2015 GORKHA (NEPAL) EARTHQUAKE

Performance of Masonry Structures

Durgesh C. Rai

Vaibhav Singhal

S Lalit Sagar

Bhushan Raj S

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National Information Center on Earthquake Engineering

Indian Institute of Technology Kanpur

THE MASONRY SOCIETY

12th North American Masonry Conference

Masonry: Science • Craft • Art

Denver, Colorado May 17 – 20, 2015

Department of Civil Engineering

UNIVERSITY OF COLORADO

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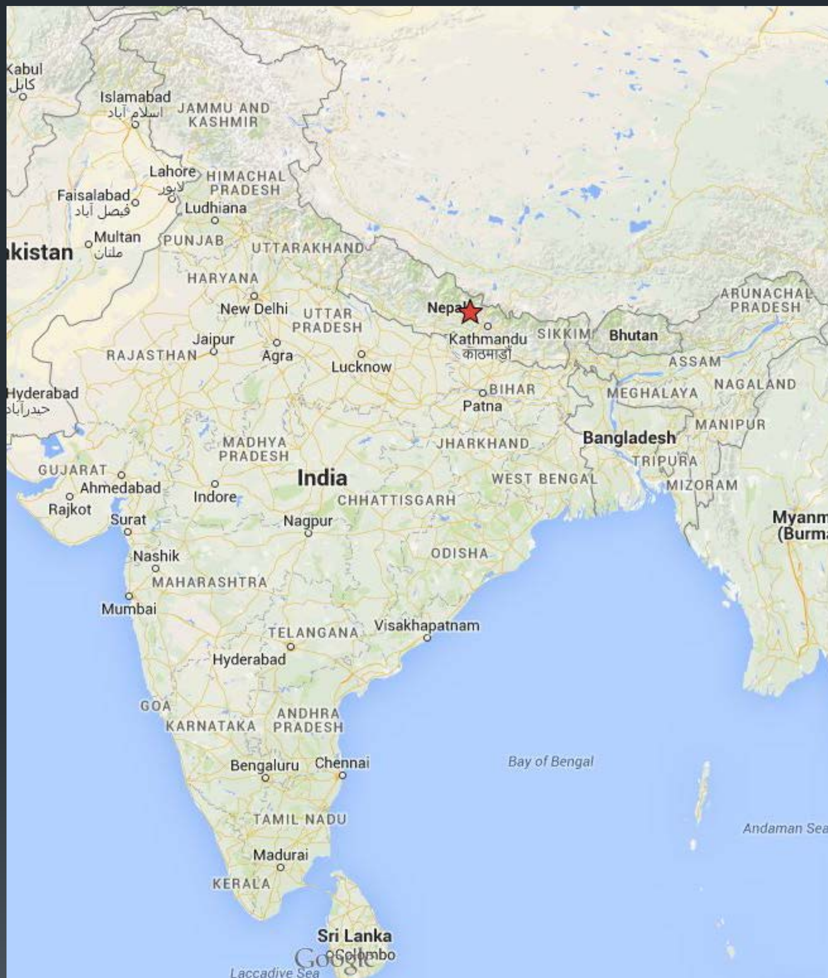
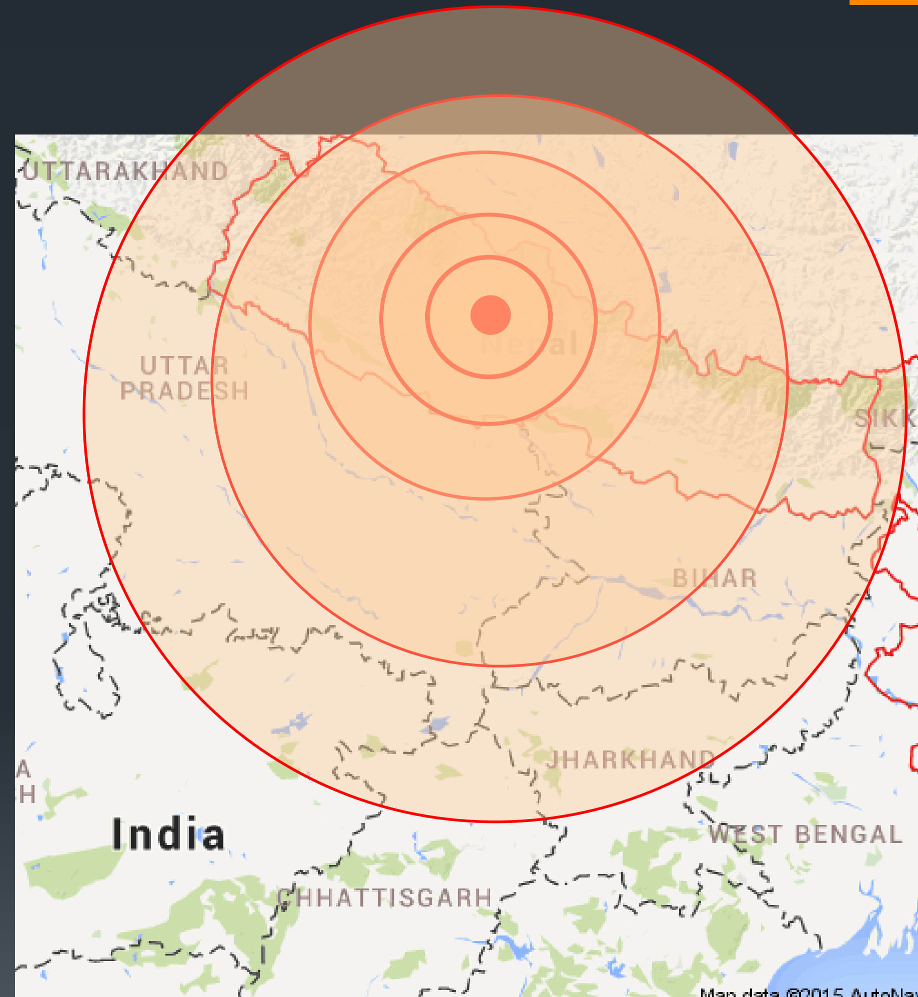
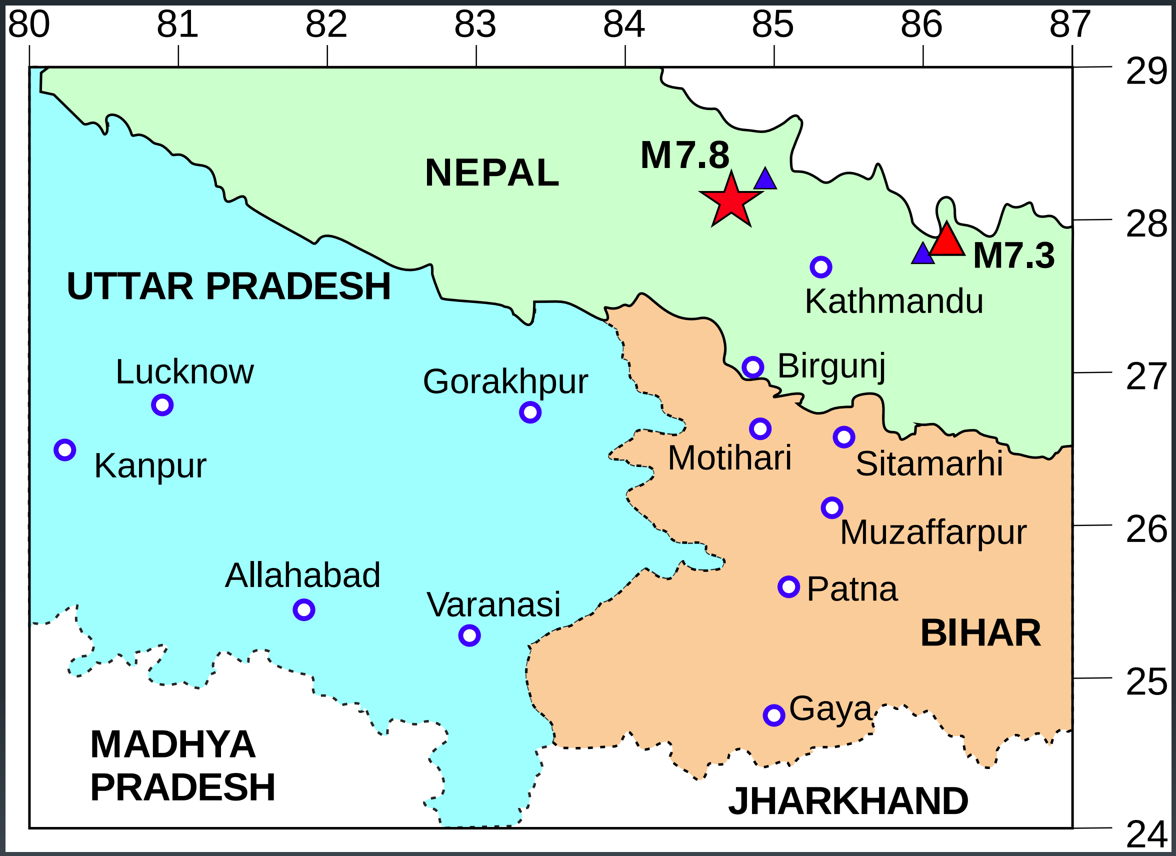
2015 Gorkha (Nepal) Earthquake





2015 Gorkha (Nepal) Earthquake…

- M7.8 Gorkha, Nepal
- Maximum Intensity IX
- 25th April 2015 at 11:56 am (UTC+5:45)
- 80 km NW of Kathmandu at a depth of 15.0 km (USGS)
- Tremor lasted for 90-100 seconds
- Four major aftershocks
  - ⇨ M6.6 on 25th April
  - ⇨ M6.7 on 26th April
  - ⇨ M7.3 on 12th May ▲
  - ⇨ M6.3 on 12th May



Statistics (as on 18 May 2015)

- Total death toll ~ 8,600
  - ⇨ 8,492 in Nepal
  - ⇨ 78 in India, 25 in China, 4 in Bangladesh
- No. of people injured ~ 18,950
  - ⇨ 17,803 in Nepal
  - ⇨ 560 in India, 383 in China, 200 in Bangladesh
- Buildings damaged (NSET, Nepal)
  - ⇨ Completely destroyed ~ 489,500
  - ⇨ Partially destroyed ~ 262,600
  - ⇨ 35 of the 75 districts have been affected in central and western parts of Nepal

