# Experimental Analysis of Pressure Vessel

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***Abstract*—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.**

## I. INTRODUCTION

### A. *Pressure Vessel*

A 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 & outside. The intesnally pressurized cylindrical vessel with oblique nozzle is considered for experimental analysis. The three dimensional non linear elastic plastic finite element analysis is performed. Also experimental hydrostatic test at increasing pressure in step is also conducted to validate with F.E.A. result. Hence present study provides some useful data to serve as a check on existing design method & a basis for developing more accurate guideline.

## II. LITERATURE REVIEW

Parag mahajan et.al[1] has done experimental analysis of cylindrical vessel with radial nozzle & validated the results with finite element analysis & found they are in good agreement.

N. Li. et.al[2] studied the plastic limit load of cylindrical vessels with different lateral angles Q under increasing internal loading. Three full size test vessel with different structure dimensions were fabricated for testing. A three dimensional non linear, finite element numerical simulation was also performed. The plastic limit load was obtained using twice elastic slope method & result are validated which are in good agreement.

Z.F. Sang et.al.[3] Considered two cases for experiment & FE. Analysis of cylindrical shell with radial nozzle & cylindrical shell with $30^0$ lateral nozzle. In both cases inelastic stress analysis was performed for vessel to nozzle intersection diameter ratio (d/D=0.526) under increasing internal pressure from experimental & non- linear finite elements method. The determination of the limit load due to internal pressure is performed by an experimental study for comparison with finite element analysis. The result of both method are in good agreement.

H.F. Wang et.al.[4] has investigated the elastic stress and deformation of pressurized cylinder with a hillside nozzle. Two full –scale test models were designed & fabricated specially for the test. A 3D finite element numerical analysis was also performed, the elastic stress concentration range, deformation characteristic, & stress concentration factor was obtained. Experimental analysis & its result are compared with non linear finite element analysis.

TABLE 1. COMPARISION BETWEEN THE ANALYSIS & TEST RESULT

| | $\sigma_{elastic}$ (MPa) | | K | |
|---|---|---|---|---|
| ***Model*** | ***Test*** | ***F E A*** | ***Test*** | ***F E A*** |
| $30^0$ | 146.9 | 150.0 | 2.17 | 2.22 |
| $45^0$ | 143.5 | 142.3 | 2.12 | 2.10 |



Conclusion from above literature review are

- From the point of view of the stress concentration, limit load & burst pressure, the acute corner in the longitudinal section of model with $30^0$ lateral is the weakest location.
- Compared with radical nozzles, the hillside nozzle exhibit less stress concentration moreover, the S.C.F. declines with the increment of the angle.

## III. METHOD TO CALCULATE LIMIT LOAD

### A. *Twice Elastic Slope Method by Experimental Data*

For distortion measurement test, the limit load are 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 ‘Ɵ’.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.

