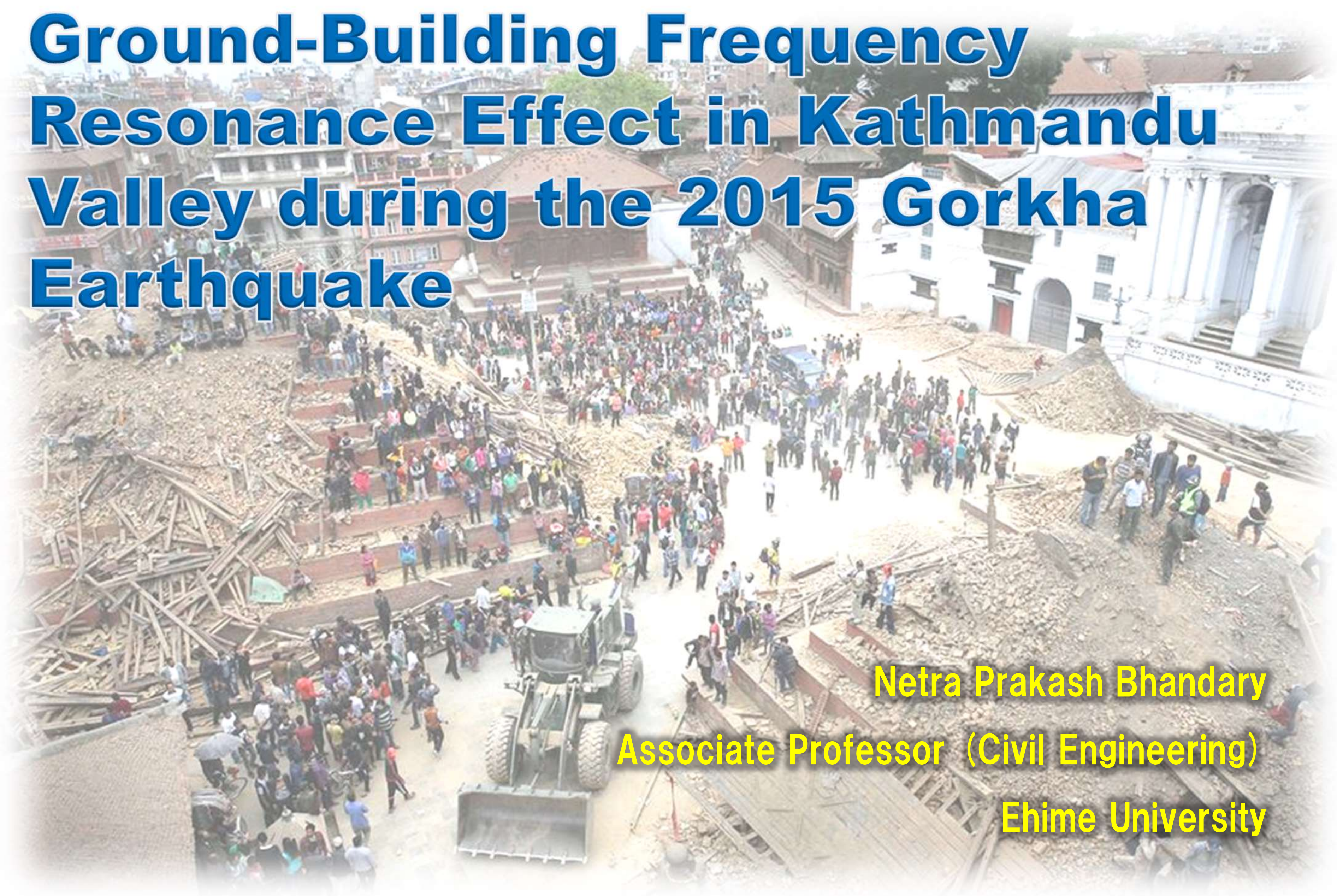


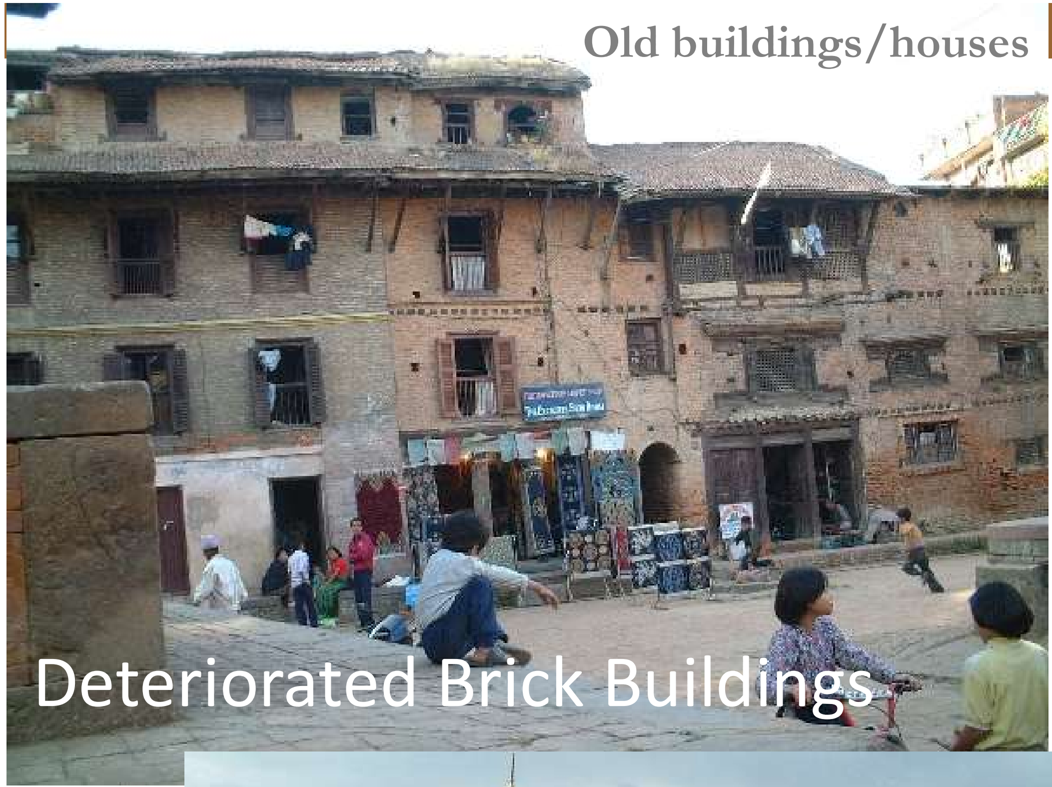
Ground-Building Frequency Resonance Effect in Kathmandu Valley during the 2015 Gorkha Earthquake

Netra Prakash Bhandary
Associate Professor (Civil Engineering)
Ehime University

About me

- **Full Name: Netra Prakash Bhandary**
- **Nepalese national, Born: 1969 in Nepal**
- **Educated in Nepal until high school**
- **University: India (Aligarh Muslim University)**
- **Work Experience: 1 year in a construction company, 3 years in an engineering college in Nepal**
- **Graduate Study: Ehime University (Master: 1998-2000, Doctor: 2000-2003)**
- **Current job: Associate Professor, Ehime University (Since 2003)**
- **What I teach? Mechanics, Differential and Integral Calculus, Soil Mechanics, etc.**
- **Family Structure: Four (with two daughters: 19 and 10)**

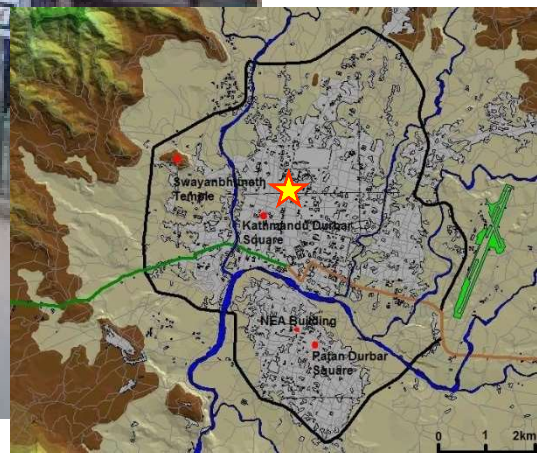
Old buildings/houses



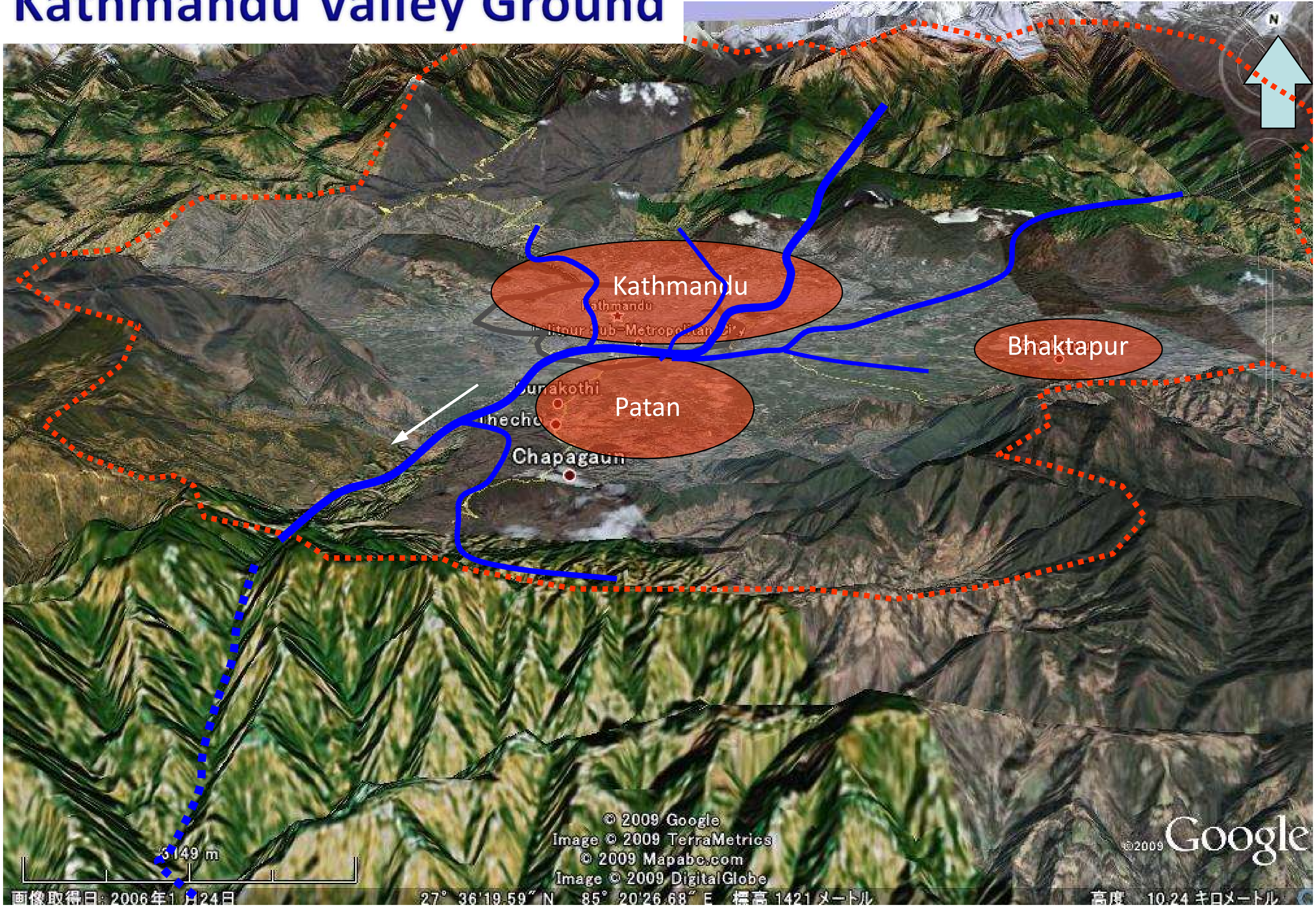
Slender buildings/houses

(Improper design??)

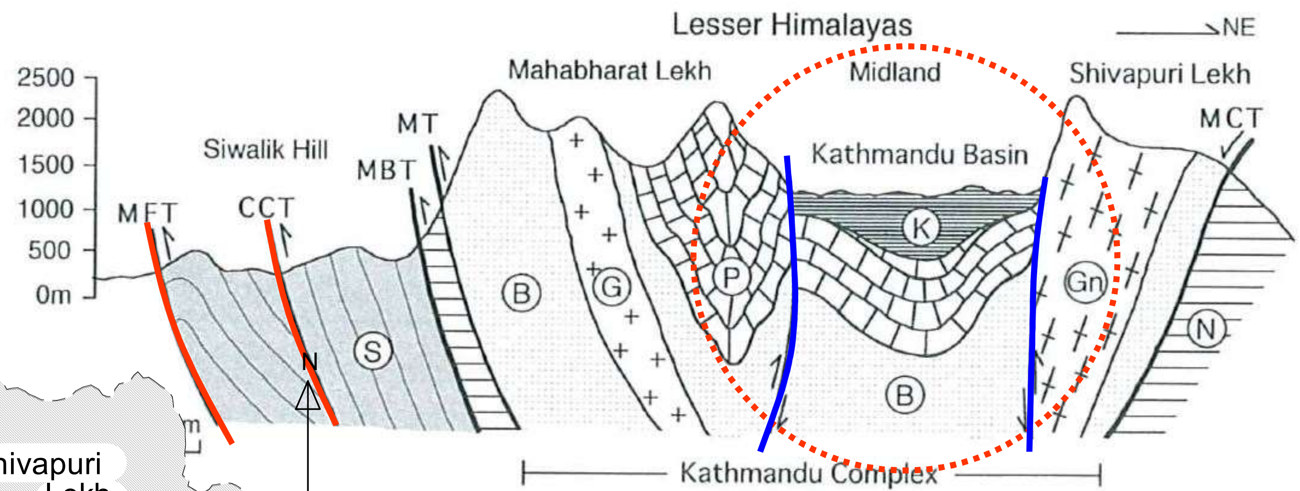
Narrows Streets, Improperly Constructed Buildings



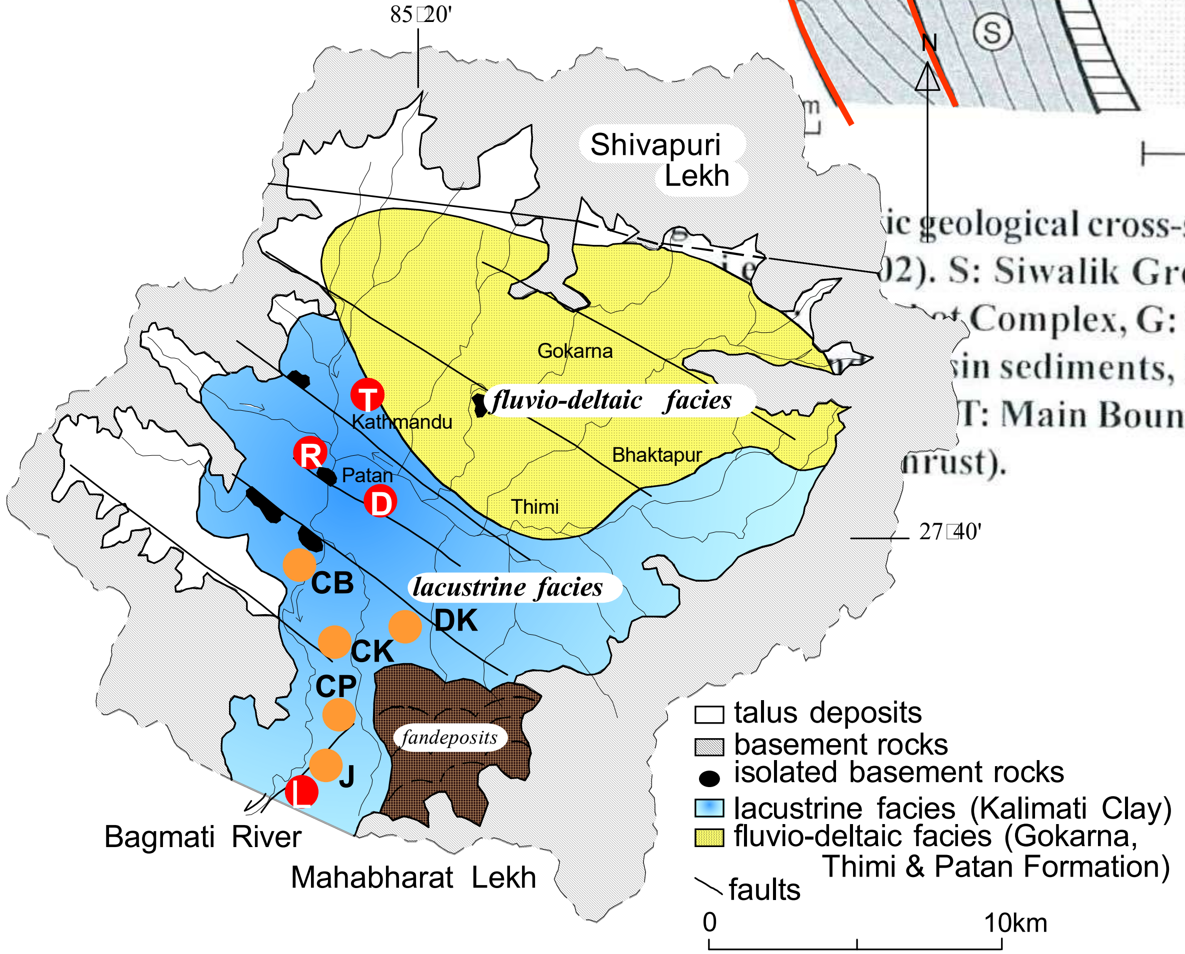
Kathmandu Valley Ground



Geological Structure of Kathmandu Valley



ic geological cross-section in the Central Nepal Himalaya (after
02). S: Siwalik Group, B: Bhimphedi Group, P: Phulchauki
Complex, G: Granite, Gn: Gneiss and Granite Complex,
sin sediments, MFT: Main Frontal Thrust, CCT: Central
T: Main Boundary Thrust, and MT: Mahabharat Thrust
nrust).



Towards Earthquake Disaster Risk Mitigation

- Brick Masonry: Mud mortar, Lime mortanr, Cement mortar, Historical structures old and weak
- RC frammed structures: Beam-column with brick or concrete block walls/partitions

※Main Problems

- Hospitals, Number of Beds
- Second-stage disaster (Fire, Diseases, etc.)
- Shelter Area (not identified), Tundikhel and other free grounds
- Lifeline damage: Water pipes (very old), Power lines, Road damage due liquefaction and landslides, etc.

