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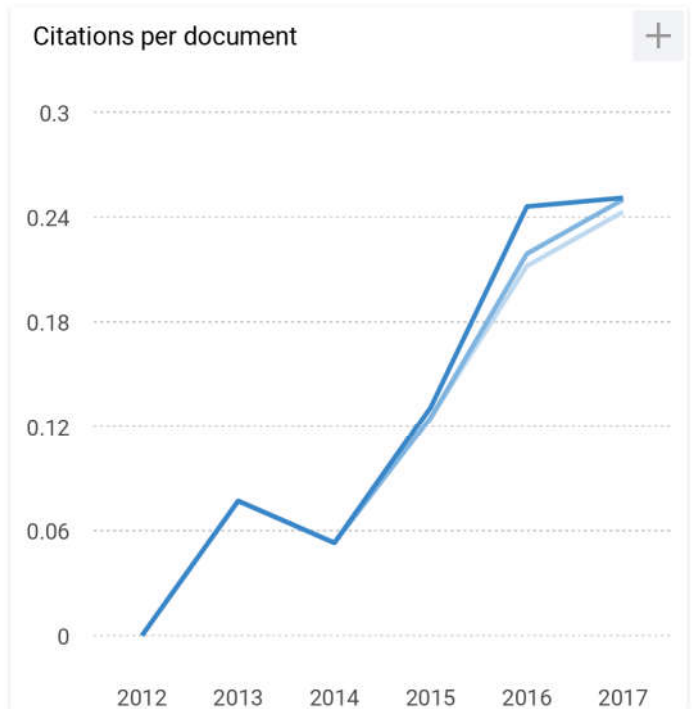
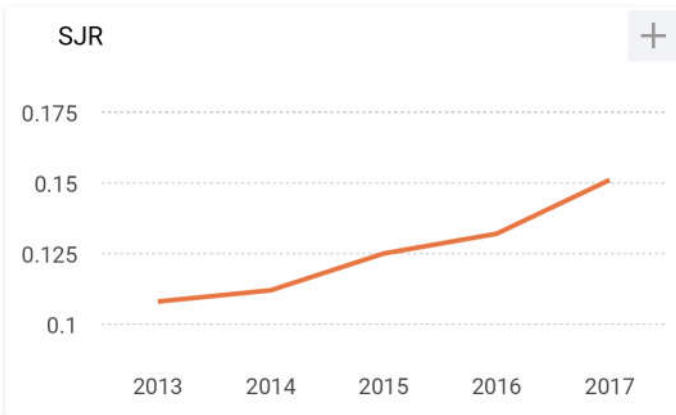
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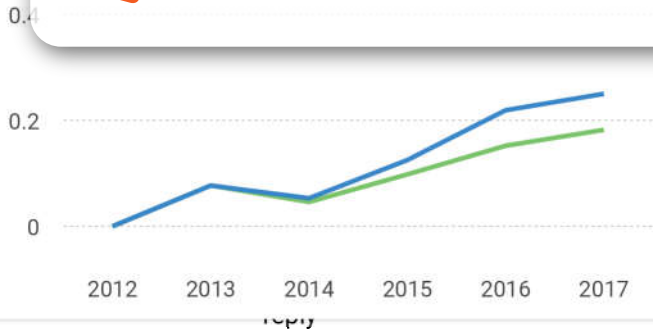
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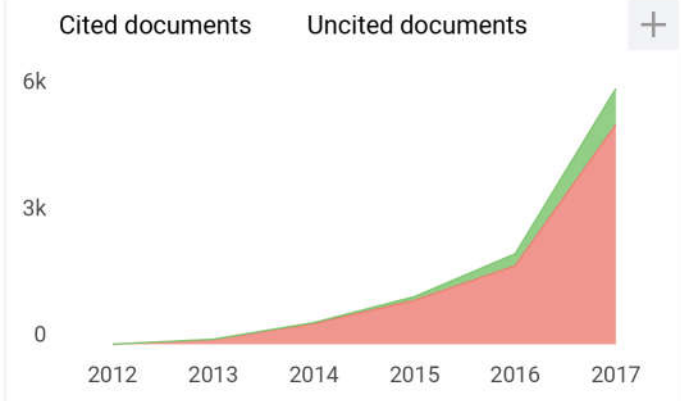
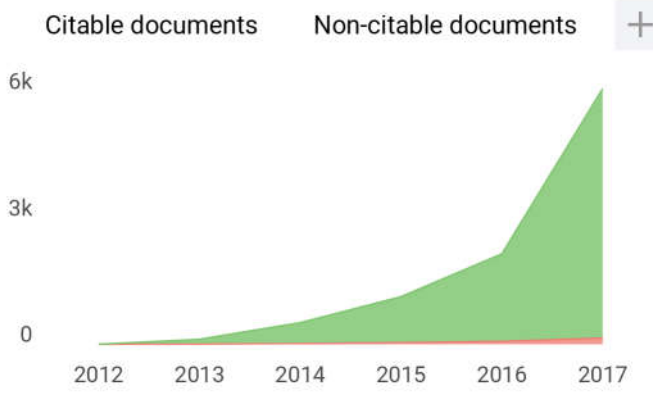


