

# 【第Ⅰ部】地震関連情報の報告

## ネパールの構造物事情について

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Kathmandu Valley, Nepal

# 報告内容

- 背景
- 近年の歴史的建造物被害
- カトマンズの地震危険度
- 歴史的建造物を対象とした建物調査
  - トモグラフィによる建物調査
  - 微動計による建物の振動調査
- レンガ壁の要素試験
- 実験・計測を基にした構造物のモデル化と解析
- 狹隘地区構造物群の脆弱度評価への適用

*Backgrounds*

# 背景

## ◆ 立命館大学グローバルCOEプログラム（2008–2012） 『歴史都市を守る「文化遺産防災学」推進拠点』

- ・ネパール・カトマンズプロジェクト
  - 歴史的建造物の耐震性評価
  - 狹隘地区の脆弱度評価

(この研究は、立命館大学・谷口仁士教授、土岐憲三教授、大窪健之教授、板谷直子准教授、京都大学・古川愛子准教授、トリブバン大学・マスキー教授、ハリ講師と共同で行われたものです。)

## ◆ カトマンズにおける他の地震防災関連調査

- ・ JICA: 2002年「カトマンズ盆地地震防災対策計画調査」  
(カトマンズ盆地の地震防災計画の立案、地震防災のためのデータベースと地震被害想定の作成)
- ・ WB: 2011年 Nepal Hazard Risk Assessment(ネパール全土)
- ・ UNDP: 2012年 Multi Hazard Survey(カトマンズ)
- ・ JICA: 2014年ネパール国カトマンズ盆地における地震災害リスクアセスメントプロジェクト詳細計画調査
- ・ 愛媛大学: 2006年よりカトマンズにサテライトオフィス

# Damage to World Heritage due to Recent Earthquakes

- **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)

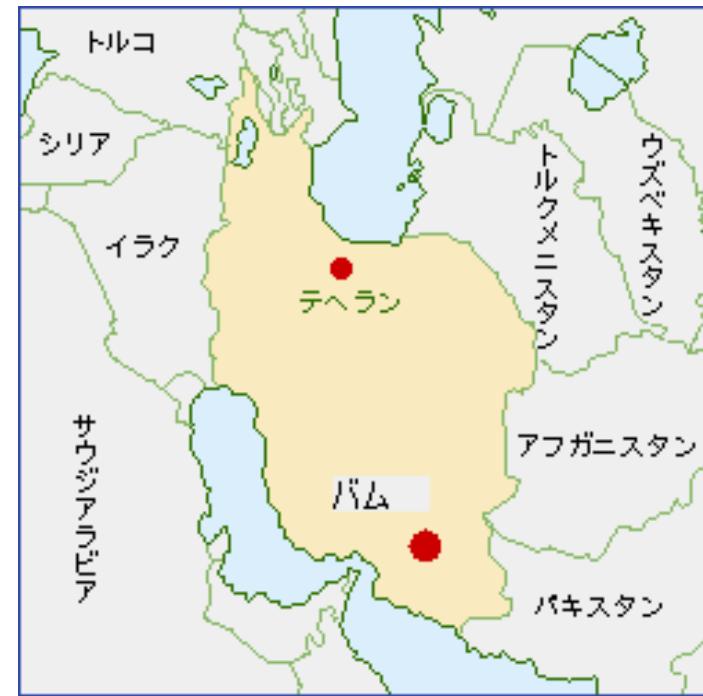
- **Nepal Kathmandu Valley**

2015/4/24, Mw7.9

Fatality: more than 8,000

Cultural heritage in 1979

List of WH in Danger (2003)







**Pranbanan**  
**(Hindu temple compound)**

2006年ジャワ島中部地震



(hurry911.cocolog-nifty.com)



(www.toptweet.org)

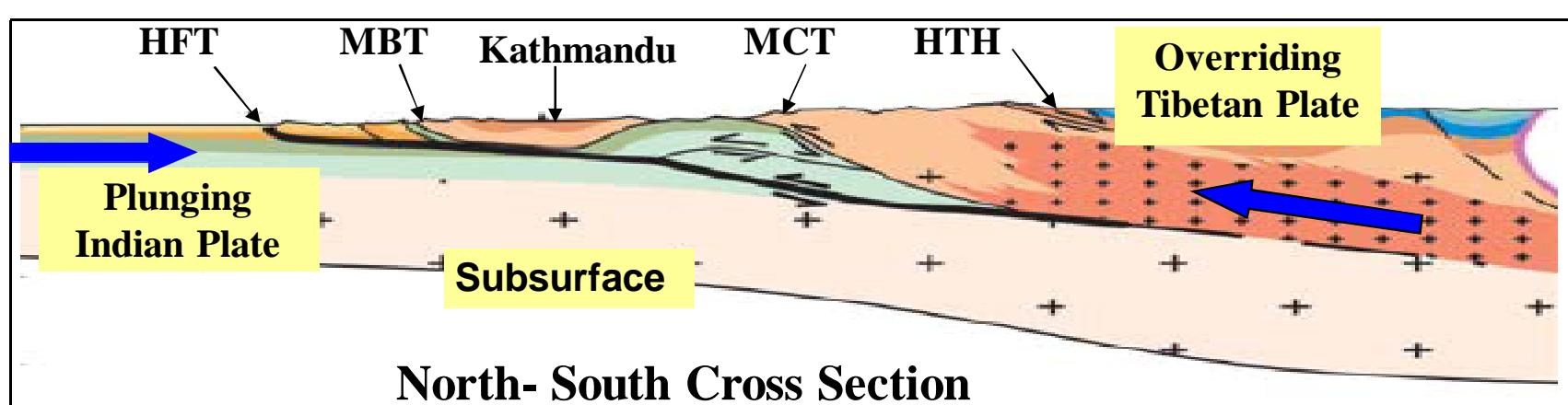
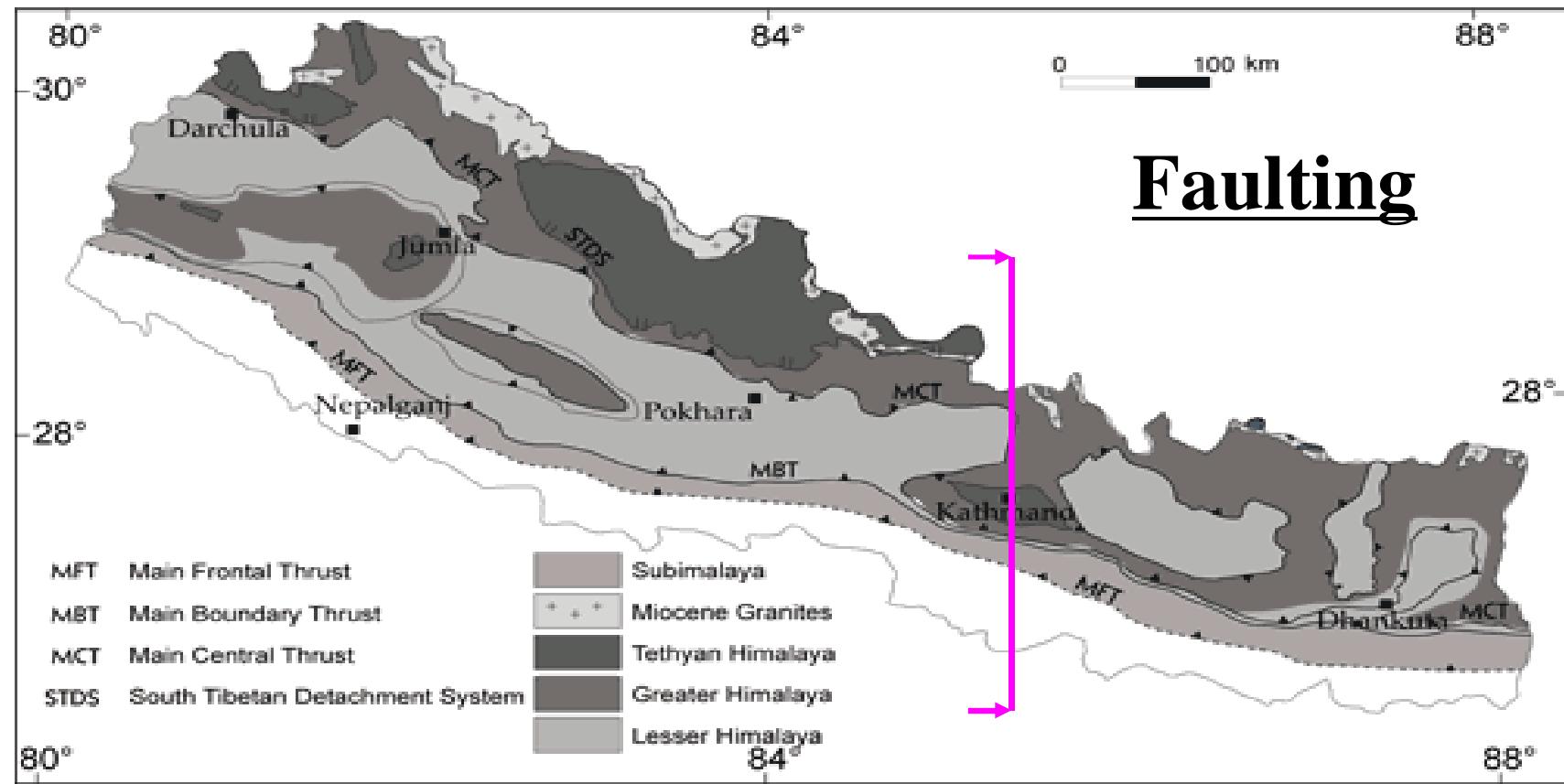


(blogs.itmedia.co.jp)



(ダラハラ塔:enigme.black)





# 7 World Heritage sites: Kathmandu Valley





パタン王宮広場



(newssite.biz)

# Past Earthquakes and Damage in Nepal



1934 Nepal Bihar earthquake (M8.1) (Amatya [2008])

# Nyatapola (five tiered) Temple, Bhaktapur



**Damage in 1934 earthquake**



**Contemporary view**

# Degu Taleju Temple, Patan Durbar

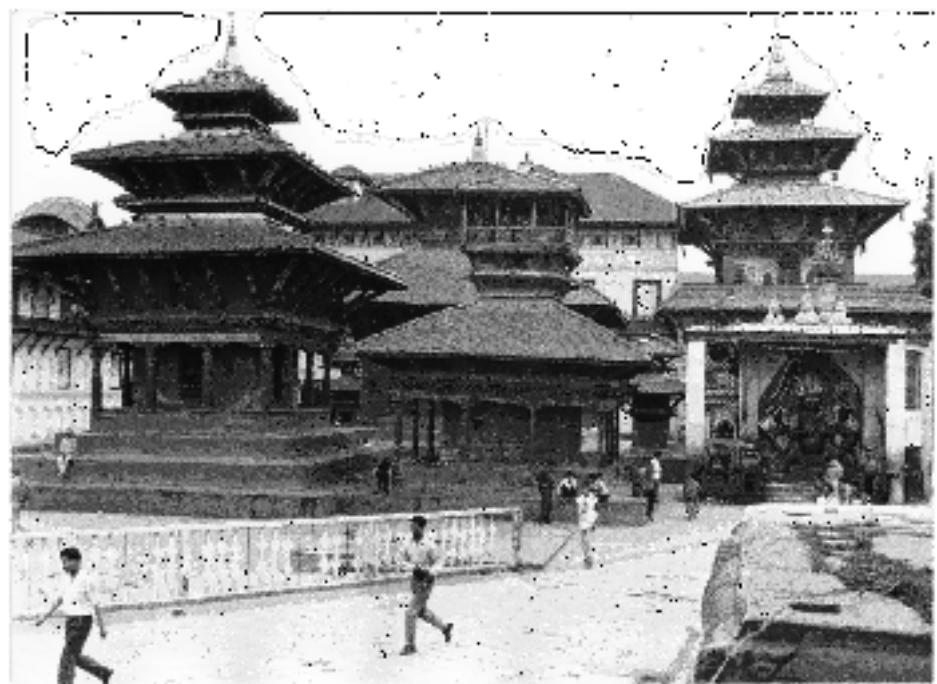


**Destruction in  
1934 earthquake**

**Contemporary view after  
reconstruction.**



# Kathmandu Durbar Square



**during 1934 earthquake (left) and contemporary state (right)**

Photos in 1934: courtesy of Prof. Maskey (Tribhuvan Univ.)

