ANALYSIS OF SOME CRITICAL POINTS THAT MAY INFLUENCE CERNAVODA NPP NUCLEAR SAFETY DURING AN EARTHQUAKE AND SOLUTIONS TO INCREASE THE SAFETY MARGIN

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The paper is a general presentation of the main critical points in Cernavoda NPP- Unit 1 and 2 respect of seismic behavior, which from the authors' viewpoint are:

- Fuelling Machine coupled to a fuel channel;
- The pipe leg of the Emergency Core Cooling System (ECCS) having supports on the inner structure, the containment and the staircase structure in B area;
- Live Steam pipe legs installed on the reactor containment and service building.

Keywords: critical points, safety margin, SERB device, hysteresis diagram.

1. Introduction

For to overtake the seismic loads in safe conditions, Cernavoda NPP was seismically qualified by the maximum stiffening of the buildings as well as by the stiffening of the equipment and pipe network anchorage to the buildings.

In spite of all the seismic qualification measures implemented at Cernavoda NPP, there are still 3 critical points in which a major earthquake might initiate a nuclear accident with severe consequences. These critical points have resulted from some studies and research works conducted by SITON for the last 20 years [1,2,3].

2. Site seismicity and Cernavoda NPP seismic qualification

2.1. Fuelling Machine coupled to a fuel channel

Between the fuel channels and the fuelling machine there are large seismic relative movements imposed by the relative movements between Calandria vault and the inner structures. These relative movements are due to the fact that the geometry and structure of Calandria vault are ' slender ' and connected to the reactor building inner structure only at El. 100. During an earthquake, the fuelling machine (F/M) is stiff anchored to the inner structure and the fuel channel is connected to Calandria vault by the end plates. During an earthquake , the relative displacement between Calandria vault and the inner structure is a displacement

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imposed for the fuel channel that is leading to local overloads in the pressure tube and thus to high risk of breaking.

To limit the relative displacements between Calandria vault and the inner structures can be done by the installation of some controlled elasticity and damping devices at El. 117.00 which are meant to reduce the relative displacement between the two structures several times.

2.2 The pipe leg of the Emergency Core Cooling System (ECCS) having supports on the inner structure, the containment and the staircase structure in B area.

The seismic input for this pipe leg is under-evaluated for the attachment points on the perimetral wall and the containment, the inner structure and the structure of the staircase in B area.

The response spectra (FRS) and the seismic movement of the anchoring points (SAM) for the containment are determined on a stick type model which are under-evaluated for the perimetral wall and the boundary of the inner structure platforms where the ECCS supports are placed. They are representative for the imaginary axis and for the central area of the inner structure floors.

The relative seismic movement between the anchoring points of the ECCS pipe leg , installed on the inner structure, the containment and the B area staircase are high. These relative movements are due to the stiffness between the three structures and to the mass and stiffness asymmetry of the inner structures. The reduction of the mass and stiffness asymmetry cannot be done because the geometry of the inner structures is imposed by technological requirements and nuclear safety. The insertion of some dissipating devices in order to decrease the relative movement between these sub-structures, have small effects because the self torque movements of the inner structures have quite high frequency.

The reduction of the ECCS loads may be done by the installation of some supports with controlled elasticity and damping that are capable to overtake quite large displacements and damp the pipe seismic movements.

2.3 Live Steam pipe legs installed on the reactor containment and service building

The seismic input for these pipe legs is under-evaluated for the reactor containment and for the Service Building (S/B).

For the S/B , the response spectra and the seismic movements of the anchoring supports are determined at the elevation the supports are attached to the pipes (the roof elevation for pipe legs 2,3, and Bldg. L). Between the axes of the pipes and the support flange, there is a several meter difference which result in an amplification of the seismic movement and it was not evaluated in the pipe seismic qualification analysis.

The reduction of the live steam pipe loads may be done by the installation of some supports with controlled elasticity and damping, witch replace the snabers and classical supports, that are capable to overtake large relative displacements and damp the seismic movements and the movements generated by shocks and vibrations.

3. Solutions for to increase the safety margin of a CANDU PHR 700 plant against seismic actions.

The paper proposes a solution to increase the safety margin in the main critical points of CERNAVODA- CANDU PHWR 700 by reducing the relative movement between the calandria vault and the inner structures that may overload the fuel channel coupled to the fueling machine (F/M).

