Monograph:

Hajirasouliha, I. orcid.org/0000-0003-2597-8200 and Nabid, N. (2020) A novel friction-wall system for seismic strengthening of substandard RC buildings. Report. RCUK-TUBITAK Research Partnership Project on "Rapid Earthquake Risk Assessment and Post-Earthquake Disaster Management Framework for Substandard Buildings in Turkey" . The University of Sheffield

A Novel Friction-wall System for Seismic Strengthening of Substandard RC Buildings

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Progress Report

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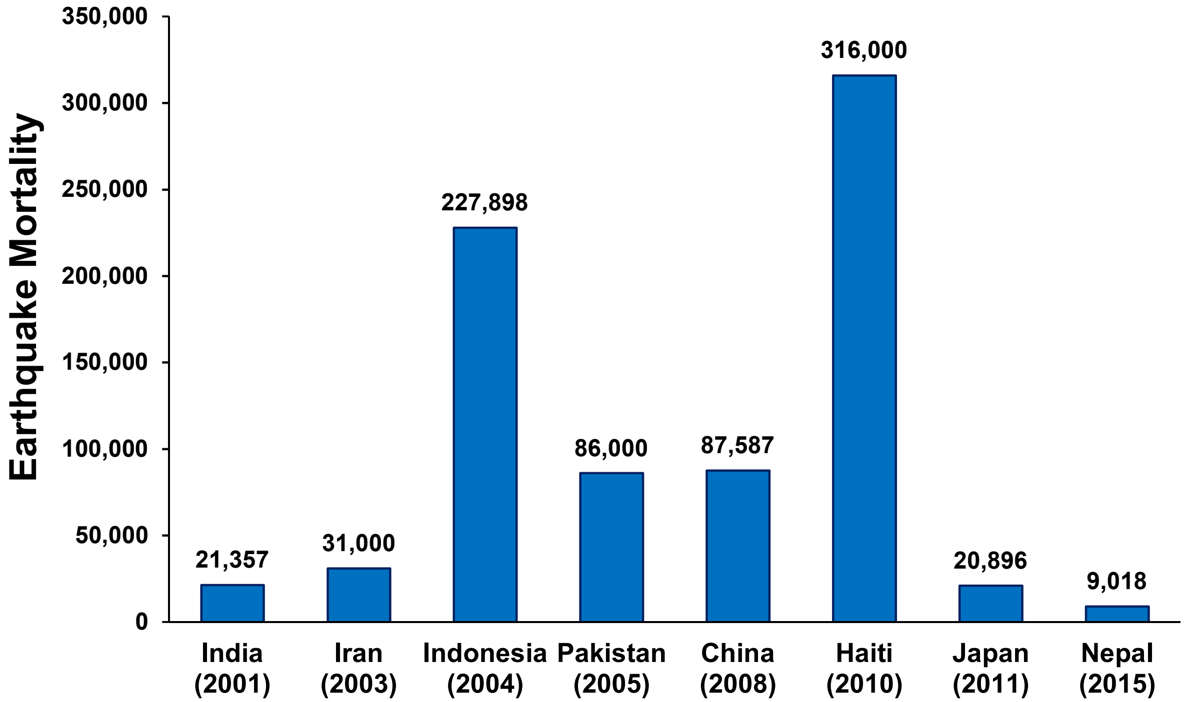
Outline

- Introduction
- Proposed Friction-Wall System
- Practical Design Solution
- Performance-based Optimisation
  - Single-objective optimisation
  - Multi-objective optimisation
- Summary and Conclusions

Bam Earthquake 2003, Iran

Introduction



- Severe damage and extensive mortality
- Need for efficient and cost-effective strengthenin[g] solutions

Friction-based Energy Dissipation Systems

- Brace-type dampers

- Stress concentration
- Blocking the openings

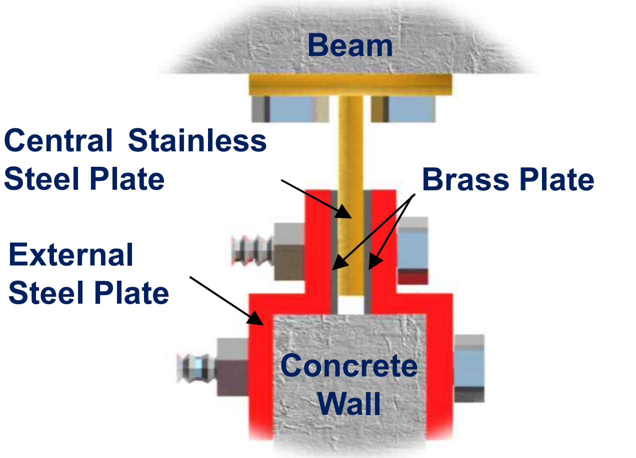
- Wall-type dampers

- Less stress concentration
- Higher energy dissipation
- Larger Opening
- More adjustable

Proposed Friction Wall Damper:

➢ Components:

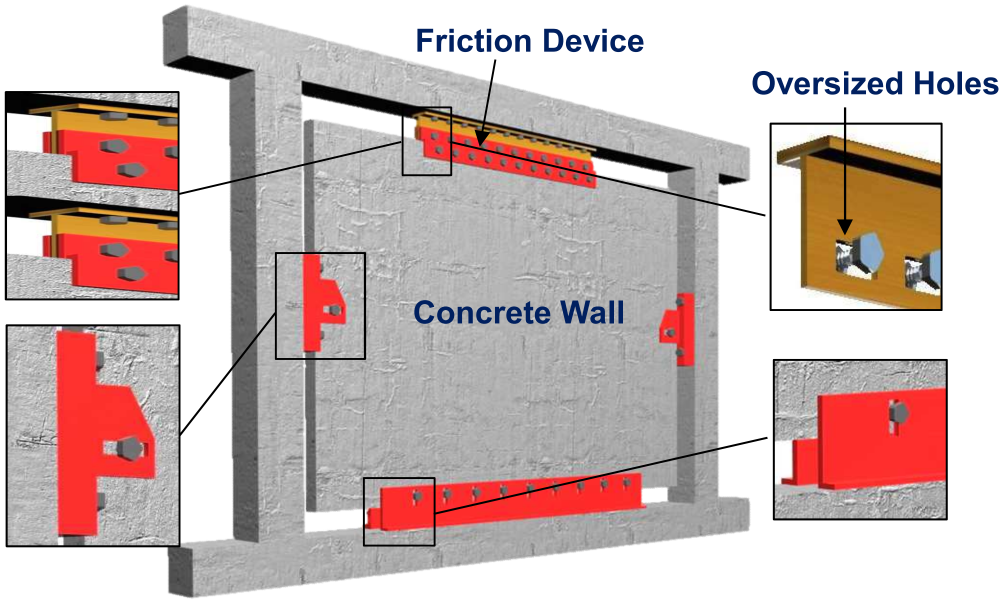
- Concrete wall panel
- Vertical supports to columns
- Horizontal support to lower floor beam
- Friction connection to upper floor beam



