Final Workshop on J-RAPID-Nepal
June 21st and 22st, 2016

Re-evaluation of seismic vulnerability on historic structures based on damage investigation of the 2015 Nepal earthquake and proposal of retrofitting methods

(Research period: 2015.07～2016.06)

Junji Kiyono

Kyoto University, JAPAN

Prem Nath Maskey

Tribhuvan University, NEPAL

Research Members

Team Leader:

Prof. Junji Kiyono (Kyoto University)

Members (Japan side):

Prof. Fumio Yamazaki (Chiba University)
Prof. Takeyuki Okubo (Ritsumeikan University)
Assoc. Prof. Aiko Furukawa (Kyoto University)
Assoc. Prof. Naoko Itaya (Ritsumeikan University)
Mr. Rishi Ram Parajuli (Kyoto University)

Members (Nepal side):

Prof. Prem Nath Maskey (Tribhuvan University)
Dr. Hari Ram Parajuli (Tribhuvan University)

Research Outline and Objectives

Backgrounds

- Recent earthquake damage to world heritages
- The 2015 Gorkha earthquake and historical structures

Previous studies

- Seismic hazard analysis
- Global COE program of Ritsumeikan University (2008-2012)
  - Investigation of historic buildings
  - Preliminary laboratory test and numerical simulation

Objectives

- Field investigation in damaged area
- Re-examine seismic capacity of building by laboratory test
- Propose strengthening and retrofitting methods
- Vulnerability assessment from physical and social aspects

Present and on-going researches

Backgrounds

Background

Recent earthquake damage to World Heritages

- **Iran Bam Earthquake**

  2003/12/26, Mw6.5

  Fatality: more than 20,000

  Bam and its cultural Landscape (2004)

  Arg-e Bam, soon list of WH in danger (2004)

- **Central Java Earthquake**

  2006/5/27, Mw6.3

  Fatality: 5,716

  Borobudur Temple Compounds (1991)

  Pranbanan Temple Compounds (1991)

- **Nepal Kathmandu Valley**

  2015/4/24, Mw7.8

  Fatality: 8,857

  Cultural heritage (1979)

  List of WH in Danger (2003)

