GEER Reconnaissance

Engineering Seismology and Geotechnical Engineering

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Geotechnical Extreme Events Reconnaissance

Turning Disaster into Knowledge

Outline

- GEER Background & Team
- Seismo-Tectonic setting
- The Earthquake event and ground shaking
- Ground Response – Kathmandu Basin
- Liquefaction and cyclic failure
- Slope Stability and Landsliding
- Hydropower plants
- Concluding remarks

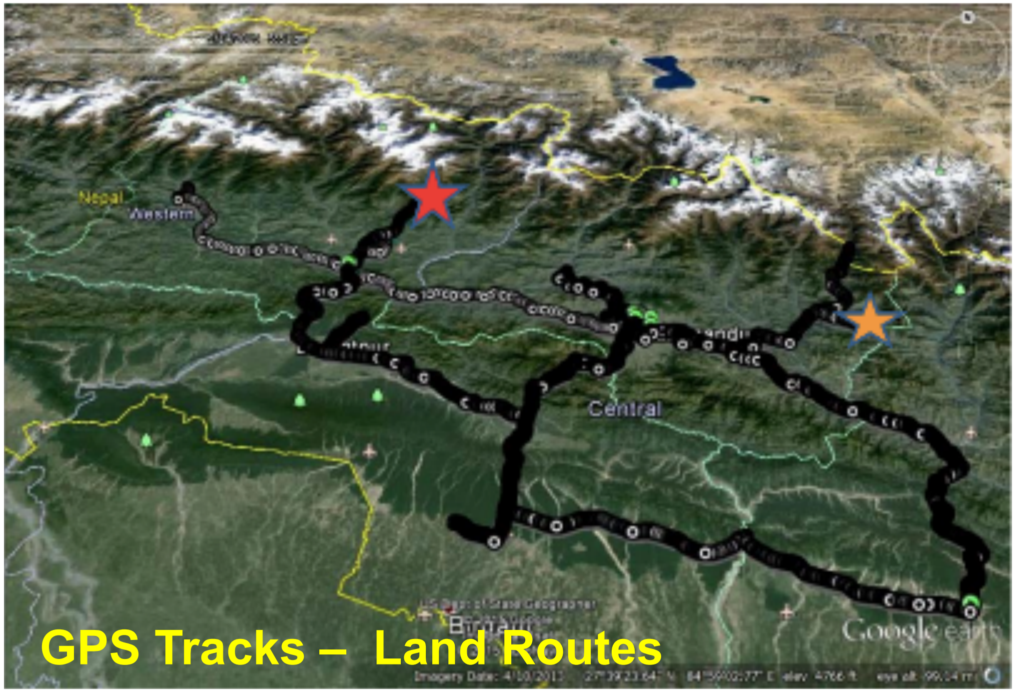
Importance of Field Studies

- Geotechnical Engineering is an experience-driven field
- Response of natural soil deposits cannot be easily replicated
- Field observations shape our understanding
- Collect perishable data
- Develop and implement new technologies
- Document the geotechnical effects of extreme events to advance the profession's understanding
- Train a new generation of engineers

GEER Nepal team

-US, European and Nepalese based members,

-Educational institutions, government agencies, utilities and private sector.



Team A

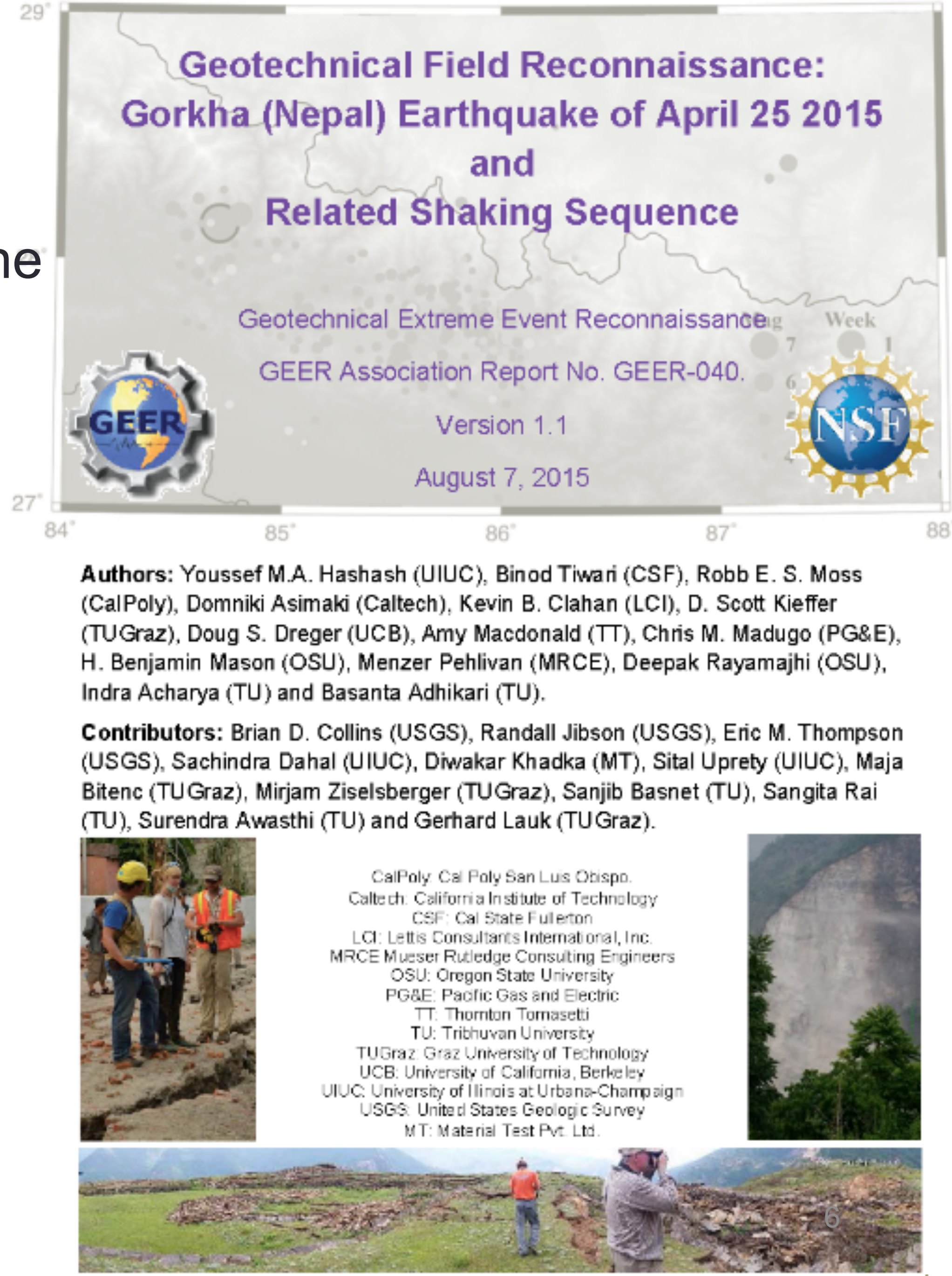
- Initial Reconnaissance:
  - Surface Rupture (None)
  - Liquefaction
  - Landslides

