Design and Analysis of Pressure Vessel Skirt Considering Seismic Load as Per Uniform Building Code

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***Abstract*—The support structure of a high pressure vessel is subjected to many different types of loads like internal pressure, dead weight, operating weight, nozzle forces and moments, seismic loads, wind loads etc. The basic support structure needs to withstand all such load combinations. The paper presents design of skirt as basic component of vessel based on Uniform Building Code (UBC). Here, stresses are calculated based on combined load considerations, primarily internal pressure, dead weight and seismic load, and found to be safe.**

***Keywords*— Pressure vessel, skirt, uniform building code, seismic load, ASME**

I. INTRODUCTION

All the Pressure vessels, Column or Reactors are to be supported on foundation using various vessel supports like skirt. Many researchers have attempted to design and analyze support structure of vessel [1, 2]. The various vessel-supporting methods are discussed.

Various types of skirts are available such as cylindrical, conical, lug support on vessel, conical support on shell, leg support etc. Which skirt is applicable and need to attach for support is depend upon parameters such as required height of vessel, available space, intensity of external forces such as wind & seismic etc.

Cylindrical Skirt:

As shown in Fig. 1, cylindrical skirt is extensively used to support cylindrical vessels. The pressure vessel is supported on cylinder, welded directly to the bottom head. The skirt consists of various cut outs for outlet nozzles & manholes. The skirt not only allows the vessel to be placed at required height in the plant but also allow proper bolting arrangement with civil foundation. The thickness of the skirts is calculated using combined force theory. These types of skirt supports are widely used in low pressure, low weight & normal heights.

II. DESIGN CONSIDERATIONS

Support structures have to be designed on the criteria of combined load considerations. Several loads such as Wind/Seismic loads, External loads on nozzles due to piping joints, Operating weight of vessel etc. are acting on support structures simultaneously. With these combinations of loads, stresses are analyzed in structures.

If we assume that various load combinations are acting on support structures like skirt, base ring etc. Various possibilities of failure for them (support structures) must be considered, which are listed as per followings.

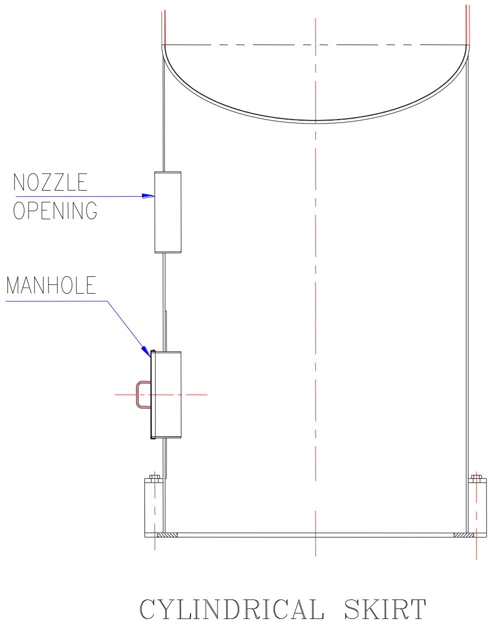

Figure 1

A. Skirt may fail in following conditions,

a Induced tensile stress due to uneven expansion of different materials at skirt to shell junction where temperature gradient along skirt length is very high,

b Induced compressive stress due to operating weight of entire vessel along with Seismic/Wind bending moments,

c If the length of skirt is considerably long, it may lose it’s elastic stability, and buckle under (self-weight)load of the vessel and/or external loads (if in considerable amount) at nozzles.

To design skirt is an iterative method. In which, first assume thickness of skirt; with this thickness analyze stresses corresponding to above load combinations. If stresses, induced due to above combined loads are not with in the allowable limits, increase the thickness and repeat it till satisfy the condition.

While, for safe side of design, thickness of skirt sections are chosen such that, with all above acted loads, induced stresses (both tensile and compressive) must be lesser than corresponding permissible values at given condition for skirt and other related sections.

