



## Approaches, concepts and experience in design of seismic upgrades at NPP "Kozloduy"

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**ABSTRACT:** NPP "Kozloduy" is situated in the north-west part of Bulgaria on the Danube river bank. EQE-Bulgaria under contracts with NPP "Kozloduy" has elaborated projects for seismic upgrading of a series of building structures at the site of the plant. As the process of implementation of these projects has already started, it is possible to point out some specific problems that have appeared. Some interesting conclusions have been drawn from the experience in analysing and upgrading of such complex industrial structures.

### 1. INTRODUCTION

The existing structures have been designed for an anticipated seismic input motion with 0.1g peak ground acceleration. With the application of stronger safety requirements for NPPs it was cleared up that the facilities of Kozloduy NPP should be designed to withstand a safe shutdown earthquake (SSE) with 0.2g peak ground acceleration. Considerable efforts have been made by experts from different institutions, essentially supported by IAEA, to develop adequate seismic input characteristics for the seismic qualification of facilities associated with the safe shutdown of the plant. This included development of a free field Response Spectrum for Kozloduy site, anchored at 0.2g PGA, approved by IAEA [1], Figure 1.

The preliminary seismic analyses of the described in the beginning building structures using the 5% site specific response spectrum showed the need of seismic structural upgrading.

### 2. DESCRIPTION OF THE BUILDING STRUCTURES

The Spent Fuel Storage Building is a cast in place and pre-cast concrete industrial type building constructed in 1986 at Kozloduy NPP site. The building is approximately rectangular measuring about 78 by 46 meters in plan and rises 37 meters above ground. Figure 2 and Figure 3 show the current configuration of the building. It is comprised of two main parts - Main Hall, with high-bay (between axes 1 and 7) and low-bay (between axes 7 and 14) and Auxiliary Building (between rows A and B). There are two travelling cranes to handle the spent fuel - a high capacity crane (160t) servicing the high-bay and a light capacity crane (16t) servicing both bays. The structure is composed of two sub-structures: the pre-cast concrete construction above Elevation 7.20m, and the monolithic concrete block below this elevation where the spent fuel pools are housed and which supports the pre-cast building elements. Figures 2 and 3 show typical sections of the building.

The Main Pump Station-2 is a cast in place and pre-cast concrete building. It is approximately rectangular measuring about 78 by 14 meters in plan and rises 10 m. above

ground (Figure 4). There are two travelling cranes for servicing the pumps - one crane(8t) inside the building and another crane (5t) outside. The structure is composed by two construction types: pre-cast concrete construction above the ground, and monolithic concrete block with height of 12 metres, where the pumps are housed, below the ground.

All the pumps in the River-bank Pump Station and the Emergency Pump Station are housed in one and the same building. The building itself is placed at the Danube river bank. It is approximately rectangular measuring about 102 by 10 meters in plan and rises 10 meters above ground. The structure of this building is similar to that of the Central Pump Station, but the monolithic concrete block under the ground level is 32 meters high. There is a gap in the whole structure that separates the emergency pumps block from that of the other pumps. There are two cranes to handle the pumps - one inside and another outside of the building. The cranes are similar to those in the central pump station.

The Diesel Generator Building-2 is a cast in place and pre-cast concrete industrial building. It is approximately rectangular measuring about 54 by 36 meters in plan and rises 13 meters above ground. The building is separated in six identical modules, where the engines and the supporting facilities are placed. Thus, there are six cranes that move in transverse direction and handle the engines. This separation is only by technology reasons and there are no structural gaps in longitudinal direction.

### 3. UPGRADING CONCEPTS

One of the first problems to be solved when determining an upgrading concept is the choice of proper material for the strengthening elements - steel or concrete. The choice should be made in accordance with: the structural features of the building, the technological processes requirements of the equipment housed inside and the free space around the building, etc.

A key factor for the selection of a specific upgrading concept is the client's requirement for quick and easy for implementation building upgrades that will impose no breaks in the technological process. That is why usually steel is preferred as material for the construction of upgrading elements.

