Study on the Seismic Fragility Assessment of Interconnected Electrical Cabinets

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1. Introduction

This study emphasis on the probabilistic seismic response of the electrical cabinets considering the grouping effect. To this end three numerical models, a standalone cabinet and two and three interconnected cabinets were analyzed. Using the statistical response under the 40-ground motions the fragility curves were developed for different damage states. The developed fragility function was crosschecked with Nuclear regulatory commission guideline (NUREG).

The input excitation and the corresponding damage state are the two parameters that are considered to highlight its effect on the seismic capacity of the electrical cabinet when a single cabinet and a group of cabinets are subjected to the same seismic excitation. A significant alteration in the seismic capacity was observed that accounts for 28% and 50% reduction in the mean probability of failure for two and three cabinets. This reduction in the seismic response is attributed to the additional stiffness offered by the number of interconnected cabinets.

2. Seismic Capacity Evaluation

This study follows the lognormal cumulative distribution function, which is considered as one of the typical ways for the seismic fragility analysis of the structures [1,2]. The fragility function defines two parameters, median and the standard deviation represented by θ and β. These parameters can be determined by the two well-known methods, maximum likelihood estimation and linear regression analysis [3,4]. In addition, defining a threshold value for the seismic risk assessment of the cabinet varies significantly based on the scenario that includes the intensity measure (IM), damage state (DM), and properties of the structure with the ground motion.

2.1 *Selection and Scaling Ground Motion*

A set of 40 ground motions were selected from the PEER NGA database. The selected motions were scaled to the design response spectrum (RG 1.60). The RG 1.60 spectrum having 0.3g in the horizontal direction was used to scale the input motions.

2.2 *Grouping effect*

The seismic response of the structure can be evaluated by the consideration of its dynamic parameters. Any change in these parameters can alter the overall response of the structure. To include the grouping effect of the cabinet, it was considered that the connection between the cabinets is fixed and due to this consideration, the rigid links were assigned. It was assured that the assigned rigid link will group the cabinet together and is not inducing any change in the dynamic characteristic of the structure and the friction between the cabinets are neglected. Fig.1. represents the typical cabinet's model for the grouping effect

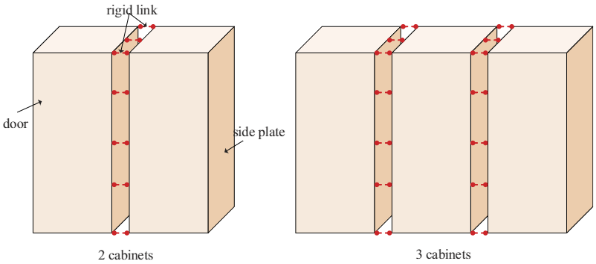


Fig. 1. Interconnected cabinet assembly

2.3 *Intensity Measure and Damage states*

Since the cabinet facility is sensitive to acceleration this study proposes the use of spectral acceleration (Sa) as the intensity measure. As mentioned in the NUREG [5], the response of the acceleration-sensitive component in the electric cabinet is an important factor, which should be considered carefully for evaluating the dynamic characteristics.

The *Sa* was first introduced by Cordova [6] which is defined as the geometric mean of two *Sa* components at a range of the period of interest. Therefore, the *Sa* becomes the proposed intensity measure (IM) to overcome the drawbacks

$$S_a(T_i) = \left[\prod_{i=1}^{n} Sa(T_i)\right]^{1/n} \qquad (1)$$

Where n is the number of periods of interest used for determining the *Sa* in the frequency range of interest for cabinet range 4-16 Hz.

The damage limit states in seismic fragility analysis can be employed as maximum displacement or acceleration at the peak of the structure (θ *max*) the inter-story drift ratio (θ)[7], or the stress (σ) for evaluating the engineering demand parameter (EDPs). Determining these limits for the damage measures vary for different structures such as bridges, wind turbine or nuclear power plant and its components. In this study, NUREG guidelines are followed to define the damage states by considering the spectral acceleration as an EDPs for the acceleration sensitive electrical cabinets.

