Seismic Performance Enhancement of an Existing Reinforced Concrete Building Using In-Frame Damping Devices

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ABSTRACT:

Enhancement of the seismic performance of the structure can be categorized into two approaches. The first approach is the conventional retrofit design that requires the enhancement of strength and ductility of the buildings. The second approach relies on the advanced techniques based on seismic isolation and energy dissipating systems in such a way to reduce the forces generated from the earthquake shaking. The energy dissipating systems plays major role by reducing the seismic energy and minimizing possible damage in structural and non-structural members. The energy dissipation process can be realized by employing energy dissipation devices that works in various principles such as, frictional sliding, yielding of metals, fluid viscous dampers, etc.

In this paper, the effect of different types of damper devices on the seismic performance of an existing 24 storey reinforced concrete Telecom building located in Istanbul/Turkey has been investigated. Istanbul is located in one of the most seismically active regions and being the financial hub of the country, the level of seismic hazard is extraordinary, thereby increasing the need for the structures to meet the minimum performance criteria.

Preliminary seismic assessment of the building has been carried out according to the provisions of Turkish Earthquake Code (TEC 2007) and Istanbul Earthquake Code for High-rise Building (İYBDY 2008). Seismic performance of the building was determined to be below Life Safety level and therefore several traditional and advanced retrofit options have been considered. Due to architectural and operational limitations it has been decided to improve building's performance by means of energy dissipation devices, first time to be employed in Turkey. Two types of energy dissipation device systems have been studied namely wall-type viscoelastic dampers and the Chevron-type steel hysteretic dampers. The dampers have been designed to be installed at the exterior frames, so that they will be visible at the facade of the building. Nonlinear time history analyses have been performed using seven pairs of ground motion records. The selection and scaling of the earthquake records are based on İYBDY (2008). The nonlinear analyses results of the two models have shown that both dampers types have similar performance enhancement on the global response of the structure.

Keywords: Viscoelastic dampers, steel hysteretic dampers, time-history analysis, seismic performance enhancement, reinforced concrete building.

1. INTRODUCTION

The aim of this study is to compare and evaluate the performance of the existing building retrofitted using added dampers.

The classical approach towards mitigation of earthquake risk in a structure usually based on improving the capacity to resist the demand. However, more contemporary approach is to reduce the demand rather than increasing the capacity by means of advanced techniques such as seismic isolation and passive energy dissipation. These techniques differ from each other in terms of structural mechanics, level of reduction in demand, installation and cost. Seismic isolation acts in series with the structure by absorbing the energy and filtering out the motion before entering in to the structure. Energy dissipation devices or dampers on the other hand, works in parallel with the structure allowing all energy to pass in to the combined system and dissipates based on the characteristics of each component.

The effectiveness of the isolation system relies on lengthening the response through period shift, whereas added dampers have minor effect on the building period and relies entirely on the combined response of structure and devices. The reduction of demand from the seismic isolation can occur by a factor of 5 to 7 but the reductions caused by dampers can generally range between 15-25%. Seismic isolation is most effective for new buildings in terms of both cost and installation, whereas damping devices are equally applicable in both existing as well as new buildings and are generally cheaper to install and less intrusive than isolation.

2. BUILDING PERFORMANCE IMPROVEMENT USING MODERN TECHNIQUES / ENERGY DISSIPATION USING ADDED DAMPERS

The dampers are most effective in flexible buildings with relatively longer fundamental periods due to the fact that the activation of devices is dependent on the inter-storey drift. However, the operational limitations and degree of intrusion in the existing structure also makes dampers a preferable method of performance improvement than isolation, even in less flexible buildings.

There are four main categories of damping devices, which are discussed below in brevity:

- Hysteretic Dampers: These are the deformation dependent dampers works on the principal of metal yielding. The energy dissipation is provided by the yielding of steel in general, which may be configured to yield in axial, bending or by using lead which yields in shear. They are generally provided as diagonal brace for axial yielding.
- Friction Dampers: This type of damper works on the principal of slip movement at an optimum load during seismic excitations before the yielding of any structural member occurs. The friction produced on the sliding surfaces due to slip allows the dissipation of the energy by means of friction rather than by the yielding of the device components or any of the structural members.
- Fluid Viscous Dampers: Viscous dampers mostly comprises of fluid dampers similar to the shock absorbers of an automobiles. They provide the resisting force which is directly proportional to the applied velocity. Once displaced the fluid in the piston compresses and dissipates energy as a function of fluid viscosity.
- Viscoelastic Dampers: The most common form of viscoelastic damper consist of sandwiching two layers of high damping polymer between a central plate and two side plates. These dampers have the elastic force component which is displacement dependent as well as the viscous force component which depends on the applied velocity.

3. BUILDING CHARACTERISTICS AND CURRENT SEISMIC HAZARD AT SITE

An existing reinforced concrete building is required to be retrofitted in order to improve its seismic performance as per the latest seismic code and specifications of Turkey. The structure consists of 24 stories with one basement and is in use since thirty-six years. The building is being used as the headquarter of a telecommunication company in Turkey making it a vital structure that should be operational after a major seismic event. Since the structure was designed and constructed using the outdated codes and specification, the better knowledge of the seismic hazard of the city of Istanbul and in the presence of latest seismic design and evaluation codes there was an urgent need for the assessment of building and to evaluate its seismic performance to comply with the current seismic hazard.

The structure has a considerably symmetrical plan layout composed of a concrete core wall connected in the middle with columns through cast in place beams and slabs. The plan dimensions of the building at a typical storey are 30x30 m. The typical storey height is 3.20 m and the total height of the structure is 64 m above ground. A typical plan of the building is shown in Figure 1.