The vessel to skirt junction is subjected to the following stresses:

a. Stress due to dead weight of the vessel,
b. Discontinuity stresses due to unequal growth of various parts subjected to pressure,
c. Stress due to Seismic/Wind loads,
d. Stress due to differential thermal expansion between vessel and skirt,

III. SEISMIC DESIGN CONSIDERATIONS

In this Seismic Design consideration, calculation of Shear Forces and Bending Moments at different elevations can be calculated as per following steps as according to UBC-1997 Code system. The adopted material properties and dimensions are given in Table 1 & 2 respectively.

1 Seismic consideration is purely related to intensity of vibration. Vibrational intensity is directly proportional to time interval (no. of cycles per second). At first, time period of vibration due to possible earthquake intensity or according to seismic zone as per given specification, has to be calculated. Design Base Shear is inversely proportional to time period, subsequently it can be calculated. Time period varies with height and weight of section. So time period at primarily and design base shear secondarily are different for various sections (skirt, shell, dished end etc.) of vessel.

2 There are Maximum and Minimum limits for Design base shear, which have been proposed in UBC-1997. These both limits are universal for all sections. Once these limits are calculated, check whether induced values of design base shear, calculated by step 1, of various sections are within proposed limits.

3 Shear Force of section depends upon above calculated Design base shear, weight and height of that section. Simple empirical formulae will yield the calculation of Shear Force. Subsequently, Cumulative Shear Force and Bending Moment for that section can be obtained as same way as corresponding wind calculations.

Herein, as per all above steps, a two segments of skirt (one made of Cast Steel and other made of Alloy Steel) has been designed as per UBC.

IV. NUMERICAL STUDY FOR SKIRT CALCULATIONS

Seismic data

Code	:	UBC-1997
Seismic factor	:	4
Seismic zone coefficient:		0.4
Exposure for seismic	:	D
Importance factors	:	$I = 1.25$ & $I_P = 1.50$
Near source factors	:	$N_v = 1.2$ & $N_a = 1.0$

As per required data for seismic calculation given in specification:

<u>Step 1</u>. For **Design Base Shear**,

$$V_{seismic\ e} = \frac{C_v I}{RT} W_{total}$$

Where, C_v = Seismic coefficient depends upon soil profile (exposure D) and seismic zone coefficient

$= 0.64N_v$

$= 0.768$

R = Numerical coefficient depend upon structural type

$= 2.9$

T = Elastic fundamental period of vibration depend upon height, in second if height in feet,

$= C_t(h_e)^{0.75}$

Where, C_t = Coefficient, for steel moment twisting frame = 0.035

h_e = Height of section e,

W_{total}=Total dead weight of reactor = 1073680 lb. (4775967 kg)

For **skirt (C.S.)** example, required data are taken as per specification:

Height of C.S. Skirt $= h_{css}$ = 240 Inch (6096 mm)

Elastic period of vibration T_{css} =

$$C_t(h_e)^{0.75} = 0.035(20)^{0.75} = 0.331 \text{ s}$$

$$V_{seismic\ css} = \frac{C_v I}{RT_{css}} W_{total} = \left[\frac{0.768\times1.25}{2.9\times0.331}\right]\times1073680$$

$= 1073791.853$ lb. (4776464 N)

<u>Step-2.</u> Maximum and Minimum Base Shear limits are,

$$V_{max} = \frac{2.5C_a I}{R} W_{total} = \frac{2.5\times0.44\times1.25}{2.9}\times1073680$$

$= 509072.4$ lb. (2264467 N)

Where, C_a = Seismic coefficient depends upon soil profile (exposure D) and seismic zone coefficient.

$= 0.44N_a = 0.44$

$$V_{min} = \frac{0.8zN_v I}{R} W_{total} = \frac{0.8\times0.4\times1.2\times1.25}{2.9}\times1073680$$

$= 177694.04$ lb. (790422.5 N)

For **skirt (C.S.),** required data given are,

l_{css} = 240 Inch (6096 mm)

D_{css} = 169.84 + 2x1.496

= 172.832 Inch (4391 mm)

Values of Design base shear for all the sections of vessel must be between Maximum and Minimum limits, calculated as above. Here, V_{max} and V_{min} remain constant for all sections because they don't depend upon height of section,

Step-3. For **Shear Force**,

Seismic shear force $=(F_{seismic})_{css}= \dfrac{(V_{seismice} - F_t)W_e h_e}{1.4 \times \sum_{i=}^{n} W_i h_i}$

Where, F_t = Portion of base shear,

= $0.07T_eV$, but if T_e <0.7 then F_t = 0 lb.

