Dynamic Responses of High-Rise Base-Isolated Building during the 2011 Great East Japan Earthquake

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Summary

Seismic responses of a high-rise base-isolated building in Tokyo Institute of Technology were recorded during the 2011 Tohoku-oki earthquake. This paper explains a variety of numerical techniques such as transfer function curve-fitting procedure for system identification, comparison with conventional structure by modal analysis, damper hysteresis, axial force variation of rubber bearing, and dynamic characteristic variation due to input amplitude. Reliability of recorded results is confirmed by various methods, and applicabilities of the techniques for the high-rise isolated building are discussed.

Keywords: Earthquake Records; High-Rise Building; Base-Isolated Structure; System Identification; Modal Analysis; 2011 Tohoku-Oki Earthquake

Target Building and Monitoring System

Target Building is a 20-story office building of Tokyo Institute of Technology located in Yokohama (Fig.1). The floors are composed with hybrid structure both steel beams and CFT columns. So called Mega-Braces are installed on the both sides of building because the horizontal stiffness is necessary to maintain the seismic isolation effects. The plan of the isolation floor and the types of each devise are shown in Fig. 2. To avoid the large tensile forces during a major earthquake, the rubber bearings are allowed to move upward within 20 mm of gap distance (Fig. 2a).

In this monitoring system, the accelerometers are placed on the 1st, BI-, 2nd, 7th, 14th and 20th floor. In order to measure the story drift of the isolated floor directly, the displacement sensors for long and short stroke are installed (Figs. 4a and 4b). In order to measure the up-lift behavior of corner bearings, the displacement sensors for short stroke are installed as shown in Fig. 4c.

Fig. 1: Target bldg.

Recorded Data

Peak ground accelerations were 51.4 gal and 67.1 gal in the X- and Y-direction. Peak accelerations at the 20th floor were 87.7 gal and 116.6 gal in the X- and Y-direction. Fig. 7 compares the deformations of isolation system obtained from the scratched lines created by the trace recorders, and data from wire type displacement sensors. The deformations obtained from the three distinct methods agree well, validating the measurement method and data. Peak deformations of 69 and 91mm are recorded in X- and Y-directions, respectively.

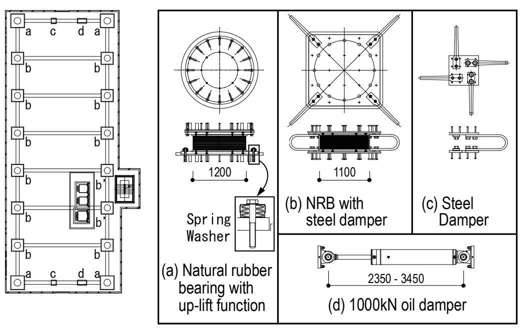


Fig. 2: Distribution of NRBs and dampers

System Identification and Interpretations by Modal Analysis

Natural frequencies, damping ratios and modal participation vectors are computed by curve-fitting the idealized transfer function assuming steady-state response to the empirical transfer function estimated from acceleration data (Fig. 8).

Using such modal properties and the base acceleration records, mode-superposition time history analysis is performed for the story where the sensor is located to obtain acceleration and displacement. The displacements and accelerations are compared with the recorded data, and good match between them.

By using mode-superposition method, the isolation effect could be estimated (Fig. 11). Although the difference of displacement between the seismic-resistant case and the isolated case is not so large, the acceleration of the seismic-resistant case is twice as much as that of the isolated case.

Nonlinear Behavior Due to Steel Damper

The isolation floor hysteresis are clearly showing the linear and bilinear nature of the response caused by the steel damper. The envelope curves are in excellent agreement with the design curves, therefore the steel damper has functioned as previously supposed. The linear stiffness after large deformation declines slightly.

Up-Lift Behavior of NRB

Axial force of rubber bearing is calculated from the CFT column strain and Mega-brace strain. 1mm up-lift are observed just one time (Fig. 15, 88 sec), then the axial force arrives the design gravity load. Therefore, up-lift timing is able to be expected by estimating the variation of axial force and supported gravity load of the NRB.

