Stress Analysis of Plenums and End-Shield of 100 MW Research Reactor

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Abstract

Different analysis procedures adopted for the analysis of large components of pile block of Dhruva research reactor are explained. Loads coming onto these components are identified which depend upon the reactor conditions. An analysis method is explained to make use of plate elements for nonlinear temperature gradient across thickness. Results obtained for these components are also quoted.

1. Introduction

The general arrangement of pile block of 100MW(thermal) Dhruva research reactor is shown in fig 1. Calendria of this reactor is a single walled stainless steel AISI type 304L vessel /1/. It consists of bottom plenum, lower sub-shell, main shell, upper sub-shell, top plenum and upper sub-shell extension. Another major component of pile block is the End-Shield, which provides shielding between the service space and the reactor core.

The two enclosures of the calendria, i.e. top and bottom plenums are composite tube sheets. Besides the mechanical loads coming onto the plenums, such as moderator pressure, fuel channel weights, buoyancy due to vault water etc., they are also subjected to thermal loads due to heat generation by nuclear radiations. These loads vary in magnitudes as well as in directions depending upon the reactor conditions. This demands for a complete stress analysis of the plenums for different loading conditions and also it is required to compute maximum stress range seen by any point for different combinations of conditions.

End-Shield is also a composite tube sheet in which three tube sheets are integrally connected by lattice tubes. Though thermal load on the End-Shield is found to be negligible and also loads on the End-Shield do not change with the reactor conditions, a detail stress analysis is called for due to large weights it carries in the form of steel balls and water for shielding purpose.

In the present work detail stress analysis of both plenums and End-Shield is carried out. The following sections deal with the finite element modelling, types of loads, analysis procedures and also results obtained for these components.

2. Analysis of Plenums

As mentioned above top and bottom plenums are composite tube sheets. In case of top plenum two circular tube sheets are integrally connected by lattice tubes and an outer
peripheral shell. Whereas bottom plenum consists of two triangular shaped tube sheets. Heavy water enters the bottom plenum through three inlet pipes connected at the three corners of the triangular tube sheets. The choice of triangular tube sheets minimises heavy water inventory. Mechanical and thermal loads coming onto the both plenums change with the reactor conditions. Five set of loadings for top plenum and three set of loadings for bottom plenum are identified which correspond to normal and accidental reactor conditions.

Various thermal analysis are done to obtain temperature distributions in top and bottom plenums for different volumetric heat generations and heat transfer coefficients/2/. To obtain temperature distribution in perforated region of the plenums, an axisymmetric thermal analysis of one lattice is done isolating it from the rest/3/. This is because a similar temperature distribution is expected to be repeated for every lattice and hence no heat flow conditions between lattice boundaries can be assumed. A separate thermal analysis is done to compute temperature distribution in the outer rim of the top plenum which is an axisymmetric body.

A finite element model by plate and beam elements with the concept of equivalent plate theory and stress multipliers/4/ seems to be unavoidable for stress computations, as computer memory and cost required for a complete 3-D model may be prohibitive. Thermal loads on a plate element is restricted by linear thermal gradient only, whereas in the present case highly nonlinear temperature distribution is obtained due to consideration of volumetric heat generation. To overcome these conflicting requirements, in the present work a new analysis method with the concept of seperating out a linear gradient from a nonlinear temperature distribution is used such that remaining nonlinear distribution is as symmetric as possible with respect to midplane of each tube sheet. This ensures negligible transverse deflection of the composite tube sheet due to symmetric nonlinear gradients only. Hence non-dilation nature of this stress field allows one to compute stress distribution by analysing some simplified model. In the present case axisymmetric model of each plenum, in which lattice tubes are simulated by axisymmetric concentric shells having equivalent axial stiffness is used to compute stress distribution due to nonlinear symmetric temperature distribution only. Linear gradient along with other mechanical loads are then used on plate and beam models of plenums /5/. Superimposing stresses from both the analysis, final stresses are obtained. Fig.2 and Fig.3 show the deflection patterns obtained for top and bottom plenums corresponding to different reactor conditions respectively. Also fig.4 shows the maximum stress intensities obtained for various reactor conditions for top and bottom plenums.

To compute maximum stress range seen by any point of the plenums different paths are identified through which reactor is expected to go during its life time. These paths are the different combination of reactor conditions mentioned above. No transient analysis is attempted with the assumption that reactor attains these conditions quasi-statically. Fatigue cycles associated to maximum stress range are found to be much more than the reactor is expected to see. Fig 5 summarises the analysis procedure adopted for the plenums.

3. Analysis of End-Shield

The general arrangement of End-Shield is shown in fig.1. This consists of three tube
sheets connected integrally by lattice tubes and a shell at the outer periphery. The top tube sheet is extended at the outer periphery and a box type section is made which rests on an octagonal annular shield. The End-Shield carries large quantity of steel balls and also water for shielding. Steel balls are kept on a perforated stool type of structure, which is kept between top and middle tube sheets. The outer ring of the stool touches the middle tube sheet only near the outer periphery. This arrangement reduces the vertical deflection of the End-Shield.

