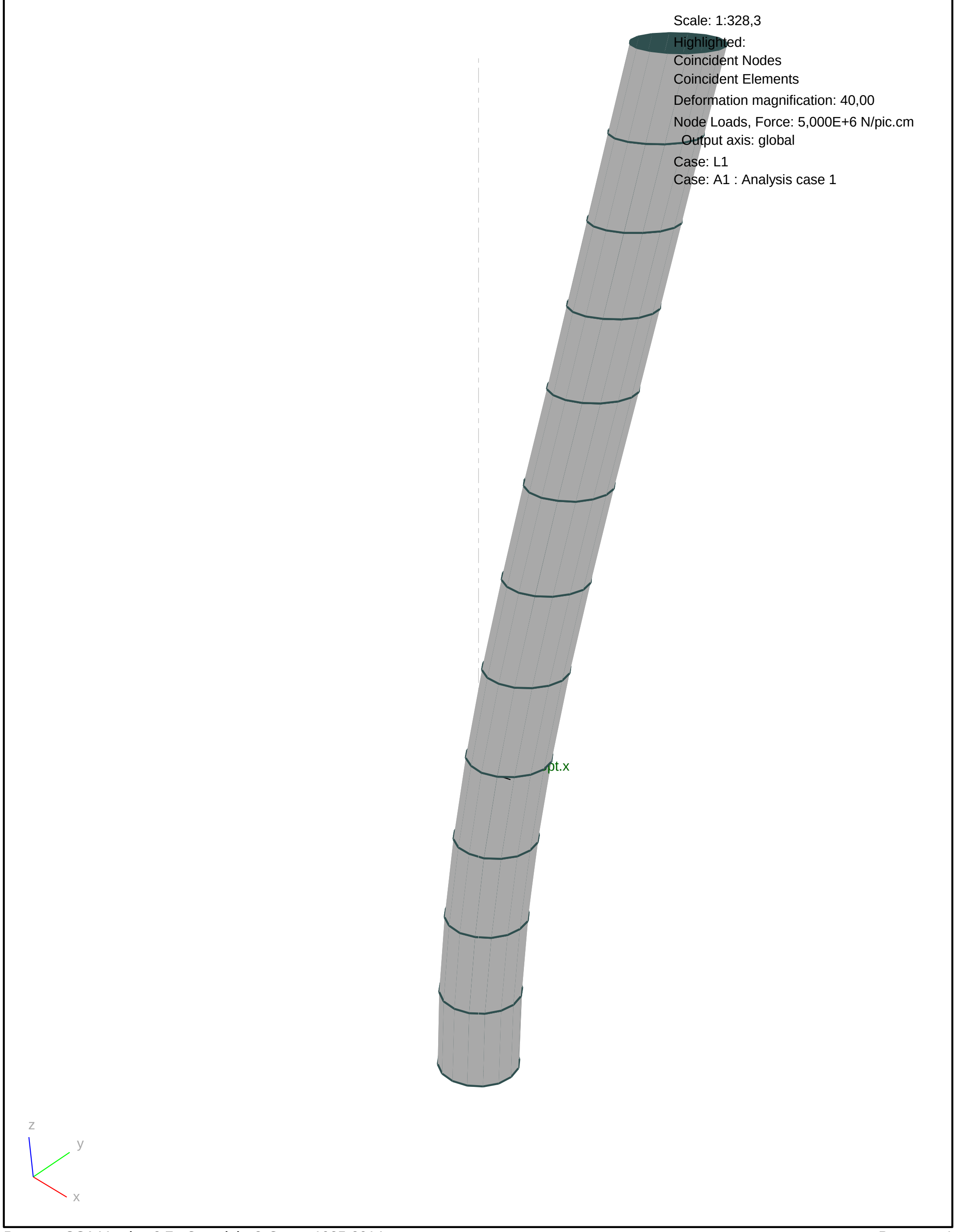

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Hinged connection, spring at support

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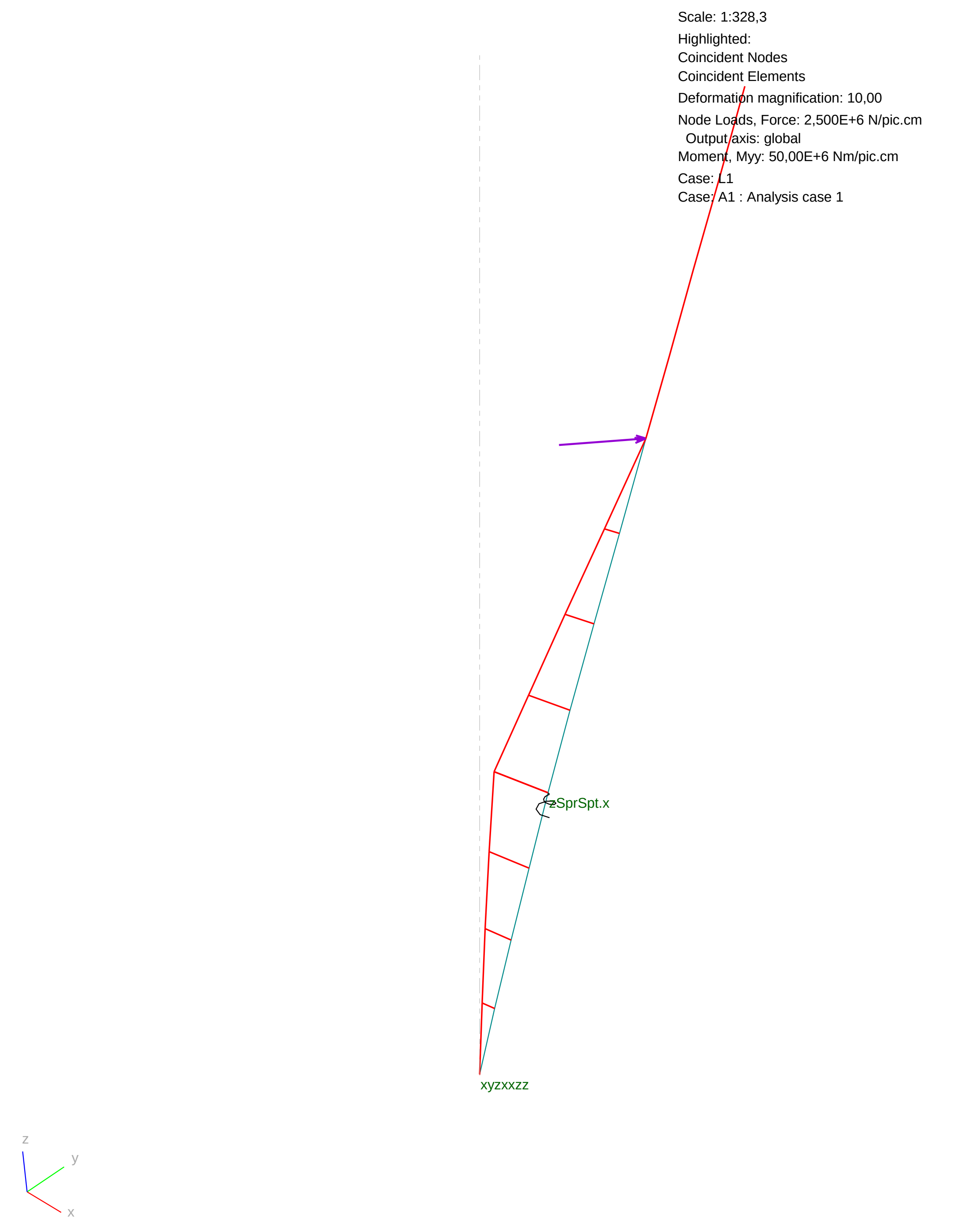

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Job No.	Sheet No.	Rev.
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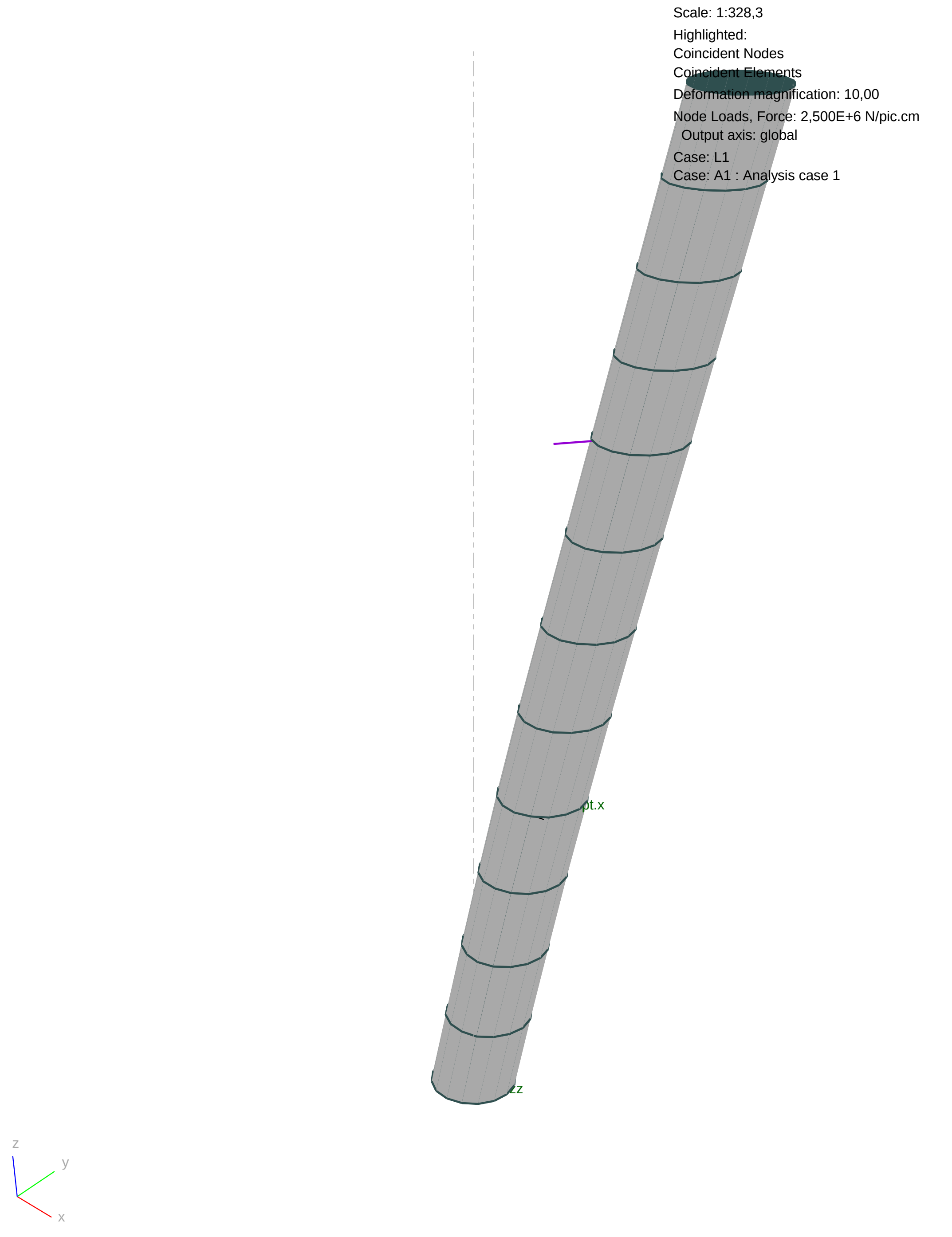
Tower modelling
Hinged connection, spring at support



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A.5. External sea-fastening structure modelling

Maple calculations and results - X direction

>

Simple frame - X direction

> *restart*

> *with*(*LinearAlgebra*)

[*&x*, *Add*, *Adjoint*, *BackwardSubstitute*, *BandMatrix*, *Basis*, *BezoutMatrix*, *BidiagonalForm*, *BilinearForm*, *CARE*, *CharacteristicMatrix*, *CharacteristicPolynomial*, *Column*, *ColumnDimension*, *ColumnOperation*, *ColumnSpace*, *CompanionMatrix*, *CompressedSparseForm*, *ConditionNumber*, *ConstantMatrix*, *ConstantVector*, *Copy*, *CreatePermutation*, *CrossProduct*, *DARE*, *DeleteColumn*, *DeleteRow*, *Determinant*, *Diagonal*, *DiagonalMatrix*, *Dimension*, *Dimensions*, *DotProduct*, *EigenConditionNumbers*, *Eigenvalues*, *Eigenvectors*, *Equal*, *ForwardSubstitute*, *FrobeniusForm*, *FromCompressedSparseForm*, *FromSplitForm*, *GaussianElimination*, *GenerateEquations*, *GenerateMatrix*, *Generic*, *GetResultDataType*, *GetResultShape*, *GivensRotationMatrix*, *GramSchmidt*, *HankelMatrix*, *HermiteForm*, *HermitianTranspose*, *HessenbergForm*, *HilbertMatrix*, *HouseholderMatrix*, *IdentityMatrix*, *IntersectionBasis*, *IsDefinite*, *IsOrthogonal*, *IsSimilar*, *IsUnitary*, *JordanBlockMatrix*, *JordanForm*, *KroneckerProduct*, *LA_Main*, *LUDecomposition*, *LeastSquares*, *LinearSolve*, *LyapunovSolve*, *Map*, *Map2*, *MatrixAdd*, *MatrixExponential*, *MatrixFunction*, *MatrixInverse*, *MatrixMatrixMultiply*, *MatrixNorm*, *MatrixPower*, *MatrixScalarMultiply*, *MatrixVectorMultiply*, *MinimalPolynomial*, *Minor*, *Modular*, *Multiply*, *NoUserValue*, *Norm*, *Normalize*, *NullSpace*, *OuterProductMatrix*, *Permanent*, *Pivot*, *PopovForm*, *ProjectionMatrix*, *QRDecomposition*, *RandomMatrix*, *RandomVector*, *Rank*, *RationalCanonicalForm*, *ReducedRowEchelonForm*, *Row*, *RowDimension*, *RowOperation*, *RowSpace*, *ScalarMatrix*, *ScalarMultiply*, *ScalarVector*, *SchurForm*, *SingularValues*, *SmithForm*, *SplitForm*, *StronglyConnectedBlocks*, *SubMatrix*, *SubVector*, *SumBasis*, *SylvesterMatrix*, *SylvesterSolve*, *ToeplitzMatrix*, *Trace*, *Transpose*, *TridiagonalForm*, *UnitVector*, *VandermondeMatrix*, *VectorAdd*, *VectorAngle*, *VectorMatrixMultiply*, *VectorNorm*, *VectorScalarMultiply*, *ZeroMatrix*, *ZeroVector*, *Zip*] **(1)**

$$> K := Matrix\left(3, \left\{(1,1) = \frac{24\,EIc}{H^3}, (1,2) = \frac{6\,EIc}{H^2}, (1,3) = \frac{6\,EIc}{H^2}, (2,2) = 4\,EIc\cdot\frac{1}{H} + 4\,EIb\cdot\frac{1}{L}, (2,3) = \frac{2\,EIb}{L}, (3,3) = 4\,EIc\cdot\frac{1}{H} + 4\,EIb\cdot\frac{1}{L}\right\}, fill = 0, shape = symmetric\right)$$

$$K := \begin{bmatrix} \frac{24\,EIc}{H^3} & \frac{6\,EIc}{H^2} & \frac{6\,EIc}{H^2} \\ \frac{6\,EIc}{H^2} & \frac{4\,EIc}{H} + \frac{4\,EIb}{L} & \frac{2\,EIb}{L} \\ \frac{6\,EIc}{H^2} & \frac{2\,EIb}{L} & \frac{4\,EIc}{H} + \frac{4\,EIb}{L} \end{bmatrix} \quad \textbf{(2)}$$

$$> F := Matrix(3, 1, [ftop, 0, 0])$$

(3)

$$F := \begin{bmatrix} ftop \\ 0 \\ 0 \end{bmatrix} \quad (3)$$

> $U := LinearSolve(K, F)$

$$U := \begin{bmatrix} \frac{1}{12} \frac{ftop\,(3\,EIb\,H + 2\,EIc\,L)\,H^3}{(6\,EIb\,H + EIc\,L)\,EIc} \\ -\frac{1}{4} \frac{L\,ftop\,H^2}{6\,EIb\,H + EIc\,L} \\ -\frac{1}{4} \frac{L\,ftop\,H^2}{6\,EIb\,H + EIc\,L} \end{bmatrix} \quad (4)$$

Example at H 22 m

> $L := 2800$

$$L := 2800 \quad (5)$$

> $H := 5000$

$$H := 5000 \quad (6)$$

> $EIc := 6.3969 \cdot 10^{14}$

$$EIc := 6.396900000\ 10^{14} \quad (7)$$

> $EIb := 1.0129 \cdot 10^{15}$

$$EIb := 1.012900000\ 10^{15} \quad (8)$$

> $ftop := 1549626.1$

$$ftop := 1.5496261\ 10^{6} \quad (9)$$

> $evalf(U)$

$$\begin{bmatrix} 14.72390194 \\ -0.0008427604420 \\ -0.0008427604420 \end{bmatrix} \quad (10)$$

>

>

Braced frame - X direction

> *restart*

> *with*(*LinearAlgebra*)

[*&x*, *Add*, *Adjoint*, *BackwardSubstitute*, *BandMatrix*, *Basis*, *BezoutMatrix*, *BidiagonalForm*, *BilinearForm*, *CARE*, *CharacteristicMatrix*, *CharacteristicPolynomial*, *Column*, *ColumnDimension*, *ColumnOperation*, *ColumnSpace*, *CompanionMatrix*, *CompressedSparseForm*, *ConditionNumber*, *ConstantMatrix*, *ConstantVector*, *Copy*, *CreatePermutation*, *CrossProduct*, *DARE*, *DeleteColumn*, *DeleteRow*, *Determinant*, *Diagonal*, *DiagonalMatrix*, *Dimension*, *Dimensions*, *DotProduct*, *EigenConditionNumbers*, *Eigenvalues*, *Eigenvectors*, *Equal*, *ForwardSubstitute*, *FrobeniusForm*, *FromCompressedSparseForm*, *FromSplitForm*, *GaussianElimination*, *GenerateEquations*, *GenerateMatrix*, *Generic*, *GetResultDataType*, *GetResultShape*, *GivensRotationMatrix*, *GramSchmidt*, *HankelMatrix*, *HermiteForm*, *HermitianTranspose*, *HessenbergForm*, *HilbertMatrix*, *HouseholderMatrix*, *IdentityMatrix*, *IntersectionBasis*, *IsDefinite*, *IsOrthogonal*, *IsSimilar*, *IsUnitary*, *JordanBlockMatrix*, *JordanForm*, *KroneckerProduct*, *LA_Main*, *LUDecomposition*, *LeastSquares*, *LinearSolve*, *LyapunovSolve*, *Map*, *Map2*, *MatrixAdd*, *MatrixExponential*, *MatrixFunction*, *MatrixInverse*, *MatrixMatrixMultiply*, *MatrixNorm*, *MatrixPower*, *MatrixScalarMultiply*, *MatrixVectorMultiply*, *MinimalPolynomial*, *Minor*, *Modular*, *Multiply*, *NoUserValue*, *Norm*, *Normalize*, *NullSpace*, *OuterProductMatrix*, *Permanent*, *Pivot*, *PopovForm*, *ProjectionMatrix*, *QRDecomposition*, *RandomMatrix*, *RandomVector*, *Rank*, *RationalCanonicalForm*, *ReducedRowEchelonForm*, *Row*, *RowDimension*, *RowOperation*, *RowSpace*, *ScalarMatrix*, *ScalarMultiply*, *ScalarVector*, *SchurForm*, *SingularValues*, *SmithForm*, *SplitForm*, *StronglyConnectedBlocks*, *SubMatrix*, *SubVector*, *SumBasis*, *SylvesterMatrix*, *SylvesterSolve*, *ToeplitzMatrix*, *Trace*, *Transpose*, *TridiagonalForm*, *UnitVector*, *VandermondeMatrix*, *VectorAdd*, *VectorAngle*, *VectorMatrixMultiply*, *VectorNorm*, *VectorScalarMultiply*, *ZeroMatrix*, *ZeroVector*, *Zip*] **(1)**

> *with*(*MTM*)

[*ElementwiseAnd*, *ElementwiseNot*, *ElementwiseOr*, *Map*, *Minus*, *Mod*, *Zip*, abs, *acos*, *acosh*, *acot*, *acoth*, *acsc*, *acsch*, *array_dims*, *asec*, *asech*, *asin*, *asinh*, *atan*, *atanh*, *besseli*, *besselj*, *besselk*, *bessely*, *ccode*, ceil, *char*, *coeffs*, *collect*, *colspace*, *compose*, *conj*, cos, cosh, *cosint*, cot, coth, csc, csch, *ctranspose*, *det*, *diag*, *diff*, *digits*, *dirac*, *disp*, *double*, *dsolve*, *eig*, *end*, *eq*, erf, exp, *expand*, *expm*, *ezcontour*, *ezcontourf*, *ezmesh*, *ezmeshc*, *ezplot*, *ezplot3*, *ezpolar*, *ezsurf*, *ezsurfc*, *factor*, *findsym*, *finverse*, *fix*, floor, *fortran*, *fourier*, frac, γ, *gcd*, *ge*, *gt*, *heaviside*, *horner*, *horzcat*, hypergeom, *ifourier*, *ilaplace*, *imag*, *int*, *int16*, *int32*, *int64*, *int8*, *inv*, *isreal*, *iztrans*, *jacobian*, *jordan*, *lambertw*, *laplace*, *latex*, *lcm*, *ldivide*, *le*, *limit*, log, log10, *log2*, *lt*, *mfun*, *mldivide*, *mpower*, *mrdivide*, *mtimes*, *ne*, *null*, *numden*, *numel*, *plus*, *poly*, *poly2sym*, *power*, *pretty*, *procread*, *prod*, *quorem*, *rank*, *rdivide*, *real*, round, *rref*, sec, sech, *simple*, *simplify*, sin, *single*, sinh, *sinint*, *size*, *solve*, *sort*, sqrt, *struct*, *subs*, *subsasgn*, *subsref*, *sum*, *svd*, *sym2poly*, *symsum*, tan, tanh, *taylor*, *times*, *transpose*, *tril*, *triu*, *uint16*, **(2)**

uint32, uint64, uint8, vertcat, vpa, ζ, ztrans]

> $K := Matrix\left(3, \left\{(1,1) = \frac{24\,EIc}{H^3} + \frac{12\sin(\alpha)^2\,EIc}{l^3} + \frac{EAc\cdot\cos(\alpha)^2}{l}, (1,2) = \frac{6\,EIc}{H^2} + \frac{6\sin(\alpha)\,EIc}{l^2}, (1,3) = \frac{6\,EIc}{H^2}, (2,2) = 4\,EIc\cdot\frac{1}{H} + 4\,EIb\cdot\frac{1}{L} + \frac{4\,EIc}{l}, (2,3) = \frac{2\,EIb}{L}, (3,3) = 4\,EIc\cdot\frac{1}{H} + 4\,EIb\cdot\frac{1}{L} + \frac{4\,EIc}{l}\right\}, shape = symmetric\right)$

$$K := \left[\left[\frac{24\,EIc}{H^3} + \frac{12\sin(\alpha)^2\,EIc}{l^3} + \frac{EAc\cos(\alpha)^2}{l}, \frac{6\,EIc}{H^2} + \frac{6\sin(\alpha)\,EIc}{l^2}, \frac{6\,EIc}{H^2}\right], \left[\frac{6\,EIc}{H^2} + \frac{6\sin(\alpha)\,EIc}{l^2}, \frac{4\,EIc}{H} + \frac{4\,EIb}{L} + \frac{4\,EIc}{l}, \frac{2\,EIb}{L}\right], \left[\frac{6\,EIc}{H^2}, \frac{2\,EIb}{L}, \frac{4\,EIc}{H} + \frac{4\,EIb}{L} + \frac{4\,EIc}{l}\right]\right] \quad \textbf{(3)}$$

>

> $F := Matrix(3, 1, [ftop, 0, 0])$

$$F := \begin{bmatrix} ftop \\ 0 \\ 0 \end{bmatrix} \quad \textbf{(4)}$$

> $\alpha := \pi - \beta$

$$\alpha := \pi - \beta \quad \textbf{(5)}$$

> $\beta := \mathrm{atan}\left(\frac{H}{L}\right)$

$$\beta := \arctan\left(\frac{H}{L}\right) \quad \textbf{(6)}$$

> $l := \sqrt{L^2 + H^2}$

$$l := \sqrt{H^2 + L^2} \quad \textbf{(7)}$$

> $L := 2800$

$$L := 2800 \quad \textbf{(8)}$$

>

Example at H 22

> $EIb := 1\cdot 10^{15}$

$$EIb := 1000000000000000 \quad \textbf{(9)}$$

> $H := 5000$

$$H := 5000 \quad \textbf{(10)}$$

> $EAc := \frac{EIc}{4\cdot 10^4}$

$$EAc := \frac{1}{40000}\,EIc \quad \textbf{(11)}$$

> $U := LinearSolve(K, F)$

> $evalf(U)$

$$\left[\left[\left(5.355012940\ 10^{18}\ ftop\left(1.766863719\ 10^{34}\ EIc^3 + 5.207551243\ 10^{49}\ EIc^2 + 4.710031245\ 10^{64}\ EIc + 1.253409785\ 10^{79}\right)\right) \Big/ \left(\left(4.760486606\ 10^{24}\ EIc^2 + 9.91385753\ 10^{39}\ EIc + 3.6609667\ 10^{54}\right)\left(2.259967629\ 10^{19}\ EIc + 2.35046333\ 10^{34}\right) EIc\right)\right], \left[-\left(1.518384675\ 10^{23}\ ftop\left(1.661452304\ 10^{26}\ EIc^2 + 2.836390104\ 10^{41}\ EIc + 1.152792306\ 10^{56}\right)\right) \Big/ \left(\left(4.760486606\ 10^{24}\ EIc^2 + 9.91385753\ 10^{39}\ EIc + 3.6609667\ 10^{54}\right)\left(2.259967629\ 10^{19}\ EIc + 2.35046333\ 10^{34}\right)\right)\right], \left[-\frac{1.325902218\ 10^{7}\ ftop\left(5.058804486\ 10^{22}\ EIc + 8.0998066\ 10^{36}\right)}{4.760486606\ 10^{24}\ EIc^2 + 9.91385753\ 10^{39}\ EIc + 3.6609667\ 10^{54}}\right]\right] \quad (12)$$

> $ftop := 1549626.51$

$$ftop := 1.54962651\ 10^{6} \quad (13)$$

> $EIc := 6.4 \cdot 10^{14}$

$$EIc := 6.400000000\ 10^{14} \quad (14)$$

> U

$$\left[\left[\left(3.691405692\ 10^{71}\left(3.470580726\ 10^{78}\sqrt{821} - 3.080273321\ 10^{79}\right)\right) \Big/ \left(\left(1660162983 + 328937500\sqrt{821}\right)^2 \left(30374386044830552345\sqrt{821} + 1089252181199483601547\right)\left(2.442243923\ 10^{56} - 8.106232178\ 10^{54}\sqrt{821}\right)\left(63816591015577919293 + 1899087439452363695\sqrt{821}\right)\left(1.740052703\ 10^{35} - 4747718598630909237500000000000000\sqrt{821}\right)\right)\right], \left[-\left(6.042934530\ 10^{80}\left(9.759856922\ 10^{54}\sqrt{821} + 8.521115112\ 10^{55}\right)\right) \Big/ \left(\left(1660162983 + 328937500\sqrt{821}\right)\left(30374386044830552345\sqrt{821} + 1089252181199483601547\right)\left(2.442243923\ 10^{56} - 8.106232178\ 10^{54}\sqrt{821}\right)\left(63816591015577919293 + 1899087439452363695\sqrt{821}\right)\left(1.740052703\ 10^{35} - 4747718598630909237500000000000000\sqrt{821}\right)\right)\right], \left[-\left(4.463186185\ 10^{44}\left(-8.586540560\ 10^{36}\sqrt{821} + 2.865071396\ 10^{38}\right)\right) \Big/ \left(\left(1660162983 + 328937500\sqrt{821}\right)\left(30374386044830552345\sqrt{821} + 1089252181199483601547\right)\left(2.442243923\ 10^{56} - 8.106232178\ 10^{54}\sqrt{821}\right)\right)\right]\right] \quad (15)$$

> $simplify(\,\mathbf{(15)})$

$$\begin{bmatrix} 1.960591507 \\ -0.0001891201941 \\ -0.0000695603335 \end{bmatrix} \quad (16)$$

Maple calculations and results - Y direction

>

Simple frame - Y direction

> *restart*

> *with*(*LinearAlgebra*)

[&x, Add, Adjoint, BackwardSubstitute, BandMatrix, Basis, BezoutMatrix, BidiagonalForm, BilinearForm, CARE, CharacteristicMatrix, CharacteristicPolynomial, Column, ColumnDimension, ColumnOperation, ColumnSpace, CompanionMatrix, CompressedSparseForm, ConditionNumber, ConstantMatrix, ConstantVector, Copy, CreatePermutation, CrossProduct, DARE, DeleteColumn, DeleteRow, Determinant, Diagonal, DiagonalMatrix, Dimension, Dimensions, DotProduct, EigenConditionNumbers, Eigenvalues, Eigenvectors, Equal, ForwardSubstitute, FrobeniusForm, FromCompressedSparseForm, FromSplitForm, GaussianElimination, GenerateEquations, GenerateMatrix, Generic, GetResultDataType, GetResultShape, GivensRotationMatrix, GramSchmidt, HankelMatrix, HermiteForm, HermitianTranspose, HessenbergForm, HilbertMatrix, HouseholderMatrix, IdentityMatrix, IntersectionBasis, IsDefinite, IsOrthogonal, IsSimilar, IsUnitary, JordanBlockMatrix, JordanForm, KroneckerProduct, LA_Main, LUDecomposition, LeastSquares, LinearSolve, LyapunovSolve, Map, Map2, MatrixAdd, MatrixExponential, MatrixFunction, MatrixInverse, MatrixMatrixMultiply, MatrixNorm, MatrixPower, MatrixScalarMultiply, MatrixVectorMultiply, MinimalPolynomial, Minor, Modular, Multiply, NoUserValue, Norm, Normalize, NullSpace, OuterProductMatrix, Permanent, Pivot, PopovForm, ProjectionMatrix, QRDecomposition, RandomMatrix, RandomVector, Rank, RationalCanonicalForm, ReducedRowEchelonForm, Row, RowDimension, RowOperation, RowSpace, ScalarMatrix, ScalarMultiply, ScalarVector, SchurForm, SingularValues, SmithForm, SplitForm, StronglyConnectedBlocks, SubMatrix, SubVector, SumBasis, SylvesterMatrix, SylvesterSolve, ToeplitzMatrix, Trace, Transpose, TridiagonalForm, UnitVector, VandermondeMatrix, VectorAdd, VectorAngle, VectorMatrixMultiply, VectorNorm, VectorScalarMultiply, ZeroMatrix, ZeroVector, Zip] **(1)**

> $K := Matrix\left(3, \left\{(1,1) = \frac{12\,EIc}{H^3}\cdot n,\ (1,2) = \frac{6\,EIc}{H^2},\ (1,3) = \frac{6\,EIc}{H^2},\ (2,2) = 4\,EIc\cdot\frac{1}{H} + 4\,EIb\cdot\frac{1}{L},\ (2,3) = \frac{2\,EIb}{L},\ (3,3) = 4\,EIc\cdot\frac{1}{H} + 4\,EIb\cdot\frac{1}{L}\right\}, shape = symmetric\right)$

$$K := \begin{bmatrix} \frac{12\,EIc\,n}{H^3} & \frac{6\,EIc}{H^2} & \frac{6\,EIc}{H^2} \\ \frac{6\,EIc}{H^2} & \frac{4\,EIc}{H} + \frac{4\,EIb}{L} & \frac{2\,EIb}{L} \\ \frac{6\,EIc}{H^2} & \frac{2\,EIb}{L} & \frac{4\,EIc}{H} + \frac{4\,EIb}{L} \end{bmatrix} \quad \mathbf{(2)}$$

> $n := 6$

$$n := 6 \quad \mathbf{(3)}$$

> $F := Matrix(3, 1, [6\cdot \text{ftop}, 0, 0])$

$$F := \begin{bmatrix} 6\,ftop \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

> $U := LinearSolve(K, F)$

$$U := \begin{bmatrix} \frac{1}{18} \frac{fs\,(3\,EIb\,H + 2\,EIc\,L)\,H^3}{(2\,EIb\,H + EIc\,L)\,EIc} \\ -\frac{1}{6} \frac{L\,fs\,H^2}{2\,EIb\,H + EIc\,L} \\ -\frac{1}{6} \frac{L\,fs\,H^2}{2\,EIb\,H + EIc\,L} \end{bmatrix} \quad (5)$$

Example at H 22

> $H := 6500$

$$H := 6500 \quad (6)$$

> $L := 3950$

$$L := 3950 \quad (7)$$

> $EIc := 6.4\cdot 10^{14}$

$$EIc := 6.400000000\ 10^{14} \quad (8)$$

> $EIb := 1.01\cdot 10^{15}$

$$EIb := 1.010000000\ 10^{15} \quad (9)$$

>

> $ftop := 1846772.96$

$$ftop := 1.84677296\ 10^{6} \quad (10)$$

> $evalf(U)$

$$\begin{bmatrix} 83.51006186 \\ -0.003936688242 \\ -0.003936688242 \end{bmatrix} \quad (11)$$

>

>

Braced frame - Y direction

> *restart*

> *with*(*LinearAlgebra*)

[&x, Add, Adjoint, BackwardSubstitute, BandMatrix, Basis, BezoutMatrix, BidiagonalForm, BilinearForm, CARE, CharacteristicMatrix, CharacteristicPolynomial, Column, ColumnDimension, ColumnOperation, ColumnSpace, CompanionMatrix, CompressedSparseForm, ConditionNumber, ConstantMatrix, ConstantVector, Copy, CreatePermutation, CrossProduct, DARE, DeleteColumn, DeleteRow, Determinant, Diagonal, DiagonalMatrix, Dimension, Dimensions, DotProduct, EigenConditionNumbers, Eigenvalues, Eigenvectors, Equal, ForwardSubstitute, FrobeniusForm, FromCompressedSparseForm, FromSplitForm, GaussianElimination, GenerateEquations, GenerateMatrix, Generic, GetResultDataType, GetResultShape, GivensRotationMatrix, GramSchmidt, HankelMatrix, HermiteForm, HermitianTranspose, HessenbergForm, HilbertMatrix, HouseholderMatrix, IdentityMatrix, IntersectionBasis, IsDefinite, IsOrthogonal, IsSimilar, IsUnitary, JordanBlockMatrix, JordanForm, KroneckerProduct, LA_Main, LUDecomposition, LeastSquares, LinearSolve, LyapunovSolve, Map, Map2, MatrixAdd, MatrixExponential, MatrixFunction, MatrixInverse, MatrixMatrixMultiply, MatrixNorm, MatrixPower, MatrixScalarMultiply, MatrixVectorMultiply, MinimalPolynomial, Minor, Modular, Multiply, NoUserValue, Norm, Normalize, NullSpace, OuterProductMatrix, Permanent, Pivot, PopovForm, ProjectionMatrix, QRDecomposition, RandomMatrix, RandomVector, Rank, RationalCanonicalForm, ReducedRowEchelonForm, Row, RowDimension, RowOperation, RowSpace, ScalarMatrix, ScalarMultiply, ScalarVector, SchurForm, SingularValues, SmithForm, SplitForm, StronglyConnectedBlocks, SubMatrix, SubVector, SumBasis, SylvesterMatrix, SylvesterSolve, ToeplitzMatrix, Trace, Transpose, TridiagonalForm, UnitVector, VandermondeMatrix, VectorAdd, VectorAngle, VectorMatrixMultiply, VectorNorm, VectorScalarMultiply, ZeroMatrix, ZeroVector, Zip] **(1)**

> *with*(*MTM*)

[ElementwiseAnd, ElementwiseNot, ElementwiseOr, Map, Minus, Mod, Zip, abs, acos, acosh, acot, acoth, acsc, acsch, array_dims, asec, asech, asin, asinh, atan, atanh, besseli, besselj, besselk, bessely, ccode, ceil, char, coeffs, collect, colspace, compose, conj, cos, cosh, cosint, cot, coth, csc, csch, ctranspose, det, diag, diff, digits, dirac, disp, double, dsolve, eig, end, eq, erf, exp, expand, expm, ezcontour, ezcontourf, ezmesh, ezmeshc, ezplot, ezplot3, ezpolar, ezsurf, ezsurfc, factor, findsym, finverse, fix, floor, fortran, fourier, frac, γ, gcd, ge, gt, heaviside, horner, horzcat, hypergeom, ifourier, ilaplace, imag, int, int16, int32, int64, int8, inv, isreal, iztrans, jacobian, jordan, lambertw, laplace, latex, lcm, ldivide, le, limit, log, log10, log2, lt, mfun, mldivide, mpower, mrdivide, mtimes, ne, null, numden, numel, plus, poly, poly2sym, power, pretty, procread, prod, quorem, rank, rdivide, real, round, rref, sec, sech, simple, simplify, sin, single, sinh, sinint, size, solve, sort, sqrt, struct, subs, subsasgn, subsref, sum, svd, sym2poly, symsum, tan, tanh, taylor, times, transpose, tril, triu, uint16, **(2)**

uint32, uint64, uint8, vertcat, vpa, ζ, ztrans]

> $K := Matrix\left(3, \left\{(1,1) = \frac{12\,EIc}{H^3}\cdot n + \frac{12\sin(\alpha)^2\,EIc}{l^3}\cdot n + \frac{EAc\cdot\cos(\alpha)^2}{l}\cdot n, (1,2) = \frac{6\,EIc}{H^2} + \frac{6\sin(\alpha)\,EIc}{l^2}, (1,3) = \frac{6\,EIc}{H^2}, (2,2) = 4\,EIc\cdot\frac{1}{H} + 4\,EIb\cdot\frac{1}{L} + \frac{4\,EIc}{l}, (2,3) = \frac{2\,EIb}{L}, (3,3) = 4\,EIc\cdot\frac{1}{H} + 4\,EIb\cdot\frac{1}{L} + \frac{4\,EIc}{l}\right\}, shape = symmetric\right)$

$$K := \left[\left[\frac{12\,EIc\,n}{H^3} + \frac{12\sin(\alpha)^2\,EIc\,n}{l^3} + \frac{EAc\cos(\alpha)^2\,n}{l}, \frac{6\,EIc}{H^2} + \frac{6\sin(\alpha)\,EIc}{l^2}, \frac{6\,EIc}{H^2}\right], \left[\frac{6\,EIc}{H^2} + \frac{6\sin(\alpha)\,EIc}{l^2}, \frac{4\,EIc}{H} + \frac{4\,EIb}{L} + \frac{4\,EIc}{l}, \frac{2\,EIb}{L}\right], \left[\frac{6\,EIc}{H^2}, \frac{2\,EIb}{L}, \frac{4\,EIc}{H} + \frac{4\,EIb}{L} + \frac{4\,EIc}{l}\right]\right] \quad \textbf{(3)}$$

> $n := 6$

$$n := 6 \quad \textbf{(4)}$$

> $F := Matrix(3, 1, [6\cdot ftop, 0, 0])$

$$F := \begin{bmatrix} 6\,ftop \\ 0 \\ 0 \end{bmatrix} \quad \textbf{(5)}$$

> $\alpha := \pi - \beta$

$$\alpha := \pi - \beta \quad \textbf{(6)}$$

> $\beta := \mathrm{atan}\left(\frac{H}{L}\right)$

$$\beta := \arctan\left(\frac{H}{L}\right) \quad \textbf{(7)}$$

>

> $l := \sqrt{L^2 + H^2}$

$$l := \sqrt{H^2 + L^2} \quad \textbf{(8)}$$

Example at H 22

> $L := 3957$

$$L := 3957 \quad \textbf{(9)}$$

> $H := 6500$

$$H := 6500 \quad \textbf{(10)}$$

>

> $EIb := 1.01\cdot 10^{15}$

$$EIb := 1.010000000\ 10^{15} \quad \textbf{(11)}$$

> $EAc := \frac{EIc}{4.96\cdot 10^4}$

$$EAc := 0.00002016129032\ EIc \quad \textbf{(12)}$$

>

> $U := LinearSolve(K, F)$

>

> $evalf(U)$

$$\Big[\Big[\big(9.965782098\ 10^{69}\ ftop\ \big(6.513875530\ 10^{101}\ EIc^3 + 1.754415104\ 10^{117}\ EIc^2 + 1.444685533\ 10^{132}\ EIc + 3.53509561\ 10^{146}\big)\big) \Big/ \big(\big(1.569115420\ 10^{85}\ EIc^2 + 2.83631442\ 10^{100}\ EIc + 9.5533913\ 10^{114}\big)\ \big(3.182415688\ 10^{77}\ EIc + 2.87620206\ 10^{92}\big)\ EIc\big)\Big],$$
$$\Big[-\big(4.083171032\ 10^{74}\ ftop\ \big(3.211855465\ 10^{93}\ EIc^2 + 4.891471878\ 10^{108}\ EIc + 1.797312629\ 10^{123}\big)\big) \Big/ \big(\big(1.569115420\ 10^{85}\ EIc^2 + 2.83631442\ 10^{100}\ EIc + 9.5533913\ 10^{114}\big)\ \big(3.182415688\ 10^{77}\ EIc + 2.87620206\ 10^{92}\big)\big)\Big],$$
$$\left[-\frac{4.573610323\ 10^{20}\ ftop\ \big(5.550894573\ 10^{69}\ EIc + 9.3573344\ 10^{83}\big)}{1.569115420\ 10^{85}\ EIc^2 + 2.83631442\ 10^{100}\ EIc + 9.5533913\ 10^{114}}\right]\Big] \quad \textbf{(13)}$$

> $EIc := 6.4 \cdot 10^{14}$

$$EIc := 6.400000000\ 10^{14} \quad \textbf{(14)}$$

> $ftop := 1846772.96$

> U

$$\Big[\Big[\big(1.193936371\ 10^{228}\ \big(4.566608906\ 10^{143}\ \sqrt{57907849} - 1.307587761\ 10^{147}\big)\big) \Big/ \big(\big(576000000000000 + 1275374689693\ \sqrt{57907849}\big)^{2}$$
$$\big(392875460837692840144181427946047090404899051624088459111643609911460018500\ \sqrt{57907849} + 35322141162993627423648121501432829910799247667772700391161226093284667 87820801\big)\ \big(8.474219194\ 10^{116} - 1.068750158\ 10^{113}\ \sqrt{57907849}\big)$$
$$\big(180681168302266240675759205640615870035752511190883806 49 + 202238882423567146806256352777174021408893030680650 0\ \sqrt{57907849}\big)$$
$$\big(2.143991275\ 10^{93} - 21718227682250341730144512831954951630235595493850298247682242645674645 9235370182625000000\ \sqrt{57907849}\big)\big)\Big],$$
$$\Big[-\big(3.045100462\ 10^{231}\ \big(5.518086367\ 10^{119}\ \sqrt{57907849} + 2.044321029\ 10^{123}\big)\big) \Big/ \big(\big(576000000000000 + 1275374689693\ \sqrt{57907849}\big) \quad \textbf{(15)}$$

(
392875460837692840144181427946047090404899051624088459111643609911460018502\
0 $\sqrt{57907849}$
+ 353221411629936274236481215014328299107992476677727003911612260932846667\
87820801) (8.474219194 10^{116}
− 1.068750158 10^{113} $\sqrt{57907849}$)
(18068116830226624067575920564061587003575251119088380649
+ 20223888242356714680625635277717402140889303068065000 $\sqrt{57907849}$)
(2.143991275 10^{93}
− 217182276822503417301445128319549516302355954938502982476822426456746455\
9235370182625000000 $\sqrt{57907849}$))],
[- (1.019445781 10^{122} (-3.243208046 10^{81} $\sqrt{57907849}$ + 2.916821334 10^{85})) /
((576000000000000
+ 1275374689693 $\sqrt{57907849}$)
(
392875460837692840144181427946047090404899051624088459111643609911460018502\
0 $\sqrt{57907849}$
+ 353221411629936274236481215014328299107992476677727003911612260932846667\
87820801) (8.474219194 10^{116} − 1.068750158 10^{113} $\sqrt{57907849}$))]]

> *evalf*(*U*)

$$\begin{bmatrix} 6.690459809 \\ -0.0005053491100 \\ -0.0001999191671 \end{bmatrix} \qquad \textbf{(16)}$$

>

>

Externally braced frame - Y direction

> *restart*

> *with*(*LinearAlgebra*)

[&x, Add, Adjoint, BackwardSubstitute, BandMatrix, Basis, BezoutMatrix, BidiagonalForm, BilinearForm, CARE, CharacteristicMatrix, CharacteristicPolynomial, Column, ColumnDimension, ColumnOperation, ColumnSpace, CompanionMatrix, CompressedSparseForm, ConditionNumber, ConstantMatrix, ConstantVector, Copy, CreatePermutation, CrossProduct, DARE, DeleteColumn, DeleteRow, Determinant, Diagonal, DiagonalMatrix, Dimension, Dimensions, DotProduct, EigenConditionNumbers, Eigenvalues, Eigenvectors, Equal, ForwardSubstitute, FrobeniusForm, FromCompressedSparseForm, FromSplitForm, GaussianElimination, GenerateEquations, GenerateMatrix, Generic, GetResultDataType, GetResultShape, GivensRotationMatrix, GramSchmidt, HankelMatrix, HermiteForm, HermitianTranspose, HessenbergForm, HilbertMatrix, HouseholderMatrix, IdentityMatrix, IntersectionBasis, IsDefinite, IsOrthogonal, IsSimilar, IsUnitary, JordanBlockMatrix, JordanForm, KroneckerProduct, LA_Main, LUDecomposition, LeastSquares, LinearSolve, LyapunovSolve, Map, Map2, MatrixAdd, MatrixExponential, MatrixFunction, MatrixInverse, MatrixMatrixMultiply, MatrixNorm, MatrixPower, MatrixScalarMultiply, MatrixVectorMultiply, MinimalPolynomial, Minor, Modular, Multiply, NoUserValue, Norm, Normalize, NullSpace, OuterProductMatrix, Permanent, Pivot, PopovForm, ProjectionMatrix, QRDecomposition, RandomMatrix, RandomVector, Rank, RationalCanonicalForm, ReducedRowEchelonForm, Row, RowDimension, RowOperation, RowSpace, ScalarMatrix, ScalarMultiply, ScalarVector, SchurForm, SingularValues, SmithForm, SplitForm, StronglyConnectedBlocks, SubMatrix, SubVector, SumBasis, SylvesterMatrix, SylvesterSolve, ToeplitzMatrix, Trace, Transpose, TridiagonalForm, UnitVector, VandermondeMatrix, VectorAdd, VectorAngle, VectorMatrixMultiply, VectorNorm, VectorScalarMultiply, ZeroMatrix, ZeroVector, Zip] **(1)**

> *with*(*MTM*)

[ElementwiseAnd, ElementwiseNot, ElementwiseOr, Map, Minus, Mod, Zip, abs, acos, acosh, acot, acoth, acsc, acsch, array_dims, asec, asech, asin, asinh, atan, atanh, besseli, besselj, besselk, bessely, ccode, ceil, char, coeffs, collect, colspace, compose, conj, cos, cosh, cosint, cot, coth, csc, csch, ctranspose, det, diag, diff, digits, dirac, disp, double, dsolve, eig, end, eq, erf, exp, expand, expm, ezcontour, ezcontourf, ezmesh, ezmeshc, ezplot, ezplot3, ezpolar, ezsurf, ezsurfc, factor, findsym, finverse, fix, floor, fortran, fourier, frac, γ, gcd, ge, gt, heaviside, horner, horzcat, hypergeom, ifourier, ilaplace, imag, int, int16, int32, int64, int8, inv, isreal, iztrans, jacobian, jordan, lambertw, laplace, latex, lcm, ldivide, le, limit, log, log10, log2, lt, mfun, mldivide, mpower, mrdivide, mtimes, ne, null, numden, numel, plus, poly, poly2sym, power, pretty, procread, prod, quorem, rank, rdivide, real, round, rref, sec, sech, simple, simplify, sin, single, sinh, sinint, size, solve, sort, sqrt, struct, subs, subsasgn, subsref, sum, svd, sym2poly, symsum, tan, tanh, taylor, times, transpose, tril, triu, uint16, **(2)**

uint32, uint64, uint8, vertcat, vpa, ζ, ztrans]

$$> K := Matrix\left(3, \left\{(1,1) = \frac{12\ EIc}{H^3} \cdot n + \frac{24 \sin(\beta)^2\ EIc}{lb^3}, (1,2) = \frac{6\ EIc}{H^2} + \frac{6 \sin(\beta)\ EIc}{lb^2}, (1,3) = \frac{6\ EIc}{H^2}, (2,2) = 4\ EIc \cdot \frac{1}{H} + 4\ EIb \cdot \frac{1}{L} + \frac{4\ EIc}{lb}, (2,3) = \frac{2\ EIb}{L}, (3,3) = 4\ EIc \cdot \frac{1}{H} + 4\ EIb \cdot \frac{1}{L} + \frac{4\ EIc}{lb}\right\}, shape = symmetric\right)$$

$$K := \begin{bmatrix} \frac{12\ EIc\ n}{H^3} + \frac{24 \sin(\beta)^2\ EIc}{lb^3} & \frac{6\ EIc}{H^2} + \frac{6 \sin(\beta)\ EIc}{lb^2} & \frac{6\ EIc}{H^2} \\ \frac{6\ EIc}{H^2} + \frac{6 \sin(\beta)\ EIc}{lb^2} & \frac{4\ EIc}{H} + \frac{4\ EIb}{L} + \frac{4\ EIc}{lb} & \frac{2\ EIb}{L} \\ \frac{6\ EIc}{H^2} & \frac{2\ EIb}{L} & \frac{4\ EIc}{H} + \frac{4\ EIb}{L} + \frac{4\ EIc}{lb} \end{bmatrix} \quad \textbf{(3)}$$