## *Hazard Analysis in Kathmandu*

# Historical Earthquake Data Used

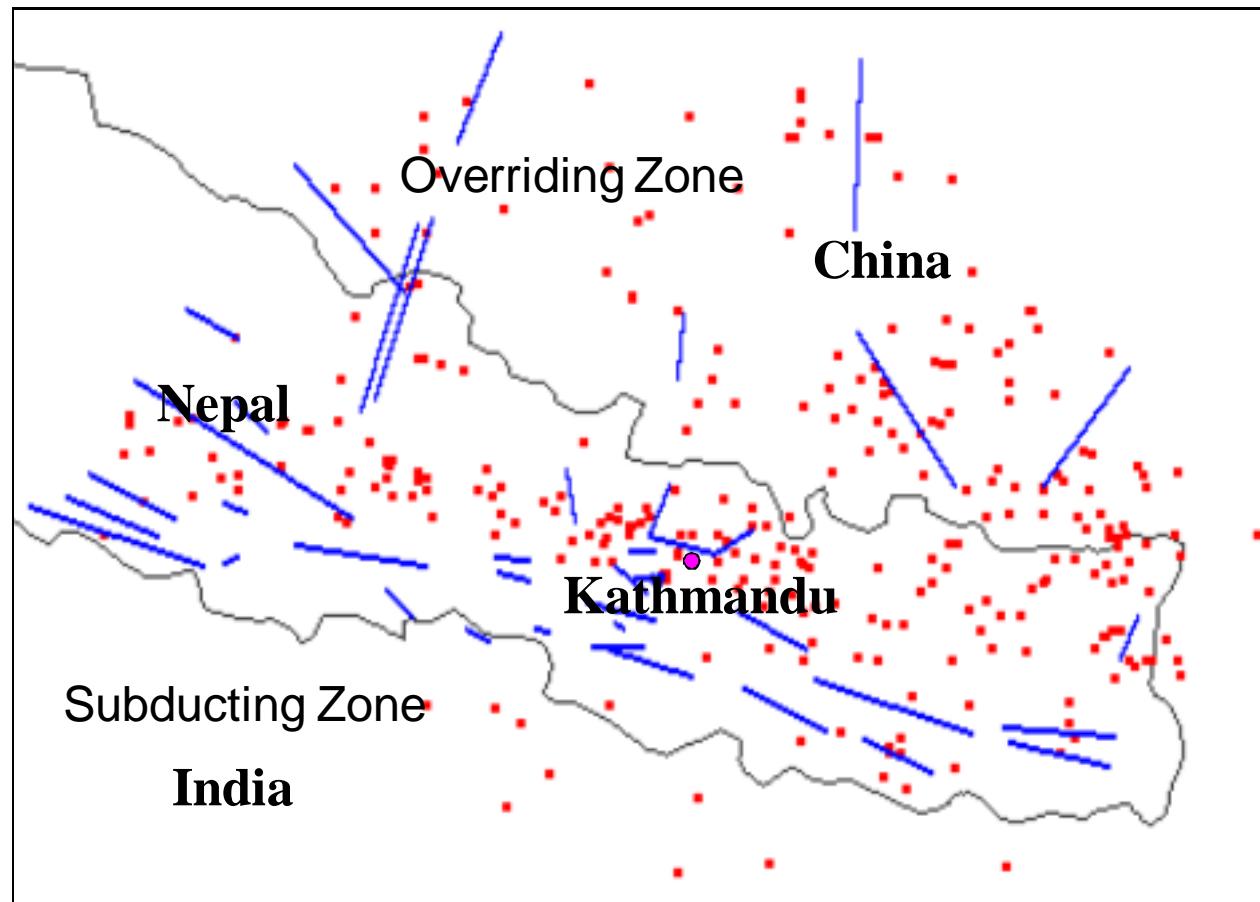
Year		Magnitude					Total events
Start	End	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	
1100	1931	1	2	5	5	2	15
1932	1936	1	2	1	1	1	6
1937	1941		2				2
1942	1946		1				1
1947	1951		1				1
1952	1956		4	2			6
1957	1961		2				2
1962	1966	7	5	1			13
1967	1971	11	3	1			15
1972	1976	13	3				16
1977	1981	12					12
1982	1986	14					14
1987	1991	29	2	1			32
1992	1996	19	1	1			21
1997	2001	23	2				25
2002	2006	16					16
Total events		146	30	12	6	3	197

United States Geological Survey/National Earthquake Information Center – NEIC

<http://earthquake.usgs.gov/regional/neic/>

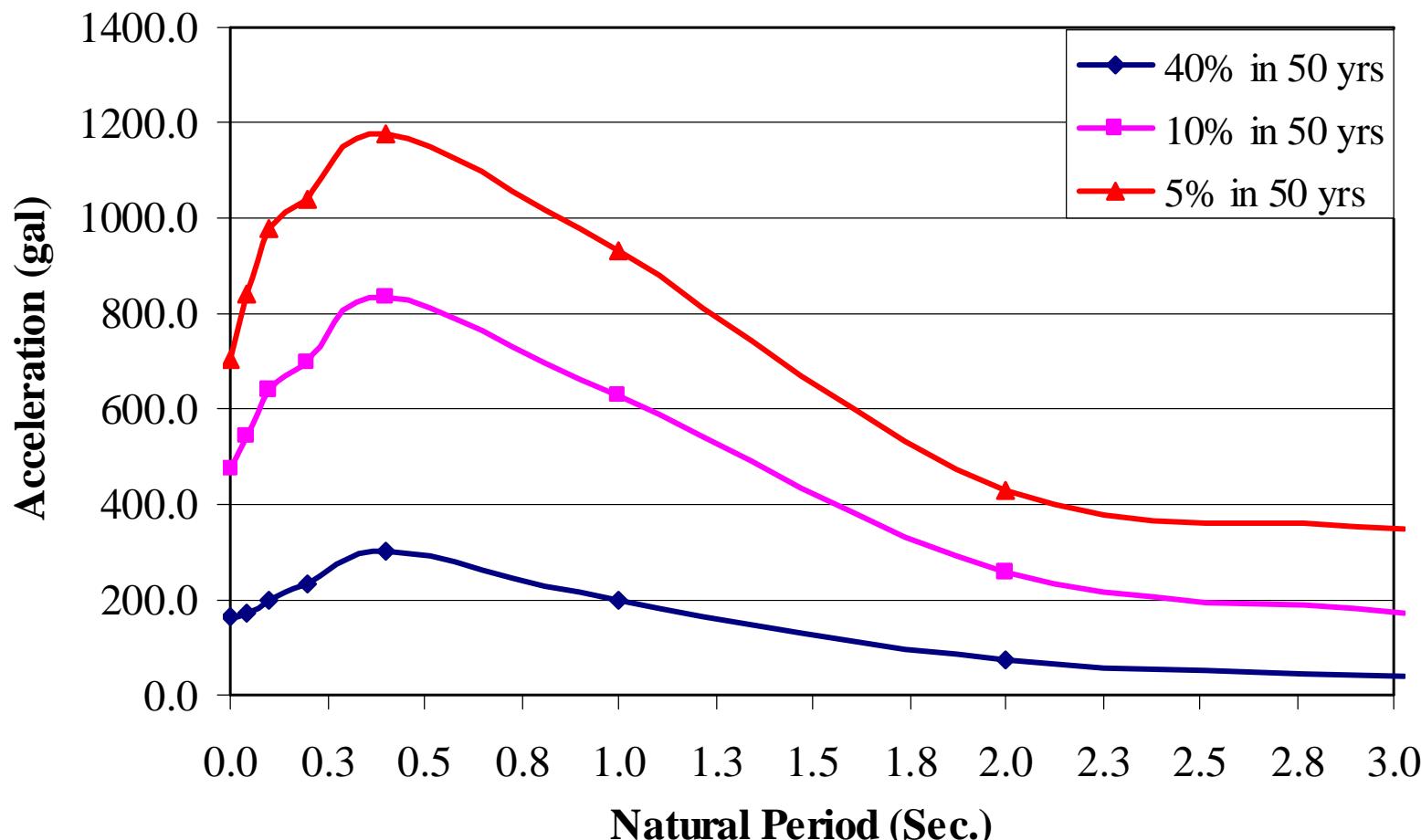
# Seismic Activities

Kathmandu  
27.7N  
85.2E



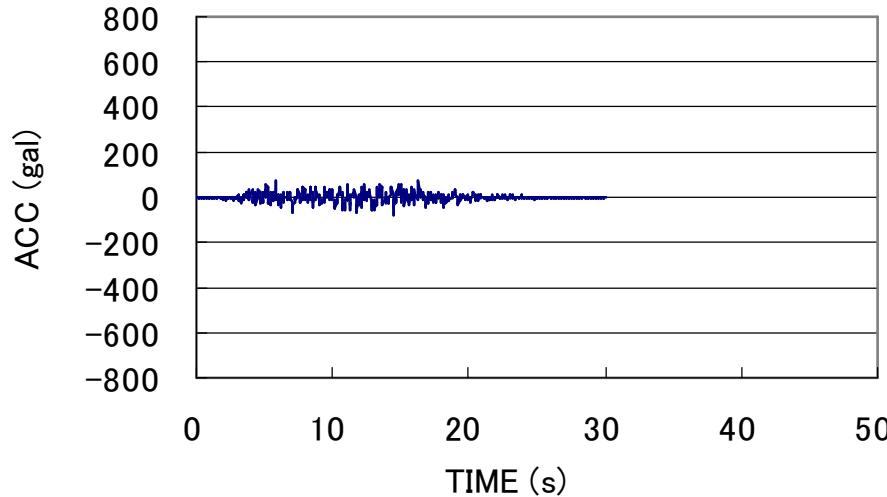
(by H.R. Parajuli., J.Kiyono, et.al [2008])

