SEISMIC RETROFIT OF EXISTING TALL BUILDINGS WITH SUPPLEMENTAL ENERGY DISSIPATION DEVICES

PEER Tall Building Initiative Project

Principal Investigator: Stephen Mahin, UC Berkeley
Graduate Student Researcher: Shanshan Wang, UC Berkeley

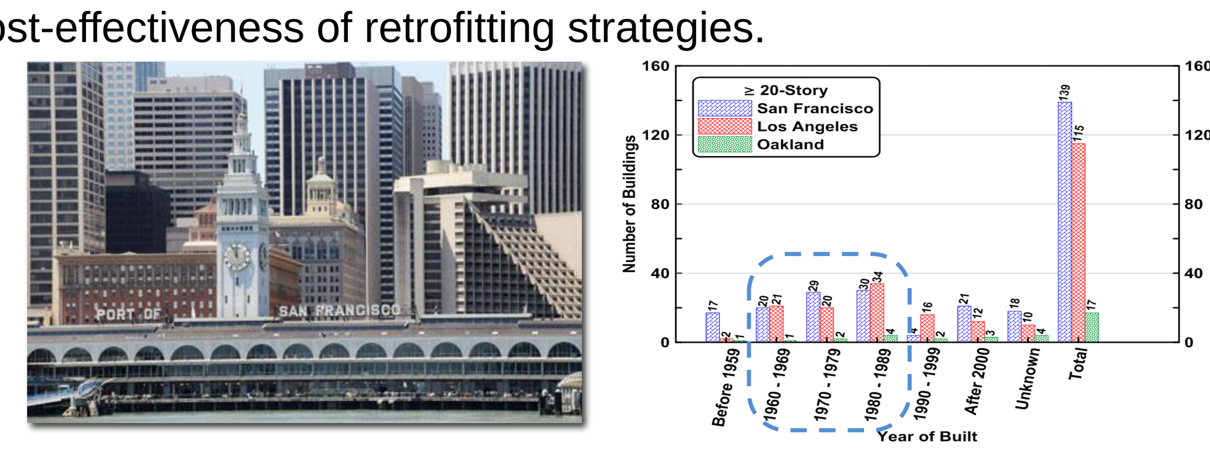
Berkeley
UNIVERSITY OF CALIFORNIA

Background of TBI-2

The phase 1 of the Tall Building Initiative (**TBI-1**) of the Pacific Earthquake Engineering Research (PEER) center has examined the performance of newly constructed tall buildings, and culminated in a series of guidelines. However, there are many old tall buildings exist in the U.S and around the world, many of them were constructed when the earthquake-resistant design procedures were not fully developed.

- Do they pose an unacceptable seismic risk?
- Could they be economically upgraded?

Objective of TBI-2 Assess the seismic performance of existing tall buildings and examine the cost-effectiveness of retrofitting strategies.



Existing tall buildings in the U.S.

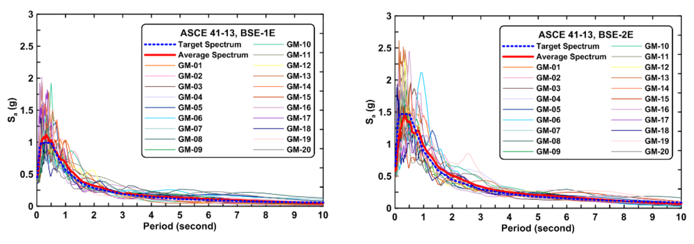
Case Study Building

Selected building 35-story steel moment resisting frame constructed in 1971

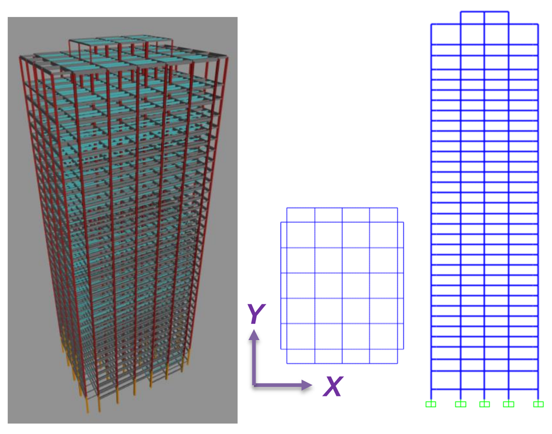
Numerical model 3D analytical models generated using OpenSees

