The University of Florence

September 3, 2018

Similarities and Differences Between Earthquake and Rainfall Induced Landslides

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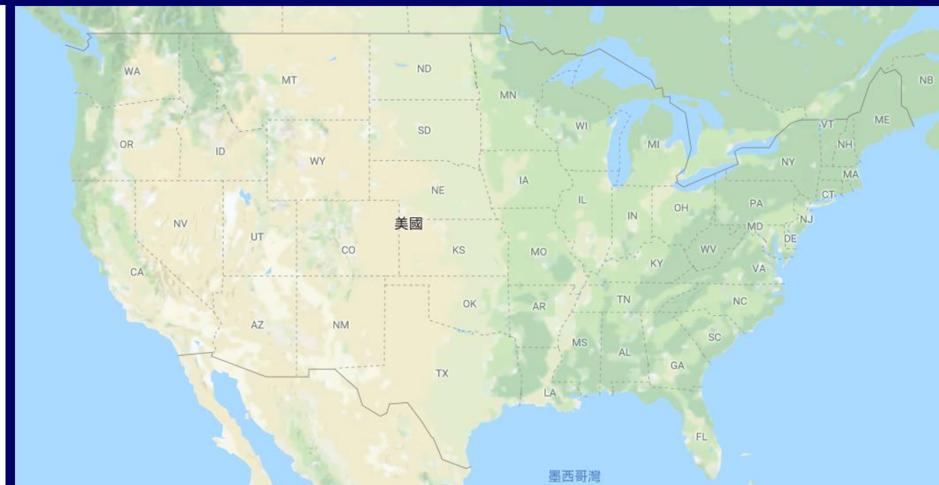
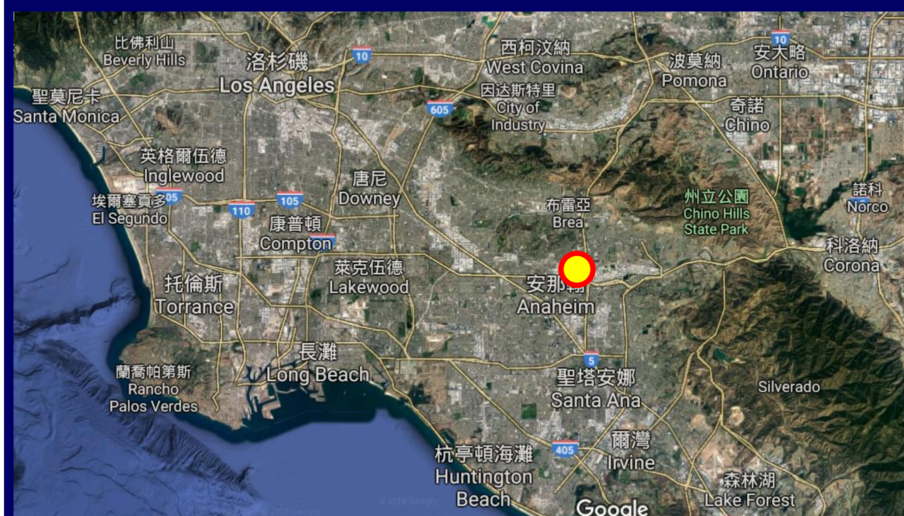
UNESCO Chair on the Prevention and Sustainable Management of Geo-Hydrological Hazards, University of Florence, Italy

California State University, Fullerton





CALIFORNIA STATE UNIVERSITY FULLERTON™

IPL A Programme of the ICL for ISDR

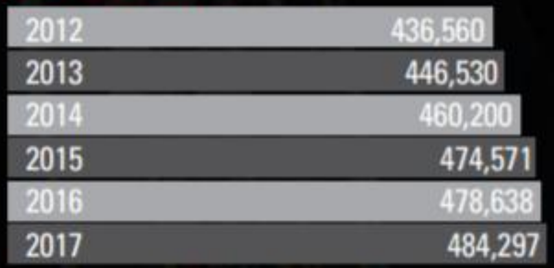
UNESCO Chair on the Prevention and Sustainable Management of Geo-Hydrological Hazards, University of Florence, Italy

UNIVERSITÀ DEGLI STUDI FIRENZE

DEGREES CONFERRED 2016–17

Bachelor's Degrees	98,771	82.8%
Master's Degrees	19,963	16.7%
Doctoral Degrees	540	0.5%
Total	**119,274**	**100%**

SYSTEMWIDE ENROLLMENT FALL 2012–17



FALL 2017 ENROLLMENT BY CAMPUS

BAKERSFIELD 9,863	LOS ANGELES 28,253	SAN JOSÉ 33,409
CHANNEL ISLANDS 7,053	MARITIME ACADEMY 1,050	SAN LUIS OBISPO 22,188
CHICO 17,789	MONTEREY BAY 7,131	SAN MARCOS 13,893
DOMINGUEZ HILLS 15,179	NORTHRIDGE 39,816	SONOMA 9,223
EAST BAY 15,435	POMONA 25,894	STANISLAUS 10,003
FRESNO 25,168	SACRAMENTO 30,661	INTERNATIONAL PROGRAMS 509
FULLERTON 40,439	SAN BERNARDINO 20,461	CALSTATETEACH 1,033
HUMBOLDT 8,347	SAN DIEGO 34,828	**TOTAL 484,297**
LONG BEACH 37,065	SAN FRANCISCO 29,607	

GRADUATE STUDIES

54,521
POST BACCALAUREATE/GRADUATE STUDENTS ENROLLED IN FALL 2017

19,963
MASTER'S DEGREES WERE AWARDED IN 2016–17

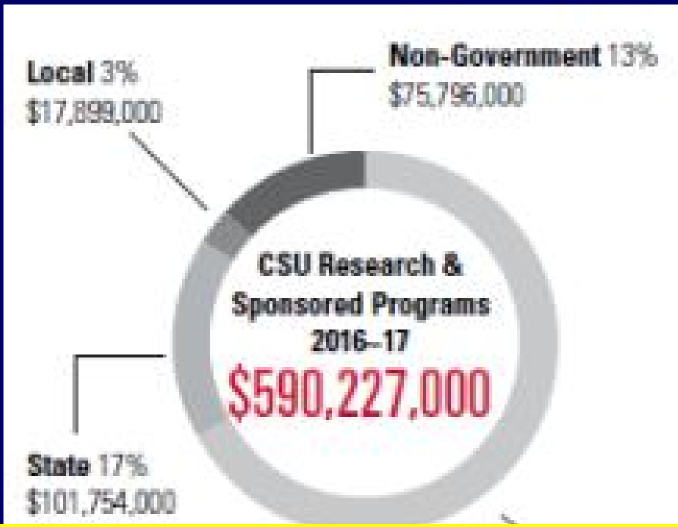
2,122
DOCTORAL STUDENTS FROM DIVERSE BACKGROUNDS

TOTAL FULL-TIME FACULTY BY ACADEMIC RANK

Professor	36.7%	4,804
Associate Professor	17.6%	2,311
Assistant Professor	24.1%	3,157
Lecturer	21.6%	2,831
Total	**100%**	**13,103**

TOTAL FACULTY BY TIMEBASE

Full-Time	48.8%	13,103
Part-Time	51.2%	13,755
Total	**100%**	**26,858**



CAMPUS BUDGETS 2017-18
(General Fund and Gross Tuition Fee & Other Fee Revenue)

BAKERSFIELD 128,904,000	LONG BEACH 447,749,000	SAN DIEGO 434,543,000
CHANNEL ISLANDS 115,258,000	LOS ANGELES 296,577,000	SAN FRANCISCO 371,155,000
CHICO 220,652,000	MARITIME ACADEMY 43,299,000	SAN JOSÉ 388,912,000
DOMINGUEZ HILLS 173,796,000	MONTEREY BAY 113,173,000	SAN LUIS OBISPO 333,756,000
EAST BAY 201,569,000	NORTHRIDGE 433,906,000	SAN MARCOS 167,789,000
FRESNO 293,004,000	POMONA 292,558,000	SONOMA 123,296,000
FULLERTON 426,028,000	SACRAMENTO 339,181,000	STANISLAUS 124,030,000
HUMBOLDT 136,056,000	SAN BERNARDINO 237,734,000	CAMPUS TOTAL $5,842,925,000

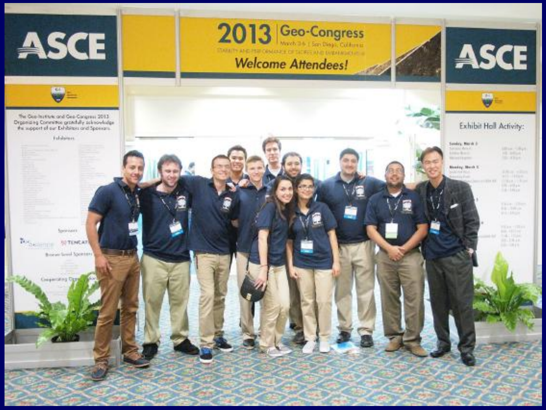
CSU Fullerton NATIONAL RANKINGS

- Among the nation's top 25 "Most Innovative Schools"
- Among top public "National Universities"
- Online graduate engineering program – top 15th among national universities.
- Ranked No. 5 in the nation for baccalaureate degrees awarded to underrepresented students
- Ranked No. 1 in California and No. 2 in the nation among top colleges and universities awarding degrees to Hispanics

CIVIL ENGINEERING

- 642 undergrad, 275 grad students
- 15 Full time faculty members

My Research Group



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University of Florence, Italy

UNIVERSITÀ DEGLI STUDI FIRENZE

My Research Group




Over **210 students** that I mentored in the past 12 years who **co-authored more than 170 articles** with me are lead geotechnical engineers in USA and abroad.

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UNIVERSITÀ DEGLI STUDI FIRENZE

About Me

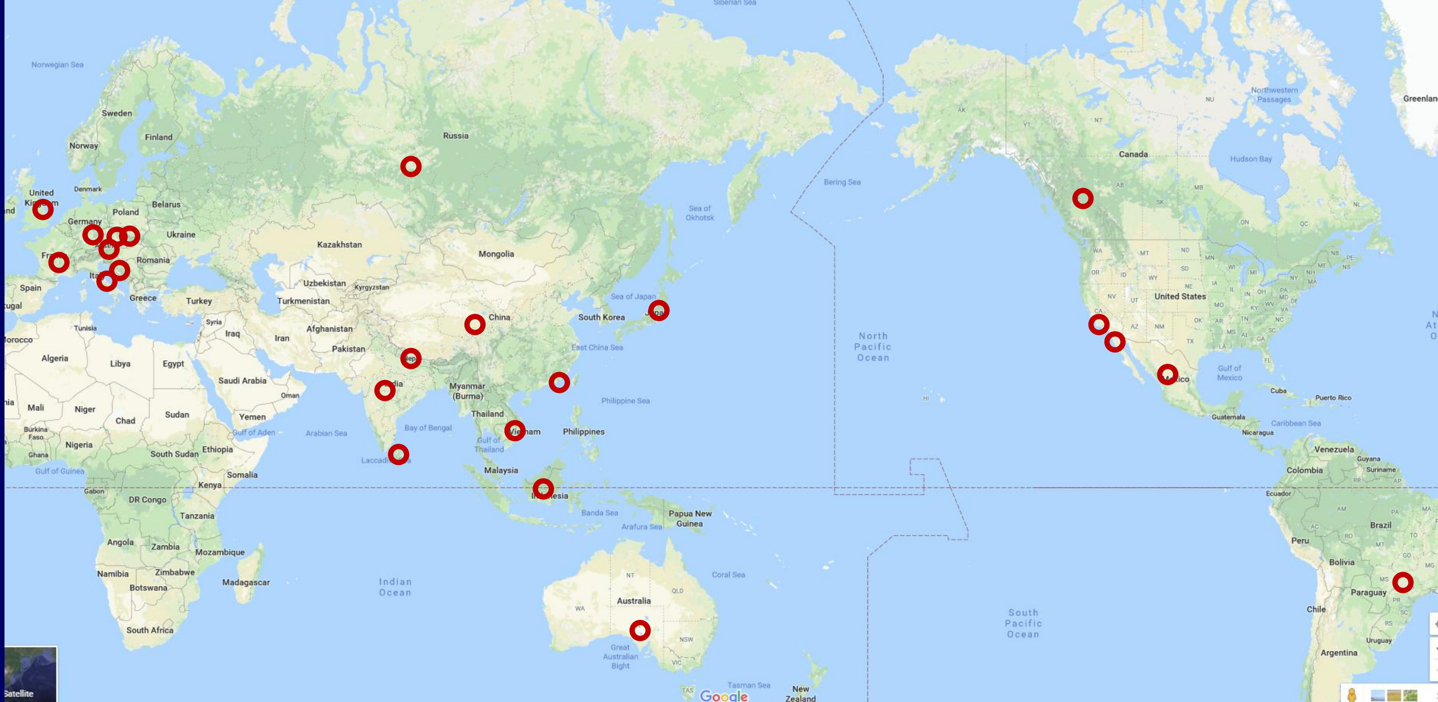

Afghanistan
Pakistan
Nepal
Bhutan
Bangladesh
Myanmar (Burma)
India
Bay of Bengal


सडक विभाग
Government of Nepal
Ministry of Physical Planning and Works
DEPARTMENT OF ROADS


