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SEISMICITY AND SEISMIC RESPONSE OF THE SOVIET-DESIGNED VVER REACTOR PLANTS*

by

D. C. Ma, J. Gvildys, C. Y. Wang, B. W. Spencer, J. J. Sienicki, & R. W. Seidensticker

Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

and

E. E. Purvis, III

Department of Energy
Washington D.C., 20545, U.S.A

*This work was performed by the U.S. DOE Analysis Team.

INTRODUCTION

On March 4, 1977, a strong earthquake occurred at Vrancea, Romania, about 350 km from the Kozloduy plant in Bulgaria. Subsequent to this event, construction of the unit 2 of the Armenia plant was delayed over two years while seismic features were added. On December 7, 1988, another strong earthquake struck northwest Armenia about 90 km north of the Armenia plant. Extensive damage of residential and industrial facilities occurred in the vicinity of the epicenter. The earthquake did not damage the Armenia plant. Following this event, the Soviet government announced that the plant would be shutdown permanently by March 18, 1989, and the station converted to a fossil-fired plant. This paper presents the results of the seismic analyses of the Soviet-designed VVER (Water-cooled, Water moderated Energy Reactor) plants. Also presented is the information concerning seismicity in the regions where VVERs are located and information on seismic design of VVERs. The reference units are the VVER-440 model V230 (similar to the two units of the Armenia plant) and the VVER-1000 model V320 units at Kozloduy in Bulgaria. The information provides an initial basis for understanding the seismicity and seismic response of VVERs under seismic events.

SEISMICITY

The seismicity at the VVER sites is expressed by the grade of the MSK-64 intensity scale (named after Mededev, Sponhener and Kanik, 1964 version). This scale has twelve grade points which is generally comparable to the Modified Mercalli scale. Four values of MSK-64 intensity are highlighted herein:

- -- intensity VII which corresponds with architectural damage
- -- intensity VIII which corresponds with structural damage
- -- intensity IX which corresponds with severe structural damage and collapse of some buildings
- -- intensity x which corresponds with collapse of many buildings

The correlation between the MSK-64 intensity and the peak ground acceleration is presented in Table 2. Note that the ground acceleration (or the design force) is reduced by one-half as the intensity is decreased one level. In the current Soviet practice, the design earthquake of VVER plant is equal to the site intensity + 1 on the MSK-64 scale. For example, if the site intensity is determined to be VIII, the plant is designed for an earthquake of intensity of IX (VIII + 1).

An important feature in the Soviet practice is the concept of "microzonation."

'Microzonation is a technique that consists of locally raising or lowering the intensities of a regional seismicity map by considering the local soil conditions. This practice effectively means that the design force is one-half or double the earthquake that is expected in the region. Microzonation maps are the most important documents from which the maximum acceleration, predominant frequency content, and duration of the ground motion at the plant sites are determined.

Figure 1 shows a regional seismic zoning map and the locations of VVER-440 and VVER-1000 stations in the western Soviet Union and the Eastern European countries. In the European part of the Soviet Union where VVER stations have been constructed, the regions of significant seismicity are located in the south where the Soviet Union borders on Turkey and Iran. The Armenia station with two VVER-440 model V270 units and the Crimea Station with two VVER-1000 model V320 units under construction are located in regions of high seismic intensities (intensity VIII and above). The other VVER stations that are in high seismicity regions (intensity VI and above) include the Odessa, South Ukraine and Khmelnitskiy Stations. In the Eastern Europe countries, the Bulgaria Kozloduy site containing four VVER-440 model V230 units and two VVER-1000 model V320 units and the planned Belene site containing four VVER-1000 model V320 units are shown to be in a region of intensity VI on Figure 1. However, the intensity at the site exceeds VI, on the basis of damage observed following the 1977 Vrancea earthquake. These two sites are regarded to have an intensity of VIII. Czechoslovakia has local regions of maximum intensity VIII. The Bohunice plant and the recent Mochovce plant are located at site of intensity VII. The Paks plant in Hungary has a site intensity of VII or less. The VVER stations in Poland and East Germany are located in regions of relatively low seismicity. The two Cuban Juragua VVER-440 model V318 units under construction has site intensity of VIII. In particular, this plant was designed for a peak ground acceleration of 0.3 g, corresponding to MSK-64 intensity of IX.

