ASEISMIC DESIGN AND ANALYSIS OF THE PRIMARY COOLANT LOOP AND SAFETY RELATED PIPING SYSTEMS OF RUSSIAN DESIGN NPP WWER-440.

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ABSTRACT

This paper presents the results of seismic analysis of Safety Related Piping Systems of the typical WWER-440 NPP. The methodology of this analysis is based on WANO Terms of Reference and ASME BPVC. The different possibilities for seismic upgrading of Primary Coolant Loop System (PCLS) were considered. The first one is increasing of hydraulic snubber units and the second way is installation of limited number of High Viscous Dampers (HVD).

INTRODUCTION

One of the most important safety-related systems of WWER-type NPPs are the piping providing Reactor Safe Shutdown function. Mainly these piping are located in Steam Generator (SG) and Main Cooling Pump (MCP) Boxes. On many of WWER plants these systems were designed according to former Soviet Union Standards and Rules, particularly by rather conservative PNAE Code. Nevertheless in some cases questions of seismic protection of the WWER units was out of the plant general design and criteria. That is why in the stream of the world community efforts to upgrade the nuclear safety of NPPs the great emphasis has been made for seismic reanalysis of WWER plants according to modern international practice.

This paper focuses on solving of seismic resistance problem for one of the old project of WWER-440-230 NPP. Initially in start-up period there were no any aseismic devices on PCLS and other safety related piping to withstand an earthquake and other extreme dynamic loads. The years after a number of hydraulic snubbers were installed on many of WWER units in spite of western practice to eliminate or reduce snubbers. This paper presents an accurate seismic analysis of safety related piping systems including PCLS according to modern international Standards on the base of accumulated engineering experience on other WWER NPPs.

METHODOLOGICAL BACKGRAUND FOR SEISMIC ANALYSIS

The main requirements for seismic analysis of equipment and piping of the WWER NPP are condensed in WANO developed "Terms of Reference and Technical Specification for Seismic Upgrading Design of KNPP Units 1 and 2" [1]. This document prescribes using of the Seismic Margin Assessment and ASME BPVC, Section III approaches as methodological background [2] for seismic analysis of safety related piping located in Steam Generator and Main Cooling Pump Box. The Terms of Reference contains the following general recommendations for load combinations and allowable stress limits in seismic analysis, Table 1. The first column of this table shows the safety classes according to SRP 3.2.2 [3]. In the second column of the table are shown the load combinations (without brackets) strictly according to Terms of Reference and in brackets are pointed the load combinations in interpretation of SRP 3.9.3. The third column presents the formulas that were selected from ASME BPVC for implementation of Terms of Reference recommendations. The description of allowable stresses is shown in the fourth column of Table 1 and in the Table 2.

Table 1 Correspondence between Load Combinations and Calculated Stresses

Class	Load Combination	Equations (NB-3650, NC-3650)	Allowable Stresses
1	DL+LL (P+DL+LL)	$B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot M_i$, (9)	1.5 S_m
	DL+LL+EQi (P+DL+LL+EQi)	$B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot M_i$, (9)	3.0 S_m
	T+EQm (P+DL+LL+EQm)	$C_1 \cdot \frac{P_o \cdot D_o}{2 \cdot t} + C_2 \cdot \frac{D_o}{2 \cdot I} \cdot M_i$, (10)	3.0 S_m
2	DL+LL (P+DL+LL)	$B_1 \cdot \frac{P \cdot D_o}{2 \cdot t_n} + B_2 \cdot \frac{M_A}{Z}$, (8)	1.5 S_h
	DL+LL+EQi (P+DL+LL+EQi)	$B_1 \cdot \frac{P_{max} \cdot D_o}{2 \cdot t_n} + B_2 \cdot \frac{M_A + M_B}{Z}$, (9)	3.0 S_h
	T+EQm	$\frac{i \cdot M_C}{Z}$, (10)	S_A

Table 2 Allowable Stresses

Class	Description	Allowable Stresses
1	S_m	min $\left\{S_T/3; 1.1S_T^T/3; S_Y / 1.5; S_Y^T/1.5\right\}$
2	S_c, S_h	min $\left\{S_T/4; 1.1S_T^T/4; S_Y / 1.5; S_Y^T/1.5\right\}$
	S_A	$1.25*S_c+0.25*S_h$

Table 3 Basis for Seismic Capacity Evaluation of Piping and Equipment Supports.

Element of Support	Load Combination	Failure Mode	Allowable Stresses
Steel Structure	DL+LL+T DL+LL+T+EQi+EQm	Plastic Collapse	Sall 1.6 Sall; 0.7 Su [1)]
Fixed Joints	DL+LL+T DL+LL+T+EQi+EQm	Plastic Collapse	0.5 Su; 0.7 Su [1)]
Welded Joints	DL+LL+T DL+LL+T+EQi+EQm	Brittle	0.3 Su 0.42 Su [1)]
Springs of Hangers	DL+LL+T DL+LL+T+EQi+EQm	Limited compression	Pmax

[1)] The level of allowable stresses is defined according to Appendix F of ASME BPVC [2].

