SEISMIC ASSESMENT AND UPGRADING OF TR-2 RESEARCH REACTOR BUILDING

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Introduction

At the present time, there are numerous programs underway in many countries around the world for the evaluation of seismic safety of research reactors and for their upgrading to increase seismic safety. Research reactors are usually located at or near city centers. So, the seismic safety of research reactors located in high seismic areas but close to urban settlements is a vital issue. Many areas in Turkey are exposed to seismic hazard. For example, a devastating earthquake occurred in Turkey at the eastern end of Marmara Sea on August 17 1999 (03:02 Local Time, Latitude: 40.70N, Longitude: 29.91E, Depth: 15.9 km, Magnitude: 7.4). The epicenter was located near Gölcük, a town located about 4 km from İzmit City in the Kocaeli province. Field surveys confirmed that the western part the North Anatolian Fault Zone had caused the main shock. A few buildings also collapsed in residential parts of Avcılar district in İstanbul, about 5 km away from the TR-2 research reactor building. Seismic instruments at the reactor-building basement and at the base of another surface building produced records during earthquake. The peak acceleration values of the time histories recorded at the basement of reactor and the other building were 0.12g and 0.18g, respectively. The TR-2 reactor has been designed for a base shear force of 0.1 times its weight. Inspection of the reactor building by engineers after the earthquake showed that there was no damage on the reactor building, systems and components.

The TR-2 research reactor was built between 1957-1962, and at that time a site specific design basis earthquake was not considered in the design of the reactor building. Considering the exposure of the facility to damaging ground motions, the seismic qualification of the TR-2 reactor building was re-assessed and upgrading project was developed accordingly. This paper summarizes the findings.

2. Description of the Reactor Building

The reactor building is a reinforced concrete frame structure. The plan dimensions of building are 23.54x32.58 m. The building has an embedment to a depth of 9.12 m. The height of the building is 11.25 m from the grade level. The structure has a thick base slab and embedded part is covered by shear walls acting as retaining walls. The embedment part of the structure consists of four levels. Above grade level, the superstructure consists 10 one-way frames supported directly on reinforced basement walls. The superstructure supports a moving crane.

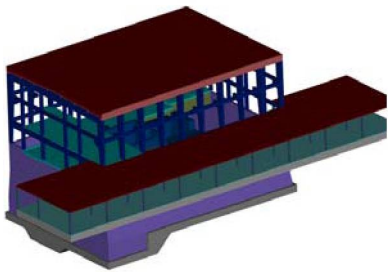


FIG. 1. TR-2 reactor and auxiliary building

2.1 As-is Building Properties

In the evaluation of the seismic safety of the reactor building, an adequate parameter variation are used to cover reasonable uncertainties in the soil and structural modelling. The as-is building properties and geometry were taken from original drawings and checked with current conditions.

2.2 Conrete Strength

Six samples were taken from shear walls and columns of the reactor building to find out the strength of concrete. Compresion strengths of conrete samples varied from 30 MPa to 41 MPa. So, compression strength of the concrete was used as 30 MPa in analyses. The modulus of elesticity of concrete was calculated using the following formula given in Ref. [5].

$$E = 10\,270\,(f_{ck})^{0.5} + 140\,000 \qquad (kg/cm^2)$$

3. Description of Analysis Input

3.1 Elastic Seismic Loads

Review Level Earthquake (RLE) for TR-2 research reactor site has been found as 0.40g, peak ground acceleration (PGA) in horizontal direction. The 0.40g PGA is assumed to be a mean estimate for a 500 year of return periods (Ref. [1]). Acceleration Response specturm obtained from the Turkish earthquake resistant design code (Ref. [2]) and normalized to 0.40g (Figure 2) was used in the analysis. The peirod of T_A and T_B taken from the Turkish earthquake resistant design code according to the TR-2 site condision are 0.15 sec. And 0.40 sec. respectively. The Building Importance Factor and Seismic Load Reduction Factor were taken as 1.5 and 2.25 respectively.

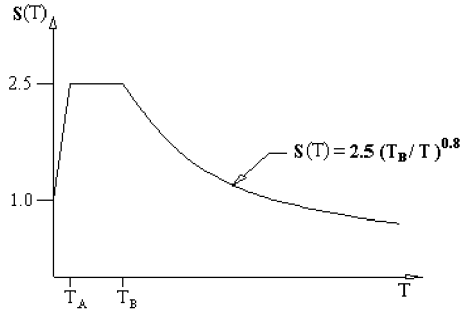


FIG. 2. Spectral Accelerations

S *(T)*= Spectrum Coefficient , T_A,T_B =Spectrum Characteristic Periods, sec

3.2 Soil properties of theTR-2 site

Detailed soil investigation studies were conducted at the TR-2 site in 1984 (Ref. [3]). Soils underlying the TR-2 reactor building are stiff to very stiff clays and silts down to considerable depths. Bedrock was not encountered within the depth of 75 m borehole exploration. The groundwater table is stabilized at about 36.20m. The seismic reeponse of a building are greatly affected by soil. Since high uncertainties in soil data was exist, the typical range of shear modulus variation (0.5G [Lower bound], 1G [best estimate] and 2G [upper bound])are used in analyses.

