Field investigation of M6.4 Yangbi earthquake and prompt damage assessment using RED-ACT

Xinzheng LU, Qingle Cheng, Yifan Fei, Yi Gu

Institute of Disaster Prevention and Mitigation

Department of Civil Engineering, Tsinghua University

Email: luxz@tsinghua.edu.cn

Website: www.luxinzheng.net

Outlines

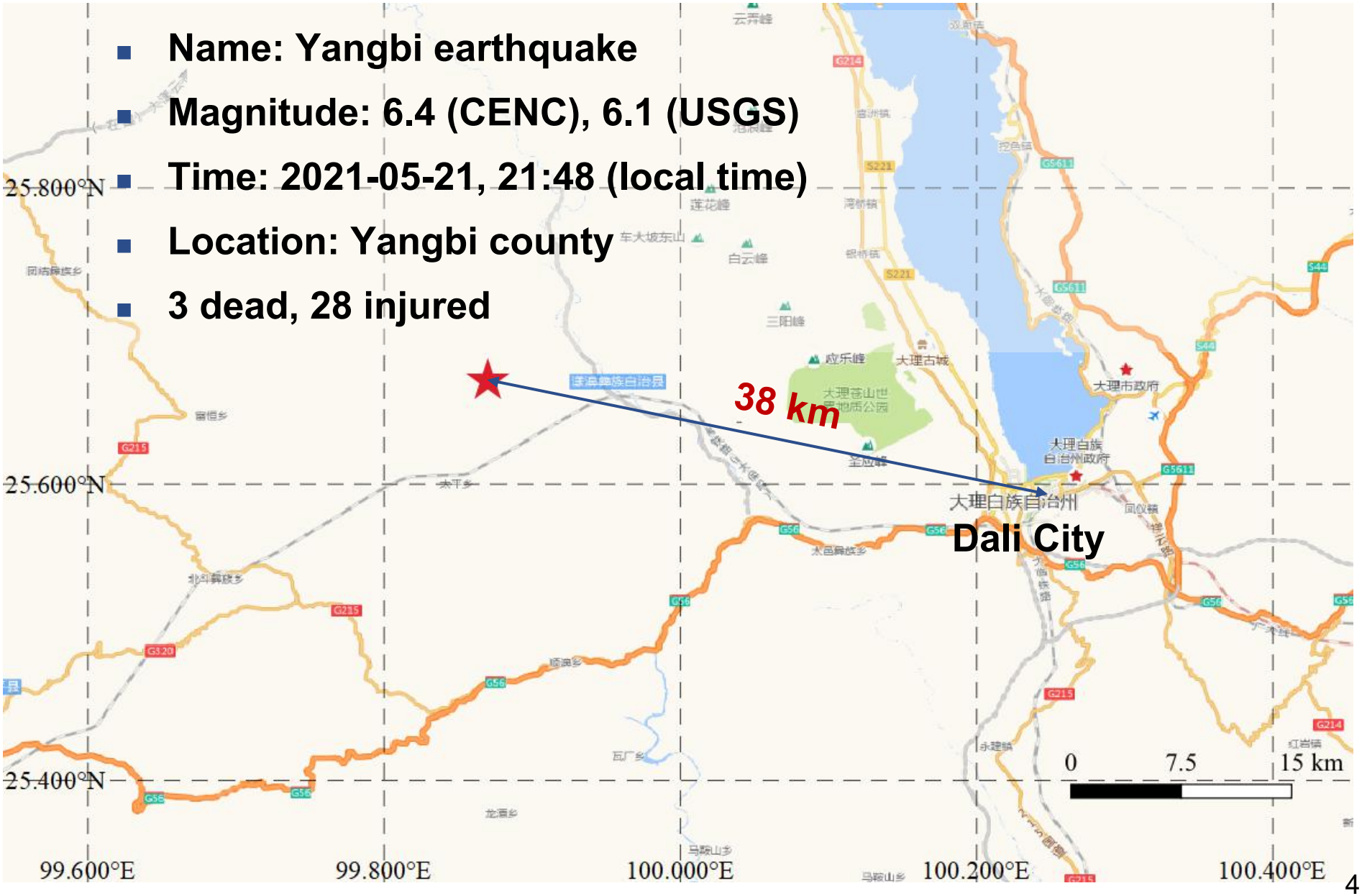
1. Introduction of M6.4 Yangbi earthquake
2. Field investigation
3. Prompt damage assessment using RED-ACT
4. Other applications of RED-ACT
5. Conclusions

Outlines

1. Introduction of M6.4 Yangbi earthquake
2. Field investigation
3. Prompt damage assessment using RED-ACT
4. Other applications of RED-ACT
5. Conclusions

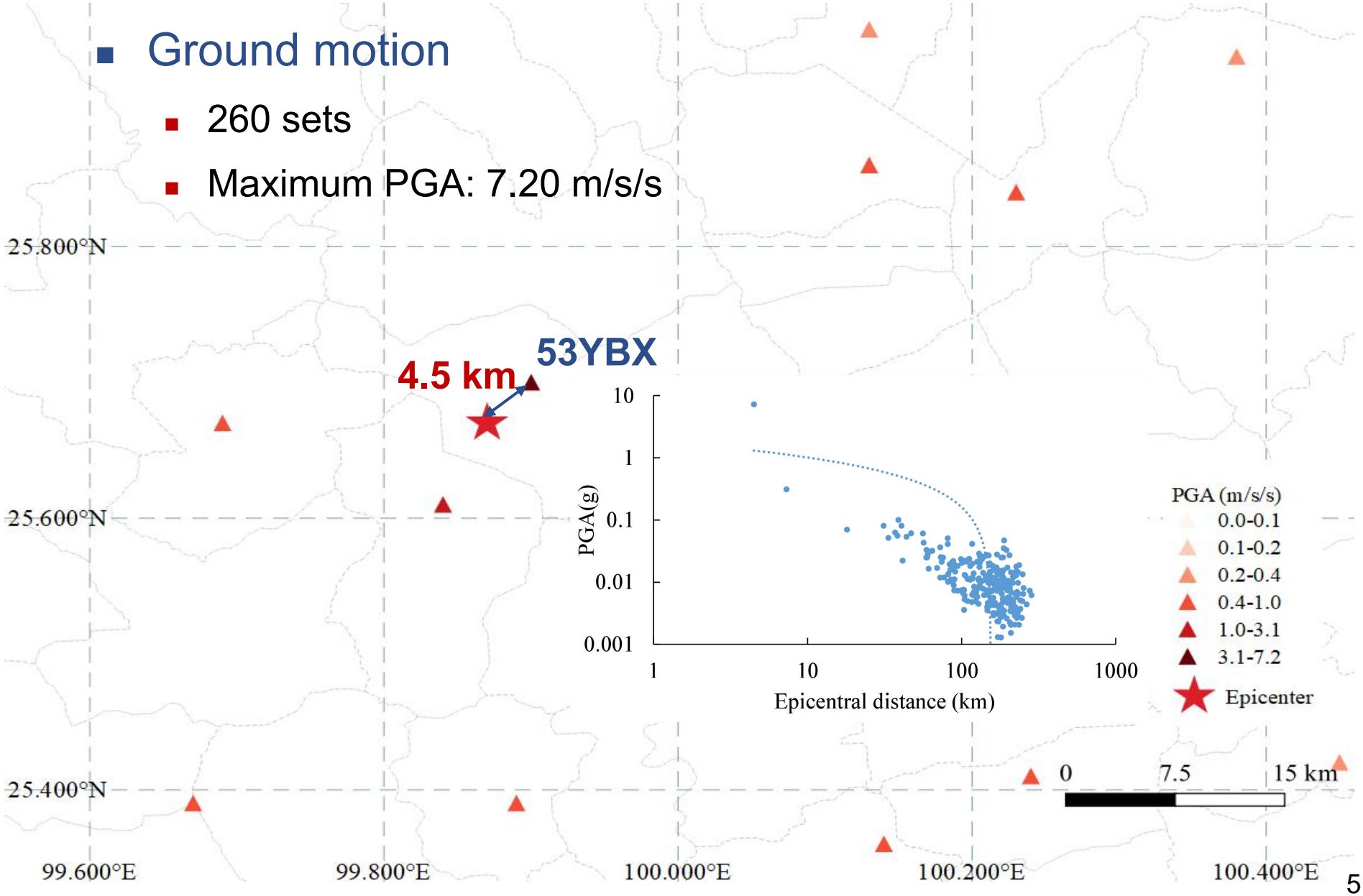
1. Introduction of M6.4 Yangbi earthquake

- **Name: Yangbi earthquake**
- **Magnitude: 6.4 (CENC), 6.1 (USGS)**
- **Time: 2021-05-21, 21:48 (local time)**
- **Location: Yangbi county**
- **3 dead, 28 injured**



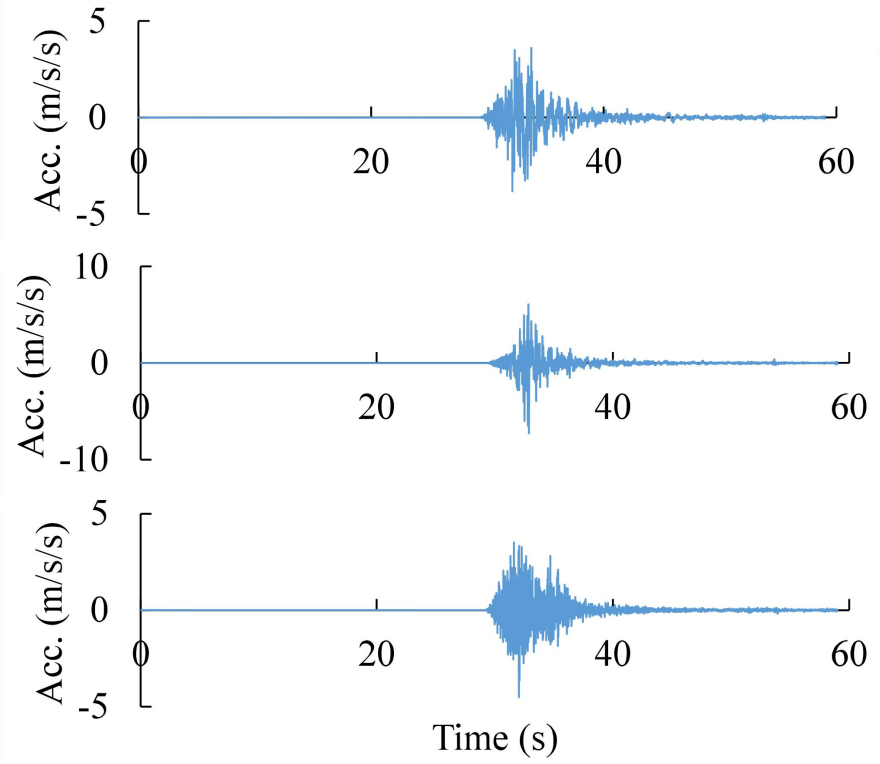
1. Introduction of M6.4 Yangbi earthquake

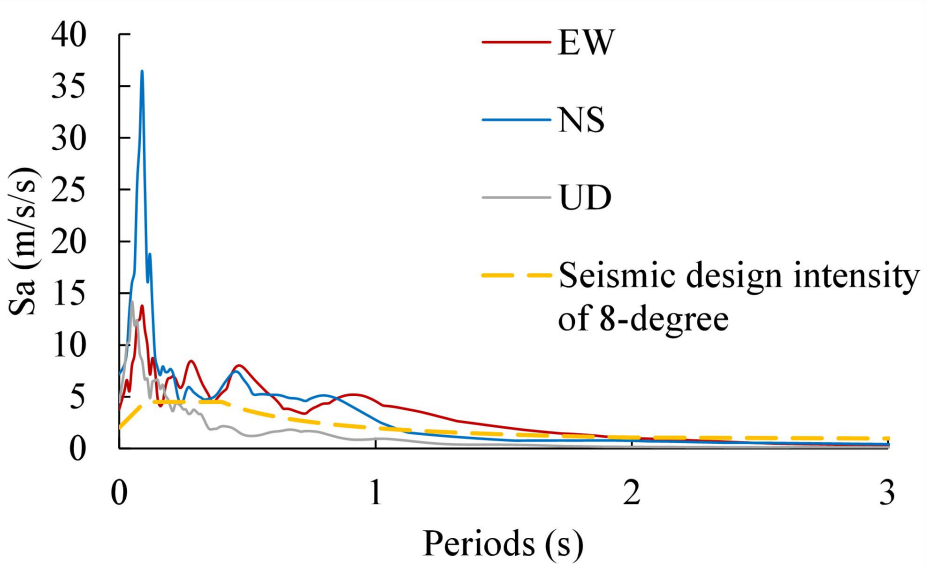
- Ground motion
  - 260 sets
  - Maximum PGA: 7.20 m/s/s



