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INVESTIGATION OF THE EFFECTIVENESS OF EARTHQUAKE DISASTER MITIGATION FOR TECHNOLOGIES OF VIBRATION ISOLATION, ABSORPTION AND EARTHQUAKE-RESISTANCE

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Abstract

Since Zhang Heng invented the wind seismograph in 132 AD, humanity has gained the ability to measure ground vibrations and has sought to reduce earthquake disasters through technologies such as vibration isolation, absorption, and earthquake-resistance. Seismic design specifications for buildings have continuously been fortified to enhance ground vibration resistance after major earthquakes. However, despite these increased fortification levels, the death toll in subsequent major earthquakes has remained high. This paper presents research findings that suggest the following: (1) The effectiveness of earthquake disaster reduction in buildings hinges on whether engineers can transform non-seismic-resistant conditions into seismic-resistant ones. (2) The actual function of technologies for vibration isolation, absorption, and earthquake-resistance is merely to increase the ground vibration resistance of buildings that already meet earthquake-resistant conditions, and therefore does not contribute significantly to earthquake disaster mitigation. Based on these conclusions, the authors recommend that seismic-resistant and non-seismic-resistant conditions of buildings be explicitly included in seismic design specifications. This approach would ensure the correct implementation of seismic reinforcement designs and greatly enhance the effectiveness of earthquake disaster mitigation.

Keywords: shear band, vibration isolation, vibration absorption, vibration resistance.

Introduction

There are five types of earthquakes: tectonic earthquakes, volcanic earthquakes, subsidence earthquakes, earthquakes induced by reservoir water storage, and earthquakes induced by artificial explosions (China Earthquake Disaster Prevention Center, 2006; Coffey, 2019). Among these, tectonic earthquakes with a magnitude greater than 6.0 (M > 6.0) are the ones that can cause significant disasters (Hsu, 2022). The primary effect of tectonic earthquakes is shear banding, which accounts for more than 90% of the total earthquake energy. The secondary effect is ground vibration, which accounts for less than 10% of the total earthquake energy (Coffey, 2019).

Figure 1 illustrates various structural failures caused by significant earthquakes: Figure 1(a) shows the collapse of a temple during the 921 Jiji earthquake in 1999. Figure 1(b) depicts the fall failure of a high-rise building during the 0206 Meinong earthquake in 2016. Figure 1(c) illustrates the collapse of a large hotel building during the 0206 Hualien earthquake in 2018.

(a) Jiji Earthquake in 1999 (Nantou, Taiwan)

(b) Meinong Earthquake in 2016 (Tainan, Taiwan)

(c) Hualien Earthquake in 2018 (Hualien, Taiwan)

Figure 1. Cases of building fall failures induced by previous earthquakes in Taiwan (Hsu, et al., 2018).

The appraisal items include: (1) compression tests of concrete core specimens; (2) tensile tests of steel bar specimens and inspection of water-quenched steel bars; (3) inspection of the dimensions of beams and columns, including the cross-sectional area and number of steel bars; (4) inspection of the number and spacing of stirrups; (5) comparison of new geological boring data with original geological boring data; (6) inspection of the binding of beam and column steel bars; and (7) review of structural analyses and design drawings (Tainan Civil Technicians Association, 2016).

If a building collapses and results in fatalities during a tectonic earthquake, the court will file an appeal based on the above appraisal report. The appeal content includes: (1) insufficient number or excessively large spacing of steel bars (Chinese National Standards, 2018), eccentricity of beams and columns, improper increase of floor area, and underestimation of minimum total seismic lateral shear; (2) errors in structural analysis (National Regulations Database, 2020), errors in architectural drawings, inadequate work supervision, and construction shortcuts, among other issues (Taiwan High Court Tainan Branch Court, 2017).