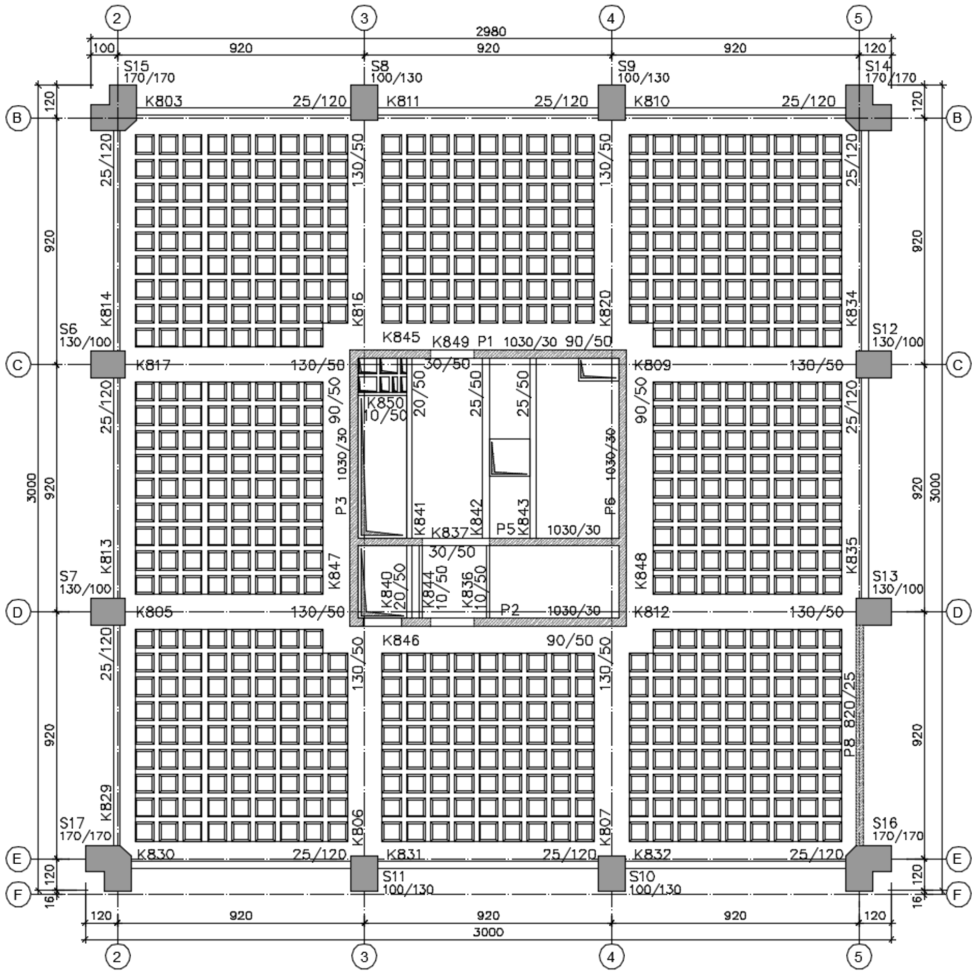


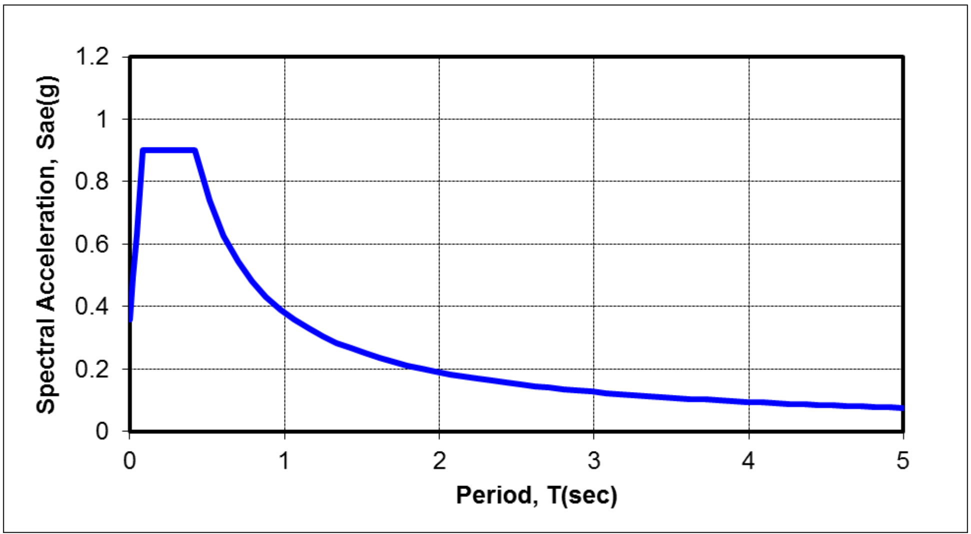
Figure 1: Typical plan layout of the structure

The mechanical properties of the structural materials are determined using tensile strength test for the reinforcement and core testing for concrete and are summarized in Table 1.

Table 1: Mechanical properties of materials

Concrete	Avg. compressive strength = 18 MPa
Reinforcement (deformed)	Yield strength = 275 MPa Ultimate strength = 325 MPa

Seismic hazard of the site was evaluated using the code based response spectrum for 475 year return period earthquake, as shown in Figure 2, in accordance with Istanbul Earthquake Code for High-rise Buildings, İYBDY (2008).