1. Introduction of M6.4 Yangbi earthquake

- Ground motion
  - 260 sets
  - Maximum PGA: 7.20 m/s/s
  - 53YBX, 4.5 km





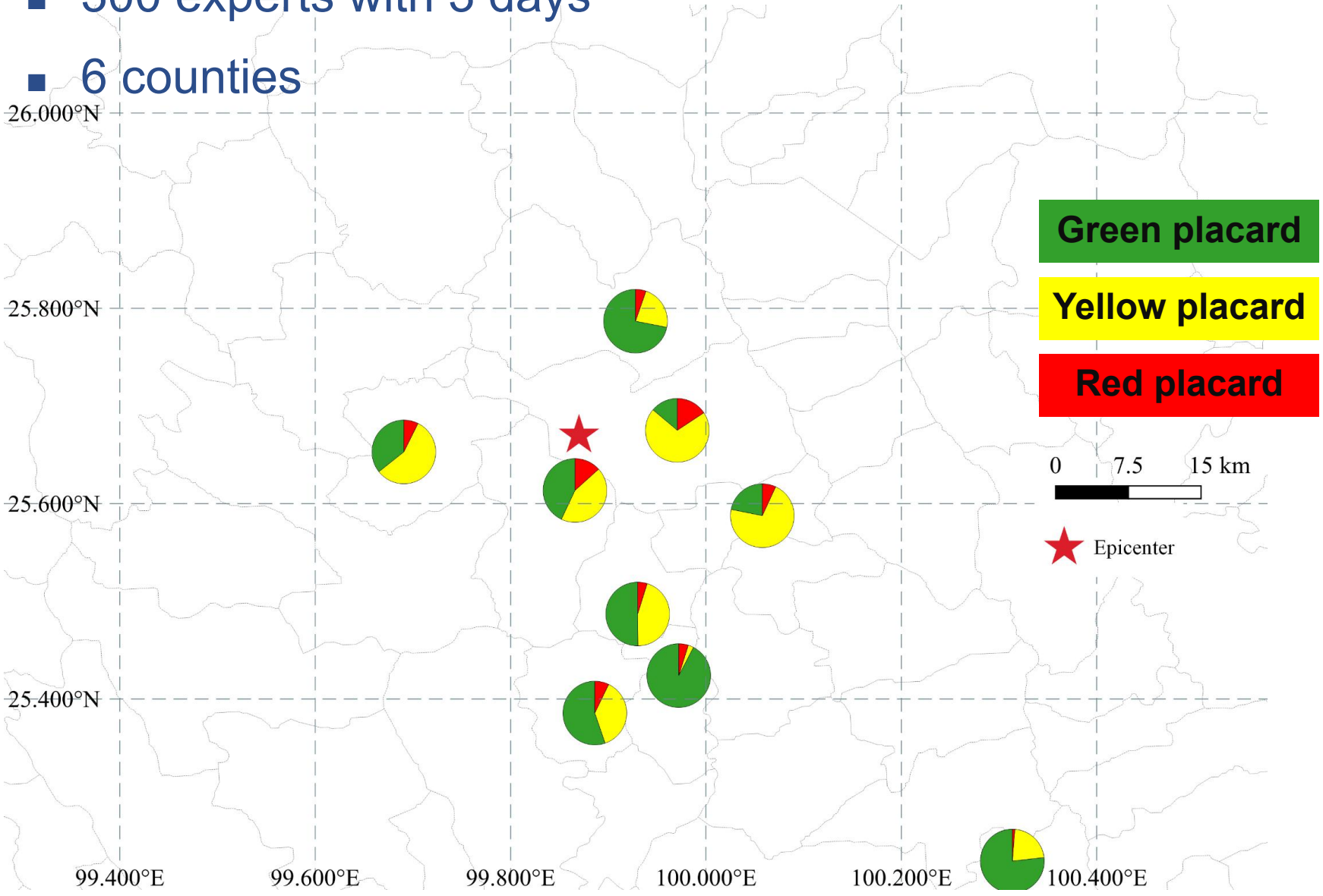
The corresponding peak ground acceleration (PGA) of the design earthquake (i.e., exceedance probability of 10% in 50 years) is 200

Outlines

1. Introduction of M6.4 Yangbi earthquake
2. Field investigation
3. Prompt damage assessment using RED-ACT
4. Other applications of RED-ACT
5. Conclusions

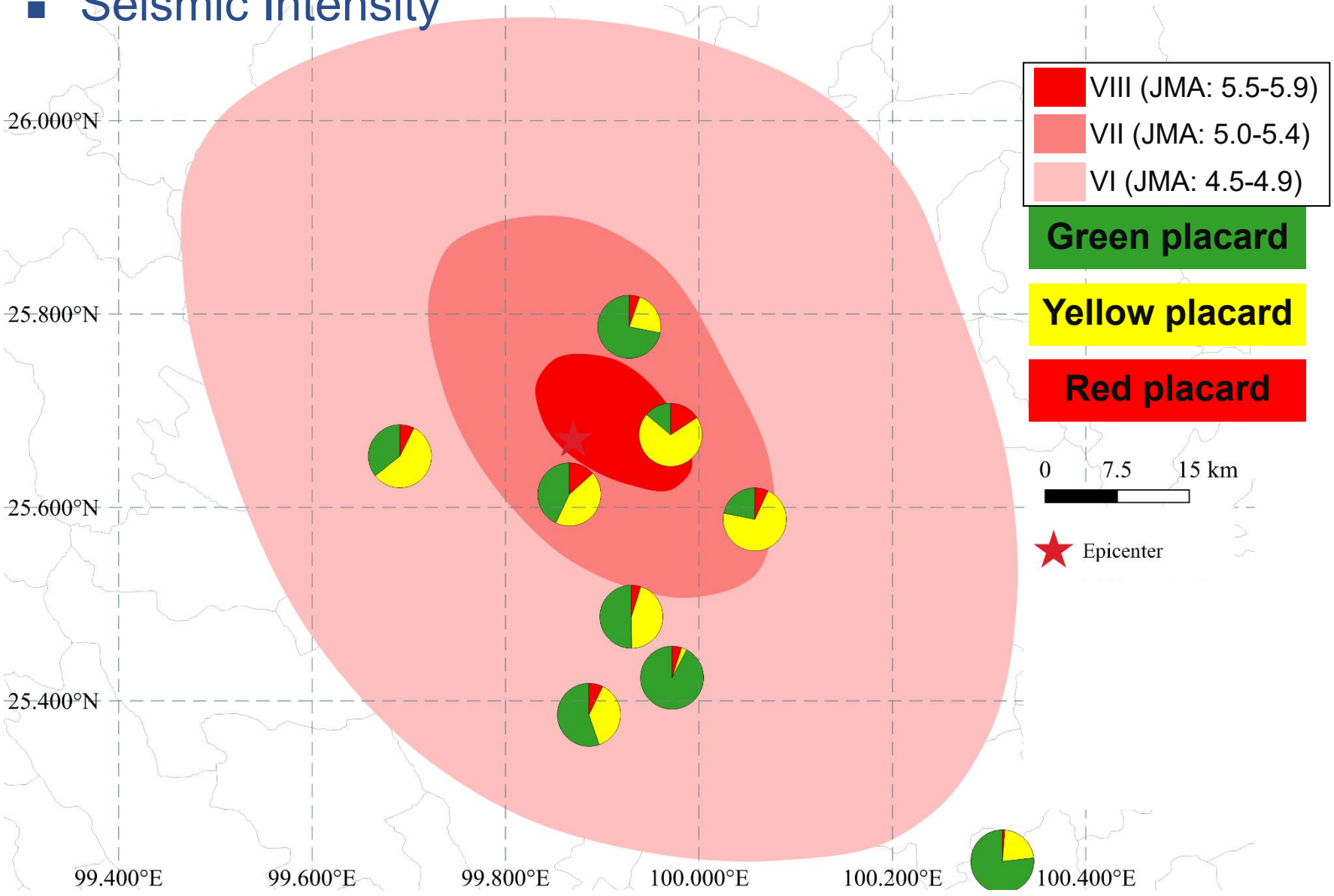
2. Field investigation

- 300 experts with 3 days
- 6 counties



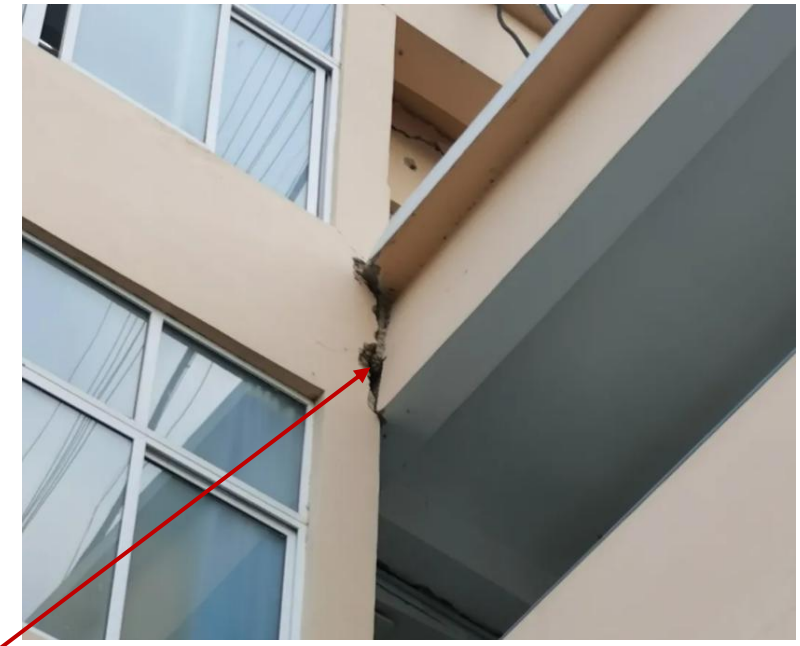
2. Field investigation

- Seismic Intensity



2. Field investigation: Damage to structures

- The buildings with formal seismic design and construction have good seismic capacity



Slight damage

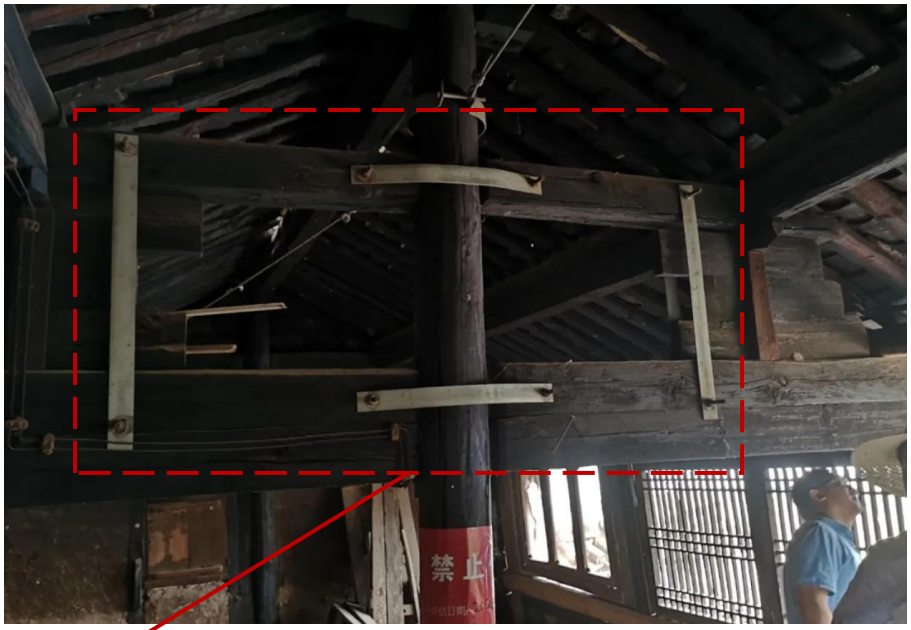
2. Field investigation: Damage to structures

- The seismic capacity of rural buildings is generally weak

Partially collapsed

2. Field investigation: Damage to strengthened building

- Seismic Reinforcement Project of Rural buildings
  - Since 2004
  - **Three strengthening method** for rural buildings



Steel braces

between wood components to improve the integrity

2. Field investigation: Damage to strengthened building

- Seismic Reinforcement Project of Rural buildings
  - Since 2004
  - **Three strengthening method** for rural buildings

Steel diagonal braces
between wood components to improve the overall deformation ability

Steel tie rods
between wood components to improve the overall deformation ability

2. Field investigation: Damage to strengthened building

- Seismic Reinforcement Project of Rural buildings
  - Since 2004
  - **Three strengthening method** for rural buildings

