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Design of Pipe Shoe Support for Horizontal Large Bore Lines

Pramodh Rajkumar.G¹, Venkat Rao Nelluri²

Fluor Daniel India Pvt Limited, Gurugram, Haryana, India¹

Fluor Daniel India Pvt Limited, Gurugram, Haryana, India²

ABSTRACT: There are many cases in the usual engineering practice where the actual loads on the pipe supports are more than that of the standard supports and hence the pipes have to be supported with Non standard Pipe supports. There are various ways to check and ensure that the specially designed Non standard pipe support is designed as per the code requirement. Such one example is discussed in this paper, a shoe support on a 96" cooling water line has been evaluated.

Since shoes play a vital role in supporting the pipe network and to maintain its stability, it should be designed in such a way that it can afford the Pipe dead weight load, the internal pressure of the pipe due to liquid that flow through the pipe, lateral Guide loads due to Operating conditions like thermal and occasional loads. Similarly Axial loads due to thermal, occasional and frictional effect.

Stresses are calculated using both mathematical approach and ABAQUS software. A model of horizontal cooling water line and shoe support is created in ABAQUS, with all necessary boundary conditions. The analysis reveals the zone of high localized stress at the junction part of the pressurized pipe and Shoe support due to operating conditions in ABAQUS. Local stresses of the attachment and the structural integrity of the shoe has been evaluated using manual method. The results obtained from both the methods are compared with allowable stress value for safe designing.

KEYWORDS: Abaqus, NSPS- Non standard pipe support, Cradle, Web plate, Ribs, Kellogs, B31.3

NOMENCLATURES:

D	Outside diameter of pipe (mm)
R	Outside Radius of pipe (mm)
t	Thickness of the Pipe ($t_{\text{pipe}} + t_{\text{cradle}} - CA$) (mm)
E	Young's modulus of elasticity (N/mm^2)
F	Friction force (N)
t_t	Thickness of the plates used for fabricating the Shoe (mm)
P	Internal Pressure of the pipe (N/mm^2)
F_x	Axial force along the pipe (N)
F_y	Circumferential force lateral to the pipe (N)
F_z	Vertical force (N)
SL	Longitudinal stress (N/mm^2)
SC	Circumferential stress (N/mm^2)
f_{by}	Bending stress along Y-Y axis (N/mm^2)
f_{bx}	Bending stress along X-X axis (N/mm^2)
F_{by}	Bending allowable stress along Y-Y axis (N/mm^2)
F_{bx}	Bending allowable stress along X-X axis (N/mm^2)
f_a	Axial Stress (N/mm^2)

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F_a	Allowable axial stress (N/mm^2) ($0.6 * F_{yield}$)
h	Shoe height (mm)
L	Shoe length (mm)
S_{xx}	Section modulus along X-X axis (mm^3)
S_{yy}	Section modulus along Y-Y axis (mm^3)
C	Inner distance between legs (mm)
CA	Corrosion Allowance (mm)

I. INTRODUCTION

Piping supports and restraints are an integral part of all engineering piping system. Supports and restraints are provided to carry the deadweight of the pipe, the fluid medium, any inline valves, instruments, insulation, etc.

The main intention of this work is to avoid the repeated failures of Pipe supports during operation and to provide the allowable forces in each direction that a given shoe can withstand. This paper helps to select the shoe based on the actual loads, and explains the method to evaluate the stresses due to the combined effects of loads on shoe. The complicated shape of the shoe used to support the Cooling water line has been evaluated using the manual calculations prepared based on AISC (H1-3) and the result were compared with that of the FEA results.

Normally the Horizontal run of the cooling water lines are supported by Pipe shoe, these pipes are supported in interval based on the Pipe span or based on the analysis result

The purpose of this study is to verify the design of non- standard pipe support which is used to support the cooling water line of DN2400. This is to ensure compliance with the allowable stress limit when loaded with the maximum pressure, operating and slug loads. The evaluation includes

1. Local stresses evaluation due to welding of external attachment to the pressurized pipe based on Kellogg's method and structural integrity of the attached member based on AISC (H1-3).
2. FEA analysis using Abaqus.