Two types of seismic excitation were stipulated for analysis: Review Level Earthquake (RLE) and Local Earthquake (LE) defined in terms of Response Spectra. ZPGA level for RLE was assumed as 0.16g. For the systems which were supported on different elevation levels of structure the envelope spectra has been developed according to Appendix N of ASME Code [4]. For evaluation of seismic capacity of considered systems two analytical approaches have been used:
Response Spectrum Modal Analysis Method (RSMAM) and Time History Analysis (THA). In case of TH analysis the TH acceleration was generated from target Response Spectra following to demands of Appendix N of ASME Code (N-1210). The damping ratio for all piping systems was accepted as 0.05 [1].

The load combinations and allowable stresses for seismic capacity evaluation of piping and equipment supports were also defined on the basis of [1, 2] recommendations, Table 3.

One of the most important features of the present methodology is possibility of using of inelastic demand-capacity ratio (ductility factor) that essentially decreases the conservatism of traditional Code (ASME as well as PNAE) approaches. The following recommended values of these inelastic coefficients were implemented to current analysis [5]:

- Distribution System Supports - Fu = 1.25
- Welded Joints of Piping Supports - Fu = 1.0
- Piping - Fu = 1.5

For the following elements of distribution systems the Fu coefficients were used conventionally in terms of device's operability under seismic excitation according to supplier's catalogues [6,7]:

- Springs of Hanger support - Fu = 1.0
- Hydraulic Snubbers - Fu = 1.0
- GERB Dampers (Nseism) - Fu = 1.0
  (Nseism = Nnom x 1,7)
- CVS HV Dampers - Fu = 1.0

The strength analysis (seismic capacity of structure) was defined using the above pointed coefficients by the following formula [16]:

- Stresses (reactions) from the inertial part of seismic load (EQi):

$$S_{Eid} = \frac{S_{Ei}}{F_U} \qquad (1)$$

- Stresses (reactions) from the seismic anchor movement (EQm):

$$S_{Emd} = F_U \cdot S_{Em} \qquad (2)$$

One of the serious obstacles for providing correct analysis of running plants is gathering of necessary authentic information and input data. The only way to solve this problem is realization of walkdown procedure for each system to be analyzed for defining the real terms of equipment, piping, system and their supports installation and operating. It is quite usual that in many cases the typical WWER-type NPPs shortcoming like insufficient lateral restraining is recognized.

The present seismic analysis covers the following systems and their elements: small and large bore piping, piping supports and piping nozzles (Reactor Pressure Vessel, Steam Generator, Pressurizer).

ANALYSIS RESULTS

The full finite-element analytical model of WWER-440 piping systems located in Steam Generator and Main Cooling Pump Box is shown in figure 1.

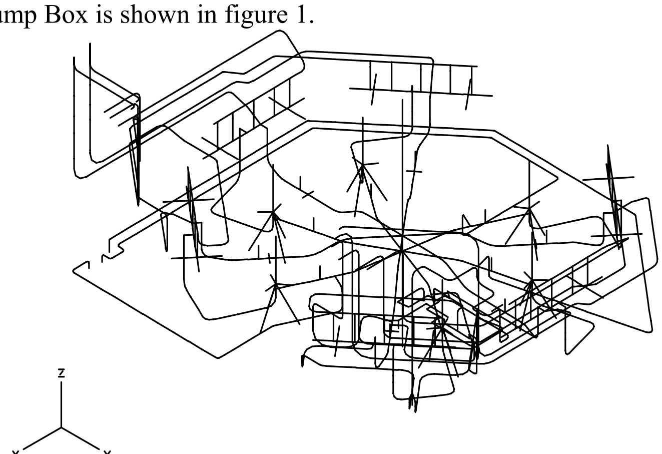

Figure 1 Complex Analytical Model of SG and MCP Box piping

This sketch includes detailed models practically of all large bore hot piping (with diameter more than 100 mm) and simplified models of Reactor Pressure Vessel, SG, MCP and connected equipment for all of six loops of PCLS.

The further consideration for more clear description of the main obtained results will be based on analysis of the first Primary Coolant Loop, Figure 2.

