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SEISMIC STRENGTHENING OF OVERHEAD ROADS BETWEEN REACTOR BUILDINGS OF WWER-1000MW TYPE NPP

George Stoyanov*
EQE Bulgaria AD
1 H. Smirnenski blvd.
1164 Sofia, Bulgaria
Phone: (+359 2) 9632049
Fax: (+359 2) 9631976
E-mail: gss@eqe.bg
gs_stoyanov@yahoo.com

Marin Jordanov
EQE Bulgaria AD
1 H. Smirnenski blvd.
1164 Sofia, Bulgaria
Phone: (+359 2) 9632049
Fax: (+359 2) 9631976
E-mail: mjj@eqe.bg

ABSTRACT

This paper presents results obtained during the upgrading design of overhead roads (OHR) between WWER-1000MW Reactor Units at Kozloduy NPP. In order to avoid the deficiencies of OHR seismic capacity different approaches were developed based on the site and structure specifics. Overhead roads are precast RC structures. They consist of pedestrian gallery and pipeline RC box, connecting reactor buildings with auxiliary building. They are mounted at approximately 10m above ground level. The overhead roads are evaluated at their as-is status and a seismic upgrading of the structure is designed. The analysis of the upgraded structure is performed for Review Level Earthquake (RLE). Soil-Structure Interaction (SSI) effects are taken into account through equivalent soil springs with frequency adjusted stiffnesses. The upgraded structure is checked for conformance with the specially developed technical design specification based on International, US and Bulgarian standards and codes, taking into account site specific conditions. The general approach is consistent with up-to-date practice for evaluation and upgrade of nuclear power plant facilities. The existing site conditions and Owner’s requirements are taken into account during development of the upgrading. The proposed upgrading measures can be divided in two major categories global and local. Special attention is paid to improvement of the ductile behavior of the structure through new detailing and upgrading of existing connection. These measures are grouped in two final design concepts and after a comparative study one of them is chosen for implementation. For the upgraded structure response spectra are derived at locations where equipment is attached.

Keywords: overhead roads, upgrading concepts, RLE, Soil-Structure Interaction, seismic upgrade, local and global ductile behavior.

1. INTRODUCTION

This paper summarizes the approach, methods used, design calculations, results and conclusions from the upgrading design of overhead roads between reactor buildings and auxiliary building of WWER type nuclear power station. The as-built structure composition and analysis is described and discussed in details in [1]. The major conclusion derived from it was that due to the increased seismic demand (after the site seismic hazard reevaluation) the existing structure requires development of upgrading measures, which will allow for better distribution of lateral forces and improvement of structure ductile behavior.

2. ALTERNATIVES FOR UPGRADING AND ANALYSIS

Different upgrading alternatives for OHR structure were considered and evaluated. Their advantages and disadvantages are summarized below.

In view of the obtained D/C ratios higher than 1.0 from the seismic evaluation of the as-built structure (see [1]) a global strengthening approach has been chosen. The global strengthening introduces new structural subsystems with which the existing structure significantly improves its seismic behavior and achieves reasonable safety margins for the new seismic demand and structure categorization.

Upgrading of the Main Frame (MF) is considered in longitudinal and transverse direction based on the found deficiencies of the existing structure.

In longitudinal direction four different alternatives for upgrading of Main Frame are considered as reasonable for implementation.

A: X-type vertical steel braces arranged in two spans (where feasible);

B: Portal type vertical steel braces arranged in almost all spans;

C: Seismic strengthening of all columns with jackets, especially in the most heavily loaded areas where biaxial bending occurs. This can be achieved basically by three types of jacketing: reinforced concrete, steel and carbon jacketing.

D: Development of rigid connections between longitudinal frames, which consist of MF columns and RC box (RCB) beam in longitudinal direction.

Proposed upgrading schemes for longitudinal direction are illustrated on Figures 1 to 3 using Segment 1 of the OHR as a sample.

