An Inertial Force-Limiting Floor Anchorage System for Low-Damage Building Structures

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9/3/2018
Project Introduction

IFAS Concept

- Provides a deformable (ductile) connection between the floor system (GLRS) and the primary vertical plane LFRS elements (e.g., shear walls, braced frames)
- Designed with a predefined design strength ($F_y$) to partially uncouple the GLRS and the LFRS
- The structure acts as a traditional structure for daily loads
Project Introduction

IFAS Concept (Con’t)

• The IFAS will reach its design strength in a strong earthquake...
• ...and deform, thereby transforming the seismic demands into relative displacement between the GLRS and the LFRS...
• ...dissipating energy and lowering seismic demands

Reduce Floor acceleration and LFRS drift demand in earthquakes

A moat accommodating relative displacement between the GLRS and LFRS is required.
Project Introduction

IFAS device development and full-scale testing at NEES@Lehigh

Design half-scale IFAS devices

Provide an IFAS design space

Half-scale shake table testing at NEES@UCSD

Predict State

Calibration

3D numerical model of the shake table test specimen at UA

Demonstrate IFAS concept

Parametric study to develop an IFAS design space at UA

Provide IFAS property

1.0DL + 0.25LL w/P-Δ
Analytical Study

Analytical Study


IFAS Configuration

Section view

- Shear wall
- Gravity columns
- Slab

Plan view

- Rubber bearing
- Moat
- Shear wall
- Slab
- Through rods
- Base plate
- Deformable connection

Buckling restrained brace (BRB) or Friction damper (FD)
Analytical Study

Numerical Model

IFAS: nonlinear spring
Lumped wall mass
Wall: Elastic beam with base plastic hinge

1.0DL + 0.25LL w/P-Δ

Lumped GLRS mass

Slab: Elastic beam with plastic hinges at both ends

Column: Elastic beam with base plastic hinge

Force (kips)

Deformation (in)

BRB + RB

FD + RB

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Analytical Study

Response Envelopes (DBE):
- **Benefits**
- **Tradeoffs**

**Floor acceleration**

- Reduced floor acceleration

**LFRS drift**

- Reduced LFRS Demand

**Relative displacement**

- Increased relative displacement

**GLRS drift**

- Increased GLRS drift

\[ \alpha = \sum \frac{F_y}{F_{px}} \]

- Traditional

10 Earthquakes

1.0DL + 0.25LL w/P-Δ
Analytical Study

Parametric Study Results (Con’t)

Parametric response (12-story structure):

Benefits

Relative displacement in DBE

Wall

Slab movement

Impact force

Displacement

Device force-displacement behavior

Force

Concrete crush force

Impact force can be gradually picked up

Tradeoffs

GLRS inter-story drift

Wall

Slab

Impact force

Displacement

Bumper

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Shake Table Test

Test Specimen Introduction

Test specimen description:

- Half-scale four-story reinforced concrete structure.
- Permits direct comparison between IFAS & traditional.
- LFRS: post-tensioned precast rocking walls.
- GLRS: flat slab floor system with precast columns.
Shake Table Test

Test Specimen Introduction

Test specimen description:

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- Permits direct comparison between IFAS & traditional.
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- GLRS: flat slab floor system with precast columns.

For test repeatability (to compare IFAS to traditional structure)

Courtesy of Nema Arpit
Shake Table Test

Test specimen description:

- LFRS eccentricity was purposely introduced for torsional response.

![Diagram of test specimen]

Table motion direction

N

C.O.R

C.O.M

Pre-cast columns

North wall

Pocket foundation

Pedestal foundation

Transverse wall

Table motion

Courtesy of Nema Arpit

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Shake Table Test

Test Phases

Two test phases:

- Phase I: IFAS is used between the GLRS and LFRS (IFAS Structure). 14 tests.
- Phase II: Dowels are used to connect the GLRS and LFRS (Traditional Structure). 5 tests.
Shake Table Test

Structural roof twisting comparison between Phase I and Phase II
Shake Table Test

Wall base rotation comparison between Phase I and Phase II:

- Significant LFRS drift reduction can be observed in all tests if combine north wall and west wall base rotation.

**Five earthquake records**
- SE DBE
- SE MCE
- BE SVC
- BE DBE
- BE MCE

![Graphs showing base rotation comparison](image)
GLRS resultant floor acceleration envelope comparison between Phase I and Phase II:

- Acceleration reduction was not observed in Phase I in comparison to Phase II (blue to red).
Shake Table Test

Validation of the IFAS Effectiveness

- **PII Simulation (Pristine)**
- **PII Simulation (damaged)**
- **PII Test**
- **PI Simulation (Pristine)**

**White noise test case**

- **Day 2**
- **Day 3**
- **Day 4**
- **Day 5**
- **Day 6**
- **Day 7**
- **Day 8**

**Period (s)**

- **0.75s**
- **0.55s**

**Acceleration (g)**

- **0**
- **0.5**
- **1**
- **1.5**
- **2**

**Level**

- **0**
- **1**
- **2**
- **3**
- **4**

**Slab twisting**

- **Level**
- **Twisting (rad)**

- **0.005**
- **0.01**
- **0.015**
- **0.02**

**North wall drift**

- **Level**
- **Drift (%)**

- **0.005**
- **0.01**
- **0.015**
- **0.02**
- **0.025**
- **0.03**
- **0.035**
- **0.04**
Conclusions

- The IFAS can effectively decrease the floor acceleration and LFRS drift via performing analytical studies on 2D evaluation structure models.

- The shake table test validated the effectiveness of the IFAS in reducing LFRS drift and slab twisting.

- The 3D nonlinear model can properly match the test structure response and validate the effectiveness of the IFAS in reducing LFRS drift, floor acceleration and slab twisting.
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Questions?

Thank you for your attention!