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Design and Optimization of Saddle For Horizontal Pressure Vessel

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ABSTRACT

It is imperative for an engineer to design and analyse the pressure vessel that will provide safety, durability and serviceability to the end user. Accomplishing this task will require a very good knowledge of design parameters, the most important being, geometry of pressure vessel that must be analysed to comply design standards. The design of saddle support for the pressure vessel is also a part of this analysis. The most common method adopted by American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code for design of saddle support was developed by L. P. Zick in 1951. Zick's analysis was based on the assumption that the supports are rigid and not connected to the vessel shell. In reality, most vessels have flexible supports that are welded onto the vessel shell. In the present paper, the saddle design is optimized for a material quantity and in turn for the cost by reducing number of gusset plates and thickness thereof. The task is accomplished by analysis of pressure vessel and saddle by finite element analysis (FEA) based software PV Elite. The result of this analysis shows a measurable 20 percent reduction in the material quantity post optimization.

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I. INTRODUCTION

A Pressure vessel is a closed cylindrical vessel widely used in industries like process, power, oil and gas for the storage of fluid or gaseous products. These are of two types, horizontal and vertical. Pressure vessels are subjected to pressure loading i.e. internal or external operating pressure different from ambient pressure. For horizontal vessel the saddle supporting plays an important role in the performance of the equipment. A proper saddle supporting improves safety and durability. Horizontal pressure vessels are usually supported on two vertical cradles called saddles. The use of more than two saddles is unnecessary and should be avoided. The reason behind not using more than two saddles is to avoid an indeterminate structure, both theoretically and practically. With two saddles, there is a high tolerance for soil settlement with no change in shell stresses or loading. Even where soil settlement is not an issue, it is difficult to ensure that the load is uniformly distributed. ASME Code does not have specific procedures for the design of saddles or the induced stresses in the vessel. While the ASME Code does have allowable maximum stresses for the stresses in the vessel shell, the code does not specifically address the support components themselves. The purpose of this paper is to help understand the extent to which the saddle parameters like number of gusset plates and their thickness can be practically optimized. The optimized designs parameters reduce the direct material cost and indirect cost such as transportation and construction.

I. LITERATURE REVIEW

A methodology for the determination of the stresses in the shell and heads of a horizontal vessel supported on saddles was first published in 1951 by L. P. Zick [1] [9]. This procedure has been used, with certain refinements since that time, and is often called Zick's analysis, or the stresses are referred to as Zick's stresses. The presence of supports has two distinct effects on the vessel. Firstly it interferes with the normal expansion of the vessel due to internal pressure or temperature change; secondly the concentrated support reaction induces highly localized stresses in the support region [3]. A rigid support will give rise to greater stress concentration compared to a flexible one. The main cause of stress concentration is the abrupt transition of structural rigidity between the support and the vessel [3]. The saddle structure itself is stressed, as all forces acting on the vessel are ultimately transferred to the support. The saddle support will have subsidiary stress and the internal stress of the pressure vessel, therefore saddle support is critical while designing the horizontal type pressure vessel. Therefore the design of the saddle and determination of the stresses induced in it are important steps during the design of horizontal pressure vessel. The study of stress behaviour of the pressure vessel with different configurations of saddle supports shows that the location of saddle at a distance less than the one fourth of the vessel length is the most effective one [4]. The maximum load on a saddle as given by Megyesy [2] may be conservative or liberal, depending upon the value of the ratio A/L used. However the design of the saddle structure may be optimized by redesigning selectively [5]. The selection of saddle radius also affects the stresses in the pressure vessel and can benefit up to 50% reduction in shell stresses if it is designed 1 to 2 % larger than vessel diameter [6]. The use of supports of high stiffness like concrete is unfavourable taking into account the strength of the vessel. The supports should be located near the vessel ends, thus taking full advantage of the increased stiffness of the head, due to both its shape and increased thickness relative to the vessel shell [7]. Finite element analysis of Pressure vessel by David Heckman also advocates the use of computer programs instead of hand calculations for analysing the high stress areas and different end connections; Researchers have determined the optimal radius of the support with a preliminary clearance between the vessel and saddle. In the area of the vessel-saddle contact constant distribution of the contact pressure along the vessel, but varying circumferentially is assumed. A parametric analysis is performed to reduce the stress concentration at the saddle horn. Mr. Tooth analytically and experimentally determined the stresses in real supports of multilayered GRP vessel Banks presented the approximate solution of the strain state [8].

