Structural Design Of Overhanging Pressure Vessel Support Used In Pyrolysis Process Using Non- Linear Finite Element Analysis For Structural Stability

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ABSTRACT:

Nitrous Oxide is obtained by "ammonium nitrate pyrolysis synthesis". Ammonium nitrate is a moderately sensitive explosive and a very powerful oxidizer. Above 240o C, the nitrate can even detonate. Hence it is imperative to maintain temperature below 240o C. The reaction needs two types of pressure vessels, one is inclined vessel (IV) which is used to control rate of reaction and another overhanging vessel (OV) which is used to store produced nitrous oxide. The rate of the reaction and its temperature is controlled by the inclination of the IV mechanically. At lower inclinations, the reaction will progress rapidly and as the inclination will increases, the rate of reaction to reduce. Thus in effect, the inclination of IV will control the rate of reaction, which is an exothermic reaction. This in turn will control the temperature of the reaction consequently the temperature without hampering the process. The overhanging vessel is acts as storage for Nitrous Oxide, which if take support of the IV, it will not be stable as IV constantly moving to control the rate of reaction. However still the overhanging vessel has to sit on top of the IV and cannot take support from the ground as in a Typical Skirt or Leg Support. This paper presents about FEA used to design analysis of support structure by using design by analysis method, around the vessel which gives lateral supports and the vessel is free from the bottom. In this, loads like internal pressure, self weight, wind load and sets of boundary conditions according to wind load direction and ground support are considered and accordingly FEA of overhang vessel and its support is carried out to ensure safety and structural stability.

1. INTRODUCTION:

Mechanical design is the design of a component for optimum size, shape, etc. against failure under the application of operational loads. A good design should also minimize the cost of material and cost of production. *Design* is associated with the calculation of dimensions of a component to withstand the applied loads and perform the desired function. *Analysis* is associated with the estimation of displacements or stresses in a component of assumed dimensions so that adequacy of assumed dimensions is validated. *Optimum design* is obtained by many iterations of modifying dimensions of the component based on the calculated values of displacements and/or stresses. A.Th. Diamantoudis [1] has represented has presented a comparative study on design by analysis and design by formula of pressure vessel. Gyeong, Hoi Koo [2] have presented preliminary structural evaluations of the reactor vessel and support design. Imran M.Jamadar have [4] studied Inclined pressure vessel used for production of nitrous oxide by ammonium nitrate pyrolysis reaction by passing the steam at around 2000C and 1.37895 Mpa over the ammonium nitrate contained in the cylindrical vessel. Inclined pressure vessel (IPV) analyzed using finite element analysis to find out stresses in the vessel for its structural stability. Z. Sanal [3] has presented two pressure vessel problems, where the large displacement and plastic straining response of the structure is simulated by geometrically and materially nonlinear finite element analysis. N. El-Abbasi et.al [5] had a three-dimensional finite element analysis of a pressure vessel resting on flexible saddle supports. Alwyn S. Tootha et.al [8] has the current design methods aim to minimize the thermal stresses.

2. RELEVANCE

The Objective of the Inclined Vessel is to have large scale production of Nitrous Oxide Nitrous Oxide is useful as, a rocket propellant, in race cars for power push (For high instantaneous acceleration) and inert Gas in food packaging to prevent bacterial growth. Nitrous Oxide is manufactured by a process termed as "pyrolysis".

Pyrolysis is a special case of thermolysis, and is most commonly used for organic materials. Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen. Ammonium nitrate is a moderately sensitive explosive and a very powerful oxidizer. Above 240 deg C, the nitrate can even detonate Hence it is imperative to maintain temp below 240 deg C.