3. Development of fragility function

The output of fragility estimation is an estimate of the cumulative probability of being in or exceeding each damage state for the given ground shaking. Time history analysis for the cabinet structure corresponds to the intensity measure define by Cordova [6] is followed. The fragility functions are obtained using the maximum likelihood estimation (MLE). The prob-ability of being in or exceeding a given damage state is modeled as a cumulative lognormal distribution.

$$P(d_s|S_a) = \Phi\left[\frac{1}{\beta_d} ln\left(\frac{\bar{S}_d}{\bar{S}_{d,ds}}\right)\right] \qquad (2)$$

where $S_{d,ds}$ is the median value of the spectral displacement at which the acceleration sensitive component reaches the threshold of the damage state, β_d is the standard deviation of the natural logarithm of spectral acceleration of the damage state d_s and Φ is the standard normal cumulative distribution function (CDF) The CDF of a lognormal distribution was used to define a fragility function. In the present study, the fragility curves were generated by a damage state (DS) given the average spectral acceleration, S_a. Thus, the fragility function can be written as follows

$$P(DS|IM) = \Phi\left[\frac{1}{\beta}\ln\left(\frac{IM}{\theta}\right)\right] \qquad (3)$$

In which P is the probability that a ground motion with $S_a = x$ will cause the structure to collapse, θ and β are the median and the standard deviation of the intensity measures; Φ is the standard normal CDF. The fragility function parameters, θ and β, were obtained by maximizing the likelihood function.

$$\left\{\hat{\theta},\ \hat{\beta}\right\} = \underset{\theta,\beta}{\arg\max}\ \ln(Likelihood) \qquad (4)$$

4. Result and discussion

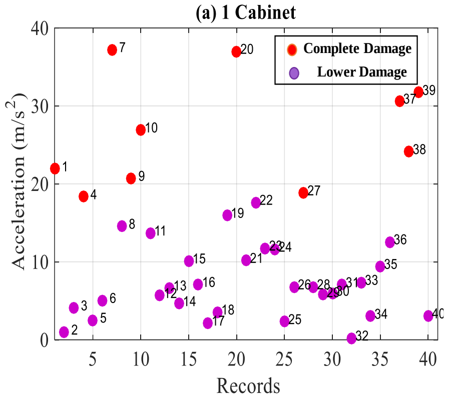
In fragility assessment underestimating any scenario can cause a profound impact on loss estimation analysis. For this cause, the cabinet with the grouping effects are investigated. It is noteworthy that the damage states for the single and group of the cabinet are the same.

Fig. 2 represents the peak acceleration response under the 40 set of earthquakes. The red colors manifest the functional failure of the cabinets in which the rely chattering may occur while the purple color corresponds to other recoverable damage as per NUREG recommendation. The acceleration was calculated at the top of cabinet. In-case of two cabinets the acceleration was found to be the same at the top as the cabinets are linked using rigid links. As per NUREG, the threshold 1.8g at zero period acceleration (ZPA) corresponds to the fragility level for the functional failure of the cabinets like rely chattering while the threshold level below 1.8g can be corresponds to any lower damage that can be recoverable both the levels represents the functional failure, in Fig. 2(a) a single cabinet is more vulnerable as compared to two and three cabinets together. The grouping effect causes a considerable change in the natural frequency of the cabinets that eventually results in lowering the seismic response of the interconnected cabinets. Table 1 depicts the natural frequency for the cabinets.

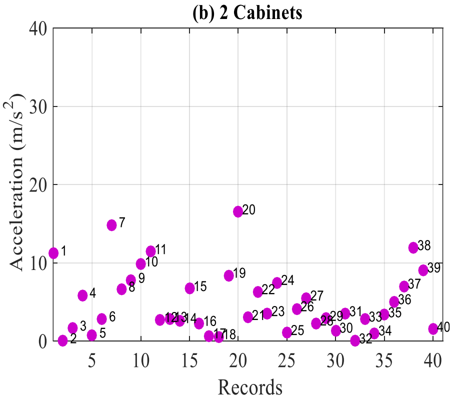
Table 1. Change in natural frequency due to grouping

Direction	FEM Models		
	1-Cabinet	2-Cabinet	3-Cabinet
Front-Back	14.55	15.24	15.76
Side-Side	15.12	20.15	21.61

(a) 1 Cabinet



(b) 2 Cabinets



(c) 3 Cabinets

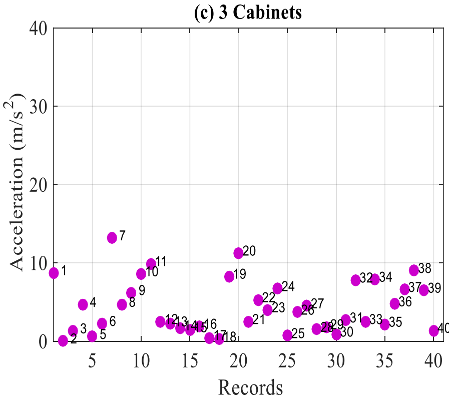


Fig.2 Peak acceleration response

The fragility curves are developed corresponds to the NUREG guidelines. Fig. 3 represents the curves for the three cases of acceleration sensitive cabinet based on HAZUS methodology. The median value of spectral acceleration for the different damage states considering the grouping effects are enlisted in Table 2.

