Effectiveness of Different Types of Seismic Isolation Estimated by Numerical Comparative Study

Alexander Kultsep(✉)

CVS (CKTI-Vibroseism) Co. Ltd, Saint Petersburg, Russia
akultsep@gmail.com

Abstract. Building collapses due to recent severe earthquakes have activated searching for effective seismic protection systems. A comparative study of the most popular systems has been performed using numerical model of the well-known test building experimentally investigated at the world's biggest E-Defense shaking table in Japan. In the presented study the calculation models for the following seismic isolation systems were prepared: a) a model for rigid supported building; b) a model with triple pendulum bearings (TPB); c) a model with rubber bearings (RB) combined with viscous dampers (VD); d) a model with the Base Control System (BCS) consisting of coil springs and viscous dampers; e) a model with kinematic supports (KS) often used in Russia. The models a) and b) were validated using test results. Models were prepared considering most of the nonlinear effects in the isolation devices. The calculation results show good effectiveness of TPB, RB and BSC systems in reduction of seismic horizontal accelerations. At the same time, the addition of seismic ground motion in vertical direction significantly increases the building horizontal acceleration response in case of TPB and RB systems, i.e. the strong 3D interaction between horizontal and vertical motion was presented. For these systems amplification of high frequency vertical motion was also observed. In the case of BCS, the calculated 3D interaction was much less compared to other systems and there was no vertical response amplification. KS failed under the test conditions which required using of additional motion restriction devices in the KS design. Conclusions: simple realistic models for different isolation systems have been proposed. TPB, RB-VD have good performance, BCS has been selected as the most preferable system.

Keywords: 3D Base Isolation · BCS · LRB · TPB · Kinematic supports · Analysis

1 Experimental Data Reference

1.1 Description of Experimental Data

The steel frame building with concrete floors investigated experimentally in Japan with different seismic isolation systems [1] was used in this study as a test model.

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1.2 Numerical Model Verification

In order to check the developed numerical model of the building the following calculations were performed and compared with test results: eigenvalue analysis with rigid base, seismic response calculation for the building with rigid base and for the building equipped with seismic isolation based on triple pendulum bearings (TPB).

Table 1 gives the results of eigenfrequency calculation compared to measured frequencies according to [1]; a good agreement between the observed and calculated frequencies can be seen. The total mass of the building was considered as 494 t.

Table 1. Calculated and measured eigenfrequencies.

No	Frequency measured [1], Hz	Frequency calculated, Hz
1	1.39	1.39
2	1.42	1.43
3	2.20	1.75
4	2.21	-
5	4.83	4.46
6	4.72	4.57

Comparison of the calculated and measured system response values for rigid base configuration and for SIS using TPB is presented in Fig. 1 and Fig. 2. The effect of horizontal response increase due to 3D seismic excitation is well represented for both measured and calculated data. Also, the maximum acceleration value can be reproduced by calculation.

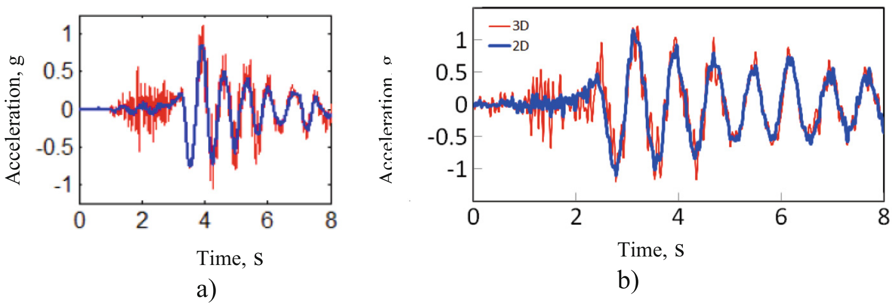

Fig. 1. Horizontal seismic response (Y) of the 5th floor of the fixed (Rigid) base configuration structure under horizontal X.Y (2D) excitation (blue lines) and X, Y, Z (3D) excitation (red lines). a) measured [1]; b) calculated c) TBP configuration measured [1], d) TBP configuration calculated.