Nepal
Kathmandu
12 years


Institute of Engineering
Pulchowk Campus


14 years
Palungtar
पालुङटार
Bhanu
भानु
Mirkot Village Rd
Prithvi Hwy
Siddha Gufa (Cave)
Bimal Nagar
Dhuwakot
धुवाँकोट



2006-2012

Assistant Professor

2012-2015

Associate Professor

2015-

Professor

Collaboration

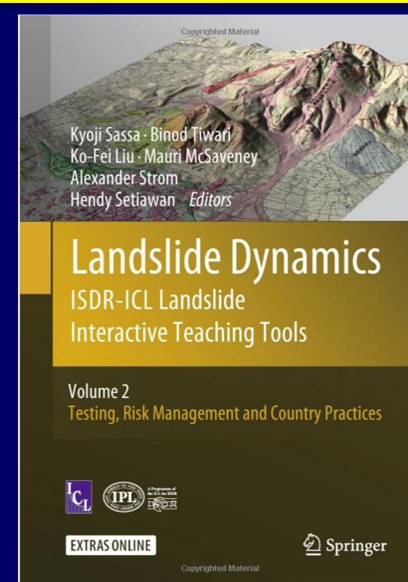
My contribution in world landslide community

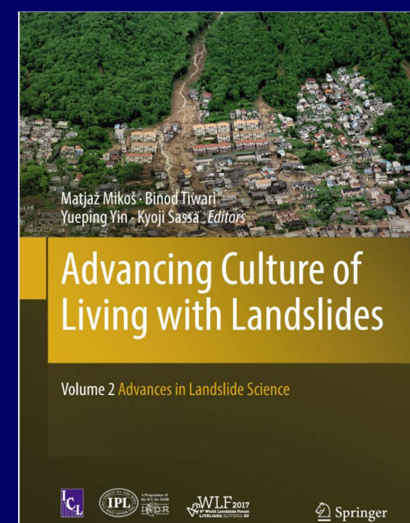
G-I GEO-INSTITUTE ASCE

ICL

ICGdR

CUR™



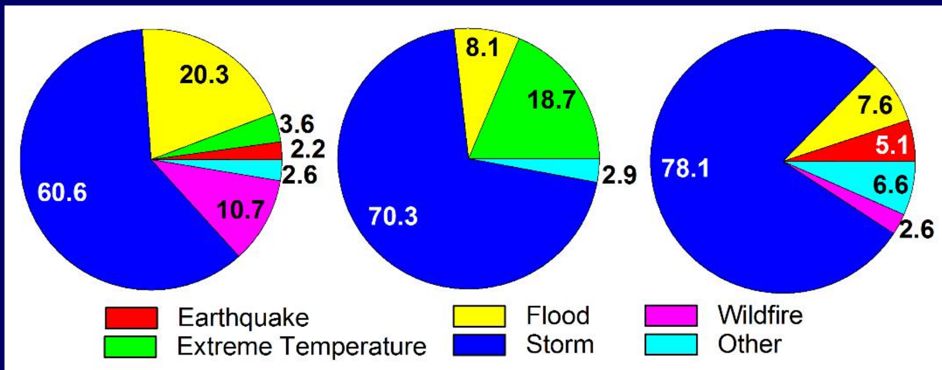


Contents

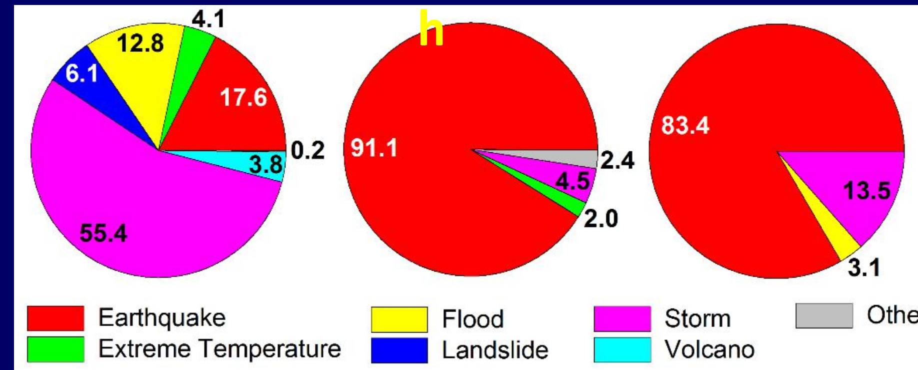
Major Types of Natural Disasters

- Earthquakes
- Landslides
- Floods
- Storm and Hurricane
- Extreme Weather
- Tsunami
- Wild Fire
- Volcanic Eruption

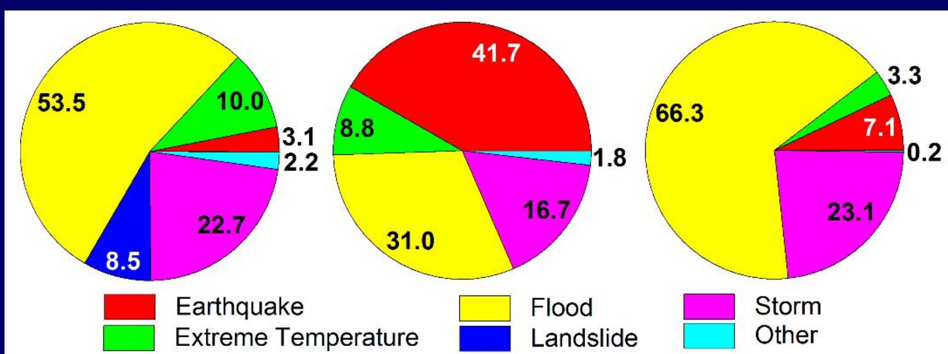
Frequency **Death** **Economic Loss** **Frequency** **Deat h** **Economic Loss**



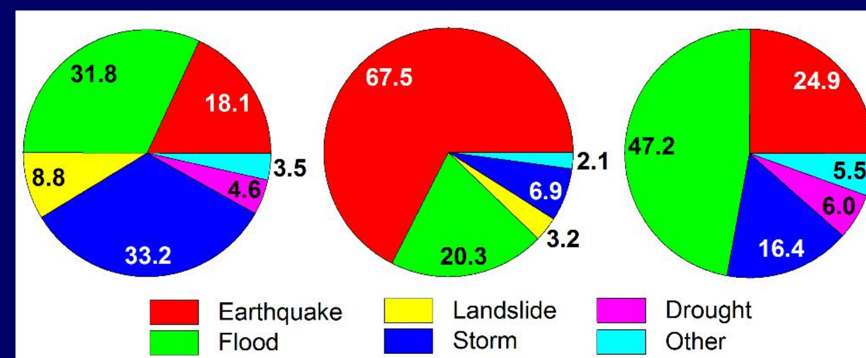
USA



Japan



India



China

Period: 1990-2014

Source: UN International Strategy for Disaster Reduction

Average Loss Per Year

Country	Death	Property Loss (B$)
USA	477	104
Canada	4	7
Japan	2,133	132
UK	84	4
China	10,469	64
India	2,377	20
Mexico	82	6
Brazil	205	9
Nepal	211	0.3

