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Influence of Nozzle Stiffness on Equipment Nozzle Loads and Local Stresses, a Comparative Study

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***Abstract* – In Petroleum Refineries, petrochemical plants and fixed / floating offshore installations piping design depends mainly on stress analysis. Stress analysis is one of the important parameters which dictate piping layout and support fixation. As a part of analysis piping engineer mainly checks piping stresses, Nozzle loads and displacements for finalizing the line for construction. In the above parameters Nozzle loads play a vital role in finalizing the concerned line as well as equipment vendor nozzle details. Nozzle stiffness is the important parameter in evaluation of various components of nozzle loads. The objective of this paper is to explain the effect/influence of stiffness generated from three different methods (Anchor, WRC and Finite element method) on nozzle load evaluation and shell/nozzle junction stresses. This paper also explains advantages/disadvantages of these methods which will enable user to go for optimization of piping layout and support design in real life problems.**

***Index Terms* – Nozzle stiffness, CAEASR II, Anchor, NOZPRO, WRC, Nozzle flexibilities, Vessel / nozzle intersection, General membrane and local stresses**

I. INTRODUCTION

Piping engineers mostly use CAESAR II software which is widely used in energy industry for pipe stress analysis. Welding research council standard WRC 297 and finite element software NOZPRO which is developed by Paulin research group are also being used in energy industry for evaluating nozzle stiffness and local stresses at shell/nozzle intersection points. Nozzle stiffness values evaluated by WRC standard and finite element software NOZPRO can be fed as an input to pipe stress analysis software in calculating nozzle loads and these loads can be further used in finite element tools to check the local stress behavior at shell / nozzle intersection points. Equipment governing code ASME section VIII division 2 furnishes some guide lines for qualifying these local stresses. Piping engineer need to make use of these nozzle flexibilities and local stress behavior in clearing the concerned piping isometric and associated equipment nozzle drawing for fabrication.

II. ANALYSIS

In any piping analysis user come across three directional forces and moments. Forces are categorized as axial force, circumferential force, longitudinal force and moments are categorized as Torsional moment, longitudinal moment and circumferential moment. Axial force induces axial stress and longitudinal/circumferential forces induce shear stresses in the respective directions in piping system. Torsional moment induces shear stress and longitudinal/circumferential moments induce bending stresses in piping system.

Local stresses at vessel/nozzle intersection are mainly governed by Axial force, Circumferential and longitudinal bending moments. Axial force induced mainly depends on axial stiffness of the nozzle, whereas bending moments depend on Circumferential and longitudinal stiffness (bending stiffness) of the nozzle.

Axial stiffness:

Axial stiffness of the pipe mainly depends on young’s modulus and geometrical parameters of the pipe.

$$\text{Axial stiffness } (Ka) = EA/L \qquad (1)$$

Where,

- E is the young’s modulus of pipe material
- A is the cross sectional area of the pipe
- L is the length of the pipe

$$\text{Cross sectional area of the pipe } (A) = \pi\,(D_0^2 - D_i^2)/4 \qquad (2)$$

Where,

- D_0 is Outer diameter of the pipe
- D_i is Inner diameter of the pipe

Circumferential/Longitudinal stiffness($K_{c/l}$):

Circumferential/Longitudinal stiffness of the pipe also depends on Young’s modulus and other geometrical parameters of the pipe.

$$\text{Circumferential/Longitudinal stiffness } (K_{c/l}) = 3EI/L^3 \qquad (3)$$

Where,

- I is the Moment of inertia of the pipe and E, L are already furnished above.