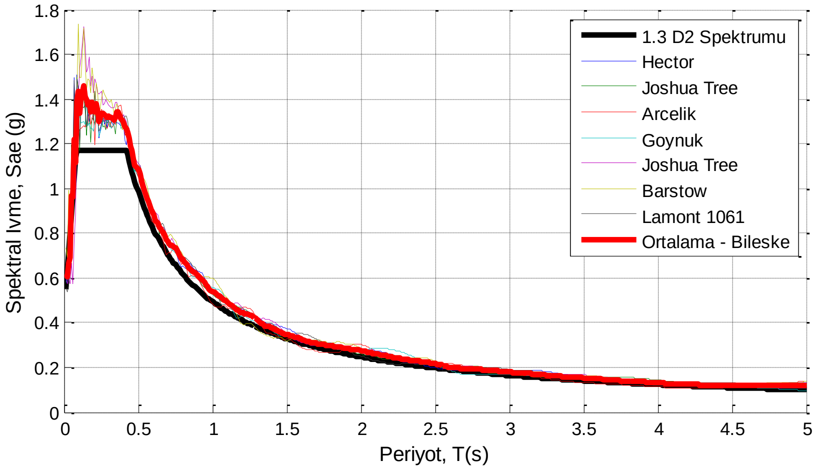
Design Earthquake	Return Period/Prob. of Exceedance	S_S=0.2 sec Spectral Acc. (g)	S_1=1.0 sec Spectral Acc. (g)
(PGA=0.36g)	475years-10% in 50 yrs.	0.90	0.38

Figure 2: Design response spectrum based on İYBDY (2008)

In order to carry out the Time-history analyses, ground motion selection and scaling was carried based on the target spectrum provided in Figure 2. The selected ground motions and their characteristics are given in Table 2 whereas Figure 3 shows the spectra of scaled ground motions and the target spectrum.

Table 2: Selected ground motions and their characteristics

Earthquake	Moment Magnitude	Fault Mechanism	Station	Epicentral Distance (km)	Shortest Distance (km)	Soil (NEHRP)
Hector Mine 16.10.1999	7.1	Strike slip	Hector	26.5	11.7	C
Hector Mine 16.10.1999	7.1	Strike slip	Joshua Tree	52.3	31.1	C
Kocaeli 17.8.1999	7.5	Strike slip	Arcelik	53.6	13.5	C
Kocaeli 17.8.1999	7.5	Strike slip	Goynuk	77.6	31.7	C
Landers 28.06.1992	7.3	Strike slip	Joshua Tree	13.7	11.03	C
Landers 28.06.1992	7.3	Strike slip	Barstow	94.8	34.9	C
Duzce 12.11.1999	7.1	Strike slip	Lamont 1061	31.6	11.5	C



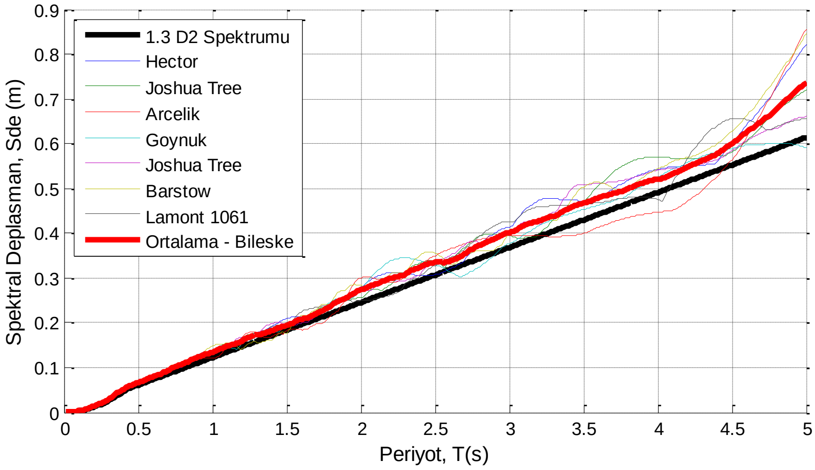


Figure 3: Acceleration and displacement spectrum for scaled ground motions

4. RETROFITTING USING IN-FRAME DAMPING DEVICES

The analytical model of the building was prepared using SAP2000 software. The preliminary demand/capacity analysis using linear elastic procedure indicates insufficient capacity of several columns, beams and core walls in various stories under the current seismic demand implying the necessity for retrofitting.

Several conventional retrofitting options were employed and evaluated in order to improve the performance of the building such as increasing the thickness of core walls, providing external shear walls in the middle bays of the building as well as increasing the column cross-sections. However, all approaches end up making the building more stiff thereby attracting more forces as generally observed in the case of conventional methods. An additional constraint to the use of conventional techniques is imposed by the building use which requires the building to remain fully operational during the entire retrofitting operation. The classical strengthening methods do not provide this leisure hence it was decided to use passive energy dissipation devices for retrofitting to minimize intrusion to the building.

Two types of energy dissipation device systems have been studied, namely, wall-type viscoelastic dampers and the Chevron-type steel hysteretic dampers. In order to minimize operational and architectural interference, the devices have to be located in the peripheral frames of the building to. The middle bays of the building were selected for the installation of the dampers that have service shafts at the mid-spans, as shown in Figure 4.