Implementation of the X-type vertical braces will reduce the bending and shear seismic forces in the columns and will direct the seismic load path through braces to the foundations. Disadvantage of X-type vertical bracing is that it will concentrate bigger forces in the corresponding foundation, leading to its upgrading, and the benefit from the smaller number of upgrading elements will be lost.

Portal type vertical steel braces have the advantage that the lateral seismic loads will be uniformly transferred to the foundations, but their implementation will require more upgrading elements. Using of this upgrading alternative will avoid high values of forces in the existing structural members and connections. Also based on the assessment of the existing foundation capacity could be expected that the foundations will not need further upgrading.

Implementation of reinforced concrete jacketing for seismic strengthening of the columns will result in longitudinal seismic load path transfer through bending and shear of upgraded columns, which will have the required higher capacity. Four-sided jacketing of the columns with a ductile design, which will be implemented by adding concrete, longitudinal reinforcement and closely-spaced ties, has the best seismic behavior and monolithic action. Implementation of other materials as steel or carbon fibers for jacketing was also considered as an option.

The creation of rigid connections between the MF columns and RCB beams will change the longitudinal moment distribution along the height of MF columns in a more relaxed manner. Along with this to MF columns can be added shear capacity by jacketing for the increased shear demand. RCB is not highly stressed element (with D/C ratios not exceeding 0.6) and it can accumulate additional forces and moments. The only concern about RCB is that it has radioactive protection functions and increasing its seismic loading increases the potential damaging risk.

In transverse direction three alternatives for upgrading are considered as reasonable for implementation, namely:

A: Steel horizontal truss for local strengthening of RC girder of the Main Frame, arranged in each axis, with additional steel plates jacketing of the existing girder-to-column connection;

B: Seismic strengthening of all girders and girder-to-column connections with solid walled steel beams and steel plates jacketing in each axis, which will be used as supports for UF strengthening.

C: Connection between MF beam and RCB beam, which will create stiffer composite beam with double benefit: MF beam will work together in bending with part of the RCB and RCB bearings will not be so heavily loaded because of seismic force redistribution.

On Figures 4 to 6 are presented the upgrading measure alternatives in transverse direction on typical transverse elevation across the main axes of the OHR.