The proposed solutions also provide a safety margin for earthquakes of a level higher than a DBE provided that the other structures that contribute to obtaining the safety margin for a certain system, are not distroyed by the earthquake of that level.

For to reduce such displacements, SITON proposes the installation of four(4) SERB-B-199 devices at El.117 between the inner structure floor at that elevation and the upper part of Calandria vault, on B-D direction, and two(2) such devices on A-C direction (the first solution), and four (4) SERB-B-204 devices inclined at 60 degrees on B-D direction (the second solution), as see in fig. 3.1 and 3.2. The displacements due to thermal expansion of the concrete structures, are overtaken by such devices with small stresses in their anchoring points to the reinforced concrete structure while limiting the relative seismic movements to values of about 3 times smaller than the cases without such connections and damping them.

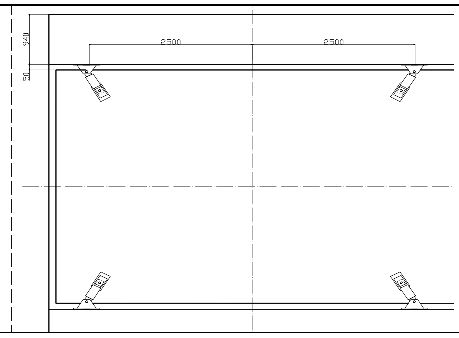
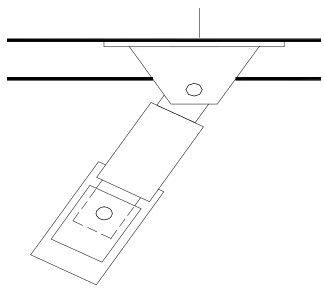
	

Fig.3.1 Assembling devices SERB –B-204 between calandria vault and inner structure	Fig.3.2 Assembling detail for SERB-B204 device

The large damping capacity of the devices including at very small displacements, is improving the overall seismic behavior of the inner structures and Calandria vault by the reduction of the seismic movement amplification.

In the area in which the installation of SERB devices is proposed to be done (El. 117 between Calandria vault and the inner structure floor) the radiation field is quite low and many carbon steel components are located within.

Technically, the solution may be applied both to the existing CANDU units and to new units, ACR type NPPs inclusively.

For to evaluate the relative displacements between the reactor inner structures and Calandria vault, a complex mathematical model was conceived and it includes: the R/B foundation ground, R/B foundation, the containment, the inner structure and Calandria vault. The mathematical model (see fig. 3.3 -3.4) is so conceived that it can evaluate by computations, the overall movement of the R/B and the relative movement among the R/B component structures, also considering the reciprocal influence of a sub-structure movement on the other.

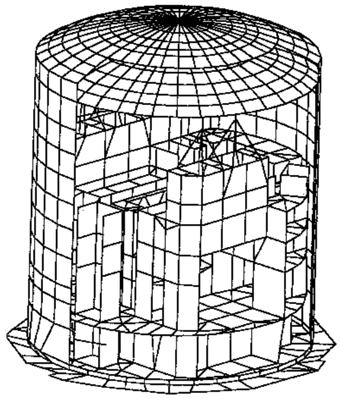


Fig. 3.3. Cernavoda NPP – Reactor Building (R/B)- Inner structures.

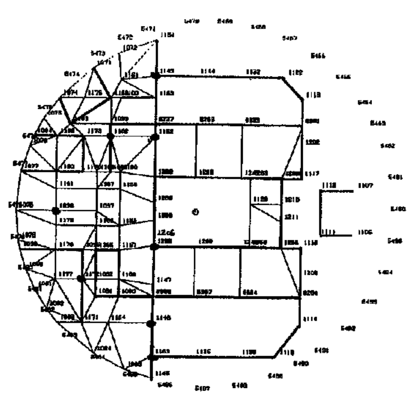


Fig. 3.4. Cernavoda NPP –R/B. Inner structures. El. 117 m

For to evaluate the increase of the safety margin, the analyses regarding the seismic behavior of the inner structures and calandria vault have been conducted in two steps:

Step 1 – calandria vault unanchored on top to the inner structures;

Step 2 – calandria vault anchored on top to the inner structures with SERB devices.

The stiffness and damping characteristics of the mechanical devices SERB proposed to limit the seismic displacements between calandria vault and inner structures , have been experimentally determined with several prototypes which were designed, constructed and experimented by SITON.