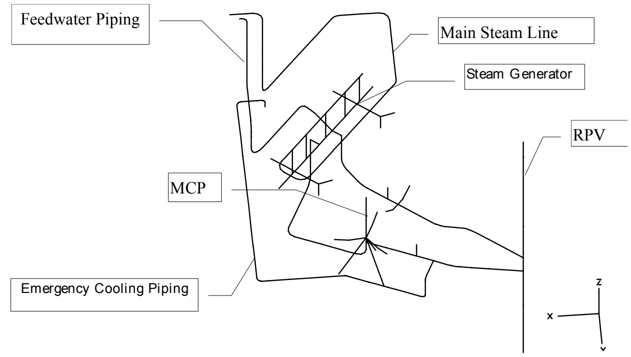

Figure 2 Analytical Model of the first PCLS

PCLS without seismic restraining (initial design)

The first natural frequency of PCLS is shown in figure 3.

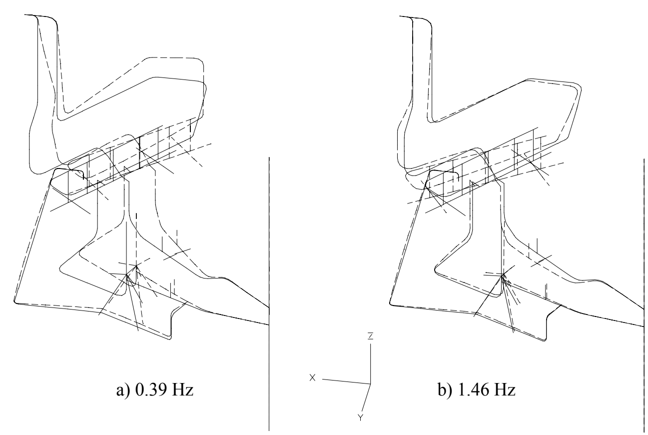

Figure 3 First natural modes of PCLS without seismic restraining

The low level of PCLS natural frequencies leads to intensive seismic response of structure. The displacement of SG achieves more than 500 mm. Additionally the analysis of PCLS without seismic restraining shows that for many of piping elements (runs, bends and tee elements) the safety requirements are not satisfied even in case of using non-conservative ductility approach. That means that seismic upgrading of PCLS has to be performed obligatory to meet the demands earthquake protection and Terms of Reference. Thus the installation of hydraulic snubbers that was performed in eighties on a number of Ukrainian and East European WWER NPP Units is quite feasible and was in the stream of that and previous time experience.

PCLS with Snubber Restraining

Figure 4 demonstrates the principal location and types of hydraulic snubbers that usually are installed on PCLS.

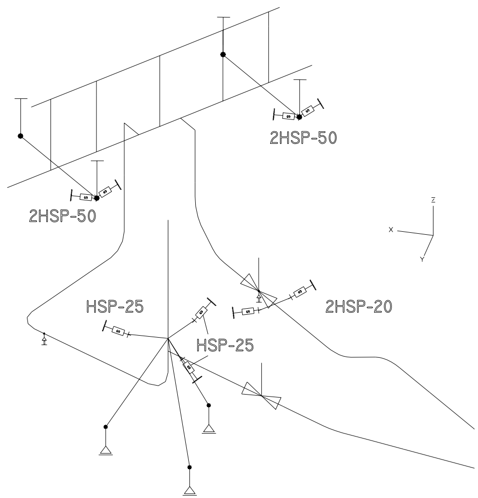

Figure 4 Snubber Location for Loop No 1 of PCLS

The accurate comprehensive non-linear TH analysis of this system has been performed to obtain the realistic dynamic response of the PCLS and snubber reactions. Dynamic characteristics of the snubbers based on their direct testing including specific velocity locking limits of the snubber's piston recommended by manufacturer [6] were involved in this analysis, Figure 5.

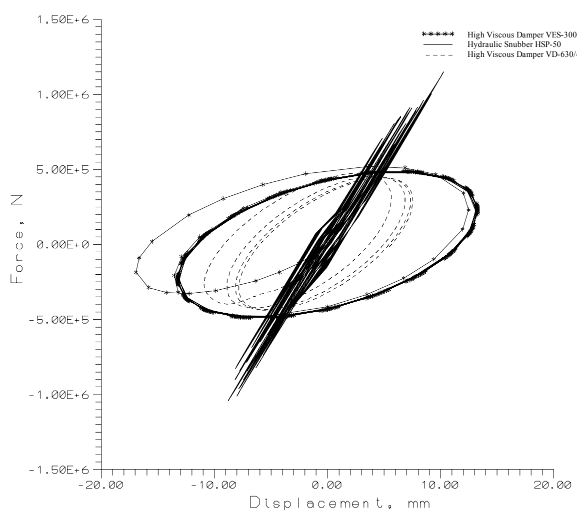

Figure 5 Dynamic characteristics of the ST Hydraulic Snubbers and High Viscous Dampers under sinusoidal 1 Hz excitation

This kind of analysis shows that there are not problems in seismic safety of PCLS and connected piping as itself. However the dynamic reaction of snubbers for some of devices exceeds the recommended capacity (limit load) of snubber for several times, Figure 6.