$$NH_4\,NO_3\,(s) \rightarrow 2\,H_2\,O\,(g) + N_2\,O\,(g)$$

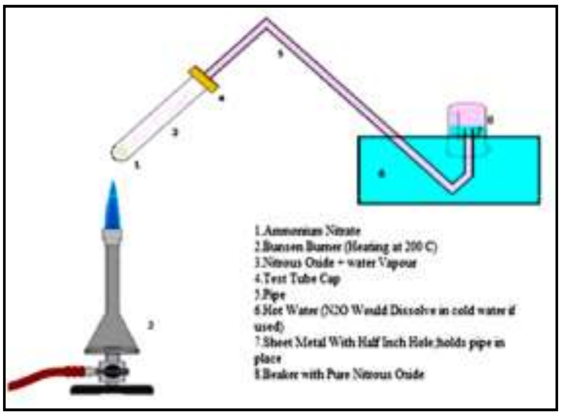


Fig 1.1 Laboratory production

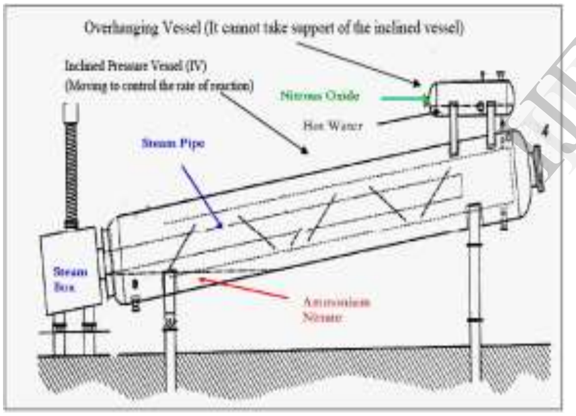


Fig 1.2 Block Diagram of Pressure Vessels

3. ASPECT OF DESIGN:

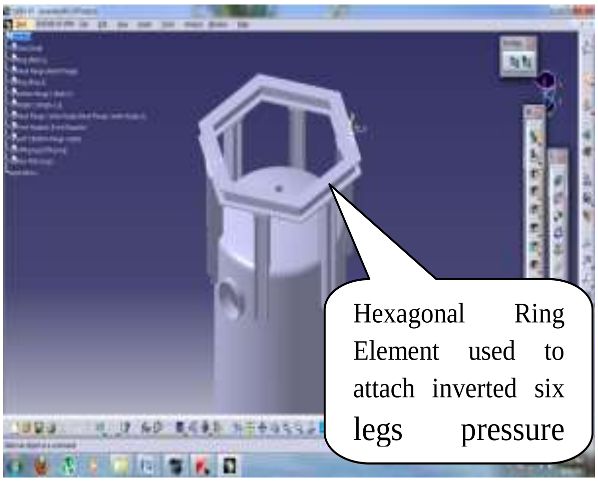
The Overhanging vessel (OH) as shown in Fig. 1.2 is the one which acts as storage for Nitrous Oxide. Though in the block diagram it is shown to be rested on the inclined vessel, in reality it cannot take support of the inclined vessel (IV). As the IV will be constantly moving to control the rate of reaction, the support will not be stable. However still the vessel has to sit on top of the IV and cannot take support from the ground as in a Typical Skirt or Leg Support. The concept is to create a support structure around the vessel which will give lateral supports and the vessel will be free from the bottom.

4. ANALYSIS APPROACH

Finite Element Analysis method is used for the analysis of this project work. This is an alternative method used for the design work. Modeling of a vessel with its supportive structure is a first step in the analysis of the overhanging pressure vessel for storage of nitrous oxide in the said chemical process. Vessel structure must be stiff enough to have minimum deformation of 38 mm in accordance to its overall height of 13.6 m as per the requirement of chemical process. This can be achieved by having different configurations of structure models. These models are analyzed for the maximum deformation with ANSYS 12.0

4.1Modeling

The model of pressure vessel is required to be inverted and supported from the above and free from the bottom. This achieved by different of supportive structure with modeling software CATIA V5R18. Required height of the vessel to occupy inclined vessel which is a part of chemical process is approximately 13.6 meter. But to support the inverted pressure vessel with six legs structural element is needed, to weld the six legs. Best possible way to attach six legs is, to have hexagonal ring element as shown in figure 6.2. Thereafter a hexagonal ring supported by horizontal elements and vertical legs with 'I' cross section from up to ground to achieve required height.



Hexagonal Ring Element used to attach inverted six legs pressure

Fig 4.1 Hexagonal shaped ring used to support symmetrical six legs of vessel

4.2 Material and Meshing

Engineers are always searching for ways to use advanced materials to make products lighter and stronger for different applications.

Since it is important to design a structure, to support pressure vessel which is free from bottom, it is required to use structural steel as a material in the analysis with the given material properties in the table.

Table 4.1 Material Properties

Sr. No.	Property	Value
1	Material	Structural Steel
2	Density	7.85e-05 kg/m^3
3	Modulus of elasticity	2 e+9 (MPa)
4	Poisson's Ratio	0.3
5	Thermal Conductivity	6.05e-002 W mm^-1 C^-1
6	Resistivity	1.7e-004 ohm mm
7	Compressive Yield Strength	250 MPa

The accuracy of the results of FE model is highly dependent on the mesh employed. In general, a finer mesh will produce more accurate results than a coarser mesh.

