SEISMIC ANALYSIS OF PFBR IN-VEssel TRANSFER MACHINE

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1 INTRODUCTION

The In-Vessel Transfer machine (IVIM) is used to handle core subassemblies consisting of fuel, control, blanket and reflector subassemblies in the core and storage positions. This is a tall structure of about 12 m height above operating floor of RCB during fuel handling condition and an additional structure of about 6 m height is added during maintenance. IVIM is supported on Small Rotating Plug (SRP). A tubular structure called gripper assembly is used to handle the fuel subassemblies. It slides through a leak tight container. A linear actuator which is used to operate the gripping fingers is mounted at the top end of the gripper assembly. Guide tube guides the gripper assembly below the roof slab. Gripper hoisting mechanism is used for moving gripper assembly upwards/downwards by means of a steel rope. Top structure rotating mechanism is used to rotate the top structure so that gripping fingers can be aligned with the fuel subassembly during fuel handling. Scraper box is for removing sodium from outer tube of the gripper subassembly and gate valves are used to isolate the reactor cover gas during maintenance. Lead screws and its driving mechanism are employed to lift the guide tube when IVIM is not required for fuel handling. Additional top structure is provided for maintenance work on IVIM. To avoid any undue over loading of the gripper assembly, tension sensing elements are provided at the top of the top structure (Fig.1).

On the whole IVIM is a very tall complex structure having concentric pipes of gripper assembly, guide tube & leak tight container, eccentric pipes of top structure pipes, lead screws and eccentric masses which represent top structure rotating, tension sensing, lead screw driving mechanisms, and ladder etc. Hence the structural response of IVIM structure has to be assessed under seismic conditions in order to check its integrity and functional requirement.

2 DESIGN REQUIREMENTS

Under OBE, IVIM should remain functional. Hence the stresses should be limited to ASME code values. The OBE is treated as level C condition since it is possible to inspect it after OBE. However stresses in the bolts are to be limited to level B so that the stresses are within the elastic limit.
which will avoid any leakage as well as gross tilting of IVIM structure. Elastic deflections do not have any limit as such provided the consequences of impact do not produce unacceptable stresses and also permanent deformation which obstructs the movement of gripper.

3 ANALYSIS METHODOLOGY

The structure is analysed for the seismic acceleration values of 0.2g for SSE (ZPA) and 0.065g for OBE (ZPA) for horizontal excitation. For vertical excitation, half of the horizontal seismic acceleration values have been taken. The seismic analysis is carried out in two phases. In the first phase, a time history analysis of a beam model consisting of containment building, base raft, concrete vault, main vessel etc., is performed. For this, the spectrum compatible accelerogram corresponding to the given design response spectra is used. From this analysis, the floor response spectra at SRP level is obtained. This floor response spectra at SRP level for horizontal direction which has been used in the subsequent response spectrum analysis, is given in Fig.2. From the analysis, global stresses and deflections have been found. Calculations have been done to analyse the stresses in the bolts which are used to connect leak tight container with SRP and structure for gate valves, and top structure with slewing ring and contact stress between gripper assembly and guide tube due to impact. Since the analysis is linear the results can be extrapolated to higher values of seismic accelerations.

3.1 Modelling features

IVIM is a tall complex non-axisymmetric structure. It is having flexible parts like gripper assembly which is hung through a rope and many sliding components. These features make the modelling more complex. The following are salient points of modelling (Fig.3):

- The 3-D beam elements of 'FAPEC' code have been used to model the structure.
- The leak tight container is modelled realistically.
- The two lead screws are modelled with correct distance from leak tight container.
- The inertial effects of guide tube hoisting mechanism and upper bearing of lead screws are taken care by lumping their masses in the lead screw as M6 and M7 respectively.
- From leak tight container structures for gate valves and vertical stiffeners are modelled. The mass of the gate valves, standing platform and top structure rotating mechanism including geared motor and scraper box are lumped and indicated as M9, M10 and M11 respectively. The top structure is then modelled.
- The three pipes and two rails are placed properly with respect to each other. The ladder mass including the mass of the persons at top, is lumped at two places and indicated as M12.
- The bottom portion of the gripper assembly is immersed in the sodium. Fluid structure interaction effects have been taken through lumped mass technique.
- The other important lumped masses are hoisting mechanism (M13), tension sensing mechanism and pulleys (M14), flanges (M15,M16), stiffeners joining vertical pipes (M17) sodium mass (M18), and linear actuator for gripper (M4).
- The mass of fuel subassembly is included during fuel handling condition
and the additional top structure is modelled for maintenance condition. Hence the modelling of IVIM is done for following conditions.

1. Fuel handling condition
2. Reactor operating condition
3. IVIM maintenance condition

- For vertical excitation the whole mass of the gripper assembly is lumped in the top structure. Moreover, the inertial effects of lumped masses are different for two horizontal directions.
- The sliding contacts in some of the structures between inner and outer tube of gripper assembly, gripper assembly and rails are modelled by master slave option. This allows the sliding contacts to move together in horizontal direction and independently in vertical direction. Hence modelling is different for two horizontal and one vertical excitations.