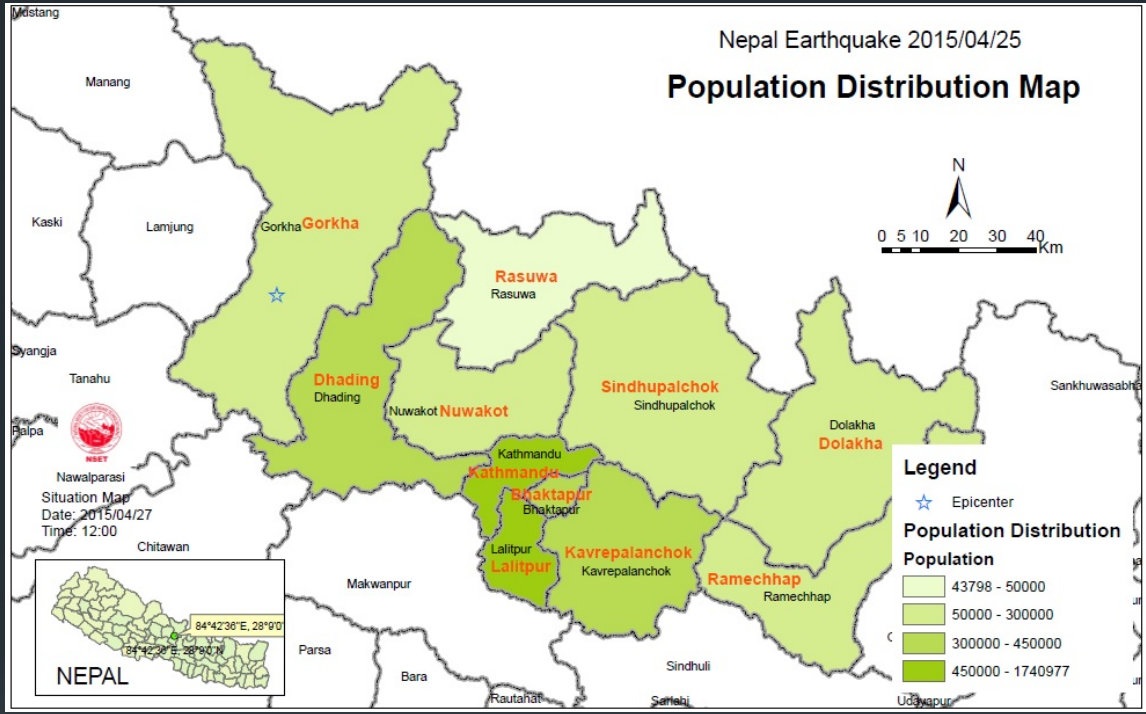
Population Distribution

NEPAL

- ~ 27 million population
- 184 persons/sq. km.
- Fourteen zones, 75 districts

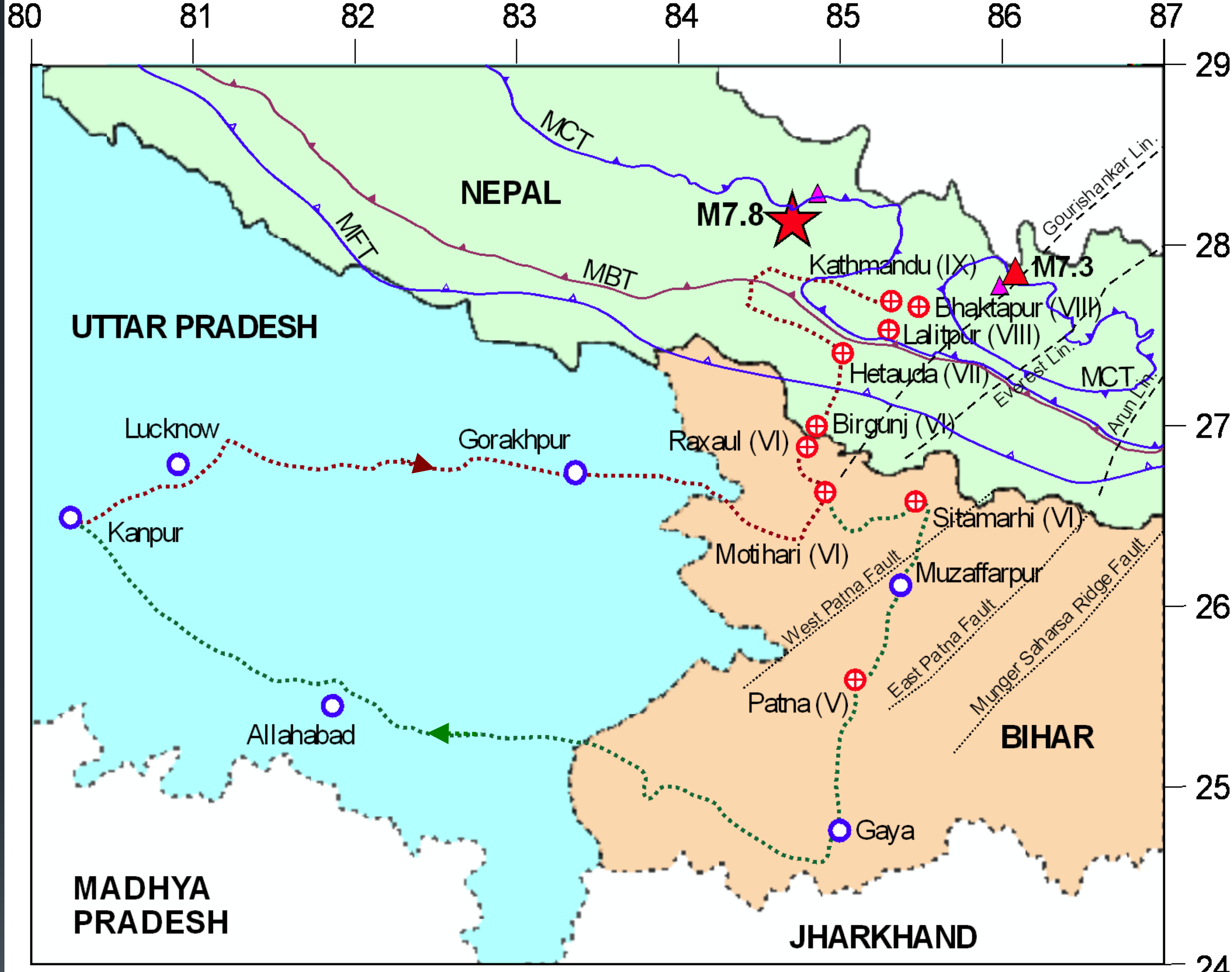
INDIA

State	Popul. Density (sq.km)
Bihar	1105
Uttar Pradesh	822
West Bengal	1037



Source: NSET

Field Trip

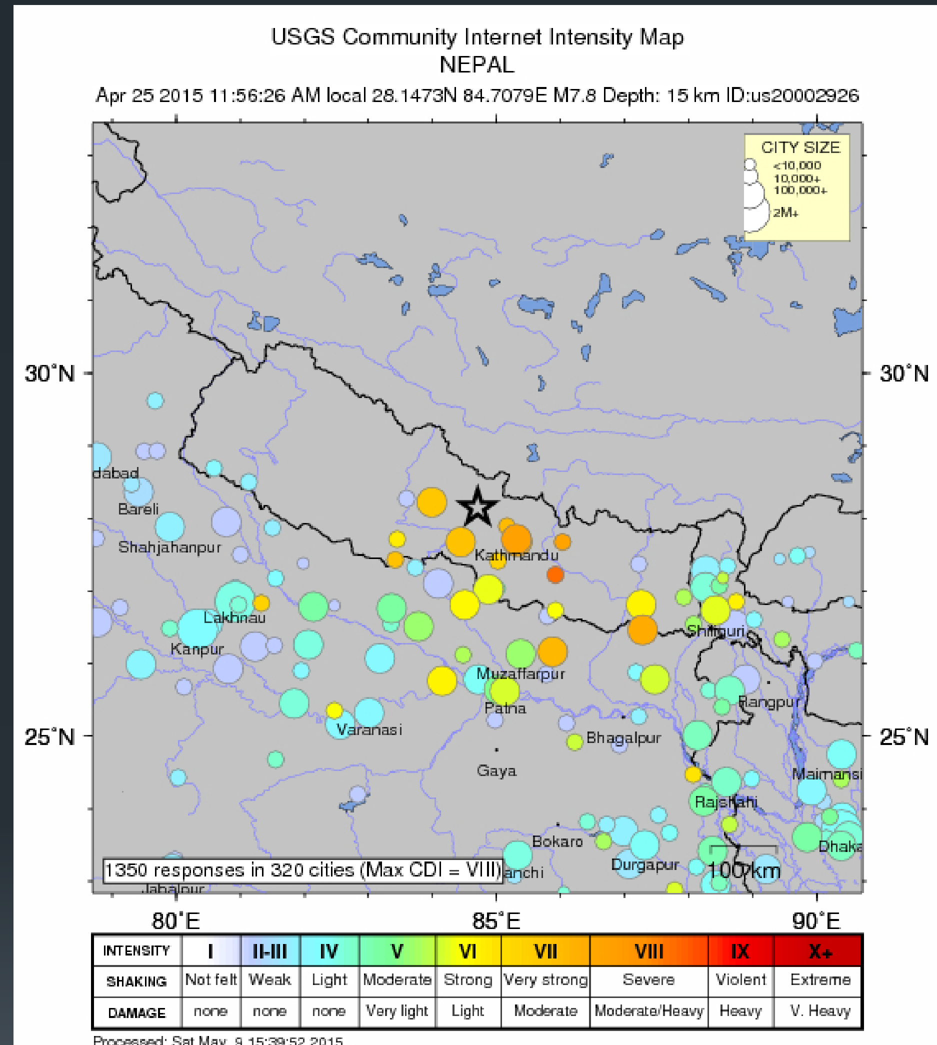


Major cities/towns visited

Intensity Map

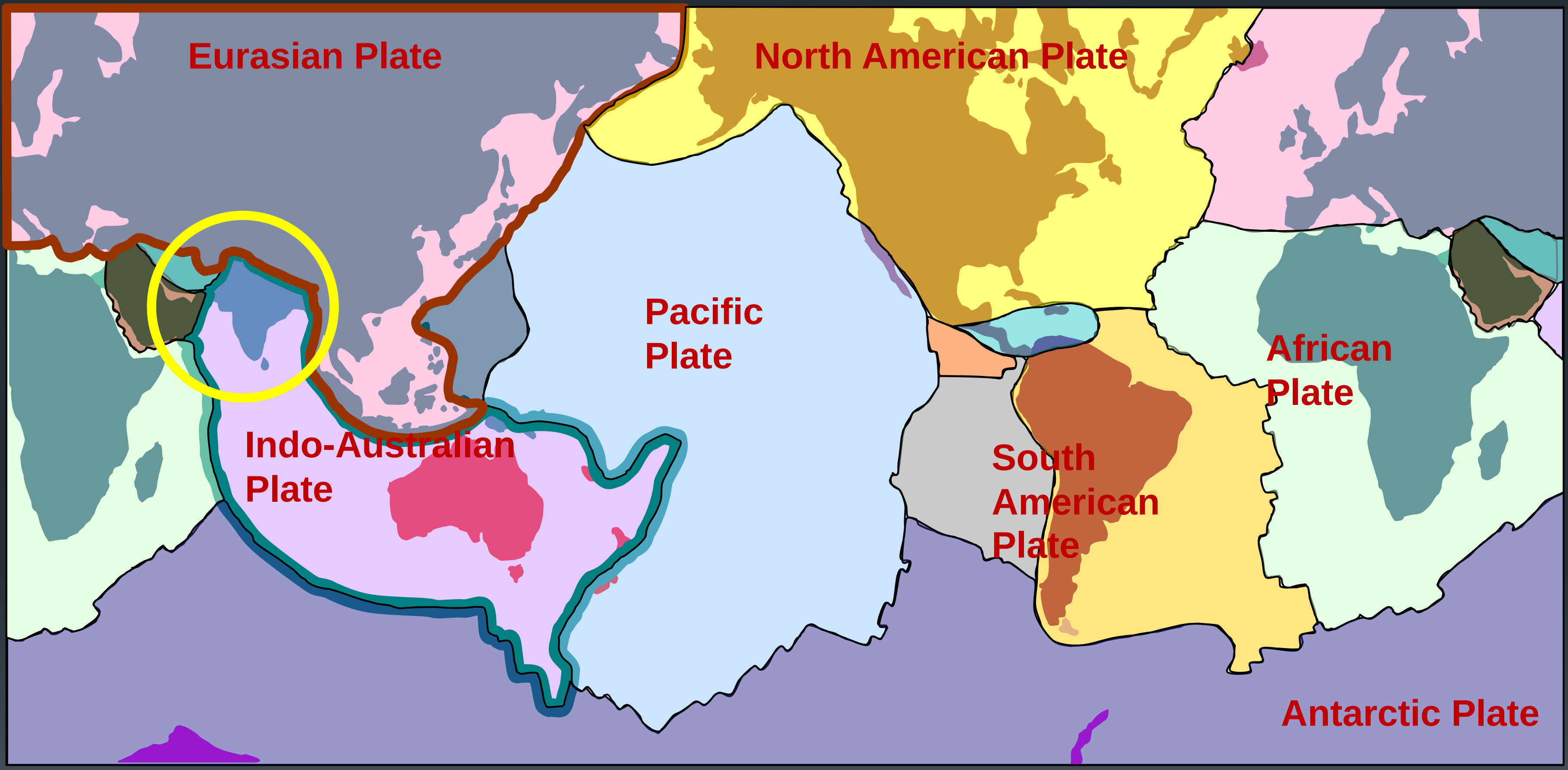
Intensity at important cities

- **Intensity IX**
  - Kathmandu
- **Intensity VIII and VII**
  - Bhaktapur, Lalitpur, Gorkha, Sindhupalchok, Nuwakot, Hetauda
- **Intensity VI**
  - Birgunj, Raxaul, Sitamarhi, Motihari
- **Intensity V**
  - Muzaffarpur, Patna, Kolkata
- **Intensity IV**
  - Varanasi, Lucknow, Kanpur, New Delhi