Conclusions

Dynamic properties and behaviors of a high-rise isolated building were discussed by using records which were obtained on mainly March 11, 2011.

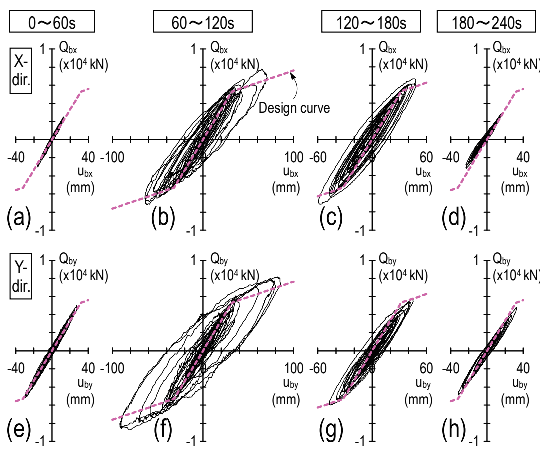
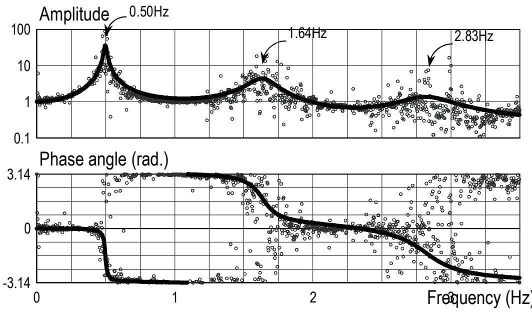
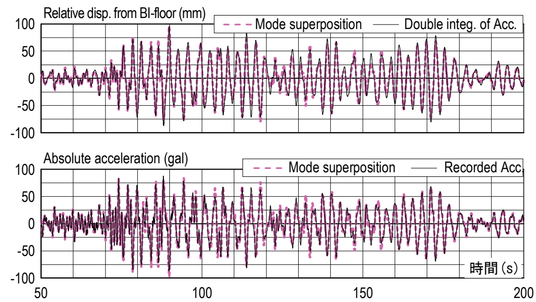


Fig.12: Relationships between shear force and story drift of BI-floor, (a) ~ (d): X-dir. (e) ~ (h): Y-dir.



(b) derived from 20FL. acc. and 2FL. acc. (above isolator)

Fig. 8: Ttransfer function and curve-fittingn



(b) Analysis of superstructure, using 2FL acc. as input.

Fig. 10: Comparisons of top-level behavior between recorded data and modal analysis

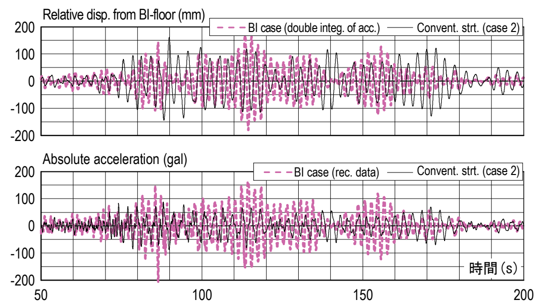


Fig. 11: Comparisons of isolated case and conventional struct. case

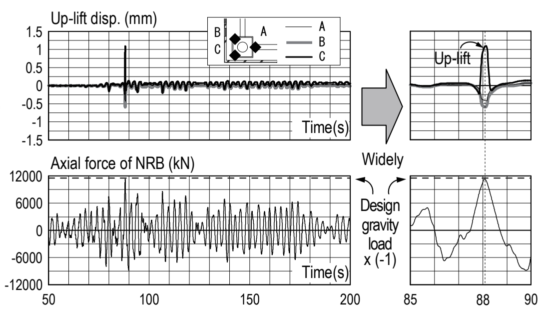


Fig. 15: Up-lift behavior of NRB