Major Investigations/Studies

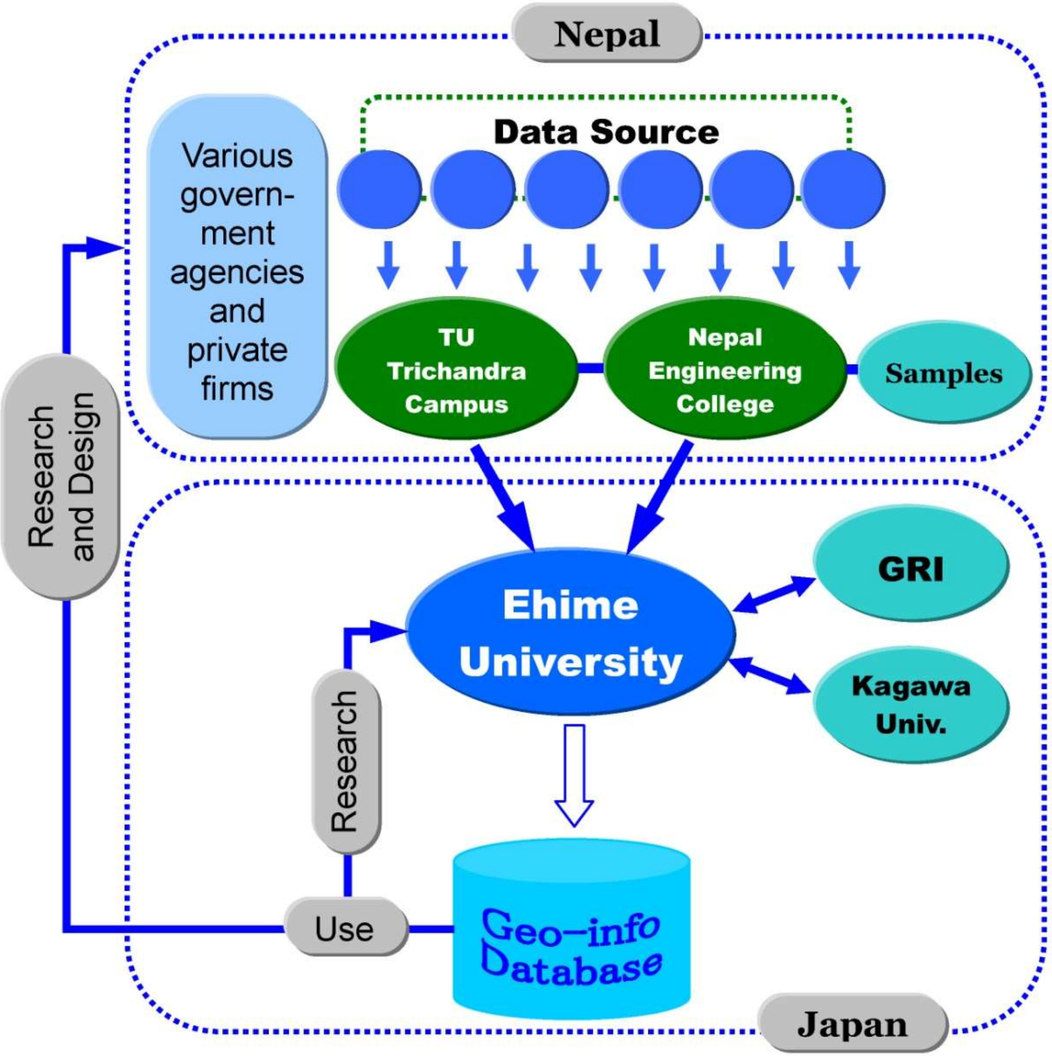
- UNDP study (1992)
- JICA study (2001-2002)
  - Scenario Earthquakes (3 cases)
  - Liquefaction hazard prediction
  - Landslide hazard prediction
  - Lifeline damage prediction (Power line, Water line, Roads, Bridges, Telephone line, etc.)
  - Building structural damage prediction
  - Human casualty estimation
  - Evacuation routes and Evacuation space
  - Etc.
- Disaster Mitigation Activities of NSET and International Agencies

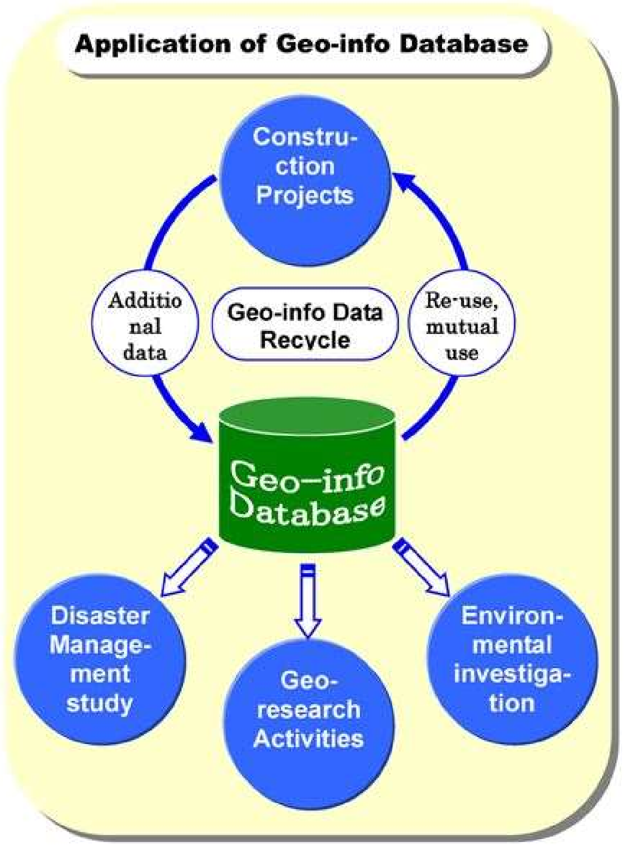
Ehime University Plan/Studies

(※2008 onwards)

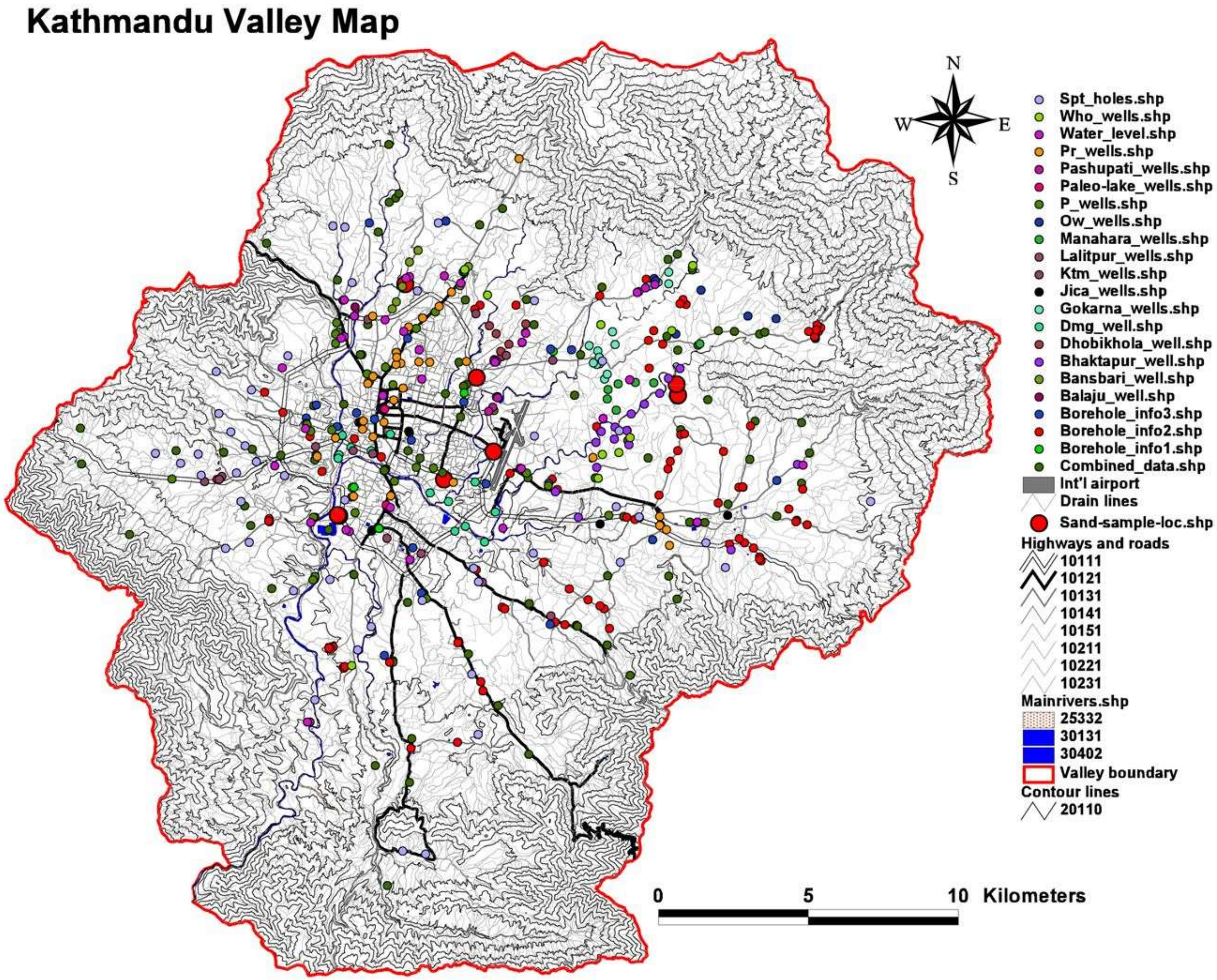
- Geo-info database preparation and use
- Ambient vibration measurement and earthquake motion analysis
- Earthquake accelerometer installation and data acquisition
- Ground subsidence due to groundwater exploitation (planned)
- Earthquake disaster education

Network Concept for Geo-info Database of Kathmandu Valley

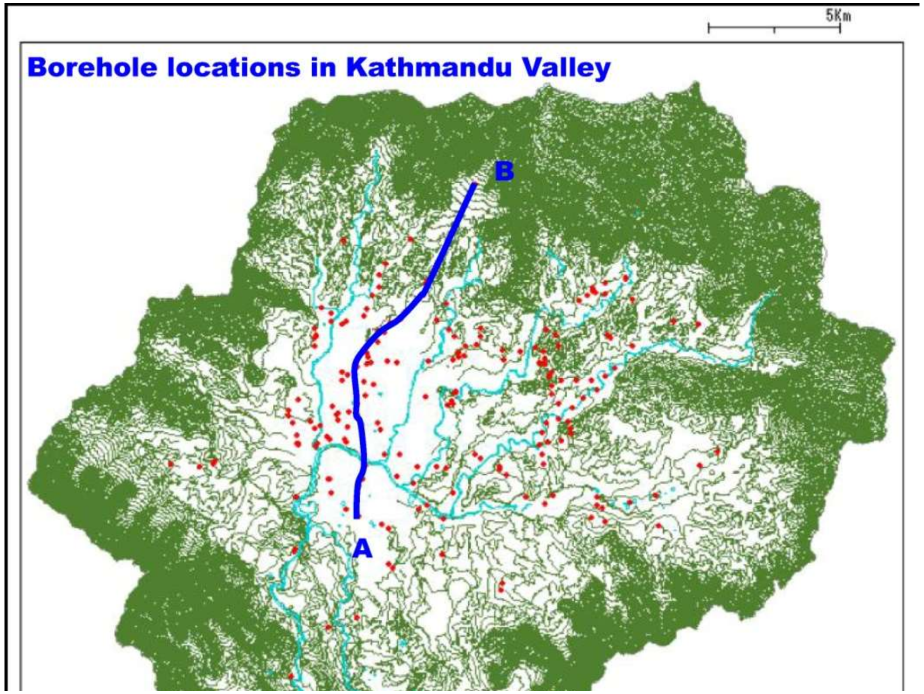




Available Borehole Data in Kathmandu (1980～2002)

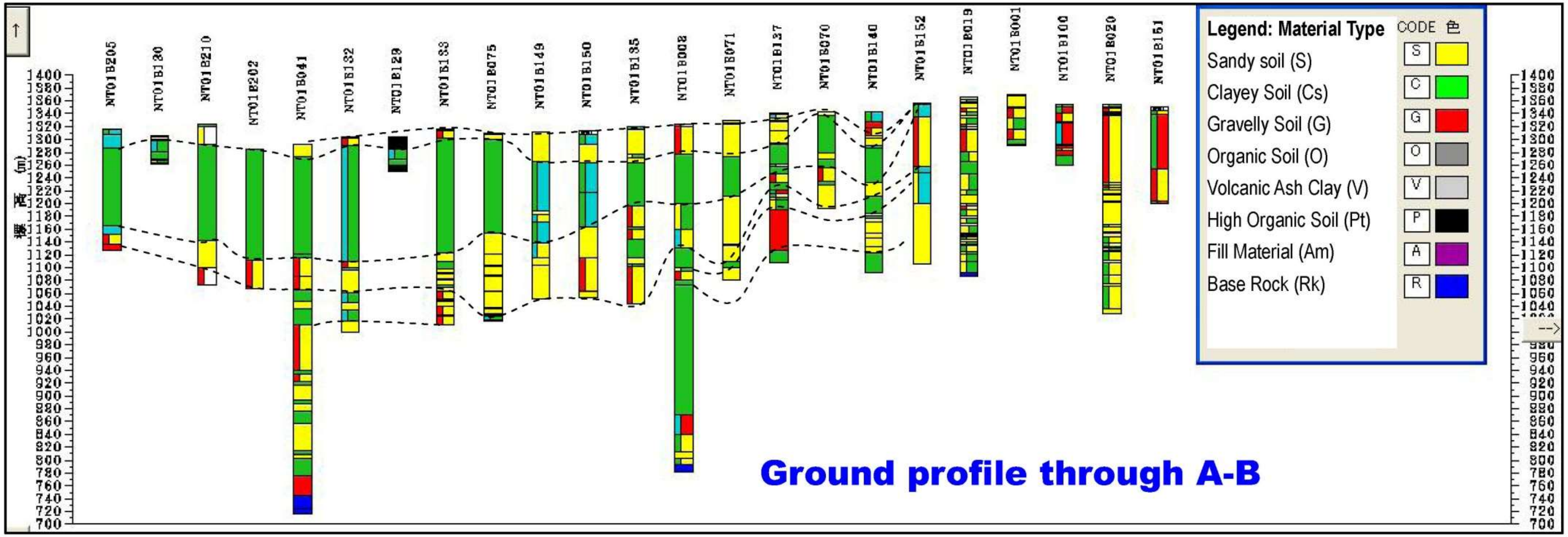


Geo-info Database Preparation (Preliminary)



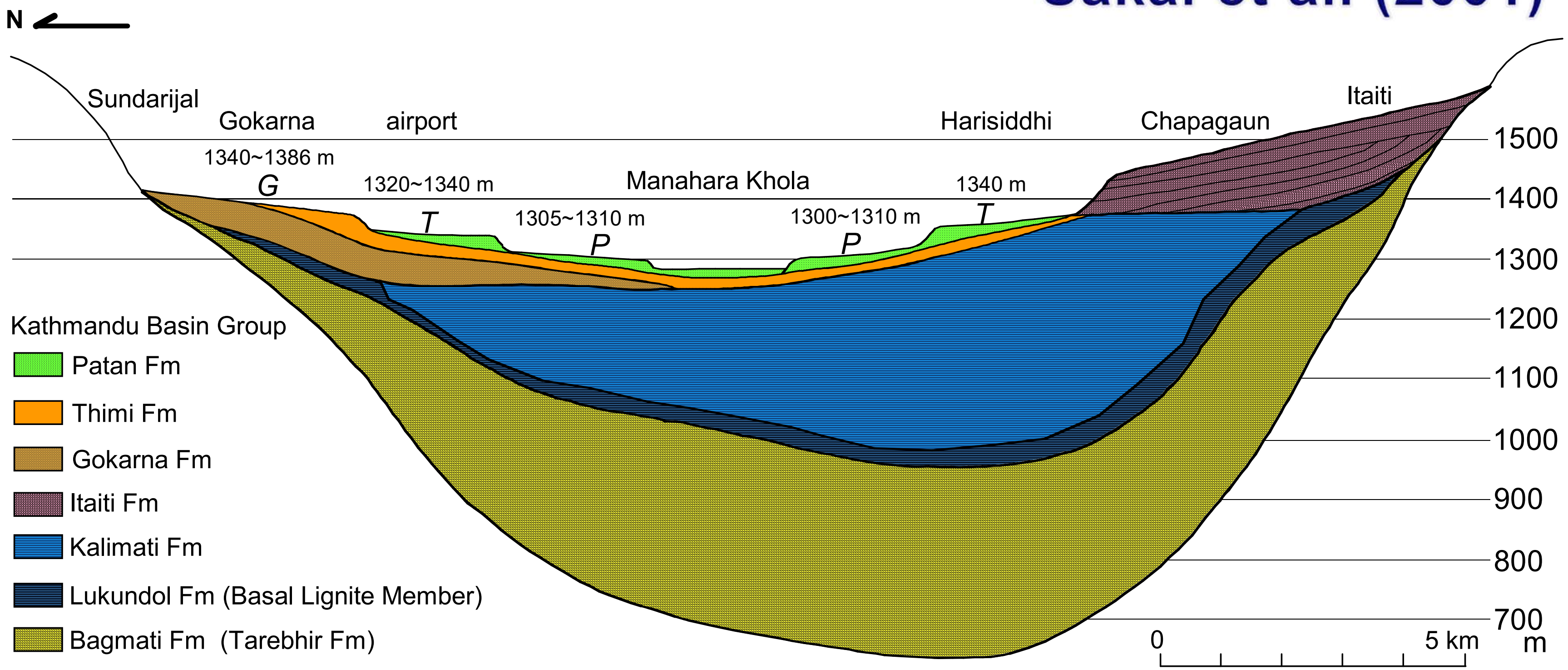
Borehole Information：

Multi-purpose boring

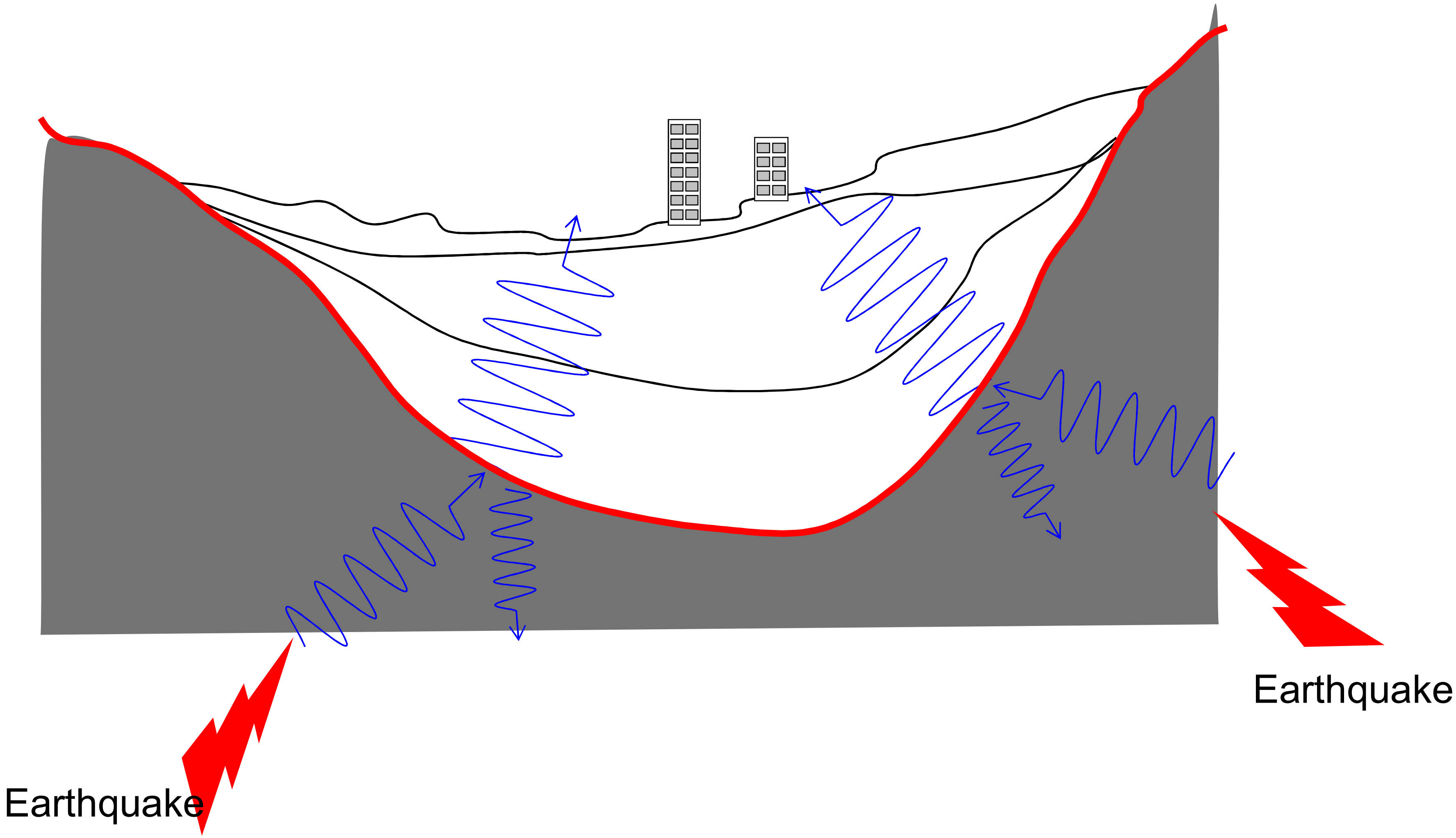


Estimated Sediment Deposit in Kathmandu Valley

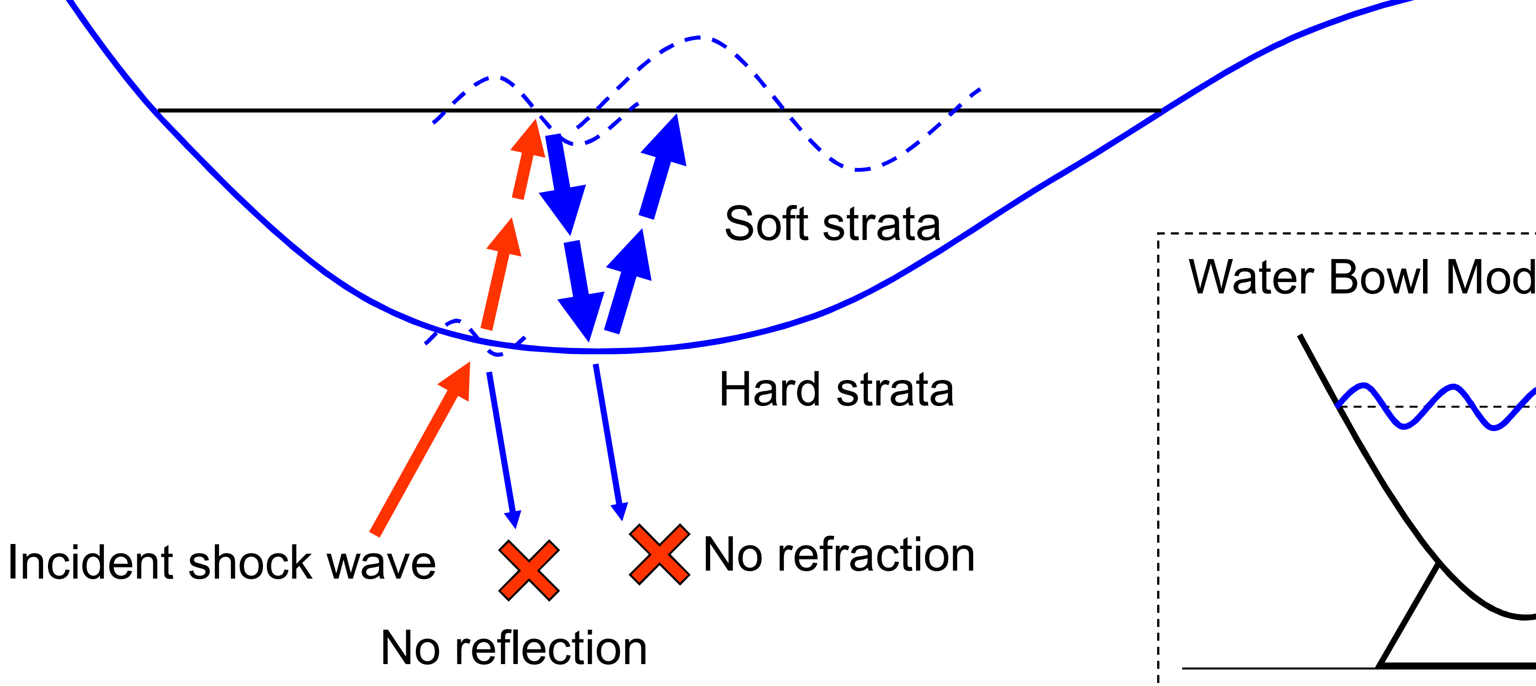
Sakai et al. (2001)