Source: UN International Strategy for Disaster Reduction

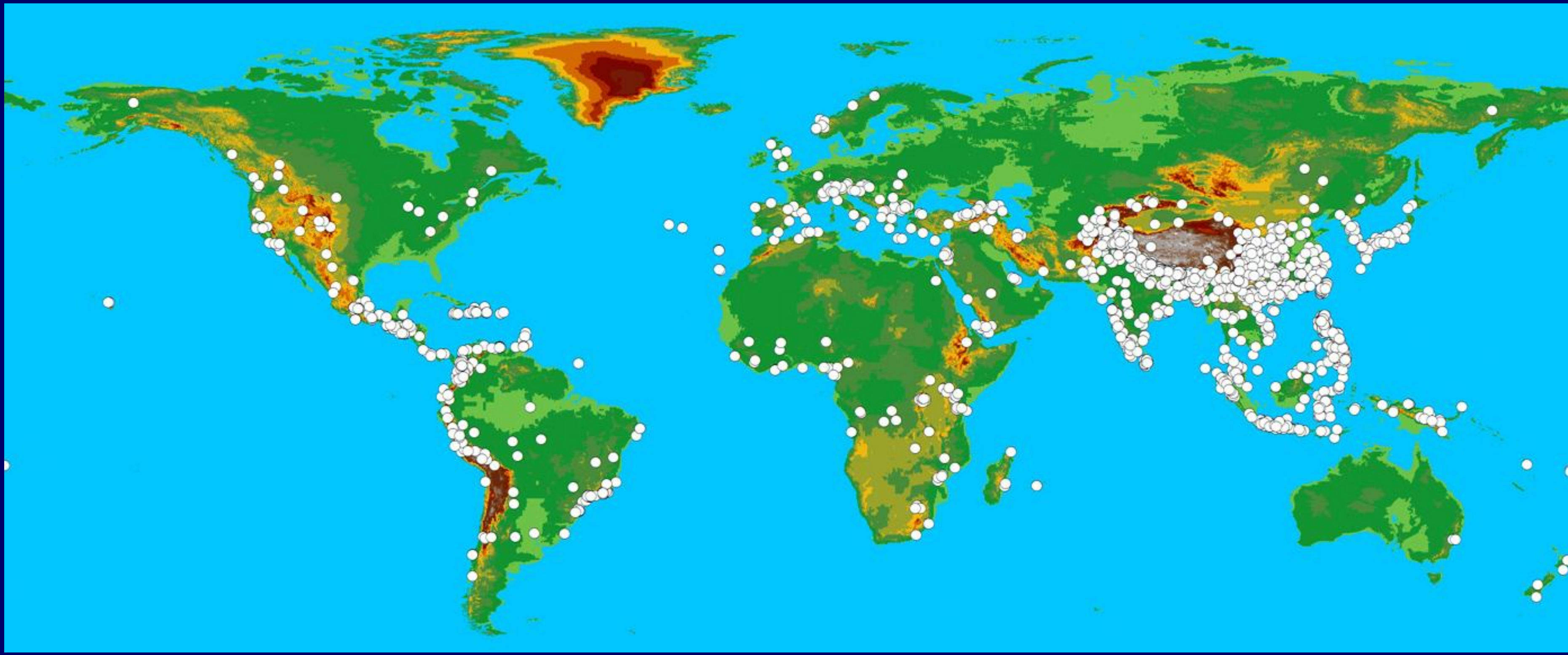
Losses Due to Landslides

Source: various publications and blogs

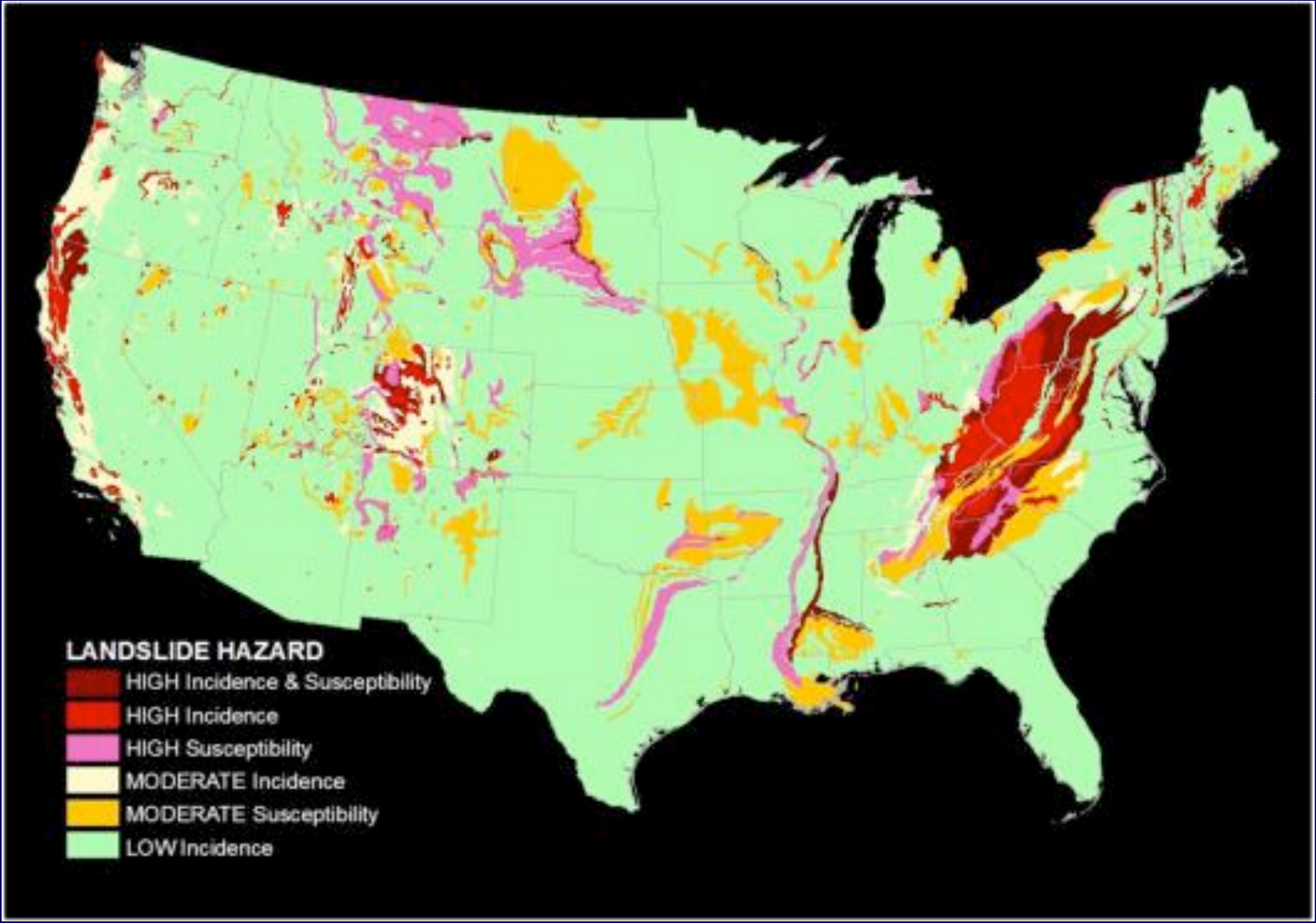
- Worldwide loss 600 people/yr
  - Japan $4 billion
  - USA $ 1 - 3 billion 25 – 50 people
  - Nepal 364 people
  - Italy $ 1 - 2 billion
  - India $ 1 – 2 billion
  - China as high as India
- Actual landslide loss has not been well covered as they are considered as part of other disaster
- Landslides loss effects: transportation facilities, buildings, and many other infrastructures

- One statistics say - 2,620 fatal landslides occurred between 2004 and 2010, killing 32,322 people.

Fatal Landslides: 2004-2010

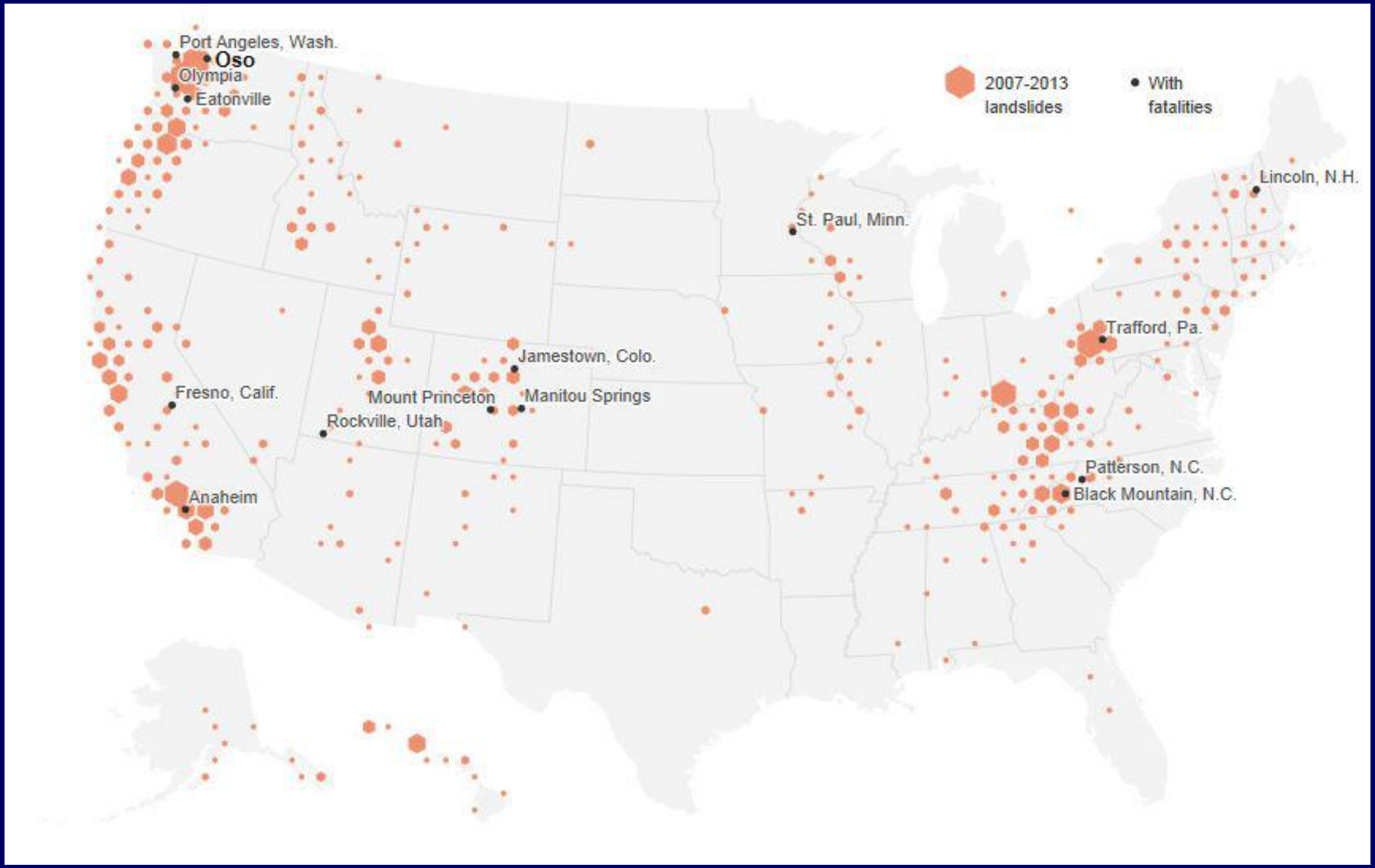


Source: https://www.nature.com/news/death-toll-from-landslides-vastly-underestimated-1.11140



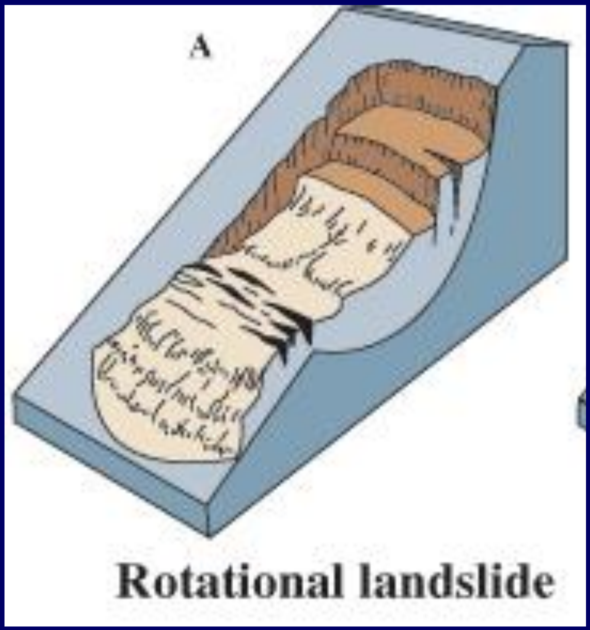
Source: Roth and Keaton

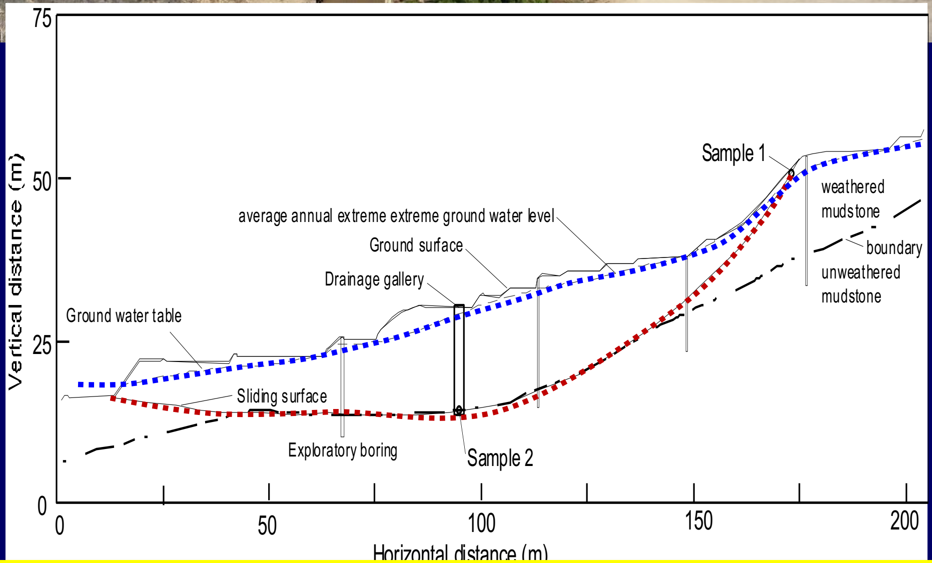
Over 100,000 landslides occur in USA per year