Team B

- Liquefaction – detailed testing
- Dams and hydropower projects
- Helicopter reconnaissance
- Ground Motions

Our Report

- Issued within 3 months of the event.
- Rapid dissemination of observations.
- Spring board for future detailed investigations
- Includes GPS station data
- Available online: http://www.geerassociation.org



Geotechnical Field Reconnaissance: Gorkha (Nepal) Earthquake of April 25 2015 and Related Shaking Sequence

Geotechnical Extreme Event Reconnaissance

GEER Association Report No. GEER-040.

Version 1.1

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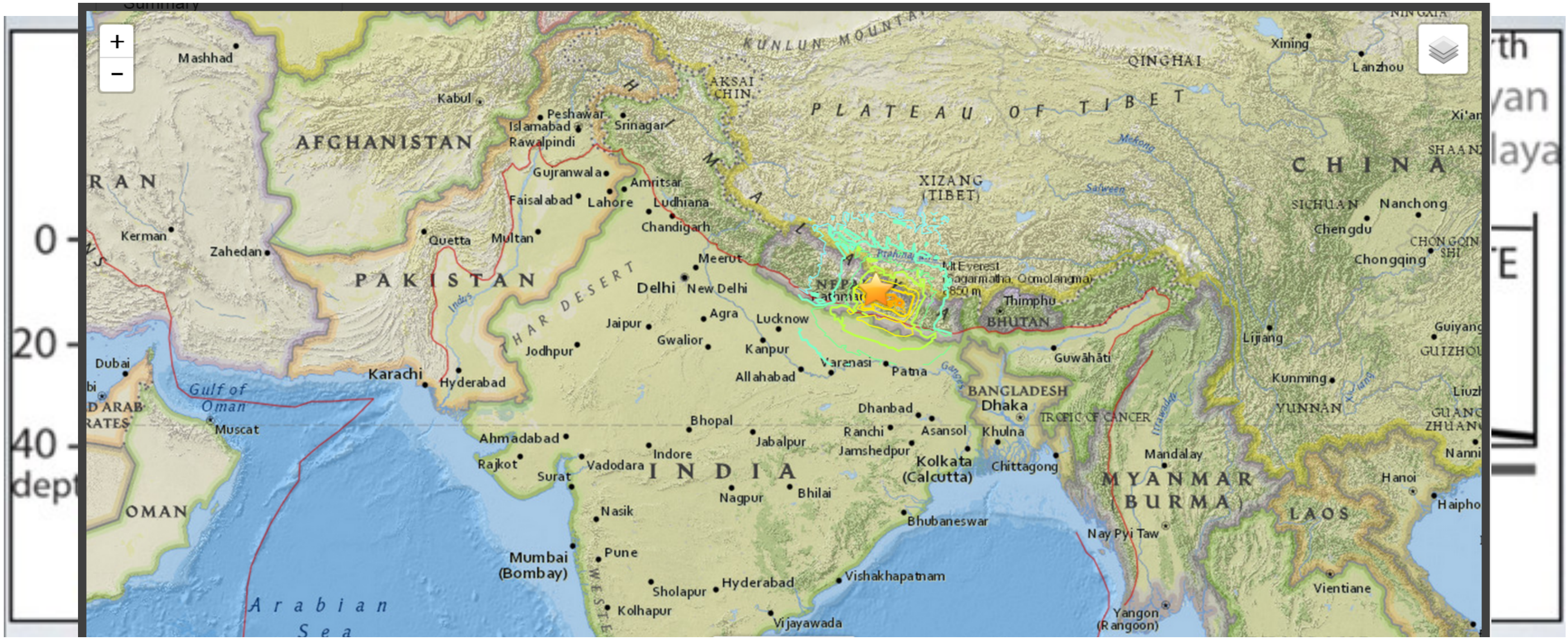
CalPoly: Cal Poly San Luis Obispo
Caltech: California Institute of Technology
CSF: Cal State Fullerton
LCI: Letts Consultants International, Inc.
MRCE Mueser Rutledge Consulting Engineers
OSU: Oregon State University
PG&E: Pacific Gas and Electric
TT: Thornton Tomasetti
TU: Tribhuvan University
TUGraz: Graz University of Technology
UCB: University of California, Berkeley
UIUC: University of Illinois at Urbana-Champaign
USGS: United States Geologic Survey
MT: Material Test Pvt. Ltd.

Main Topics

- Tectonic, Geologic, and Geomorphic Setting
- Seismological information and recorded ground motions
- Ground Response
- Slope Stability and Landslides
- Liquefaction and cyclic soil failures
- Performance of Dams and Hydropower Facilities
- Performance of Roadways, Bridges and Retaining Structures
- Performance of Building Structures

Seismo-tectonic setting

- Collision of the Indian plate into the Eurasian plate
- 40-50 mm/year of northward convergence.
- Three major thrust faults: Main Central Thrust fault (MCT), Main Boundary Thrust fault (MBT), and Main Frontal thrust fault (MFT),
- Recurring Earthquakes