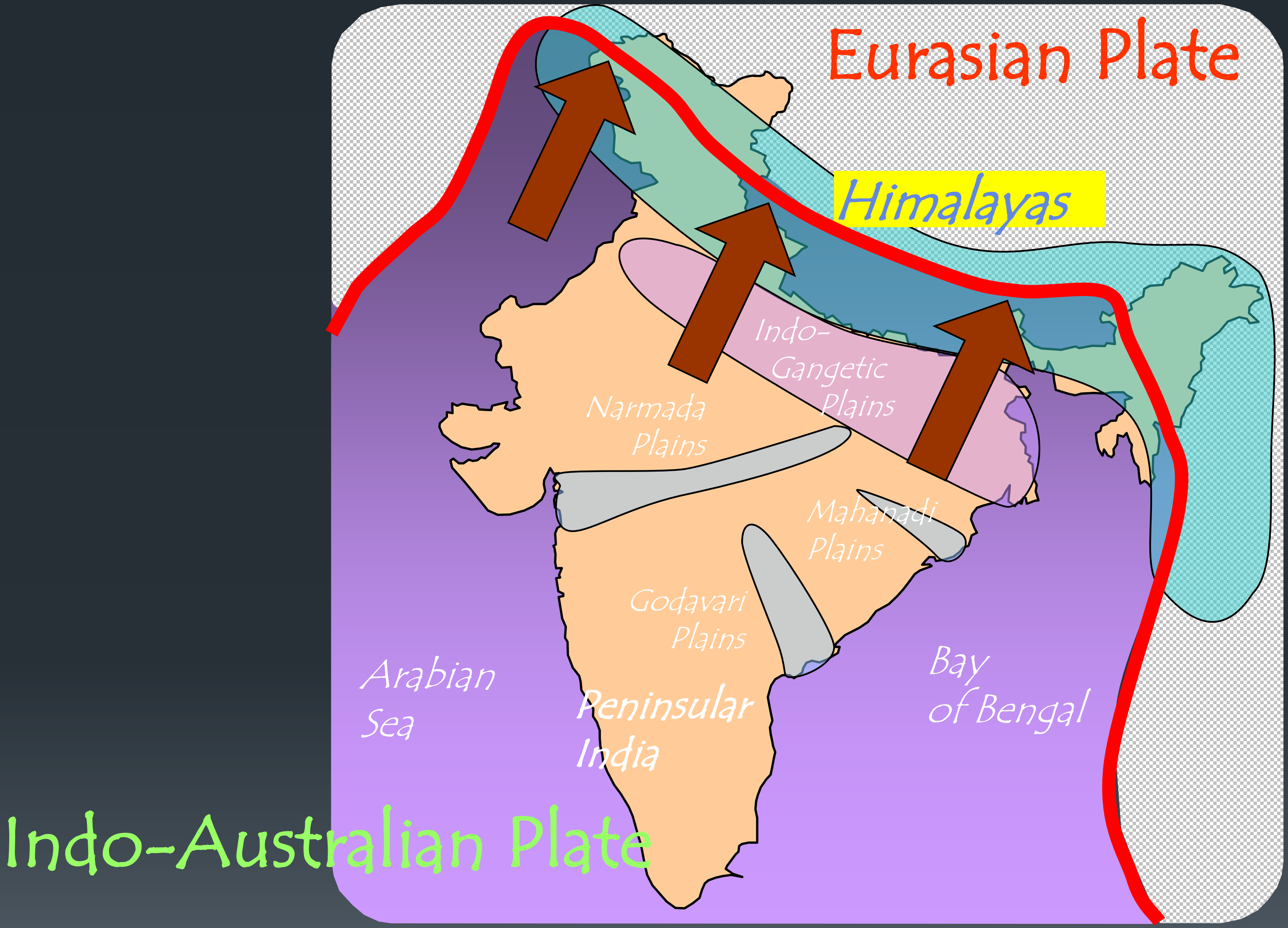


Source: USGS

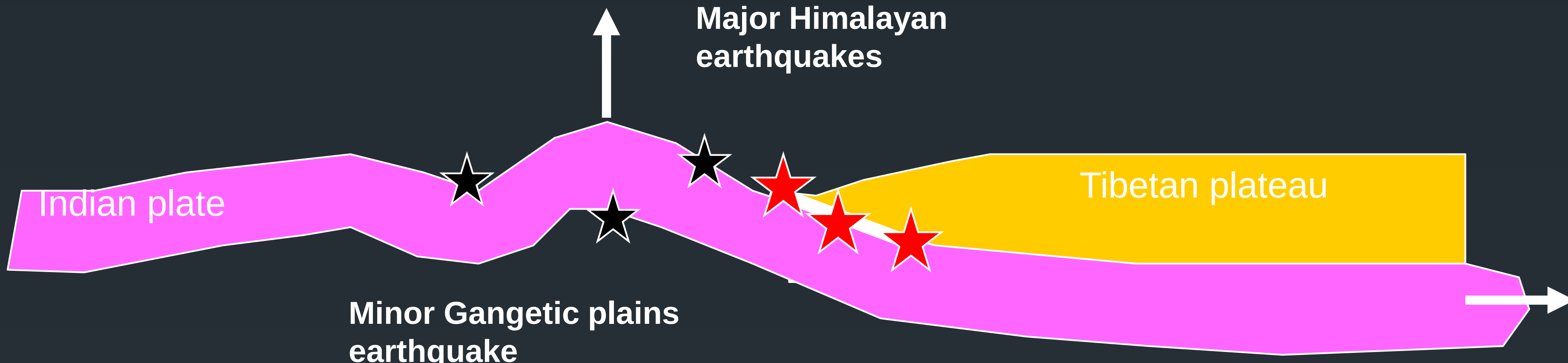
Seismic Setting

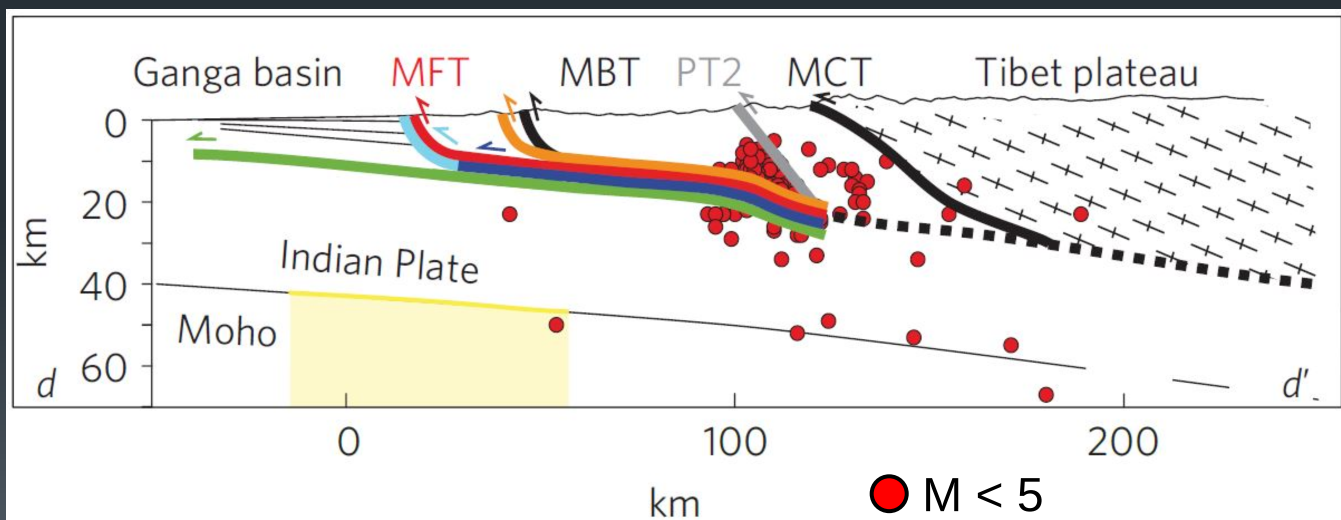


Tectonic plate boundaries

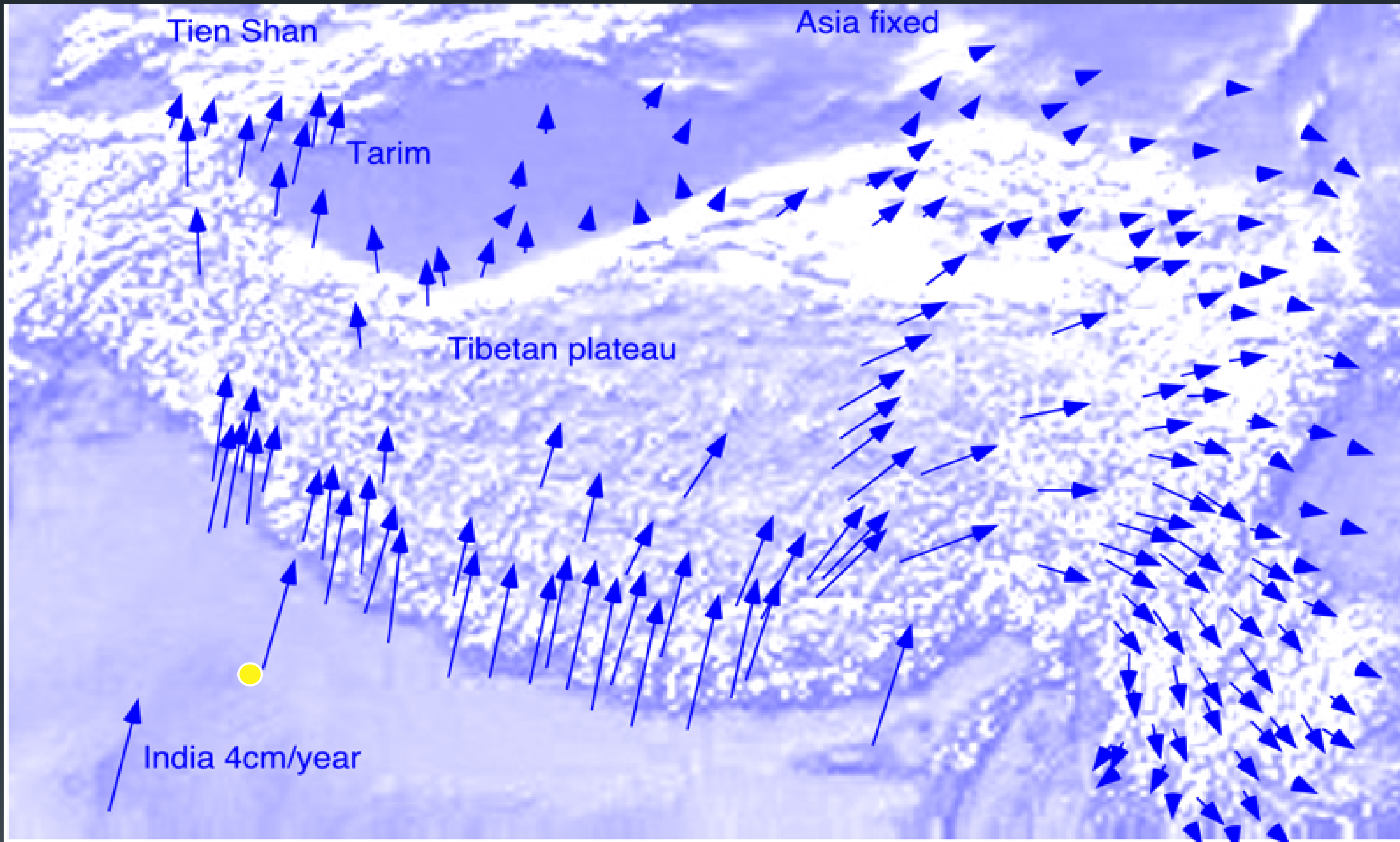


Tectonic plate boundaries…



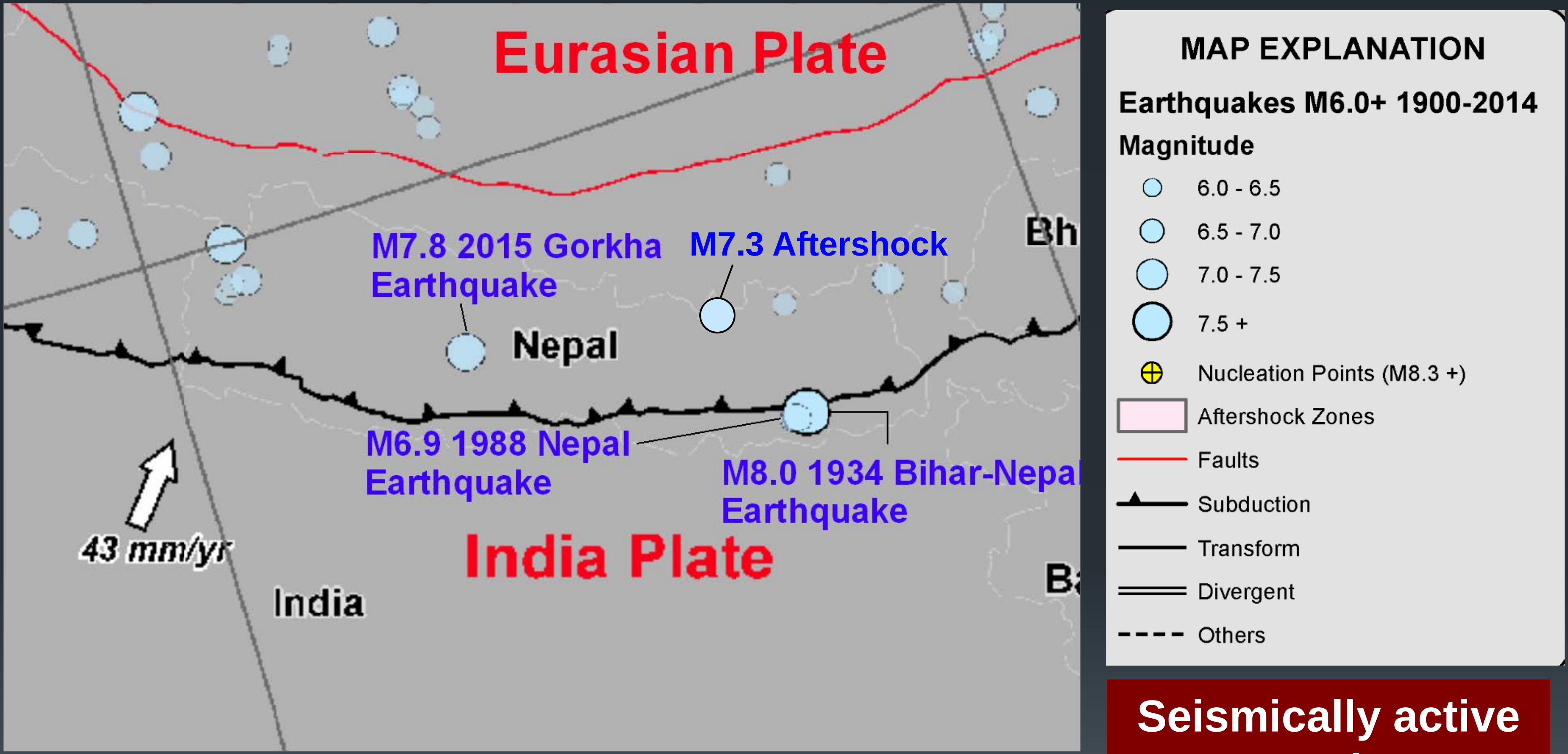


Sapkota et al. (2013)