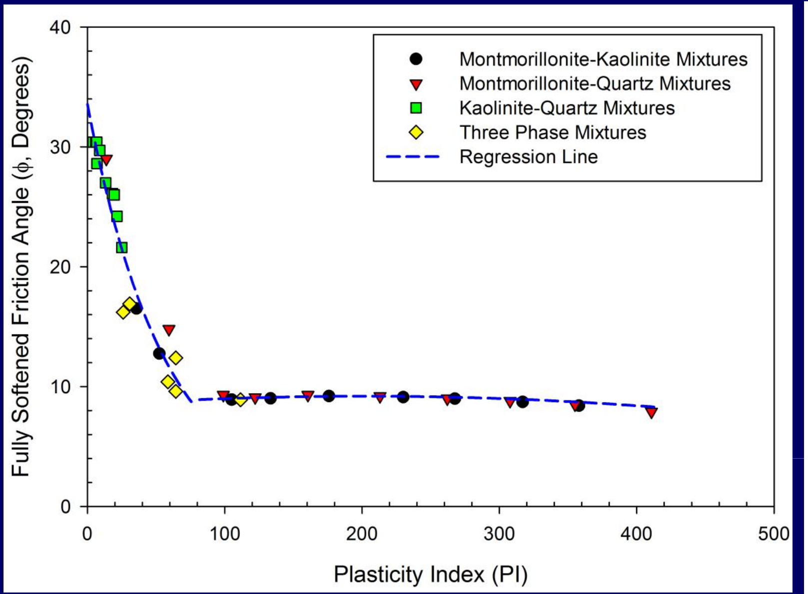


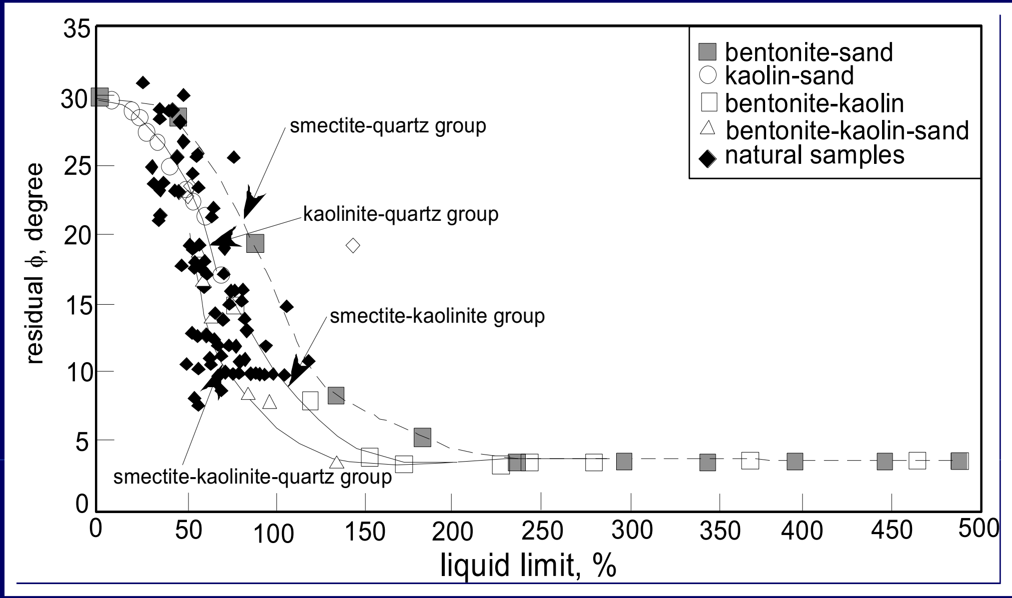
Source: National Geographic

Major Types of Landslides

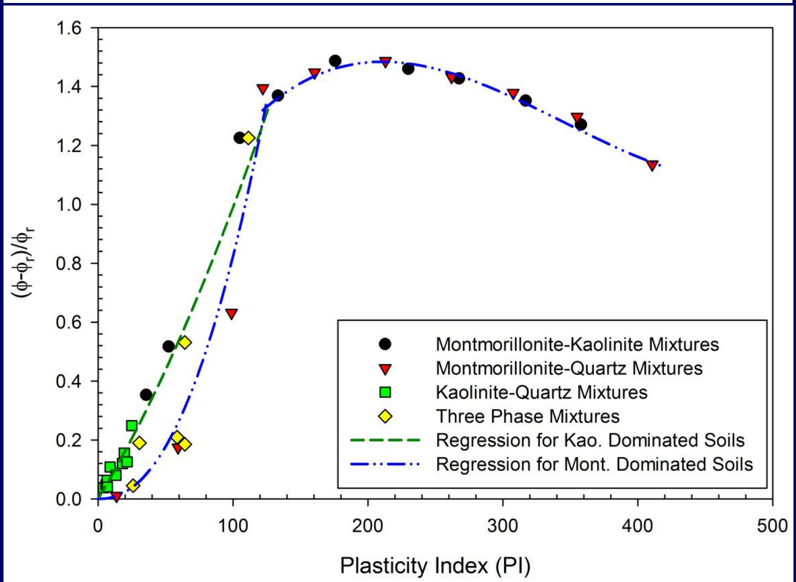




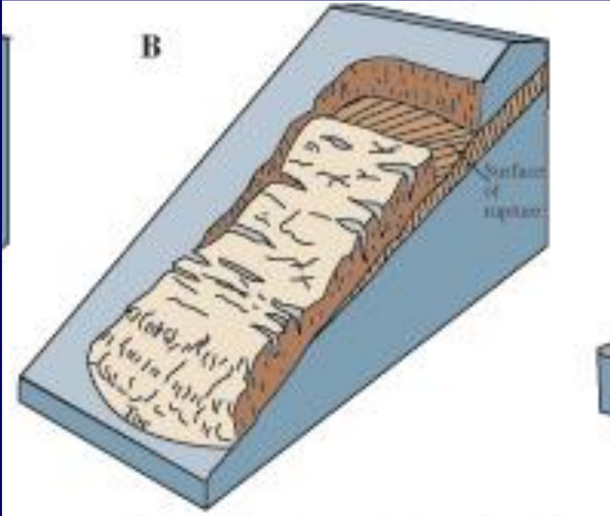




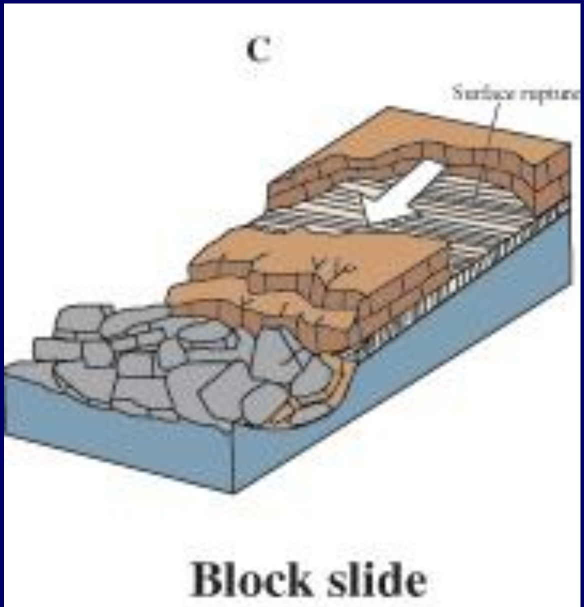
Tiwari and Marui (2005)

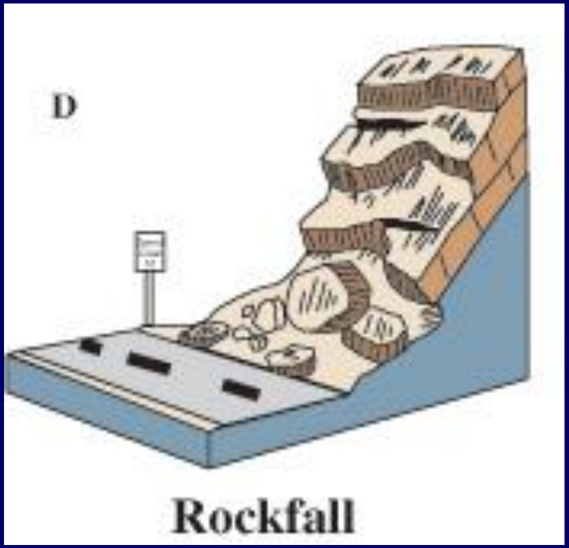


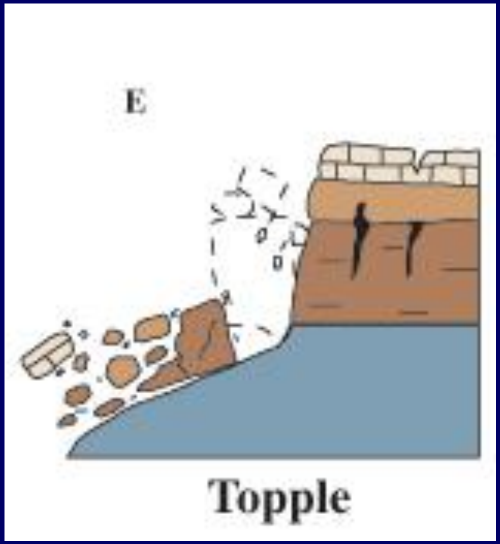
Tiwari and Ajmera (2011)



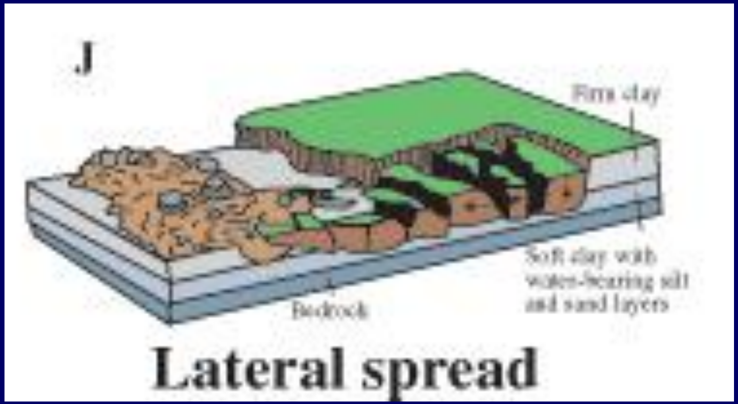
Translational landslide

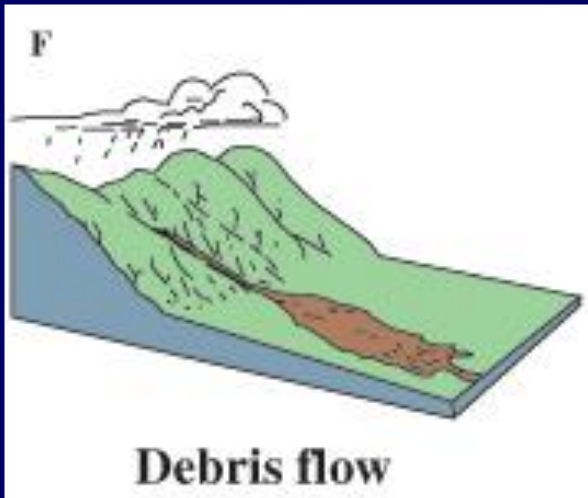

C
Surface rupture
Block slide


D
Rockfall

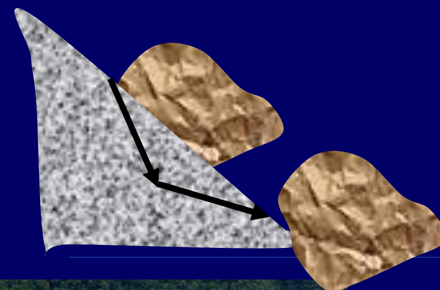

E
Topple


LETY
Y JUAN

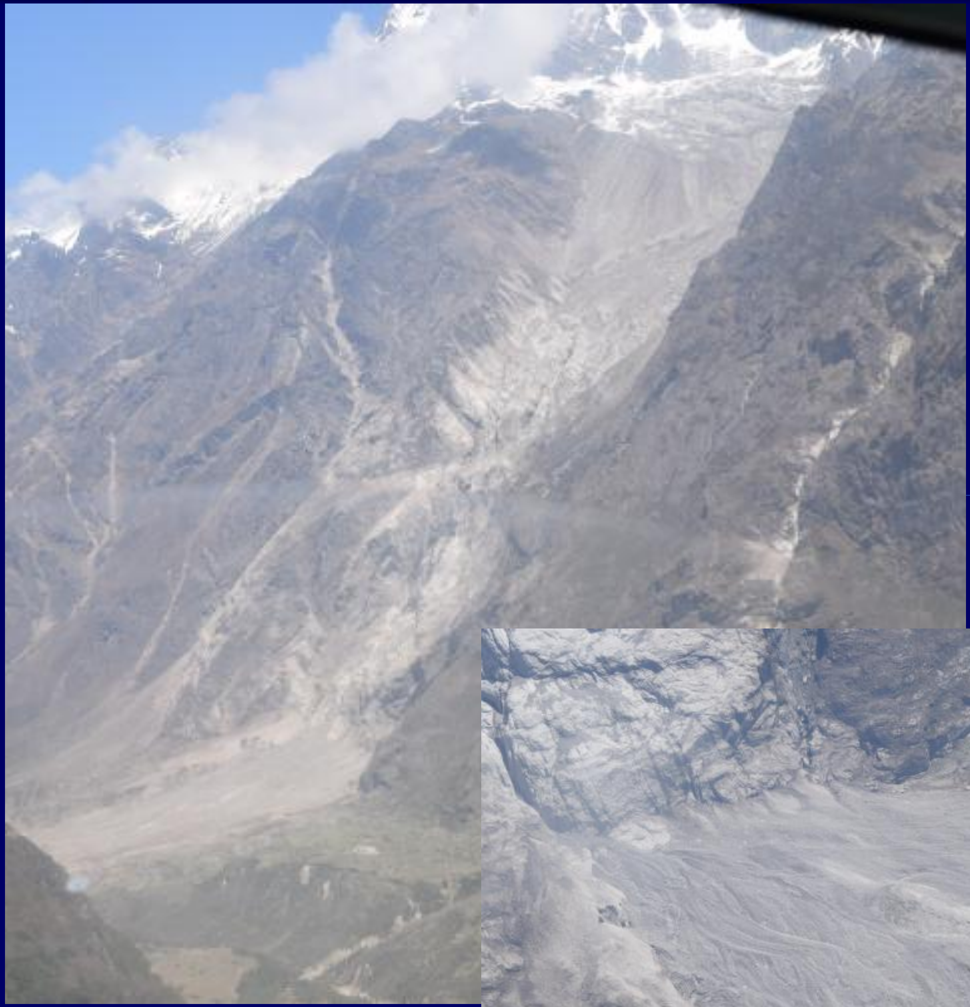

J
Firm clay
Soft clay with water-bearing silt and sand layers
Bedrock
Lateral spread