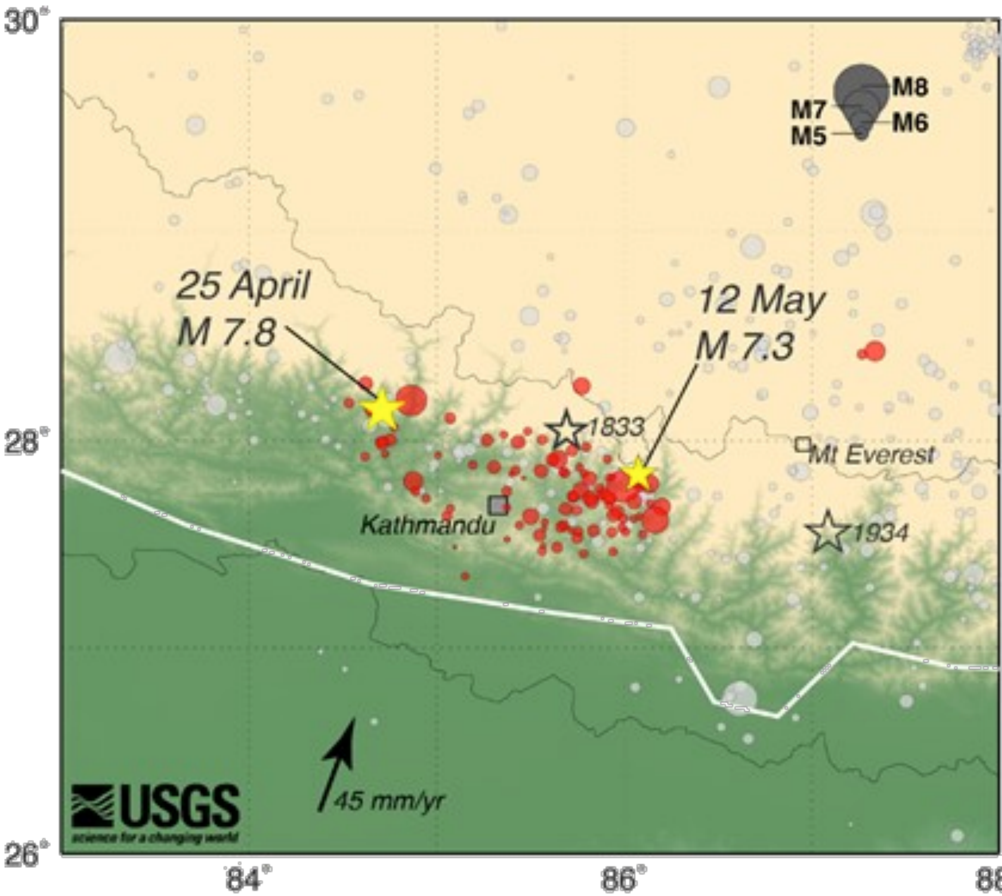


The Earthquake Sequence

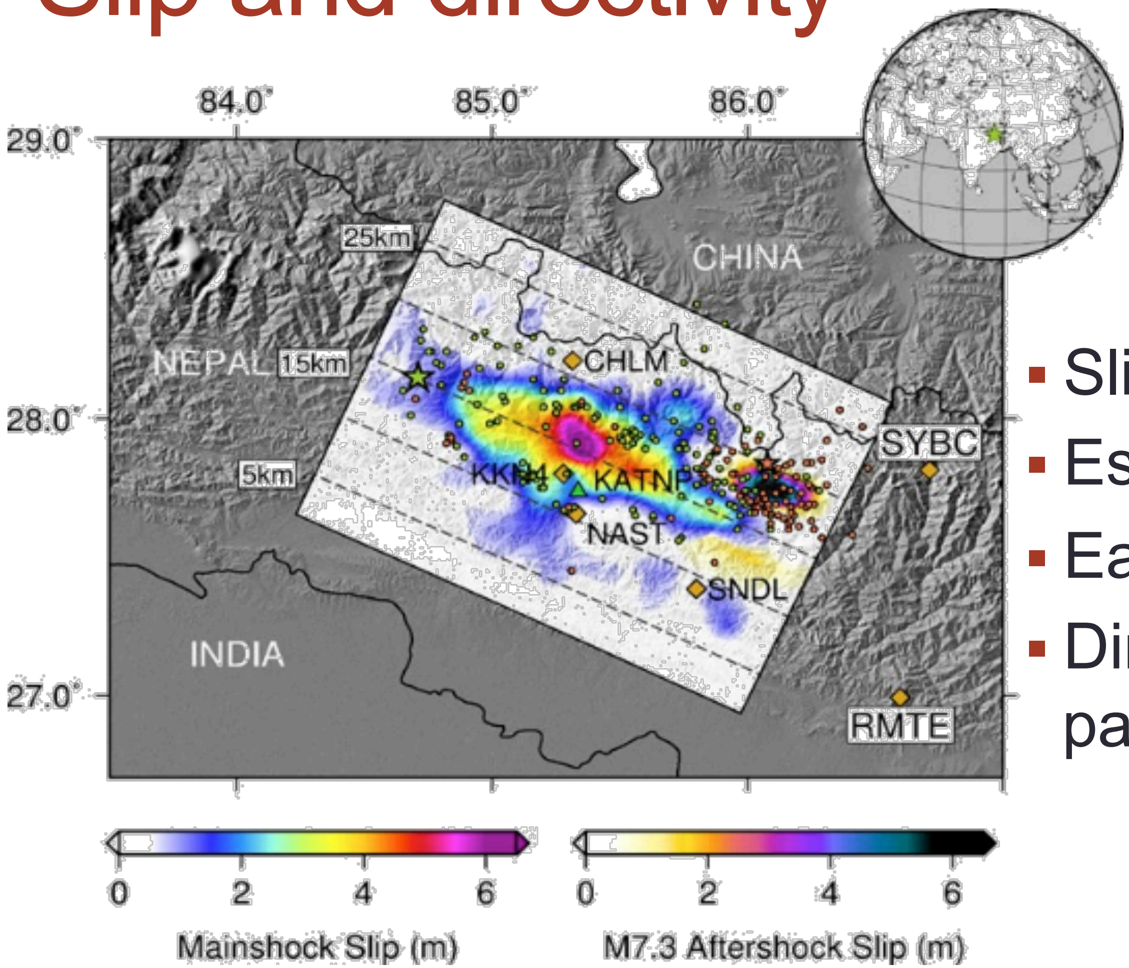
- ***April 25, 2015*, M_w = 7.8**
- 5 aftershocks Mw > 6.0
- ***May 12, 2015*, M_w = 7.3**

- No evidence of surface rupture
- Elevated groundwater levels and significantly increased spring and stream flow volumes reported in the watersheds all along the MBT for more than several weeks following the April 25, 2015 Gorkha earthquake