# Probabilistic Response Spectra



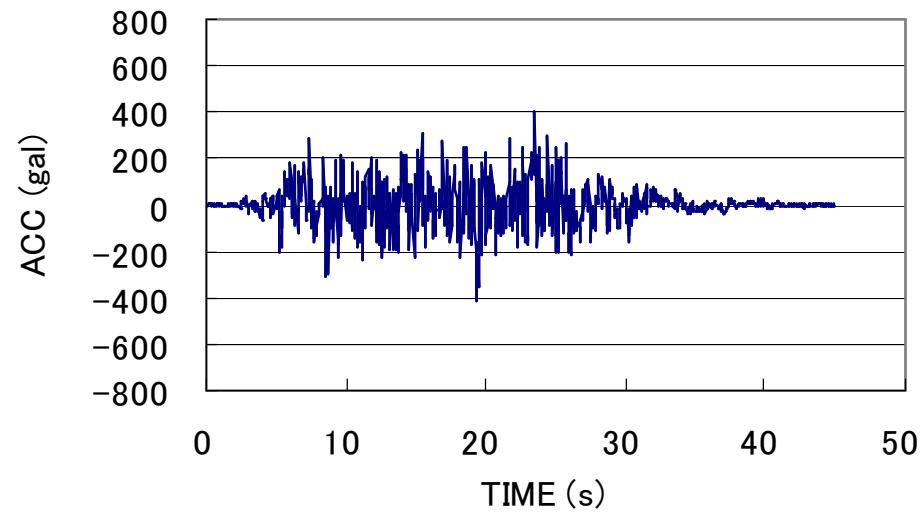
(5% damping in soft soil)

# Synthesized Ground Motion



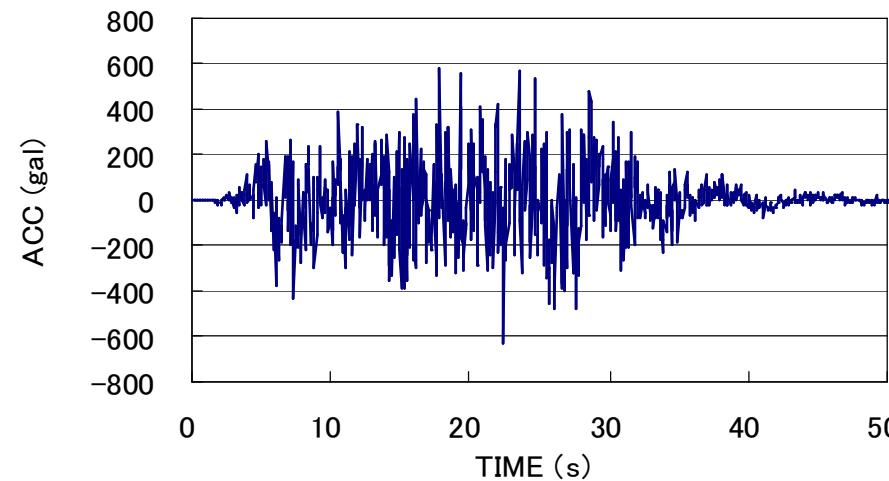
40% in 50 years

震度4程度



10% in 50 years

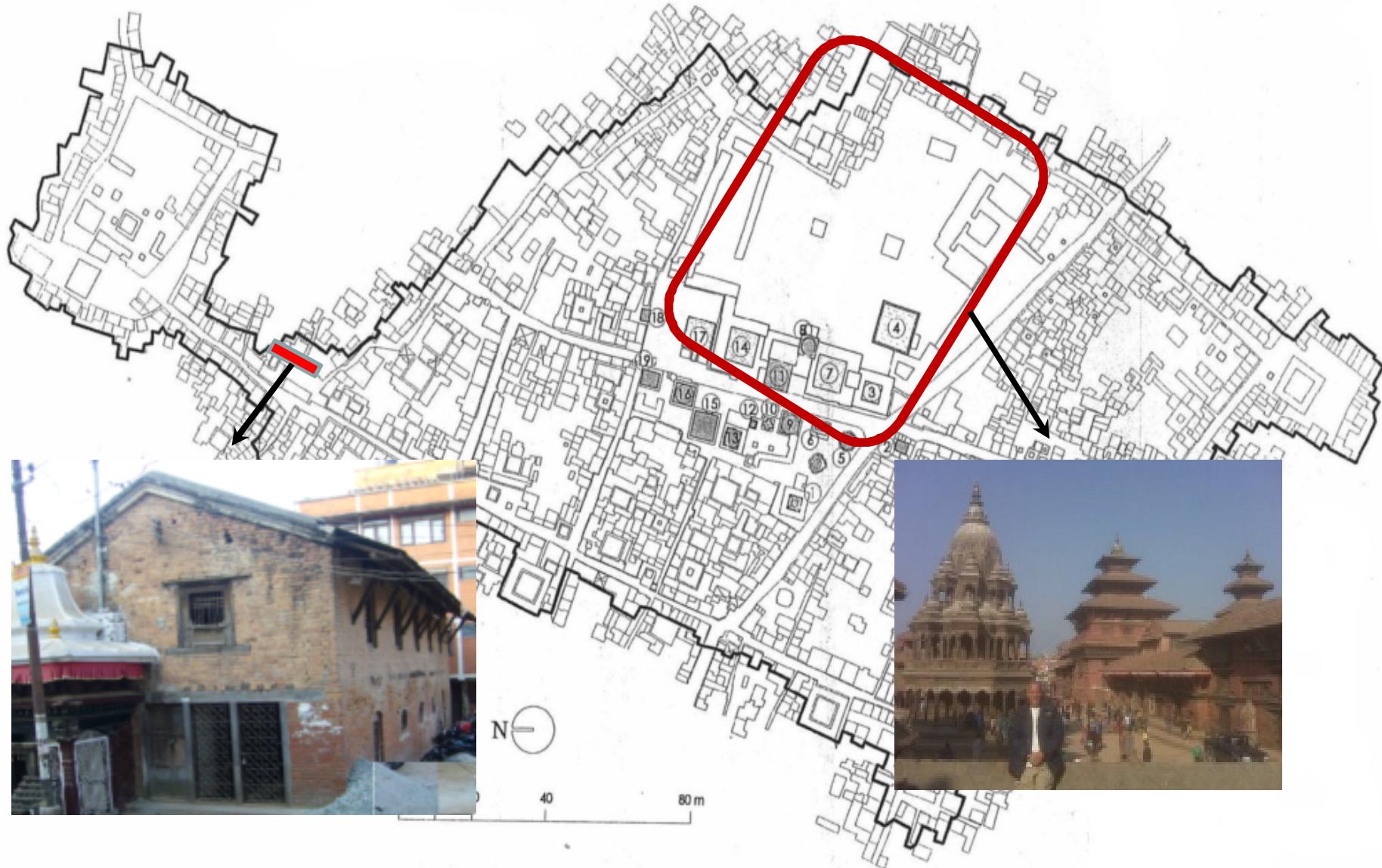
震度5弱～5強程度



5% in 50 years 震度5強～6弱程度

*Investigation of Historic Building (1)*  
*(Elastic Wave Tomography)*

# Target Building (Royal Palace Square in Patan)





# Detailed test: Elastic Wave Tomography

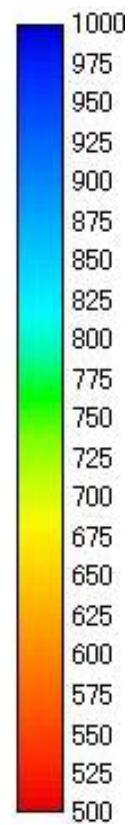
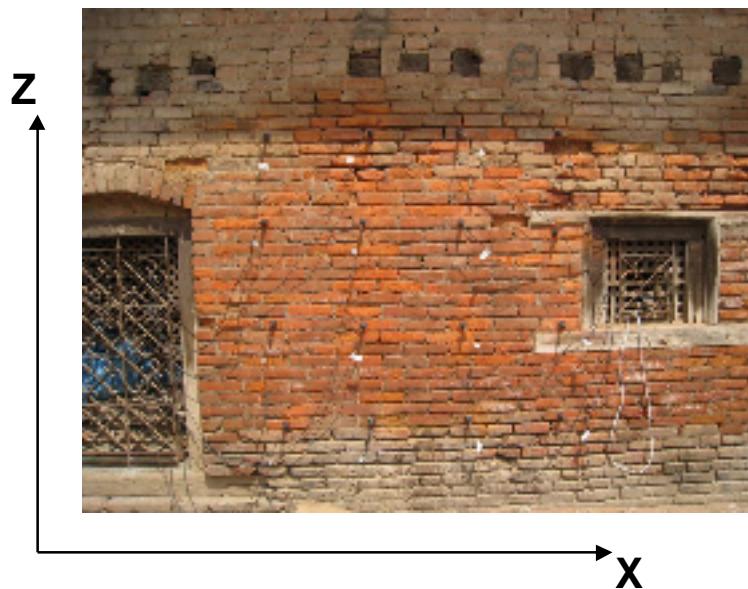
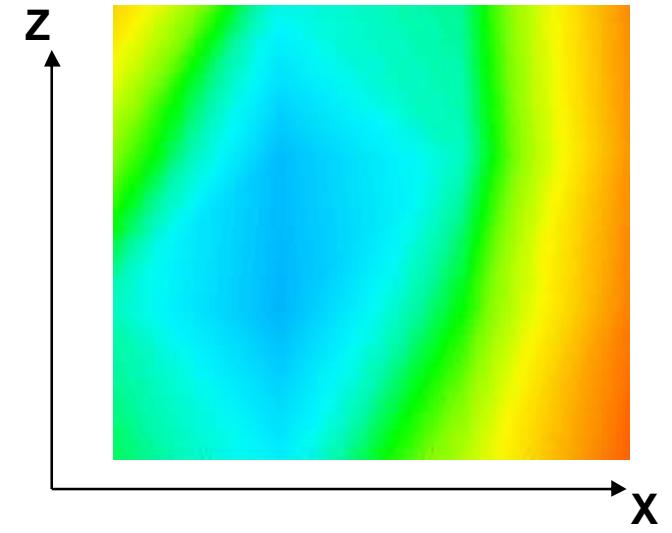
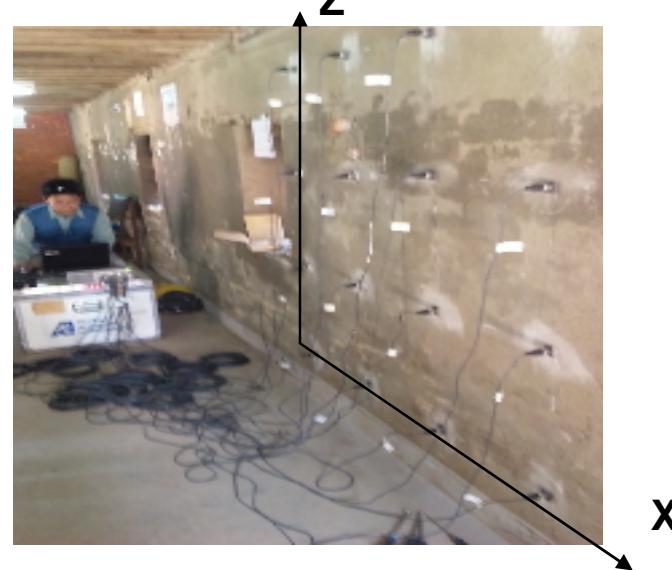
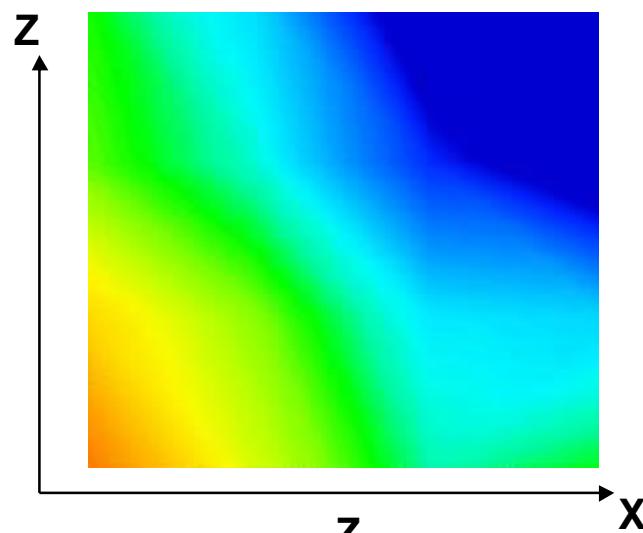


Data Logger GX-1 (TEAC)  
200kHz sampling



Acceleration Sensor  
(SAF51, Fuji Ceramic Co. Ltd.)