The method used by EPRI for the analysis of IIHX of 1000 MWe reactor is followed here for the present analysis [EPRI 1978]

4 RESULTS OF ANALYSIS

4.1 Free Vibration Analysis

The free vibration analysis of IVIM is performed for all operating conditions in three directions. Their natural frequencies and natural mode shapes have been extracted. The important natural mode shapes along with their natural frequencies have been shown in Fig.5.

4.2 Displacement Response

Response spectra analysis of IVIM is performed. The displacement response of the structure has been obtained by square root of sum of the squares technique. Displacement at some critical locations (Fig.4) have been given in Table 1.

4.3 Stresses

The stress (Pl+Pb) at critical locations (Fig.4) have been extracted for all the operating conditions from the response analysis of IVIM and given in Table 2. Since the structure is very tall and supported in only one point, bending stress is predominant. Primary membrane stress is negligibly small (< 1 MPa) and it is not reported.

5 CONCLUSION

The seismic analysis of IVIM is performed. All the complexities due to presence of flexible cables, sliding joints, gears, bolts, sodium etc. have been taken care in the model. Considering the asymmetric in the structures, different types of modelling for two horizontal and one vertical directions have been developed. The analysis involves free vibration analysis and subsequent seismic analysis. Following are the results:

- Natural mode shapes have been extracted and given.
- Dynamic stresses and deflections have been estimated for IVIM under OBE of 0.065 g and SSE of 0.2 g. The overall stresses and deflections are well within the acceptable values.
- The adequacy of the bolts has been checked. The contact stress between gripper assembly and guide tube due to impact is also acceptable.
- It is found that the deflections are within the elastic limit.
- Results, after extrapolating to higher values of seismic accelerations, indicated that the present structure can withstand up to 0.4 g of SSE and 0.1 g of OBE.

- Under OBE, the integrity of subassembly is assessed when it is held by gripper subassembly. The peak acceleration during 0.065g OBE (ZPA) at the gripper fingers is 5.4 m/s whereas, the permissible acceleration at this point is 25 m/s for the structural integrity of subassembly sheath which corresponds to 0.3g OBE (ZPA). Further the fracture mechanics analysis has also been done for fuel subassembly to see whether brittle fracture is possible. Under the assumption of a severe through crack of depth equal to thickness of sheath at the highly stressed location, the stress intensity factor for mode-I fracture ($K_I$) is 8 MPa m, which is less than the permissible value of 20 MPa m ($K_{IC}$). That is up to 0.15g OBE (ZPA), there is no fear of brittle fracture.

Table 1 Horizontal displacement (mm) at critical locations (Fig 5)

<table>
<thead>
<tr>
<th>Location</th>
<th>Fuel handling</th>
<th>Reactor operating</th>
<th>Maintenance</th>
</tr>
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<tr>
<td></td>
<td>SSE</td>
<td>OBE</td>
<td>SSE</td>
</tr>
<tr>
<td>1.</td>
<td>47.75</td>
<td>42.75</td>
<td>46.4</td>
</tr>
<tr>
<td>2.</td>
<td>45.75</td>
<td>41.75</td>
<td>45.7</td>
</tr>
<tr>
<td>1.*</td>
<td>245.96</td>
<td>97.25</td>
<td>173.18</td>
</tr>
<tr>
<td>2.*</td>
<td>233.46</td>
<td>89.1</td>
<td>159.06</td>
</tr>
<tr>
<td>3.</td>
<td>49.6</td>
<td>47.9</td>
<td>90.36</td>
</tr>
<tr>
<td>4.</td>
<td>68.92</td>
<td>36.75</td>
<td>69.38</td>
</tr>
<tr>
<td>5.</td>
<td>10.06</td>
<td>5.3</td>
<td>7.80</td>
</tr>
<tr>
<td>6.</td>
<td>7.48</td>
<td>3.93</td>
<td>7.43</td>
</tr>
<tr>
<td>7.</td>
<td>2.64</td>
<td>1.4</td>
<td>2.68</td>
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</table>

*Deflection when gripper assembly and guide tube are moving independently

Table 2 Stress intensity (MPa) at important critical locations (Fig 5)

<table>
<thead>
<tr>
<th>Location</th>
<th>Fuel handling</th>
<th>Reactor operating</th>
<th>Maintenance</th>
</tr>
</thead>
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<td></td>
<td>SSE</td>
<td>OBE</td>
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<tr>
<td>a</td>
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<td>73.97</td>
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<tr>
<td>b</td>
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<td>40.33</td>
<td>80.40</td>
</tr>
<tr>
<td>c</td>
<td>52.28</td>
<td>27.51</td>
<td>37.8</td>
</tr>
<tr>
<td>d</td>
<td>15.0</td>
<td>7.87</td>
<td>12.8</td>
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REFERENCE


Fig. 1. Schematic sketch of IVTM

Fig. 2. Floor response spectra at SRP

Fig. 3. Model of IVTM for seismic analysis

Fig. 4. Critical locations of IVTM
Under fuel handling condition

Under reactor operating condition

Fig. 4. Free vibration mode shapes of IVTM