Seismic Qualification of Heatexchanger at WWER-1000 MW Type NPP

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ABSTRACT

The objective of the study is seismic qualification of already installed heat exchanger and its supporting structure in operating WWER-1000 MW type NPP. The criteria of ASME code are applied both for the equipment and for the supporting structure. Detailed finite element model is developed to simulate the operating parameters and as-built conditions of the equipment and its supports. The plant specific floor response spectra are used in the analysis. The seismic adequacy of the heat exchanger is clarified on the basis of the results from the study. It is estimated that these conclusions are also valid for similar equipment at another unit of the same NPP.

1. INTRODUCTION

The aim of the performed analysis is to evaluate the response of the heat exchanger under consideration at conditions of increased zero period acceleration from 0.1g to 0.2g. The results from the calculations are compared to the criteria for equipment class 3 , according to ASME ND [1], ASME NF [2], ASME NCA[3].

On meeting the criteria for seismic resistant equipment the heat exchanger (HE) will be qualified for the new seismic input. If not, measures for additional reinforcement will be proposed.

1.1 Brief Description of the Equipment

The HE is located in the reactor containment and consists of vertical cylindrical vessel with outer diameter 325 mm, thickness 12 mm, with 2 horizontal supports- sliding and fixed one, and 2 vertical supports, mounted on steel frames, the last attached at certain floor elevation and steel column.

Main technical characteristics:

Total height= 5370 mm	Outer Diameter= 325 mm	
Total mass (empty)= 1460 kg	Total mass (full)= 1460 kg	Supports mass (total) = 215 kg

1.2 Load Cases

- LG1 – Dead weight of equipment components;
- LTEMP1 – Loading from service temperature;
- LPRES1 - Loading from service pressure
- SP3 – Multi axial seismic excitation

For the analysis purposes the relevant floor response spectra (FRS) at 4% damping for the three directions are used for design earthquake OBE, considering local earthquakes. FRS for OBE (Operational Basis Earthquake) are derived through scaling with factor 0.5 of FRS for RLE (Review Level Earthquake) for the applicable elevation (Node 6134). The plotted forms of the RLE spectra are shown in Figures 1-1; 1-2;1-3.

The dynamic analysis was performed using Ritz vector modal analysis, with first 15 modes which are combined under CQC method at damping 0.04. The directional combination was performed under SRSS rule.

- LNOZZSRSS – Resultant forces in the attached pipeline nozzles, under Loading from normal operation and OBE,

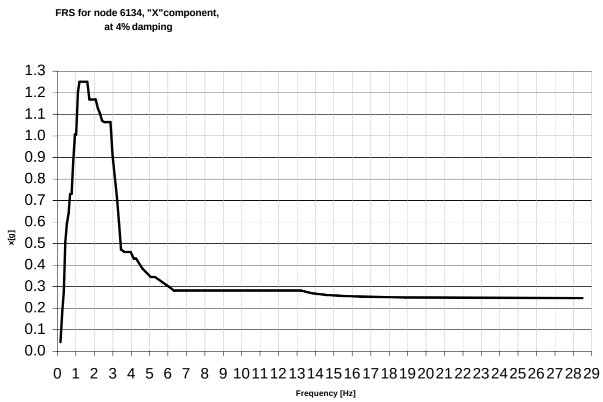

Fig. 1-1. Floor Response Spectra, "X" component, ;