# 2D tomography



# Results

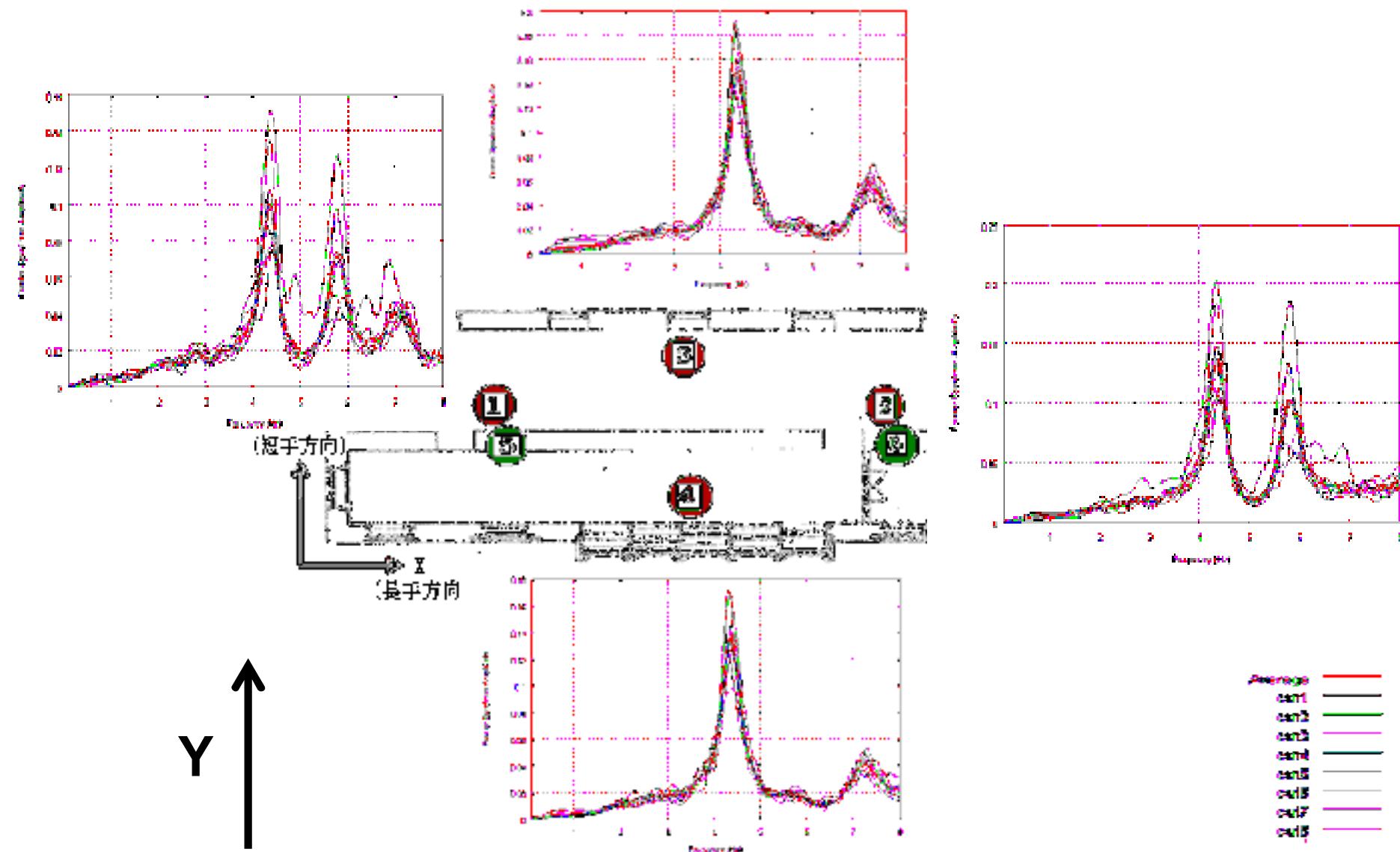
- P-wave velocity of Intact brick
  - about 2,500m/sec
- Apparent P-wave velocity of wall :
  - $30,000/x$  (x: thickness of wall[cm])
- Average P-wave velocity of masonry wall:
  - 500m/sec~1000m/sec
- Brick quality is very poor because of the aging and underground water absorption

*Investigation of Historic Building (2)*  
*(Microtremor Observation)*

# Microtremor Observation



# Fourier spectra in Y direction on 2<sup>nd</sup> floor



# Translation and torsion component

- Translation (in-phase)  
sum of two components

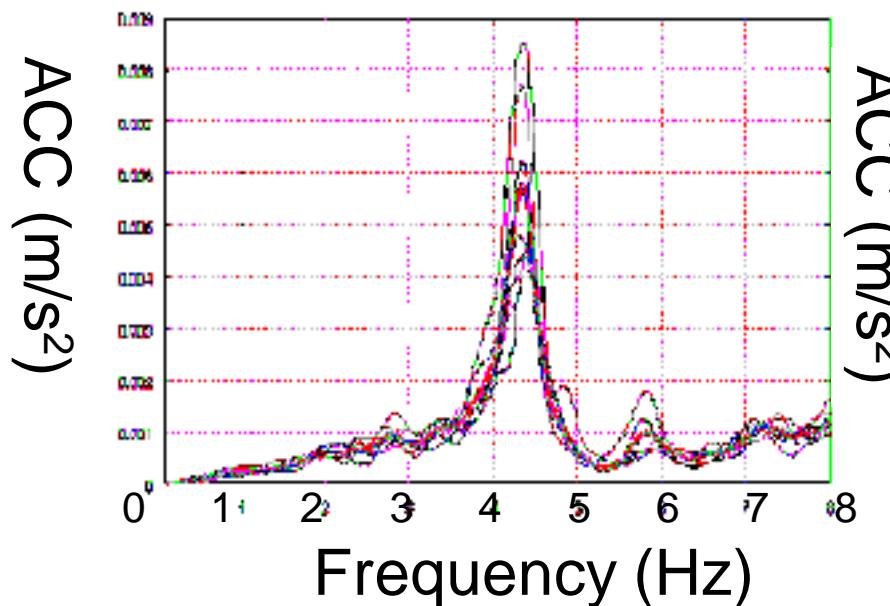
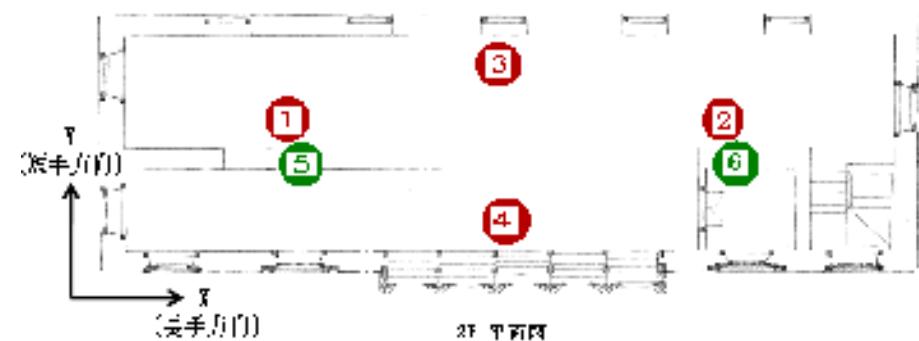