Steel braces

Steel diagonal braces

Steel tie rods

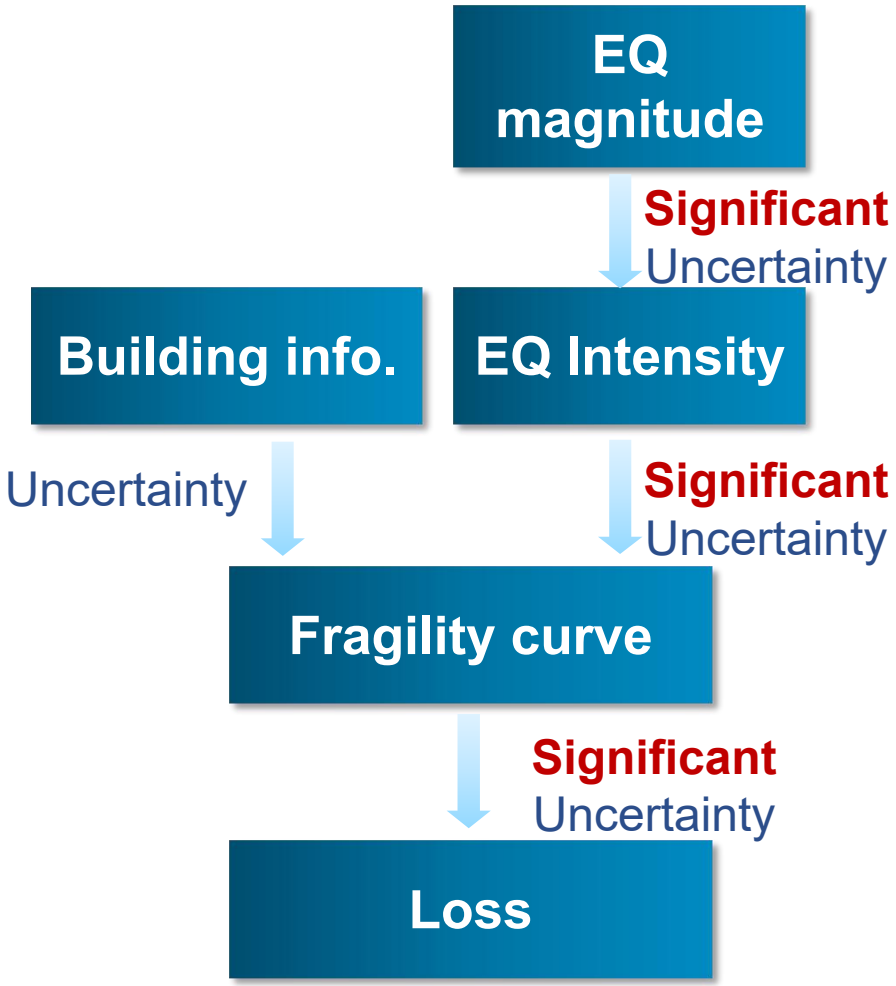
  - About **300 $** per building
  - **Inexpensive, simple and anti-collapse**

Outlines

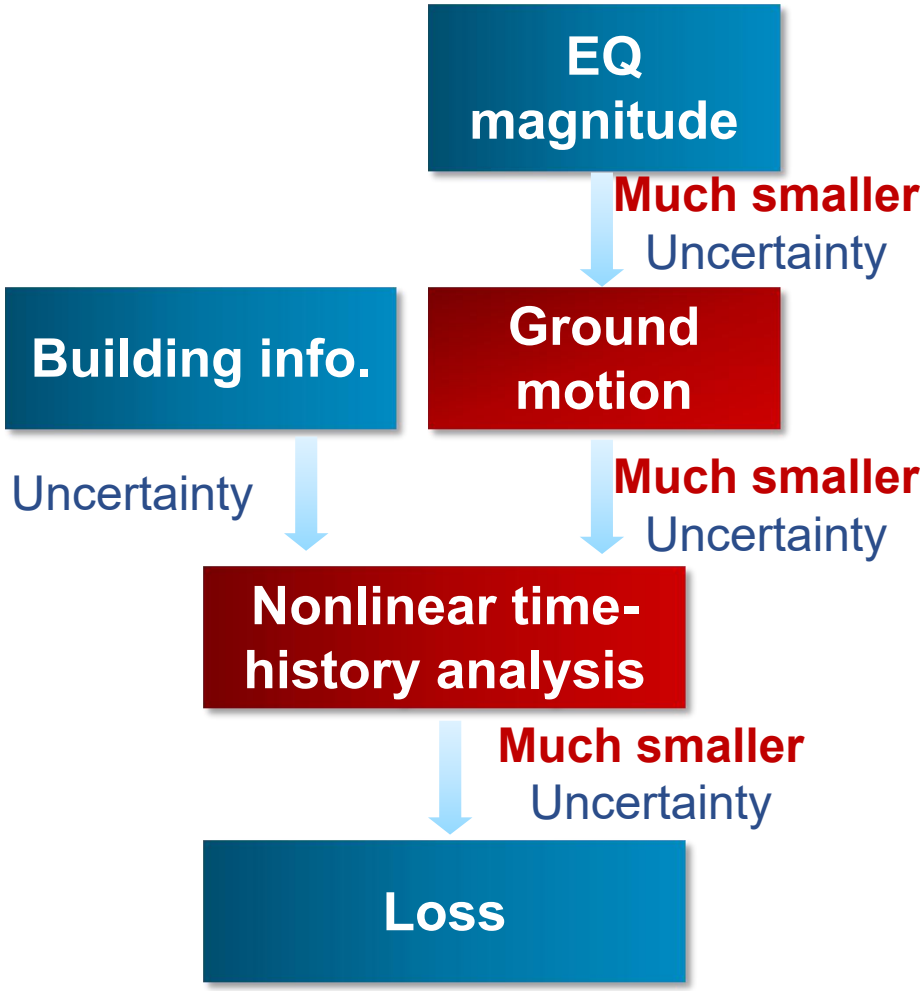
1. Introduction of M6.4 Yangbi earthquake
2. Field investigation
3. Prompt damage assessment using RED-ACT
4. Other applications of RED-ACT
5. Conclusions

3.Prompt damage assessment using RED-ACT

Conventional method

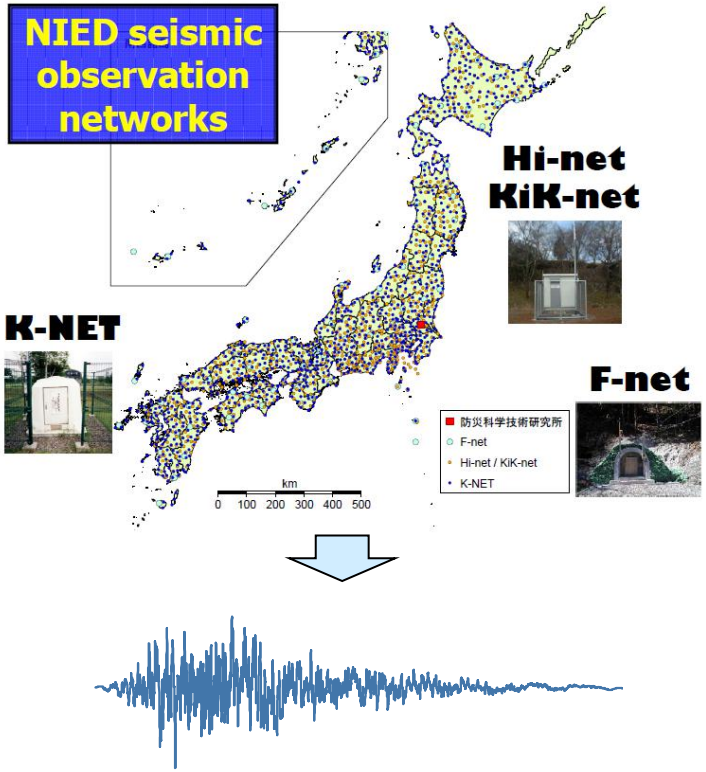


Proposed method



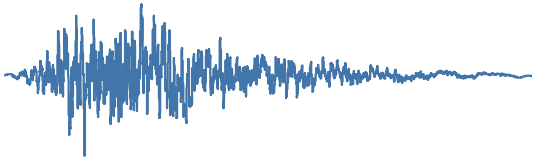
3.Prompt damage assessment using RED-ACT

Densely-distributed strong motion network



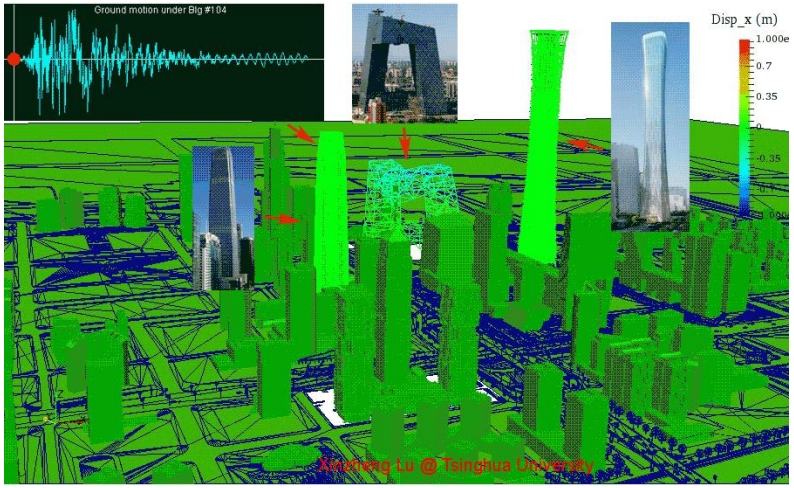
Actual ground motion records

City-scale nonlinear time-history analysis



Earthquake ground motion

Input



Rapidly evaluate seismic damage

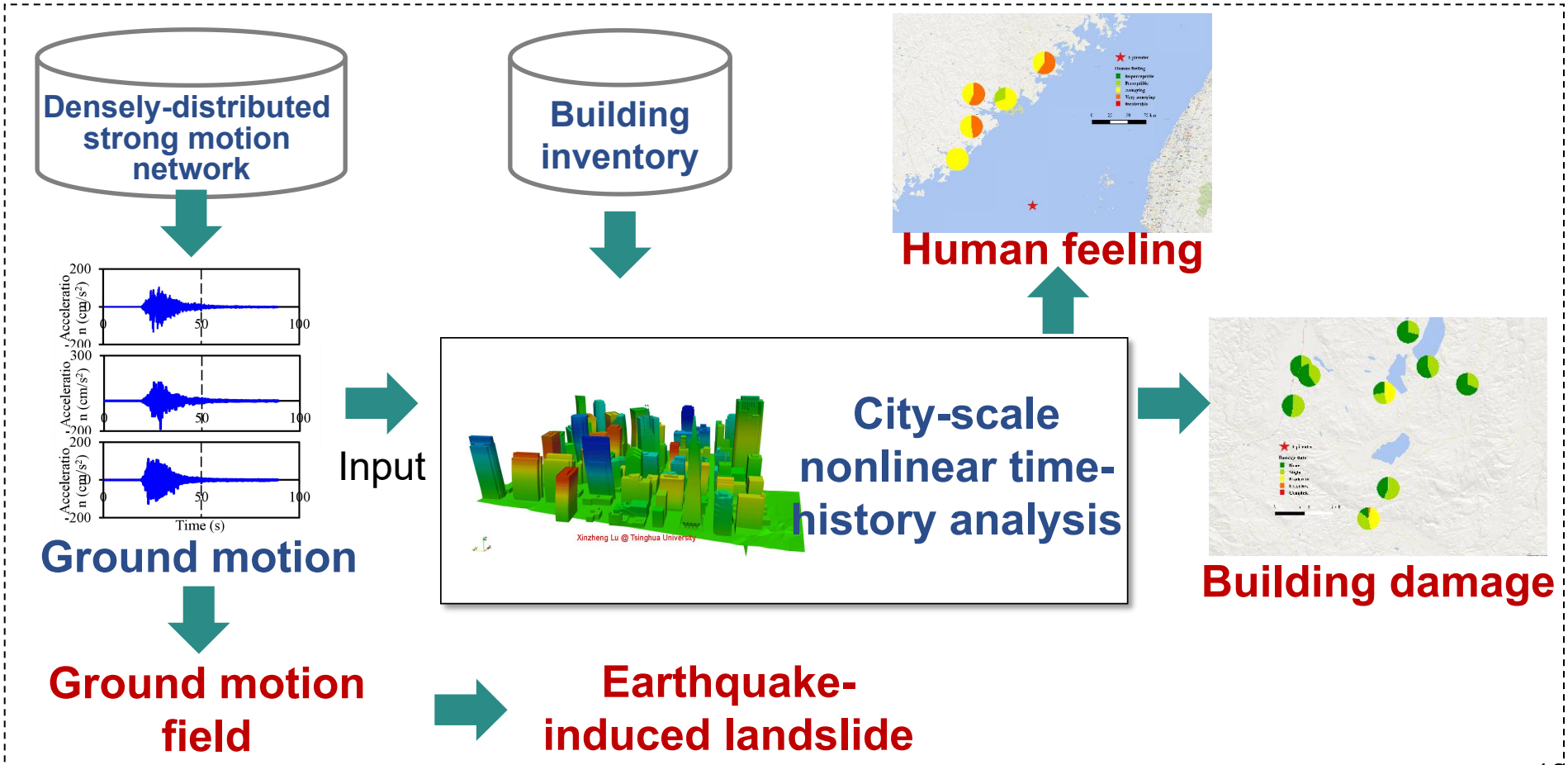
1 + 1 > 2 !