Background

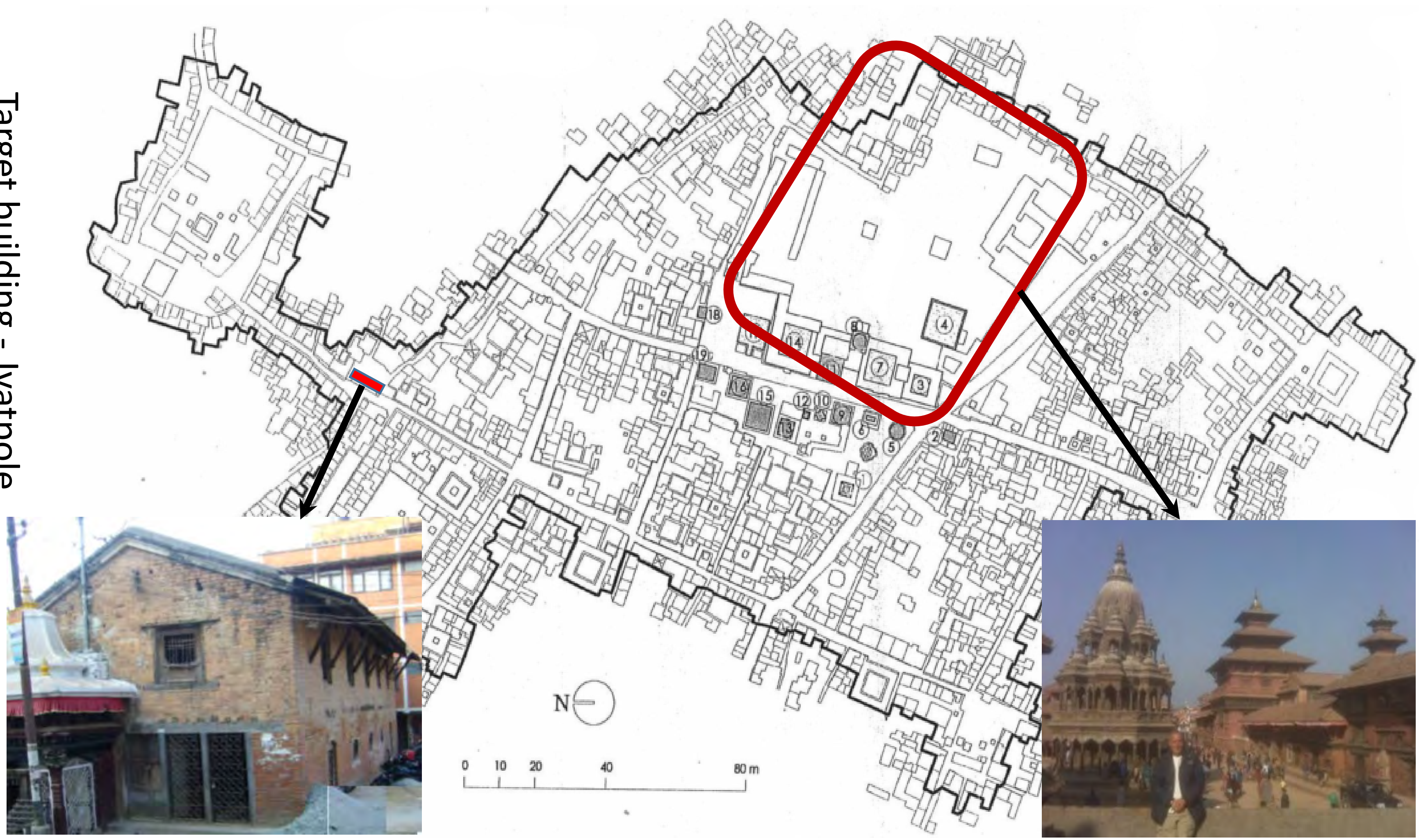
7 World heritage sites in Kathmandu

Previous Studies

Previous Study

Historic building investigation

Target building - Jyatpole

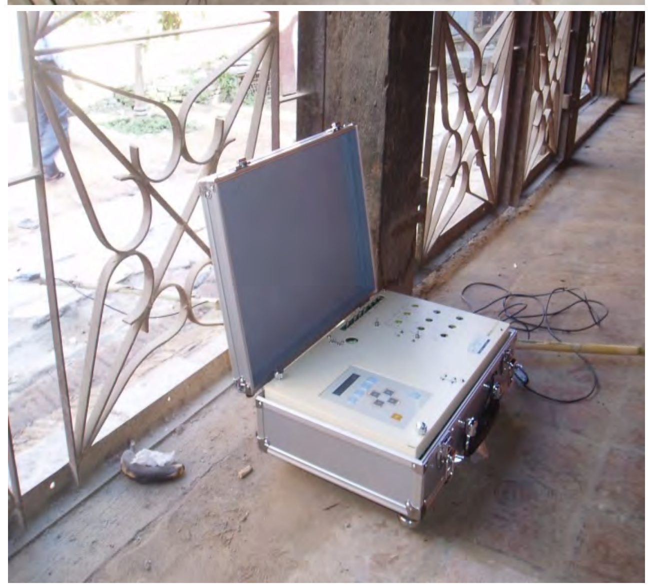


Previous Study

Historic building investigation

- Ground Floor
  - 4 points
- First Floor
  - 4 points
- Second Floor
  - 2 points

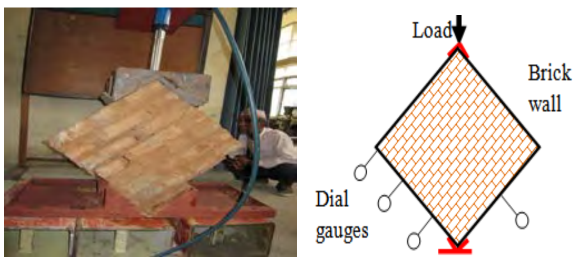
❖Obtained natural periods of building from the Fourier spectra of micro-tremor observations



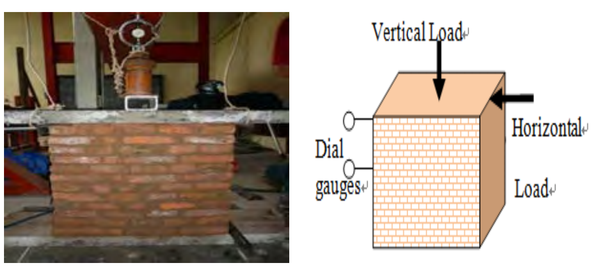
Previous Study

Laboratory test

Compression test



Shear test



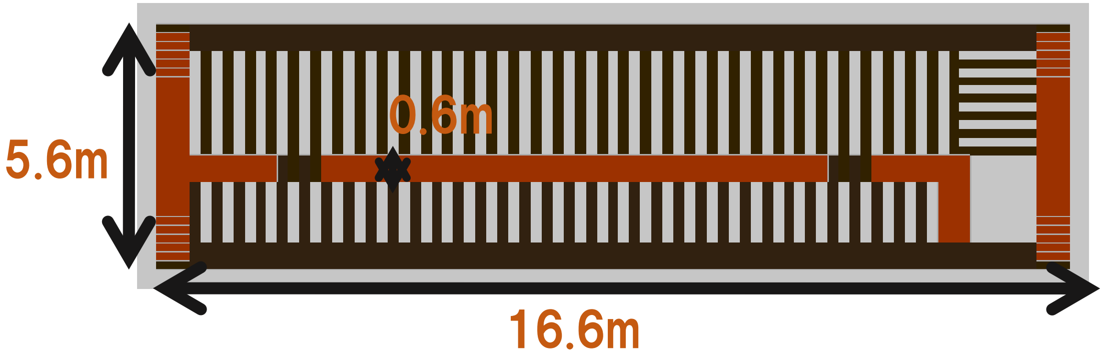
Combined test

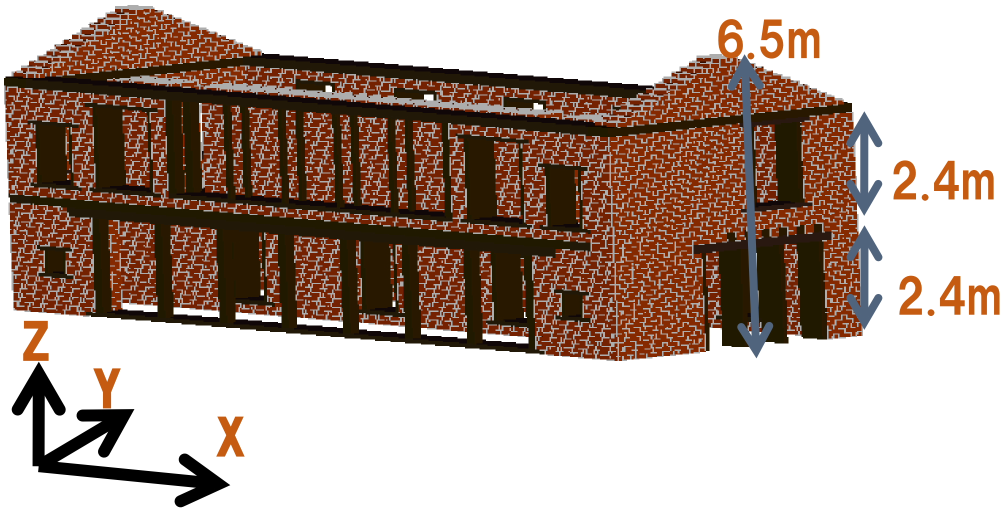
Loading Test at Tribhuvan Univ.