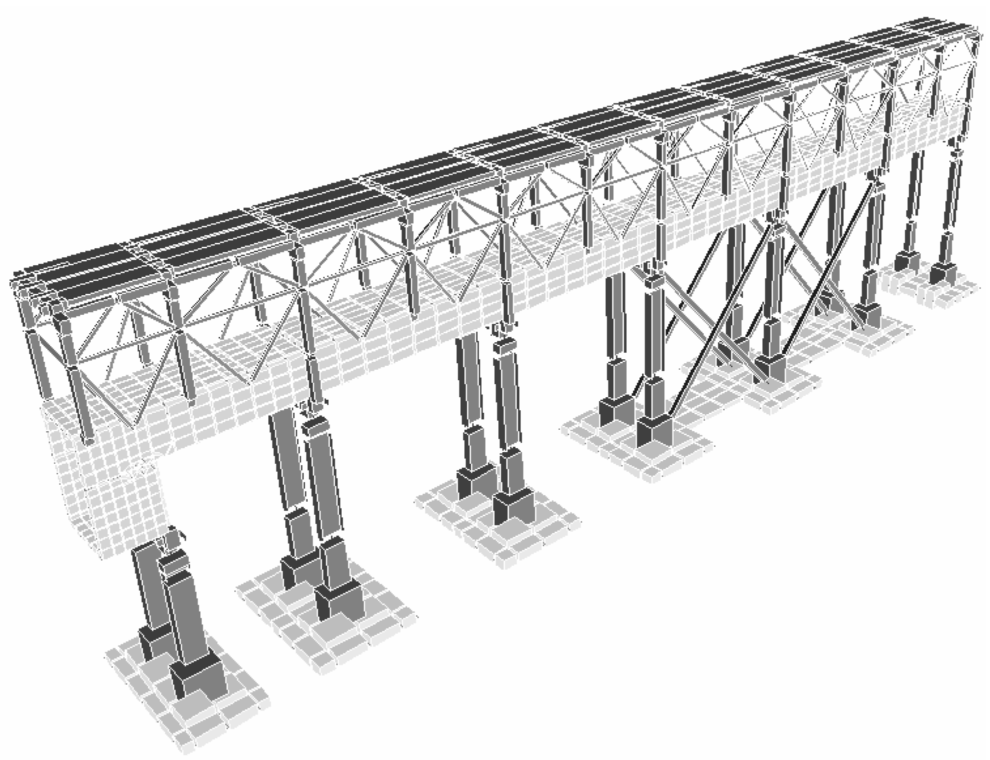

Figure 1 X-type vertical steel braces arranged in two spans in longitudinal direction along with UF longitudinal strengthening

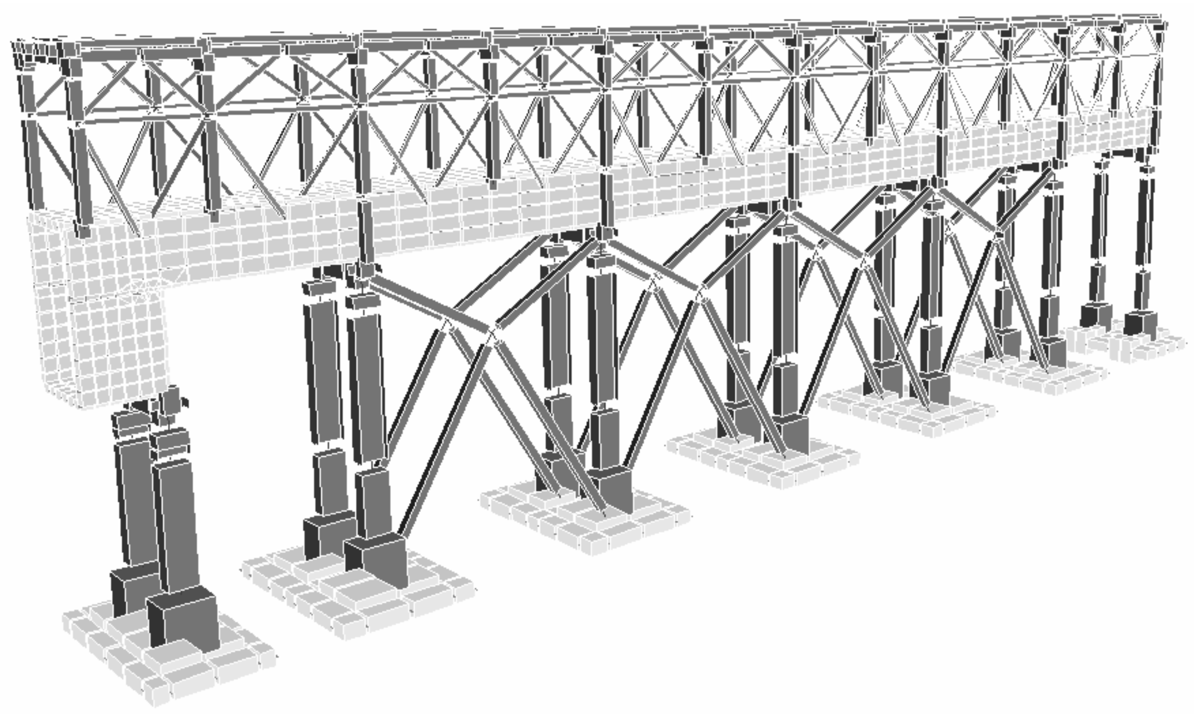

Figure 2 Portal type vertical steel braces arranged in all spans in longitudinal direction