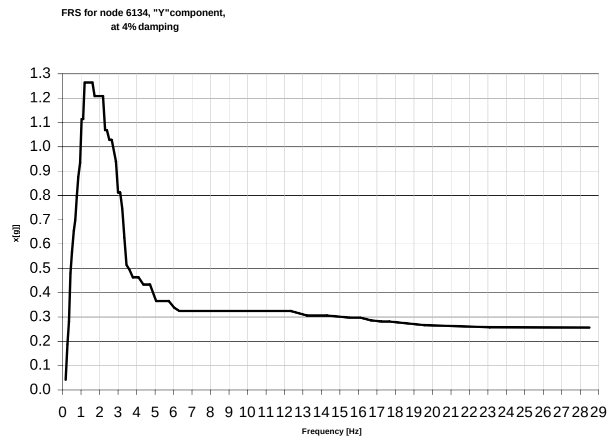

Fig. 1-2. Floor Response Spectra, "Y" component

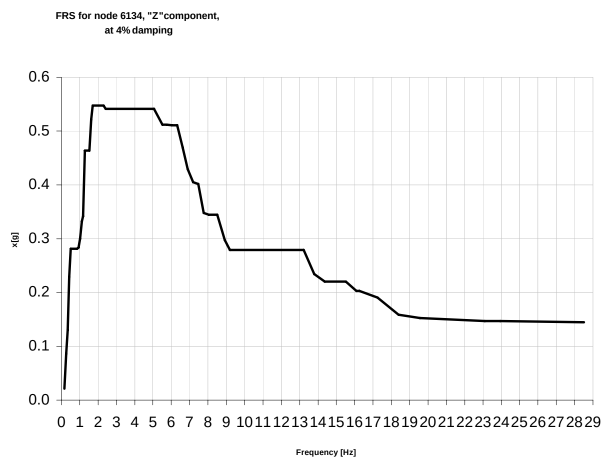

Fig. 1-3 Vertical Floor Response Spectra, "Z" component

1.3 Load Combination

NCEMDE=

LG1+LTEMP1+LPRES1±LNOZZSRSS±SP3, as defined in 1.2.

2 BACKGROUND OF THE STUDY

2.1 Equipment Modeling

The analytic model was generated based on the available drawings and performed walk downs. The model is 3 dimensional with SHELL type finite elements. This approach allows fast check of the stresses without implementation of any simplifications, that is the used 3D model reflects in every detail the real equipment structure.

The main vessel body is modeled by SHELL elements with 12 mm and outer diameter 325 mm. In circumferential direction are used 36 elements and in longitudinal direction – 86 rows. General view of the model is shown on Fig.2-1.

The compensator is modeled by SHELL elements with thickness 6 (8) mm. The thickness of the stiffening internal cylindrical shell of the pipes bundle is 3 mm and the two pipe fixing plates at both ends of the bundle are with 40 mm thickness. These plates are modeled with reduced bending rigidity, to account for the openings for the pipes.

Heat exchanger pipes are 130 pieces with cross section D16x1 mm and are modeled as FRAME type finite elements. The fixing grids are modeled again with SHELL elements with thickness 5 mm for membrane behavior and 2 mm for bending behavior. In this manner their participation in the bundle response is limited to restraint of the mutual horizontal displacements of the single pipes without affecting their bending behavior.

The supporting steel structure is modeled, using FRAME type finite elements with cross sections of channels UPN 120 (UPN 140) and SHELL elements for the stiffeners (vertical and horizontal plates).

The bolt connections are also properly modeled to consider the real behavior of the connections for shear and axial force.

2.2 Boundary and Load Conditions

The boundary conditions are taken into consideration with the applied forces in the nozzles at the pipes attachment and adopted mathematical model with the detailed supporting structures.

These forces for each nozzle are provided in separate load cases and further combined according to SRSS rule in one combination used also as design combination.