- Torsion (anti-phase)  
difference of two components

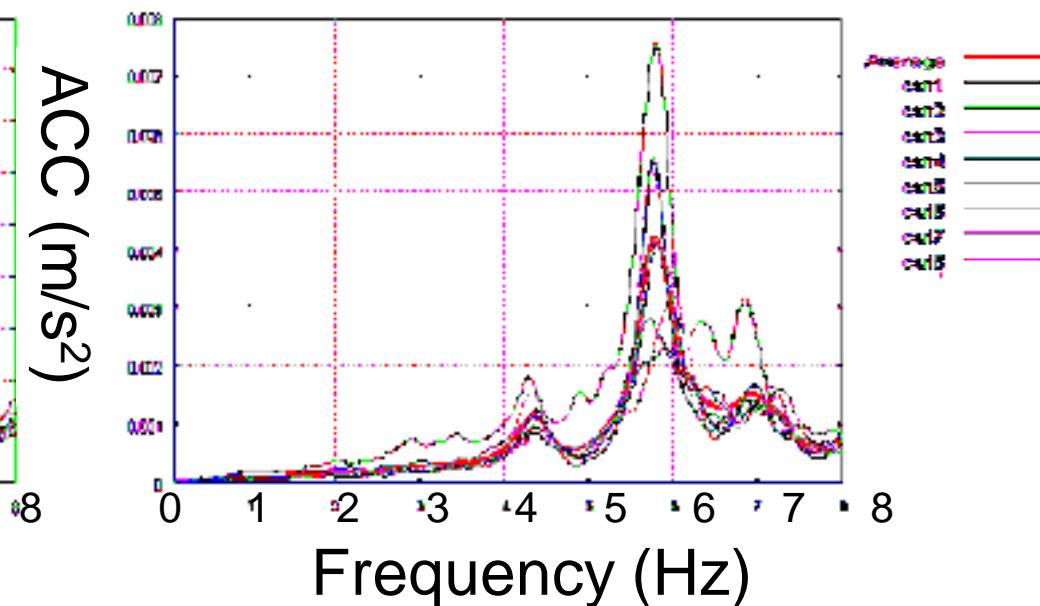


# Y direction on 2<sup>nd</sup> floor

- Use data at ① and ②
- Translation: 4.3Hz
- Torsion 5.8Hz



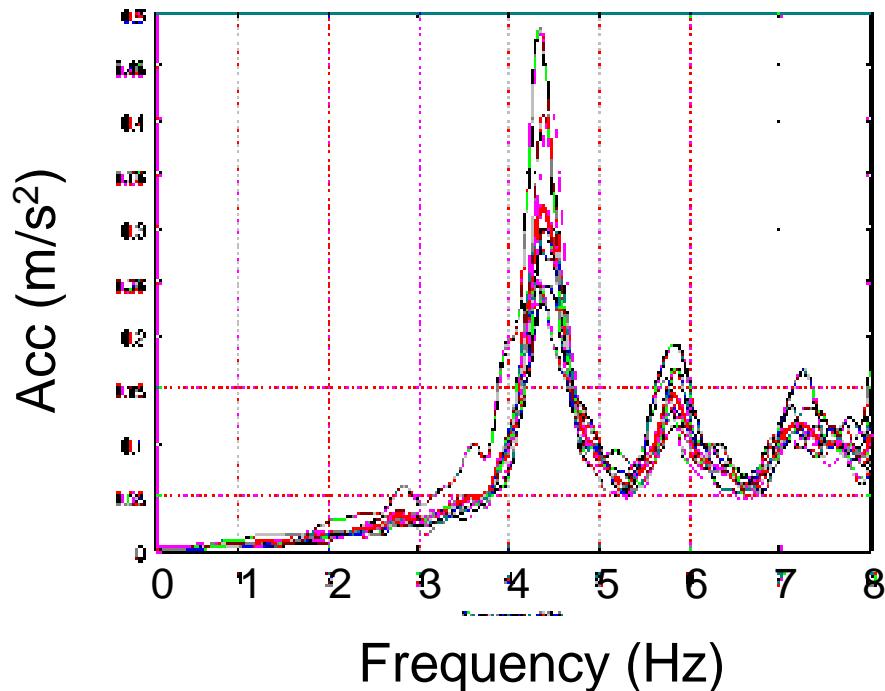
Translation



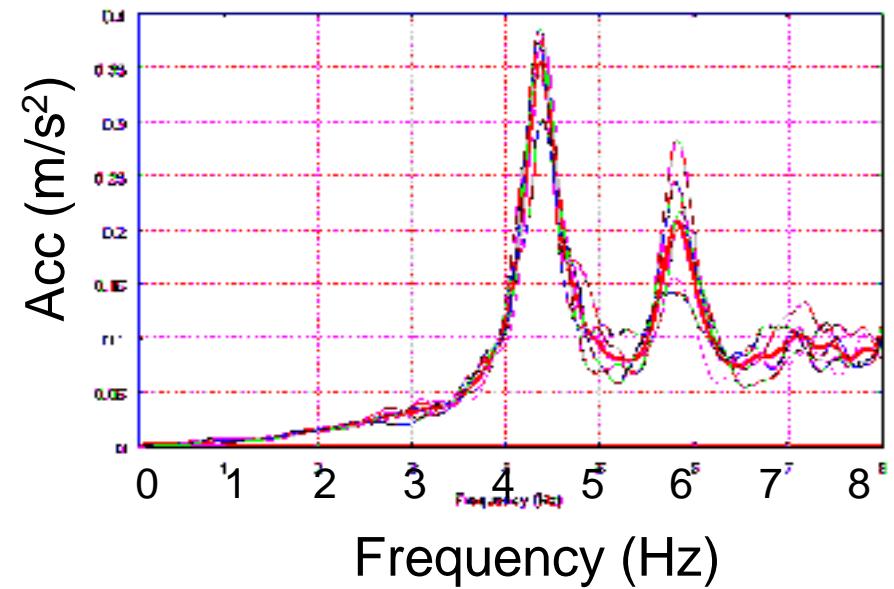
Torsion

# Verification of Modeling

Observed values are used to verify the modeling for numerical simulation



Numerical Simulation

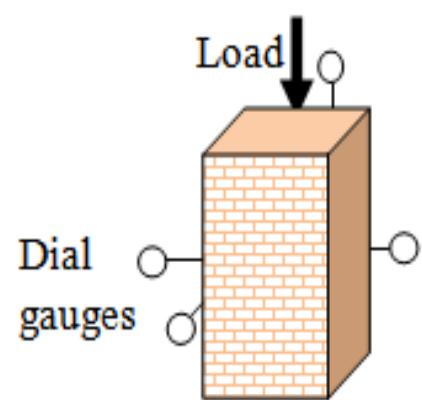


Observation

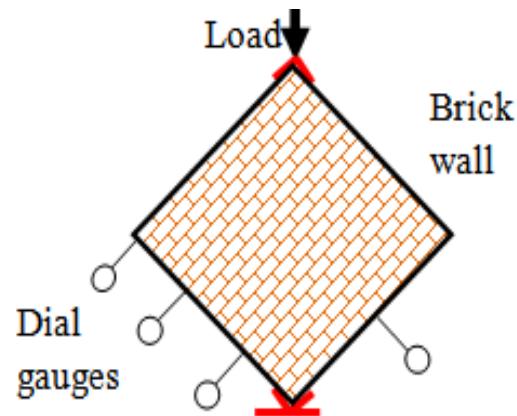
Observation point: ⑤

## *Element Test for Brick and Wall*

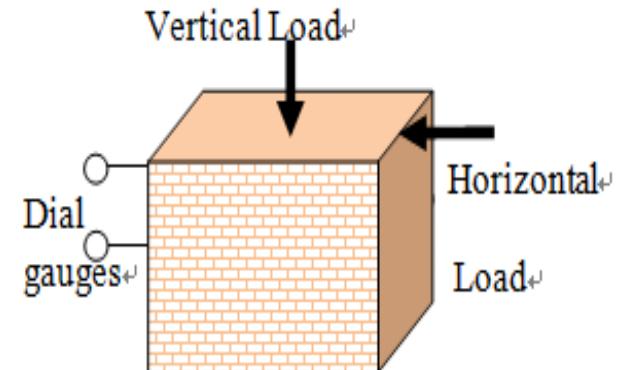
# Loading Test at Tribhuvan Univ.



Compression test



Shear test



Combined test

# Combined Test

Lateral  
loads

Vertical  
Loads

Dial  
Gauges



Mud bonded wall



# Diagonal Shear Test

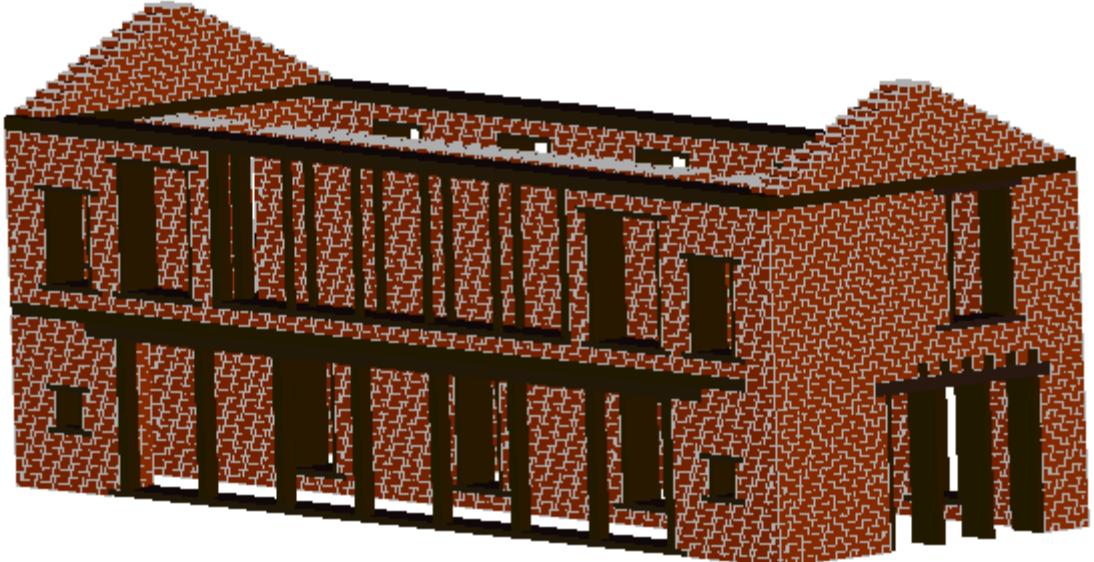


# Parameters Obtained

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

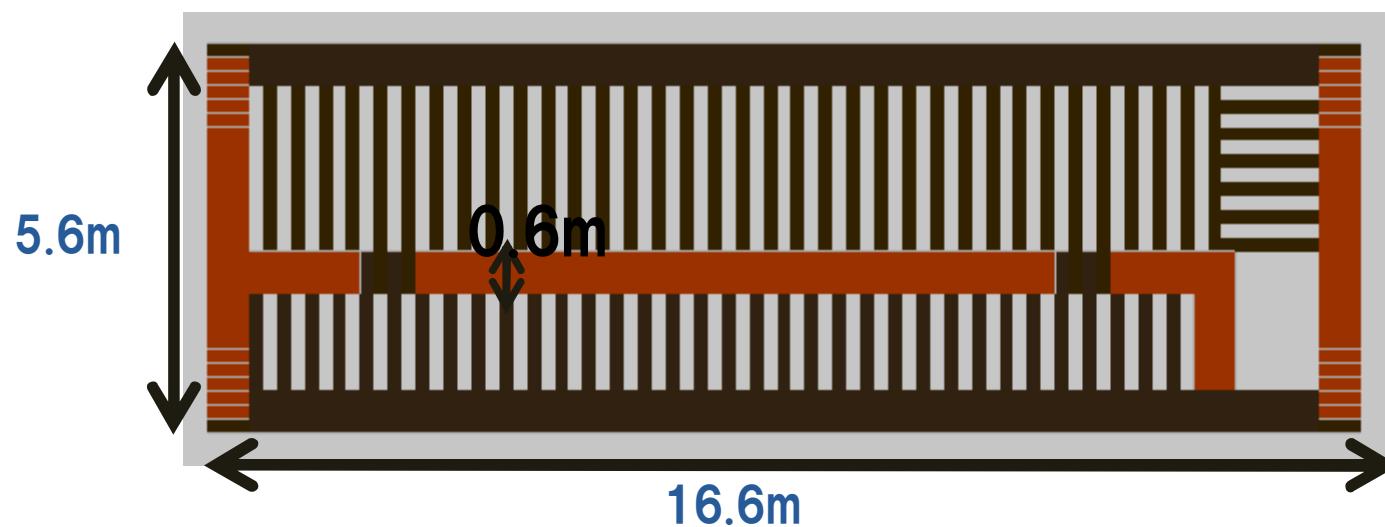
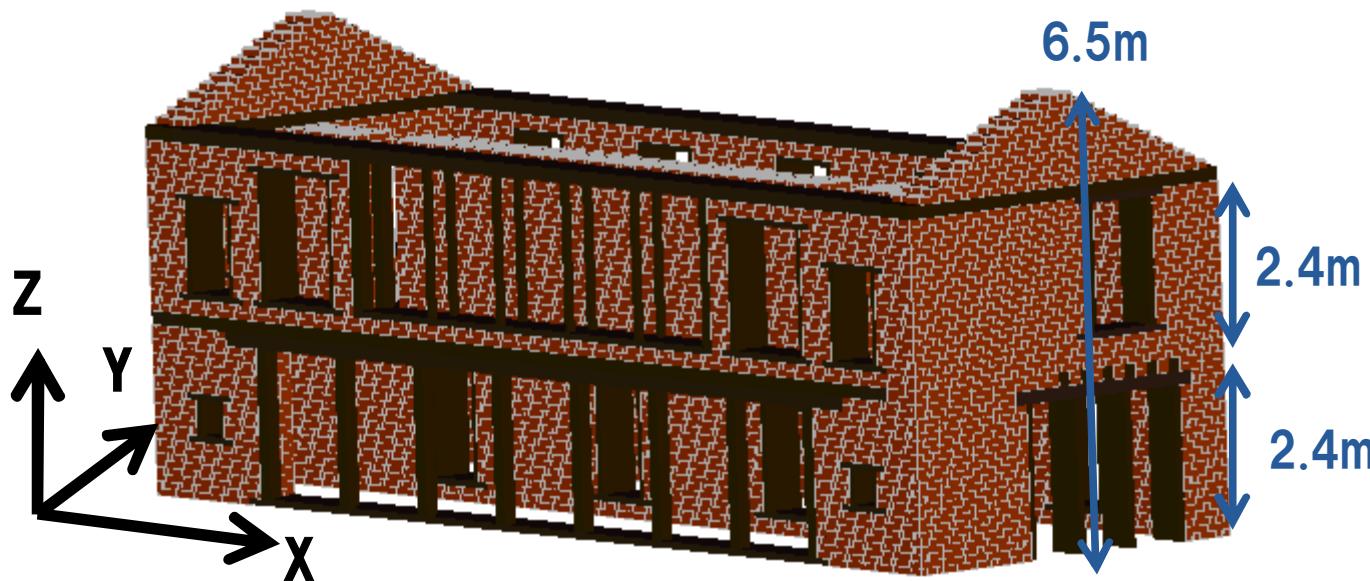
*Numerical Simulation*

