Elastic Stress Analysis for Heat Exchanger Channel Head for Protection Against Plastic Collapse and protection against local failure (FEA)

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1. OVERVIEW:

When perform Elastic Stress Analysis on pressure vessels components, the Stresses are computed using an elastic analysis, classified into categories, and limited to allowable values that have been conservatively established such that a plastic collapse will not occur. The ASME section 8 Div. 2 part 5 provide guidance to evaluate stresses with respect to the elastic stress and criteria for plastic collapse. In this example Heat Exchanger channel Head potions are evaluated for elastic analysis method and results are compared to plastic collapse criterion and local failure criterion. . The Ansywork bench software is used for modelled & used for all analysis.

2. DESIGN DATA FOR CHANNEL HEAD

Channel Girth Flange material: SA350 LF2 Cl.1
Shell material: SA516 Gr70
Ellipsoidal Head material 2:1: SA516 Gr70
Nozzle Pipe: SA350LF2 Cl 1
Nozzle Flange: SA 350 LF2 Cl.1
Internal diameter of Channel head: 1504 mm
Thickness of shell/Elliptical head: 25mm
Nozzle internal diameter: 200 mm
Nozzle thickness: 20 mm
Nozzle flange rating: #300 WN RF
Design temperature: 65ºC
Internal design Pressure: 2 MPa
Axial Nozzle load: 17400 N
Nozzle Thrust pressure :5.54 MPa

3.0 PROTECTION AGAINST ELASTIC STRESS ANALYSIS

The Elastic Stress Analysis are carried out location for compliance with respect to the elastic stress analysis criteria for plastic collapse and local failure as per guidance provided in ASME Sec VIII Div 2 part 5.2.2. Internal pressure is the load that was considered with respect its axial thrust pressure in the nozzle location and nozzle axial force was added into the input

3.1 STRESS CATEGORIZATION.

General Primary Membrane Equivalent Stress (Pm): The general primary membrane equivalent stress is the equivalent stress, derived from the average value across the thickness of a section, of the general primary stresses produced by the design internal pressure and other specified mechanical loads but excluding all secondary and peak stresses.

Local Primary Membrane Equivalent Stress (PL):The local primary membrane equivalent stress is the equivalent stress, derived from the average value across the thickness of a section, of the local primary stresses produced by the design pressure and specified mechanical loads but excluding all secondary and peak stresses

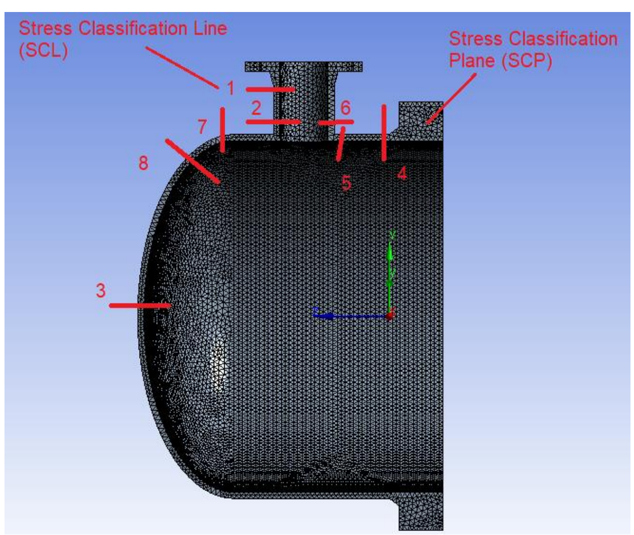
Bending Stress (Pb): The variable component of normal stress, the variation may or may not be linear across the section thickness.

Peak Stress(F): The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress that is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion.