The comparison study is made for the max loads that has been acceptable by each method and allowable values for the shoe has been finalized.

II. DESIGN OF NONSTANDARD SHOE

CONSTRUCTION OF THE NSPS

The construction of the NSPS, has Base plate, web Ribs and cradle, the cradle plate is used to carry the pressure pipe and has the internal diameter same as that the outer diameter of the pipe. The total dead weight of the pipe is directly distributed to cradle plate and then transferred to the base plate through web and rib plates. The web and ribs are designed to carry or support the cradle plate. They are located bottom of the cradle plate and above the base plate. Web and Ribs are welded on the base plate and the same is supported on structural member or on concrete pedestal.

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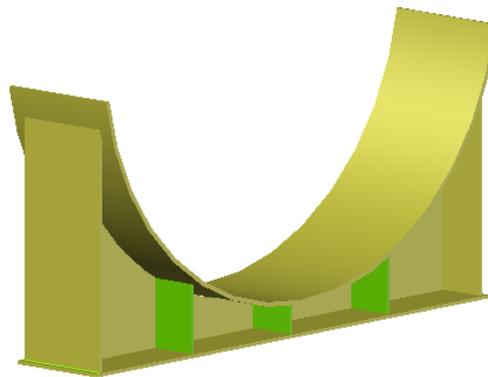
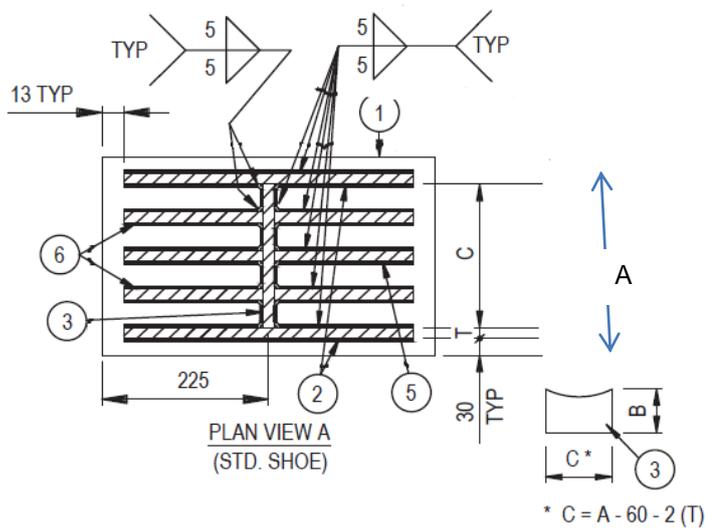


Fig-1 Horizontal NSPS

DIMENSIONAL DETAILS OF THE NSPS



Pipe size	2400
Dim 'A'	2460

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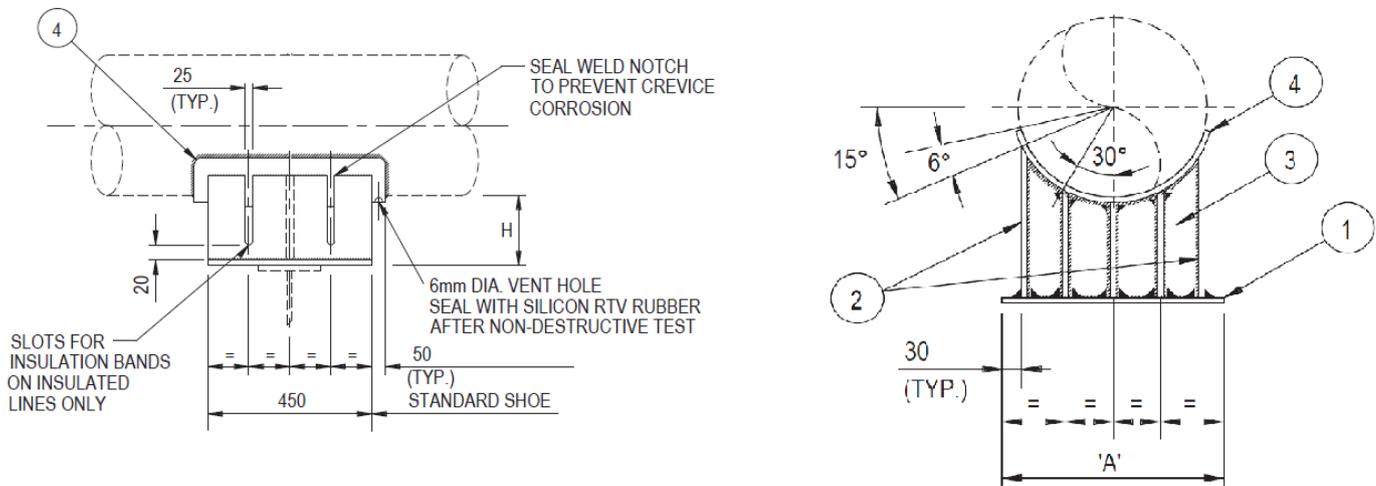


