SEISMIC ASSESSMENT OF KOZLODUY VVER 440, MODEL 230 NUCLEAR POWER PLANT

by

Philippe Monette and Robert Baltus

Westinghouse Energy Systems International
Brussels, Belgium

Peter Yanev and Robert Campbell

EQE Engineering
San Francisco, Ca, U.S.A.

1 INTRODUCTION

There is international concern regarding the safety of the Soviet designed VVER-440 Model 230 nuclear power plants. The International Atomic Energy Association (IAEA) is sponsoring missions to evaluate the various concerns raised about this particular model. Among the concern is the seismic resistance of the design. This paper is a preliminary report of the findings of an IAEA sponsored walkdown of the VVER-440, Model 230's at Kozloduy, Bulgaria, in May 1991.

The scope of the IAEA mission was to determine the lower bound seismic capacity of the plant and to make recommendations for improvements to increase the seismic resistance.

The methodology utilized in the assessment is that described in Reference 1 for evaluations of seismic margin in U.S. Nuclear Power Plants subjected to earthquakes beyond their design basis. Included in the assessment is the establishment of a safe shutdown path which would include the capability to mitigate a small break in the primary system, performance of a walkdown of the safe shutdown path and calculation of the high-confidence-of-low-probability-of-failure (HCLPF) of the safe shutdown path. This paper covers the study up through the walkdown and presents engineering judgement as to the seismic capacity of the plant. HCLPF capacity calculations will be performed in the future for a few selected components which are believed to be the governing elements.

2 DESCRIPTION OF THE PLANT

The Kozloduy, Bulgaria site contains four (4) VVER-440, Model 230 units. Units 3 and 4 are of a later design and contain improved safety systems over those of Units 1 & 2. Each double unit installation contains a main building, a diesel generator building and a service water pump building. Included in the main building are an accident localization compartment, an electrical building for each unit and a common turbine hall. Figure 1 shows the VVER layout for a double unit installation.

The primary system consists of six loops each containing a horizontal steam generator, a primary coolant pump and a motor operated isolation valve in the hot leg and the cold leg respectively. A pressurizer connects to the primary system via two surge lines and a spray line.

The design basis accident for the four units is a 100 mm inside diameter line break with unidirectional flow through a 32 mm orifice insert. The accident mitigation system consists of a high pressure injection system and a spray system for the accident localization compartment. The accident localization compartment functions as a confinement for the one bar overpressure resulting from the DBA.

Units 3 and 4 contain a low pressure injection system but the DBA confinement design is unchanged.

Core cooling under both normal and accident conditions is provided by the steam generators. During emergency shutdown conditions, the primary coolant circulates through the steam generators by natural circulation, the steam generators are cooled by an emergency feedwater system. Steam is dumped to atmosphere during operation of the emergency feedwater system.

Long term decay heat removal is accomplished by a closed loop circulation of water through the steam generators and through decay heat removal heat exchangers cooled by service water.

Important support systems are service water, emergency AC power and DC battery power. These VVER units do not use a closed loop component cooling water system All heat loads are rejected directly to the service water system.

Redundancy is present for most essential systems. The unit 1 & 2 service water system is a single train system with redundant pumps for all essential and non-essential heat loads whereas units 3 & 4 have three separate trains of service water. A single closed loop decay heat removal system with redundant pumps is shared between two adjacent units and is limited in capacity to cooling one unit at a time. Three trains of main station batteries are shared by two units. All other safety functions have a two or three train system. Units 3 & 4 have increased redundancy over units 1 & 2.

Isolation of main steam and feedwater occurs upon plant trip. The main steam isolation valve is slow in closing, thus structural integrity of the main steam line down to the turbine is essential to prevent overcooling

The purification system for the primary coolant is not automatically isolated in an emergency shutdown, thus structural integrity of its components (letdown heat exchanger, regenerative heat exchanger and filters) is essential.

Although it was not the scope of this study to determine deficiencies in the system design, it was vital to understand the system functions and isolation functions in order to select the essential components for evaluation.