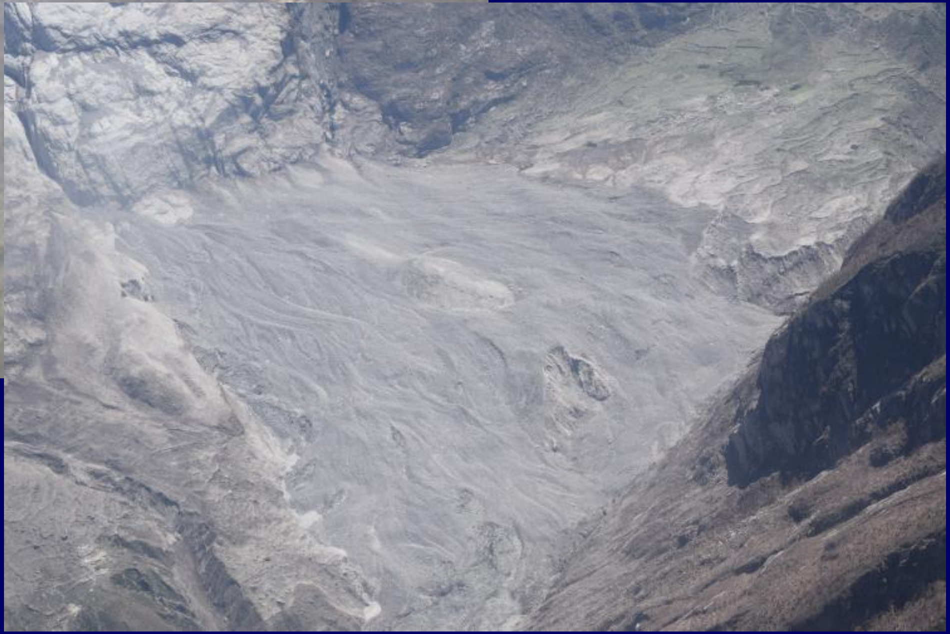


$$\textit{Debris Production Rate} = \frac{35{,}600\, Q^{1.67}\, Rr^{0.72}}{(5 + V.I.)^{2.67}}$$




G
Debris avalanche

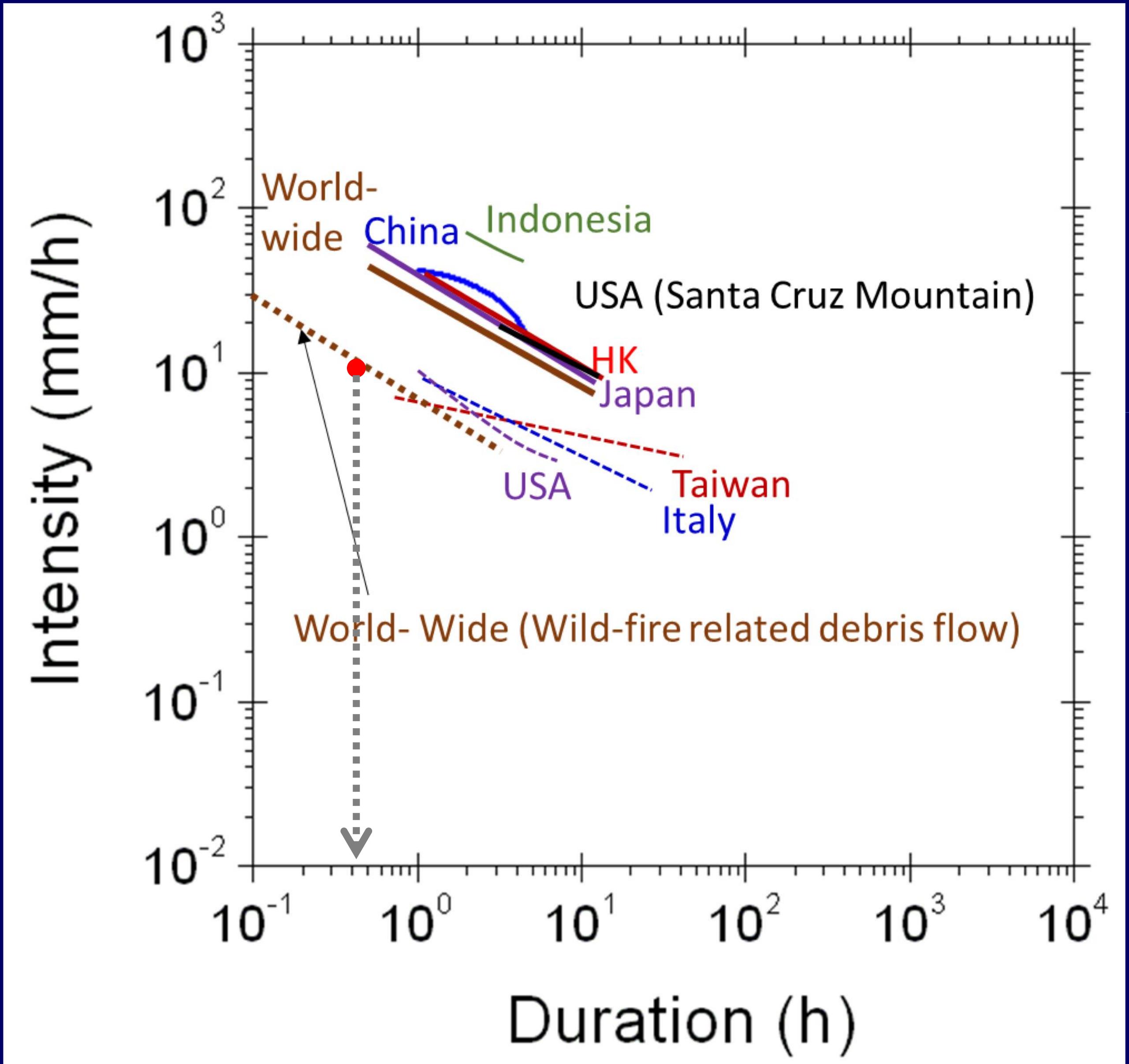




Major Triggers of landslides

- Intense Rainfall
- Rapid Snow Melts
- Water Level Changes and coastal evolution
- Volcanic Eruption
- Earthquakes
- Anthropogenic Causes
  - Wildfire
  - Faulty construction of infrastructures
  - Deforestation
  - Inappropriate quarrying at hill slope and mining
  - Paddy cultivation in steep slopes
  - Poor water management
  - Improper farming practices Over grazing

Intense Rainfall

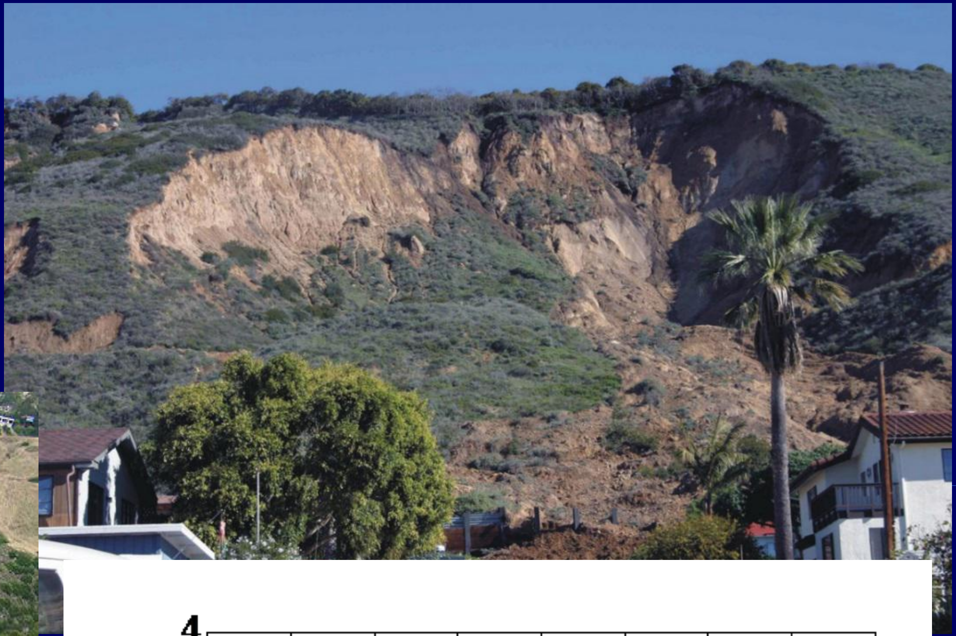


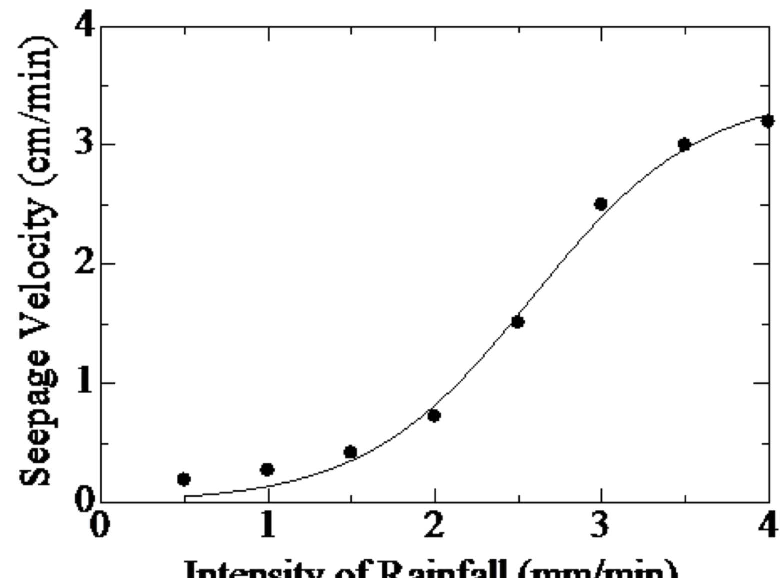
Jibson RW (1989) Debris flow in southern Porto Rico. Geological Society of America, Special Paper 236, 29–55

Cannon SH, Gartner JE (2005) Wildfire-related debris flow from a hazards perspective. In: Debris flow Hazards and Related Phenomena (Jakob M, Hungr O, eds). Springer Berlin Heidelberg, 363-385

Wieczorek GF (1987) Effect of rainfall intensity and duration on debris flows in central Santa Cruz Mountains. In: Debris flow/avalanches: process, recognition, and mitigation (Costa JE, Wieczorek GF, eds). Geological Society of America, Reviews in Engineering Geology, 7: 93–104

- **Intense Rainfall**





Richter et al. (2010)

Tiwari et al. (2014)

- **Intense Rainfall**

Wartman et al. (2015)

