CHAPTER 4

DEVELOPMENT OF NUMERICAL MODEL

OF ROOF SLAB

The geometric model of the roof slab shown in Figure 4.1 is developed using ANSYS software by specifying the key dimensions as parameters. The parametric model will be used for performing sensitivity analysis and design optimization using FEA where the parameters could be varied within design limits.

Figure 4.1 Geometric model of the roof slab
4.1 FINITE ELEMENT MODELING OF ROOF SLAB

The parametric dimensions of the existing roof slab given in Table 4.1 are the height of the roof slab and various thicknesses such as plate thickness and shell thickness. The dimensions are assigned as individual parameters and defined as real constants in the finite element model. The various dimensional parameters of the roof slab are highlighted in Figure 4.2.

Table 4.1 Geometrical description of roof slab

<table>
<thead>
<tr>
<th>Description of geometry</th>
<th>Parameter</th>
<th>Value (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of the roof slab</td>
<td>H</td>
<td>1.80</td>
</tr>
<tr>
<td>Thickness of top/bottom plate</td>
<td>T₁</td>
<td>0.03</td>
</tr>
<tr>
<td>Thickness of inner shell</td>
<td>T₂</td>
<td>0.03</td>
</tr>
<tr>
<td>Thickness of outer shell</td>
<td>T₃</td>
<td>0.03</td>
</tr>
<tr>
<td>Thickness of the radial stiffener</td>
<td>T₄</td>
<td>0.03</td>
</tr>
<tr>
<td>Thickness of IHX and PSP shell</td>
<td>T₅</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Figure 4.2 Parametric dimensioning of the roof slab model
A four-node quadrilateral shell element (SHELL63) is used for meshing as it has combined bending-membrane, in-plane and normal load capabilities. In order to ensure that a mesh independent solution is obtained, seven finite element models were examined with increasing number of elements: 1,26,336, 1,30,397, 1,36,663, 1,41,502, 1,47,407, 1,53,645, and 1,59,300. It was found that the difference in the result of deflection obtained using fourth and fifth models is minimal and hence the fourth model shown in Figure 4.3 is adopted for further numerical simulations.

![Figure 4.3 Finite element model of the roof slab](image)

The surface model of the roof slab prior to meshing consists of a number of areas and each area is glued with the adjacent area for ensuring nodal connectivity. The outer shell, top plate, bottom plate and radial stiffeners are assigned with low carbon A48P2 steel and the main vessel with AISI 316LN steel material. The material properties of the components of roof slab at the working temperature of 100\(^\text{o}\)C are given in Table 4.2.
Table 4.2 Properties of materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus (N/mm²)</th>
<th>Poisson’s ratio</th>
<th>Density (kg/mm³)</th>
<th>Average yield strength (N/mm²)</th>
<th>Ultimate strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A48-P2</td>
<td>2.05x10⁵</td>
<td>0.30</td>
<td>7.850x10⁻⁶</td>
<td>225</td>
<td>470 (UTS)</td>
</tr>
<tr>
<td>316LN</td>
<td>1.785 x 10⁵</td>
<td>0.30</td>
<td>7.850 x10⁻⁶</td>
<td>128</td>
<td>515(UTS)</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.3 x 10⁵</td>
<td>0.30</td>
<td>2.400 x10⁻⁶</td>
<td>-</td>
<td>35(UCS)</td>
</tr>
</tbody>
</table>

The loads acting on the roof slab are listed in Table 4.3 and the location of each component of the roof slab is indicated in Figure 4.2. The total load supported by the roof slab is more than 3800 tonnes.

Table 4.3 Component loads acting on roof slab

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Description</th>
<th>No. of units</th>
<th>Load (MN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main Vessel(MV) and other components</td>
<td>1</td>
<td>21.00</td>
</tr>
<tr>
<td>2</td>
<td>Intermediate Heat Exchanger</td>
<td>4</td>
<td>4.03</td>
</tr>
<tr>
<td>3</td>
<td>Primary Sodium Pump</td>
<td>2</td>
<td>1.92</td>
</tr>
<tr>
<td>4</td>
<td>Large Rotatable Plug and its components</td>
<td>1</td>
<td>4.74</td>
</tr>
<tr>
<td>5</td>
<td>Decay Heat Exchanger</td>
<td>4</td>
<td>0.48</td>
</tr>
<tr>
<td>6</td>
<td>Self weight including shielding</td>
<td>-</td>
<td>6.10</td>
</tr>
<tr>
<td></td>
<td><strong>Total load</strong></td>
<td></td>
<td><strong>38.27</strong></td>
</tr>
</tbody>
</table>
4.2 BOUNDARY AND LOADING CONDITIONS

The support shell is reinforced with internal stiffeners (Figure 4.2) and the gaps between stiffeners are filled with concrete in the reactor vault (Figure 1.2), thus arresting the mobility of the roof slab in all directions. The loads of various components supported by the roof slab can be incorporated using three methods viz. (i) uniformly distributed load, (ii) load per node and (iii) effective density.