For **C. S. Skirt** example,

$$\text{Seismic shear force} = \frac{(V_{seismiccss} - F_t)W_{css}h_{css}}{1.4 \times \sum_{i=}^{n} W_i h_i}$$

$$= \frac{(5090724 - 0.0) \times 88000 \times 10}{1.4 \times 48107540}$$

= 6651.52 lb. (29587.44 N)

Cumulative Seismic Shear Force,

$(F_{seismic})_{css}$ = 6651.52 + 385255.8

Step-4. For **Bending Moment**,

$(M_{seismic})_e= (F_{seismic})_e x h_e + (C_{seismic})_{e+1} x l_e + (M_{seismic})_{e+1} + (M_r)_e$

Where, $(M_{seismic})_e$ & $(M_{seismic})_{e+1}$= Moment due to seismic of element e & e+1 respectively,

$(M_r)_e$ = Resultant moment of M_X & M_Z

$(F_{seismic})_e$ = Seismic shear force due to section e,

$(C_{seismic})_{e+1}$= Cumulative seismic shear force due to next top section,

h_e = Height of C. G. of element e from base of entire vessel,

For **skirt (C.S.),**

$(M_{seismic})_{css}$= 6651.52 x10 + 0.00

= 66515.2 lb.-ft. ($9.02X10^7$ N-mm)

Cumulative Seismic Bending Moment for C.S. skirt,

$(M_{seismic})_{css}$ = 11636899 + 0.00 + 6651.52x10 + 385255.8x20

= 19408530.2 lb.-ft ($2.63x10^{10}$ N-mm)

By same way, One can find out Shear Force, Bending Moment, Cumulative Shear Force and Cumulative Bending Moment for other sections (A.S.Skirt) of vessel, whose calculated values are given in Table 3.

V. COMBINED LOADS FOR SKIRT CALCULATIONS

Many loadings are acting together. Hence, combined loads are adopted to analyze stress calculations in skirt. Here, internal pressure, dead weight and seismic loads are combined to demonstrate the calculations of stresses induced at skirt sections.

Compressive and tensile stresses at various sections for this second load case (Internal pressure, Operating weight and Seismic moment) can be calculated.

Following example, of C. S. Skirt, suffices complete understanding of above load case.

For **C. S. Skirt**,

Induced stress for combined loads,

$$S_{css} = \frac{pD_{css}}{4t_{css}} \pm \frac{4M_{seismic}}{\Pi D_{mcss}^2 t_{css}} - \frac{(W_{ope})_{css}}{\Pi D_{mcss} t_{css}}$$

$$= \frac{0.00x169.84}{4x1.496} \pm \frac{4x19408530x12}{3.14x171.336^2 x1.496} - \frac{88000}{3.14x171.336x1.496}$$

For tensile stress,

$(S_{css})_{tens}$= 0.00 + 6755.78 - 109.34

= 6646.44 PSI (45.83 N/mm^2)

For compressive stress,

$(S_{css})_{comp}$= 0.00 - 6755.78 - 109.34

= -6865.12 PSI (47.34 N/mm^2)

Therefore,

$$\text{Tensile ratio} = \frac{(S_e)_{tens}}{[(S_e)_{tens}]allow}$$

Allowable tensile ratio must be less than 1.00.

For C. S. Skirt,

$$R_{tens} = \frac{(S_{css})_{tens}}{[(S_{css})_{tens}]allow} = \frac{6646.44}{14337.4}$$

= 0.464<1.00

$$\text{Compression ratio} = \frac{(S_e)_{comp}}{[(S_e)_{comp}]allow}$$

Allowable compression ratio must be less than 1.00.