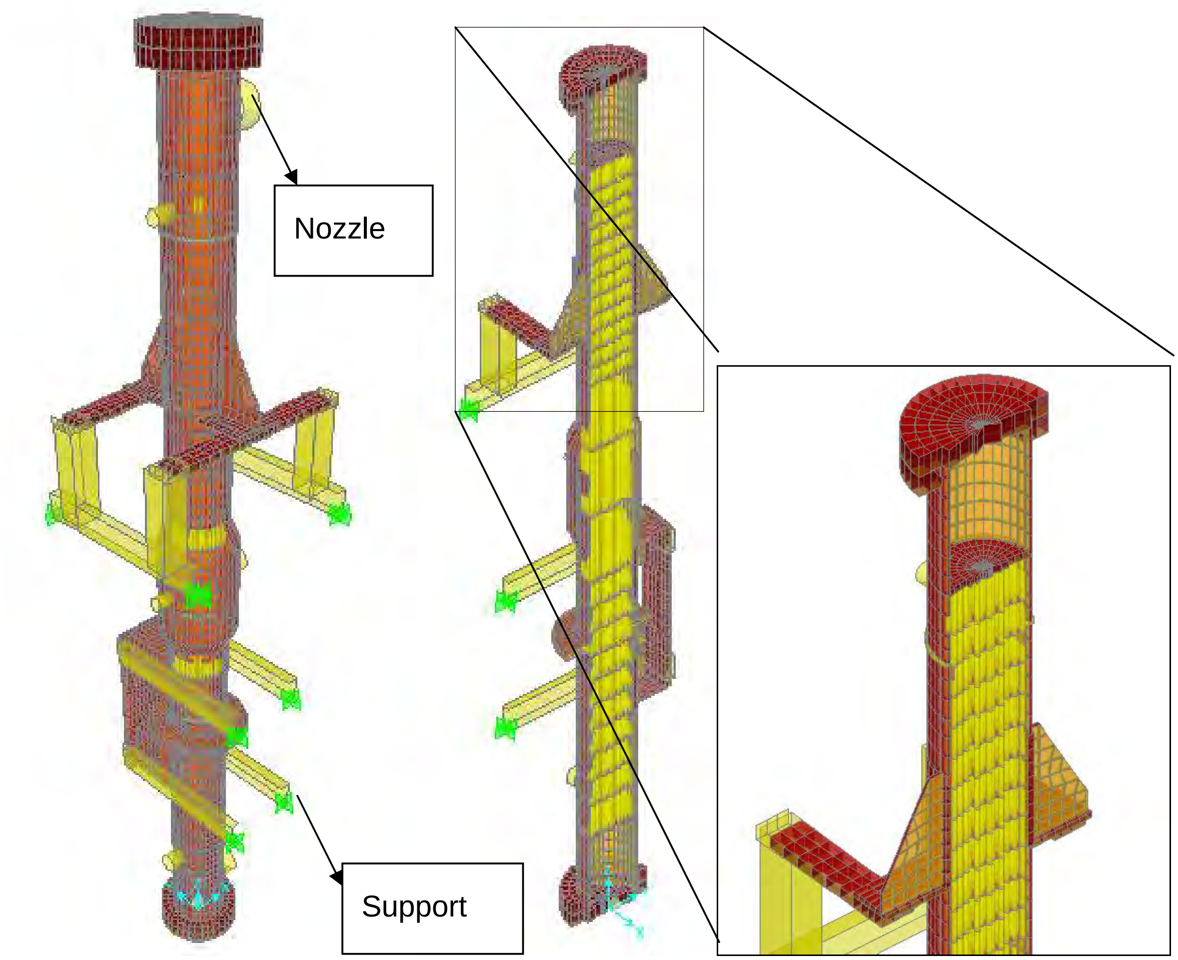

Fig. 2-1 General view of the model

2.3 Design basis

The design class of the equipment is defined as Class 3 ASME ND [1], ASME NCA [3].

The design capacity of the supports and connection elements were checked according to ASME, Section III, Subsection NF, [2]. According to ASME NF-3321 when linear elastic analysis is performed the allowable stressed for Level B are increased with the factors from Table NF-3523(b)-1 for linear supports

Analysis was performed for Level B, according to the requirements of ASME.

The allowable stresses were calculated for design temperature 150°C.

2.4 Design Check According to ASME

For the HE body and the nozzles (ASME ND), Level B , according to Table 3 ND-3321-1:

$$\sigma_m \leq 1.10\ S = 1.1*110.25 = 121.27\ \text{Mpa} \quad (1)$$

$$(\sigma_m \text{ or } \sigma_l) + \sigma_b \leq 1.65\ S = 1.65*110.25 = 181.91 \quad (2)$$

For the supports (ASME NF):