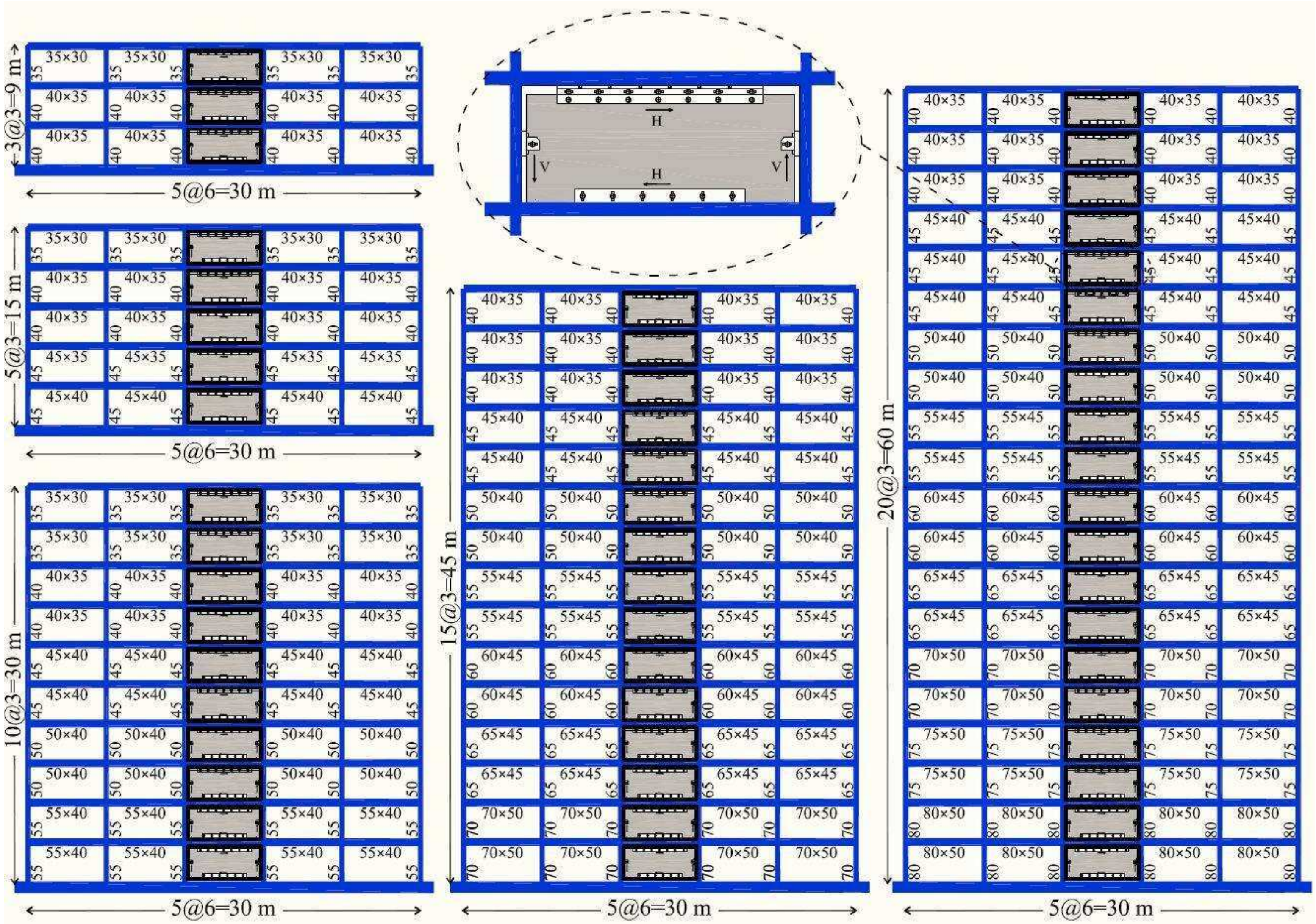
Friction Device

➢ Advantages:

- No brittle shear failure
- No stress concentration
- Easy assembly
- Easy adjustment



Modelling and Assumptions



Geometry of the reference RC frames equipped with friction wall dampers

Prototype Slip Load Distribution Patterns:

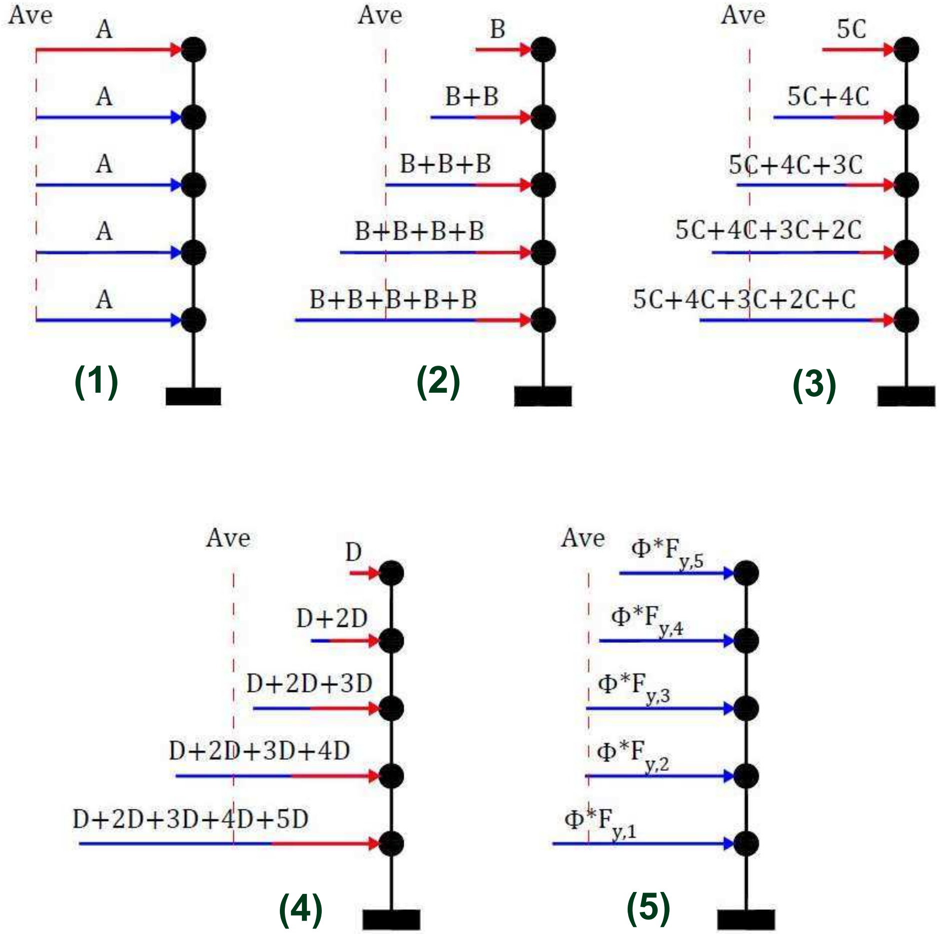
1) Uniform (Conventional design)