Table 5.6
Examples of Stress Classification

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Any shell including cylinders, cones, spheres, and formed heads	Shell plate remote from discontinuities	Internal pressure	General membrane	P_m
			Gradient through plate thickness	Q
		Axial thermal gradient	Membrane	Q
			Bending	
	Near nozzle or other opening	Net-section axial force and/or bending moment applied to the nozzle, and/or internal pressure	Local membrane	P_L
			Bending	Q
			Peak (fillet or corner)	F
	Any location	Temperature difference between shell and head	Membrane	Q
			Bending	
	Shell distortions such as out-of-roundness and dents	Internal pressure	Membrane	P_m
			Bending	Q
Cylindrical or conical shell	Any section across entire vessel	Net-section axial force, bending moment applied to the cylinder or cone, and/or internal pressure	Membrane stress averaged through the thickness, remote from discontinuities; stress component perpendicular to cross section	P_m
			Bending stress through the thickness; stress component perpendicular to cross section	P_b
	Junction with head or flange	Internal pressure	Membrane	P_L
			Bending	Q
Dished head or conical head	Crown	Internal pressure	Membrane	P_m
			Bending	P_b
	Knuckle or junction to shell	Internal pressure	Membrane	P_L [Note (1)]
			Bending	Q

3.2 Linearization of Stress Results for Stress Classification. Results from an elastic stress analysis can be used to compute the equivalent linearized membrane and bending stresses for comparison to the limits in ASME SEC VIII DIV 2, 5.2.2.4 using the methods described in Annex 5-A.



Membrane and bending stresses are developed on cross sections through the thickness of a component. These sections are called stress classification planes (SCPs). In a planar geometry, a Stress Classification Line (SCL) is obtained by reducing two opposite sides of a SCP to an infinitesimal length. SCPs are flat planes that cut through a section of a component and SCLs are straight lines that cut through a section of a component. SCLs are surfaces when viewed in an axisymmetric or planar geometry. The Stress Classification Line Orientation and Validity Guidelines are taken from Figure 5-A.3 of Annex 5A and as per above Figure.

3.3 Assessment Procedure

STEP A – The load cases are analyzed to evaluate "load-controlled" loads such as pressure and externally applied reactions due to weight effects (Nozzle axial Load) The loads to be considered in the assessment shall include, but not be limited to, those given in Table 5.1 of ASME Section VIII Div 2 The load combinations that shall be considered for each loading condition shall include, but not be limited to those given in Table 5.3 of ASME Section VIII Div. 2 and here design case in Normal operation ,

Table 5.1
Loads and Load Cases to Be Considered in a Design

Loading Condition	Design Loads
Pressure testing	*(1)* Dead load of component plus insulation, fireproofing, installed internals, platforms, and other equipment supported from the component in the installed position *(2)* Piping loads including pressure thrust *(3)* Applicable live loads excluding vibration and maintenance live loads *(4)* Pressure and fluid loads (water) for testing and flushing equipment and piping unless a pneumatic test is specified *(5)* Wind loads
Normal operation	*(1)* Dead load of component plus insulation, refractory, fireproofing, installed internals, catalyst, packing, platforms, and other equipment supported from the component in the installed position *(2)* Piping loads including pressure thrust *(3)* Applicable live loads *(4)* Pressure and fluid loading during normal operation *(5)* Thermal loads

The internal pressure of 2 (Mpa), axial thrust pressure of 5.54 (Mpa) and axial load of nozzle 17400 (N) are considered load cases,

1) The finite element model has been developed in ANSYS work bench 19.2 version

2) Due to symmetry in geometry and loading, an 3D axisymmetric solid model is generated. To capture proper membrane behavior in the model the shell shall be extended a distance of 5 $\sqrt{Rt}$ below the head to shell transition. But here5 $\sqrt{Rt}$ is not applicable due to the geometry constraint. The FE model is illustrated in Figure 1. The model was generated with the ANSYS work bench 19.2 version.