At some places it is imposed to use both material - steel and concrete. The application of concrete structures is connected with: longer period of construction, "wet processes", dismantling of existing equipment and ensuring enough place for the formwork. So, the implementation of concrete as material for upgrading elements (predominantly new shear walls) is limited only for places where all these problems can be avoided or minimised.

Another important moment is the exact definition of the purposes of the upgrading - to protect definite equipment, to prevent the whole building from collapsing and to protect the equipment inside, or to protect neighbouring facilities by upgrading the structure which is a source of system interaction.

The idea for constructing local protecting structures only over the safety related pumps and equipment in the Main Pump Station was very attractive and was seriously discussed. Similar pumps and equipment in some foreign nuclear power plants are situated in open-air. Thus, the survival criteria of the overground part of the structure are connected only with the danger of direct fall of heavy pieces like roof panels and pre-cast beams on safety related equipment. The whole overground part of the building would not be upgraded.

The construction of local protecting structures requires enough place and their dimensions should be co-ordinated with the exploitation of the crane and the normal maintenance of the pumps. These structures have to neutralise considerable dynamic loading due to the shock of falling heavy pieces (up to 8.0 tons) from 4.5 m height. This could be achieved either through big own mass of the structures (several times bigger than the mass of falling pieces) or through plastic deformability (tens of centimetres). The big mass can be easily achieved, but the protecting structures must be light enough (less than 8 tons) in order to be handled by the crane. If they are made of discountable pieces this will impede the normal exploitation of the

pumps because of delayed access. The big plastic deformability of the protecting structures is difficult to be realised due to lack of space.

An additional argument for rejection of the local protecting structures is the danger the pumps together with their protecting structures to remain buried under the ruins of the building after SSE, so that nevertheless the safety related pumps will work normally during and after an earthquake they will be inaccessible. All the above mentioned facts and reasons make the idea of applying local shields in this building not applicable.

The situation with the River-bank Pump Station was similar. Since the important pumps there are those, placed in the Emergency Pump Block, it was decided to upgrade only this block and the neighbouring block of the River-bank Pump Station.

#### 4. MODELLING OF THE STRUCTURES

The preparation for the computer modelling starts with a thorough investigation of the existing structure. This includes study of the existing design and erection documentation, study of the calculations and codes active for the time when the structure has been designed and defining the differences with the new codes and evaluation criteria, and finally - conducting of a walkdown. It is very important to compare the notes from the walkdown with the design drawings, since there are always discrepancies between the design and it's execution.

During the development of the concepts a lot of variants for longitudinal and transverse upgrading structures and details were tried and tested. Sometimes it is practical at the initial stage simple independent 2D beam computer models to be developed. After clarifying the final proposed variants detailed 3D computer models for all structures were developed using the programme codes SAP'90 or COSMOS/M version 1.75, Figure 7. Static and dynamic analyses of the detailed 3D models were conducted in order to evaluate the existing structures and after relevant changes in the models - to estimate the upgrading effect and size the new members.

If there is a regularity in the building structure in both transverse and longitudinal directions there is no significant difference in the obtained results from 2D and 3D models - less than 15% in the values of the first vibration periods in both directions (the 3D model is stiffer) and less than 20% in the force distribution. The differences are due mainly to the locating of the bridge cranes and rotation of the buildings. This is why in the detailed 3D models the travelling cranes and the sub-crane structures were paid special attention. The crane mass can develop very large seismic forces, but it cannot cause movements of the supporting nodes at the wheels in opposite directions, so the crane also supports the lateral resistance of the adjacent columns by distributing the inertial forces to more than one pair of columns. The sub-crane structures transfer vertical and horizontal transversal and longitudinal crane loads. For transversal horizontal and seismic loads, the sub-crane structures are vulnerable. The detailed modelling of the cranes was done mainly for evaluating the sub-crane structure upgrading [2].