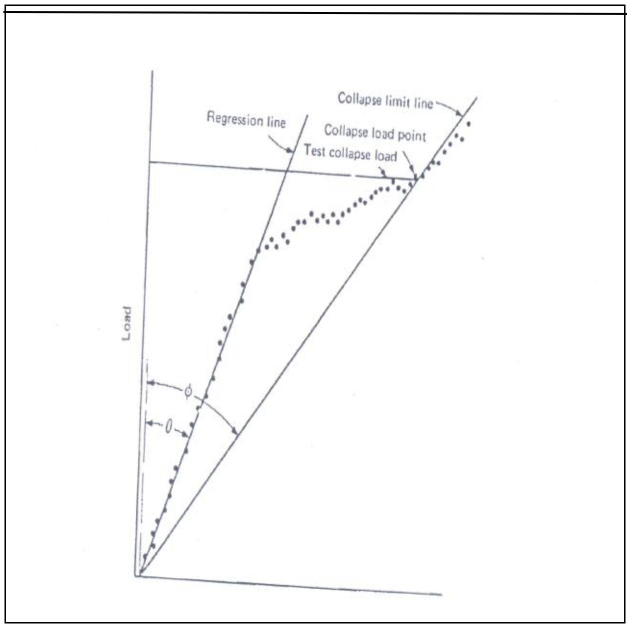


Fig. 1 TESM by Experimental Data

## B. *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.

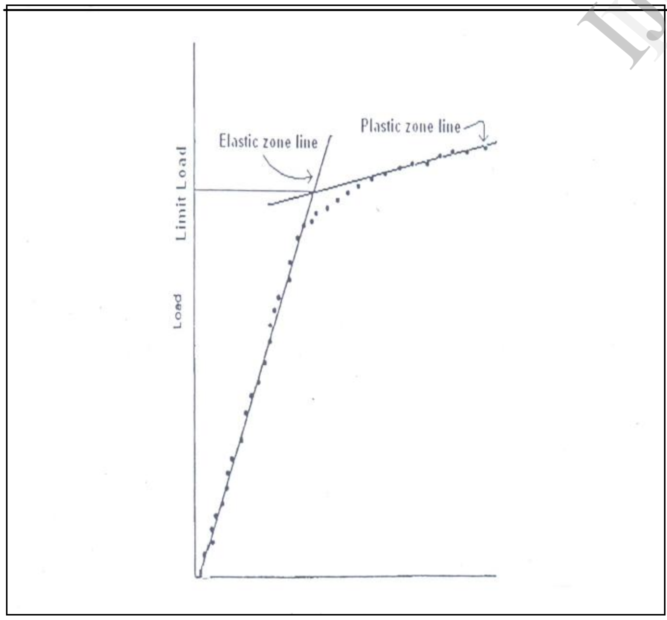


Fig. 2 TIM by Experimental Data

## IV. EVALUATION OF LIMIT LOAD BY EXPERIMENTAL METHOD

Experimental test is conducted on oblique nozzle ($45^0$ with shell axis ). Distortion measurement i.e. change in dia. at various location is done. Pressure was increased in the steps an given in the table no. .

Material of shell – SA – 516 Gr.70
Material of nozzle – SA – 516 Gr.70
Design code- ASME section VIII, div-I, Edition-2011
Design Pressure = Pi=1.8 MPa,
External pressure = 3.26 MPa
Max. Allowable working pressure = 3.26 MPa
Weight of vessel = 900 kg

### A. *Material Properties*

The material used for the cylinder & nozzle is low carbon steel ie is SA 516 Gr.70. The engg. Stress strain curved was obtained by performing ultimate tensile testing by using the specimen of material used. The fig. 1 shows stress strain curved. Mech. Properties of the material are an listed in table 2.

TABLE 2. MATERIAL PROPERTIES

| **Material** | **Yield Strength** | **Ultimate Strength** |
|---|---|---|
| SA-516 Gr. 70 | 360 MPa | 543 MPa |



| | **Chemical Composition %** | | | | | **E (N/m)** | **μ** | **ρ (kg/m$^3$)** |
|---|---|---|---|---|---|---|---|---|
| | ***C*** | ***Mn*** | ***Si*** | ***S*** | ***P*** | | | |
| SA-516 Gr. 70 | 0.2-0.31 | 0.7-1.3 | 0.1-0.45 | 0.035 max. | 0.035 max. | 2 x $10^5$ | 0.3 | 7833 |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| **Strain (μ€)** | 2000 | 37500 | 45000 | 64000 | 93000 | 16950 | 209000 |
| **(Mpa) Stress** | 360 | 362 | 381 | 430 | 479.5 | 534 | 543 |

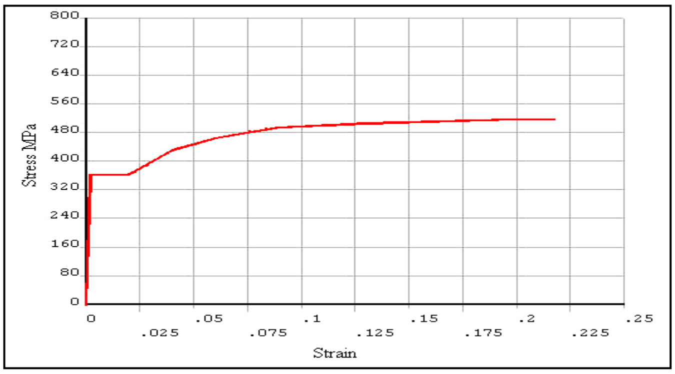


Fig. 3 Material model in ANSYS

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 fig. 2 & 3.

