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Experimental Method to Analyse Limit Load in Pressure Vessel

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Abstract: *Pressure vessel contains with different inlet & outlet openings called nozzle or valves. The design parameter of these valves may different in one pressure vessel. These valves cause geometric discontinuity of the pressure vessel wall hence stress concentration may occur around the valve or nozzle. Since due to the high stress concentration there may be the chances of failure of vessel junction. Hence detail stress distribution analysis needs to be done for pressure vessel. Determination of limit pressure at different location on pressure vessel by using finite element method is less time consuming and it avoid complex mathematical work at difficult geometries. So, it is essential to validate the result. Experiments is conducted on oblique nozzle (45^0 with shell axis) & result obtained are used to validate the finite element results. Distortion measurement test by measuring change in diameter of vessel after vessel is pressurized using water. Twice elastic slope method & Tangent intersection method are used to find out limit load estimation of cylindrical vessel with oblique (45^0) nozzle.*

Keywords*: Pressure vessel, Limit load, Nozzle, Twice Elastic Slope Method, Tangent Intersection Method, Internal pressure etc.*

I. INTRODUCTION

Pressure vessel is a closed container designed to hold gases or liquids at a pressure different from the ambient pressure. It is applied with a differential pressure between inside and outside. In the field of pressure vessel design, welded pipe nozzles and welded nozzles of vessels are generally subjected to high loads. Because of nozzle necessary for the exchange of fluid or gas causes high stresses at the edge of opening merely caused by operating pressure. This basic load is overlaid by additional loads due to connected pipe. These additional load results for example from restrained thermal expansions, vibration of pipes or shock pressures caused by the opening of valves. Pressure Vessels are generally used in Storage vessels (for liquefied gases such as ammonia, chlorine, propane, butane, household gas cylinders etc.), Chemical industries (as a distillation tower, domestic hot water storage tank etc.), Medical field (as a autoclaves), Aero-space (as a habitat of spaceship), Nuclear (as a nuclear vessels), Pneumatic & hydraulic reservoirs under pressure, Rail vehicle airbrake reservoir, road vehicle airbrake reservoir, power, food and many other industries.

Opening in pressure vessel in the region of shells or heads are required to serve the following purpose

- Man ways for in and out of vessel to perform routine maintenance and repair.
- Holes for draining and cleaning the vessel.
- Hand hole openings for inspecting the vessel from outside.
- Nozzle attached to pipes to convey the working fluid inside and outside of the vessel.

Also, various failure mode of pressure vessel in industrial pressure vessels fail due to

- Excessive elastic deformation- induced stresses and elastic bending
- Elastic instability- column instability and vessel shell under axial load
- Plastic instability, brittle rupture, corrosion etc.

Now, the pressurized cylindrical vessel with oblique nozzle is considered for experimental analysis. The three dimensional nonlinear elastic plastic finite element analysis is performed. Also experimental hydrostatic test at increasing pressure in step is also conducted to validate with FEA result and hence present study provides some useful data to serve as a check on existing design method & basis for developing more accurate guideline.