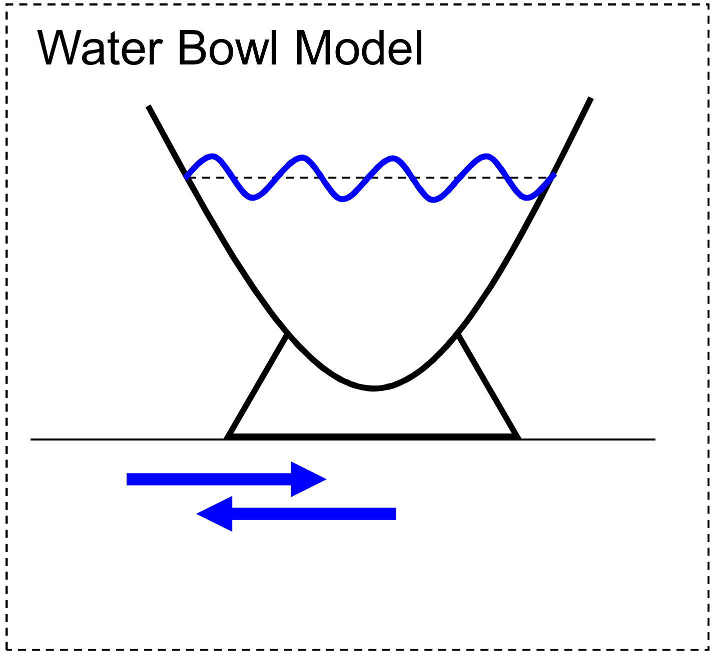


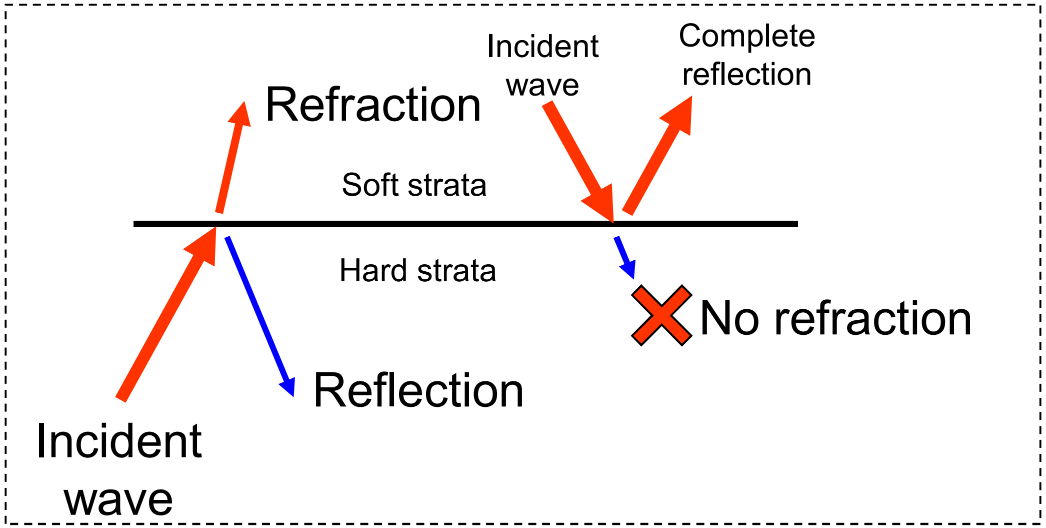
Typical feature of Kathmandu deposit



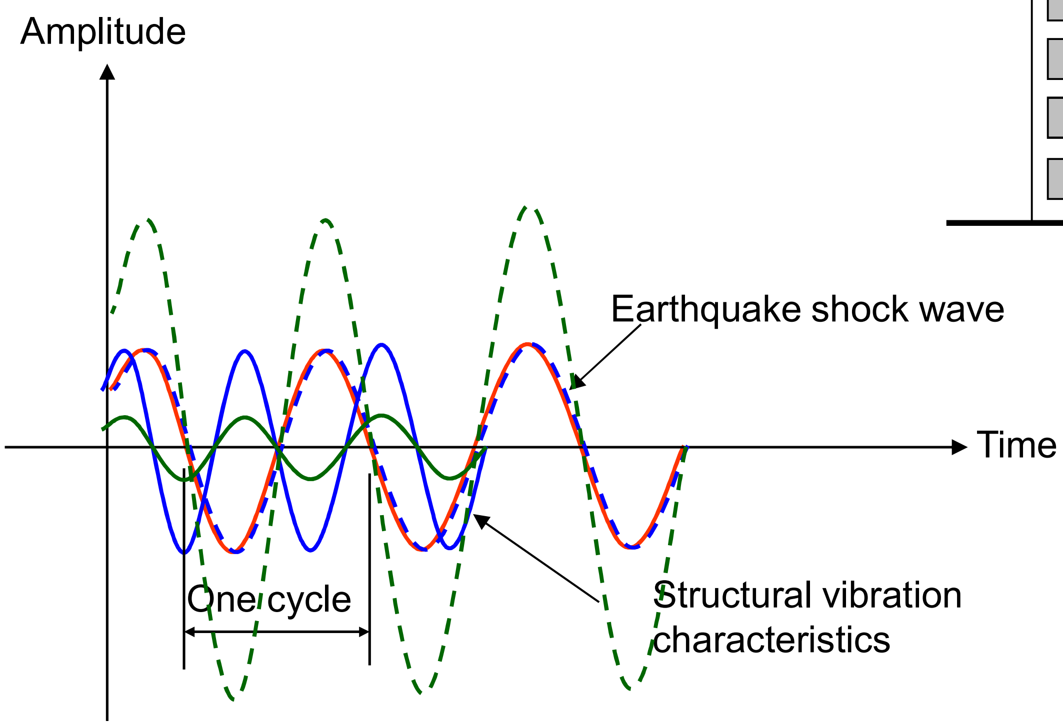
Shock Wave Transfer in Ground

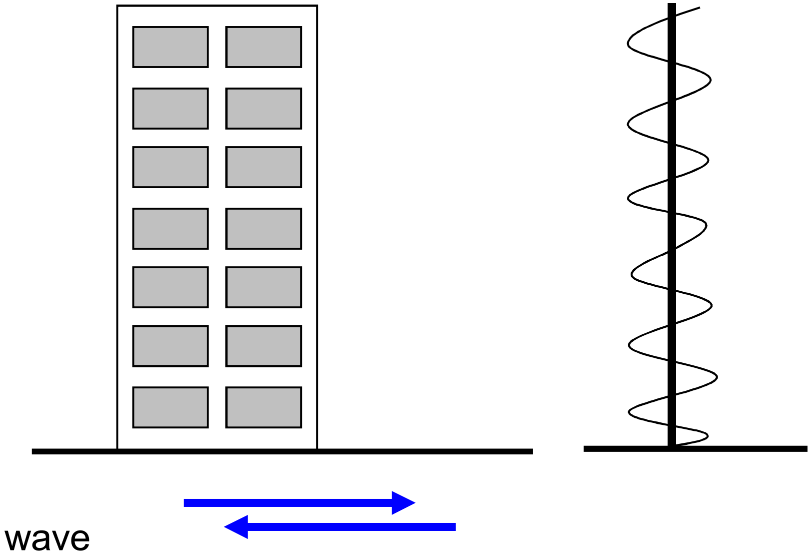




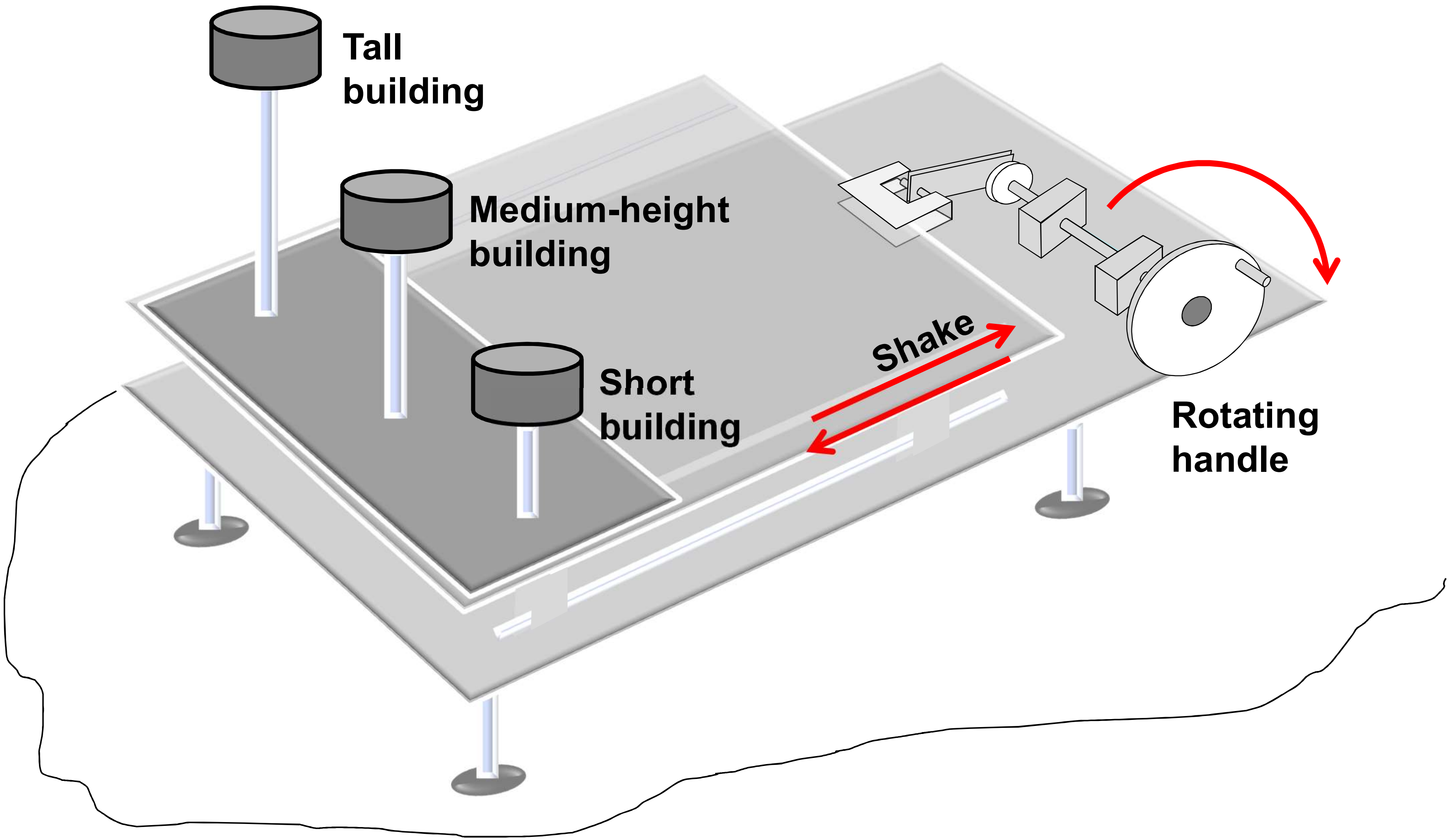


Natural Period and Excitation





Small-scale Shake Table Demo (Resonance Effect)

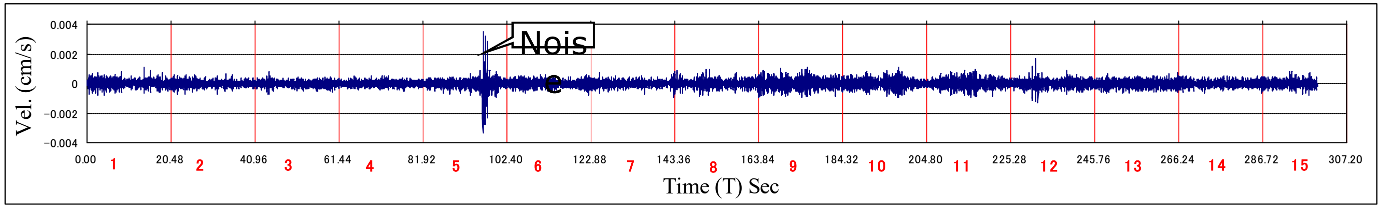



SPEED CONTROL UNIT
POWER
LOW
HIGH
RUN

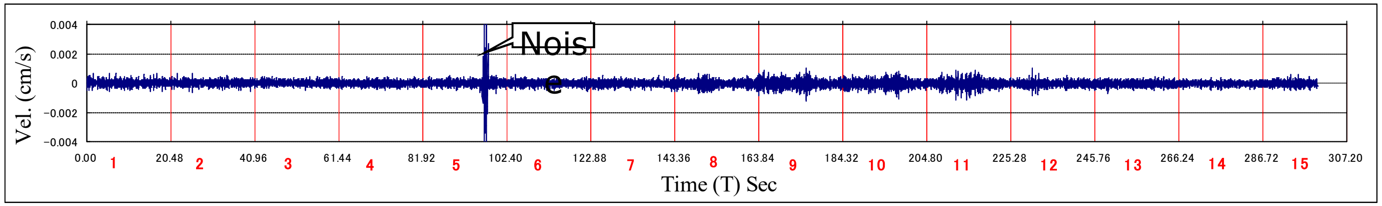
Instrument used in MT Survey

Three components (EW, NS and UP) of ground motion (velocity) measured at single station

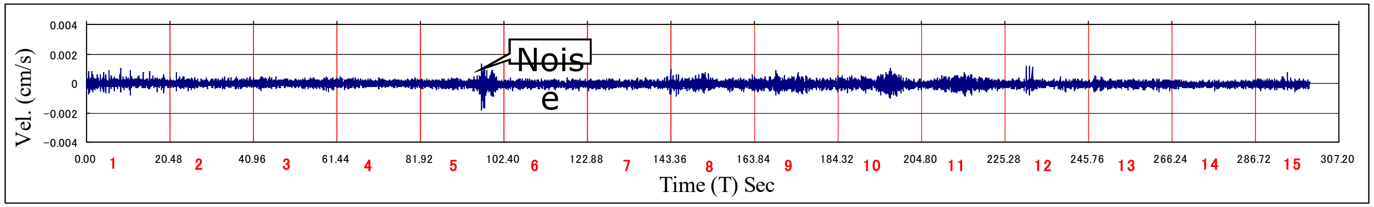
North- South (NS) component data



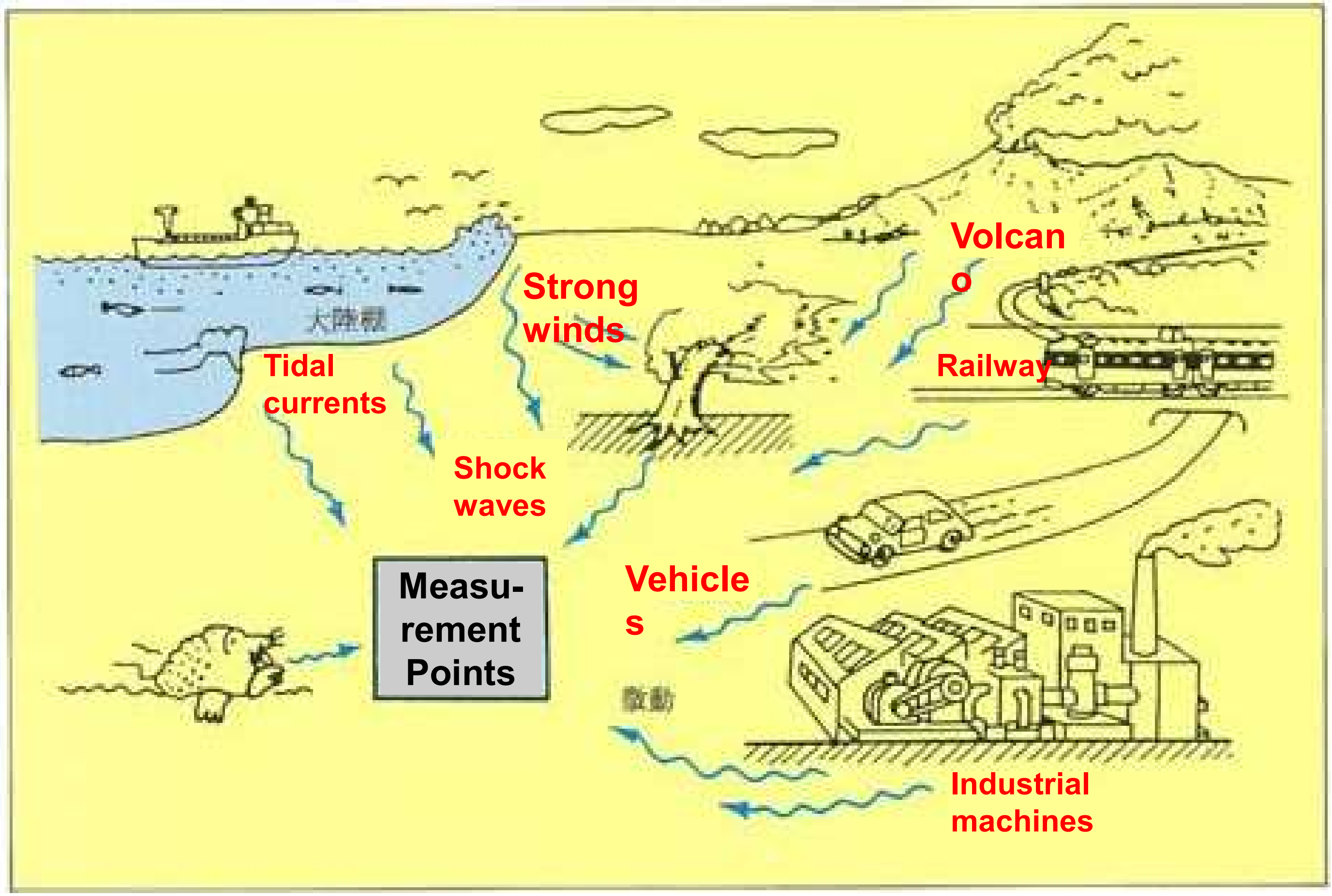
East- West (EW) component data



Vertical (UP) component data



Microtremor sources

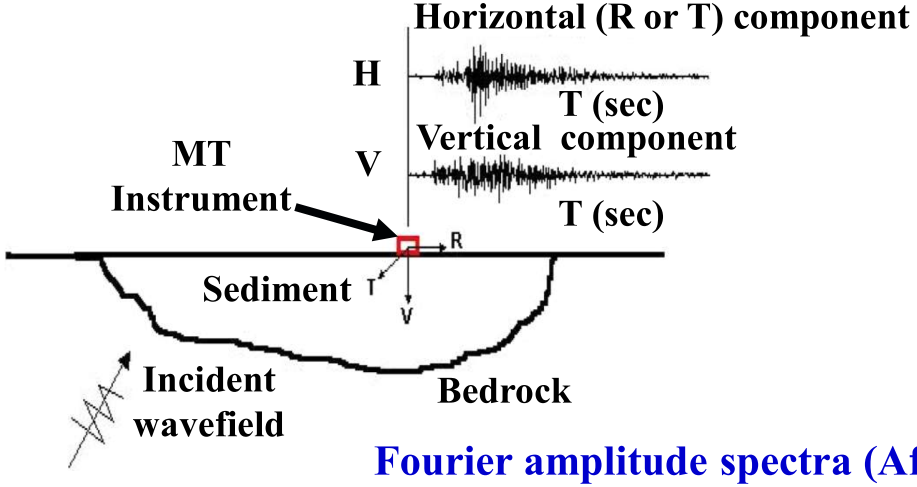


(From Tokyo Soil Research)

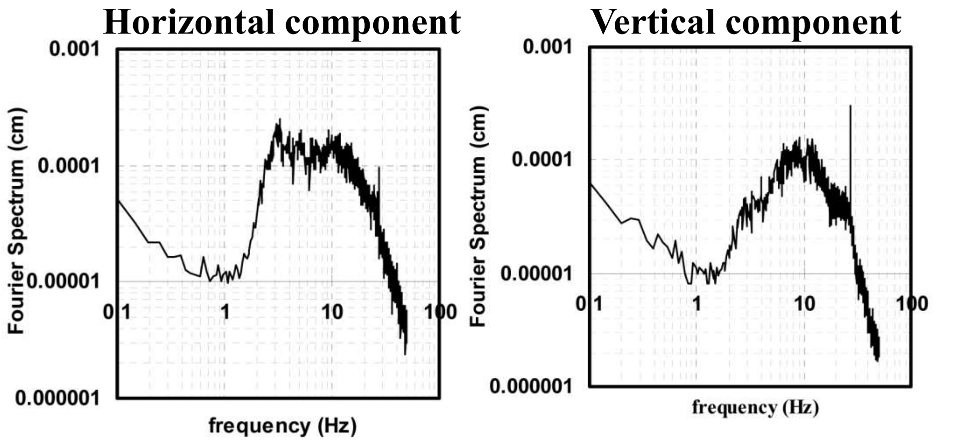
Kathmandu:

- Vehicle movement
- Winds
- Industrial machines
- etc.