$> F := Matrix(3, 1, [6 \cdot ftop, 0, 0])$

$$F := \begin{bmatrix} 6\ ftop \\ 0 \\ 0 \end{bmatrix} \quad \textbf{(4)}$$

$> n := 6$

$$n := 6 \quad \textbf{(5)}$$

\>

$> lb := \sqrt{B^2 + H1^2}$

$$lb := \sqrt{B^2 + H1^2} \quad \textbf{(6)}$$

$> \beta := atan\left(\frac{H1}{B}\right)$

$$\beta := \arctan\left(\frac{H1}{B}\right) \quad \textbf{(7)}$$

\>

Example at H 25, top floors = 5 m so externally braced floors = 6 m

$> H := 6000$

$$H := 7500 \quad \textbf{(8)}$$

$> H1 := 2 \cdot H$

$$H1 := 15000 \quad \textbf{(9)}$$

$> L := 3957$

$$L := 3957 \quad \textbf{(10)}$$

$> B := 2800$

$$B := 2800 \quad \textbf{(11)}$$

$> EIb := 1.01 \cdot 10^{15}$

$$EIb := 1.010000000\ 10^{15} \quad \textbf{(12)}$$

> $EAc := \dfrac{EIc}{4.96 \cdot 10^{4}}$

$$EAc := 0.00002016129032\, EIc \qquad \textbf{(13)}$$

> $U := LinearSolve(K, F)$

> $evalf(U)$

$$\begin{aligned}&[[(2.251630364\ 10^{23}\ ftop\ (3.056284485\ 10^{43}\ EIc^{3} + 1.232135728\ 10^{59}\ EIc^{2} \\ &\quad + 1.526571369\ 10^{74}\ EIc + 5.530056911\ 10^{88}))/((4.489736602\ 10^{29}\ EIc^{2} \\ &\quad + 1.372828842\ 10^{45}\ EIc + 6.97157665\ 10^{59})\ (3.601638903\ 10^{26}\ EIc \\ &\quad + 5.274653893\ 10^{41})\ EIc)], \\ &\quad [-(6.336991187\ 10^{27}\ ftop\ (1.801979382\ 10^{35}\ EIc^{2} + 4.017352809\ 10^{50}\ EIc \\ &\quad + 2.018580636\ 10^{65}))/((4.489736602\ 10^{29}\ EIc^{2} + 1.372828842\ 10^{45}\ EIc \\ &\quad + 6.97157665\ 10^{59})\ (3.601638903\ 10^{26}\ EIc + 5.274653893\ 10^{41}))], \\ &\quad \left[\frac{8.568075710\ 10^{6}\ ftop\ (-2.990275476\ 10^{29}\ EIc - 1.463264078\ 10^{44})}{4.489736602\ 10^{29}\ EIc^{2} + 1.372828842\ 10^{45}\ EIc + 6.97157665\ 10^{59}}\right]]\end{aligned} \qquad \textbf{(14)}$$

> $simplify(\,\textbf{(14)}\,)$

$$\begin{aligned}&[[(4.503260728\ 10^{20}\ (7.64071121\ 10^{8}\ EIc^{3} + 3.080339320\ 10^{24}\ EIc^{2} + 3.816428422\ 10^{39}\ EIc \\ &\quad + 1.382514228\ 10^{54})\ ftop)/(EIc\ (3.601638903\ 10^{9}\ EIc \\ &\quad + 5.274653893\ 10^{24})\ (2.244868301\ 10^{9}\ EIc^{2} + 6.864144210\ 10^{24}\ EIc \\ &\quad + 3.485788325\ 10^{39}))], \\ &\quad [-(6.336991187\ 10^{16}\ (9.00989691\ 10^{8}\ EIc^{2} + 2.008676404\ 10^{24}\ EIc \\ &\quad + 1.009290318\ 10^{39})\ ftop)/((3.601638903\ 10^{9}\ EIc \\ &\quad + 5.274653893\ 10^{24})\ (2.244868301\ 10^{9}\ EIc^{2} + 6.864144210\ 10^{24}\ EIc \\ &\quad + 3.485788325\ 10^{39}))], \\ &\quad \left[-\frac{1.713615142\ 10^{7}\ ftop\ (7.47568869\ 10^{8}\ EIc + 3.658160195\ 10^{23})}{2.244868301\ 10^{9}\ EIc^{2} + 6.864144210\ 10^{24}\ EIc + 3.485788325\ 10^{39}}\right]]\end{aligned} \qquad \textbf{(15)}$$

> $EIc := 6.4 \cdot 10^{14}$

$$EIc := 6.400000000\ 10^{14} \qquad \textbf{(16)}$$

> $ftop := 1846773$

$$ftop := 1846773 \qquad \textbf{(17)}$$

> U

$$\begin{aligned}&[[(1.716083552\ 10^{95}\ (-3.451238499\ 10^{86}\ \sqrt{5821} + 2.378126717\ 10^{89}))/ \\ &\quad ((1577912021288 + 791015625\ \sqrt{5821})^{2}\ (91440751732121454129362356 25\ \sqrt{5821} \\ &\quad + 11949884122407422324353763 77438)\ (6.602756477\ 10^{60} \\ &\quad - 6.347805733\ 10^{58}\ \sqrt{5821})\ (346086381595809744000052 16 \\ &\quad + 2278991751454183225940 25\ \sqrt{5821})\ (1.290542025\ 10^{42} \\ &\quad - 698038413309277777751218365213450000000 0\ \sqrt{5821}))],\end{aligned} \qquad \textbf{(18)}$$

$$\left[-(188677799988788722448236968590178738778974388501798789959317544540602726933616960878051192017597500000 0\,(1.060256880\;10^{63}\sqrt{5821} + 4.518849131\;10^{65}))\,/\,((1577912021288 + 791015625\sqrt{5821})\,(914407517321214541293623562 5\sqrt{5821} + 1194988412240742232435376377438)\,(6.602756477\;10^{60} - 6.347805733\;10^{58}\sqrt{5821})\,(3460863815958097440000521 6 + 2278991751454183225940 25\sqrt{5821})\,(1.290542025\;10^{42} - 698038413309277777512183652134500000000\sqrt{5821}))\right],$$

$$\left[(490623597001770713225911365943378646396344136049000000 00\,(3.776789396\;10^{42}\sqrt{5821} - 6.258559915\;10^{44}))\,/\,((1577912021288 + 791015625\sqrt{5821})\,(9144075173212145412936235625\sqrt{5821} + 1194988412240742232435376377438)\,(6.602756477\;10^{60} - 6.347805733\;10^{58}\sqrt{5821}))\right]\Big]$$

> *simplify*(**(18)**, '*constant*')

$$\begin{bmatrix} 103.0195685 \\ -0.004674765452 \\ -0.003036703533 \end{bmatrix} \quad \textbf{(19)}$$

>

X-Direction - partial displacements (hinged)

Y direction

F coeff	0.643	H TOT	22000	25000	27500	30000

Displacements [mm]

BRACED

Recap

Column	Beam	Ic	Ac	Ib	Eic	Eac	Eib	6500.0				6000.0				5500.0				5000.0			
								1.55E+06	1.36E+06	1.24E+06	1.14E+06	1.55E+06	1.36E+06	1.24E+06	1.14E+06	1.55E+06	1.36E+06	1.24E+06	1.14E+06	1.55E+06	1.36E+06	1.24E+06	1.14E+06
								u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30
CHS406	heb700	3.74E+08	1.96E+04	2.57E+09	7.68E+13	4.02E+09	5.27E+14	39.7	34.9	31.7	29.1	32.3	28.5	25.8	23.7	26.0	22.9	20.7	19.1	20.7	18.2	16.5	15.2
CHS457	heb700	9.70E+08	4.27E+04	2.57E+09	1.99E+14	8.75E+09	5.27E+14	15.4	13.6	12.3	11.3	12.6	11.1	10.0	9.2	10.1	8.9	8.1	7.4	8.1	7.1	6.4	5.9
CHS508	heb700	1.36E+09	4.79E+04	2.57E+09	2.79E+14	9.82E+09	5.27E+14	11.0	9.7	8.8	8.1	9.0	7.9	7.2	6.6	7.2	6.4	5.8	5.3	5.8	5.1	4.6	4.2
CHS559	heb700	1.85E+09	5.30E+04	2.57E+09	3.78E+14	1.09E+10	5.27E+14	8.2	7.2	6.5	6.0	6.7	5.9	5.3	4.9	5.4	4.7	4.3	3.9	4.3	3.8	3.4	3.1
CHS610	heb700	2.43E+09	5.81E+04	2.57E+09	4.99E+14	1.19E+10	5.27E+14	6.2	5.5	5.0	4.6	5.1	4.5	4.1	3.7	4.1	3.6	3.3	3.0	3.3	2.9	2.6	2.4
CHS660	heb700	3.12E+09	6.31E+04	2.57E+09	6.40E+14	1.29E+10	5.27E+14	4.9	4.3	3.9	3.6	4.0	3.5	3.2	2.9	3.2	2.8	2.6	2.4	2.6	2.3	2.0	1.9
CHS406	heb800	3.74E+08	1.96E+04	3.59E+09	7.68E+13	4.02E+09	7.36E+14	34.6	30.4	27.6	25.4	28.2	24.8	22.5	20.7	22.7	19.9	18.1	16.6	18.0	15.8	14.4	13.2
CHS457	heb800	9.70E+08	4.27E+04	3.59E+09	1.99E+14	8.75E+09	7.36E+14	13.4	11.8	10.7	9.9	11.0	9.6	8.7	8.0	8.8	7.8	7.0	6.5	7.0	6.2	5.6	5.1
CHS508	heb800	1.36E+09	4.79E+04	3.59E+09	2.79E+14	9.82E+09	7.36E+14	9.6	8.5	7.7	7.1	7.8	6.9	6.3	5.8	6.3	5.6	5.0	4.6	5.0	4.4	4.0	3.7
CHS559	heb800	1.85E+09	5.30E+04	3.59E+09	3.78E+14	1.09E+10	7.36E+14	7.1	6.3	5.7	5.2	5.8	5.1	4.6	4.3	4.7	4.1	3.7	3.4	3.7	3.3	3.0	2.7
CHS610	heb800	2.43E+09	5.81E+04	3.59E+09	4.99E+14	1.19E+10	7.36E+14	5.4	4.8	4.3	4.0	4.4	3.9	3.5	3.2	3.6	3.1	2.8	2.6	2.8	2.5	2.3	2.1
CHS660	heb800	3.12E+09	6.31E+04	3.59E+09	6.40E+14	1.29E+10	7.36E+14	4.3	3.7	3.4	3.1	3.5	3.1	2.8	2.5	2.8	2.5	2.2	2.1	2.2	2.0	1.8	1.6
CHS406	heb900	3.74E+08	1.96E+04	4.94E+09	7.68E+13	4.02E+09	1.01E+15	30.4	26.8	24.3	22.3	24.8	21.8	19.7	18.2	19.9	17.5	15.9	14.6	15.8	13.9	12.6	11.6
CHS457	heb900	9.70E+08	4.27E+04	4.94E+09	1.99E+14	8.75E+09	1.01E+15	11.8	10.4	9.4	8.7	9.6	8.5	7.7	7.1	7.8	6.8	6.2	5.7	6.2	5.4	4.9	4.5
CHS508	heb900	1.36E+09	4.79E+04	4.94E+09	2.79E+14	9.82E+09	1.01E+15	8.5	7.4	6.7	6.2	6.9	6.1	5.5	5.1	5.6	4.9	4.4	4.1	4.4	3.9	3.5	3.2
CHS559	heb900	1.85E+09	5.30E+04	4.94E+09	3.78E+14	1.09E+10	1.01E+15	6.3	5.5	5.0	4.6	5.1	4.5	4.1	3.7	4.1	3.6	3.3	3.0	3.3	2.9	2.6	2.4
CHS610	heb900	2.43E+09	5.81E+04	4.94E+09	4.99E+14	1.19E+10	1.01E+15	4.8	4.2	3.8	3.5	3.9	3.4	3.1	2.9	3.1	2.8	2.5	2.3	2.5	2.2	2.0	1.8
CHS660	heb900	3.12E+09	6.31E+04	4.94E+09	6.40E+14	1.29E+10	1.01E+15	3.7	3.3	3.0	2.7	3.1	2.7	2.4	2.2	2.5	2.2	2.0	1.8	2.0	1.7	1.6	1.4

UNBRACED

Recap

Column	Beam	Ic	Ac	Ib	Eic	Eac	Eib	6500.0				6000.0				5500.0				5000.0			
								1.55E+06	1.36E+06	1.24E+06	1.14E+06	1.55E+06	1.36E+06	1.24E+06	1.14E+06	1.55E+06	1.36E+06	1.24E+06	1.14E+06	1.55E+06	1.36E+06	1.24E+06	1.14E+06
								u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30
CHS406	heb700	3.74E+08	1.96E+04	2.57E+09	7.68E+13	4.02E+09	5.27E+14	381.0	335.3	303.7	279.4	300.4	264.4	239.5	220.3	232.1	204.2	185.0	170.2	175.0	154.0	139.5	128.3
CHS457	heb700	9.70E+08	4.27E+04	2.57E+09	1.99E+14	8.75E+09	5.27E+14	154.0	135.5	122.7	112.9	121.8	107.2	97.1	89.3	94.5	83.1	75.3	69.3	71.6	63.0	57.0	52.5
CHS508	heb700	1.36E+09	4.79E+04	2.57E+09	2.79E+14	9.82E+09	5.27E+14	112.8	99.3	89.9	82.7	89.5	78.7	71.3	65.6	69.5	61.2	55.4	51.0	52.8	46.5	42.1	38.7
CHS559	heb700	1.85E+09	5.30E+04	2.57E+09	3.78E+14	1.09E+10	5.27E+14	86.0	75.7	68.6	63.1	68.3	60.1	54.5	50.1	53.2	46.9	42.4	39.0	40.6	35.7	32.3	29.7
CHS610	heb700	2.43E+09	5.81E+04	2.57E+09	4.99E+14	1.19E+10	5.27E+14	67.7	59.6	54.0	49.7	53.9	47.5	43.0	39.5	42.1	37.1	33.6	30.9	32.2	28.3	25.7	23.6
CHS660	heb700	3.12E+09	6.31E+04	2.57E+09	6.40E+14	1.29E+10	5.27E+14	55.0	48.4	43.9	40.4	43.9	38.6	35.0	32.2	34.4	30.3	27.4	25.2	26.4	23.2	21.0	19.3
CHS406	heb800	3.74E+08	1.96E+04	3.59E+09	7.68E+13	4.02E+09	7.36E+14	377.8	332.5	301.1	277.1	297.7	262.0	237.3	218.3	229.8	202.2	183.2	168.5	173.1	152.3	138.0	126.9
CHS457	heb800	9.70E+08	4.27E+04	3.59E+09	1.99E+14	8.75E+09	7.36E+14	150.8	132.7	120.2	110.6	119.1	104.8	95.0	87.4	92.2	81.2	73.5	67.6	69.7	61.4	55.6	51.1
CHS508	heb800	1.36E+09	4.79E+04	3.59E+09	2.79E+14	9.82E+09	7.36E+14	109.7	96.6	87.5	80.5	86.8	76.4	69.2	63.7	67.3	59.3	53.7	49.4	51.0	44.9	40.7	37.4
CHS559	heb800	1.85E+09	5.30E+04	3.59E+09	3.78E+14	1.09E+10	7.36E+14	83.0	73.0	66.1	60.8	65.8	57.9	52.4	48.2	51.1	45.0	40.7	37.5	38.8	34.2	30.9	28.5
CHS610	heb800	2.43E+09	5.81E+04	3.59E+09	4.99E+14	1.19E+10	7.36E+14	64.8	57.0	51.6	47.5	51.4	45.3	41.0	37.7	40.1	35.3	31.9	29.4	30.5	26.8	24.3	22.4
CHS660	heb800	3.12E+09	6.31E+04	3.59E+09	6.40E+14	1.29E+10	7.36E+14	52.2	45.9	41.6	38.3	41.5	36.5	33.1	30.4	32.4	28.5	25.8	23.8	24.7	21.8	19.7	18.1
CHS406	heb900	3.74E+08	1.96E+04	4.94E+09	7.68E+13	4.02E+09	1.01E+15	375.6	330.5	299.4	275.4	295.8	260.3	235.8	216.9	228.2	200.8	181.9	167.3	171.8	151.1	136.9	126.0
CHS457	heb900	9.70E+08	4.27E+04	4.94E+09	1.99E+14	8.75E+09	1.01E+15	148.6	130.8	118.5	109.0	117.3	103.2	93.5	86.0	90.7	79.8	72.3	66.5	68.4	60.2	54.6	50.2
CHS508	heb900	1.36E+09	4.79E+04	4.94E+09	2.79E+14	9.82E+09	1.01E+15	107.6	94.7	85.7	78.9	85.0	74.8	67.7	62.3	65.8	57.9	52.5	48.3	49.8	43.8	39.7	36.5
CHS559	heb900	1.85E+09	5.30E+04	4.94E+09	3.78E+14	1.09E+10	1.01E+15	80.8	71.1	64.4	59.3	64.0	56.3	51.0	46.9	49.6	43.7	39.5	36.4	37.6	33.1	29.9	27.6
CHS610	heb900	2.43E+09	5.81E+04	4.94E+09	4.99E+14	1.19E+10	1.01E+15	62.7	55.2	50.0	46.0	49.7	43.7	39.6	36.4	38.6	34.0	30.8	28.3	29.3	25.8	23.3	21.5
CHS660	heb900	3.12E+09	6.31E+04	4.94E+09	6.40E+14	1.29E+10	1.01E+15	50.1	44.1	40.0	36.8	39.8	35.0	31.7	29.2	31.0	27.3	24.7	22.7	23.6	20.7	18.8	17.3

X-Direction - partial displacements (fixed)

Y direction

F coeff	0.643		H TOT		
		22000	25000	27500	30000

Displacements [mm]

BRACED

Recap

Column	Beam	Ic	Ac	Ib	Eic	Eac	Eib	6500.0				6000.0				5500.0				5000.0			
								6.64E+05	5.84E+05	5.29E+05	4.87E+05	6.64E+05	5.84E+05	5.29E+05	4.87E+05	6.64E+05	5.84E+05	5.29E+05	4.87E+05	6.64E+05	5.84E+05	5.29E+05	4.87E+05
								u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30
CHS406	heb700	3.74E+08	1.96E+04	2.57E+09	7.68E+13	4.02E+09	5.27E+14	17.0	15.0	13.6	12.5	13.8	12.2	11.0	10.2	11.1	9.8	8.9	8.2	8.8	7.8	7.1	6.5
CHS457	heb700	9.70E+08	4.27E+04	2.57E+09	1.99E+14	8.75E+09	5.27E+14	6.6	5.8	5.3	4.8	5.4	4.7	4.3	3.9	4.3	3.8	3.5	3.2	3.4	3.0	2.7	2.5
CHS508	heb700	1.36E+09	4.79E+04	2.57E+09	2.79E+14	9.82E+09	5.27E+14	4.7	4.2	3.8	3.5	3.9	3.4	3.1	2.8	3.1	2.7	2.5	2.3	2.5	2.2	2.0	1.8
CHS559	heb700	1.85E+09	5.30E+04	2.57E+09	3.78E+14	1.09E+10	5.27E+14	3.5	3.1	2.8	2.6	2.9	2.5	2.3	2.1	2.3	2.0	1.8	1.7	1.8	1.6	1.5	1.3
CHS610	heb700	2.43E+09	5.81E+04	2.57E+09	4.99E+14	1.19E+10	5.27E+14	2.7	2.3	2.1	2.0	2.2	1.9	1.7	1.6	1.8	1.5	1.4	1.3	1.4	1.2	1.1	1.0
CHS660	heb700	3.12E+09	6.31E+04	2.57E+09	6.40E+14	1.29E+10	5.27E+14	2.1	1.8	1.7	1.5	1.7	1.5	1.4	1.3	1.4	1.2	1.1	1.0	1.1	1.0	0.9	0.8
CHS406	heb800	3.74E+08	1.96E+04	3.59E+09	7.68E+13	4.02E+09	7.36E+14	14.8	13.0	11.8	10.9	12.1	10.6	9.6	8.8	9.7	8.5	7.7	7.1	7.7	6.8	6.1	5.7
CHS457	heb800	9.70E+08	4.27E+04	3.59E+09	1.99E+14	8.75E+09	7.36E+14	5.8	5.1	4.6	4.2	4.7	4.1	3.7	3.4	3.8	3.3	3.0	2.8	3.0	2.6	2.4	2.2
CHS508	heb800	1.36E+09	4.79E+04	3.59E+09	2.79E+14	9.82E+09	7.36E+14	4.1	3.6	3.3	3.0	3.4	3.0	2.7	2.5	2.7	2.4	2.2	2.0	2.2	1.9	1.7	1.6
CHS559	heb800	1.85E+09	5.30E+04	3.59E+09	3.78E+14	1.09E+10	7.36E+14	3.0	2.7	2.4	2.2	2.5	2.2	2.0	1.8	2.0	1.8	1.6	1.5	1.6	1.4	1.3	1.2
CHS610	heb800	2.43E+09	5.81E+04	3.59E+09	4.99E+14	1.19E+10	7.36E+14	2.3	2.0	1.9	1.7	1.9	1.7	1.5	1.4	1.5	1.3	1.2	1.1	1.2	1.1	1.0	0.9
CHS660	heb800	3.12E+09	6.31E+04	3.59E+09	6.40E+14	1.29E+10	7.36E+14	1.8	1.6	1.5	1.3	1.5	1.3	1.2	1.1	1.2	1.1	1.0	0.9	1.0	0.8	0.8	0.7
CHS406	heb900	3.74E+08	1.96E+04	4.94E+09	7.68E+13	4.02E+09	1.01E+15	13.0	11.5	10.4	9.6	10.6	9.3	8.5	7.8	8.5	7.5	6.8	6.3	6.8	6.0	5.4	5.0
CHS457	heb900	9.70E+08	4.27E+04	4.94E+09	1.99E+14	8.75E+09	1.01E+15	5.1	4.5	4.0	3.7	4.1	3.6	3.3	3.0	3.3	2.9	2.6	2.4	2.6	2.3	2.1	1.9
CHS508	heb900	1.36E+09	4.79E+04	4.94E+09	2.79E+14	9.82E+09	1.01E+15	3.6	3.2	2.9	2.7	3.0	2.6	2.4	2.2	2.4	2.1	1.9	1.7	1.9	1.7	1.5	1.4
CHS559	heb900	1.85E+09	5.30E+04	4.94E+09	3.78E+14	1.09E+10	1.01E+15	2.7	2.4	2.1	2.0	2.2	1.9	1.7	1.6	1.8	1.6	1.4	1.3	1.4	1.2	1.1	1.0
CHS610	heb900	2.43E+09	5.81E+04	4.94E+09	4.99E+14	1.19E+10	1.01E+15	2.0	1.8	1.6	1.5	1.7	1.5	1.3	1.2	1.3	1.2	1.1	1.0	1.1	0.9	0.9	0.8
CHS660	heb900	3.12E+09	6.31E+04	4.94E+09	6.40E+14	1.29E+10	1.01E+15	1.6	1.4	1.3	1.2	1.3	1.2	1.0	1.0	1.1	0.9	0.8	0.8	0.8	0.7	0.7	0.6

UNBRACED

Recap

Column	Beam	Ic	Ac	Ib	Eic	Eac	Eib	6500.0				6000.0				5500.0				5000.0			
								6.64E+05	5.84E+05	5.29E+05	4.87E+05	6.64E+05	5.84E+05	5.29E+05	4.87E+05	6.64E+05	5.84E+05	5.29E+05	4.87E+05	6.64E+05	5.84E+05	5.29E+05	4.87E+05
								u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30
CHS406	heb700	3.74E+08	1.96E+04	2.57E+09	7.68E+13	4.02E+09	5.27E+14	163.2	143.6	130.1	119.7	128.7	113.2	102.6	94.3	99.4	87.5	79.2	72.9	74.9	65.9	59.7	55.0
CHS457	heb700	9.70E+08	4.27E+04	2.57E+09	1.99E+14	8.75E+09	5.27E+14	65.9	58.0	52.6	48.3	52.2	45.9	41.6	38.3	40.5	35.6	32.2	29.7	30.6	27.0	24.4	22.5
CHS508	heb700	1.36E+09	4.79E+04	2.57E+09	2.79E+14	9.82E+09	5.27E+14	48.3	42.5	38.5	35.4	38.3	33.7	30.5	28.1	29.8	26.2	23.7	21.8	22.6	19.9	18.0	16.6
CHS559	heb700	1.85E+09	5.30E+04	2.57E+09	3.78E+14	1.09E+10	5.27E+14	36.8	32.4	29.4	27.0	29.3	25.7	23.3	21.5	22.8	20.1	18.2	16.7	17.4	15.3	13.8	12.7
CHS610	heb700	2.43E+09	5.81E+04	2.57E+09	4.99E+14	1.19E+10	5.27E+14	29.0	25.5	23.1	21.3	23.1	20.3	18.4	16.9	18.0	15.9	14.4	13.2	13.8	12.1	11.0	10.1
CHS660	heb700	3.12E+09	6.31E+04	2.57E+09	6.40E+14	1.29E+10	5.27E+14	23.6	20.7	18.8	17.3	18.8	16.5	15.0	13.8	14.7	13.0	11.7	10.8	11.3	9.9	9.0	8.3
CHS406	heb800	3.74E+08	1.96E+04	3.59E+09	7.68E+13	4.02E+09	7.36E+14	161.8	142.4	129.0	118.6	127.5	112.2	101.6	93.5	98.4	86.6	78.4	72.2	74.1	65.2	59.1	54.4
CHS457	heb800	9.70E+08	4.27E+04	3.59E+09	1.99E+14	8.75E+09	7.36E+14	64.6	56.8	51.5	47.4	51.0	44.9	40.7	37.4	39.5	34.8	31.5	29.0	29.9	26.3	23.8	21.9
CHS508	heb800	1.36E+09	4.79E+04	3.59E+09	2.79E+14	9.82E+09	7.36E+14	47.0	41.4	37.5	34.5	37.2	32.7	29.6	27.3	28.8	25.4	23.0	21.1	21.8	19.2	17.4	16.0
CHS559	heb800	1.85E+09	5.30E+04	3.59E+09	3.78E+14	1.09E+10	7.36E+14	35.5	31.3	28.3	26.1	28.2	24.8	22.4	20.7	21.9	19.3	17.4	16.1	16.6	14.6	13.2	12.2
CHS610	heb800	2.43E+09	5.81E+04	3.59E+09	4.99E+14	1.19E+10	7.36E+14	27.7	24.4	22.1	20.3	22.0	19.4	17.6	16.2	17.2	15.1	13.7	12.6	13.1	11.5	10.4	9.6
CHS660	heb800	3.12E+09	6.31E+04	3.59E+09	6.40E+14	1.29E+10	7.36E+14	22.3	19.7	17.8	16.4	17.8	15.6	14.2	13.0	13.9	12.2	11.1	10.2	10.6	9.3	8.4	7.8
CHS406	heb900	3.74E+08	1.96E+04	4.94E+09	7.68E+13	4.02E+09	1.01E+15	160.8	141.5	128.2	117.9	126.7	111.5	101.0	92.9	97.7	86.0	77.9	71.7	73.5	64.7	58.6	53.9
CHS457	heb900	9.70E+08	4.27E+04	4.94E+09	1.99E+14	8.75E+09	1.01E+15	63.6	56.0	50.7	46.7	50.2	44.2	40.0	36.8	38.8	34.2	31.0	28.5	29.3	25.8	23.4	21.5
CHS508	heb900	1.36E+09	4.79E+04	4.94E+09	2.79E+14	9.82E+09	1.01E+15	46.1	40.5	36.7	33.8	36.4	32.0	29.0	26.7	28.2	24.8	22.5	20.7	21.3	18.7	17.0	15.6
CHS559	heb900	1.85E+09	5.30E+04	4.94E+09	3.78E+14	1.09E+10	1.01E+15	34.6	30.5	27.6	25.4	27.4	24.1	21.8	20.1	21.2	18.7	16.9	15.6	16.1	14.2	12.8	11.8
CHS610	heb900	2.43E+09	5.81E+04	4.94E+09	4.99E+14	1.19E+10	1.01E+15	26.8	23.6	21.4	19.7	21.3	18.7	17.0	15.6	16.5	14.5	13.2	12.1	12.5	11.0	10.0	9.2
CHS660	heb900	3.12E+09	6.31E+04	4.94E+09	6.40E+14	1.29E+10	1.01E+15	21.5	18.9	17.1	15.7	17.0	15.0	13.6	12.5	13.3	11.7	10.6	9.7	10.1	8.9	8.0	7.4

X-Direction - total displacements (hinged)

X- Direction	H22								H25								H27.5								H30							
nfr	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
nno	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
nuf	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Hi	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0
Layout 1	504.7	399.1	309.5	234.5	880.2	694.0	536.1	404.2	444.2	351.2	272.3	206.3	774.6	610.7	471.8	355.7	402.3	318.1	246.7	186.9	701.6	553.2	427.4	322.2	370.1	292.7	226.9	171.9	645.5	508.9	393.2	296.4
	203.3	161.2	125.5	95.5	355.6	281.4	218.2	165.3	178.9	141.9	110.4	84.0	313.0	247.6	192.0	145.5	162.0	128.5	100.0	76.1	283.5	224.3	174.0	131.8	149.1	118.2	92.0	70.0	260.8	206.3	160.0	121.2
	148.7	118.1	92.1	70.2	260.6	206.6	160.6	122.0	130.8	104.0	81.1	61.8	229.4	181.8	141.4	107.4	118.5	94.2	73.4	56.0	207.8	164.7	128.0	97.2	109.0	86.6	67.5	51.5	191.1	151.5	117.8	89.5
	113.1	90.0	70.3	53.8	198.7	157.8	123.0	93.7	99.5	79.2	61.9	47.3	174.8	138.9	108.2	82.4	90.1	71.8	56.1	42.9	158.4	125.8	98.0	74.7	82.9	66.0	51.6	39.4	145.7	115.7	90.2	68.7
	88.8	70.8	55.5	42.5	156.4	124.6	97.3	74.4	78.1	62.3	48.8	37.4	137.7	109.6	85.7	65.4	70.8	56.5	44.2	33.9	124.7	99.3	77.6	59.3	65.1	52.0	40.7	31.2	114.7	91.4	71.4	54.5
	71.9	57.5	45.2	34.7	127.1	101.4	79.5	60.9	63.3	50.6	39.7	30.5	111.9	89.3	69.9	53.6	57.4	45.9	36.0	27.7	101.3	80.9	63.3	48.5	52.8	42.2	33.1	25.5	93.2	74.4	58.3	44.6
	495.2	391.2	303.0	229.2	872.7	687.6	530.8	399.8	435.8	344.2	266.6	201.7	768.0	605.1	467.1	351.8	394.7	311.8	241.5	182.7	695.6	548.1	423.1	318.7	363.1	286.9	222.2	168.1	640.0	504.3	389.2	293.2
	197.3	156.2	121.3	92.1	348.3	275.2	213.1	161.1	173.6	137.5	106.8	81.0	306.5	242.2	187.5	141.7	157.2	124.5	96.7	73.4	277.7	219.4	169.8	128.4	144.7	114.5	89.0	67.5	255.5	201.8	156.2	118.1
	143.4	113.7	88.4	67.3	253.5	200.6	155.6	117.8	126.2	100.0	77.8	59.2	223.1	176.5	136.9	103.7	114.3	90.6	70.5	53.6	202.1	159.9	124.0	93.9	105.1	83.4	64.9	49.3	185.9	147.1	114.1	86.4
	108.2	86.0	67.0	51.1	191.7	151.9	118.1	89.7	95.2	75.7	59.0	44.9	168.7	133.7	103.9	78.9	86.3	68.5	53.4	40.7	152.8	121.1	94.1	71.5	79.4	63.0	49.1	37.4	140.6	111.4	86.6	65.7
	84.3	67.1	52.4	40.0	149.6	118.8	92.6	70.5	74.2	59.1	46.1	35.2	131.7	104.6	81.4	62.0	67.2	53.5	41.8	31.9	119.3	94.7	73.8	56.2	61.9	49.2	38.4	29.4	109.7	87.1	67.9	51.7
	67.8	54.0	42.3	32.4	120.5	95.9	74.9	57.1	59.7	47.6	37.2	28.5	106.0	84.4	65.9	50.3	54.0	43.1	33.7	25.8	96.1	76.4	59.7	45.5	49.7	39.6	31.0	23.7	88.4	70.3	54.9	41.9
	487.9	385.1	298.0	225.2	867.5	683.2	527.1	396.8	429.3	338.9	262.3	198.2	763.4	601.3	463.8	349.1	388.9	307.0	237.6	179.5	691.5	544.6	420.1	316.3	357.8	282.4	218.6	165.2	636.2	501.0	386.5	291.0
	192.8	152.5	118.3	89.6	343.3	270.9	209.5	158.1	169.7	134.2	104.1	78.8	302.1	238.4	184.3	139.1	153.7	121.6	94.3	71.4	273.6	215.9	167.0	126.0	141.4	111.8	86.7	65.7	251.7	198.6	153.6	115.9
	139.5	110.4	85.7	65.1	248.5	196.3	152.0	114.9	122.7	97.2	75.4	57.3	218.7	172.8	133.8	101.1	111.2	88.0	68.3	51.9	198.1	156.5	121.2	91.6	102.3	81.0	62.9	47.7	182.2	144.0	111.5	84.3
	104.7	83.0	64.6	49.1	186.7	147.7	114.6	86.8	92.1	73.1	56.8	43.2	164.3	130.0	100.8	76.4	83.5	66.2	51.5	39.1	148.9	117.8	91.3	69.2	76.8	60.9	47.3	36.0	136.9	108.3	84.0	63.6
	81.1	64.4	50.2	38.2	144.8	114.7	89.1	67.7	71.4	56.7	44.1	33.6	127.4	101.0	78.5	59.5	64.6	51.3	40.0	30.4	115.4	91.5	71.1	53.9	59.5	47.2	36.8	28.0	106.2	84.1	65.4	49.6
	64.8	51.5	40.2	30.7	115.8	91.9	71.5	54.4	57.0	45.3	35.4	27.0	101.9	80.9	63.0	47.9	51.6	41.1	32.0	24.4	92.3	73.3	57.0	43.4	47.5	37.8	29.5	22.5	84.9	67.4	52.5	39.9

X- Direction	H22								H25								H27.5								H30							
nfr	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0
nno	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
nuf	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Hi	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0
Layout 2	195.7	158.8	127.2	100.5	482.0	380.1	293.6	221.4	209.1	139.7	112.0	88.5	424.2	334.5	258.4	194.8	156.0	126.6	101.4	80.1	384.2	302.9	234.0	176.4	143.5	116.4	93.3	73.7	353.5	278.7	215.3	162.3
	76.3	62.0	49.8	39.4	194.8	154.1	119.5	90.5	82.1	54.6	43.8	34.6	171.4	135.6	105.2	79.7	60.9	49.5	39.7	31.4	155.2	122.8	95.3	72.2	56.0	45.5	36.5	28.9	142.8	113.0	87.6	66.4
	54.8	44.5	35.7	28.3	142.7	113.2	88.0	66.8	59.1	39.2	31.4	24.9	125.6	99.6	77.4	58.8	43.7	35.5	28.5	22.5	113.8	90.2	70.1	53.3	40.2	32.7	26.2	20.7	104.7	83.0	64.5	49.0
	40.7	33.1	26.6	21.1	108.8	86.4	67.4	51.3	44.1	29.1	23.4	18.5	95.7	76.1	59.3	45.1	32.4	26.4	21.2	16.8	86.7	68.9	53.7	40.9	29.8	24.3	19.5	15.4	79.8	63.4	49.4	37.6
	31.1	25.3	20.4	16.1	85.7	68.2	53.3	40.7	34.0	22.3	17.9	14.2	75.4	60.0	46.9	35.8	24.8	20.2	16.2	12.9	68.3	54.4	42.5	32.5	22.8	18.6	14.9	11.8	62.8	50.0	39.1	29.9
	24.5	20.0	16.0	12.7	69.6	55.6	43.5	33.3	26.9	17.6	14.1	11.2	61.3	48.9	38.3	29.3	19.5	15.9	12.8	10.1	55.5	44.3	34.7	26.6	18.0	14.6	11.8	9.3	51.0	40.7	31.9	24.4
	173.0	140.3	112.4	88.7	477.9	376.6	290.7	218.9	188.8	123.5	98.9	78.1	420.6	331.4	255.8	192.7	137.9	111.8	89.6	70.7	380.9	300.2	231.7	174.5	126.9	102.9	82.4	65.1	350.5	276.2	213.2	160.6
	67.4	54.8	43.9	34.7	190.8	150.7	116.7	88.2	73.9	48.2	38.6	30.5	167.9	132.6	102.7	77.6	53.8	43.7	35.0	27.7	152.1	120.1	93.0	70.3	49.5	40.2	32.2	25.4	139.9	110.5	85.6	64.7
	48.3	39.3	31.5	24.9	138.8	109.8	85.2	64.5	53.2	34.6	27.7	21.9	122.2	96.7	75.0	56.8	38.5	31.3	25.1	19.9	110.7	87.5	67.9	51.4	35.4	28.8	23.1	18.3	101.8	80.5	62.5	47.3
	35.9	29.2	23.4	18.5	105.0	83.2	64.7	49.1	39.6	25.7	20.6	16.3	92.4	73.2	56.9	43.2	28.6	23.3	18.7	14.8	83.7	66.3	51.5	39.1	26.3	21.4	17.2	13.6	77.0	61.0	47.4	36.0
	27.4	22.3	17.9	14.2	81.9	65.1	50.7	38.6	30.4	19.6	15.8	12.5	72.1	57.3	44.6	34.0	21.9	17.8	14.3	11.3	65.3	51.9	40.4	30.8	20.1	16.4	13.1	10.4	60.1	47.7	37.2	28.3
	21.6	17.6	14.1	11.2	66.0	52.5	41.0	31.3	24.0	15.5	12.4	9.8	58.1	46.2	36.1	27.5	17.2	14.0	11.2	8.9	52.6	41.9	32.7	24.9	15.8	12.9	10.3	8.2	48.4	38.5	30.1	22.9
	154.5	125.3	100.3	79.1	475.1	374.2	288.6	217.3	172.3	110.2	88.2	69.6	418.1	329.3	254.0	191.2	123.2	99.9	79.9	63.1	378.7	298.2	230.1	173.2	113.3	91.9	73.5	58.0	348.4	274.4	211.7	159.3
	60.2	48.9	39.1	30.9	188.0	148.3	114.7	86.6	67.4	43.0	34.4	27.2	165.4	130.5	100.9	76.2	48.0	38.9	31.2	24.6	149.8	118.2	91.4	69.0	44.1	35.8	28.7	22.7	137.9	108.8	84.1	63.5
	43.1	35.0	28.1	22.2	136.1	107.5	83.2	62.9	48.4	30.8	24.7	19.5	119.7	94.6	73.3	55.4	34.4	27.9	22.4	17.7	108.5	85.7	66.4	50.2	31.6	25.7	20.6	16.3	99.8	78.8	61.0	46.2
	32.0	26.0	20.8	16.5	102.3	80.9	62.7	47.5	36.0	22.9	18.3	14.5	90.0	71.2	55.2	41.8	25.5	20.7	16.6	13.1	81.5	64.5	50.0	37.9	23.5	19.1	15.3	12.1	75.0	59.3	46.0	34.9
	24.4	19.9	15.9	12.6	79.3	62.8	48.8	37.1	27.6	17.5	14.0	11.1	69.8	55.3	43.0	32.6	19.5	15.8	12.7	10.1	63.2	50.1	38.9	29.5	17.9	14.6	11.7	9.3	58.2	46.1	35.8	27.2
	19.2	15.6	12.5	9.9	63.4	50.3	39.2	29.8	21.8	13.8	11.0	8.7	55.8	44.3	34.5	26.2	15.3	12.5	10.0	7.9	50.5	40.1	31.2	23.8	14.1	11.5	9.2	7.3	46.5	36.9	28.7	21.9

X-Direction - total displacements (fixed

X- Direction	H22								H25								H27.5								H30							
nfr	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
nno	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
nuf	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Hi	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0
Layout 1	216.1	170.9	132.5	100.4	376.9	297.2	229.6	173.1	190.2	150.4	116.6	88.4	331.7	261.5	202.0	152.3	172.3	136.2	105.6	80.0	300.4	236.9	183.0	138.0	158.5	125.3	97.2	73.6	276.4	217.9	168.4	126.9
	87.0	69.0	53.7	40.9	152.3	120.5	93.5	70.8	76.6	60.8	47.3	36.0	134.0	106.0	82.2	62.3	69.4	55.0	42.8	32.6	121.4	96.0	74.5	56.4	63.8	50.6	39.4	30.0	111.7	88.4	68.5	51.9
	63.7	50.6	39.4	30.1	111.6	88.5	68.8	52.2	56.0	44.5	34.7	26.5	98.2	77.9	60.5	46.0	50.7	40.3	31.4	24.0	89.0	70.5	54.8	41.6	46.7	37.1	28.9	22.1	81.9	64.9	50.4	38.3
	48.4	38.5	30.1	23.0	85.1	67.6	52.7	40.1	42.6	33.9	26.5	20.3	74.9	59.5	46.4	35.3	38.6	30.7	24.0	18.4	67.8	53.9	42.0	32.0	35.5	28.3	22.1	16.9	62.4	49.6	38.6	29.4
	38.0	30.3	23.8	18.2	67.0	53.3	41.7	31.8	33.5	26.7	20.9	16.0	59.0	46.9	36.7	28.0	30.3	24.2	18.9	14.5	53.4	42.5	33.2	25.4	27.9	22.2	17.4	13.4	49.1	39.1	30.6	23.3
	30.8	24.6	19.3	14.9	54.4	43.4	34.0	26.1	27.1	21.7	17.0	13.1	47.9	38.2	29.9	22.9	24.6	19.6	15.4	11.8	43.4	34.6	27.1	20.8	22.6	18.1	14.2	10.9	39.9	31.9	25.0	19.1
	212.1	167.5	129.7	98.2	373.7	294.5	227.3	171.2	186.6	147.4	114.2	86.4	328.9	259.1	200.0	150.7	169.0	133.5	103.4	78.2	297.9	234.7	181.2	136.5	155.5	122.8	95.1	72.0	274.1	215.9	166.7	125.6
	84.5	66.9	51.9	39.4	149.2	117.8	91.2	69.0	74.3	58.9	45.7	34.7	131.3	103.7	80.3	60.7	67.3	53.3	41.4	31.4	118.9	93.9	72.7	55.0	61.9	49.1	38.1	28.9	109.4	86.4	66.9	50.6
	61.4	48.7	37.9	28.8	108.6	85.9	66.6	50.5	54.0	42.8	33.3	25.3	95.5	75.6	58.6	44.4	48.9	38.8	30.2	23.0	86.5	68.5	53.1	40.2	45.0	35.7	27.8	21.1	79.6	63.0	48.9	37.0
	46.3	36.8	28.7	21.9	82.1	65.1	50.6	38.4	40.8	32.4	25.2	19.2	72.2	57.2	44.5	33.8	36.9	29.3	22.9	17.4	65.4	51.9	40.3	30.6	34.0	27.0	21.0	16.0	60.2	47.7	37.1	28.2
	36.1	28.7	22.4	17.1	64.1	50.9	39.6	30.2	31.8	25.3	19.7	15.1	56.4	44.8	34.9	26.5	28.8	22.9	17.9	13.7	51.1	40.6	31.6	24.0	26.5	21.1	16.5	12.6	47.0	37.3	29.1	22.1
	29.0	23.1	18.1	13.9	51.6	41.1	32.1	24.5	25.5	20.4	15.9	12.2	45.4	36.1	28.2	21.5	23.1	18.4	14.4	11.1	41.1	32.7	25.6	19.5	21.3	17.0	13.3	10.2	37.8	30.1	23.5	17.9
	208.9	164.9	127.6	96.5	371.5	292.6	225.7	169.9	183.9	145.1	112.3	84.9	326.9	257.5	198.6	149.5	166.5	131.5	101.7	76.9	296.1	233.2	179.9	135.4	153.2	120.9	93.6	70.7	272.4	214.6	165.5	124.6
	82.6	65.3	50.6	38.4	147.0	116.0	89.7	67.7	72.7	57.5	44.6	33.8	129.4	102.1	78.9	59.6	65.8	52.1	40.4	30.6	117.2	92.5	71.5	54.0	60.6	47.9	37.1	28.1	107.8	85.1	65.8	49.6
	59.7	47.3	36.7	27.9	106.4	84.1	65.1	49.2	52.6	41.6	32.3	24.5	93.6	74.0	57.3	43.3	47.6	37.7	29.3	22.2	84.8	67.0	51.9	39.2	43.8	34.7	26.9	20.4	78.0	61.7	47.7	36.1
	44.8	35.5	27.6	21.0	80.0	63.3	49.1	37.2	39.5	31.3	24.3	18.5	70.4	55.7	43.2	32.7	35.7	28.3	22.0	16.7	63.7	50.4	39.1	29.6	32.9	26.1	20.3	15.4	58.6	46.4	36.0	27.3
	34.7	27.6	21.5	16.4	62.0	49.1	38.2	29.0	30.6	24.3	18.9	14.4	54.6	43.2	33.6	25.5	27.7	22.0	17.1	13.0	49.4	39.2	30.4	23.1	25.5	20.2	15.7	12.0	45.5	36.0	28.0	21.2
	27.7	22.1	17.2	13.1	49.6	39.4	30.6	23.3	24.4	19.4	15.1	11.6	43.6	34.6	27.0	20.5	22.1	17.6	13.7	10.5	39.5	31.4	24.4	18.6	20.3	16.2	12.6	9.6	36.4	28.9	22.5	17.1

X- Direction	H22								H25								H27.5								H30							
nfr	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0
nno	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
nuf	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Hi	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0
Layout 2	83.8	68.0	54.5	43.1	206.4	162.8	125.7	94.8	89.5	59.8	47.9	37.9	181.6	143.2	110.6	83.4	66.8	54.2	43.4	34.3	164.5	129.7	100.2	75.6	61.4	49.9	40.0	31.6	151.4	119.4	92.2	69.5
	32.7	26.6	21.3	16.9	83.4	66.0	51.2	38.8	35.2	23.4	18.7	14.8	73.4	58.1	45.0	34.1	26.1	21.2	17.0	13.4	66.5	52.6	40.8	30.9	24.0	19.5	15.6	12.4	61.2	48.4	37.5	28.4
	23.5	19.1	15.3	12.1	61.1	48.5	37.7	28.6	25.3	16.8	13.5	10.7	53.8	42.6	33.1	25.2	18.7	15.2	12.2	9.7	48.7	38.6	30.0	22.8	17.2	14.0	11.2	8.9	44.8	35.5	27.6	21.0
	17.4	14.2	11.4	9.0	46.6	37.0	28.8	22.0	18.9	12.5	10.0	7.9	41.0	32.6	25.4	19.3	13.9	11.3	9.1	7.2	37.1	29.5	23.0	17.5	12.8	10.4	8.3	6.6	34.2	27.1	21.2	16.1
	13.3	10.9	8.7	6.9	36.7	29.2	22.8	17.4	14.5	9.6	7.7	6.1	32.3	25.7	20.1	15.3	10.6	8.7	6.9	5.5	29.2	23.3	18.2	13.9	9.8	8.0	6.4	5.1	26.9	21.4	16.7	12.8
	10.5	8.5	6.9	5.4	29.8	23.8	18.6	14.3	11.5	7.5	6.0	4.8	26.2	20.9	16.4	12.6	8.4	6.8	5.5	4.3	23.8	19.0	14.9	11.4	7.7	6.3	5.0	4.0	21.9	17.4	13.7	10.5
	74.1	60.1	48.1	38.0	204.7	161.3	124.5	93.8	80.9	52.9	42.3	33.4	180.1	141.9	109.5	82.5	59.1	47.9	38.4	30.3	163.1	128.5	99.2	74.7	54.3	44.1	35.3	27.9	150.1	118.3	91.3	68.8
	28.9	23.5	18.8	14.9	81.7	64.5	50.0	37.8	31.7	20.6	16.5	13.1	71.9	56.8	44.0	33.2	23.0	18.7	15.0	11.8	65.1	51.4	39.8	30.1	21.2	17.2	13.8	10.9	59.9	47.3	36.6	27.7
	20.7	16.8	13.5	10.7	59.4	47.0	36.5	27.6	22.8	14.8	11.9	9.4	52.3	41.4	32.1	24.3	16.5	13.4	10.8	8.5	47.4	37.5	29.1	22.0	15.2	12.3	9.9	7.8	43.6	34.5	26.8	20.3
	15.4	12.5	10.0	7.9	44.9	35.6	27.7	21.0	17.0	11.0	8.8	7.0	39.6	31.4	24.4	18.5	12.3	10.0	8.0	6.3	35.8	28.4	22.1	16.8	11.3	9.2	7.4	5.8	33.0	26.1	20.3	15.4
	11.8	9.6	7.7	6.1	35.1	27.9	21.7	16.5	13.0	8.4	6.8	5.3	30.9	24.5	19.1	14.5	9.4	7.6	6.1	4.8	28.0	22.2	17.3	13.2	8.6	7.0	5.6	4.5	25.7	20.4	15.9	12.1
	9.2	7.5	6.0	4.8	28.3	22.5	17.6	13.4	10.3	6.6	5.3	4.2	24.9	19.8	15.4	11.8	7.4	6.0	4.8	3.8	22.5	17.9	14.0	10.7	6.8	5.5	4.4	3.5	20.7	16.5	12.9	9.8
	66.2	53.6	42.9	33.9	203.4	160.2	123.6	93.0	73.8	47.2	37.8	29.8	179.0	141.0	108.8	81.9	52.8	42.8	34.2	27.0	162.2	127.7	98.5	74.2	48.5	39.3	31.5	24.8	149.2	117.5	90.6	68.2
	25.8	20.9	16.8	13.2	80.5	63.5	49.1	37.1	28.8	18.4	14.7	11.6	70.8	55.9	43.2	32.6	20.5	16.7	13.4	10.6	64.2	50.6	39.2	29.6	18.9	15.3	12.3	9.7	59.0	46.6	36.0	27.2
	18.5	15.0	12.0	9.5	58.3	46.0	35.6	27.0	20.7	13.2	10.6	8.4	51.3	40.5	31.4	23.7	14.7	12.0	9.6	7.6	46.4	36.7	28.4	21.5	13.5	11.0	8.8	7.0	42.7	33.8	26.1	19.8
	13.7	11.1	8.9	7.1	43.8	34.6	26.9	20.4	15.4	9.8	7.9	6.2	38.5	30.5	23.6	17.9	10.9	8.9	7.1	5.6	34.9	27.6	21.4	16.2	10.1	8.2	6.5	5.2	32.1	25.4	19.7	14.9
	10.5	8.5	6.8	5.4	34.0	26.9	20.9	15.9	11.8	7.5	6.0	4.8	29.9	23.7	18.4	14.0	8.3	6.8	5.4	4.3	27.1	21.4	16.7	12.6	7.7	6.2	5.0	4.0	24.9	19.7	15.3	11.6
	8.2	6.7	5.4	4.3	27.2	21.6	16.8	12.8	9.3	5.9	4.7	3.7	23.9	19.0	14.8	11.2	6.6	5.3	4.3	3.4	21.6	17.2	13.4	10.2	6.0	4.9	3.9	3.1	19.9	15.8	12.3	9.4