2) Uniform Cumulative

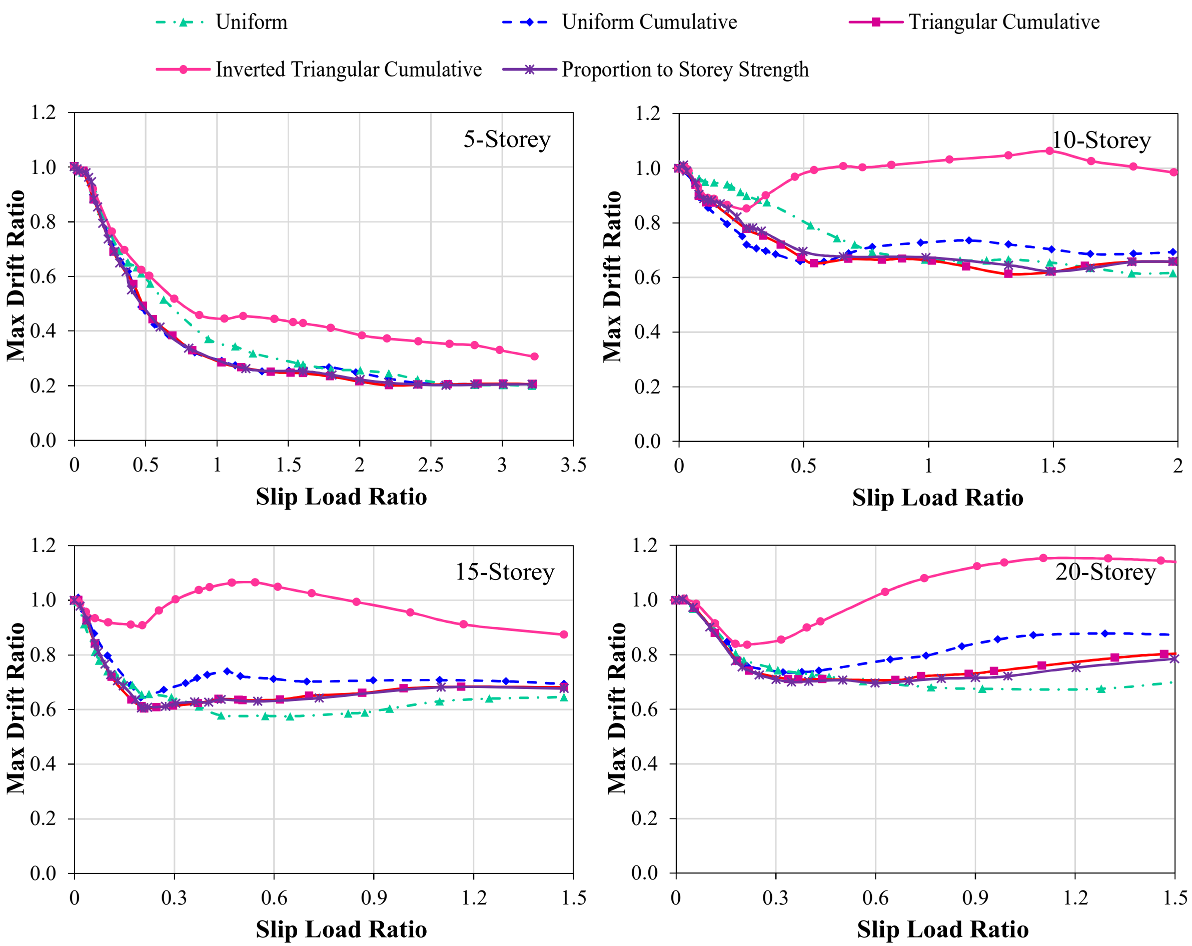
3) Triangular Cumulative

4) Inverted Triangular Cumulative

5) Proportional to the Storey Shear Strength ($F_{y,i}$)



Displacement Demand



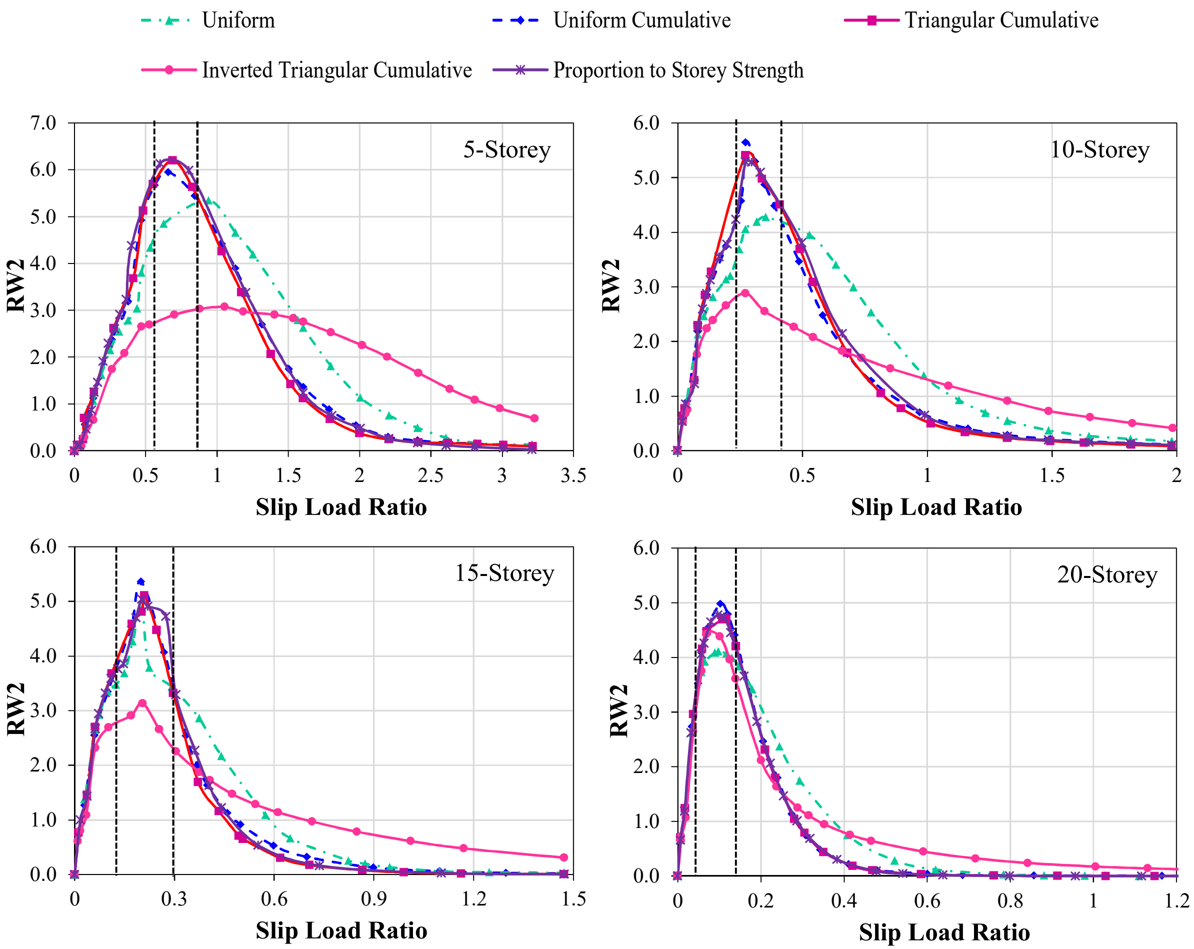
Slip load ratio:

$$F_{SR} = \frac{\sum_{i=1}^{n} F_{s,i}}{\sum_{i=1}^{n} F_{y,i}}$$

F_{SR}: slip Load Ratio
$F_{s,i}$: slip load of the i^{th} storey
$F_{y,i}$: storey shear strength

Optimum range?

Energy Dissipation Capacity



Variation of R_{W2} as a function of slip load ratio, average of six selected earthquakes

Energy parameter:

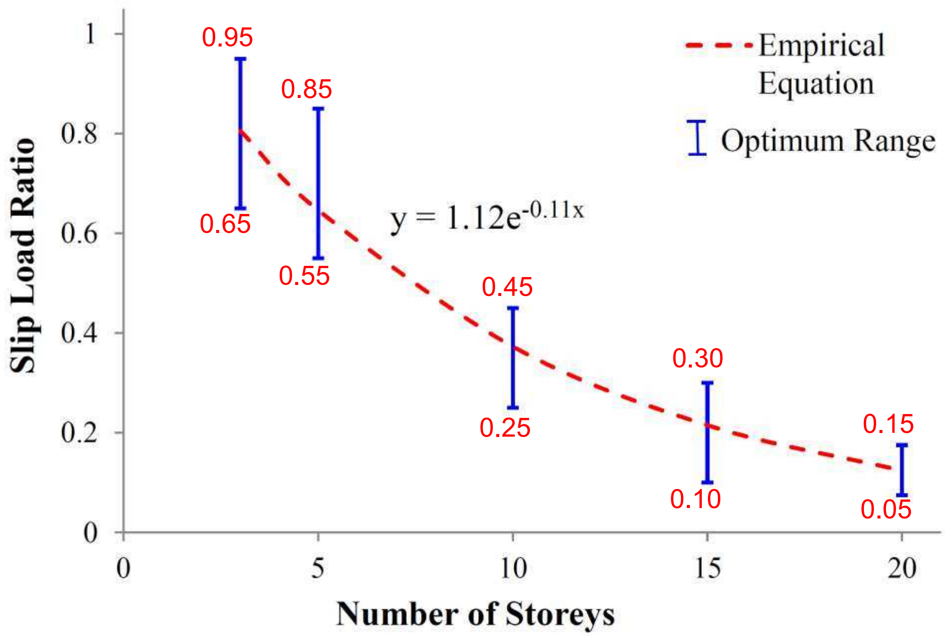
$$R_{w2} = \frac{W_{sf}}{(W_{sb} + W_{sc})_{cs}}$$

W_{sf}: work of friction devices
W_{sb}: static work of beams
W_{sc}: static work of columns

There is an optimum range for slip load ratios that, on average, leads to maximum energy dissipation.

Design Equation

Based on the optimum slip load ranges obtained from different seismic performance indices, an empirical equation is proposed for more efficient design of friction-based wall dampers.



Best Slip Load Ratio

$$R = 1.12e^{-0.11n}$$

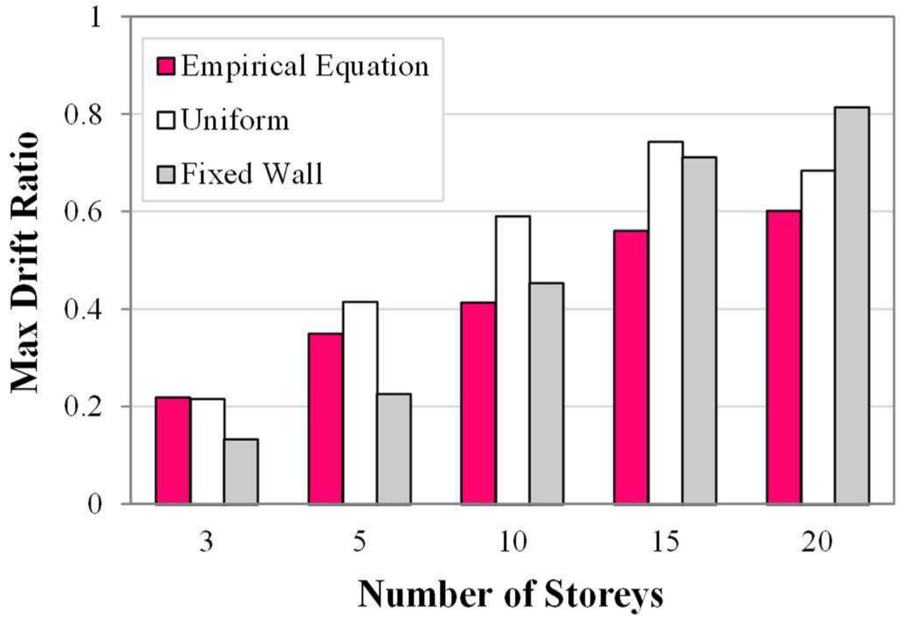
R: best slip load ratio
n: number of storeys