10 years of GPS

Seismicity

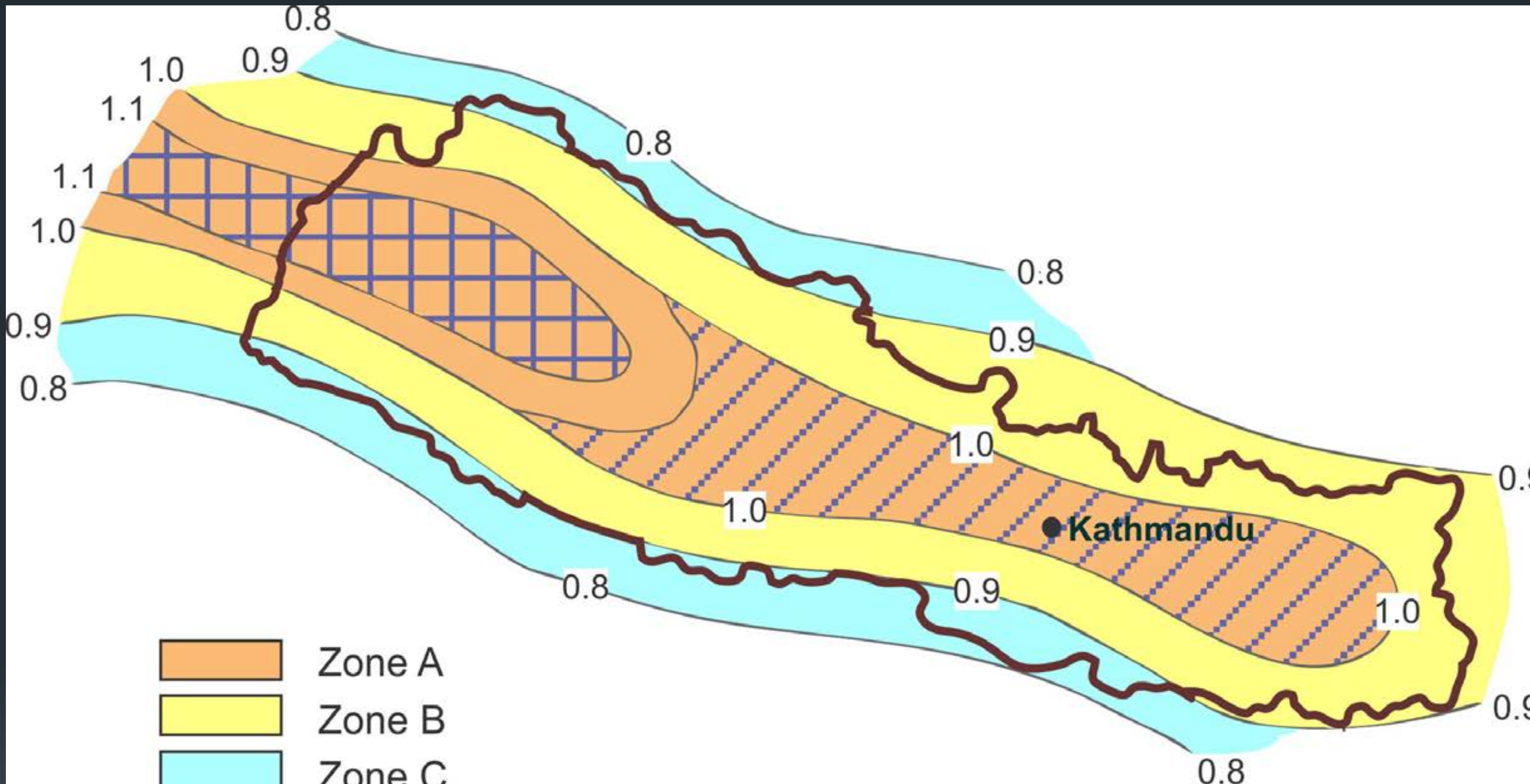


Past Earthquakes M6.0+

Source: USGS

Seismically active region

Seismic Hazard… **NEPAL**



~90% Nepal's land area under
Moderate-to-Severe Seismic Hazard

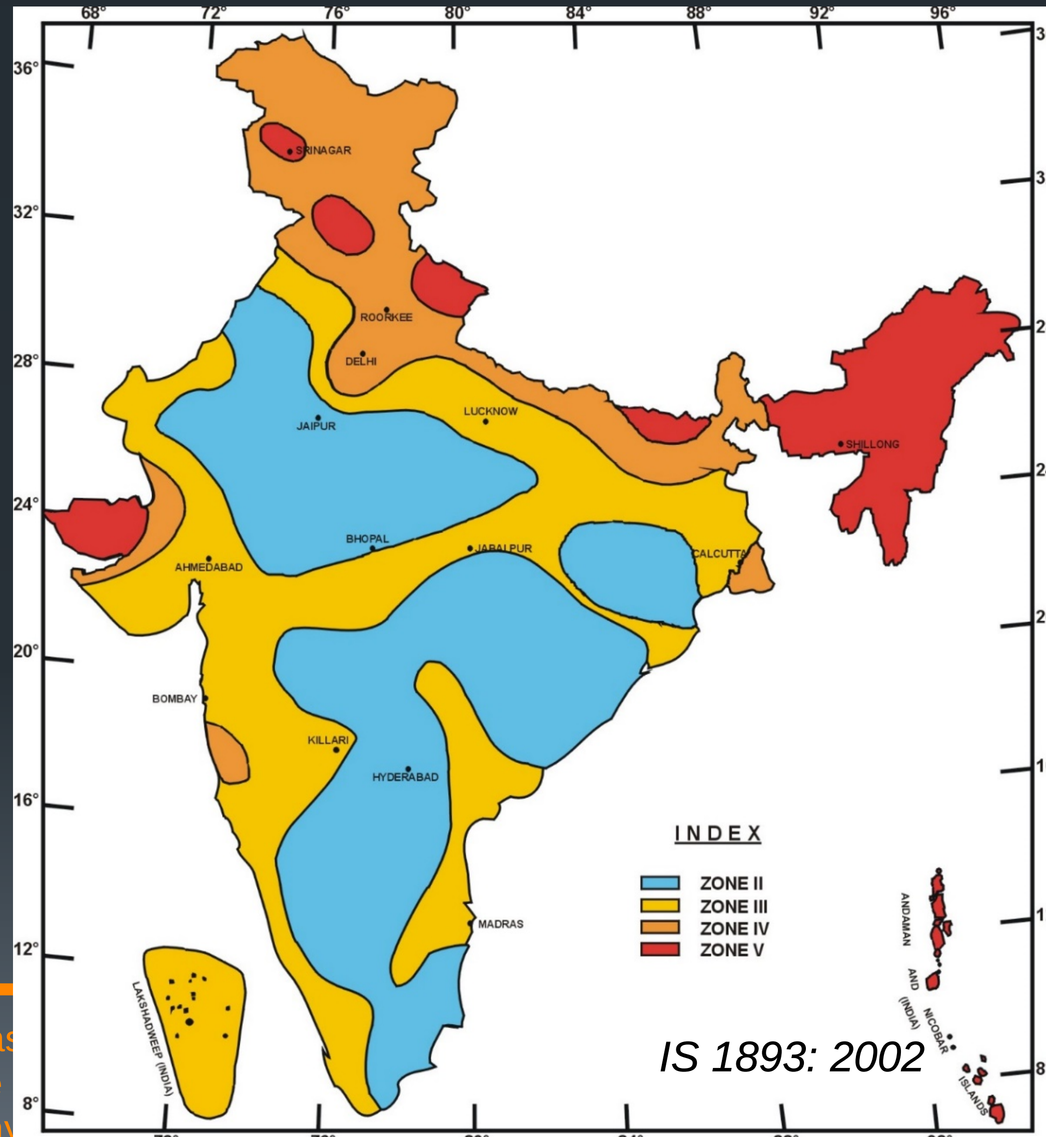
NBC 105: 1994

Seismic Hazard… **INDIA**

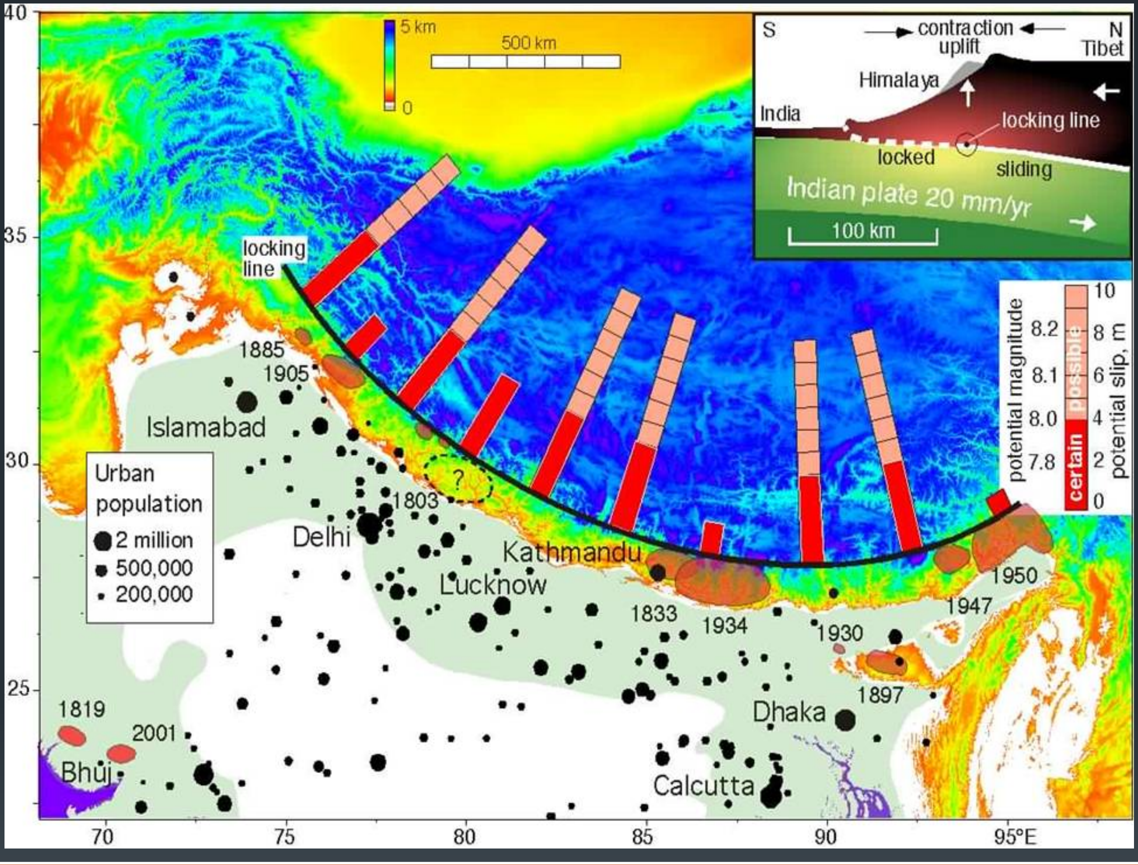
Zone Factor, *Z*

II	0.10
III	0.16
IV	0.24
V	0.36

~60% India's land area under
Moderate-to-Severe Seismic Hazard



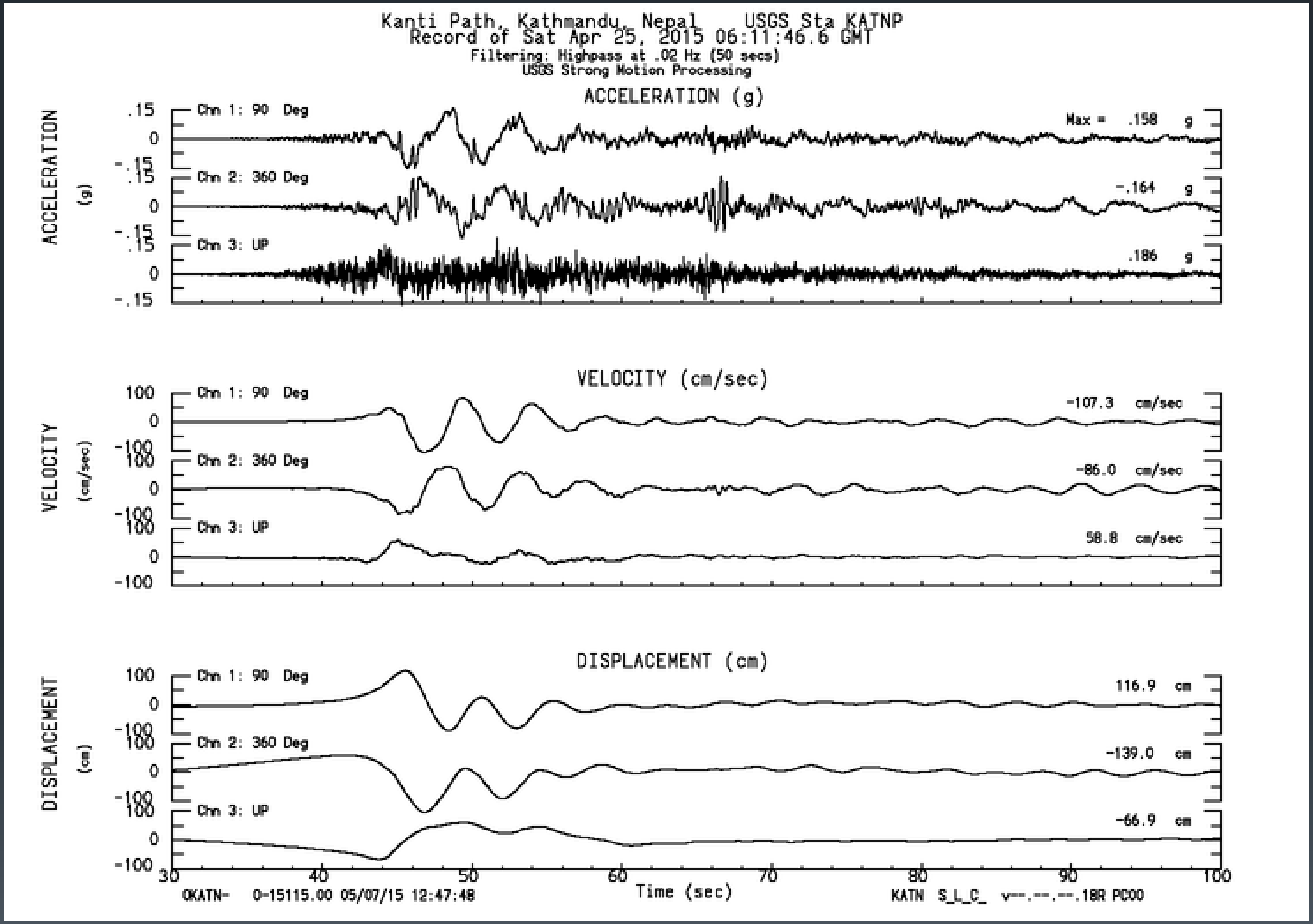
Future Seismic Hazard



Bilham 2005

Several M>8 earthquakes are probable either as repeat events of historical ruptures or ‘gap filling’ earthquakes in the intervening regions’ (Bilham & Ambraseys, 2005)

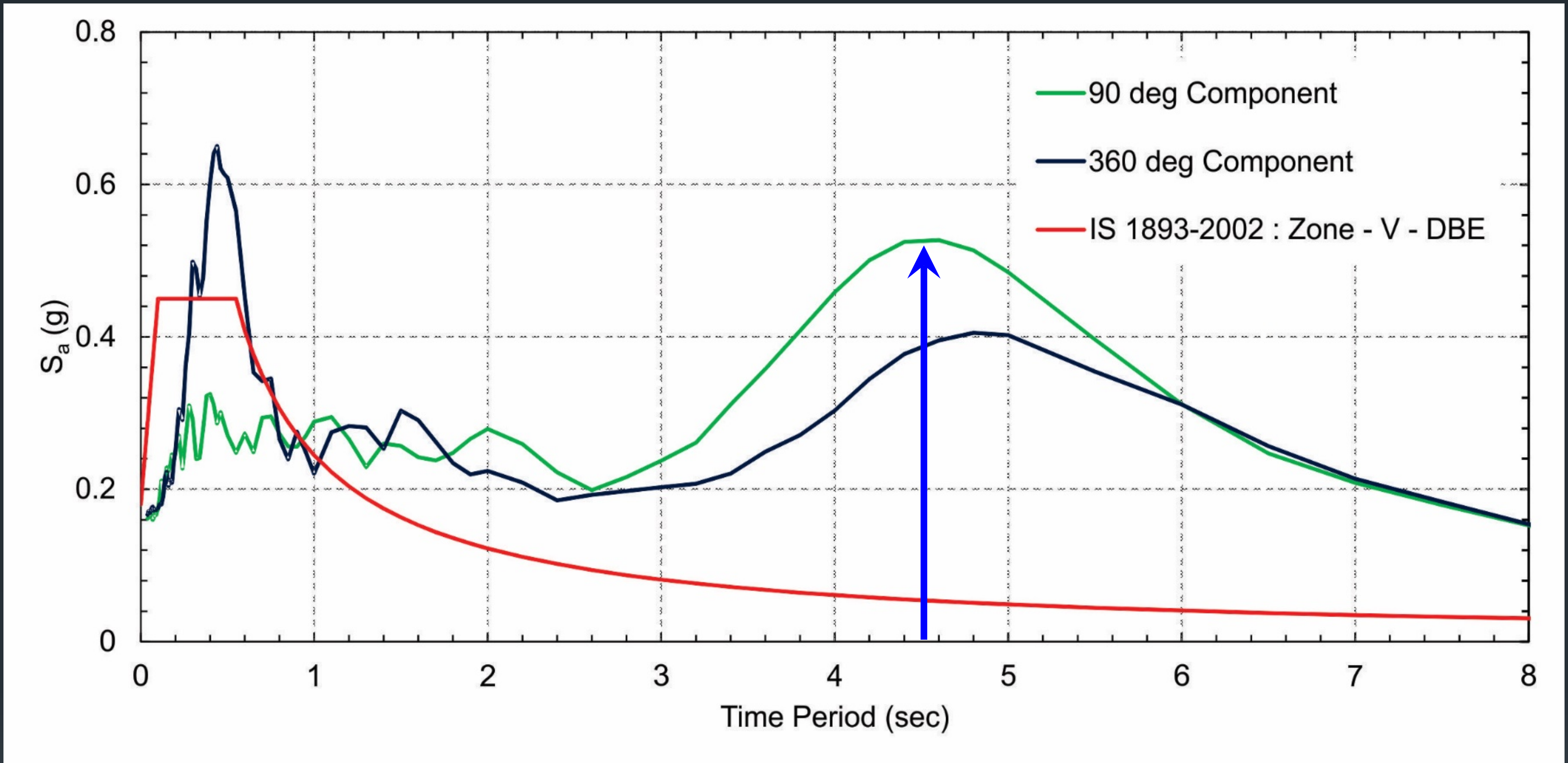
Ground Motion Record



Peak acceleration = 0.16*g*

Source: CESMD

Ground Motion Record…



Unusual higher acceleration between 4 to 6 second period

Response Spectrum of recorded ground motion and its comparison with Indian design spectrum

