Master Thesis in Marine Technology - 2013
Design of a Novel Cylindrical Flare Tower

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Problem

Existing flare towers are mainly designed as standard truss work. One of the main advantages with this type of structure is the small amount of material required to obtain sufficient capacity. However, the production of such structures has proven to be demanding and expensive. A novel structural concept for a flare tower is to be investigated.

Introduction

Flare towers, or flare stacks, are found on both industrial plants and on oil production sites. In industrial plants flare towers serves their main purpose by burning of flammable gas released from pressure relief valves. On offshore oil productions sites the flare towers are primarily used for burning of natural gas, which is associated with the production of oil. This is mainly performed at offshore oil rigs or platforms which does not have any connection with gas piping or infrastructure for transportation of gas. The flare is often elevated so that it is not a hazard to personnel and process on the onshore or offshore installation.
Existing flare towers are mainly designed as standard truss work and is used as supporting structure for the flare pipe. One of the main advantages with this type of structure is the small amount of material required to obtain sufficient capacity. This gives a low weight compared to the overall strength of the structure.
However, the production of such structures has proven to be demanding and expensive. There are a large amount of joints and as the truss work flare tower are of great dimensions, the process of welding becomes time consuming. The welded joints will also be more exposed to fatigue since the stresses tend to concentrate at these points.
A cylindrical concept for a flare tower is to be investigated. If such a design will prove to have sufficient strength capacity it would have several advantages. The construction of the cylindrical flare tower would be less complex, giving reduced cost due to less production time. An optimization of the flare tower can give reduced weight and shield the flare pipe against wind loads. In addition, the stresses will be less concentrated around certain points such as welded joints, giving a structure less exposed to fatigue.
However, this type of design will be far more vulnerable to wind loads with a larger area which will be subjected to wind. The wind speeds at the top of the flare tower will be of great magnitude on an offshore location, giving large stresses near the bottom of the tower due to the moment. The focus in this assignment will be as low weight as possible and reduced production costs, but the eigenfrequency and dynamic response of the flare tower will also be of great concern.
For slender offshore structures (e.g. free spanning pipelines, risers, anchor lines), one can often observe vibrations. This phenomenon is called vortex induced vibrations and is associated with the forces developed due to vortex shedding on each side of the cylinder. For the flare tower, elastic motions are most likely to occur and vortex induced vibrations will be of great interest.

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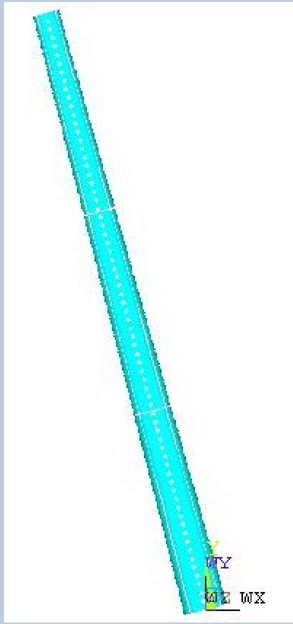
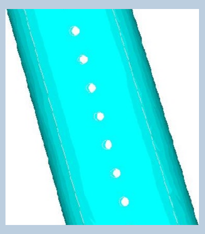
Modeling

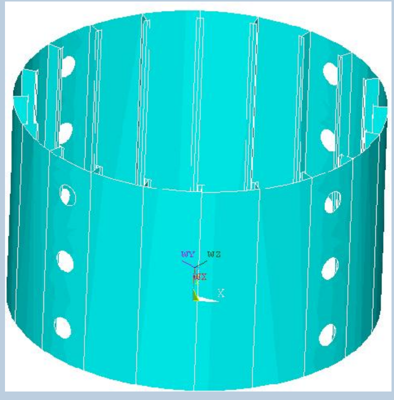
For design purposes the flare tower is divided in to three sections due to the fact that the stresses will be of a much larger magnitude at the lower part of the flare tower, than of those at the upper part. Some sections of the flare tower could be strengthened with with ring stiffeners and/or longitudinal stiffeners. The diameter of the tower should not only be of such dimension that it gives sufficient strength capacity and space for the flare pipe, but also giving easy access to flare piping for maintenance and inspection. The flare tower will be designed in such manner that it withstands the stresses that occur in the cylinder, with buckling as a potential collapse mode. In this process, all calculations are performed using spreadsheets for easy change of parameters and to study the relationship between weight and load capacity. As the dimensions are modified the stresses changes. This creates an iterative process to get sufficient capacity with respect to resistance against yield and buckling. To decrease the production costs, the tower is divided in to three sections, with different attributes and actions to prevent failure and oversized design. Each section will consist of rolled plates, welded together to construct a full flare tower. The flare tower has an inclination of 15 degrees.
The total height from process deck to top of the flare tower was set to 70 meters, which is not unrealistic with reference to existing flare towers. There is also an air gap of 16 meters, which will give higher wind loads as the wind speed strongly depends on the height. A conical structure was developed, with decreasing diameter from bottom to top. The diameter at the bottom was set to 5 meters and a top diameter of 3 meters proved to be sufficient. The lower section of the has a shell thickness of 23 mm and both longitudinal and ring stiffeners. Longitudinal stiffeners are not present in the mid part of the tower, but ring stiffeners are applied. This section has a wall thickness of 10 mm. The top section has no additional stiffening and 8 mm wall thickness.