In summary, the VVER stations located in regions of significant seismic intensity (MSK-64 intensity of VIII or above) are the Armenia Station and the Crimea station in Soviet Union and the Kozloduy station and the planned Belene station in Bulgaria and the Juragua station in Cuba. Detailed information on seismicity as well as seismic design practices and regulations for VVERs can be found in Reference 1 (DOE/NE-0084 Revision 2).

SEISMIC RESPONSE OF THE VVER PLANTS

Seismic analyses of the major VVER structures, components and piping systems were carried out. Because of space limitation, only the seismic response of the reactor buildings and the primary coolant loops are presented.

Reactor Buildings of the VVER-440 Model V230 and VVER-1000 Model V320

Figure 2 shows the elevation view of the VVER-440 model V230 main building. This is an industrial type of building, comprising of a turbine hall, a control and auxiliary equipment section, a reactor section, and an exhaust ventilation center. Major components of the primary loops and the reactor are supported at ground level. The skeleton of the main building is made of precast reinforced concrete columns. Figure 3 shows the mathematical model used in the analysis. The reactor section forms a rigid box, serving as the foundation for the precast skeleton. Soil conditions of the Kozloduy site were used in the analysis. Figure 4 shows an amplified deformed configuration of the main building and the calculated maximum accelerations under a reference earthquake with peak acceleration of 0.3 g. This figure indicates that the exterior columns in the turbine hall have large deformations due to the heavy mass of the exterior concrete wall slabs. The calculated dominant mode of the main building in the lateral direction has a frequency of 2.5 Hz. The highest seismic stresses occur in the interior columns of the turbine hall above the crane support location due to the reduced column section at the crane support.

Figure 5 shows the VVER-1000 model V320 reactor building which consists primarily of a prestressed-concrete cylindrical containment, a reactor section, equipment rooms between two thick concrete mats, and the office buildings around the containment. Major components and the reactor are supported about 25 m above the grade level. Figure 6 shows the mathematical model and the calculated maximum acceleration at various locations under the 0.3-g reference earthquake. The VVER-1000 reactor building has two calculated dominant modes. They are 4.3 Hz for the containment and 7.5 Hz for the reactor section. The maximum seismic stresses occur at the bottom of the containment shell.

Primary Coolant Loops of the VVER-440 Model V230 and VVER-1000 Model V320

In order to allow thermal expansion of the primary coolant loops, steam generators, pumps and pipes, both the VVER-440s and the VVER-1000s had no rigid supports prior to the 1977 Vrancea earthquake. Pipelines were free to move, horizontal steam generators were suspended, and circulation pumps had movable ball type supports. The reactor vessel was the only fixed element in the piping system. During the 1977 Vrancea earthquake, one of the steam generators moved a distance of 12 cm. Since the 1977 Vrancea earthquake, major components of the primary loops were reinforced by the hydraulic shock absorbers.

The mathematical models for the VVER-440 model V230 and the VVER-1000 model V320 primary coolant loops are shown in Figs. 7 and 8, respectively. Two cases were studied: with and without shock absorbers. The outer diameter of the loop assumed in the analyses was 56 cm for the VVER-440 and 99 cm for the VVER-1000. The wall thickness assumed was 3.2 cm for the VVER-440 and 9.9 cm for the VVER-1000. The hydraulic shock absorbers used in the analyses are shown in Table 2. The calculated seismic response of the primary loops of the VVER-440 and VVER-1000 under the 0.3-g reference ground acceleration are shown in Table 5. Note that the VVER-440 loops are located near ground level, whereas the VVER-1000 loops are located 26 m above the grade. Therefore, the VVER-1000 primary loops are subjected to higher support-motions than those of the VVER-440 (in this case, 0.603 g vs. 0.3 g). Figure 9 shows the lateral movements of the VVER-440 primary loop for the case without shock absorbers. The maximum movement is 36 cm at the steam generator. If the magnitude of the reference earthquake is scaled down to 0.15 g, the calculated movement would be about 18 cm, which is close to the measured movement of the steam generator of the Kozloduy plant during the 1977 Vraneca earthquake. This is consistent with the assessed peak ground acceleration of 0.1 g - 0.15 g at the Kozloduy site during the 1977 earthquake.

