Post-Earthquake Damage Screening of Structures

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Densely built-up high-rises

Visual inspection

Quick inspections in past EQs

- Tohoku EQ (2011): over **95,000 buildings** inspected and 11,700 tagged unsafe (MLIT)
- Large EQ in Tokyo metropolitan area → over a month
Structurally Deficient Infrastructure

Bridge collapse in Minnesota  Blade failure of wind turbine

Needs for continuous monitoring of aging / structurally deficient structures.
Paradigm Shift in Earthquake Engineering

- Redundant
  - Collapse prevention
- Robust
  - Coping with uncertainty
- Resilient
  - Continuity / rapid recovery

Enhanced safety margin

Quick screening for decision on building occupancy

E-Defense: full-scale steel frame

"Reduced downtime in social activities"

High-rise VIDEO

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Challenges for Structural Integrity Assessment

- Damage screening after extreme events

- Early detection of a sign of failure
Outline

• **Introduction**
  – Damage Inspection and monitoring of structures
  – Structural integrity assessment

• **Data-driven Structural Integrity Assessment**
  – Wireless autonomous sensing of suspension bridge
  – Local damage detection of building structures

• **Summary and Future Directions**
Data-driven Structural Integrity Assessment

- Visual-based approach
- EE (Electric and Electronic)-based approach

- Visual-based approach
- EE (Electric and Electronic)-based approach

Structural members covered by finishing

Lack of objective information in visual inspection

Elements in damper buckle after certain story drift...

- 0.5% story drift
- 1% story drift
- 2% story drift

Damper capable of memorizing experienced deformation
Data-driven Structural Integrity Assessment

- Visual-based approach
- EE (Electric and Electronic)-based approach

Wireless sensing network + Web-based cyberenvironment
Application of Emerging Technologies

Low-cost / low maintenance sensing

Vibration-Based  Data-Mining

Feature Extraction  IT-based Data Processing

Piezoelectric  Wireless

Cloud data share

Database / Web

MEMS  Cloud data share

Wireless  Database / Web

Vibration-Based  Data-Mining

Feature Extraction  IT-based Data Processing

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MEMS  Cloud data share

Wireless  Database / Web
WIRELESS AUTONOMOUS SENSING
Internet-enabled Wireless Autonomous Sensing

- 28 units, 80 channels
  - MEMS Accelerometers
  - Environment Sensors
  - Autonomous data transfer to remote server

Sever-client model

- 147 m
- 728 m
- 181 m

Model details:
- Narada DAQ
- Client API
- Sensor Log
- Data Mining
- Researchers' Platform
- On-site Narada Servers
- MEMS Accelerometers
- Environment Sensors
- Autonomous data transfer to remote server

Database code generation tool

HDF5 Library

SQL Database

SC Site: SensStore Server

Media wiki

Wiki Server

Other Examples

South

North

UNIT = m

- Tri-axis accelerometer
- Potentiometer
- Climate station
- *Narada server*
Wireless Sensing Package Powered by Solar

- Elimination of cost and labor for cable installation
- Powered by solar panel

**Narada wireless unit**
4-Ch input, 2-Ch output

**All-weather package:** Narada, Acc, Solar power circuit, Low-pass filter

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Wireless Sensing at Suspension Bridge

Girder vibration

Solar-powered sensing network

Acceleration time history
(2/3/2011 @2pm)
LOCAL DAMAGE DETECTION
Challenges toward Practical Applications

• **Damage detection capability**

Lv. 1: **Damage existence**
Lv. 2: **Rough location**
Lv. 3: **Member location and degree**
Lv. 4: **Residual strength**

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Challenges toward Practical Applications

- IASC-ASCE structural health monitoring benchmark
- US-Japan joint research

Global damage detection
- Story-level
- Several sensors

Local damage detection
- Member-level
- Dense-array of sensors

- Residual strength
- Member location and degree
- Rough location
- Damage existence

- Current status

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Local Damage Detection and Structural Integrity

- How to fusion data from heterogeneous sensing network?

Structural analysis + local damage detection + measured building response

- Dense sensor array at representative story
- Sensor network for local damage
- Maximum response
- Spot-check of structural response

Sensor location

Floor

Damage probability

Predicted damage location

Fairly plausible to damage

Highly plausible to damage

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Testbed for Local Damage Detection

- **5 story, 1/3.75 scaled steel frame**
  - 4 m x 1 m x 5 m
  - Total weight 8.7 ton
- **Damage simulation**
  - Removal or yielding of links around joints

**Joint details**

**Testbed overview**

Steel beam-end fracture in Kobe EQ

Column elephant buckling (Kurata et al., 2007)
Testbed for Local Damage Detection

- Dynamic testing of 1/3.75 scaled steel frame
- Simulated damage embedded around joints

Frame Test

Shake Table Testing

Joint details
Two measurement systems

Wireless system

• No cables and low-cost
• Stable communication but not 100%
• Slow data rate

Wired system

• Lots of cables
• Stable communication
• Fast data rate
Local Damage Detection with Dynamic Stain Sensing

- Monitoring of inner force distribution of structure
- No need of high-precision calibration

Results from shake table testing

Changes in force distribution
Independent from input motions
Web-based Autonomous Data Processing

Web-based data look-up

Structural Health Monitoring Web-Database

Objective Database Information
Current objective database is 5 story shaking table test

Searching Setup Session
This session can provide you searching assistance to obtain the comparison of measured data.

Keyword searching
No searching keywords has been saved yet. Skip this keyword searching. It is recommended to make some objective searching keywords to enhance usability.

Selected terms searching

Results Preview
32 data have been found in the objective database.

Analysis reference setup
Reference of normalized standard deviation has not been stored yet. If you want to set this data as reference data, please click analysis execute button.

Reference data name

Statistical evaluation

Damage location estimate

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http://steel-shm.dpri.kyoto-u.ac.jp/SHMdatabase/index_SHM.php

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Damage Detection using Machine-Learning

1. Pre-analysis
2. Damage classifier construction

Learning dataset
{mode shapes, frequencies, etc}

Classify damage patterns
Classifier

3. Response measurement
4. Damage state estimation

Supply dataset
{mode shapes, frequencies, etc}
Summary

• Data-driven damage screening system:
  – Provides **objective information** to inspectors and decision makers **in a quick manner.**

• Applications of emerging technologies:
  – Enables **low-cost, easy-to-install** system configurations.
  – Achieves member-level **local damage detection**.

→ **Enhances the resiliency of structures and community against extreme events.**
Long-term Significance of the Work

• **Open Research / Applications:**
  - **Collaborative efforts** with practitioners and social scientist, and decision makers for real-life applications
  - **Tie-in installation** with other systems (e.g. a with energy monitoring system) for reducing cost and labor associated with system installation

• **Views in 5-10 years**
  - **Market expansion** in damage screening and monitoring systems
  - **Standardization and generalization** for real-life applications

*Thank you for your attention!!*