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Static Structural and Transient Thermal Analysis of APR1400 Reactor Pressure Vessel

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1.0 Introduction

Advanced Power Reactor 1400MWe (APR1400) vessels are designed taking into considerations parameters of pressures, weights, temperatures and volumes. These parameters are chosen based on ASME codes. An elaborate knowledge of operational conditions of the RV is important to assure longevity in the structural and thermal integrity of the vessels. Any compromise on the vessel may cause rapture, which in turn may exhibit grave physical injury and property damage [1].

The objective of this study was to undertake RV analysis under structural loading conditions. It also did transient thermal analysis for temperate and heat flux distributions in the vessel under thermal loading conditions.

2.0 Methods and Results

2.1 Finite Element Analysis (FEA)

The study used design approach based on FEA to remove undue conservatism of current codes for engineering design. This approach has widely been used by various researches on both fracture mechanics and stress analysis of various parts of reactor vessels [2], hence justifying its use for this research.

The RV was modeled in ANSYS Workbench, with the major parameters being 2330mm and 2445mm inner and outer radius of cylindrical section of the RV, 2495mm outer radius for the hemispherical section, 165mm lower head thickness of the RV.

The model was then shafted and considerations made for the cold leg (including its associated support base) and hot leg regions. The design based approach portrays completeness of design information and ability to simulate both ideal and realistic conditions [3].

2.2 Meshing

A medium-sized tetrahedron mesh was used for static structural and transient thermal analysis to improve the mesh quality and closeness of the result. This was aimed to further assist in visualizing exact behavior of the pressure vessel. The result of the meshing operation is as shown in Fig. 1 below.

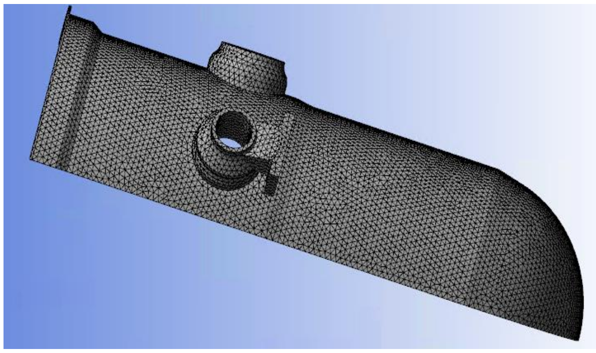

Fig. 1. Meshing of the RV

2.3 ANSYS Design Parameters

Some of the mechanical properties of steel that are taken into account during the design of APR1400 are as in Table 1 below.

Table 1: ANSYS design parameters

S/No.	Particulars	Properties
1	Density	7833 Kg/m^3
2	Modulus of elasticity	2 x 10^5 N/mm^2
3	Poison's ratio	0.3
4	Closure head pressure	0.1103Mpa
5	RV Internal pressure	17.237MPa
6	RV Internals loadings	16.23MPa
7	Internal temperatures	343.3^0C

2.4 Boundary Conditions

Transient thermal and static structural conditions were applied on various sections of the model. Thermal conditions of temperature and convection process parameters were applied on appropriate surfaces.

Static structural conditions of internal pressure and loads, frictionless support on cut plane condition are applied on appropriate planes and surfaces [4].

2.5 Analysis Results

According to ASME Section III NB codes, linearized stress analysis is performed on the vessel body at four (4) locations: Top flange, vessel cross-section, cold and hot leg nozzle locations. Results of the linearized stress paths are shown in Fig. 2, Fig. 3, Fig 4 and Fig. 5 below.