# Modeling with Refined DEM

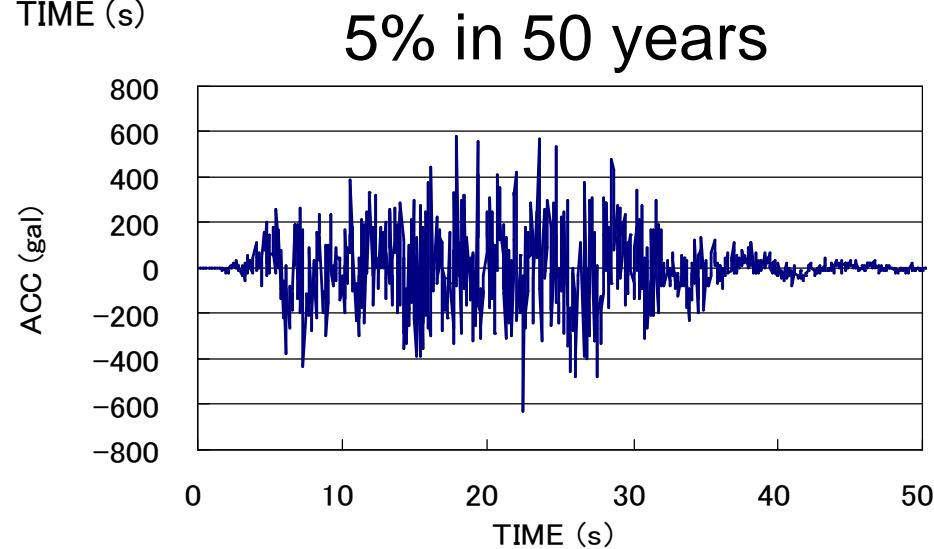
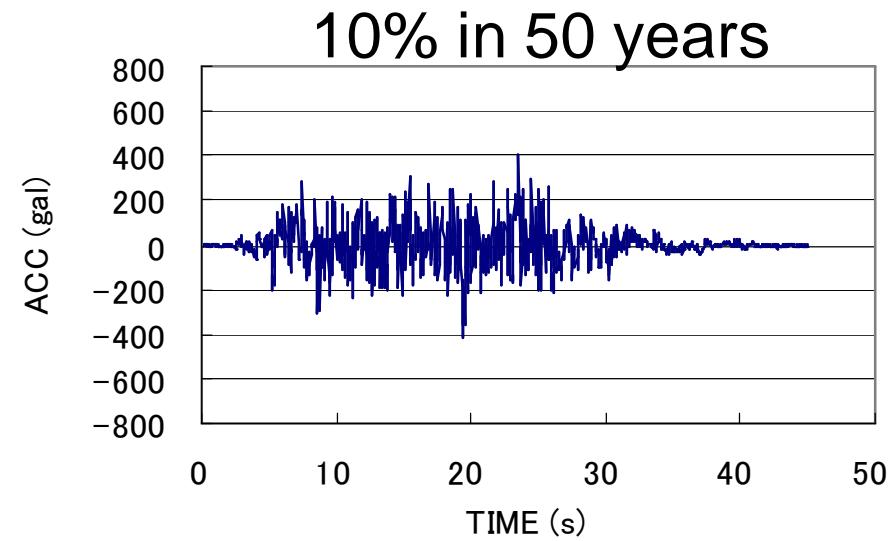
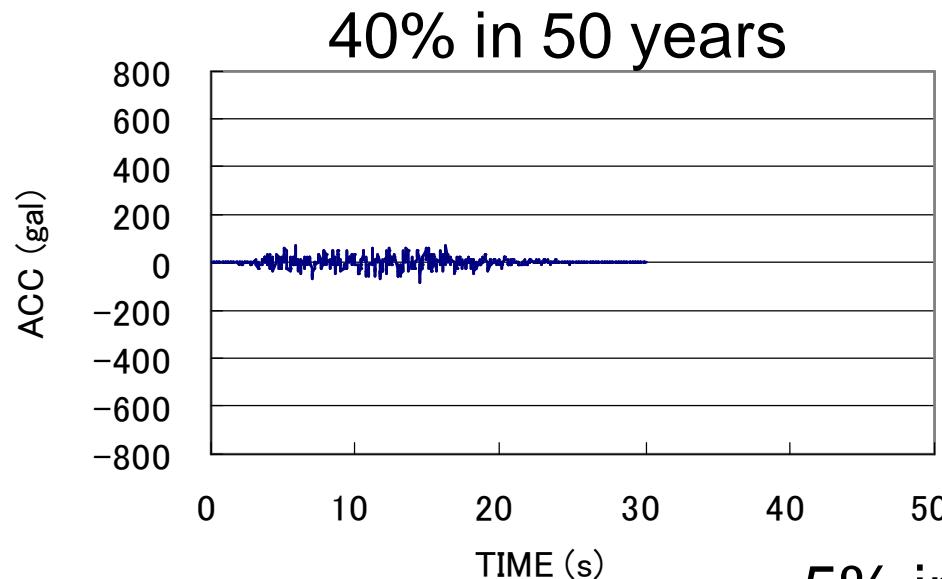


- Total number of elements 63,978  
Rectangular parallelepiped
- Size of bricks 10cm × 10cm × 20cm

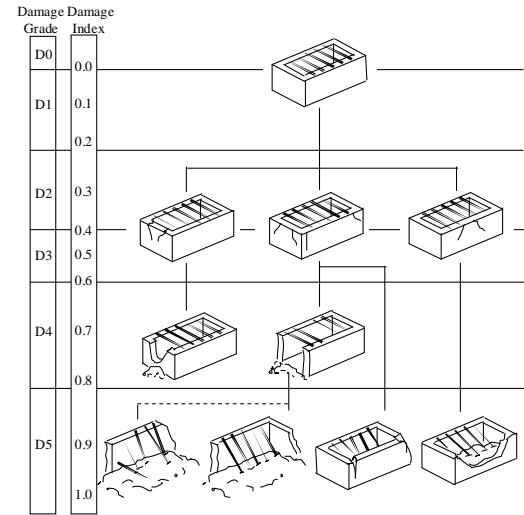
# Dimension



# Input Ground Motion

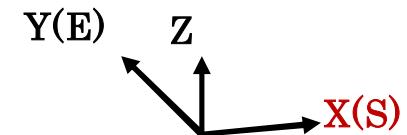


# Damage Index



Damage Grade	Damage Index	Damage Description	Damage State
D0	0.0	No damage	No damage
D1	0.0~0.2	Negligible to sight damage	Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
D2	0.2 ~ 0.4	Moderate damage	Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
D3	0.4 ~ 0.6	Substantial to heavy damage	Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
D4	0.6 ~ 0.8	Very heavy damage	Serious failure of walls, partial structural failure of roofs and floors
D5	0.8 ~ 1.0	Destruction	Total or near total collapse

**40% in 50 years**



**Input in X direction**

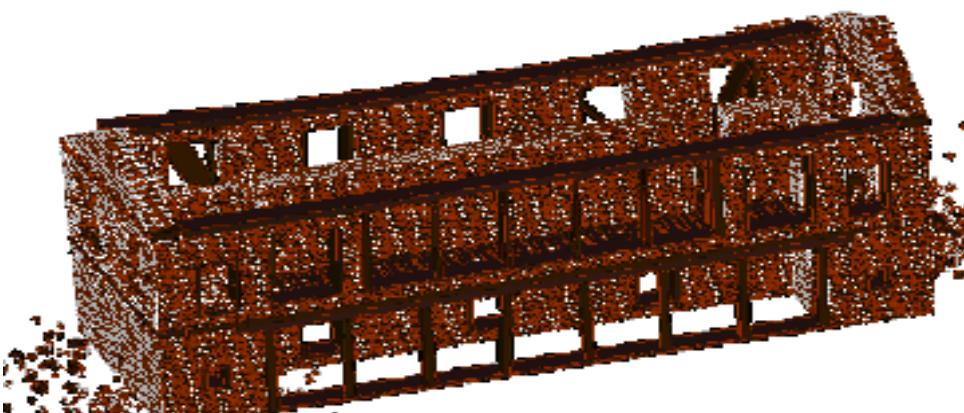


25.00[sec]

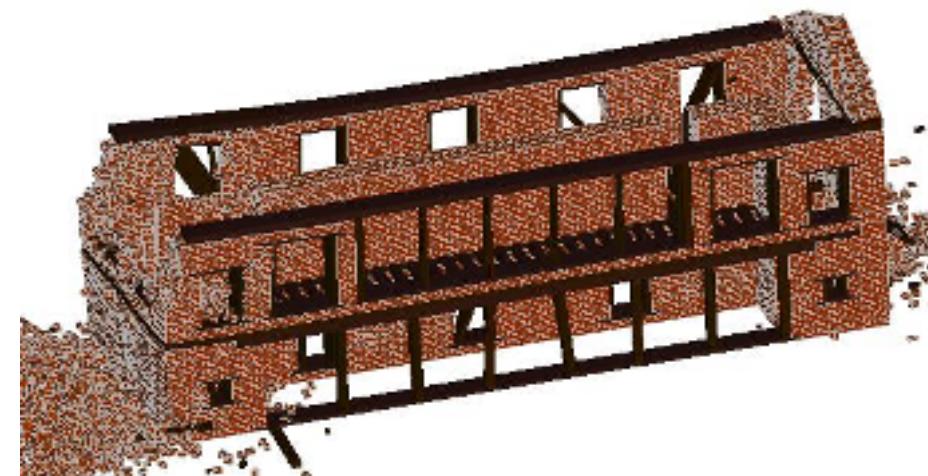


**Damage Index = 0.6**

**Input in Y direction**

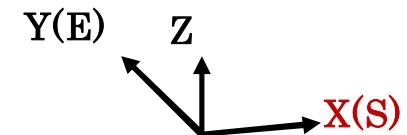


25.00[sec]