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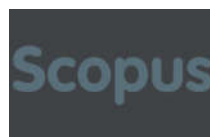
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4th International Conference on Rehabilitation and Maintenance in Civil Engineering (ICRMCE)

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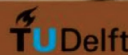
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Preface



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As a system that connects the shore and supports the growth of communities, infrastructure builds roads, bridges, ports, power plants, water supply, underground spaces, is vital and essential for the development of human society. It supports manufacture of products, creates jobs, facilitates mobility of goods and people, helps distribution of water and energy, keeps people healthy, and protects communities from natural and man-made hazards. Infrastructure drives economic growth in many countries and enables society to thrive and have better living condition. People recognise the importance of infrastructure when they discover that it fails to serve their needs

In developing countries there is an obvious demand to build more infrastructures to boost the economy, distribute income, and move forward the progress of these countries. Despite the careful planning, design, and construction many infrastructures exhibit unsatisfactory performance and deteriorates in its operational phase of service life. In developed countries, many infrastructures have achieved its end of service life and shows ageing phenomena with declining function and performances.

In the era where our planet is now under severe ecological stress, depletion of natural resources, and threat of adverse climate change, it's not just a matter of building more. We must maintain our infrastructure stocks to its adequate level of performances in order to sustain our earth life support capabilities and capacities. Building or maintaining, infrastructure needs to sustainable.

The 4th International Conference on Rehabilitation and Maintenance in Civil Engineering raise this issue by taking theme of "Smart Rehabilitation and Maintenance in Civil Engineering for Sustainable Construction". Public works professionals, engineers, planners, policy makers, researchers, academicians, and students gather together to discuss and share ideas on the issues of rehabilitation, repairs, maintenance, and its wide aspect within the field of civil engineering. In meeting highly technical specifications, tackling challenging problem, and addressing community needs, the conference provides a forum for broad spectrum of relevant topics.

The keynote papers address innovative technology in construction system that to make buildings resilient and sustainable, the use of artificial intelligence for managing and maintaining large scale, complex and interconnected asset, ingenious rehabilitation techniques and waterproofing, and perspectives of maintenance at urban scale.

All peer reviewed papers published in the proceedings discuss various topics from detailed engineering rehabilitation techniques and numerical modelling of service life prediction, to the higher abstraction such as maintenance strategies and policies. The papers examines multiscale level of infrastructure from material levels to the structural levels to the networks of infrastructure at urban level. The papers address testing and inspection procedure to the use of new innovative material and techniques for Restoration, preservation, rehabilitation and maintenance. The paper covers wide areas of rehabilitation and maintenance in the field of Civil Engineering; material, structure, soil mechanics, transportation, water resources, and construction management

The proceedings of the 4th International Conference on Rehabilitation and Maintenance in Civil Engineering (ICRMCE) provides wealth of information and ideas for the professionals in civil engineering in supporting their day-to-day works of rehabilitation and maintenance of infrastructure.