Conclusions

VVERs have been, and are being, constructed in regions of significant seismic intensity. These include the two Armenia VVER-440 model V270 units and the two Crimea VVER-1000 model V320 units in Soviet Union, the four VVER-440 model V230 units and the two VVER-1000 model V320 units at Kozloduy and the four planned Belene VVER-1000 model V320 units in Bulgaria and the two Juragua VVER-440 model V318 units in Cuba. As a result of the 1988 Armenia earthquake, the two Armenia units will be shut down and several planned units in high seismicity regions cancelled. The information presented in this paper provides an initial basis for understanding the Soviet-designed VVER plants under seismic events.

Acknowledment

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References

1. DOE/NE-0084, Revision 2, "Overall Plant Design Description VVER Water-Cooled, Water Moderated Energy Reactor," U.S. Department of Energy.

Table 1.

MSK-64 Scale and Ground Acceleration

MSK-64 Intensity	Peak ground acceleration (g)
V	.012-.025
VI	.025-.05
VII	.05 -.10
VIII	.10 -.20
IX	.20 -.40
X	.40 -.80

Table 2.

Hydraulic Shock Absorbers

	VVER-440
Steam generator	8 (50-tons) absorbers
Pump	3 (25-tons) absorbers
Isolation Valve	1 (5-ton) absorber
	VVER-1000
Steam generator	8 (50-tons) absorbers
Pump	5 (170-tons) absorbers

Table 3.

Response of the Primary Loops under 0.3-g Ground Motion.

	VVER-440, V230		VVER-1000	
	No Shock Absorber	Reinforced by Shock Absorber	No Shock Absorber	Reinforced by Shock Absorber
Dominant Frequency	0.3 Hz	9.4 Hz	0.9 Hz	6.8 Hz
Maximum Displacement	36 cm at steam generator	0.0984 cm	18.3 cm	1.11 cm
Magnitude and Location of Maximum Seismic Stress	57 ksi at reactor inlet nozzle	3.9 ksi at elbow below primary pump	45 ksi at reactor outlet nozzle	16.5 ksi at pipe near steam generator