Analysis method

- Nonlinear response analysis
- Two basic safety hazard levels (BSE-1E and BSE-2E)
- 20 set of 3-component GMs for each hazard level



Ground motions



Structure configuration

Seismic Vulnerabilities

The building failed to meet the performance objectives suggested by the ASCE 41, and had a number of seismic vulnerabilities:

- Forms soft-story region in stories 5-12
- High percentage of beam-to-column connection ruptures or complete failures
- High axial demand-to-capacity ratios in columns
- Column tension forces developed at building bases and may not be adequately transferred to the foundation

Retrofit Strategies

Intent of the retrofit

- Reduce the drift concentration and number of beam-to-column connections failure to ensure the overall stability of the structure under the BSE-2E hazard

1st stage retrofit – Initial treatment of most critical issues

- Fix the brittle column splices
- Remove the massive exterior cladding

2nd stage retrofit – Use supplemental energy dissipation devices

- Fluid Viscous Dampers (FVDs)
- Viscous Wall Dampers (VWDs)
- Buckling Restrained Braces (BRBs)

Supplemental energy dissipation devices

Design issues

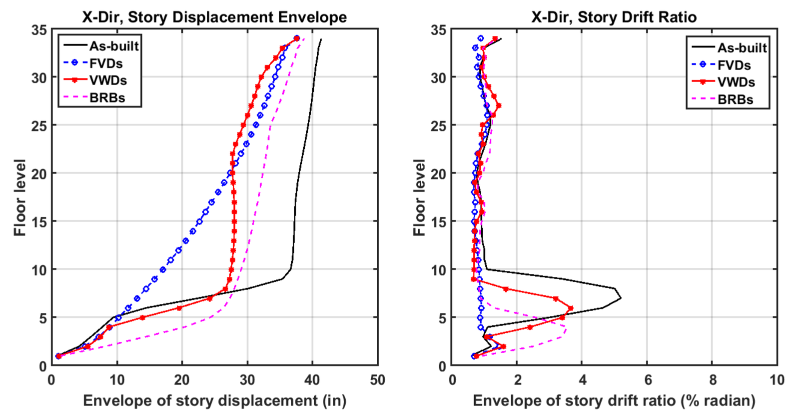
- Effective damping ratio: 8% (*X*-direction) and 13% (*Y*-direction)
- Locations: four exterior frames; distributed at multiple bays; 1-25 stories

Analytical Results

Three representative ground motions under BSE-2E are selected for nonlinear response history analysis, and the maximum responses are presented.

Displacement and drift ratio

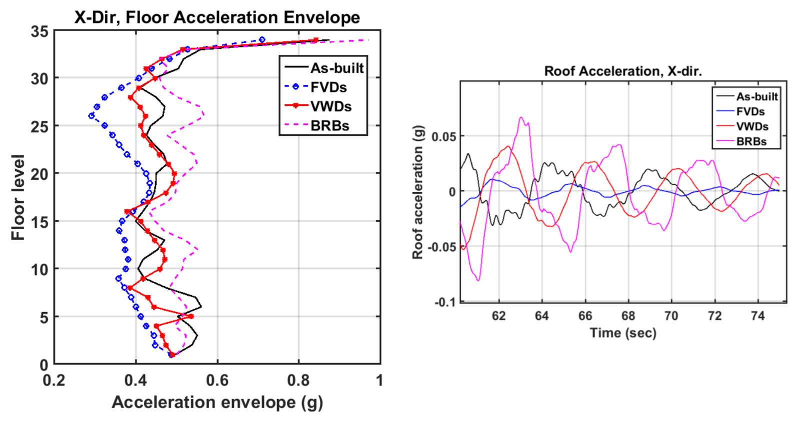
- Peak roof displacement reduction are close in all cases
- FVDs are the most effective to reduce concentrated drift ratios
- BRBs and VWDs still result in a concentration of drift at lower stories