Worst Consequence – Landslide Dam

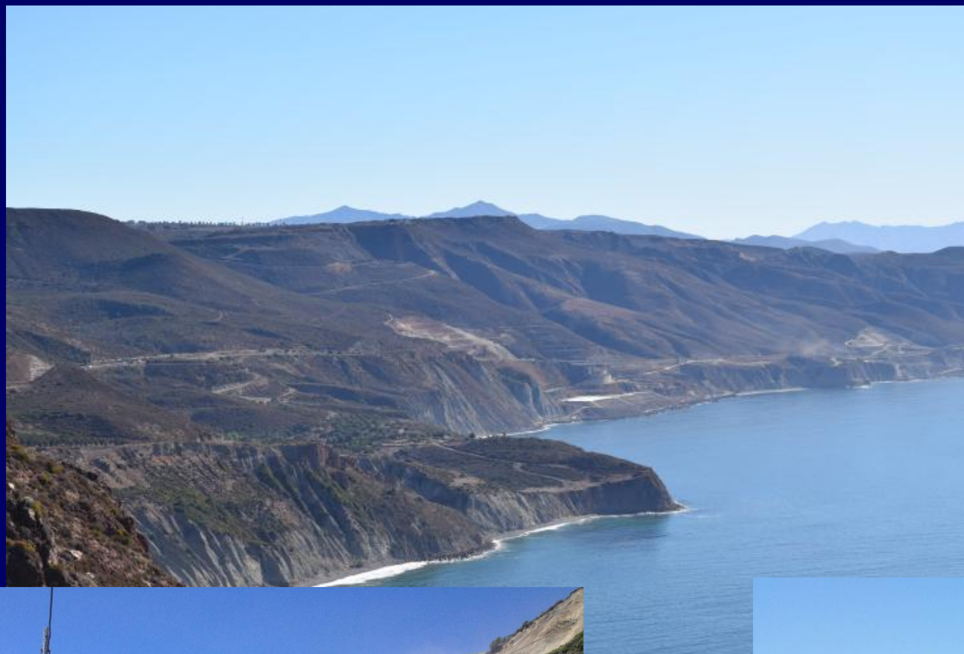
Worst Consequence – Landslide Dam

Worst Consequence – Landslide Dam

Worst Consequence – Landslide Dam

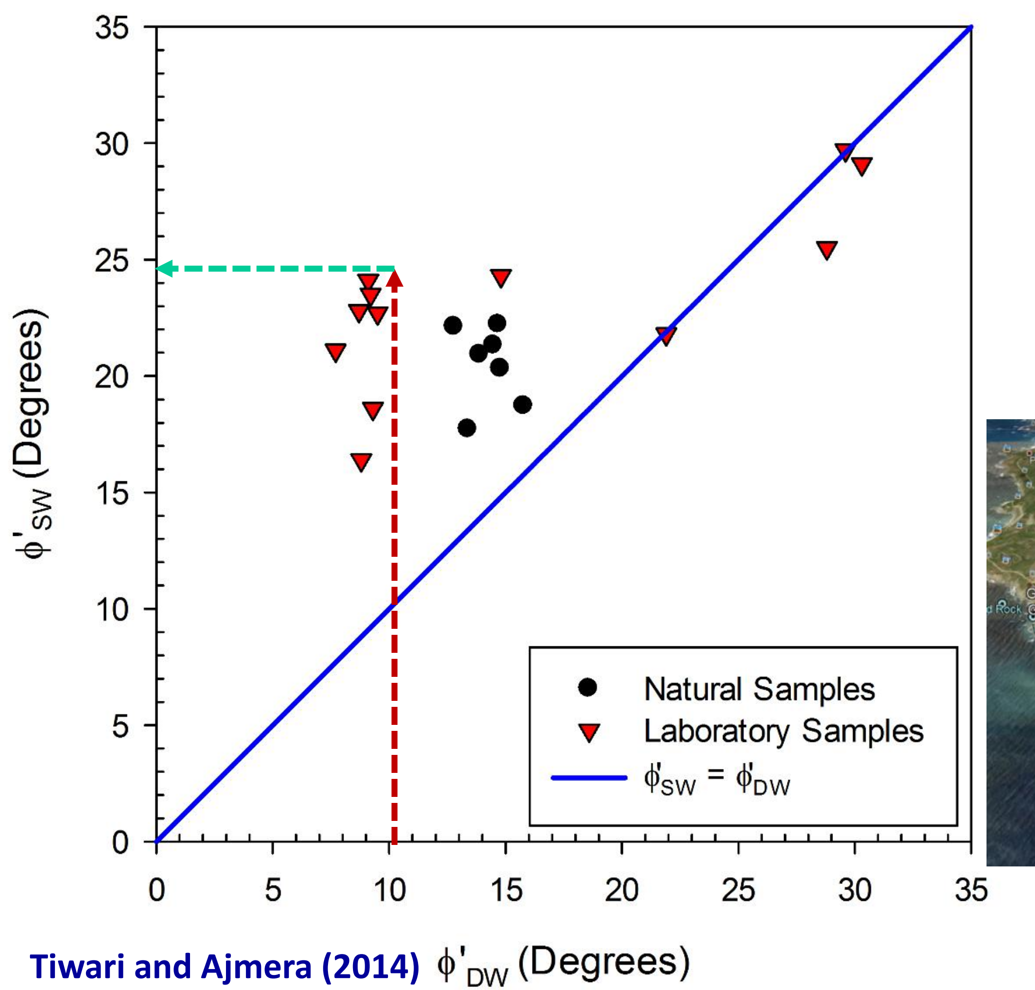
Worst Consequence – Landslide Dam

- Coastal Evolution



Caltrans, District 5

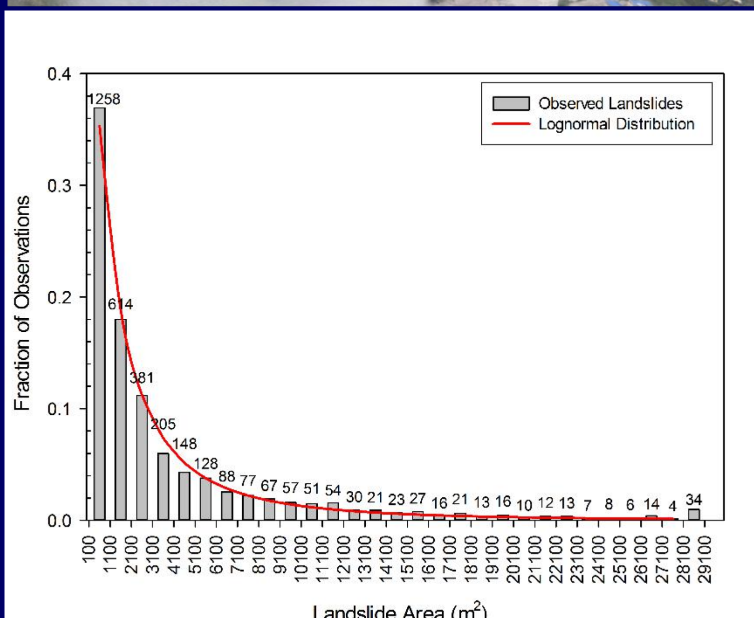
Coastal Evolution

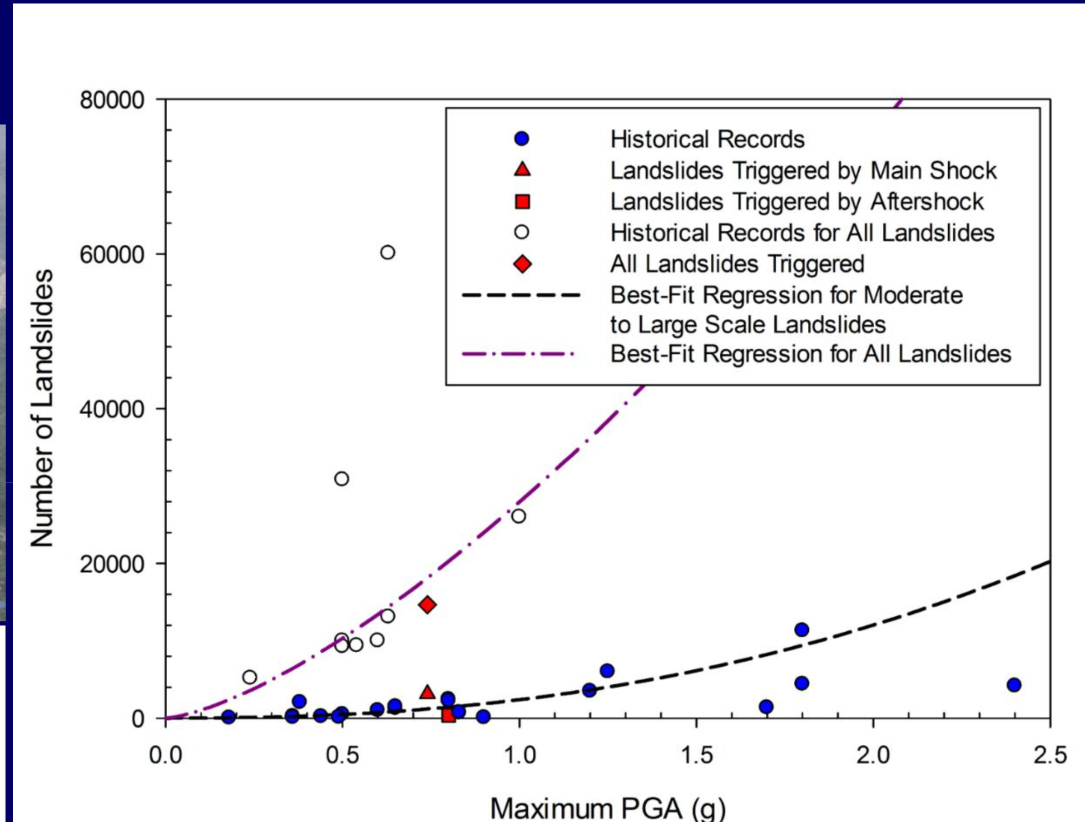


Tiwari and Ajmera (2014)