Variable	Brick	Mortar
Mass density (kg/m^3)	1.76×10^3	1.71×10^3
Young's modulus (N/m^2)	3.87×10^8	3.30×10^7
Poisson's ratio	0.11	0.19
Tensile strength f_t (N/m^2)	-	0.0
Shear strength c (N/m^2)	-	9.0×10^4
Friction angle ϕ	-	42.5°
Compressive strength (N/m^2)	-	1.58×10^6

Previous Study

Modeling for simulation





Present Researches

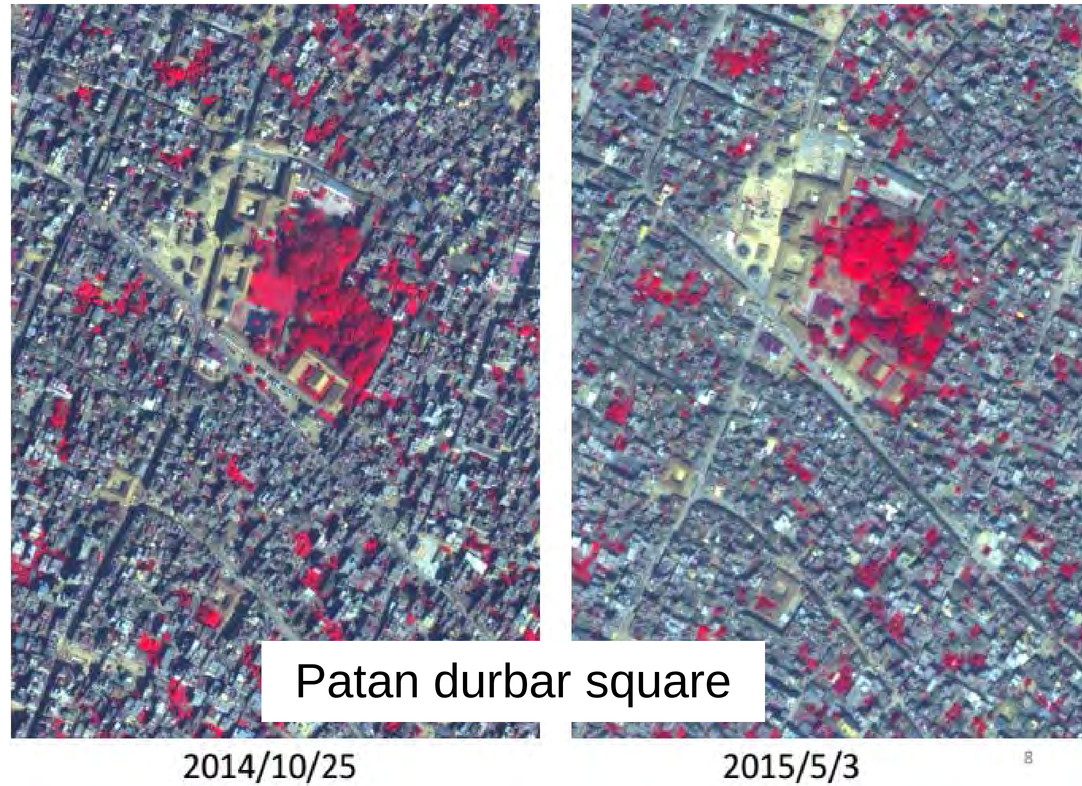
Field investigation in Kathmandu




Damage Assessment via Satellite Image Processing

Damage assessment for world heritage sites and targeted area in Lalitpur.

3D model of Swayambhu (bottom left) and original aerial image by UAV.



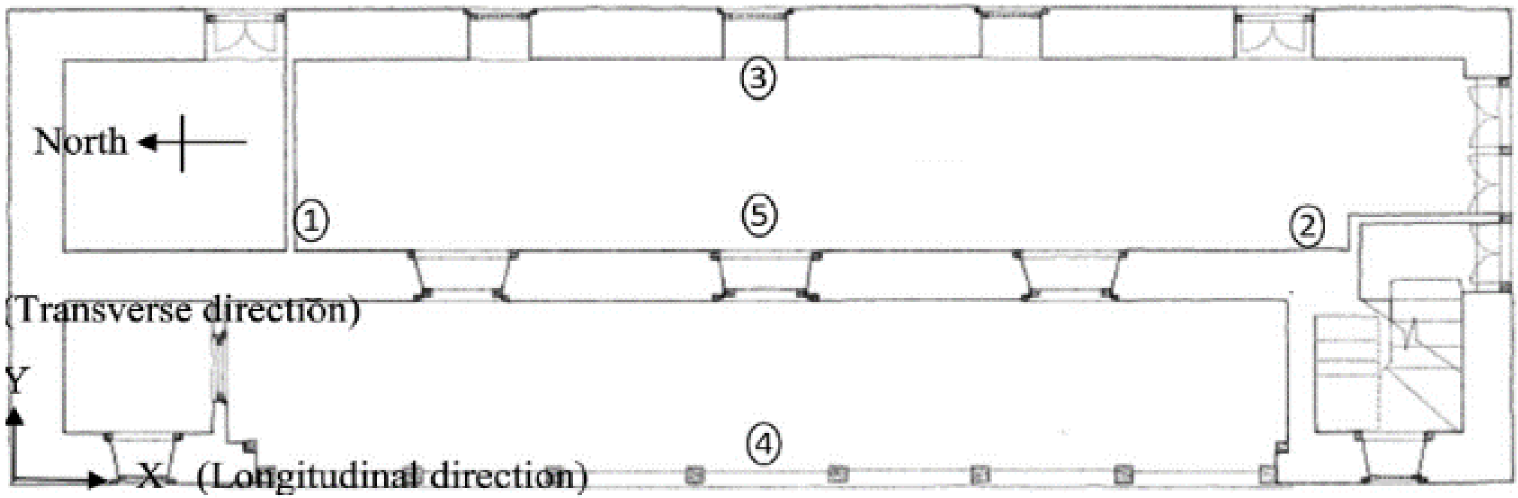
Re-evaluate Seismic Capacity of Building