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Improving resilience of moment frames using steel pipe dampers

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Abstract. Earthquake resiliency of moment resisting frames, either new or existing ones, are important for maintaining community functionality. Improving earthquake resiliency needs a strong initiative in reducing earthquake risk. Steel pipe dampers can be used to increase earthquake resiliency. Steel pipe dampers, when installed at strategic locations in the moment frame structures, dissipate most of the earthquake energy in structures through inelastic deformation so that other components of the structure are protected. Steel pipe dampers control vibration in moment frame structures and are a disposable component in structures so that the damaged dampers can be replaced easily. Steel pipe dampers are cheap and require low workmanship, therefore the recovery time after disasters is short and the cost of recovery is low. Utilizing steel pipe dampers in passive energy dissipation systems help maintain community functionality during and after disasters. Lateral displacements were quantified and used as performance indicators. Significant drift and inter story drift reduction were achieved during a numerical study. All structural components, except the steel pipe dampers, remain elastic, indicating the effectiveness of the dampers in reducing the losses due to earthquakes.

1 Introduction

Earthquake resiliency of moment resisting frames, either new or existing ones, are important for maintaining their functionality. Hazards (corrosion induced damage, for example) pose continuing and significant threats to structures by reducing their capability to withstand the effect of seismic events and to recover the original functionality of the structures efficiently. Simulation to the probability of failure is necessary to evaluate components that play a dominant role in building failure [1]. Vertical steel pipe dampers are capable to dissipate most of the earthquake energy in structures through inelastic deformation so that other deteriorated components of the structure are protected. Therefore, vertical steel pipe dampers, when installed at strategic locations in the moment frame structures, can be used to improve earthquake resiliency of moment resisting frames.

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2 Vertical steel pipe dampers

Figure 1 shows the strategy and the details of a newly developed vertical steel pipe damper. The vertical steel pipe dampers are high performance dampers capable of dissipating earthquake energy due to their high stiffness, high yield strength and large ductility as shown in Figure 2.

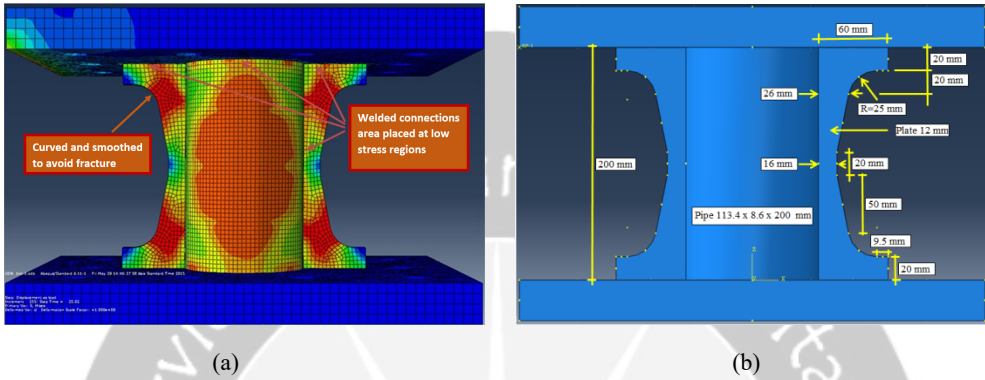


Fig 1. Vertical steel pipe damper: (a) The strategy to avoid early fracture and failure in welded connections and (b) Dimensions of the damper.

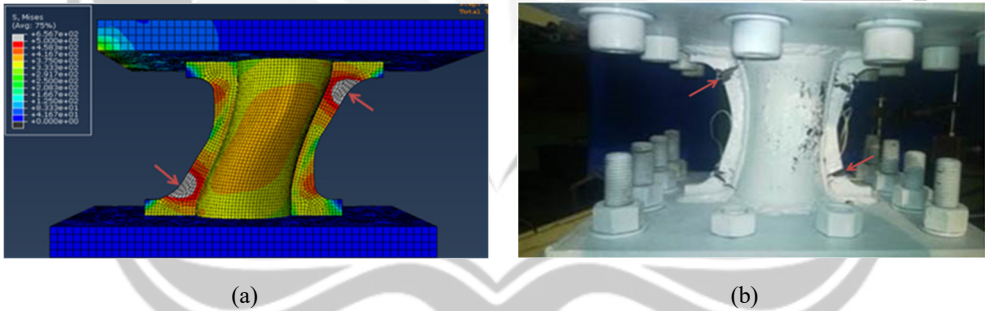


Fig 2. Vertical steel pipe damper: (a) Numerical simulation and (b) Tested specimen.