Geological Hazard

Ground Movements

Vertical movement of ground which resulted in severe damages to roads

Landslides

Landslide on road to Kathmandu, Nepal

Performance of Buildings

"In a way, earthquake engineering is a cartoon of other branches of engineering. Earthquake effects on structures systematically bring out the mistakes made in design and construction – even the most minute mistakes"

Emilio Rosenblueth and Nathan Newmark (1971)

Performance of URM Buildings

- Old unreinforced masonry buildings suffered maximum damage due to their deteriorated strength over the years

Complete collapse of URM buildings in Nikoshera, Bhaktapur

Performance of URM Buildings…

Typical out-of-plane failure of URM walls

- Out-of-plane collapse of load bearing masonry walls of old buildings was widely observed in many parts of Nepal
- Poor connection with the diaphragm and cross walls led to such collapse

Performance of URM Buildings…

More examples of out-of-plane failure of URM walls

Performance of URM Buildings…

Formation of cracks at the corners of the URM buildings in Bhaktapur

- Most of the URM structures lost significant strength due to formation of vertical cracks at the corners of the building, reducing the out-of-plane stability of the walls drastically

Performance of URM Buildings…

Step-type shear cracks in URM walls

- Damage due to absence of continuous horizontal bands around openings
- Step-type shear cracks were formed over the entire storey height

Performance of URM Buildings…

Collapse of the roof and failure of supporting wall

- Weak diaphragms and their poor connection with the masonry wall caused collapse of floor as well as failure of supporting walls

Performance of URM Buildings…

Pancake collapse of top storey of a 3 storey URM building, Kathmandu

Performance of URM Buildings… **INDIA**

School building in Motihari, Bihar
(Photo: PTI)

Masonry house in Madhubani, Bihar
(Photo: PTI)

Performance of RC Frame Buildings

Pancake collapse of many RC buildings, Kathmandu

- Poor performance due to inadequate size and poor reinforcement detailing of columns

Performance of RC Frame Buildings…

Failure of 4-storey buildings which also led to damages in adjacent buildings by pounding

Performance of RC Frame Buildings…

Open ground storey failure of 5 storey building, Kathmandu

- Provision of open ground storey was common practice to be used for utility purposes

Performance of RC Frame Buildings…

Weak storey failure of two adjacent buildings, Kathmandu

Masonry Infills in RC Frame Buildings

- Extensive damage to masonry infills has been reported

Diagonal cracks in the pier region between two openings

Inadequate strength due to use of half-brick thick infill

Diagonal shear crack in infill walls of RC buildings

Masonry Infills in RC Frame Buildings…

RC members absent at the corners of the building

Masonry Infills in RC Frame Buildings…

Diagonal and shear sliding crack at mid-height of wall

Horizontal crack in the infill wall due to differential settlement

Masonry Infills in RC Frame Buildings…

Absence of confining members around the openings

Masonry Infills in RC Frame Buildings…

Masonry crushing and plastic hinge formation in column

Partial collapse of RC buildings in Kathmandu

Masonry Infills in Tall RC Buildings

Separation of infill for boundary frames

Cracks in walls projecting beyond column line

- Separation of infill from boundary frame was very common in multi-storey buildings
- Extensive cracking was observed in infills

Masonry Infills in Tall RC Buildings…

Diagonal cracks in the masonry panels

Combined in-plane and out-of-plane failure of infill panel

16 storey building in Patan

Poor Construction Practices

Buildings with poor geometric configuration (Too long)

Poor Construction Practices…

Buildings with poor geometric configuration (Too long)

Poor Construction Practices…

Box type construction: Extension of wall beyond column line

Poor Construction Practices…

New construction started within 10 days of the event on 25th April without assessment of strength of structure

Free Standing Structures

Free standing or unsupported walls collapsed at most places

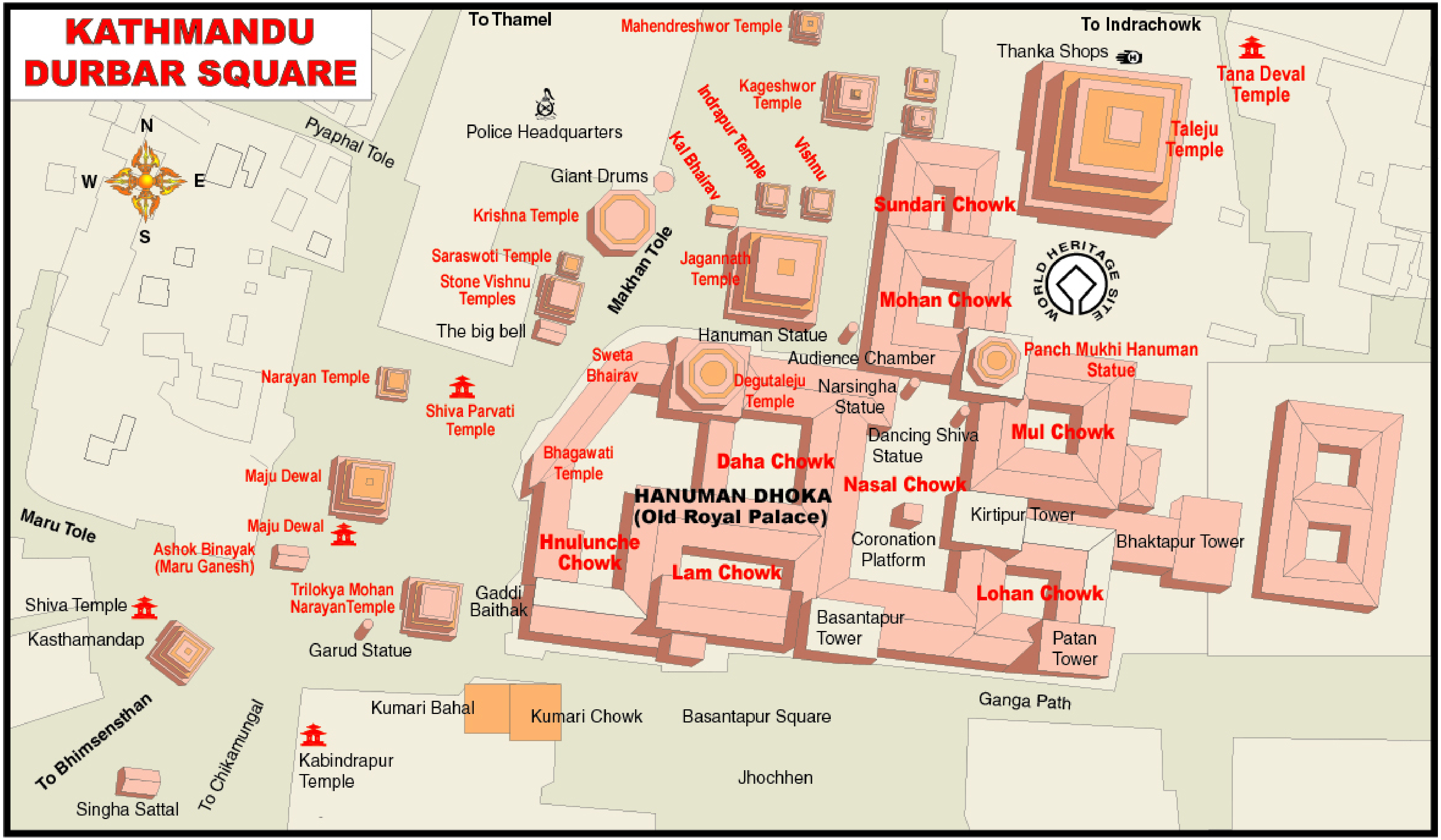
Cultural Heritage Structures

Heritage Structures

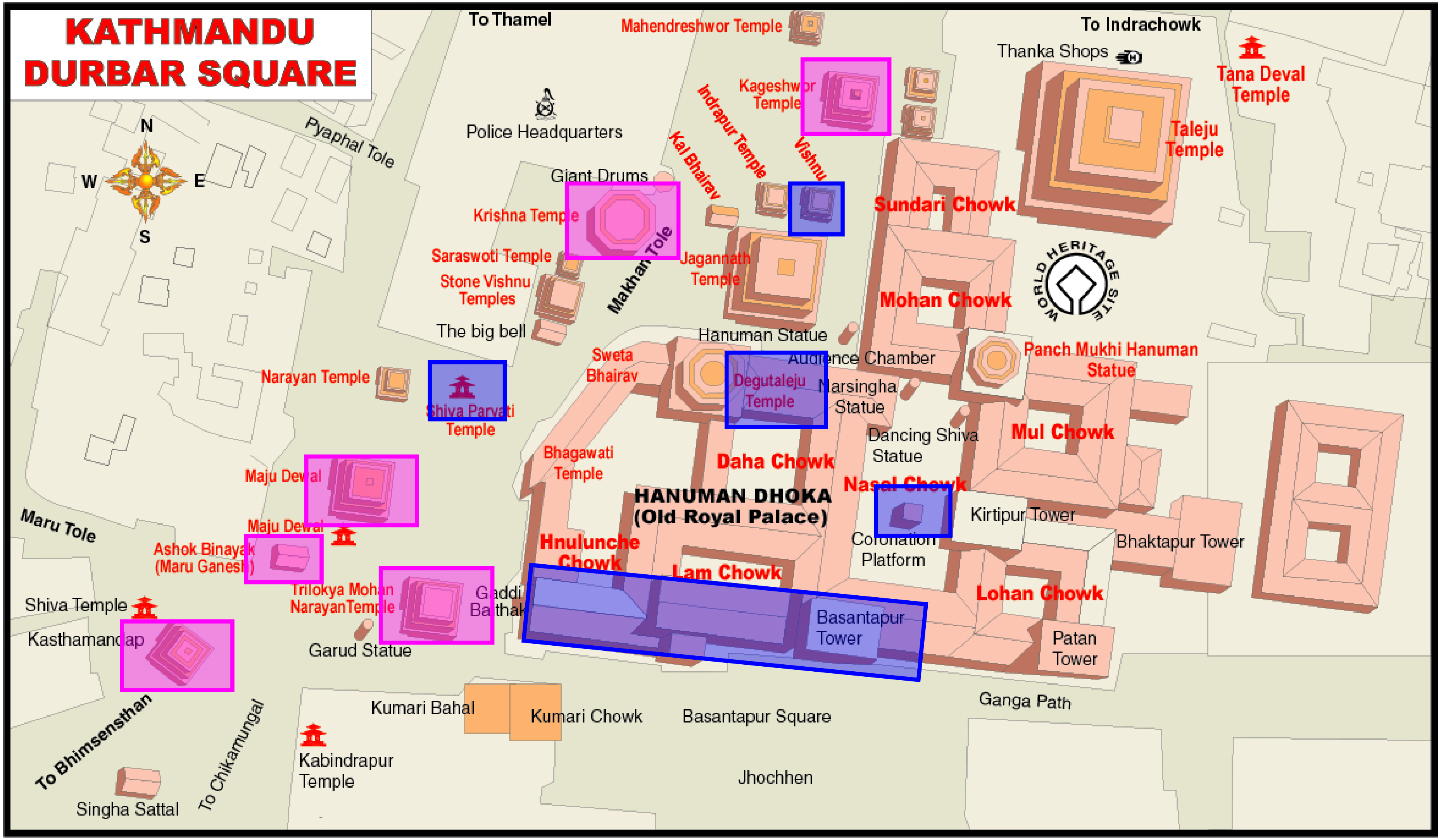
- Kathmandu valley is dotted with about more than 250 cultural heritage structures
- Most of the temples built in Dega style (similar to pagoda style) with timber frames and brick masonry walls
- Dressed external wythe with brick rubble masonry in the core

Heritage Structures…

- Durbar squares are urban centers with palace, temples and public spaces
  - Three Durbar squares: Patan, Kathmandu and Bhaktapur listed under the UNESCO world heritage sites
  - Most of the principal monuments were built between 12th and 18th century
  - In 1833 and 1934 earthquake, many of the monuments were destroyed and some of them were rebuilt to their original state
  - During this event of 25 April 2015 many of these temples and monuments suffered partial to completed collapse