3) Apply the material properties given below to the appropriate components of the model. Material assignments are below

Material properties at 65ºC				
Material	Youngs modulus (MPA)	Poisson ration	Yield strength (MPa)	Allowable stress (Sm) as per table 5A of Section II C(MPa)
SA350 LF2 Cl1	200 E3	0.3	250	156

SA 516 Gr 70	200E3	0.3	250	164

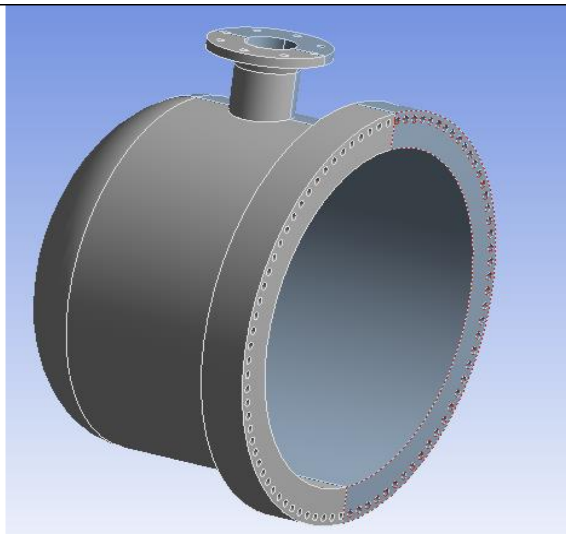
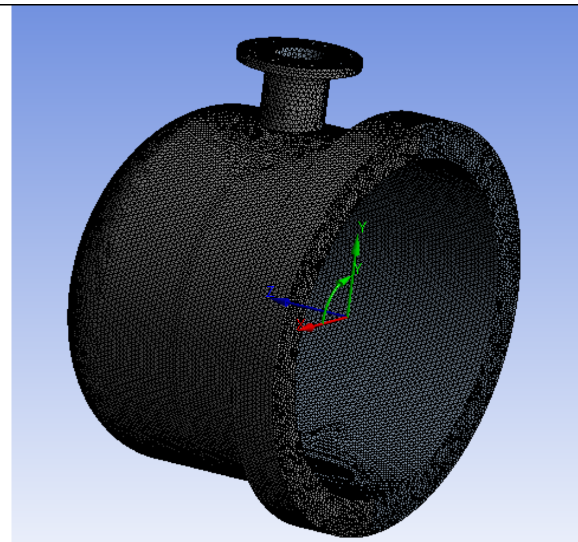
	

Fig1, 3D Geometry	Fig 2 3D Modeler

4) Apply the internal pressure load to the pressure boundaries of the vessel and an appropriate pressure thrust load to the nozzle and nozzle Axial load. Applied the appropriate boundary conditions to after meshing (fig,2)

5). Run analysis and reviewed results for Deformation and Von mises equivalent stress below figure 3&4