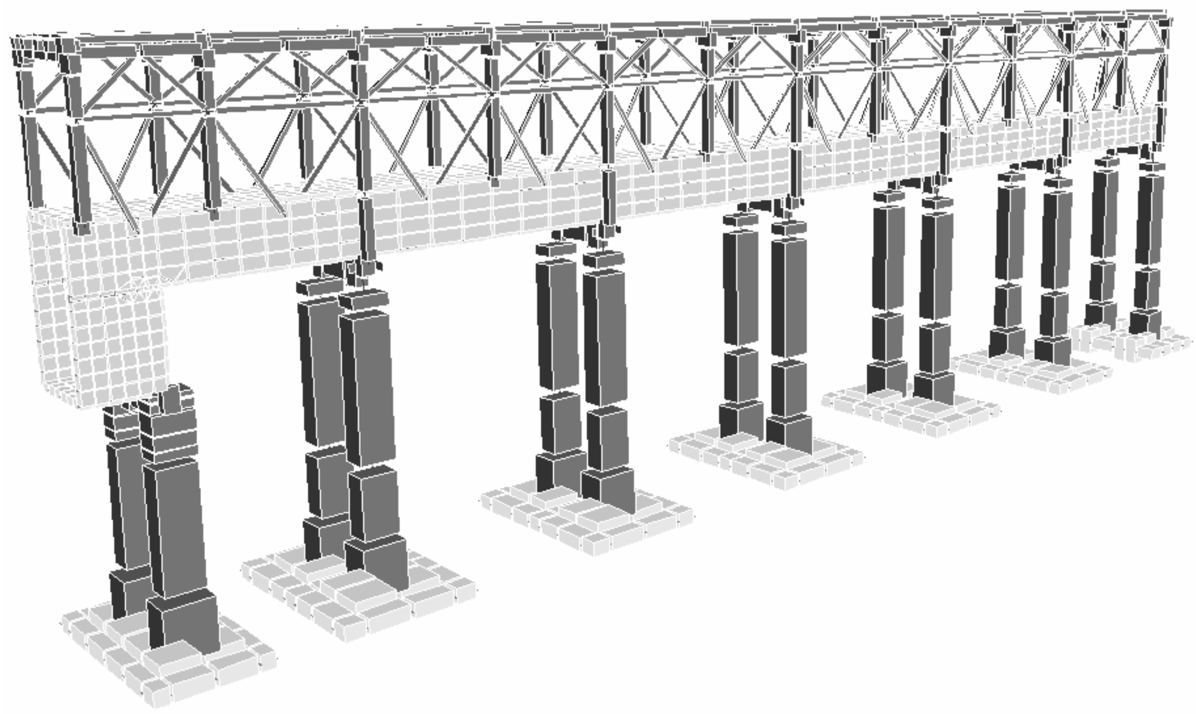

Figure 3 Seismic strengthening of all MF columns with reinforced concrete jacket

It should be pointed out that two other alternatives could be considered for seismic upgrading in transverse direction:

-side bracing at each column axis by mounting of skewed strong rods outside of current structure outline and

-a seismic strengthening by introduction of new reinforced concrete shear wall between supporting columns on any two or three bays of OHR.

These two alternatives are not feasible for implementation due to the required heavy construction works as well as to the reduction of the access in the area of OHR on the site.

All alternatives described above should be accompanied by upgrading of all column bases down to their connections with the foundations. In this manner a new ductile behavior of the columns will be achieved.

Upgrading of the Upper Frame (UF) is considered in longitudinal and transverse direction based on the found deficiencies of the existing structure.

In longitudinal direction two alternatives for upgrading of Upper Frame are considered as reasonable for implementation. Those are:

A: K-type vertical steel braces introduced along the length of the segment. The number of these framings is subject to precise calculation.

B: Doubling of the Upper frames with steel structure in combination with type B transverse strengthening of the MF, which is shown on Fig.4.

In transverse direction one alternative for upgrading of the UF beams is considered as reasonable for implementation in all connection details along Upper Frame.

Upgrading of all connections should ensure the required capacity against the calculated demand, considering appropriate ductile detailing, which should prevent a brittle type of failure.

Upgrading of UF columns may be accomplished by the doubling of the UF as discussed above. Another way for achieving enough capacity is by development of connection between UFA columns at top plate of RCB along with column strengthening where needed. Thus the effective length of UFA and UFB columns will be equalized and a more uniform distribution of forces between UFA and UFB can be achieved.