Microtremor observations in Jhatpole

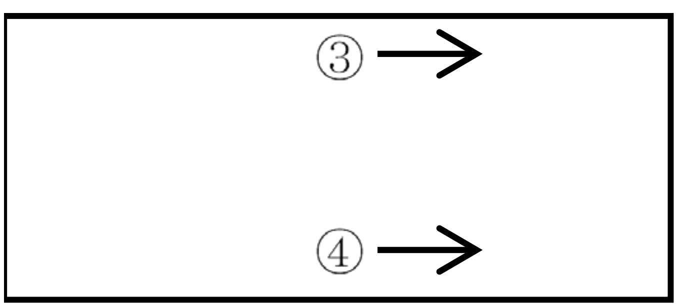
Before and After the Earthquake

2009.5.27 | 2015.9.16

Measurement Location

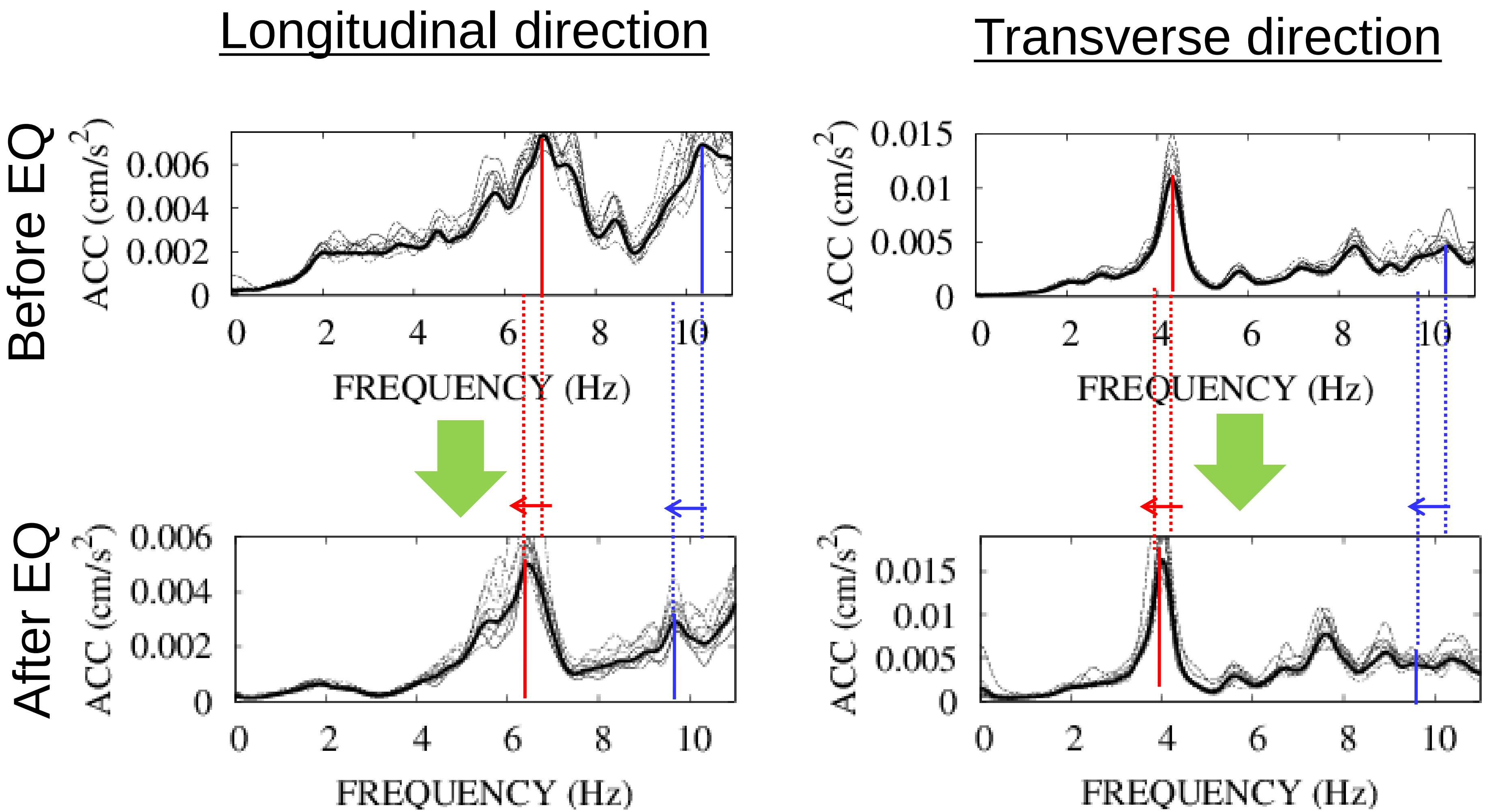


Longitudinal direction:③＋④



Transverse direction:①＋②

Comparison of Fourier Amplitude Before and After the Earthquake



Vibration Characteristics Before and After the Earthquake

Natural frequency in longitudinal direction (x)

	Before earthquake	After earthquake	Rate of change
1st mode	6.86Hz	6.43Hz	-6.27%
2nd mode	10.2Hz	9.74Hz	-4.51%

Natural frequency in transverse direction (y)

	Before earthquake	After earthquake	Rate of change
1st mode	4.33Hz	4.02Hz	-7.16%
2nd mode	8.38Hz	7.64Hz	-8.83%

Laboratory Experiments

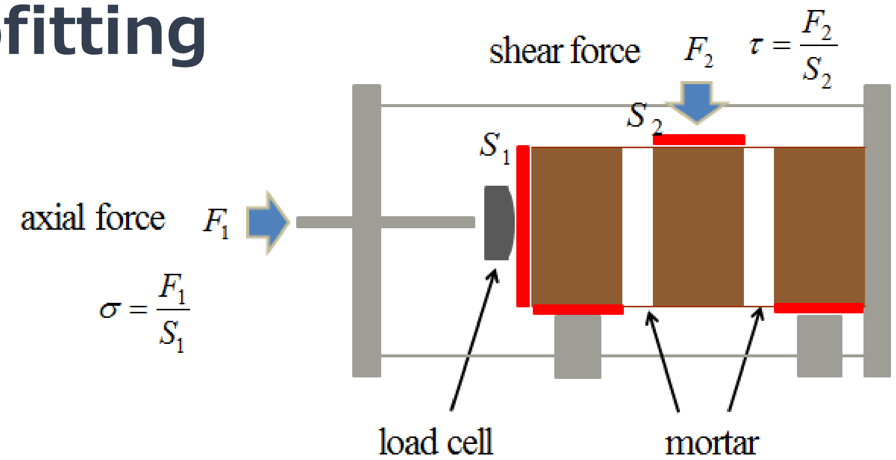
For developing the strengthening and retrofitting methods