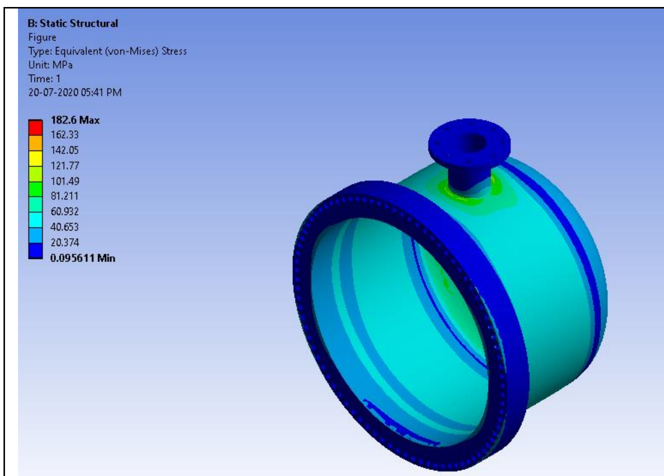


Fig: 3 Von mises equivalent stress

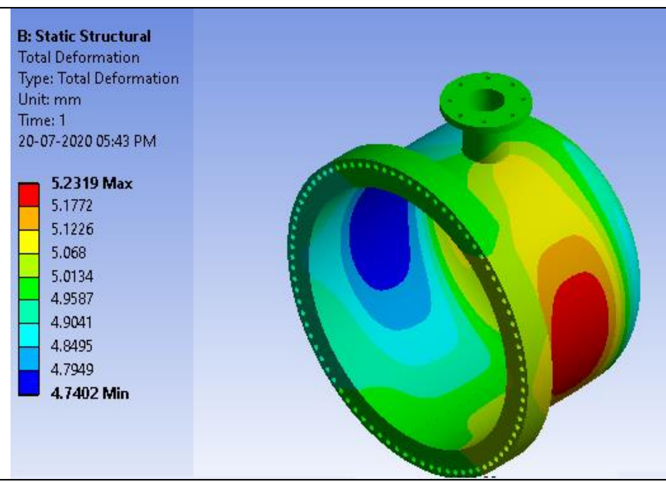


Fig 4 Deformation

STEP b) The Through wall stress linearization (Figure 5 to 12) were conducted at corroded areas in the shell location to provide data for assessment. The resultant von Misses stresses for Pm, PL, and Pb stress categories are summarized in Table 1

1. Placed proper stress tensor to an appropriate category for a component obtained by using ASME section VIII div. 2 Figure 5.1 and Table 5.6. The equivalent stresses Q and F do not required protection against plastic collapse.

2. Sum the stress tensors (stresses are added on a component basis) assigned to each equivalent stress category. The final result is a stress tensor representing the effects of all the loads assigned to each equivalent stress category.

3. The Pm equivalent stresses occur away from the head to shell junction, and PL and PL + Pb +Q equivalent stresses occur at the junction.

4. To evaluate protection against plastic collapse and local failure, compare the computed equivalent stress to their corresponding allowable values. See Table 4 for evaluation results.

For protection against plastic collapse for Elastic Analysis

Pm ≤Sm

PL≤1.5S $_{PL}$

PL+Pb≤1.5S$_{PL}$

The allowable limit on the local primary membrane and local primary membrane plus bending stress, S_{PL}, is computed as the maximum value of the quantities shown below.

a) 1.5Sm

b) S_y except the value of 1.5*S*m shall be used when the ratio of the minimum specified yield strength to the ultimate tensile strength exceeds 0.70,
S_{y} = 250/485 =0.515 < 0.70, this is not applicable
or when the value of the allowable stress *S*m is governed by time-dependent properties- Not applicable