More Accurate

3.Prompt damage assessment using RED-ACT

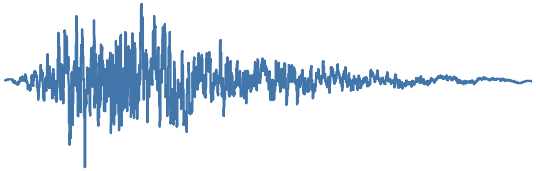
Recorded ground motion + **City-scale nonlinear time-history analysis**

Real-time Earthquake Damage Assessment RED-ACT



3.1 City-scale Nonlinear Time history analysis

- What is **City-scale nonlinear time-history analysis?**
  (NLTHA)



Earthquake ground motion

Input

Building

Structural dynamics

Seismic damage

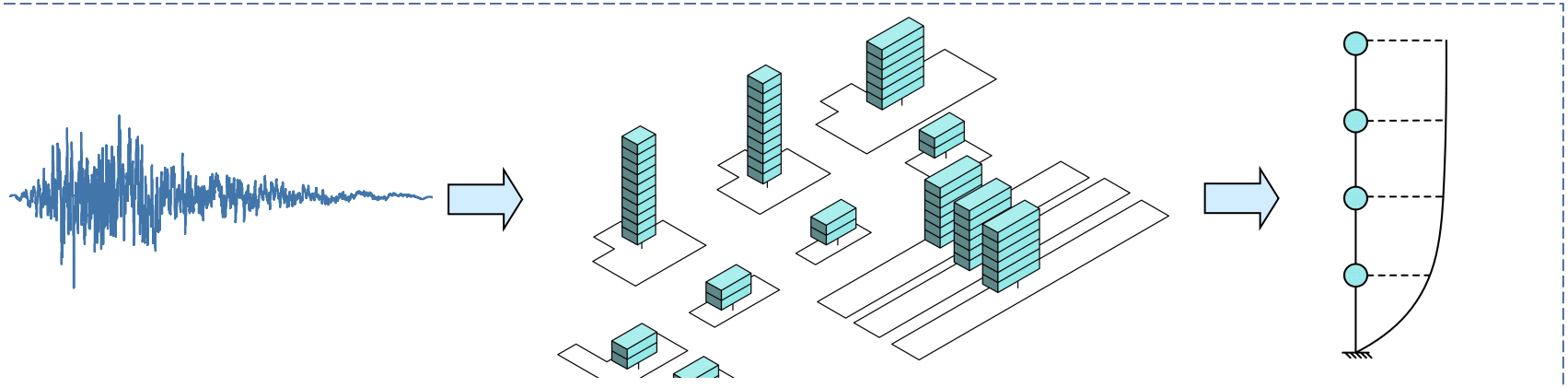
Input

City

Structural dynamics

3.1 City-scale Nonlinear Time history analysis

Structural dynamic models (Physics driven model)



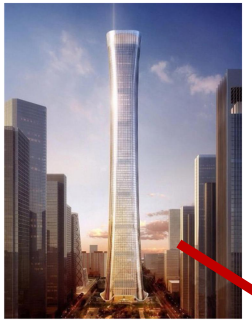
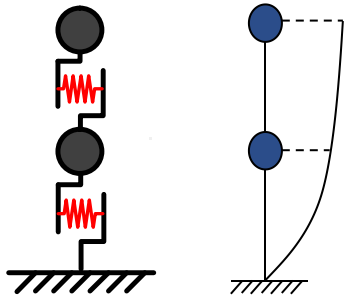
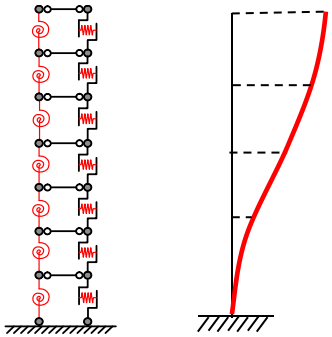
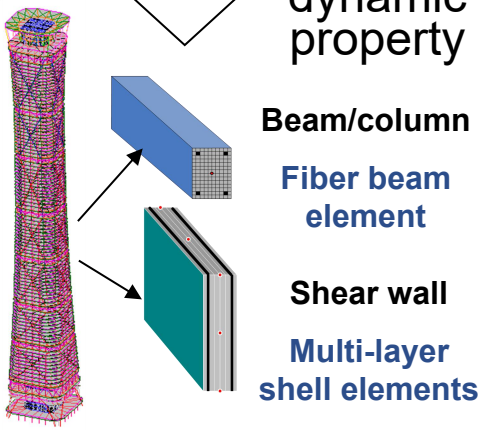
Advantages

- **Strictly following the fundamental of structural dynamics**
- **Accurately represent the features of individual buildings**
- **Accurately represent the characteristics of earthquakes**

Lu XZ, Guan H, Earthquake Disaster Simulation of Civil Infrastructures: From Tall Buildings to Urban Areas (2nd edition), Singapore: Springer, 2021.

3.1 City-scale Nonlinear Time history analysis

- Multi-scale structural dynamic models

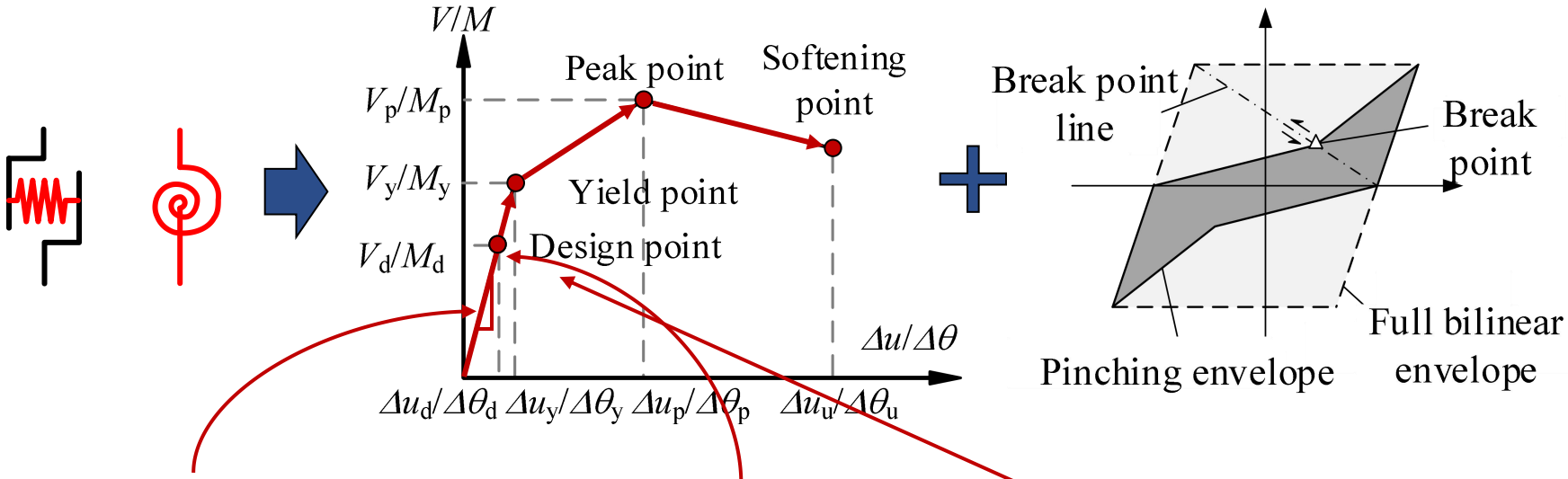
Multi-story buildings	Tall buildings	Special buildings
		
Shear deformation mode	Flexural-shear deformation mode	Complex dynamic property
		
MDOF shear model	MDOF flexural shear model	Refined FE model

Moderate-fidelity models

High-fidelity models

3.1.1 Parameter determination method

Each parameter has a clear physical meaning



Empirical formula

RC frame

$$T_1 = 0.25 + 0.00053H^2/\sqrt[3]{B}$$

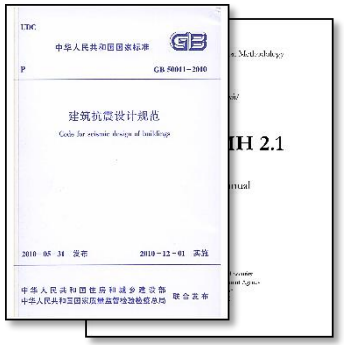
RC shear wall structures

$$T_1 = 0.03h^{0.9}$$

$$T_2 = 0.27T_1$$

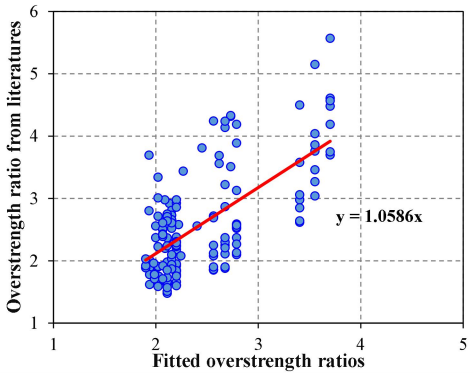
…

Codes



Suitable for different countries

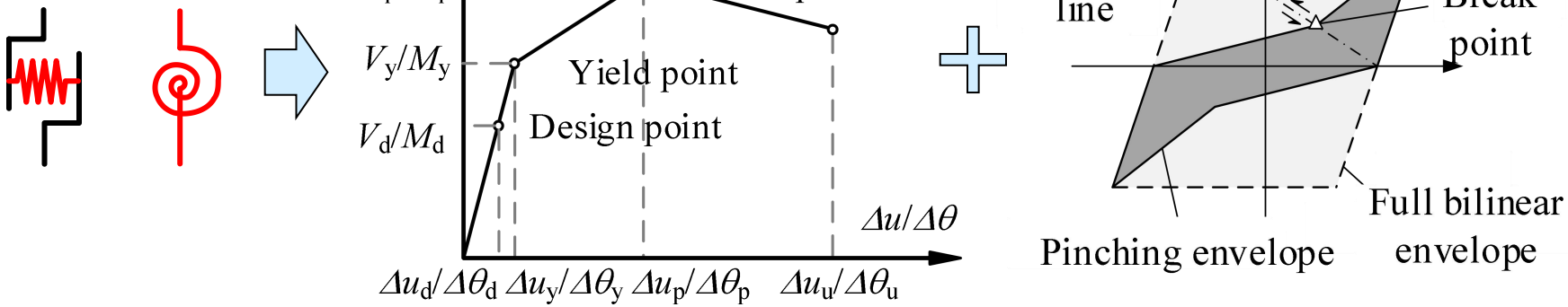
Test data



Parameter determination and damage assessment for THA-based regional seismic damage prediction of multi-story buildings, *Journal of Earthquake Engineering*, 2016

3.1.1 Parameter determination method

- Parameters adapted for Japan



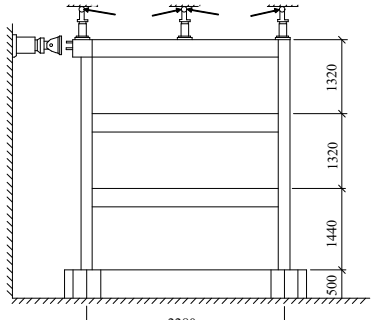
	Yield point	Ductility factor
Wood structures	$V_y = \alpha_y k_0 \frac{h}{120}$	$\begin{cases} \mu = 7.2 - 3.6Y/30, Y \le 30 \\ \mu = 3.6, Y > 30 \end{cases}$
RC structures	$V_y = \alpha_y \beta_y 0.2mg$	$\begin{cases} \mu = 7 - 5Y/30, Y \le 30 \\ \mu = 2, Y > 30 \end{cases}$
Steel structures	$V_y = \alpha_y \beta_y 0.2mg$	$\begin{cases} \mu = 5 - 3Y/30, Y \le 30 \\ \mu = 2, Y > 30 \end{cases}$