TABLE 3. DIMENSION OF EXPERIMENTAL VESSELS

| Dimension (mm) | D | D | T | t | L | d/D | T/t | D/t | H | l1 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1012 | 213 | 12 | 8.2 | 2000 | 0.21 | 1.46 | 84 | 250 | 500 |

TABLE 4. STEP OF PRESSURE INCREMENT

| 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 |

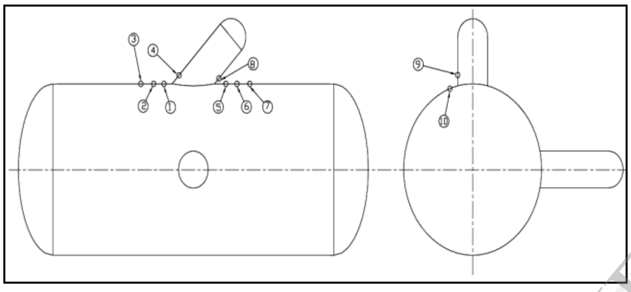

Fig. 4 Various Location on Pressure Vessels

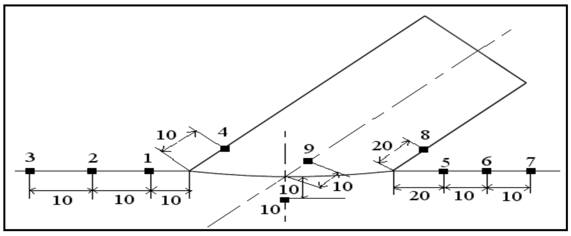


Fig. 5 Distance (in mm) from Weld Intersection

TABLE 5. GRAPH NO.1&2(LOCATION NO.1)

| Step | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| P | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 |
| Strain | 0.02 X $10^{-2}$ | 0.04 X $10^{-2}$ | 0.05 X $10^{-2}$ | 0.08 X $10^{-2}$ | 0.12 X $10^{-2}$ | 0.25 X $10^{-2}$ | 0.47 X $10^{-2}$ |
| D | 1012.2 | 1012.4 | 1012.5 | 1012.8 | 1013.2 | 1014.53 | 1016.7 |

TABLE 6. GRAPH NO.3&4 (LOCATION NO.4)

| 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 7. GRAPH NO.5&6 (LOCATION NO.5)

| Step | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| P | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 |
| Strain | 0.02X $10^{-2}$ | 0.05 X $10^{-2}$ | 0.07 X $10^{-2}$ | 0.1 X $10^{-2}$ | 0.14 X $10^{-2}$ | 0.2 X $10^{-2}$ | 0.08 X $10^{-2}$ |
| D | 1012.2 | 1012.5 | 1012.7 | 1013 | 1013.4 | 1014 | 1014.8 |

TABLE 8. GRAPH NO.7&8 (LOCATION NO.8)

| Step | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| P | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 |
| Strain | 0.02 X $10^{-2}$ | 0.05 X $10^{-2}$ | 0.07 X $10^{-2}$ | 0.1 X $10^{-2}$ | 0.14 X $10^{-2}$ | 0.2 X $10^{-2}$ | 0.28 X $10^{-2}$ |
| D | 213.04 | 213.1 | 213.14 | 213.21 | 213.29 | 214.4 | 213.59 |