Analysis process of microtremor data

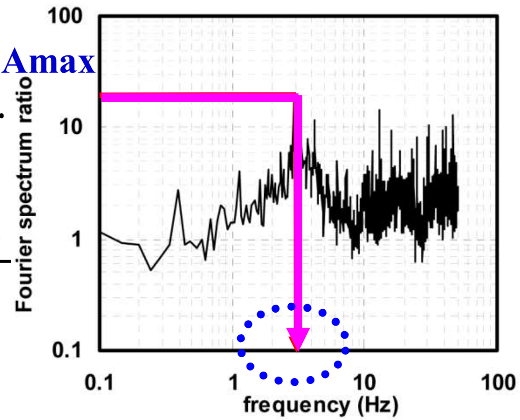


Fourier amplitude spectra (Af)



Transfer Function or
H/V Spectral Ratio

$$H/V = \frac{A(f)\ \text{Horizontal}}{A(f)\ \text{Vertical}}$$



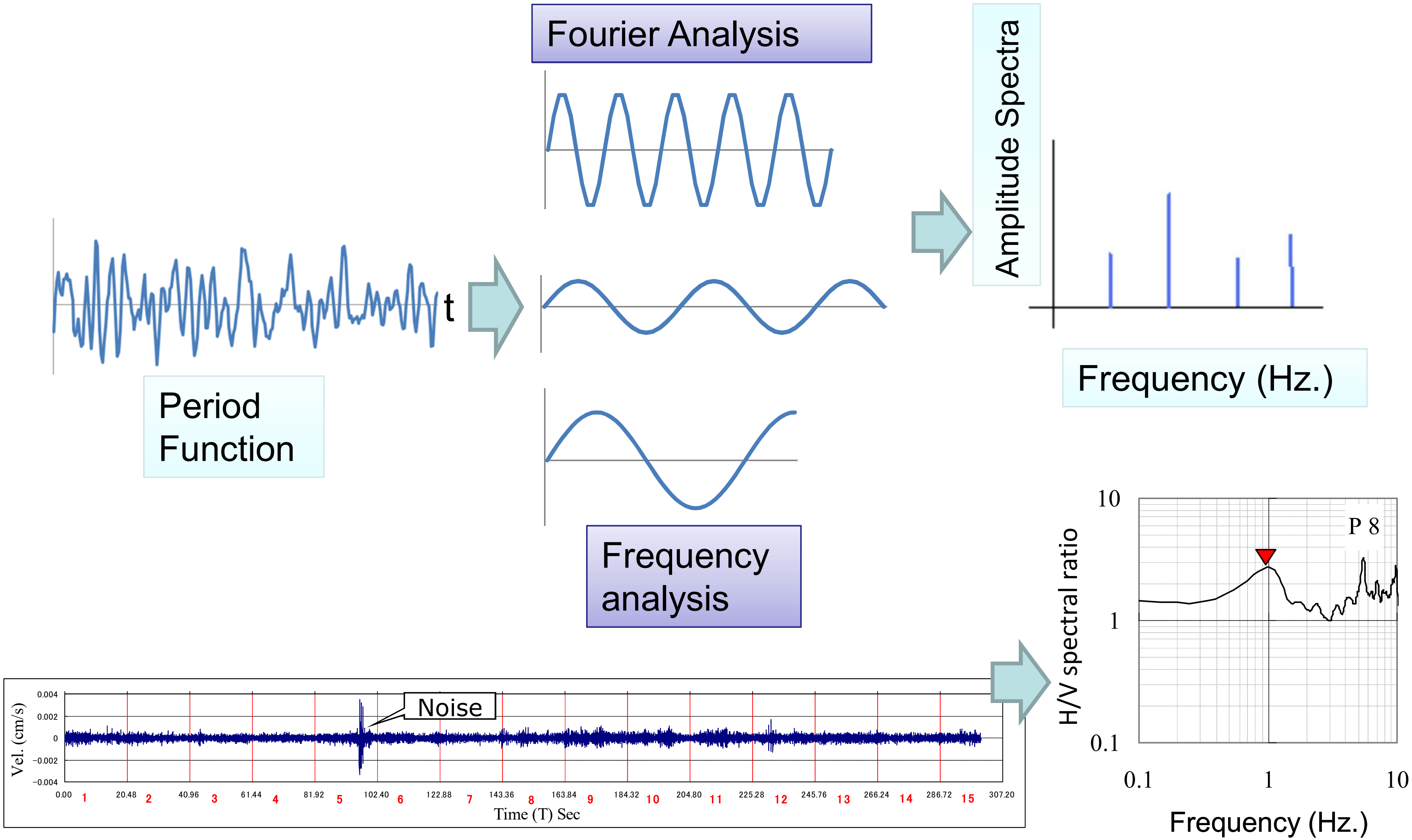
Three components (EW, NS and UP) of ground motion (velocity) measured at single station (Time domain)

Fast Fourier Transform

Fourier amplitude versus frequency (Frequency domain)

Frequency correspondences to maximum value of H/V ratio gives the predominant frequency of the site

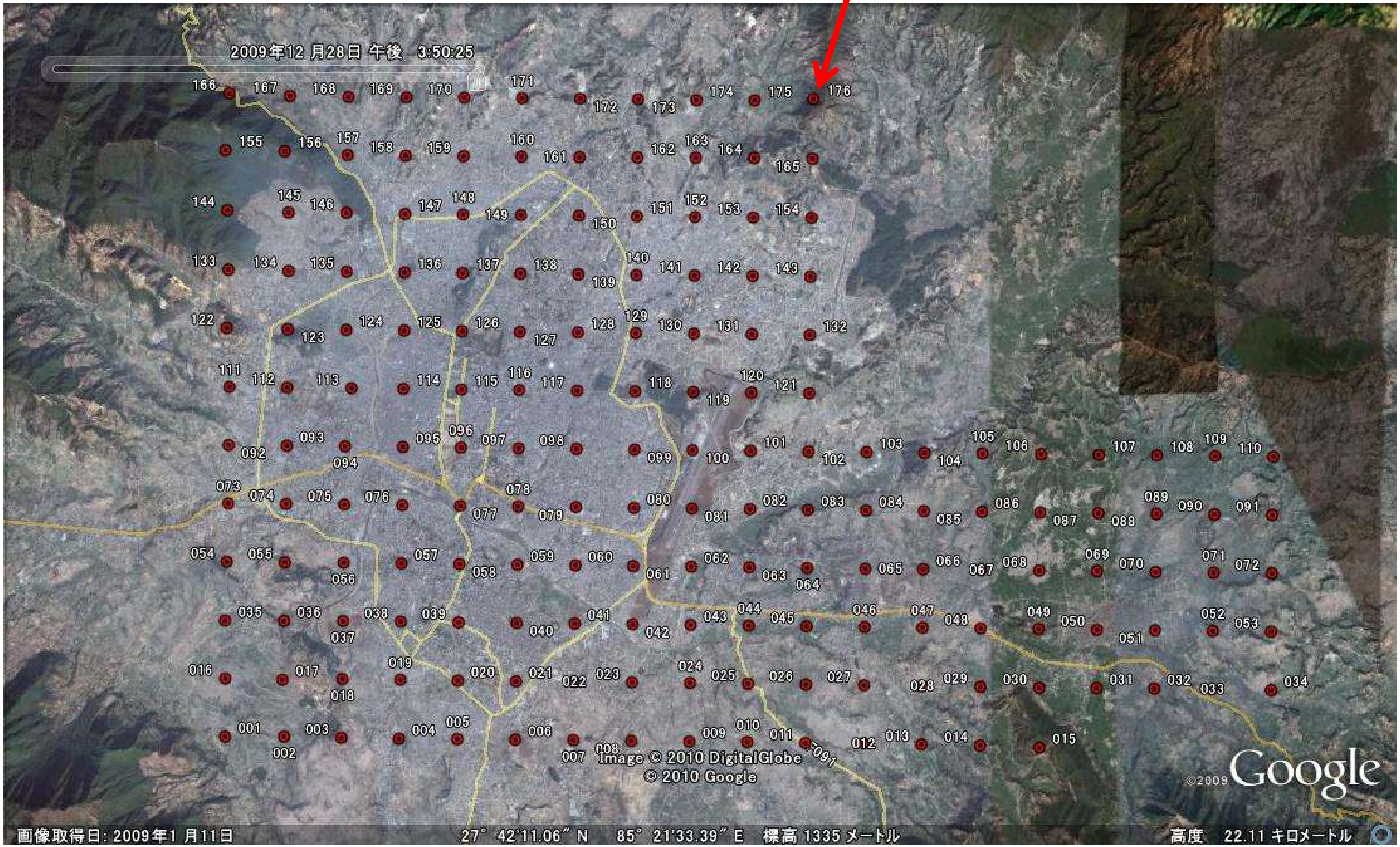
Fourier Analysis



Second-stage Ambient Vibration Measurement

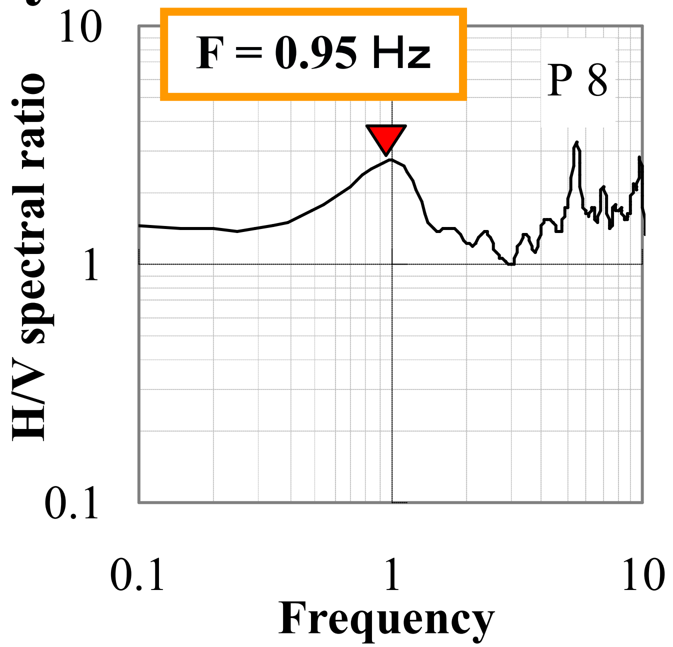
（Paudyal et al. 2012）

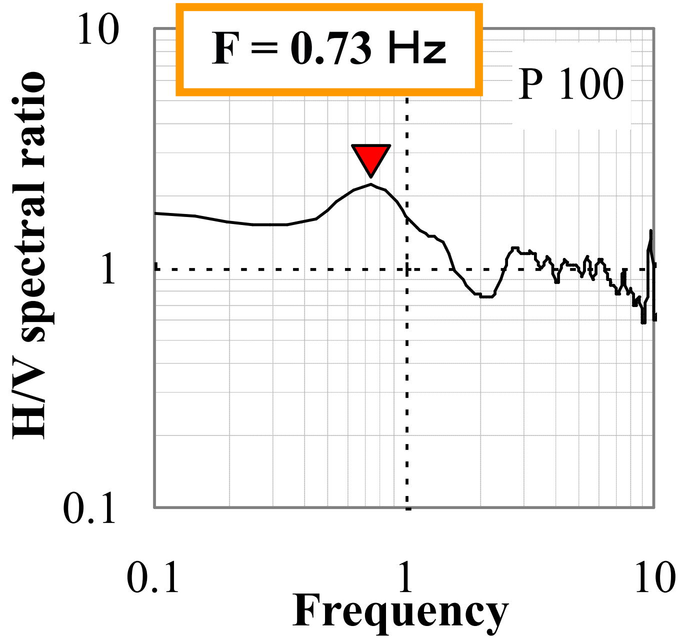
Total: 176 points

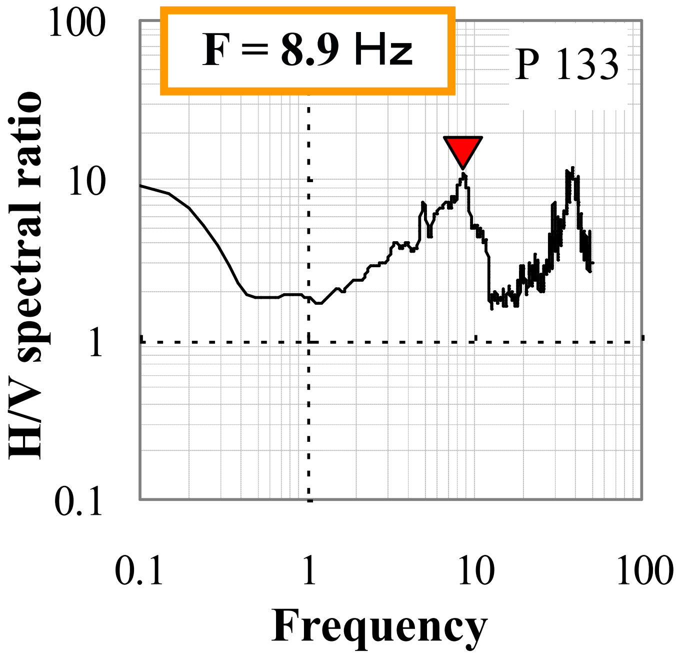


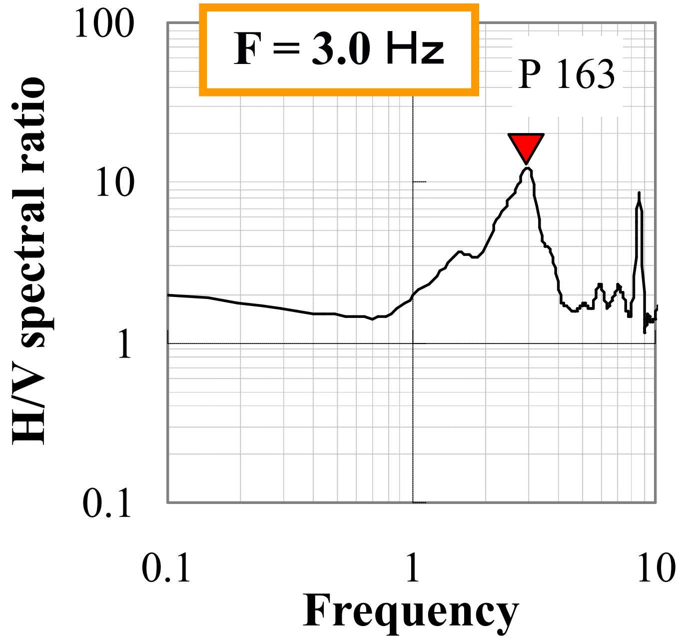
Analysis and result

(F – Predominant frequency of the sites)





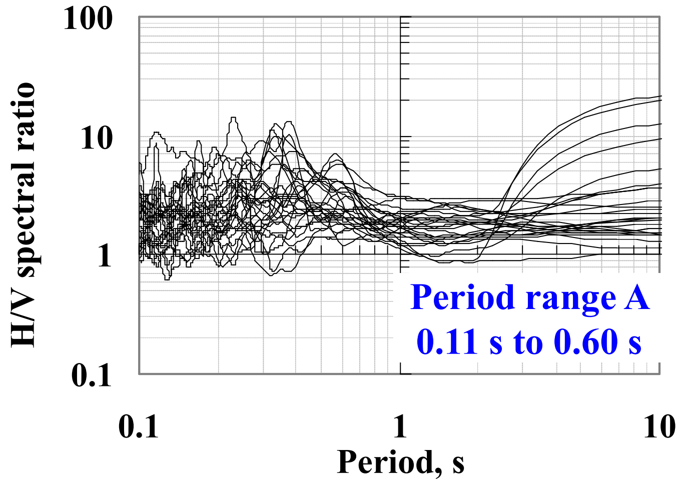


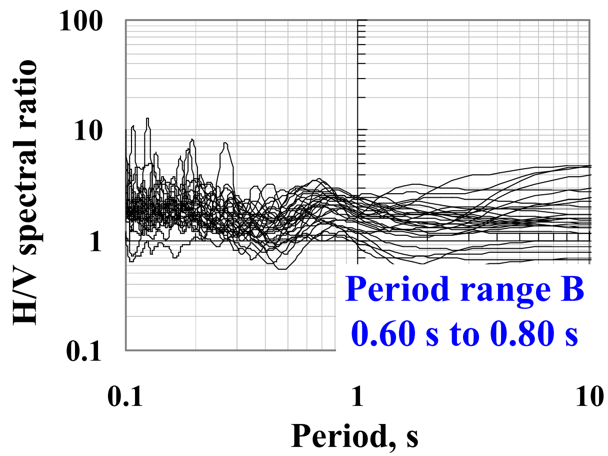


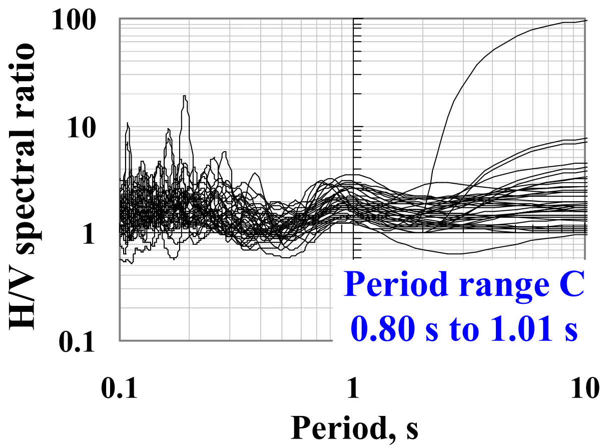
H/V spectral ratio of 5 zones

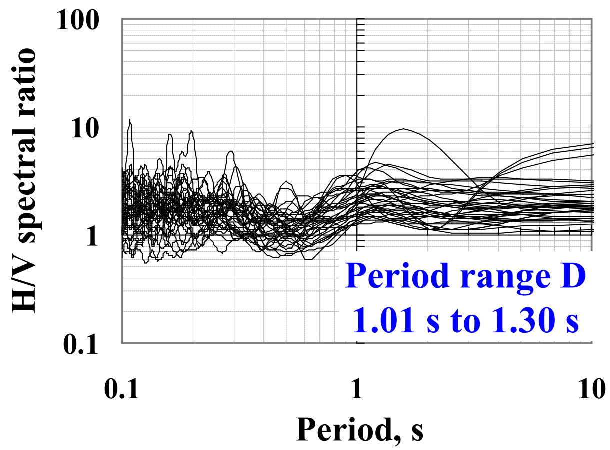
- Study area is divided into five different range of predominant period using natural break technique which regroups similar values together and represents the distribution properly

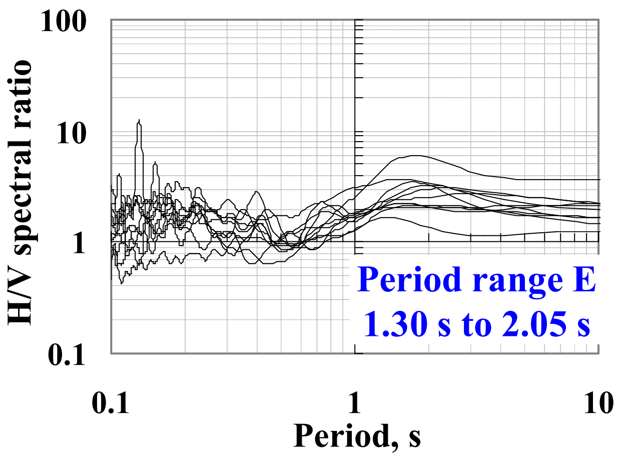
Predominant period range	Description of zone
A	0.11 s to 0.60 s
B	0.60 s to 0.80 s
C	0.80 s to 1.01 s
D	1.01 s to 1.30 s
E	1.30 s to 2.05 s