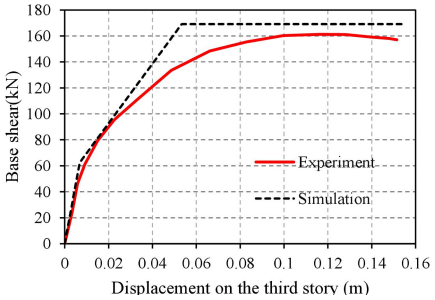
(Data source provided by Ji Dang)

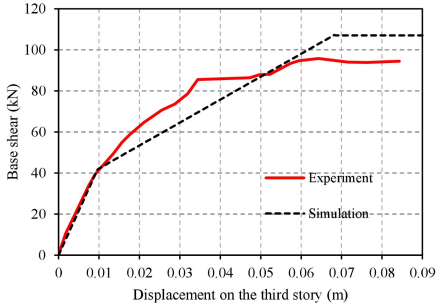
3.1.2 Higher accuracy of prediction

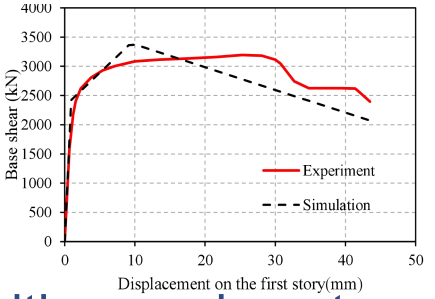
- Validation

Experiment



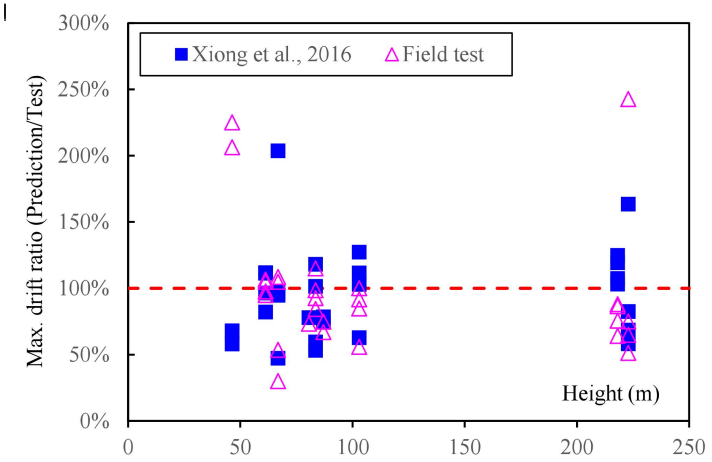






Agree well with experiment

Monitoring



Error of maximal drift:

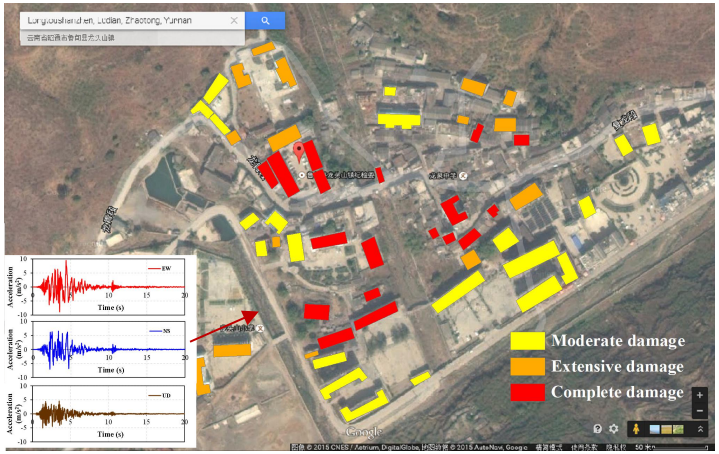
-4.6% (Proposed method)

-2.8% (Period updated)

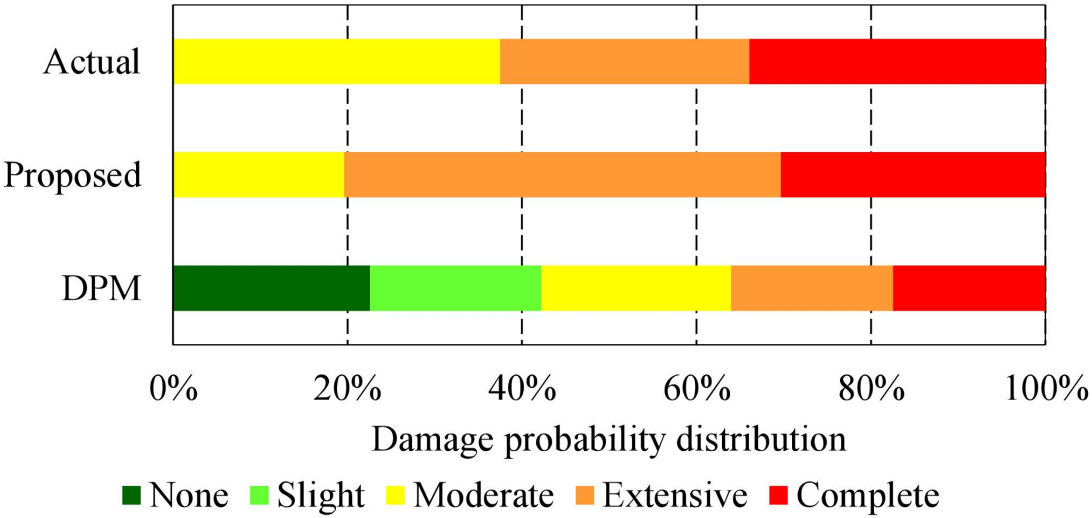
Parameter determination and damage assessment for THA-based regional seismic damage prediction of multi-story buildings, *Journal of Earthquake Engineering*, 2016

3.1.2 Higher accuracy of prediction

- Ludian Earthquake (M 6.5), 2014, China



Actual damage of Longtoushan Town



Compare with actual damage and DPM method

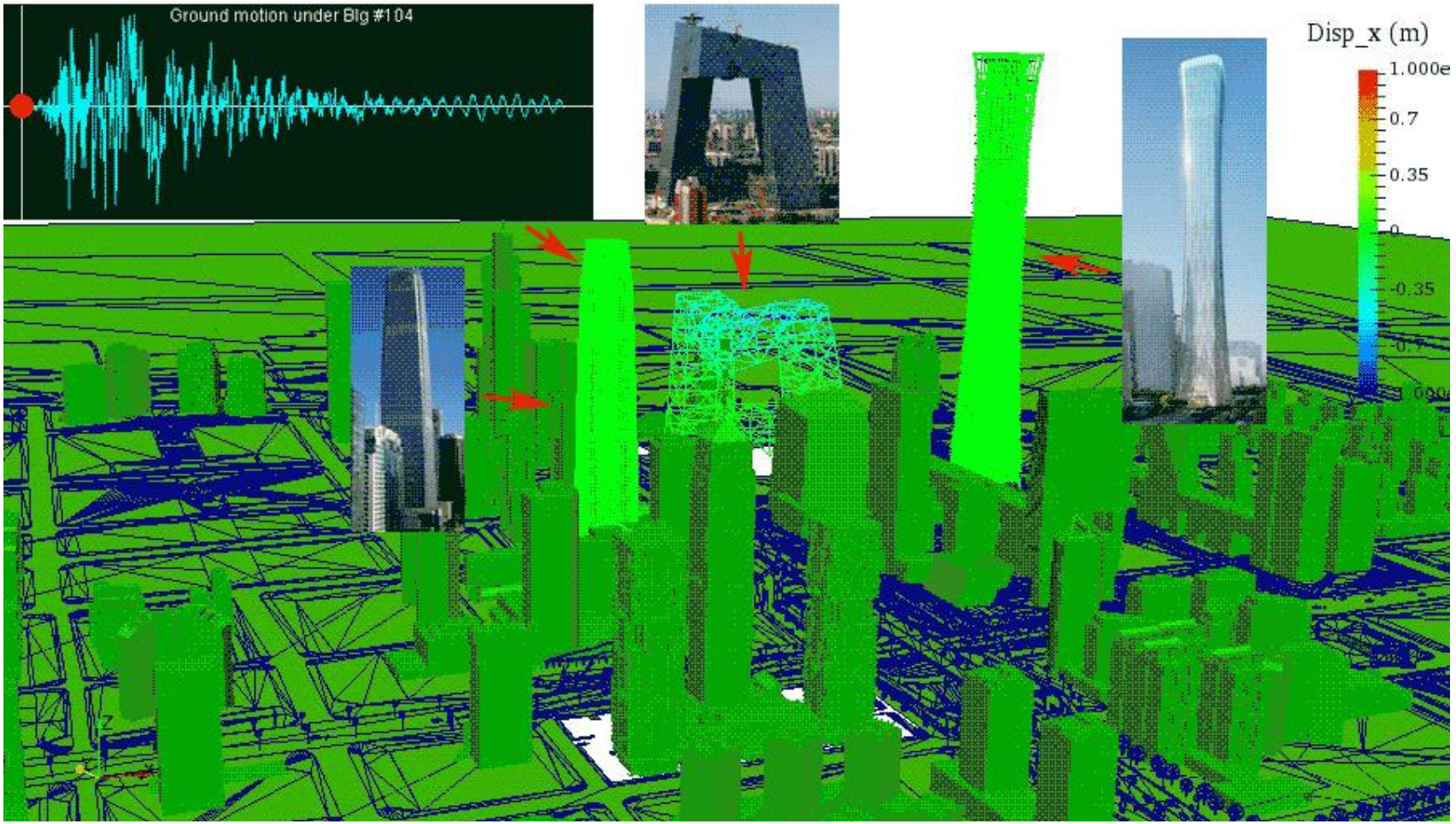
(DPM: Damage Probability Matrices)

- ✓ **Agree well with actual damage**
- ✓ **More accurate than the traditional DPM method**

Parameter determination and damage assessment for THA-based regional seismic damage prediction of multi-story buildings, *Journal of Earthquake Engineering*, 2016

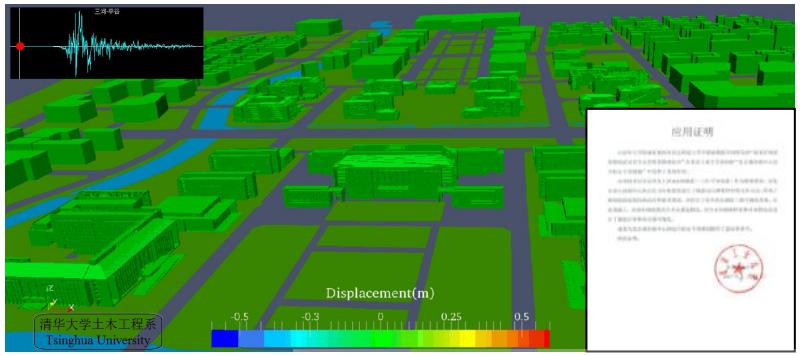
3.1 City-scale Nonlinear Time history analysis

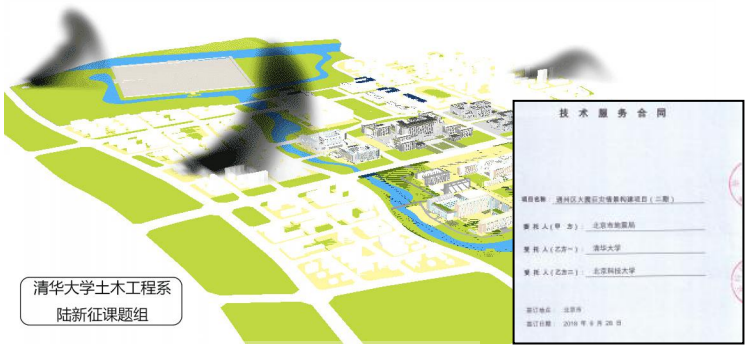
1. Explicit physical mechanism
2. Higher accuracy
3. Adaptive data resolutions
4. Intuitive and intelligible visualization
5. Death, Dollar, Downtime & Resilience
6. Various secondary disasters



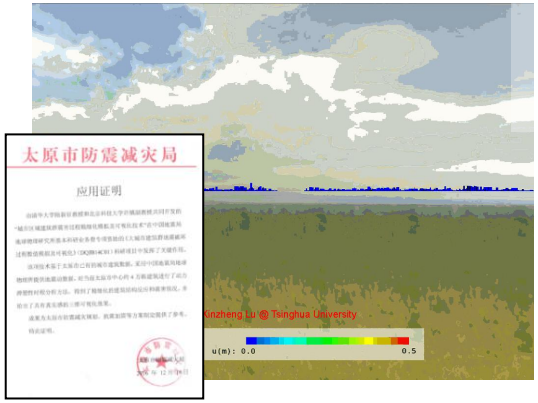
Beijing CBD, 1679 Sanhe-Pinggu M8.0 Earthquake