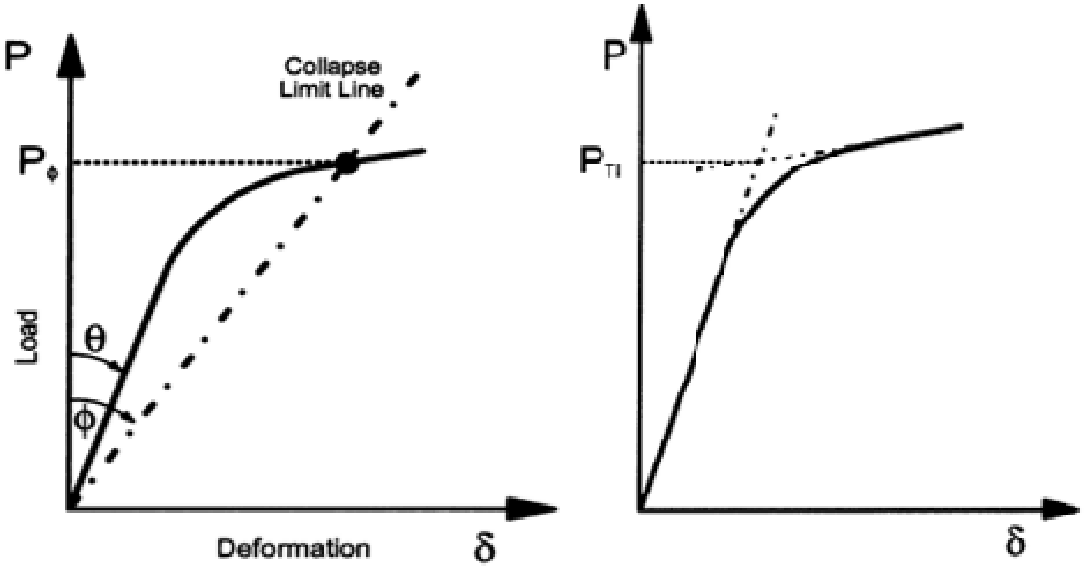
II. METHODS TO CALCULATE LIMIT LOAD

2.1 Twice Elastic Slope Method by Experimental Data

For distortion measurement test, the limit load is plotted as the ordinate & the lateral strain as the abscissa. The regression line as determined from the data in the linear elastic range is drawn. The angle that the regression line makes with the ordinate is called ‘θ’.A second straight line ,here after called the collapse limit line ,is drawn through the intersection of regression line with the abscissa so that it makes an angle $\phi=\tan^{-1}(2\tan \theta)$ with the ordinate. The intersection of the collapse limit line with the curve is the limit load as shown in figure 1.

2.2 Tangent Intersection method by Experimental Data

To calculate limit load of structure there are two test procedures distortion measurement and strain measurement. For distortion measurement tests, the loads are plotted on the ordinate and the lateral strain are plotted on the abscissa. The one tangent is drawn to the elastic zone & similarly another tangent is to plastic zone. The load corresponding to the intersection of the two straight line is defined as the limit load as shown in figure 1.



Twice elastic slope method **Tangent Insertion Method**

Figure 1: Showing the methods to calculate Limit Load

III. PRESSURE VESSEL MODEL DEFINITION AND PROPERTIES

Experimental test is conducted on oblique nozzle (450 with shell axis).Distortion measurement i.e. change in dia. at various location is done. Pressure was increased in the steps shown in table II.

3.1 Dimensions of Model Vessels

The dimensions of vessel considered under analysis are as given in table I and dimensions of vessel under experimental analysis are shown in table III.

Material of shell	516 Gr.70
Material of nozzle	516 Gr.70
Design code	ASME section VIII, div-I, Edition-2007
Design pressure	Internal pressure=1.8 MPa External pressure = 0.1034 MPa
Max. allow able working pressure	3.26 MPa
Weight of vessel	900 kg

Table I: Parameters of model vessel for analysis

Step No.	1	2	3	4	5	6	7	8	9
Pressure (MPa)	0.5	1	1.5	2	2.5	3	3.5	4	4.5

Table II: Steps of pressure increase

The vessel was pressurized with positive displacement hydraulic hand pump. Two pressure gauges were used to indicate the internal pressure having pressure range 0-16 Mpa. Before going to actual test several pressure cycle were performed to ensure linear response. The max pressure during the test is 5 Mpa. The various location and it distance in mm from intersection is shown in figure 2 &3.