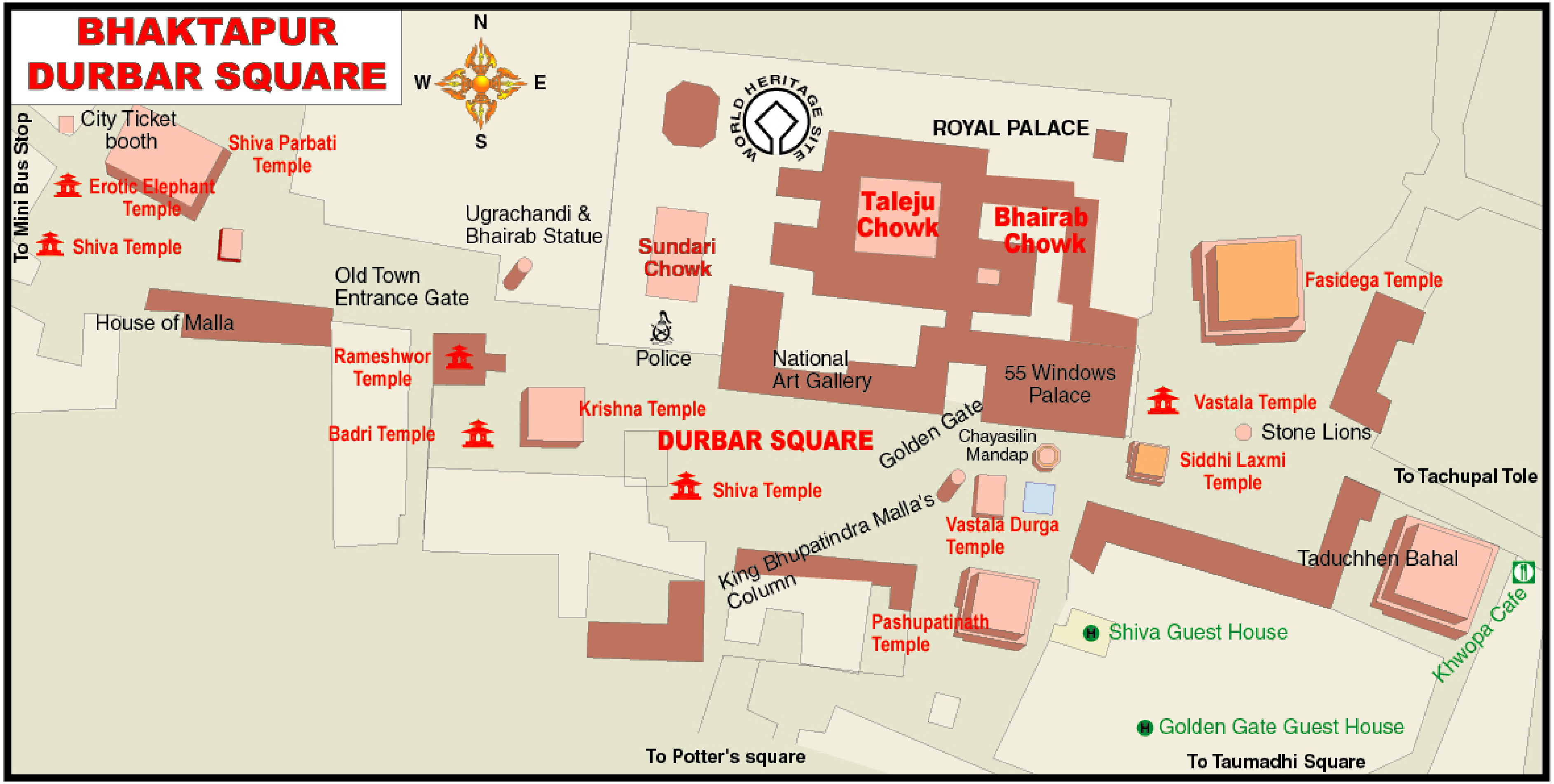


www.digitalhimalaya.com



Complete collapse

Partial collapse



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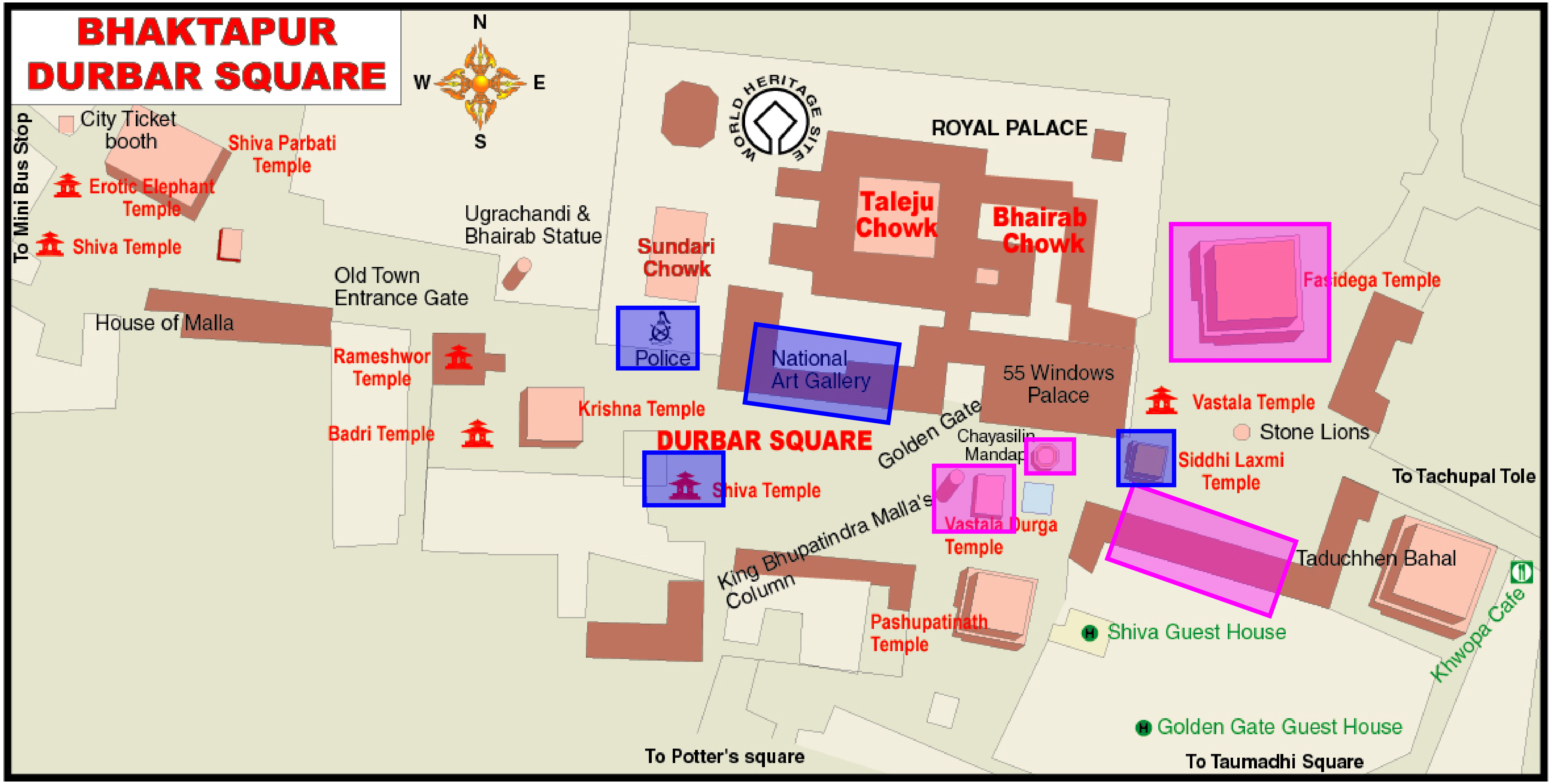

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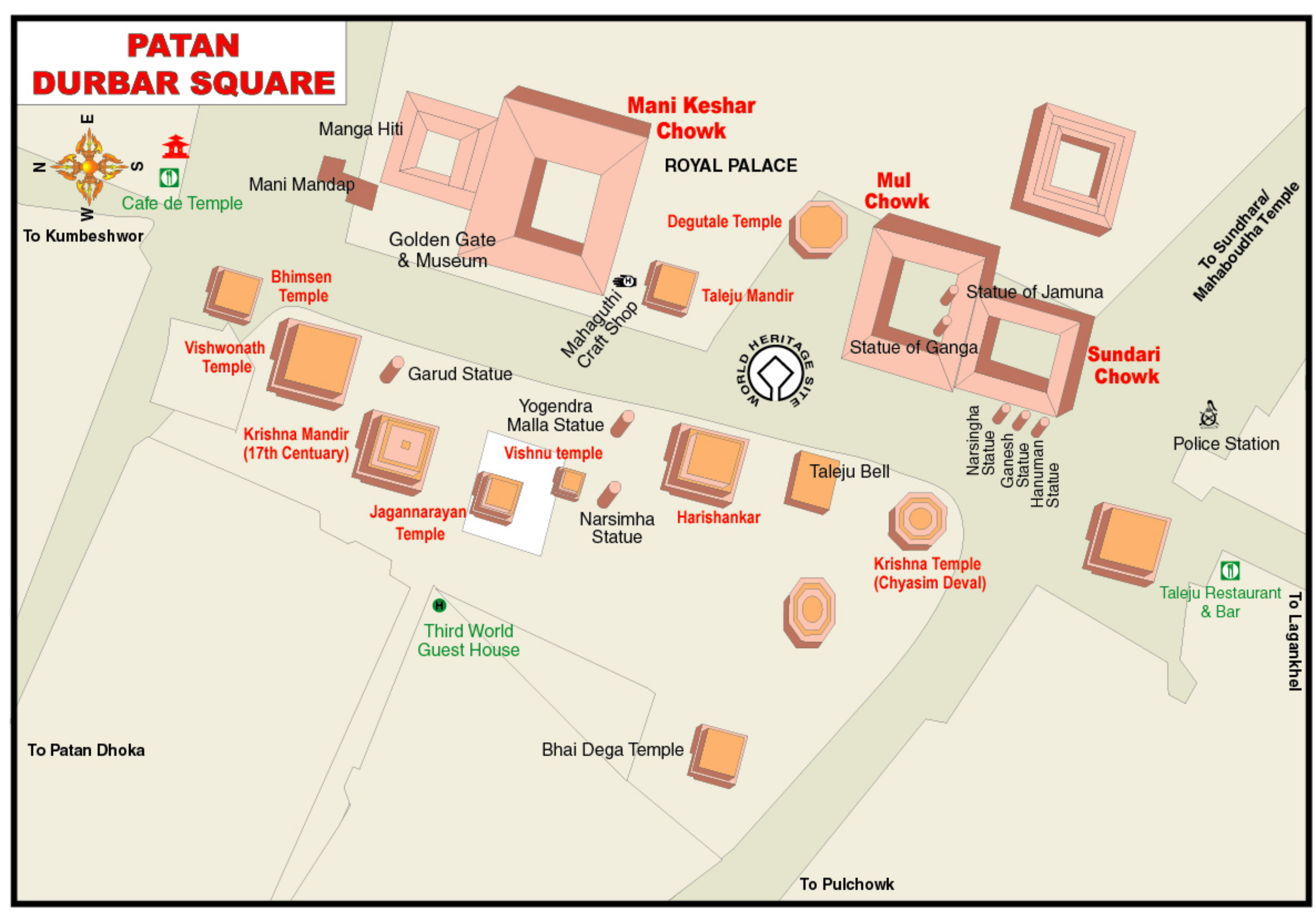
Partial collapse



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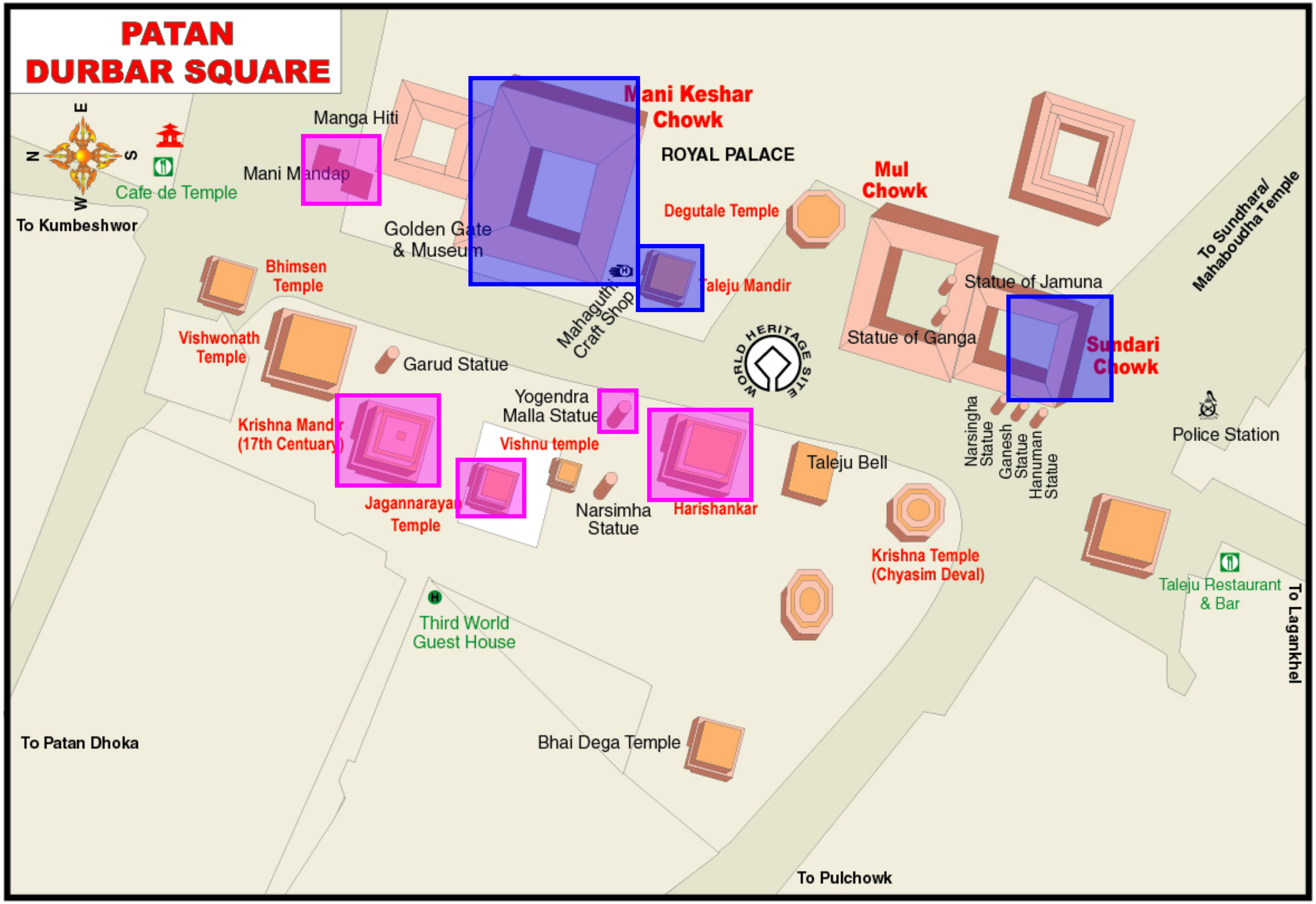