1934 The Great Nepal-Bihar Earthquake largest number of casualties, Mw=8.1



Slip and directivity

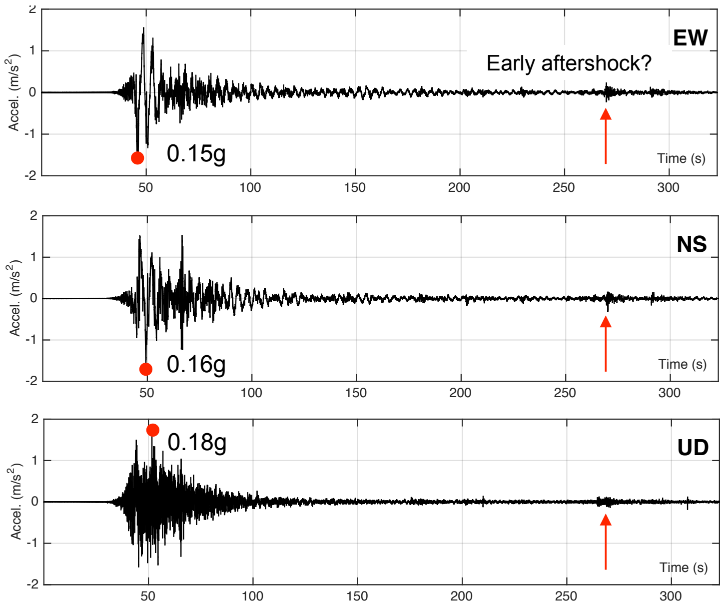


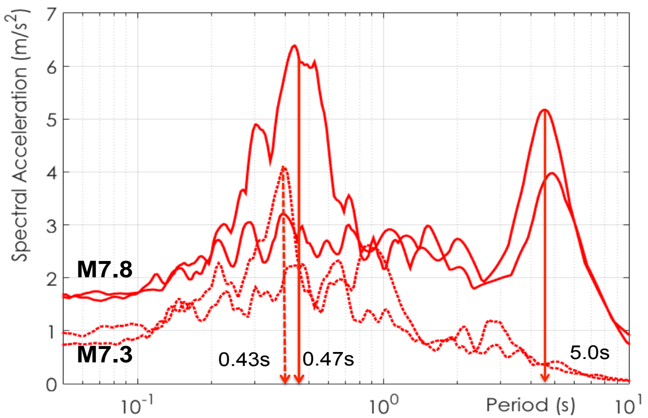
Galetzka et al. (2015) slip model.

- Slip area ~120x80km
- Estimated slip of up to 6m
- East- South East rupture
- Directivity – Damage patterns

Ground Motions

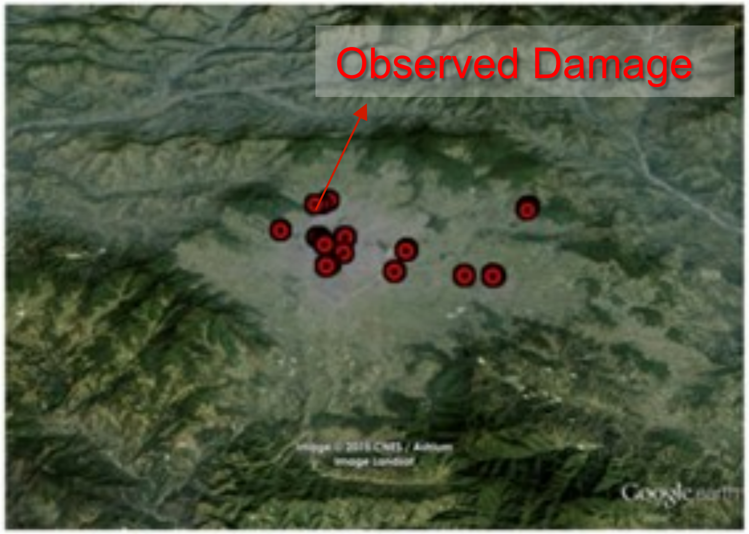
- One Accelerometer (Kathmandu) and GPS stations
- Main Shock
  - Very low peak ground acceleration PGA = 0.16g
  - A very long period (5s) predominant pulse
- Evidence of nonlinear site effects and period elongation

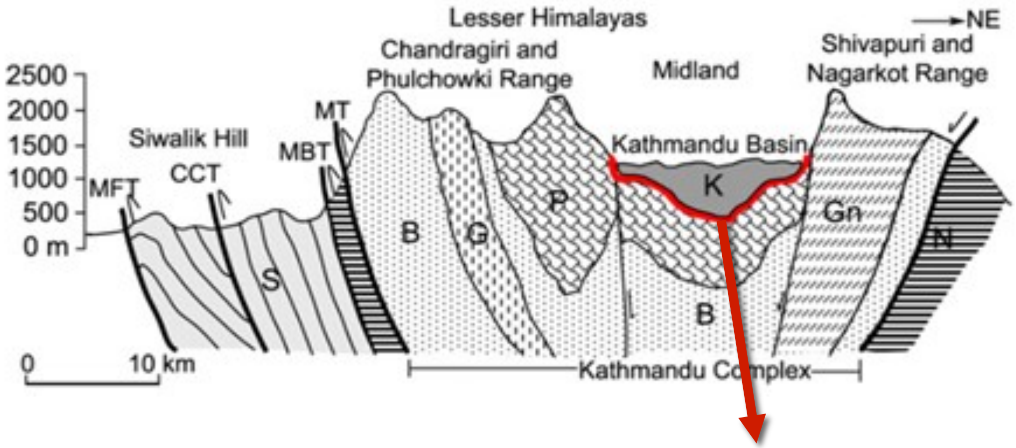


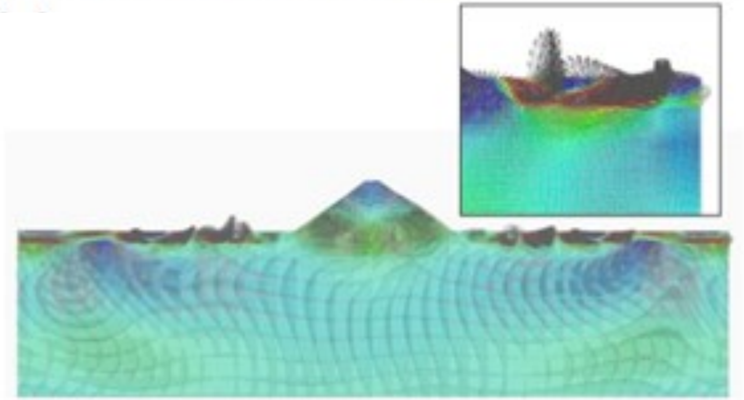


Ground Response – Basin effects

- Kathmandu Basin
- Thick deposits > 500 m
- Basin Amplification – Ground motions
- Basin Edge Amplification