Dismounting of heavy roof and cladding panels and their replacement with lightweight steel structure can significantly improve the seismic behavior of the structure, due to the mass reduction of the highest part of the structure.

Upgrading of bearings of RC box is required due to their limited shear capacity for transferring of the seismic horizontal forces from box itself to the Main Frame girders. Proposed upgrading measure is to add shear transfer members, attached to the RC box and to the Main Frame girder.

Connections and joints are the weakest links in prefabricated concrete structures especially where dry connections with weldings are applied. In few existing connection details an unfavorable brittle behavior can occur. It is very important that the connections and joints be detailed in a manner to provide adequate overstrength and sufficient ductility.

Upgrading of the foundations will be required if new X-type vertical steel braces are implemented in view of the high concentrated forced that they should transfer to the foundations. Upgrading of the foundations will require introduction of new foundation body incorporating the existing foundations. Accompanying excavation works should be considered also.

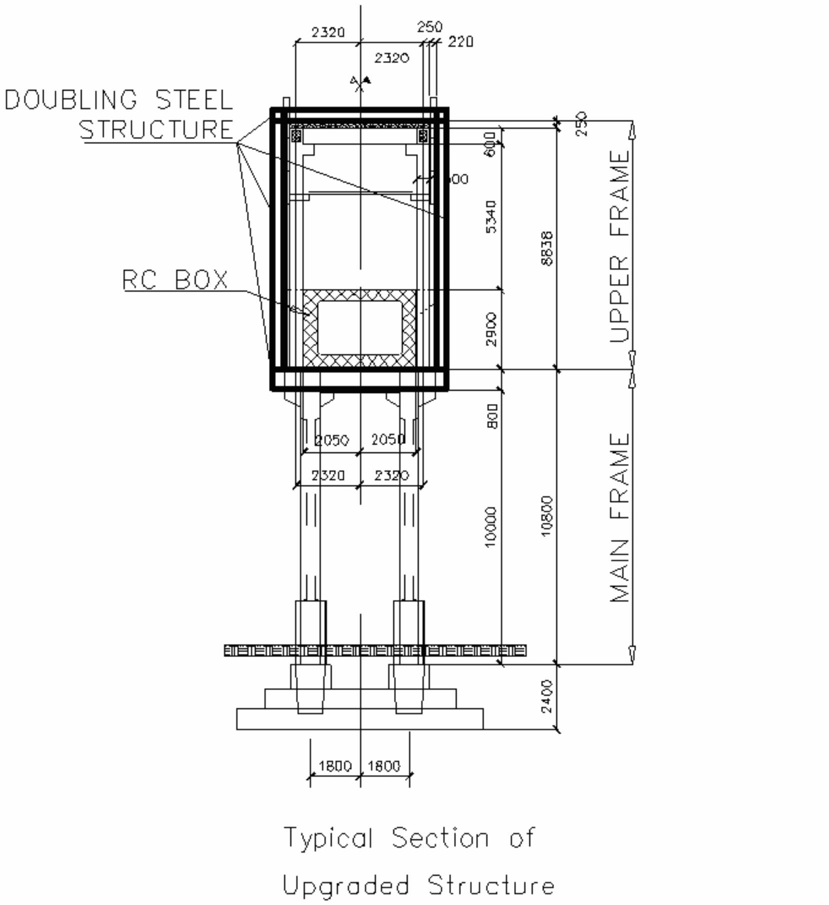

Figure 4 Doubling of the MF beam and UFA frame for strengthening

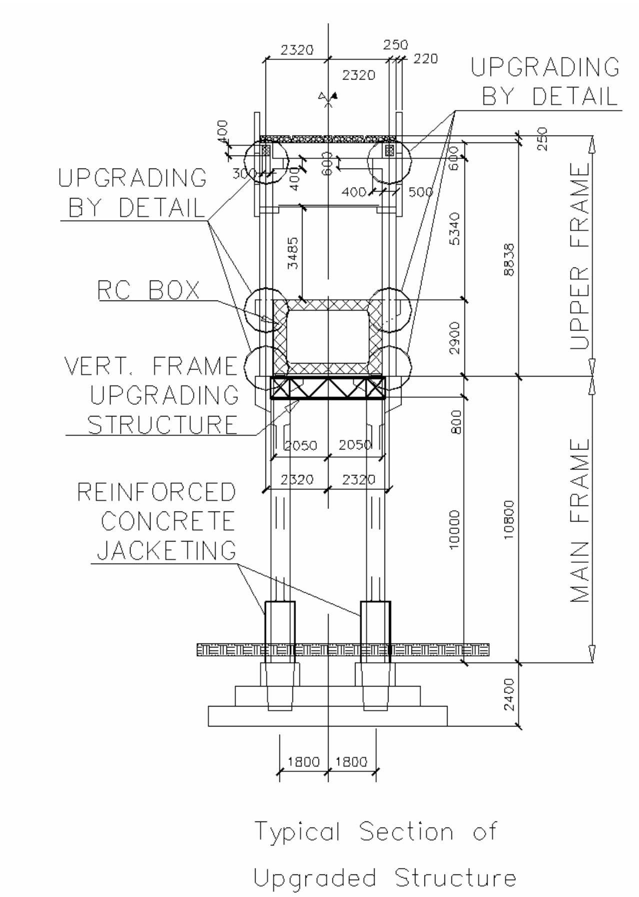

Figure 5 Vertical frame for strengthening of RC girder of the Main Frame, with jacketing of the existing girder-to-column connection

Implementation of the upgrading measures could be done by priorities. In view that in the RC box radioactive fluids piping is mounted the first priority should be implementation of upgrading measures on the Main Frame structure. As a second priority the measures for seismic strengthening of the Upper Frame structure should be implemented.

Below is presented a complex upgrading variant for the OHR structure. The developed model in [1] is used as a basis. Static and dynamic analyses are performed using structural models developed for each of the OHR segments as described in [1]. Some modifications in modeling of soil-structure interaction (SSI) effects are made taking into account the rotational stiffness of the foundations of the segments. Non-linear elements with stiffness and damping properties are used in the models to present the soil seismic behavior instead of the springs elements used during model development and as-built structure seismic evaluation [1].

New strengthening elements are implemented in the structural models as discussed above. They are shown with designations on Figures 7 and 8.