$$\text{Moment of inertia of pipe (I)} = \pi\,(D_0^4 - D_i^4)/64 \qquad (4)$$

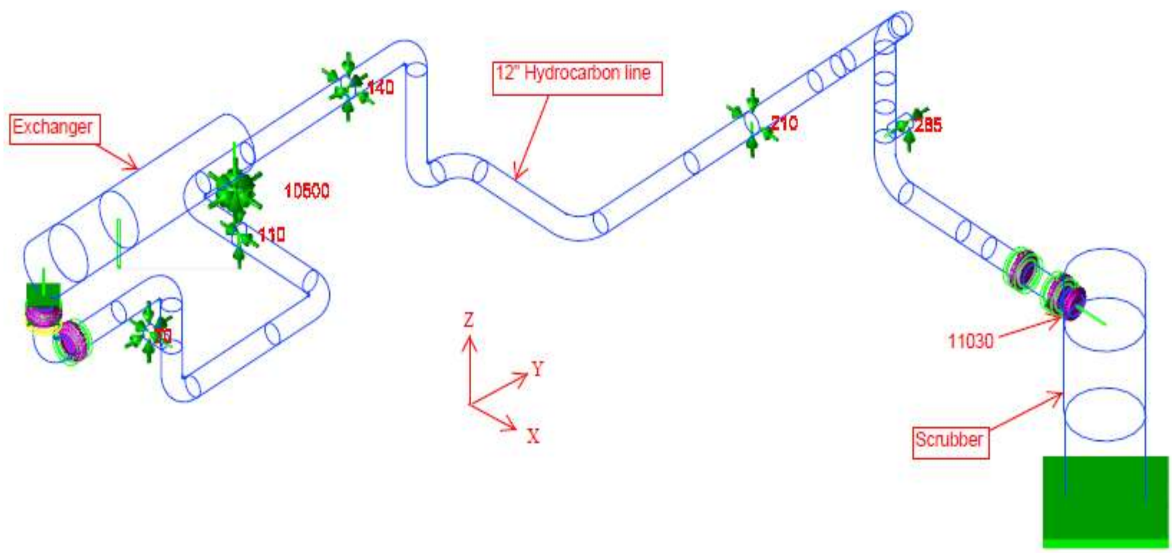


Fig 1. Hydro carbon line (12" size) isometric showing supports and equipment details

Line shown in the present case study (Refer fig.1) is a 12" hydro carbon line in a Petro chemical plant. It is connected between Scrubber vessel and Exchanger. Material of the above hydro carbon line is Duplex stainless steel (ASTM A790 UNS S31803).

Other process and mechanical parameters are as follows.

Design temperature = 250 deg.C.
Design Pressure = 19 bar
Pipe thickness = 9.525 mm
Corrosion allowance = 0 mm
Material class = 300 #
Nozzle thickness = 12 mm
Vessel Outer diameter = 1248 mm
Vessel thickness = 24 mm

In the present problem exchanger nozzle loads are within vendor allowable limits. Since problem lies with Scrubber nozzle loads, our discussion is focused on scrubber nozzle. Analysis is performed with 3 different stiffness.

a) Anchor stiffness: Stress analysis is performed with consideration of full anchor at scrubber nozzle with imposed thermal displacements from vessel anchor point. Stress analysis software considers default higher stiffness values for the anchor and evaluates the loads. These loads are tabulated in results column and compared with equipment vendor allowable loads.

b) WRC 297 stiffness: Geometrical parameters (Vessel outer diameter, thickness, Nozzle outer diameter, thickness, Reinforcement pad diameter, thickness, stiffener distance from either side of the nozzle) are given as an input to analysis software for generation of nozzle stiffness values. Evaluated stiffness values are listed below.

Table 1. Stiffness values from WRC 297 analysis

Axial stiffness	$1.75X10^{11}$ N/mm
Longitudinal stiffness	$6.73x10^{6}$ Nm/deg
Circumferential stiffness	$1.58x10^{5}$ Nm/deg

Above stiffness values are used in piping stress analysis to evaluate nozzle loads and these are compared with equipment vendor allowable loads in Results section. Local stresses are also calculated with WRC 297 module and these are tabulated/ compared with allowable stresses in next section.

c) Finite element analysis (FEA) stiffness: Nozzle is modeled in **NOZPRO,** version 8.5 finite element software along with vessel up to some portion (refer fig 2) to have proper continuity for analysis. Ends of the vessel portion on either side are fixed (both translations and rotations) to have proper boundary condition. Nozzle reinforcement pad is also modelled in order to take the area reinforcement effect into account. Stiffness values are calculated from the analysis and these values are listed in below table.