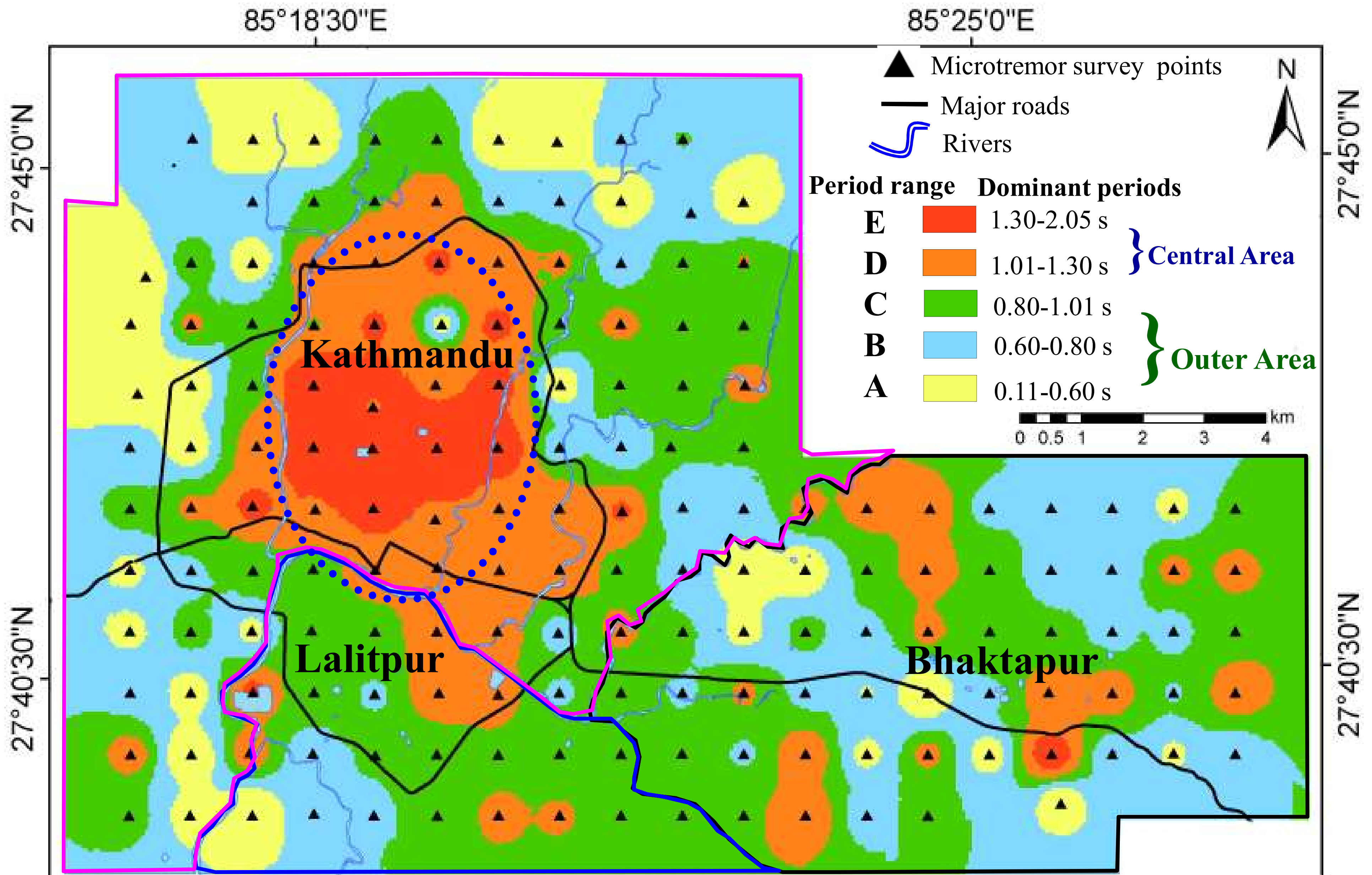






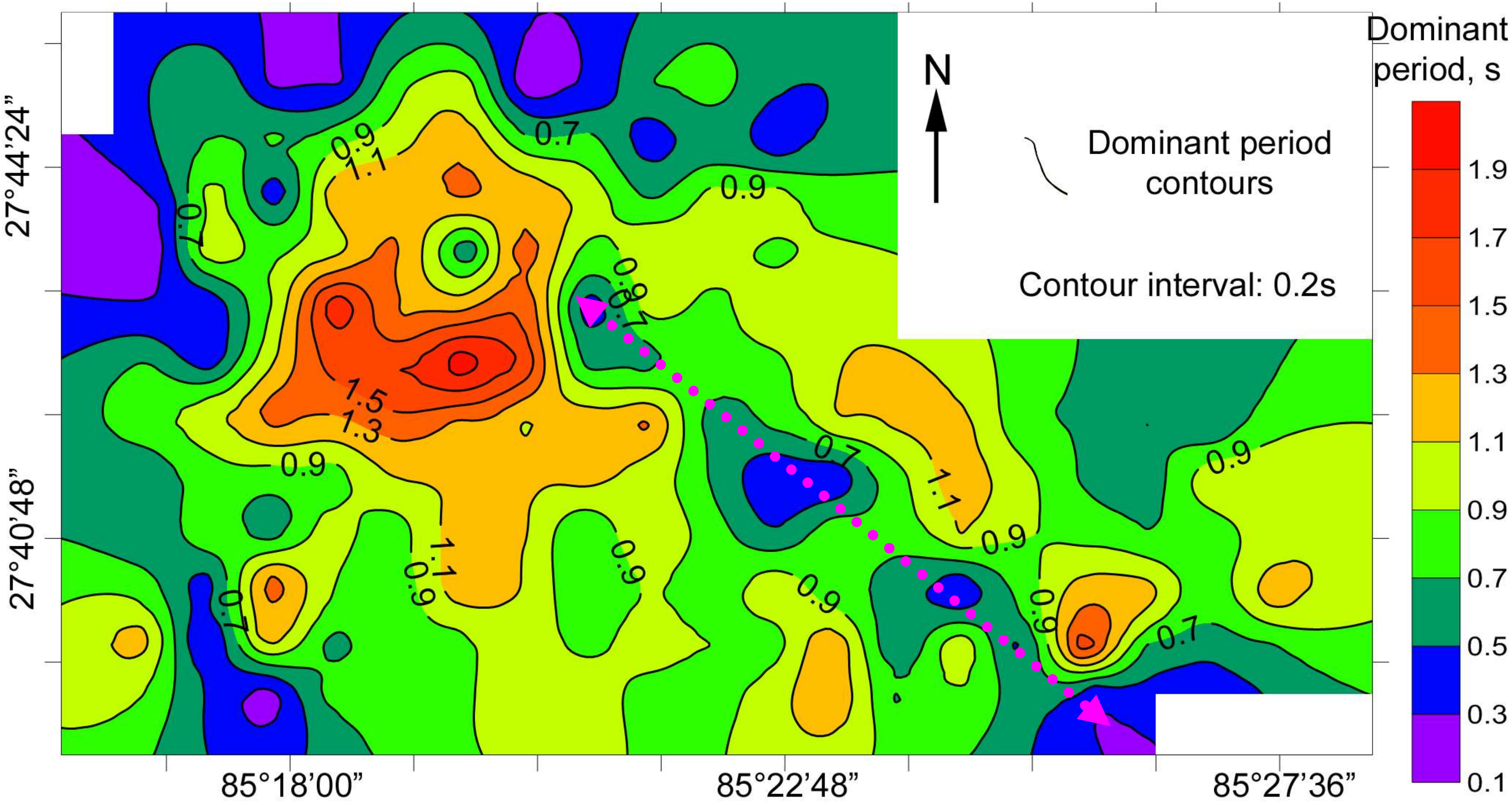


Seismic microzonation map of the study area



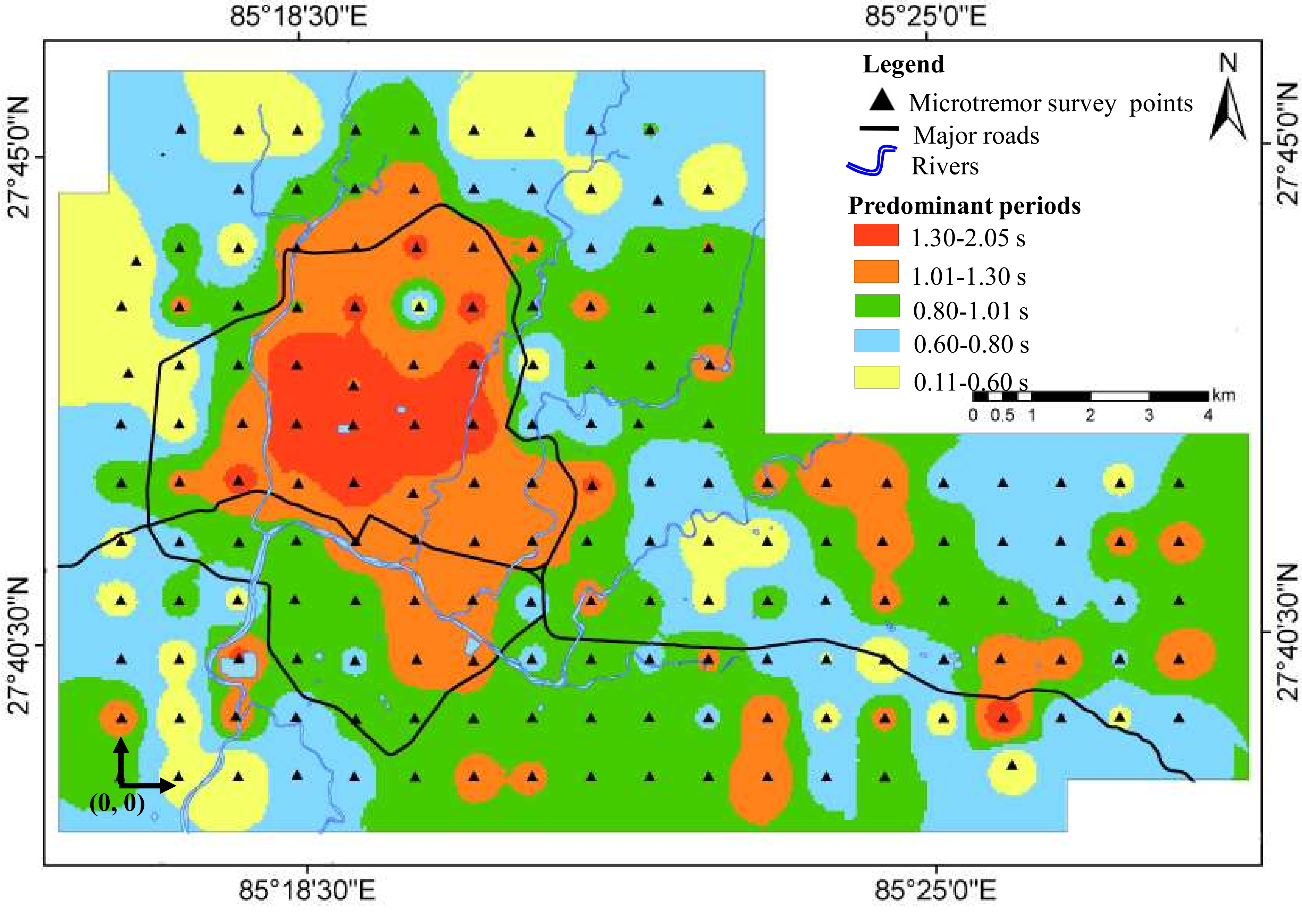
- **Period in the study area varies from 0.1-2.05 s**
- **Period in central part varies from 1-2 s, which covers about 30% of the urban area of the valley**

Predominant period contours for the Kathmandu Valley

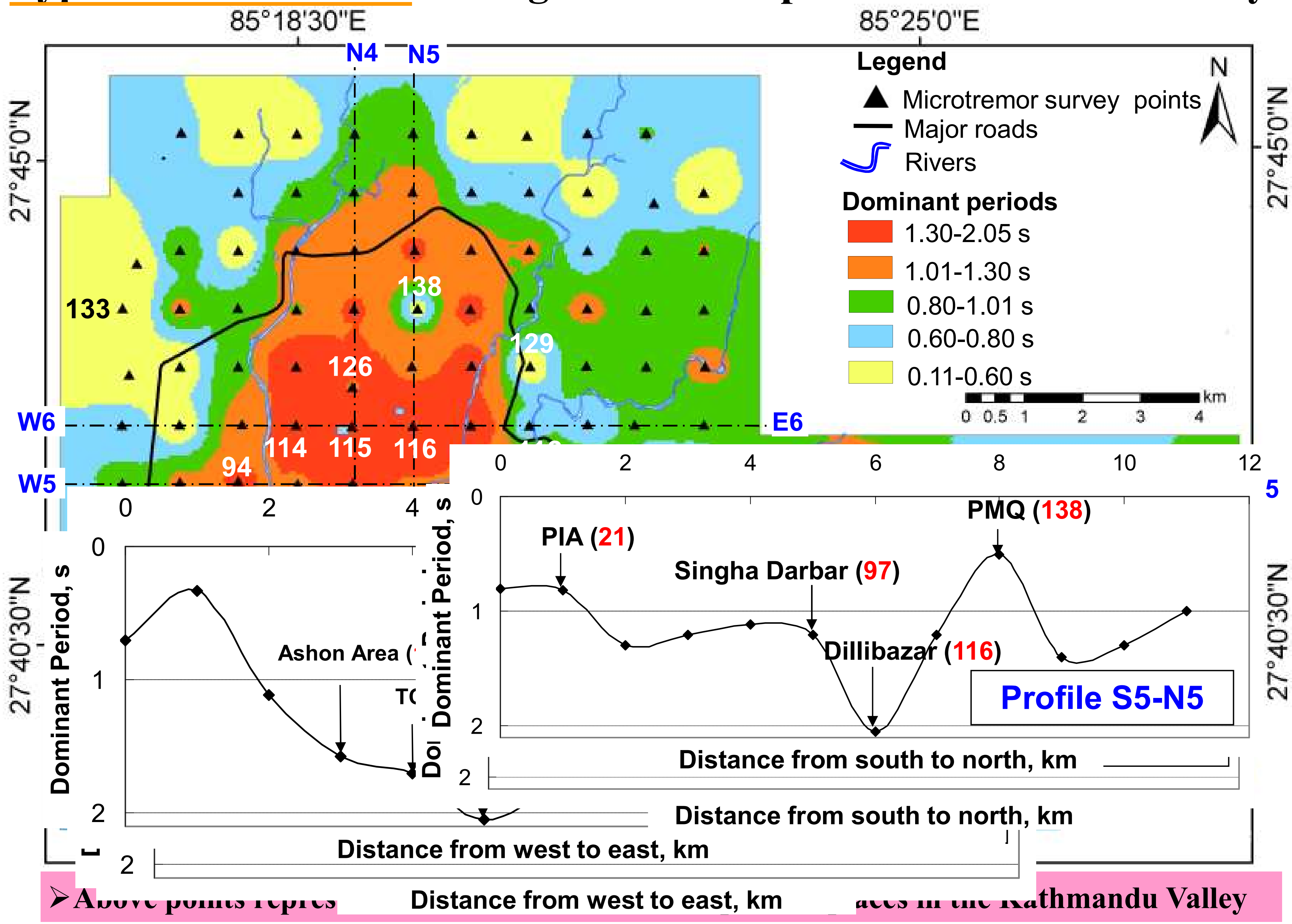


- Higher period range in the eastern and western part of the valley is separated by the long low period line extended from north-west to south-east in the valley

Profiles based on the predominant period of ground



Typical cross-sections through the center part of Kathmandu Valley



➢ Above points repres… …aces in the Kathmandu Valley

Soft sediment depth mapping formulae in different parts of the world

- **Ibs-von Seht and Wohlenberg (1999), $h=96\ f_r^{-1.388}$**
- **Parolai et al. (2002), $h=108\ f_r^{-1.551}$**
- **Dinesh et al. (2010), $h=(58+-8.8)\ f_r^{(-0.95+-0.1)}$**
- **Hinzen et al. (2004), $h = 137\ f_r^{-1.190}$**
- **Garcia-Jerez et al. (2006), $h = 194.6\ f_r^{-1.140}$**
- **Motamed et al. (2007), $h = 135.2\ f_r^{-1.979}$**
- **D'Amcio et al. (2008), $h = 140\ f_r^{-1.172}$**
- **Gosar et al. (2010), $h=105.5\ f_r^{-1.25}$**
- **Delgardo et al. (2000), $h= 55.11\ f_r^{-1.256}$**
- **Birgoen et al. (2009), $h= 150.99\ f_r^{-1.1531}$**
- **Ozalaybey et al. (2011), $h = 141\ f_r^{-1.27}$**
- **Sukumaran et al. (2011), $h = 102.1 f_r^{-1.47}$**

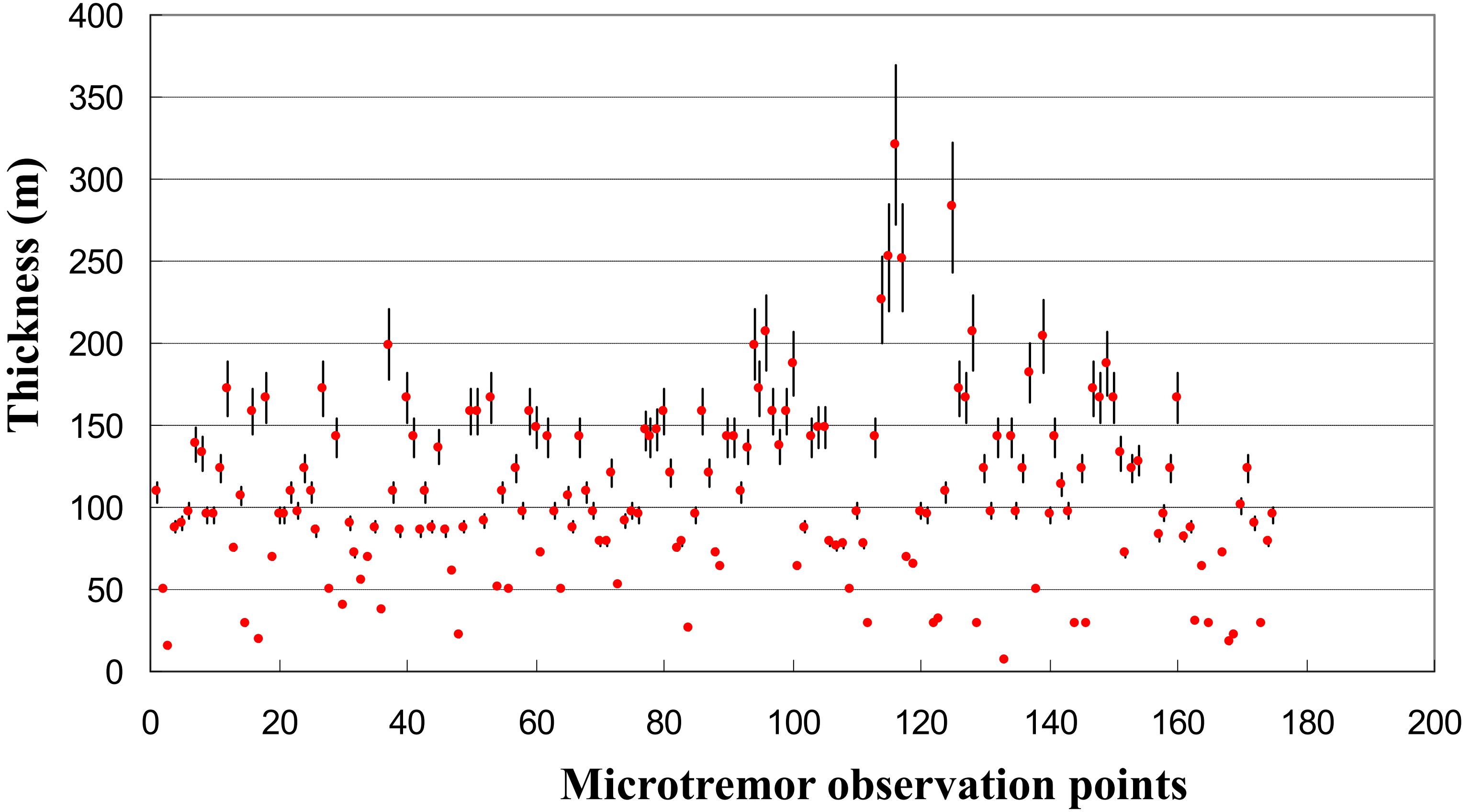
Selected relationships

- **Ibs-von Seht and Wohlenberg (1999), $h=96\ f_r^{-1.388}$**
- **Parolai et al. (2002), $h=108\ f_r^{-1.551}$**
- **Birgoen et al. (2009), $h= 150.99\ f_r^{-1.1531}$**
- **Ozalaybey et al. (2011), $h = 141\ f_r^{-1.27}$**

- **Poposed relationships are based on the observed data in the area of varying depth ranging from few meter to 1257 m**
- **The results of the propsed relationship showed very strong relationship (R^2 value 0.995) between resonant frequency and thickness of the sediment**

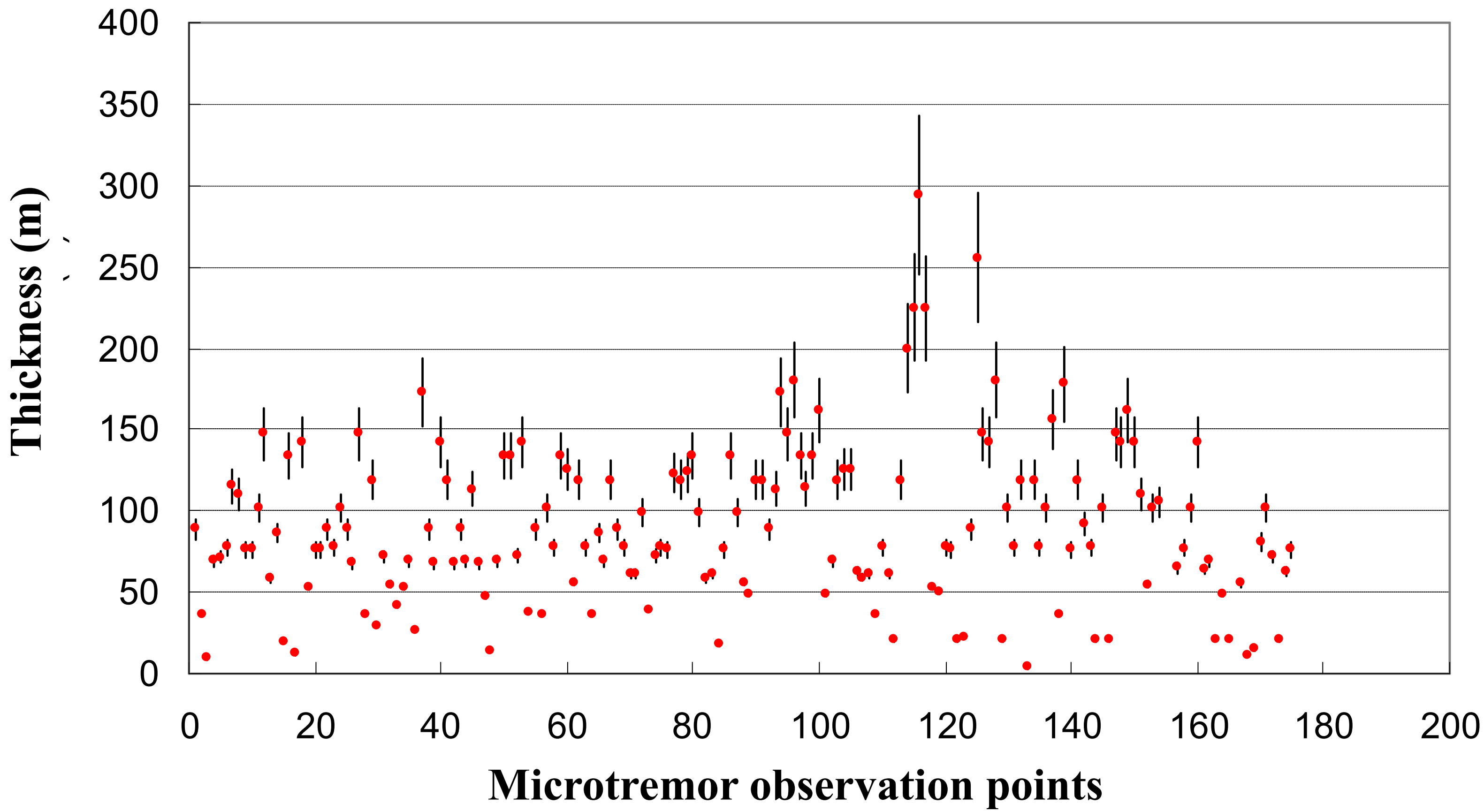
- **In this study, it is assumed that the H/V spectral ratio depends primarily on the site characteristics rather the geographical location**