Fig-2 Cross section of NSPS

	MK. NO.	DESCRIPTION	QTY REQD
STANDARD SHOE	①	15 THK. x A x 450 CARBON STEEL PLATE, ASTM-A36	1
	②	15 THK. x B x 424 CARBON STEEL PLATE, ASTM-A36 ("B" = SHOP TRIM TO SUIT HEIGHT "H" OF SHOE)	2
	③	15 THK. x B x C CARBON STEEL PLATE, ASTM-A36 ("B" = SHOP TRIM TO SUIT HEIGHT "H" OF SHOE)	1
	④	550 LENGTH	1
	⑤	15 THK. x (H MINUS 35) x 205 CARBON STEEL PLATE, ASTM-A36	2
	⑥	15 THK. x B x 205 CARBON STEEL PLATE, ASTM-A36 ("B" = SHOP TRIM TO SUIT HEIGHT "H" OF SHOE)	4

Table-1 Description of NSPS

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DESIGN OF NSPS BY MATHEMATICAL APPROACH

Structural integrity calculation based on (AISC H1-3)

For the member which is subjected to Bending with Axial compression

$$\left(\frac{f_a}{F_a}\right) \leq 0.15$$

$$\left(\frac{f_a}{F_a}\right) + \left(\frac{f_{bx}}{F_{bx}}\right) + \left(\frac{f_{by}}{F_{by}}\right) \leq 1.0$$

$$f_{by} = \frac{M_{by}}{S_{yy}} ; f_{bx} = \frac{M_{bx}}{S_{xx}} \text{ and } f_a = \frac{F_z}{A}$$

$$M_{by} (\text{Moment due to Lateral force}) = F_y * h$$

$$M_{bx} (\text{Moment due to Axial force}) = F_x * h$$

$$A = 5 * (L * t_t) + (C * t_t) - 3(t_t)^2$$

Calculation of section modulus

$$S_{yy} = \frac{I_{yy}}{C_y} \text{ and } S_{xx} = \frac{I_{xx}}{C_x}$$

Where

$$I_{xx} = \frac{bh^3}{12} ; I_{yy} = \frac{b^3h}{12}$$

$$I_{xx} = I(\text{Rectangle}) - I(\text{Empty})$$

$$I(\text{Rectangle}) = \frac{L(C + 2t_t)^3}{12}$$

$$I(\text{Empty}) = I(\text{empty1}) + I(\text{empty2})$$

$$\text{Based on Parallel Axis theorem} = I_{xx} = I_{x'} + Ad^2$$

$$I(\text{empty1}) = 4 \left\{ \frac{\left(\frac{L-t_t}{2}\right) * \left(\frac{C}{4} - t_t\right)^3}{12} + \left(\frac{L-t_t}{2}\right) \left(\frac{C}{4} - t_t\right) \left(\frac{C}{8}\right)^2 \right\}$$