Table 2. Stiffness values from FE Analysis

Axial stiffness	$3.25X10^{5}$ N/mm

Longitudinal stiffness	3.92x105 Nm/deg
Circumferential stiffness	$1.36x10^5$ Nm/deg

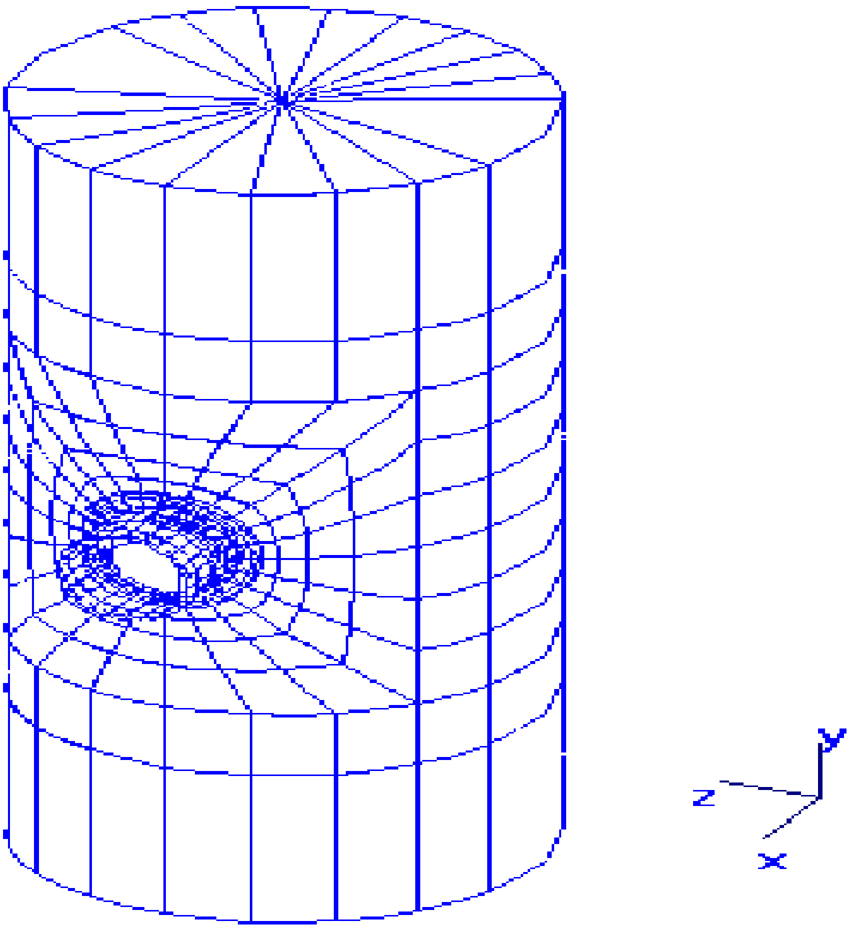


Fig.2 Finite element analysis model of vessel and nozzle from NOZPRO analysis.

Stiffness values mentioned in table 2 are used in piping stress analysis to evaluate nozzle loads and these are compared with equipment vendor allowable loads in Results section. Local stresses are also calculated with NOZPRO analysis and these are tabulated/compared with allowable stresses in next section.

III. RESULTS

a) Nozzle loads:

Pipe stress analysis with consideration of 3 different stiffness at the nozzle has resulted the following nozzle loads.

Table 3. Nozzle loads with different stiffness values

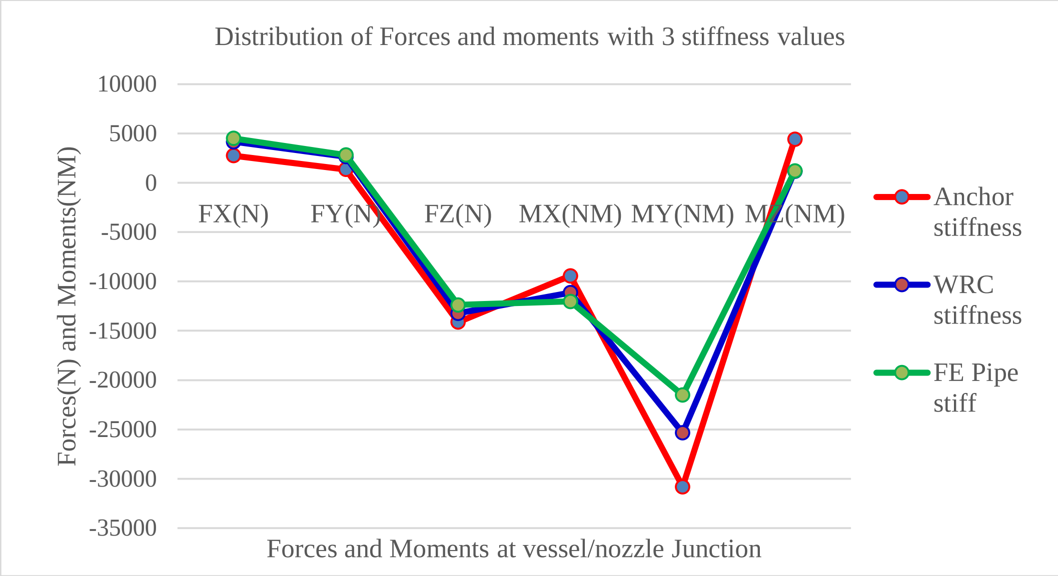
Nozzle Stiffness	FX (N)	FY (N)	FZ (N)	MX (NM)	MY (NM)	MZ (NM)
Anchor	2742	1351	-14128	-9439	-30803	4416
WRC Stiffness	4151	2650	-13232	-11138	-25340	1175
FE analysis stiffness	4500	2803	-12385	-12037	-21515	1191
Allowable loads	16800	12600	16800	22920	15280	15280

