Seismic Energy Dissipation and Damage Control of Building Structures in Recent Years

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1. Introduction

- The State Key Laboratory of Disaster Reduction in Civil Engineering was founded in 1983. It includes Wind Tunnel Testing Division, Shaking Table Testing Division, and Ground Motion Monitoring Division.

- The fundamental research in this Lab. is generally combined with engineering application and aimed at the design code developments of local and national.
• **Research groups in Earthquake Engineering**
  • Building structures (concrete and composite)
  • Building structures (steel)
  • Bridge structures
  • Lifeline systems
  • Ground motion and instrumentation
  • Laboratory divisions
2. TMD Control System

- The system is composed of tuned mass, tuned springs, and tuned damper (using servomotor).

Principle of the servomotor TMD system
Shaking table tests were carried out on a 3-story steel frame structure equipped with this system under various seismic inputs.
Test results vs Numerical analysis

- The earthquake responses of the structure were reduced significantly.
- The damping ratio and the characteristics of frequency spectrum of the seismic input had a significant effect on the control efficiency of this system.
- The analytical model is developed for the tested structure, and the calculation results agree well with the test results.
3. Combined Energy-dissipation System

combined energy-dissipation system installed in a frame
The working principle of the system

- Under wind load or minor earthquakes, the lead rubber damper behaves elastically and oil damper provides small damping force and stiffness.

- Under strong earthquakes the lead rubber damper develops elasto-plastic deformation and the stiffness to the structure is decreased, and the oil damper provides larger damping force but smaller stiffness.
Shaking table tests were carried out on a 3-story steel frame structure and R C. frames with the energy-dissipation system in each story.
Application of Combined Energy-dissipation System

Case 1: Shanghai-Expo Theme Pavilion
Application of New Combined Energy-dissipation System

Case 2: Dujiangyan Primary School Bldg
Application of New Combined Energy-dissipation System

Case 3: Office Bldg of DJY Gas Comp.
Application of New Combined Energy-dissipation System

Case 4: SH Jingan-Shixi Middle School Bldg
Application of New Combined Energy-dissipation System

Case 5: Shanghai Sinopec Office Building
4. Adjacent Buildings Connected by Fluid Dampers

- A series of theoretical and experimental studies were carried out to study the feasibility of linking adjacent buildings or connecting podium structures to a main building by fluid dampers to improve their seismic performance and to prevent the pounding between them.
Three connection conditions between the two frames were involved: connected by rigid steel rods, connected by fluid dampers, or without any connections.

Adjacent structures linked by fluid dampers in testing
The test results show that the damping ratios of both buildings could be increased significantly and so their seismic responses could be reduced effectively if appropriate parameters for the fluid dampers were selected.

Finite element analysis shows the nonlinear earthquake responses have good agreement with the test results.
Application of Adjacent Buildings Connected by Fluid Dampers

Case: Shanghai Shimao International Tower

Podium

Tower
Damper Parameters
40 pieces
\( F = 600 \text{kN} \)
\( \alpha = 0.15 \)
\( C = 250 \)

Building height:
Tower: 333 m
Podium: 49.6 m
5. Displacement-dependent Dampers

Hole-added damping and stiffness (HADAS) by Taiwan

Device in testing
Application of Displacement-dependent Dampers

Case 1: Pekin Union Hospital
Application of Displacement-dependent Dampers

Case 2: Bldg of SH Bank of Communications
Application of Displacement-dependent Dampers

Case 3: Zhengda Himalaya Tower
Application of Displacement-dependent Dampers

Case 4: Stadium at Southwest University of Science & Technology
6. Combined Isolation System

- The isolation system for the test was composed of four rubber bearings and two frictional sliding bearings.

- To verify the effectiveness of this system, a 1/12-scale and three-story steel frame model was tested on the shaking table with base fixed (FIX) and isolated (SLD) separately for comparison.
Layout of isolators and typical plan
Base isolated structural model
The effectiveness of sliding isolators is enhanced by adding rubber bearings and thereby to reduce the residual displacements to manageable levels.

The isolation system has good re-centering capability under different input level with a small residual displacement.

The vertical component of the ground motion has significant effect on the axial loads, and tension may occur in rubber bearings.
Numerical analysis

- A new simplified analytical model for the tested structure is developed by using finite element analysis.

- The superstructure and the rubber bearing are supposed to be elastic, the frictional force in the slider is simulated by the Coulomb-friction characteristics, and the damping of the rubber bearing and slider is taken as viscous damping.
Application of combined isolation system

Case: Shanghai International Circuit Press Center

Large Span Mega-truss Structure
7. Inter-story Seismic Isolation

- The method of inter-story seismic isolation was developed to improve the seismic performance of existing old buildings, especially in the case of adding story to original buildings.
Concept illustration of inter-story isolation
Comparing of shaking table test on frame structure models with different inter-story isolation scheme
• The test results show that compared with common structures without this system, the earthquake responses of the structures with this system were reduced by 20%~40%.

• The calculation and design method has been developed to analyze and to design the inter-story isolation system.

• This method has been applied to more than twenty strengthening projects in China.
8. Study on Design Code

• National seismic design code (deformation checking criteria, elasto-plastic analysis methods,…).

• **Shanghai local codes:**
  • Seismic design code (chief editor– Xilin Lu, Tongji University, **10 major revisions** to National code, 2003)
  • Seismic evaluation and retrofitting code (chief editor– Xilin Lu, 2000)
9. Summary

- The seismic energy dissipation and damage control of building structures were studied with applications as well as standards and design codes in recent years.

- The energy dissipation technologies will be more acceptable for easy construction, low cost and high performance.
The end!

Thank you for your attention!