II. CONVENTIONAL DESIGN APPROACH

The design parameters of pressure vessel (here it's a flash drum) under study are as per Table I. The manual calculation is carried out as per procedure given by Dennis Moss [1] for the given input parameters. The schematic diagram of the vessel is depicted in figure 1. Accordingly saddle is located so as to limit all the calculated stresses (S1 to S14) within the allowable limits. The output results thus obtained by manual calculation and the dimensional details in fabrication drawing are listed in Table II. As per Dennis Moss Saddle properties like number of gusset plate n = [W/24 +1] is empirically found. This has effect on width of wear plate as per following equation.

$$G_t = \sqrt{\frac{5.012\, F_L}{J\,(n-1)F_b}}\left[h + \frac{W}{1.96}(1 - \sin\alpha\right.$$

Where F_L & F_b are maximum longitudinal force & allowable bending stress respectively.

TABLE I
INPUT PARAMETERS

Parameter	Notation	Dimension	Unit
Distance from tangent line of head to the centre of saddle	A	2100	mm
Length of the vessel	L	9500	mm
Inside diameter of the vessel	D	3200	mm
Thickness of the shell	t_s	17	mm
Width of the saddle	H	316	mm
Thickness of the head	T	17	mm
Contact angle of saddle	θ	150	deg
Outside Diameter	D_o	3234	mm
Design Pressure	P	11.3	Bar g
Vessel Empty Weight	W_e	43281	kg
Vessel Operating weight	W_o	110827	kg
Maximum wind speed	V	58.9	m/sec
Importance Factor		1.25	-
Snow Load		0.7	kN/m^2
Insulation thickness		100	mm
Base Elevation		30275	mm

PROPOSED DESIGN APPROACH

In order to optimize the gusset thickness and number of gussets the FEA based software tool like PV Elite can be used that will prove saving in material cost. Using PV Elite all the input design parameters as per Table I are entered on the appropriate fields carefully. In The next step the number of gusset plate are reduced one by one. For further optimization the thickness of the gusset plates is reduced by unit quantity each time running the analysis and checking for calculated stresses. In doing so the results obtained are listed in Table II. Further optimization is possible by using more sophisticated FEA tools Like ANSYS that would lead cost saving in the form of direct material, its handling and construction. FEA is a numerical technique for finding approximate solutions to boundary value problems. FEA is used to solve numerically the governing equations for stress within the wall material.

The solution provides a complete stress distribution in the saddle supports. FEA is an extremely sophisticated tool for solving numerous engineering problems and is widely accepted in many branches of industry. It is a numerical technique for finding approximate solutions to boundary value problems. FEA is used to solve numerically the governing equations for stress within the wall material. The solutions provide a complete stress distribution in the saddle supports. Complete solid models of the pressure vessel and saddle support can be created with the pressure vessel filled with liquid and subjected to the operating weight (Figure 1). Meshing is required to be selected and limited to study the stresses for saddle support region under defined loading conditions. Appropriate extents of support saddles located at sliding and fixed side can be considered for application of displacement boundary condition.