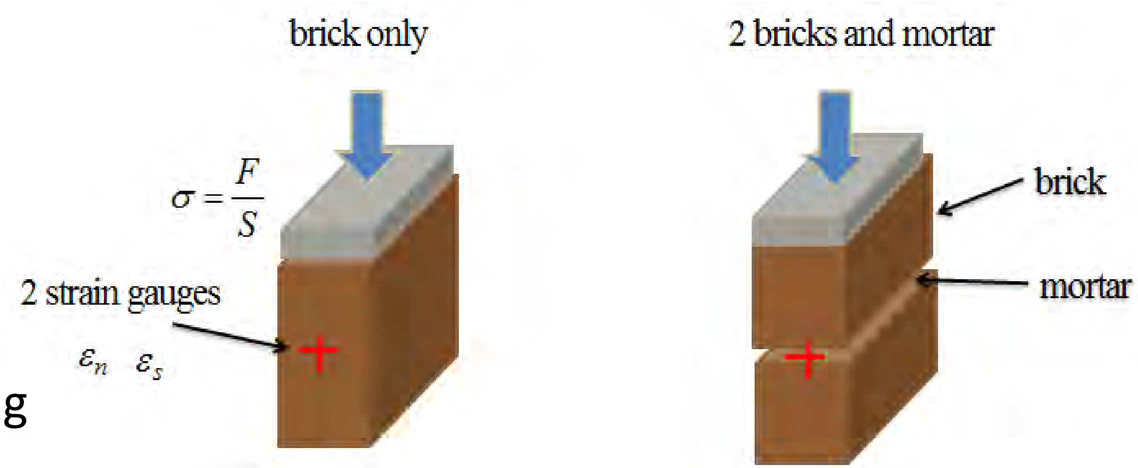
Brick masonry elements!

With and without reinforcement

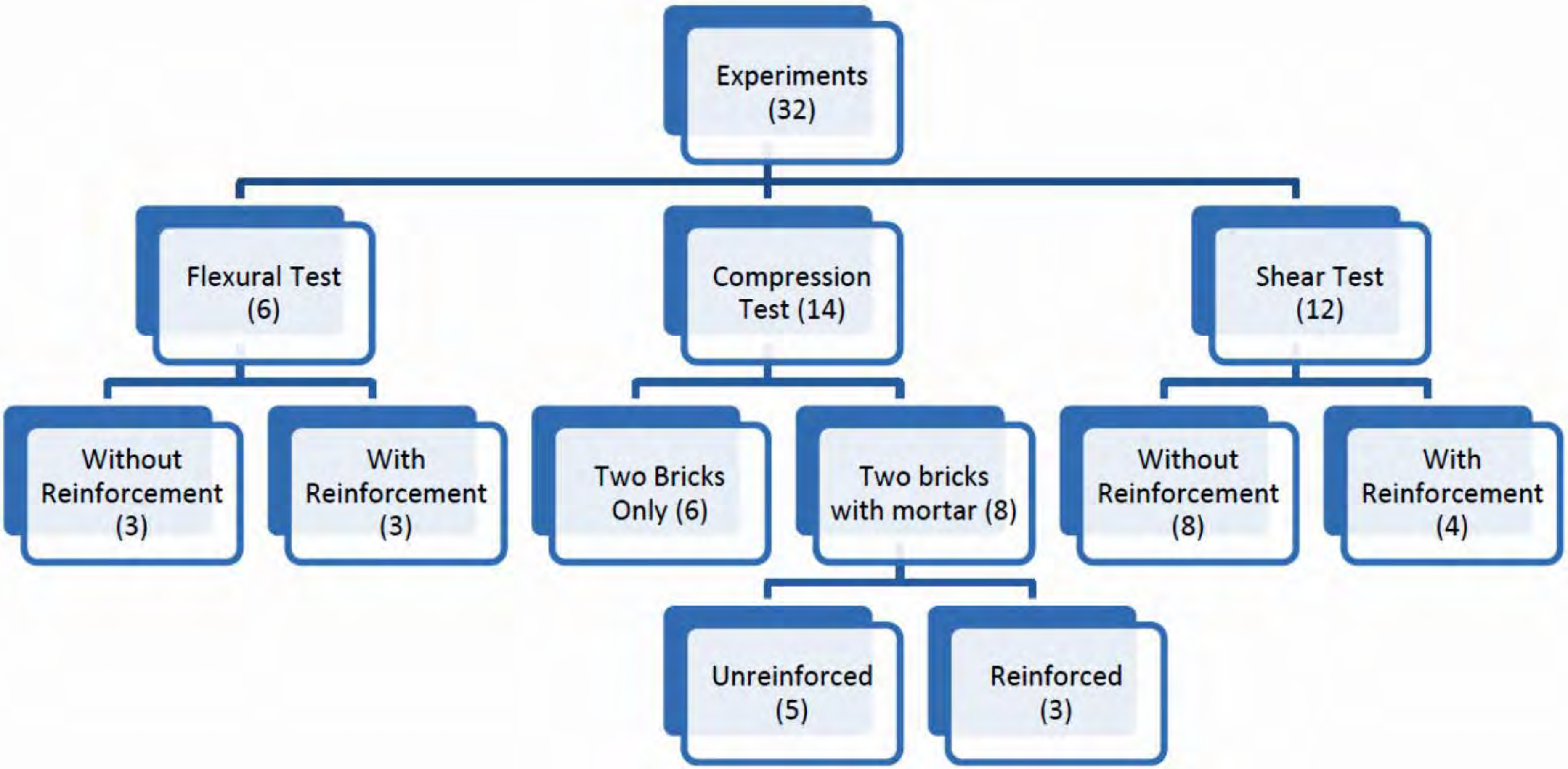
Material Properties:

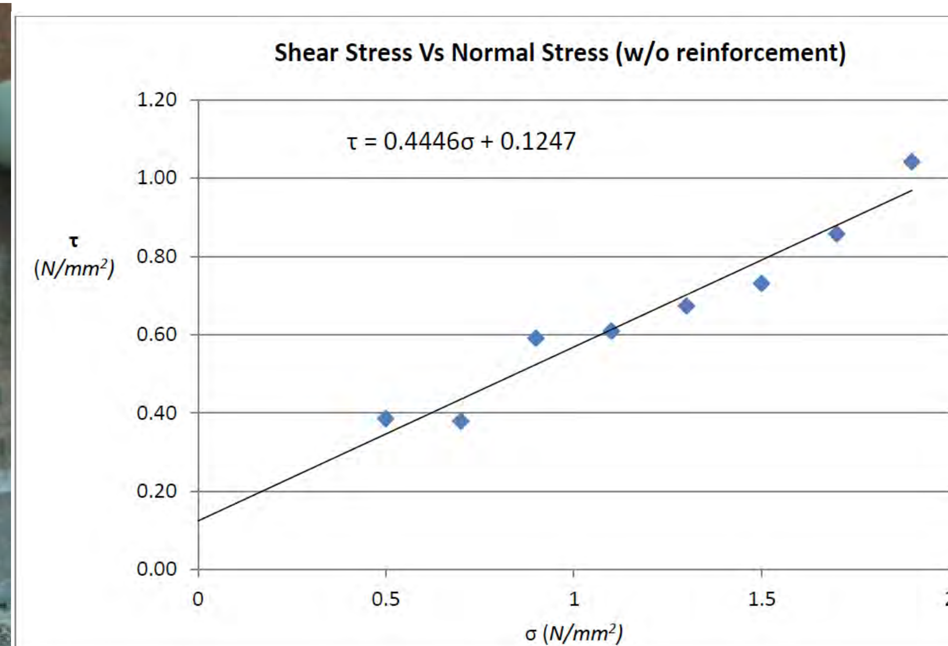
- Density
- Young's modulus
- Poisson's ratio
- Tensile strength
- Bond strength
- Friction angle
- Compression strengthening



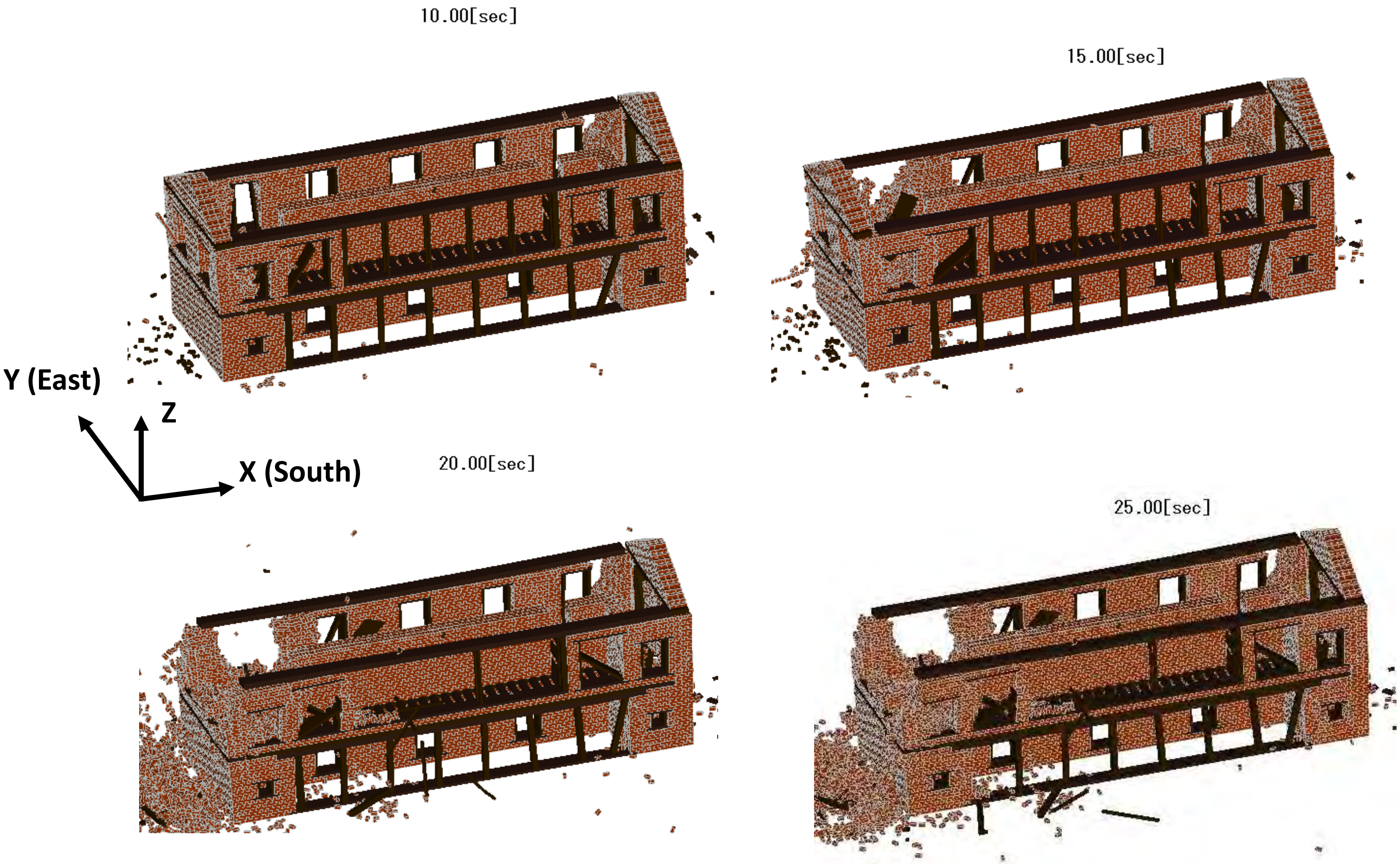


Hierarchy of Laboratory Tests




Shear Stress Vs Normal Stress (w/o reinforcement)
τ = 0.4446σ + 0.1247
τ (N/mm²)
σ (N/mm²)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
0.5
1
1.5