Y-Direction - partial displacements (hinged)

Y direction H TOT Displacements [mm]

F coeff 0.766 22000 25000 27500 30000

BRACED

Recap

								6500.0				6000.0				5500.0				5000.0			
								1.85E+06	1.63E+06	1.47E+06	1.35E+06	1.85E+06	1.63E+06	1.47E+06	1.35E+06	1.85E+06	1.63E+06	1.47E+06	1.35E+06	1.85E+06	1.63E+06	1.47E+06	1.35E+06
Column	Beam	Ic	Ac	Ib	Eic	Eac	Eib	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30
CHS406	heb700	3.74E+08	1.96E+04	2.57E+09	7.68E+13	4.02E+09	5.27E+14	72.4	63.7	57.7	53.1	60.9	53.6	48.5	44.6	50.7	44.6	40.4	37.2	42.4	37.3	33.8	31.1
CHS457	heb700	9.70E+08	4.27E+04	2.57E+09	1.99E+14	8.75E+09	5.27E+14	28.0	24.6	22.3	20.5	23.5	20.7	18.8	17.3	19.6	17.3	15.6	14.4	16.4	14.4	13.1	12.0
CHS508	heb700	1.36E+09	4.79E+04	2.57E+09	2.79E+14	9.82E+09	5.27E+14	20.0	17.6	15.9	14.6	16.8	14.8	13.4	12.3	14.0	12.3	11.1	10.3	11.7	10.3	9.3	8.6
CHS559	heb700	1.85E+09	5.30E+04	2.57E+09	3.78E+14	1.09E+10	5.27E+14	14.7	13.0	11.7	10.8	12.4	10.9	9.9	9.1	10.3	9.1	8.2	7.6	8.6	7.6	6.9	6.3
CHS610	heb700	2.43E+09	5.81E+04	2.57E+09	4.99E+14	1.19E+10	5.27E+14	11.2	9.8	8.9	8.2	9.4	8.3	7.5	6.9	7.8	6.9	6.2	5.7	6.5	5.8	5.2	4.8
CHS660	heb700	3.12E+09	6.31E+04	2.57E+09	6.40E+14	1.29E+10	5.27E+14	8.7	7.7	7.0	6.4	7.3	6.5	5.9	5.4	6.1	5.4	4.9	4.5	5.1	4.5	4.1	3.7
CHS406	heb800	3.74E+08	1.96E+04	3.59E+09	7.68E+13	4.02E+09	7.36E+14	63.1	55.5	50.3	46.3	53.0	46.7	42.3	38.9	44.2	38.9	35.2	32.4	36.9	32.5	29.4	27.1
CHS457	heb800	9.70E+08	4.27E+04	3.59E+09	1.99E+14	8.75E+09	7.36E+14	24.4	21.5	19.4	17.9	20.5	18.0	16.3	15.0	17.1	15.0	13.6	12.5	14.3	12.6	11.4	10.5
CHS508	heb800	1.36E+09	4.79E+04	3.59E+09	2.79E+14	9.82E+09	7.36E+14	17.4	15.3	13.9	12.8	14.6	12.9	11.7	10.7	12.2	10.7	9.7	8.9	10.2	9.0	8.1	7.5
CHS559	heb800	1.85E+09	5.30E+04	3.59E+09	3.78E+14	1.09E+10	7.36E+14	12.8	11.3	10.2	9.4	10.8	9.5	8.6	7.9	9.0	7.9	7.2	6.6	7.5	6.6	6.0	5.5
CHS610	heb800	2.43E+09	5.81E+04	3.59E+09	4.99E+14	1.19E+10	7.36E+14	9.7	8.6	7.8	7.1	8.2	7.2	6.5	6.0	6.8	6.0	5.4	5.0	5.7	5.0	4.5	4.2
CHS660	heb800	3.12E+09	6.31E+04	3.59E+09	6.40E+14	1.29E+10	7.36E+14	7.6	6.7	6.1	5.6	6.4	5.6	5.1	4.7	5.3	4.7	4.2	3.9	4.4	3.9	3.5	3.3
CHS406	heb900	3.74E+08	1.96E+04	4.94E+09	7.68E+13	4.02E+09	1.01E+15	55.5	48.8	44.2	40.7	46.7	41.1	37.2	34.2	38.9	34.2	31.0	28.5	32.5	28.6	25.9	23.8
CHS457	heb900	9.70E+08	4.27E+04	4.94E+09	1.99E+14	8.75E+09	1.01E+15	21.4	18.9	17.1	15.7	18.0	15.9	14.4	13.2	15.0	13.2	12.0	11.0	12.5	11.0	10.0	9.2
CHS508	heb900	1.36E+09	4.79E+04	4.94E+09	2.79E+14	9.82E+09	1.01E+15	15.3	13.5	12.2	11.2	12.9	11.3	10.3	9.4	10.7	9.4	8.5	7.9	8.9	7.9	7.1	6.6
CHS559	heb900	1.85E+09	5.30E+04	4.94E+09	3.78E+14	1.09E+10	1.01E+15	11.3	9.9	9.0	8.3	9.5	8.4	7.6	7.0	7.9	7.0	6.3	5.8	6.6	5.8	5.3	4.8
CHS610	heb900	2.43E+09	5.81E+04	4.94E+09	4.99E+14	1.19E+10	1.01E+15	8.6	7.5	6.8	6.3	7.2	6.3	5.7	5.3	6.0	5.3	4.8	4.4	5.0	4.4	4.0	3.7
CHS660	heb900	3.12E+09	6.31E+04	4.94E+09	6.40E+14	1.29E+10	1.01E+15	6.7	5.9	5.3	4.9	5.6	4.9	4.5	4.1	4.7	4.1	3.7	3.4	3.9	3.4	3.1	2.9

UNBRACED

Recap

								6500.0				6000.0				5500.0				5000.0			
								1.85E+06	1.63E+06	1.47E+06	1.35E+06	1.85E+06	1.63E+06	1.47E+06	1.35E+06	1.85E+06	1.63E+06	1.47E+06	1.35E+06	1.85E+06	1.63E+06	1.47E+06	1.35E+06
Column	Beam	Ic	Ac	Ib	Eic	Eac	Eib	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30
CHS406	heb700	3.74E+08	1.96E+04	2.57E+09	7.68E+13	4.02E+09	5.27E+14	670.1	589.7	534.1	491.4	527.6	464.3	420.6	386.9	406.9	358.1	324.4	298.4	306.2	269.5	244.1	224.6
CHS457	heb700	9.70E+08	4.27E+04	2.57E+09	1.99E+14	8.75E+09	5.27E+14	263.9	232.2	210.3	193.5	208.1	183.1	165.8	152.6	160.7	141.4	128.1	117.9	121.2	106.6	96.6	88.8
CHS508	heb700	1.36E+09	4.79E+04	2.57E+09	2.79E+14	9.82E+09	5.27E+14	190.2	167.4	151.6	139.5	150.1	132.1	119.6	110.1	116.0	102.1	92.5	85.1	87.5	77.0	69.8	64.2
CHS559	heb700	1.85E+09	5.30E+04	2.57E+09	3.78E+14	1.09E+10	5.27E+14	142.1	125.1	113.3	104.2	112.2	98.7	89.4	82.3	86.8	76.4	69.2	63.7	65.5	57.7	52.2	48.1
CHS610	heb700	2.43E+09	5.81E+04	2.57E+09	4.99E+14	1.19E+10	5.27E+14	109.3	96.2	87.1	80.1	86.3	76.0	68.8	63.3	66.8	58.8	53.3	49.0	50.5	44.4	40.3	37.0
CHS660	heb700	3.12E+09	6.31E+04	2.57E+09	6.40E+14	1.29E+10	5.27E+14	86.5	76.1	68.9	63.4	68.3	60.1	54.5	50.1	52.9	46.6	42.2	38.8	40.0	35.2	31.9	29.3
CHS406	heb800	3.74E+08	1.96E+04	3.59E+09	7.68E+13	4.02E+09	7.36E+14	667.5	587.4	532.0	489.5	525.4	462.4	418.8	385.3	405.1	356.5	322.9	297.1	304.7	268.1	242.9	223.5
CHS457	heb800	9.70E+08	4.27E+04	3.59E+09	1.99E+14	8.75E+09	7.36E+14	261.5	230.2	208.5	191.8	206.1	181.4	164.3	151.1	159.1	140.0	126.8	116.7	119.8	105.5	95.5	87.9
CHS508	heb800	1.36E+09	4.79E+04	3.59E+09	2.79E+14	9.82E+09	7.36E+14	188.1	165.5	149.9	137.9	148.3	130.5	118.2	108.7	114.5	100.8	91.3	84.0	86.3	76.0	68.8	63.3
CHS559	heb800	1.85E+09	5.30E+04	3.59E+09	3.78E+14	1.09E+10	7.36E+14	140.1	123.3	111.7	102.8	110.5	97.3	88.1	81.1	85.5	75.2	68.1	62.7	64.5	56.7	51.4	47.3
CHS610	heb800	2.43E+09	5.81E+04	3.59E+09	4.99E+14	1.19E+10	7.36E+14	107.5	94.6	85.7	78.8	84.9	74.7	67.6	62.2	65.6	57.8	52.3	48.1	49.6	43.6	39.5	36.3
CHS660	heb800	3.12E+09	6.31E+04	3.59E+09	6.40E+14	1.29E+10	7.36E+14	84.9	74.7	67.6	62.2	67.0	59.0	53.4	49.2	51.9	45.7	41.4	38.0	39.2	34.5	31.2	28.7
CHS406	heb900	3.74E+08	1.96E+04	4.94E+09	7.68E+13	4.02E+09	1.01E+15	665.7	585.8	530.6	488.1	523.9	461.0	417.6	384.2	403.8	355.3	321.9	296.1	303.6	267.2	242.0	222.7
CHS457	heb900	9.70E+08	4.27E+04	4.94E+09	1.99E+14	8.75E+09	1.01E+15	259.9	228.7	207.1	190.6	204.7	180.1	163.2	150.1	157.9	139.0	125.9	115.8	118.9	104.6	94.8	87.2
CHS508	heb900	1.36E+09	4.79E+04	4.94E+09	2.79E+14	9.82E+09	1.01E+15	186.5	164.1	148.6	136.7	146.9	129.3	117.1	107.8	113.4	99.8	90.4	83.2	85.5	75.2	68.1	62.7
CHS559	heb900	1.85E+09	5.30E+04	4.94E+09	3.78E+14	1.09E+10	1.01E+15	138.6	122.0	110.5	101.7	109.3	96.2	87.1	80.2	84.4	74.3	67.3	61.9	63.6	56.0	50.7	46.7
CHS610	heb900	2.43E+09	5.81E+04	4.94E+09	4.99E+14	1.19E+10	1.01E+15	106.1	93.4	84.6	77.8	83.7	73.7	66.7	61.4	64.7	56.9	51.6	47.4	48.8	42.9	38.9	35.8
CHS660	heb900	3.12E+09	6.31E+04	4.94E+09	6.40E+14	1.29E+10	1.01E+15	83.6	73.6	66.6	61.3	66.0	58.1	52.6	48.4	51.0	44.9	40.7	37.4	38.5	33.9	30.7	28.2

EXTERNALLY BRACED

Recap

								6500.0				6000.0				5500.0				5000.0			
								1.85E+06	1.63E+06	1.47E+06	1.35E+06	1.85E+06	1.63E+06	1.47E+06	1.35E+06	1.85E+06	1.63E+06	1.47E+06	1.35E+06	1.85E+06	1.63E+06	1.47E+06	1.35E+06
Column	Beam	Ic	Ac	Ib	Eic	Eac	Eib	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30
CHS406	heb700	3.74E+08	1.96E+04	2.57E+09	7.68E+13	4.02E+09	5.27E+14	177.8	369.2	374.2	510.4	237.0	461.5	467.8	638.0	316.1	576.8	584.7	797.5	421.4	721.0	730.9	996.9
CHS457	heb700	9.70E+08	4.27E+04	2.57E+09	1.99E+14	8.75E+09	5.27E+14	69.6	144.3	146.3	199.3	92.8	180.4	182.9	249.2	123.7	225.5	228.6	311.5	164.9	281.8	285.7	389.3
CHS508	heb700	1.36E+09	4.79E+04	2.57E+09	2.79E+14	9.82E+09	5.27E+14	50.0	103.6	105.0	143.0	66.7	129.5	131.3	178.8	88.9	161.8	164.1	223.5	118.5	202.3	205.2	279.4
CHS559	heb700	1.85E+09	5.30E+04	2.57E+09	3.78E+14	1.09E+10	5.27E+14	37.2	77.0	78.1	106.3	49.6	96.3	97.7	132.9	66.1	120.4	122.1	166.1	88.2	150.4	152.6	207.7
CHS610	heb700	2.43E+09	5.81E+04	2.57E+09	4.99E+14	1.19E+10	5.27E+14	28.5	59.0	59.8	81.4	38.0	73.7	74.8	101.7	50.7	92.1	93.5	127.1	67.6	115.2	116.9	158.9
CHS660	heb700	3.12E+09	6.31E+04	2.57E+09	6.40E+14	1.29E+10	5.27E+14	22.5	46.4	47.2	64.1	30.0	58.0	58.9	80.1	40.0	72.6	73.7	100.1	53.3	90.7	92.1	125.1
CHS406	heb800	3.74E+08	1.96E+04	3.59E+09	7.68E+13	4.02E+09	7.36E+14	177.8	369.2	374.2	510.4	237.0	461.5	467.8	638.0	316.1	576.8	584.7	797.5	421.4	721.0	730.9	996.9
CHS457	heb800	9.70E+08	4.27E+04	3.59E+09	1.99E+14	8.75E+09	7.36E+14	69.6	144.3	146.3	199.3	92.8	180.4	182.9	249.2	123.7	225.5	228.6	311.5	164.9	281.8	285.7	389.3
CHS508	heb800	1.36E+09	4.79E+04	3.59E+09	2.79E+14	9.82E+09	7.36E+14	50.0	103.6	105.0	143.0	66.7	129.5	131.3	178.8	88.9	161.8	164.1	223.5	118.5	202.3	205.2	279.4
CHS559	heb800	1.85E+09	5.30E+04	3.59E+09	3.78E+14	1.09E+10	7.36E+14	37.2	77.0	78.1	106.3	49.6	96.3	97.7	132.9	66.1	120.4	122.1	166.1	88.2	150.4	152.6	207.7
CHS610	heb800	2.43E+09	5.81E+04	3.59E+09	4.99E+14	1.19E+10	7.36E+14	28.5	59.0	59.8	81.4	38.0	73.7	74.8	101.7	50.7	92.1	93.5	127.1	67.6	115.2	116.9	158.9
CHS660	heb800	3.12E+09	6.31E+04	3.59E+09	6.40E+14	1.29E+10	7.36E+14	22.5	46.4	47.2	64.1	30.0	58.0	58.9	80.1	40.0	72.6	73.7	100.1	53.3	90.7	92.1	125.1
CHS406	heb900	3.74E+08	1.96E+04	4.94E+09	7.68E+13	4.02E+09	1.01E+15	177.8	369.2	374.2	510.4	237.0	461.5	467.8	638.0	316.1	576.8	584.7	797.5	421.4	721.0	730.9	996.9
CHS457	heb900	9.70E+08	4.27E+04	4.94E+09	1.99E+14	8.75E+09	1.01E+15	69.6	144.3	146.3	199.3	92.8	180.4	182.9	249.2	123.7	225.5	228.6	311.5	164.9	281.8	285.7	389.3
CHS508	heb900	1.36E+09	4.79E+04	4.94E+09	2.79E+14	9.82E+09	1.01E+15	50.0	103.6	105.0	143.0	66.7	129.5	131.3	178.8	88.9	161.8	164.1	223.5	118.5	202.3	205.2	279.4
CHS559	heb900	1.85E+09	5.30E+04	4.94E+09	3.78E+14	1.09E+10	1.01E+15	37.2	77.0	78.1	106.3	49.6	96.3	97.7	132.9	66.1	120.4	122.1	166.1	88.2	150.4	152.6	207.7
CHS610	heb900	2.43E+09	5.81E+04	4.94E+09	4.99E+14	1.19E+10	1.01E+15	28.5	59.0	59.8	81.4	38.0	73.7	74.8	101.7	50.7	92.1	93.5	127.1	67.6	115.2	116.9	158.9
CHS660	heb900	3.12E+09	6.31E+04	4.94E+09	6.40E+14	1.29E+10	1.01E+15	22.5	46.4	47.2	64.1	30.0	58.0	58.9	80.1	40.0	72.6	73.7	100.1	53.3	90.7	92.1	125.1

Y-Direction - partial displacements (fixed)

Y direction

F coeff	0.766	H TOT	22000	25000	27500	30000

Displacements [mm]

BRACED

Recap

Column	Beam	Ic	Ac	Ib	Eic	Eac	Eib	6500.0				6000.0				5500.0				5000.0			
								7.91E+05	6.96E+05	6.30E+05	5.80E+05	7.91E+05	6.96E+05	6.30E+05	5.80E+05	7.91E+05	6.96E+05	6.30E+05	5.80E+05	7.91E+05	6.96E+05	6.30E+05	5.80E+05
								u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30
CHS406	heb700	3.74E+08	1.96E+04	2.57E+09	7.68E+13	4.02E+09	5.27E+14	31.0	27.3	24.7	22.7	26.1	22.9	20.8	19.1	21.7	19.1	17.3	15.9	18.1	16.0	14.5	13.3
CHS457	heb700	9.70E+08	4.27E+04	2.57E+09	1.99E+14	8.75E+09	5.27E+14	12.0	10.5	9.6	8.8	10.1	8.9	8.0	7.4	8.4	7.4	6.7	6.2	7.0	6.2	5.6	5.1
CHS508	heb700	1.36E+09	4.79E+04	2.57E+09	2.79E+14	9.82E+09	5.27E+14	8.5	7.5	6.8	6.3	7.2	6.3	5.7	5.3	6.0	5.3	4.8	4.4	5.0	4.4	4.0	3.7
CHS559	heb700	1.85E+09	5.30E+04	2.57E+09	3.78E+14	1.09E+10	5.27E+14	6.3	5.6	5.0	4.6	5.3	4.7	4.2	3.9	4.4	3.9	3.5	3.2	3.7	3.2	2.9	2.7
CHS610	heb700	2.43E+09	5.81E+04	2.57E+09	4.99E+14	1.19E+10	5.27E+14	4.8	4.2	3.8	3.5	4.0	3.5	3.2	3.0	3.4	3.0	2.7	2.5	2.8	2.5	2.2	2.1
CHS660	heb700	3.12E+09	6.31E+04	2.57E+09	6.40E+14	1.29E+10	5.27E+14	3.7	3.3	3.0	2.7	3.1	2.8	2.5	2.3	2.6	2.3	2.1	1.9	2.2	1.9	1.7	1.6
CHS406	heb800	3.74E+08	1.96E+04	3.59E+09	7.68E+13	4.02E+09	7.36E+14	27.0	23.8	21.5	19.8	22.7	20.0	18.1	16.7	18.9	16.7	15.1	13.9	15.8	13.9	12.6	11.6
CHS457	heb800	9.70E+08	4.27E+04	3.59E+09	1.99E+14	8.75E+09	7.36E+14	10.4	9.2	8.3	7.7	8.8	7.7	7.0	6.4	7.3	6.4	5.8	5.4	6.1	5.4	4.9	4.5
CHS508	heb800	1.36E+09	4.79E+04	3.59E+09	2.79E+14	9.82E+09	7.36E+14	7.4	6.6	5.9	5.5	6.3	5.5	5.0	4.6	5.2	4.6	4.2	3.8	4.4	3.8	3.5	3.2
CHS559	heb800	1.85E+09	5.30E+04	3.59E+09	3.78E+14	1.09E+10	7.36E+14	5.5	4.8	4.4	4.0	4.6	4.1	3.7	3.4	3.9	3.4	3.1	2.8	3.2	2.8	2.6	2.4
CHS610	heb800	2.43E+09	5.81E+04	3.59E+09	4.99E+14	1.19E+10	7.36E+14	4.2	3.7	3.3	3.1	3.5	3.1	2.8	2.6	2.9	2.6	2.3	2.1	2.4	2.1	1.9	1.8
CHS660	heb800	3.12E+09	6.31E+04	3.59E+09	6.40E+14	1.29E+10	7.36E+14	3.3	2.9	2.6	2.4	2.7	2.4	2.2	2.0	2.3	2.0	1.8	1.7	1.9	1.7	1.5	1.4
CHS406	heb900	3.74E+08	1.96E+04	4.94E+09	7.68E+13	4.02E+09	1.01E+15	23.8	20.9	18.9	17.4	20.0	17.6	15.9	14.7	16.6	14.6	13.3	12.2	13.9	12.2	11.1	10.2
CHS457	heb900	9.70E+08	4.27E+04	4.94E+09	1.99E+14	8.75E+09	1.01E+15	9.2	8.1	7.3	6.7	7.7	6.8	6.2	5.7	6.4	5.7	5.1	4.7	5.4	4.7	4.3	3.9
CHS508	heb900	1.36E+09	4.79E+04	4.94E+09	2.79E+14	9.82E+09	1.01E+15	6.5	5.8	5.2	4.8	5.5	4.8	4.4	4.0	4.6	4.0	3.7	3.4	3.8	3.4	3.1	2.8
CHS559	heb900	1.85E+09	5.30E+04	4.94E+09	3.78E+14	1.09E+10	1.01E+15	4.8	4.3	3.9	3.5	4.1	3.6	3.2	3.0	3.4	3.0	2.7	2.5	2.8	2.5	2.3	2.1
CHS610	heb900	2.43E+09	5.81E+04	4.94E+09	4.99E+14	1.19E+10	1.01E+15	3.7	3.2	2.9	2.7	3.1	2.7	2.5	2.3	2.6	2.3	2.0	1.9	2.1	1.9	1.7	1.6
CHS660	heb900	3.12E+09	6.31E+04	4.94E+09	6.40E+14	1.29E+10	1.01E+15	2.9	2.5	2.3	2.1	2.4	2.1	1.9	1.8	2.0	1.8	1.6	1.5	1.7	1.5	1.3	1.2

UNBRACED

Recap

Column	Beam	Ic	Ac	Ib	Eic	Eac	Eib	6500.0				6000.0				5500.0				5000.0			
								7.91E+05	6.96E+05	6.30E+05	5.80E+05	7.91E+05	6.96E+05	6.30E+05	5.80E+05	7.91E+05	6.96E+05	6.30E+05	5.80E+05	7.91E+05	6.96E+05	6.30E+05	5.80E+05
								u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30
CHS406	heb700	3.74E+08	1.96E+04	2.57E+09	7.68E+13	4.02E+09	5.27E+14	286.9	252.5	228.7	210.4	225.9	198.8	180.1	165.7	174.3	153.4	138.9	127.8	131.1	115.4	104.5	96.2
CHS457	heb700	9.70E+08	4.27E+04	2.57E+09	1.99E+14	8.75E+09	5.27E+14	113.0	99.4	90.1	82.9	89.1	78.4	71.0	65.3	68.8	60.6	54.9	50.5	51.9	45.7	41.4	38.0
CHS508	heb700	1.36E+09	4.79E+04	2.57E+09	2.79E+14	9.82E+09	5.27E+14	81.5	71.7	64.9	59.7	64.3	56.6	51.2	47.1	49.7	43.7	39.6	36.4	37.5	33.0	29.9	27.5
CHS559	heb700	1.85E+09	5.30E+04	2.57E+09	3.78E+14	1.09E+10	5.27E+14	60.9	53.6	48.5	44.6	48.0	42.3	38.3	35.2	37.2	32.7	29.6	27.3	28.1	24.7	22.4	20.6
CHS610	heb700	2.43E+09	5.81E+04	2.57E+09	4.99E+14	1.19E+10	5.27E+14	46.8	41.2	37.3	34.3	37.0	32.5	29.5	27.1	28.6	25.2	22.8	21.0	21.6	19.0	17.2	15.9
CHS660	heb700	3.12E+09	6.31E+04	2.57E+09	6.40E+14	1.29E+10	5.27E+14	37.0	32.6	29.5	27.2	29.3	25.8	23.3	21.5	22.7	19.9	18.1	16.6	17.1	15.1	13.7	12.6
CHS406	heb800	3.74E+08	1.96E+04	3.59E+09	7.68E+13	4.02E+09	7.36E+14	285.8	251.5	227.8	209.6	225.0	198.0	179.3	165.0	173.5	152.7	138.3	127.2	130.5	114.8	104.0	95.7
CHS457	heb800	9.70E+08	4.27E+04	3.59E+09	1.99E+14	8.75E+09	7.36E+14	112.0	98.6	89.3	82.1	88.3	77.7	70.4	64.7	68.1	60.0	54.3	50.0	51.3	45.2	40.9	37.6
CHS508	heb800	1.36E+09	4.79E+04	3.59E+09	2.79E+14	9.82E+09	7.36E+14	80.5	70.9	64.2	59.1	63.5	55.9	50.6	46.6	49.0	43.2	39.1	36.0	37.0	32.5	29.5	27.1
CHS559	heb800	1.85E+09	5.30E+04	3.59E+09	3.78E+14	1.09E+10	7.36E+14	60.0	52.8	47.8	44.0	47.3	41.7	37.7	34.7	36.6	32.2	29.2	26.8	27.6	24.3	22.0	20.2
CHS610	heb800	2.43E+09	5.81E+04	3.59E+09	4.99E+14	1.19E+10	7.36E+14	46.0	40.5	36.7	33.8	36.3	32.0	29.0	26.6	28.1	24.7	22.4	20.6	21.2	18.7	16.9	15.6
CHS660	heb800	3.12E+09	6.31E+04	3.59E+09	6.40E+14	1.29E+10	7.36E+14	36.3	32.0	29.0	26.6	28.7	25.3	22.9	21.0	22.2	19.5	17.7	16.3	16.8	14.8	13.4	12.3
CHS406	heb900	3.74E+08	1.96E+04	4.94E+09	7.68E+13	4.02E+09	1.01E+15	285.0	250.8	227.2	209.0	224.3	197.4	178.8	164.5	172.9	152.2	137.8	126.8	130.0	114.4	103.6	95.4
CHS457	heb900	9.70E+08	4.27E+04	4.94E+09	1.99E+14	8.75E+09	1.01E+15	111.3	97.9	88.7	81.6	87.7	77.1	69.9	64.3	67.6	59.5	53.9	49.6	50.9	44.8	40.6	37.3
CHS508	heb900	1.36E+09	4.79E+04	4.94E+09	2.79E+14	9.82E+09	1.01E+15	79.8	70.3	63.6	58.6	62.9	55.4	50.2	46.1	48.6	42.7	38.7	35.6	36.6	32.2	29.2	26.8
CHS559	heb900	1.85E+09	5.30E+04	4.94E+09	3.78E+14	1.09E+10	1.01E+15	59.4	52.2	47.3	43.5	46.8	41.2	37.3	34.3	36.2	31.8	28.8	26.5	27.3	24.0	21.7	20.0
CHS610	heb900	2.43E+09	5.81E+04	4.94E+09	4.99E+14	1.19E+10	1.01E+15	45.4	40.0	36.2	33.3	35.8	31.5	28.6	26.3	27.7	24.4	22.1	20.3	20.9	18.4	16.7	15.3
CHS660	heb900	3.12E+09	6.31E+04	4.94E+09	6.40E+14	1.29E+10	1.01E+15	35.8	31.5	28.5	26.2	28.3	24.9	22.5	20.7	21.8	19.2	17.4	16.0	16.5	14.5	13.1	12.1

EXTERNALLY BRACED

Recap

Column	Beam	Ic	Ac	Ib	Eic	Eac	Eib	6500.0				6000.0				5500.0				5000.0			
								7.91E+05	6.96E+05	6.30E+05	5.80E+05	7.91E+05	6.96E+05	6.30E+05	5.80E+05	7.91E+05	6.96E+05	6.30E+05	5.80E+05	7.91E+05	6.96E+05	6.30E+05	5.80E+05
								u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30	u22	u25	u27.5	u30
CHS406	heb700	3.74E+08	1.96E+04	2.57E+09	7.68E+13	4.02E+09	5.27E+14	76.1	158.1	160.3	218.6	101.5	197.6	200.3	273.2	135.3	247.0	250.4	341.5	180.5	308.8	313.0	426.9
CHS457	heb700	9.70E+08	4.27E+04	2.57E+09	1.99E+14	8.75E+09	5.27E+14	29.8	61.8	62.6	85.4	39.7	77.2	78.3	106.7	53.0	96.5	97.9	133.4	70.6	120.7	122.4	166.7
CHS508	heb700	1.36E+09	4.79E+04	2.57E+09	2.79E+14	9.82E+09	5.27E+14	21.4	44.4	45.0	61.3	28.5	55.4	56.2	76.6	38.1	69.3	70.3	95.7	50.7	86.6	87.9	119.6
CHS559	heb700	1.85E+09	5.30E+04	2.57E+09	3.78E+14	1.09E+10	5.27E+14	15.9	33.0	33.5	45.5	21.2	41.2	41.8	56.9	28.3	51.5	52.3	71.1	37.8	64.4	65.4	88.9
CHS610	heb700	2.43E+09	5.81E+04	2.57E+09	4.99E+14	1.19E+10	5.27E+14	12.2	25.2	25.6	34.8	16.3	31.6	32.0	43.6	21.7	39.5	40.0	54.4	28.9	49.3	50.1	68.1
CHS660	heb700	3.12E+09	6.31E+04	2.57E+09	6.40E+14	1.29E+10	5.27E+14	9.6	19.9	20.2	27.4	12.8	24.9	25.2	34.3	17.1	31.1	31.6	42.9	22.8	38.8	39.4	53.6
CHS406	heb800	3.74E+08	1.96E+04	3.59E+09	7.68E+13	4.02E+09	7.36E+14	76.1	158.1	160.3	218.6	101.5	197.6	200.3	273.2	135.3	247.0	250.4	341.5	180.5	308.8	313.0	426.9
CHS457	heb800	9.70E+08	4.27E+04	3.59E+09	1.99E+14	8.75E+09	7.36E+14	29.8	61.8	62.6	85.4	39.7	77.2	78.3	106.7	53.0	96.5	97.9	133.4	70.6	120.7	122.4	166.7
CHS508	heb800	1.36E+09	4.79E+04	3.59E+09	2.79E+14	9.82E+09	7.36E+14	21.4	44.4	45.0	61.3	28.5	55.4	56.2	76.6	38.1	69.3	70.3	95.7	50.7	86.6	87.9	119.6
CHS559	heb800	1.85E+09	5.30E+04	3.59E+09	3.78E+14	1.09E+10	7.36E+14	15.9	33.0	33.5	45.5	21.2	41.2	41.8	56.9	28.3	51.5	52.3	71.1	37.8	64.4	65.4	88.9
CHS610	heb800	2.43E+09	5.81E+04	3.59E+09	4.99E+14	1.19E+10	7.36E+14	12.2	25.2	25.6	34.8	16.3	31.6	32.0	43.6	21.7	39.5	40.0	54.4	28.9	49.3	50.1	68.1
CHS660	heb800	3.12E+09	6.31E+04	3.59E+09	6.40E+14	1.29E+10	7.36E+14	9.6	19.9	20.2	27.4	12.8	24.9	25.2	34.3	17.1	31.1	31.6	42.9	22.8	38.8	39.4	53.6
CHS406	heb900	3.74E+08	1.96E+04	4.94E+09	7.68E+13	4.02E+09	1.01E+15	76.1	158.1	160.3	218.6	101.5	197.6	200.3	273.2	135.3	247.0	250.4	341.5	180.5	308.8	313.0	426.9
CHS457	heb900	9.70E+08	4.27E+04	4.94E+09	1.99E+14	8.75E+09	1.01E+15	29.8	61.8	62.6	85.4	39.7	77.2	78.3	106.7	53.0	96.5	97.9	133.4	70.6	120.7	122.4	166.7
CHS508	heb900	1.36E+09	4.79E+04	4.94E+09	2.79E+14	9.82E+09	1.01E+15	21.4	44.4	45.0	61.3	28.5	55.4	56.2	76.6	38.1	69.3	70.3	95.7	50.7	86.6	87.9	119.6
CHS559	heb900	1.85E+09	5.30E+04	4.94E+09	3.78E+14	1.09E+10	1.01E+15	15.9	33.0	33.5	45.5	21.2	41.2	41.8	56.9	28.3	51.5	52.3	71.1	37.8	64.4	65.4	88.9
CHS610	heb900	2.43E+09	5.81E+04	4.94E+09	4.99E+14	1.19E+10	1.01E+15	12.2	25.2	25.6	34.8	16.3	31.6	32.0	43.6	21.7	39.5	40.0	54.4	28.9	49.3	50.1	68.1
CHS660	heb900	3.12E+09	6.31E+04	4.94E+09	6.40E+14	1.29E+10	1.01E+15	9.6	19.9	20.2	27.4	12.8	24.9	25.2	34.3	17.1	31.1	31.6	42.9	22.8	38.8	39.4	53.6

Y-Direction - total displacements (hinged)

Y- Direction	H22								H25							
nfr	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0
nno	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
nuf	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Hi	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0
Layout 1	322.6	358.8	417.5	506.1	920.3	825.6	773.7	770.0	496.6	568.6	666.1	795.6	1022.6	979.4	979.6	1027.8
	125.6	139.9	162.9	197.7	361.4	324.4	304.0	302.5	193.6	221.8	260.0	310.6	401.1	384.2	384.1	402.8
	89.9	100.2	116.8	141.8	260.2	233.5	218.9	217.7	138.7	159.0	186.5	222.9	288.5	276.3	276.2	289.6
	66.7	74.4	86.8	105.4	194.0	174.2	163.3	162.4	103.0	118.1	138.5	165.6	215.0	205.9	205.8	215.7
	50.9	56.8	66.4	80.7	149.0	133.8	125.4	124.6	78.6	90.3	105.9	126.7	165.0	158.0	157.8	165.4
	39.9	44.6	52.2	63.5	117.7	105.7	99.0	98.4	61.8	71.0	83.3	99.7	130.2	124.7	124.5	130.4
	304.0	343.1	404.4	495.2	908.4	815.5	765.3	763.0	480.2	554.8	654.6	786.0	1012.1	970.5	972.2	1021.7
	118.4	133.8	157.9	193.5	355.5	319.4	299.9	299.0	187.2	216.5	255.5	306.9	395.9	379.8	380.5	399.8
	84.8	95.9	113.2	138.8	255.4	229.6	215.6	215.0	134.2	155.2	183.3	220.2	284.4	272.8	273.4	287.2
	62.9	71.2	84.1	103.2	190.2	171.0	160.6	160.2	99.6	115.3	136.2	163.7	211.6	203.1	203.5	213.8
	48.0	54.4	64.3	79.0	145.7	131.1	123.1	122.8	76.1	88.1	104.1	125.2	162.1	155.6	155.9	163.8
	37.7	42.8	50.6	62.2	114.9	103.4	97.2	96.9	59.8	69.3	81.9	98.5	127.8	122.7	122.9	129.1
	288.8	330.3	393.8	486.3	898.9	807.6	758.7	757.5	466.9	543.6	645.2	778.2	1003.8	963.5	966.4	1016.8
	112.5	128.8	153.7	190.0	350.9	315.5	296.6	296.4	182.0	212.1	251.9	303.9	391.8	376.4	377.7	397.5
	80.6	92.4	110.3	136.4	251.7	226.5	213.0	212.9	130.5	152.1	180.7	218.1	281.1	270.1	271.1	285.4
	59.8	68.6	82.0	101.4	187.1	168.4	158.5	158.4	96.9	113.0	134.3	162.1	208.9	200.8	201.6	212.3
	45.6	52.4	62.7	77.6	143.2	128.9	121.4	121.4	74.0	86.4	102.7	124.0	159.9	153.7	154.3	162.5
	35.9	41.2	49.3	61.1	112.7	101.6	95.7	95.7	58.2	67.9	80.8	97.6	125.9	121.1	121.6	128.0

Y- Direction	H27.5								H30							
nfr	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0
nno	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
nuf	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Hi	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0
Layout 1	489.7	564.8	665.6	798.4	966.1	936.9	949.5	1008.8	616.6	727.3	871.9	1059.0	1054.9	1069.6	1133.1	1252.5
	190.9	220.4	259.9	311.8	378.9	367.5	372.3	395.4	240.4	283.7	340.2	413.3	413.4	419.0	443.7	490.2
	136.9	158.1	186.4	223.8	272.6	264.3	267.8	284.3	172.3	203.4	244.0	296.5	297.2	301.2	318.8	352.1
	101.6	117.4	138.6	166.4	203.2	197.0	199.5	211.7	127.9	151.1	181.3	220.3	221.3	224.3	237.4	262.1
	77.7	89.8	106.0	127.3	155.9	151.1	153.0	162.3	97.8	115.5	138.6	168.5	169.7	171.9	181.9	200.8
	61.1	70.6	83.4	100.2	123.0	119.3	120.7	128.1	76.9	90.8	109.1	132.6	133.9	135.6	143.4	158.2
	474.8	552.3	655.2	789.7	956.6	928.9	942.8	1003.2	603.0	715.8	862.3	1051.0	1046.2	1062.2	1127.0	1247.4
	185.2	215.6	255.8	308.5	374.2	363.5	369.0	392.6	235.1	279.2	336.5	410.2	409.0	415.3	440.7	487.7
	132.8	154.6	183.6	221.4	268.8	261.2	265.1	282.1	168.5	200.2	241.4	294.3	293.7	298.3	316.4	350.1
	98.6	114.9	136.4	164.6	200.1	194.4	197.4	210.0	125.2	148.7	179.3	218.7	218.5	221.9	235.4	260.5
	75.4	87.9	104.4	126.0	153.3	149.0	151.3	160.9	95.7	113.7	137.1	167.3	167.3	169.9	180.3	199.4
	59.3	69.1	82.2	99.2	120.9	117.5	119.3	126.9	75.2	89.5	107.9	131.7	131.9	133.9	142.1	157.1
	462.7	542.2	646.7	782.6	949.1	922.5	937.6	998.8	591.8	706.4	854.5	1044.5	1039.3	1056.4	1122.1	1243.4
	180.5	211.6	252.5	305.7	370.5	360.4	366.5	390.5	230.8	275.6	333.5	407.7	405.6	412.5	438.3	485.7
	129.4	151.8	181.2	219.4	265.9	258.7	263.1	280.4	165.5	197.7	239.2	292.5	291.0	296.0	314.5	348.6
	96.1	112.8	134.7	163.2	197.6	192.4	195.7	208.6	122.9	146.8	177.7	217.4	216.3	220.0	233.9	259.2
	73.5	86.3	103.1	124.9	151.2	147.3	149.9	159.8	93.9	112.3	135.9	166.3	165.5	168.4	179.0	198.4
	57.8	67.9	81.1	98.3	119.1	116.0	118.1	125.9	73.9	88.3	107.0	130.9	130.3	132.6	141.0	156.2

Y-Direction - total displacements (fixed)

Y- Direction	H22								H25							
nfr	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0
nno	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
nuf	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Hi	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0
Layout 1	138.2	153.7	178.8	216.7	394.1	353.5	331.3	329.7	212.7	243.5	285.2	340.7	437.9	419.4	419.5	440.1
	53.8	59.9	69.8	84.7	154.8	138.9	130.2	129.5	82.9	95.0	111.3	133.0	171.8	164.5	164.5	172.5
	38.5	42.9	50.0	60.7	111.4	100.0	93.7	93.2	59.4	68.1	79.8	95.4	123.6	118.3	118.3	124.0
	28.5	31.9	37.2	45.1	83.1	74.6	69.9	69.5	44.1	50.6	59.3	70.9	92.1	88.2	88.1	92.4
	21.8	24.3	28.4	34.5	63.8	57.3	53.7	53.4	33.7	38.6	45.4	54.2	70.6	67.6	67.6	70.8
	17.1	19.1	22.3	27.2	50.4	45.2	42.4	42.1	26.5	30.4	35.7	42.7	55.8	53.4	53.3	55.8
	130.2	146.9	173.2	212.1	389.0	349.2	327.7	326.7	205.6	237.6	280.3	336.6	433.4	415.6	416.3	437.5
	50.7	57.3	67.6	82.8	152.2	136.8	128.4	128.1	80.2	92.7	109.4	131.4	169.5	162.6	162.9	171.2
	36.3	41.1	48.5	59.5	109.4	98.3	92.3	92.1	57.5	66.5	78.5	94.3	121.8	116.8	117.1	123.0
	26.9	30.5	36.0	44.2	81.4	73.2	68.8	68.6	42.7	49.4	58.3	70.1	90.6	87.0	87.1	91.5
	20.6	23.3	27.5	33.8	62.4	56.1	52.7	52.6	32.6	37.7	44.6	53.6	69.4	66.6	66.8	70.1
	16.1	18.3	21.7	26.6	49.2	44.3	41.6	41.5	25.6	29.7	35.1	42.2	54.7	52.5	52.6	55.3
	123.7	141.5	168.6	208.3	384.9	345.8	324.9	324.4	199.9	232.8	276.3	333.2	429.8	412.6	413.8	435.4
	48.2	55.2	65.8	81.4	150.3	135.1	127.0	126.9	78.0	90.8	107.9	130.1	167.8	161.2	161.7	170.2
	34.5	39.6	47.2	58.4	107.8	97.0	91.2	91.2	55.9	65.1	77.4	93.4	120.4	115.7	116.1	122.2
	25.6	29.4	35.1	43.4	80.1	72.1	67.9	67.9	41.5	48.4	57.5	69.4	89.5	86.0	86.3	90.9
	19.5	22.4	26.8	33.2	61.3	55.2	52.0	52.0	31.7	37.0	44.0	53.1	68.5	65.8	66.1	69.6
	15.4	17.6	21.1	26.2	48.3	43.5	41.0	41.0	24.9	29.1	34.6	41.8	53.9	51.8	52.1	54.8

Y- Direction	H27.5								H30							
nfr	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0
nno	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
nuf	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Hi	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0
Layout 1	209.7	241.9	285.0	341.9	413.7	401.2	406.6	432.0	264.1	311.4	373.4	453.5	451.7	458.0	485.2	536.4
	81.8	94.4	111.3	133.5	162.3	157.4	159.4	169.3	102.9	121.5	145.7	177.0	177.0	179.4	190.0	209.9
	58.6	67.7	79.8	95.8	116.7	113.2	114.7	121.7	73.8	87.1	104.5	127.0	127.3	129.0	136.5	150.8
	43.5	50.3	59.3	71.2	87.0	84.4	85.4	90.7	54.8	64.7	77.6	94.3	94.8	96.0	101.6	112.2
	33.3	38.5	45.4	54.5	66.7	64.7	65.5	69.5	41.9	49.5	59.4	72.2	72.7	73.6	77.9	86.0
	26.2	30.3	35.7	42.9	52.7	51.1	51.7	54.8	32.9	38.9	46.7	56.8	57.3	58.1	61.4	67.8
	203.3	236.5	280.6	338.2	409.6	397.8	403.8	429.6	258.2	306.5	369.3	450.1	448.0	454.9	482.6	534.2
	79.3	92.3	109.6	132.1	160.2	155.7	158.0	168.1	100.7	119.6	144.1	175.7	175.1	177.9	188.7	208.8
	56.9	66.2	78.6	94.8	115.1	111.8	113.5	120.8	72.2	85.8	103.4	126.0	125.8	127.7	135.5	149.9
	42.2	49.2	58.4	70.5	85.7	83.2	84.5	89.9	53.6	63.7	76.8	93.7	93.6	95.0	100.8	111.5
	32.3	37.6	44.7	53.9	65.6	63.8	64.8	68.9	41.0	48.7	58.7	71.6	71.7	72.8	77.2	85.4
	25.4	29.6	35.2	42.5	51.8	50.3	51.1	54.3	32.2	38.3	46.2	56.4	56.5	57.4	60.8	67.3
	198.1	232.2	276.9	335.1	406.4	395.1	401.5	427.7	253.4	302.5	365.9	447.3	445.0	452.4	480.5	532.4
	77.3	90.6	108.1	130.9	158.7	154.3	156.9	167.2	98.8	118.0	142.8	174.6	173.7	176.6	187.7	208.0
	55.4	65.0	77.6	94.0	113.8	110.8	112.7	120.1	70.9	84.6	102.4	125.3	124.6	126.7	134.7	149.3
	41.2	48.3	57.7	69.9	84.6	82.4	83.8	89.3	52.6	62.9	76.1	93.1	92.6	94.2	100.1	111.0
	31.5	37.0	44.1	53.5	64.8	63.1	64.2	68.4	40.2	48.1	58.2	71.2	70.9	72.1	76.6	85.0
	24.8	29.1	34.7	42.1	51.0	49.7	50.6	53.9	31.6	37.8	45.8	56.0	55.8	56.8	60.4	66.9