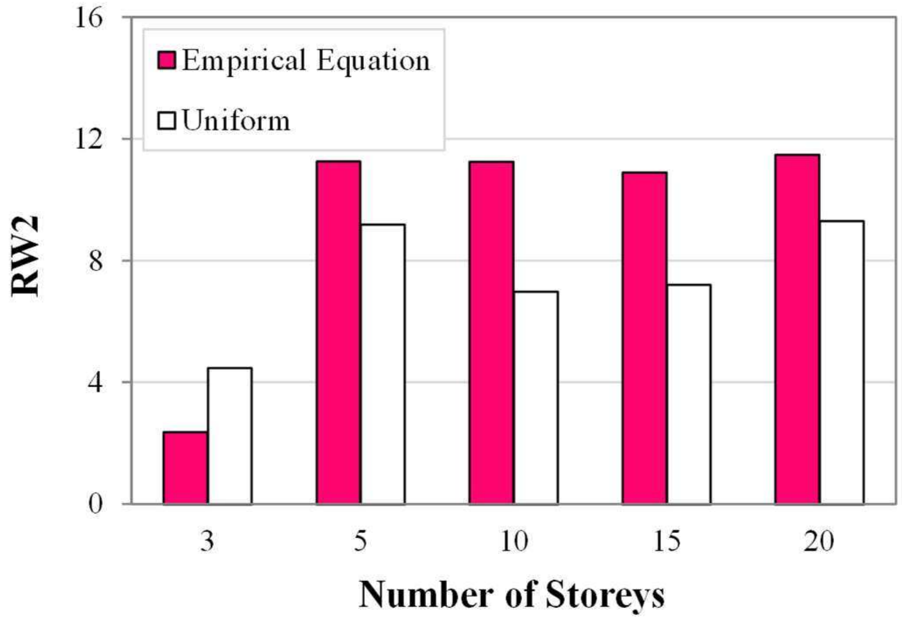
Load Distribution

$$F_{s,i} = \frac{1.12e^{-0.11n} \times (n+1-i)}{n(n+1)/2} \times \sum_{1}^{n} F_{y,i}$$

$F_{s,i}$: slip load of the i^{th} storey
$F_{y,i}$: storey shear strength

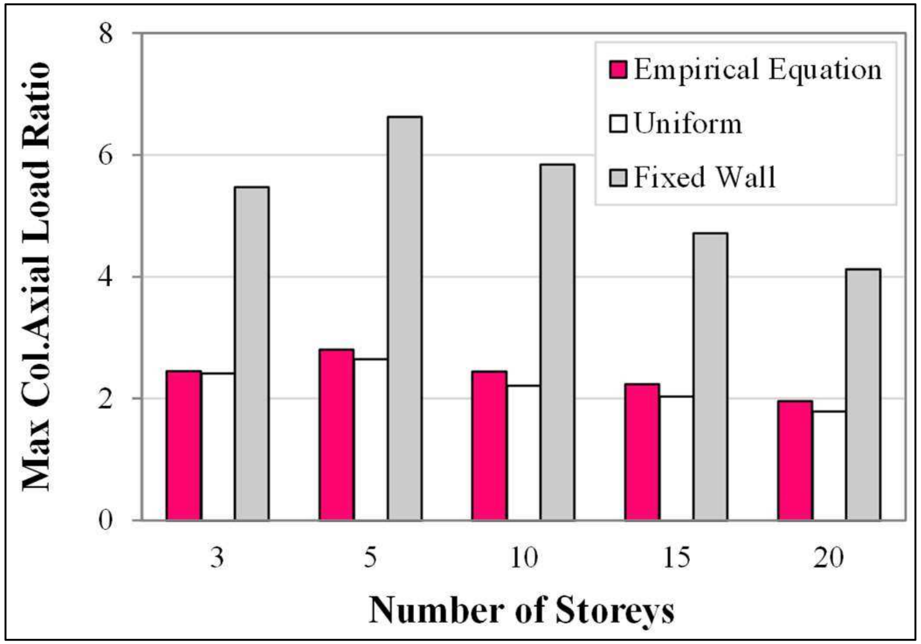
Efficiency of the proposed practical design solution:





By increasing the energy dissipation, maximum inter-storey drift is reduced compared to conventional design method

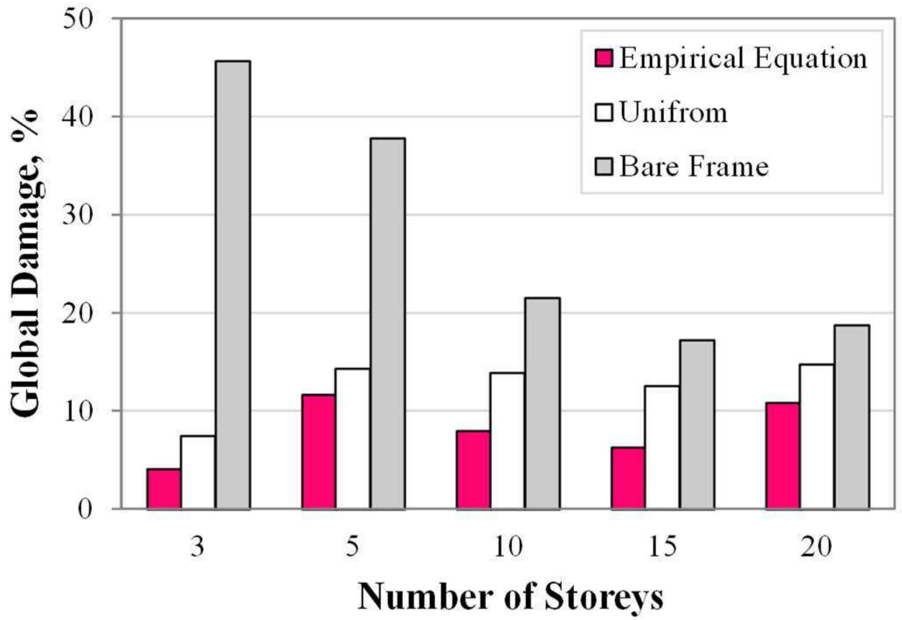
Efficiency of the proposed practical design solution:

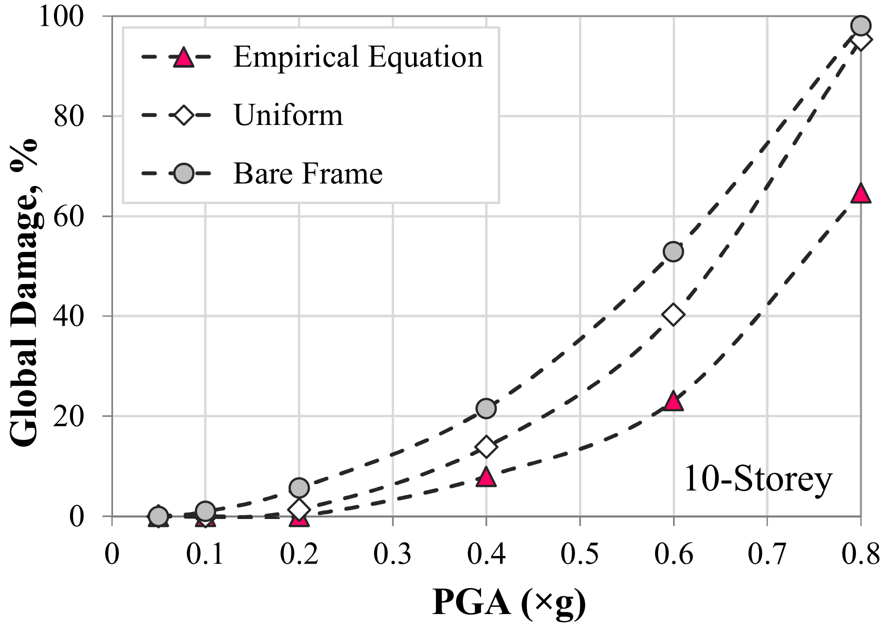


Axial load in the columns is significantly reduced

Cumulative Damage Index

- Using the proposed design solution leads to significant reduction (up to 83%) in the global damage index compared to the conventional design.
- The proposed equation is efficient at all PGA levels.