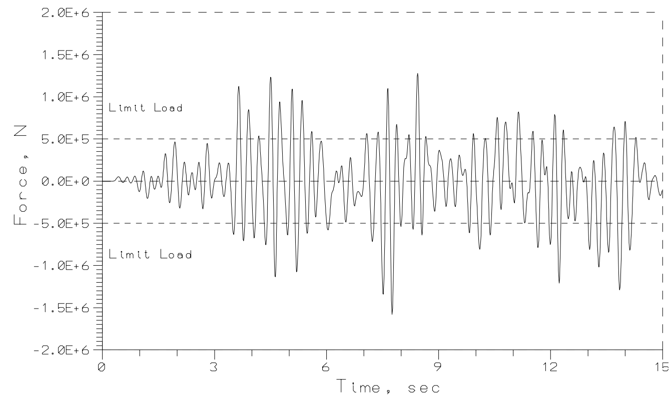

Figure 6 TH seismic reaction force in overloaded snubber

That is why for meeting the requirements of seismic criteria the additional number of hydraulic snubbers has to be installed. The analysis shows that only double increasing of snubbers with the same load capacity under SG will solve practically the problem of PCLS seismic resistance. The reaction force of snubbers in this case do not exceed more than on 12% their nominal catalogue load capacity that seems to be acceptable. The total number of snubbers for one PC loop in this case increases from 9 to 13.

PCLS with High Viscous Dampers restraining (possible seismic upgrading)

In recent years the more reliable HVD technology has been widely implemented in seismic upgrading of WWER, PWR, BWR and other types of NPPs [7]. The dynamic characteristics, analytical model and significant advantages of these devices were investigated in literature in details [8-15], Figure 5. For purposes of this analysis the 4-parameters Maxwell Model of Viscous Damper that correctly reflects frequency-depended dynamic properties of HVD has been used [11].

Two variants of proposed location for case of HVD installation for PCLS is shown on Figures 7, 8.

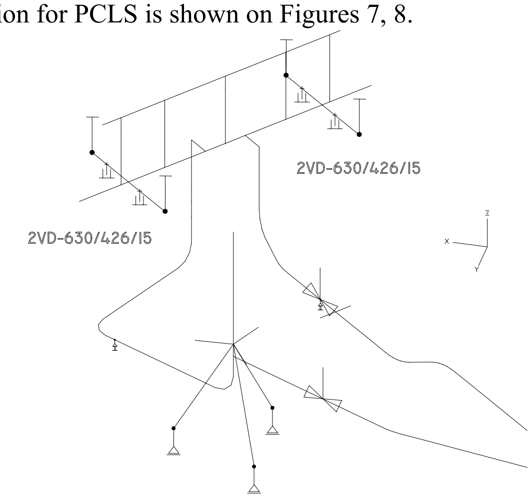

Figure 7 HVD location for Loop No 1 of PCLS (variant A)

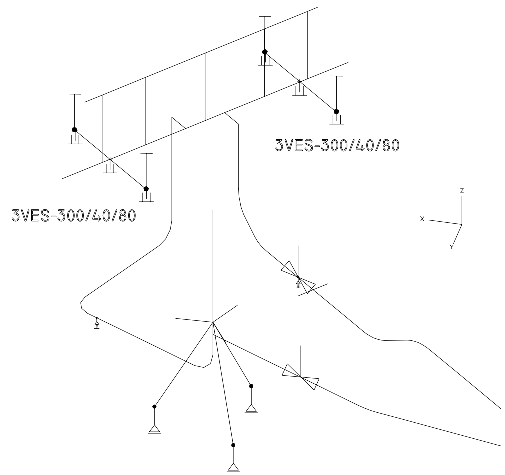

Figure 8 HVD location for Loop No 1 of PCLS (variant B)

Time History Analysis of PCLS with HVD shows that four units of VD-630/426-15 is enough to provide sufficient seismic resistance of the Loop. In case of VES-300/40/80 installation this number increases up to 6 devices. In both cases stresses in piping, nozzles and supports are meet seismic criteria and requirements.

CONCLUSIONS

1. The accurate seismic analysis of WWER-440 NPP Safety Related Piping Systems and Nozzle Zones including PCLS has been performed to find out the way of possible seismic upgrading.
2. It was shown that for withstanding to earthquake with ZPGA more than 0.1g the application of special seismic devices to the WWER-440 Primary Loop is strictly recommended.
3. The analyses show that PCLS meets the seismic criteria and requirements in case of 13 snubbers versus 6 or 4 High Viscous Dampers depending on type of these devices. The additional benefit of HVD technology is high reliability of devices and low maintenance cost.

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