- Compression and bending (ASME NF 3322):

$$\frac{f_a}{F_a \cdot K_{bk}} + \frac{C_{mx} \cdot f_{bx}}{(1 - f_a / F'_{ex})F_{bx} \cdot K_s} + \frac{C_{my} \cdot f_{by}}{(1 - f_a / F'_{ey})F_{by} \cdot K_s} \leq 1.0; \quad (3)$$

$$\frac{f_a}{0.6 \cdot Sy} + \frac{f_{bx}}{F_{bx} \cdot K_s} + \frac{f_{by}}{F_{by} \cdot K_s} \leq 1.0, \quad (4)$$

Where $F'_e = \dfrac{12\pi^2 E}{23(Kl/r)^2}$;

Tension and bending (ASME NF):

$$\frac{f_a}{0.6 \cdot Sy} + \frac{f_{bx}}{F_{bx} \cdot K_s} + \frac{f_{by}}{F_{by} \cdot K_s} \leq 1.0; \quad (5)$$

Shear (ASME NF)

$$f_v/(F_v*K_v) \leq 1; \quad (6)$$

3 RESULTS FROM THE ANALYSIS

A response spectrum analysis was performed with SAP2000.

3.1 Main Dynamic and Response Parameters

TABLE: Modal Participating Mass Ratios							
Mode Num	**Period**	**UX**	**UY**	**UZ**	**SumUX**	**SumUY**	**SumUZ**
Unitless	Sec	Unitless	Unitless	Unitless	Unitless	Unitless	Unitless
1	0.1301	0.1129	0.0000	0.0000	0.1129	0.0000	0.0000
2	0.0845	0.7807	0.0000	0.0000	0.8936	0.0000	0.0000
3	0.0519	0.0711	0.0001	0.0000	0.9647	0.0001	0.0000
4	0.0498	0.0000	0.4385	0.0063	0.9648	0.4386	0.0063
5	0.0410	0.0000	0.0254	0.6738	0.9648	0.4640	0.6801

6	0.0396	0.0000	0.0199	0.2648	0.9648	0.4839	0.9449
7	0.0339	0.0000	0.0858	0.0007	0.9648	0.5697	0.9456
8	0.0260	0.0097	0.0000	0.0000	0.9745	0.5698	0.9456
9	0.0154	0.0001	0.0726	0.0001	0.9746	0.6423	0.9457
10	0.0129	0.0017	0.0377	0.0014	0.9763	0.6801	0.9471
11	0.0078	0.0008	0.0012	0.0139	0.9771	0.6813	0.9610
12	0.0076	0.0005	0.2348	0.0000	0.9775	0.9160	0.9610