Comparison between depths calculated using Ibs-von Seht and Wohlenberg (1999), Parolai et al. (2002), Birgöen et al. (2009) and Özalaybey et al. (2011) relationships



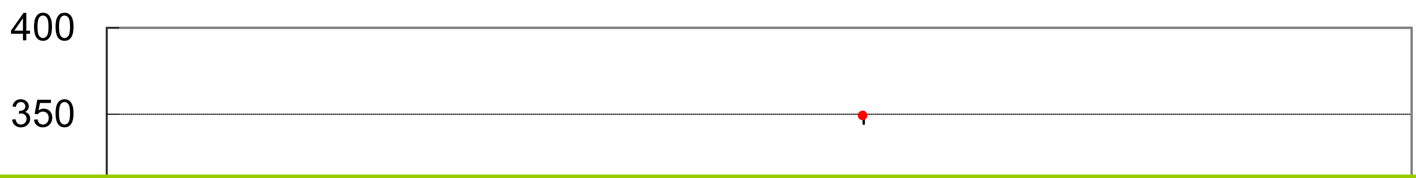
- Depth of sediment is calculated using the proposed relationship
- The circle indicates the average value whereas the length of the line suggests deviation from the average
- Average standard deviation = 41.88

Comparison between depths calculated using Ibs-von Seht and Wohlenberg (1999), and Parolai et al. (2002) relationships (Group First)



- The circle indicates the average value whereas the length of the line suggests deviation from the average
- Average standard deviation = 48.55

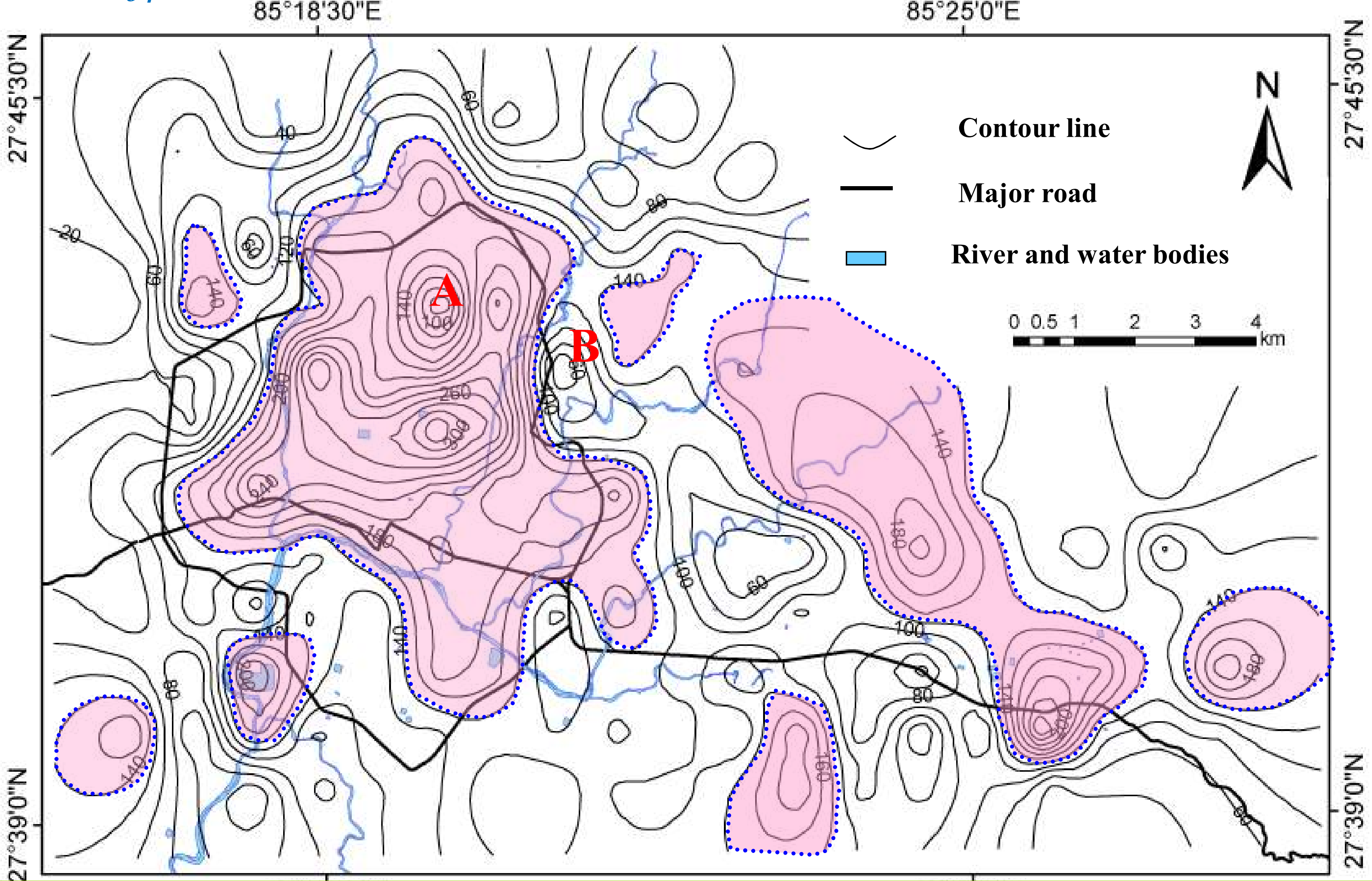
Comparison between depths calculated using Birgöen et al. (2009) and Özalaybey et al. (2011) relationships (Group Second)



- The depth calculated using these proposed equations show significantly smaller variations in the thickness due to comparable geotechnical characteristics of the geological formation
- Further averaged the values estimated to obtained the best fit equation
- Proposed frequency depth relationship for Kathmandu Valley

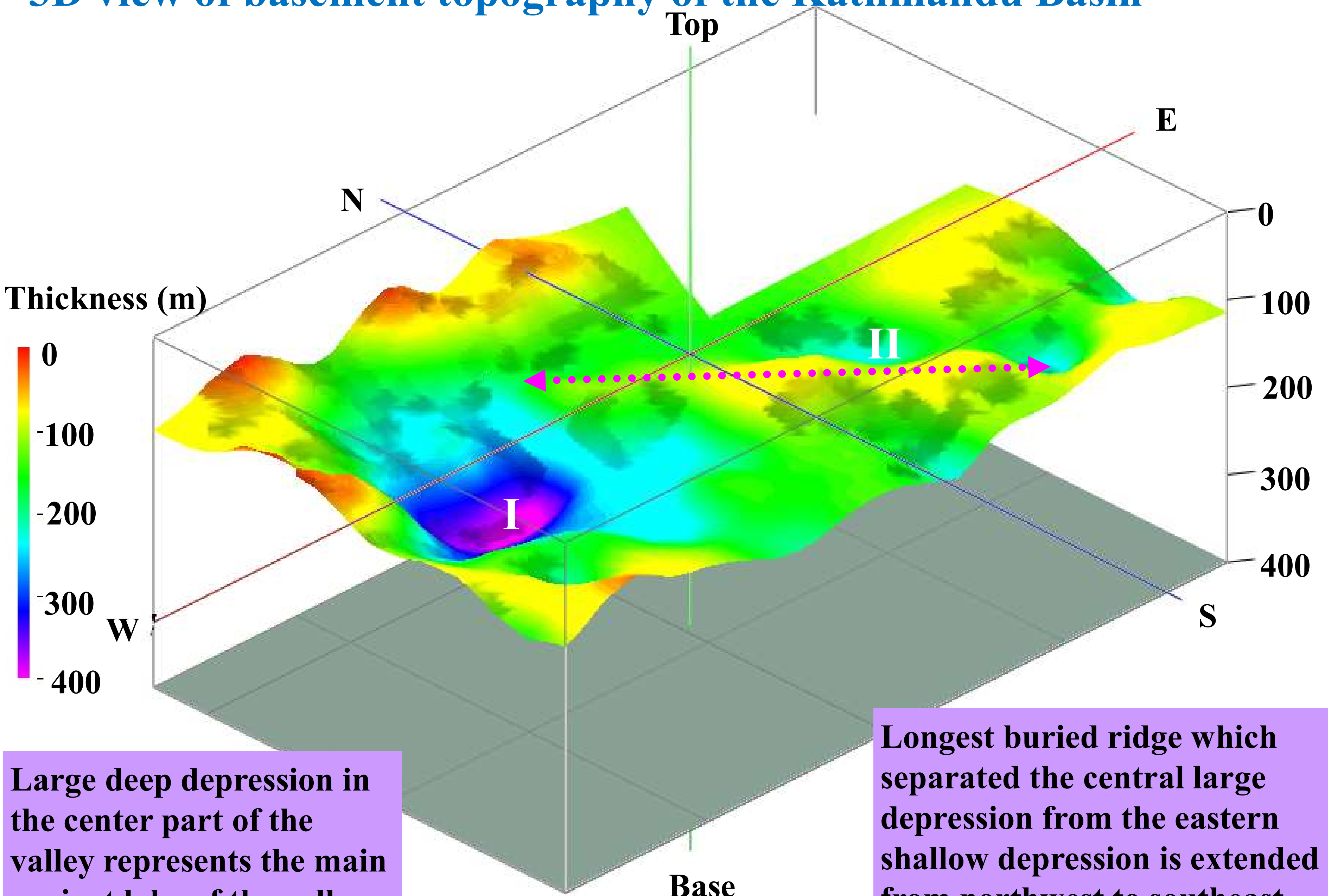
$$D=146.01f_r^{-1.2079}$$

Basement Contour map for the Kathmandu Basin based on the proposed relation, $D=146.01f_r^{-1.2079}$



A number of depressions are seen which are connected/separated by the buried ridges

3D view of basement topography of the Kathmandu Basin

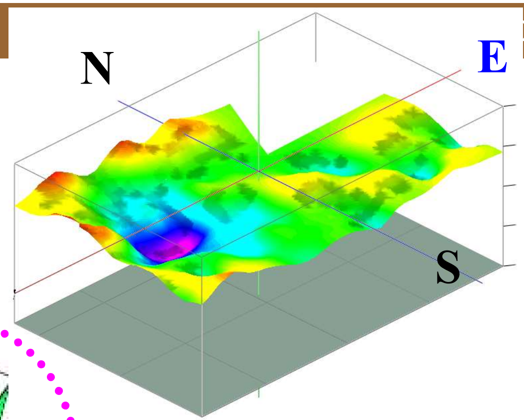


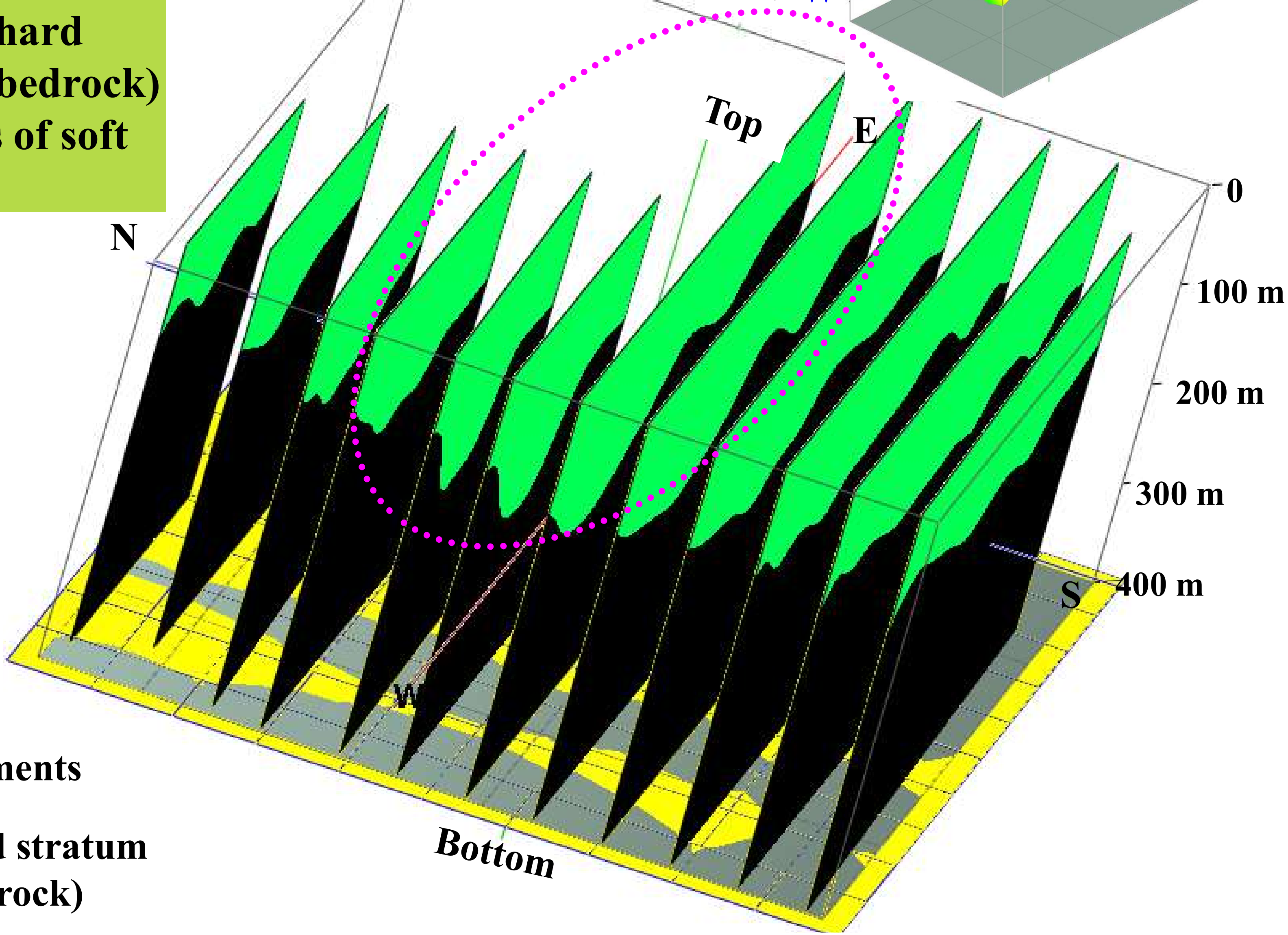
Large deep depression in the center part of the valley represents the main ancient lake of the valley

Longest buried ridge which separated the central large depression from the eastern shallow depression is extended from northwest to southeast

West-East sections

Cross profiles showing the contact of soft sediment and hard stratum (Eng.bedrock) and variations of soft sediments

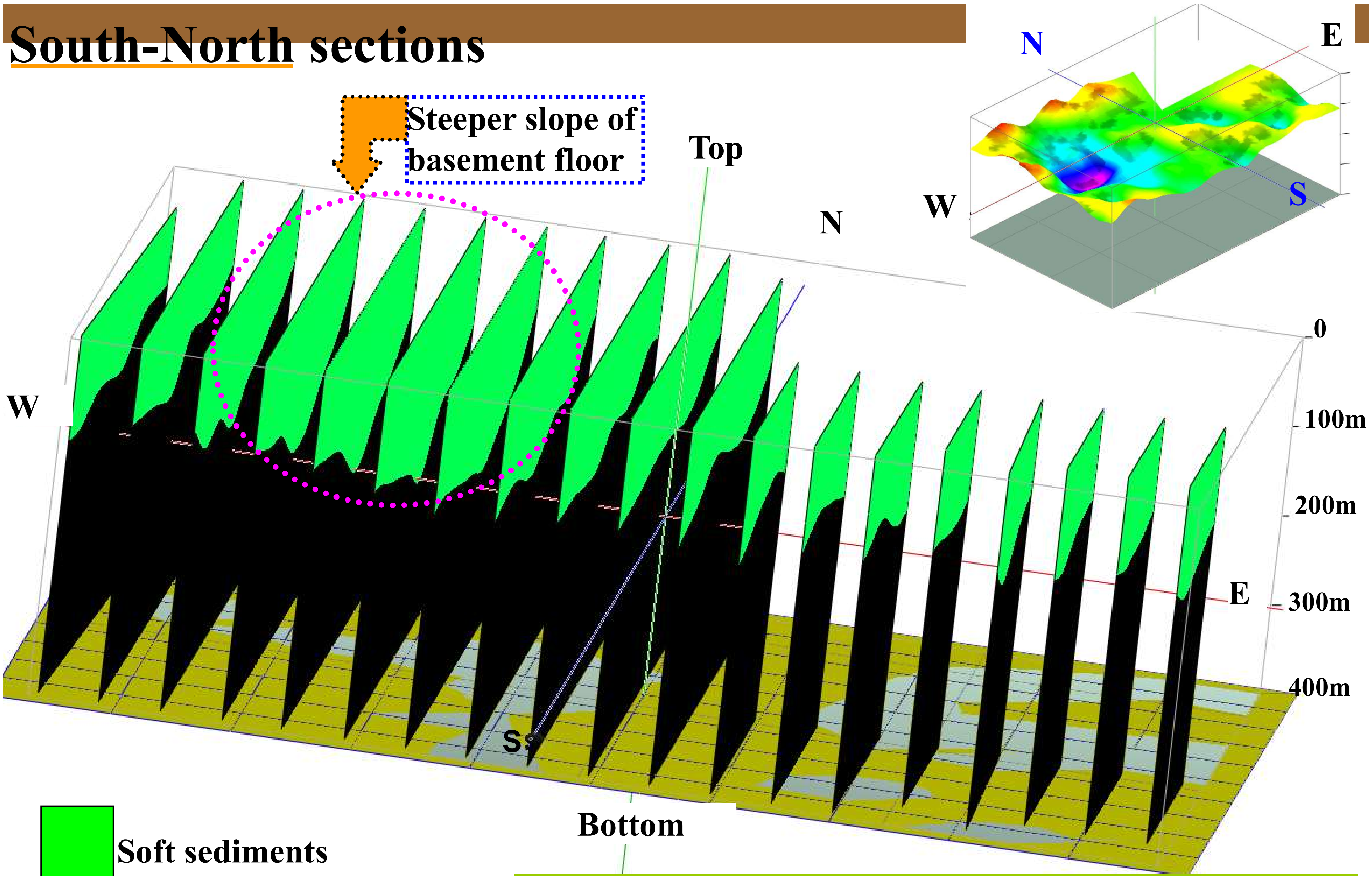




Soft sediments

Hard stratum (Bedrock)

South-North sections

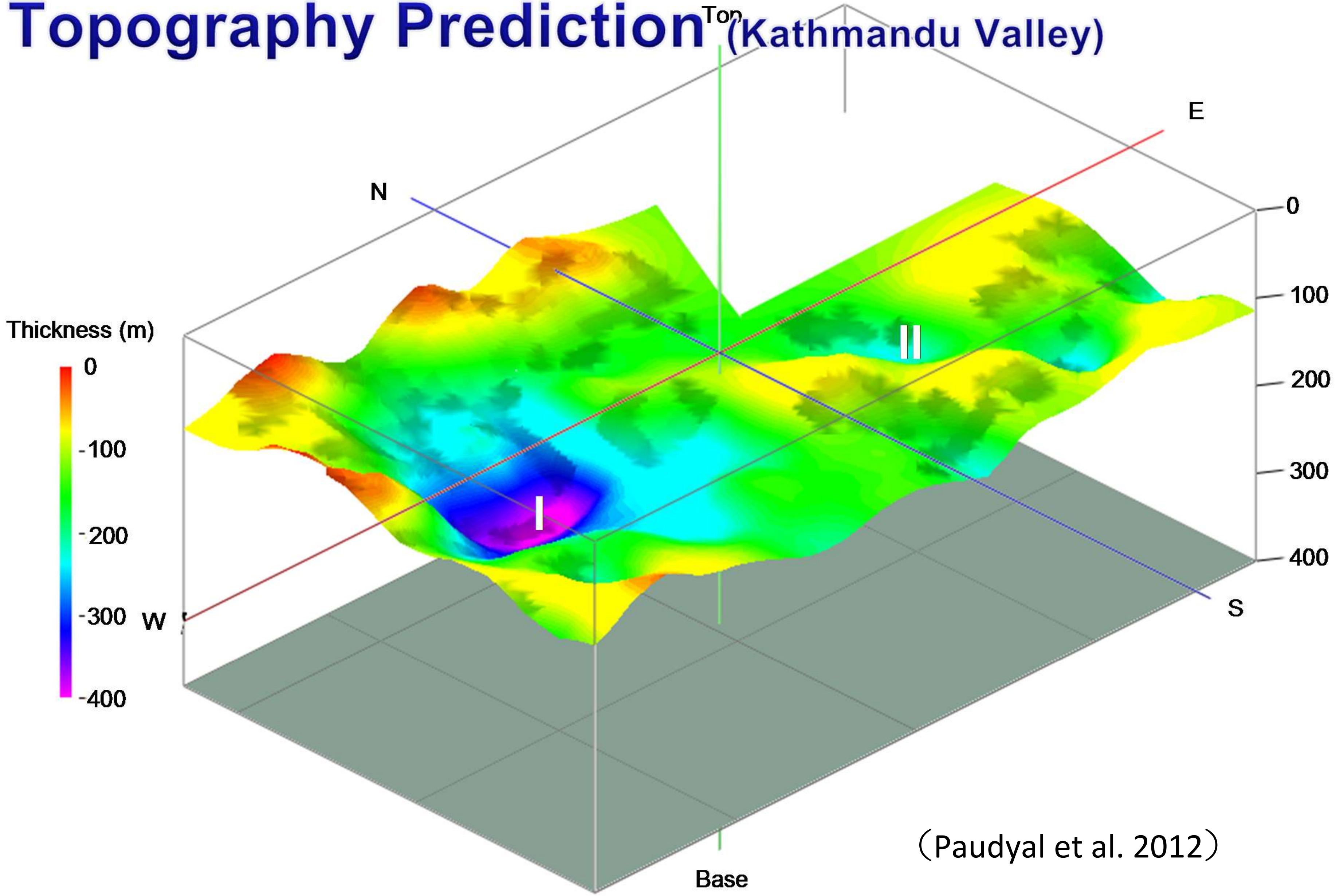


Soft sediments

Hard stratum (Bedrock)