3.1 City-scale Nonlinear Time history analysis





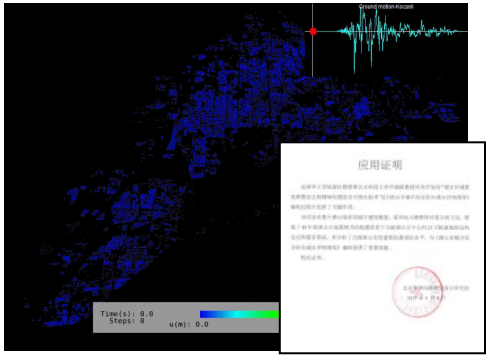
Beijing 2nd Adm Center (2017), Tongzhou District (2018) & Daxing District (2019)



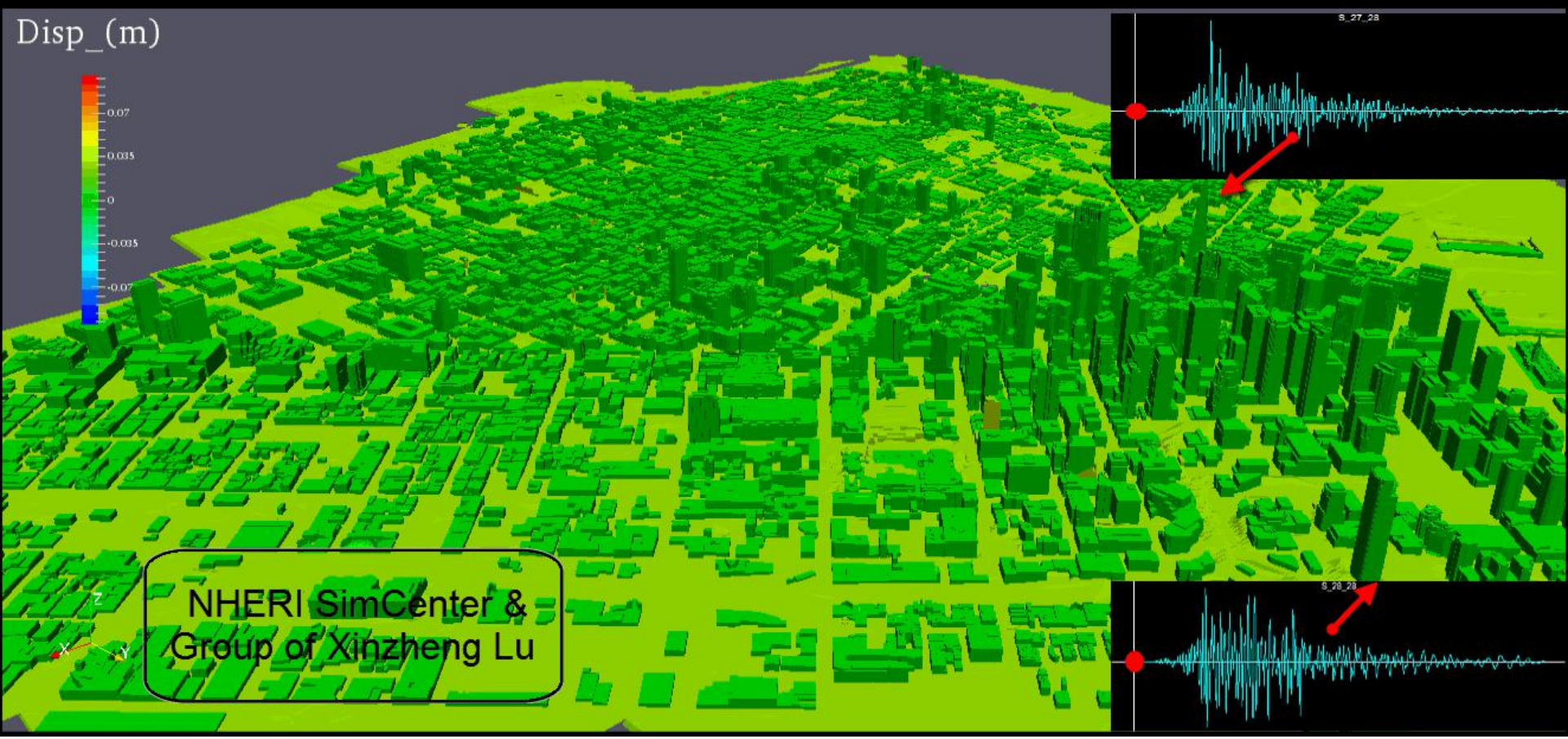
Taiyuan (2017)

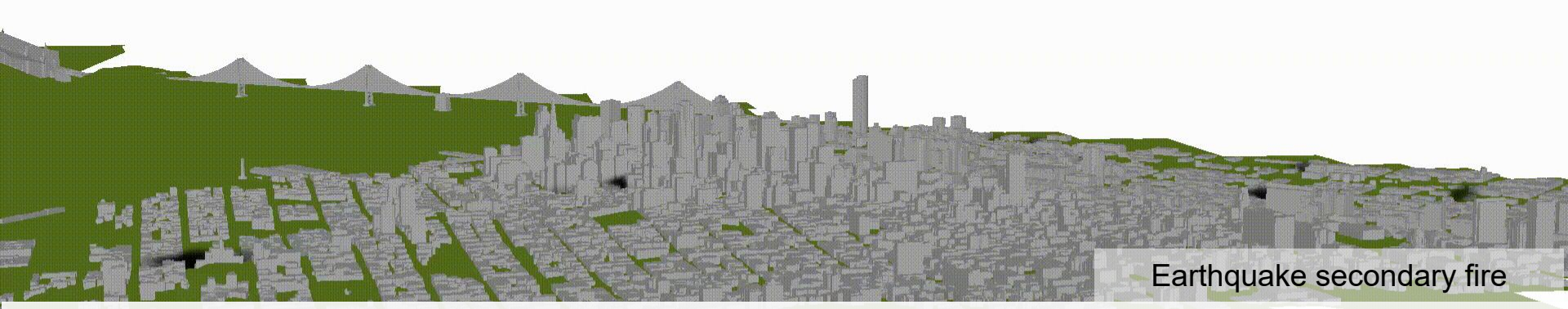
Xiong'An (2017)

New Beichuan (2018)



Tangshan (2016)





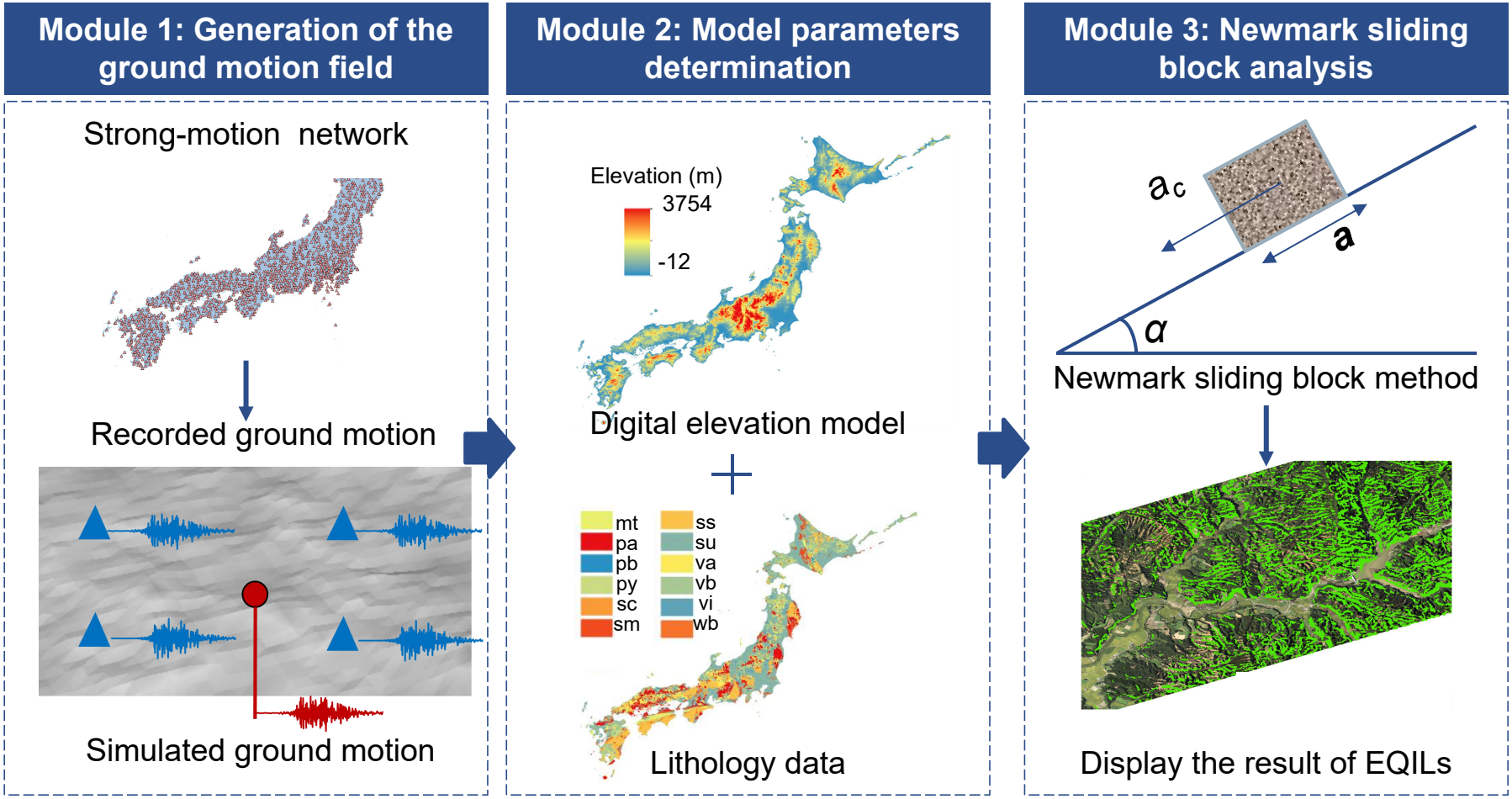
Earthquake secondary fire

San Francisco Bay Area, M 7.0 Earthquake of Hayward Fault

1,843,351 buildings, Courtesy NHERI SimCenter

3.2 Earthquake-induced landslides assessment

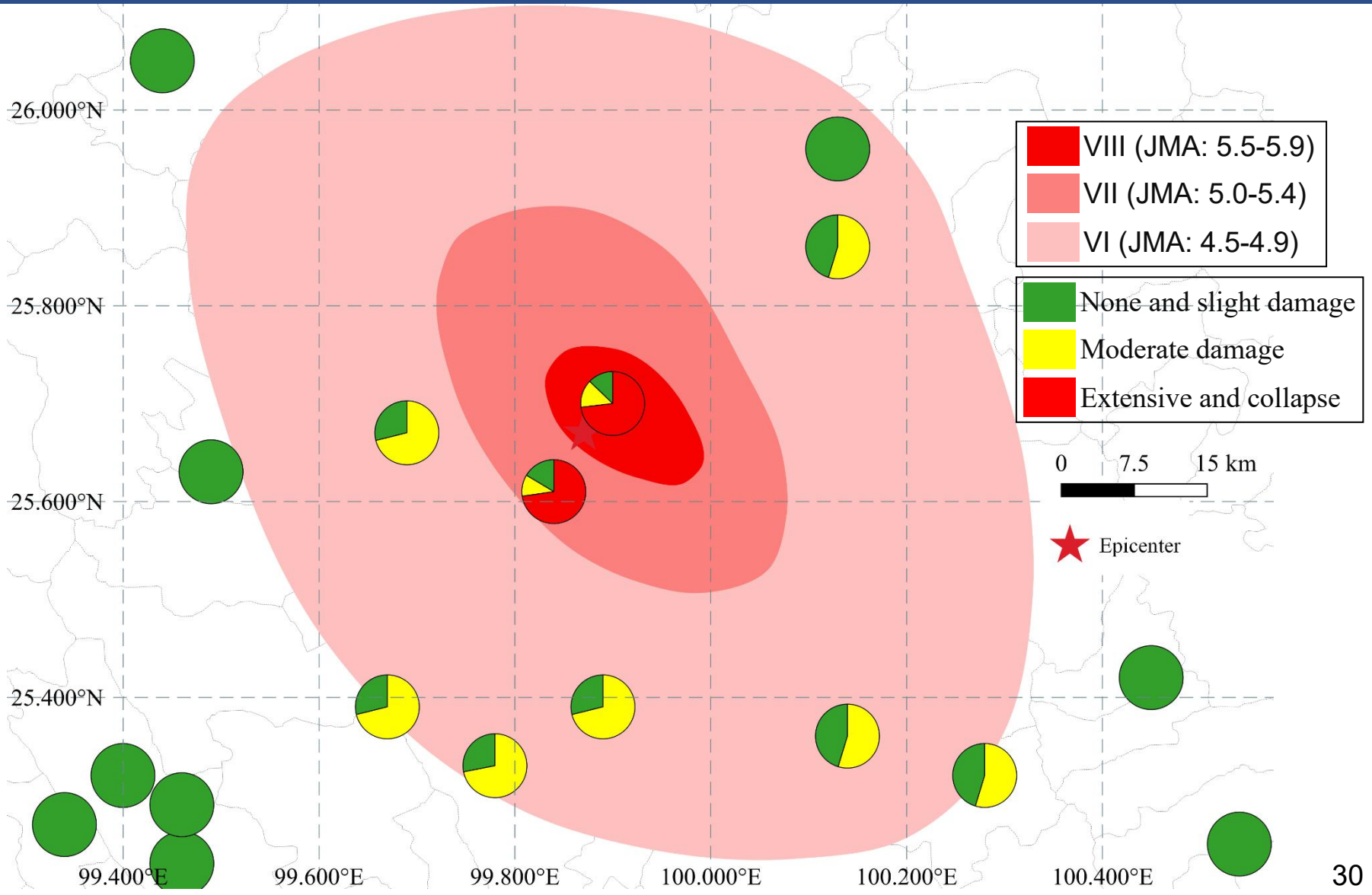
- Near-real-time prompt assessment for regional EQILs