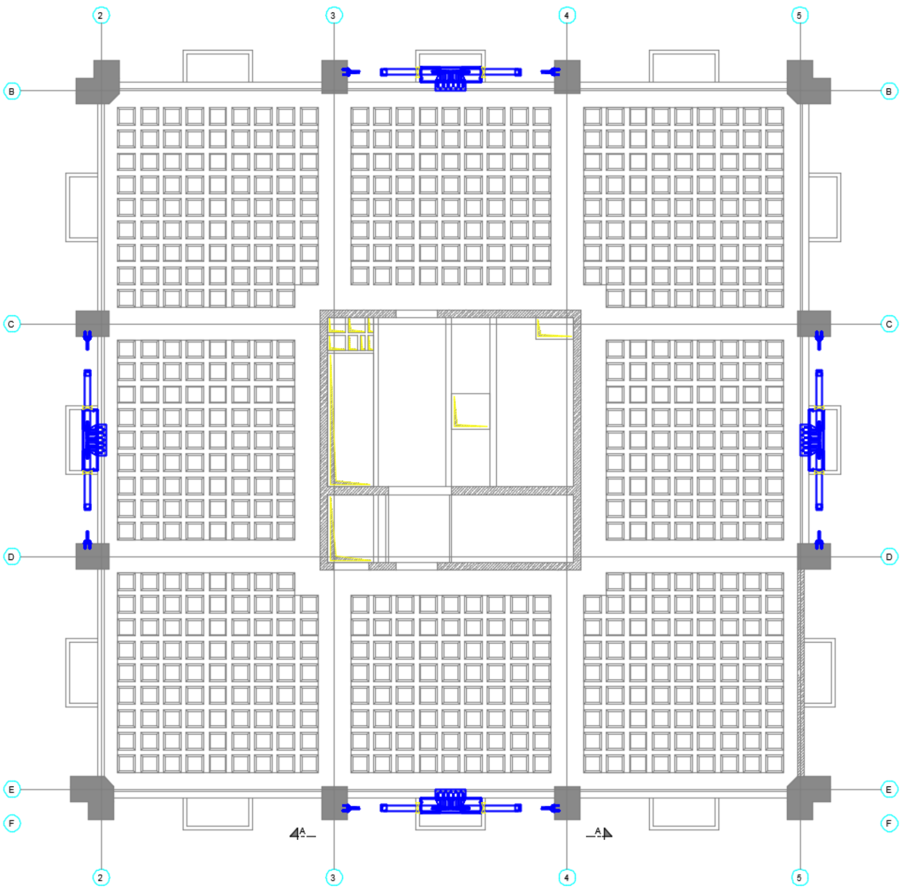


Figure 4: Location of damping devices at the middle peripheral frame

The mechanical and geometric properties of the viscoelastic dampers are given in Table 3 and Figure 5 respectively. The viscoelastic dampers are composed of two panels of high damping rubber sandwiched between the steel plates and connected to the concrete beams at the story level. A total of 240 viscoelastic damping devices were used with eight devices per floor and applied between 7th to 22nd storeys. This type of damper is efficient in terms of installation and aesthetics as the entire assembly remains inside the service shaft without the need of any demolition, as shown in the installation drawings in Figure 6.

Table 3: Properties of viscoelastic damper

Temperature	20	℃	K_{eq}	17.071812	kN/mm
Frequency	0.1	Hz	h_{eq}	0.348914	
Displacement	15	mm	C_{eq}	18.960426	kN/(mm/s)
Strain Ratio	1		1st Stiffness K_u	197.7984	kN/mm
			2nd Stiffness K_d	6.951007	kN/mm
			Yield Load Q_d	151.81207	kN