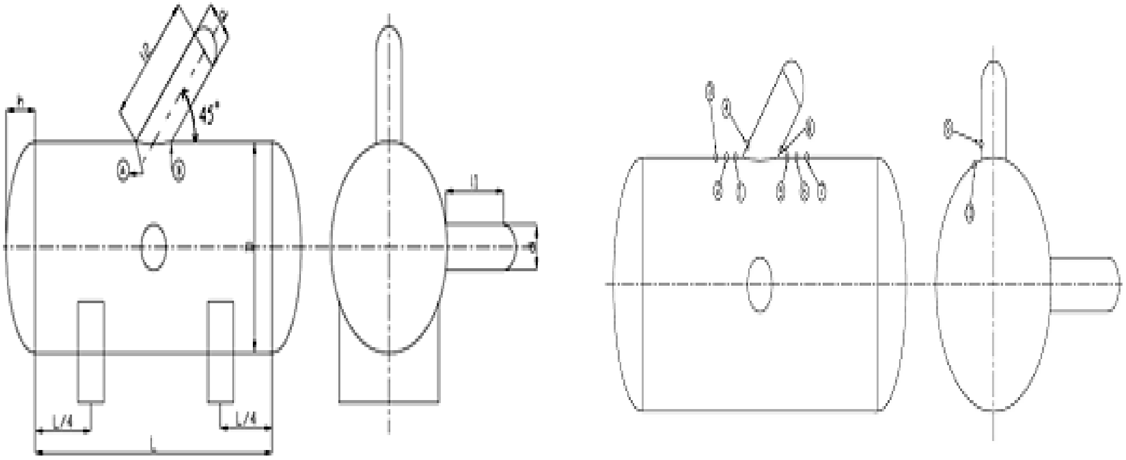


Figure 2: Various Locations on Pressure Vessel

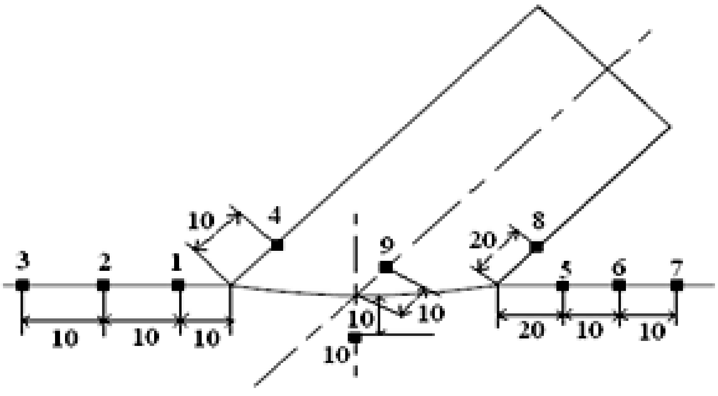


Figure 3: Distance (in mm.) from weld intersection.

Parameter	**Dimension**
Mean Dia. of shell	1012 mm
Mean dia. of nozzle	213 mm
Thickness of shell	12 mm
Thickness of nozzle	8.20 mm
Length of shell	2000 mm
Length of nozzle	700 mm

	D	D	T	t	L	d/D	T/t	D/t	H	l 1
Dimension (mm)	1012	213	12	8.2	2000	0.21	1.46	84	250	500

Table III: Dimensions of Experimental Vessel

3.2 Material Properties

Material used for analysis is SA 516 Gr.70 (low carbon steel). As the main purpose of this work is to find the limit pressure of the shell intersection, the yield, ultimate stress & stress – strain curve of the material are important parameters. The material properties and chemical composition are given in table IV and table V. The material model used for analysis is multi linear isotropic hardening model which is described by seven points are considered to define material behavior which are noted in table VI.

	Chemical Composition %					**E** (N/mm^2)
SA-516 Gr. 70	**C**	**Mn**	**Si**	**S**	**P**	2x10^5
	0.2-0.31	0.7-1.3	0.1-0.45	0.035 max.	0.035 max.	