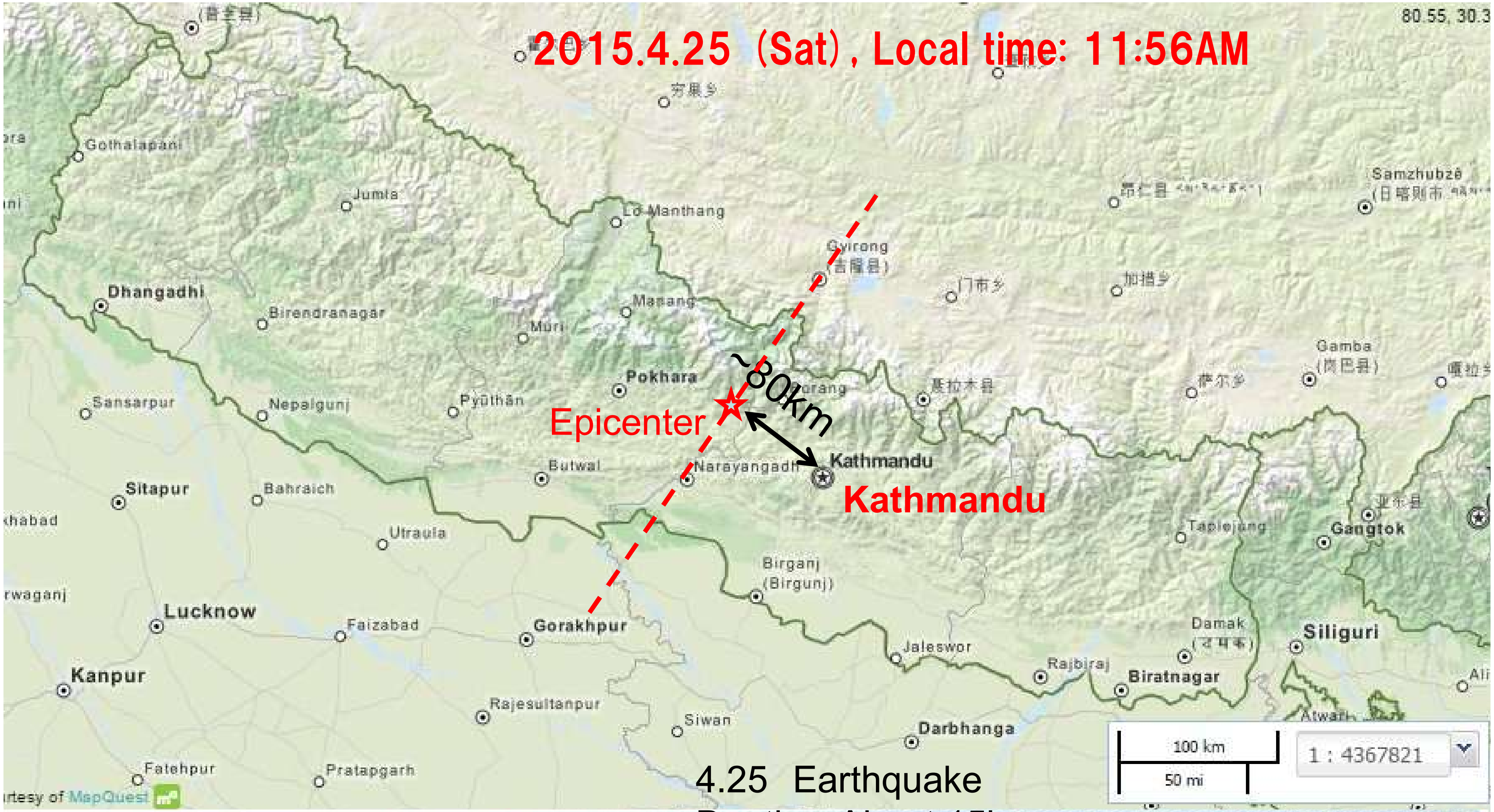
Cross profiles showing the contact of soft sediment and hard stratum (Eng.bedrock) and variations of soft sediments

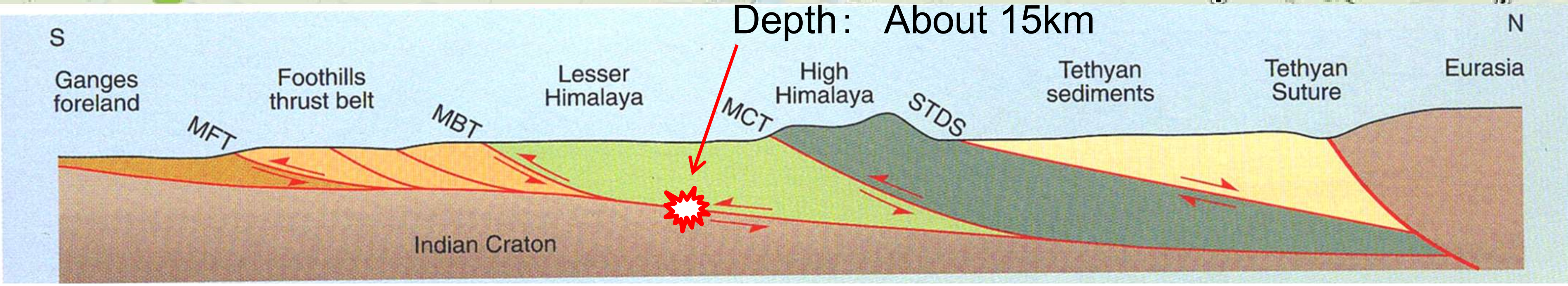
Ambient Vibration-based Basement Topography Prediction (Kathmandu Valley)



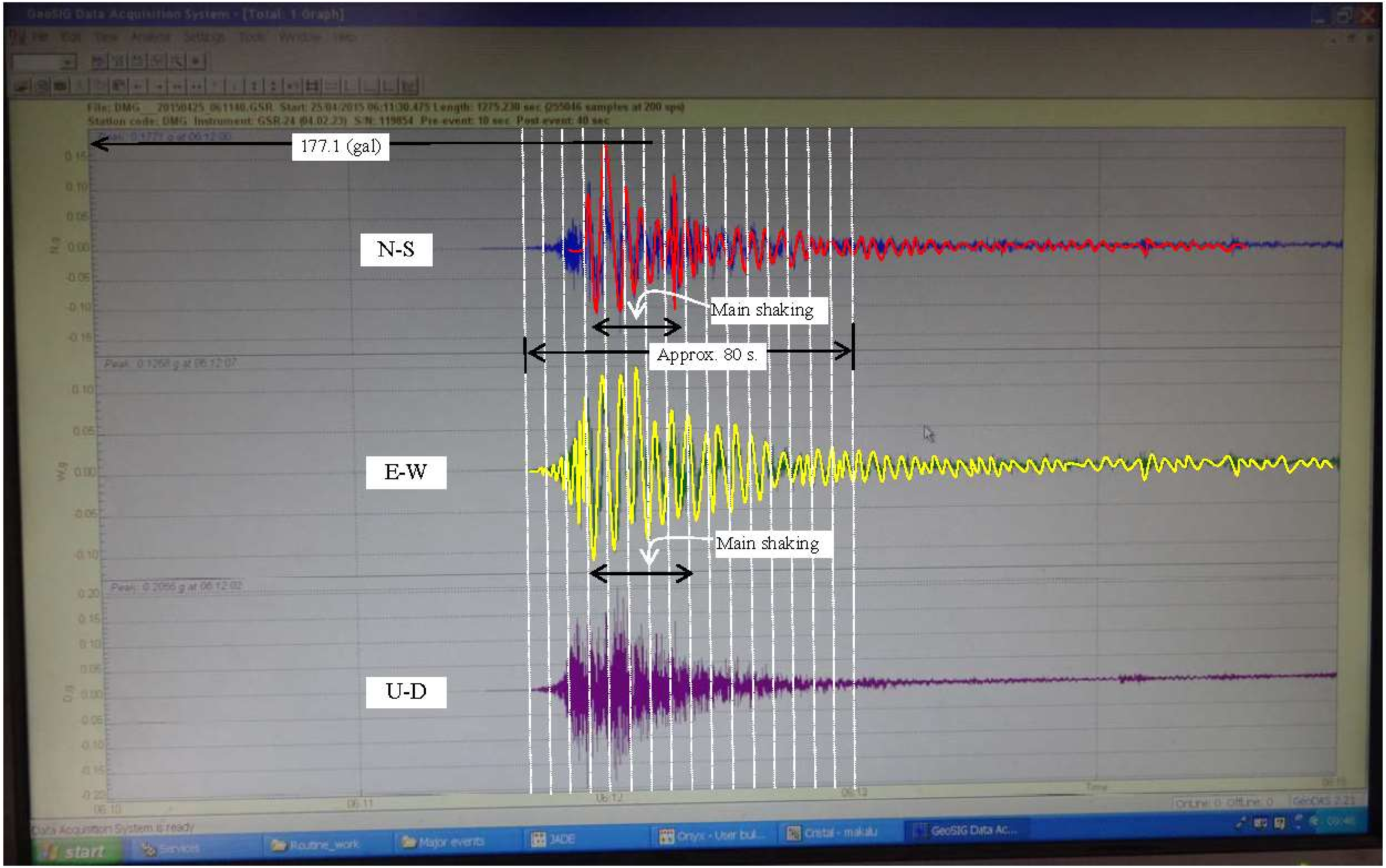
（Paudyal et al. 2012）

The 2015 Gorkha Earthquake


2015.4.25 (Sat), Local time: 11:56AM
Epicenter
~80km
Kathmandu
Gothalapani
Jumla
Lo Manthang
Gyirong
Dhangadhi
Birendranagar
Manang
Muri
Pokhara
Sansarpur
Nepalgunj
Pyūthān
Butwal
Narayangadh
Sitapur
Bahraich
Utraula
Birganj
(Birgunj)
Lucknow
Faizabad
Gorakhpur
Jaleswor
Rajbiraj
Biratnagar
Damak
Siliguri
Gangtok
Taplejung
Samzhubzê
Gamba
Kanpur
Rajesultanpur
Siwan
Darbhanga
Fatehpur
Pratapgarh
100 km
50 mi
1 : 4367821

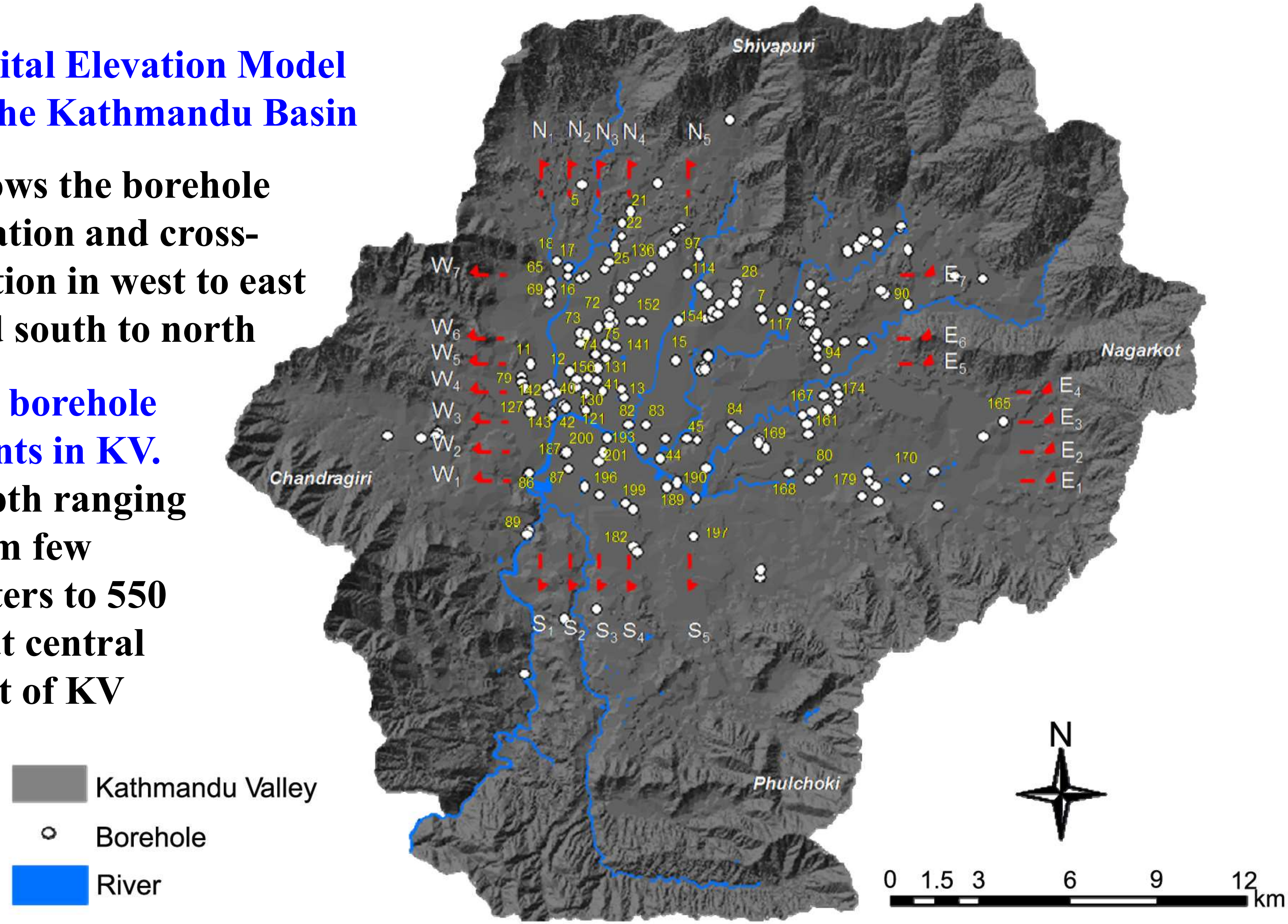

4.25 Earthquake
Depth: About 15km
S
N
Ganges foreland
Foothills thrust belt
Lesser Himalaya
High Himalaya
Tethyan sediments
Tethyan Suture
Eurasia
MFT
MBT
MCT
STDS
Indian Craton

Earthquake Acceleration Data (DMG Nepal 2015)



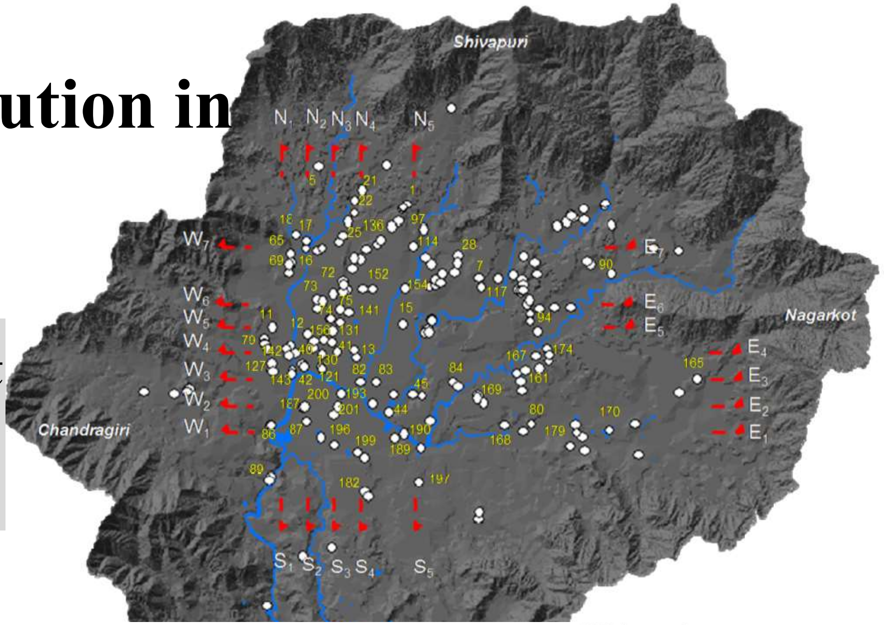
Borehole and sediment distribution in the Kathmandu Valley

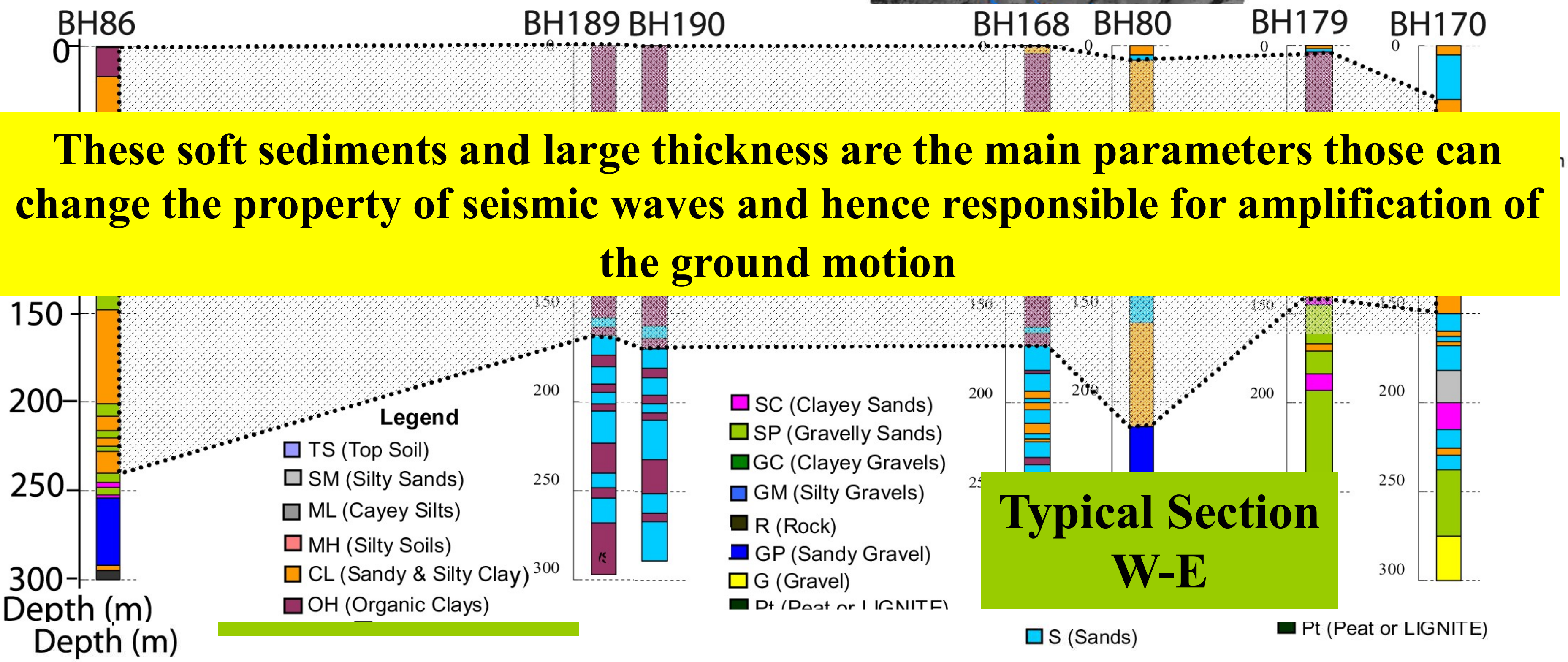
- **Digital Elevation Model of the Kathmandu Basin**
- **Shows the borehole location and cross-section in west to east and south to north**
- **340 borehole points in KV.** **Depth ranging from few meters to 550 m at central part of KV**



Borehole and sediment distribution in the Kathmandu Valley

Variation of thickness of sediments in different location of valley (area enclosed by black dotted line represents the soft soil layer)