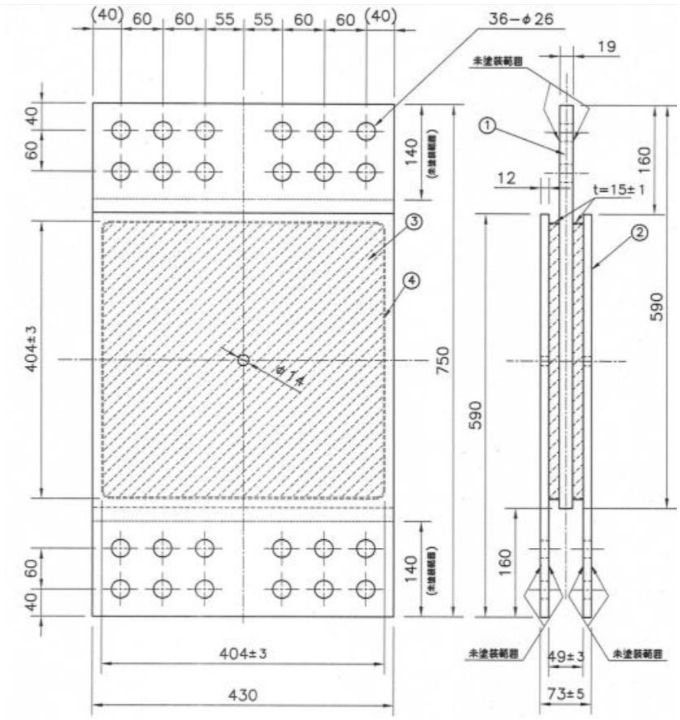


Figure 5: Geometrical properties of high damping viscoelastic damper

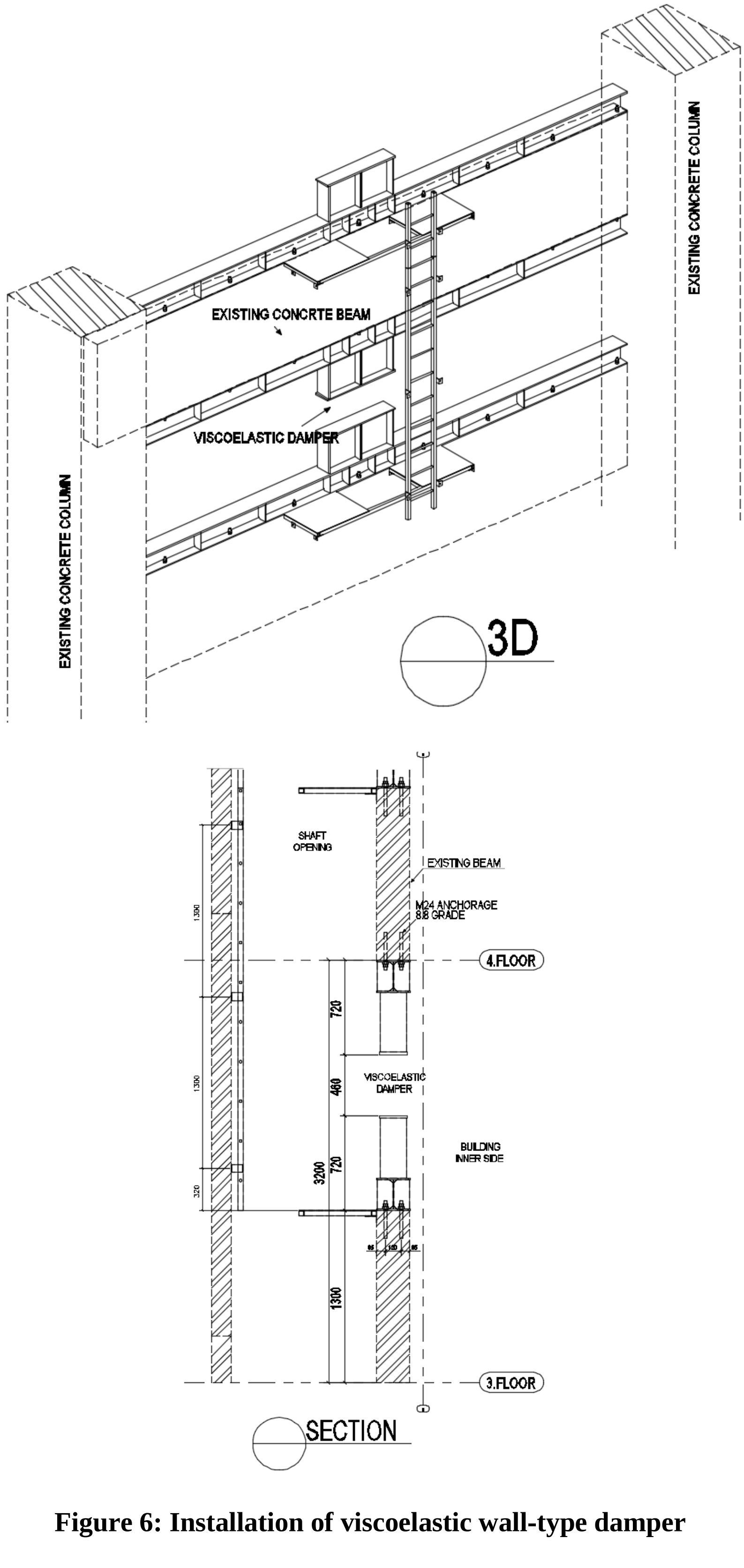


Figure 6: Installation of viscoelastic wall-type damper

As another alternative retrofitting method, chevron-type steel hysteretic dampers are used connected between the columns of the middle bay. The mechanical and geometrical properties of the steel hysteretic dampers are provided in Table 4 and Figure 7, respectively. These dampers are installed in-frame at the exterior of the building whereas connection with the beams is concealed within the concrete service shaft, as shown in Figure 8. Eight dampers were installed per storey with a total of one hundred twenty devices between 7th and 22nd floor.

Table 4: Properties of steel hysteretic BRAD dampers

BRB BRAD DAMPER TECHNICAL PROPERTIES:

F_1 (kN)	d_1 (mm)	K_1 (kN/mm)	F_2 (kN)	d_2 (mm)	K_2 (kN/mm)
479	1,56	307,1	519	15	2,98

STEEL STRUT MECHANICAL PROPERTIES:

Strut dia. (mm)	Thickness (mm)	Length (mm)	Stiffness (kN/mm)
203	10	2050	621.1

COMBINED PROPERTIES OF BRB DAMPER AND STEEL STRUTS:

$K_{1,eq}$ (kN/mm)	F_1 (kN)	$K_{2,eq}$ (kN/mm)	r	n
205,5	479	2,96	0,014	2

Where;
r: Post-yield stiffness ratio ($r = K_{2,eq}/K_{1,eq}$)
n: Yielding exponent