$$I(\text{empty2}) = 4 \left\{ \frac{\left(\frac{L-t_t}{2}\right) * \left(\frac{C}{4} - t_t\right)^3}{12} + \left(\frac{L-t_t}{2}\right) \left(\frac{C}{4} - t_t\right) \left(\frac{C}{4} + \frac{C}{8}\right)^2 \right\}$$

$$I_{yy} = I(\text{Rectangle}) - I(\text{Empty})$$

$$I(\text{Rectangle}) = \frac{L^3(C + 2t_t)}{12}$$

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$$I(\text{empty1}) = 8 \left\{ \frac{\left(\frac{L-t_t}{2}\right)^3 * \left(\frac{C}{4} - t_t\right)}{12} + \left(\frac{L-t_t}{2}\right) \left(\frac{C}{4} - t_t\right) \left(\frac{L}{4}\right)^2 \right\}$$

$$C_x = \frac{(C + 2t_t)}{2} \text{ and } C_y = \frac{L}{2}$$

LOCAL STRESS EVALUATION BY KELLOGG'S METHOD.

As per M.W Kellogg's catalogue for any attachment to the pipe shell the summation of bending stress and pressure stress is

$$S_l = 1.17(f_{bz} + 1.5f_a) \frac{\sqrt{R}}{t^{1.5}} + \frac{PR}{2t}$$

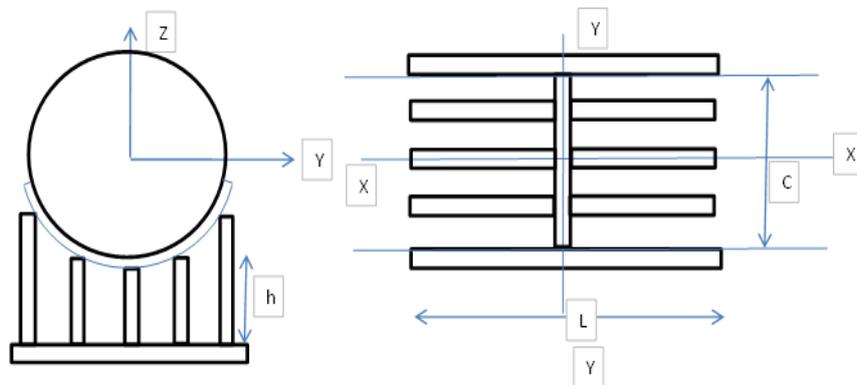
$$S_c = 1.75(f_R + f_a) \frac{\sqrt{R}}{t^{1.5}} + \frac{PR}{t}$$

Where

$$f_R = \sqrt{(f_{bz})^2 + (f_{bx})^2}$$

SAMPLE CALCULATION

- X Axial Direction of the Pipe
- Y Lateral Direction of the Pipe
- Z Vertical



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Input			
Material	A36(CS)		
Vertical load	FY	550000	N
Lateral Load	FZ	165000	N
Axial Load	Fx	165000	N
Inner Distance bt legs	C	2370	mm
Plate thickness	t	15	mm
Length of the Shoe	L	450	mm
Shoe Height	h	600	mm
Diameter of the Pipe	Do	2400	mm
Area	A	68625	mm ²
thickness of the pipe		44	mm (t of pipe+cradle-CA)

Where			
Yield Strength	F _{yield}	248	N/mm ²
Allowable bending 0.6xFy	F _b	148.8	N/mm ²
Allowable Axial 0.6xFy	F _a	148.8	N/mm ²
Internal Pressure	P	1.5	N/mm ²

Structural Integrity			
Axial stress ratio	fa/Fa	0.05	<.15 OK
Stress ratio		0.17	<1.0 OK

Local stress check (Kellogg's)			
$Sl = 1.17(f_{bz} + 1.5f_a) \frac{\sqrt{R}}{t^{1.5}} + \frac{PR}{2t}$	Sl=126.88	0.62	
$Sc = 1.75(f_R + f_a) \frac{\sqrt{R}}{t^{1.5}} + \frac{PR}{t}$	Sc=188.00	0.91	

FINITE ELEMENT MODEL

MODEL CONFIGURATION

The model configuration is shown in Figure 3. The geometry was modeled in millimeters and followed the 'SI mm' unit convention (mm, N, Nmm, MPa). The model included a 5000 mm (2 times pipe diameters) on both sides from the center extension to reduce the influence of the model constraints. It was assumed that the cradle plate was in full contact with the parent pipe and separation was not possible.