For C. S. Skirt,

$$R_{comp} = \frac{(S_{css})_{comp}}{\left[(S_{css})_{comp}\right]_{allow}} = \frac{-6865.12}{-12387.9}$$
$$= 0.554<1.00$$

Other sections of vessel for that above consideration can be calculated by same method. Their stresses are tabulated in Table 4.

CONCLUSIONS

The usage of pressure vessel becomes inevitable due to rapid growth of process industries day by day.

Design of skirt sections has not been covered under ASME code and their dimensions are calculated with general design principles. Stress analysis of these components has been carried out with combined load cases; it has been found that stresses, produced due to combined loads, are within its allowable limits.

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Table 1. Material properties of skirt as per ASME Section II, Part D,

Component	**Material specification**	**Stress Intensity in PSI(N/mm^2) as per ASME Section II Part D**		
		At Design Temperature	**At Ambient Temperature**	**Yield At Room Temperature**
Skirt(LAS)	SA387 Gr22 CL2	22080(152.24)	25000(172.38)	45000(310.28)
Skirt(CS) at 450˚F	SA516 Gr70	21100(145.50)	23300(160.65)	38000(262.64)

Table 2. Dimensions of different components of PV

REQUIRED DATA		**VALUE**	**UNIT**	**REQUIRED DATA**	**VALUE**	**UNIT**
Design Pressure	Internal	1260(8.69)	PSI(N/mm^2)	Ope. Pressure	1130(7.79)	PSI(N/mm^2)
	External	15(0.10)	PSI(N/mm^2)	Ope. Temperature	760(404.44)	° F(° C)
Design Temp.	Internal	830(443.33)	° F(° C)	Shell ID Shell height	162.59(4130) 602(15291)	Inch(mm) Inch(mm)
	Atmospheric	30(-1.11)	° F(° C)	Overlay Thickness	0.3(7.62)	Inch(mm)
Corrosion Allowance Shell Heads Skirt Basering Gussets Compression ring		 0.375(9.525) 0.375(9.525) 0.125(3.175) 0.125(3.175) 0.125(3.175) 0.125(3.175)	 Inch(mm) Inch(mm) Inch(mm) Inch(mm) Inch(mm) Inch(mm)	Head Inside Radius (Bottom and top)	81.89(2080)	Inch(mm)
				Insulation thickness for Reactor	4.0000(101.6)	
Insulation thickness for Reactor		4.0000(101.6)	Inch(mm)	Height of C. S. Skirt	48(1219.2)	Inch(mm)
Inside diameter	C. S. Skirt	169.84(4314)	Inch(mm)			
	A.S. Skirt	169.84(4314)	Inch(mm)	Height A.S. Skirt	240(6096)	Inch(mm)
	A.S. Skirt	240(6096)	Inch(mm)			

Table 3. Shear Force and Bending Moment Calculations for Skirt Sections

Section	Ht. Of Sec. l_e feet	Dist. Fr. Base h_e feet	Fund. Period of Vib'n T_e sec	Base Shear $V_{seismic\ e}$ lb.	CG of se'n. fr. Base h_b feet	Wt of each section W_e lb	Mult'n $W_e h_e$	Force $F_{seismic}$ lb.	Cum S. F. $C_{seismic\ e}$ lb	Cum B. M. $M_{seismic\ e}$ lb.ft.
SKIRT (C.S.)	20	10	0.331	1073792	10	88000	880000	6651.522	**391907**	**19408530**
SKIRT (A.S.)	4	2	0.099	3590153	22	13450	295900	2236.574	385255.8	11636899

Table 4. Stress Calculations for Skirt Sections

Section	Dia. of each section (Inch)	Operating Weight of section (lb)	Seismic Bending Moment (lb-ft)	Thickness (Inch)	Induced Tensile Stress (PSI)	Induced Compressive Stress (PSI)	Allow. Tensile Stress (PSI)	Allow. Compressive Stress (PSI)
SKIRT (C. S.)	169.84	88000	1.94E+07	1.496	**6643.1**	**-6861.6**	14337.4	-12387.9
SKIRT (A. S.)	169.84	13450	1.16E+07	1.2598	**4801.0**	**-4840.8**	20556.48	-10210.1