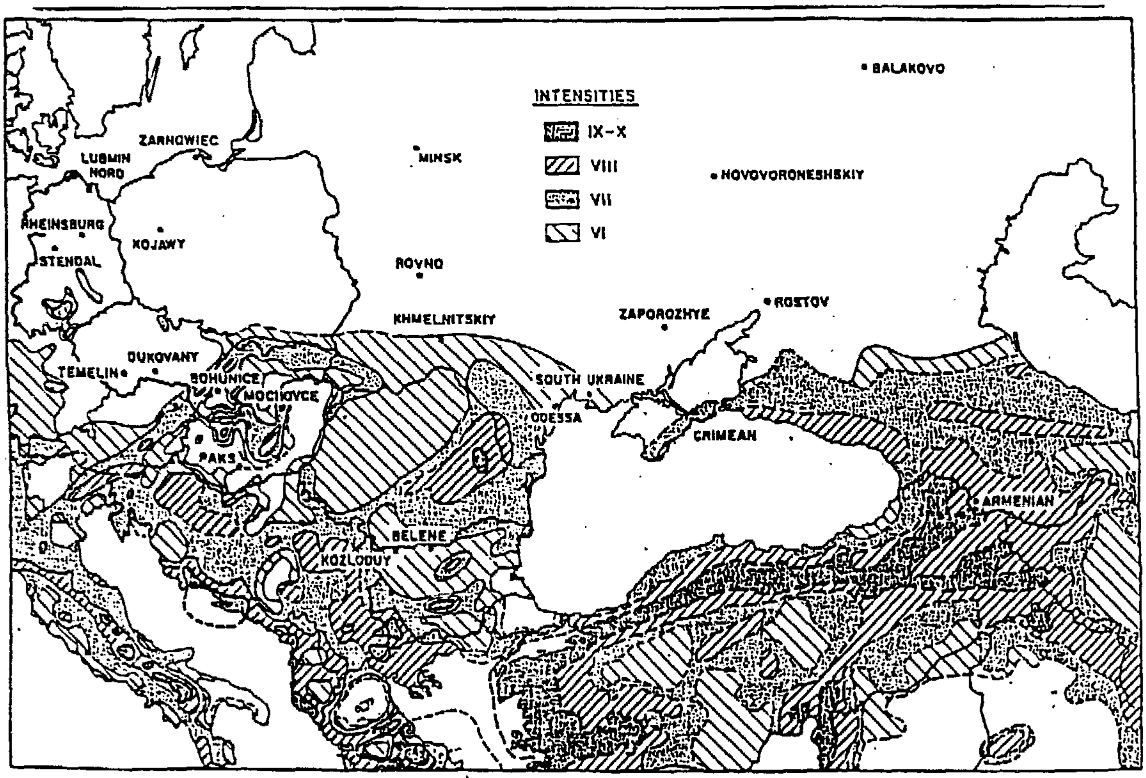

Figure 1. Seismicity and Locations of VVER Stations.

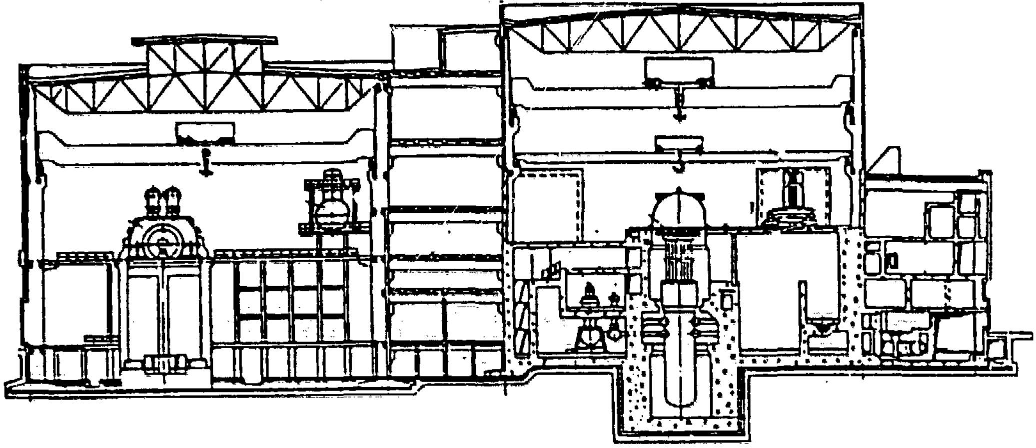

Figure 2. VVER-440 Model V230 Main Building.