so Sm will govern instead S_{PL}.The equation will be written as

Pm ≤Sm

PL≤1.5S Sm

PL+Pb≤1.5 Sm

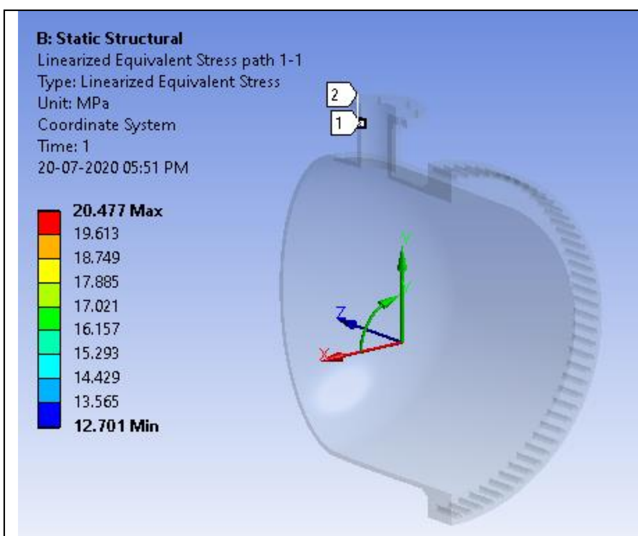


Fig: 5 Linearized stress 1-1

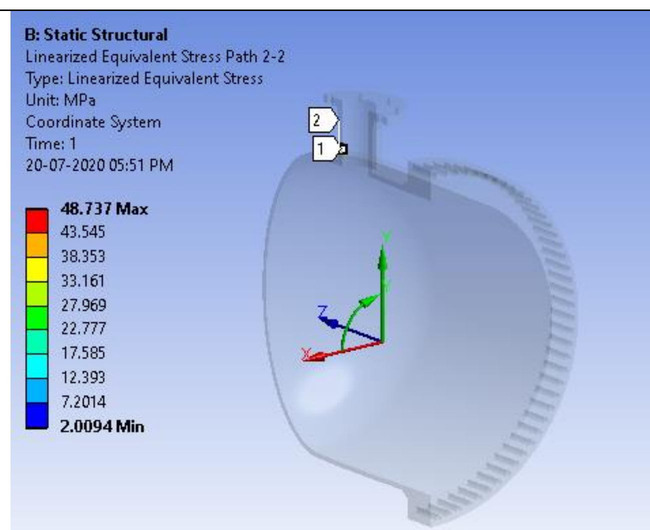


Fig: 6 Linearized stress 2-2

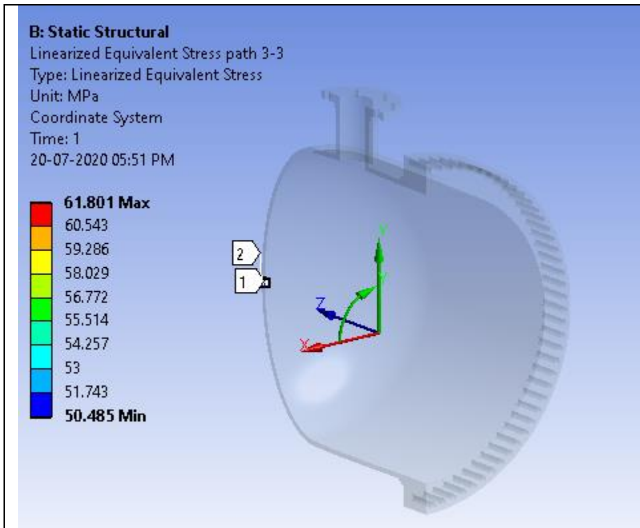


Fig: 7 Linearized stress 3-3

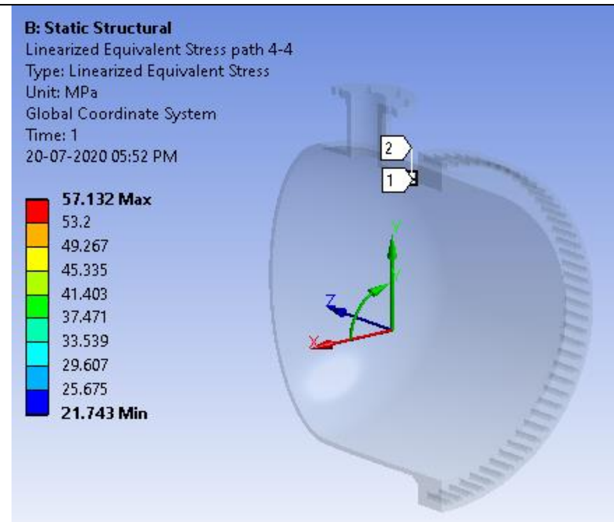


Fig: 8 Linearized stress 4-4

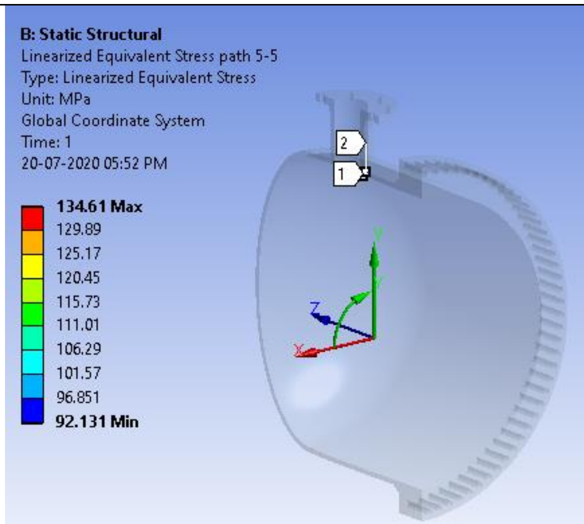


Fig: 9 Linearized stress 5-5

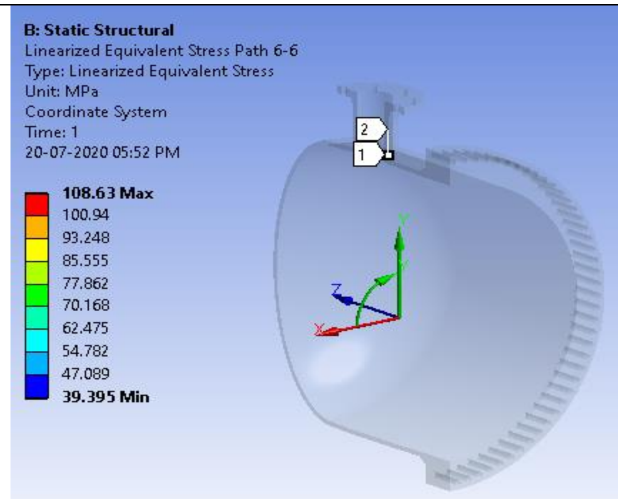


Fig: 10 Linearized stress 6-6

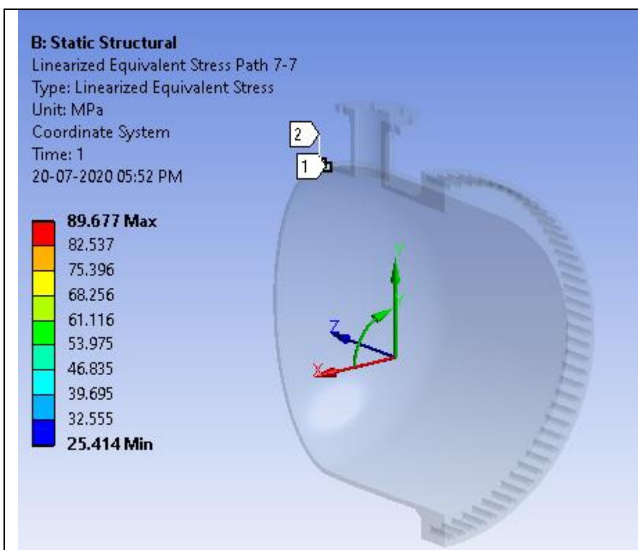


Fig: 11 Linearized stress 7-7

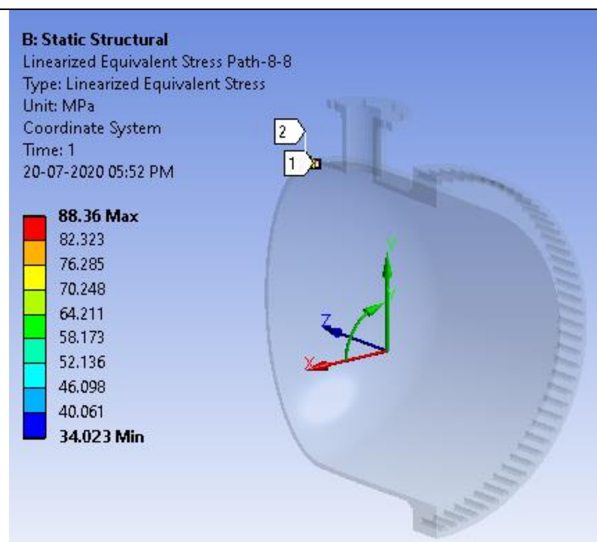


Fig: 12 Linearized stress 8-8

Table: 1

Stress categories (MPa)	Linearized Equivalent Stress Path from ANSYS workbench analysis							
	SCL 1-1	SCL 2-2	SCL 3-3	SCL 4-4	SCL 5-5	SCL 6-6	SCL 7-7	SCL 8-8