FX, FY, FZ values are in Newtons and MX, MY, MZ values are in Newton meters.

As per the piping isometric (Fig. 1) nozzle axis is in X axis. Appropriate terms used for these forces & moments in applicable codes and standards are as follows.

FX = Axial force; FY = Circumferential force; FZ = Longitudinal force.

MX = Torsional moment; MY = Longitudinal moment; MZ = Circumferential moment.



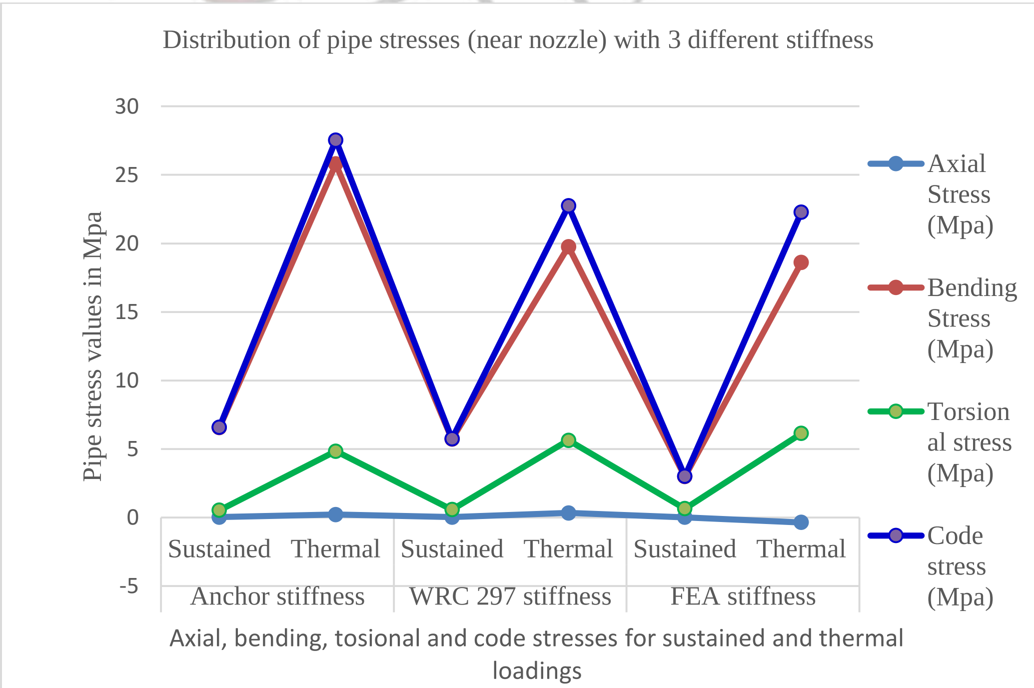
Graph 1 Nozzle loads with different stiffness values

b) Pipe stresses: After nozzle loads, a study was done to check the effect of nozzle stiffness on pipe stresses near scrubber nozzle. These results are tabulated in the following table.

Table 4. Stress values in pipe portion near nozzle with 3 different stiffness

Location	Stiffness	Load type	Axial Stress (Mpa)	Bending Stress (Mpa)	Torsional stress (Mpa)	Code stress (Mpa)	Allowable stress (Mpa)
Pipe portion near scrubber nozzle	Anchor stiffness	Sustained	0.03	6.55	0.53	6.58	188.4
		Thermal	0.21	25.8	4.84	27.54	305.6
	WRC 297 stiffness	Sustained	0.03	5.71	0.57	5.74	188.4
		Thermal	0.33	19.76	5.63	22.74	305.6
	FEA stiffness	Sustained	0.02	2.98	0.64	3	188.4
		Thermal	-0.36	18.61	6.13	22.29	305.6

Graphical representation of these stresses is shown in the following graph which explains the effect of various stiffness on different categories of stresses.