3 SEISMIC DESIGN BASIS

Units 1 & 2 were operational in 1974 and 1975 respectively. They were originally constructed in accordance with standard building practice. No special provisions were made for seismic loading. In 1977 an earthquake in Vrancea Romania affected the site. There were no recording instruments and it was estimated that the free field ground motion reached maximum 0.1 g. After the earthquake some minor structural damage was reported and a seismic upgrade program was started. Several modifications were made to the primary system and ECCS systems. Snubbers were added to the steam generators, the primary coolant pumps and to the hot leg near the hot leg isolation valve. Snubbers were added to the high pressure injection system piping and the main steam lines within the accident localization compartment. Battery racks were replaced with rugged, well anchored racks.

Additional evaluations have been made of equipment and piping by the All Union Nuclear Power Engineering Research and Development Institute, USSR, and several recommendations were made for seismic upgrades. Supports were added to the pressurizer, the letdown and regenerative heat exchangers and the decay heat removal heat exchangers. Additional bolting and welding was added to the primary coolant filters. Other recommendations were made which have not been implemented. Of particular importance are the recommended modifications to the deaerator supports which have not been accomplished.

The structural design for units 3 & 4 was essentially the same as for 1 & 2, except the diesel building. Some backfit measures were implemented into building structures, including reinforcement of connections between precast reinforced concrete beams and columns. Equipment modifications made to units 1 & 2 were also incorporated into units 3 & 4 which were completed in 1980 and 1982 respectively. In addition, units 3 & 4 have considerably more bracing to electrical equipment than 1 & 2.

Seismic modifications to the equipment are based upon generic in-structure spectra developed for a 0.1g pga. These spectra peak at about 0.5 Hz and drop off significantly at about 2.5 Hz. Current studies being conducted by the Bulgarian Academy of Sciences indicate that the in-structure spectral shape will have significantly more amplification above 2.5 Hz which will increase the design loading for most equipment. The peak ground acceleration level will also increase by perhaps as much of 50%, so that the newly defined demand in equipment may double.

4 DESIGN REVIEW AND WALKDOWNS

4.1 Building structures review

The buildings housing safe shutdown equipment include all sections of the main building, the diesel buildings and the service water pumping station.

The seismic capacity of the building structures was assessed by reviewing the design drawings and some analysis results including handcalculations of the structural frames in the electrical and diesel buildings, and 3-dimensional finite element analysis of the main building. This review identified the critical load paths and weak elements or assemblies which experienced severe damage and caused the collapse of similar buildings subjected to earthquakes.

The thick monolythic reinforced concrete structures such as the reactor confinement and the lower part of pumping station were rapidly screened out as they have obviously a high seismic capacity.

Most of the other buildings were walked down in order to confirm the opinion established during the design review and to examine closer the critical elements.

In the main building, the critical locations included the following:

a. Connection of the turbine hall outer column into the foundation footing,
b. seating and anchorage of the turbine roof truss at the top of concrete column,
c. connection of the precast concrete beams between the turbine hall and reactor building,
d. upper section of the reactor building outer wall at the construction joint above the thickness step change.

The probably weakest structure is the pump house above grade level. It contains several weak elements which failed in similar industrial buildings during intensity 8 and 9 earthquakes in Armenia. These elements include mid-raise brick walls and poor connections of precast concrete panels to columns, as well as uncertain connections of precast concrete roof elements.

The diesel buildings comprise also weak assembly of precast concrete elements including partition brick walls, unstable beam arrangement supporting the heavy roof in building 1 & 2 and weak columns and slabs with large openings in building 3 & 4.

4.2 Equipment walkdown

The walkdowns were conducted mainly on Unit 1, considered to be typical of the other units, or less resistant in certain areas than the newer units 3 and 4. For the confinement area, unit 4 was visited, as it was in refueling outage. For some critical components in the Turbine Hall, all units were reviewed.

The list of safe shutdown components was established based on review of layout drawings, systems flow diagrams and electrical one-line diagrams, as well as by detailed discussions with plant personnel.

All the components in the list were reviewed for

- Structural adequacy
- Proper anchorage
- Systems interaction hazards.