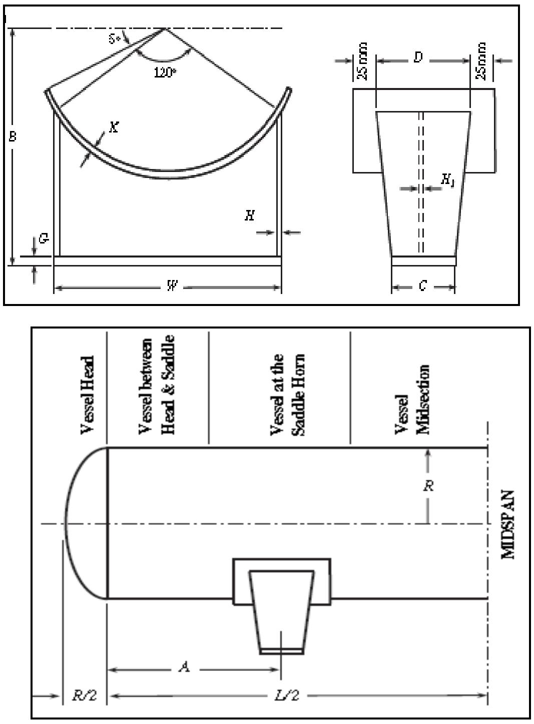


Fig. 1 Schematic Diagram

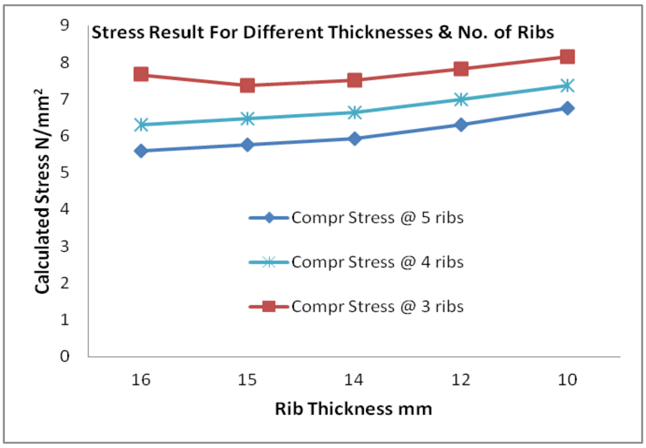
III. Observation

The conventional approach corresponds to design by experience used down many years whereas finite element analysis corresponds to design by analysis. The stress distribution of various geometric parameters of gussets and number of gussets of saddle can be observed to select the optimal size of saddle. The Table II shows the effect of number of gussets on the value of calculated stresses obtained from the analysis results. From the Table II it is understood that for 10 mm gusset thickness with three gussets, the obtained stress result value falls below the stress limit without compromising safety of equipment.

TABLE II
OUTOUT PARAMETERS

No. of gusset plates, n	Stiffener Rib thickness, t_w (mm)	Compressive Stress, Sc (N./mm²)	Bending stress on outside rib, S_{cao} (N./mm²)	Bending stress on inside rib, S_{cai} (N./mm²)
5	16	5.59	147.40	153.74
5	15	5.76	147.19	153.65
5	14	5.93	146.94	153.55
5	12	6.31	146.33	153.30
5	10	6.74	145.51	152.98
4	16	6.31	146.20	154.12
4	15	6.47	146.06	154.03
4	14	6.63	145.74	153.93
4	12	6.98	144.98	153.70
4	10	7.38	143.96	153.39
3	16	7.67	153.74	153.92
3	15	7.38	143.96	154.13
3	14	7.52	143.53	154.03
3	12	7.82	142.49	153.79
3	10	8.14	141.10	153.47

The stress results obtained in the Handbook are the stresses acting on the area of the Gusset plate in (N/mm²). From the results of design calculations and analysis it is observed that analysis results are closed to that design value which is acceptable.



The plot above shows the calculated compressive stress increases as thickness of the rib decreases.

IV. Conclusion

As a common engineering practice the recommended thickness & number of gusset plates are used while designing the saddle support for horizontal pressure vessel. Needless to say, the same has been a proven design and the case of overdesign too. In practice, project engineering schedules leave least scope to act on optimizing the saddle thickness and gusset plate quantity. This is the objective of this project work and shall be the matter of future scope to find its practical implementation. A 20 percent reduction in the direct material cost and indirect cost is achieved. Further there is a scope for significant amount of material saving as this approach can be extended to pipe shoe support. The amount of primary support for the pipe lies in the range of 50 to 100 tons for an average project.

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