The principal load combination that is used is:

$$DL + 0,25.LL + CRL + E$$

DL - dead load (includes equipment loads);

LL - live load (includes snow loads);

CRL - crane loads;

E - seismic loads.

The sizing calculations are done according to the Bulgarian Code [7,8]. The steel profiles for the upgrading elements are chosen from the available on the Bulgarian market. The new shear walls are sized to transfer the seismic forces to the monolithic foundations [8].

The connections are carefully designed according to the requirements of UBC [9] and Bulgarian Codes [7,8]. The connections of the upgrading elements must ensure the full load transfer from the connected elements to the adjacent supporting structure. At the same time, the main upgrading elements must ensure the bearing capacity of the main structure under

combined loads. The ties between new and existing elements are made by strips, anchor bolts passing through reinforced concrete elements and anchor bolts with epoxy clay.

## 5. IMPLEMENTATION PROBLEMS OF THE SEISMIC UPGRADING DESIGNS

The main problems during the implementation of newly designed seismic upgrades are:

- great discrepancies between the initial design and its real execution (existing structure);
- heavy pre-cast concrete wall panels that usually could not be dismantled - this brings serious problems in upgrading in transversal direction;
- limited space around the buildings that forbid the usage of heavy cranes for the assembly of upgrading;
- limited space for the new upgrading elements inside the buildings;
- time limitation in the basic technological process interruption or prohibition for interruption the processes at all;

Hereafter are some examples of these problems and ideas how they were solved.

The Main Pump Station at NPP Kozloduy is a comparatively small building, but a lot of problems occurred during the design of its upgrading. Most of them are due to the specific exploitation conditions of that kind of industrial facilities. For example, the operation of the pumps should not be interrupted during the construction works or the high voltage cables above the building should not be switched off simultaneously. The first design for upgrading of the building was done by EQE Bulgaria as a subcontractor of EQE International in 1992. The main concept of this design is illustrated on Figure 6. Some construction activities started in 1994 but a lot of problems connected with the inaccurate position of buried high voltage cables around the building occurred. This was the reason for suspending the implementation works and the Plant Authorities assigned the task of studying the implementation problems and developing a new upgrading concept, Figure 5. The new seismic upgrading structures must be placed inside the building and that dismantling of wall panels is prohibited.

Serious problems occurred during the implementation of the seismic upgrade of the River-bank Pump Station and the Emergency Pump Station. This happened because of wrong initial information obtained from the operational staff. They did not clearly understand the requirements of the construction work. As it was declared in the beginning, that there are no problems with the necessary dismantling and replacement of the high-voltage switcher cabinets, the location of these cabinets was not taken into account in the initial design. Later, the information about the possibilities of moving the cabinets was changed and this brought automatically a lot of changes in the design. Finally, two of the initially designed steel vertical braces had to be substituted with concrete shear walls, the configuration of another brace was changed and the location of the last one was changed.

## 6. CONCLUSIONS

In any case the design of upgrading or strengthening of an existing building structure is more complex and difficult than the design of a new seismic resistant structure, Figures 8 and 9. On the other hand the difficulties and complexity of the design process are much less compared to the complexity and difficulties of the construction process. According to our experience with similar buildings, the presence of the designer on the construction site in order to make field sketches and quick design changes is essentially important.

It is always worth considering several alternative concepts for seismic upgrading of complex structures. Some of the conceptual upgrades may not work as expected in the stage of detailed design and others may even come out not to be applicable.

Special conclusions were drawn out of the computer modelling experience. The development of detailed models of complex building structures should be done very carefully.

Complex models may come out to be very sensitive when conducting spectral seismic analysis. Extremely important is the mass distribution which should be made close to reality and, at the same time, reasonable to be processed.

The detailed design of connections may sometimes result in changing of the whole upgrading concept when there is lack of space to construct the connection, or the adjacent structural member has no sufficient capacity or adequate configuration.

In spite of all problems, the upgrading of existing nuclear and other important industrial facilities must be done in order to reduce the ecological and environmental risk in this part of Europe and our experience in this field can be helpful and applicable in similar and other cases.