Volcanic Eruption

Earthquakes



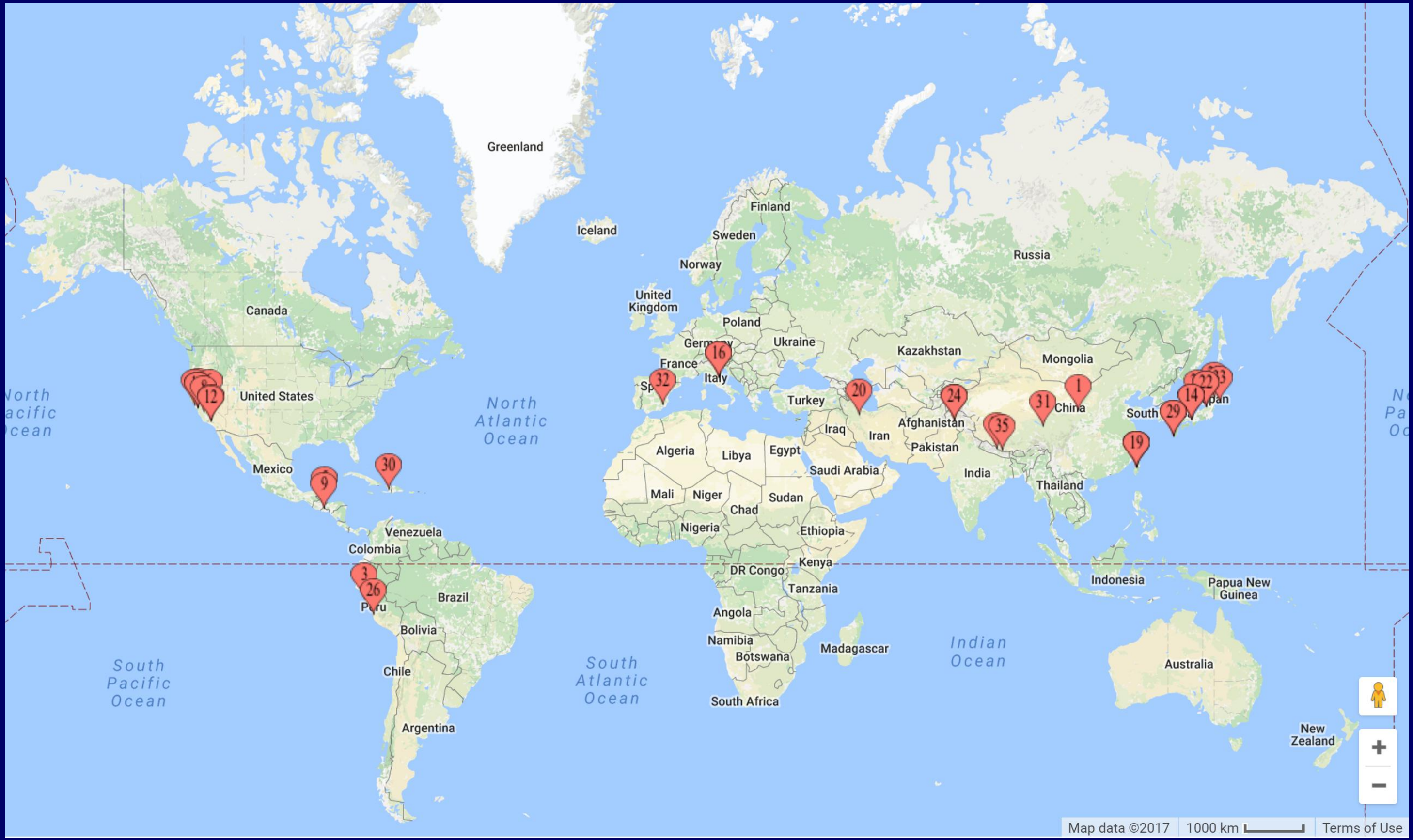


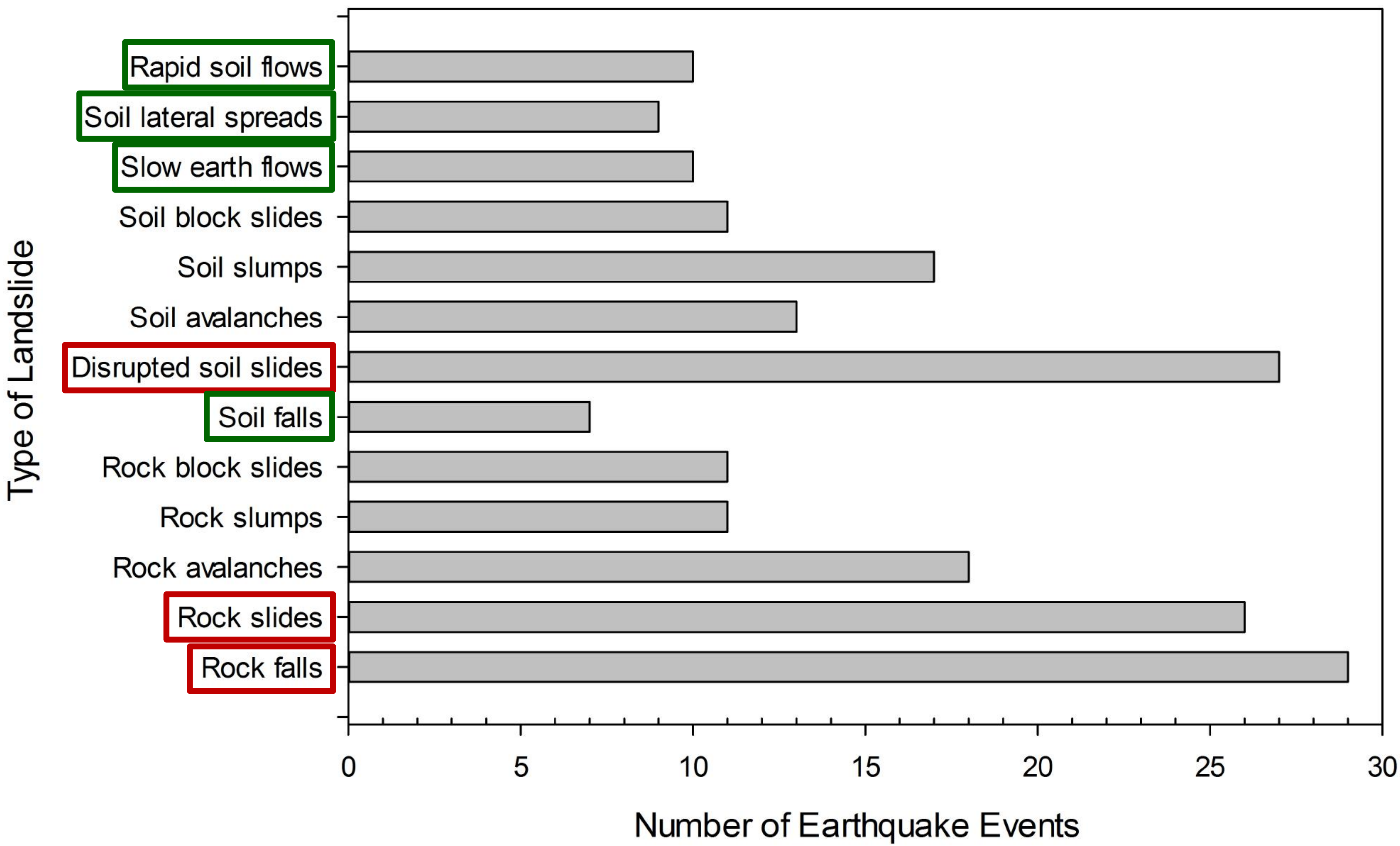
Tiwari, B., and Ajmera, B. 2017 Landslides Triggered by Earthquakes from 1920 to 2015, Fourth World Landslide Forum, Ljubljana, Slovenia, May 2017 (Key note Lecture), 2 (1), 5-15.

Tiwari, B., Ajmera, B., and Dhital, S. 2017. “Characteristics of Moderate to Large Scale Landslides Triggered by the Mw8 Gorkha Earthquake and Its Aftershocks,” Landslides, Springer Nature, 14 (4), 1297-1318

- **35 earthquake events occurring between 1920 and 2015**
- **Magnitudes ranging from 5.1 to 9.0**
- **Peak ground accelerations (PGA) ranging from 0.18 g to 2.4 g**
- **Maximum Modified Mercalli Intensity (MMI) ranging from VI to XII**
- **Focal depths ranging from 1 km to 45 km**

Tiwari, B., and Ajmera, B. 2017 Landslides Triggered by Earthquakes from 1920 to 2015, Fourth World Landslide Forum, Ljubljana, Slovenia, May 2017 (Key note Lecture), 2 (1), 5-15.





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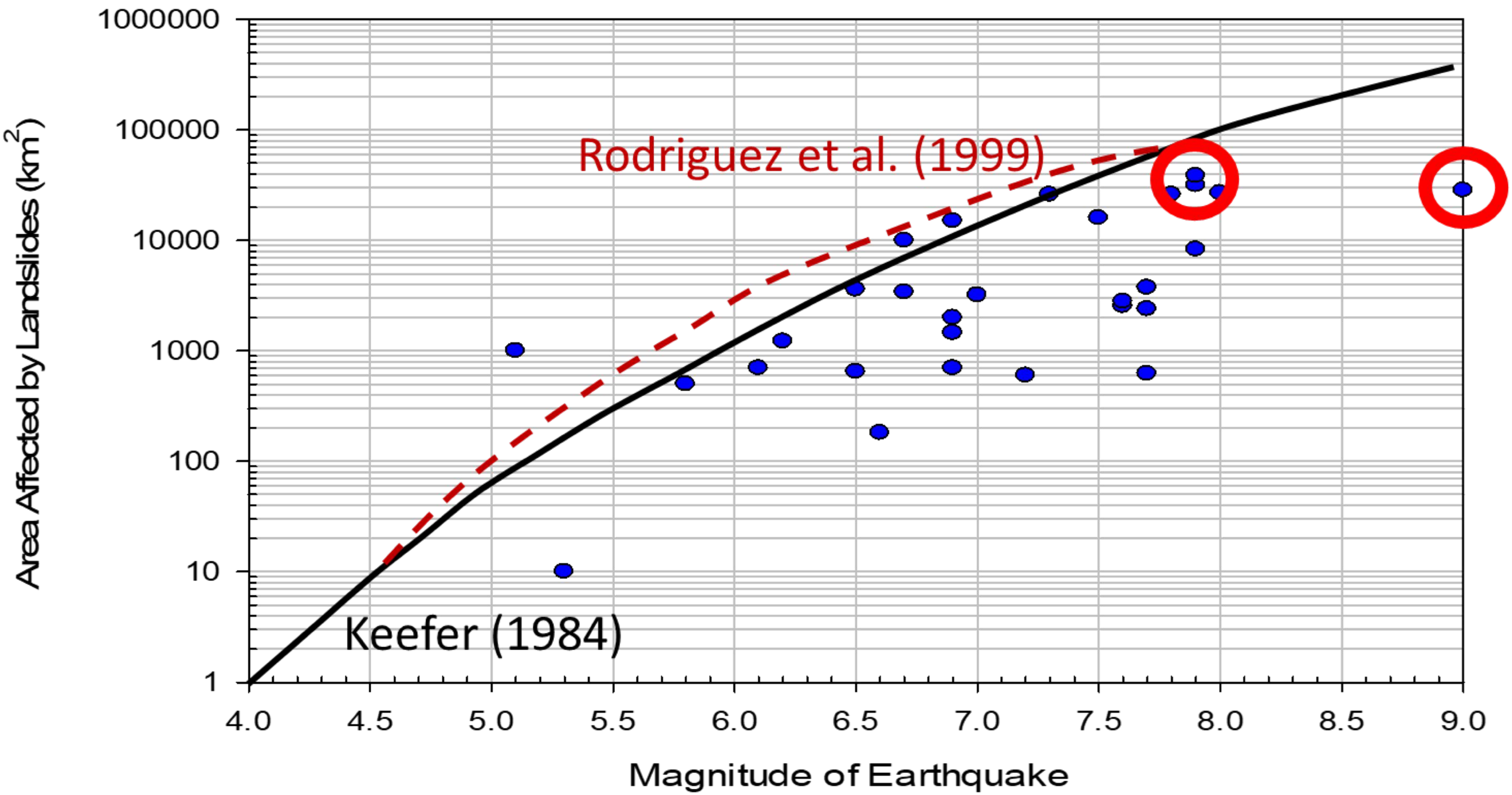
Category	Magnitude	Max. PGA (g)
All Landslides	5.1	0.18
Rock falls	5.1	0.24
Rock slides	5.3	0.18
Rock avalanches	5.1	0.18
Rock slumps	5.3	0.18
Rock block slides	5.3	0.18
Soil falls	5.1	0.36
Disrupted soil slides	5.1	0.24
Soil avalanches	5.3	0.18
Soil slumps	5.3	0.18
Soil block slides	5.1	0.18
Slow earth flows	5.1	0.18
Soil lateral spreads	6.5	0.38
Rapid soil flows	5.3	0.18

- A minimum magnitude of 5 was needed to trigger landslides
- Larger peak ground accelerations required to trigger rock slides, soil falls, and disrupted soil slides
- Soil lateral spreads tended to have higher lower bound values for both magnitude and maximum peak ground acceleration
- Does not suggest that specific types of landslides will not occur at lower seismic parameters

Tiwari, B., and Ajmera, B. 2017 Landslides Triggered by Earthquakes from 1920 to 2015, Fourth World Landslide Forum, Ljubljana, Slovenia, May 2017 (Key note Lecture), 2 (1), 5-15.