The Steel pipe dampers are disposable components in structures, hence damaged dampers can be replaced easily. Steel pipe dampers are cheap and require low workmanship, therefore the recovery time after disasters is short and the cost of recovery is low.

3 Passive energy dissipation systems

Passive energy dissipation systems are effective for vibration control of moment frames. Vertical steel pipe dampers provide supplemental damping that can be incorporated in both new construction and seismic retrofit applications to produce much larger equivalent damping (~30%). Passive energy dissipation systems inherently require a performance based-design approach. A new strategy based on the concept of passive structural control provide structural designers with powerful tools for performance-based design. Dynamic inelastic analysis by modeling the building as a bare frame building, neglecting possible contributions from non-structural components, was done using PERFORM-3D software [2].

3.1 Dampers configuration and earthquake loadings

A four-story steel moment resisting frame shown in Figure 3 was used to study the application of the vertical steel pipe damper. A number of end releases were applied so that the lateral load resisting systems in the building are the peripheral frames. One-way slab systems were applied to all floors. The secondary beams are not shown in Figure 3.

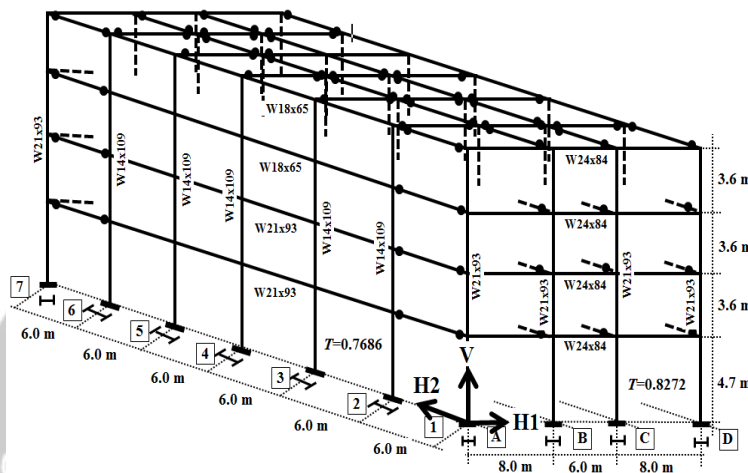


Fig. 3. Four-story steel moment resisting frame (the dampers are not shown).

The superimposed specified loads are as follows:

Gravity loading:

- Live load: Roof LL = 1.0 KPa, Floor LL = 2.4 KPa
- Dead load: Floor weight plus topping = 3.6 KPa, Partitions = 1 KPa

Materials:

- Concrete: 24.0 MPa
- Reinforcing steel: ASTM A572 steel, grade 50 $f_y = 345$ MPa

Elements dimension:

- Exterior columns: W21x93 (along H1), and W14x109 (along H2)
- Interior columns: W12x72 (along H2)
- Exterior beams: W24x84 (along H1), W21x93 and W18x95 (along H2)
- Interior beams: W24x84 (along H1), W21x93 and W18x95 (along H2)

Fundamental periods:

- $T = 0.8272$ seconds (along H1)
- $T = 0.7689$ seconds (along H2)

The configuration of the dampers in the peripheral frames along H1 and H2 are shown in Figure 4. The required number of dampers in each story had been estimated using the energy-based method proposed by Benavent-Climent [3]. The required lateral stiffness and lateral strength of the damper for near-fault ground motion were determined from input energy spectra for moderate-seismicity regions proposed by Benavent-Climent et al. [4]. Auxiliary structures in the form of triangular bracings are needed to install dampers between two points where large relative motion exists during earthquakes. Auxiliary structures shown in Figure 4 were chosen to minimize the influence of axial forces to the dampers. When the dampers yield, they lose their stiffness. The presence of the axial forces when the dampers dissipate energy reduce the effectiveness of the dampers as shown in Figure 5.