In the first method, the weight of the component is applied as distributed load by dividing the component weight with the corresponding surface area over which the component is seated. In the second method, the component weight is converted into load per node, i.e., by dividing the component weight with the total number of nodes attached to the corresponding surface area over which the component is seated. In the last method, the density of the flange where the component is mounted is altered, so that the new weight of the flange equals the sum of actual weight of the flange and the respective component weight. The effective density used to account for the component load is derived as given below:

\[
\text{Total mass } 'M' = M_s + M_c \tag{4.1}
\]

where \( M_s \) - Mass of the flange where the component rests

\( M_c \) - Component mass

(i.e.,) \( \rho_{\text{eff}} \cdot V_s = \rho_s \cdot V_s + M_c \tag{4.2} \)

Rearranging the terms,

\[
\rho_{\text{eff}} = \rho_s + \frac{M_c}{V_s} \tag{4.3}
\]

where \( \rho_{\text{eff}} \) - effective density
\[ \rho_s \] - density of the material

\[ M_c \] - component mass

\[ V_s \] - volume of the flange where the component rests

All the above mentioned methods can be used for performing the static analysis of the structure, but for free vibration analysis, only the effective density method is suitable as the external loads cannot be applied. For static analysis, all the component loads except main vessel load are applied using the first method i.e., by uniformly distributed load, on their respective flange areas as mentioned in Table 4.4. The main vessel load and the shielding concrete load are applied based on second method, i.e., by load per node. The self weight of the entire roof slab is applied by invoking the ‘gravity’ option in the software.

**Table 4.4 Conversion of component load to distributed load**

<table>
<thead>
<tr>
<th>Description of Component</th>
<th>Load (MN)</th>
<th>Flange area (m²)</th>
<th>Distributed load ( \times 10^5 ) (N/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermediate heat exchanger</td>
<td>1.01</td>
<td>1.116</td>
<td>9.02</td>
</tr>
<tr>
<td>Flask</td>
<td>2.50</td>
<td>1.116</td>
<td>22.4</td>
</tr>
<tr>
<td>Primary sodium pump</td>
<td>0.96</td>
<td>0.695</td>
<td>13.8</td>
</tr>
<tr>
<td>Large rotatable plug</td>
<td>4.74</td>
<td>7.140</td>
<td>6.64</td>
</tr>
<tr>
<td>Decay heat exchanger</td>
<td>0.12</td>
<td>0.353</td>
<td>3.40</td>
</tr>
</tbody>
</table>
The gap between the top and bottom plates excluding the penetrations are filled with concrete as a biological shielding for nuclear reaction. The concrete is filled on several cooling box sectors shown in Figure 4.4 and concrete load will be acting through the contact edges of the cooling box on the bottom plate.

**Figure 4.4 Details of cooling box sectors**

The concrete load on each cooling box varies due to the difference in the volume of the cooling box. The weight of each cooling box is applied at the nodes in the bottom plate along the contact edges of the cooling box. The nodes along the common line between any two boxes will share the loads of adjacent boxes. The details of cooling box load, load per node along cooling box edges and load at common lines between adjacent cooling boxes are given in Table 4.5.
Table 4.5 Concrete load on each cooling box

<table>
<thead>
<tr>
<th>Cooling box sectors</th>
<th>Weight (N)</th>
<th>No. of nodes</th>
<th>Load per node (N)</th>
<th>Load per node along common lines (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2,02,086</td>
<td>250</td>
<td>808</td>
<td>1,528</td>
</tr>
<tr>
<td>B</td>
<td>2,59,965</td>
<td>361</td>
<td>720</td>
<td>1,547</td>
</tr>
<tr>
<td>C</td>
<td>2,84,490</td>
<td>344</td>
<td>827</td>
<td>1,609</td>
</tr>
<tr>
<td>D</td>
<td>2,9,4300</td>
<td>376</td>
<td>782</td>
<td>1,760</td>
</tr>
<tr>
<td>E</td>
<td>2,84,490</td>
<td>291</td>
<td>977</td>
<td>1,844</td>
</tr>
<tr>
<td>F</td>
<td>2,16,801</td>
<td>250</td>
<td>867</td>
<td>1,592</td>
</tr>
<tr>
<td>I</td>
<td>2,61,927</td>
<td>361</td>
<td>725</td>
<td>1,592</td>
</tr>
<tr>
<td>G</td>
<td>2,98,224</td>
<td>344</td>
<td>866</td>
<td>1,716</td>
</tr>
<tr>
<td>H</td>
<td>2,84,490</td>
<td>335</td>
<td>850</td>
<td>1,800</td>
</tr>
<tr>
<td>J</td>
<td>2,84,490</td>
<td>299</td>
<td>951</td>
<td>1,759</td>
</tr>
</tbody>
</table>

Figure 4.5 represents a portion of concrete load applied on the nodes along the edges of the cooling boxes A, J and H.

![Concrete load on cooling box](image)

Figure 4.5 Concrete load applied along the cooling box edges
The roof slab model with the applied boundary conditions and component loads are shown in Figure 4.6.

![Figure 4.6 Roof slab model with component loads and constraint](image-url)
Since the support shell of the roof slab is filled with concrete internally and covered with concrete in the reactor vault externally as well, the roof slab is constrained in all directions. Hence the stiffeners of support shell and the bottom surface of the support shell of the roof slab are constrained in all degrees of freedom. The concrete load and main vessel load are given as point loads and the component weights are applied as surface loads. The magnitude of total reaction forces based on finite element analysis is verified for static equilibrium to ensure that all the applied loads are taken into account. The numerical model presented in this chapter is adopted for static and dynamic analyses.