DETAILED SENSITIVITY ANALYSIS OF NUMERICAL MODEL OF AN EXISTING BASE-ISOLATED BUILDING

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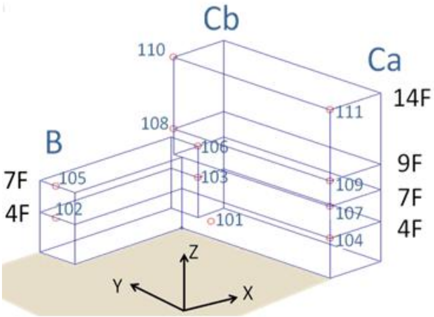
1. INTRODUCTION

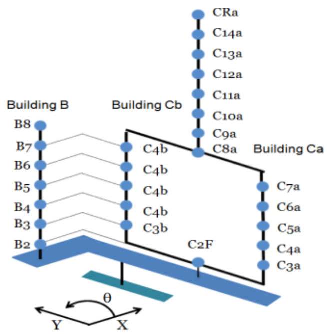
Dynamic analysis is widely used especially in the application of seismic response analysis that also aims at discussing the safeties of existing structures. However, inaccuracies in the outputs are due to a lot of uncertainties in the modeling process, e.g., physical uncertainty, modeling uncertainty, and human factors. This causes the reliability of numerical outputs cannot describe the actual responses of the structure. This study aims to clarify the causes of inaccuracies of numerical seismic responses due to the physical uncertainties of the model, and analyze the global sensitivity of uncertain model parameters by analysis of variance (ANOVA) by using a numerical model of an existing base-isolated building.

2. TARGET STRUCTURE AND NUMERICAL MODEL

The target structure is the buildings of Shibaura Institute of Technology (SIT) located in Tokyo Bay area. It is an asymmetric base-isolated building installed with a structural monitoring system (Fig. 1(a)) [1]. The monitoring system has recorded successfully more than 140 earthquake responses since 2010. The 3-year (2010-2012) monitoring data provides comprehensive database to study possible changes in structural parameters under different earthquake events including the strongest shaking in the Great East Japan Earthquake occurred in March 11th, 2011.



(a)



(a) Locations of accelerometers (b) Lumped mass model

Fig. 1 SIT building

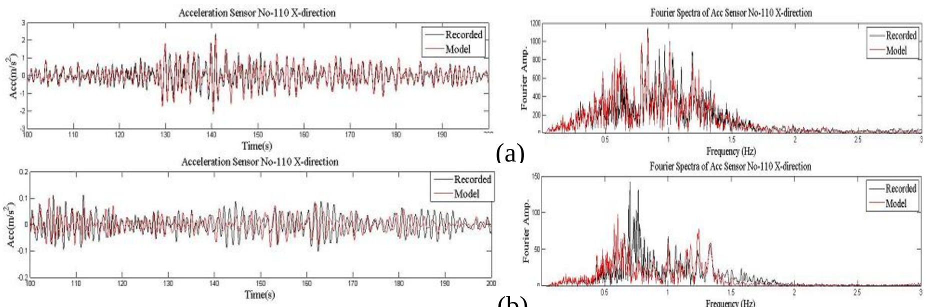


Fig. 2 Comparison of time histories and spectra between recorded and simulated accelerations for (a) main shock (b) small earthquake

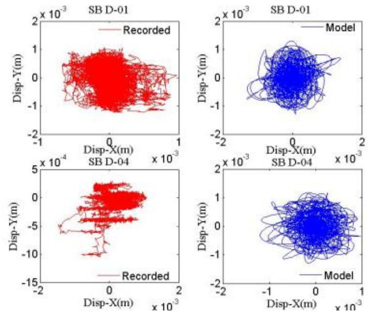


Fig. 3 Displacement orbit of one of sliding bearings under small earthquake

The building was described by a three dimensional lumped-mass model with 81 DOFs (Fig. 1(b)) with considering nonlinear properties of the base-isolation devices. The seismic responses were then verified by comparing with the monitoring data acquired in some earthquakes. The outputs in a large input (the main shock of Great East Japan Earthquake) showed good agreement between numerical outputs and recorded data in both time domain and frequency domain (Fig. 2(a)). However, there were not good agreements in the responses of small earthquakes before and after the main shock especially in the frequency range of 0.7-1.0Hz, e.g., the result shown in Fig. 2(b). This frequency range was dominated at torsional resonance modes of building [2]. On the other hand, it was recognized that, in this target building, the resonant modes of superstructure were also excited in the main shock due to the asymmetric geometry [2]. Additionally, Fig.3 indicates that the displacement orbits, which were calculated by the numerical responses, in some of sliding bearings; D-01 at Bldg. C and D-04 at Bldg. B also do not show agreements with the recorded orbits for both magnitude and direction in small earthquake (March 9th, 2011). Therefore, the parameter uncertainties of both base isolation devices and the superstructure must be considered to construct a more validated model.