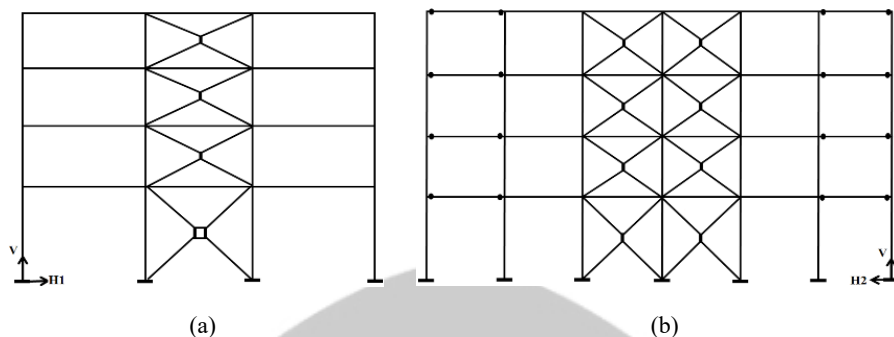


Fig. 4. Configuration of the dampers in peripheral frames: (a) Two peripheral frames along H1, and (b) Two peripheral frames along H2.

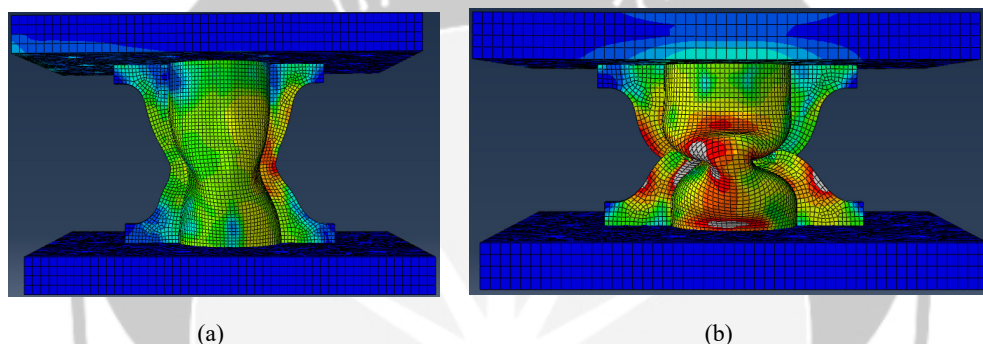


Fig. 5. Influence of axial forces when dampers dissipate energy: (a) Small axial force and (b) Large axial force.

Four earthquakes with different characteristics were chosen for numerical simulation. The steel dampers installed in the moment resisting frames (see Figure 4) are part of the passive energy dissipation system. The chosen earthquake accelerograms were the N-S component of El-Centro 1940, Fukushima Hamadori 2011 (ABSH13 station), Padang 2009 and Chi Chi 1999 (CHY028 station). Peak Ground Acceleration (PGA) of El-Centro 1940 is the lowest. The PGA of the other three accelerograms were scaled down to the PGA of El-Centro 1940 (0.3129 g).

3.2 Results of the simulation study

The analytical model of the four-story steel moment resisting frame shown in Figure 4 was developed using the PERFORM-3D software. Test result data of the vertical steel pipe damper were used to model shear vs. lateral displacement of the damper. The seismic isolator component in PERFORM-3D was used to model the damper as shown in Figure 6. Nonlinear dynamic analysis was done for moment resisting frames without and with dampers. The inter-story drifts for moment resisting frames without and with dampers are shown in Figure 7. Comparing Figure 7a and Figure 7b it can be seen that the inter-story drifts were reduced significantly due to the presence of dampers in the moment resisting frame. The dissipated strain energy of each component of the moment resisting frame with dampers is shown in Table 1. Only the vertical steel pipe dampers dissipate energy. All other components except the dampers remain elastic. The presence of the dampers installed at strategic locations in the four-story steel moment frame were able to protect the structure against strong earthquakes.

Extensive yielding in dampers is the energy dissipation mechanism. By dissipating inelastic energy, the dampers control the vibration of the structure during strong earthquakes.