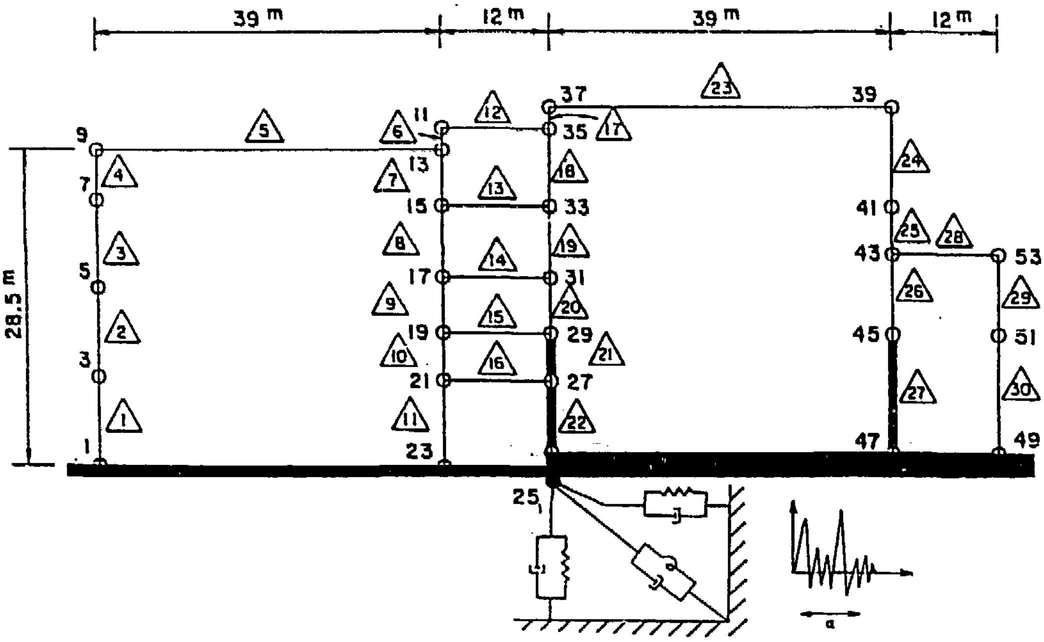

Figure 3. Mathematical Model of the VVER-440 Model V230 Main Building.

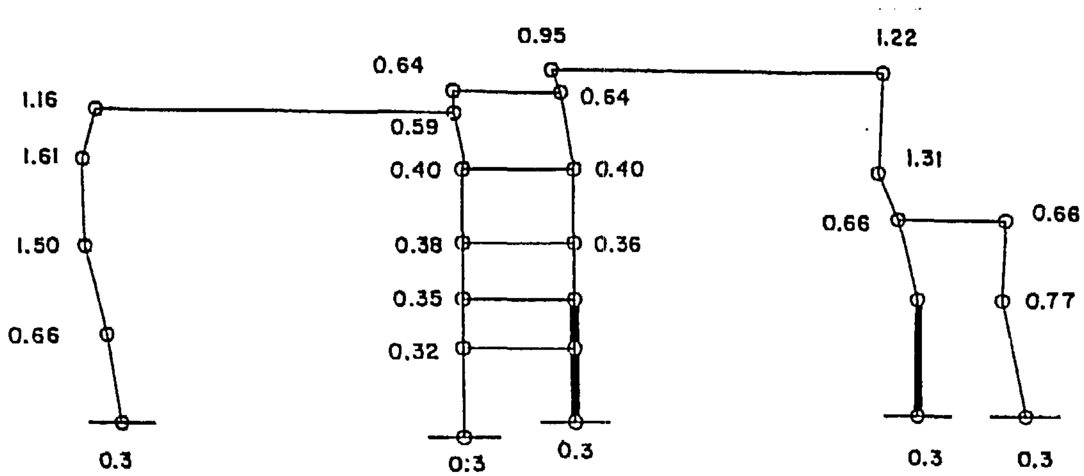

Figure 4. Amplified Deformed Configuration and the Calculated Accelerations.

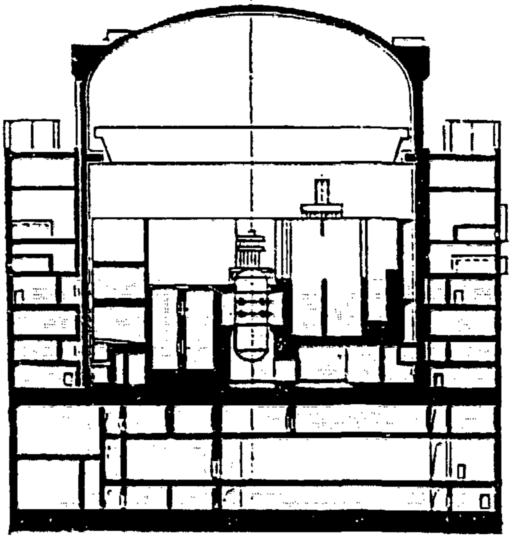

Figure 5. VVER-1000 Reactor Building.