Table IV: Chemical composition

Material	SA-516 Gr. 70
Yield Strength	360 MPa
Ultimate Strength	543 MPa
Modular of elasticity	180000
Poisson's Ratio	0.30
Density ρ	7833 kg/m^3

Table V: Material Properties

Strain (µЄ)		**Stress (MPa)**
1	2000	360
2	37500	362
3	45000	381
4	64000	430
5	93000	47935
6	16950	534
7	209000	543

Table VI: Multi linear material model points

3.3 Boundary Conditions

- Hoop displacement and longitudinal displacement in nodes at one end of the shell on strained to zero.
- On the other end of the shell equivalent thrust (PD/4t) is applied .Similarly on the other end of the nozzle equivalent thrust (Pd/2t) is applied.
- Pressure was applied internally with increment steps.
- Symmetry boundary conditions in the plane along the longitudinal direction of the shell.

IV. RESULTS AND DISCUSSIONS

FEM analysis and actual measurement readings were plotted on graph and compared.

4.1 FEM Analysis

Material model is defined in ANSYS and deformation & stress distribution are plotted at location no.4 and location no.10. Material Model builds in ANSYS shown in figure 4.

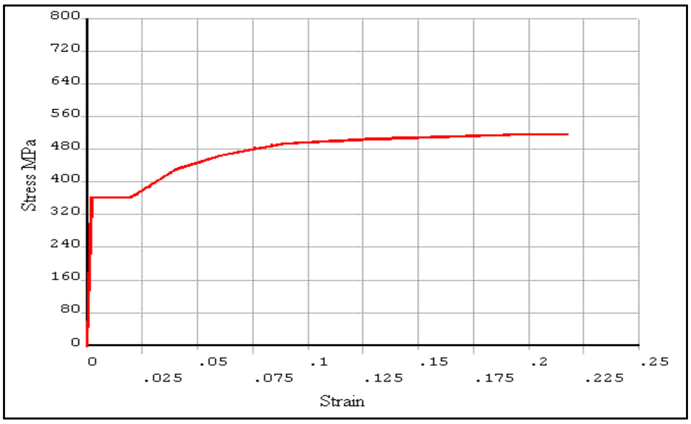


Figure 4: Material model in ANSYS

4.2 Experimental Readings

Experimental readings for same location which was considered in Ansys are performed actually and readings tabulated in graph format showing in figure 5, 6 for location No.4 and figure 7, 8 for location No.10.

Step	1	2	3	4	5	6	7
P	0.5	1	1.5	2	2.5	3	3.5
Strain	0.03 X 10^{-2}	0.05 X 10^{-2}	0.07 X 10^{-2}	0.09 X 10^{-2}	0.13 X 10^{-2}	0.23 X 10^{-2}	0.47 X 10^{-2}
D	213.06	213.1	213.12	213.19	213.29	213.48	214

Table VII: Graph no.1&2 (location no.4)

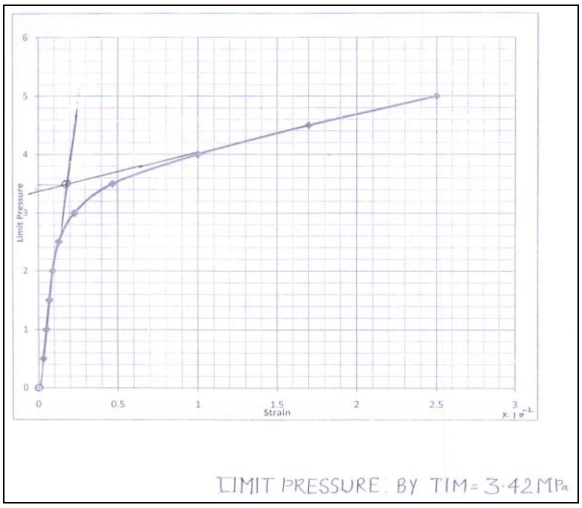


Figure 5: Graph1 for location no. 4 by TEM

Figure 6: Graph2 for location no. 4 by TESM.