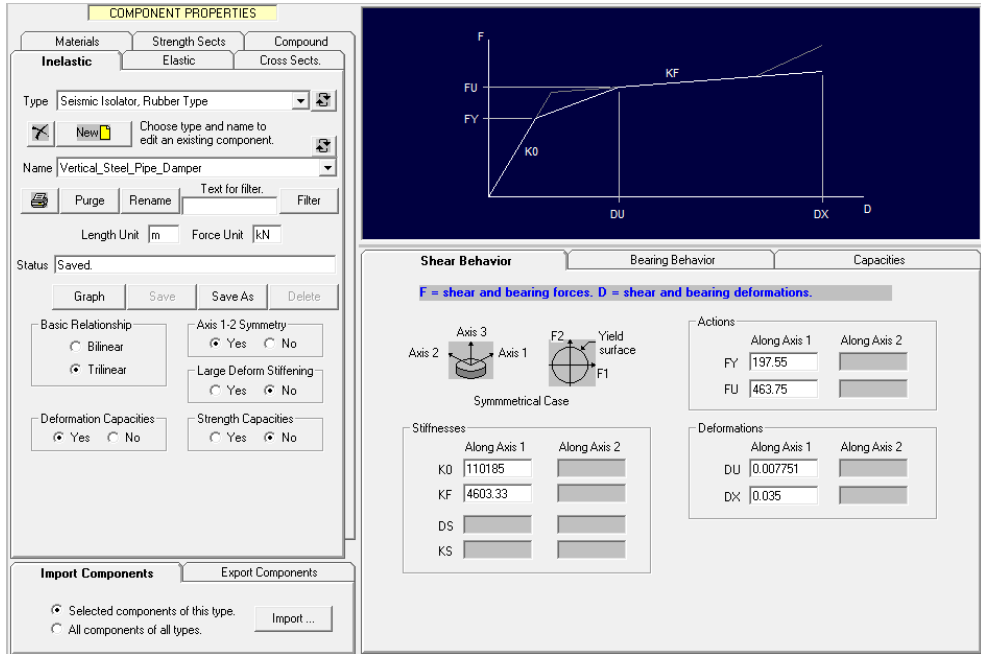


Fig. 6. Trilinear model of the force vs. displacement of the vertical pipe damper.

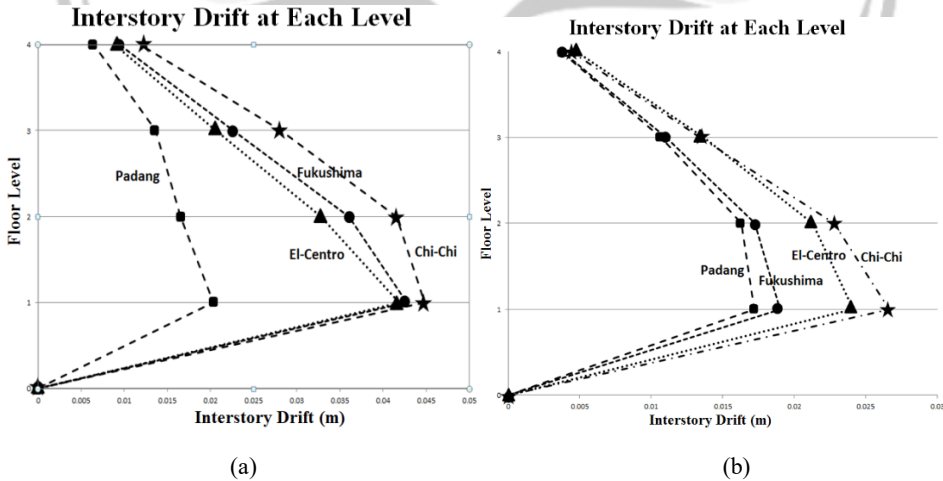


Fig. 7. Inter-story drift due to four earthquakes: (a) Frame without dampers and (b) Frame with dampers.

Table 1. Dissipated inelastic energy in kN.m at each component of the peripheral frames along H1.

Group name	Earthquake			
	El-Centro - 1940	Fukushima – 2011	Padang - 2009	Chi-Chi - 1999
Perimeter Columns	0	0	0	0
Perimeter Beams	0	0	0	0
Interior Columns	0	0	0	0
Interior Beams	0	0	0	0
Connection Panel Zones - along H1	0	0	0	0
Connection Panel Zones - along H2	0	0	0	0
Vertical Steel Pipe Dampers	261.49	422.4	202.35	233.29
Bracing HSS-H1-1st floor	0	0	0	0
Bracing HSS-H2-1st floor	0	0	0	0
Bracing HSS-H2-other floors	0	0	0	0
Bracing HSS-H1 other floors	0	0	0	0
Total for All Groups	261.49	422.4	202.35	233.29