**Damage Index = 0.6**

**10% in 50 years**

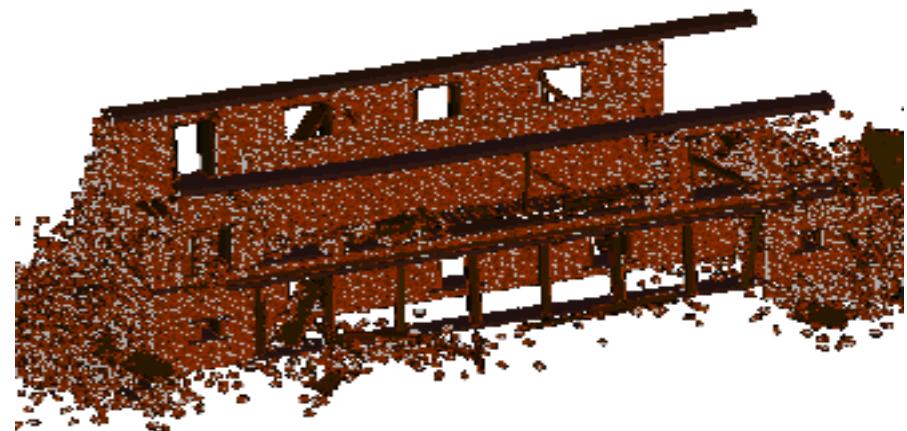


**Input in X direction**

15.00[sec]



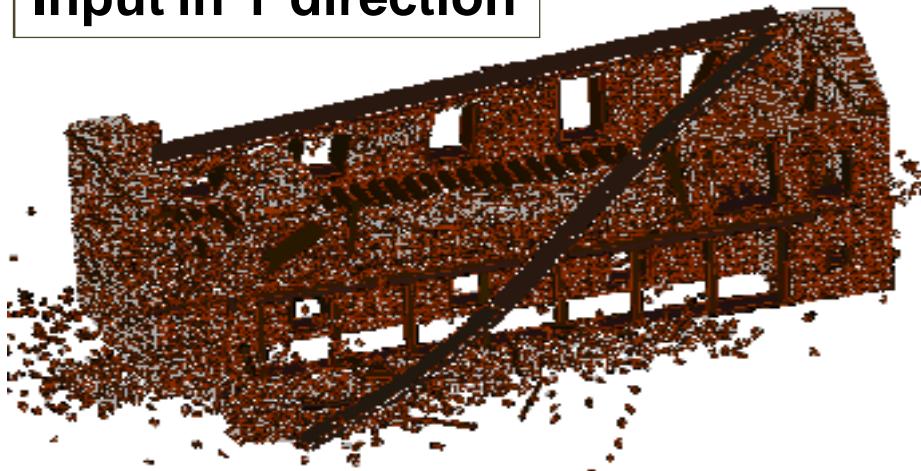
40.00[sec]



**Damage Index = 0.8**

**Input in Y direction**

5.00[sec]

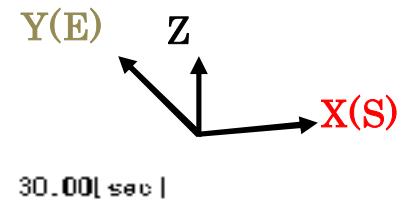


20.00[sec]

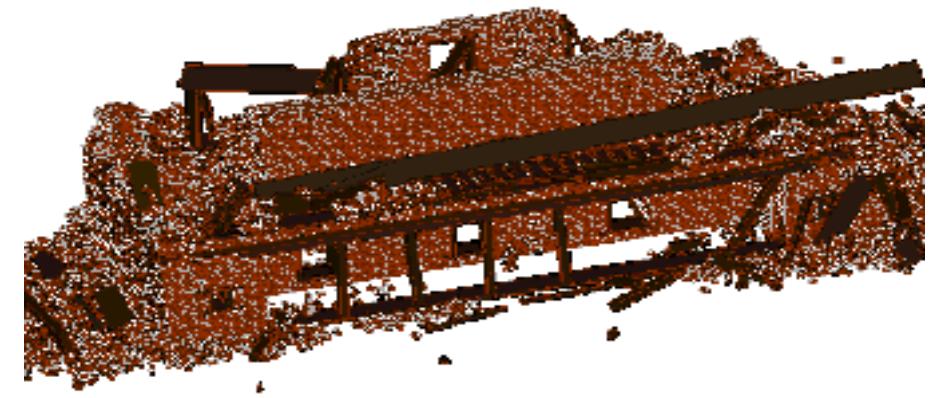
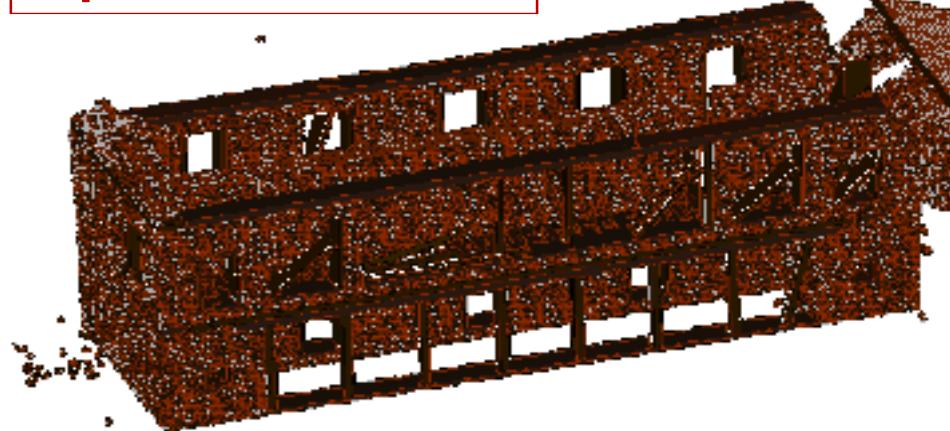


**Damage Index = 1.0**

**5% in 50 years**



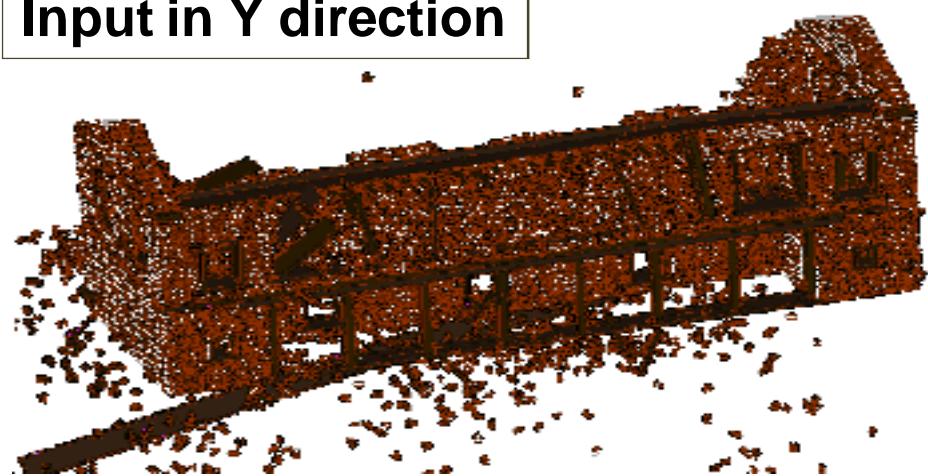
**Input in X direction**



30.00[sec]

**Damage Index = 0.8**

**Input in Y direction**

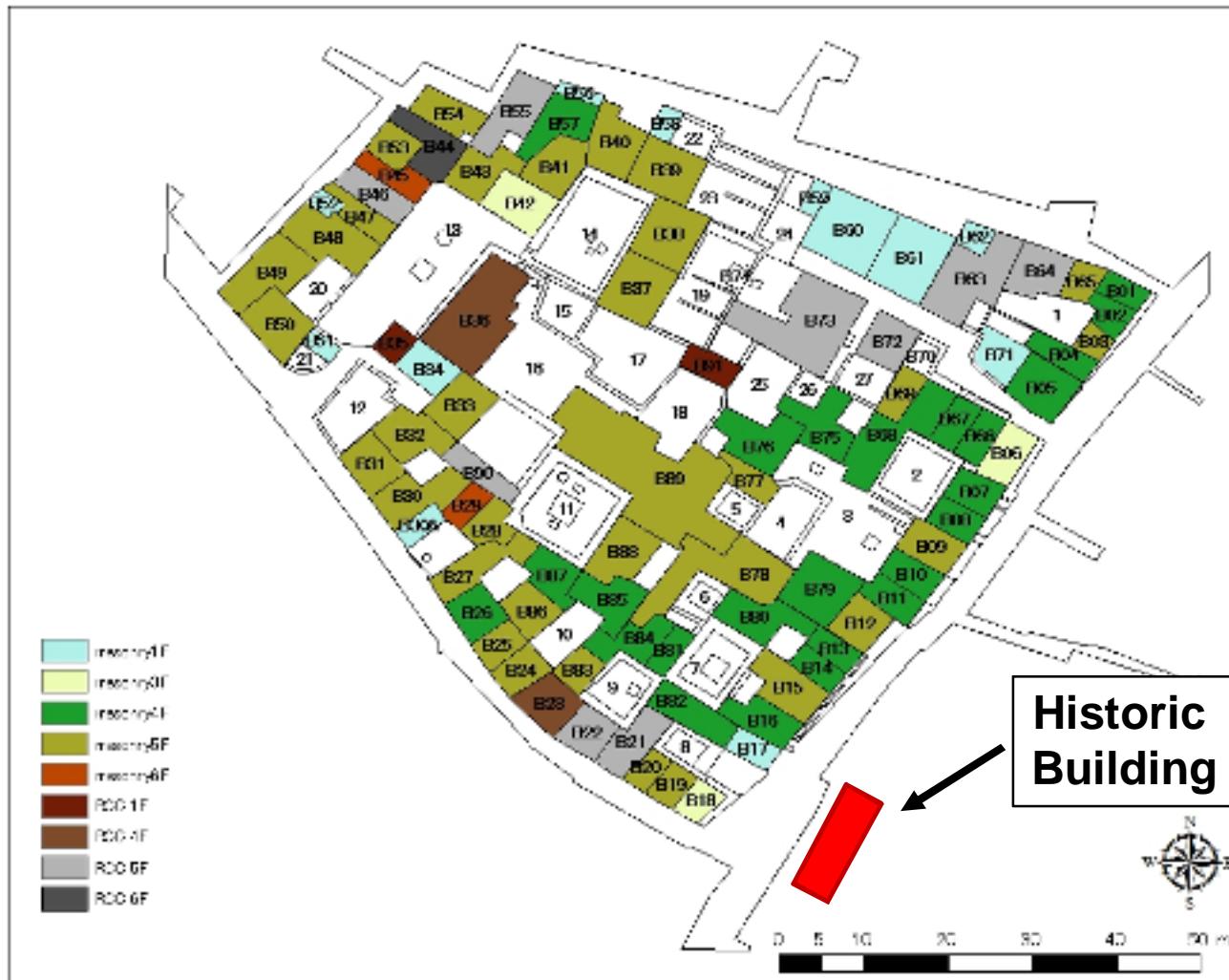


20.00[sec]

**Damage Index = 1.0**

*Vulnerability Assessment of an Area*

# Jhatapol Area



- Most of the buildings are unreinforced masonry buildings which have high possibility to get severe damage during an earthquake.