## REFERENCES

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7. *Steel Structures Design Code*, Sofia Bulgaria, 1987
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9. *Uniform Building Code*, 1991 Edition, International Conference of Building Officials, Whittier, California

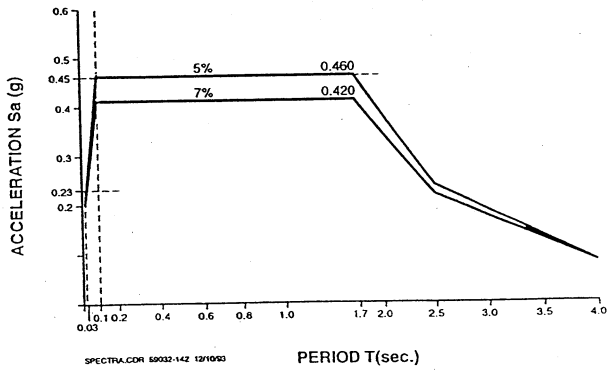


Figure 1. Kozloduy NPP Site Specific Response Spectra

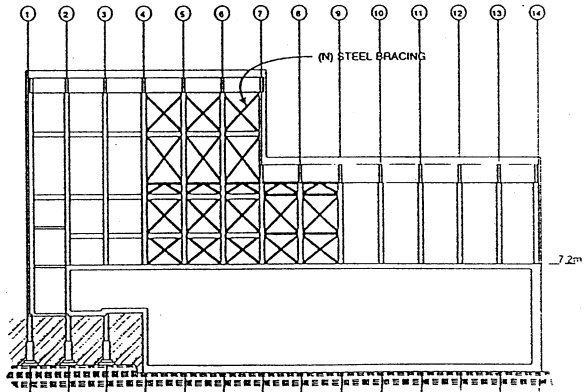


Figure 2. Longitudinal Vertical Steel Braces

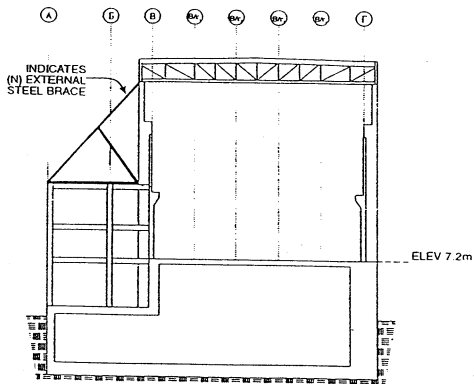


Figure 3. Transverse External Steel Brace at High-bay Section