By the conducted analyses, the seismic accelerations and displacements of calandria vault and inner structures in the area adjacent to the reactor vessel, were determined. The relative displacements between the two structures are reduced with the increase of the stiffness of the elements which make the connection between the reactor vessel and the inner structures. For the calandria vault unanchored on top, the relative displacements between the calandria vault and the inner structures an 115 elevation are ranging between 10.6 and 13.52 mm. For the case of calandria vault unanchored to the inner structures at the upper elevation, the displacements are almost all the time in anti-phase. For the case of calandria vault anchored to the inner structures at the upper elevation, the displacements are actually in-phase and their maximum values occur at the same time or at very close times.

Table 1

Elevation 115 – Relative displacements in the corner nodes of the calandria vault end plate and the nodes in the same locations on the inner structure in R/B. (Case of unanchored vault).

CALANDRIA VAULT				INNER STRUCTURE				Difference
Node	Dir	Depl (mm)	Node	Dir	Depl (mm)	Node	Dir	Depl (mm)
1148	1	-3.71	-	1205	1	7.86	+	11.57
1148	2	5.50	+	1205	2	5.09	+	10.60
1151	1	5.34	+	1208	1	7.31	+	12.65
1151	2	5.50	+	1208	2	5.03	+	10.53
1209	1	4.80	+	1191	1	-7.95	-	12.76
1209	2	5.30	+	1191	2	-7.48	-	12.78
1212	1	-3.73	-	1194	1	9.79	+	13.52
1212	2	5.27	+	1194	2	6.38	+	11.65
						Depl. Medie	=	12.01
						Dev. Standard	=	1.09

Table 2

Elevation 115 – Relative displacements in the corner nodes of the calandria vault end plate and the nodes in the same locations on the inner structure in R/B. (Case of anchored vault).

K = 1E10 N/m; Damp = 60%								
CALANDRIA VAULT				INNER STRUCTURE				Difference
Node	Dir	Depl (mm)	Sign	Nod	Dir	Depl (mm)	Sign	Nod
1148	1	5.67	+	1205	1	6.46	+	-0.79
1148	2	-5.33	-	1205	2	-5.50	-	0.17
1151	1	5.82	+	1208	1	6.15	+	-0.33
1151	2	-5.39	-	1208	2	-5.44	-	0.05
1209	1	5.70	+	1191	1	6.04	+	-0.34
1209	2	-4.88	-	1191	2	-5.00	-	0.13
1212	1	5.81	+	1194	1	5.98	+	-0.17

1212	2	-4.87	-	1194	2	-5.01	-	0.15
						Depl. Medie = Dev. Standard =		-0.14 0.33

Considering the results of the conducted analysis, for to reduce the relative movement between the calandria vault and the inner structure, the proposal was to anchor them at an upper elevation of calandria vault (El. 116) by means of some SERB devices (fig 3.5).

The devices satisfy the following requirements:

1- allow movements from different thermal expansions of such structures;

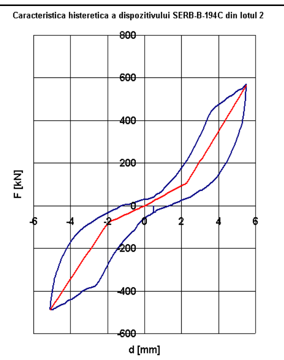
2- reduce the relative seismic movements between the two structures and to make them vibrate in-phase;

3- make possible the overtaking of the big elastic dynamic loads (between 1000 KN –3000KN);

4- operate throughout the plant life-span (30 years) without repairs;

5- the strength and operation of the devices remain unaltered by the radiation field they are located in;

Fig 3.5 illustrates SERB-B-194 devices proposed to limit the relative displacements between calandria vault and inner structures.

	
Fig. 3.5. SERB 194 B devices	Fig. 3.4. Force- distortion hysteresis diagram

For to evaluate the seismic stresses such relative displacements may generate in the most sensitive components of the fuel channel, the following simplifying cases are made:

- components are only axially stressed on maximum distortion;
- transversal distortion on components is neglected;
- the elongation of the axially stressed component is made only in the minimum stiffness area if the stiffness is smaller than 10 times the stiffness of the other areas of the component which participate in the total distortion of the fuel channel.