This dramatic change in the fragility function can correspond to the structural dynamic modification, the inertia of the system and support boundary condition. Grouping the cabinets together turn to increase the integral stiffness of the system more effectively which results in the decrement in the acceleration response of the cabinet system. Levels of seismic intensity and difference in the probability of sustaining damage for a group of cabinets and a single cabinet vary about 28% and this extends up to 50% for three cabinets.

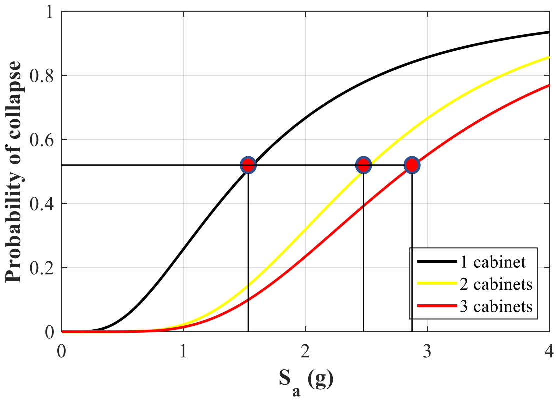


Fig.3 Fragility curves based on NUREG

Table 2 Peak acceleration threshold for Cabinets

Case	One-Cabinet		Two-Cabinets		Three-Cabinets	
	θ	β	θ	β	θ	β
Acc. (g)	1.861	0.66	2.4	0.45	2.8	0.41

These changes are more prominent as the intensity of the input excitation increased. It is noteworthy that the difference in the median value for the group of cabinets varies significantly compared to the one cabinet structure. This summarizes the effect of the grouping of the cabinet facility on the seismic capacity that varies about 30% for two and increases with the number of cabinets.

5. Conclusions

The seismic capacity evaluation of cabinet structure is investigated using the linear time history analysis. The cabinet models were examined using a set of 40 ground motions that are spectrally matched to the DRS (RG 1.60). Using the IDA method, the structure is examined with the varying amplitude of PGA ranging (0.1–4g).

The input excitation and the corresponding damage state are the two parameters that are considered to highlight its effect on the seismic capacity of the electrical cabinet when a single cabinet and a group of cabinets are subjected to the same seismic excitation. Fragility analysis is conducted that manifests the significance of considering the grouping effect for the cabinets. The seismic evaluation reveals that the cabinet structure is a sensitive component of NPP and thus the grouping effect induces a very pro-found impact on the dynamic characteristic and seis-mic response of the cabinet system. This dramatic alteration in the dynamic characteristic of the structures is mainly induced by the structural dynamic modification and support boundary conditions of the cabinets. Based on this study, the grouping effect of the cabinet structure is an important parameter to be considered in the seismic capacity evaluation of the cabinet structure in the NPP.

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REFERENCES

[1] Shinozuka M, Feng MQ, Kim H, et al. Statistical analysis of fragility curves. Report. Multidisciplinary Center for Earthquake Engineering Research, MCEER-03-0002;2003.

[2] Ellingwood BR. Earthquake risk assessment of building structures. Reliab Eng Syst Safe.2001;74(3):251–262

[3] Günay S, Mosalam KM. PEER performance-based earthquake engineering methodology, revisited.J Earthq Eng.2013;17(6):829–858.

[4] Zentner I. Numerical computation of fragility curves for NPP equipment. Nucl Eng Des.2010;240(6):1614–1621.

[5] Bandyopadhyay KK, Hofmayer CH, Kassir MK, et al. Seismic fragility of nuclear power plant components: phase 2, motor control center, switchboard, panel board and power supply. Long Island (NY): Department of Nuclear Energy, Brookhaven National Laboratory; 1987. (No. NUREG/CR–4659-VOL. 2).

[6] Cordova, P.P. Deierlin, G.G. Mehnay, S.S. et al. Development of two parameter seismic intensity measure and probabilistic assessment procedure in: The Second US-Japan Workshop on Performance based Earthquake Engineering Methodology for reinforced concrete building structure,2000 pp 187-206 September.

[7] EESK A Study on the seismic design criteria. Prepared for the Ministry of Construction and Transportation by Earthquake Engineering Society of Korea. Vol. 1; Korea;1997