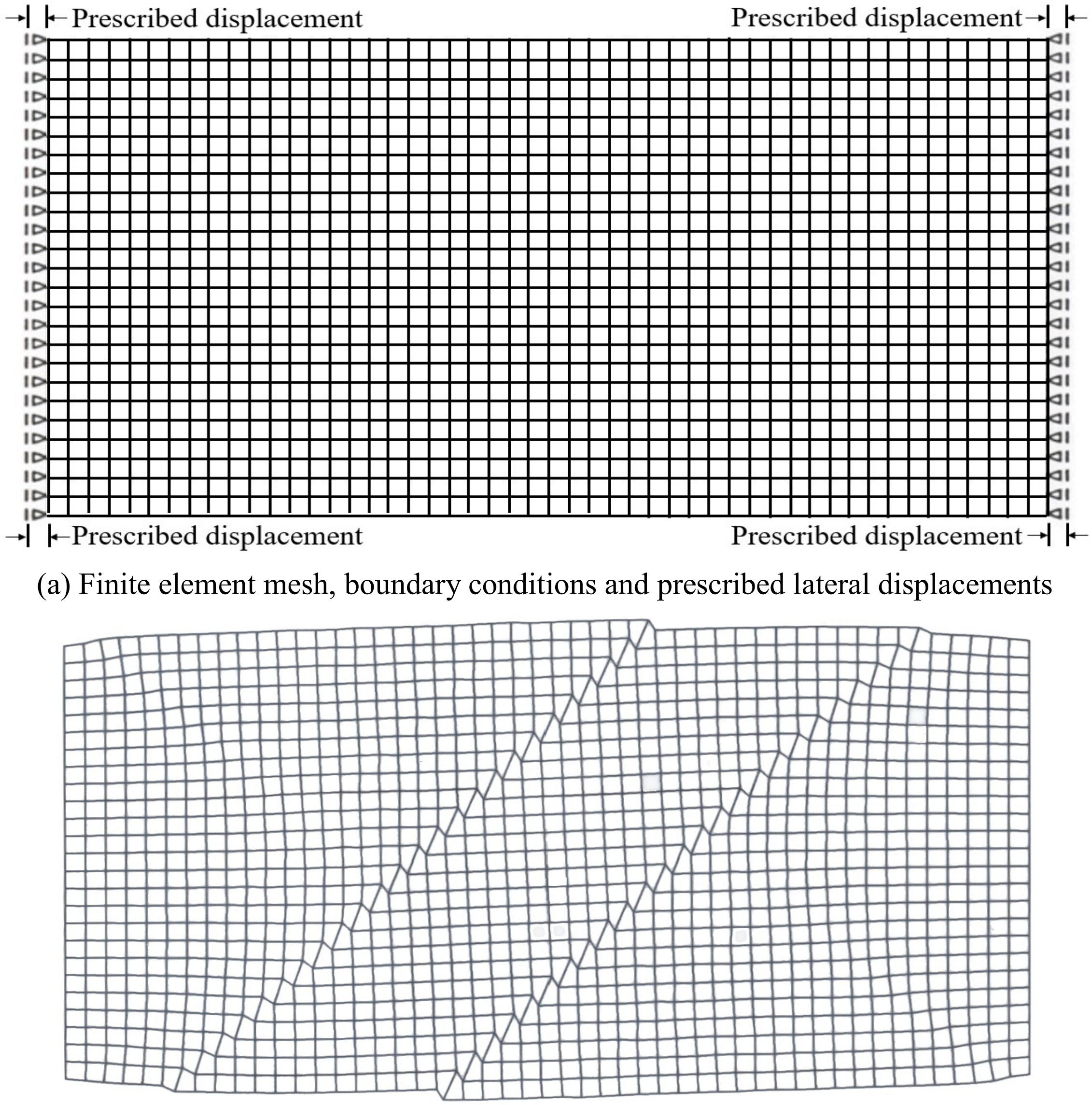
Since earthquakes with a magnitude greater than 6.0 are likely to occur in Taiwan every ten years, if the identification results of the above-mentioned causes of building failures were accurate, then the buildings shown in Figure 1 would fail within ten years of completion. Additionally, if there were buildings similar to those shown in Figure 1 in the same area, these buildings should also experience failure during the same tectonic earthquake. However, this is not the case. Therefore, it is crucial to explore the effectiveness of technologies for vibration isolation, absorption, and earthquake-resistance in earthquake disaster mitigation.

Shear Banding Effect of Tectonic Earthquakes

Figure 2 shows the Chelongpu fault excavated in Zhushan after the 921 Earthquake, where the academic term for commonly known faults is shear bands. As seen in Figure 3, shear banding induces the uplift-tilting effect.

Figure 2. Shear bands appearing in Zhushan of Taiwan during the 921 Jiji Earthquake (Hsu, 2018).