X-Direction - total stiffness

X- Direction	H22								H25								H27.5								H30							
Layout 1	1 BRACED				NOT BRACED				1 BRACED				NOT BRACED				1 BRACED				NOT BRACED				1 BRACED				NOT BRACED			
	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0
	3.07E+03	3.88E+03	5.01E+03	6.61E+03	1.76E+03	2.23E+03	2.89E+03	3.83E+03	3.49E+03	4.41E+03	5.69E+03	7.51E+03	2.00E+03	2.54E+03	3.28E+03	4.36E+03	3.85E+03	4.87E+03	6.28E+03	8.29E+03	2.21E+03	2.80E+03	3.63E+03	4.81E+03	4.19E+03	5.29E+03	6.83E+03	9.01E+03	2.40E+03	3.04E+03	3.94E+03	5.23E+03
	7.62E+03	9.61E+03	1.24E+04	1.62E+04	4.36E+03	5.51E+03	7.10E+03	9.37E+03	8.66E+03	1.09E+04	1.40E+04	1.84E+04	4.95E+03	6.26E+03	8.07E+03	1.07E+04	9.56E+03	1.21E+04	1.55E+04	2.04E+04	5.47E+03	6.91E+03	8.91E+03	1.18E+04	1.04E+04	1.31E+04	1.68E+04	2.21E+04	5.94E+03	7.51E+03	9.68E+03	1.28E+04
	1.04E+04	1.31E+04	1.68E+04	2.21E+04	5.95E+03	7.50E+03	9.65E+03	1.27E+04	1.18E+04	1.49E+04	1.91E+04	2.51E+04	6.76E+03	8.52E+03	1.10E+04	1.44E+04	1.31E+04	1.65E+04	2.11E+04	2.77E+04	7.46E+03	9.41E+03	1.21E+04	1.59E+04	1.42E+04	1.79E+04	2.29E+04	3.01E+04	8.11E+03	1.02E+04	1.32E+04	1.73E+04
	1.37E+04	1.72E+04	2.20E+04	2.88E+04	7.80E+03	9.82E+03	1.26E+04	1.65E+04	1.56E+04	1.96E+04	2.50E+04	3.27E+04	8.86E+03	1.12E+04	1.43E+04	1.88E+04	1.72E+04	2.16E+04	2.76E+04	3.61E+04	9.79E+03	1.23E+04	1.58E+04	2.08E+04	1.87E+04	2.35E+04	3.00E+04	3.93E+04	1.06E+04	1.34E+04	1.72E+04	2.26E+04
	1.75E+04	2.19E+04	2.79E+04	3.64E+04	9.91E+03	1.24E+04	1.59E+04	2.08E+04	1.98E+04	2.49E+04	3.17E+04	4.14E+04	1.13E+04	1.41E+04	1.81E+04	2.37E+04	2.19E+04	2.74E+04	3.50E+04	4.57E+04	1.24E+04	1.56E+04	2.00E+04	2.61E+04	2.38E+04	2.98E+04	3.81E+04	4.97E+04	1.35E+04	1.70E+04	2.17E+04	2.84E+04
	2.15E+04	2.69E+04	3.43E+04	4.46E+04	1.22E+04	1.53E+04	1.95E+04	2.55E+04	2.45E+04	3.06E+04	3.90E+04	5.07E+04	1.39E+04	1.74E+04	2.22E+04	2.89E+04	2.70E+04	3.38E+04	4.30E+04	5.60E+04	1.53E+04	1.92E+04	2.45E+04	3.15E+04	2.94E+04	3.67E+04	4.68E+04	6.09E+04	1.66E+04	2.08E+04	2.66E+04	3.47E+04
	3.13E+03	3.96E+03	5.11E+03	6.76E+03	1.78E+03	2.25E+03	2.92E+03	3.88E+03	3.56E+03	4.50E+03	5.81E+03	7.68E+03	2.02E+03	2.56E+03	3.32E+03	4.40E+03	3.93E+03	4.97E+03	6.42E+03	8.48E+03	2.23E+03	2.83E+03	3.66E+03	4.86E+03	4.27E+03	5.40E+03	6.97E+03	9.22E+03	2.42E+03	3.07E+03	3.98E+03	5.29E+03
	7.86E+03	9.92E+03	1.28E+04	1.68E+04	4.45E+03	5.63E+03	7.27E+03	9.62E+03	8.93E+03	1.13E+04	1.45E+04	1.91E+04	5.06E+03	6.40E+03	8.26E+03	1.09E+04	9.86E+03	1.24E+04	1.60E+04	2.11E+04	5.58E+03	7.06E+03	9.12E+03	1.21E+04	1.07E+04	1.35E+04	1.74E+04	2.29E+04	6.07E+03	7.68E+03	9.92E+03	1.31E+04
	1.08E+04	1.36E+04	1.75E+04	2.30E+04	6.11E+03	7.73E+03	9.96E+03	1.31E+04	1.23E+04	1.55E+04	1.99E+04	2.62E+04	6.95E+03	8.78E+03	1.13E+04	1.49E+04	1.36E+04	1.71E+04	2.20E+04	2.89E+04	7.67E+03	9.69E+03	1.25E+04	1.65E+04	1.47E+04	1.86E+04	2.39E+04	3.14E+04	8.34E+03	1.05E+04	1.36E+04	1.79E+04
	1.43E+04	1.80E+04	2.31E+04	3.03E+04	8.08E+03	1.02E+04	1.31E+04	1.73E+04	1.63E+04	2.05E+04	2.63E+04	3.45E+04	9.19E+03	1.16E+04	1.49E+04	1.96E+04	1.80E+04	2.26E+04	2.90E+04	3.81E+04	1.01E+04	1.28E+04	1.65E+04	2.17E+04	1.95E+04	2.46E+04	3.15E+04	4.14E+04	1.10E+04	1.39E+04	1.79E+04	2.36E+04
	1.84E+04	2.31E+04	2.96E+04	3.87E+04	1.04E+04	1.30E+04	1.67E+04	2.20E+04	2.09E+04	2.62E+04	3.36E+04	4.40E+04	1.18E+04	1.48E+04	1.90E+04	2.50E+04	2.30E+04	2.90E+04	3.71E+04	4.86E+04	1.30E+04	1.64E+04	2.10E+04	2.76E+04	2.51E+04	3.15E+04	4.03E+04	5.28E+04	1.41E+04	1.78E+04	2.28E+04	3.00E+04
	2.29E+04	2.87E+04	3.66E+04	4.79E+04	1.29E+04	1.62E+04	2.07E+04	2.71E+04	2.60E+04	3.26E+04	4.16E+04	5.44E+04	1.46E+04	1.84E+04	2.35E+04	3.08E+04	2.87E+04	3.60E+04	4.60E+04	6.00E+04	1.61E+04	2.03E+04	2.60E+04	3.40E+04	3.12E+04	3.91E+04	5.00E+04	6.53E+04	1.75E+04	2.20E+04	2.82E+04	3.70E+04
	3.18E+03	4.02E+03	5.20E+03	6.88E+03	1.79E+03	2.27E+03	2.94E+03	3.91E+03	3.61E+03	4.57E+03	5.91E+03	7.82E+03	2.03E+03	2.58E+03	3.34E+03	4.44E+03	3.98E+03	5.05E+03	6.52E+03	8.63E+03	2.24E+03	2.85E+03	3.69E+03	4.90E+03	4.33E+03	5.49E+03	7.09E+03	9.38E+03	2.44E+03	3.09E+03	4.01E+03	5.33E+03
	8.04E+03	1.02E+04	1.31E+04	1.73E+04	4.51E+03	5.72E+03	7.40E+03	9.80E+03	9.13E+03	1.15E+04	1.49E+04	1.97E+04	5.13E+03	6.50E+03	8.41E+03	1.11E+04	1.01E+04	1.27E+04	1.64E+04	2.17E+04	5.66E+03	7.18E+03	9.28E+03	1.23E+04	1.10E+04	1.39E+04	1.79E+04	2.36E+04	6.16E+03	7.80E+03	1.01E+04	1.34E+04
	1.11E+04	1.40E+04	1.81E+04	2.38E+04	6.24E+03	7.89E+03	1.02E+04	1.35E+04	1.26E+04	1.59E+04	2.05E+04	2.71E+04	7.09E+03	8.97E+03	1.16E+04	1.53E+04	1.39E+04	1.76E+04	2.27E+04	2.99E+04	7.82E+03	9.90E+03	1.28E+04	1.69E+04	1.52E+04	1.91E+04	2.46E+04	3.25E+04	8.50E+03	1.08E+04	1.39E+04	1.84E+04
	1.48E+04	1.87E+04	2.40E+04	3.16E+04	8.30E+03	1.05E+04	1.35E+04	1.79E+04	1.68E+04	2.12E+04	2.73E+04	3.59E+04	9.43E+03	1.19E+04	1.54E+04	2.03E+04	1.86E+04	2.34E+04	3.01E+04	3.96E+04	1.04E+04	1.32E+04	1.70E+04	2.24E+04	2.02E+04	2.55E+04	3.27E+04	4.31E+04	1.13E+04	1.43E+04	1.84E+04	2.43E+04
	1.91E+04	2.41E+04	3.09E+04	4.06E+04	1.07E+04	1.35E+04	1.74E+04	2.29E+04	2.17E+04	2.73E+04	3.51E+04	4.61E+04	1.22E+04	1.53E+04	1.98E+04	2.60E+04	2.40E+04	3.02E+04	3.88E+04	5.09E+04	1.34E+04	1.69E+04	2.18E+04	2.87E+04	2.61E+04	3.28E+04	4.21E+04	5.53E+04	1.46E+04	1.84E+04	2.37E+04	3.12E+04
	2.39E+04	3.01E+04	3.86E+04	5.05E+04	1.34E+04	1.69E+04	2.17E+04	2.85E+04	2.72E+04	3.42E+04	4.38E+04	5.74E+04	1.52E+04	1.92E+04	2.46E+04	3.24E+04	3.00E+04	3.77E+04	4.84E+04	6.34E+04	1.68E+04	2.12E+04	2.72E+04	3.57E+04	3.26E+04	4.10E+04	5.26E+04	6.89E+04	1.83E+04	2.30E+04	2.95E+04	3.88E+04

	H22				H25				H27.5				H30			
FIXED	4.35E+04	4.35E+04	4.35E+04	4.35E+04	2.61E+04	2.61E+04	2.61E+04	2.61E+04	1.81E+04	1.81E+04	1.81E+04	1.81E+04	1.26E+04	1.26E+04	1.26E+04	1.26E+04
HINGED	1.65E+04	1.65E+04	1.65E+04	1.65E+04	1.28E+04	1.28E+04	1.28E+04	1.28E+04	1.06E+04	1.06E+04	1.06E+04	1.06E+04	8.88E+03	8.88E+03	8.88E+03	8.88E+03

X- Direction	H22								H25								H27.5								H30							
Layout 2	1 BRACED				NOT BRACED				1 BRACED				NOT BRACED				1 BRACED				NOT BRACED				1 BRACED				NOT BRACED			
	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0	6500.0	6000.0	5500.0	5000.0
	7.92E+03	9.76E+03	1.22E+04	1.54E+04	3.21E+03	4.08E+03	5.28E+03	7.00E+03	7.41E+03	1.11E+04	1.38E+04	1.75E+04	3.65E+03	4.63E+03	6.00E+03	7.96E+03	9.94E+03	1.22E+04	1.53E+04	1.93E+04	4.03E+03	5.12E+03	6.62E+03	8.78E+03	1.08E+04	1.33E+04	1.66E+04	2.10E+04	4.38E+03	5.56E+03	7.20E+03	9.55E+03
	2.03E+04	2.50E+04	3.11E+04	3.94E+04	7.96E+03	1.01E+04	1.30E+04	1.71E+04	1.89E+04	2.84E+04	3.54E+04	4.47E+04	9.04E+03	1.14E+04	1.47E+04	1.95E+04	2.55E+04	3.13E+04	3.91E+04	4.94E+04	9.98E+03	1.26E+04	1.63E+04	2.15E+04	2.77E+04	3.41E+04	4.25E+04	5.37E+04	1.09E+04	1.37E+04	1.77E+04	2.33E+04
	2.83E+04	3.48E+04	4.34E+04	5.48E+04	1.09E+04	1.37E+04	1.76E+04	2.32E+04	2.62E+04	3.95E+04	4.93E+04	6.23E+04	1.23E+04	1.56E+04	2.00E+04	2.64E+04	3.55E+04	4.37E+04	5.44E+04	6.87E+04	1.36E+04	1.72E+04	2.21E+04	2.91E+04	3.86E+04	4.75E+04	5.92E+04	7.47E+04	1.48E+04	1.87E+04	2.40E+04	3.16E+04
	3.81E+04	4.68E+04	5.83E+04	7.36E+04	1.42E+04	1.79E+04	2.30E+04	3.02E+04	3.51E+04	5.32E+04	6.63E+04	8.36E+04	1.62E+04	2.04E+04	2.61E+04	3.43E+04	4.78E+04	5.87E+04	7.32E+04	9.23E+04	1.79E+04	2.25E+04	2.89E+04	3.79E+04	5.19E+04	6.38E+04	7.95E+04	1.00E+05	1.94E+04	2.44E+04	3.14E+04	4.12E+04
	4.98E+04	6.11E+04	7.61E+04	9.60E+04	1.81E+04	2.27E+04	2.91E+04	3.81E+04	4.56E+04	6.95E+04	8.65E+04	1.09E+05	2.06E+04	2.58E+04	3.30E+04	4.32E+04	6.24E+04	7.67E+04	9.55E+04	1.20E+05	2.27E+04	2.85E+04	3.65E+04	4.77E+04	6.79E+04	8.34E+04	1.04E+05	1.31E+05	2.47E+04	3.10E+04	3.96E+04	5.19E+04
	6.32E+04	7.76E+04	9.66E+04	1.22E+05	2.23E+04	2.79E+04	3.56E+04	4.65E+04	5.76E+04	8.82E+04	1.10E+05	1.38E+05	2.53E+04	3.17E+04	4.05E+04	5.28E+04	7.93E+04	9.74E+04	1.21E+05	1.53E+05	2.79E+04	3.50E+04	4.47E+04	5.83E+04	8.62E+04	1.06E+05	1.32E+05	1.66E+05	3.04E+04	3.80E+04	4.86E+04	6.34E+04
	8.96E+03	1.10E+04	1.38E+04	1.75E+04	3.24E+03	4.12E+03	5.33E+03	7.08E+03	8.21E+03	1.26E+04	1.57E+04	1.98E+04	3.68E+03	4.68E+03	6.06E+03	8.04E+03	1.12E+04	1.39E+04	1.73E+04	2.19E+04	4.07E+03	5.16E+03	6.69E+03	8.88E+03	1.22E+04	1.51E+04	1.88E+04	2.38E+04	4.42E+03	5.61E+03	7.27E+03	9.65E+03
	2.30E+04	2.83E+04	3.53E+04	4.47E+04	8.12E+03	1.03E+04	1.33E+04	1.76E+04	2.10E+04	3.22E+04	4.01E+04	5.07E+04	9.23E+03	1.17E+04	1.51E+04	2.00E+04	2.88E+04	3.55E+04	4.43E+04	5.60E+04	1.02E+04	1.29E+04	1.67E+04	2.20E+04	3.13E+04	3.86E+04	4.81E+04	6.09E+04	1.11E+04	1.40E+04	1.81E+04	2.40E+04
	3.21E+04	3.94E+04	4.92E+04	6.22E+04	1.12E+04	1.41E+04	1.82E+04	2.40E+04	2.91E+04	4.48E+04	5.59E+04	7.07E+04	1.27E+04	1.60E+04	2.07E+04	2.73E+04	4.02E+04	4.95E+04	6.17E+04	7.80E+04	1.40E+04	1.77E+04	2.28E+04	3.01E+04	4.37E+04	5.38E+04	6.71E+04	8.48E+04	1.52E+04	1.92E+04	2.48E+04	3.27E+04
	4.32E+04	5.31E+04	6.62E+04	8.36E+04	1.48E+04	1.86E+04	2.40E+04	3.16E+04	3.91E+04	6.03E+04	7.52E+04	9.50E+04	1.68E+04	2.12E+04	2.72E+04	3.59E+04	5.42E+04	6.66E+04	8.30E+04	1.05E+05	1.85E+04	2.34E+04	3.01E+04	3.96E+04	5.89E+04	7.24E+04	9.02E+04	1.14E+05	2.01E+04	2.54E+04	3.27E+04	4.30E+04
	5.65E+04	6.94E+04	8.65E+04	1.09E+05	1.89E+04	2.38E+04	3.06E+04	4.02E+04	5.09E+04	7.89E+04	9.83E+04	1.24E+05	2.15E+04	2.71E+04	3.47E+04	4.56E+04	7.08E+04	8.71E+04	1.09E+05	1.37E+05	2.37E+04	2.99E+04	3.84E+04	5.04E+04	7.70E+04	9.46E+04	1.18E+05	1.49E+05	2.58E+04	3.25E+04	4.17E+04	5.48E+04
	7.18E+04	8.82E+04	1.10E+05	1.39E+05	2.35E+04	2.95E+04	3.78E+04	4.95E+04	6.44E+04	1.00E+05	1.25E+05	1.57E+05	2.67E+04	3.35E+04	4.30E+04	5.63E+04	9.01E+04	1.11E+05	1.38E+05	1.74E+05	2.95E+04	3.70E+04	4.74E+04	6.21E+04	9.79E+04	1.20E+05	1.50E+05	1.89E+05	3.20E+04	4.02E+04	5.16E+04	6.75E+04
	1.00E+04	1.24E+04	1.55E+04	1.96E+04	3.26E+03	4.14E+03	5.37E+03	7.13E+03	8.99E+03	1.41E+04	1.76E+04	2.23E+04	3.71E+03	4.71E+03	6.10E+03	8.10E+03	1.26E+04	1.55E+04	1.94E+04	2.46E+04	4.09E+03	5.20E+03	6.74E+03	8.95E+03	1.37E+04	1.69E+04	2.11E+04	2.67E+04	4.45E+03	5.65E+03	7.32E+03	9.73E+03
	2.57E+04	3.17E+04	3.96E+04	5.01E+04	8.24E+03	1.04E+04	1.35E+04	1.79E+04	2.30E+04	3.60E+04	4.50E+04	5.70E+04	9.37E+03	1.19E+04	1.54E+04	2.03E+04	3.23E+04	3.98E+04	4.97E+04	6.29E+04	1.03E+04	1.31E+04	1.69E+04	2.25E+04	3.51E+04	4.33E+04	5.40E+04	6.84E+04	1.12E+04	1.42E+04	1.84E+04	2.44E+04
	3.59E+04	4.42E+04	5.52E+04	6.99E+04	1.14E+04	1.44E+04	1.86E+04	2.46E+04	3.20E+04	5.03E+04	6.27E+04	7.94E+04	1.29E+04	1.64E+04	2.12E+04	2.80E+04	4.51E+04	5.55E+04	6.93E+04	8.76E+04	1.43E+04	1.81E+04	2.34E+04	3.09E+04	4.90E+04	6.03E+04	7.53E+04	9.53E+04	1.55E+04	1.97E+04	2.54E+04	3.36E+04
	4.84E+04	5.96E+04	7.43E+04	9.40E+04	1.52E+04	1.92E+04	2.47E+04	3.26E+04	4.31E+04	6.77E+04	8.45E+04	1.07E+05	1.72E+04	2.18E+04	2.81E+04	3.70E+04	6.07E+04	7.47E+04	9.32E+04	1.18E+05	1.90E+04	2.40E+04	3.10E+04	4.09E+04	6.60E+04	8.12E+04	1.01E+05	1.28E+05	2.07E+04	2.61E+04	3.37E+04	4.45E+04
	6.34E+04	7.79E+04	9.72E+04	1.23E+05	1.95E+04	2.47E+04	3.17E+04	4.18E+04	5.62E+04	8.86E+04	1.10E+05	1.40E+05	2.22E+04	2.80E+04	3.61E+04	4.75E+04	7.95E+04	9.78E+04	1.22E+05	1.54E+05	2.45E+04	3.09E+04	3.98E+04	5.25E+04	8.64E+04	1.06E+05	1.33E+05	1.67E+05	2.66E+04	3.36E+04	4.33E+04	5.70E+04
	8.06E+04	9.91E+04	1.24E+05	1.56E+05	2.44E+04	3.08E+04	3.96E+04	5.20E+04	7.12E+04	1.13E+05	1.40E+05	1.77E+05	2.78E+04	3.50E+04	4.49E+04	5.91E+04	1.01E+05	1.24E+05	1.55E+05	1.96E+05	3.07E+04	3.86E+04	4.96E+04	6.52E+04	1.10E+05	1.35E+05	1.68E+05	2.13E+05	3.33E+04	4.20E+04	5.39E+04	7.09E+04

	H22				H25				H27.5				H30			
FIXED	4.35E+04	4.35E+04	4.35E+04	4.35E+04	2.61E+04	2.61E+04	2.61E+04	2.61E+04	1.81E+04	1.81E+04	1.81E+04	1.81E+04	1.26E+04	1.26E+04	1.26E+04	1.26E+04
HINGED	1.65E+04	1.65E+04	1.65E+04	1.65E+04	1.28E+04	1.28E+04	1.28E+04	1.28E+04	1.06E+04	1.06E+04	1.06E+04	1.06E+04	8.88E+03	8.88E+03	8.88E+03	8.88E+03

(grey)	stiffness not sufficient for both the situations
(green)	stiffness sufficient for hinged situation
(red)	stiffness sufficient for both the situations

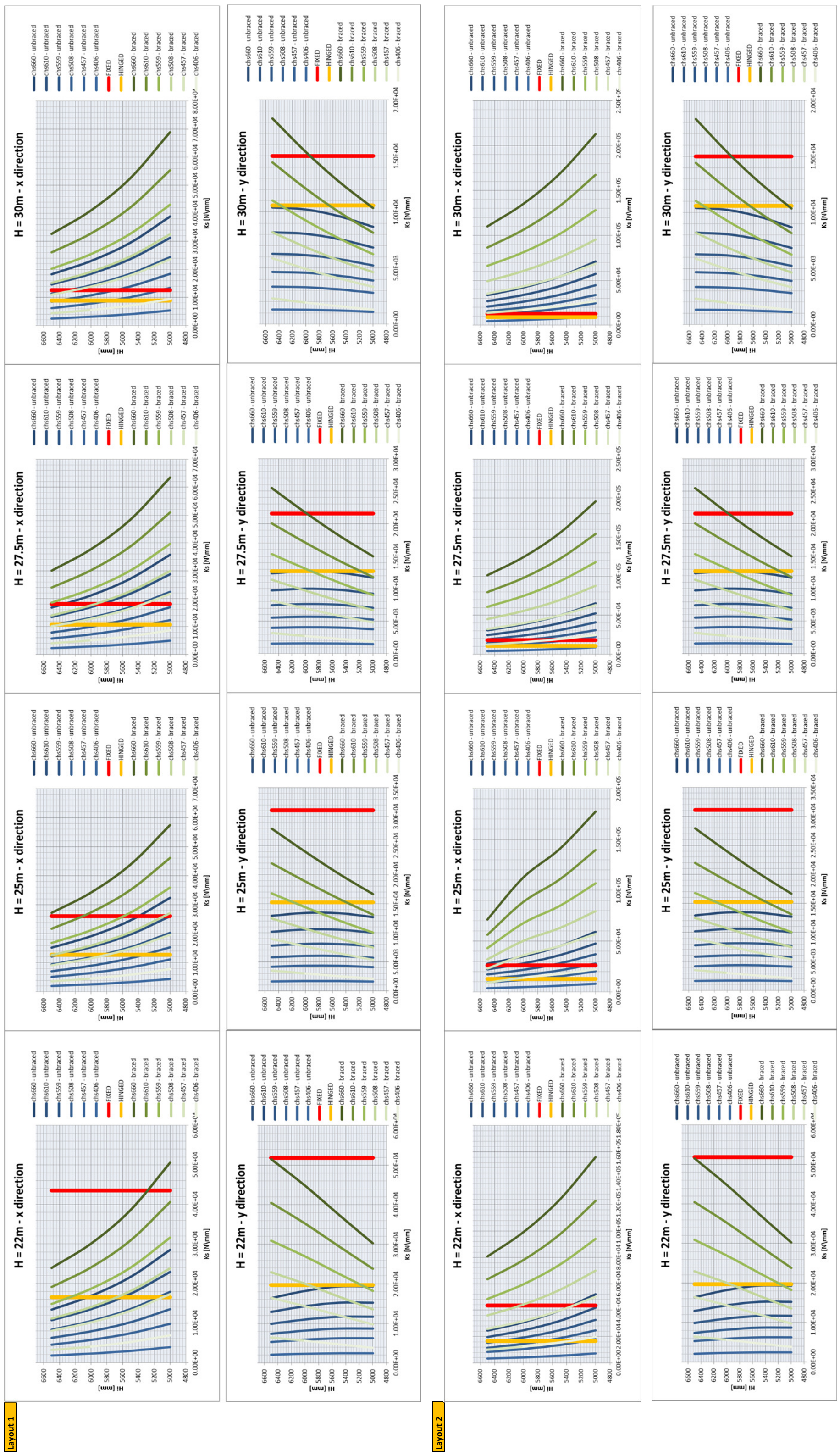
Y-Direction - total stiffness

Y- Direction	H22								H25							
Layout 1	2 BRACED				1 BRACED				2 BRACED				1 BRACED			
	6500	6000	5500	5000	6500	6000	5500	5000	6500	6000	5500	5000	6500	6000	5500	5000
	5.72E+03	5.15E+03	4.42E+03	3.65E+03	2.01E+03	2.24E+03	2.39E+03	2.40E+03	3.27E+03	2.86E+03	2.44E+03	2.04E+03	1.59E+03	1.66E+03	1.66E+03	1.58E+03
	1.47E+04	1.32E+04	1.13E+04	9.34E+03	5.11E+03	5.69E+03	6.07E+03	6.11E+03	8.40E+03	7.33E+03	6.25E+03	5.23E+03	4.05E+03	4.23E+03	4.23E+03	4.03E+03
	2.05E+04	1.84E+04	1.58E+04	1.30E+04	7.10E+03	7.91E+03	8.44E+03	8.48E+03	1.17E+04	1.02E+04	8.72E+03	7.29E+03	5.63E+03	5.88E+03	5.88E+03	5.61E+03
	2.77E+04	2.48E+04	2.13E+04	1.75E+04	9.52E+03	1.06E+04	1.13E+04	1.14E+04	1.58E+04	1.38E+04	1.17E+04	9.81E+03	7.56E+03	7.89E+03	7.90E+03	7.53E+03
	3.63E+04	3.25E+04	2.78E+04	2.29E+04	1.24E+04	1.38E+04	1.47E+04	1.48E+04	2.07E+04	1.80E+04	1.53E+04	1.28E+04	9.85E+03	1.03E+04	1.03E+04	9.83E+03
	4.62E+04	4.14E+04	3.54E+04	2.91E+04	1.57E+04	1.75E+04	1.87E+04	1.88E+04	2.63E+04	2.29E+04	1.95E+04	1.63E+04	1.25E+04	1.30E+04	1.31E+04	1.25E+04
	6.08E+03	5.38E+03	4.57E+03	3.73E+03	2.03E+03	2.26E+03	2.41E+03	2.42E+03	3.38E+03	2.93E+03	2.48E+03	2.07E+03	1.61E+03	1.67E+03	1.67E+03	1.59E+03
	1.56E+04	1.38E+04	1.17E+04	9.55E+03	5.19E+03	5.78E+03	6.16E+03	6.18E+03	8.68E+03	7.51E+03	6.36E+03	5.29E+03	4.10E+03	4.28E+03	4.27E+03	4.06E+03
	2.18E+04	1.93E+04	1.63E+04	1.33E+04	7.23E+03	8.05E+03	8.57E+03	8.59E+03	1.21E+04	1.05E+04	8.87E+03	7.38E+03	5.72E+03	5.96E+03	5.95E+03	5.66E+03
	2.94E+04	2.59E+04	2.20E+04	1.79E+04	9.71E+03	1.08E+04	1.15E+04	1.15E+04	1.63E+04	1.41E+04	1.19E+04	9.93E+03	7.68E+03	8.00E+03	7.99E+03	7.60E+03
	3.85E+04	3.39E+04	2.87E+04	2.34E+04	1.27E+04	1.41E+04	1.50E+04	1.50E+04	2.14E+04	1.84E+04	1.56E+04	1.30E+04	1.00E+04	1.04E+04	1.04E+04	9.92E+03
	4.90E+04	4.32E+04	3.65E+04	2.97E+04	1.61E+04	1.79E+04	1.90E+04	1.91E+04	2.72E+04	2.34E+04	1.98E+04	1.65E+04	1.27E+04	1.32E+04	1.32E+04	1.26E+04
	6.39E+03	5.59E+03	4.69E+03	3.80E+03	2.05E+03	2.29E+03	2.43E+03	2.44E+03	3.48E+03	2.99E+03	2.52E+03	2.09E+03	1.62E+03	1.69E+03	1.68E+03	1.60E+03
	1.64E+04	1.43E+04	1.20E+04	9.72E+03	5.26E+03	5.85E+03	6.23E+03	6.23E+03	8.93E+03	7.66E+03	6.45E+03	5.35E+03	4.15E+03	4.32E+03	4.30E+03	4.09E+03
	2.29E+04	2.00E+04	1.67E+04	1.35E+04	7.34E+03	8.16E+03	8.67E+03	8.67E+03	1.25E+04	1.07E+04	8.99E+03	7.45E+03	5.78E+03	6.02E+03	5.99E+03	5.69E+03
	3.09E+04	2.69E+04	2.25E+04	1.82E+04	9.87E+03	1.10E+04	1.17E+04	1.17E+04	1.68E+04	1.44E+04	1.21E+04	1.00E+04	7.78E+03	8.09E+03	8.06E+03	7.66E+03
	4.05E+04	3.52E+04	2.95E+04	2.38E+04	1.29E+04	1.43E+04	1.52E+04	1.52E+04	2.19E+04	1.88E+04	1.58E+04	1.31E+04	1.02E+04	1.06E+04	1.05E+04	1.00E+04
	5.15E+04	4.48E+04	3.74E+04	3.02E+04	1.64E+04	1.82E+04	1.93E+04	1.93E+04	2.79E+04	2.39E+04	2.01E+04	1.67E+04	1.29E+04	1.34E+04	1.34E+04	1.27E+04
FIXED		5.19E+04	5.19E+04	5.19E+04	5.19E+04				FIXED	3.11E+04	3.11E+04	3.11E+04	3.11E+04			
HINGED		1.97E+04	1.97E+04	1.97E+04	1.97E+04				HINGED	1.52E+04	1.52E+04	1.52E+04	1.52E+04			

Y- Direction	H27.5								H30							
Layout 1	2 BRACED				1 BRACED				2 BRACED				1 BRACED			
	6500	6000	5500	5000	6500	6000	5500	5000	6500	6000	5500	5000	6500	6000	5500	5000
	3.01E+03	2.61E+03	2.21E+03	1.84E+03	1.52E+03	1.57E+03	1.55E+03	1.46E+03	2.20E+03	1.86E+03	1.55E+03	1.28E+03	1.28E+03	1.27E+03	1.20E+03	1.08E+03
	7.71E+03	6.68E+03	5.66E+03	4.72E+03	3.88E+03	4.01E+03	3.95E+03	3.72E+03	5.63E+03	4.77E+03	3.98E+03	3.28E+03	3.28E+03	3.23E+03	3.05E+03	2.76E+03
	1.08E+04	9.31E+03	7.90E+03	6.58E+03	5.40E+03	5.57E+03	5.50E+03	5.18E+03	7.86E+03	6.66E+03	5.55E+03	4.57E+03	4.56E+03	4.50E+03	4.25E+03	3.85E+03
	1.45E+04	1.25E+04	1.06E+04	8.85E+03	7.25E+03	7.47E+03	7.38E+03	6.95E+03	1.06E+04	8.96E+03	7.47E+03	6.15E+03	6.12E+03	6.04E+03	5.71E+03	5.17E+03
	1.90E+04	1.64E+04	1.39E+04	1.16E+04	9.44E+03	9.74E+03	9.62E+03	9.07E+03	1.39E+04	1.17E+04	9.77E+03	8.04E+03	7.98E+03	7.88E+03	7.45E+03	6.75E+03
	2.41E+04	2.08E+04	1.76E+04	1.47E+04	1.20E+04	1.23E+04	1.22E+04	1.15E+04	1.76E+04	1.49E+04	1.24E+04	1.02E+04	1.01E+04	9.99E+03	9.44E+03	8.56E+03
	3.10E+03	2.67E+03	2.25E+03	1.86E+03	1.54E+03	1.58E+03	1.56E+03	1.47E+03	2.25E+03	1.89E+03	1.57E+03	1.29E+03	1.29E+03	1.27E+03	1.20E+03	1.09E+03
	7.95E+03	6.83E+03	5.75E+03	4.77E+03	3.93E+03	4.05E+03	3.99E+03	3.75E+03	5.76E+03	4.85E+03	4.02E+03	3.30E+03	3.31E+03	3.26E+03	3.07E+03	2.78E+03
	1.11E+04	9.52E+03	8.02E+03	6.65E+03	5.48E+03	5.64E+03	5.55E+03	5.22E+03	8.04E+03	6.76E+03	5.61E+03	4.60E+03	4.61E+03	4.54E+03	4.28E+03	3.87E+03
	1.49E+04	1.28E+04	1.08E+04	8.94E+03	7.36E+03	7.57E+03	7.46E+03	7.01E+03	1.08E+04	9.10E+03	7.55E+03	6.19E+03	6.20E+03	6.10E+03	5.75E+03	5.20E+03
	1.95E+04	1.68E+04	1.41E+04	1.17E+04	9.60E+03	9.88E+03	9.73E+03	9.15E+03	1.42E+04	1.19E+04	9.87E+03	8.10E+03	8.09E+03	7.97E+03	7.51E+03	6.79E+03
	2.48E+04	2.13E+04	1.79E+04	1.48E+04	1.22E+04	1.25E+04	1.23E+04	1.16E+04	1.80E+04	1.51E+04	1.25E+04	1.03E+04	1.03E+04	1.01E+04	9.53E+03	8.62E+03
	3.18E+03	2.72E+03	2.28E+03	1.88E+03	1.55E+03	1.60E+03	1.57E+03	1.47E+03	2.29E+03	1.92E+03	1.58E+03	1.30E+03	1.30E+03	1.28E+03	1.21E+03	1.09E+03
	8.16E+03	6.96E+03	5.83E+03	4.81E+03	3.97E+03	4.08E+03	4.02E+03	3.77E+03	5.87E+03	4.91E+03	4.06E+03	3.32E+03	3.34E+03	3.28E+03	3.09E+03	2.79E+03
	1.14E+04	9.70E+03	8.12E+03	6.71E+03	5.54E+03	5.69E+03	5.60E+03	5.25E+03	8.18E+03	6.85E+03	5.66E+03	4.63E+03	4.65E+03	4.58E+03	4.31E+03	3.89E+03
	1.53E+04	1.30E+04	1.09E+04	9.02E+03	7.45E+03	7.65E+03	7.52E+03	7.06E+03	1.10E+04	9.22E+03	7.62E+03	6.23E+03	6.26E+03	6.16E+03	5.79E+03	5.22E+03
	2.00E+04	1.71E+04	1.43E+04	1.18E+04	9.73E+03	1.00E+04	9.82E+03	9.21E+03	1.44E+04	1.21E+04	9.96E+03	8.15E+03	8.19E+03	8.04E+03	7.57E+03	6.83E+03
	2.55E+04	2.17E+04	1.81E+04	1.50E+04	1.24E+04	1.27E+04	1.25E+04	1.17E+04	1.83E+04	1.53E+04	1.27E+04	1.03E+04	1.04E+04	1.02E+04	9.61E+03	8.67E+03
	FIXED	2.15E+04	2.15E+04	2.15E+04	2.15E+04				FIXED	1.50E+04	1.50E+04	1.50E+04	1.50E+04			
	HINGED	1.27E+04	1.27E+04	1.27E+04	1.27E+04				HINGED	1.06E+04	1.06E+04	1.06E+04	1.06E+04			

(grey)	stiffness not sufficient for both the situations
(green)	stiffness sufficient for hinged situation
(red)	stiffness sufficient for both the situations

Graphs for comparison - total stiffness



Hinged situation - final solution (X-direction)

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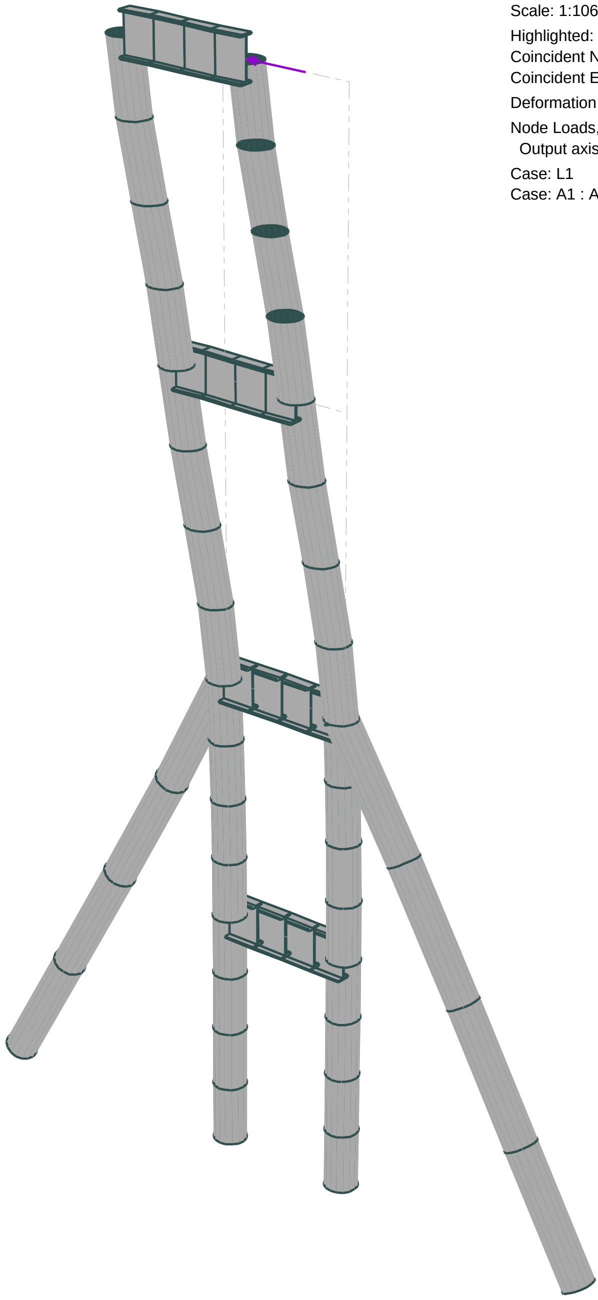
Final solution - X direction
Htot 22 m, Hi 6 m, unbraced, layout1, final

Job No.	Sheet No.	Rev.
1		

Drg. Ref.

Made by	Date	Checked
GI	14-lug-2014	

Scale: 1:106,9
Highlighted:
Coincident Nodes
Coincident Elements
Deformation magnification: 25,00
Node Loads, Force: 1,250E+6 N/pic.cm
Output axis: global
Case: L1
Case: A1 : Analysis case 1



Program GSA Version 8.7 Copyright © Oasys 1985-2014 Page 1
C:\Users\Giuse\Desktop\SHL\Finals\Fmod\Final1\H22_Hi6_l1_nb_x_all.gwb Printed 15-lug-2014 Time 15:22

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Final solution - X direction
Htot 22 m, Hi 6 m, unbraced, layout1, final

Job No.	Sheet No.	Rev.
1		
Drg. Ref.		
Made by GI	Date 14-lug-2014	Checked

Displacements

Displacements reported at nodes; fully restrained nodes are excluded
Output axes: global

Node	Case	Ux [m]	Uy [m]	Uz [m]	|U| [m]	Rxx [rad]	Ryy [rad]	Rzz [rad]	|R| [rad]	Uxy [m]
1	A1	-0,04584	0,0	0,0	0,04584	0,0	-0,004373	0,0	0,004373	0,04584
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	A1	-0,09037	0,0	0,0	0,09037	0,0	-0,002608	0,0	0,002608	0,09037
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	A1	-0,04584	0,0	0,0	0,04584	0,0	-0,004388	0,0	0,004388	0,04584
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	A1	-0,09065	0,0	0,0	0,09065	0,0	-0,002630	0,0	0,002630	0,09065
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
8	A1	-0,003185	0,0	0,0	0,003185	0,0	-0,001949	0,0	0,001949	0,003185
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
9	A1	-0,003185	0,0	0,0	0,003185	0,0	-0,001948	0,0	0,001948	0,003185
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
10	A1	842,9E-6	0,0	0,0	842,9E-6	0,0	-9,859E-6	0,0	9,859E-6	842,9E-6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
11	A1	842,9E-6	0,0	0,0	842,9E-6	0,0	-10,04E-6	0,0	10,04E-6	842,9E-6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Maxima

Node	Case	Ux	Uy	Uz	|U|	Rxx	Ryy	Rzz	|R|	Uxy
10	A1	***842,9E-6***	0,0	0,0	842,9E-6	0,0	-9,859E-6	0,0	9,859E-6	842,9E-6
7	A1	-0,09065	***0,0***	0,0	0,09065	0,0	-0,002630	0,0	0,002630	0,09065
1	A1	-0,04584	0,0	***0,0***	0,04584	0,0	-0,004373	0,0	0,004373	0,04584
7	A1	-0,09065	0,0	0,0	***0,09065***	0,0	-0,002630	0,0	0,002630	0,09065
8	A1	-0,003185	0,0	0,0	0,003185	***0,0***	-0,001949	0,0	0,001949	0,003185
1	A2	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0
2	A1	-0,09037	0,0	0,0	0,09037	0,0	-0,002608	***0,0***	0,002608	0,09037
6	A1	-0,04584	0,0	0,0	0,04584	0,0	-0,004388	0,0	***0,004388***	0,04584
7	A1	-0,09065	0,0	0,0	0,09065	0,0	-0,002630	0,0	0,002630	***0,09065***

Minima

Node	Case	Ux	Uy	Uz	|U|	Rxx	Ryy	Rzz	|R|	Uxy
7	A1	***-0,09065***	0,0	0,0	0,09065	0,0	-0,002630	0,0	0,002630	0,09065
2	A1	-0,09037	***0,0***	0,0	0,09037	0,0	-0,002608	0,0	0,002608	0,09037
1	A1	-0,04584	0,0	***0,0***	0,04584	0,0	-0,004373	0,0	0,004373	0,04584
1	A2	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0	0,0	0,0
9	A1	-0,003185	0,0	0,0	0,003185	***0,0***	-0,001948	0,0	0,001948	0,003185
6	A1	-0,04584	0,0	0,0	0,04584	0,0	***-0,004388***	0,0	0,004388	0,04584
1	A2	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0	0,0
1	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0
1	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

Reactions

Reactions due to restraints, spring supports, applied displacements and grounded springs
Output axes: global

Node	Case	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
1	A1	0,0	0,0	3,001E+6	3,001E+6				
	A2	0,0	0,0	0,0	0,0				
2	A1	0,0	0,0	1,794E+6	1,794E+6				
	A2	0,0	0,0	0,0	0,0				
6	A1	0,0	0,0	-3,001E+6	3,001E+6				
	A2	0,0	0,0	0,0	0,0				
7	A1	0,0	0,0	-1,794E+6	1,794E+6				
	A2	0,0	0,0	0,0	0,0				
8	A1	0,0	0,0	-218900,	218900,				
	A2	0,0	0,0	0,0	0,0				
9	A1	0,0	0,0	218800,	218800,				
	A2	0,0	0,0	0,0	0,0				
10	A1	0,0	0,0	6818,	6818,				
	A2	0,0	0,0	0,0	0,0				
11	A1	0,0	0,0	-6818,	6818,				
	A2	0,0	0,0	0,0	0,0				
12	A1	-47430,	0,0	0,0	47430,	0,0	-117300,	0,0	117300,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13	A1	-47450,	0,0	0,0	47450,	0,0	-117300,	0,0	117300,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
14	A1	822200,	0,0	-1,554E+6	1,758E+6	0,0	-130600,	0,0	130600,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
15	A1	822300,	0,0	1,554E+6	1,758E+6	0,0	-130800,	0,0	130800,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Maxima

Node	Case	Fx	Fy	Fz	|F|	Mxx	Myy	Mzz	|M|
15	A1	***822300,***	0,0	1,554E+6	1,758E+6	0,0	-130800,	0,0	130800,
15	A1	822300,	***0,0***	1,554E+6	1,758E+6	0,0	-130800,	0,0	130800,
1	A1	0,0	0,0	***3,001E+6***	3,001E+6				
1	A1	0,0	0,0	3,001E+6	***3,001E+6***				
14	A1	822200,	0,0	-1,554E+6	1,758E+6	***0,0***	-130600,	0,0	130600,
12	A2	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0	0,0
12	A2	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0
15	A1	822300,	0,0	1,554E+6	1,758E+6	0,0	-130800,	0,0	***130800,***

Minima

Node	Case	Fx	Fy	Fz	|F|	Mxx	Myy	Mzz	|M|
13	A1	***-47450,***	0,0	0,0	47450,	0,0	-117300,	0,0	117300,
14	A1	822200,	***0,0***	-1,554E+6	1,758E+6	0,0	-130600,	0,0	130600,
6	A1	0,0	0,0	***-3,001E+6***	3,001E+6				
1	A2	0,0	0,0	0,0	***0,0***				
15	A1	822300,	0,0	1,554E+6	1,758E+6	***0,0***	-130800,	0,0	130800,
15	A1	822300,	0,0	1,554E+6	1,758E+6	0,0	***-130800,***	0,0	130800,
12	A1	-47430,	0,0	0,0	47430,	0,0	-117300,	***0,0***	117300,
12	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

Nodal Forces and Moments

Forces reported are the forces at the node acting on the element; these may differ from

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Job No.	Sheet No.	Rev.
1		

Drg. Ref.

Made by	Date	Checked
GI	14-lug-2014	

Final solution - X direction

Htot 22 m, Hi 6 m, unbraced, layout1, final

Node	Case	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]

the forces reported for element ends when the element has end releases or is offset.
When reported in local output axes, forces are in element local directions related to the node and +ve axial forces are tensile.
2D elements are not considered.
Output axes: global

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
1	A1	1	772000,	2,636E-9	0,0	772000,	2,956E-9	2,128E+6	0,0	2,128E+6
		5	-775500,	0,0	0,0	775500,	0,0	2,068E+6	0,0	2,068E+6
		7	3443,	0,0	3,001E+6	3,001E+6	0,0	-4,196E+6	0,0	4,196E+6
	A2	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	A1	1	-772000,	-2,636E-9	0,0	772000,	-5,859E-9	2,504E+6	0,0	2,504E+6
		2	772100,	0,0	1,794E+6	1,953E+6	0,0	-2,504E+6	0,0	2,504E+6
	A2	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	A1	3	777600,	1,490E-9	0,0	777600,	-3,028E-9	2,145E+6	0,0	2,145E+6
		6	-774100,	0,0	0,0	774100,	0,0	2,062E+6	0,0	2,062E+6
		7	-3443,	0,0	-3,001E+6	3,001E+6	0,0	-4,208E+6	0,0	4,208E+6
	A2	3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	A1	2	-772100,	0,0	-1,794E+6	1,953E+6	0,0	-2,520E+6	0,0	2,520E+6
		3	-777600,	-1,490E-9	0,0	777600,	-3,924E-9	2,520E+6	0,0	2,520E+6
	A2	2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
8	A1	5	775500,	0,0	0,0	775500,	0,0	2,585E+6	0,0	2,585E+6
		8	-741,8	0,0	1,335E+6	1,335E+6	0,0	-1,870E+6	0,0	1,870E+6
		13	47530,	0,0	0,0	47530,	0,0	-366900,	0,0	366900,
		14	-822300,	0,0	-1,554E+6	1,758E+6	0,0	-348300,	0,0	348300,
	A2	5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		13	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		14	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
9	A1	6	774100,	0,0	0,0	774100,	0,0	2,583E+6	0,0	2,583E+6
		8	741,8	0,0	-1,335E+6	1,335E+6	0,0	-1,868E+6	0,0	1,868E+6
		11	47350,	0,0	0,0	47350,	0,0	-366300,	0,0	366300,
		15	-822200,	0,0	1,554E+6	1,758E+6	0,0	-348000,	0,0	348000,
	A2	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		11	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		15	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
10	A1	9	99,84	0,0	6818,	6819,	0,0	-9479,	0,0	9479,
		12	47430,	0,0	0,0	47430,	0,0	-119800,	0,0	119800,
		13	-47530,	0,0	0,0	47530,	0,0	129300,	0,0	129300,
	A2	9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		13	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
11	A1	9	-99,84	0,0	-6818,	6819,	0,0	-9611,	0,0	9611,
		10	47450,	0,0	0,0	47450,	0,0	-119900,	0,0	119900,
		11	-47350,	0,0	0,0	47350,	0,0	129500,	0,0	129500,
	A2	9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		10	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		11	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	A1	12	-47430,	0,0	0,0	47430,	0,0	-117300,	0,0	117300,
	A2	12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13	A1	10	-47450,	0,0	0,0	47450,	0,0	-117300,	0,0	117300,
	A2	10	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
14	A1	15	822200,	0,0	-1,554E+6	1,758E+6	0,0	-130600,	0,0	130600,
	A2	15	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
15	A1	14	822300,	0,0	1,554E+6	1,758E+6	0,0	-130800,	0,0	130800,
	A2	14	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Maxima

Node	Case	Elem	Fx	Fy	Fz	|F|	Mxx	Myy	Mzz	|M|
15	A1	14	***822300,***	0,0	1,554E+6	1,758E+6	0,0	-130800,	0,0	130800,
1	A1	1	772000,	***2,636E-9***	0,0	772000,	2,956E-9	2,128E+6	0,0	2,128E+6
1	A1	7	3443,	0,0	***3,001E+6***	3,001E+6	0,0	-4,196E+6	0,0	4,196E+6
1	A1	7	3443,	0,0	3,001E+6	***3,001E+6***	0,0	-4,196E+6	0,0	4,196E+6
1	A1	1	772000,	2,636E-9	0,0	772000,	***2,956E-9***	2,128E+6	0,0	2,128E+6
8	A1	5	775500,	0,0	0,0	775500,	0,0	***2,585E+6***	0,0	2,585E+6
6	A1	6	-774100,	0,0	0,0	774100,	0,0	2,062E+6	***0,0***	2,062E+6
6	A1	7	-3443,	0,0	-3,001E+6	3,001E+6	0,0	-4,208E+6	0,0	***4,208E+6***

Minima

Node	Case	Elem	Fx	Fy	Fz	|F|	Mxx	Myy	Mzz	|M|
8	A1	14	***-822300,***	0,0	-1,554E+6	1,758E+6	0,0	-348300,	0,0	348300,
2	A1	1	-772000,	***-2,636E-9***	0,0	772000,	-5,859E-9	2,504E+6	0,0	2,504E+6
6	A1	7	-3443,	0,0	***-3,001E+6***	3,001E+6	0,0	-4,208E+6	0,0	4,208E+6
1	A2	1	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0	0,0
2	A1	1	-772000,	-2,636E-9	0,0	772000,	***-5,859E-9***	2,504E+6	0,0	2,504E+6
6	A1	7	-3443,	0,0	-3,001E+6	3,001E+6	0,0	***-4,208E+6***	0,0	4,208E+6
9	A1	6	774100,	0,0	0,0	774100,	0,0	2,583E+6	***0,0***	2,583E+6
1	A2	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

Program GSA Version 8.7 Page 2
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Hinged situation - final solution (Y-direction)

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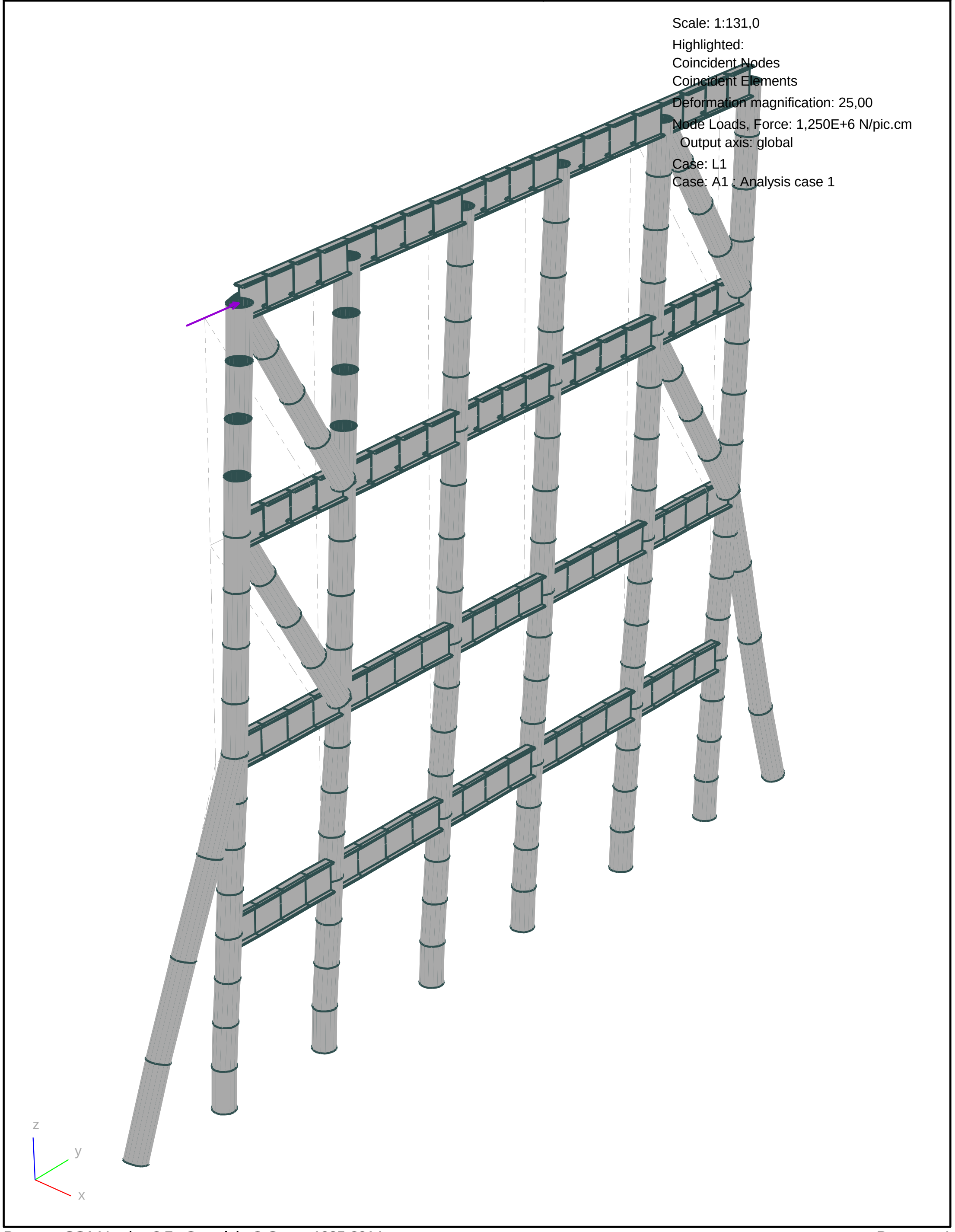
Final solution - Y direction
Htot 22 m, Hi 6 m, 2 part. braced, layout1,final

Job No.	Sheet No.	Rev.
1		

Drg. Ref.