TABLE 9. GRAPH NO.9&10 (LOCATION NO.9)

| Step | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| **P** | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 |
| **Strain** | 0.02 X $10^{-2}$ | 0.03 X $10^{-2}$ | 0.04 X $10^{-2}$ | 0.06 X $10^{-2}$ | 0.08 X $10^{-2}$ | 0.12 X $10^{-2}$ | 0.202 X $10^{-2}$ |
| **D** | 1012.2 | 1012.3 | 1012.4 | 1012.6 | 1013.8 | 1013.2 | 1014 |

TABLE 10. GRAPH NO.11&12 (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 $10^{-2}$ | 0.19 X $10^{-2}$ | 0.26 X $10^{-2}$ |
| **D** | 1012.30 | 1012.5 | 1012.7 | 1012.9 | 1013.3 | 1013.9 | 1014.6 |

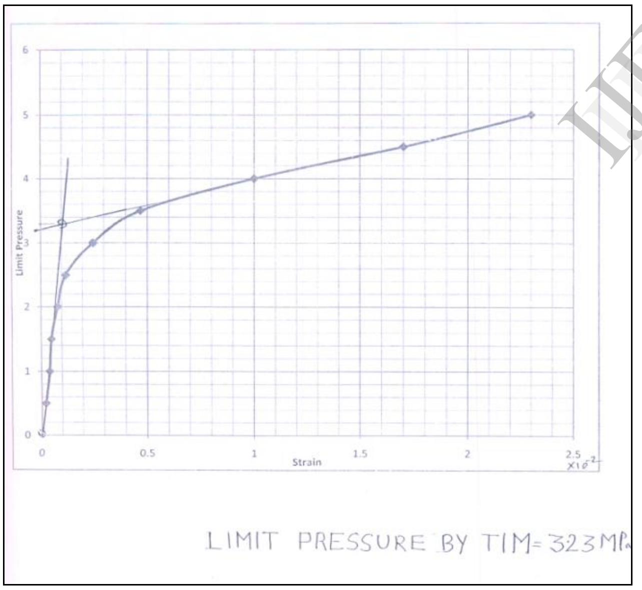


Fig. 6 Graph 1

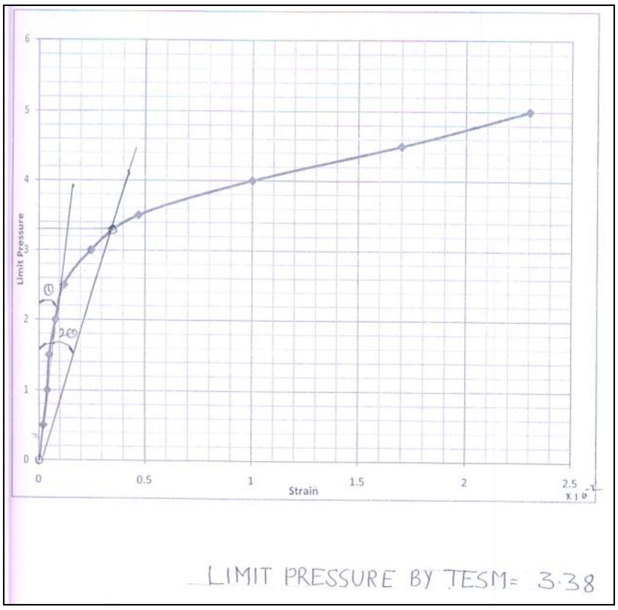


Fig. 7 Graph 2

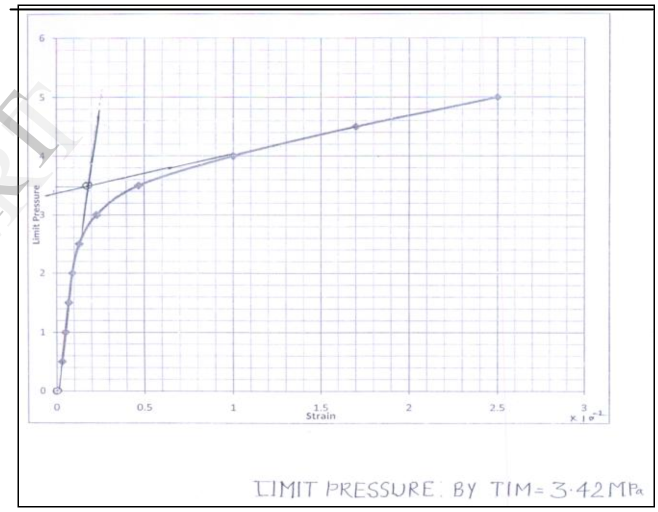


Fig. 8 Graph 3

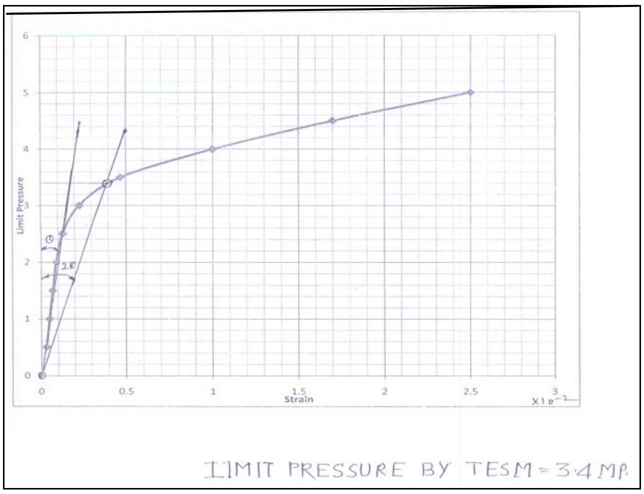


Fig. 9 Graph4


Fig. 10 Graph5

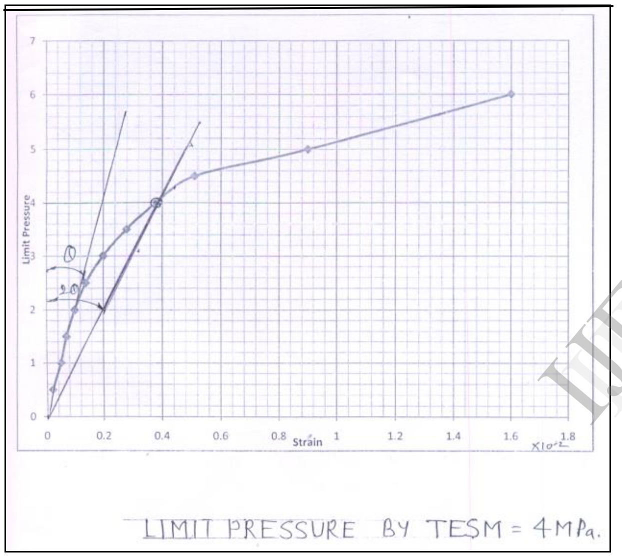


Fig. 11 Graph6


Fig. 12 Graph 7

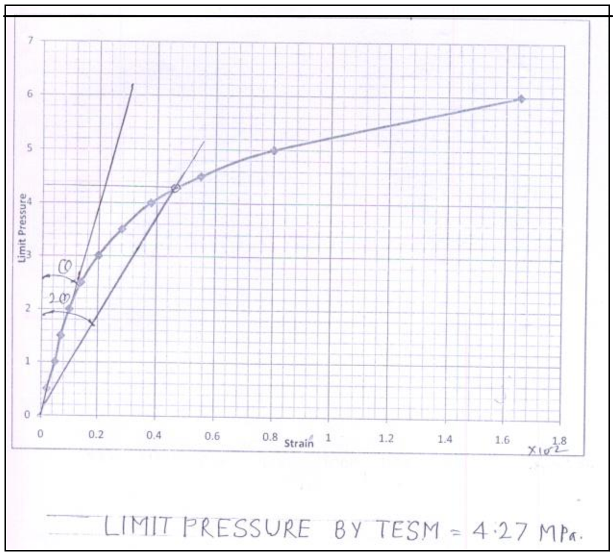


Fig. 13 Graph 8


Fig. 14 Graph 9

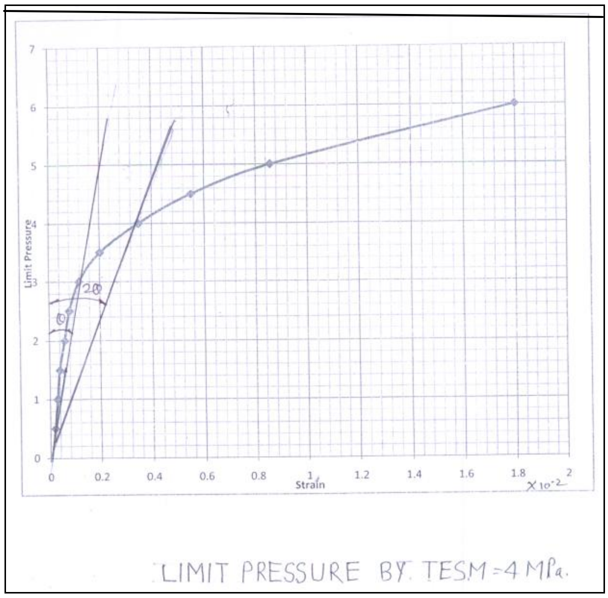


Fig. 15 Graph 10

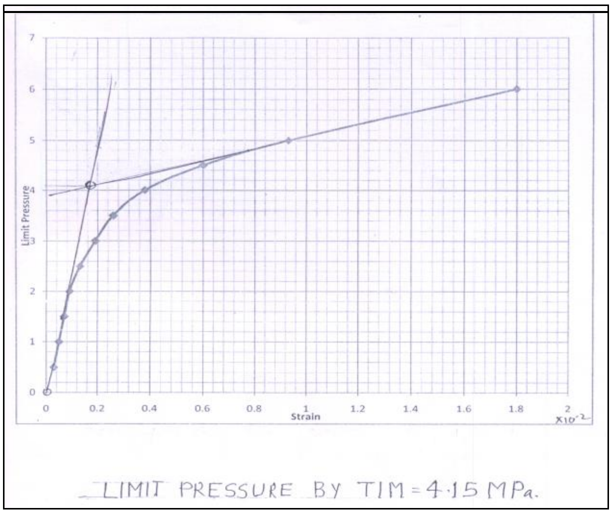


Fig. 16 Graph 11

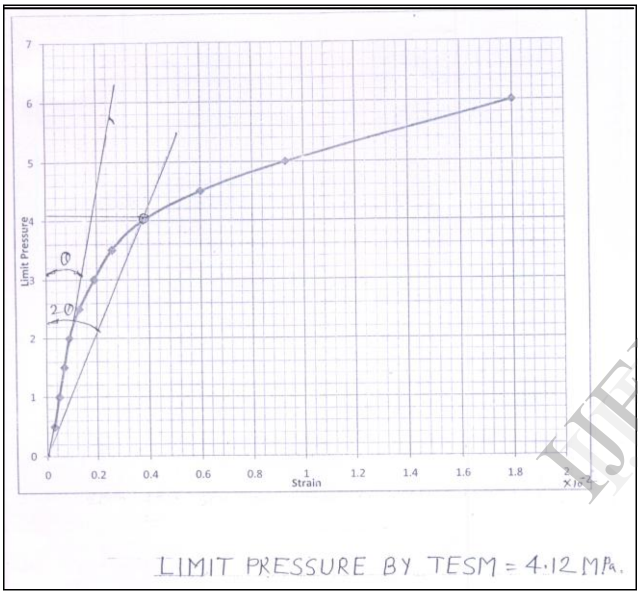