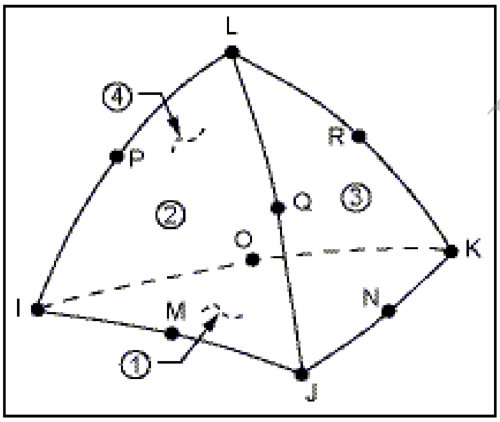


Fig 4.2 Element used for meshing Solids 187

4.3 Boundary conditions

The supports will have to be design keeping the factors in mind such that Wind Load, and Self Weight.

Self Weight: The pressure vessel and supportive structure weight cause the force to act on structure. This will cause deformation in the vertical direction.

Wind Load: For analysis wind load is applied on vertical face of vessel in the form of uniformly distributed load. There are two cases consider of wind flow which are shown below. One in which wind load is acting normal to legs configuration and another in which wind load is acting along the legs.

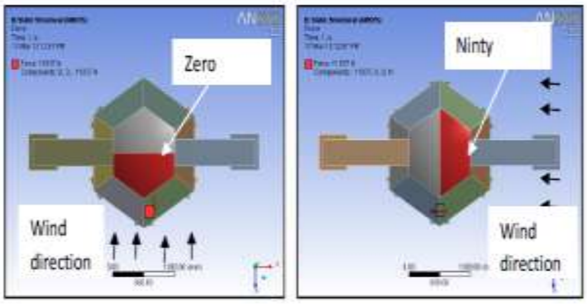


Fig 4.3 two sets of boundary conditions according to direction of wind force

Wind force is calculated by referring 'Pressure Vessel Design Manual', by Denis Moss

Wind Load/ Force (F) $= q_z * G_f * C_f * A_f$
$= 5058$ lb
$= 23000$ N

Where, $q_z = 0.00256\ K_z K_{zt} V^2 I = 30.3$
Gf = 2.65
Cf = 0.9
Af = 70 Ft^2

Analysis 4.4

Hexagonal ring is used to attach six legs of vessel Hexagonal shape will provide support to each six legs since numbers of legs to the vessel are six.

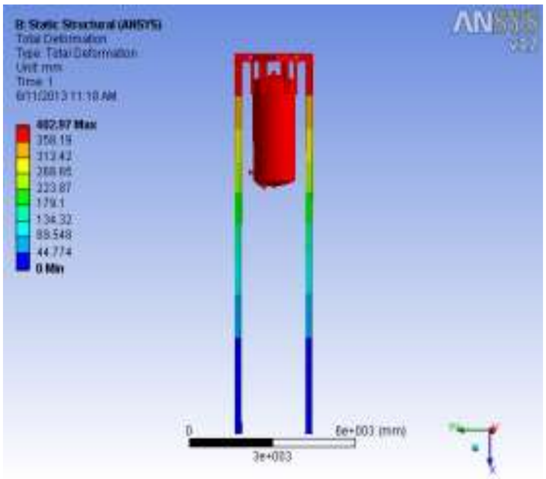


Fig 4.4 Deformation with Hex Ring [240*226*15.5*26] and leg size [240*226*15.5*26]

The cross section of the ring varied to have four different models, prepared with CATIA are imported in ANSYS 12.0 software to have their structural analysis. Hexagonal ring with geometrical variation as design variable has been analyzed. The analysis results are shown in the table 4.2 Figure 4.3 shows the one of the analysis of the vessel with hanging structure

The deformation table and graph for hexagonal ring element comprehensible that variation in cross section of hexagonal ring does not affect the deformation value and also stress value in the analysis. This concludes that with variation in cross section of the hexagonal ring element does not affect the overall deformation.