Displacement and drift ratio

Floor acceleration

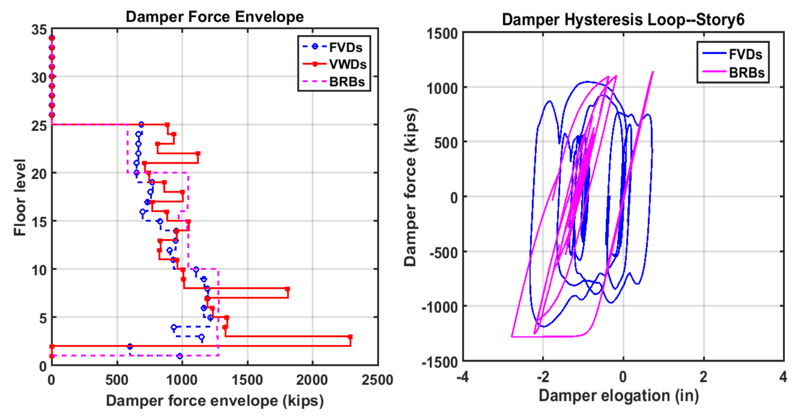
- FVDs help reduce the peak floor accelerations by about 30% over story height
- VWDs have limited effect in suppressing peak floor accelerations
- BRBs bring about larger acceleration demands
- Only FVDs contribute to a rapid decay of structural vibrations



Floor acceleration

Damper/BRB forces

- All devices give fairly large forces, ranging from 1200 to 2300 kips
- FVDs have the smallest force demands
- Dampers generally dissipate more energy than BRBs at the same location



Damper/BRB response

Other Design Considerations

- Columns have large compressive demand-to-capacity ratios, and addition of dampers/BRBs may worsen the situation
- The force capacities of dampers/BRBs are fairly large, thus the adequacy of beam-to-column connections need to be evaluated
- Large braces are needed to drive the dampers/BRBs
- Beams are more prone to failure with introduction of VWDs, and proper upgrades of beams need to be accompanied for desired control effect
- Not enough connection between base plates and foundation

Cost Analysis

Cost analysis using the Performance Assessment Calculation Tool (PACT) is conducted in the framework of Performance Based Earthquake Engineering (PBEE)

- Retrofit strategy with FVDs is the most cost-effective
- Initial costs of dampers/BRBs are small compared to the repair cost

Loss estimation comparison

Scenario	Mean repair cost[2]	Initial damper cost[3]	Mean repair time	Probability of unsafe placard
As-built[1]	$451 M	/	253 weeks	98%
FVD	$28 M	$6.4M	40 weeks	28%
VWD	$320 M	$8.4M	193 weeks	70%
BRB	$237 M	$1.7M	162 weeks	60%

[1] As-built case refers to building with only stage-1 retrofitting
[2] A replacement cost is assumed to be $475 M
[3] Based on limited information from manufacturers and engineers

Conclusions

- A representative 35-story steel moment resisting frame was found be problematic and failed to meet the performance objectives suggested by ASCE-41
- Retrofit strategies using FVDs, VWDs and BRBs are compared
- FVDs are the most effective to reduce structural responses, and have the least interaction with existing structural members, thus using FVDs is the most promising solution for upgrading the selected tall building
- Large-capacity dampers/BRBs are needed, and further optimization is desired
- Additional methods to address the vulnerable columns are necessary

This project was made possible with support from:

PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

UC Berkeley ▪ Caltech ▪ OSU ▪ Stanford ▪ UC Davis ▪ UC Irvine ▪ UC Los Angeles ▪ UC San Diego ▪ USC ▪ U Washington

peer.berkeley.edu