Graph 2 Pipe stresses for different load cases with different stiffness

c) Local stresses: This aspect is one of the important points in qualifying the equipment nozzle against pressure and external piping loads. A study was done to check the effect of nozzle stiffness on these local stresses. Normal piping stress analysis will not give any local stresses at vessel nozzle point. It means that the stress analysis in Caesar II with consideration of an anchor stiffness at nozzle will not result any local stresses. Hence comparison is done for other two cases.

As per ASME section VIII Division 2 following local stresses need to be checked for clearing the nozzle.

i) Pm shall be limited to 1 Smh
j) Pm+Pl shall be limited to 1.5 Smh
k) Pm+Pl+Q shall be limited to 3.0 Sm(ave)

Where Pm is general membrane stress due to pressure and sustained loads

Pm+Pl is combination of general and local membrane stress due to Pressure and sustained loads

Pm+Pl+Q is combination of general, local membrane stress due to Pressure & sustained loads and secondary loads.

Secondary loads are primarily due to thermal loads and this includes both membrane and bending effects.

Where, Smh is hot allowable stress intensity and Sm (ave) is average of hot and cold allowable stress intensities.

Following figures (3,4 and 5) which are extracted from NOZPRO show the stress distribution plots for various categories of local stresses at vessel/nozzle junction.

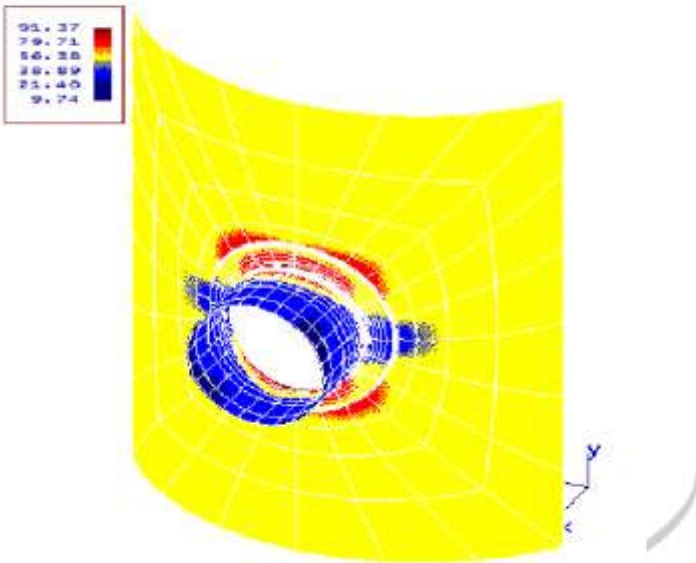


Fig.3 General membrane stress due to sustained loads (Pm)

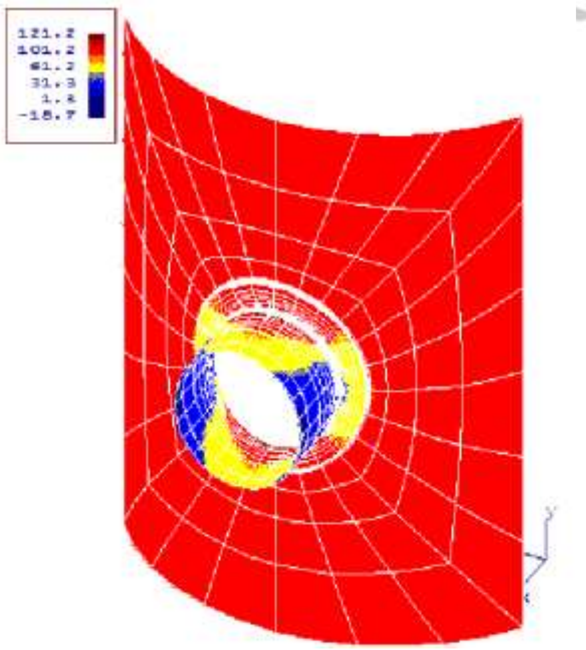


Fig.4 General and local membrane stress due to sustained loads (Pm+Pl)