Extensive use of earthquake experience data was made to focus on the vulnerabilities which are known to have caused failure in the past large motion earthquakes. Engineering judgement was also used based on observations in the field and limited drawing review. This process allowed the generation of a relative ranking of the safety related components according to their seismic capacity, rated low, medium or high.

Table 1 provides a list of the most vulnerable components, i.e. those with the least seismic resistance (rated low).

A discussion of the walkdown results is provided below for some of the key items.

5 SEISMIC CAPACITY ASSESSMENT

5.1 Building structures capacity

The review confirmed the intensive use of precast concrete elements for the columns, beams, slabs, roofs and panel walls of building portions above grade level. In the original design most of these elements had poor connections or no connection at all to sustain the seismic loadings.

The amount of reinforcement needed will depend on the seismicity level retained for the plant upgrade, which is not yet established. For the following considerations, it has been assumed that the target ground motion will be comprised between 0.1 and 0.2g, based upon discussions with site personnel and with members of the Bulgarian Academy of Sciences.

The seismic backfit program implemented for the main building was based on 0.1g input level. It led to addition or reinforcement of horizontal ties between beams and columns in the auxiliary building sections around the reactor building, including the intermediate building connected to the turbine hall. More recent analysis currently conducted by Bulgarian Academy of Sciences using a 3-dimensional finite element model, seems to indicate that a few elements could not sustain 0.1g because of load concentration on the turbine hall frames adjacent to the reactor building extremity wall. That preliminary analysis did not consider adequately the effects of soil structure interaction, which may decrease the structure response due to soft soil effect and potentially counterbalance the impact of increasing the seismic input level.

Some other modeling assumptions need also to be verified in light of the analysis results, such as the capacity of precast concrete slabs and wall panels to sustain in plane membrane and shear forces, and to transmit these loads to skeleton frames without breaking the connections.

The diesel building reinforcements recommended after the 1977 earthquake were not thoroughly implemented, even for units 3 & 4. Recent analysis conducted by Energoproekt identified some local overstress for a seismic code type of loading equivalent to approximately 0.08g. After walkdown of the structures, it seems feasible to upgrade them up to a target level of 0.2g with a reasonable amount of reinforcement based on up-to-date analysis.

The pump station building has apparently not been analyzed for seismic loading. The structural weaknesses identified during the walkdown could be corrected with a limited amount of reinforcement, considering the simple shape of the structure above grade and the space available around the weak elements.

Finally, several other structures which were not examined in detail during this walkdown, might require a seismic capacity assessment when the site seismicity level will be established. These items include the stability of the canal and the risk of soil liquefaction, the turnover of diesel motor pedestal and the potential impact of chimney stack collapse in case of soil compaction.

5.2 Equipment capacity

The walkdowns revealed that the majority of the equipment inside the reactor building can be shown to have HCLPF capacities well above 0.1g. This includes the primary system and NSS equipment supports, the general category of pumps and motor-operated valves, the heat exchangers and most of the large bore piping.

However some of the ECCS and Spent Fuel Cooling pump inlet piping have miter bends which are smaller in size than the rest of the suction piping and would be subject to loads from large unsupported tributary spans. The presence of problematic bellows was also noted.

The boron concentration tank (Unit 3 and 4 only) is flat bottom and unanchored. It is however intended to remove this tank from the plant.

Outside the Reactor Building, equipment items with adequate seismic capacities include the batteries, which are well confined in their racks, the diesel generators and most of the piping. The high capacity assigned to the piping is by reference to the earthquake experience data and does not imply that margins exist with respect to specific code allowables. The piping is mostly rod hung or spring hung and essentially designed for dead weight loads.

Some of the larger size mechanical components which were found to have marginal or insufficient anchorage capacity are:

- the Deaerators, which have very poor connections to the structural steel supports
- the DHR Vertical Heat Exchangers which have inadequate bracing at the top
- the Demineralized Water Tank and the Diesel Fuel Oil Storage Tank, which are not anchored.