Figure 8 shows four of the time histories of energy dissipation due to the Chi-Chi 1999, Padang 2009, El-Centro 1940 and Fukushima 2011 earthquakes. The strain and kinetic energies due to the four earthquakes diminish quickly when the dampers start yielding. Therefore, the strain and kinetic energy are not shown in Figure 8. Four graphs showing inelastic energy to input energy ratio (Eh/Eir) time histories of the four earthquakes above indicate that the inelastic energy dissipation is stable for each earthquake. The inelastic energy to maximum inelastic energy ratio (Eh/Eh_m) of the Chi-Chi and Padang earthquakes indicate that the maximum dissipated inelastic energy for both earthquakes was reached quickly.

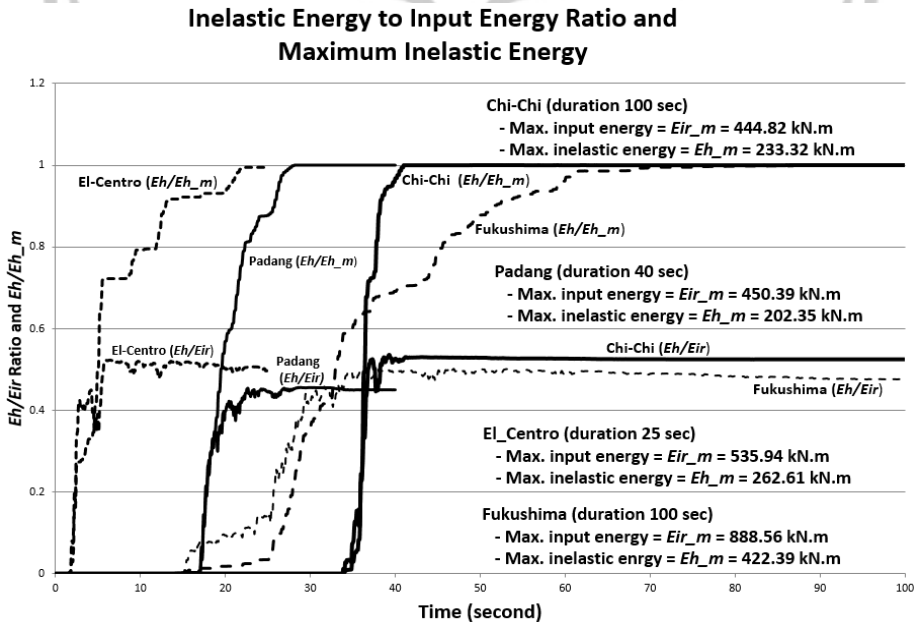


Fig 8. Time histories of energy dissipation due to Chi-Chi 1999, Padang 2009, El-Centro 1940 and Fukushima 2011 earthquakes.

4 Improving physical resilience of moment resisting frames

Time invariant capacity design criteria that do not account for environmental hazards is currently used for seismic design of moment frames. As shown in Figure 9, hazards (corrosion induced damage and earthquakes) pose continuing and significant threats to structures by reducing the capability to withstand the effect of seismic events and to recover to the original functionality of the structures efficiently. In Figure 9, moderate, strong and very strong earthquakes were assumed to happen in succession starting from moderate earthquake.

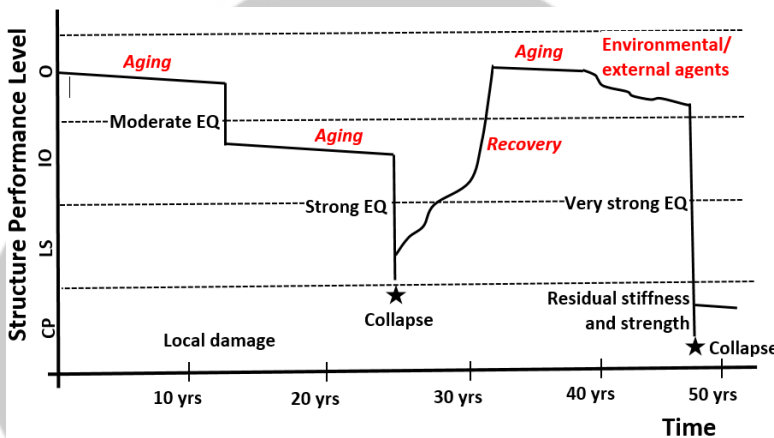


Fig. 9. Hazards pose continuing and significant threats to structures.