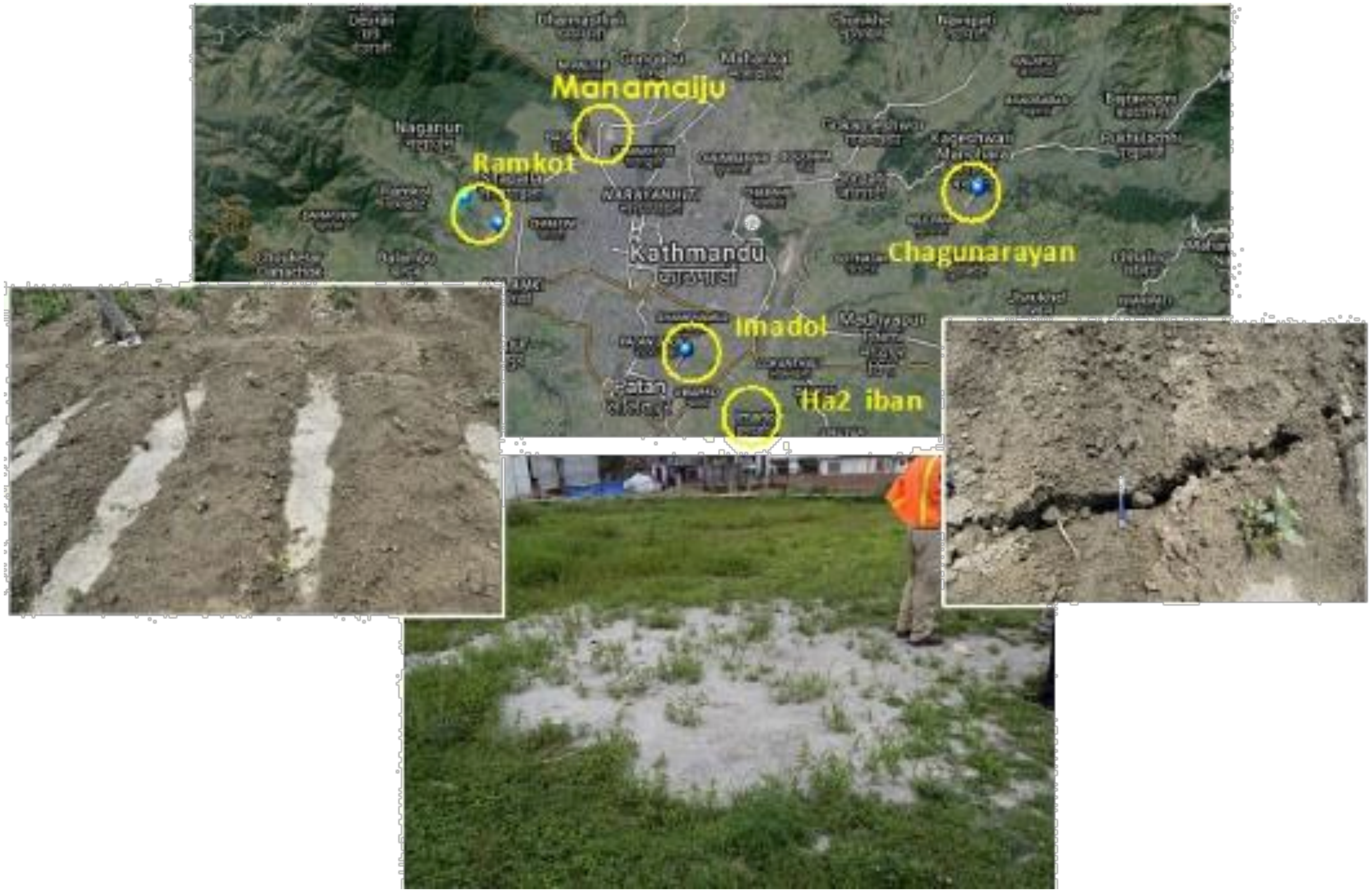


Ground Response – Basin Edge effects

- Concentration of building damage

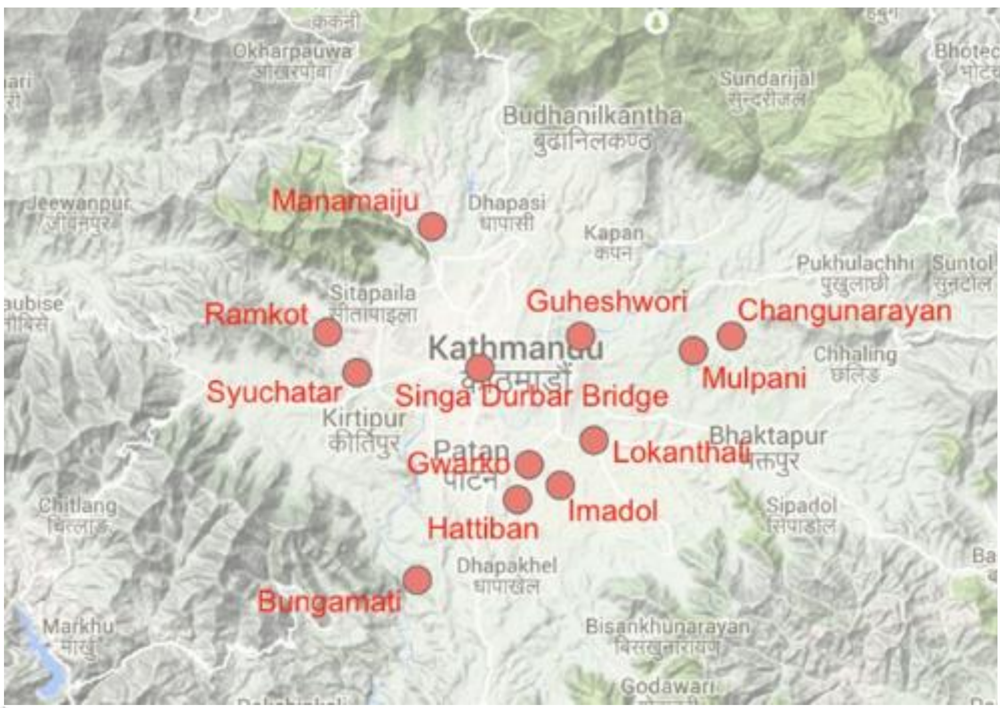
Ground Response – Basin Edge effects

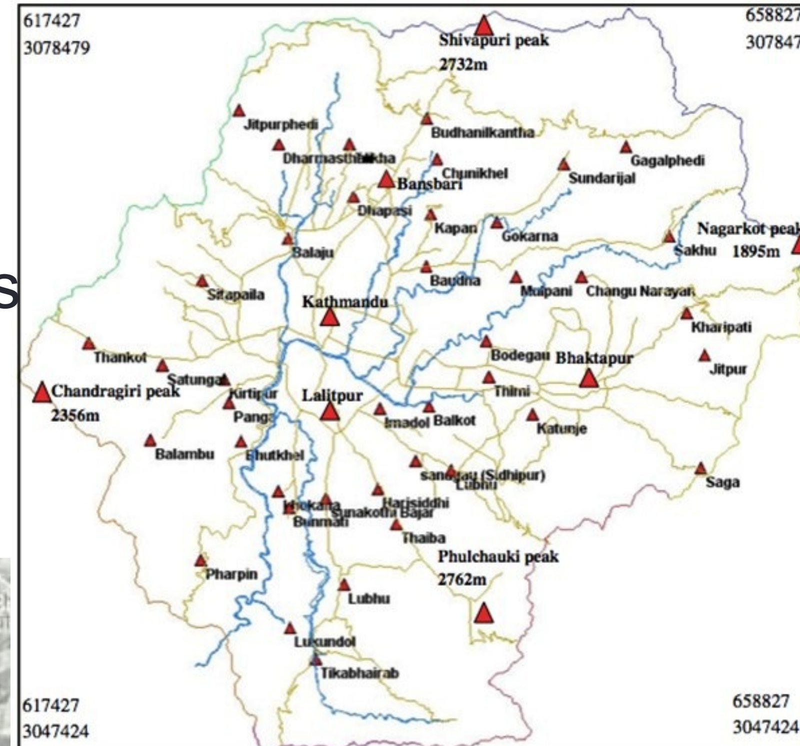
- Concentration of ground failures

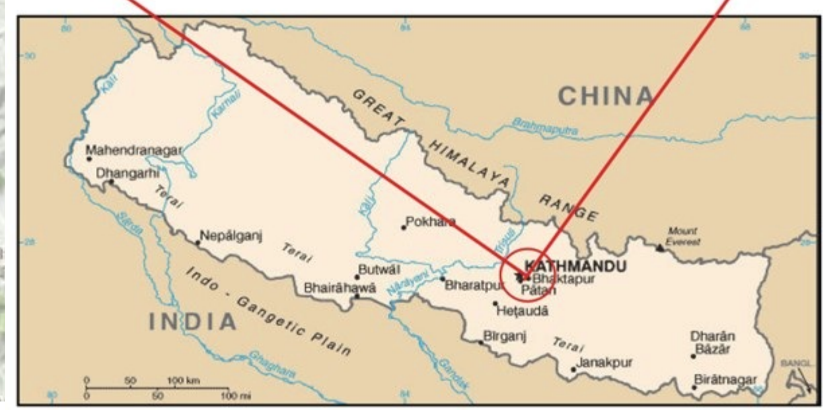


Liquefaction and Lateral Spreading

- Kathmandu Basin recent deposits
- Shallow Water table: 0.5-9 m
- Dry season