Step	1	2	3	4	5	6	7
P	0.5	1	1.5	2	2.5	3	3.5
Strain	0.03 X 10^{-2}	0.05 X 10^{-2}	0.07 X 10^{-2}	0.09 X 10^{-2}	0.13 X 10^{-2}	0.19 X 10^{-2}	0.26 X 10^{-2}
D	1012.30	1012.5	1012.7	1012.9	1013.3	1013.9	1014.6

Table VIII: Graph no.3&4 (location no.10)

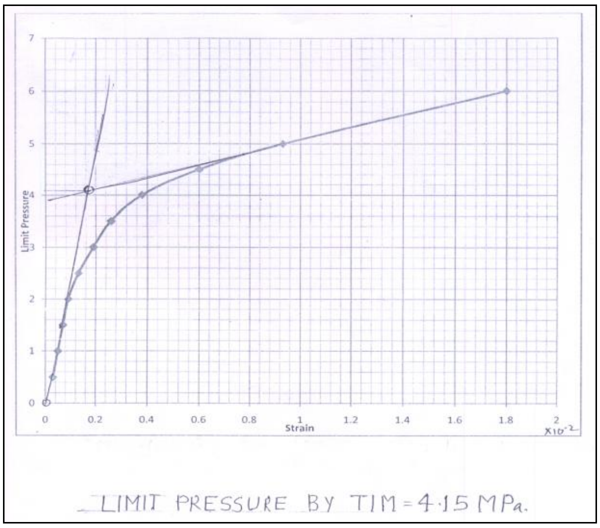


Figure 7: Graph3 for location no. 10 by TEM

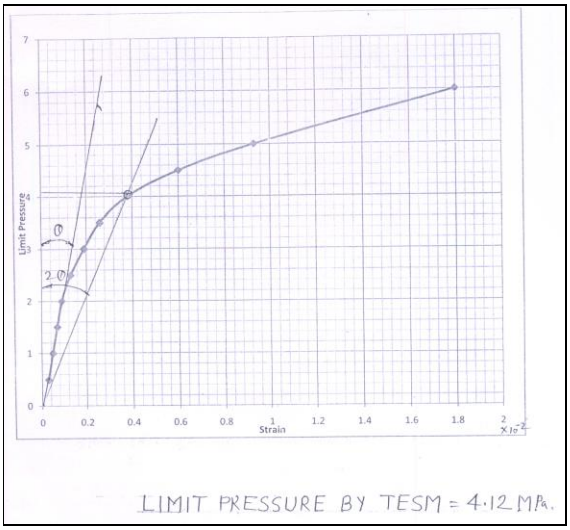


Figure 8: Graph4 for location no. 10 by TESM

Comparison between experimental test results and FEM results by both methods i.e. TIM and TESM are compared as shown in table IX.

Model oblique nozzle	**Location No. 4**				**Location No. 10**			
	TEST (MPa)		**FEM (MPa)**		**TEST (MPa)**		***FEM (MPa)***	
	TIM	TESM	TIM	TESM	TIM	*TESM*	*TIM*	*TESM*
45^0	3.42	3.4	4.38	4.18	4.15	4.12	4.65	4.15
% Deviation from actual value (Min) (FEM Value-Exp. Value) / (Exp. Value)	22.94 % by TESM				0.7 % by TESM			

Table IX: Comparison of FEM and Experimental results

V. CONCLUSION

1. Experimental result are in good agreement with finite element result. Also, FEA is accurate and precise computational tool to simulate the model and predict the failure location of lateral (inclined) connection configuration and successfully interpret the result in required format.

2. To evaluate the limit load using various methods TIM, TESM, PWC, the TESM & TIM is the method to estimate the lower value of limit load & is more effective for higher elastic slope of load V/S strain plot.

3. Definite deformation occurs at the intersection area of shell and nozzle, it result the intersection region shrinks in longitudinal section of the shell and nozzle, while bulging appears at transverse section.

4. Plasticity starts at the acute side of nozzle junction and smoothly grows near around joint across the obtuse side.

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