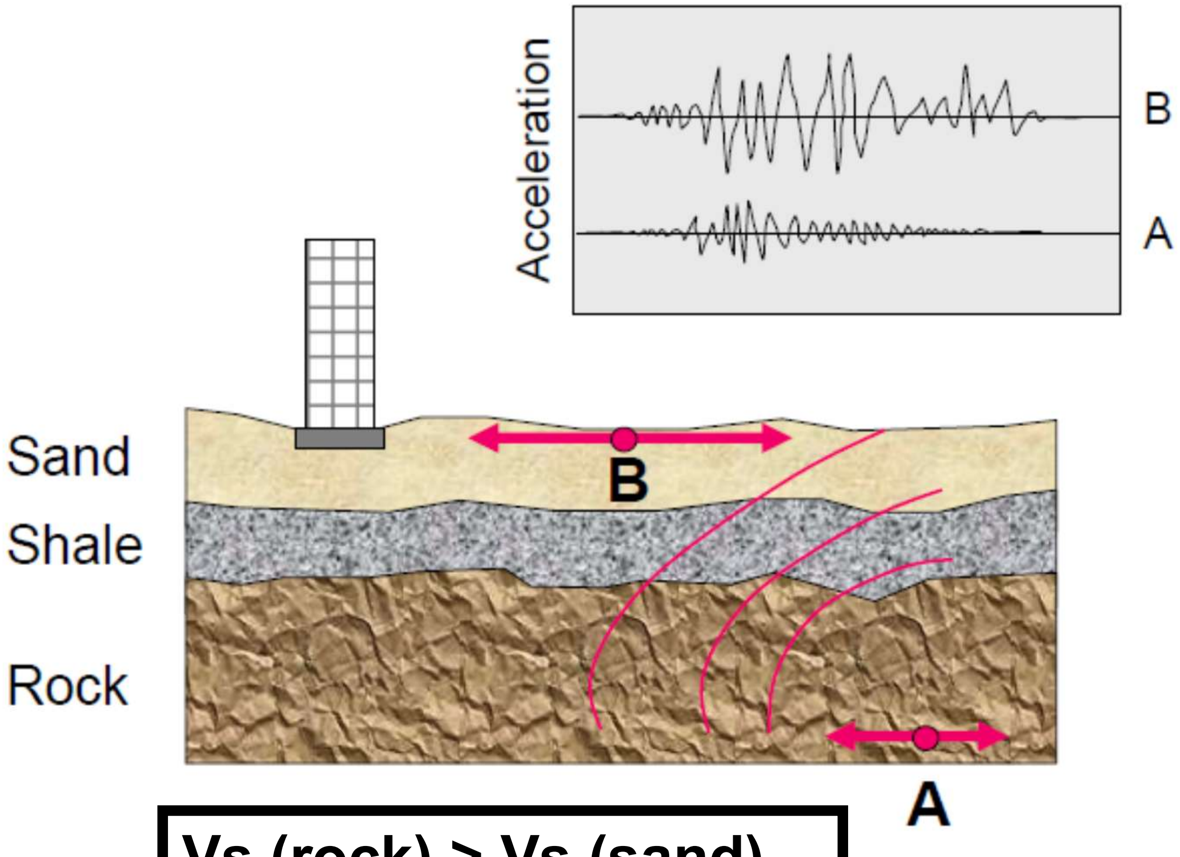
These soft sediments and large thickness are the main parameters those can change the property of seismic waves and hence responsible for amplification of the ground motion

Typical Section W-E

Soft ground effect

Soil profile acts as filter

- ❑ Change in frequency content of motion
- ❑ Amplification or de-amplification of ground motions can occur
- ❑ Duration of motion is increased



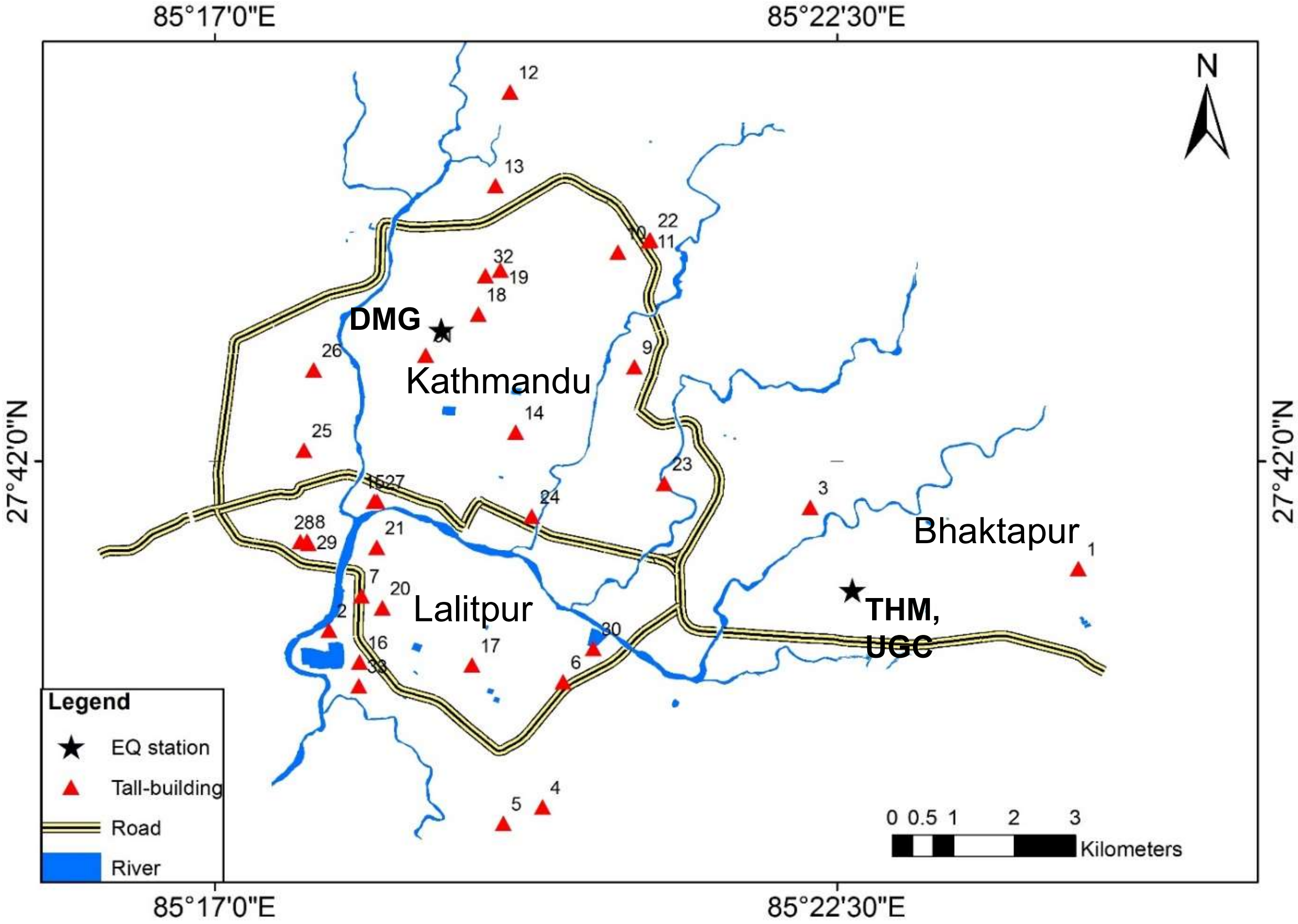
Vs (rock) > Vs (sand)

The soil profile acts as filter modifying the amplitude and nature of the motions.

Study Locations

- **Microtremor measurements in 33 tall-buildings and nearby free-field**
- **Measure microtremeor in strong ground motion sites as well i.e. DMG and THM, UGC**

Kathmandu Valley

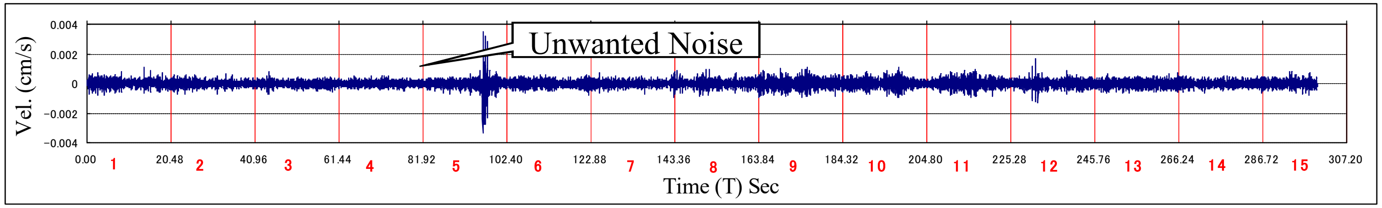


Microtremor Measurement

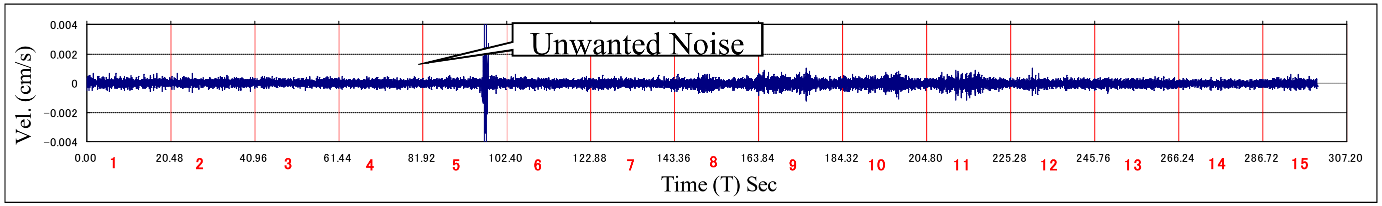
Three components (EW, NS and UP) for ground motion (velocity) measured at single station

And three components (Longitudinal direction (X), Transvers direction (Y) and Vertical direction (Z)) for buildings

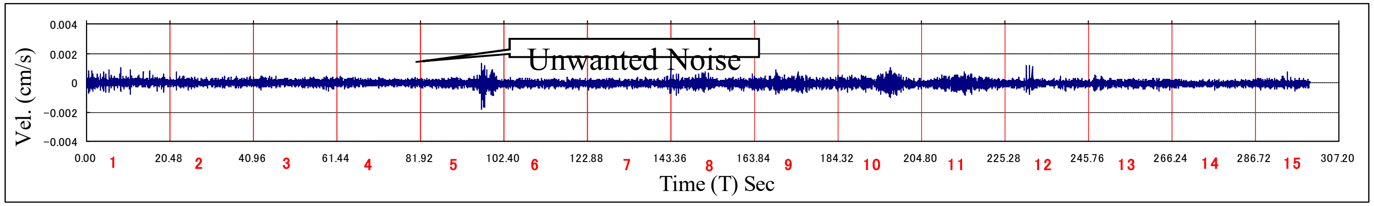
EW/Longitudinal direction (X)



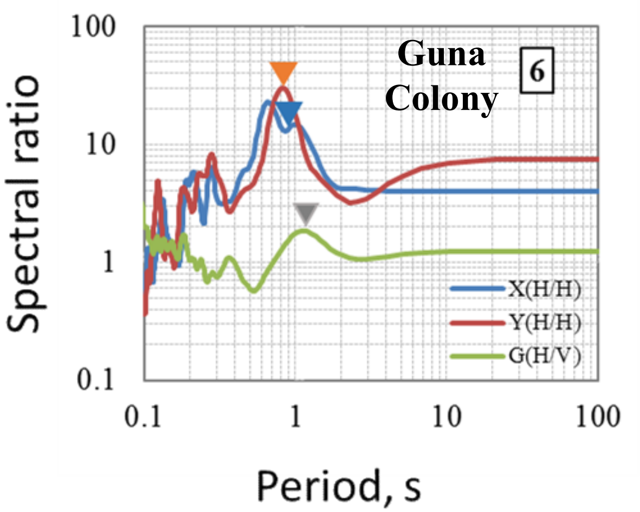
NS/Transverse direction (Y)



Vertical directon (Z)



Analysis and Results



Building: Guna Colony (No. 6)

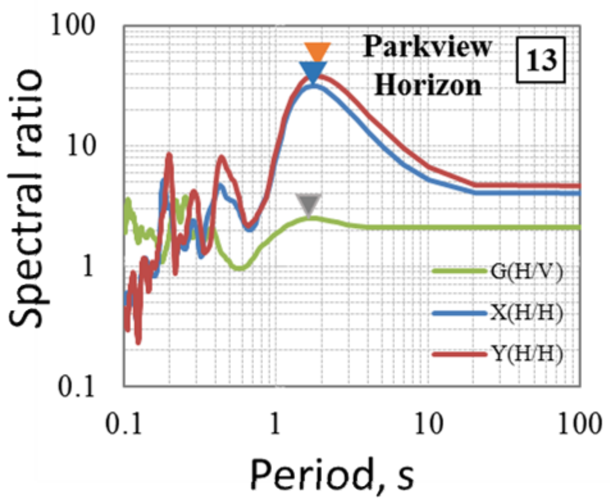
Story:12

Building Type: Reinforce Cement Concrete (RCC)

Predominant Period of Bldg. in longitudinal dir. (TBX) = 0.9 s

Predominant Period of Bldg. in transverse dir. (TBY)=0.85 s

Predominant Period of nearby free field (Tavg) = 1.15 s



Building: Park Horizon Dhapasi (No. 13)

Story:17

Building Type: Reinforce Cement Concrete (RCC)

Predominant Period of Bldg. in longitudinal dir. (TBX)= 1.82 s

Predominant Period of Bldg. in transverse dir. (TBY) = 1.92 s

Predominant Period of nearby free field (Tavg)= 1.85 s

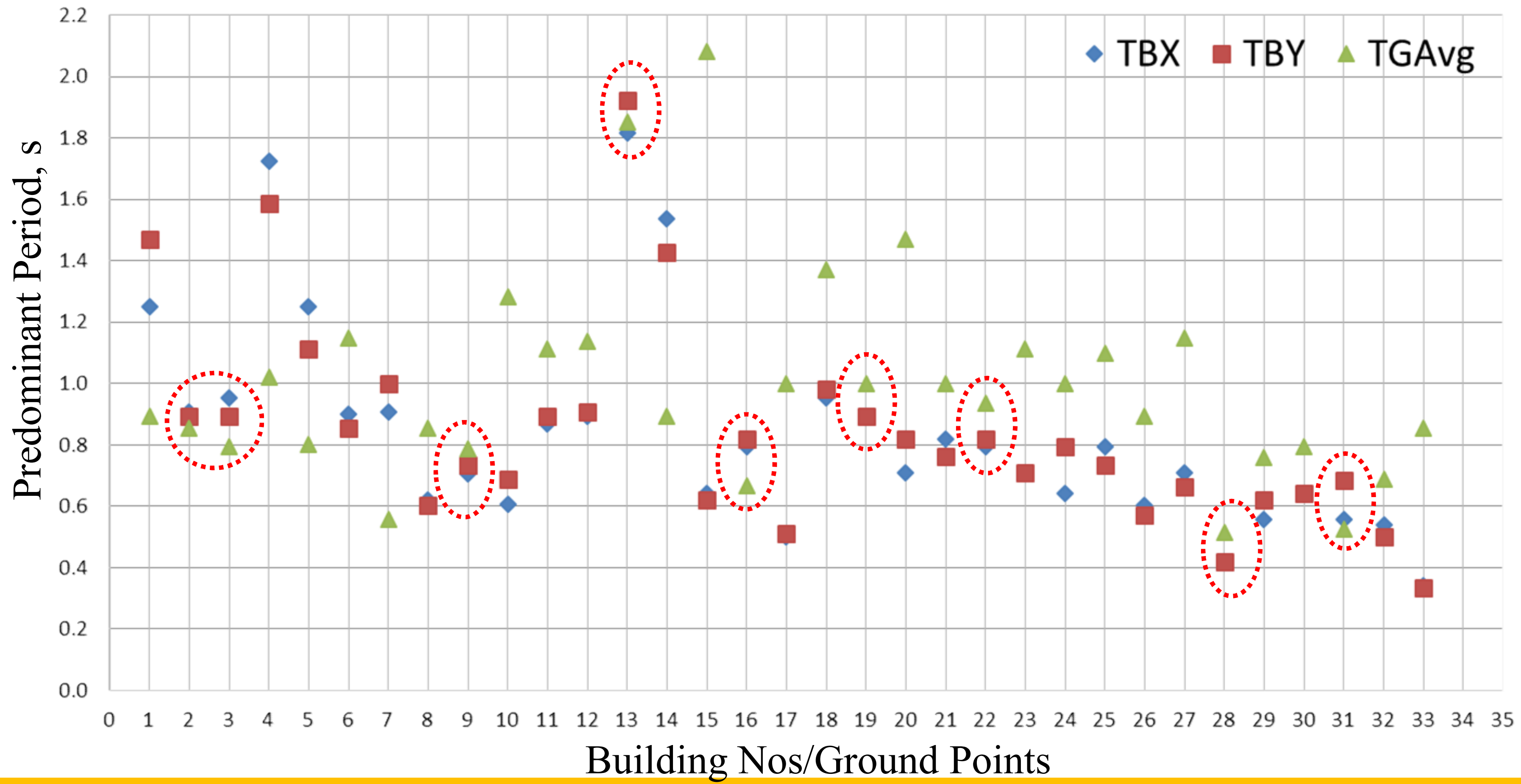
X(H/H) - floor-spectral ratio vs. period graph for longitudinal direction of building

Y(H/H) - floor-spectral ratio vs. period graph for transverse direction of building

G(H/V) - the horizontal-to-vertical spectral ratio vs. period graph in nearby free-field

Analysis and results

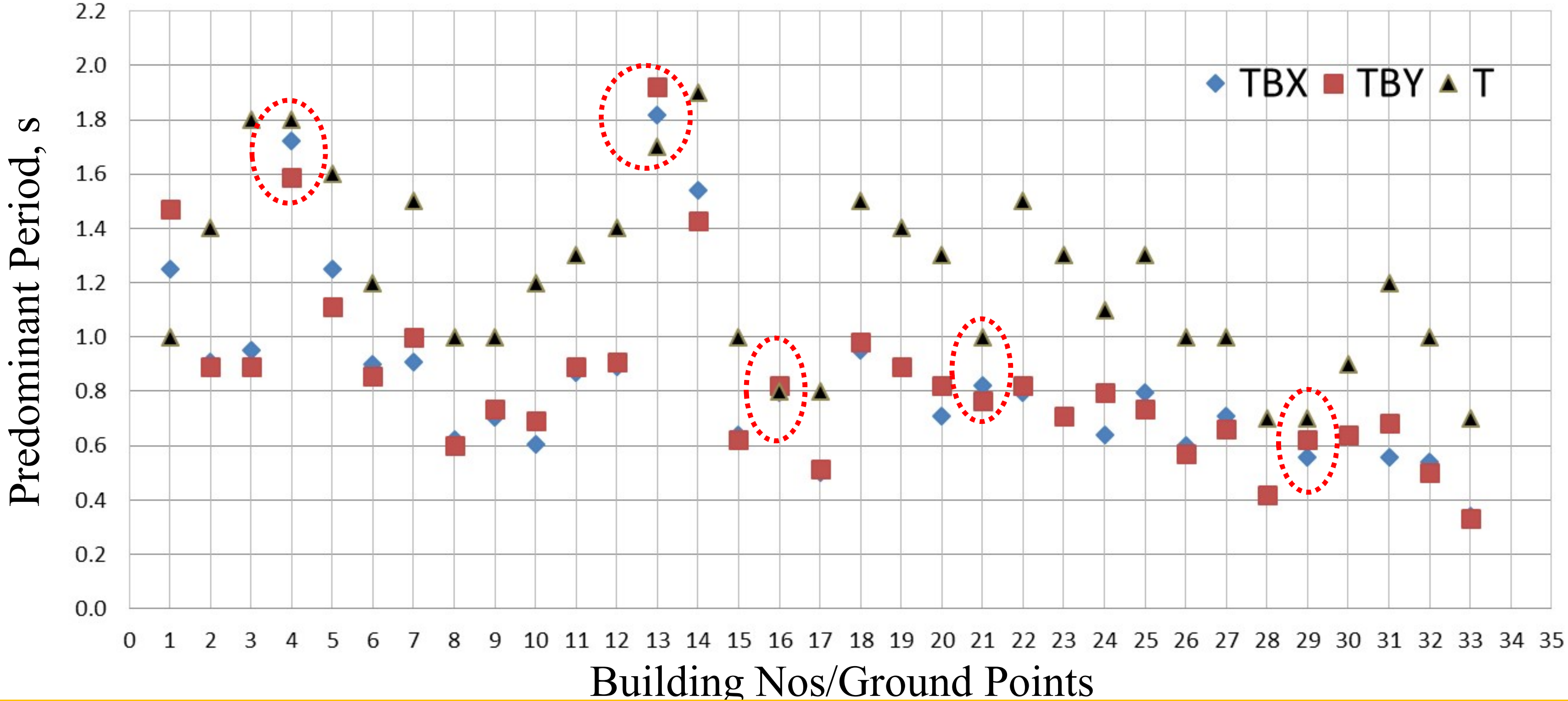
Comparative diagram of Period along Longitudinal direction (TBX) and Period along Transverse direction (TBY) of Building and Fundamental Period of free-field (TGAvg)



- ❑ Predominant period of about **60% tall-buildings are close to** the predominant period of ground
- ❑ About **25% tall buildings** predominate period are **almost equal to** that of the free-field's predominant period

Analysis and results

Comparative diagram of Period along Longitudinal direction (TBX) and Period along Transverse direction (TBY) of Building using MT observation and Period based on Kramer (1996) (T=0.1N, N-number of story of building)



- ❑ Fundamental periods of vibration of about **20% tall buildings are equivalent to** the calculated period from Kramer (1996) (T=0.1N).
- ❑ About **80% buildings periods are found to be lower than** the calculated period according to Kramer (1996) (T=0.1N).
- ❑ Period obtained from Kramer (1996) is usually higher than the actual period of the buildings obtained using microtremor measurement (Al-Nimry et al. (2014).