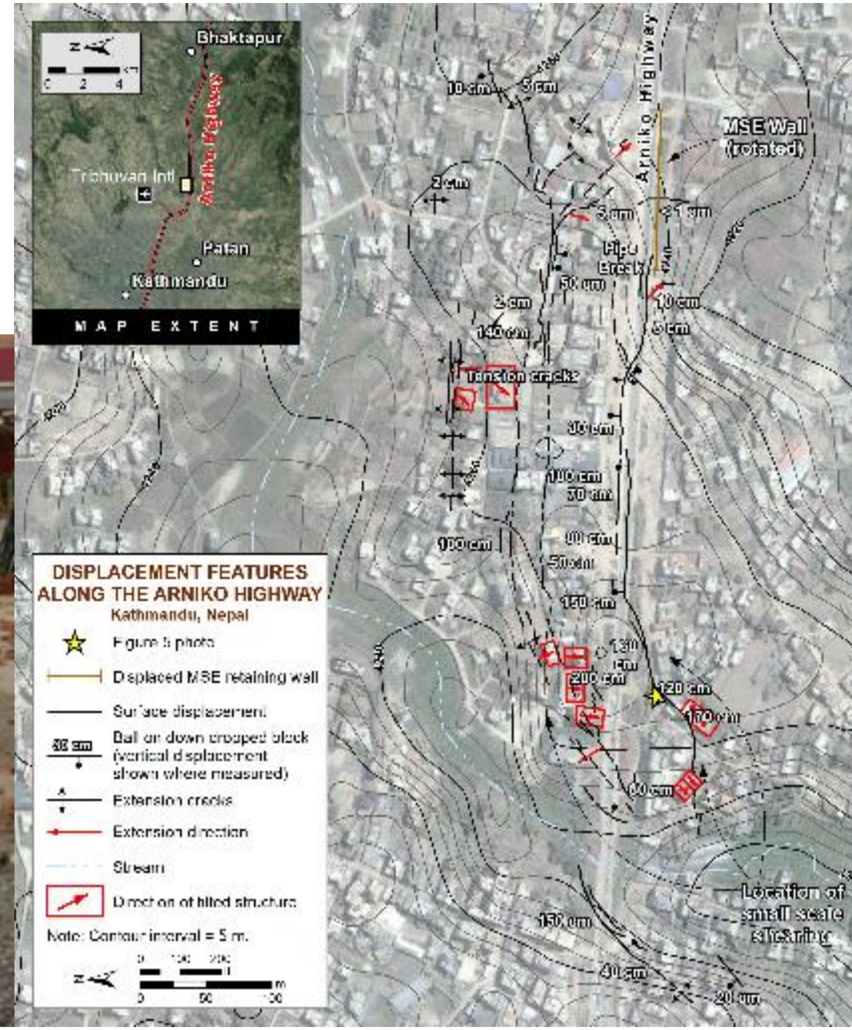






Lokanthali - Liquefaction and Cyclic Soil Failures

- Large lateral cracks
- 2 m deep fissures
- 1.2 m of nearly vertical offset

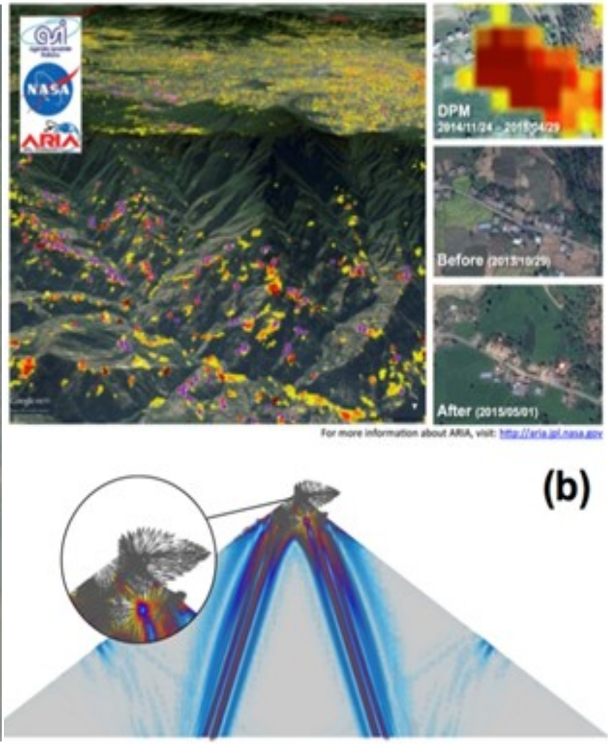


Lokanthali – Liquefaction and cyclic failure

- PI=7 - 9 and w_c/LL is > 1
- Either soil experienced increased pore pressures and underwent cyclic mobility or experienced a structural breakdown of a sensitive clay and hence cyclic failure,