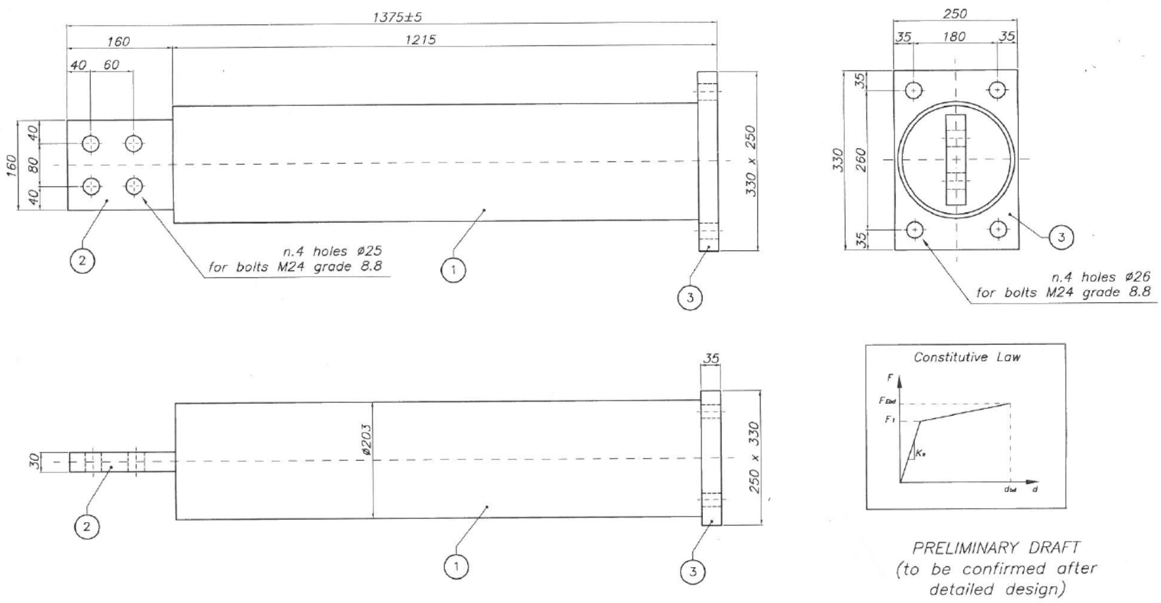


Figure 7: Geometrical properties of steel hysteretic BRAD type dampers

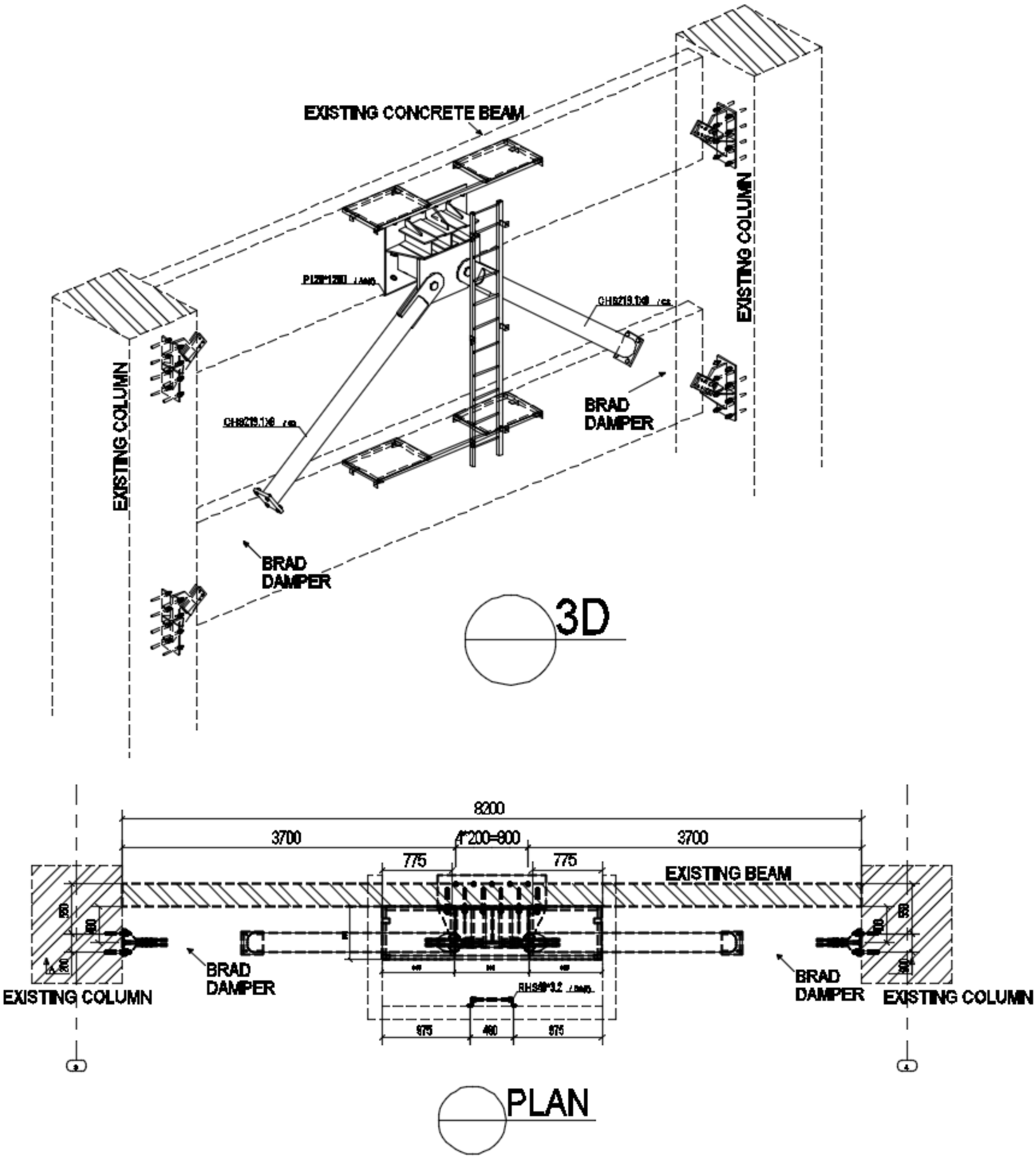


Figure 8: Installation of steel hysteretic BRAD damper

5. PERFORMANCE EVALUATION OF THE STRUCTURE

A series of nonlinear time history analyses were performed to evaluate the performance improvement provided by both damper types. The response parameters are compared with the response of the existing building without dampers. Figure 9 presents the average drift comparison calculated by the time history analyses for each the damper type against existing building. Both devices appear to be more effective in upper storeys due to increased displacements and velocities. None of the device appears to be prominent than the other in reducing the drifts. Figure 10 shows the reduction in drifts in each principal direction. The plots indicate reduction in drift in the range of 8 to 15%.

Typical intermediate beam forces are compared with and without dampers in Table 5. These results reveal that supports moments are reduced up to 22% and lies within the range of allowable capacity of the section.