Figure 3(a) shows the structural analysis model of a symmetric and stable plate subjected to prescribed symmetric lateral displacements. When the strain reaches the plastic range, the plate loses stability and symmetry due to strain softening, resulting in the formation of shear bands, as shown in Figure 3(b), due to localizations of deformations.



(a) Finite element mesh, boundary conditions and prescribed lateral displacements

(b) Deformed finite element mesh

Figure 3. Finite element analysis results for a plate under lateral compression (Hsu, 2018).

As seen in Figure 3(b): (1) the numerical solution of shear bands is obtained under unstable conditions; (2) traditional structural scholars believe that unstable structures under the action of external forces have no solution; (3) when the shear band solution is obtained, the solution for highly concentrated excess pore water pressure in the groundwater within the shear bands, as shown in Figure 4, can also be determined. During shear banding, the plate will exhibit stick-slip phenomena due to frictional resistance (see Figure 5(a)), leading to deceleration-acceleration phenomena (see Figure 5(b)). This is the origin of the time history curve of ground vibration acceleration in tectonic earthquakes, as shown in Figure 6 (Hsu, 2018).

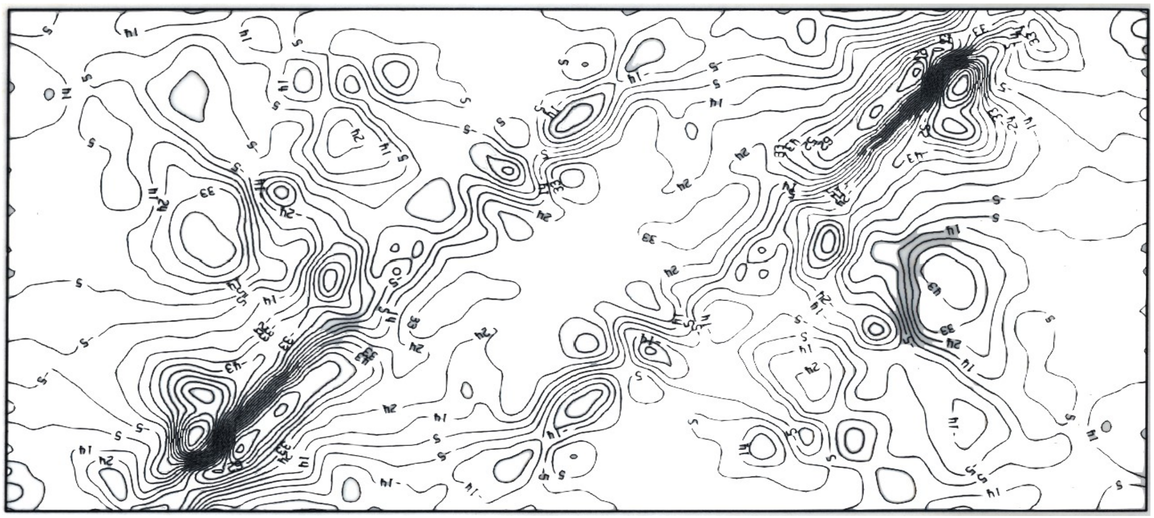


Figure 4. Contours of excess pore water pressures (Hsu, 2018).