3.3 Structural Model of Reactor Building

A 3D finite-element model of the TR-2 reactor building was generated using appropriate solid, shell, beam and spring elements. In the model, 4648 nodes and 602 frames, 1827 shells, 1334 solid elements are used. Water in the pool is modelled as an equivalent system of masses and springs as described in Ref. 4. The elastic in-plane stiffness of a solid unreinforced masonry infill panel prior to cracking is represented with an equivalent diagonal compression strut in the model. Heavy equipment, such as tanks, pump, reactor etc., are included as masses. The cranes are also included. This model is shown in Figure 3.

4. Dynamic Analysis of Structural System

Mode-superposition method are used in the analyses of the reactor building. In the mode-superposition method, the maximum internal forces and displacements are determined by the statistical combination of maximum response quantities obtained in each of the vibration modes to be considered in sufficient number. The number of modes to be considered in the analysis shall be determined such that the sum of effective modal weights (masses) corresponding to the given earthquake direction shall not be less than 90% of the total building weight (mass).

Stresses calculated for the three soil cases were obtained and used for the seismic qualificaiton of the reactor building. Maximum stresses at all the necessary elements are calculated to formally qualify the complete building. Combination of stresses due to the different load cases was made according to Turkish regulations.

5. Capacity Evaluation of Structural Elements

The capacities for all elements that are needed to qualify the complete building are calculated. These included the frames in the superstructures, beams at the roof, basement walls, reactor pool walls, and the mosonary infill walls. Capacity calculations were done according to Turkish codes (Ref. [5]). Capacity for all failure modes of each element was calculated. For example, in-plane and out of plane capacity of the mosonary, bending moment and shear force capacity of shear walls, beams, column were considered. As an example, the following formula was used to calculate bending moment capacity of the shear walls.

$$M_u = 0.5\, A_s f_{yk}\, d\, [\, 1 + (\, N / A_s f_{yk}) \,]\, (\, 1 - \gamma \,)$$

M_u : moment capacity of shear wall

A_s : total vertical reinforment area at shear wall

ρ : Total vertical reinforcement ratio at shear wall

b : Thickness of shear wall

d : Length of the shear wall

f_{yk} : Characteristic yield strength of reinforment

f_{ck} : Characteristic compresion strength of concrete

f_{cu} : Characteristic cube compresion strength of concrete

N : Axial load (multipled by load factors) on shear wall

γ : $(\alpha + \beta) / (2\beta + 0.85\, \beta_1)$

β_1 : 0.58

α : $1.2\, \rho\, f_{yk} / f_{ck}$

β : $1.2\, \rho\, N / b\, d\, f_{cu}$

The capacity/stress verificaiton was done and capacity ratio results indicated the need for seismic upgrades in some structural elements of the reactor building.

6. Seismic Upgrading of the Reactor Building

The ugrading project was developed on the basis of the results of the dynamic analyses and evaluation. Mainly seventeen shear walls out side of the building would support the structure from the top (Figure 4). These shear walls would be setteled on the pile foundation against over-turning moment. A justification of the upgrading project with respect to the safety criteria was performed. After the new series of analyses, capacity verification was performed.

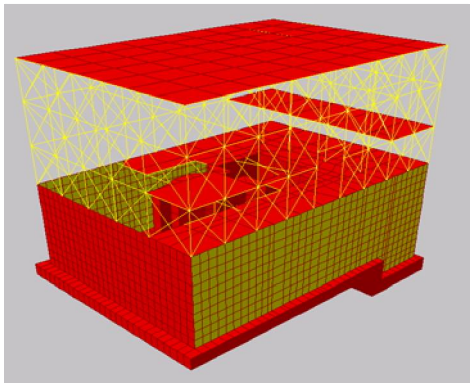


FIG. 3. Structural model of reactor building before upgrade

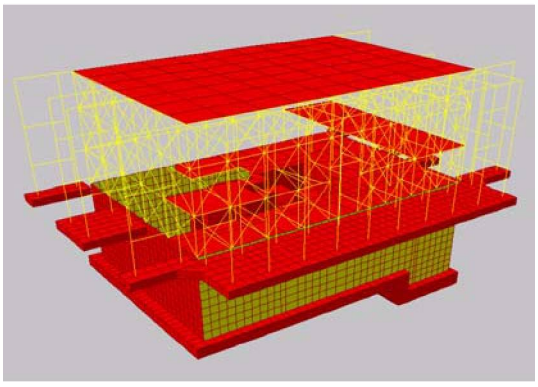


FIG. 4. Structural model of reactor building after upgrade

7. Push Over analyses results before and after upgrading

In the nonlinear static procedure or pushover analysis, seismic demands are computed by nonlinear static analysis of the structure, which is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. Pushover analyses before and after upgrade of the reactor building were carried out (Figs. 5 and 6).