Due to the large wind pressure acting on the structure, it is beneficial with cut-outs, acting as ventilation for the flare tower. The alignment and positions of the cut-outs can also be used to prevent or limit vortex induced vibrations, which will be a topic of discussion later in the thesis. These cut-outs have a diameter of 0,3 meters, with an elevation of 1 meter between each cut-out. Each section counts four cut-outs with an angle of 90 degrees between each cut-out.



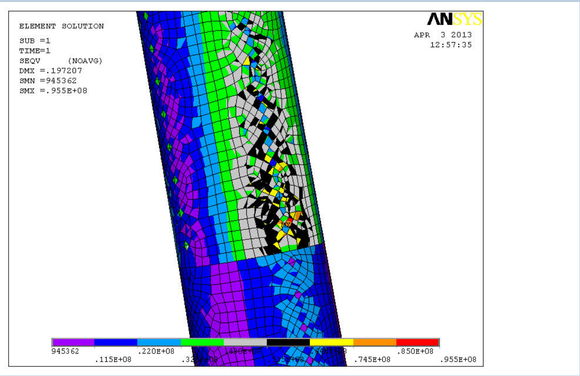
As a potential collapse mechanism, the buckling strength of the shell needs to be investigated further than the method used in the preliminary design process. To reduce computational time and simplifying the modelling process, the sections between ring stiffeners are chosen for the analyzes.



Quasi-Static Analysis

The Frøya wind model serves as a quasi-static wind load, with representation of both mean wind pressure and pressure due to wind gusts and wind turbulence. The wind pressure are applied on 1/4 of the surface area in the direction of the flare tower inclination, which will be worst case scenario combined with horizontal platform movements in the same direction. Since the wind speed increases rapidly by height, three different pressures are applied by the length of the tower since the wind profile is not linear, and a pressure gradient would be misrepresentative. The longitudinal and ring stiffeners are not represented in the model, but the equivalent thickness due to longitudinal stiffening is given as the shell thickness for each section, by the formula[3, p. 9]

$$t_e = t + \frac{A}{s} \tag{1}$$

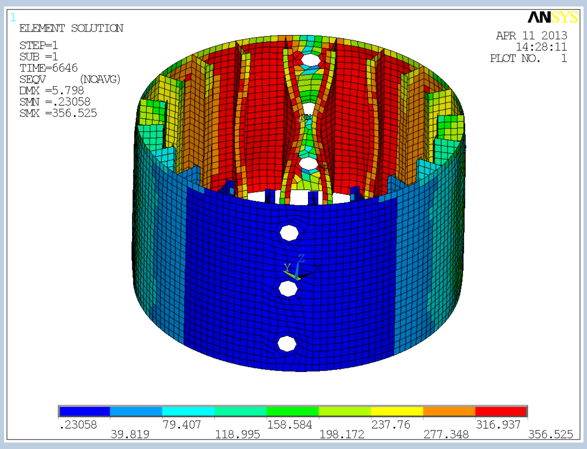


Dynamic Analysis

The response of the structure is an important aspect in structural analysis. The fluctuating wind speed may prove to excite the flare tower in such manner that the dynamic response will give higher stresses than of those obtained in the quasi-static analysis.
A wind spectrum, eigenfrequencies and damping coefficients were calculated, as they are all prerequisites for performing a random-vibration analysis in ANSYS. The peak Von Mises stresses of 75.8 MPa, occurs at resonance with the mode shape asscociated to a eigenfrequency of approximately 11.6 Hz.

Buckling

An eigenvalue buckling analysis is ran, giving a small applicable out-of-plane perturbation and determining the buckling mode shape. The deformations are later scaled by the maximum fabrication tolerance according to DNV[4]. A non-linear analysis is utilized to find the buckling capacity and potential residual strength of the shell structure. The buckling capacity proves to be far beyond those based on a linear model.



Conclusion

The novel flare tower concept shows that it is a worthy competetor to the traditional flare tower designs. With lower construction cost and easy access for maintenance it could be a realistic alternative. The cylindrical structure shows sufficient capacity to withstand enviromental loads, but should not be implemented without small modifications.