Ground Response – Topographic effects

- Significant damage on top of ridges and on hill sides
- Ground motion is significantly amplified
- Not currently accounted for in building codes

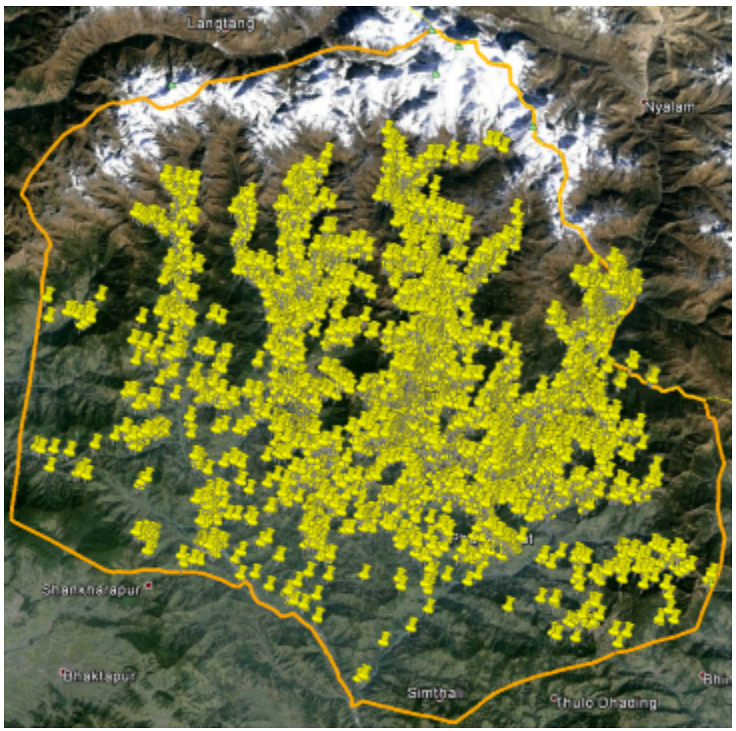


Slope Stability and Landsliding

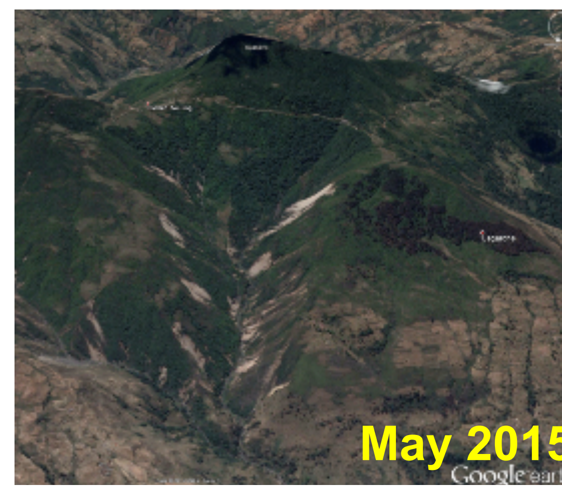
- Steep slopes produced by rapid tectonic uplift create high landslide hazard even in the absence of ground shaking
- Dominant cause of damage
- Concentrated east of the epicenter – directivity
- Damaged or destroyed villages
- Thousands of casualties
- Blocked roads
- Dammed rivers

Slope Stability and Landsliding

- Tens of thousands of landslides
- Failure surfaces parallel to slopes
- Up to 10 m deep.