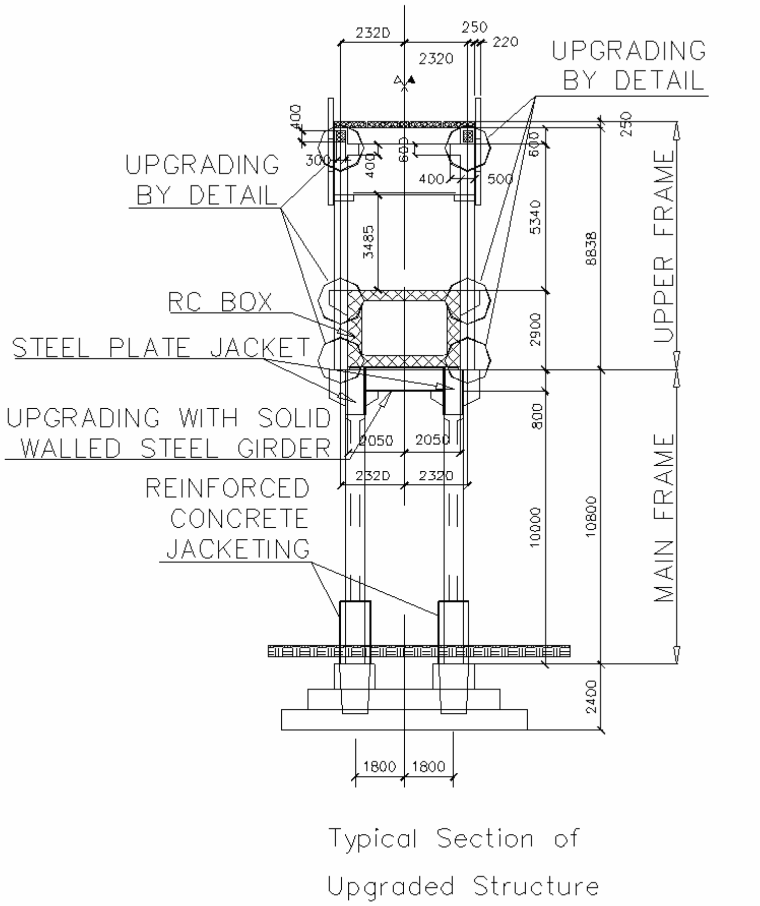

Figure 6 Solid walled steel beam for strengthening of RC girder of the Main Frame, with steel plate jacketing of the existing girder-to-column connection