Preliminary Analysis

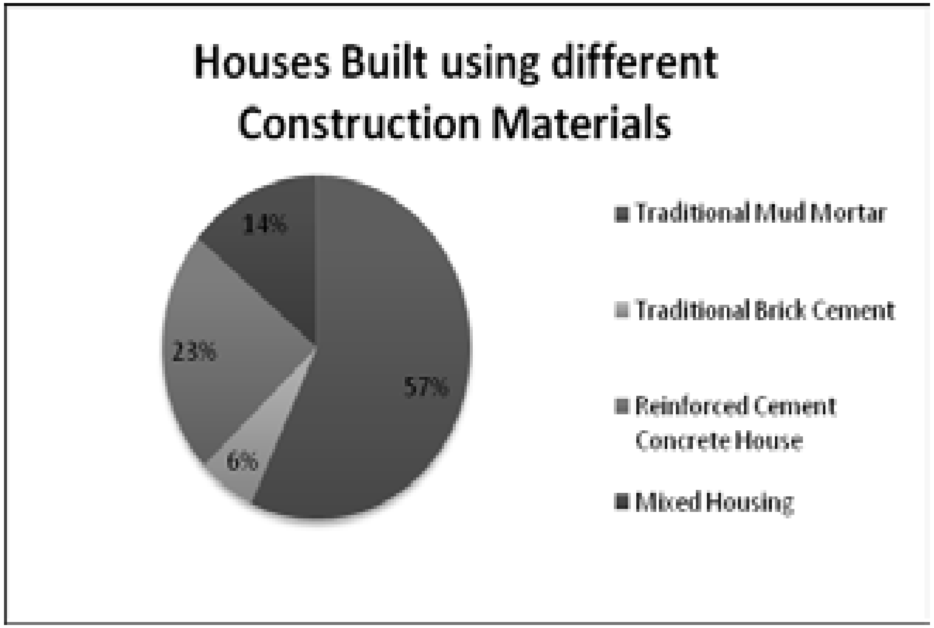


Seismic behavior in case of 40% in 50 years input ground motion

On-going research

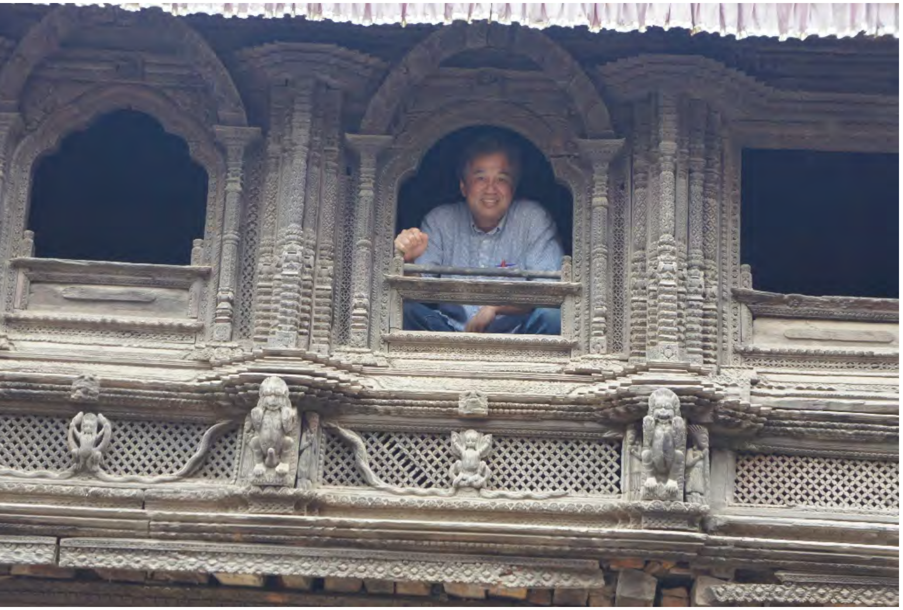
- **Numerical simulations taking into account the data of recent laboratory tests (Dr.Furukawa)**
- **Numerical simulations taking into account the proposed strengthening and retrofitting techniques (Prof. Maskey, Dr.Hari)**
- **Vulnerability assessment of the target area**
  - Evacuation condition of traditional courtyards in Patan (Prof.Okubo)
  - Impact of the quake on traditional settlement, Bungamati, Lalitpur

(Dr.Itaya, Dr.Jigyasu)



Acknowledgement

This rsearch was done under the support of J-RAPID program of Japan Science and Technology Agency (JST). We express our sincere appreciation to JST.



Final Workshop on J – RAPID – Nepal
June 21st and 22nd, 2016

Damages of Historical Structures Strengthening/Retrofitting Techniques

Prem Nath Maskey

Tribhuvan University, NEPAL

Gorkha Earthquake of April 25, 2015

- A strong earthquake of **M_W 7.8** (**M_S 8.1**) at 11:56 AM on **April 25, 2015** occurred at **Barpak, Gorkha**.
- The hypocenter (focus) of the earthquake was at a depth of less than **15 km** from the surface.
- The main earthquake was followed by a powerful aftershock of **M_W 7.4** on **May 12, 2016**.
- **461 numbers** of aftershocks with magnitude **$M_L \geq 4$** till **June 21, 2016**; Latest: aftershock of **$M_L = 4.4$** on **June 21, 2016**.
- **8,841** reported casualties, **22,309** injured people (MOHA 2015)
- Centuries-old structures were destroyed at all the **seven monument zones** of the **UNESCO enlisted Kathmandu Valley World Heritage Site** including some at **the Kathmandu Durbar Square, the Patan Durbar Square, the Bhaktapur Durbar Square, the Changu Narayan Temple, the Boudhanath Stupa, the Pashupaninath and the Swayambhunath Stupa**.