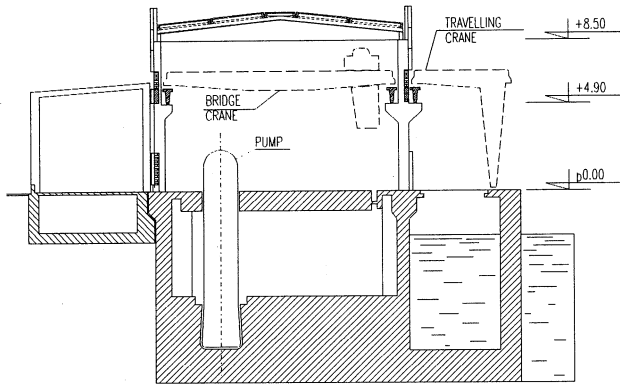


Figure 4. Main Pump Station - Cross Section

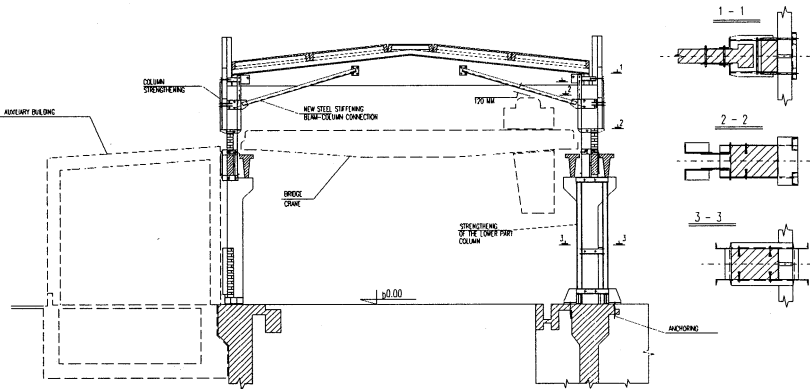


Figure 5. Main Pump Station - Variant of Transverse Upgrading

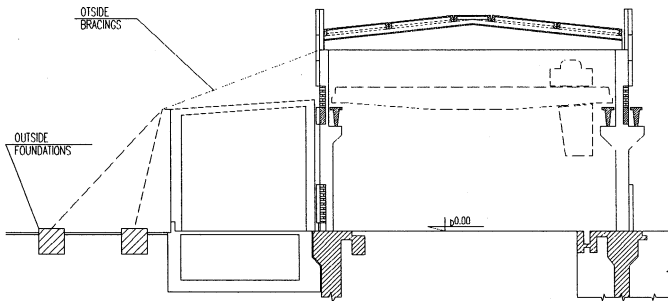


Figure 6. Main Pump Station - Initial Upgrading Design Concept in 1992

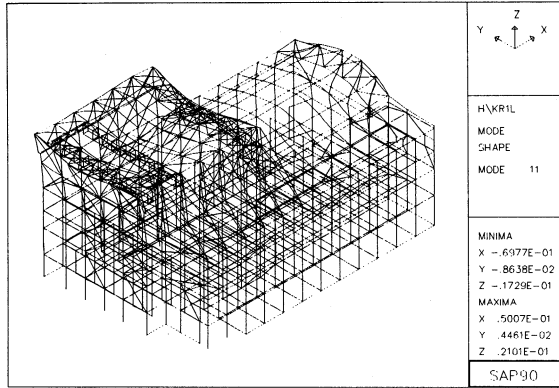


Figure 7. SAP'90 Structural Model

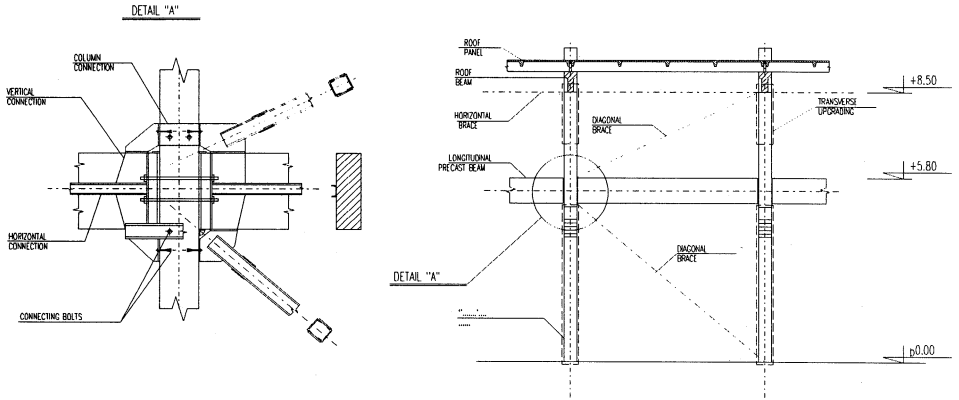


Figure 8. Longitudinal Upgrading of a Building

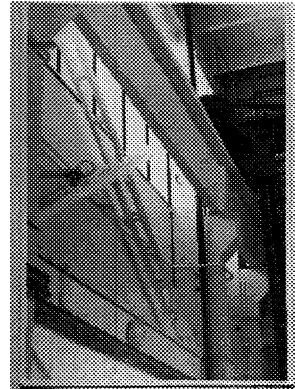


Figure 9. Details from Executed Seismic Upgrading Designs