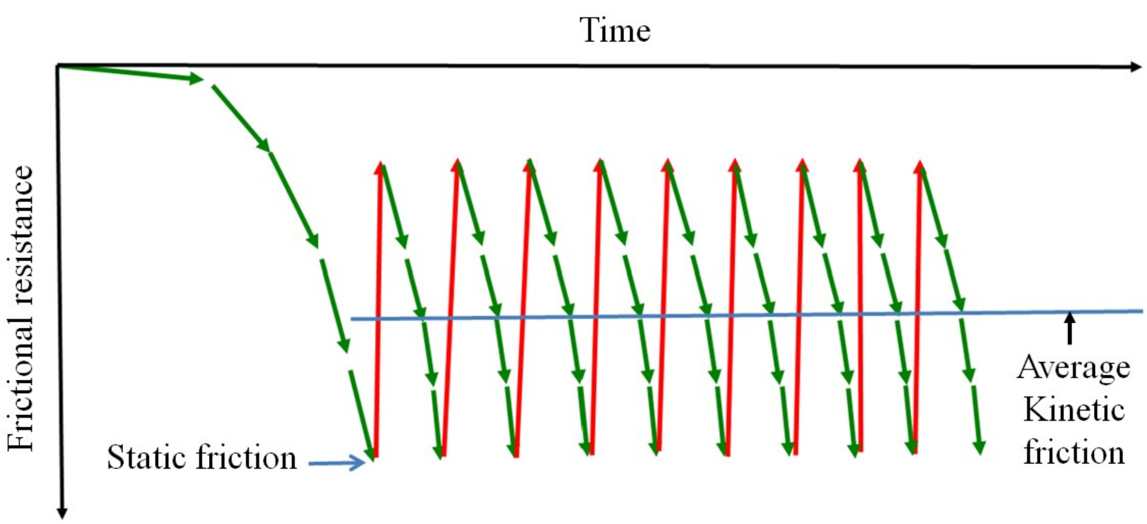


Figure 5. Stick-slip phenomenon in shear bandings
(redrawn from Lambe and Whitmam, 1969).

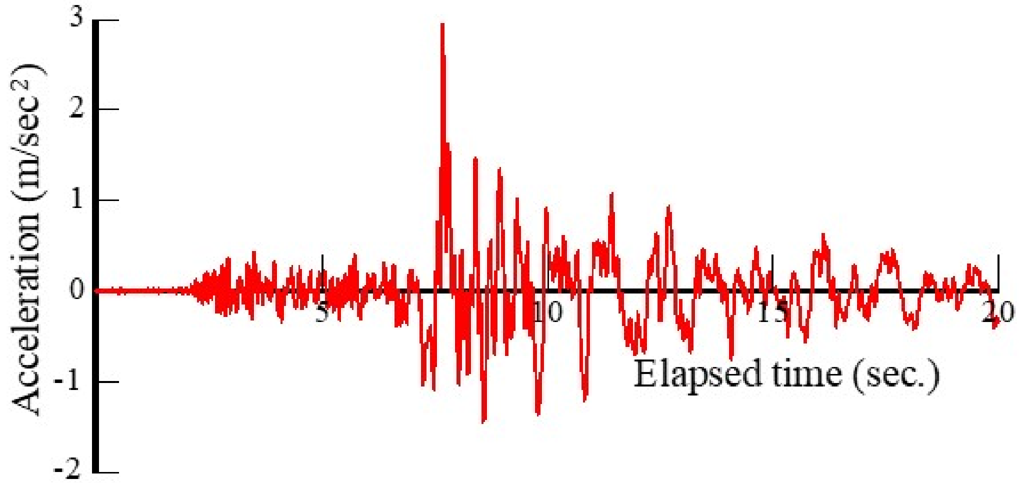


Figure 6. Ground vibration acceleration time-history curve of the seismometer record (Hsu, 2018).

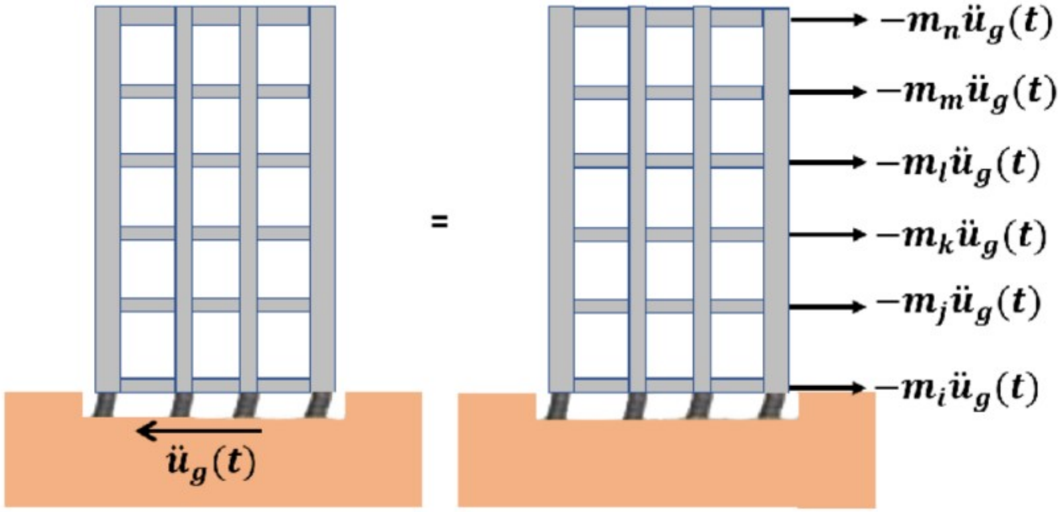
Seismic-Resistant and Non-Seismic-Resistant Conditions of Buildings