Complete collapse

Partial collapse

Performance of Heritage Structures…

Image: Corbis Ian Trower

Dharahara Tower (203 ft tall) nine storeys

Performance of Heritage Structures…

Durbar Square in Sundhara, Kathmandu

Performance of Heritage Structures…

Damaged Temples in Bhaktapur

Performance of Heritage Structures…

Sway of Timber frame and masonry collapse of Temple in Patan

Performance of Heritage Structures…

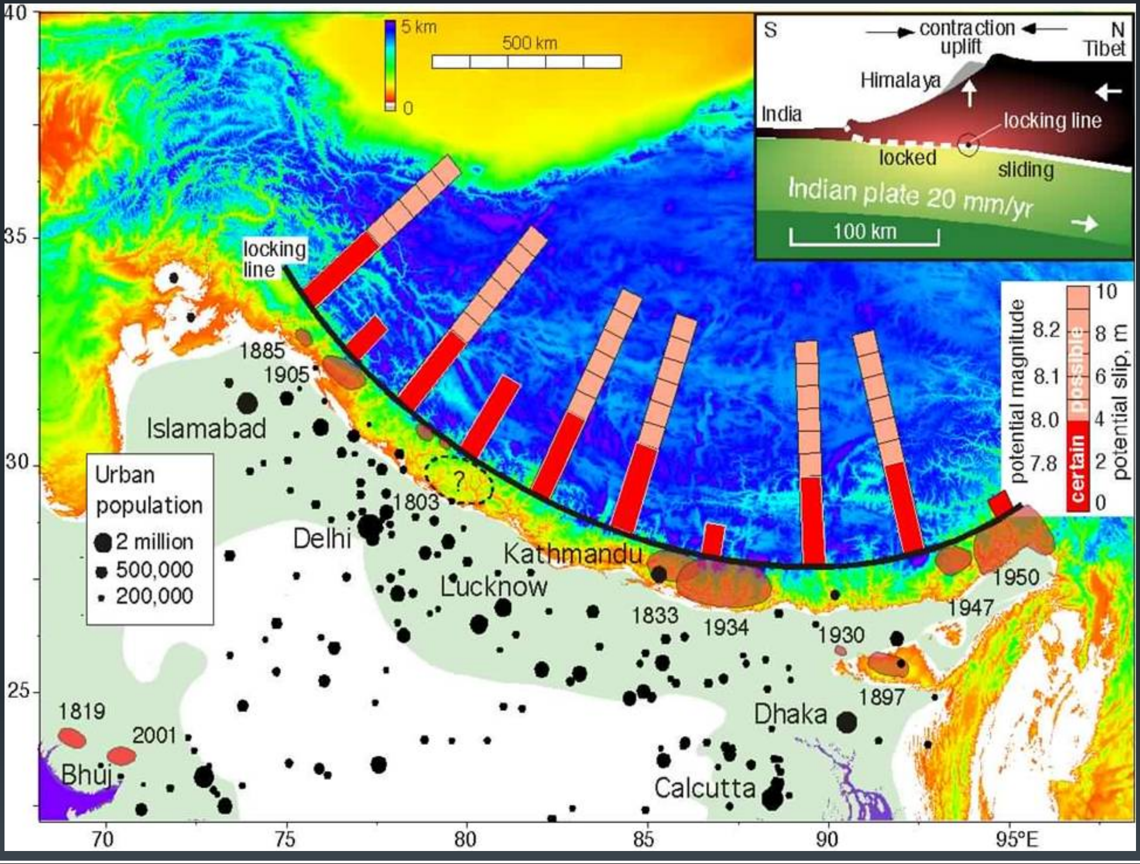
Failure of Dega Type Structures

Performance of Heritage Structures…

Good performance of few stone masonry temples

Looking Back…

Future Seismic Hazard



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1934 Bihar-Nepal Earthquake

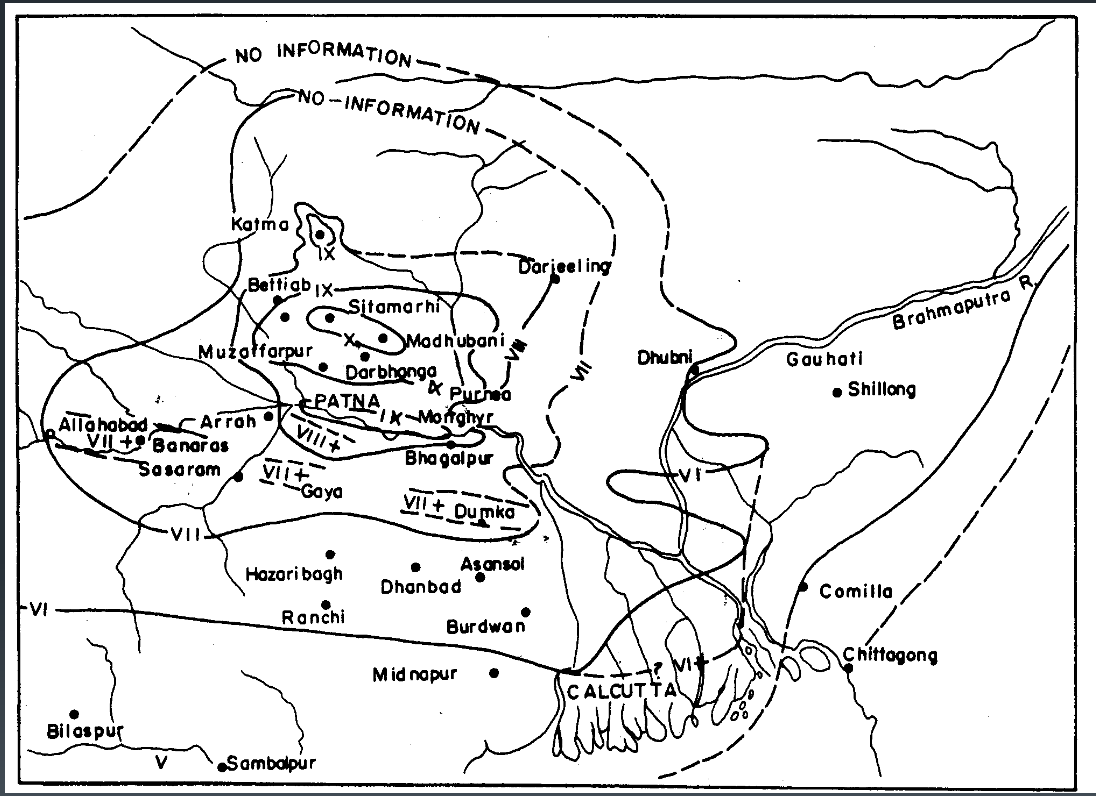
- 15 January 1934
  - Around 2:13pm
- Deaths
  - 7253 in India and 3400 in Nepal
- Magnitude 8.4
- Maximum intensity X (Mercalli scale) in about 80×20 miles
  - Intensity X also at Munger and in Kathmandu Valley (about 100 miles from main damage area)

1934 Bihar-Nepal Earthquake…

- Slump Belt
  - 190 mile long, up to 40 miles wide
  - Excessive liquefaction
  - Buildings slumped into alluvium
  - Subsidence of embankments (roads/rails)
  - Uplift of bottoms in tanks
  - Fissures / emissions of sand and water
    - one fissure : 15’ deep, 30’ wide, 900’ long!

1934 Bihar-Nepal Earthquake…

- More damage and strong shaking at Munger and in Kathmandu valley in 1934 Bihar-Nepal Earthquake



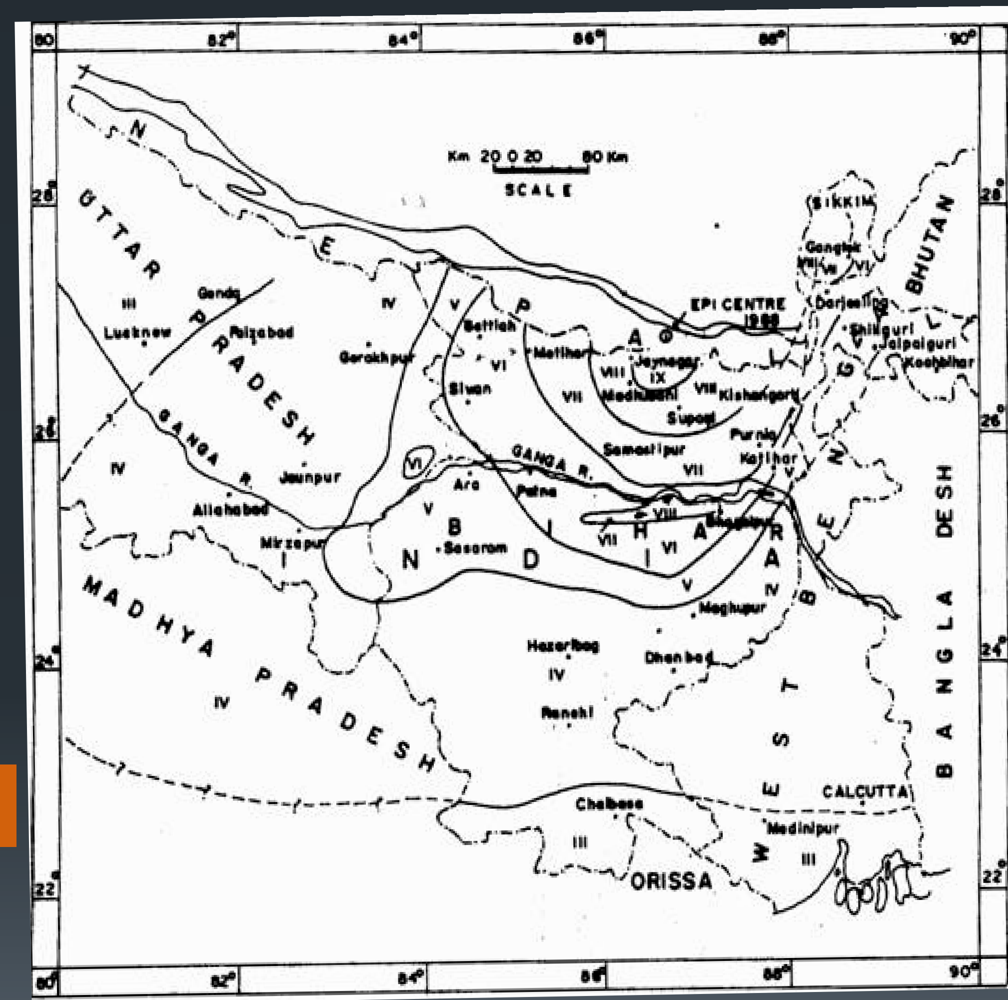
Isoseismal of 1934 earthquake

~ 130 km × 30 km area intensity X (I to X Mercalli)

Geological survey of India, 1939

1988 Bihar-Nepal Earthquake (M6.5)

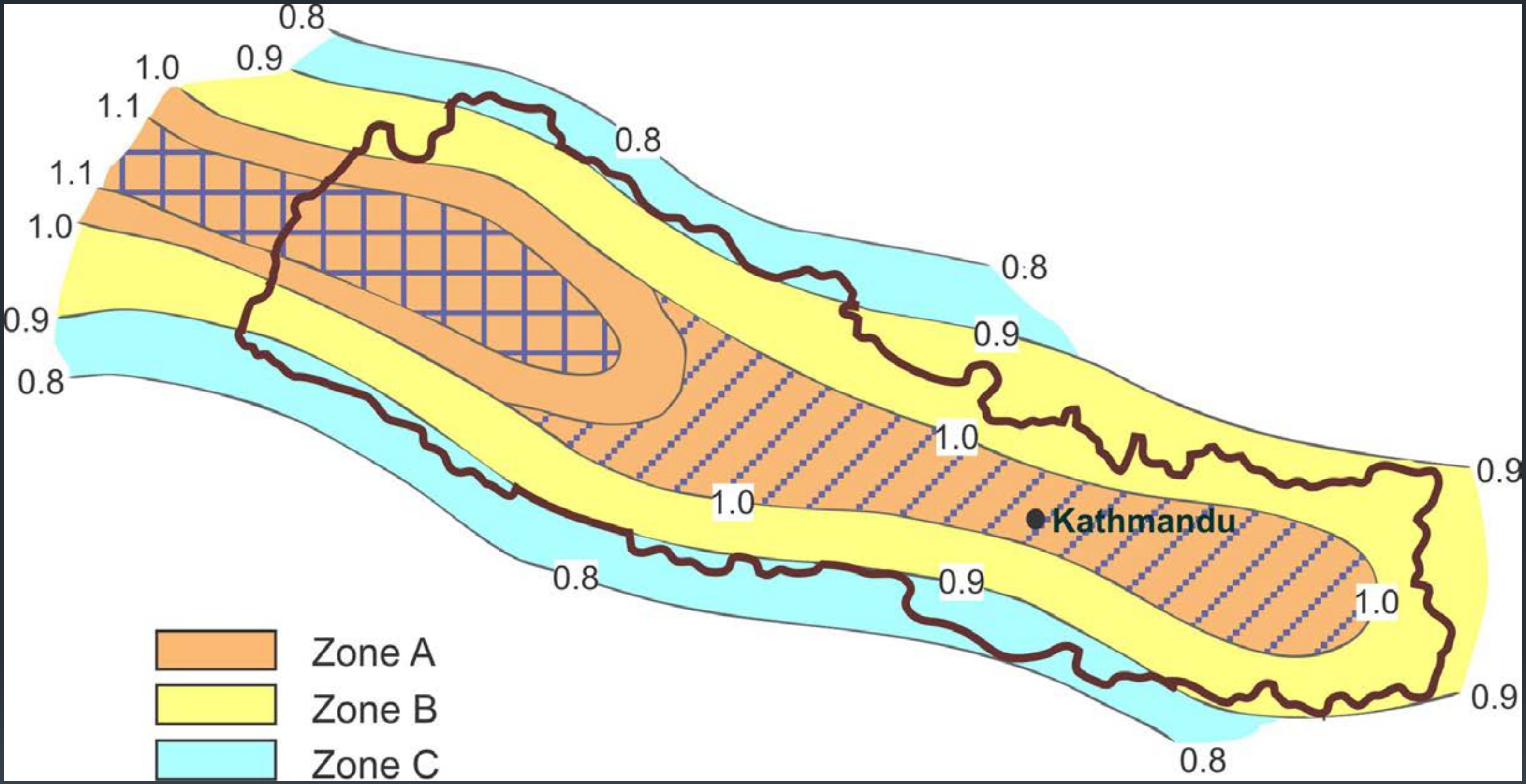
- Magnitude 6.5; August 21, 1988; 4:39 hours
- Killed ~ 1,004 persons
- Maximum intensity IX (I – XII MM Scale)