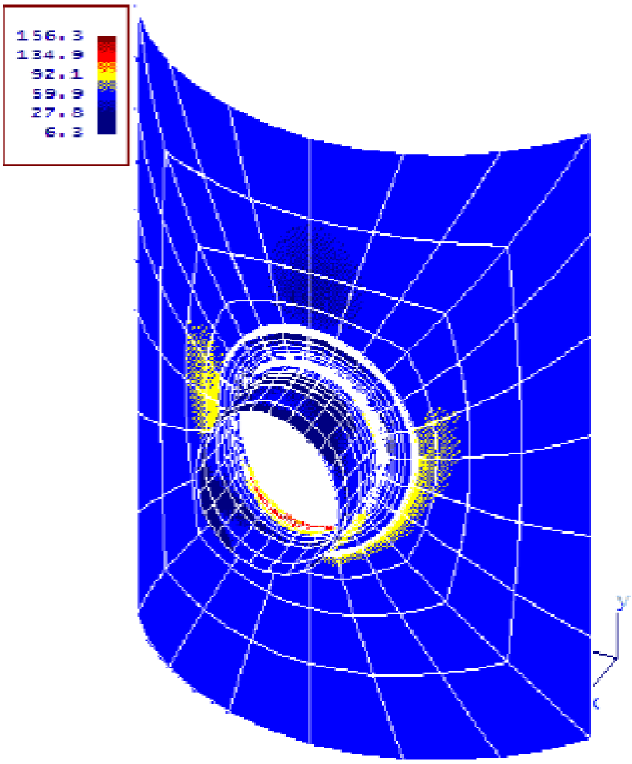
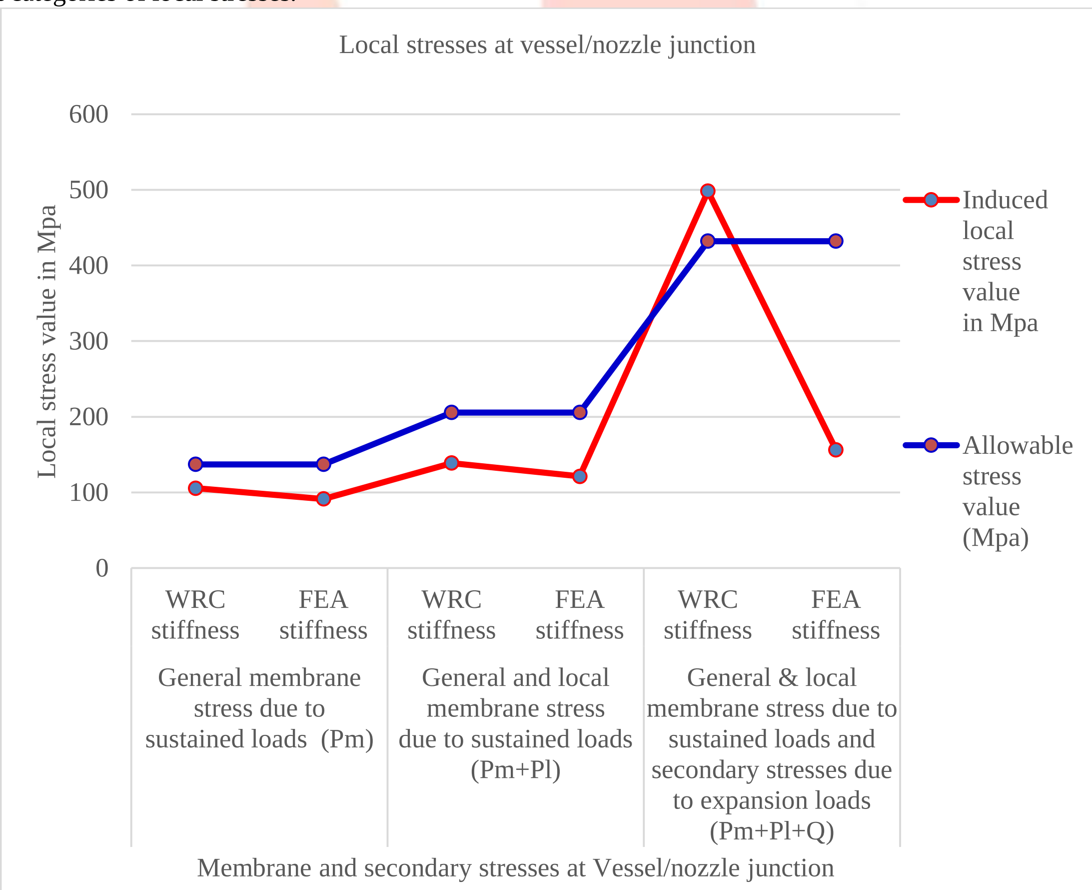


Fig.5 General, local membrane stress due to sustained loads and Secondary stresses due to expansion loads (Pm+Pl+Q)

Graphical representation of the stresses is shown in the following graph which explains the effect of WRC and FE analysis stiffness on different categories of local stresses.