Before the definition of seismic-resistant and non-seismic-resistant conditions for buildings, structures were considered seismic-resistant only if they met the ground vibration resistance specified in the latest seismic design codes. As a result, all old and low-rise buildings in Taiwan have been identified as non-seismic-resistant and dangerous. Conversely, new high-rise buildings are identified as seismic-resistant and safe. However, Figure 1(b) shows that the building that collapsed during the 0206 Meinong Earthquake in 2016 was mistakenly identified as seismic-resistant and safe, rather than non-seismic-resistant and dangerous.

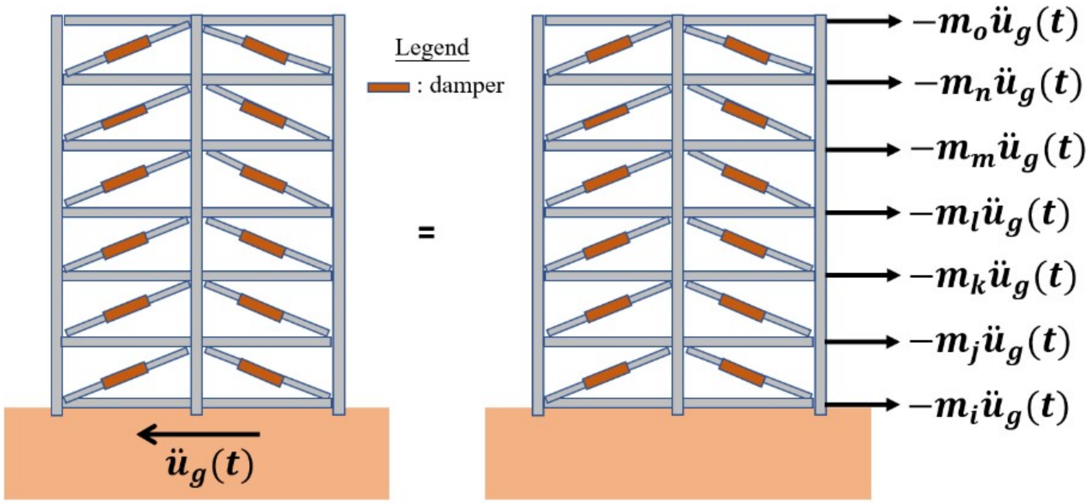
To prevent such erroneous identifications from happening again, Hsu (2022) defined seismic-resistant conditions as those in which buildings will not fail during tectonic earthquakes if the ground on which the building is located does not suffer from the shear banding effect. Conversely, non-seismic-resistant conditions are defined as those in which buildings will fail during tectonic earthquakes if the ground on which the building is located does suffer from the shear banding effect.

The Effectiveness of Technologies for Vibration Isolation, Absorption, and Earthquake-Resistance in Earthquake Disaster Mitigation