Membrane	13.558	20.627	56.218	30.637	98.952	73.924	42.544	50.037
Bending (Inside)	10.576	27.193	5.6556	31.231	58.195	34.799	48.86	44.175
Bending (Outside)	10.576	27.193	5.6556	31.231	58.195	34.799	48.86	44.175
Membrane + Bending (Inside)	14.312	47.723	50.563	57.119	128.75	108.62	86.749	87.64
Membrane+ Bending (Centre)	13.558	20.627	56.218	30.637	98.952	73.924	42.544	50.037
Membrane + Bending (Outside	19.66	7.2396	61.873	19.66	23.778	98.887	39.41	29.483
Peak (Inside)	1.0949	1.8726	7.8624e-002	1.0949	1.3561e-002	16.1	1.511e-002	4.1024
Peak (Centre)	1.0977	1.8659	7.6569e-002	1.0977	5.9395e-014	14.263	2.2508e-011	0.63383
Peak (Outside)	1.1004	1.8593	7.2932e-002	1.1004	1.3561e-002	20.94	1.511e-002	1.1801
Total (Inside)	14.489	48.737	50.485	14.489	57.132	134.61	108.63	89.677
Total (Center)	12.937	19.821	56.294	12.937	30.637	95.026	73.924	42.317
Total (Outside)	20.477	5.9162	61.801	20.477	23.784	106.71	39.395	28.7