Table 4.2 Deformation with change in 'I' shape for Hexagonal Ring

Sr No	Cross Section of Hexagonal Ring				Defor. With Wind Load mm	Max. Stress MPa
	h mm	b mm	t_w mm	Area mm^4		
1	152.4	152.4	15	6408	434.25	775.75
2	180	166	14	9512	392.23	718.94
3	220	206	15	12850	404.72	793.94
4	240	226	15.5	14666	402.97	727.78

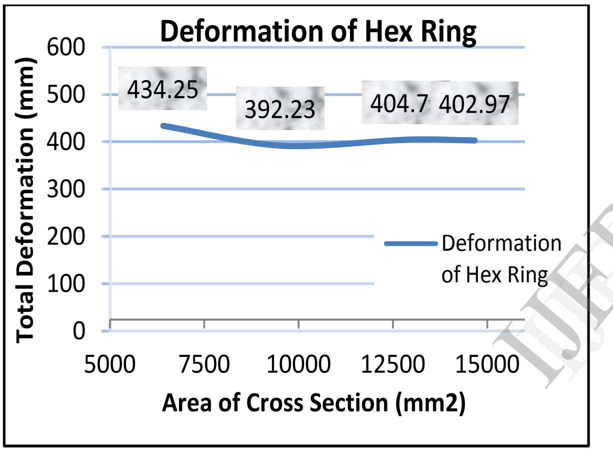


Fig 4.5 Graph of Total deformation Vs Area of c/s of Hex Ring

With this conclusion Hexagonal Ring 'I' shape cross section [152.4 *152.4 *15] with minimum area is selected for the further analysis. In these models no any lateral support is given to the pressure vessel and hence deformation may quite high than minimum value required. This can be minimized by addition of lateral support from two vertical long legs to the vessel shell. After fixed size of hexagonal ring element, horizontal element and two vertical legs dimensions are need to be finalized. Therefore these two dimensions are considered as geometrical design variables. With these geometrical variable models with different configurations are prepared. Thereafter these models are imported in ANSYS 12.0, subjected to analysis and maximum total deformations and stress values are recorded.

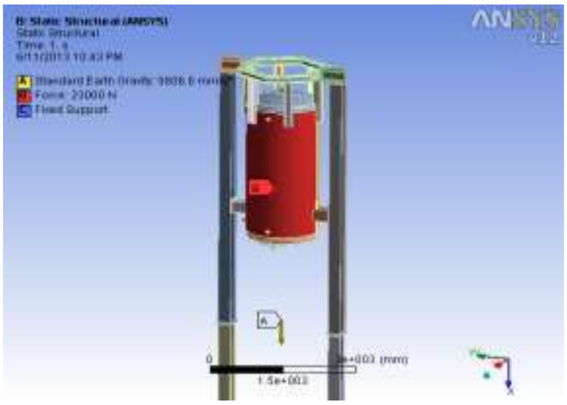


Fig 4.6 Boundary conditions with loads and added lateral element for two legs configuration

Three different cross sections were used for the vertical long legs, horizontal elements and lateral elements of the structure. These three models where considered as geometrical design variable. One more design variable is to have different configuration. Two different configurations are used with two long vertical legs support structure and another with four long legs support structure.

Table 4.3 Cross section used for the horizontal element, vertical long legs and lateral element

Sr. No.	Height h (mm)	Width b (mm)	Web Thickness t_w (mm)	Area of Cross Section (mm^4)
1	290	268	18	21470
2	340	310	21	29682
3	377	309	21	30957

Analysis is carried out with two legs support structure and four legs support structure and subjected to wind load in two different direction.

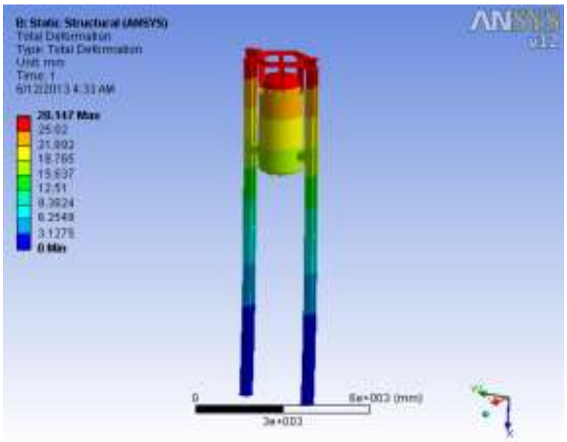


Fig 4.7 (a) Deformation of two legs structure of c/s [377*309*21*40] and wind normal to legs