Traditional Constructions in Kathmandu Valley

- Essentially unreinforced brick masonry wall-structural system.
- Historical, monumental and residential buildings.
- Temples, palaces, shrines, public places
- Low rise dwelling houses
- Tiered temples and large palaces.

Historical Structures in Kathmandu Valley

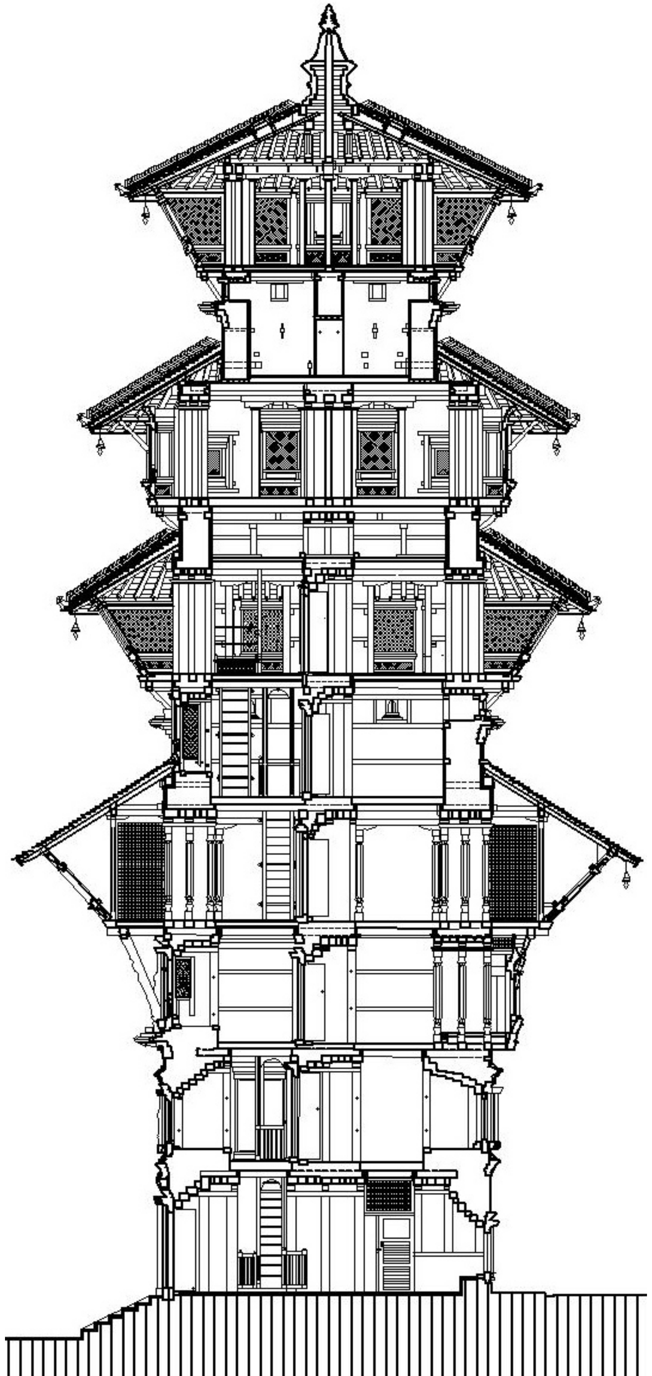
- Basic concept of EQ resistant design
- Best available materials
- Best workmanship and technology
- Bricks, rich mud mortar, timber and stone
- Structural system based on un-reinforced brick masonry in mud mortar
- Un-reinforced masonry structures vulnerable to earthquake actions

Peculiar features of Historical structures in Kathmandu Valley

- Symmetrical planning (mass and rigidity)
- Triple wall system in dwelling houses
- Openings with double timber framing
- Timber framing of walls
- Connection of timber floors
- Upper floor in timber frames
- Smaller opening sizes
- Courtyard system
- High plinths for many temples
- Gradual reduction in wall thickness in upward direction

Kasthamandap Temple, Kathmandu

9-storied Palace
(Hanuman Dhoka Durbar Square)



7- storied Palace (Nuwakot Durbar)

Damage of historical structures

- In the **Kathmandu Valley**, many buildings and structures of historical importance have collapsed or sustained severe damages.
- In the **Kathmandu Valley** only more than **30 monumental structures** completely collapsed, and about **120 historical structures** heavily or partially damaged. In general, the earthquake damage in the cultural heritage sites is unprecedented and unexpected. Most of the structures in the monument zones were constructed in **17th and 18th centuries** and some of them dates back to even **15th century**. These are heritage structures and the monument zones are **heritage sites of cultural importance**.

Kathmandu Durbar Square

Patan Durbar Square

Bhaktapur Durbar Square

Earthquake Damage of Heritage Structures

Damages in Buildings
Gorkha Earthquake April 25, 2015

Main Reasons for Earthquake Damages

- During the visual assessment, based on the nature of damages of the structures, the main reasons for the extensive damages of the heritage structures, in general, are:
  - **Lack of maintenance and repair**
  - **Deterioration of materials**
  - **Ageing of materials**
  - **Isolated alteration of structural elements/connections**
- However, a detailed investigation is recommended to establish the structural reasons for failure or damage of individual structure. It should be recognized that such a detailed structural investigation require **a substantial resource in terms of time and effort**.

Strengthening/Retrofitting Techniques

- Restriction of materials use
- Traditional technology
- Limitations of unreinforced masonry
- Planning and configuration
- Detailed seismic vulnerability assessment – prerequisite
- Confinement of structural URM walls
- Timber floors – limited in-plane stiffness
- **Vertical upright posts and horizontal ties of timber at strategic locations**



Conclusion

- Survival of traditional historical structures.
- Engineering interpretation of Traditional technology.
- Detailed damage and vulnerability assessment.
- In-situ assessment of materials' properties.
- Introduction of strict Regular maintenance management system.