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Preliminary Seismic Performance Evaluation of RPS Cabinet in a Research Reactor

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1. Introduction

The reactor protection system (RPS) of a low power research reactor such as TRIGA performs a reactor shutdown to protect the core under the reactor pool when the reactor deviates from normal operation due to any malfunction of the equipment, mishandling by operators, or external causes [1]. This RPS cabinet mainly provides the operators with the physical interface to monitor and handle the RPS.

The objective of this paper is to perform seismic analyses and evaluate the preliminary structural integrity and seismic capacity of the RPS cabinet. For this purpose, a 3-D finite element model of the RPS cabinet is developed and its modal analyses are carried out for analyzing the dynamic characteristics. Response time history analyses and related safety evaluation are performed for the RPS cabinet subjected to seismic loads. Finally, the seismic margin and seismic fragility of the RPS cabinet are investigated [2].

2. Design of RPS Cabinet

The RPS cabinet is composed of a cabinet, ventilation system, smoke detector, door open/close sensor, square lamp, bistable circuit, coincidence circuit, initiation circuit, actuation circuit, and other equipment which are necessary for protective operation. The RPS cabinet is usually installed in the floor of the main control room by using anchor bolts. The configuration of the RPS cabinet is shown in Fig. 1.

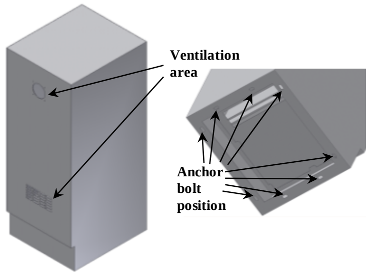


Fig. 1. Configuration of the RPS cabinet

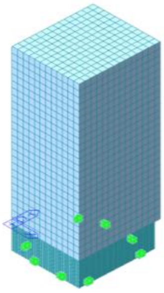


Fig. 2. 3-D finite element models of the RPS cabinet

3. Modeling of RPS Cabinet

The 3-D finite element model of the RPS cabinet in Fig. 2 was developed by utilizing MIDAS GEN program. All parts of the RPS cabinet structure are modeled as plate elements and point masses. The total number of elements is 9411, and the total number of nodes is 9663. The total weight of the RPS cabinet is about 187 kg.

The boundary conditions of the RPS cabinet are shown in Fig. 2. The displacement and rotation fixed boundary conditions are imposed on the anchor bolt positions of the RPS cabinet since it is bolted to the floor. Most parts of the RPS cabinet are made up as the structural steel (SS400). The maximum strength of the structural steel is 450 MPa.

4. Seismic Response Time History and Fragility Analysis of RPS Cabinet

The modal analysis of the developed finite element model is performed. It can be observed that the first natural frequency is 16.38 Hz.

The response time history analyses are performed to evaluate the structural responses of the RPS cabinet under the acceleration time history data of EL Centro scaled to peak ground acceleration (PGA) of 0.3g for the horizontal direction (hor.), and 0.2g for the vertical direction (ver.), respectively. In the response time history analyses, the modal superposition method is adopted to evaluate the responses of the system. Total 30 modes are considered for the modal superposition to take into account a modal effective mass of 90% of the model.

The seismic margin of the RPS cabinet is investigated under an increase of the seismic loads and the seismic fragility framework proposed by Kennedy and Ravindra [2]. The seismic fragility of a structure or equipment is defined as the conditional frequency of a failure for a given value of the seismic response parameter, which illustrates the probabilistic capability of a structure or equipment against a ground motion causing structural damage.

4.1. Design Loads and Load Combination

The weight of the main RPS cabinet is about 157 kg. The electrical components and panels are about 30 kg. The horizontal and vertical acceleration time history data at El Centro scaled to the PGA 0.3g and 0.2g, respectively, as shown in Fig.3, are used as the seismic load in the RPS cabinet.

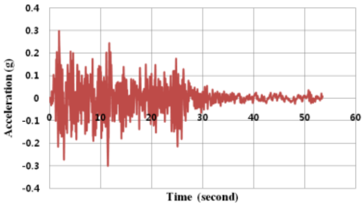
4.2. Results

The effective stresses (von-mises stress) of the RPS cabinet under the acceleration time history data scaled to the PGA 0.3g and 0.2g are evaluated as shown in Fig.4. The maximum effective stress is 62.89 MPa which is less than the structural design limit, 450 MPa.