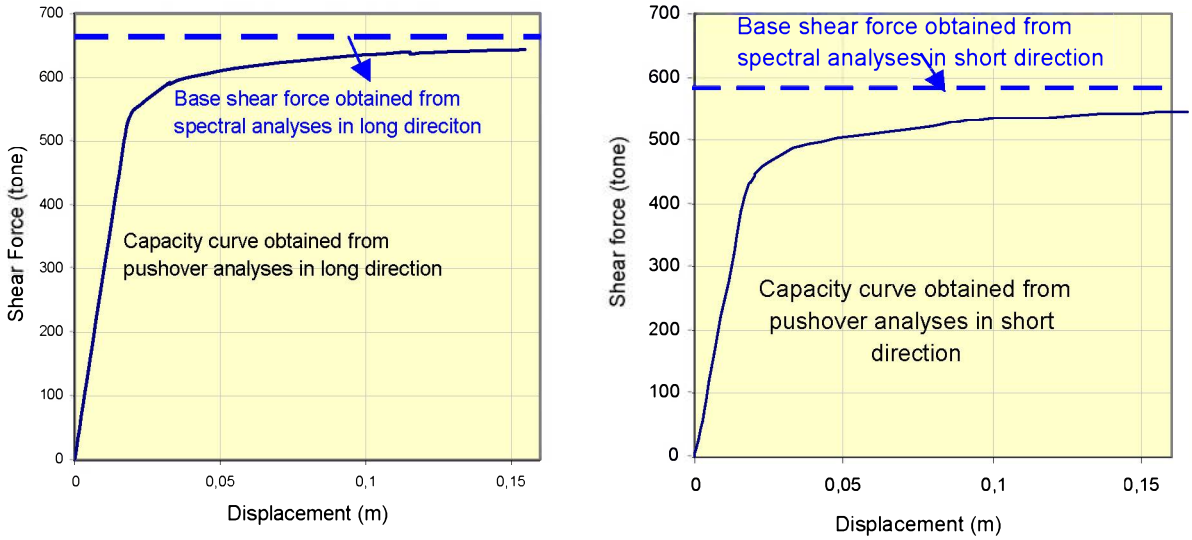


FIG. 5. Load deformation curve based on the base shear force and roof displacement result of the reactor building before upgrade

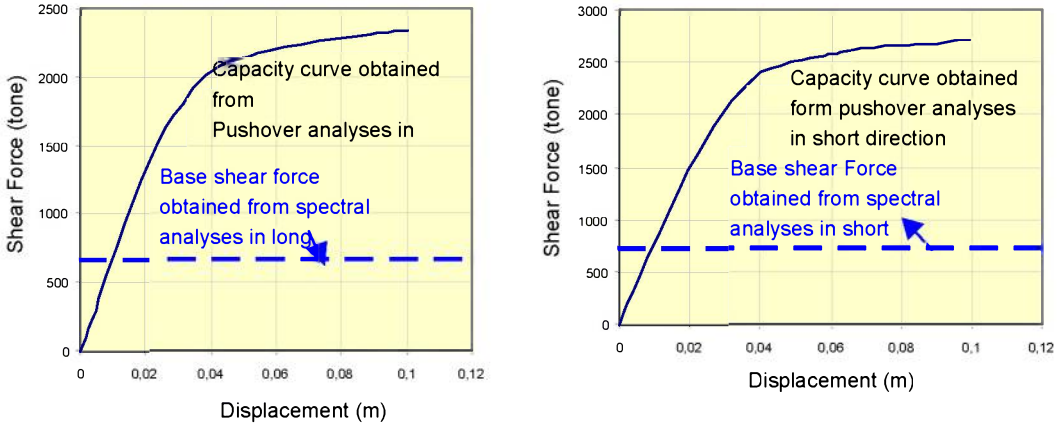


FIG.6. Load deformation curve based on the base shear force and roof displacement result of the reactor building after upgrade

8. Conclusions

Upgrading project was developed for TR-2 research reactor building. A justification of the upgrading project for all failure modes of each element with respect to the criteria was performed. After the new series of analyses, capacity verification was performed. Pushover analysis revealed that capacity of the reactor building will be increased significantly after upgrading. During the generation of the upgrading project of the reactor building, different alternative solutions are considered. For example, replacing of the roof of the building with light steel truss roof sistem, adding shear walls and mounting existing columns or adding steel brace between frames etc. But, putting shear wall to the out side from the top of the structure was thought as the best solution for easy application and prevention of possible damage to mechanical and electrical equipments.

References

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