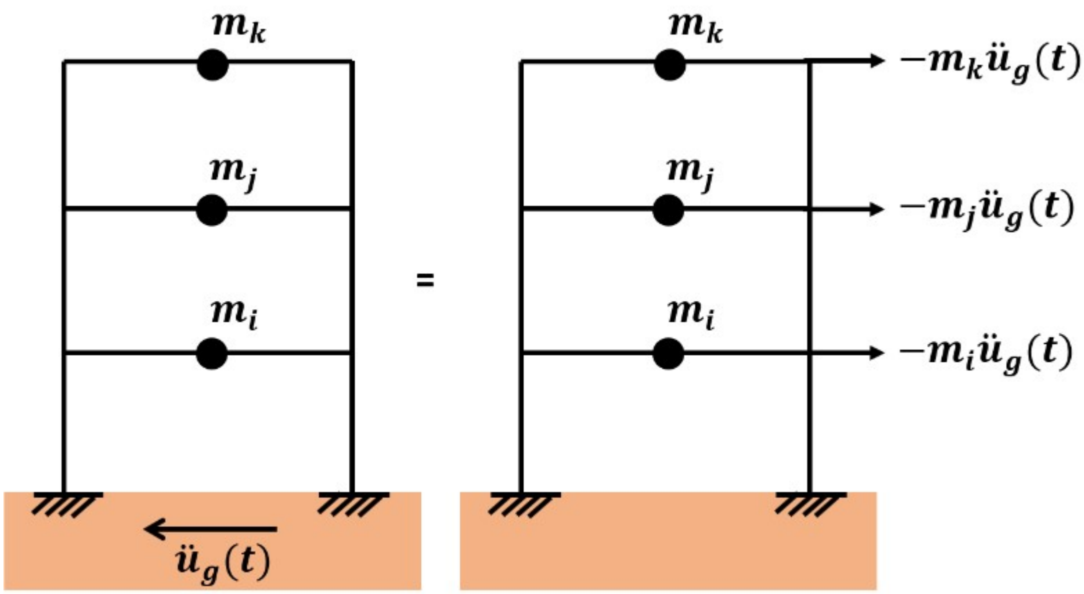
Figures 7(a) to 7(c) respectively show the structural analysis models of vibration isolation, absorption, and earthquake-resistance for buildings that meet seismic-resistant conditions under the effect of horizontal ground vibrations acceleration caused by tectonic earthquakes.



(a) Structural analysis model of vibration-isolated buildings



(b) Structural analysis model of vibration absorption buildings



(c) Structural analysis model of vibration-resistant buildings

Figure 7. The structural analysis models of vibration isolation, absorption and earthquake-resistance of buildings that meet the seismic-resistant conditions.

Currently, scholars and experts in earthquake disaster mitigation believe that using isolation pads, dampers, and vibration-resistant structural elements can increase the effectiveness of earthquake disaster mitigation. Therefore, the seismic design code for buildings permits the use of vibration isolation pads, dampers, and seismic structural elements, as shown in Figures 7(a) to 7(c). However, before buildings adopt these technologies of vibration isolation, absorption, and earthquake-resistance, they already meet seismic-resistant conditions due to the absence of shear banding effects on the building's site. Consequently, these buildings will not fail during tectonic earthquakes.

Since effective earthquake disaster mitigation involves changing non-seismic-resistant conditions into seismic-resistant ones, the actual function of the aforementioned technologies of vibration isolation, absorption, and earthquake-resistance is merely to increase the ground vibration resistance of buildings that are already seismic-resistant. Therefore, these technologies do not significantly improve the effectiveness of earthquake disaster mitigation in buildings.

Conclusions and Recommendations

Since the invention of the seismograph, public awareness of earthquakes has primarily focused on the vibration effects of tectonic earthquakes. Consequently, building design specifications have predominantly aimed to fortify structures against ground vibrations. Scholars and experts have thus developed various technologies for vibration isolation, absorption, and earthquake-resistance. However, despite these advancements, the number of earthquake victims remains high. In this context, the authors of this paper explore the actual disaster mitigation effectiveness of current technologies of building vibration isolation, absorption, and earthquake-resistance, considering the seismic-resistant and non-seismic-resistant conditions of buildings. Based on the research results, the following conclusions are drawn:

1. There are five types of earthquakes. Among these, tectonic earthquakes with a magnitude greater than 6.0 are the ones capable of causing significant disasters. The primary disaster-causing effect of such tectonic earthquakes is the shear banding effect, with ground vibration being a secondary effect. Therefore, the current seismic design specifications, which primarily fortify against secondary ground vibration effects, are not highly effective in mitigating earthquake disasters.

2. Buildings that already meet seismic-resistant conditions before adopting technologies of vibration isolation, absorption, and earthquake-resistance will not fail during tectonic earthquakes. In such cases, these technologies do not significantly contribute to earthquake disaster mitigation.

Based on these conclusions, the authors propose the following recommendations:

1. Seismic design specifications should be revised to address the primary disaster-causing effect of tectonic earthquakes, which is the shear banding effect. By focusing on this primary effect, the effectiveness of earthquake disaster mitigation can be substantially improved.

2. Given that buildings meeting seismic-resistant conditions do not fail in tectonic earthquakes, the role of technologies of vibration isolation, absorption, and earthquake-resistance should be reevaluated. Resources and efforts may be better allocated towards enhancing the overall structural resilience of buildings to withstand the shear banding effect.

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