The member forces for columns supporting the hysteretic dampers are compared with the existing and the PM interaction diagram is presented in Figure 11. The results indicate that moments are reduced to a significant level up to 50% whereas the axial forces of these members are increased due to the reactions transferred by the dampers.

The fundamental time period of the structure generally remains unaffected and the average reduction in storey drift remains in the range of 8-12%.

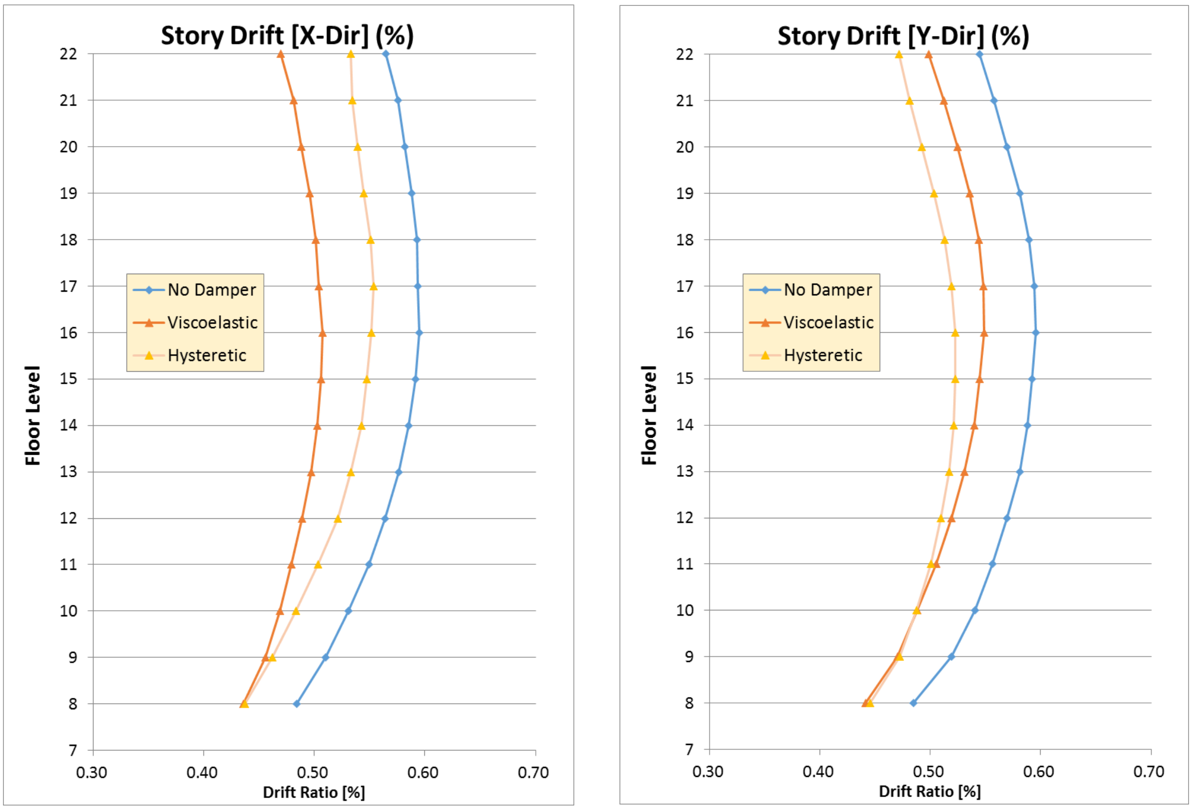


Figure 9: Comparison of storey drift (%)