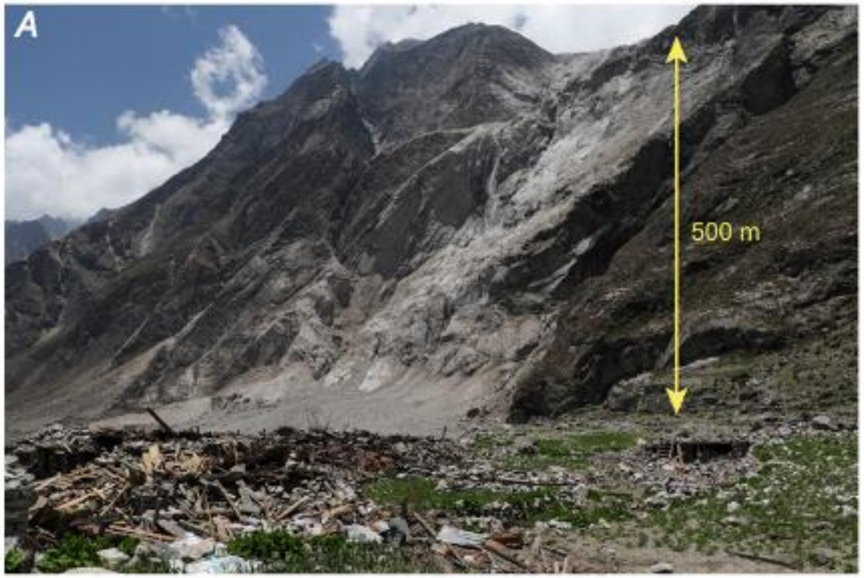


Sindhupalchok District more than 6,000 new or reactivated landslides



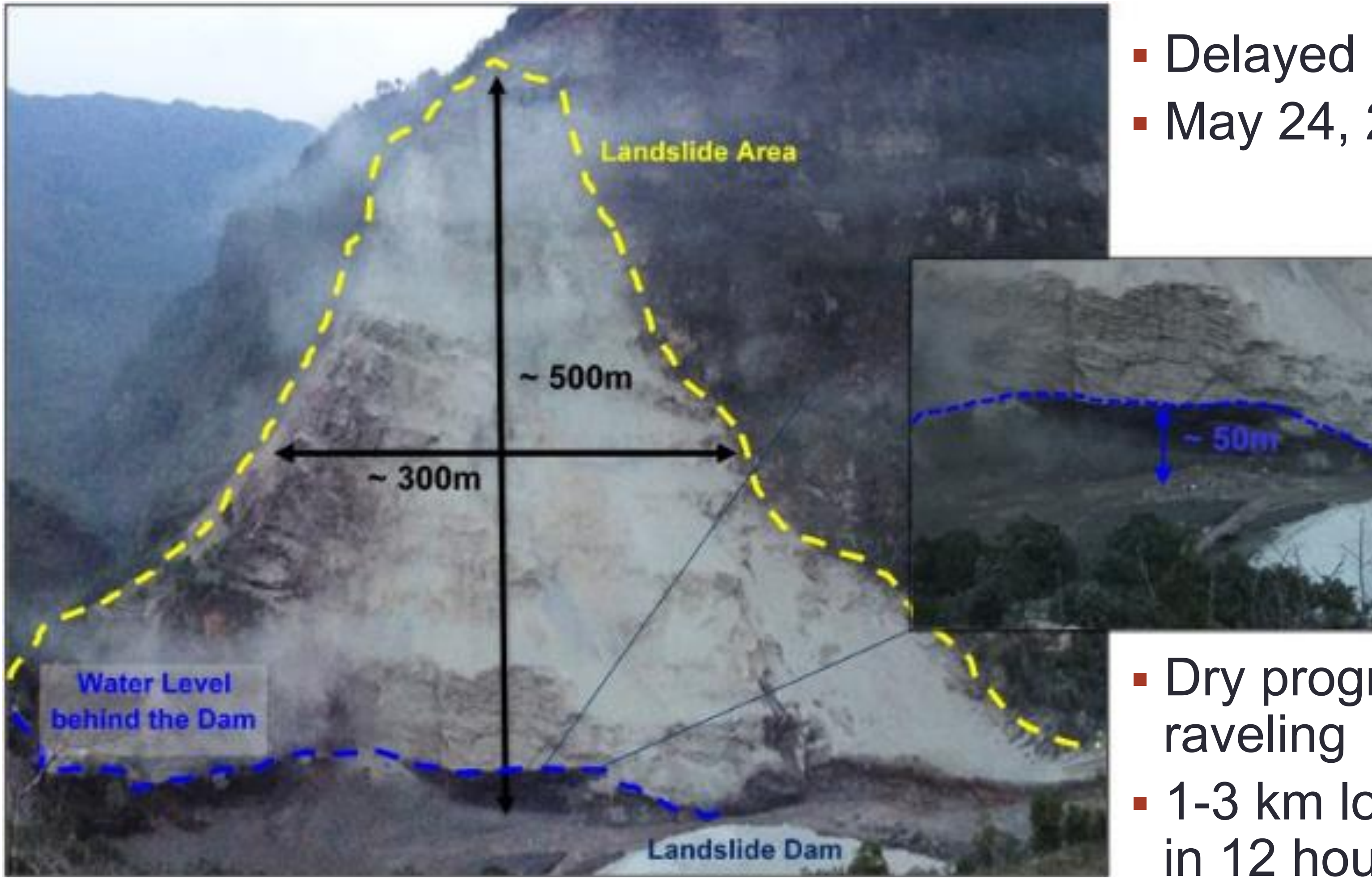
Langtang Landslide

- Largest and most destructive landslide from EQ
- Glacial ice mixed with soil and rock
- Buried Langtang village
- ~200 casualties
- Airblast flattened outlying structures and forests up to 1 km distance
- Estimated velocities 22-99m/sec



Collins and Jibson (2015)

Kali Gandaki Landslide



- Delayed triggering
- May 24, 2015

- Dry progressive raveling
- 1-3 km long lake in 12 hours

Dams and Hydropower Facilities

- Nepal has potential for 42,000 MW, 2nd largest in the world,
- Currently 20 major project + micro projects, 800 MW, less than the 1,400 MW need.
- Damage to 6 Nepal Hydroelectric Authority (190 MW) and 10 private producers (80 MW)
- GEER Team visited projects along:
  - Trishuli River closer to the main shock epicenter and
  - Sunkoshi River closer to the main aftershock epicenter.

Dams and Hydropower Facilities

Squares: under construction.
Circles: completed.

Red marks: damaged/ non-operational due to earthquake damage,

Observed Hyrdo Projects Damage

Project	In operation at time of EQ	Rockfall, landslide	Debris flow	Settlement	Tension cracks	Damage to structure	Damage to tunnels, canals or penstocks	Damage to equipment	Damage to site roads	Damage to access roads	Resumed Operation	Remaining Risks	Comments
Rasuwagadhi		x	x		x	x	x	x	x			x	Under construction. Temporary coffer dam breached by rockfall, inundating dam construction area. Minor rockfall in unlined tunnel section.
Chilime	x	x				x					x		Rocks fell through roof of secondary structures.
Upper Trishuli 3A								x	x	x		x	Under construction. Access roads covered by rockfalls. Large rocks impacted equipment yard, hydro camp, and sand catcher.
Trishuli	x			x			x				x		Settlement of fill caused minor cracking of secondary structures at headworks. Settlement of canal walls caused cracking of liner and piping.

Projects along Trishuli River

- Causes:
  - Rockfalls and landslides
  - Debris flow
  - Settlements
  - Tension Cracks

- Types of Damage
  - Damage to structure
  - Tunnels, canals, penstocks
  - Equipment
  - Access roads

Project	In operation at time of EQ	Rockfall, landslide	Debris flow	Settlement	Tension cracks	Damage to structure	Damage to tunnels, canals or penstocks	Damage to equipment	Damage to site roads	Damage to access roads	Resumed operation	Remaining risks	Comments
Upper Bhotekoshi	x	x	x			x	x	x	x			x	Headworks: Minor rockfall impact damage to handrails and surficial damage to the concrete gravel catcher structure. Penstock/PowerHouse: Rockfall impact to penstocks above powerhouse causing leak. Resulting debris flow damaged hydrocamp buildings, scoured the penstock liner and inundated powerhouse area.
Sunkoshi	?					x	x						Significant damage to headworks from June 2014 landslide and subsequent landslide dam breach during last monsoon season. Some additional structural shaking damage observed and expected to be from recent earthquake events. Damage to canal also noted from recent earthquakes.
Sanima	?					x							Micro hydropowerhouse damaged by shaking mostly. Infill wall collapsed.

Projects along Sunkoshi River

Upper Bhotekoshi Project - 45 MW

Upper Tamakoshi Project – Settlement Damage

Concluding Remarks

- Major destructive earthquake in a long series of earthquakes
- Ground motions in Kathmandu Valley:
  - Basin amplification
  - Basin edge effects
- Landslide hazard: other shaking events, monsoons
- Hydropower projects – significant vulnerability, not limited to the dam structures
- Need for more ground motion data
- Implications beyond Nepal
  - Factors for basin effects in building codes
  - Factors for topographic effects in building codes
- Report at: http://www.geerassociation.org