Fig. 17 Graph 12

## V. RESULT

TABLE 11. COMPARISION OF EXPERIMENTAL READINGS WITH FEM BY BOTH TIM & TESM METHOD

| Model oblique nozzle | Location No. 8 | | | | Location No. 9 | | | | Location No. 4 | | | | Location No. 5 | | | | Location No. 10 | | | | Location No. 1 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *TEST (Mpa)* | | *FEM (Mpa)* | | *TEST (Mpa)* | | *FEM (Mpa)* | | *TEST (Mpa)* | | *FEM (Mpa)* | | *TEST (Mpa)* | | *FEM (Mpa)* | | *TEST (Mpa)* | | *FEM (Mpa)* | | *TEST (Mpa)* | | *FEM (Mpa)* | |
| | *TIM* | *TESM* | *TIM* | *TESM* | *TIM* | *TESM* | *TIM* | *TESM* | *TIM* | *TESM* | *TIM* | *TESM* | *TIM* | *TESM* | *TIM* | *TESM* | *TIM* | *TESM* | *TIM* | *TESM* | *TIM* | *TESM* | *TIM* | *TESM* |
| $45^0$ | 4.29 | 4.27 | 4.49 | 4.65 | 4.23 | 3.85 | 5.55 | 5.48 | 3.42 | 3.4 | 4.38 | 4.18 | 4.08 | 4.00 | 4.67 | 4.22 | 4.15 | 4.12 | 4.65 | 4.15 | 3.23 | 3.38 | 4.48 | 4.13 |

## VI. CONCLUSION

- It is observed that limit load obtain by experimental and finite element result is different for different location depending on its distance from weld section . the location no. 4 positioned at nearest distance ( 10 mm on obtuse side of