Near-real-time prompt assessment for regional earthquake-induced landslides using recorded ground motions, *Computers & Geosciences*, 2021

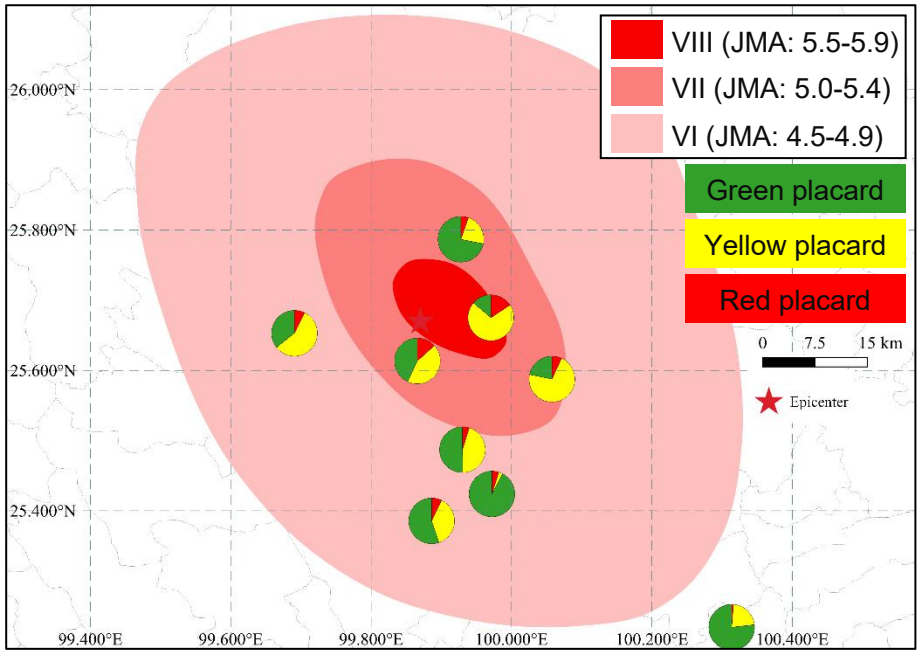
3.3 Prompt damage assessment using RED-ACT

RED-ACT

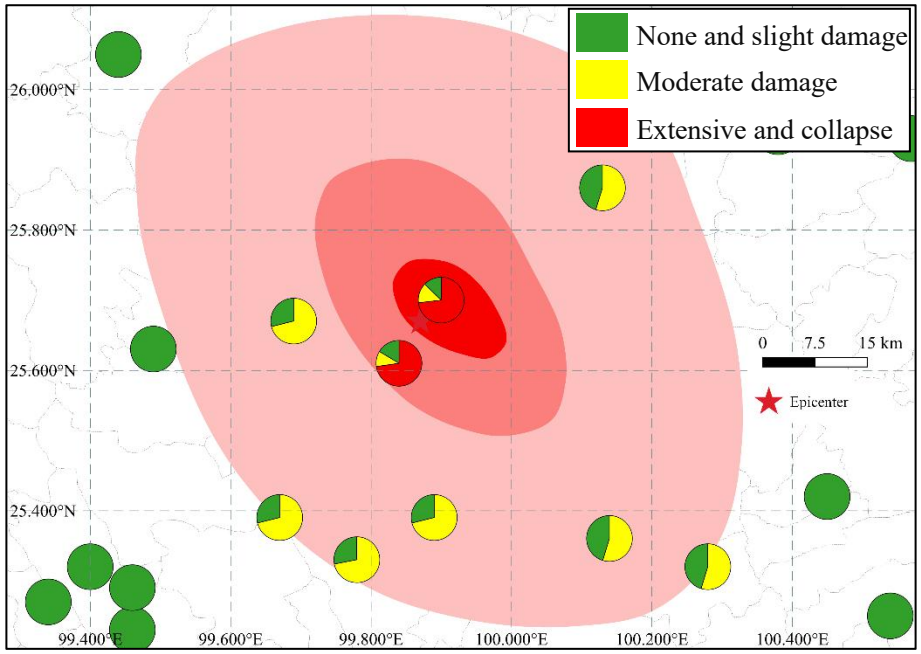


3.3 Prompt damage assessment using RED-ACT

- Compared with actual damage



Field investigation



RED-ACT

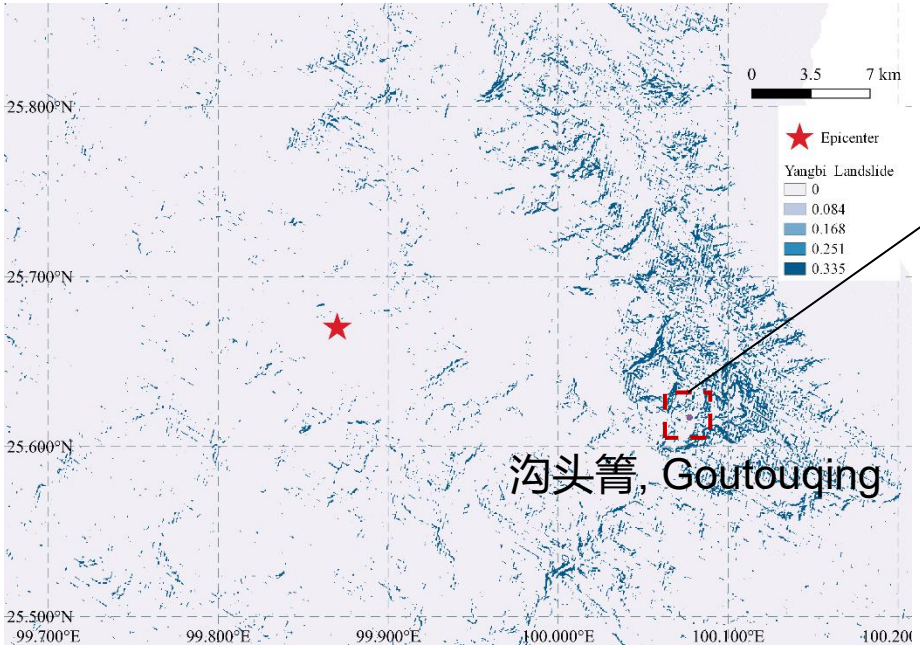
- **300 experts**
- **3 days**

- **1 student**
- **< 1 h after getting ground motion**

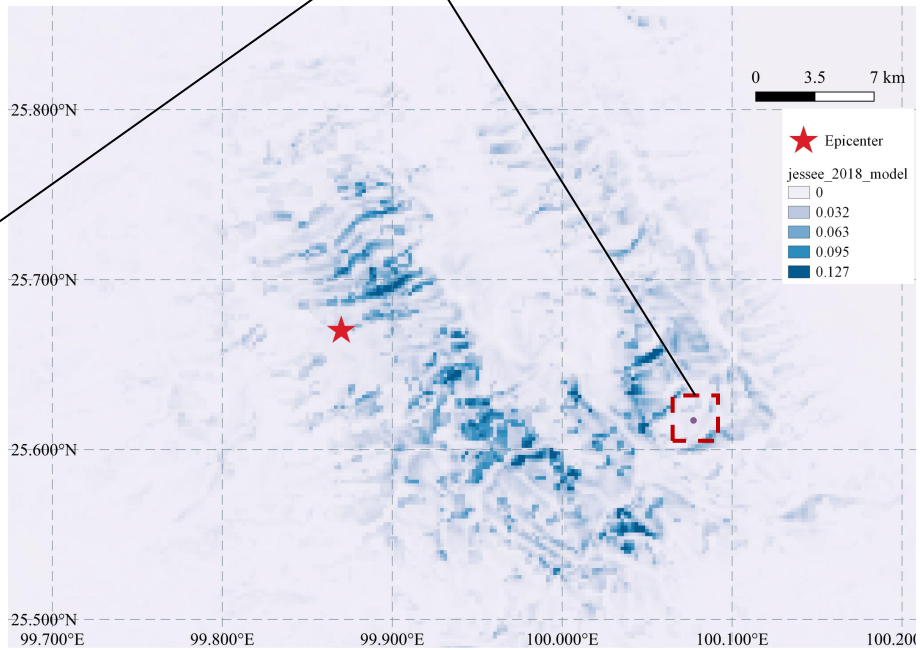
3.3 Prompt damage assessment using RED-ACT

- EQILs assessment
  - Our method: high probability
  - PAGER: low probability
  - Agree well with actual damage

Landslide location



Our method



PAGER

Wald et al., 2010. PAGER--Rapid assessment of an earthquake's impact.

Outlines

1. Introduction of M6.4 Yangbi earthquake
2. Field investigation
3. Prompt damage assessment using RED-ACT
4. Other applications of RED-ACT
5. Conclusions

4.Other applications of RED-ACT

- Jiuzhaigou Earthquake (M 7.0), 2017, China

2017.08.08 四川九寨沟 7.0 级地震破坏力分析

清华大学土木工程系防灾减灾工程研究所

致谢和声明：

感谢中国地震局“国家强震动台网中心”为本研究提供数据支持。本分析仅供科研使用，具体灾情和灾损分析应根据现场调查情况确定。

本分析由张磊、顾栋炼、程庆乐、田源、曾翔等研究生及中国地震局工力所林旭川博士等共同完成，其中张磊负责地震动处理和反应谱分析，顾栋炼负责单体建筑分析工作，程庆乐负责区域建筑分析工作。

- **< 2 h** after getting ground motion
- **< 5 h** after earthquake

Predictions of some agencies

“Hundreds casualties”, “Tens of thousands of collapse”

[redacted]减灾中心　2017 年 8 月 8 日 22 时

四川省九寨沟县 7 级地震快速评估

- 初步判断，此次地震可能造成 2.4 万间房屋倒塌或严重损坏，11.2 万间房屋一般损坏；地震可能造成数十人至上百人死亡，上千人受伤（依据 2010 年人口普查数据）。

Our prediction

“Very small possibility of collapse”

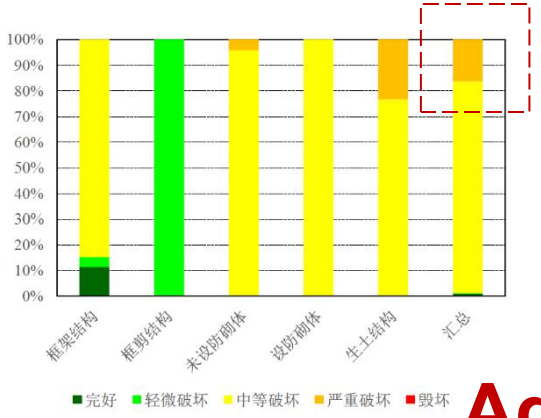


图 10 九寨百河强震台站地震动记录对阿坝地区典型农村的破坏力

Site investigation report

“73,671 damaged, 76 collapsed”