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The support was meshed using 3D linear stress elements (C3D8R) for the stress analysis. The stress analysis was defined as geometrically non-linear (i.e. elements could deform) with linear-elastic material properties. Figure 3 Meshed support configuration.

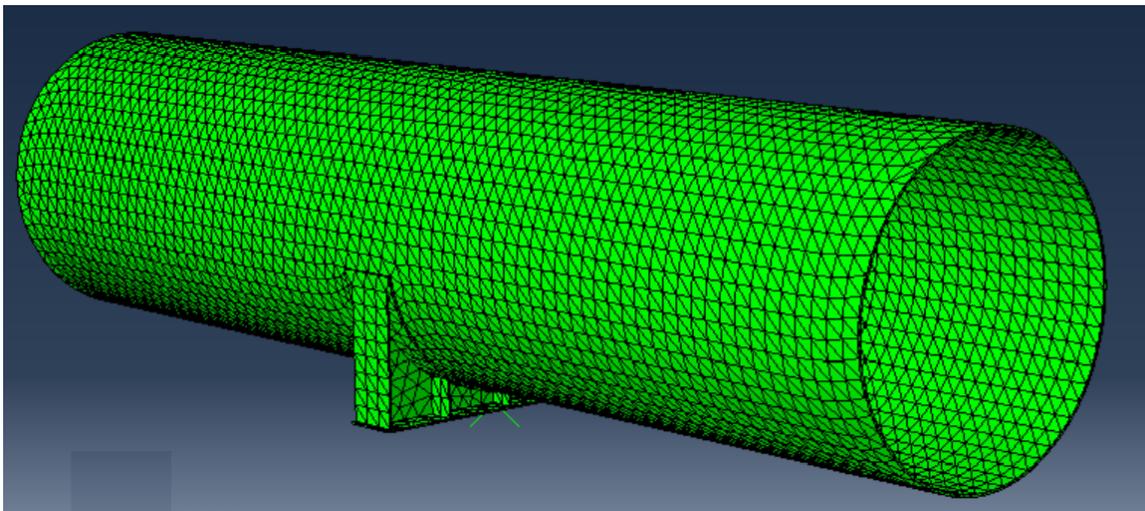


Fig-3 Support configuration of NSPS

APPLICATION OF LOADS AND BOUNDARY CONDITIONS

Loads Considered Includes:

1. Internal design Pressures.
2. Lateral, axial and vertical forces on shoe.

Boundary Conditions:

One end of the pipe is arrested in all direction, and other end of the pipe is simply supported. Internal pressure of the liquid has been applied as uniformly distributed pressure of 1.5 N/mm^2 at the inner surface of the pipe to check the maximum load bearing capacity of the shoe and the lateral, axial and vertical forces are applied at the base of the shoe by creating the reference point (RP), The reference point is created such that the forces will be applied at surface of the bottom of the shoe. Figure-4 Boundary condition and loads applied.