nozzle) on shown in fig. shows relatively lower limit load than compared to location no. 8 ( 20 mm at actute side on nozzle). The overall lower value of limit load 3.23 mpa is shown at location no. 1 (10 mm at obtuse side on shell).The value of allowable limit pressure according to ASME guidelines for experimental vessel is given by

$$p_A = (2/3)\ p_L$$
$$= 2/3 \times 3.23$$
$$p_A = 2.153 \text{ Mpa}$$

- Experimental result are in good agreement with finite element result. Limit load determination by using FEA is simple and faster for complex geometrics as compared to other methods.

- Amongs the above procedure to evaluate limit pressure by using various methods, TIM method to estimate the lower value of limit pressure is more effective for higher elastic slope of limit pressure vs strain.

- Parametric study of finite methods with different oblique angle between shell to nozzle axis, the observation is the limit pressure is increases on the angle increases till $60^0$ . The increasing rate of limit pressure decreases there after until $90^0$ i.e. radial nozzle.

RESEARCH REFERENCES

[1] Parag Mahajan & S.A. Chariwala, "Limit and plastic Analysis of pressure vessel" Sardarvallabhbhai National Institute of Technology, 2008.

[2] N. Li et.al. , " Study of plastic limit Load on pressurized cylinders and lateral nozzle" Journal of pressure vessel Technology (Nov 2008)vol. 138, pp. 30-34.

[3] Z. F. Sang, et.al, "Limit & burst pressure for a cylindrical shell interaction with intermediate diameter ratio", International Journal of Pressure Vessel and Piping (Aug 2002), Vol. 79 pp. 341-349.

[4] H.F Wang et.al. , " Elastic Stress of pressurized cylinders with Hill side nozzle " Journal of pressure vessel and Technology, Nov. 2006-vol.128 pp.625-631.

[5] P.Yang, Y. Liu, Y. ohtake and Z.cen, "Limit analysis based on a modified elastic compensation method for nozzle – to – cylinder junctions," International Journal of pressure vessel & piping (2005) vol. 82, pp 770-776.

[6] Boyle JT, Macken Zie D and Hamilton R ,"The Elastic compensation method for limit and plastic analysis : a review ." Journal of Strain Analysis (2000) vol-35 (3) pages 171-187.

[7] Martin Muscat, & Robert Hamilton "A Work criterion for plastic collapse'," International Journal of pressure vessels and piping (2003) vol. -80 pages 49-59.