4.0 PROTECTION AGAINST LOCAL FAILURE:

ELASTIC ANALYSIS — TRIAXIAL STRESS LIMIT

In addition to protection against plastic collapse the calculation, the local failure criteria shall be made for a channel head. This analysis procedures provides an approximation of the protection against local failure based on the results. The algebraic sum of the three linearized primary principal stresses from Ansys work bench results are utilised for below formula. The total (membrane +bend peak) principal stress summation as shown on result table 2 and the values shall less than or equal to 4 time of allowable stare (Sm).

$$\sigma 1 + \sigma 2 + \sigma 3 \leq 4S$$

Where

$\sigma 1$: - 1st Principal

$\sigma 2$: -2nd Principal

$\sigma 3$: - 3rd Principal

Note The Principals stresses are Primary local membrane stress + bending stress, no peak stress is considered.

5.0 RESULT ANALYSIS

Table .2 Results of the Elastic Analysis Using Criterion from of Paragraph 5.2.2.4 & 5.3.2 of the Section VIII, Div 2, Part 5 ASME Code

			Limit load analysis for plastic collapse							Local failure analysis (triaxial stress)			
SCL No.	Location	Material	Equivalent Linearized Stresses (Mpa)				Stress Equation			1st Principle stress	2nd Principle stress	3rd Principle stress	Stress Equation
			S_m	P_m	P_L	P_b	$P_m \leq Sm$	$P_L \leq 1.5\ Sm$	$P_L + P_b \leq 1.5\ Sm$	σ1	σ2	σ3	$\sigma1+\sigma2+\sigma3 \leq 4\ Sm$
1-1	Flange/nozzle	SA350 LF2 CL.1	156	NA	13.55	NA	NA	Pass	Pass	14.03	11.71	1.10	Pass
2-2	Nozzle upper zone	SA350 LF2 CL.1	156	NA	20.62	NA	NA	Pass	Pass	21.03	27.77	0.84	Pass
3-3	Dished head crown	SA516 GR70	164	56.21	NA	5.65	Pass	NA	NA	55.30	6.74	0.058	Pass
4-4	Shell to body flange junction	SA516 GR70/SA 350 LF2 CL1	164	NA	30.63	NA	NA	Pass	Pass	27.81	36.04	0.015	Pass
5-5	Shell to nozzle junction	SA516 GR70/SA 350 LF2 CL1	164	NA	98.95	NA	NA	Pass	Pass	113.04	56.41	7.46	Pass
6-6	Nozzle to shell junction	SA516 GR70/SA 350 LF2 CL1	164	NA	73.92	NA	NA	Pass	Pass	73.88	36.84	0.015	Pass
7-7	Knuckle	SA516 GR70	164	NA	42.54	NA	NA	Pass	Pass	32.57	54.35	2.97	Pass
8-8	Head to shell junction	SA516 GR70	164	NA	50.03	NA	NA	Pass	Pass	33.81	49.08	0.63	Pass

References

ANSYS workbench (version 19.2) [FEA software]
Solid works (2015 version) [3D software]
ASME Boiler & Pressure Vessel Code, Section VIII Div.2
Dennis R. Moss, Pressure Vessel Design Manual Ed 4
ASME Section II Part D Edition.
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ASME PTB-3-2013