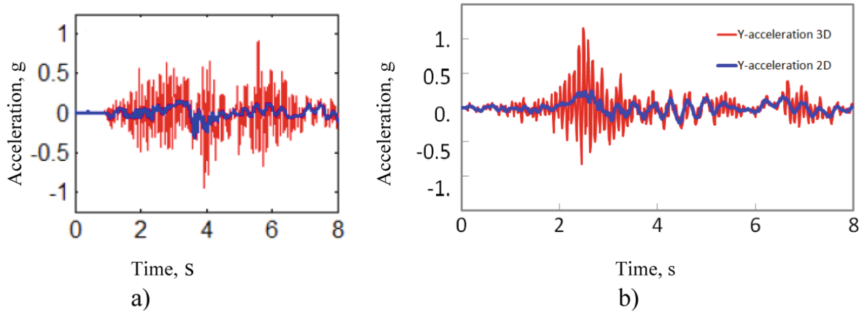

Fig. 2. Horizontal seismic response (Y) of the 5th floor of the structure equipped with TPB based SIS under horizontal X.Y (2D) excitation (blue lines) and X, Y, Z (3D) excitation (red lines). a) measured [1]; b) calculated.

2 Comparative Study

2.1 Description of Investigated SIS

A total of 9 SIS elements were introduced under building column bases. The following types of SIS were investigated:

TBP - triple pendulum bearings [2] with effective pendulum length of 7.5 m. The TBP were modeled using truss elements with large displacement option switched on and connected to the structure using rigid links. Friction with a friction factor of 0.05 was simulated using non-linear springs (Fig. 3a).

BCS – base control system with helical spring blocks and high viscous dampers [3, 4]. The helical spring blocks were modeled as beam elements. Use of this SIS resulted in reduction of the frequency of the first horizontal vibration mode to 0.7 Hz, and the vertical mode with the largest modal mass was detected at 3.0 Hz. Viscous dampers were modeled using the Maxwell model (Fig. 3b) with relative system damping of 9% for the first natural frequencies.

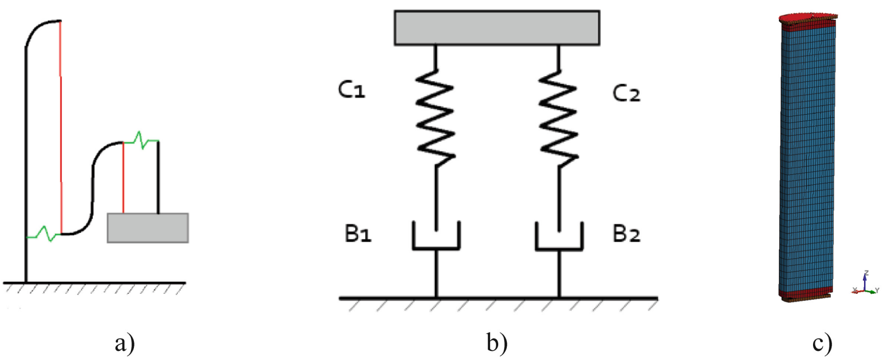

Fig. 3. Modelling of a) TPB, b) viscous dampers and c) KS.

RB – rubber supports in combination with viscous dampers. The rubber supports were modeled similar to BCS with a horizontal vibration mode of 0.55 Hz and practical rigid vertical stiffness. Viscous dampers modelling was considered identical to the BCS model.

KS – kinematic supports are special reinforced concrete columns with connecting joints at the ends placed instead of the 1st floor regular columns [2]. KS were modeled explicitly, with contact surfaces on the faces of the mesh of volumetric elements that represented the connecting joints of the devices. (Fig. 3c).

2.2 Results of Calculation

The calculations were performed for seismic excitation recorded during the Northridge earthquake (1994), reduced by 50%. System with KS collapsed under these conditions. Therefore, it was calculated under 25% seismic load level and then the seismic response results were multiplied by 2 in order to make the results comparable. Table 2 gives the results of maximum compression forces in corner columns including static load. The best isolation effect with a reduction ratio of 3.32 was detected for the TPB system. The BCS with a reduction ratio of 2.78 has also good performance.

Table 2. Corner column compression forces.

SIS type	Force, kN	Reduction ratio
RIGID	2396	-
BCS	863	2.78
RB	1005	2.38
TPB	721	3.32
KS	1308	1.83

Figure 4 presents the results of interstorey drift calculations at the building central column.

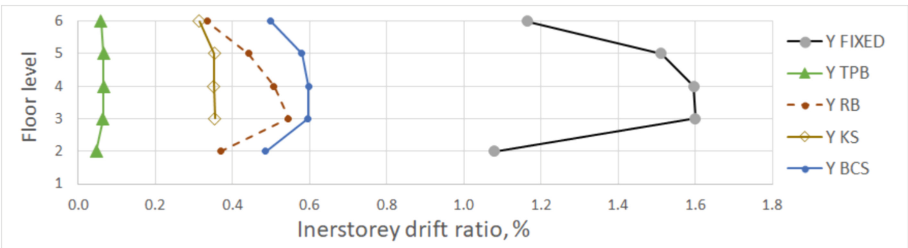

Fig. 4. Interstorey drift ratio for the investigated systems.