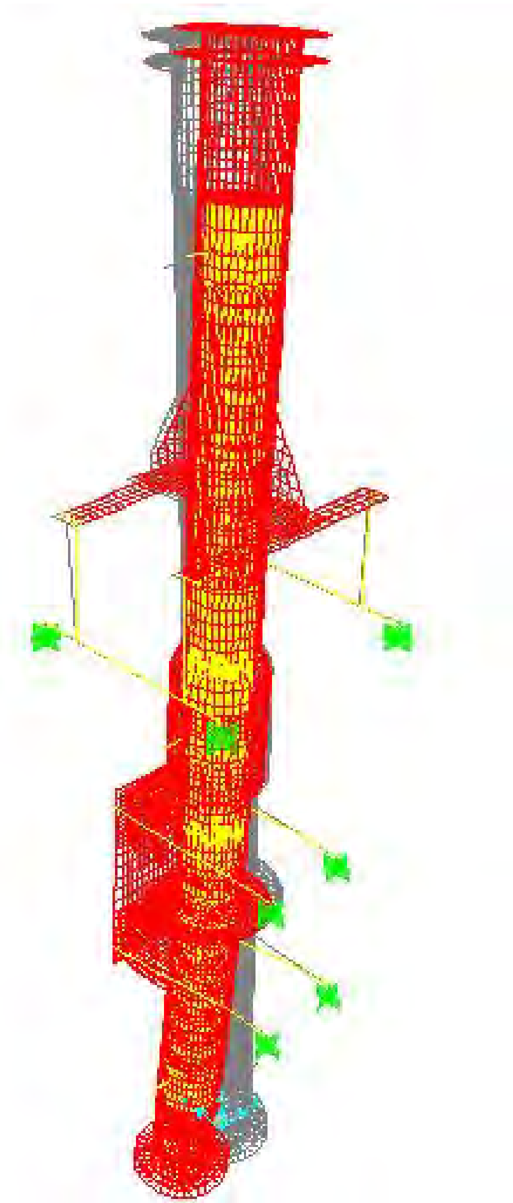

Fig. 3-1 1 st mode shape; Fig. 3-2 2 –nd mode shape

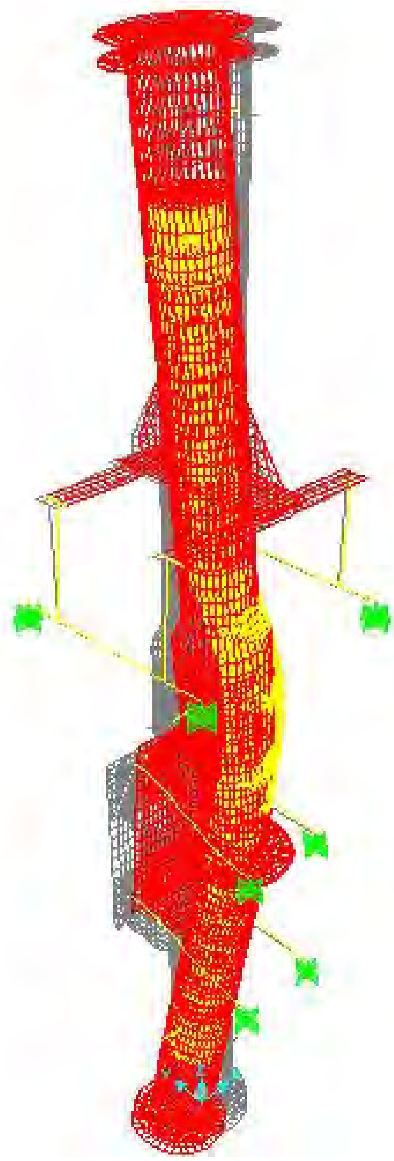

Fig. 3-3 **3 rd mode shape;**

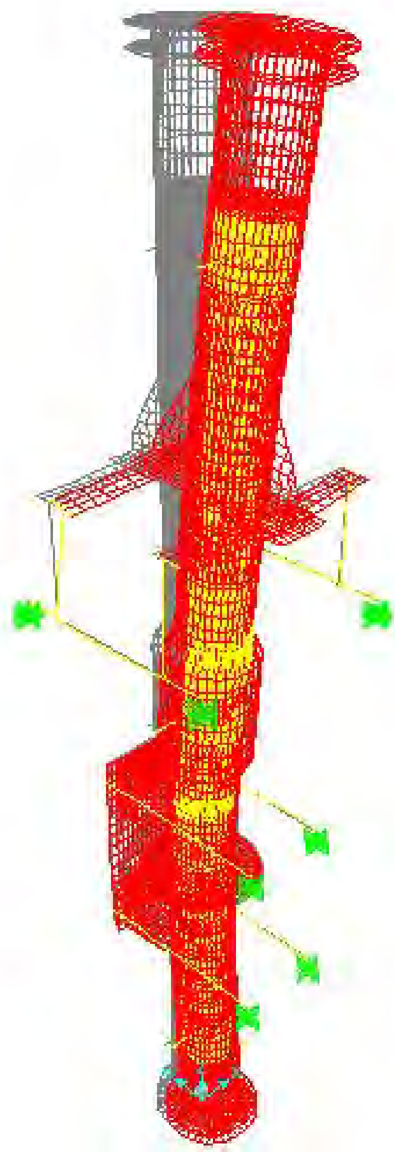

Fig. 3-4 **4 –th mode shape**

3.2 Design Checks

Table 3-1 Checks for the main body and compensator

Section/ element	$\sigma_{1,2}$=max ($\lvert\sigma_b\rvert+\lvert\sigma_m\rvert$)		1.65*S	$\sigma_{1,2}$=max $\lvert\sigma_m\rvert$		1.1*S
	σ 1(σ r)	σ 2(σ t)		σ 1(σ r)	σ 2(σ t)	
	MPa	MPa	MPa	MPa	Mpa	MPa
Main body Ø325/12 Below compensator	75	50	181.9	25	29	121.3
Main body Ø325/12 Above compensator	45	95	181.9	12.5	35	121.3
Main body Ø425/12	95	35	181.9	30	15	121.3
Compensator	135	175	181.9	85	16	121.3
Pipe plates	172	165	181.9	15	13	121.3

The next figures presents maximum and minimum combination stresses in the heat exchanger structure under the design combination.

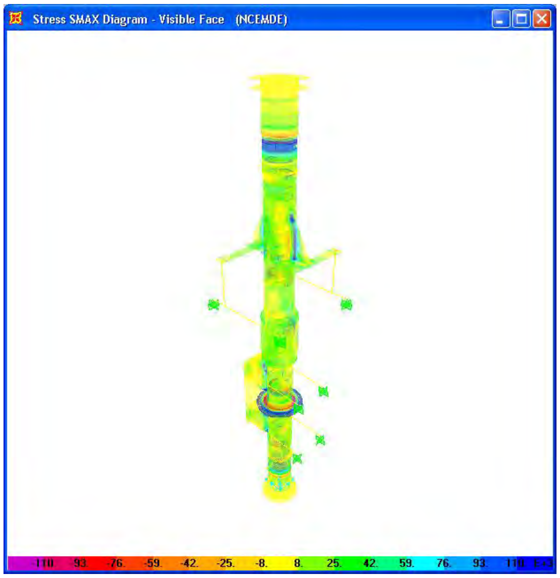

Fig. 3-5 Smax Diagram

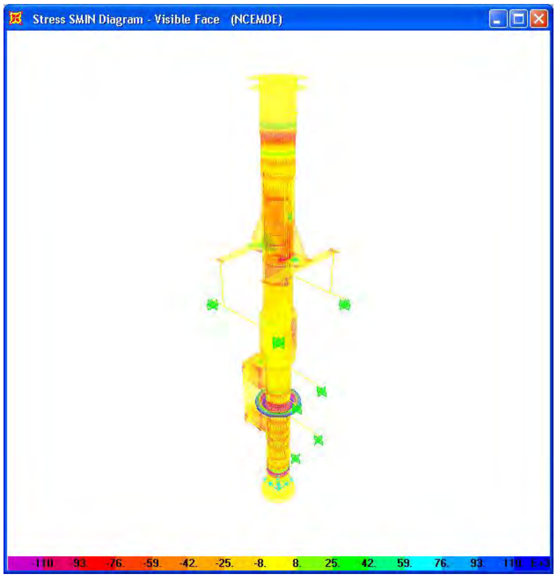

Fig. 3-6 Smin Diagram

4 CONCLUSIONS

Full static and dynamic analysis of the heat exchanger was performed to account for the increased zero ground acceleration from 0.1g to 0.2g , including local earthquakes.

When analyzing the structure procedures of the applicable design criteria documents were followed.

Design checks were done for equipment class 3 under ASME Section III, Div. 1 Subsection ND and ASME Section III, Div. 1 Subsection NF. The analysis was defined for Level B .

The results from the static and dynamic analysis of the heat exchanger have shown the following.

- The checks for design stresses for the main elements and nodes fulfilled the criteria of ASME Section III, Div. 1 Subsection ND.
- The checks for the supporting structure of the heat exchanger fulfilled the criteria of о ASME Section III, Div. 1 Subsection NF са изпълнени.

The analyzed heat exchanger is then qualified according to ASME for the defined seismic input, with no necessity to increase its seismic resistance.

5 REFERENCES

[1] ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection ND, 1995

[2] ASME BPVC, Section III Division 1 – Subsection NF, Supports, 1995

[3] ASME BPVC, Section III Subsection NCA Rules for construction of Nuclear Power Plant Components –1989