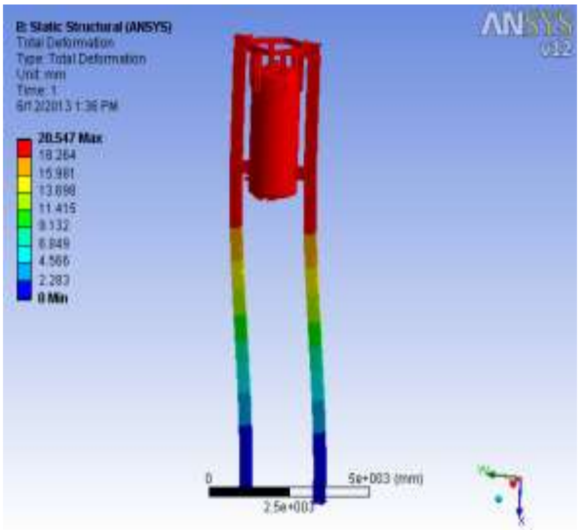


Fig 4.7 (b) Deformation of two legs structure of c/s [377*309*21*40] and wind along the legs

This variable gives twelve different cases for the analysis, three different cross sections with two legs subjected to two different wind force directions and three different cross sections with four legs subjected to two different wind force directions. Figure 4.7 shows two legs structure subjected to two different wind force directions.

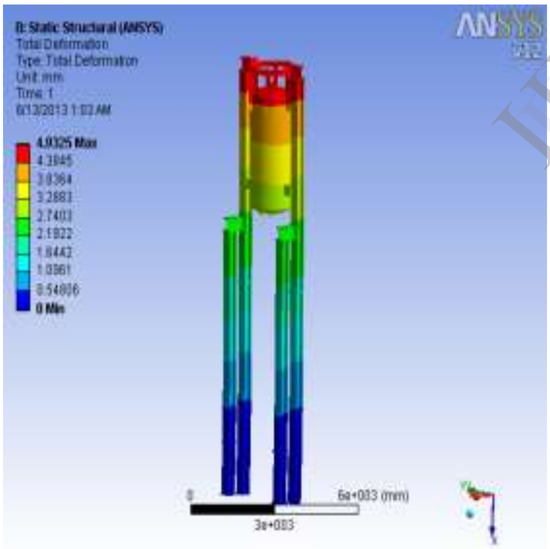


Fig 4.8 Deformation of four legs structure of c/s [377*309*21*40] and wind normal to legs

5. RESULT DISCUSSION

The structures are analyzed with material structural steel with overall height of 13000 mm Hence it is required that stress value must be less than 250 MPa and deformation less than 13000/6 mm that is 37 mm. From the graphs it is clear that a configuration no. 3 with mass 9386.6 is having stress values within the limit with deformation 28.14 mm.

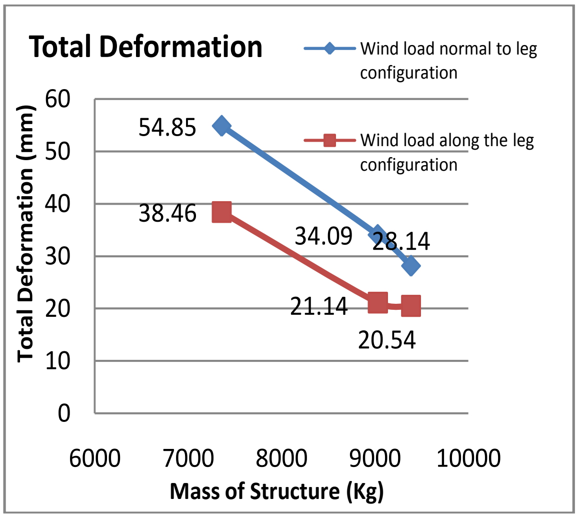
Table 5.1 Deformation and stress for 2 legs configuration and wind load acting normal to configuration

Sr. No.	Area of c/s A (mm^4)	Mass of Structure (Kg)	Total Deformation (mm)	Max. Von Mises stress (MPa)
01	21470	7359.7	54.85	423.32
02	29682	9031.2	34.09	264.08
03	30957	9386.6	28.14	221.5

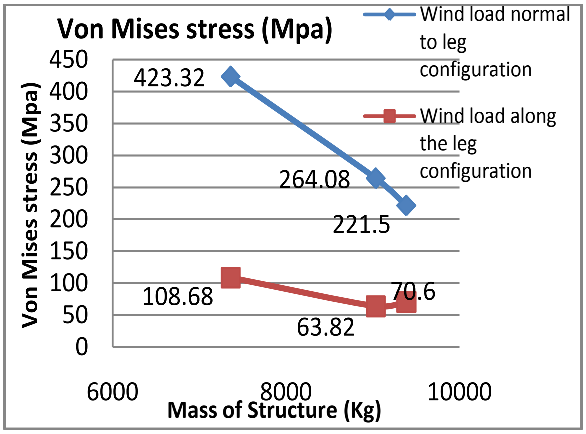
Table 5.2 Deformation and stress for 2 legs structure and wind load acting normal to legs