Figure 5 gives the results of response spectra calculation for a point on the 5th floor in Y direction (horizontal). The “FIXED” curve is for the rigid base supported structure, a high peak at 1.4 Hz (first eigenmode for fixed building) can be seen. For all systems this peak is eliminated. However the increased response spectra in high frequency area can be observed for all systems with high vertical rigidity (RB, TPB and KS). Especially for TBP based SIS, the high frequency vibration at frequencies over 50 Hz was found.

No increase in the horizontal zero period accelerations (ZPA) for any of the systems was detected. The BCS qualified as the best system in terms of ZPA reduction. Figure 6 gives the results of response spectra calculation for a point on the 5th floor in Z direction (vertical). The "FIXED" curve is for the rigid base supported structure with a high peak at 13 Hz. All systems except BCS have high response in this frequency range with no acceleration reduction or even with acceleration amplification.

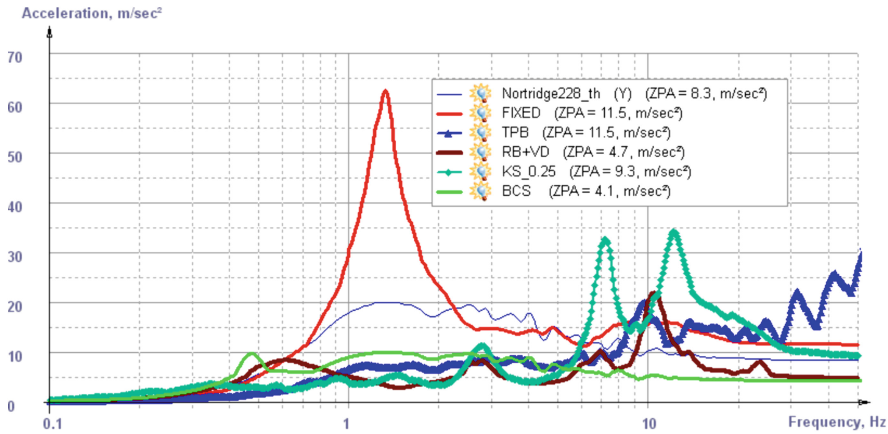

Fig. 5. Calculated response spectra (5%) in Y direction for a point on the 5th floor.

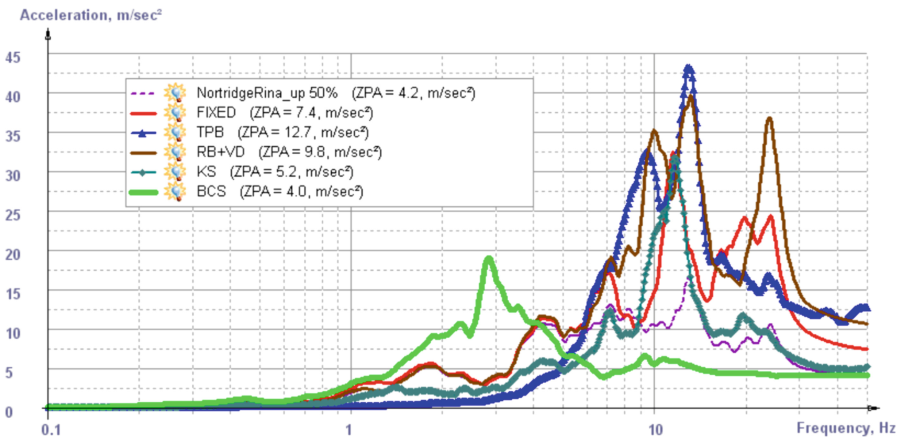

Fig. 6. Calculated response spectra (5%) in Z direction for a point on the 5th floor.

On the other hand, BCS has increased response at 3 Hz, which corresponds with SIS eigenfrequency for vertical vibration. For TPB and RB based SIS an increase in vertical

ZPA was found. BCS works effectively also in terms of vertical ZPA reduction with ZPA changing from 7.4 m/s^2 for the fixed structure to 4 m/s^2 for BCS.

3 Conclusions

Seismic isolation systems can significantly reduce the horizontal accelerations and forces in building structure elements. At the same time, when using SIS with high vertical rigidity (RB and TPB), an increase in vertical vibrations is observed, which is confirmed both by numerical experiments and measurements on full-scale buildings exposed to a ground seismic motion recorded during real earthquakes. The most balanced system at the moment is the BCS system, which allows reducing the horizontal accelerations without significantly increasing the vertical accelerations.

References

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