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A proposed numerical model for cabinets of nuclear power plants

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1. Introduction

The safety for electrical equipments in nuclear power plant (NPP) such as cabinets during earthquake is very important. It should be considered carefully to guarantee uninterrupted operation of the NPP. Usually, cabinets are calculated from finite element analysis or by using experimental tests such as shaking table tests before the installation.

It is time-consuming and expensive to use the complex FEMs every time for the analysis of equipment cabinet. For this reason, a lot of simplified and computationally efficient models have been proposed for analysis of the cabinets. Among those models, S.G. Cho *et al.* [1] suggested a nonlinear model, which used beam elements and considered the softening behavior of the cabinet structure by incorporating the Duffing's type of the restoring force. Uncoupled nonlinear by mode superposition method was applied. However, that study only considered the first natural mode of the cabinets. In this study, effects of the higher modes will be included to improve the accuracy of the analysis.

2. Analysis Method

For a beam with bxh rectangular cross-section, the equation of motion can be obtained by assembling element matrices as follows

$$[M]\{\ddot{U}\} + [K]\{U\} - \beta[K_N]\{U^3\} = \{F\} \qquad (1)$$

Where:
$\{U\}, \{F\}$ are displacement, force vectors;
$[M], [K]$, and $[K_N]$ are mass, linear stiffness, and nonlinear stiffness matrices respectively;
And β is a factor obtained as follows:

$$\beta = \frac{3}{20}\gamma h^2 \qquad (2)$$

Where γ is a proportional coefficient of strain.

The modal coordinate system can be obtained by using the modal matrix $[\phi]$ of the linear system. The displacement $\{U\}$ in the physical coordinate system can be transformed into the corresponding displacement $\{\xi\}$ in the modal coordinate system as follows:

$$\{U\} = [\phi]\{\xi\} \qquad (3)$$

$$[\phi] = [\phi_{ij}], \qquad (4)$$

$$(i = 1, \dots, n; j = 1, \dots, m)$$

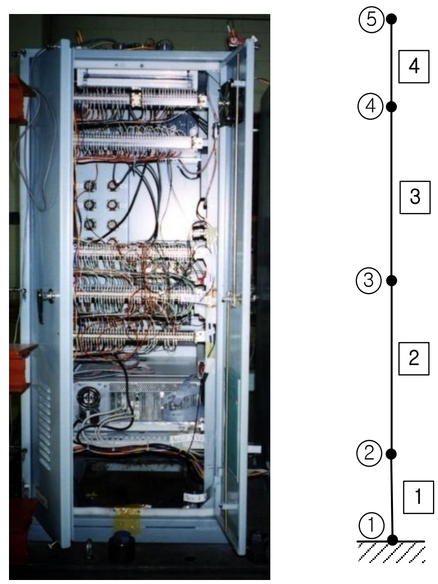
where n is the number of degrees of freedom and m is the number of modes.

In the study of S.G. Cho *et al.* [1], the authors assumed that the nonlinear dynamic responses of the system are strongly governed by the first natural mode. To increase the accuracy of the model, in this study, the first and also the second modes are considered.

3. Numerical Model

The model of the cabinet is used consistently with the previous study. A seismic monitoring system central processing unit cabinet installed in a NPP is selected as an actual model for the study. The dimension of the cabinet is $150cm$ x $80cm$ x $65cm$ and its weight is $267\ kg$ (Fig. 1a).

The numerical model of the cabinet has four beam elements as shown in Fig. 1b. The Runge-Kutta method [2, 3] is used to solve the nonlinear equations developed in the model. The results, then, are compared with the response of the equipment cabinet obtained by using shaking table tests under the earthquake.



(a) **(b)**

Fig. 1. Cabinet (a) mounted on shaking table, (b) numerical model considering four beam elements.

4. Results and discussion

The natural frequencies and modal participating masses of cabinet are shown as in Table 1. It is obvious that the first and the second modes contribute mostly the modal participating mass of the model, i.e, 63.15% and 19.08% respectively. The vibration modes of the cabinet, obtained by the numerical analysis, are shown in Fig. 2.

Table 1. Fundamental natural frequency and modal participating mass

Property	**Mode**			
	1st	**2nd**	**3rd**	**4th**
Natural frequency (Hz)	14.26	95.07	303.51	419.07
Modal participating mass (%)	63.15	19.08	6.44	11.33

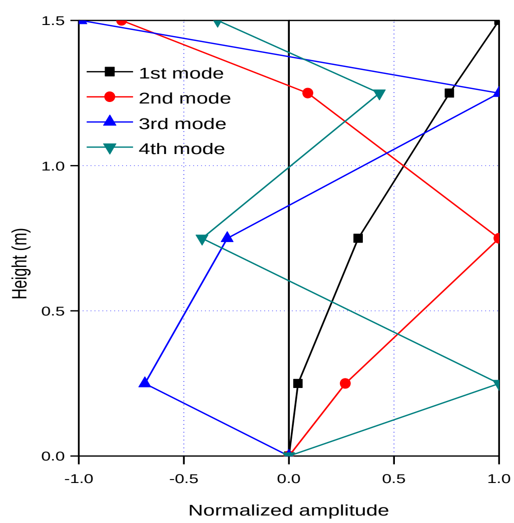


Fig. 2. Vibration modes of the cabinet obtained from the numerical model

Transfer functions of nonlinear cabinet responses are analyzed and compared with the experimental ones (Fig. 3). It can be easily seen that the results obtained from numerical model have a good agreement with the experiments. However, the transfer functions predicted by the nonlinear model have a better agreement with the experimental results than the linear model.

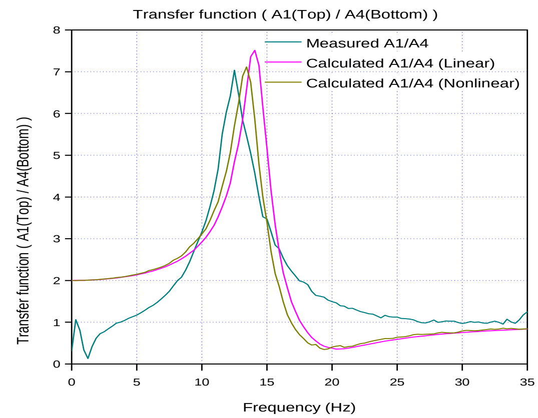


Fig. 3. Transfer functions obtained from experiments and numerical model

5. Conclusion

A proposed model of equipment cabinet structure of NPPs based on a previous simplified model has been developed for the earthquake analysis. The cabinet is modeled as beam elements, to reduce the computational effort, and the nonlinear behavior of the cabinet is taken into account by considering equivalent nonlinearity. The first and second modes are found to be dominant in the global response of the cabinet under earthquake loads. The proposed nonlinear method is expected to be useful for the prediction of seismic behavior of cabinets, particularly during the operation, owing to less computational effort required, accurate prediction of softening and no requirement of tests.

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