Made by	Date	Checked
GI	15-lug-2014	



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Job No.	Sheet No.	Rev.
1		

Final solution - Y direction

Htot 22 m, Hi 6 m, 2 part. braced, layout1,final

Drg. Ref.

Made by	Date	Checked
GI	15-lug-2014	

Displacements

Displacements reported at nodes; fully restrained nodes are excluded
Output axes: global

Node	Case	Ux [m]	Uy [m]	Uz [m]	|U| [m]	Rxx [rad]	Ryy [rad]	Rzz [rad]	|R| [rad]	Uxy [m]
6	A1	0,0	0,03953	0,0	0,03953	-985,7E-6	0,0	0,0	985,7E-6	0,03953
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	A1	0,0	0,05075	0,0	0,05075	-844,2E-6	0,0	0,0	844,2E-6	0,05075
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
8	A1	0,0	0,04197	0,0	0,04197	-726,4E-6	0,0	0,0	726,4E-6	0,04197
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
9	A1	0,0	0,05245	0,0	0,05245	-335,6E-6	0,0	0,0	335,6E-6	0,05245
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
10	A1	0,0	0,04180	0,0	0,04180	-729,8E-6	0,0	0,0	729,8E-6	0,04180
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
11	A1	0,0	0,05341	0,0	0,05341	-459,9E-6	0,0	0,0	459,9E-6	0,05341
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	A1	0,0	0,04161	0,0	0,04161	-738,3E-6	0,0	0,0	738,3E-6	0,04161
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13	A1	0,0	0,05343	0,0	0,05343	-447,7E-6	0,0	0,0	447,7E-6	0,05343
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
14	A1	0,0	0,04134	0,0	0,04134	-659,9E-6	0,0	0,0	659,9E-6	0,04134
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
15	A1	0,0	0,05253	0,0	0,05253	-505,1E-6	0,0	0,0	505,1E-6	0,05253
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16	A1	0,0	0,04389	0,0	0,04389	-0,001046	0,0	0,0	0,001046	0,04389
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
17	A1	0,0	0,05342	0,0	0,05342	-560,5E-6	0,0	0,0	560,5E-6	0,05342
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
18	A1	0,0	0,02881	0,0	0,02881	-0,001760	0,0	0,0	0,001760	0,02881
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
19	A1	0,0	0,03092	0,0	0,03092	-0,001042	0,0	0,0	0,001042	0,03092
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
20	A1	0,0	0,03073	0,0	0,03073	-0,001101	0,0	0,0	0,001101	0,03073
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
21	A1	0,0	0,03077	0,0	0,03077	-0,001093	0,0	0,0	0,001093	0,03077
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
22	A1	0,0	0,03107	0,0	0,03107	-0,001007	0,0	0,0	0,001007	0,03107
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
23	A1	0,0	0,03157	0,0	0,03157	-0,001951	0,0	0,0	0,001951	0,03157
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
24	A1	0,0	0,01355	0,0	0,01355	-0,001962	0,0	0,0	0,001962	0,01355
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
25	A1	0,0	0,01363	0,0	0,01363	-0,001390	0,0	0,0	0,001390	0,01363
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
26	A1	0,0	0,01368	0,0	0,01368	-0,001426	0,0	0,0	0,001426	0,01368
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
27	A1	0,0	0,01371	0,0	0,01371	-0,001431	0,0	0,0	0,001431	0,01371
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
28	A1	0,0	0,01372	0,0	0,01372	-0,001383	0,0	0,0	0,001383	0,01372
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
29	A1	0,0	0,01370	0,0	0,01370	-0,002165	0,0	0,0	0,002165	0,01370
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Maxima

Node	Case	Ux	Uy	Uz	|U|	Rxx	Ryy	Rzz	|R|	Uxy
15	A1	***0,0***	0,05253	0,0	0,05253	-505,1E-6	0,0	0,0	505,1E-6	0,05253
13	A1	0,0	***0,05343***	0,0	0,05343	-447,7E-6	0,0	0,0	447,7E-6	0,05343
6	A1	0,0	0,03953	***0,0***	0,03953	-985,7E-6	0,0	0,0	985,7E-6	0,03953
13	A1	0,0	0,05343	0,0	***0,05343***	-447,7E-6	0,0	0,0	447,7E-6	0,05343
6	A2	0,0	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0	0,0
15	A1	0,0	0,05253	0,0	0,05253	-505,1E-6	***0,0***	0,0	505,1E-6	0,05253
17	A1	0,0	0,05342	0,0	0,05342	-560,5E-6	0,0	***0,0***	560,5E-6	0,05342
29	A1	0,0	0,01370	0,0	0,01370	-0,002165	0,0	0,0	***0,002165***	0,01370
13	A1	0,0	0,05343	0,0	0,05343	-447,7E-6	0,0	0,0	447,7E-6	***0,05343***

Minima

Node	Case	Ux	Uy	Uz	|U|	Rxx	Ryy	Rzz	|R|	Uxy
7	A1	***0,0***	0,05075	0,0	0,05075	-844,2E-6	0,0	0,0	844,2E-6	0,05075
6	A2	0,0	***0,0***	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	A1	0,0	0,03953	***0,0***	0,03953	-985,7E-6	0,0	0,0	985,7E-6	0,03953
6	A2	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0	0,0	0,0
29	A1	0,0	0,01370	0,0	0,01370	***-0,002165***	0,0	0,0	0,002165	0,01370
7	A1	0,0	0,05075	0,0	0,05075	-844,2E-6	***0,0***	0,0	844,2E-6	0,05075
11	A1	0,0	0,05341	0,0	0,05341	-459,9E-6	0,0	***0,0***	459,9E-6	0,05341
6	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0
6	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

Reactions

Reactions due to restraints, spring supports, applied displacements and grounded springs
Output axes: global

Node	Case	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]

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Job No. 1 | Sheet No. | Rev.

Final solution - Y direction

Htot 22 m, Hi 6 m, 2 part. braced, layout1,final

Drg. Ref.

Made by GI | Date 15-lug-2014 | Checked

Node	Case	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
6	A1	0,0	0,0	-7,536E+6	7,536E+6				
	A2	0,0	0,0	0,0	0,0				
7	A1	0,0	0,0	-7,535E+6	7,535E+6				
	A2	0,0	0,0	0,0	0,0				
8	A1	0,0	0,0	7,366E+6	7,366E+6				
	A2	0,0	0,0	0,0	0,0				
9	A1	0,0	0,0	116500,	116500,				
	A2	0,0	0,0	0,0	0,0				
10	A1	0,0	0,0	-50950,	50950,				
	A2	0,0	0,0	0,0	0,0				
11	A1	0,0	0,0	-52610,	52610,				
	A2	0,0	0,0	0,0	0,0				
12	A1	0,0	0,0	62650,	62650,				
	A2	0,0	0,0	0,0	0,0				
13	A1	0,0	0,0	20900,	20900,				
	A2	0,0	0,0	0,0	0,0				
14	A1	0,0	0,0	-8,231E+6	8,231E+6				
	A2	0,0	0,0	0,0	0,0				
15	A1	0,0	0,0	-7,199E+6	7,199E+6				
	A2	0,0	0,0	0,0	0,0				
16	A1	0,0	0,0	7,541E+6	7,541E+6				
	A2	0,0	0,0	0,0	0,0				
17	A1	0,0	0,0	250100,	250100,				
	A2	0,0	0,0	0,0	0,0				
18	A1	0,0	0,0	10,06E+6	10,06E+6				
	A2	0,0	0,0	0,0	0,0				
19	A1	0,0	0,0	7,360E+6	7,360E+6				
	A2	0,0	0,0	0,0	0,0				
20	A1	0,0	0,0	-82900,	82900,				
	A2	0,0	0,0	0,0	0,0				
21	A1	0,0	0,0	91420,	91420,				
	A2	0,0	0,0	0,0	0,0				
22	A1	0,0	0,0	-270700,	270700,				
	A2	0,0	0,0	0,0	0,0				
23	A1	0,0	0,0	-2,942E+6	2,942E+6				
	A2	0,0	0,0	0,0	0,0				
24	A1	0,0	0,0	-786600,	786600,				
	A2	0,0	0,0	0,0	0,0				
25	A1	0,0	0,0	219000,	219000,				
	A2	0,0	0,0	0,0	0,0				
26	A1	0,0	0,0	-102700,	102700,				
	A2	0,0	0,0	0,0	0,0				
27	A1	0,0	0,0	103200,	103200,				
	A2	0,0	0,0	0,0	0,0				
28	A1	0,0	0,0	-265500,	265500,				
	A2	0,0	0,0	0,0	0,0				
29	A1	0,0	0,0	832600,	832600,				
	A2	0,0	0,0	0,0	0,0				
30	A1	0,0	-472500,	0,0	472500,	1,432E+6	0,0	0,0	1,432E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
31	A1	0,0	-555000,	0,0	555000,	1,565E+6	0,0	0,0	1,565E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
32	A1	0,0	-552900,	0,0	552900,	1,565E+6	0,0	0,0	1,565E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
33	A1	0,0	-553900,	0,0	553900,	1,568E+6	0,0	0,0	1,568E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
34	A1	0,0	-561100,	0,0	561100,	1,580E+6	0,0	0,0	1,580E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
35	A1	0,0	-453000,	0,0	453000,	1,410E+6	0,0	0,0	1,410E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
36	A1	0,0	-4,126E+6	11,75E+6	12,45E+6	773800,	0,0	0,0	773800,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
37	A1	0,0	-3,766E+6	-10,72E+6	11,36E+6	708600,	0,0	0,0	708600,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Maxima

Node	Case	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
37	A1	***0,0***	-3,766E+6	-10,72E+6	11,36E+6	708600,	0,0	0,0	708600,
6	A1	0,0	***0,0***	-7,536E+6	7,536E+6				
36	A1	0,0	-4,126E+6	***11,75E+6***	12,45E+6	773800,	0,0	0,0	773800,
36	A1	0,0	-4,126E+6	11,75E+6	***12,45E+6***	773800,	0,0	0,0	773800,
34	A1	0,0	-561100,	0,0	561100,	***1,580E+6***	0,0	0,0	1,580E+6
37	A1	0,0	-3,766E+6	-10,72E+6	11,36E+6	708600,	***0,0***	0,0	708600,
32	A1	0,0	-552900,	0,0	552900,	1,565E+6	0,0	***0,0***	1,565E+6
34	A1	0,0	-561100,	0,0	561100,	1,580E+6	0,0	0,0	***1,580E+6***

Minima

Node	Case	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
34	A1	***0,0***	-561100,	0,0	561100,	1,580E+6	0,0	0,0	1,580E+6
36	A1	0,0	***-4,126E+6***	11,75E+6	12,45E+6	773800,	0,0	0,0	773800,
37	A1	0,0	-3,766E+6	***-10,72E+6***	11,36E+6	708600,	0,0	0,0	708600,
6	A2	0,0	0,0	0,0	***0,0***				
30	A2	0,0	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0
34	A1	0,0	-561100,	0,0	561100,	1,580E+6	***0,0***	0,0	1,580E+6
36	A1	0,0	-4,126E+6	11,75E+6	12,45E+6	773800,	0,0	***0,0***	773800,
30	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

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Job No. 1

Sheet No.

Rev.

Final solution - Y direction

Htot 22 m, Hi 6 m, 2 part. braced, layout1 final

Drg. Ref.

Made by GI

Date 15-lug-2014

Checked

Node Case Fx [N] Fy [N] Fz [N] |F| [N] Mxx [Nm] Myy [Nm] Mzz [Nm] |M| [Nm]

Nodal Forces and Moments

Forces reported are the forces at the node acting on the element; these may differ from
the forces reported for element ends when the element has end releases or is offset.
When reported in local output axes, forces are in element local directions related to the node and +ve axial forces are tensile.
2D elements are not considered.
Output axes: global

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
6	A1	3	-467,7E-12	-187700,	0,0	187700,	548100,	-341,4E-12	0,0	548100,
		25	0,0	81260,	0,0	81260,	326300,	0,0	0,0	326300,
		26	0,0	-4,646E+6	-401700,	4,664E+6	-869100,	0,0	0,0	869100,
		78	0,0	4,753E+6	-7,134E+6	8,572E+6	-5241,	0,0	0,0	5241,
	A2	3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		25	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		26	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		78	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	A1	3	467,7E-12	187700,	0,0	187700,	578300,	1,260E-9	0,0	578300,
		4	0,0	-3,224E+6	-276800,	3,236E+6	-682400,	0,0	0,0	682400,
		31	0,0	4,877E+6	-7,258E+6	8,744E+6	104200,	0,0	0,0	104200,
	A2	3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		31	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
8	A1	5	-332,5E-12	-238700,	0,0	238700,	674400,	-1,751E-9	0,0	674400,
		24	0,0	188100,	0,0	188100,	598000,	0,0	0,0	598000,
		26	0,0	4,646E+6	401700,	4,664E+6	-737800,	0,0	0,0	737800,
		27	0,0	280900,	-293500,	406300,	-659600,	0,0	0,0	659600,
		31	0,0	-4,877E+6	7,258E+6	8,744E+6	125100,	0,0	0,0	125100,
	A2	5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		24	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		26	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		27	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		31	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
9	A1	4	0,0	3,224E+6	276800,	3,236E+6	-424900,	0,0	0,0	424900,
		5	332,5E-12	238700,	0,0	238700,	757700,	-1,610E-9	0,0	757700,
		6	0,0	-1,623E+6	-160300,	1,631E+6	-332800,	0,0	0,0	332800,
	A2	4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
10	A1	11	7,736E-12	-263000,	0,0	263000,	760200,	180,5E-12	0,0	760200,
		23	0,0	182700,	0,0	182700,	587800,	0,0	0,0	587800,
		27	0,0	-280900,	293500,	406300,	-661200,	0,0	0,0	661200,
		28	0,0	361100,	-344500,	499100,	-686800,	0,0	0,0	686800,
	A2	11	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		23	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		27	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		28	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
11	A1	6	0,0	1,623E+6	160300,	1,631E+6	-388700,	0,0	0,0	388700,
		7	0,0	-46050,	-213000,	217900,	-429000,	0,0	0,0	429000,
		11	-7,736E-12	263000,	0,0	263000,	817700,	735,2E-12	0,0	817700,
	A2	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		11	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	A1	12	-904,8E-12	-270400,	0,0	270400,	780100,	814,0E-12	0,0	780100,
		22	0,0	175000,	0,0	175000,	562700,	0,0	0,0	562700,
		28	0,0	-361100,	344500,	499100,	-691100,	0,0	0,0	691100,
		29	0,0	456500,	-281800,	536500,	-651700,	0,0	0,0	651700,
	A2	12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		22	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		28	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		29	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13	A1	7	0,0	46050,	213000,	217900,	-422800,	0,0	0,0	422800,
		8	0,0	1,524E+6	-192100,	1,536E+6	-419200,	0,0	0,0	419200,
		12	904,8E-12	270400,	0,0	270400,	842000,	214,3E-12	0,0	842000,
	A2	7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
14	A1	13	-184,4E-12	-251800,	0,0	251800,	738800,	-1,171E-9	0,0	738800,
		21	0,0	172600,	0,0	172600,	554900,	0,0	0,0	554900,
		29	0,0	-456500,	281800,	536500,	-616400,	0,0	0,0	616400,
		30	0,0	-4,843E+6	-400200,	4,859E+6	-702700,	0,0	0,0	702700,
		74	0,0	5,378E+6	-8,112E+6	9,733E+6	25440,	0,0	0,0	25440,
	A2	13	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		21	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		29	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		30	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		74	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
15	A1	8	0,0	-1,524E+6	192100,	1,536E+6	-445100,	0,0	0,0	445100,
		9	0,0	-1,686E+6	-250100,	1,704E+6	-486100,	0,0	0,0	486100,
		13	184,4E-12	251800,	0,0	251800,	771800,	561,8E-12	0,0	771800,
		35	0,0	4,798E+6	-7,141E+6	8,603E+6	159300,	0,0	0,0	159300,
	A2	8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		13	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		35	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16	A1	14	0,0	-154100,	0,0	154100,	410700,	0,0	0,0	410700,
		20	0,0	109100,	0,0	109100,	423800,	0,0	0,0	423800,
		30	0,0	4,843E+6	400200,	4,859E+6	-898000,	0,0	0,0	898000,

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Job No. 1

Sheet No.

Rev.

Final solution - Y direction

Htot 22 m, Hi 6 m, 2 part. braced, layout1,final

Drg. Ref.

Made by GI

Date 15-lug-2014

Checked

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
		35	0,0	-4,798E+6	7,141E+6	8,603E+6	63470,	0,0	0,0	63470,
	A2	14	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		20	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		30	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		35	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
17	A1	9	0,0	1,686E+6	250100,	1,704E+6	-514100,	0,0	0,0	514100,
		14	0,0	154100,	0,0	154100,	514100,	0,0	0,0	514100,
	A2	9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		14	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
18	A1	25	0,0	-81260,	0,0	81260,	161300,	0,0	0,0	161300,
		43	0,0	-4,010E+6	-657400,	4,064E+6	-1,496E+6	0,0	0,0	1,496E+6
		61	0,0	325500,	0,0	325500,	839700,	0,0	0,0	839700,
		62	0,0	3,766E+6	10,72E+6	11,36E+6	495500,	0,0	0,0	495500,
	A2	25	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		43	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		61	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		62	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
19	A1	24	0,0	-188100,	0,0	188100,	530700,	0,0	0,0	530700,
		42	0,0	318000,	-432000,	536400,	-958700,	0,0	0,0	958700,
		43	0,0	4,010E+6	657400,	4,064E+6	-1,133E+6	0,0	0,0	1,133E+6
		59	0,0	612800,	0,0	612800,	1,576E+6	0,0	0,0	1,576E+6
		78	0,0	-4,753E+6	7,134E+6	8,572E+6	-15250,	0,0	0,0	15250,
	A2	24	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		42	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		43	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		59	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		78	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
20	A1	23	0,0	-182700,	0,0	182700,	508600,	0,0	0,0	508600,
		41	0,0	-85860,	-514900,	522000,	-1,032E+6	0,0	0,0	1,032E+6
		42	0,0	-318000,	432000,	536400,	-985200,	0,0	0,0	985200,
		57	0,0	586600,	0,0	586600,	1,508E+6	0,0	0,0	1,508E+6
	A2	23	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		41	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		42	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		57	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
21	A1	22	0,0	-175000,	0,0	175000,	487000,	0,0	0,0	487000,
		40	0,0	-498800,	-423500,	654300,	-972100,	0,0	0,0	972100,
		41	0,0	85860,	514900,	522000,	-1,028E+6	0,0	0,0	1,028E+6
		55	0,0	587900,	0,0	587900,	1,513E+6	0,0	0,0	1,513E+6
	A2	22	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		40	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		41	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		55	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
22	A1	21	0,0	-172600,	0,0	172600,	480700,	0,0	0,0	480700,
		39	0,0	-947900,	-694200,	1,175E+6	-1,149E+6	0,0	0,0	1,149E+6
		40	0,0	498800,	423500,	654300,	-933400,	0,0	0,0	933400,
		53	0,0	621600,	0,0	621600,	1,602E+6	0,0	0,0	1,602E+6
	A2	21	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		39	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		40	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		53	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
23	A1	20	0,0	-109100,	0,0	109100,	230700,	0,0	0,0	230700,
		39	0,0	947900,	694200,	1,175E+6	-1,627E+6	0,0	0,0	1,627E+6
		49	0,0	4,126E+6	-11,75E+6	12,45E+6	537500,	0,0	0,0	537500,
		51	0,0	414100,	0,0	414100,	1,063E+6	0,0	0,0	1,063E+6
		74	0,0	-5,378E+6	8,112E+6	9,733E+6	-203600,	0,0	0,0	203600,
	A2	20	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		39	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		49	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		51	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		74	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
24	A1	48	0,0	-147000,	-786600,	800200,	-1,718E+6	0,0	0,0	1,718E+6
		60	0,0	472500,	0,0	472500,	930300,	0,0	0,0	930300,
		61	0,0	-325500,	0,0	325500,	787800,	0,0	0,0	787800,
	A2	48	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		60	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		61	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
25	A1	47	0,0	-89240,	-567600,	574600,	-1,269E+6	0,0	0,0	1,269E+6
		48	0,0	147000,	786600,	800200,	-1,428E+6	0,0	0,0	1,428E+6
		58	0,0	555000,	0,0	555000,	1,210E+6	0,0	0,0	1,210E+6
		59	0,0	-612800,	0,0	612800,	1,487E+6	0,0	0,0	1,487E+6
	A2	47	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		48	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		58	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		59	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
26	A1	46	0,0	-55530,	-670300,	672600,	-1,339E+6	0,0	0,0	1,339E+6
		47	0,0	89240,	567600,	574600,	-1,285E+6	0,0	0,0	1,285E+6
		56	0,0	552900,	0,0	552900,	1,200E+6	0,0	0,0	1,200E+6
		57	0,0	-586600,	0,0	586600,	1,425E+6	0,0	0,0	1,425E+6
	A2	46	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		47	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		56	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		57	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
27	A1	45	0,0	-21510,	-567100,	567500,	-1,287E+6	0,0	0,0	1,287E+6
		46	0,0	55530,	670300,	672600,	-1,342E+6	0,0	0,0	1,342E+6
		54	0,0	553900,	0,0	553900,	1,202E+6	0,0	0,0	1,202E+6
		55	0,0	-587900,	0,0	587900,	1,427E+6	0,0	0,0	1,427E+6
	A2	45	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		46	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		54	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

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Job No.	Sheet No.	Rev.
1		

Final solution - Y direction

Htot 22 m, Hi 6 m, 2 part. braced, layout1,final

Drg. Ref.

Made by	Date	Checked
GI	15-lug-2014	

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
		55	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
28	A1	44	0,0	38980,	-832600,	833500,	-1,467E+6	0,0	0,0	1,467E+6
		45	0,0	21510,	567100,	567500,	-1,265E+6	0,0	0,0	1,265E+6
		52	0,0	561100,	0,0	561100,	1,226E+6	0,0	0,0	1,226E+6
		53	0,0	-621600,	0,0	621600,	1,506E+6	0,0	0,0	1,506E+6
	A2	44	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		45	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		52	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		53	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
29	A1	44	0,0	-38980,	832600,	833500,	-1,863E+6	0,0	0,0	1,863E+6
		50	0,0	453000,	0,0	453000,	855600,	0,0	0,0	855600,
		51	0,0	-414100,	0,0	414100,	1,008E+6	0,0	0,0	1,008E+6
	A2	44	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		50	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		51	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
30	A1	60	0,0	-472500,	0,0	472500,	1,432E+6	0,0	0,0	1,432E+6
	A2	60	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
31	A1	58	0,0	-555000,	0,0	555000,	1,565E+6	0,0	0,0	1,565E+6
	A2	58	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
32	A1	56	0,0	-552900,	0,0	552900,	1,565E+6	0,0	0,0	1,565E+6
	A2	56	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
33	A1	54	0,0	-553900,	0,0	553900,	1,568E+6	0,0	0,0	1,568E+6
	A2	54	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
34	A1	52	0,0	-561100,	0,0	561100,	1,580E+6	0,0	0,0	1,580E+6
	A2	52	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
35	A1	50	0,0	-453000,	0,0	453000,	1,410E+6	0,0	0,0	1,410E+6
	A2	50	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
36	A1	49	0,0	-4,126E+6	11,75E+6	12,45E+6	773800,	0,0	0,0	773800,
	A2	49	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
37	A1	62	0,0	-3,766E+6	-10,72E+6	11,36E+6	708600,	0,0	0,0	708600,
	A2	62	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Maxima

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
13	A1	12	***904,8E-12***	270400,	0,0	270400,	842000,	214,3E-12	0,0	842000,
14	A1	74	0,0	***5,378E+6***	-8,112E+6	9,733E+6	25440,	0,0	0,0	25440,
36	A1	49	0,0	-4,126E+6	***11,75E+6***	12,45E+6	773800,	0,0	0,0	773800,
23	A1	49	0,0	4,126E+6	-11,75E+6	***12,45E+6***	537500,	0,0	0,0	537500,
22	A1	53	0,0	621600,	0,0	621600,	***1,602E+6***	0,0	0,0	1,602E+6
7	A1	3	467,7E-12	187700,	0,0	187700,	578300,	***1,260E-9***	0,0	578300,
20	A1	23	0,0	-182700,	0,0	182700,	508600,	0,0	***0,0***	508600,
29	A1	44	0,0	-38980,	832600,	833500,	-1,863E+6	0,0	0,0	***1,863E+6***

Minima

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
12	A1	12	***-904,8E-12***	-270400,	0,0	270400,	780100,	814,0E-12	0,0	780100,
23	A1	74	0,0	***-5,378E+6***	8,112E+6	9,733E+6	-203600,	0,0	0,0	203600,
23	A1	49	0,0	4,126E+6	***-11,75E+6***	12,45E+6	537500,	0,0	0,0	537500,
6	A2	3	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0	0,0
29	A1	44	0,0	-38980,	832600,	833500,	***-1,863E+6***	0,0	0,0	1,863E+6
8	A1	5	-332,5E-12	-238700,	0,0	238700,	674400,	***-1,751E-9***	0,0	674400,
10	A1	23	0,0	182700,	0,0	182700,	587800,	0,0	***0,0***	587800,
6	A2	3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

Fixed situation - compared solution (X-direction)

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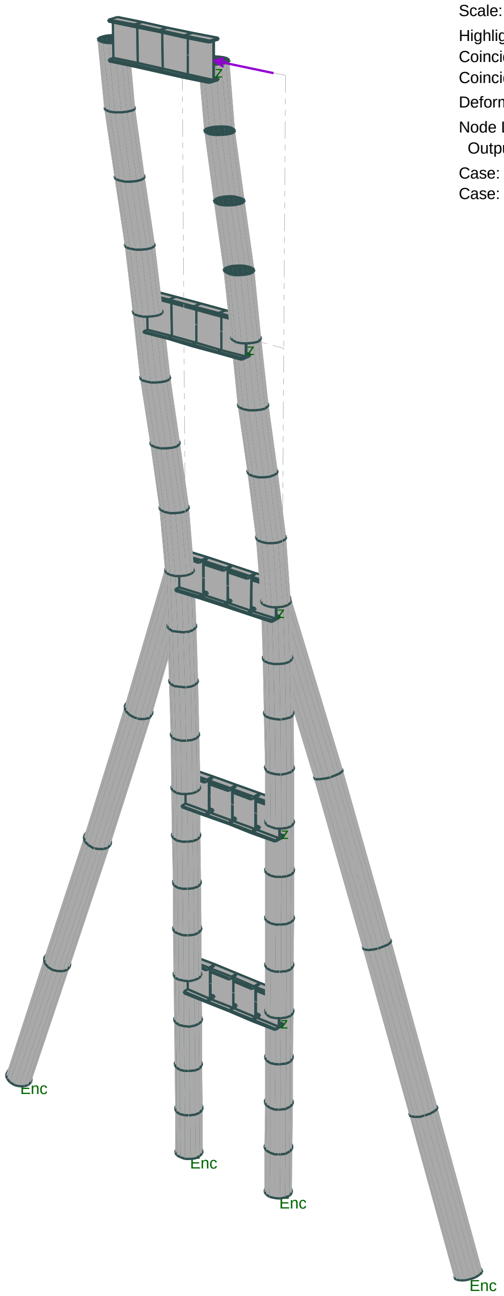
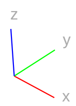
Compared solution - X direction
Htot 27.5 m, Hi 6 m, unbraced, layout1, final

Job No.	Sheet No.	Rev.
1		
Drg. Ref.		
Made by GI	Date 15-lug-2014	Checked

Scale: 1:131,4
Highlighted:
Coincident Nodes
Coincident Elements
Deformation magnification: 25,00
Node Loads, Force: 1,000E+6 N/pic.cm
Output axis: global
Case: L1
Case: A1 : Analysis case 1





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Job No.	Sheet No.	Rev.
1		

Compared solution - X direction

Htot 27.5 m, Hi 6 m, unbraced, layout1, final

Drg. Ref.

Made by	Date	Checked
GI	15-lug-2014	

Displacements

Displacements reported at nodes; fully restrained nodes are excluded
Output axes: global

Node	Case	Ux [m]	Uy [m]	Uz [m]	|U| [m]	Rxx [rad]	Ryy [rad]	Rzz [rad]	|R| [rad]	Uxy [m]
1	A1	-0,04157	0,0	0,0	0,04157	0,0	-0,003505	0,0	0,003505	0,04157
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	A1	-0,07713	0,0	0,0	0,07713	0,0	-0,002081	0,0	0,002081	0,07713
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	A1	-0,04157	0,0	0,0	0,04157	0,0	-0,003518	0,0	0,003518	0,04157
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	A1	-0,07736	0,0	0,0	0,07736	0,0	-0,002098	0,0	0,002098	0,07736
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
8	A1	-0,006856	0,0	0,0	0,006856	0,0	-0,001772	0,0	0,001772	0,006856
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
9	A1	-0,006855	0,0	0,0	0,006855	0,0	-0,001771	0,0	0,001771	0,006855
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
10	A1	-0,001171	0,0	0,0	0,001171	0,0	-216,8E-6	0,0	216,8E-6	0,001171
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
11	A1	-0,001171	0,0	0,0	0,001171	0,0	-217,0E-6	0,0	217,0E-6	0,001171
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	A1	-314,6E-6	0,0	0,0	314,6E-6	0,0	-59,92E-6	0,0	59,92E-6	314,6E-6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13	A1	-314,6E-6	0,0	0,0	314,6E-6	0,0	-59,90E-6	0,0	59,90E-6	314,6E-6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Maxima

Node	Case	Ux [m]	Uy [m]	Uz [m]	|U| [m]	Rxx [rad]	Ryy [rad]	Rzz [rad]	|R| [rad]	Uxy [m]
1	A2	***0,0***	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	A1	-0,07736	***0,0***	0,0	0,07736	0,0	-0,002098	0,0	0,002098	0,07736
1	A1	-0,04157	0,0	***0,0***	0,04157	0,0	-0,003505	0,0	0,003505	0,04157
7	A1	-0,07736	0,0	0,0	***0,07736***	0,0	-0,002098	0,0	0,002098	0,07736
8	A1	-0,006856	0,0	0,0	0,006856	***0,0***	-0,001772	0,0	0,001772	0,006856
1	A2	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0
2	A1	-0,07713	0,0	0,0	0,07713	0,0	-0,002081	***0,0***	0,002081	0,07713
6	A1	-0,04157	0,0	0,0	0,04157	0,0	-0,003518	0,0	***0,003518***	0,04157
7	A1	-0,07736	0,0	0,0	0,07736	0,0	-0,002098	0,0	0,002098	***0,07736***

Minima

Node	Case	Ux [m]	Uy [m]	Uz [m]	|U| [m]	Rxx [rad]	Ryy [rad]	Rzz [rad]	|R| [rad]	Uxy [m]
7	A1	***-0,07736***	0,0	0,0	0,07736	0,0	-0,002098	0,0	0,002098	0,07736
2	A1	-0,07713	***0,0***	0,0	0,07713	0,0	-0,002081	0,0	0,002081	0,07713
1	A1	-0,04157	0,0	***0,0***	0,04157	0,0	-0,003505	0,0	0,003505	0,04157
1	A2	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0	0,0	0,0
9	A1	-0,006855	0,0	0,0	0,006855	***0,0***	-0,001771	0,0	0,001771	0,006855
6	A1	-0,04157	0,0	0,0	0,04157	0,0	***-0,003518***	0,0	0,003518	0,04157
1	A2	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0	0,0
1	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0
1	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

Reactions

Reactions due to restraints, spring supports, applied displacements and grounded springs
Output axes: global

Node	Case	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
1	A1	0,0	0,0	2,406E+6	2,406E+6				
	A2	0,0	0,0	0,0	0,0				
2	A1	0,0	0,0	1,432E+6	1,432E+6				
	A2	0,0	0,0	0,0	0,0				
6	A1	0,0	0,0	-2,406E+6	2,406E+6				
	A2	0,0	0,0	0,0	0,0				
7	A1	0,0	0,0	-1,432E+6	1,432E+6				
	A2	0,0	0,0	0,0	0,0				
8	A1	0,0	0,0	-511300,	511300,				
	A2	0,0	0,0	0,0	0,0				
9	A1	0,0	0,0	511200,	511200,				
	A2	0,0	0,0	0,0	0,0				
10	A1	0,0	0,0	148600,	148600,				
	A2	0,0	0,0	0,0	0,0				
11	A1	0,0	0,0	-148600,	148600,				
	A2	0,0	0,0	0,0	0,0				
12	A1	0,0	0,0	41050,	41050,				
	A2	0,0	0,0	0,0	0,0				
13	A1	0,0	0,0	-41050,	41050,				
	A2	0,0	0,0	0,0	0,0				
14	A1	9007,	0,0	0,0	9007,	0,0	30180,	0,0	30180,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
15	A1	9010,	0,0	0,0	9010,	0,0	30190,	0,0	30190,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16	A1	608600,	0,0	-1,725E+6	1,829E+6	0,0	-45090,	0,0	45090,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
17	A1	608600,	0,0	1,725E+6	1,829E+6	0,0	-45190,	0,0	45190,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

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Page 1
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Job No.	Sheet No.	Rev.
1		

Drg. Ref.

Made by	Date	Checked
GI	15-lug-2014	

Compared solution - X direction

Htot 27.5 m, Hi 6 m, unbraced, layout1, final

Node	Case	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
Maxima									
17	A1	***608600,***	0,0	1,725E+6	1,829E+6	0,0	-45190,	0,0	45190,
17	A1	608600,	***0,0***	1,725E+6	1,829E+6	0,0	-45190,	0,0	45190,
1	A1	0,0	0,0	***2,406E+6***	2,406E+6				
1	A1	0,0	0,0	2,406E+6	***2,406E+6***				
16	A1	608600,	0,0	-1,725E+6	1,829E+6	***0,0***	-45090,	0,0	45090,
15	A1	9010,	0,0	0,0	9010,	0,0	***30190,***	0,0	30190,
14	A2	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0
17	A1	608600,	0,0	1,725E+6	1,829E+6	0,0	-45190,	0,0	***45190,***
Minima									
1	A1	***0,0***	0,0	2,406E+6	2,406E+6				
16	A1	608600,	***0,0***	-1,725E+6	1,829E+6	0,0	-45090,	0,0	45090,
6	A1	0,0	0,0	***-2,406E+6***	2,406E+6				
1	A2	0,0	0,0	0,0	***0,0***				
17	A1	608600,	0,0	1,725E+6	1,829E+6	***0,0***	-45190,	0,0	45190,
17	A1	608600,	0,0	1,725E+6	1,829E+6	0,0	***-45190,***	0,0	45190,
14	A1	9007,	0,0	0,0	9007,	0,0	30180,	***0,0***	30180,
14	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

Nodal Forces and Moments

Forces reported are the forces at the node acting on the element; these may differ from the forces reported for element ends when the element has end releases or is offset.
When reported in local output axes, forces are in element local directions related to the node and +ve axial forces are tensile.
2D elements are not considered.
Output axes: global

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
1	A1	1	615400,	-416,2E-12	0,0	615400,	-1,480E-9	1,694E+6	0,0	1,694E+6
		5	-618100,	0,0	0,0	618100,	0,0	1,670E+6	0,0	1,670E+6
		7	2734,	0,0	2,406E+6	2,406E+6	0,0	-3,364E+6	0,0	3,364E+6
	A2	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	A1	1	-615400,	416,2E-12	0,0	615400,	2,238E-9	1,998E+6	0,0	1,998E+6
		2	615400,	0,0	1,432E+6	1,558E+6	0,0	-1,998E+6	0,0	1,998E+6
	A2	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	A1	3	619800,	-1,303E-9	0,0	619800,	258,9E-12	1,708E+6	0,0	1,708E+6
		6	-617100,	0,0	0,0	617100,	0,0	1,665E+6	0,0	1,665E+6
		7	-2734,	0,0	-2,406E+6	2,406E+6	0,0	-3,373E+6	0,0	3,373E+6
	A2	3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	A1	2	-615400,	0,0	-1,432E+6	1,558E+6	0,0	-2,011E+6	0,0	2,011E+6
		3	-619800,	1,303E-9	0,0	619800,	106,2E-12	2,011E+6	0,0	2,011E+6
	A2	2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
8	A1	5	618100,	0,0	0,0	618100,	0,0	2,039E+6	0,0	2,039E+6
		8	-593,7	0,0	1,214E+6	1,214E+6	0,0	-1,700E+6	0,0	1,700E+6
		13	-8945,	0,0	0,0	8945,	0,0	-156300,	0,0	156300,
		14	-608600,	0,0	-1,725E+6	1,829E+6	0,0	-182800,	0,0	182800,
	A2	5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		13	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		14	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
9	A1	6	617100,	0,0	0,0	617100,	0,0	2,037E+6	0,0	2,037E+6
		8	593,7	0,0	-1,214E+6	1,214E+6	0,0	-1,699E+6	0,0	1,699E+6
		11	-9072,	0,0	0,0	9072,	0,0	-155800,	0,0	155800,
		15	-608600,	0,0	1,725E+6	1,829E+6	0,0	-182600,	0,0	182600,
	A2	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		11	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		15	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
10	A1	9	71,83	0,0	148600,	148600,	0,0	-208000,	0,0	208000,
		12	-9017,	0,0	0,0	9017,	0,0	2468,	0,0	2468,
		13	8945,	0,0	0,0	8945,	0,0	205500,	0,0	205500,
	A2	9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		13	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
11	A1	9	-71,83	0,0	-148600,	148600,	0,0	-208100,	0,0	208100,
		10	-9000,	0,0	0,0	9000,	0,0	2404,	0,0	2404,
		11	9072,	0,0	0,0	9072,	0,0	205700,	0,0	205700,
	A2	9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		10	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		11	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	A1	12	9017,	0,0	0,0	9017,	0,0	42620,	0,0	42620,
		16	-9,573	0,0	41050,	41050,	0,0	-57470,	0,0	57470,
		18	-9007,	0,0	0,0	9007,	0,0	14850,	0,0	14850,
	A2	12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		16	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13	A1	10	9000,	0,0	0,0	9000,	0,0	42600,	0,0	42600,

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Job No. 1

Sheet No.

Rev.

Compared solution - X direction

Htot 27.5 m, Hi 6 m, unbraced, layout1, final

Drg. Ref.

Made by GI

Date 15-lug-2014

Checked

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
		16	9,573	0,0	-41050,	41050,	0,0	-57460,	0,0	57460,
		17	-9010,	0,0	0,0	9010,	0,0	14860,	0,0	14860,
	A2	10	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		16	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		17	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
14	A1	18	9007,	0,0	0,0	9007,	0,0	30180,	0,0	30180,
	A2	18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
15	A1	17	9010,	0,0	0,0	9010,	0,0	30190,	0,0	30190,
	A2	17	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16	A1	15	608600,	0,0	-1,725E+6	1,829E+6	0,0	-45090,	0,0	45090,
	A2	15	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
17	A1	14	608600,	0,0	1,725E+6	1,829E+6	0,0	-45190,	0,0	45190,
	A2	14	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Maxima

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
6	A1	3	***619800,***	-1,303E-9	0,0	619800,	258,9E-12	1,708E+6	0,0	1,708E+6
7	A1	3	-619800,	***1,303E-9***	0,0	619800,	106,2E-12	2,011E+6	0,0	2,011E+6
1	A1	7	2734,	0,0	***2,406E+6***	2,406E+6	0,0	-3,364E+6	0,0	3,364E+6
1	A1	7	2734,	0,0	2,406E+6	***2,406E+6***	0,0	-3,364E+6	0,0	3,364E+6
2	A1	1	-615400,	416,2E-12	0,0	615400,	***2,238E-9***	1,998E+6	0,0	1,998E+6
8	A1	5	618100,	0,0	0,0	618100,	0,0	***2,039E+6***	0,0	2,039E+6
6	A1	6	-617100,	0,0	0,0	617100,	0,0	1,665E+6	***0,0***	1,665E+6
6	A1	7	-2734,	0,0	-2,406E+6	2,406E+6	0,0	-3,373E+6	0,0	***3,373E+6***

Minima

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
7	A1	3	***-619800,***	1,303E-9	0,0	619800,	106,2E-12	2,011E+6	0,0	2,011E+6
6	A1	3	619800,	***-1,303E-9***	0,0	619800,	258,9E-12	1,708E+6	0,0	1,708E+6
6	A1	7	-2734,	0,0	***-2,406E+6***	2,406E+6	0,0	-3,373E+6	0,0	3,373E+6
1	A2	1	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0	0,0
1	A1	1	615400,	-416,2E-12	0,0	615400,	***-1,480E-9***	1,694E+6	0,0	1,694E+6
6	A1	7	-2734,	0,0	-2,406E+6	2,406E+6	0,0	***-3,373E+6***	0,0	3,373E+6
9	A1	6	617100,	0,0	0,0	617100,	0,0	2,037E+6	***0,0***	2,037E+6
1	A2	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

Fixed situation - compared solution (Y-direction)

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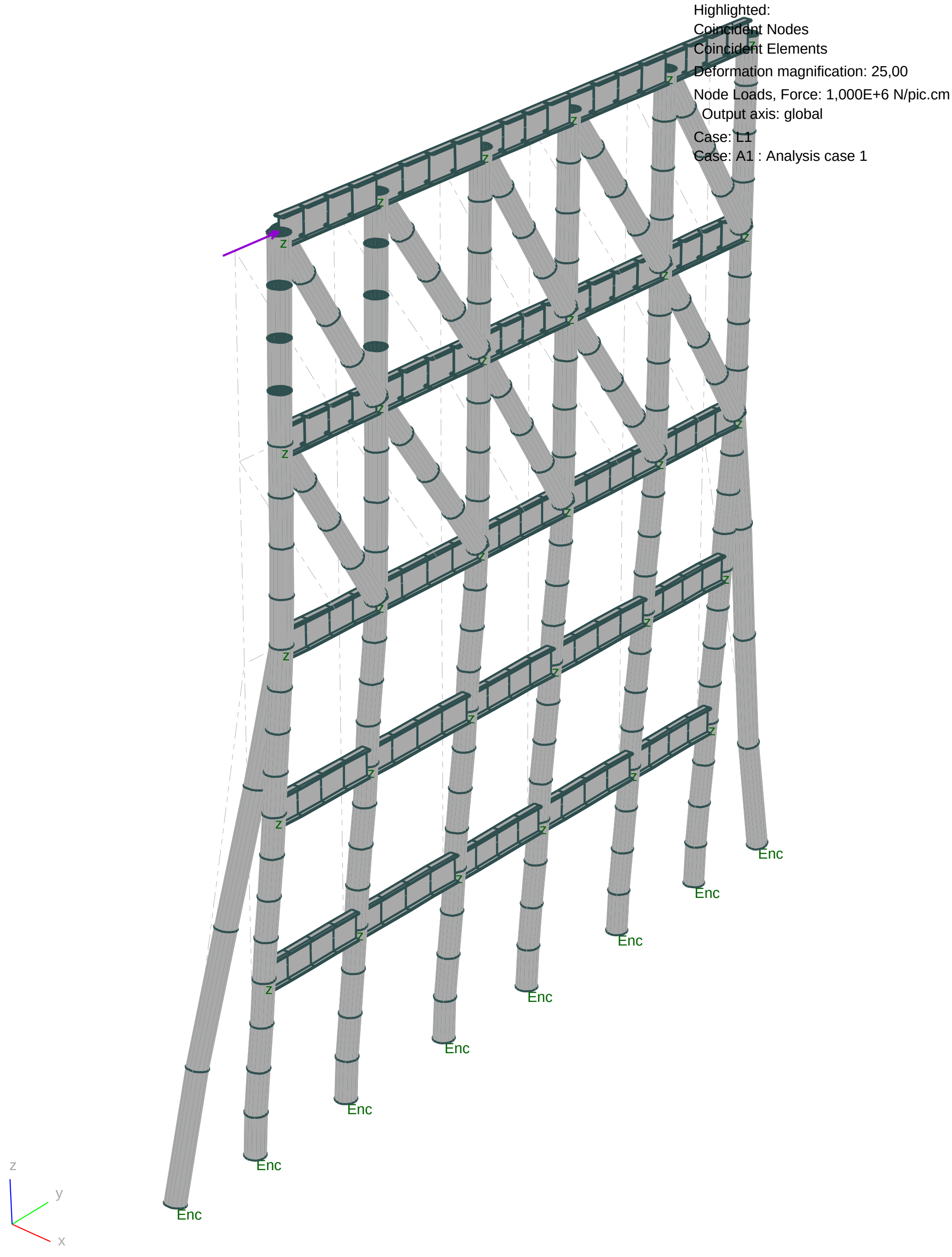
Compared solution - Y direction
Htot 27.5 m, Hi 6 m, 2 floor braced, layout1, final

Job No.	Sheet No.	Rev.
1		
Drg. Ref.		
Made by GI	Date 14-lug-2014	Checked

Scale: 1:152,4
Highlighted:
Coincident Nodes
Coincident Elements
Deformation magnification: 25,00
Node Loads, Force: 1,000E+6 N/pic.cm
Output axis: global
Case: L1
Case: A1 : Analysis case 1



Program GSA Version 8.7 Copyright © Oasys 1985-2014
C:\Users\Giuse\Desktop\SHL\Finals\Fmod\Final1\H27.5_Hi6_l1_2b_y_all.gwb
Printed 16-lug-2014
Page 1
Time 08:53

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Job No.	Sheet No.	Rev.
1		

Compared solution - Y direction

Htot 27.5 m, Hi 6 m, 2 floor braced, layout1, final

Drg. Ref.

Made by	Date	Checked
GI	14-lug-2014	

Displacements

Displacements reported at nodes; fully restrained nodes are excluded
Output axes: global

Node	Case	Ux [m]	Uy [m]	Uz [m]	|U| [m]	Rxx [rad]	Ryy [rad]	Rzz [rad]	|R| [rad]	Uxy [m]
6	A1	0,0	0,06642	0,0	0,06642	-239,7E-6	0,0	0,0	239,7E-6	0,06642
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	A1	0,0	0,07051	0,0	0,07051	-329,7E-6	0,0	0,0	329,7E-6	0,07051
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
8	A1	0,0	0,06721	0,0	0,06721	-198,5E-6	0,0	0,0	198,5E-6	0,06721
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
9	A1	0,0	0,07074	0,0	0,07074	-149,6E-6	0,0	0,0	149,6E-6	0,07074
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
10	A1	0,0	0,06792	0,0	0,06792	-171,5E-6	0,0	0,0	171,5E-6	0,06792
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
11	A1	0,0	0,07122	0,0	0,07122	-167,3E-6	0,0	0,0	167,3E-6	0,07122
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	A1	0,0	0,06838	0,0	0,06838	-181,4E-6	0,0	0,0	181,4E-6	0,06838
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13	A1	0,0	0,07175	0,0	0,07175	-159,2E-6	0,0	0,0	159,2E-6	0,07175
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
14	A1	0,0	0,06904	0,0	0,06904	-166,3E-6	0,0	0,0	166,3E-6	0,06904
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
15	A1	0,0	0,07253	0,0	0,07253	-156,4E-6	0,0	0,0	156,4E-6	0,07253
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16	A1	0,0	0,06987	0,0	0,06987	-294,4E-6	0,0	0,0	294,4E-6	0,06987
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
17	A1	0,0	0,07327	0,0	0,07327	-218,2E-6	0,0	0,0	218,2E-6	0,07327
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
18	A1	0,0	0,06195	0,0	0,06195	-0,001741	0,0	0,0	0,001741	0,06195
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
19	A1	0,0	0,06345	0,0	0,06345	-824,7E-6	0,0	0,0	824,7E-6	0,06345
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
20	A1	0,0	0,06458	0,0	0,06458	-924,8E-6	0,0	0,0	924,8E-6	0,06458
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
21	A1	0,0	0,06513	0,0	0,06513	-945,7E-6	0,0	0,0	945,7E-6	0,06513
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
22	A1	0,0	0,06531	0,0	0,06531	-908,6E-6	0,0	0,0	908,6E-6	0,06531
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
23	A1	0,0	0,06487	0,0	0,06487	-0,001743	0,0	0,0	0,001743	0,06487
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
24	A1	0,0	0,04394	0,0	0,04394	-0,002508	0,0	0,0	0,002508	0,04394
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
25	A1	0,0	0,04399	0,0	0,04399	-0,001794	0,0	0,0	0,001794	0,04399
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
26	A1	0,0	0,04407	0,0	0,04407	-0,001906	0,0	0,0	0,001906	0,04407
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
27	A1	0,0	0,04412	0,0	0,04412	-0,001931	0,0	0,0	0,001931	0,04412
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
28	A1	0,0	0,04417	0,0	0,04417	-0,001872	0,0	0,0	0,001872	0,04417
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
29	A1	0,0	0,04418	0,0	0,04418	-0,002742	0,0	0,0	0,002742	0,04418
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
38	A1	0,0	0,02144	0,0	0,02144	-0,002843	0,0	0,0	0,002843	0,02144
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
39	A1	0,0	0,02148	0,0	0,02148	-0,001789	0,0	0,0	0,001789	0,02148
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
40	A1	0,0	0,02150	0,0	0,02150	-0,001882	0,0	0,0	0,001882	0,02150
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
41	A1	0,0	0,02149	0,0	0,02149	-0,001883	0,0	0,0	0,001883	0,02149
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
42	A1	0,0	0,02147	0,0	0,02147	-0,001793	0,0	0,0	0,001793	0,02147
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
43	A1	0,0	0,02142	0,0	0,02142	-0,002833	0,0	0,0	0,002833	0,02142
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Maxima

Node	Case	Ux	Uy	Uz	|U|	Rxx	Ryy	Rzz	|R|	Uxy
17	A1	***0,0***	0,07327	0,0	0,07327	-218,2E-6	0,0	0,0	218,2E-6	0,07327
17	A1	0,0	***0,07327***	0,0	0,07327	-218,2E-6	0,0	0,0	218,2E-6	0,07327
6	A1	0,0	0,06642	***0,0***	0,06642	-239,7E-6	0,0	0,0	239,7E-6	0,06642
17	A1	0,0	0,07327	0,0	***0,07327***	-218,2E-6	0,0	0,0	218,2E-6	0,07327
6	A2	0,0	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0	0,0
15	A1	0,0	0,07253	0,0	0,07253	-156,4E-6	***0,0***	0,0	156,4E-6	0,07253
6	A2	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0	0,0
38	A1	0,0	0,02144	0,0	0,02144	-0,002843	0,0	0,0	***0,002843***	0,02144
17	A1	0,0	0,07327	0,0	0,07327	-218,2E-6	0,0	0,0	218,2E-6	***0,07327***

Minima

Node	Case	Ux	Uy	Uz	|U|	Rxx	Ryy	Rzz	|R|	Uxy
38	A1	***0,0***	0,02144	0,0	0,02144	-0,002843	0,0	0,0	0,002843	0,02144
6	A2	0,0	***0,0***	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	A1	0,0	0,06642	***0,0***	0,06642	-239,7E-6	0,0	0,0	239,7E-6	0,06642
6	A2	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0	0,0	0,0
38	A1	0,0	0,02144	0,0	0,02144	***-0,002843***	0,0	0,0	0,002843	0,02144

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Job No.	Sheet No.	Rev.
1		

Compared solution - Y direction

Htot 27.5 m, Hi 6 m, 2 floor braced, layout1, final

Drg. Ref.