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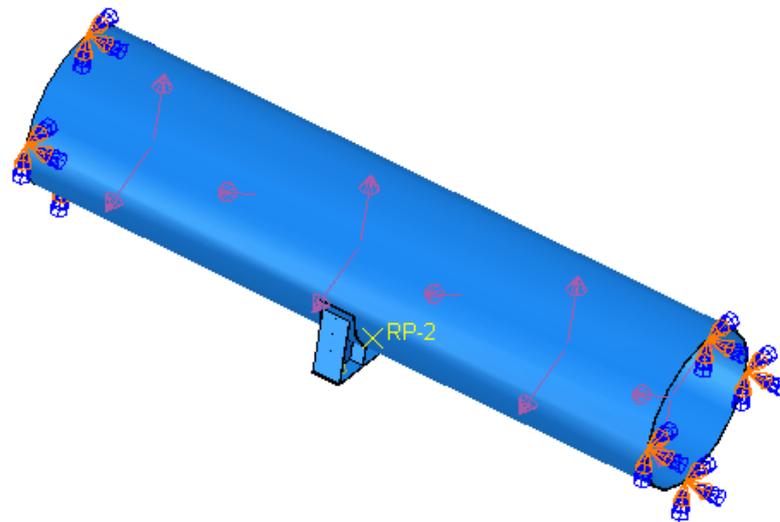
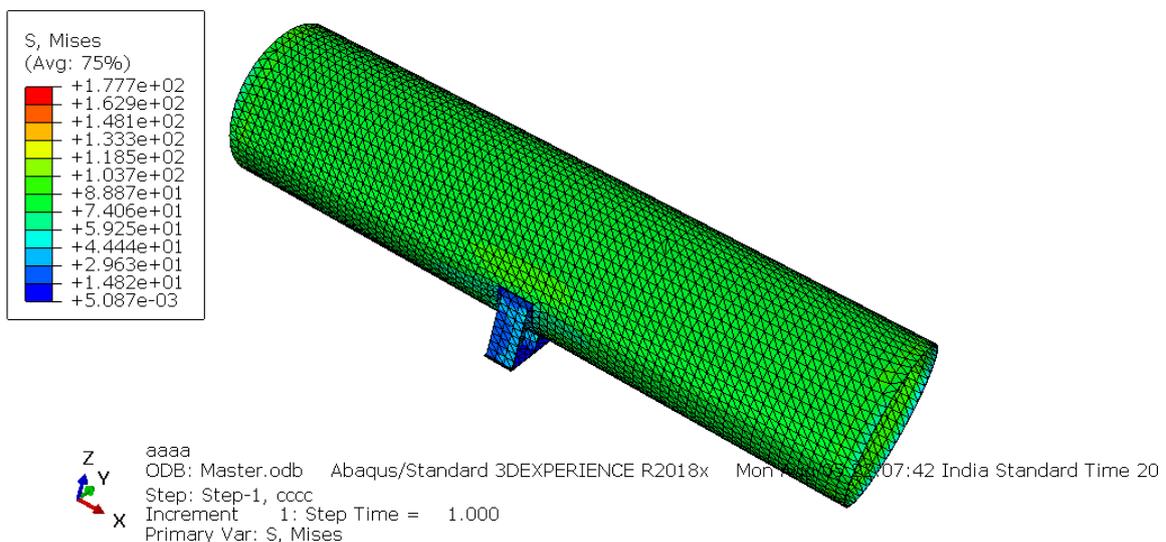


Fig-4 Boundary condition of NSPS

III. RESULTS AND DISCUSSION

The Von-Mises stress distribution is shown in Figure-5. The different stress intensities are observed across the junction. The Von-mises results at different location on the Pipe, Shoe and cradle plate are shown in figure respectively. Also the distribution of stresses corresponding to the plate thickness of the shoe and Pipe thickness which are obtained by the manual calculation and Abaqus results were tabulated.