Graph 3 Distribution of local stresses at vessel/nozzle junction with different stiffness

Local stresses with WRC stiffness and FE analysis stiffness are summarized and tabulated in the below table.

Table 5. Local stress values at Vessel/nozzle junction with different stiffness

Type of stress	Stiffness	Induced local stress value in Mpa	Allowable stress value (Mpa)
General membrane stress due to sustained loads (Pm)	WRC stiffness	105.6	137
	FEA stiffness	91.37	137
General, local membrane stress due to sustained loads (Pm+Pl)	WRC stiffness	138.8	205.7
	FEA stiffness	121.2	205.7
General, local membrane stress due to sustained loads and secondary stresses due to expansion loads (Pm+Pl+Q)	WRC stiffness	498.2	432.2
	FEA stiffness	156.3	432.2

IV. DISCUSSION

From table 1 and 2 it is clear that the stiffness values derived from FE analysis are lower than the one generated from WRC 297 analysis. In the present case study, there is a higher reduction in axial stiffness and longitudinal stiffness compared to circumferential stiffness. If we compare the nozzle loads tabulated in table 3, it is evident that longitudinal moment (MY) alone is higher than the allowable longitudinal moment with all 3 stiffness values. There are no significant variations in other components. Due to lower nozzle stiffness values, MY value is lower in magnitude with WRC and FE analysis stiffness compared to Anchor stiffness. It is clearly observed that MY value with FEA stiffness is lower than the value with WRC stiffness. Since this component is exceeding the allowable limit in both the cases, one has to check the local stresses at the vessel/nozzle junction point to clear the line as well as to qualify the nozzle against these loads.

These nozzle stiffness will have effect on stresses in pipe portion close to the nozzle. From pipe stress results presented in graph 2 and table 4, it is clear that sustained/thermal load case axial, bending, and torsional and code stresses with axial, WRC and FE analysis stiffness are with in allowable limits stipulated by ASME B 31.3 code. There are no significant variations in axial and torsional stresses. But there is a considerable reduction in bending and code stress with WRC 297 and FEA stiffness compared to Anchor stiffness. However, these stress values with FEA stiffness are lower than the one with WRC 297 stiffness.

Local stress analysis with WRC and FEA stiffness are presented in graph 3, table 5 and figures 3 to 5. From these results it is evident that the general/local membrane stress due to primary loads and secondary loads with WRC nozzle stiffness is exceeding the allowable limits specified by equipment governing code ASME section VIII division 2, whereas the same resulted due to FEA stiffness is within the allowable limits. Other category of stresses viz., general membrane stress due to primary loads and general/local membrane stresses due to primary loads are within allowable limits. However local stresses induced with FEA stiffness are lower than the one resulted due to WRC stiffness as observed in previous cases.

V. FUTURE SCOPE

- Pipe routing and support optimization
- Vibration control methods in refinery Piping
- Effect of nozzle/support stiffness on dynamic response of piping
- Comparative study on site spectra and quasi static method of seismic analysis

VI. CONCLUSION

From the above results and discussions it is very clear that conventional stress analysis with consideration of anchor stiffness will lead to higher nozzle loads and pipe stresses. One option available with piping engineer is to change the routing (or) supporting of the line. In some cases it may not be possible for piping engineer to change the routing of the line (or) add new supports due to layout/handling constraints. In such cases one has to opt for nozzle flexibility modules/local stress analysis tools like WRC and finite element analysis methods which will help in reducing the nozzle loads and evaluating local stresses at the interested points in qualifying the line and equipment nozzle. This aspect will in turn help in optimizing the pipe routing and support configuration. From the above results/discussions it can also be concluded that Finite element tool will give more realistic results than WRC module especially in terms of local stress computations which is the critical criterion for qualifying the equipment nozzles.

VII. ACKNOWLEDGMENT

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