Made by	Date	Checked
GI	14-lug-2014	

Node	Case	Ux [m]	Uy [m]	Uz [m]	|U| [m]	Rxx [rad]	Ryy [rad]	Rzz [rad]	|R| [rad]	Uxy [m]
38	A1	0,0	0,02144	0,0	0,02144	-0,002843	***0,0***	0,0	0,002843	0,02144
9	A1	0,0	0,07074	0,0	0,07074	-149,6E-6	0,0	***0,0***	149,6E-6	0,07074
6	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***	0,0
6	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

Reactions

Reactions due to restraints, spring supports, applied displacements and grounded springs
Output axes: global

Node	Case	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
6	A1	0,0	0,0	-2,582E+6	2,582E+6				
	A2	0,0	0,0	0,0	0,0				
7	A1	0,0	0,0	-2,835E+6	2,835E+6				
	A2	0,0	0,0	0,0	0,0				
8	A1	0,0	0,0	552800,	552800,				
	A2	0,0	0,0	0,0	0,0				
9	A1	0,0	0,0	-2,274E+6	2,274E+6				
	A2	0,0	0,0	0,0	0,0				
10	A1	0,0	0,0	-13550,	13550,				
	A2	0,0	0,0	0,0	0,0				
11	A1	0,0	0,0	-2,352E+6	2,352E+6				
	A2	0,0	0,0	0,0	0,0				
12	A1	0,0	0,0	-211900,	211900,				
	A2	0,0	0,0	0,0	0,0				
13	A1	0,0	0,0	-2,227E+6	2,227E+6				
	A2	0,0	0,0	0,0	0,0				
14	A1	0,0	0,0	-1,283E+6	1,283E+6				
	A2	0,0	0,0	0,0	0,0				
15	A1	0,0	0,0	-2,225E+6	2,225E+6				
	A2	0,0	0,0	0,0	0,0				
16	A1	0,0	0,0	2,309E+6	2,309E+6				
	A2	0,0	0,0	0,0	0,0				
17	A1	0,0	0,0	87890,	87890,				
	A2	0,0	0,0	0,0	0,0				
18	A1	0,0	0,0	9,953E+6	9,953E+6				
	A2	0,0	0,0	0,0	0,0				
19	A1	0,0	0,0	2,729E+6	2,729E+6				
	A2	0,0	0,0	0,0	0,0				
20	A1	0,0	0,0	2,111E+6	2,111E+6				
	A2	0,0	0,0	0,0	0,0				
21	A1	0,0	0,0	2,393E+6	2,393E+6				
	A2	0,0	0,0	0,0	0,0				
22	A1	0,0	0,0	2,315E+6	2,315E+6				
	A2	0,0	0,0	0,0	0,0				
23	A1	0,0	0,0	-6,946E+6	6,946E+6				
	A2	0,0	0,0	0,0	0,0				
24	A1	0,0	0,0	-1,010E+6	1,010E+6				
	A2	0,0	0,0	0,0	0,0				
25	A1	0,0	0,0	263600,	263600,				
	A2	0,0	0,0	0,0	0,0				
26	A1	0,0	0,0	-154600,	154600,				
	A2	0,0	0,0	0,0	0,0				
27	A1	0,0	0,0	133900,	133900,				
	A2	0,0	0,0	0,0	0,0				
28	A1	0,0	0,0	-315900,	315900,				
	A2	0,0	0,0	0,0	0,0				
29	A1	0,0	0,0	1,082E+6	1,082E+6				
	A2	0,0	0,0	0,0	0,0				
30	A1	0,0	-570400,	0,0	570400,	1,899E+6	0,0	0,0	1,899E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
31	A1	0,0	-693400,	0,0	693400,	2,115E+6	0,0	0,0	2,115E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
32	A1	0,0	-683300,	0,0	683300,	2,098E+6	0,0	0,0	2,098E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
33	A1	0,0	-683000,	0,0	683000,	2,097E+6	0,0	0,0	2,097E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
34	A1	0,0	-692400,	0,0	692400,	2,113E+6	0,0	0,0	2,113E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
35	A1	0,0	-570700,	0,0	570700,	1,899E+6	0,0	0,0	1,899E+6
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
36	A1	0,0	-2,521E+6	11,05E+6	11,34E+6	816200,	0,0	0,0	816200,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
37	A1	0,0	-2,406E+6	-10,55E+6	10,83E+6	773300,	0,0	0,0	773300,
	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
38	A1	0,0	0,0	-1,087E+6	1,087E+6				
	A2	0,0	0,0	0,0	0,0				
39	A1	0,0	0,0	346900,	346900,				
	A2	0,0	0,0	0,0	0,0				
40	A1	0,0	0,0	-143500,	143500,				
	A2	0,0	0,0	0,0	0,0				
41	A1	0,0	0,0	142500,	142500,				
	A2	0,0	0,0	0,0	0,0				
42	A1	0,0	0,0	-344500,	344500,				
	A2	0,0	0,0	0,0	0,0				
43	A1	0,0	0,0	1,086E+6	1,086E+6				
	A2	0,0	0,0	0,0	0,0				

Oasys	Site License Job No.		Sheet No.	Rev.
	1			
Compared solution - Y direction Htot 27.5 m, Hi 6 m, 2 floor braced, layout1, final	Drg. Ref.			
	Made by GI	Date 14-lug-2014	Checked	

Node	Case	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
Maxima									
30	A1	***0,0***	-570400,	0,0	570400,	1,899E+6	0,0	0,0	1,899E+6
6	A1	0,0	***0,0***	-2,582E+6	2,582E+6				
36	A1	0,0	-2,521E+6	***11,05E+6***	11,34E+6	816200,	0,0	0,0	816200,
36	A1	0,0	-2,521E+6	11,05E+6	***11,34E+6***	816200,	0,0	0,0	816200,
31	A1	0,0	-693400,	0,0	693400,	***2,115E+6***	0,0	0,0	2,115E+6
37	A1	0,0	-2,406E+6	-10,55E+6	10,83E+6	773300,	***0,0***	0,0	773300,
32	A1	0,0	-683300,	0,0	683300,	2,098E+6	0,0	***0,0***	2,098E+6
31	A1	0,0	-693400,	0,0	693400,	2,115E+6	0,0	0,0	***2,115E+6***
Minima									
35	A1	***0,0***	-570700,	0,0	570700,	1,899E+6	0,0	0,0	1,899E+6
36	A1	0,0	***-2,521E+6***	11,05E+6	11,34E+6	816200,	0,0	0,0	816200,
37	A1	0,0	-2,406E+6	***-10,55E+6***	10,83E+6	773300,	0,0	0,0	773300,
6	A2	0,0	0,0	0,0	***0,0***				
30	A2	0,0	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0
35	A1	0,0	-570700,	0,0	570700,	1,899E+6	***0,0***	0,0	1,899E+6
36	A1	0,0	-2,521E+6	11,05E+6	11,34E+6	816200,	0,0	***0,0***	816200,
30	A2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

Nodal Forces and Moments

Forces reported are the forces at the node acting on the element; these may differ from
the forces reported for element ends when the element has end releases or is offset.
When reported in local output axes, forces are in element local directions related to the node and +ve axial forces are tensile.
2D elements are not considered.
Output axes: global

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
6	A1	3	64,57E-12	-77750,	0,0	77750,	242800,	131,5E-12	0,0	242800,
		25	0,0	-47960,	0,0	47960,	16210,	0,0	0,0	16210,
		26	0,0	-1,496E+6	-102800,	1,499E+6	-216100,	0,0	0,0	216100,
		78	0,0	1,621E+6	-2,479E+6	2,963E+6	-42990,	0,0	0,0	42990,
	A2	3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		25	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		26	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		78	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	A1	3	-64,57E-12	77750,	0,0	77750,	223700,	-427,1E-12	0,0	223700,
		4	0,0	-442100,	-112500,	456200,	-270500,	0,0	0,0	270500,
		31	0,0	1,834E+6	-2,722E+6	3,283E+6	46840,	0,0	0,0	46840,
	A2	3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		31	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
8	A1	5	239,1E-12	-81350,	0,0	81350,	238800,	-66,44E-12	0,0	238800,
		24	0,0	22650,	0,0	22650,	134700,	0,0	0,0	134700,
		26	0,0	1,496E+6	102800,	1,499E+6	-195200,	0,0	0,0	195200,
		27	0,0	-1,205E+6	-74580,	1,208E+6	-173900,	0,0	0,0	173900,
		31	0,0	-1,834E+6	2,722E+6	3,283E+6	70110,	0,0	0,0	70110,
		84	0,0	1,603E+6	-2,198E+6	2,720E+6	-74590,	0,0	0,0	74590,
	A2	5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		24	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		26	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		27	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		31	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		84	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
9	A1	4	0,0	442100,	112500,	456200,	-179300,	0,0	0,0	179300,
		5	-239,1E-12	81350,	0,0	81350,	249300,	352,1E-12	0,0	249300,
		6	0,0	-818000,	-63870,	820500,	-139700,	0,0	0,0	139700,
		82	0,0	1,764E+6	-2,322E+6	2,917E+6	69760,	0,0	0,0	69760,
	A2	4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		82	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
10	A1	11	-172,3E-12	-74770,	0,0	74770,	223900,	195,3E-12	0,0	223900,
		23	0,0	1662,	0,0	1662,	85290,	0,0	0,0	85290,
		27	0,0	1,205E+6	74580,	1,208E+6	-161700,	0,0	0,0	161700,
		28	0,0	-880000,	-82800,	883800,	-163100,	0,0	0,0	163100,
		82	0,0	-1,764E+6	2,322E+6	2,917E+6	66020,	0,0	0,0	66020,
		83	0,0	1,512E+6	-2,328E+6	2,776E+6	-50360,	0,0	0,0	50360,
	A2	11	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		23	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		27	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		28	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		82	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		83	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
11	A1	6	0,0	818000,	63870,	820500,	-147700,	0,0	0,0	147700,
		7	0,0	-1,008E+6	-76610,	1,011E+6	-155300,	0,0	0,0	155300,
		11	172,3E-12	74770,	0,0	74770,	224800,	-546,1E-12	0,0	224800,
		81	0,0	1,585E+6	-2,339E+6	2,826E+6	78200,	0,0	0,0	78200,
	A2	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		11	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		81	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	A1	12	147,8E-12	-76790,	0,0	76790,	228000,	144,9E-12	0,0	228000,
		22	0,0	-4278,	0,0	4278,	68650,	0,0	0,0	68650,

Oasys Site License Job No. Sheet No. Rev.

1

Compared solution - Y direction

Htot 27.5 m, Hi 6 m, 2 floor braced, layout1, final

Drg. Ref.

Made by GI Date 14-lug-2014 Checked

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
		28	0,0	880000,	82800,	883800,	-168100,	0,0	0,0	168100,
		29	0,0	-1,102E+6	-70070,	1,104E+6	-161100,	0,0	0,0	161100,
		79	0,0	1,888E+6	-2,564E+6	3,184E+6	-43240,	0,0	0,0	43240,
		81	0,0	-1,585E+6	2,339E+6	2,826E+6	75700,	0,0	0,0	75700,
	A2	12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		22	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		28	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		29	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		79	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		81	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13	A1	7	0,0	1,008E+6	76610,	1,011E+6	-151200,	0,0	0,0	151200,
		8	0,0	-1,315E+6	-63610,	1,317E+6	-143800,	0,0	0,0	143800,
		12	-147,8E-12	76790,	0,0	76790,	232700,	275,9E-12	0,0	232700,
		80	0,0	1,701E+6	-2,240E+6	2,813E+6	62220,	0,0	0,0	62220,
	A2	7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		80	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
14	A1	13	-90,63E-12	-82690,	0,0	82690,	247000,	-32,80E-12	0,0	247000,
		21	0,0	16420,	0,0	16420,	128400,	0,0	0,0	128400,
		29	0,0	1,102E+6	70070,	1,104E+6	-154300,	0,0	0,0	154300,
		30	0,0	-1,579E+6	-108100,	1,582E+6	-183700,	0,0	0,0	183700,
		74	0,0	2,244E+6	-3,485E+6	4,145E+6	-98450,	0,0	0,0	98450,
		80	0,0	-1,701E+6	2,240E+6	2,813E+6	61020,	0,0	0,0	61020,
	A2	13	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		21	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		29	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		30	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		74	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		80	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
15	A1	8	0,0	1,315E+6	63610,	1,317E+6	-142500,	0,0	0,0	142500,
		9	0,0	-1,409E+6	-87890,	1,412E+6	-160100,	0,0	0,0	160100,
		13	90,63E-12	82690,	0,0	82690,	249100,	-293,6E-12	0,0	249100,
		35	0,0	1,481E+6	-2,201E+6	2,653E+6	53470,	0,0	0,0	53470,
	A2	8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		13	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		35	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16	A1	14	0,0	-61110,	0,0	61110,	175200,	0,0	0,0	175200,
		20	0,0	-36660,	0,0	36660,	44480,	0,0	0,0	44480,
		30	0,0	1,579E+6	108100,	1,582E+6	-248700,	0,0	0,0	248700,
		35	0,0	-1,481E+6	2,201E+6	2,653E+6	28970,	0,0	0,0	28970,
	A2	14	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		20	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		30	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		35	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
17	A1	9	0,0	1,409E+6	87890,	1,412E+6	-191500,	0,0	0,0	191500,
		14	0,0	61110,	0,0	61110,	191500,	0,0	0,0	191500,
	A2	9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		14	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
18	A1	25	0,0	47960,	0,0	47960,	-303900,	0,0	0,0	303900,
		43	0,0	-2,858E+6	-602100,	2,920E+6	-1,436E+6	0,0	0,0	1,436E+6
		61	0,0	403600,	0,0	403600,	1,107E+6	0,0	0,0	1,107E+6
		62	0,0	2,406E+6	10,55E+6	10,83E+6	632900,	0,0	0,0	632900,
	A2	25	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		43	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		61	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		62	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
19	A1	24	0,0	-22650,	0,0	22650,	1201,	0,0	0,0	1201,
		42	0,0	-1,919E+6	-352600,	1,951E+6	-770900,	0,0	0,0	770900,
		43	0,0	2,858E+6	602100,	2,920E+6	-972100,	0,0	0,0	972100,
		59	0,0	705800,	0,0	705800,	1,889E+6	0,0	0,0	1,889E+6
		78	0,0	-1,621E+6	2,479E+6	2,963E+6	-146800,	0,0	0,0	146800,
	A2	24	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		42	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		43	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		59	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		78	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
20	A1	23	0,0	-1662,	0,0	1662,	-75320,	0,0	0,0	75320,
		41	0,0	-1,050E+6	-438900,	1,138E+6	-872500,	0,0	0,0	872500,
		42	0,0	1,919E+6	352600,	1,951E+6	-815900,	0,0	0,0	815900,
		57	0,0	734700,	0,0	734700,	1,962E+6	0,0	0,0	1,962E+6
		84	0,0	-1,603E+6	2,198E+6	2,720E+6	-198500,	0,0	0,0	198500,
	A2	23	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		41	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		42	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		57	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		84	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
21	A1	22	0,0	4278,	0,0	4278,	-94330,	0,0	0,0	94330,
		40	0,0	-296900,	-373800,	477400,	-849300,	0,0	0,0	849300,
		41	0,0	1,050E+6	438900,	1,138E+6	-883100,	0,0	0,0	883100,
		55	0,0	755300,	0,0	755300,	2,014E+6	0,0	0,0	2,014E+6
		83	0,0	-1,512E+6	2,328E+6	2,776E+6	-187700,	0,0	0,0	187700,
	A2	22	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		40	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		41	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		55	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		83	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
22	A1	21	0,0	-16420,	0,0	16420,	-29870,	0,0	0,0	29870,
		39	0,0	831400,	-622200,	1,038E+6	-1,033E+6	0,0	0,0	1,033E+6

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Sheet No. Rev.

1

Compared solution - Y direction

Htot 27.5 m, Hi 6 m, 2 floor braced, layout1, final

Drg. Ref.

Made by: GI

Date: 14-lug-2014

Checked

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
		40	0,0	296900,	373800,	477400,	-832600,	0,0	0,0	832600,
		53	0,0	775800,	0,0	775800,	2,063E+6	0,0	0,0	2,063E+6
		79	0,0	-1,888E+6	2,564E+6	3,184E+6	-167300,	0,0	0,0	167300,
	A2	21	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		39	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		40	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		53	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		79	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
23	A1	20	0,0	36660,	0,0	36660,	-264400,	0,0	0,0	264400,
		39	0,0	-831400,	622200,	1,038E+6	-1,456E+6	0,0	0,0	1,456E+6
		49	0,0	2,521E+6	-11,05E+6	11,34E+6	675600,	0,0	0,0	675600,
		51	0,0	518000,	0,0	518000,	1,423E+6	0,0	0,0	1,423E+6
		74	0,0	-2,244E+6	3,485E+6	4,145E+6	-378200,	0,0	0,0	378200,
	A2	20	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		39	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		49	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		51	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		74	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
24	A1	48	0,0	-94740,	-1,010E+6	1,014E+6	-2,200E+6	0,0	0,0	2,200E+6
		61	0,0	-403600,	0,0	403600,	911000,	0,0	0,0	911000,
		101	0,0	498400,	0,0	498400,	1,289E+6	0,0	0,0	1,289E+6
	A2	48	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		61	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		101	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
25	A1	47	0,0	-129600,	-745900,	757100,	-1,653E+6	0,0	0,0	1,653E+6
		48	0,0	94740,	1,010E+6	1,014E+6	-1,838E+6	0,0	0,0	1,838E+6
		59	0,0	-705800,	0,0	705800,	1,640E+6	0,0	0,0	1,640E+6
		99	0,0	740700,	0,0	740700,	1,851E+6	0,0	0,0	1,851E+6
	A2	47	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		48	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		59	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		99	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
26	A1	46	0,0	-110900,	-900500,	907300,	-1,795E+6	0,0	0,0	1,795E+6
		47	0,0	129600,	745900,	757100,	-1,703E+6	0,0	0,0	1,703E+6
		57	0,0	-734700,	0,0	734700,	1,711E+6	0,0	0,0	1,711E+6
		97	0,0	716000,	0,0	716000,	1,787E+6	0,0	0,0	1,787E+6
	A2	46	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		47	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		57	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		97	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
27	A1	45	0,0	-71450,	-766600,	769900,	-1,738E+6	0,0	0,0	1,738E+6
		46	0,0	110900,	900500,	907300,	-1,807E+6	0,0	0,0	1,807E+6
		55	0,0	-755300,	0,0	755300,	1,762E+6	0,0	0,0	1,762E+6
		95	0,0	715800,	0,0	715800,	1,783E+6	0,0	0,0	1,783E+6
	A2	45	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		46	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		55	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		95	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
28	A1	44	0,0	-35510,	-1,082E+6	1,083E+6	-1,945E+6	0,0	0,0	1,945E+6
		45	0,0	71450,	766600,	769900,	-1,711E+6	0,0	0,0	1,711E+6
		53	0,0	-775800,	0,0	775800,	1,816E+6	0,0	0,0	1,816E+6
		93	0,0	739900,	0,0	739900,	1,840E+6	0,0	0,0	1,840E+6
	A2	44	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		45	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		53	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		93	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
29	A1	44	0,0	35510,	1,082E+6	1,083E+6	-2,385E+6	0,0	0,0	2,385E+6
		51	0,0	-518000,	0,0	518000,	1,167E+6	0,0	0,0	1,167E+6
		91	0,0	482500,	0,0	482500,	1,218E+6	0,0	0,0	1,218E+6
	A2	44	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		51	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		91	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
30	A1	100	0,0	-570400,	0,0	570400,	1,899E+6	0,0	0,0	1,899E+6
	A2	100	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
31	A1	98	0,0	-693400,	0,0	693400,	2,115E+6	0,0	0,0	2,115E+6
	A2	98	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
32	A1	96	0,0	-683300,	0,0	683300,	2,098E+6	0,0	0,0	2,098E+6
	A2	96	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
33	A1	94	0,0	-683000,	0,0	683000,	2,097E+6	0,0	0,0	2,097E+6
	A2	94	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
34	A1	92	0,0	-692400,	0,0	692400,	2,113E+6	0,0	0,0	2,113E+6
	A2	92	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
35	A1	90	0,0	-570700,	0,0	570700,	1,899E+6	0,0	0,0	1,899E+6
	A2	90	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
36	A1	49	0,0	-2,521E+6	11,05E+6	11,34E+6	816200,	0,0	0,0	816200,
	A2	49	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
37	A1	62	0,0	-2,406E+6	-10,55E+6	10,83E+6	773300,	0,0	0,0	773300,
	A2	62	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
38	A1	89	0,0	-72080,	-1,087E+6	1,089E+6	-2,441E+6	0,0	0,0	2,441E+6
		100	0,0	570400,	0,0	570400,	1,238E+6	0,0	0,0	1,238E+6
		101	0,0	-498400,	0,0	498400,	1,203E+6	0,0	0,0	1,203E+6
	A2	89	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		100	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		101	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
39	A1	88	0,0	-24840,	-740100,	740500,	-1,644E+6	0,0	0,0	1,644E+6
		89	0,0	72080,	1,087E+6	1,089E+6	-1,907E+6	0,0	0,0	1,907E+6
		98	0,0	693400,	0,0	693400,	1,699E+6	0,0	0,0	1,699E+6
		99	0,0	-740700,	0,0	740700,	1,852E+6	0,0	0,0	1,852E+6
	A2	88	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		89	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

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Job No.	Sheet No.	Rev.
1		

Compared solution - Y direction

Htot 27.5 m, Hi 6 m, 2 floor braced, layout1, final

Drg. Ref.

Made by	Date	Checked
GI	14-lug-2014	

Node	Case	Elem	Fx [N]	Fy [N]	Fz [N]	|F| [N]	Mxx [Nm]	Myy [Nm]	Mzz [Nm]	|M| [Nm]
		98	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		99	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
40	A1	87	0,0	7854,	-883600,	883600,	-1,767E+6	0,0	0,0	1,767E+6
		88	0,0	24840,	740100,	740500,	-1,686E+6	0,0	0,0	1,686E+6
		96	0,0	683300,	0,0	683300,	1,660E+6	0,0	0,0	1,660E+6
		97	0,0	-716000,	0,0	716000,	1,793E+6	0,0	0,0	1,793E+6
	A2	87	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		88	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		96	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		97	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
41	A1	86	0,0	40680,	-741100,	742200,	-1,688E+6	0,0	0,0	1,688E+6
		87	0,0	-7854,	883600,	883600,	-1,767E+6	0,0	0,0	1,767E+6
		94	0,0	683000,	0,0	683000,	1,659E+6	0,0	0,0	1,659E+6
		95	0,0	-715800,	0,0	715800,	1,796E+6	0,0	0,0	1,796E+6
	A2	86	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		87	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		94	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		95	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
42	A1	85	0,0	88220,	-1,086E+6	1,089E+6	-1,908E+6	0,0	0,0	1,908E+6
		86	0,0	-40680,	741100,	742200,	-1,647E+6	0,0	0,0	1,647E+6
		92	0,0	692400,	0,0	692400,	1,695E+6	0,0	0,0	1,695E+6
		93	0,0	-739900,	0,0	739900,	1,860E+6	0,0	0,0	1,860E+6
	A2	85	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		86	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		92	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		93	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
43	A1	85	0,0	-88220,	1,086E+6	1,089E+6	-2,434E+6	0,0	0,0	2,434E+6
		90	0,0	570700,	0,0	570700,	1,240E+6	0,0	0,0	1,240E+6
		91	0,0	-482500,	0,0	482500,	1,195E+6	0,0	0,0	1,195E+6
	A2	85	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		90	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		91	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

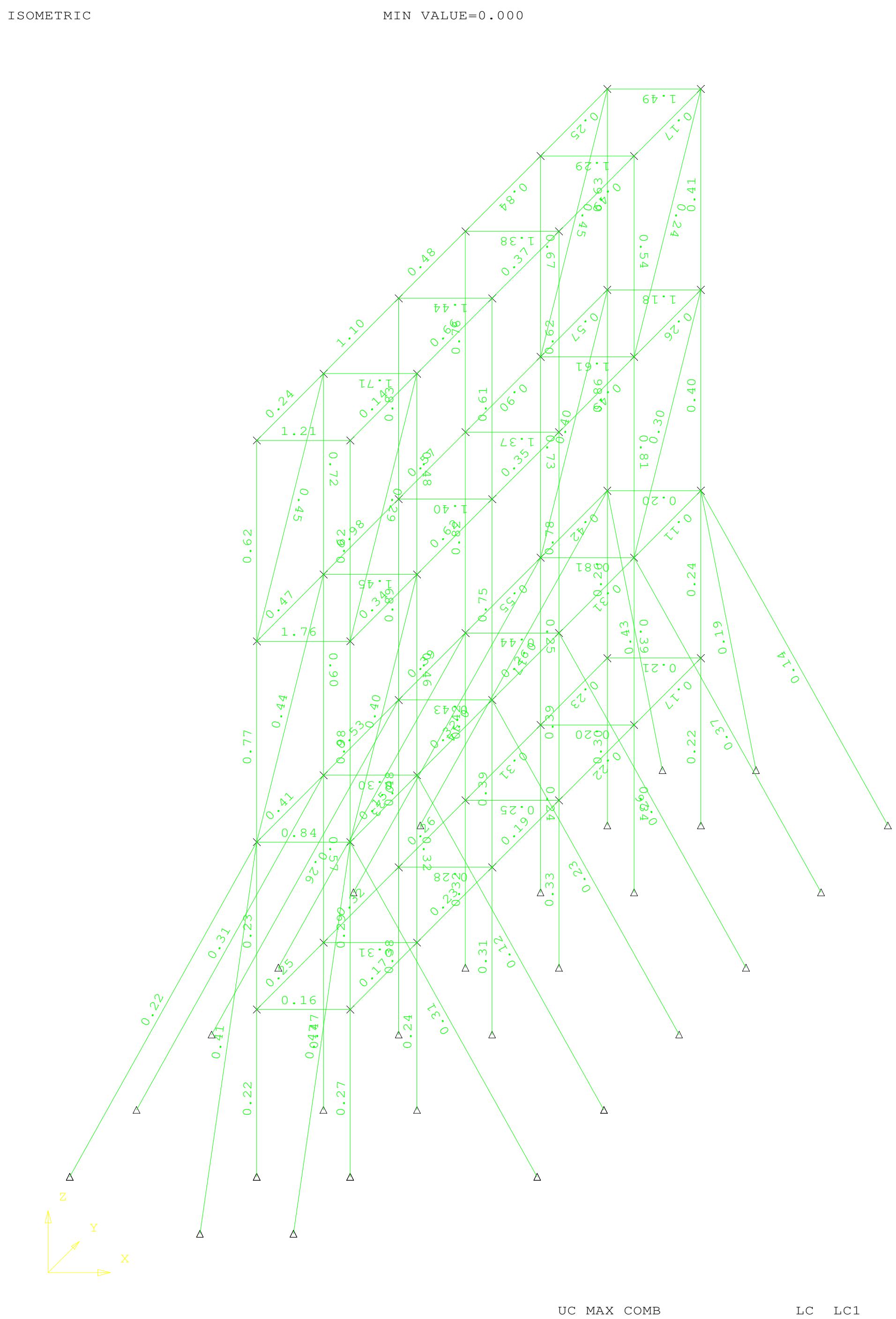
Maxima

Node	Case	Elem	Fx	Fy	Fz	|F|	Mxx	Myy	Mzz	|M|
8	A1	5	***239,1E-12***	-81350,	0,0	81350,	238800,	-66,44E-12	0,0	238800,
19	A1	43	0,0	***2,858E+6***	602100,	2,920E+6	-972100,	0,0	0,0	972100,
36	A1	49	0,0	-2,521E+6	***11,05E+6***	11,34E+6	816200,	0,0	0,0	816200,
23	A1	49	0,0	2,521E+6	-11,05E+6	***11,34E+6***	675600,	0,0	0,0	675600,
31	A1	98	0,0	-693400,	0,0	693400,	***2,115E+6***	0,0	0,0	2,115E+6
9	A1	5	-239,1E-12	81350,	0,0	81350,	249300,	***352,1E-12***	0,0	249300,
12	A1	81	0,0	-1,585E+6	2,339E+6	2,826E+6	75700,	0,0	***0,0***	75700,
38	A1	89	0,0	-72080,	-1,087E+6	1,089E+6	-2,441E+6	0,0	0,0	***2,441E+6***

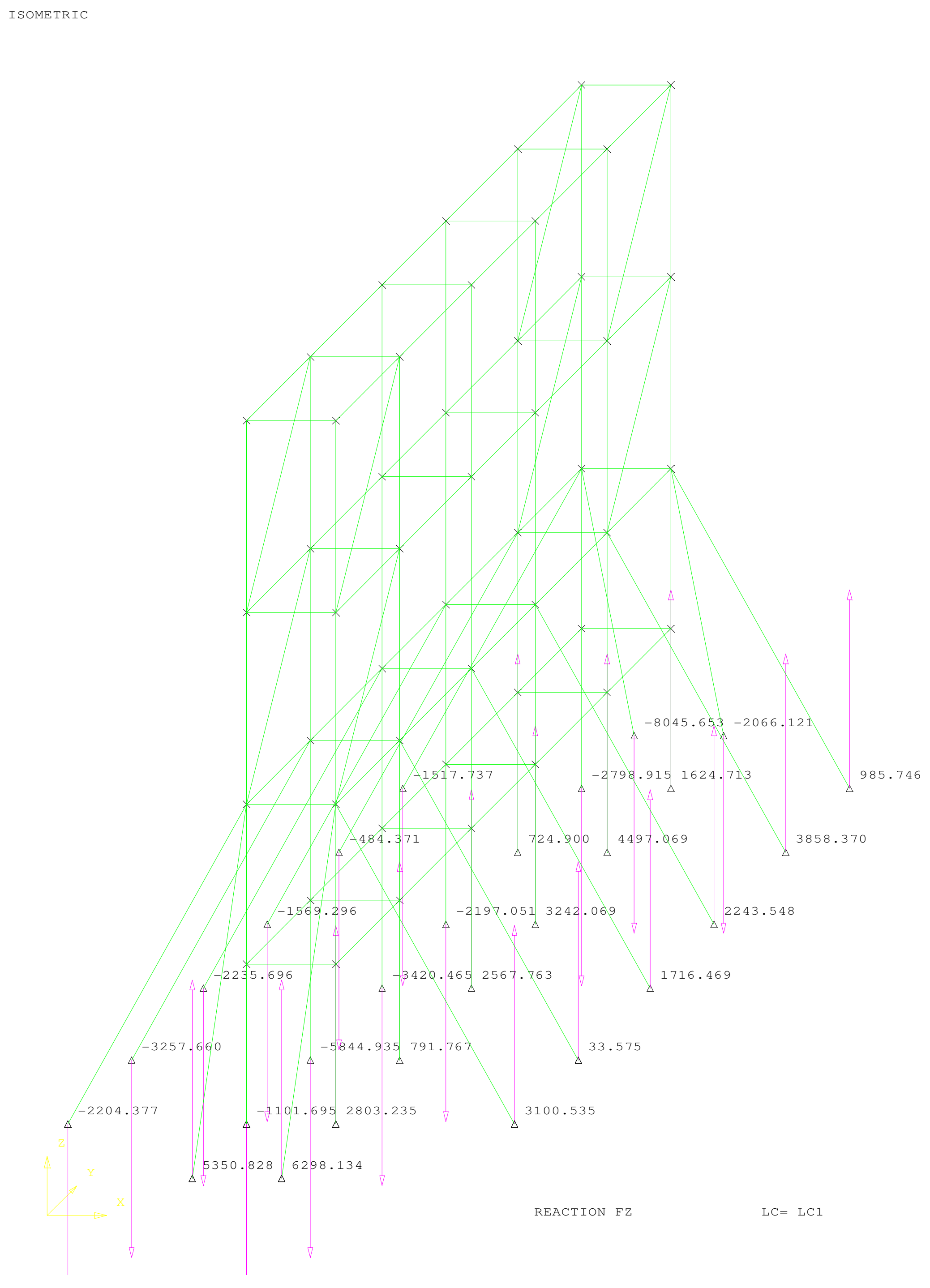
Minima

Node	Case	Elem	Fx	Fy	Fz	|F|	Mxx	Myy	Mzz	|M|
9	A1	5	***-239,1E-12***	81350,	0,0	81350,	249300,	352,1E-12	0,0	249300,
18	A1	43	0,0	***-2,858E+6***	-602100,	2,920E+6	-1,436E+6	0,0	0,0	1,436E+6
23	A1	49	0,0	2,521E+6	***-11,05E+6***	11,34E+6	675600,	0,0	0,0	675600,
6	A2	3	0,0	0,0	0,0	***0,0***	0,0	0,0	0,0	0,0
38	A1	89	0,0	-72080,	-1,087E+6	1,089E+6	***-2,441E+6***	0,0	0,0	2,441E+6
11	A1	11	172,3E-12	74770,	0,0	74770,	224800,	***-546,1E-12***	0,0	224800,
10	A1	83	0,0	1,512E+6	-2,328E+6	2,776E+6	-50360,	0,0	***0,0***	50360,
6	A2	3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	***0,0***

Hinged situation - final solution SACS unity checks



Hinged situation - final solution SACS reaction forces



A.6. Bottom support

Bottom connection, hand calculations - G=0.75 MPa

Actions	
Compressive load [kN]	5510.11
Shear Load [kN]	9484.09
Fxy,d [N]	8265166.18
Vz,d [N]	7113067.50
G [MPa]	0.75
fy [MPa]	355
α [rad]	0.0171

Coefficients	
γ f	1.40
γ ULS	1.50
γ final	1.00

Elastomer prop	
τ bond [psi]	300
τ bond [N/mm^2]	2.065

Plate inclination	
ϑ [deg]	1.1500
ϑ [rad]	0.0201

Input	
n rubber elements	2
n bearing supports	3
t elastomer [mm]	165
a - width [mm]	840
b - length [mm]	1940
t steel (el) [mm]	40
t steel (pl) [mm]	35

Connection verification				
		Actions		
rotation	τ,1 [MPa]	0.00	Δ [mm]	
vertical	τ,2 [MPa]	0.73	δ,2 [mm]	160.01
total	τ,ed [MPa]	0.73	δ,tot [mm]	160.01
		Reactions		
Bond adhesion	τ,rd1 [MPa]	2.06	verified	
Max shear	τ,rd2 [MPa]	480.04	verified	
def max	verified		δ,max [mm]	165.00

Dimensions	
A [mm^2]	1629600
Atot [mm^2]	1629600
lp [mm]	5560
te,in [mm]	165
te,out [mm]	165
S,in	1.776324395
S,out	1.776324395
Tb [mm]	165
btot [mm]	5820
l tot [mm]	5820.000

Moment allowed	
δ [mm]	36.5000
F [kN]	1081.5
Contribution [%]	0.2
M [kNm]	7462.1
Rs new [kN]	9303.9
% reduction [kN]	3.52%

STRAIN	97%

Bottom connection, hand calculations - G=2.25 MPa

Actions	
Compressive load [kN]	5510.11
Shear Load [kN]	9484.09
Fxy,d [N]	8265166.18
Vz,d [N]	7113067.50
G [MPa]	2.25
fy [MPa]	355
α [rad]	0.0171

Coefficients	
γ f	1.40
γ ULS	1.50
γ final	1.00

Elastomer prop	
τ bond [psi]	300
τ bond [N/mm^2]	2.065

Plate inclination	
ϑ [deg]	1.1500
ϑ [rad]	0.0201

Input	
n rubber elements	2
n bearing supports	3
t elastomer [mm]	165
a - width [mm]	840
b - length [mm]	1940
t steel (el) [mm]	40
t steel (pl) [mm]	35

Connection verification				
		Actions		
rotation	τ,1 [MPa]	0.00	Δ [mm]	
vertical	τ,2 [MPa]	0.73	δ,2 [mm]	53.34
total	τ,ed [MPa]	0.73	δ,tot [mm]	53.34
		Reactions		
Bond adhesion	τ,rd1 [MPa]	2.06	verified	
Max shear	τ,rd2 [MPa]	160.01	verified	
def max	verified		δ,max [mm]	165.00

Dimensions	
A [mm^2]	1629600
Atot [mm^2]	1629600
lp [mm]	5560
te,in [mm]	165
te,out [mm]	165
S,in	1.776324395
S,out	1.776324395
Tb [mm]	165
btot [mm]	5820
l tot [mm]	5820.000

Moment allowed	
δ [mm]	36.5000
F [kN]	3244.4
Contribution [%]	0.2
M [kNm]	22386.3
Rs new [kN]	8625.5
% reduction [kN]	10.55%

STRAIN	32%

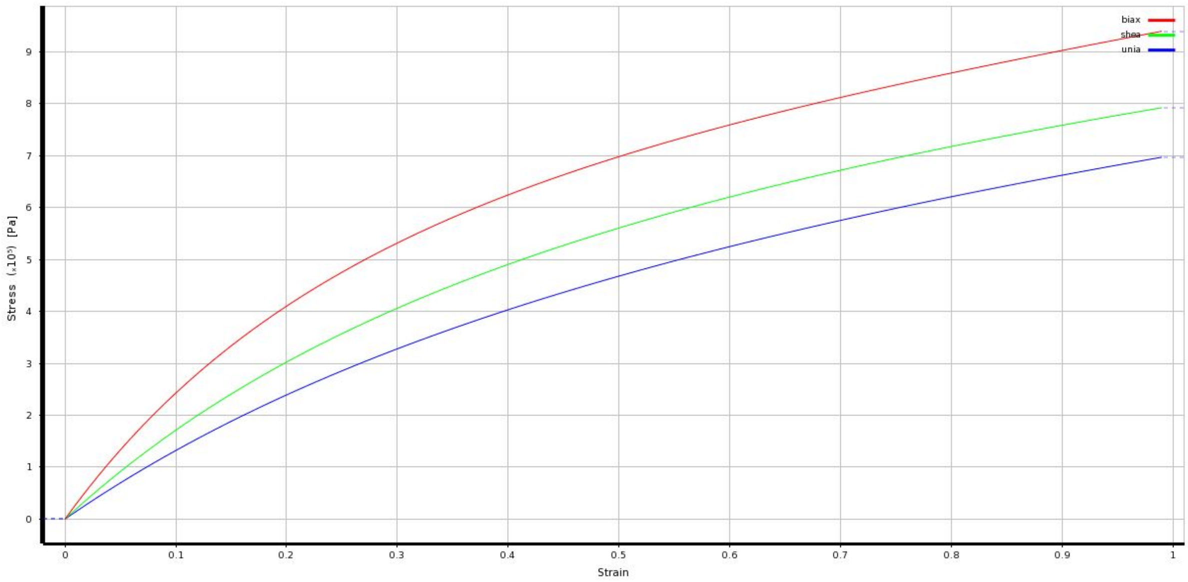
Bottom connection, hand calculations - general checks from European Standards

Rubber verifications

normal Temp - tolerance			*normal Temp*		
G	0.6		G	0.75	
Compression			*Compression*		
sigma,cd	5.09	N/mm^2	sigma,cd	1.28	N/mm^2
sigma,Rd	5.88	N/mm^2	sigma,Rd	7.35	N/mm^2
	5.97			7.46	
CHECK	0.87	**verified**	***CHECK***	0.17	**verified**
	1.16			5.73	
Shear			*Shear*		
tau	0.73	N/mm^2	tau	0.73	N/mm^2
e	1.21		eqd	0.97	
eq,d	0.01	**verified**	***eq,d***	0.01	**verified**
Rotational limit			*Rotational limit*		
vc,d	22.10	mm	*vc,d*	17.68	mm
2nd term	4.78	mm	*2nd term*	4.78	mm
CHECK	0.22	**verified**	***CHECK***	0.27	**verified**
	0.22			0.27	
Buckling stability			*Buckling stability*		
width	840.00		Frd	840.00	
t	165.00		Fzd	165.00	
CHECK	1.27	**verified**	***CHECK***	1.27	**verified**
	0.20			0.20	
Vertical deflection			*Vertical deflection*		
vc,d,total	22.10	mm	vc,d,total	17.68	mm
v,rot	7.16	mm	vmax,d	7.16	mm
	29.27	mm		*24.85*	mm

low Temp			*low Temp + tolerance*		
G	2.25		G	2.45	
Compression			*Compression*		
sigma,cd	5.09	N/mm^2	sigma,cd	1.28	N/mm^2
sigma,Rd	22.05	N/mm^2	sigma,Rd	24.01	N/mm^2
	22.38			24.37	
CHECK	0.23	**verified**	***CHECK***	0.05	**verified**
	4.34			18.72	
Shear			*Shear*		
tau	0.73	N/mm^2	tau	0.73	N/mm^2
eqd	0.32		eqd	0.30	
eq,d	0.00	**verified**	***eq,d***	0.00	**verified**
Rotational limit			*Rotational limit*		
vc,d	5.89	mm	*vc,d*	5.41	mm
2nd term	4.78	mm	*2nd term*	4.78	mm
CHECK	0.81	**verified**	***CHECK***	0.88	**verified**
	0.81			0.88	
Buckling stability			*Buckling stability*		
Frd	840.00		Frd	840.00	
Fzd	165.00		Fzd	165.00	
CHECK	1.27	**verified**	***CHECK***	1.27	**verified**
	0.20			0.20	
Vertical deflection			Vertical deflection		
vc,d,total	5.89	mm	*vc,d,total*	5.41	mm
vmax,d	7.16	mm	vmax,d	7.16	mm
	13.06	mm		*12.58*	mm

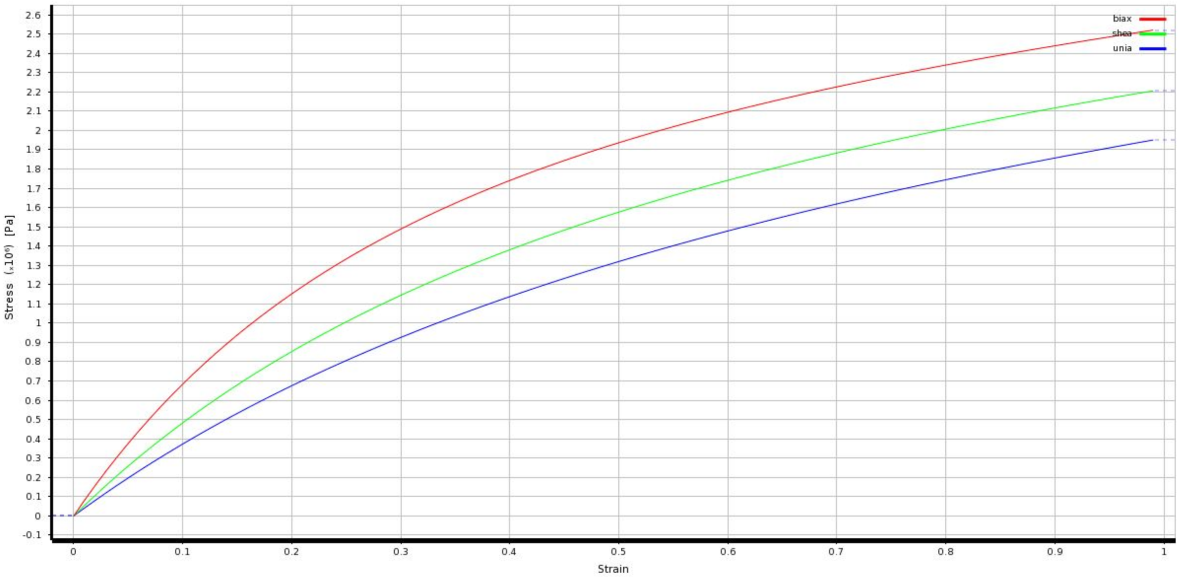
ANSYS Engineering input data - Material rubber properties, stress-strain diagram for G=0.75 MPa



Properties of Outline Row 3: Rubber1

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1000	kg m^-3		
3	Ogden 3rd Order				
4	Material Constant MU1	7.3803E+05	Pa		
5	Material Constant A1	1.3			
6	Material Constant MU2	1180	Pa		
7	Material Constant A2	5			
8	Material Constant MU3	-9810	Pa		
9	Material Constant A3	-2			
10	Incompressibility Parameter D1	4.825E-09	Pa^-1		
11	Incompressibility Parameter D2	0	Pa^-1		
12	Incompressibility Parameter D3	0	Pa^-1		

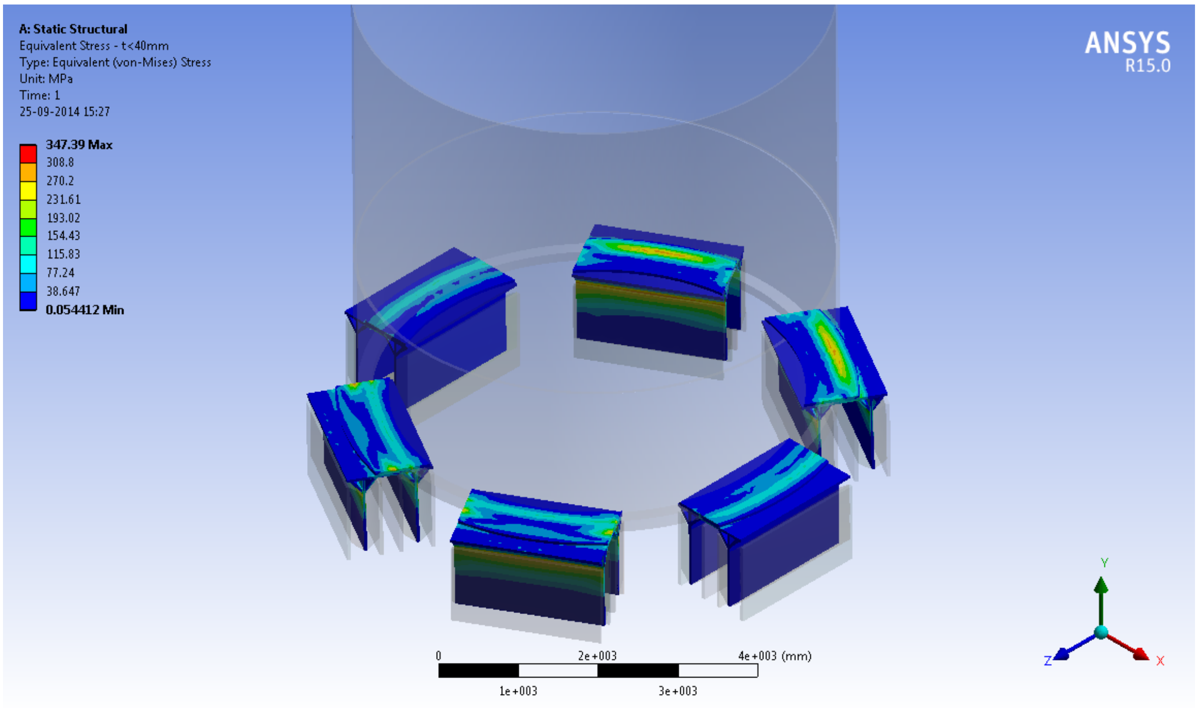
ANSYS Engineering input data - Material rubber properties, stress-strain diagram for G=2.25 MPa