The electrical and control equipment category shows a variety of anchorage details, ranging from no anchorage to strong seismic bracings in Units 3 and 4. In unit 1 and 2, the bracings were minimal and did not allow to confirm a satisfactory capacity, mainly due to lack of or poor welding to embedments. The 6 kV to 400 V Transformers are not anchored and do not have adequate supporting of the internal coils.

The instrumentation and control cable trays were found to be most often, heavily loaded and in certain placed had excessive spans and sagging.

Relays were not specifically evaluated. They are mostly of Soviet origin and U.S. experience on sensitivity is mostly not applicable. Most of the relay panels were quite flexible and would amplify horizontal motions. Most of the relays, however, had their solenoids oriented in the vertical direction which would not be as highly amplified.

6 CONCLUSIONS

Excluding system design deficiency relative to US and Western Europe standards, it was found that the plant has many seismic vulnerabilities similar to those that existed in many of the US plants prior to about 1979 when the Systematic Evaluation Program was initiated. The primary coolant system has been substantially upgraded after the 1977 Vrancea earthquake. Other upgrades have been made to weak elements in the ECCS and electrical systems. There are still a number of components that could likely survive the currently defined Safe Shutdown Earthquake of 0.1g but which would not meet current design standards. Many of the weakest components could be upgraded at a moderate cost to withstand a seismic event exceeding 0.1g.

Current studies of the site seismicity lean toward a higher peak ground acceleration and increased amplification of building motion, thus backfits that have been accomplished may become marginal for newly defined loads. However the proper consideration of soil structure interaction and detailed structural analysis using less conservative modeling assumptions, could mitigate the impact of increasing the seismic input and limit the amount of reinforcement required. In the interim, substantial improvements to seismic safety could be accomplished by simple, inexpensive modifications to equipment anchorage and some achievable improvements to connection detail of the precast concrete structures.

7 REFERENCES

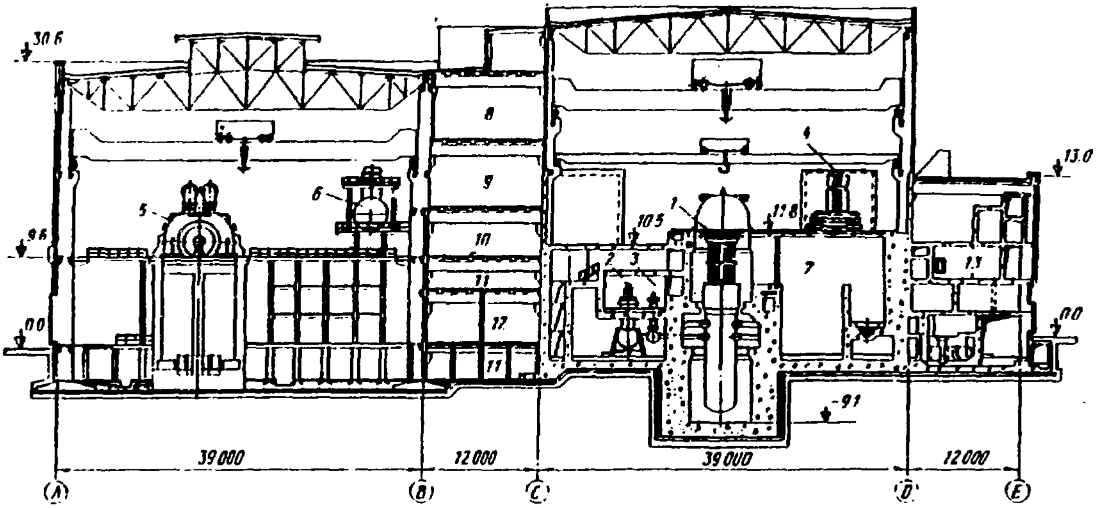
7.1. Campbell, R.D., Kennedy, R.P. et. al., "A methodology for Assessment of Nuclear Power Plant Seismic Margin", prepared for Electric Power Research Institute, EPRI Report NP-6041, October 1988.