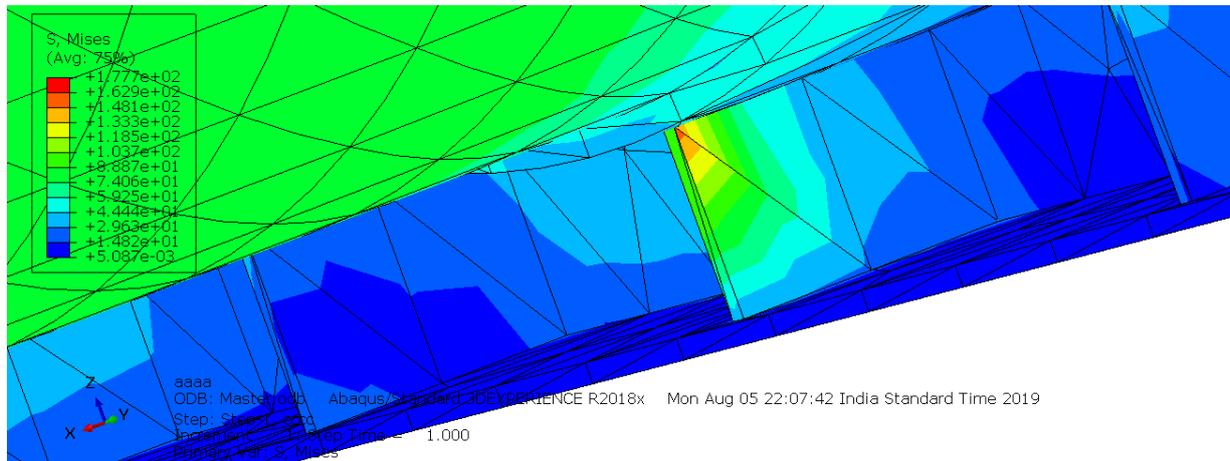
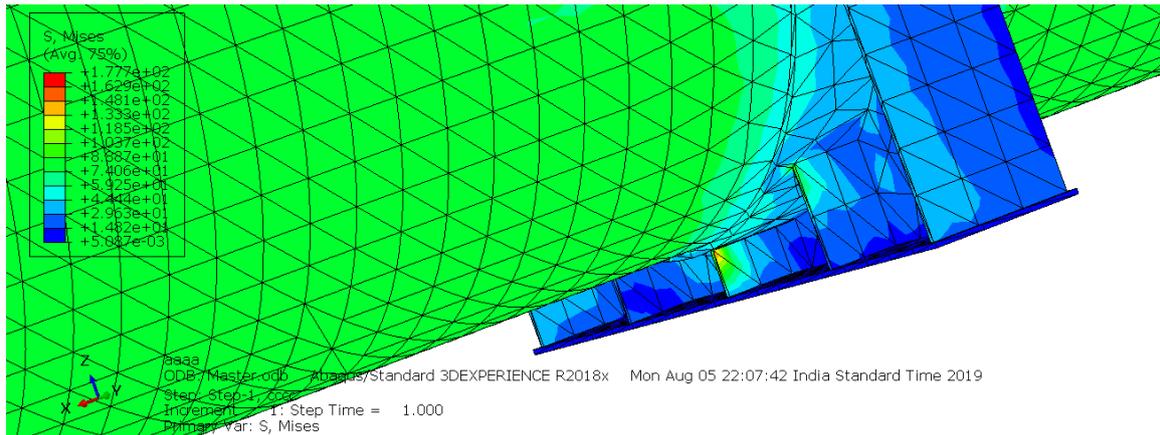


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Sr. No	Thickness		Structural Integrity check		Local Stress Check		Abaqus stresses
	(mm)		Axial Stress (fa/Fa<15%)	Stress ratio	SI	Sc	
	Pipe thickness	Shoe plate	(%)	(%)	(%)	(%)	
1	44	15	5	17	62	91	85
2	50	15	5	17	51	76	69
3	40	15	5	17	70	104	98
4	44	10	8	25	62	91	85
5	44	6	13	41	62	91	85

Table-2 Comparison of the stresses

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IV. CONCLUSION

Comparative study of the stresses obtained by Abaqus software and mathematical approach shows that stress calculated by Abaqus is lesser than that by mathematical approach and also less than the allowable stresses. It has been found that the present design is safer for the loads considered in the calculation, with the above approach the allowable loads of the given shoe can be determined, and the same can be used at other locations also as per the requirement. Similarly the shoes can be checked for the different combination of loads too. The stresses in pipe and Shoe support with different thickness are shown in Table-2.

Table-2 shows the comparison of result for the manual calculation and Abaqus Software. It is found that manual results are very much on conservative side whereas Abaqus provides themore accurate results. It has been analyzed that by doing adequate modifications in the present design we can further reduce maximum stress value at critical zone.

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