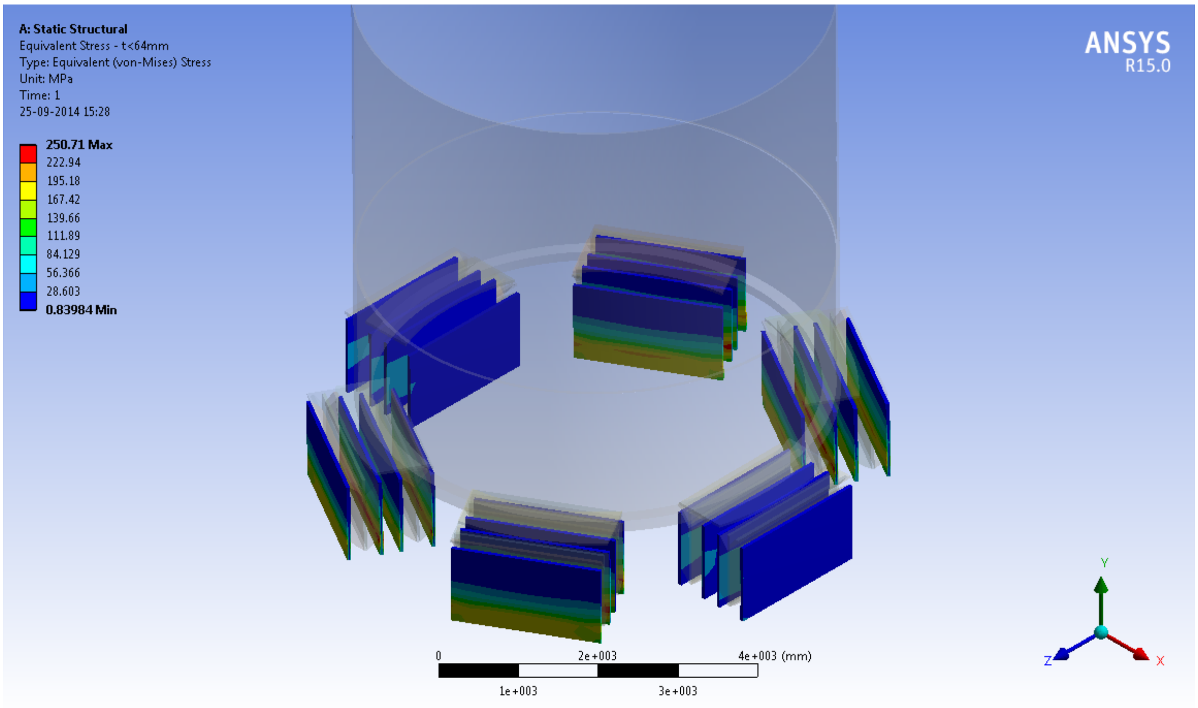
Properties of Outline Row 3: Rubber1

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1000	kg m^-3		
3	Ogden 3rd Order				
4	Material Constant MU1	2.118E+06	Pa		
5	Material Constant A1	1.3			
6	Material Constant MU2	1180	Pa		
7	Material Constant A2	5			
8	Material Constant MU3	-9810	Pa		
9	Material Constant A3	-2			
10	Incompressibility Parameter D1	4.825E-09	Pa^-1		
11	Incompressibility Parameter D2	0	Pa^-1		
12	Incompressibility Parameter D3	0	Pa^-1		

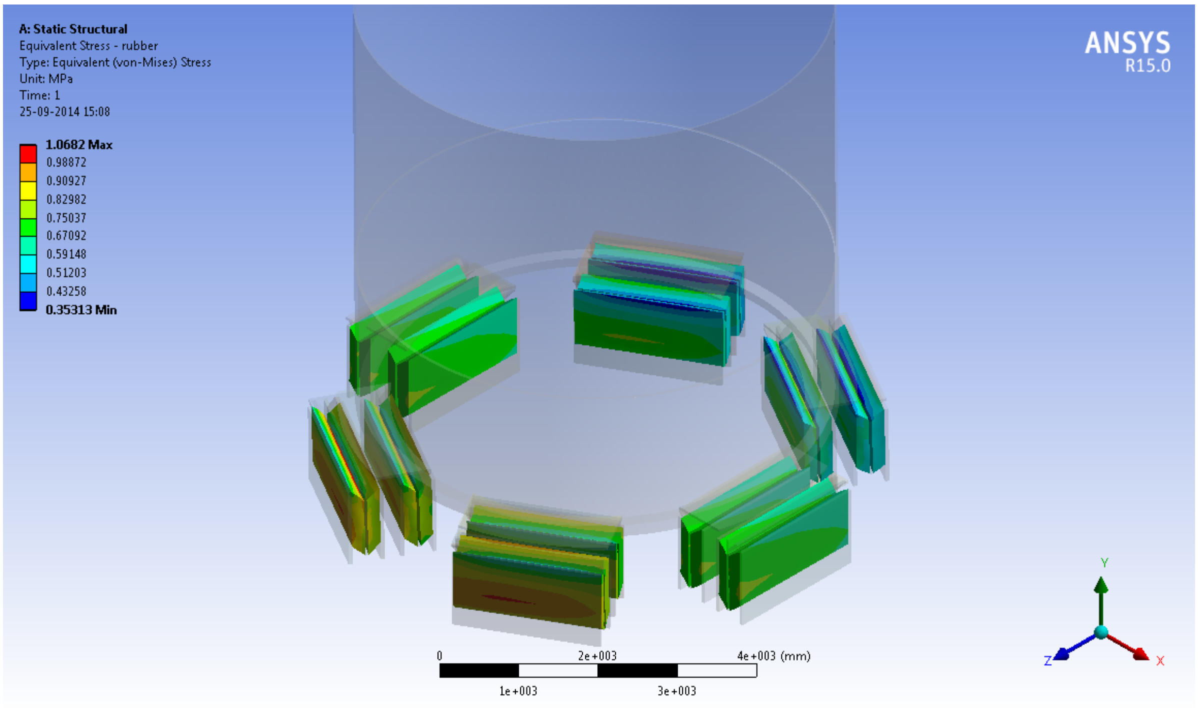
ANSYS results - Von Mises equivalent stresses on steel plates (t<40 mm), G=0.75 MPa



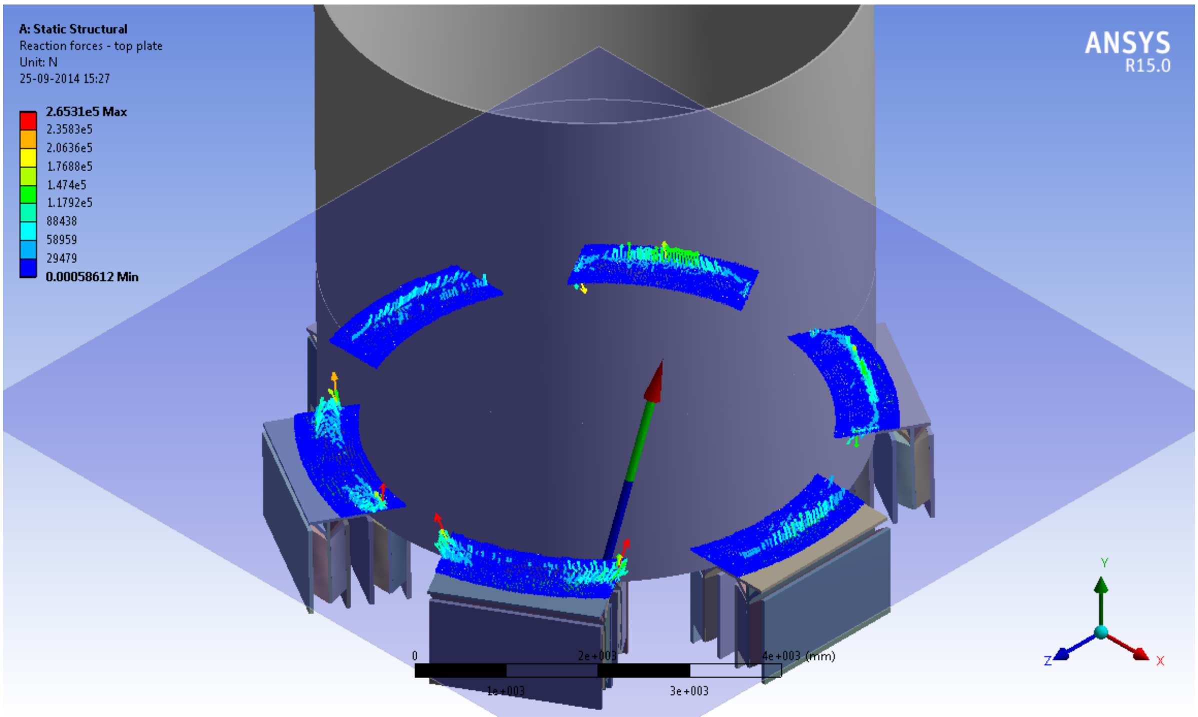
ANSYS results - Von Mises equivalent stresses on steel plates (t<64 mm), G=0.75 MPa



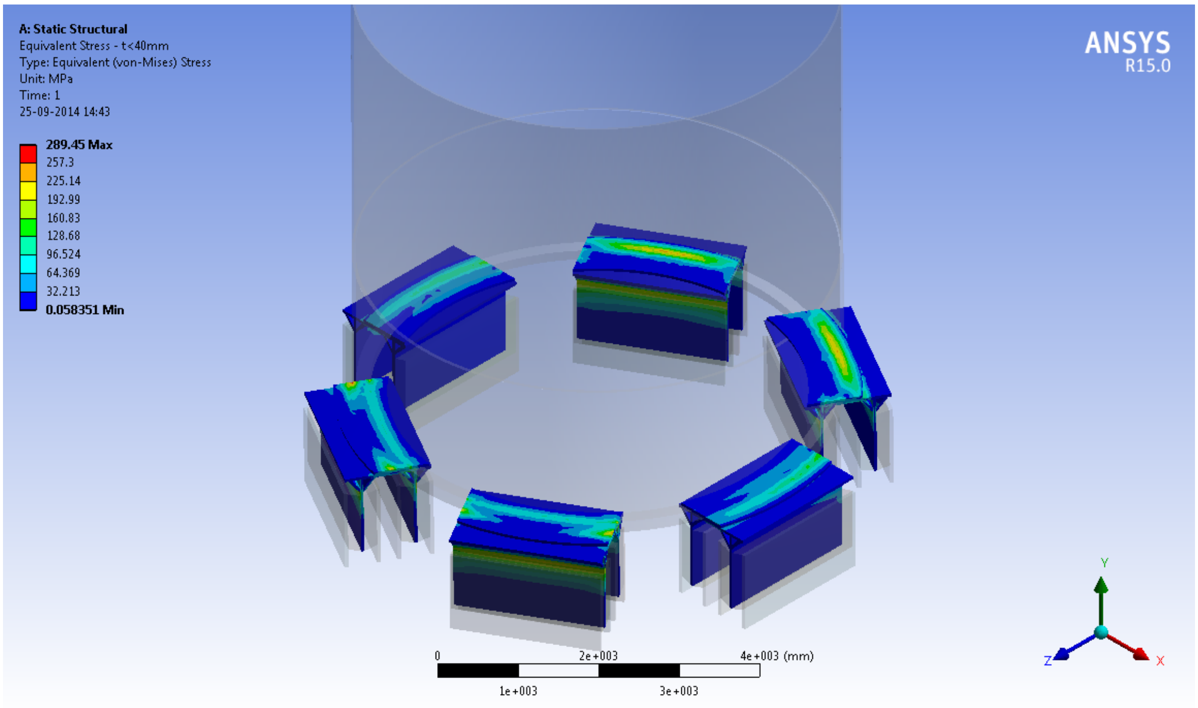
ANSYS results - Von Mises equivalent stresses on rubber elements, G=0.75 MPa



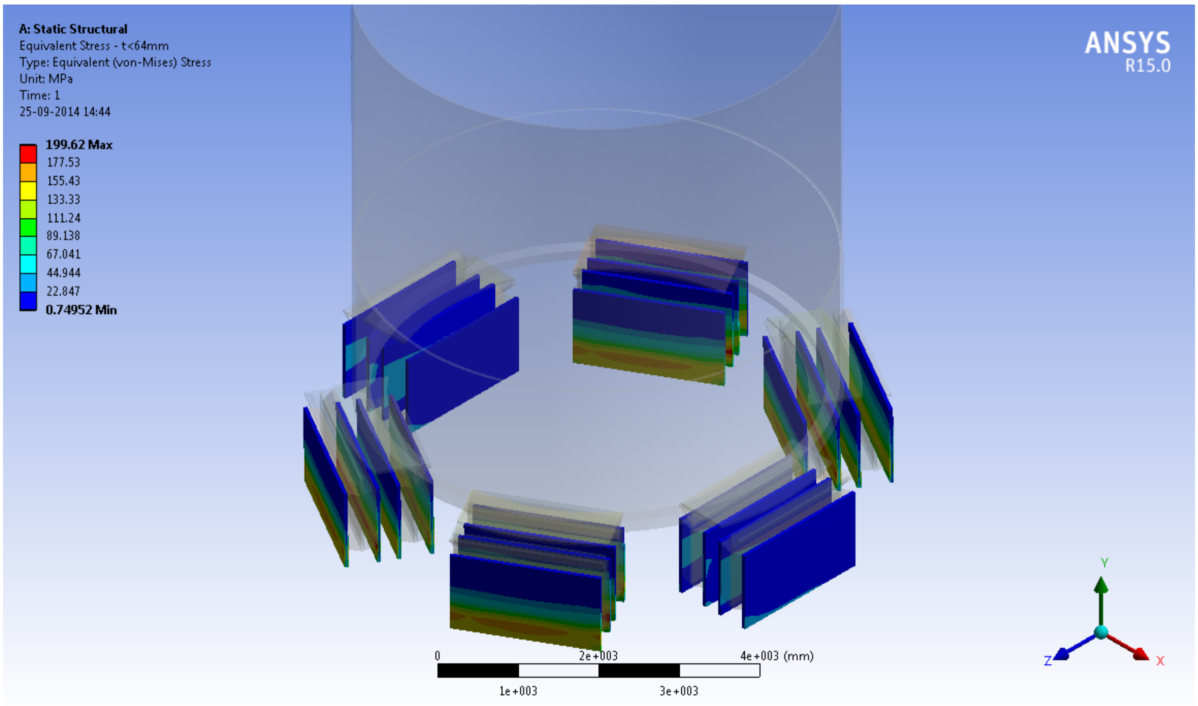
ANSYS results - Reaction forces at top plate position, G=0.75 MPa



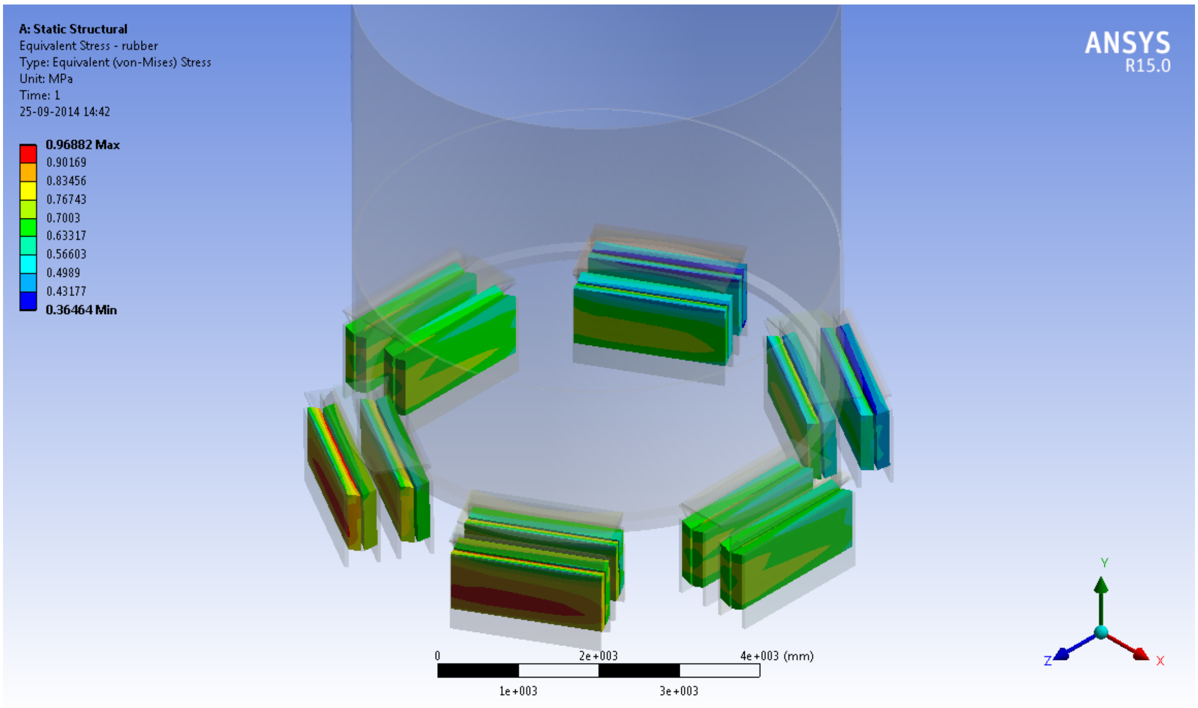
ANSYS results - Von Mises equivalent stresses on steel plates (t<40 mm), G=2.25 MPa



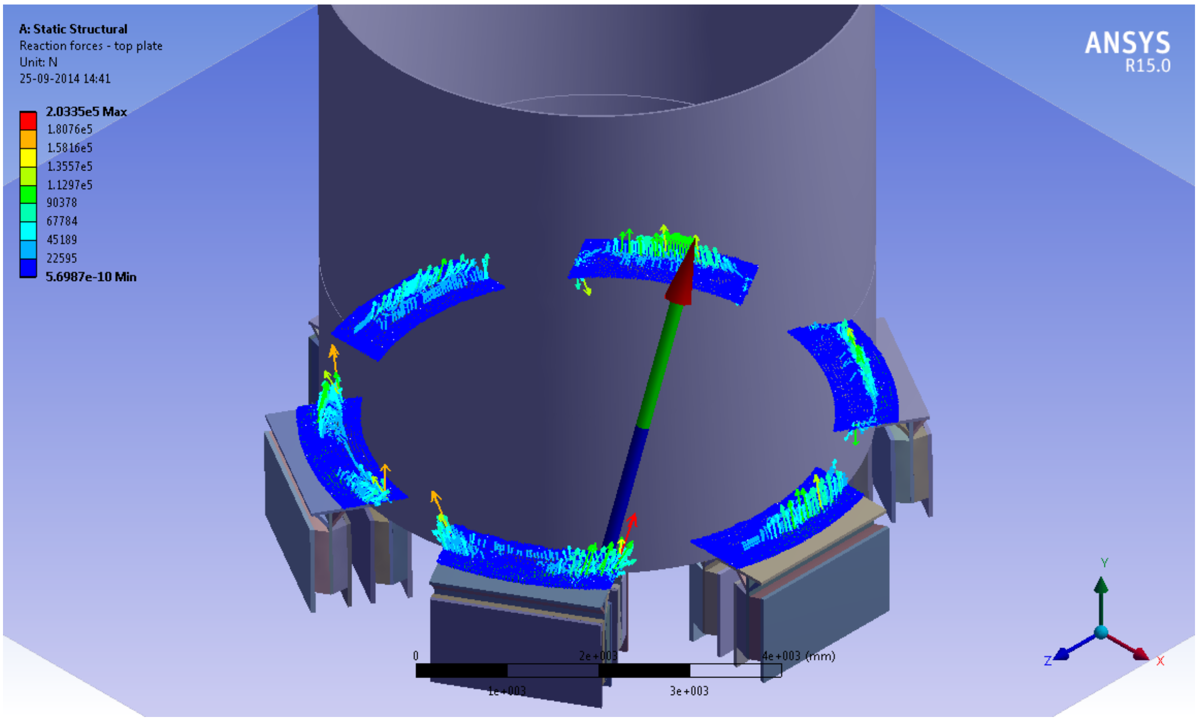
ANSYS results - Von Mises equivalent stresses on steel plates (t<64 mm), G=2.25 MPa



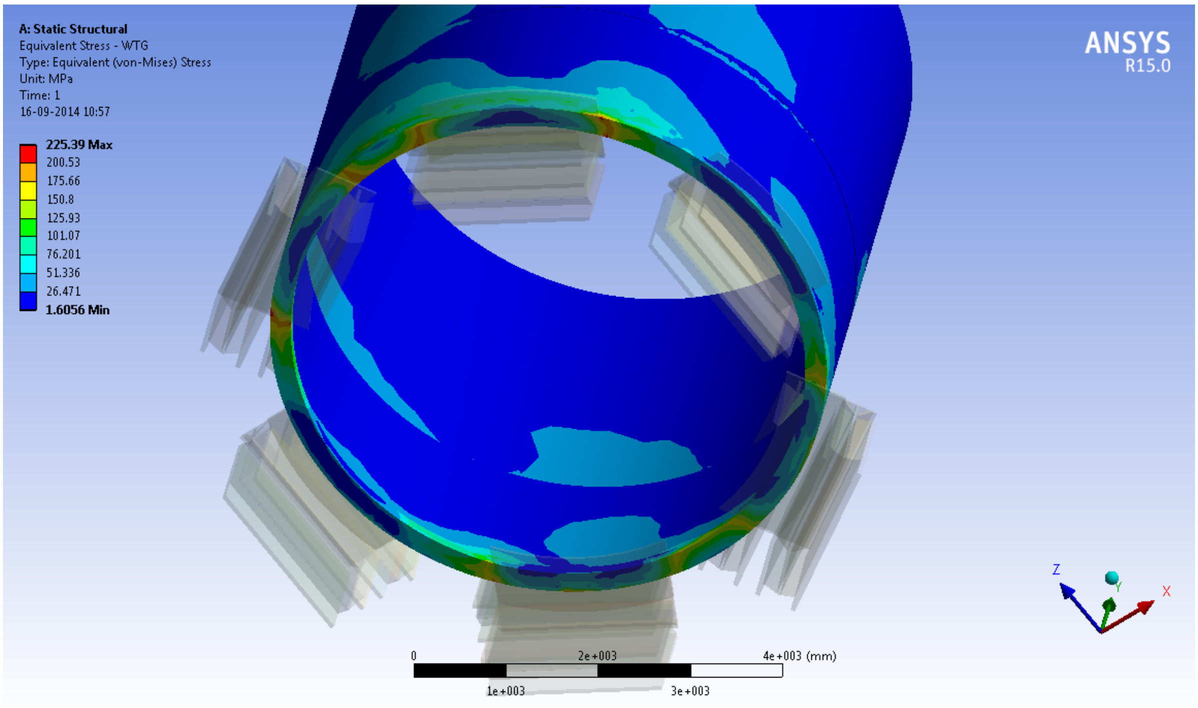
ANSYS results - Von Mises equivalent stresses on rubber elements, G=2.25 MPa



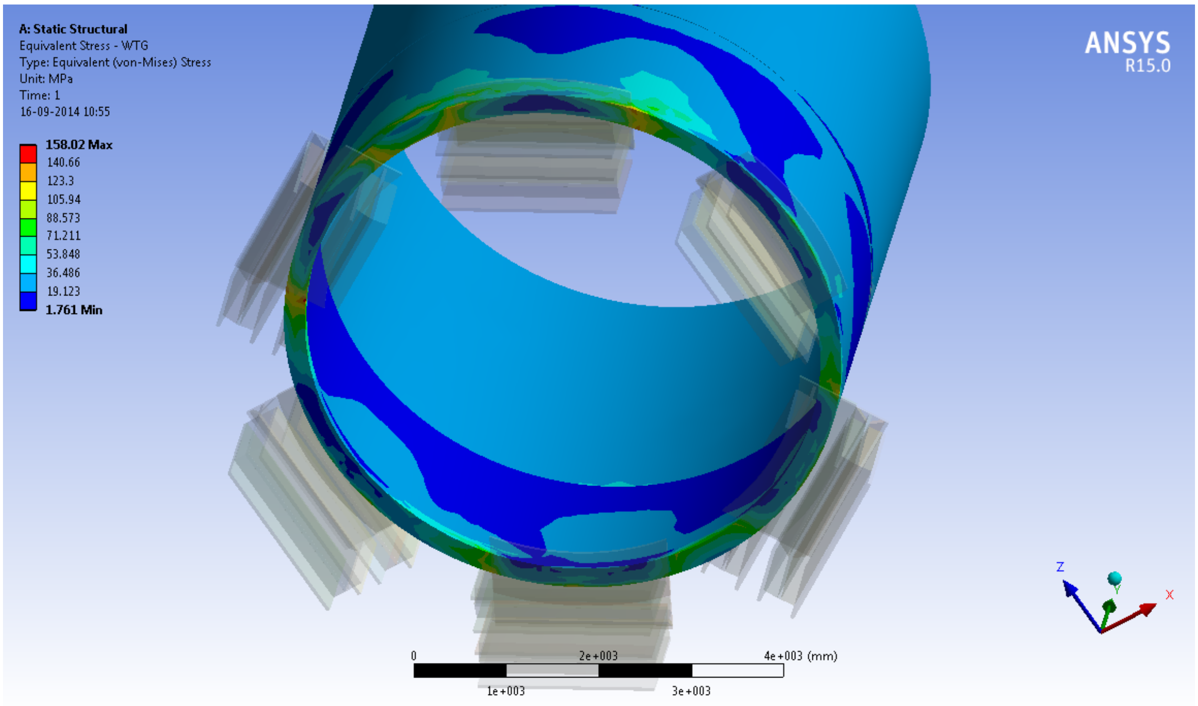
ANSYS results - Reaction forces at top plate position, G=2.25 MPa



ANSYS results - Von Mises equivalent stresses on WTG, G=0.75 MPa



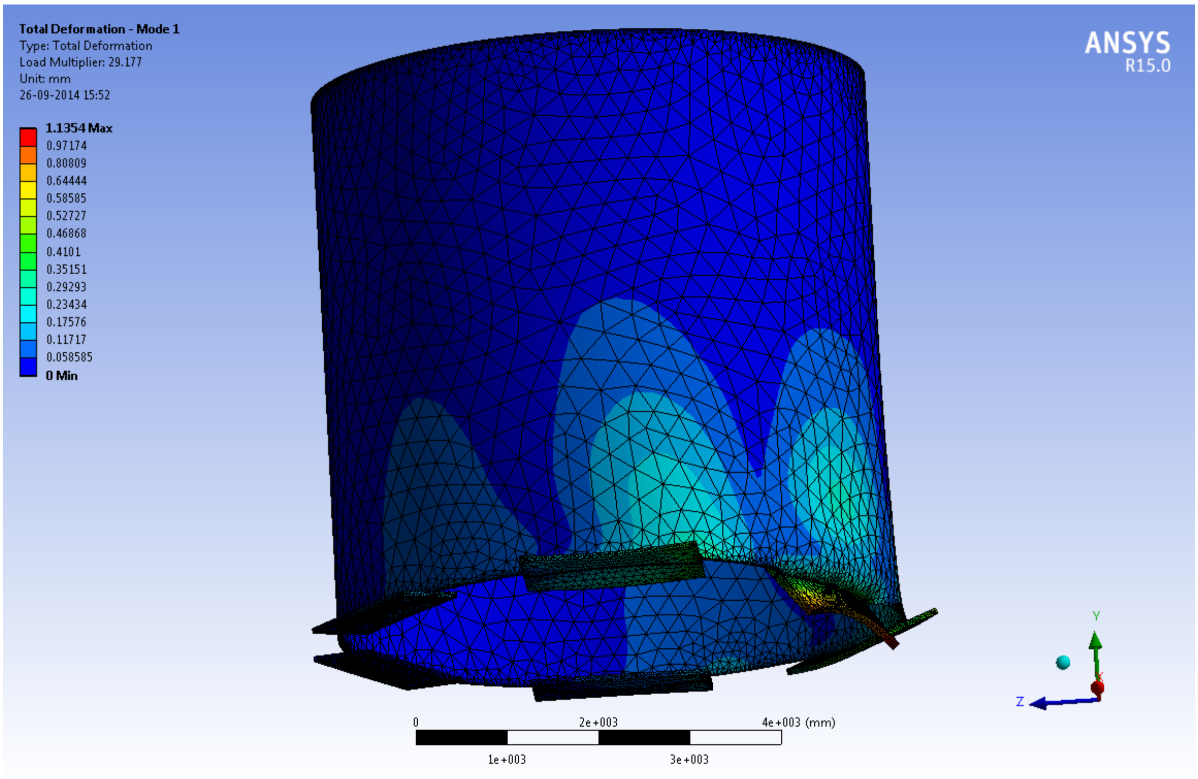
ANSYS results - Von Mises equivalent stresses on WTG, G=2.25 MPa



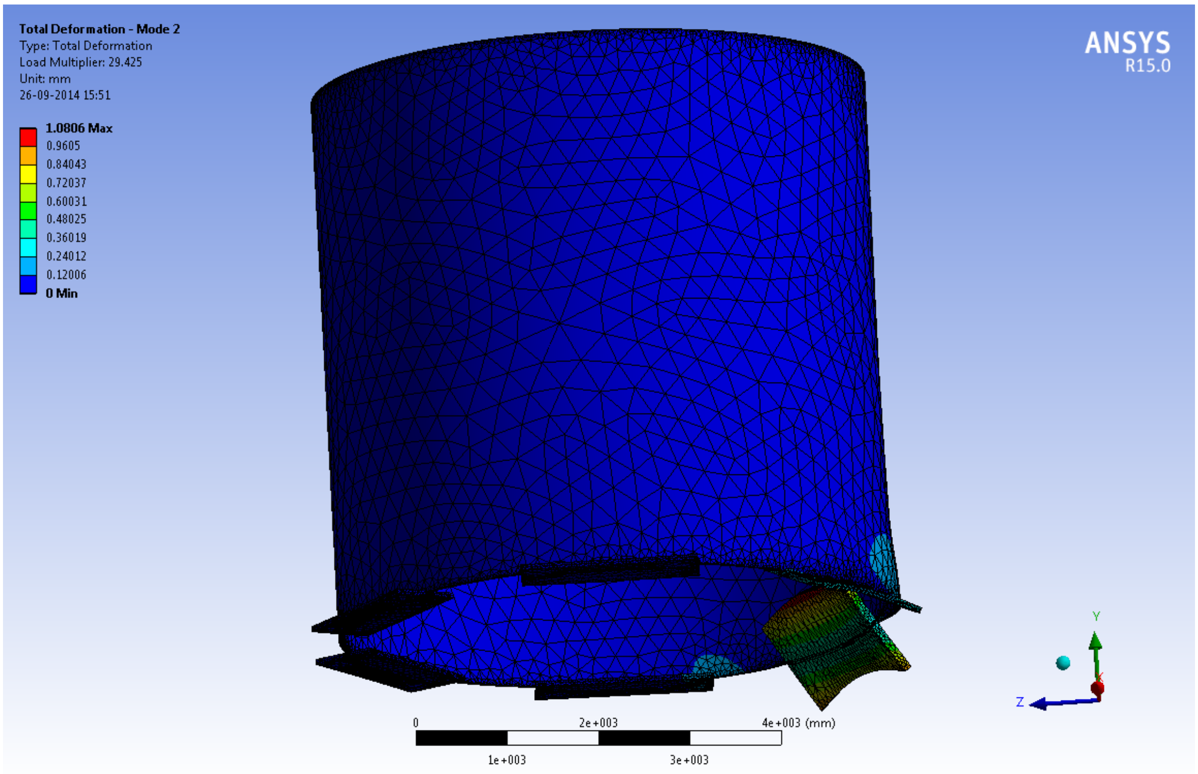
Buckling analysis - Load multipliers from ANSYS model

ANSYS R15.0	
Mode	Load Multiplier
1	29.369
2	30.393
3	35.2
4	37.247
5	42.322
6	47.348

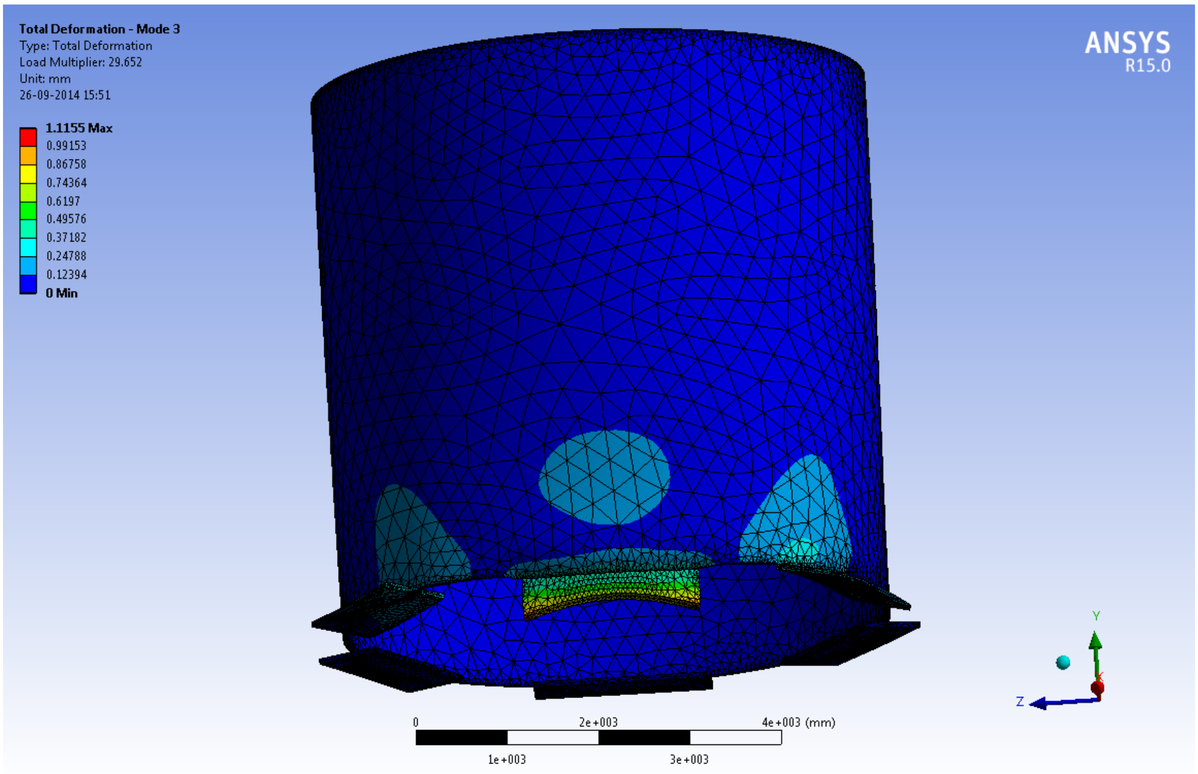
ANSYS results - Linear buckling Mode 1



ANSYS results - Linear buckling Mode 2



ANSYS results - Linear buckling Mode 3

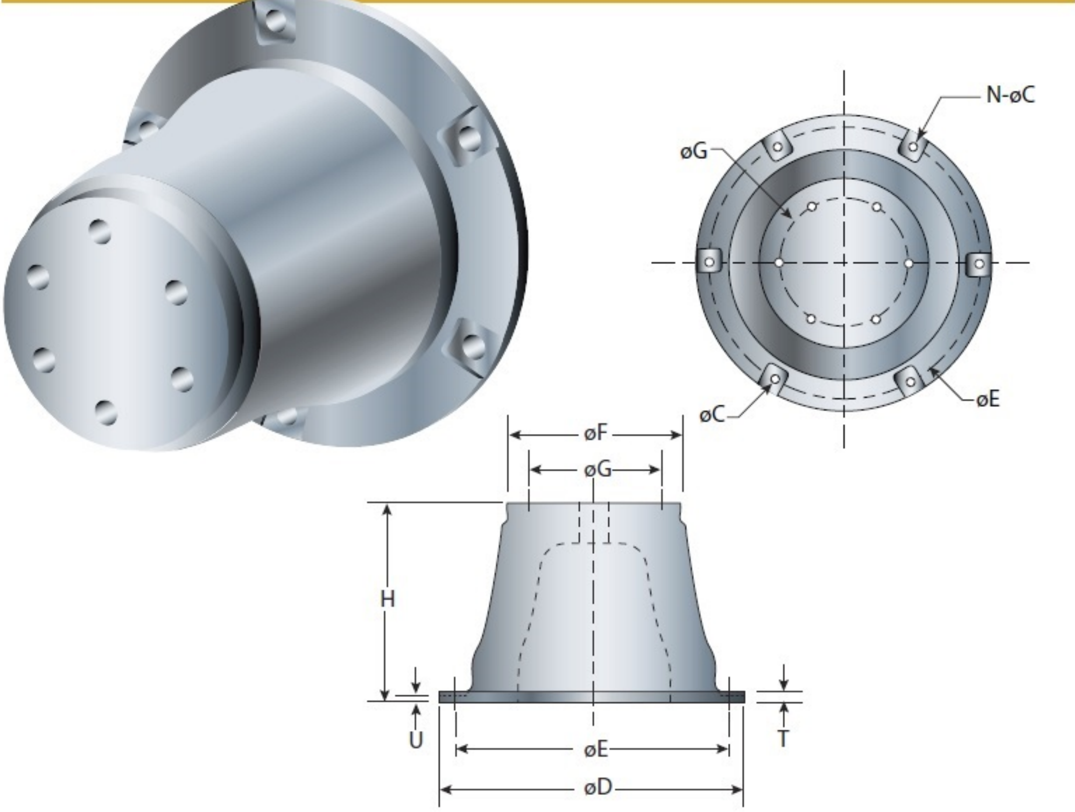


A.7. Intermediate support

Marine fenders - MARINE INTERNATIONAL MCN cone fenders

MCN CONE FENDERS

MCN GEOMETRY

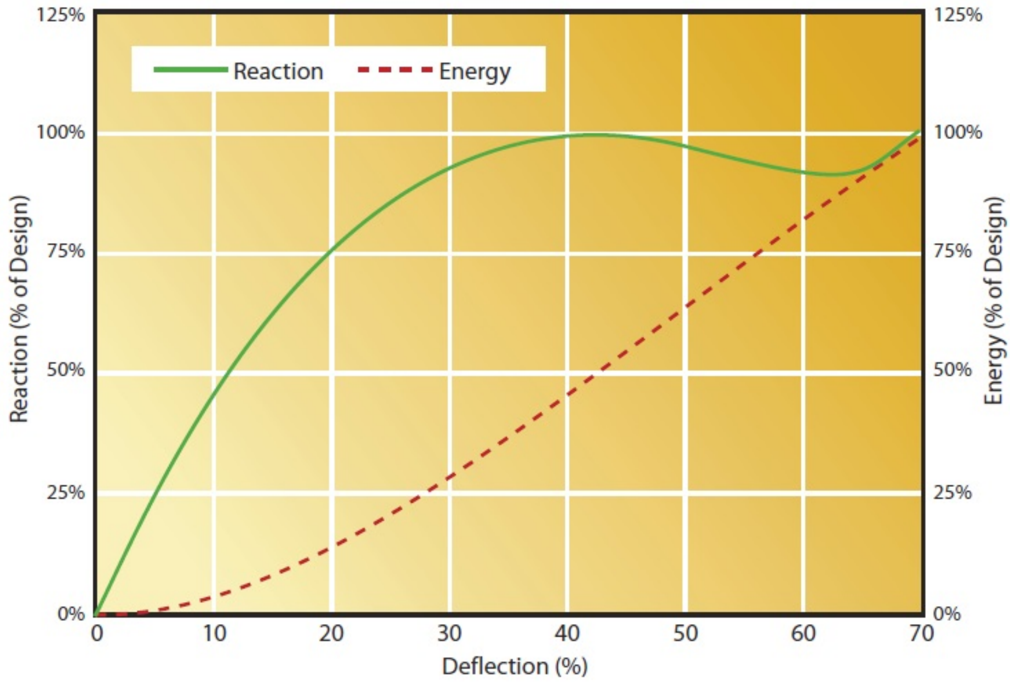


MCN DIMENSIONS

Model	H		øD		øE PCD		øF		øG PCD		T		U		N-øC		Bolt Size
	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	
MCN 500	500	19.7	750	29.5	675	26.6	425	16.7	325	12.8	25	0.98	21	0.83	4-30	4-1.18	M24
MCN 600	600	23.6	900	35.4	810	31.9	510	20.1	390	15.4	27	1.06	22	0.87	6-30	6-1.18	M24
MCN 700	700	27.6	1050	41.3	945	37.2	595	23.4	455	17.9	32	1.26	26	1.02	6-38	6-1.50	M30
MCN 800	800	31.5	1200	47.2	1080	42.5	680	26.8	520	20.5	36	1.42	29	1.14	6-44	6-1.73	M36
MCN 900	900	35.4	1350	53.1	1215	47.8	765	30.1	585	23.0	41	1.61	33	1.30	6-44	6-1.73	M36
MCN 1000	1000	39.4	1500	59.1	1350	53.1	850	33.5	650	25.6	45	1.77	37	1.46	6-50	6-1.97	M42
MCN 1100	1100	43.3	1650	65.0	1485	58.5	935	36.8	715	28.1	50	1.97	42	1.65	6-50	6-1.97	M42
MCN 1150	1150	45.3	1725	67.9	1550	61.0	998	39.3	750	29.5	52	2.05	42	1.65	6-50	6-1.97	M42
MCN 1200	1200	47.2	1800	70.9	1620	63.8	1020	40.2	780	30.7	54	2.13	44	1.73	8-50	8-1.97	M42
MCN 1300	1300	51.2	1950	76.8	1755	69.1	1105	43.5	845	33.3	59	2.32	48	1.89	8-60	8-2.36	M48
MCN 1400	1400	55.1	2100	82.7	1890	74.4	1190	46.9	930	36.6	66	2.60	54	2.13	8-60	8-2.36	M48
MCN 1600	1600	63.0	2400	94.5	2160	85.0	1360	53.5	1060	41.7	72	2.83	58	2.28	8-70	8-2.76	M52

MCN CONE FENDER TECHNICAL DATA

MCN GENERIC PERFORMANCE CURVE



Intermediate grades can be interpolated from standard grades

MCN PERFORMANCE

Model	Standard Rubber Grades																Weight	
	G4				G3				G2				G1					
	R		E		R		E		R		E		R		E			
	kN	kips	kN-m	ft-kips	kN	kips	kN-m	ft-kips	kN	kips	kN-m	ft-kips	kN	kips	kN-m	ft-kips	(kg)	(lbs)
MCN 500	307	68.9	81.3	59.9	245	55.1	65.1	48.0	196	44.1	54.7	40.3	157	35.3	43.8	32.3	140	309
MCN 600	441	99.2	140	104	353	79.4	112	83.0	282	63.5	94.5	69.7	226	50.8	75.6	55.8	230	507
MCN 700	601	135	223	164	481	108	179	132	384	86.4	150	111	308	69.1	120	88.6	390	860
MCN 800	785	176	333	246	628	141	267	197	502	113	224	165	402	90.3	179	132	540	1190
MCN 900	993	223	474	350	794	179	380	280	636	143	319	235	508	114	255	188	755	1664
MCN 1000	1226	276	650	480	981	220	521	384	785	176	437	323	628	141	350	258	1020	2249
MCN 1100	1483	333	865	638	1187	267	693	511	950	214	582	429	760	171	466	344	1505	3318
MCN 1150	1621	365	989	729	1297	292	792	584	1038	233	665	491	830	187	532	393	1600	3527
MCN 1200	1765	397	1124	829	1412	317	900	664	1130	254	756	557	904	203	605	446	1960	4321
MCN 1300	2072	466	1428	1054	1657	373	1144	844	1326	298	961	709	1061	238	769	567	2400	5291
MCN 1400	2403	540	1784	1316	1922	432	1429	1054	1538	346	1200	885	1230	277	961	709	3060	6746
MCN 1600	3139	706	2663	1964	2511	564	2133	1573	2009	452	1792	1321	1607	361	1434	1058	4600	10141

Fender dimensioning and positioning calculation

δ required [mm]	375.32
Fender R [kN]	993.00
Fender H [mm]	900.00

Acting Force - y [kN]
9643.16

area int [mm^2]	643060
area ext [mm^2]	2146800

angular dist [deg]	21.00
layers [n]	2.00

								Reaction components	
angle - local [deg]	angle - local [rad]	angle - global [deg]	δ [mm]	δ [%]	actual δ [mm]	axial reaction [%]	axial reaction [kN]	Rx [kN]	Ry [kN]
0.00	0.00	-40.00	0.0	0.0%	0.0	0.0%	0.00	0.00	0.00
1.00	0.02	-39.00	6.6	1.2%	11.0	3.1%	30.33	30.32	0.53
2.00	0.03	-38.00	13.1	2.4%	22.0	6.1%	60.65	60.61	2.12
3.00	0.05	-37.00	19.6	3.7%	33.0	9.2%	90.95	90.82	4.76
4.00	0.07	-36.00	26.2	4.9%	43.9	12.2%	121.22	120.92	8.46
5.00	0.09	-35.00	32.7	6.1%	54.9	15.3%	151.45	150.88	13.20
6.00	0.10	-34.00	39.2	7.3%	65.9	18.3%	181.64	180.65	18.99
7.00	0.12	-33.00	45.7	8.5%	76.8	21.3%	211.78	210.20	25.81
8.00	0.14	-32.00	52.2	9.7%	87.7	24.4%	241.85	239.49	33.66
9.00	0.16	-31.00	58.7	11.0%	98.6	27.4%	271.84	268.50	42.53
10.00	0.17	-30.00	65.2	12.2%	109.4	30.4%	301.76	297.17	52.40
11.00	0.19	-29.00	71.6	13.4%	120.2	33.4%	331.58	325.49	63.27
12.00	0.21	-28.00	78.0	14.6%	131.0	36.4%	361.30	353.40	75.12
13.00	0.23	-27.00	84.4	15.7%	141.7	39.4%	390.91	380.89	87.94
14.00	0.24	-26.00	90.8	16.9%	152.4	42.3%	420.40	407.91	101.70
15.00	0.26	-25.00	97.1	18.1%	163.1	45.3%	449.76	434.44	116.41
16.00	0.28	-24.00	103.5	19.3%	173.7	48.2%	478.99	460.43	132.03
17.00	0.30	-23.00	109.7	20.5%	184.2	51.2%	508.07	485.87	148.54
18.00	0.31	-22.00	116.0	21.6%	194.7	54.1%	536.99	510.71	165.94
19.00	0.33	-21.00	122.2	22.8%	205.1	57.0%	565.76	534.93	184.19
20.00	0.35	-20.00	128.4	23.9%	215.5	59.9%	594.35	558.50	203.28
21.00	0.37	-19.00	134.5	25.1%	225.8	62.7%	622.75	581.39	223.18
22.00	0.38	-18.00	140.6	26.2%	236.0	65.6%	650.97	603.57	243.86
23.00	0.40	-17.00	146.7	27.4%	246.2	68.4%	678.99	625.02	265.30
24.00	0.42	-16.00	152.7	28.5%	256.2	71.2%	706.81	645.70	287.48
25.00	0.44	-15.00	158.6	29.6%	266.2	74.0%	734.40	665.60	310.37
26.00	0.45	-14.00	164.5	30.7%	276.2	76.7%	761.78	684.68	333.94
27.00	0.47	-13.00	170.4	31.8%	286.0	79.4%	788.92	702.93	358.16
28.00	0.49	-12.00	176.2	32.9%	295.8	82.2%	815.82	720.33	383.01
29.00	0.51	-11.00	182.0	33.9%	305.4	84.8%	842.48	736.85	408.44
30.00	0.52	-10.00	187.7	35.0%	315.0	87.5%	868.88	752.47	434.44
31.00	0.54	-9.00	193.3	36.1%	324.5	90.1%	895.01	767.17	460.96
32.00	0.56	-8.00	198.9	37.1%	333.8	92.7%	920.87	780.94	487.99
33.00	0.58	-7.00	204.4	38.1%	343.1	95.3%	946.45	793.76	515.47
34.00	0.59	-6.00	209.9	39.1%	352.3	97.9%	971.74	805.61	543.39
35.00	0.61	-5.00	215.3	40.2%	361.4	100.0%	993.00	813.42	569.56
36.00	0.63	-4.00	220.6	41.1%	370.3	100.0%	993.00	803.35	583.67
37.00	0.65	-3.00	225.9	42.1%	379.1	100.0%	993.00	793.05	597.60
38.00	0.66	-2.00	231.1	43.1%	387.9	100.0%	993.00	782.49	611.35
39.00	0.68	-1.00	236.2	44.1%	396.5	100.0%	993.00	771.71	624.92
40.00	0.70	0.00	241.3	45.0%	405.0	100.0%	993.00	760.68	638.29
41.00	0.72	1.00	246.2	45.9%	413.3	100.0%	993.00	749.43	651.47
42.00	0.73	2.00	251.1	46.8%	421.6	100.0%	993.00	737.94	664.45
43.00	0.75	3.00	256.0	47.7%	429.7	100.0%	993.00	726.23	677.22
44.00	0.77	4.00	260.7	48.6%	437.6	100.0%	993.00	714.30	689.80
45.00	0.79	5.00	265.4	49.5%	445.5	100.0%	993.00	702.16	702.16
46.00	0.80	6.00	270.0	50.4%	453.2	100.0%	993.00	689.80	714.30
47.00	0.82	7.00	274.5	51.2%	460.8	100.0%	993.00	677.22	726.23
48.00	0.84	8.00	278.9	52.0%	468.2	100.0%	993.00	664.45	737.94
49.00	0.86	9.00	283.3	52.8%	475.5	100.0%	993.00	651.47	749.43
50.00	0.87	10.00	287.5	53.6%	482.6	100.0%	993.00	638.29	760.68
51.00	0.89	11.00	291.7	54.4%	489.6	100.0%	993.00	624.92	771.71
52.00	0.91	12.00	295.8	55.2%	496.4	100.0%	993.00	611.35	782.49
53.00	0.93	13.00	299.7	55.9%	503.1	100.0%	993.00	597.60	793.05
54.00	0.94	14.00	303.6	56.6%	509.7	100.0%	993.00	583.67	803.35
55.00	0.96	15.00	307.4	57.3%	516.1	100.0%	993.00	569.56	813.42
56.00	0.98	16.00	311.2	58.0%	522.3	100.0%	993.00	555.28	823.23
57.00	0.99	17.00	314.8	58.7%	528.4	100.0%	993.00	540.83	832.80
58.00	1.01	18.00	318.3	59.4%	534.3	100.0%	993.00	526.21	842.11
59.00	1.03	19.00	321.7	60.0%	540.0	100.0%	993.00	511.43	851.17
60.00	1.05	20.00	325.0	60.6%	545.6	100.0%	993.00	496.50	859.96
61.00	1.06	21.00	328.3	61.2%	551.0	100.0%	993.00	481.42	868.50
62.00	1.08	22.00	331.4	61.8%	556.3	100.0%	993.00	466.19	876.77