Earthquake resiliency of moment resisting frames, either new or existing ones, are important for maintaining their functionality. Steel pipe dampers can be used to increase earthquake resiliency. If steel pipe dampers are installed at strategic locations, they can reduce inter-story drifts up to 40% as shown in Figure 7. Significant reduction of inter-story drifts reduces the failure probability and increases the physical resilience of moment resisting frames. Significant reduction of inter-story drifts protects the structural and non-structural components in moment resisting frames as shown in Table 1. Steel pipe dampers are disposable components in moment resisting frames. Yielding dampers are designed to dissipate earthquake energy in a stable manner as shown in Figure 8. Damaged dampers can be replaced easily, therefore the time required to restore the normal level of functional performance of the system (the time of recovery) is short. Steel pipe dampers are cheap and require low cost workmanship therefore the financial and labor (the resourcefulness) required to restore the normal level of functional performance of the system are low.

Fragility curves are defined as the probability of reaching or exceeding a specific damage state under earthquake excitation. The effects of resourcefulness and recovery phase on the fragility curve due to an event of intensity I_1 is shown in Figure 10. Figure 10a shows the recovery phase at different instants between t_o and t_1 and Figure 10b illustrates how structure repair (damaged dampers replacement) shifts the fragility curve back to the original condition before the instant t_o , and finally attained at t_1 [5]. The time of recovery depends on the angle θ in Figure 10a (a large angle θ indicates short recovery time). Damage in moment frames are concentrated in steel pipe dampers. Because dampers are disposable components in moment frames, the angle θ is large meaning the recovery time is short. Because the steel pipe dampers are cheap and require low cost workmanship, the cost to bring back structure to pre-event condition is low.

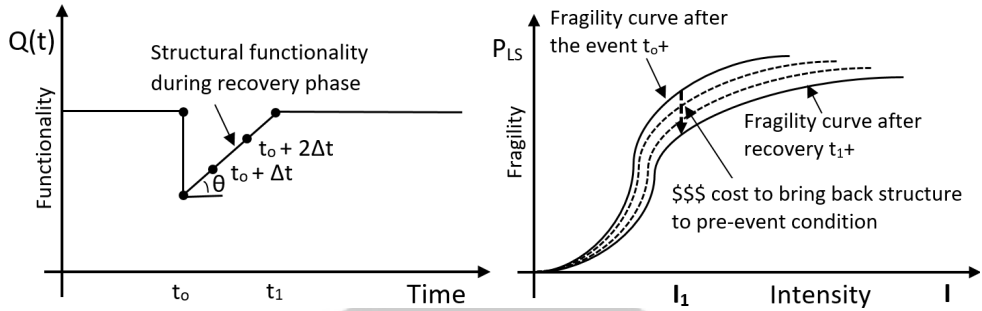


Fig. 10. Effects of resourcefulness and recovery phase on fragility curve: a) Functionality; b) Fragility curve [5].

The results of nonlinear dynamic analysis indicated that the installation of the dampers increase the story shears, member forces around the dampers and the floor accelerations. This is the drawback of all metallic dampers, including steel pipe dampers. Some nonstructural elements and components are vulnerable to excessive acceleration. Therefore, floor acceleration needs to be limited. To tackle this problem, metallic dampers can be installed in parallel with viscous dampers. The damping forces from viscous dampers are 90 degrees out of phase with displacement driven forces in the moment frames. Metallic dampers reduce lateral displacement while viscous dampers reduce acceleration demands. The combined effect of steel pipe dampers and any viscous dampers was not studied in this numerical simulation.

5 Conclusion

Simulation study to the performance of moment resisting frames equipped with steel pipe dampers under seismic excitation had been conducted. Although the use of steel pipe dampers improves the resiliency (reduces the overall earthquake response) of the moment frames, the installation of steel pipe dampers increases story shears, member forces around the dampers and floor accelerations. Steel pipe dampers were found effective in reducing lateral displacement demands, and the increase of floor accelerations could be reduced by installing viscous dampers in parallel with steel pipe dampers.

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