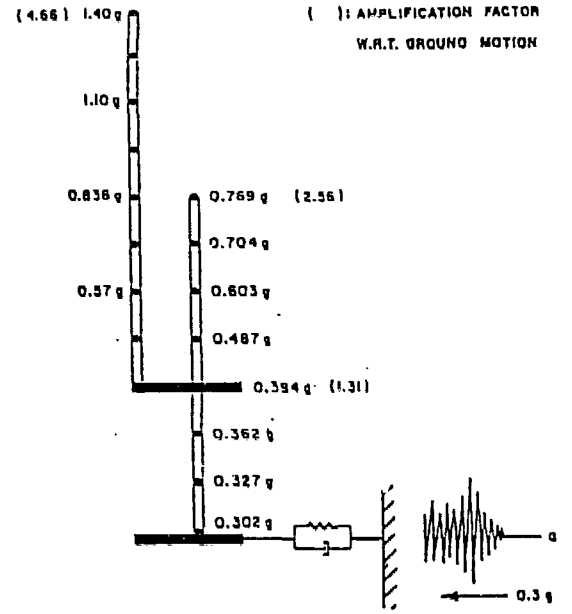

Figure 6. VVER-1000 Model and the Calculated Accelerations.

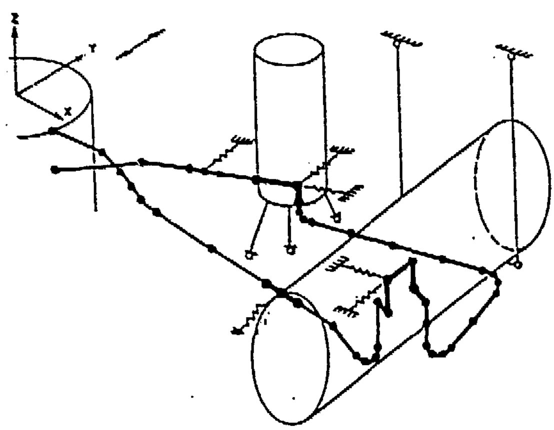

Figure 7. VVER-440 Primary Coolant Loop.

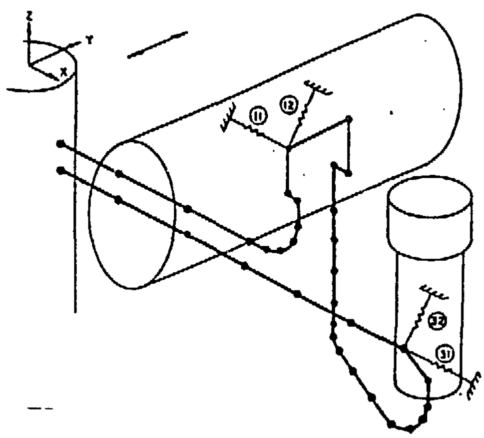

Figure 8. VVER-1000 Primary Coolant Loop.

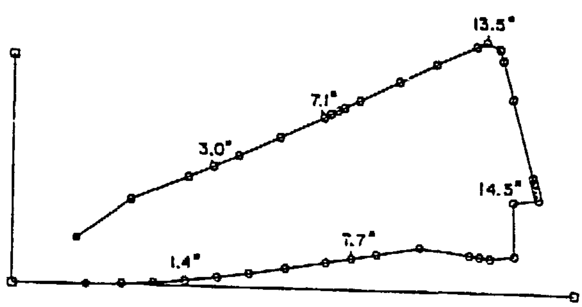

Figure 9. Movement of the VVER-440 Primary Loop (No Shock Absorbers).