To obtain a complete picture of the stress distribution in the End-Shield, three analyses are done with the three different specific aims. In the first analysis plate and beam elements are used to model the complete End-Shield but the stool which carries the steel balls. This analysis is done to estimate a gross stress distribution at different points in the End-Shield body. Weight of water, steel balls and body weight of End-Shield are the considered loads on the model. In the second analysis only stool carrying steel balls is discretised by plate elements using the concept of equivalent plate and stress multipliers. The object of this analysis is to obtain stresses in the stool, which is loaded by steel balls and its own weight. The third analysis is aimed to pick up stress concentration near the box type support at the outer periphery. Since it is necessary to consider a large number of elements to compute stress concentrations, an axisymmetric model of the End-Shield is made by the help of axisymmetric thin shell elements, in which lattice tubes are simulated by axisymmetric concentric shells having equivalent axial stiffness. This is done with the assumption that since box type support is quite a bit away from lattice tubes and hence a simulation by symmetric shells does not change the stresses concentrations in the support considerably. Fig.6 shows the maximum stresses obtained in these three analyses and locations of occurrence.

Conclusions

Different analysis procedures are shown which can be adopted to analyse large components of a nuclear reactor. Deformations and stresses obtained for these major components of Dhruva research reactor are computed and are found to be within acceptable limits.

References

5/ Bathe,K.J.,Wilson,E.L., "SAP Structural analysis program"
E - EXTENSION TUBE.
S - STUMP TUBE.
P - POISON TUBE.

FIG. 1 GENERAL PILE BLOCK ARRANGEMENT OF DHRIWA REACTOR
FIG. 2 TOP PLENUM DEFLECTION PATTERN

FIG. 3 BOTTOM PLENUM DEFLECTION PATTERN

<table>
<thead>
<tr>
<th>PLENUM</th>
<th>CASE</th>
<th>LOCATION</th>
<th>( \sigma_{\text{max}} )</th>
<th>( \sigma_{\text{avg}} )</th>
<th>( \epsilon_{\text{max}} )</th>
<th>INTERESTING FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOP</td>
<td>1</td>
<td>NEAR TO POISON TUBE</td>
<td>(-181.4)</td>
<td>(-184.6)</td>
<td>(-155.0)</td>
<td>(1540)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>INTERFACE BETWEEN PERFORATED REGION AND OUTER SLEEVE</td>
<td>16.40</td>
<td>13.7</td>
<td>1680</td>
<td>(1937)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>CENTRE</td>
<td>(-115.4)</td>
<td>(-1579.0)</td>
<td>(-137.7)</td>
<td>(1579.0)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>CENTRE</td>
<td>(-81037)</td>
<td>(-19176)</td>
<td>(-1423.0)</td>
<td>(1939)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>NEAR TO POISON TUBE</td>
<td>(-0.874)</td>
<td>(-1580.5)</td>
<td>(-325.9)</td>
<td>(1590.1)</td>
</tr>
<tr>
<td>BOTTOM</td>
<td>1</td>
<td>INTERFACE BETWEEN PERFORATED REGION AND OUTER SLEEVE</td>
<td>1720</td>
<td>-6</td>
<td>1212</td>
<td>(1720)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>(-0.0201)</td>
<td>(-0.010)</td>
<td>(-0.01)</td>
<td>(1600)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td>(-921)</td>
<td>(-511)</td>
<td>(-85925)</td>
<td>(1640)</td>
</tr>
</tbody>
</table>

TABLE LOCATIONS AND MAXIMUM STRESSES FOR TOP AND BOTTOM PLENUM
ANALYSIS OF A PLENUM

INPUTS
1. Different k, values for different cases for different surfaces
2. Heat generation for different cases

DESCRIPTION
Temperature distribution of lattice region by ANSYS
Temperature distribution of outer rim region by ANSYS
Separation of linear and non-linear temp. distribution

NONLINEAR TEMPERATURE DISTRIBUTION
LINEAR TEMPERATURE DISTRIBUTION
ANALYSIS OF EQUIVALENT AXISYMMETRIC PLATE BY PLAXIS
TRANSFORMATION OF
\[ E_s, E_a, T_{xx} \rightarrow E_s, E_a T_{yy} \]

STRESS ANALYSIS
ANALYSIS OF THE PLENUM BY SAP4
Inputs all mechanical loads
Displacements at nodes, moments and forces for all elements
Conversion of all moments and forces for plate & shell elements to stresses
Conversion of all moments and forces of beam elements to stresses
Transformation of stresses to global coordinates
Superposition with PLAXIS stresses

MODIFICATION WITH MULTIPLIER

Fatigue analysis for different identified loops
Fatigue cycles for different loops

FIG. 5 ANALYSIS PROCEDURE ADOPTED FOR A PLENUM

<table>
<thead>
<tr>
<th>NO</th>
<th>ANALYSIS AIM</th>
<th>LOCATION OF OCCURRENCE OF MAXIMUM STRESS</th>
<th>MAX. STRESS INTENSITY BY TRESCA (kg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>To compute gross stress picture in end shield main body</td>
<td>Near to octagonal support line</td>
<td>205.0</td>
</tr>
<tr>
<td>3</td>
<td>To compute stress in stool structure</td>
<td>Centre point</td>
<td>710.0</td>
</tr>
<tr>
<td>3</td>
<td>To compute stress concentration in box type support</td>
<td>Joint between box type support and top tube sheet</td>
<td>384.1</td>
</tr>
</tbody>
</table>

FIG. 6 MAXIMUM STRESSES AND LOCATION OF OCCURRENCES IN END SHIELD