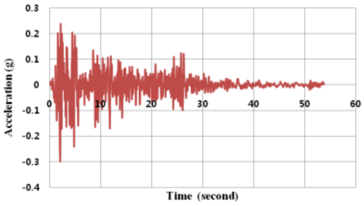
The weakest location is made in the anchor bolt positions of the RPS cabinet.

In addition, the maximum effective stresses of the RPS cabinet are analyzed according to the increase of the seismic load for investigating the seismic safety margin of the RPS cabinet. Table 1 shows the maximum effective stresses of the RPS cabinet in accordance with the increase of the PGA of the acceleration time history data. From these results, we can judge that the RPS cabinet can structurally withstand until the PGA 3g (hor.) and 2g (ver.) in a deterministic manner.

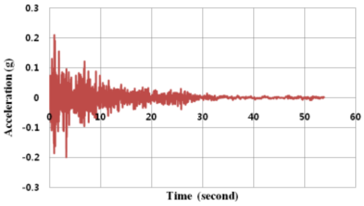
Finally, for the seismic fragility analysis, the structural failure mode of the RPS cabinet is defined when the plate of the anchor positions reaches to the maximum strength, and the logarithmic standard deviations for a randomness and uncertainty are 0.33 in this study. Fig. 5 shows a set of fragility curves of the RPS cabinet for the acceleration time history data scaled to the PGA 0.3g (hor.) and 0.2g (ver.). The high confidential and low probability of failure (HCLPF) capacity for the acceleration time history data is 0.72g (hor.) and 0.48g (ver.).



(a) East-West direction



(b) North-South direction



(c) Vertical direction

Fig. 3. Acceleration time history data (EL Centro, May 18, 1940) scaled to the PGA 0.3g (hor.) and 0.2g (ver.)

Table 1. Maximum effective stresses of the RPS cabinet according to the increase in the acceleration time history

PGA (g)	*Maximum effective stress (MPa)*
0.30 (hor.) / 0.20 (ver.)	62.89
1.00 (hor.) / 0.67 (ver.)	161.49
2.00 (hor.) / 1.33 (ver.)	304.55
3.00 (hor.) / 2.00 (ver.)	447.63

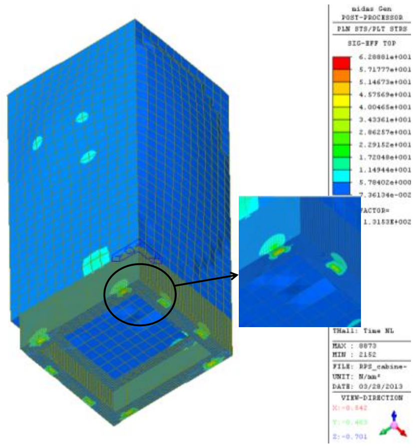


Fig. 4. Effective stresses of RPS cabinet under the acceleration time history data (PGA 0.3g (hor.) and 0.2g (ver.))

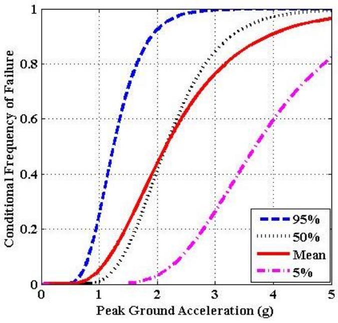


Fig. 5. Seismic fragility curve of RPS cabinet for the acceleration time history data

6. Conclusion

The seismic analysis, and preliminary structural integrity and seismic margin of the RPS cabinet under self weight and seismic load have been evaluated. For this purpose, 3-D finite element models of the RPS cabinet were developed. A modal analysis, response time history analysis, and seismic fragility analysis were then performed.

From the structural analysis results, the RPS cabinet is below the structural design limit under PGA 0.3g (hor.) and 0.2g (ver.) and structurally withstands until PGA 3g (hor.) and 2g (ver.). The HCLPF capacity of the RPS cabinet corresponding to the acceleration time history data is 0.72g (hor.) and 0.48g (ver.). Therefore, it is concluded that the RPS cabinet is safely designed in that no damage to the preliminary structural integrity and sufficient seismic margin is expected.

REFERENCES

[1] Taek-Kyu Kim, Gwi-Sook Jang, Sang-Moon Suh and Young-Ki Kim, Design Requirement for Reactor Protection System, Korea Atomic Energy Research Institute, 2013.

[2] R.P. Kennedy and M.K. Ravindra, “Seismic Fragilities for Nuclear Power Plant Risk studies”, Nuclear Engineering and Design 79, pp.47-68, 1984.