Considering the above cases it results that in cases when a misalignment between the F/M and the fuel channel due to seismic reasons occurs, the most stressed components are: the bolt which is tightening the fuel channel into calandra end plates(the fixed end of the fuel channel) and the pressure tube (the free end of the fuel channel). In the analysis, the considered actual length of the tightening bolt to the fuel channel, is l_1 = 500 mm and l_2 = 6300 mm for the pressure tube.

Table 3 gives the evaluations for the specific distortions and maximum seismic stresses generated by a DBE level earthquake in the two components of the fuel channel in the analyzed cases. Considering that the yield limit for the alloy the pressure tube is made of, is 330N/m^2 and that the seismic stresses consume over 75% of the yield limit, it results that the probability of the pressure tube breaking during a DBE earthquake, is quite great.

In case the pressure tube gets broken, the PHT system discharge may be stopped by the expansion loop between calandria tube and calandria end plate provided that no damage occurs at calandria due to the seismic event or shocks generated by the coolant flow. The stresses generated by a DBE type earthquake in the tightening bolt of fuel channel, are very high (3129 N/mm^2) because of the bolt high stiffness. Such a stress leads to pulling the bolt off the end plate of calandria or to its breaking.

In case that on top side of calandria, a connection is made between calandria and the inner structure, the seismic stresses during a DBE given by the relative movement between the two sub-structures, is reduced by about 6 times in the pressure tube and the connection bolt, reaching values ranging between 38 N/mm^2 and 59.6 N/mm^2 in the pressure tube and respectively 478.8 – 751.8 N/mm^2 in the connecting bolt.

Following to such analyses it results that by the insertion of a SERB mechanical device between calandria vault and the inner structures, the seismic displacements between these two sub-structures are very much reduced and consequently there will be a decrease of the overloads in the pressure tube and the connecting bolt of the fuel channel when the fuel channel is coupled to F/M.

Table 3

Maximum stresses generated by the elongation imposed to fuel channel components by DBE

Case	name	Element 1 (bolt)				
		l_1 (mm)			l_1 (mm)	
1	unanchored vault	500	7.45	0.00149	210000	3129
2	Anchored vault 4x4 elements k=10^8 N/m damping 40%	500	1.14	0.00228	210000	478.8
3	Anchored vault 4x4 elements k=10^9 N/m damping 50%	500	1.32	0.00264	210000	554.4

4	Anchored vault 4x4 elements $k=10^{10}$ N/m damping 60%	500	1.79	0.00358	210000	751.8
Case	name	Element 2 (pressure tube)				
		l_2 (mm)			l_2 (mm)	
1	unanchored vault	6300	7.45	0.0011825	210000	248.3
2	Anchored vault 4x4 elements $k=10^8$ N/m damping 40%	6300	1.14	0.000181	210000	38
3	Anchored vault 4x4 elemente $k=10^9$ N/m damping 50%	6300	1.32	0.0002095	210000	44
4	Cheson legat 4x4 elemente $k=10^{10}$ N/m Amortizare 60%	6300	1.79	0.0002841	210000	59.67

4. Conclusions

1. In CANDU PHWR 700 NPPs, the fuel channel coupled to the F/M is overloaded during an earthquake due to the relative movement between the calandria vault and the inner structure.
2. The installation of 4 SERB-B-204 or of 6 SERB-B-194 type devices between the inner structure and the top part of calandria vault leads to a decrease of sectional stresses in the pressure tube by about 4 times, representing thus a significant increase of the safety margin.
3. The installation of SERB type devices between calandria vault and inner structure can be implemented during the overhauling period and at a low cost (ranging between 48.000-54 000 Euro/unit).

REFERENCES

[1]. *SITON document* – Reduction of seismic hazard on Cernavoda NPP Site by the use of some mechanical devices capable to disipate the seismic energy and to control the dynamic behavior of structures, also applicable to classic buildings, Contract 313/2003, MENER 2003;

[2]. *SITON document* – Evaluation of the mass asymetry and internal structures stiffness effects on the reactor building and on the seismic input for equipment and piping systems inside the building. Technical solutions to increase the the seismic safety margin of equipment in the CANDU-PHWR 600 – reactor building, contract 285/2007;

[3]. *V. Serban, A. Panait, I. Prisecaru* "SITON solutions to increase new or existing NPP's reliability & safety by controlling, limiting and damping shocks, vibrations & seismic movements", ENERGIA NUCLEARA Magazine, **vol.18** / Nr. 1-2/2006;