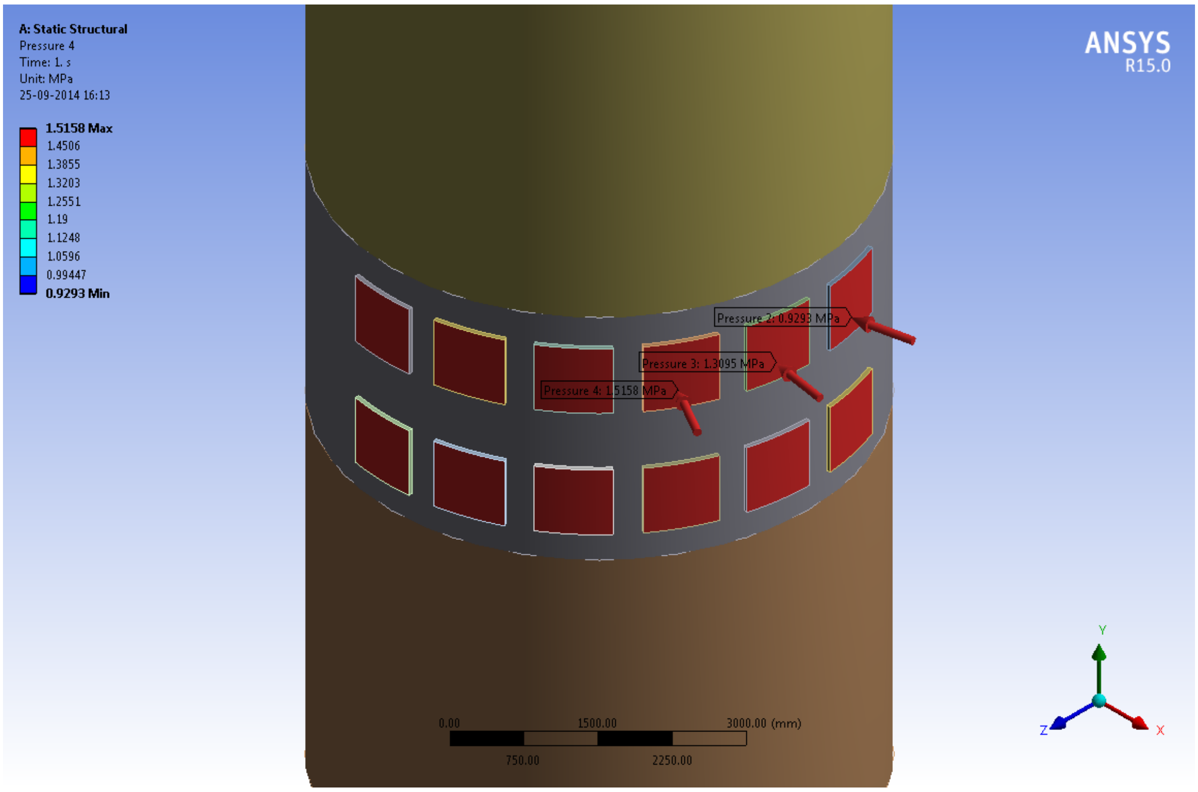
								Reaction components	
angle - local [deg]	angle - local [rad]	angle - global [deg]	δ [mm]	δ [%]	actual δ [mm]	axial reaction [%]	axial reaction [kN]	Rx [kN]	Ry [kN]
63.00	1.10	23.00	334.4	62.4%	561.3	100.0%	993.00	450.81	884.77
64.00	1.12	24.00	337.3	62.9%	566.2	100.0%	993.00	435.30	892.50
65.00	1.13	25.00	340.2	63.4%	571.0	100.0%	993.00	419.66	899.96
66.00	1.15	26.00	342.9	63.9%	575.5	100.0%	993.00	403.89	907.15
67.00	1.17	27.00	345.5	64.4%	579.9	100.0%	993.00	388.00	914.06
68.00	1.19	28.00	348.0	64.9%	584.1	100.0%	993.00	371.98	920.69
69.00	1.20	29.00	350.4	65.4%	588.2	100.0%	993.00	355.86	927.05
70.00	1.22	30.00	352.7	65.8%	592.0	100.0%	993.00	339.63	933.11
71.00	1.24	31.00	354.9	66.2%	595.7	100.0%	993.00	323.29	938.90
72.00	1.26	32.00	357.0	66.6%	599.2	100.0%	993.00	306.85	944.40
73.00	1.27	33.00	358.9	66.9%	602.5	100.0%	993.00	290.33	949.61
74.00	1.29	34.00	360.8	67.3%	605.6	100.0%	993.00	273.71	954.53
75.00	1.31	35.00	362.5	67.6%	608.5	100.0%	993.00	257.01	959.16
76.00	1.33	36.00	364.2	67.9%	611.3	100.0%	993.00	240.23	963.50
77.00	1.34	37.00	365.7	68.2%	613.9	100.0%	993.00	223.38	967.55
78.00	1.36	38.00	367.1	68.5%	616.2	100.0%	993.00	206.46	971.30
79.00	1.38	39.00	368.4	68.7%	618.4	100.0%	993.00	189.47	974.76
80.00	1.40	40.00	369.6	68.9%	620.4	100.0%	993.00	172.43	977.91
81.00	1.41	41.00	370.7	69.1%	622.2	100.0%	993.00	155.34	980.77
82.00	1.43	42.00	371.7	69.3%	623.9	100.0%	993.00	138.20	983.34
83.00	1.45	43.00	372.5	69.5%	625.3	100.0%	993.00	121.02	985.60
84.00	1.47	44.00	373.3	69.6%	626.5	100.0%	993.00	103.80	987.56
85.00	1.48	45.00	373.9	69.7%	627.6	100.0%	993.00	86.55	989.22
86.00	1.50	46.00	374.4	69.8%	628.5	100.0%	993.00	69.27	990.58
87.00	1.52	47.00	374.8	69.9%	629.1	100.0%	993.00	51.97	991.64
88.00	1.54	48.00	375.1	70.0%	629.6	100.0%	993.00	34.66	992.40
89.00	1.55	49.00	375.3	70.0%	629.9	100.0%	993.00	17.33	992.85
90.00	1.57	50.00	375.3	70.0%	630.0	100.0%	993.00	0.00	993.00

Design choice					
Position	angle - local [deg]	angle - global [deg]	R - Fxy direction [kN]	σ,WTG [Mpa]	σ,ring [Mpa]
a1	37.50	87.50	597.60	0.93	0.28
a2	58.50	108.50	842.11	1.31	0.39
a3	79.50	129.50	974.76	1.52	0.45
a4	100.50	150.50	974.76	1.52	0.45
a5	121.50	171.50	842.11	1.31	0.39
a6	142.50	192.50	597.60	0.93	0.28

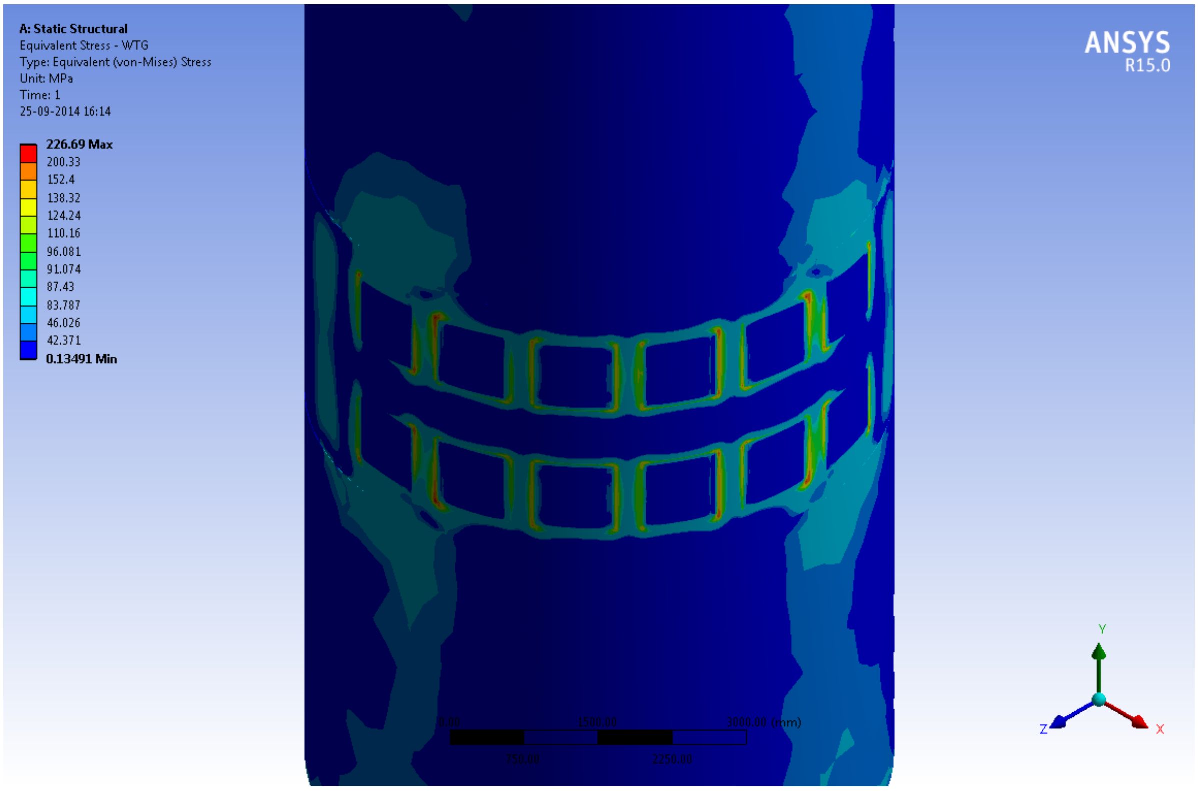
R axial [kN]	
9657.88	verified

Fender MCN - Maritime Internationa Inc.					
R [kN]	H [mm]	D [mm]	D/2 [mm]	α [rad]	α [deg]
2403	1400	2100	1050	0.24	26.99
2072	1300	1950	975	0.22	25.60
1765	1200	1800	900	0.21	24.16
1621	1150	1725	863	0.20	23.42
1483	1100	1650	825	0.20	22.66
1226	1000	1500	750	0.18	21.08
993	900	1350	675	0.17	19.43
785	800	1200	600	0.15	17.70
601	700	1050	525	0.14	15.88
441	600	900	450	0.12	13.97
307	500	750	375	0.10	11.96

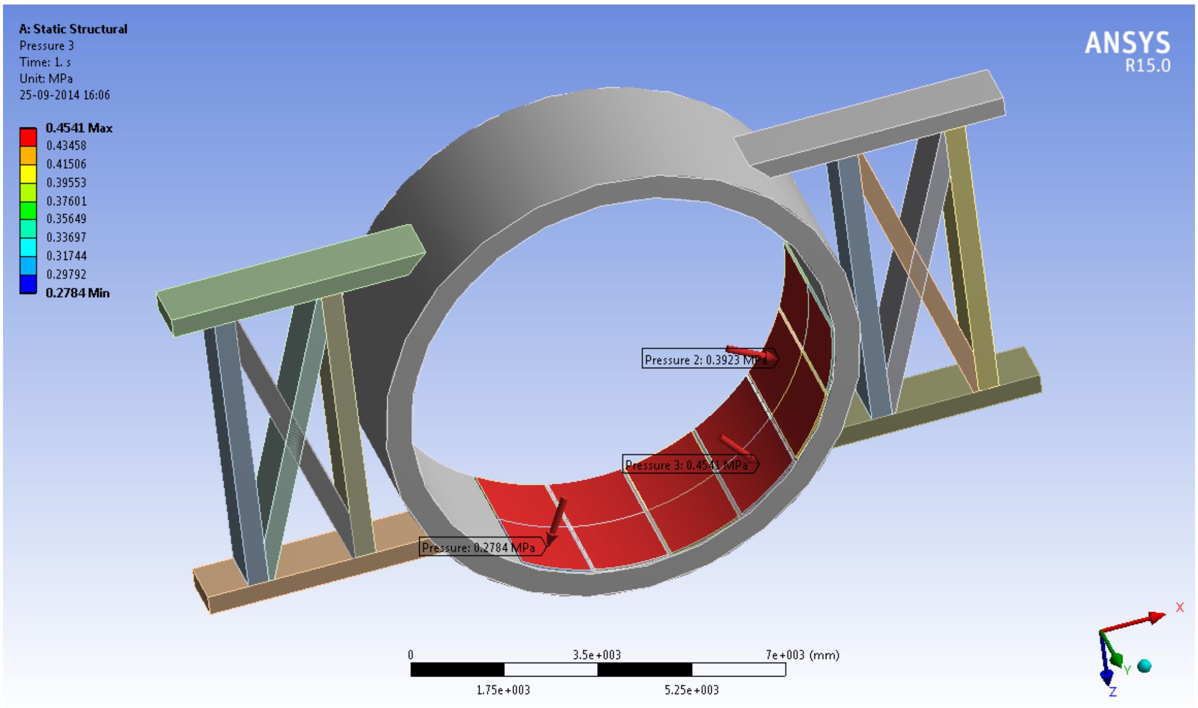
ANSYS results - Intermediate support, load application on WTG



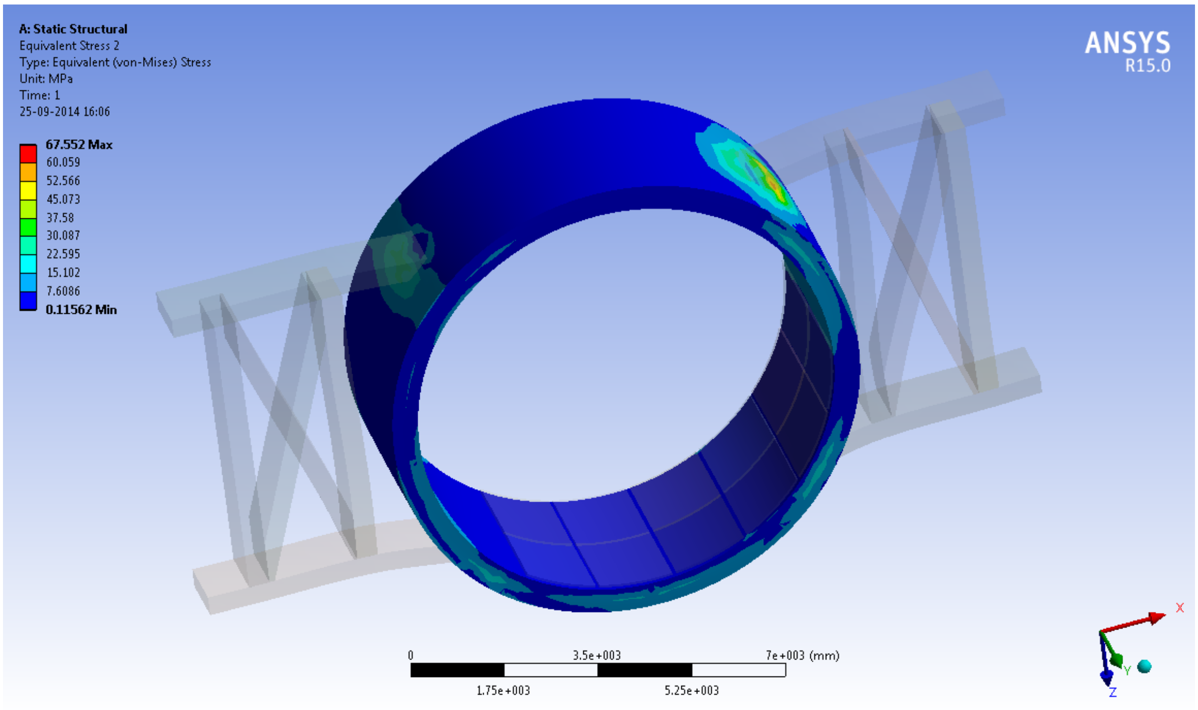
ANSYS results - Intermediate support, Von-Mises equivalent stresses on WTG



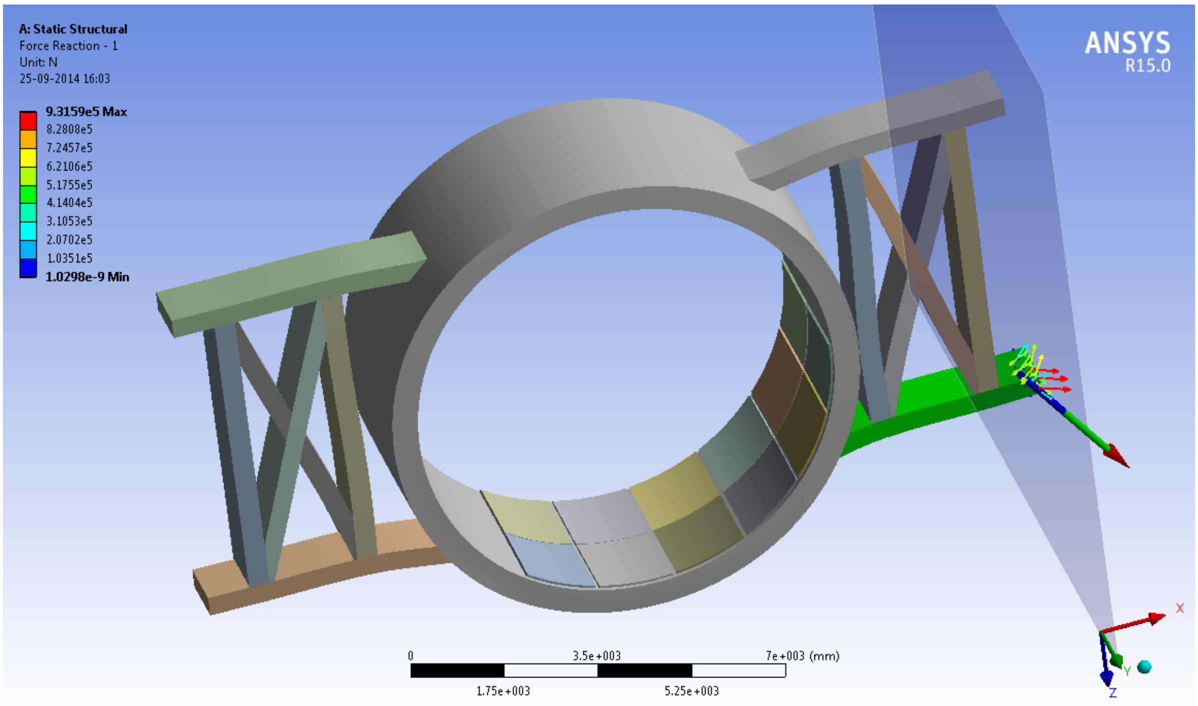
ANSYS results - clamping ring, load application

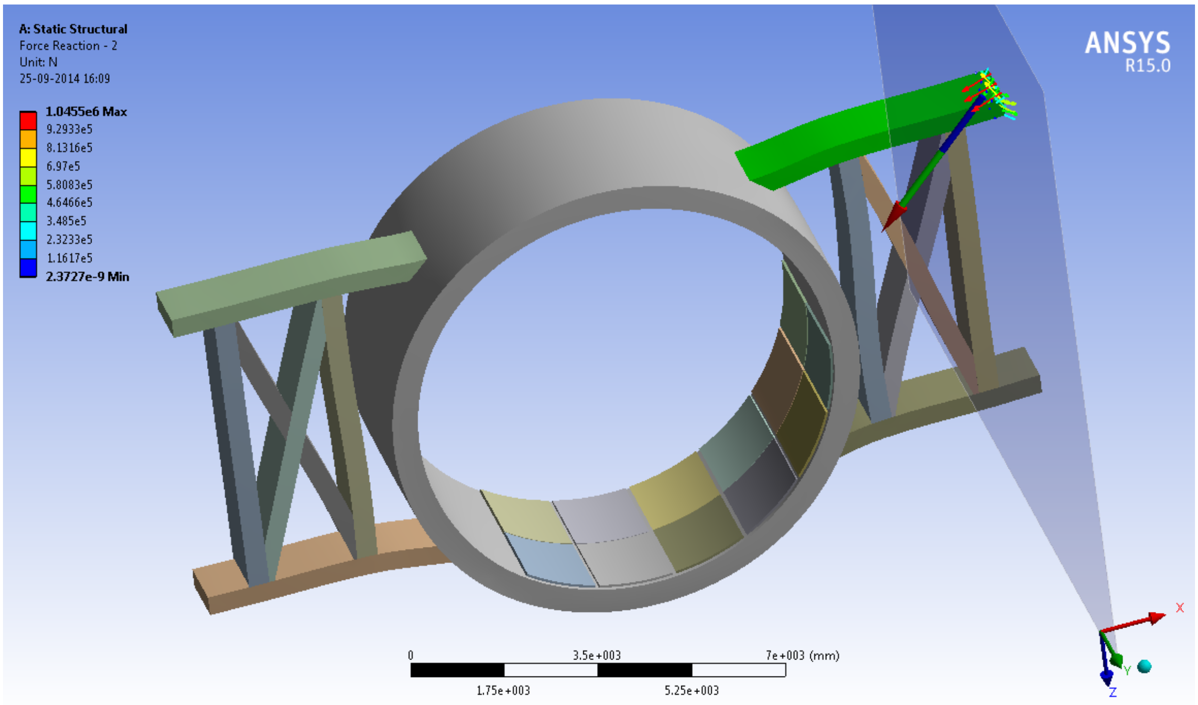


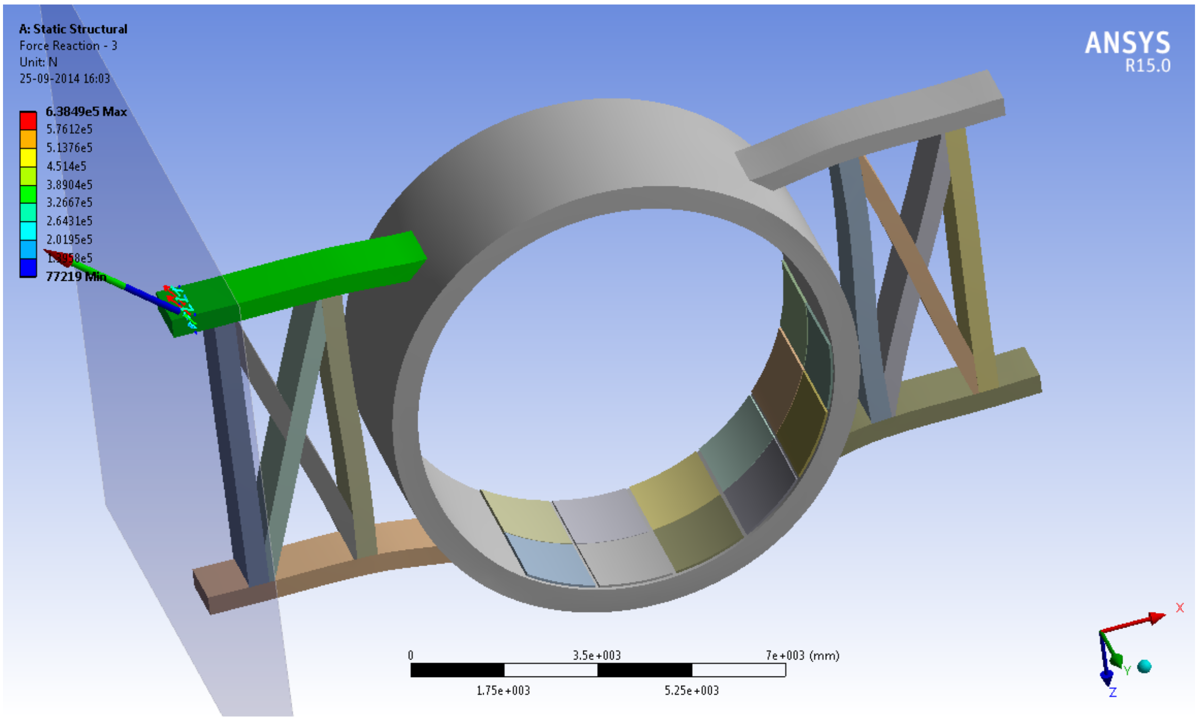
ANSYS results - clamping ring, Von-Mises equivalent stresses

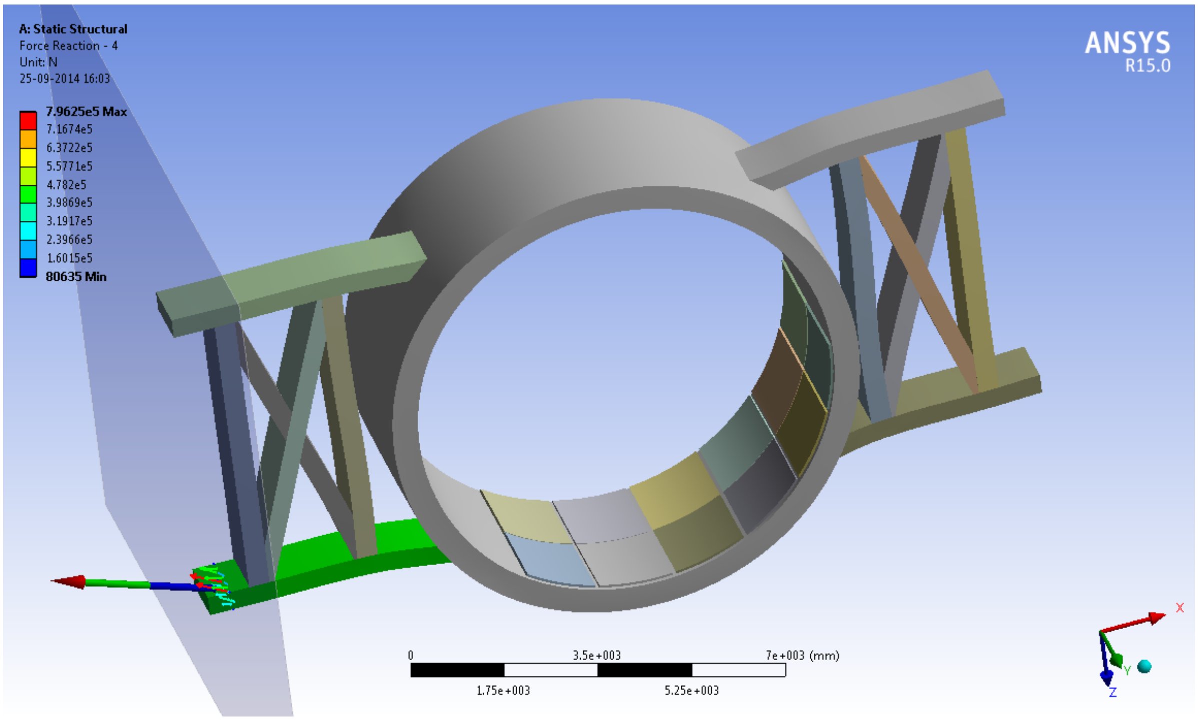


ANSYS results - Intermediate support, reaction forces






A: Static Structural
Force Reaction - 3
Unit: N
25-09-2014 16:03
6.3849e5 Max
5.7612e5
5.1376e5
4.514e5
3.8904e5
3.2667e5
2.6431e5
2.0195e5
77219 Min
ANSYS
R15.0
0
3.5e+003
7e+003 (mm)
1.75e+003
5.25e+003

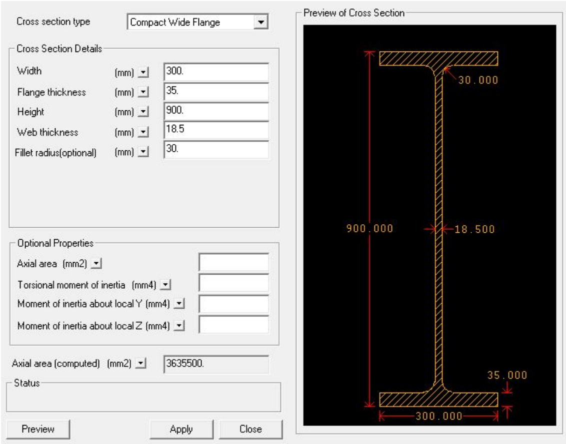

A: Static Structural
Force Reaction - 4
Unit: N
25-09-2014 16:03
7.9625e5 Max
7.1674e5
6.3722e5
5.5771e5
4.782e5
3.9869e5
3.1917e5
2.3966e5
1.6015e5
80635 Min
ANSYS
R15.0
0
3.5e+003
7e+003 (mm)
1.75e+003
5.25e+003

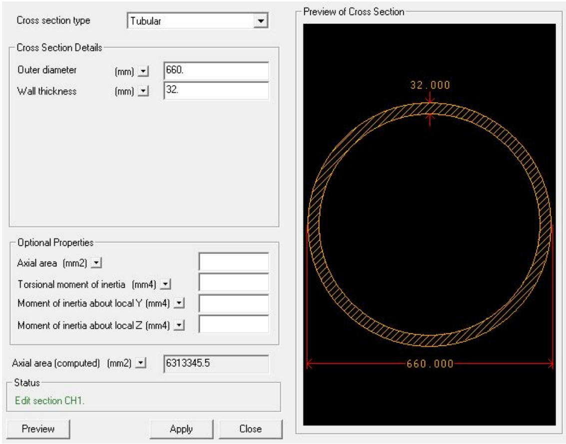
A.8. Complete solution

Allowable concentrated loads on main deck, Oleg Strashnov

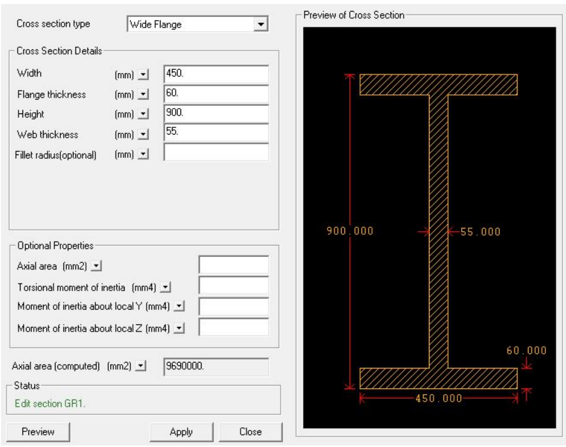
Confidential

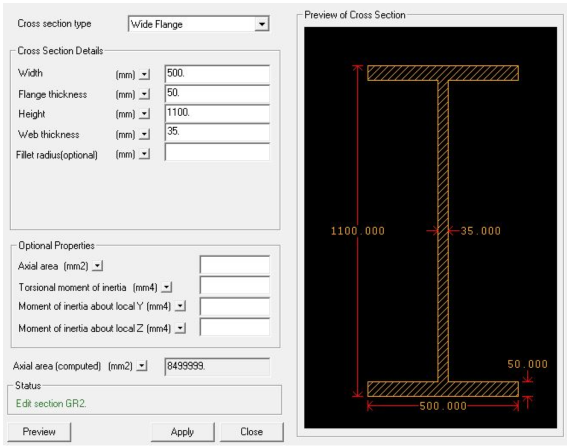
SACS model - horizontal and vertical/diagonal element cross sections



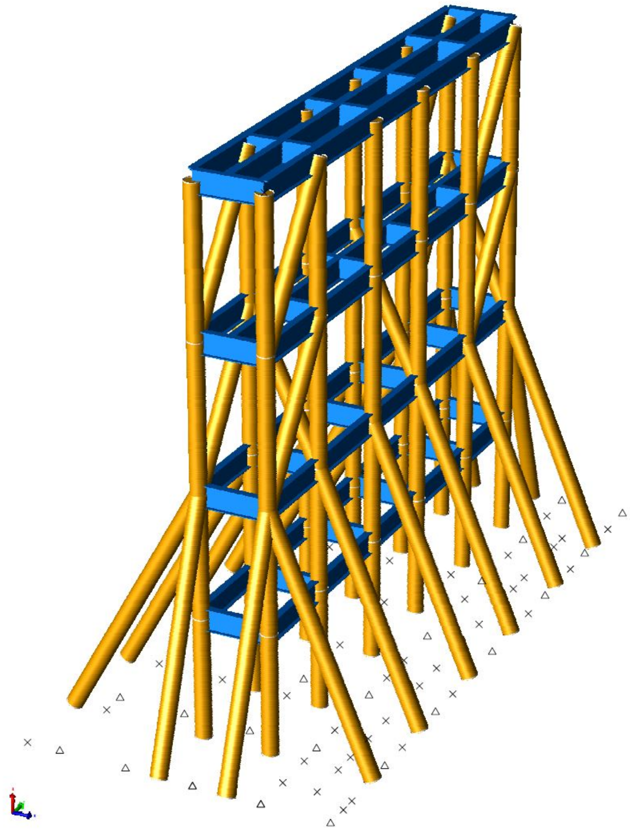


SACS model - grillage element cross sections

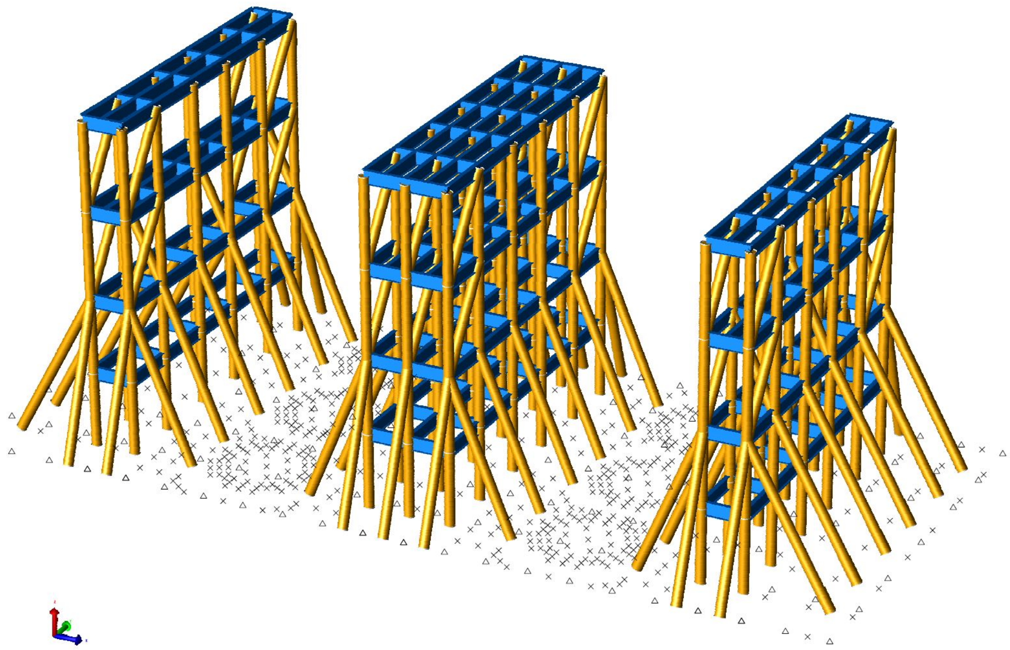




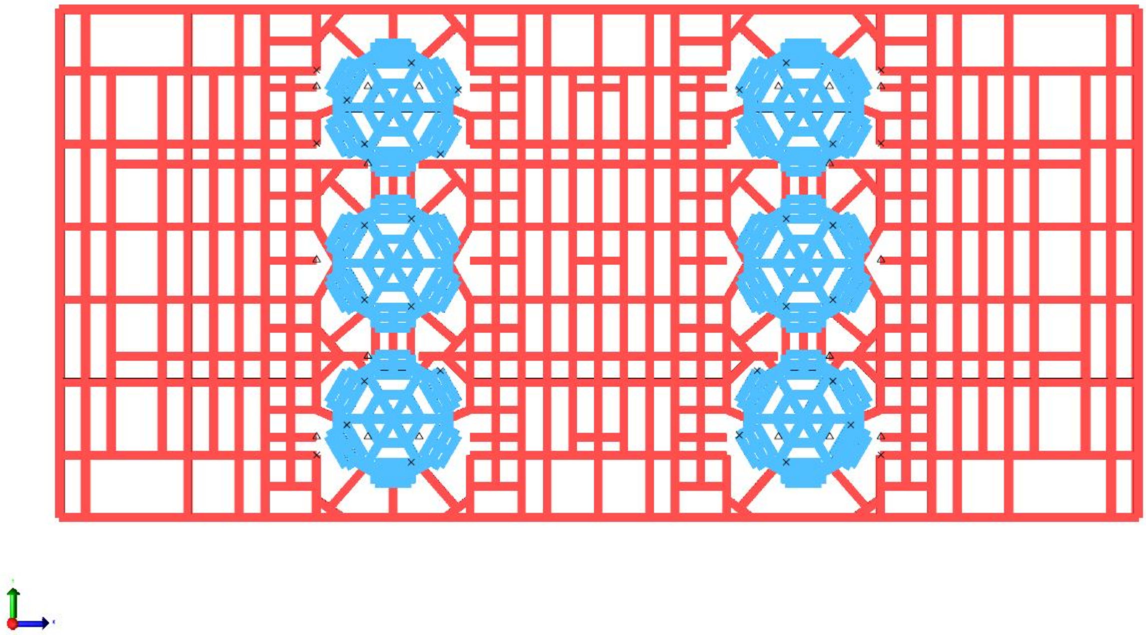
SACS model - Vertical structure, final arrangement, individual



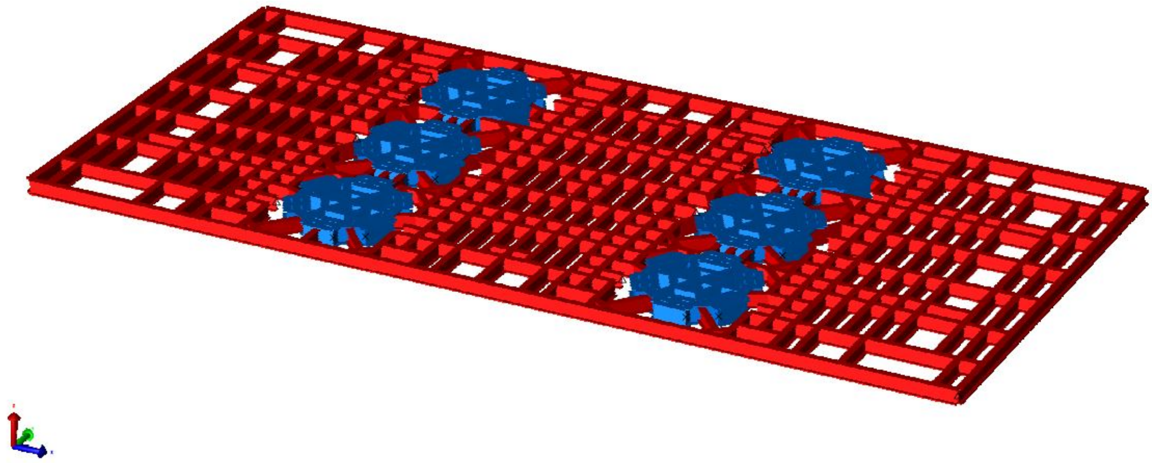
SACS model - Vertical structure, final arrangement, complete



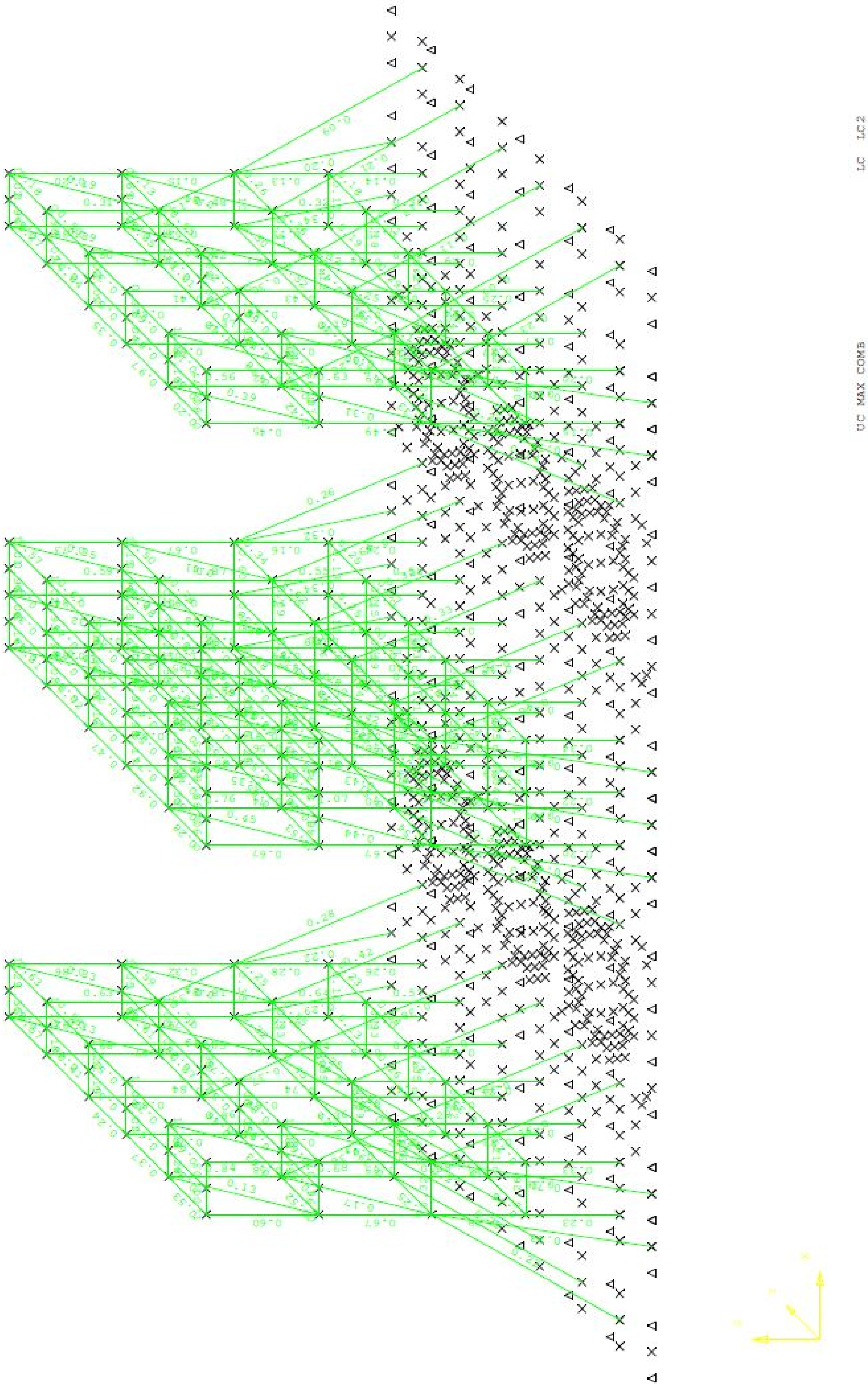
SACS model - complete grillage, top view



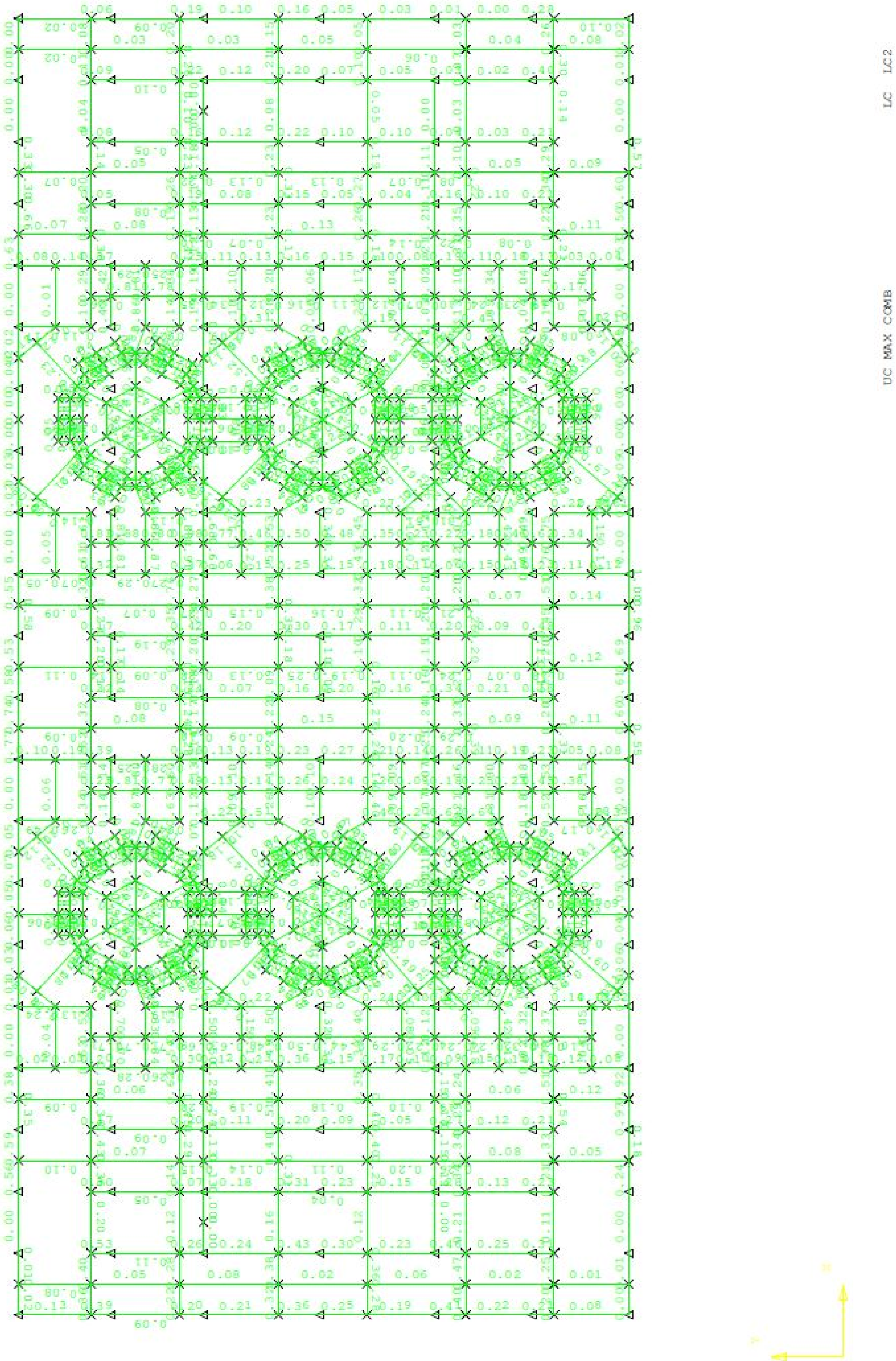
SACS model - complete grillage, 3D view



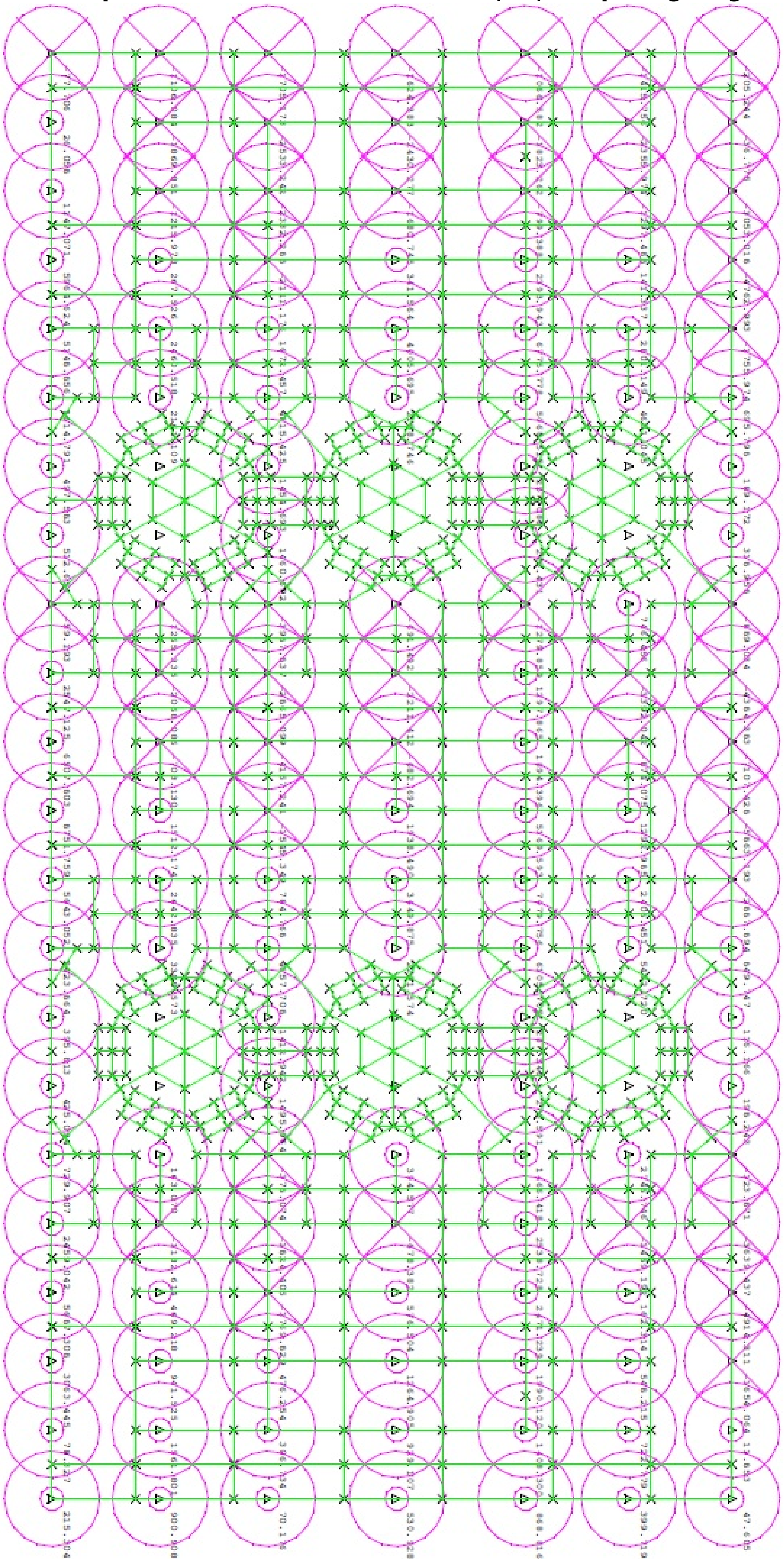
SACS outputs - combined unity checks, complete vertical structures



SACS outputs - combined unity checks, complete grillage



SACS outputs - reaction forces on the deck, Fz, complete grillage



SACS model - complete sea-fastening system