Isoseismal of 1988 earthquake

Geological survey of India, 1993

Seismic Hazard… **NEPAL**



~90% Nepal's land area under
Moderate-to-Severe Seismic Hazard

NBC 105: 1994

Seismic Hazard… **INDIA**

Zone Factor, *Z*

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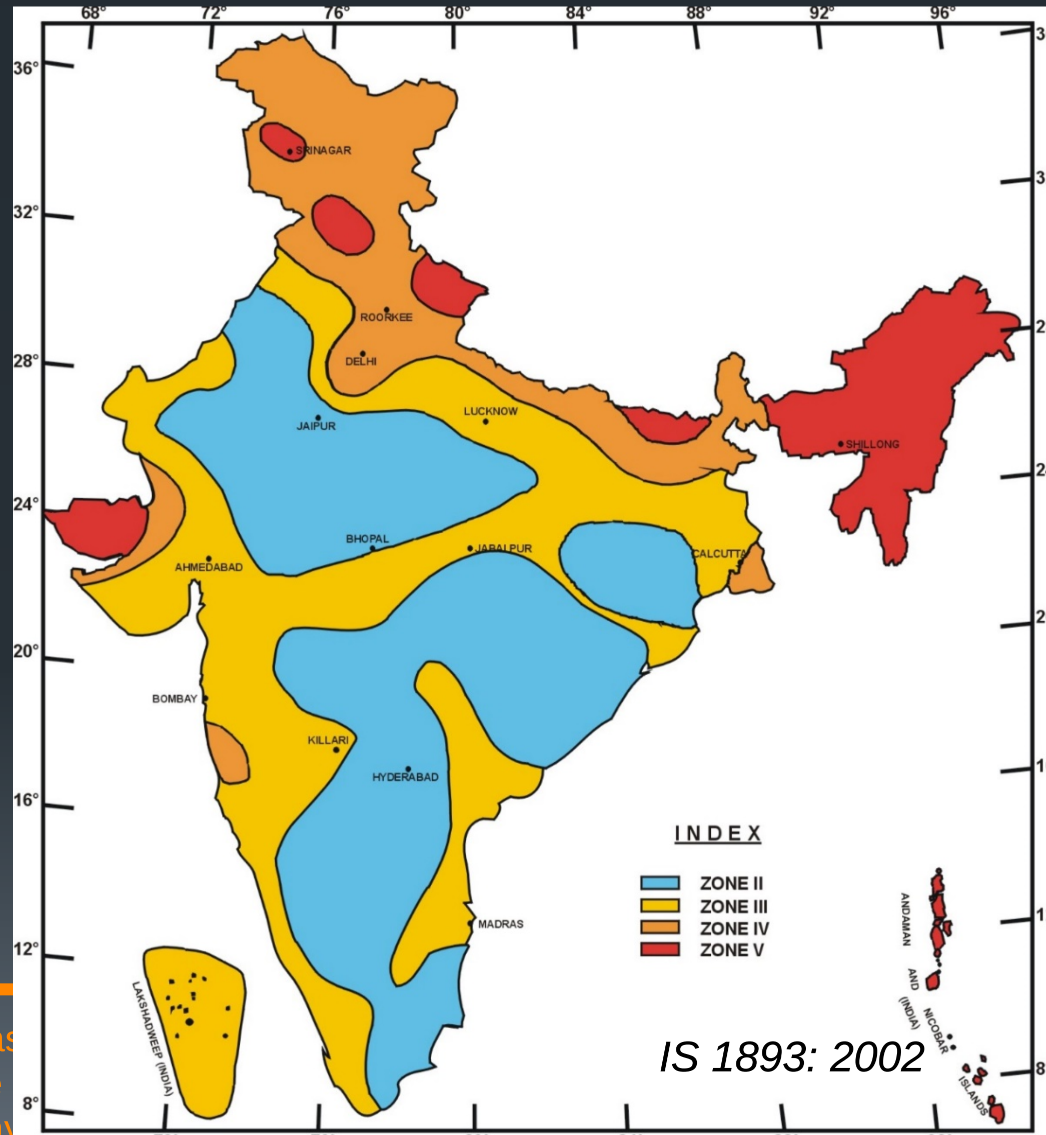
~60% India's land area under ***Moderate-to-Severe Seismic Hazard***

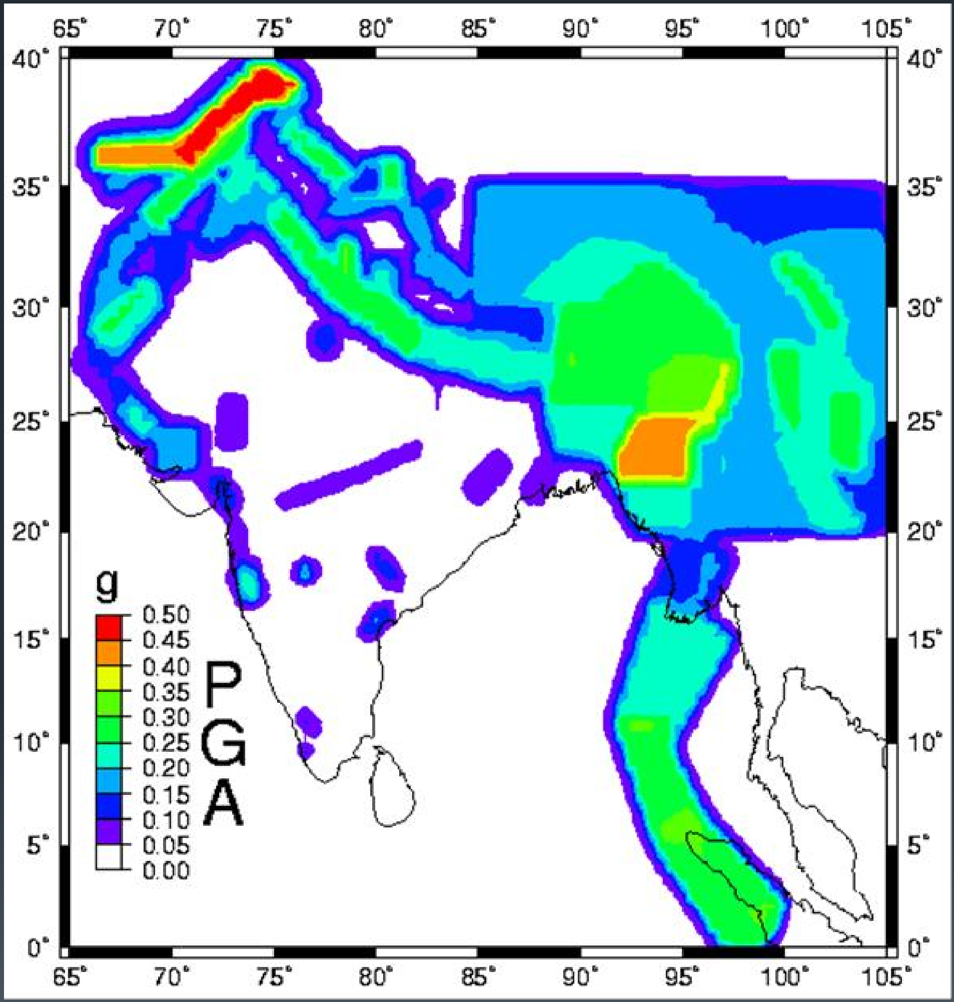


The Seismic Hazard…

GSHAP

Probabilistic map

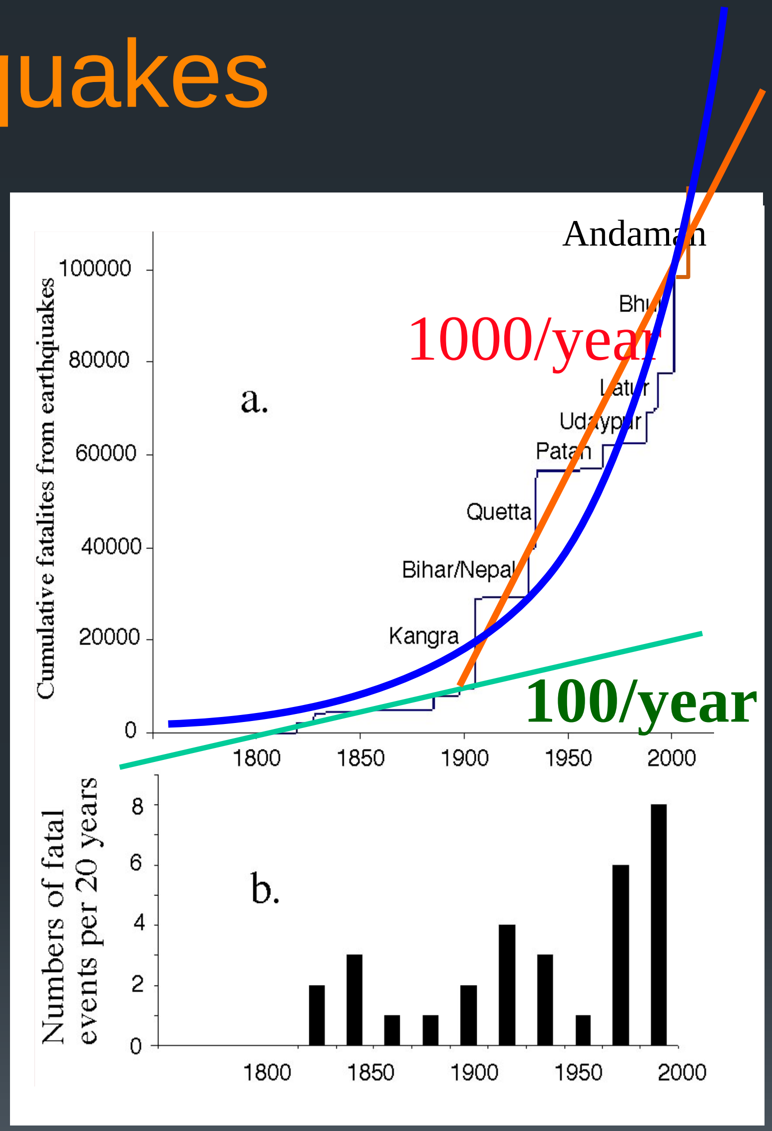
0.30 – 0.35 g



Bhatia et al. 1999

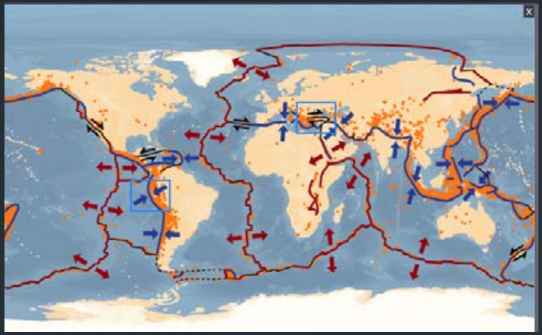
Fatalities in Earthquakes

- Fatalities have significantly increased in the last century
- Greater population at risk



Bilham 2005

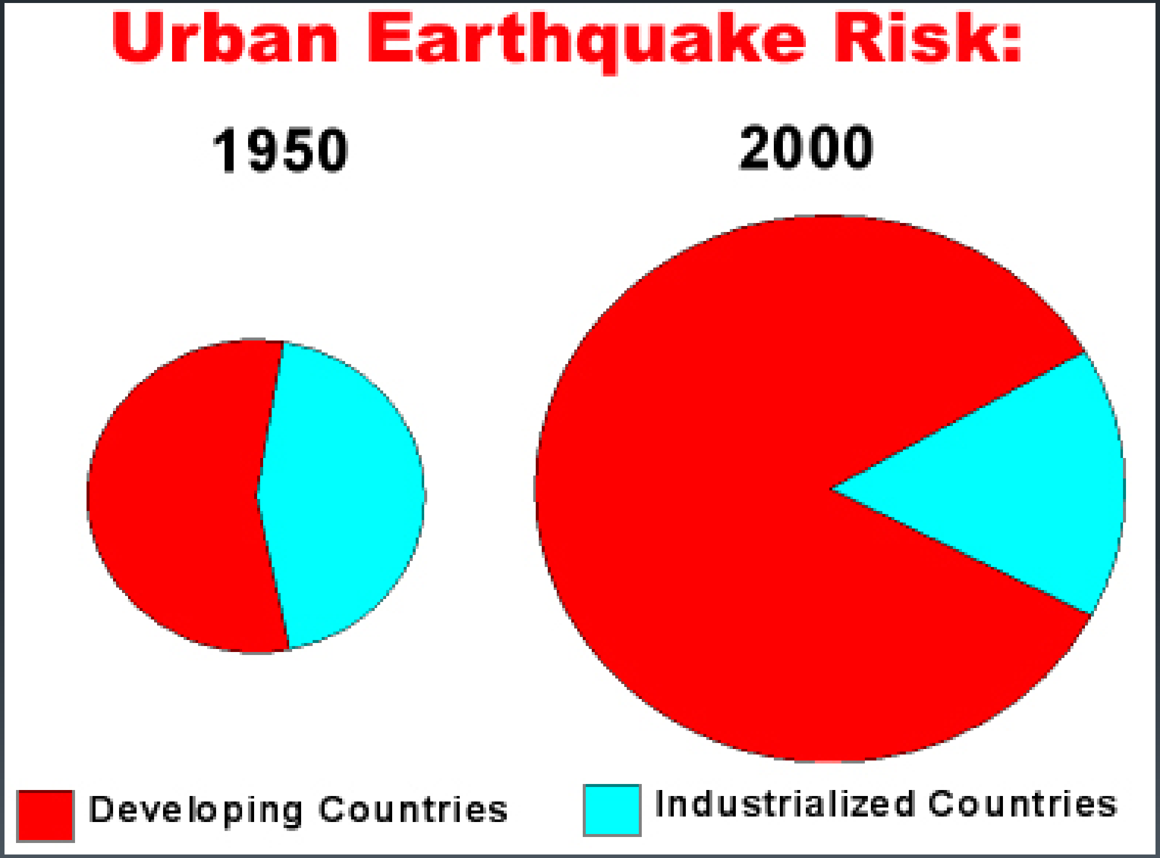
Earthquake Risk

Hazard  × **Exposure**  *Built environment* × **Vulnerability**  *Fragility*

- Disaster is unmitigated risk.
- Risk can be mitigated by reducing infrastructure vulnerability.

Earthquake Risk Reduction

- Role of Engineers



WSSI, NTU

Summary of Earthquake Effects

- The M7.8 event lead to a widespread devastation with significant number of fatalities and huge loss to property.
- Significant damage was observed in the 50~60 year old unreinforced masonry buildings because of inadequate lateral strength.
- Dramatic collapse of some RC structures can be attributed to open ground storey, poor geometric configuration of buildings, poor reinforcement detailing in structural members, etc.
- The damage to the RC buildings was aggravated due to the construction of buildings on filled-up lands, use of half-brick thick infill walls and extension of walls beyond column line.
- The cultural heritage structures, being old and weak were unable to resist the seismic forces and were damaged seriously.
- Landslides were observed, and vertical movement of soil lead to damage of roads and pedestrian bridges at some places.

Closing Remarks

- The damage to built environment, economic loss and human casualties caused by Himalayan earthquakes are increasing rather proportionally with the growth of settlement and population.
- Despite the available knowledge base, the communities in high seismic regions such as Nepal and neighbouring Indian states are not adequately prepared due to lack of implementation of earthquake-resistant building technology.
- With adherence to seismic codes and recommended construction practices, it is possible to mitigate such large-scale disasters.

Thank You