Sr. No.	Area of c/s A (mm^4)	Mass of Structure (Kg)	Total Deformation (mm)	Max. Von Mises stress (MPa)
01	21470	7359.7	38.46	108.68
02	29682	9031.2	21.14	63.82
03	30957	9386.6	20.54	70.6

These two tables give the deformation values for the two different conditions. With these values graph is plot for the total deformation of the structure under self weight and wind load normal or along the legs versus mass of the whole structure. Also another graph is plot for the von mises stress versus mass of the structure. These graphs are as shown in the following figure 7.1 and figure 7.2



(a)



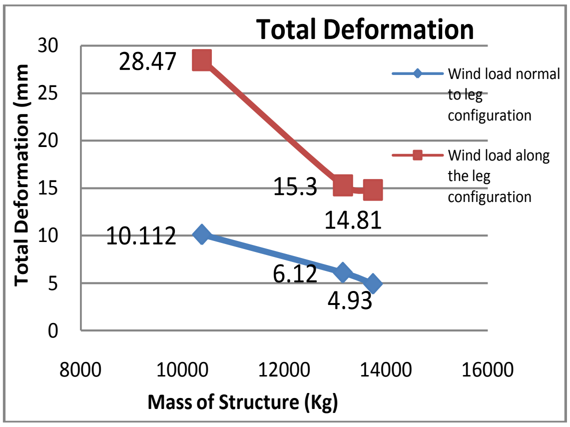
(b)

Fig 5.1 (a) & (b) Graphs of deformation snd von mises stress Vs mass of structure for two legs configuration

Structure with four legs is analyzed with the same boundary conditions and result table is prepared for the total deformation and von mises stress values. Table below will give the values for both set of boundary conditions, one with wind load acting normal to the legs configuration and another with wind load acting along the legs configuration.

Table 5.3 Deformation and stress for 4 legs structure with both sets of boundary conditions

Mass of Structure (Kg)	Wind load normal to legs		Wind load along the legs	
	Total Deformat-ion (mm)	Von Mises stress (MPa)	Total Deformat-ion (mm)	Max. Von Mises stress (MPa)
10380	10.112	89.99	28.47	97.61
13151	6.12	43.04	15.3	72.55
13741	4.93	36.43	14.81	63.51



(a)

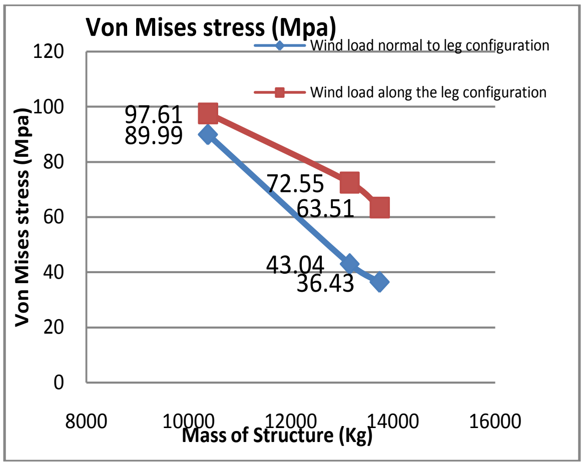


Fig Graph of von mises stress Vs mass of structure for four legs configuration

The structures are analyzed so that stress value must be less than 250 MPa and deformation less than 37 mm. From the graphs in the figure 7.1 it is clear that a configuration no. 3 with mass 9386.6 is having stress values within the limit with deformation 28.14 mm and von mises stress value 221.5 MPa with two legs structural configuration.

6. CONCLUSION

Analysis carried without lateral element and variation in hexagonal ring size as shown in graph 4.5, variation in the hexagonal ring cross section does not affect the total deformation and maximum stress of structure.

From analysis with different wind direction, Wind load acting normal to legs gives more deformation if compared with deformation with wind direction along the legs.

Structure with allowable deformation and maximum stress value within the limit and with minimum mass 9386.6 Kg and dimensions given as

Table 6.1 Final dimensions of structure

Name of Element	Height h (mm)	Width b (mm)	Web Thickness t_w (mm)	Flange Thickness t_w (mm)
Hexagonal Ring	152.4	152.4	15	15
Horizontal Strut	377	309	21	40
Lateral Element	377	309	21	40
Vertical Legs	377	309	21	40

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