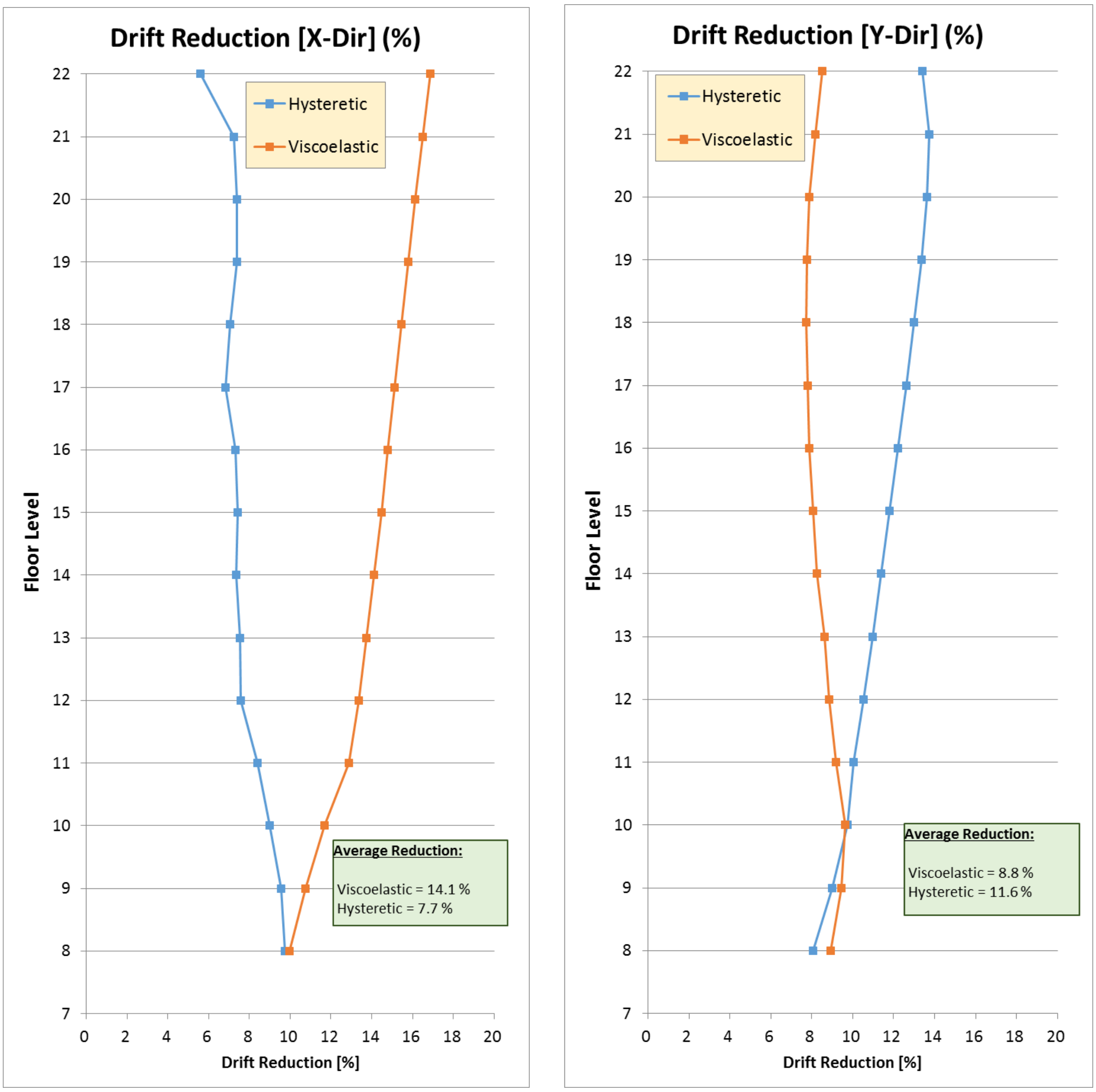
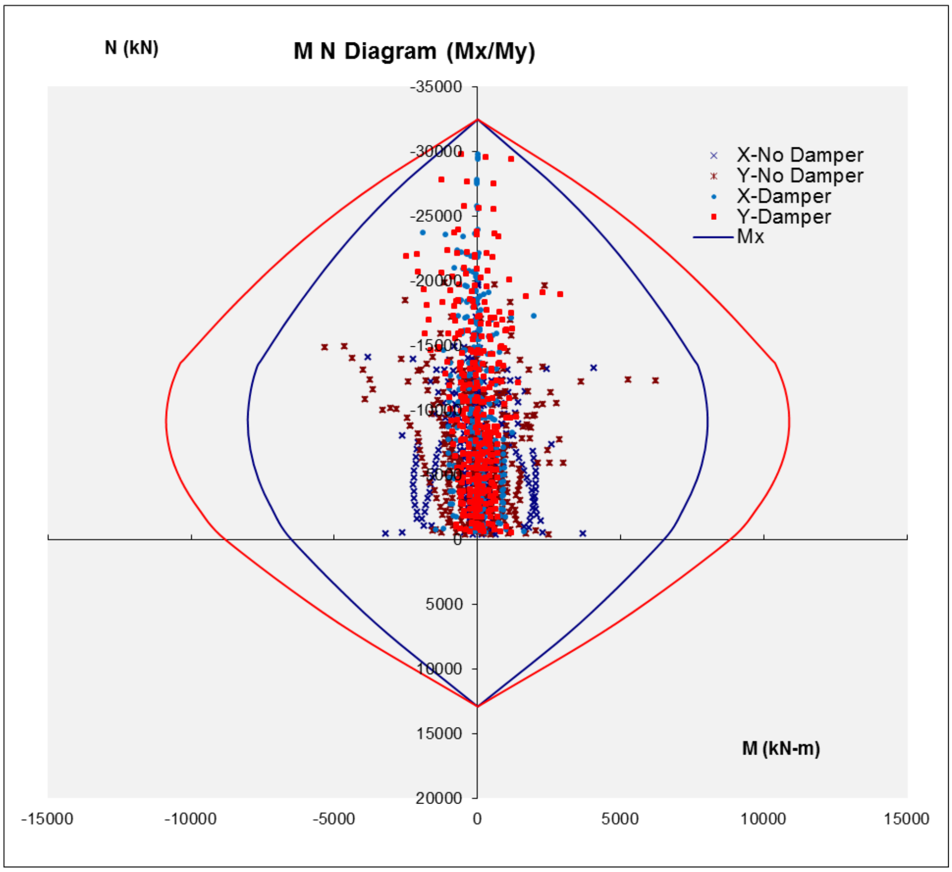


Figure 10: Comparison of storey drift reduction (%)

Table 5: Beam member forces (kN-m)

Beam size 250x1300 mm; Concrete = 18MPa/Reinforcement = 375 MPa

Location	Existing	With damper	Reinforcement ratio (%)	Capacity
Span	435	345	0.65	785
Support	1470	1150	1.05	1250



Column size 1200x1600 mm; Concrete = 18MPa/Reinforcement = 375 MPa

Figure 11: Interaction diagram of column connected with hysteretic damper

6. CONCLUSION

As it is well known, advantages of this type of energy dissipation devices directly proportional with the drift and velocity capabilities of the structural system under seismic action. Due to the restrictions imposed on construction methods that can be employed, conventional retrofitting using added shear walls is not permitted. Despite the fact that the building is sufficiently tall, existing core system considerably reduces the drifts.

As an alternative approach, it has been decided to use dampers to further reduce the drifts and velocities, but only about 10% overall reduction could be achieved.

This type of retrofit techniques can be more effective when applied to buildings that do not have sufficient shearwalls to restrict the drifts, but in this building, it was observed that they were still effective to reduce the demands on the critical members.

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