3. GLOBAL SENSITIVITY ANALYSIS OF UNCERTAIN PARAMETERS

3.1 Design of experiment

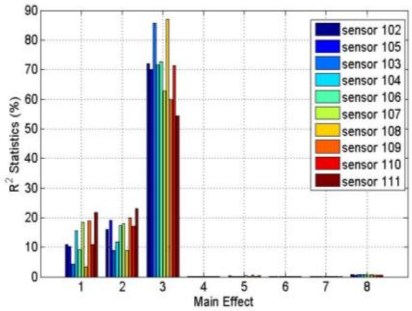
Here, the global sensitivity analysis on a small earthquake was conducted by using an input data in March 9th, 2011. As the uncertain model parameters, three parameters are selected for the superstructure; mass **M**, stiffness **K**, structural damping ratio ξ_S, and five parameters from base-isolation system; the stiffness in small displacement $\mathbf{K_1}$ of each of base isolation devices, natural rubber bearings (NRB), sliding bearings (SB), lead dampers (LD), and steel dampers (SD). It is important to determine upper and lower bounds around nominal values of selected parameters. The variations of the mechanical properties of isolators were no more than ±20% over a 50- to 100- year period, as indicated in the ACSE-4 [3]. Probability distributions of the eight uncertain parameters were given within two Cases A and B (table 1); specially in the superstructure parameters, the range of ±10% in Case A and the range of ±5% in Case B around nominal values of **M** and **K** respectively for comparison.

Table 1. Probability distribution of uncertain parameters

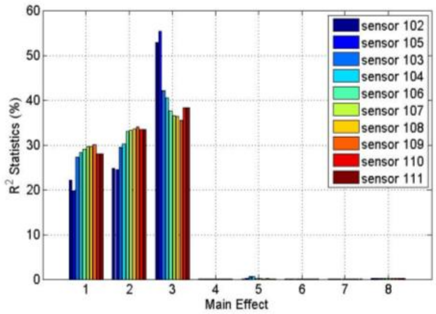
Effect No.	Description	Parameter	Nominal value	Case A		Case B	
				Lower	Upper	Lower	Upper
1	Mass of building	M	1	0.9	1.1	0.95	1.05
2	Stiffness of building	K	1	0.9	1.1	0.95	1.05
3	Damping ratio of superstructure	ξ_S	0.02	0.01	0.03	0.01	0.03
4	Stiffness of NRB	$K1_{NRB}$	1	0.8	1.2	0.8	1.2
5	Stiffness K1 of LD	$K1_{LD}$	1	0.8	1.2	0.8	1.2
6	Stiffness K1 of SB	$K1_{SB}$	1	0.8	1.2	0.8	1.2
7	Stiffness K1 of SD	$K1_{SD}$	1	0.8	1.2	0.8	1.2
8	Damping ratio of base	ξ_b	0.05	0.04	0.06	0.04	0.06

3.2 Results of global sensitivity analysis

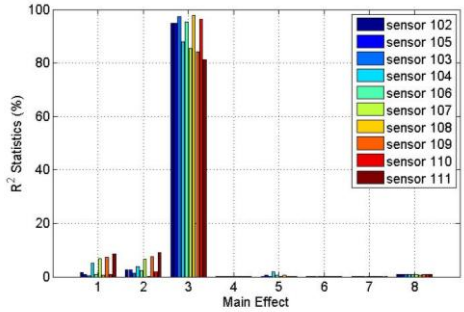
The global sensitivity analysis is the procedure for assessing the sensitivity of each of the model parameters under their uncertainties to comparative feature RMS error (RMSE). ANOVA can be adopted to analyze the spread of outputs due to varying inputs; here, the R^2-statistic is calculated to each model parameter [4].The derived R^2-statistics to the RMSE of responses in the X-direction and the Y-direction at all sensor locations are showed in Fig. 4.



(a) Case A – X direction



(b) Case A – Y direction



(c) Case B – X direction

Fig. 4 Global sensitivities of model parameters to comparative features RMSE

The result of Case A in Fig. 4(a), (b)) shows that the sensitivities of **M, K,** and ξ_S are relatively high; it can thus be said that those parameters are significantly influential to the RMSE in the small earthquake. Considering relative R^2-statistic at the different locations of sensors, both Case A and B in Fig. 4 show that **M** and **K** of Bldg. Ca (sensor #:104, 107, 109, 111) is more influential to errors between numerical outputs and recorded data than Bldg. Cb (sensor #:103, 106, 108, 110); in contrast, ξ_S of Bldg. Cb is more sensitive to RMSE of the structure than Bldg. Ca. In comparison to Case B (Fig. 4(c)), sensitivities of Case A (Fig. 4(a)) with probability distribution of ±10% are higher than Case B at **M** and **K**. It is also noticed that the parameters of base isolation devices that showed low R^2-statistic have less influence on the response of structure than ones of superstructure under the small earthquake.

4. CONCLUSION

Parameters of superstructure such as mass, stiffness and damping ratio significantly influence on analytical response of the model in small earthquake. The study also considers which parts of structure with the uncertain parameters are high sensitive to errors between numerical outputs and recorded data. In these cases, mass and stiffness of Bldg. Ca are more influential to errors than Bldg. Cb, ξ_S of Bldg. Cb is more sensitive than Bldg. Ca.

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