10-storey frame, A set of six synthetic spectrum compatible earthquakes

An optimisation method based the concept of Uniform Damage Distribution was adopted to obtain the best slip load distribution.

Proposed algorithm:

1) Initial slip load

$$F_{s,i} = \frac{1.12e^{-0.11n}}{n} \times \sum_{1}^{n} F_{y,i}$$

n: Number of storeys
i: Storey number

2) $(m+1)^{th}$ slip loads

$$\left(F_{s,i}\right)_{m+1} = \left(F_{s,i}\right)_{m} \times \left(\frac{\Delta_i}{\Delta_{ave}}\right)_{m}^{\alpha}$$

Δ: Maximum drift
m: Number of steps
α: Convergence factor

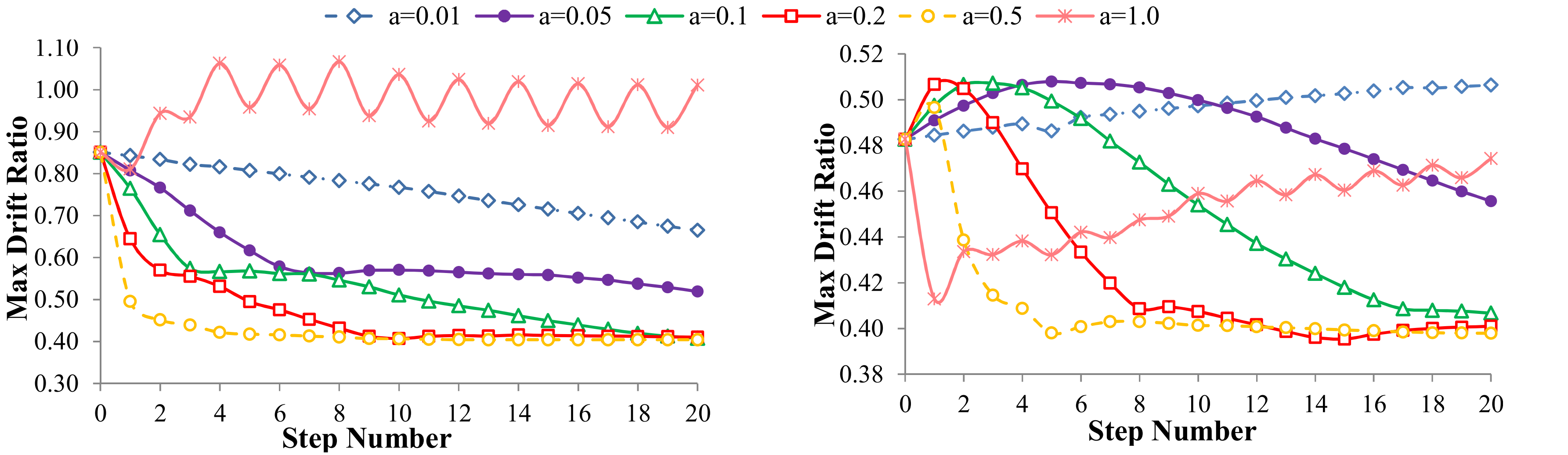
3) Scaled to the average

$$\left[\left(F_{s,i}\right)_{m+1}\right]_{scaled} = \left(\frac{\sum\left(F_{s,i}\right)_0}{\sum\left(F_{s,i}\right)_{m+1}}\right) \times \left(F_{s,i}\right)_{m+1}$$

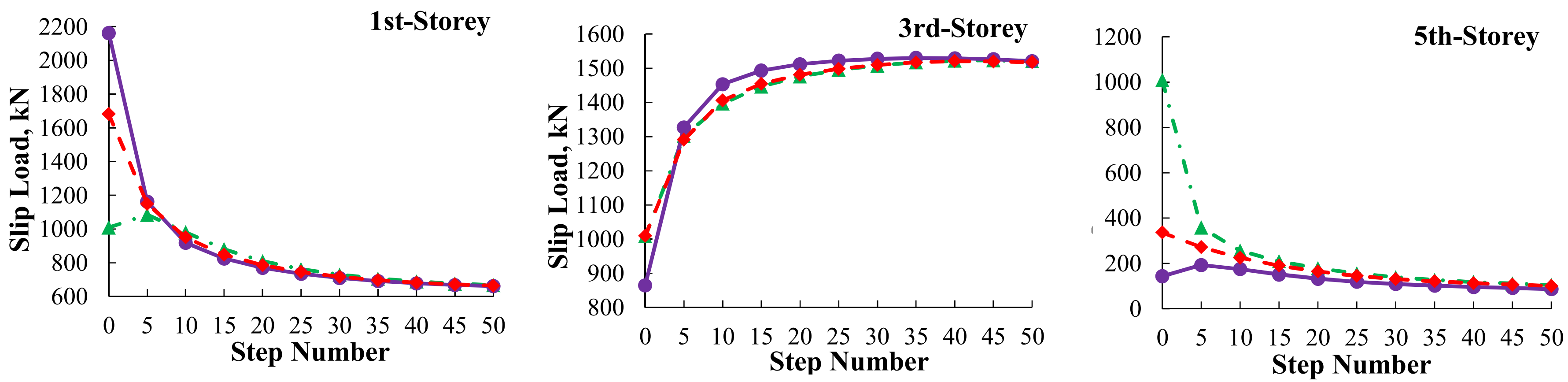
4) Covariance of drift

$$\left(COV_{\Delta}\right)_m = \left(\frac{\sqrt{(Var_{\Delta})m}}{(Ave_{\Delta})m}\right) \times 100$$

➢ Effect of convergence parameter:



➢ Effect of initial slip load distribution:

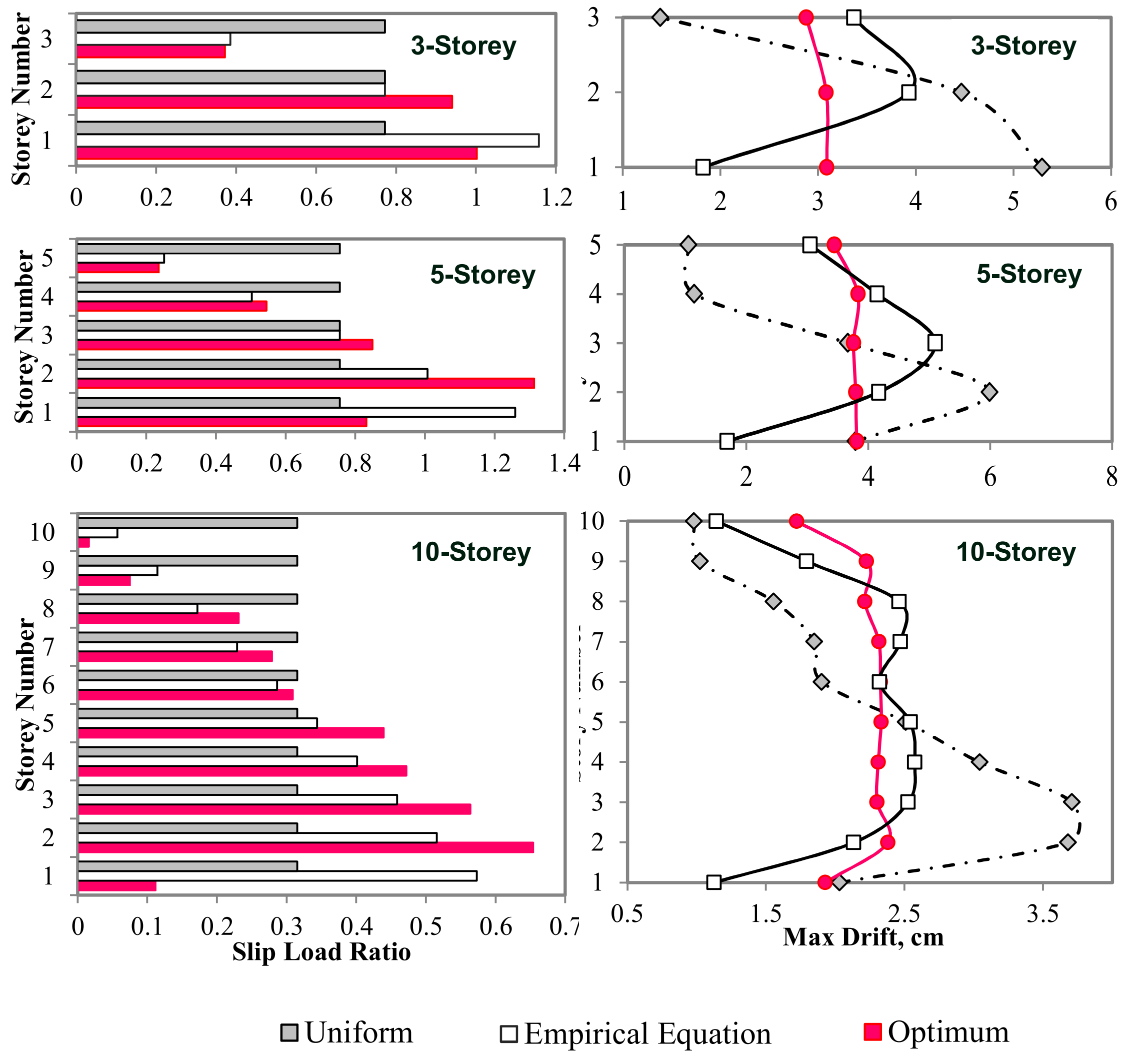


Optimum design for synthetic spectrum-compatible earthquakes:

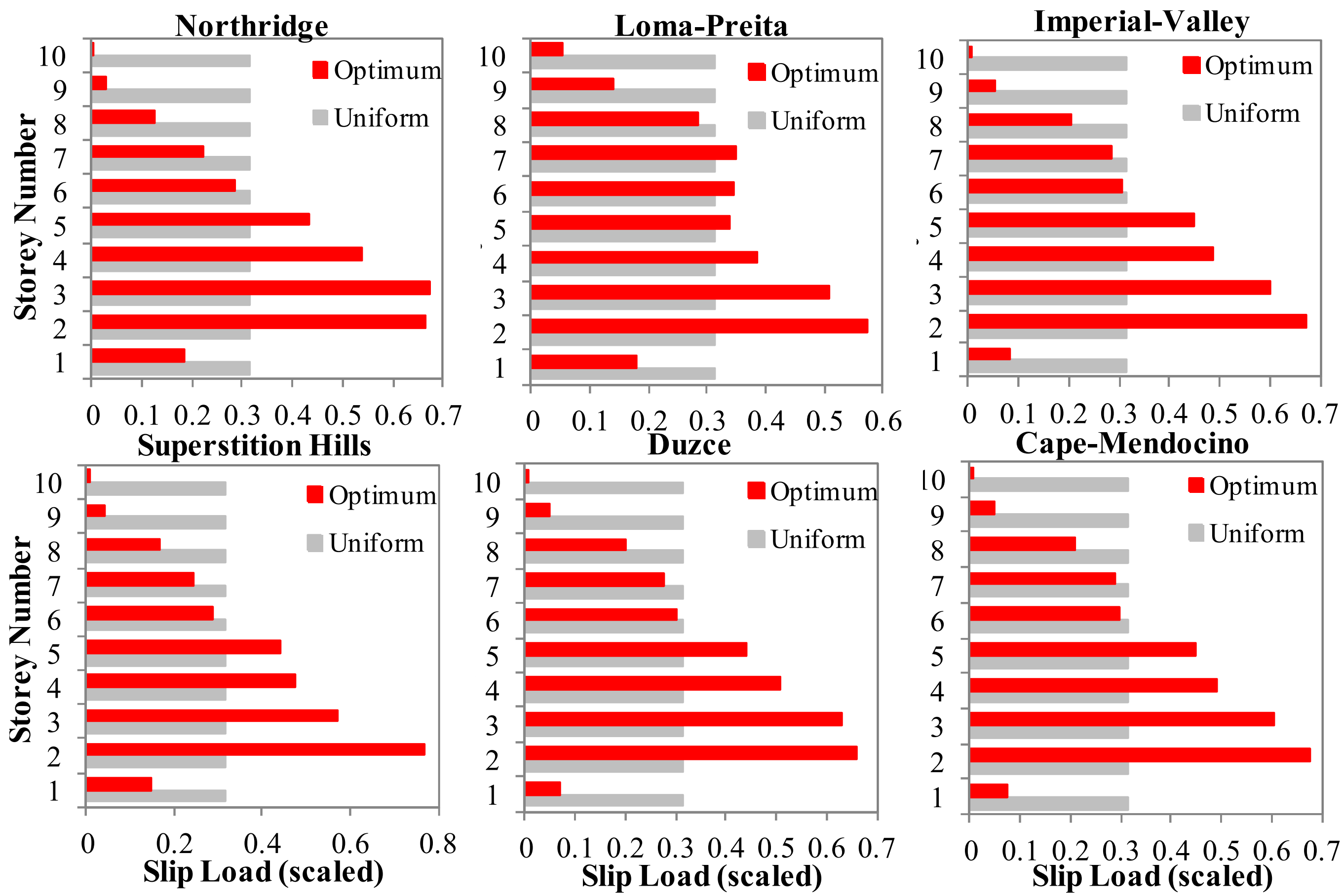
1) Up to 45% less maximum drift ratio

2) Avoiding damage localisation and soft-storey failure

3) Removing unnecessary friction wall dampers



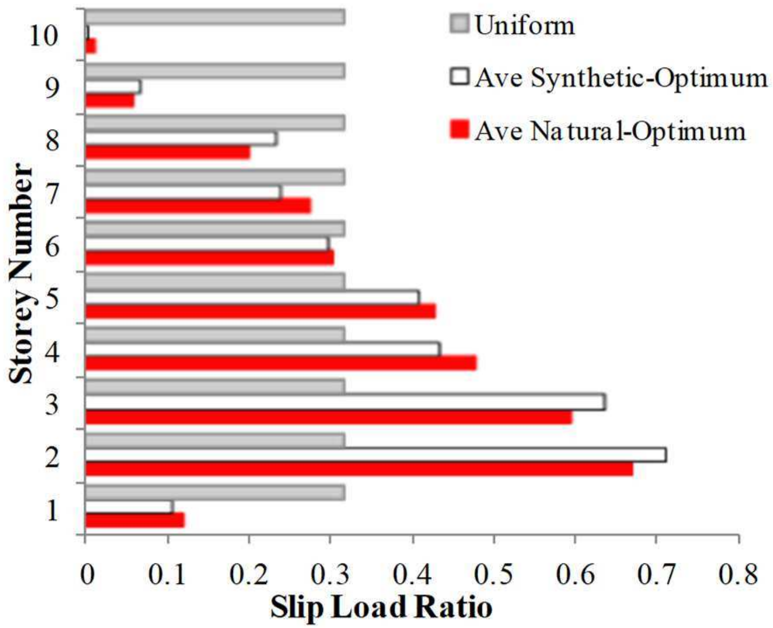
➢ Effect of design earthquake:



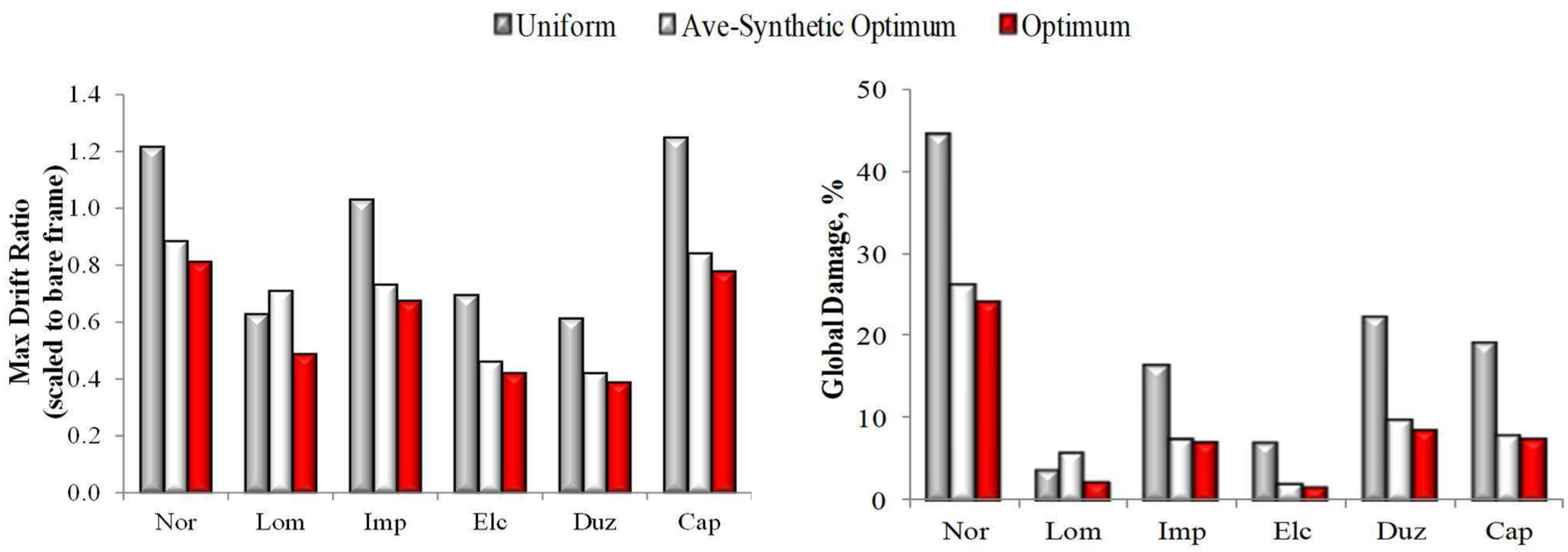
Comparison between optimum and uniform distribution of slip loads (scaled to the average storey shear strength) for 10-storey frames under six natural earthquakes

➢ Optimum Design Solution for a Code Design Spectrum

The optimum slip load distributions corresponding to the natural and synthetic earthquakes are almost identical. This implies that there is a unique optimum design solution for each frame subjected to the design spectrum.



➢ Optimum Design Solution for a Code Design Spectrum



Average of optimum slip load patterns for a set of a spectrum compatible earthquakes can be used for practical design purposes

Summary and Conclusions

- A practical performance-based design methodology was proposed for optimum design of RC frames using friction-based wall dampers and the computational efficiency of the method was demonstrated.

- Optimum design friction-based dampers could increase the energy dissipation capacity (by up to 61%) and decrease the maximum drift ratio (by up to 30%) compared to the conventional design solutions.

- Using the proposed practical design equation resulted in up to 50% lower global damage compared to the conventional design solutions.

- The seismic load uncertainty can be efficiently managed by using the average of optimum load patterns corresponding to a set of synthetic earthquakes representing the design spectrum.

Optimum Design of Friction-Walls

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Uniform Damage Distribution (UDD) Optimisation

Asadi P & Hajirasouliha I (2020) “A practical methodology for optimum seismic design of RC frames for minimum damage and life-cycle cost”, Engineering Structures, 202, 109896.

Mohammadi RK, Garoosi MR & Hajirasouliha I (2019) “Practical method for optimal rehabilitation of steel frame buildings using buckling restrained brace dampers”, Soil Dynamics and Earthquake Engineering, 123, 242-251.

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Hajirasouliha I, Pilakoutas K & Mohammadi RK (2016) “Effects of uncertainties on seismic behaviour of optimum designed braced steel frames”, Steel and Composite Structures, 20(2), 317-335.

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Uniform Damage Distribution (UDD) Optimisation (continued)

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