灾　情　简　报

第二期

[redacted] 2017 年 08 月 8 日 23 时 19 分

2017 年 08 月 08 日四川省阿坝州九寨沟县 7.0 级地震震情灾情报告

地震基本参数

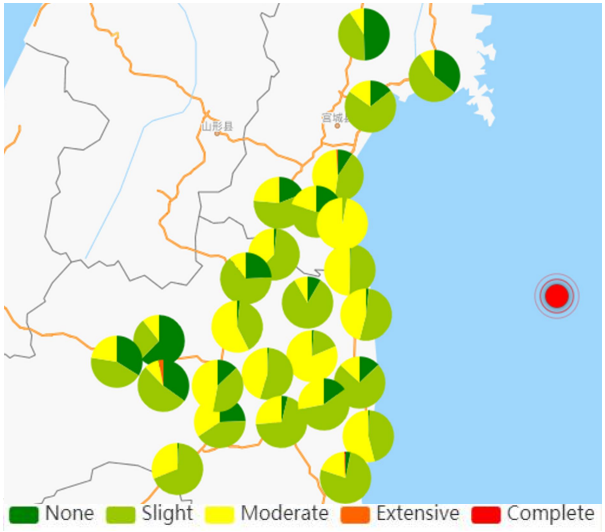
发震时间：2017 年 08 月 08 日 21 时 19 分

Agree well

4.Other applications of RED-ACT

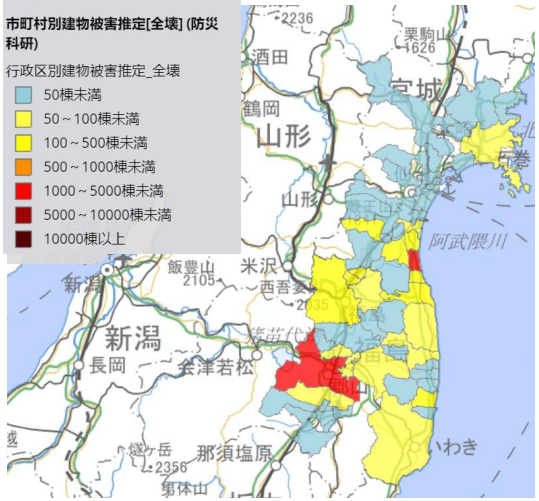
- Fukushima Earthquake (M 7.3), 2021, Japan
  - Field investigation: **small possibility of collapse**
    - Collapsed (全壊): 32, Extensive damage (半壊): 259

RED-ACT



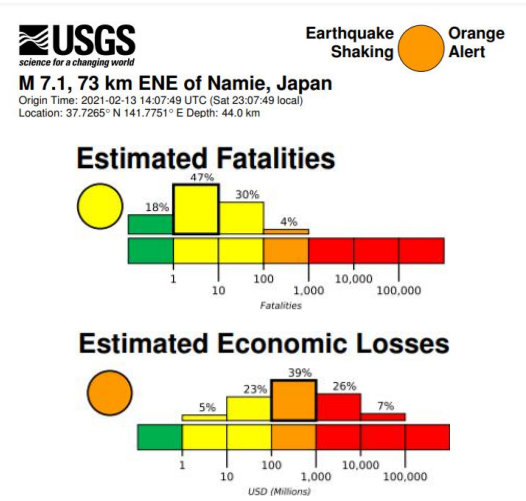
Very small possibility of collapse

NIED-CRS



50~500 buildings will collapse in a large area

USGS PAGER



Required a regional or national level response

消防庁災害対策本部. 福島県沖を震源とする地震による被害及び消防機関等の対応状況（第16報）

4.Other applications of RED-ACT

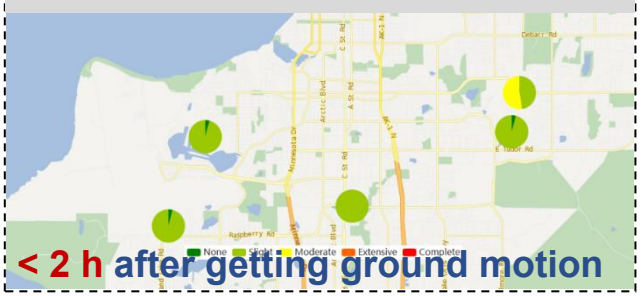
- China, USA, Japan, Italy, New Zealand, etc.

Since 2016, significant earthquakes around the world

Domestic **65**, Abroad **51**

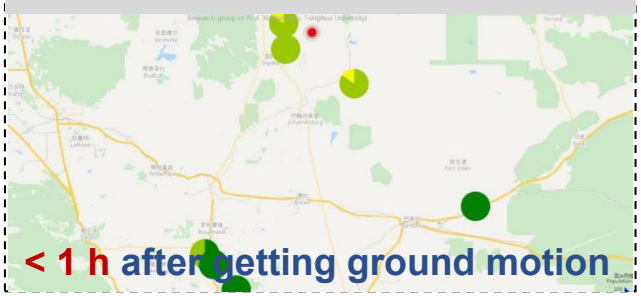
Last updated: 2021/6/15

2018 M7.0 Anchorage earthquake



< 2 h after getting ground motion

2019 M7.1 Ridgecrest earthquake



< 1 h after getting ground motion

China Earthquake Networks Center

played a **critical** role

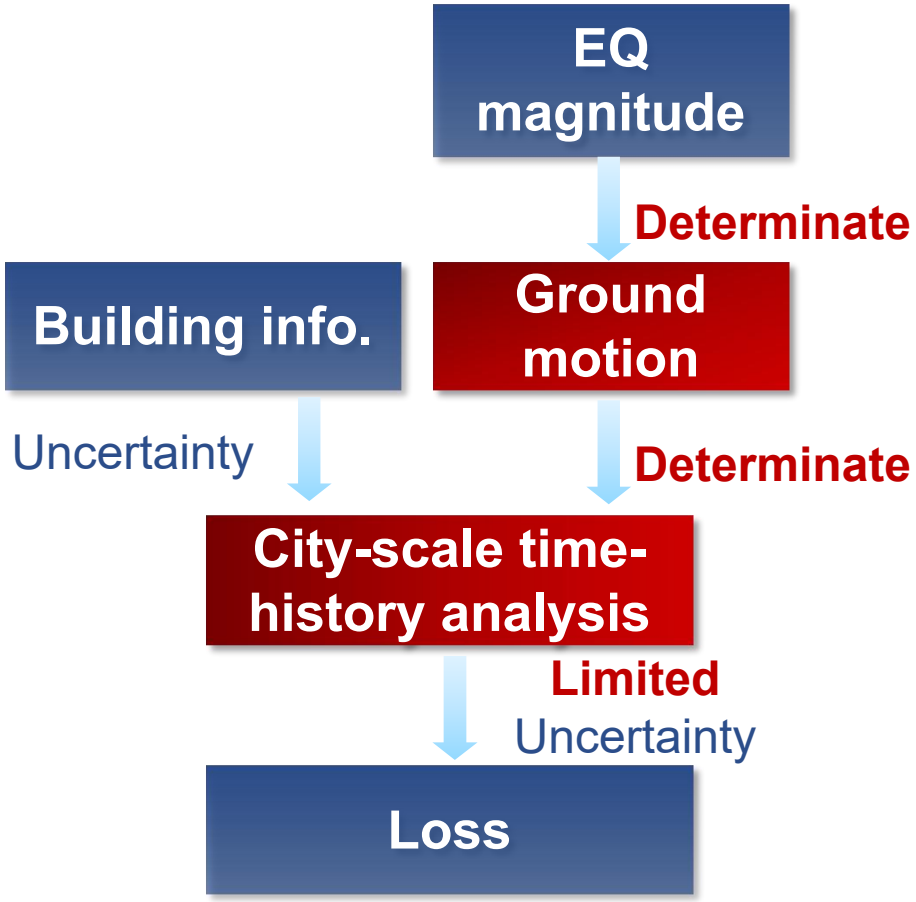
Outlines

1. Introduction of M6.4 Yangbi earthquake
2. Field investigation
3. Prompt damage assessment using RED-ACT
4. Other applications of RED-ACT
5. Conclusions

5. Conclusions

Recorded ground motion + **City-scale nonlinear time-history analysis**

Real-time Earthquake Damage Assessment (RED-ACT)



Advantages

Accurate ground motion

+

Accurate structural dynamic equations

=

Accurate seismic damage assessment

Acknowledgements

Tsinghua University

Prof. Lieping Ye, Aizhu Ren

Dr. Zhen Xu, Xiao Lu, Chen Xiong, X Zeng, Y Tian, ZB Yang

B Han, QL Cheng, DL Gu, CJ Sun

China Earthquake Administration

Prof. Mengtan Gao, Yanxiang Yu
CH Fu, XC Lin

Berkeley UNIVERSITY OF CALIFORNIA

Prof. S Mahin, Dr. F McKenna
Dr. M Schoettler

Stanford University

Prof. KH Law

Saitama University 埼玉大学

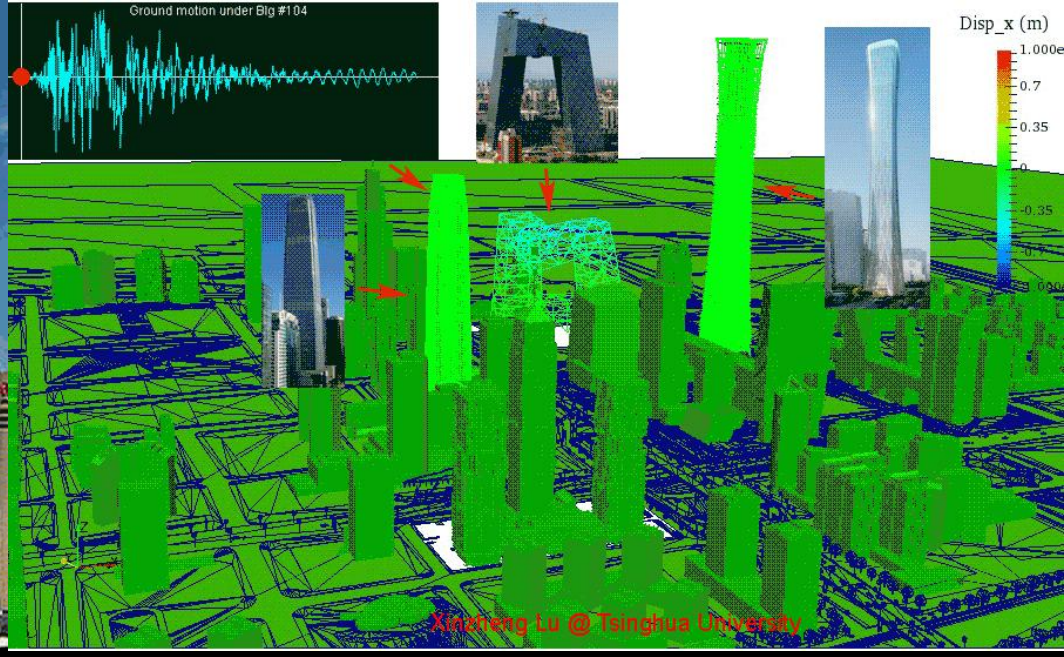
Prof. J Dang

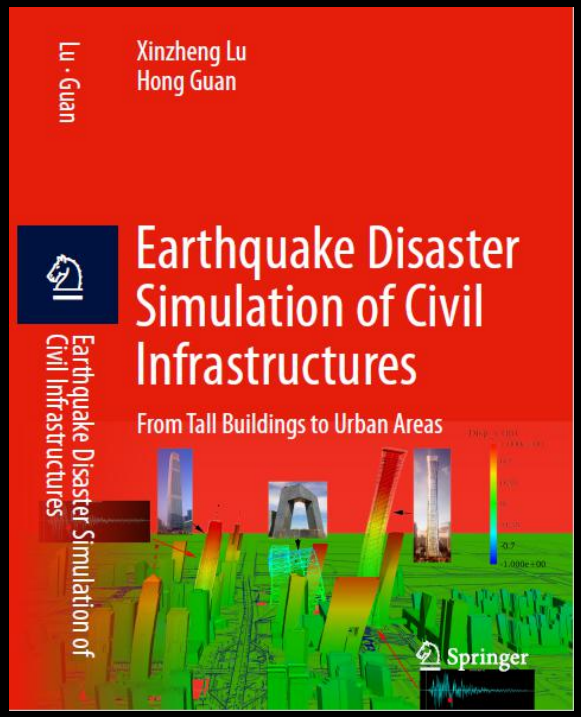
NSFC National Natural Science Foundation of China

中华人民共和国科学技术部 Ministry of Science and Technology of the People´s Republic of China

XPLORER PRIZE 科学探索奖

National Science Foundation





Thank you for your attention!

www.luxinzheng.net

luxz@tsinghua.edu.cn