7.2. U.S. Department of Energy - Team's Analyses of Soviet Designed VVERs - DOE/NE-0086 - Revision 1 - September 1989.

TABLE 1 - LIST OF LOWEST SEISMIC CAPACITY COMPONENTS

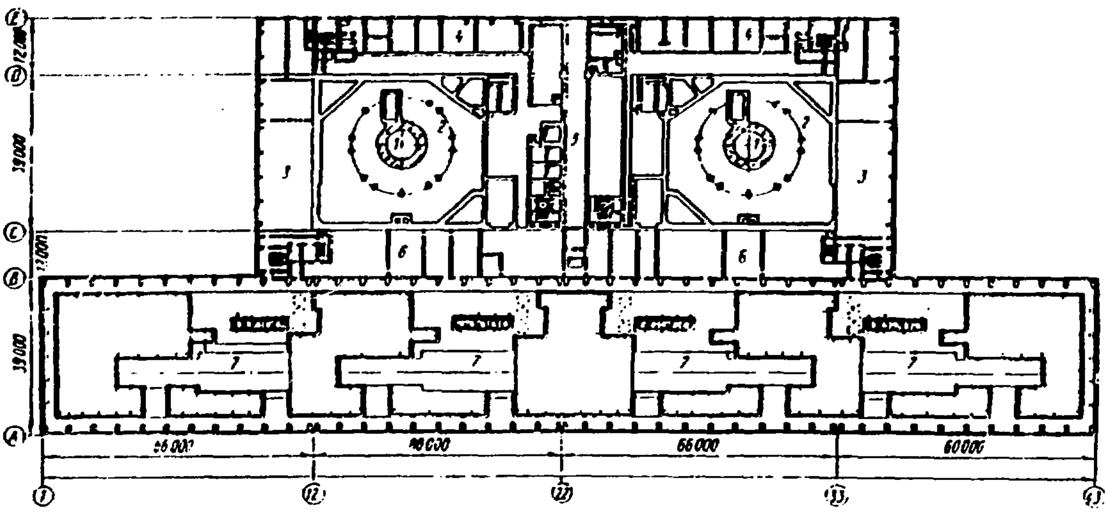
Equipment Item	System Function	Location (2)	Rating
Boron Concentration Tank (1)	Small LOCA Mitigation	Reactor Building	L
Deaerators	Initial Emergency Feedwater Supply	Turbine Hall	L
Demineralized Water Tanks	Emergency Long Term Feedwater Supply	Yard	L
Decay Heat Removal HX	Cooling to Cold Shutdown	Turbine Hall	L
Diesel Fuel Storage Tank	Diesel Generator	Diesel Building	L
Transformer 6 kV - 400 V	Emergency AC Power	Electrical Building	L
400 V Bus/Breakers	Emergency AC Power	Electrical Building	L/M
Thyristor	Emergency AC Power	Electrical Building	L/M
220 V DC Bus/Breakers	Vital DC Power	Electrical Building	L/M
220 V Distribution Panel to Solenoid Valves	Vital DC Power	Electrical Building	L/M
D.G. Load Sequencing Panel	Vital DC Power	Electrical Building	L/M
Motor Control Centers	Emergency AC Power to Valves	Turbine Building	L
Diesel Generator Control Panel	Emergency AC Power	Diesel Generator Building	L
Reactor Protection System Relay Panels	Reactor Control	Electrical Building	L/M
Instrumentation + Control Cables	Reactor Control	Electrical Building	L/M

(1) Units 3 & 4 only.
(2) All buildings contain at least one precast concrete weak element or connection with low seismic capacity, except the monolythic concrete structure of the Reactor Building.



Cross-sectional view of the main building

1 - reactor; 2 - steam generator; 3 - main circulating pump; 4 - main circulation gate valve; 5 - turbogenerator; 6 - deaerator; 7 - refueling pond; 8 - plenum ventilation centre; 9 - pipe aisle; 10 - control board room; 11 - cable shelf; 12 - switchgear location, 13 - exhaust ventilation centre



Plan of the main building

1 - reactor; 2 - steam generator cell; 3 - modular control board room; 4 - exhaust ventilation centre; 5 - transport aisle; 6 - switchgear location; 7 - turbogenerator

Figure 1 Cross-Sectional View and Plan View of the VVER-440 V230 Main Building