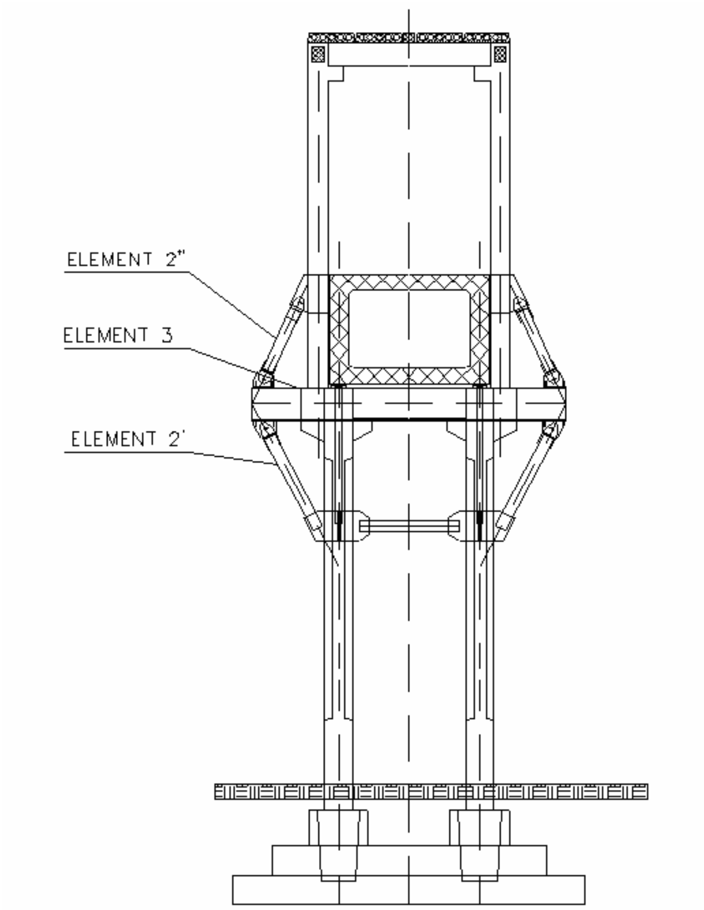

Figure 7 New elements shown on typical transverse section of OHR

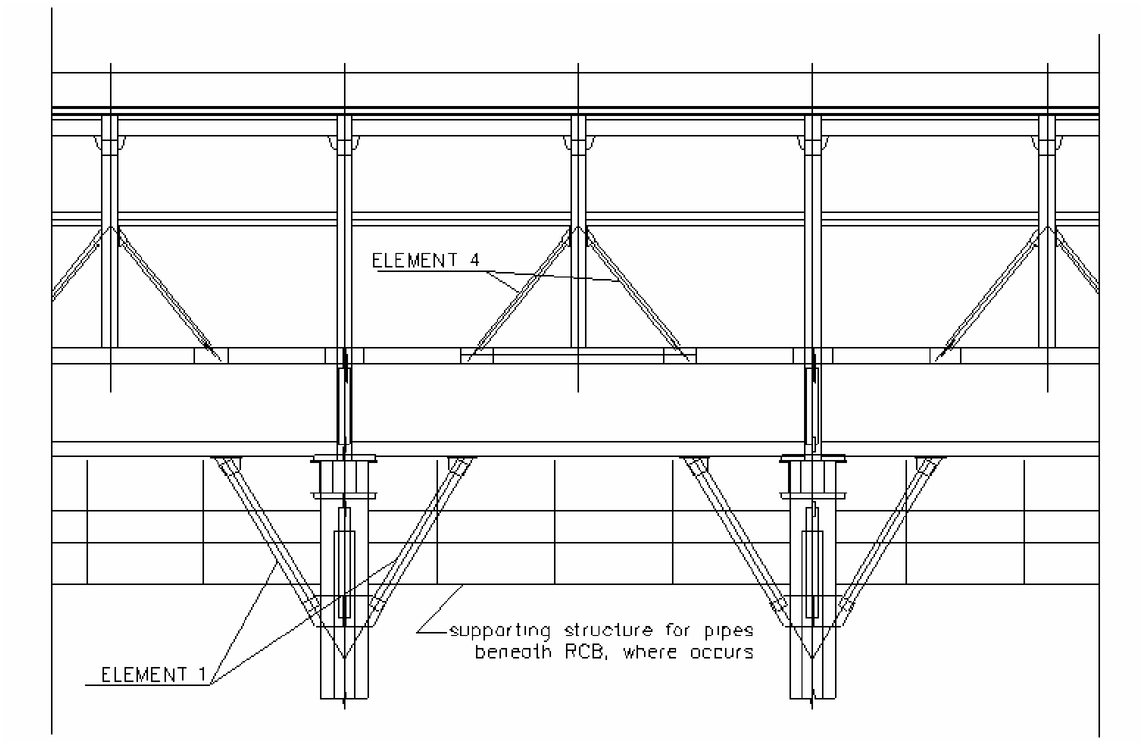

Figure 8 New elements shown on typical longitudinal section of OHR

3. ANALYSIS RESULTS AND CONCLUSIONS

The OHR structures are seismic category II structures and are analysed for their capability to withstand an earthquake with characteristics defined for RLE and scaled with coefficient of 0.5.

For category II reinforced concrete structures, the load combinations and applicable criteria can be summarized as follows, according to ACI 349-89 Code [3]:

$$DL + LL + S + 0.5RLE/F\mu$$

where:

DL - Dead Load
LL - Live Load
S - Snow Load
RLE - Review Level Earthquake
$F\mu$ - inelastic energy absorption factor; $F\mu$ values are taken in accordance with [3] and [6].

As a result from the analysis of the upgraded OHR structure under defined load cases and combinations a final design set of forces and moments was obtained, which was checked against inherent capacity. Below is a table giving comparison values for maximum demand to capacity ratios for main frames located in Segment 1.

Table 1 Maximum D/C ratios

Segment	Column	Beam	Beam to column connection
1	0.83	0.75	0.97

The new elements are redistributing the seismic loads introducing sufficient safety margin. Table 2 shows the D/C ratios of the new elements located in Segment 1, shown on figures 7 and 8.

Table 2 D/C ratios of the new elements

Segment	Element	D/C
1	1	0.83
	2'	0.80
	2"	0.63
	3	0.84
	4	0.65

At expansion joints between segments the RCB elements are separated by 7cm gap as the maximum inelastic displacement between two elements is 6.2cm. No interactions between adjacent segments can be expected.

The main purpose of this presentation of the project results was not to look for specific details of the upgrading and for specific upgrading concept, but to show how in the development of the study the structure strengthening improvements should be introduced in analysis so that more adequate utilization of the structure inherent safety margins can be achieved together with introduction of the new upgrading structural members.

4. REFERENCES

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[4] Design Code for Concrete and Reinforced Concrete Structures, Sofia, 1989

[5] SAP 2000, Rev. 7.42, CSI, Berkeley, California
[6] "Guide for Seismic Reevaluation and Design of Nuclear Facilities in Bulgaria" 2000
[7] Regulatory Guide 1.122 of NRC Development of floor design response spectra for seismic design of floor supported equipment or components.
[8] American Concrete Institute, Code Requirements for Reinforced Concrete, ACI 318-89, Rev. 92