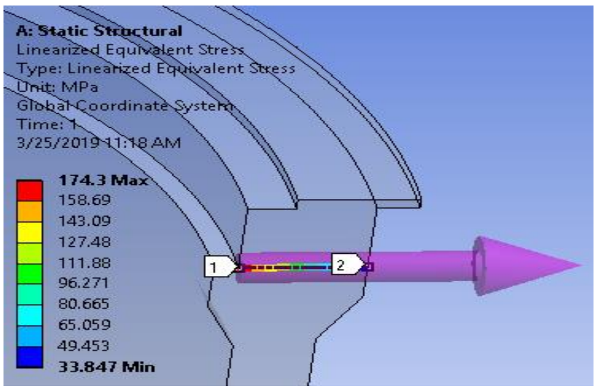

Fig. 2. Linearized stress path for top flange region

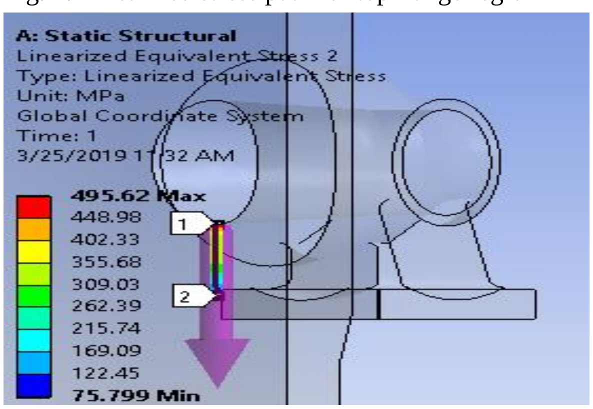

Fig. 3. Linearized stress path for cold leg

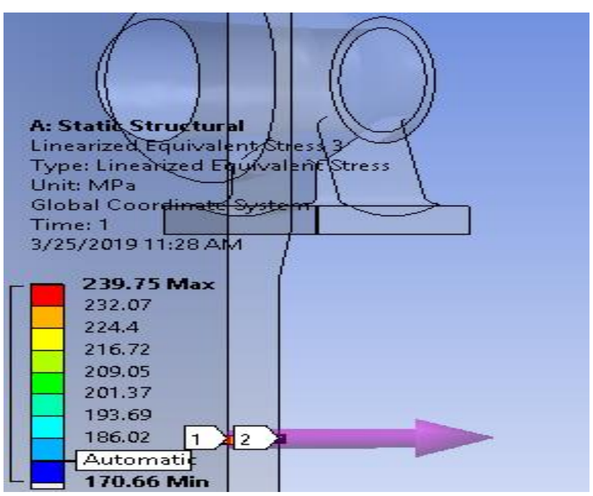

Fig. 4. Linearized stress path for RV section

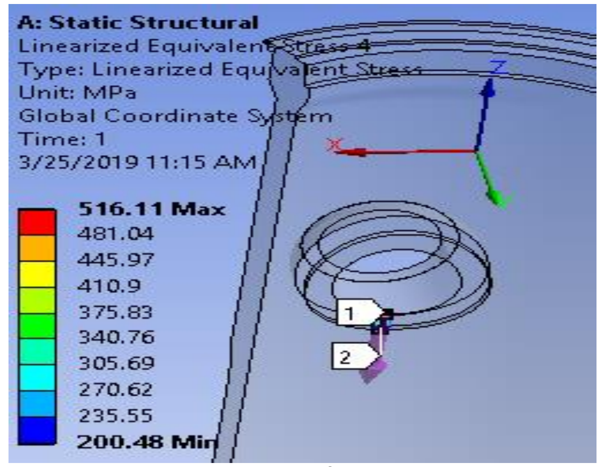

Fig. 5. Linearized stress path for hot leg

Results for the static structural analysis

From the static structural analysis, results show that the least total deformation (i.e. of 1.7275mm) is exhibited in the cold leg region with the highest i.e. 13.92mm being at the top flange of the vessel. The results of the total deformation is as illustrated in Fig. 6 below:

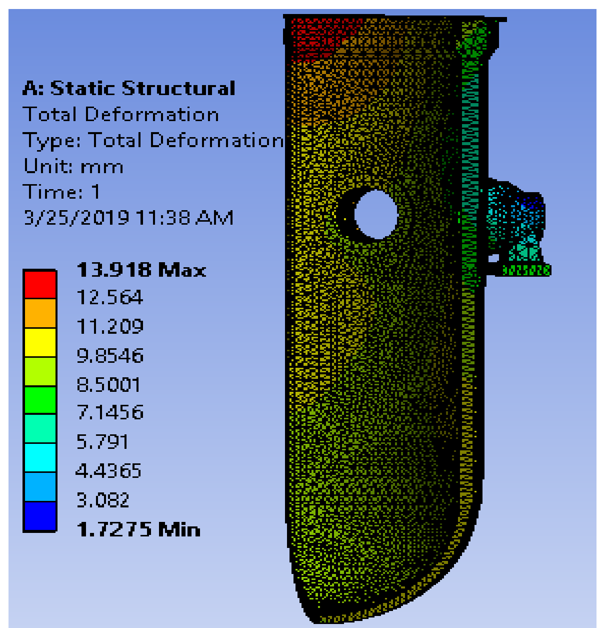

Fig. 6. Total deformation

Deformation of the vessel is caused by both thermal expansion and applied loads and is maximum at the top flange of the pressure vessel. The maximum established equivalent (Von Mises) stress across the vessel is 2149.1 MPa and is as shown in Fig. 7 below:

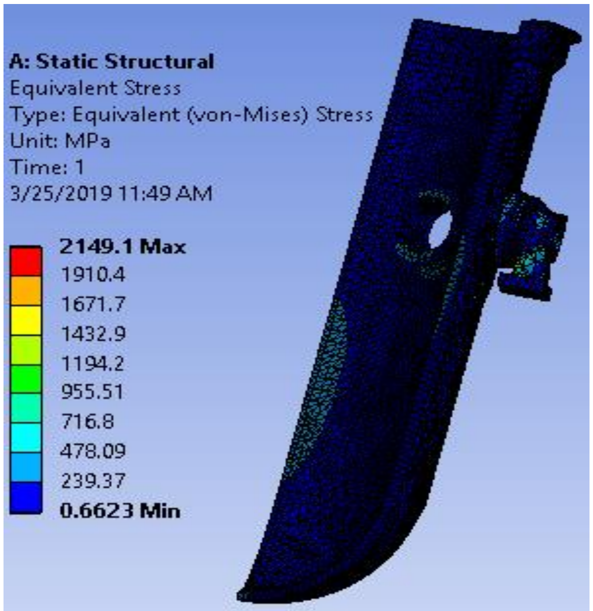

Fig. 7. Stress distribution on vessel

The total heat flux was computed in the vessel, with results shown in Fig. 8 below. Transient thermal analysis was undertaken with major model parameters given as temperature 343^0C in the internal surfaces and convection process on the exterior surface.

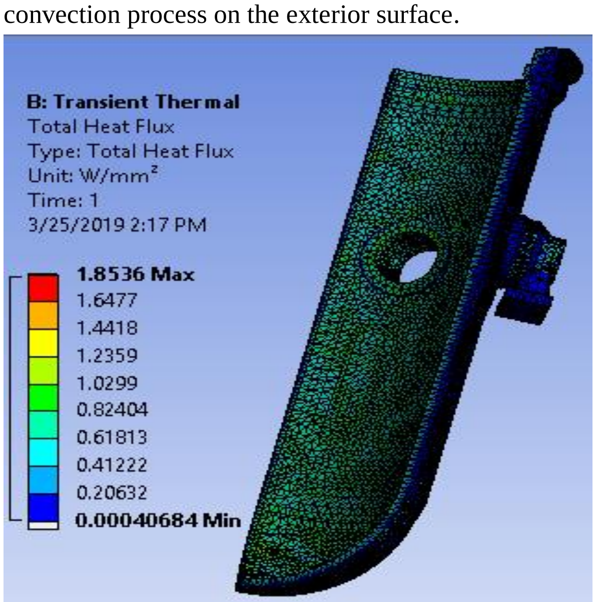

Fig. 8. Heat flux distribution on vessel

For the convection process across the exterior of the pressure vessel, a film coefficient of 0.022975 $W/mm^2.^0C$ and ambient temperature of 130^0C (step applied) was applied. The general state of nucleate boiling at the RV surface was simplified by these two parameter conditions [5].

3. Conclusions

From analysis results, maximum deformation of the APR1400 vessel occurs at top flange region of the vessel while minimum is within the cold leg regions. Equivalent (Von) Mises stress is maximum at 2149.1MPa. Also, the minimum heat flux is experienced in the top flange region of the vessel.

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