# Complete Enumeration

## Structural type

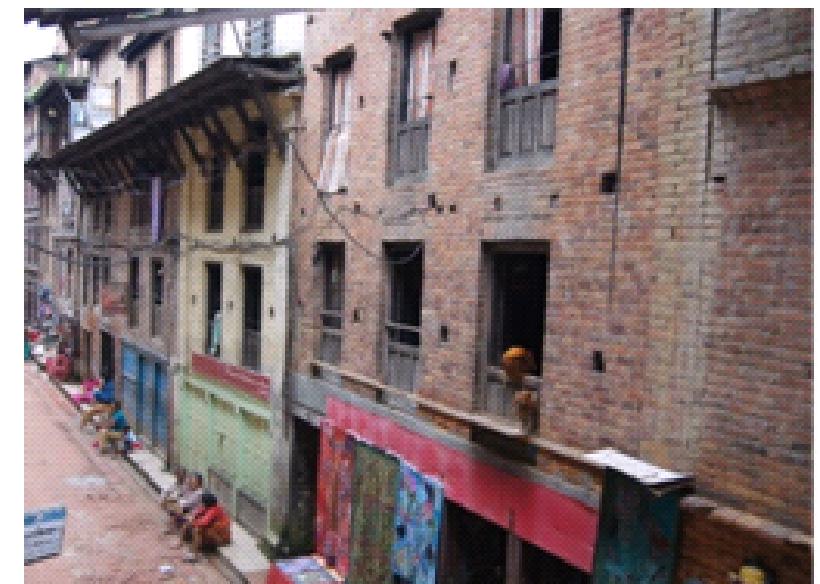
- Masonry
- Reinforced Concrete
- Confined Masonry (RCC)

## Number of Stories

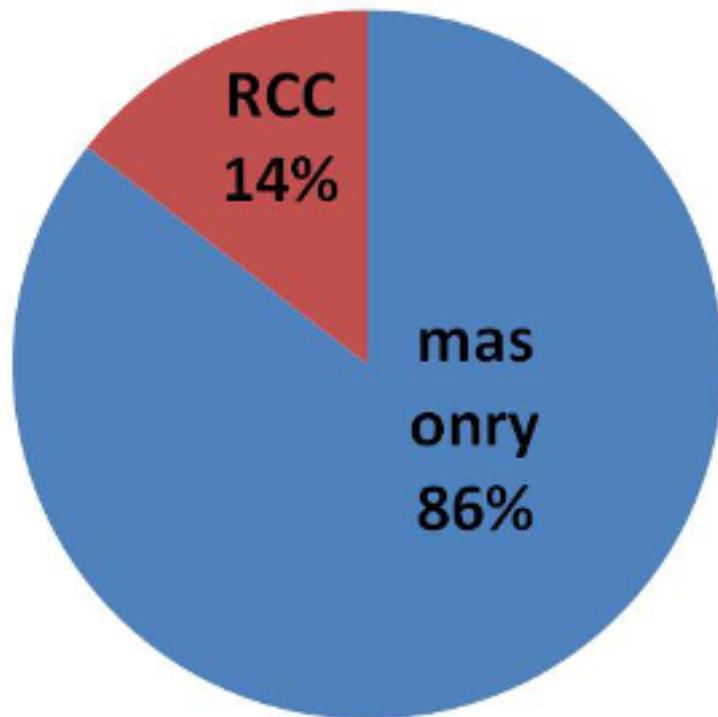
- Any additional stories?

## Single or Continuous building

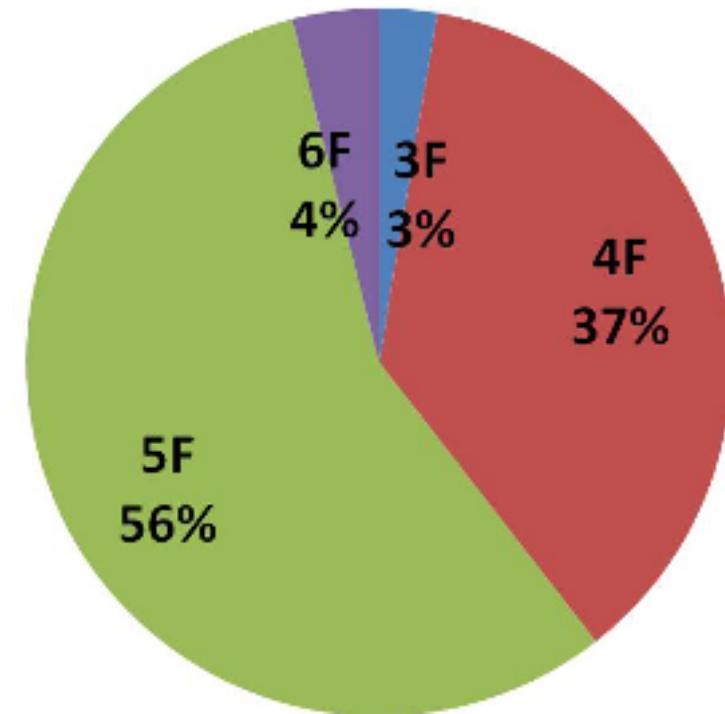
- All buildings are continuous



# Classification of Buildings

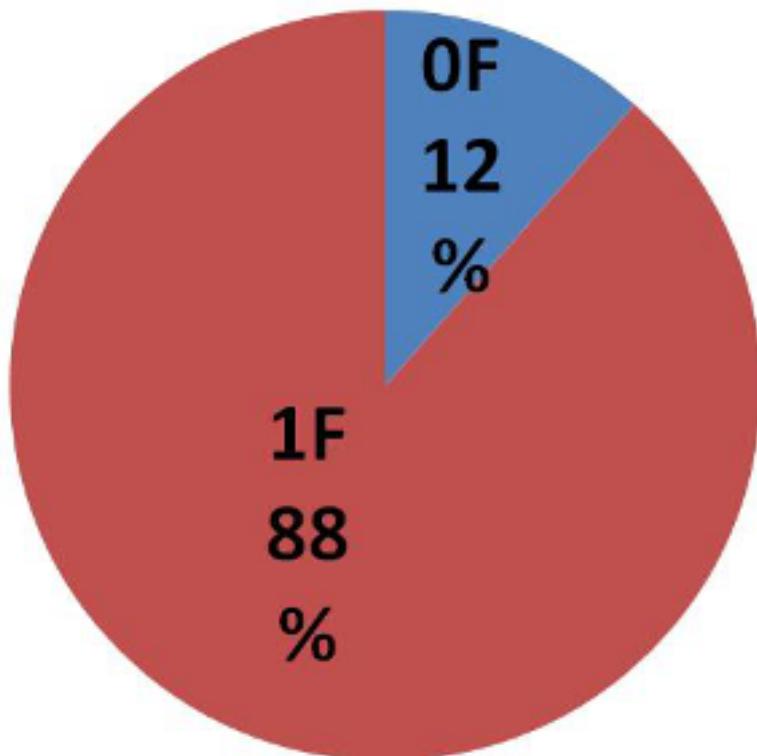


**building type**

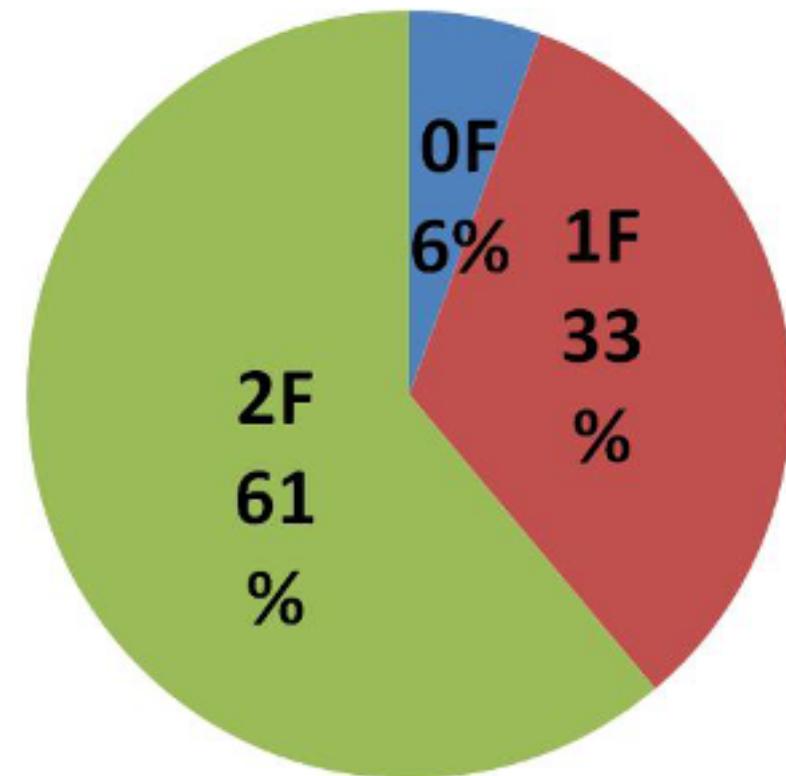


**the number of stories**

# Number of Additional Stories



4-story masonry buildings



5-story masonry buildings

# Classification of Structures by Structural Type and the Number of Stories



# Results: Damage Index (10% in 50 years)



Masonry : damage index > 0.8  
RCC : damage index < 0.2

# まとめ

- ✓ ネパールの歴史的建造物群は過去の地震でも大きな被害を経験してきた。そしてその都度、また元の材料を使って再建されてきた。
- ✓ ハザード解析より、50年40%、10%、5%の震度階級は、それぞれ震度4、震度5弱～5強、震度5強～6弱程度に対応する。
- ✓ 経年劣化や地下水の吸収等によって組積造建物のレンガの質が落ち、弾性波トモグラフィーの結果より、本来の波速の1/3～1/5程度にまで減少している。
- ✓ 2階建て歴史的組積造の卓越振動数は、短辺方向で並進・ねじれそれぞれ4.3Hzと5.8Hzであった。
- ✓ 歴史的建造物に使用されているレンガとレンガ壁の要素試験により、密度やヤング率、圧縮強度やせん断強度の値を得た。
- ✓ 弹性波トモグラフィーや要素試験で得られた値を利用して、歴史的建造物の解析モデルを作成し、微動観測による振動特性で妥当性を検証した。
- ✓ 数値解析により、耐震補強法の評価を行うとともに、歴史的建造物群の脆弱性評価を行った。震度5弱程度で歴史的建造物群は大被害を受ける。
- ✓ 近傍にすべりの大きな領域、地盤の弱い盆地構造、耐震補強を行う余裕なし、建て増しや古く耐震性のない組積造建物群、1934から80年経過…



1日も早く元の姿に戻ることを願っています