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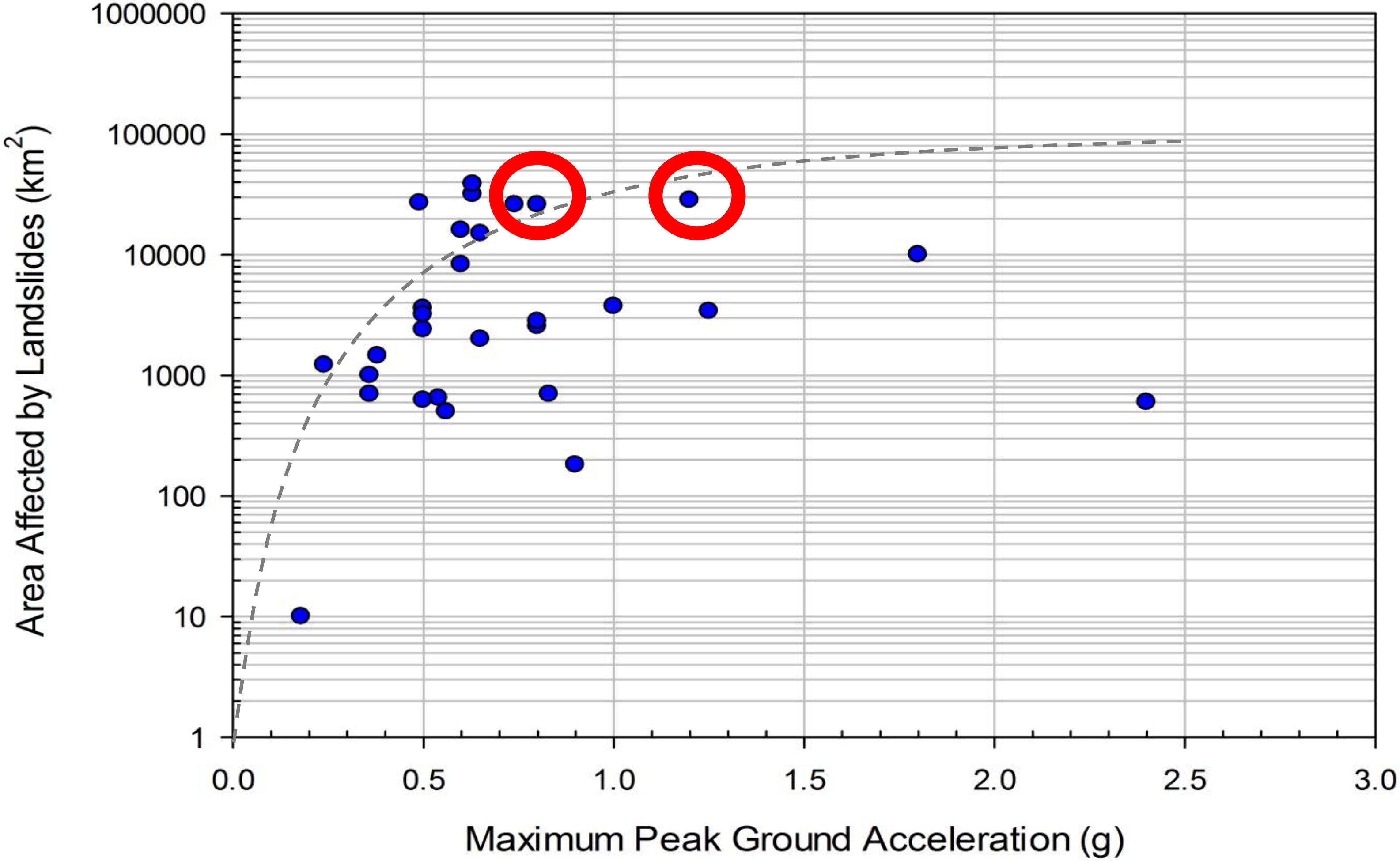
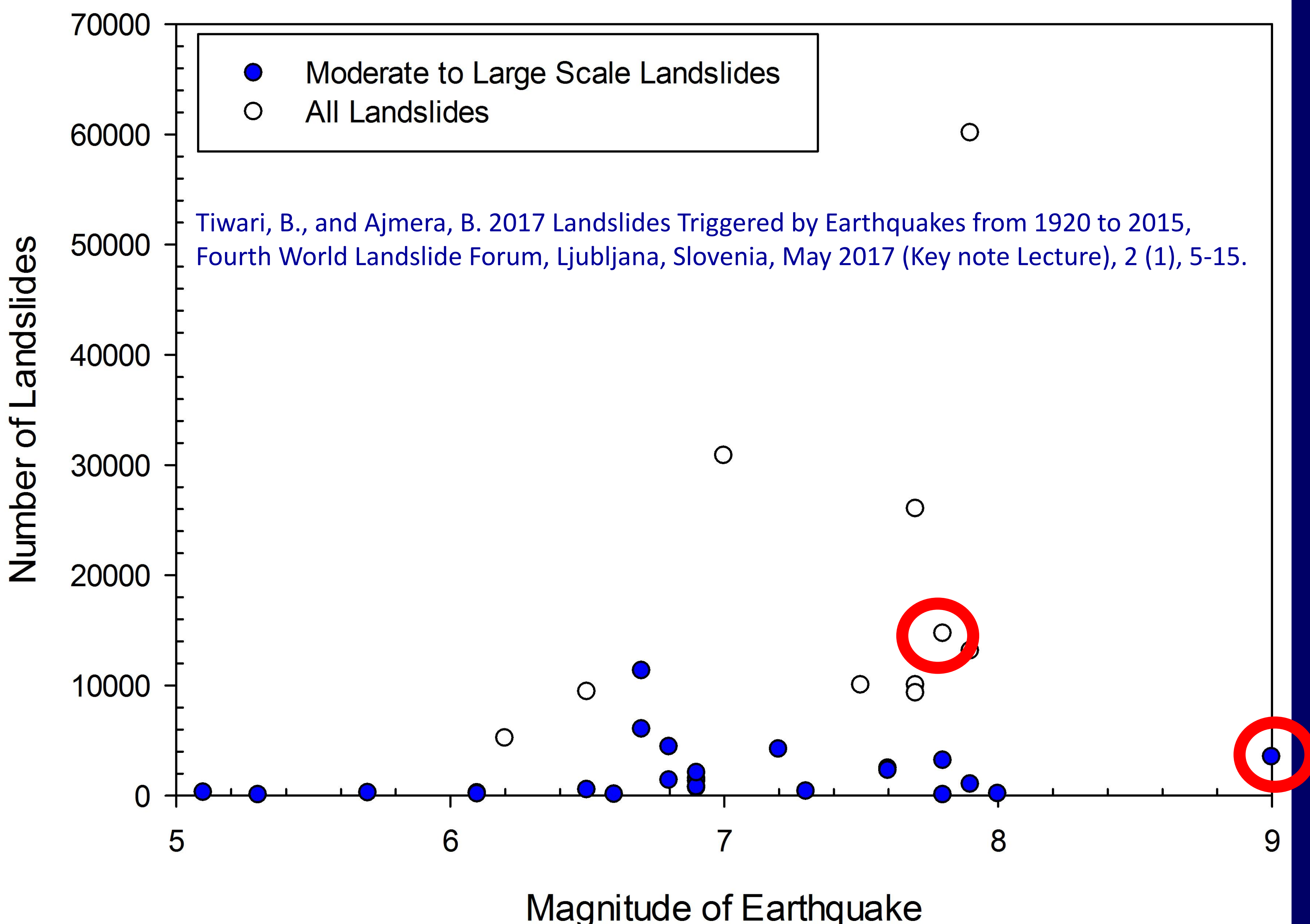


- **Area affected by the landslides may be limited by the extents of the study area**
- **Scatter may be attributed to the seismological, geological and geographic factors**
- **Not considered when preparing the upper bound for the area affected by landslides**



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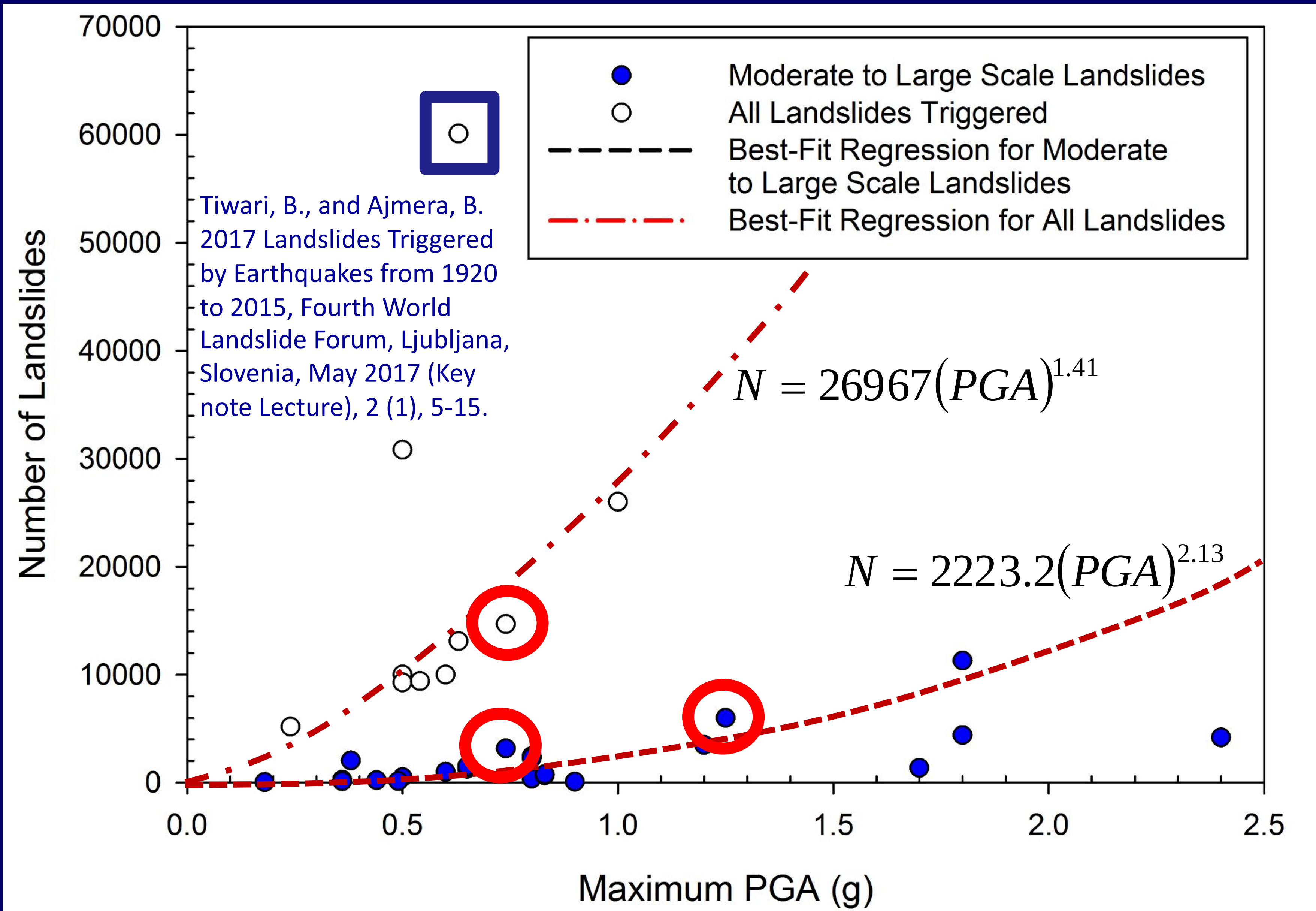
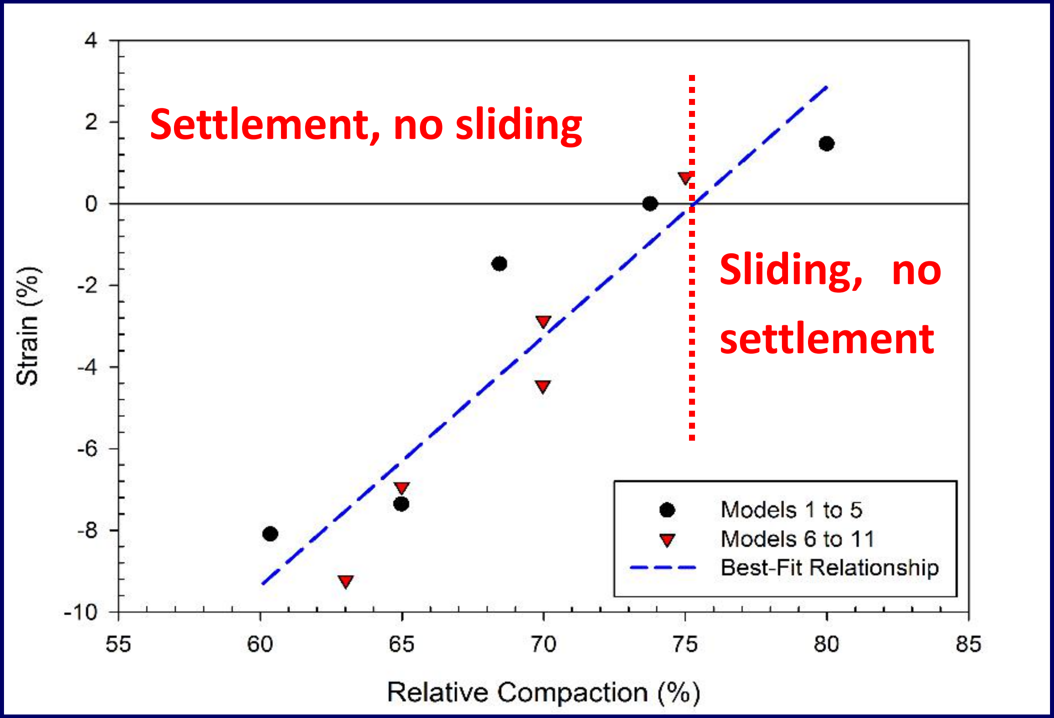
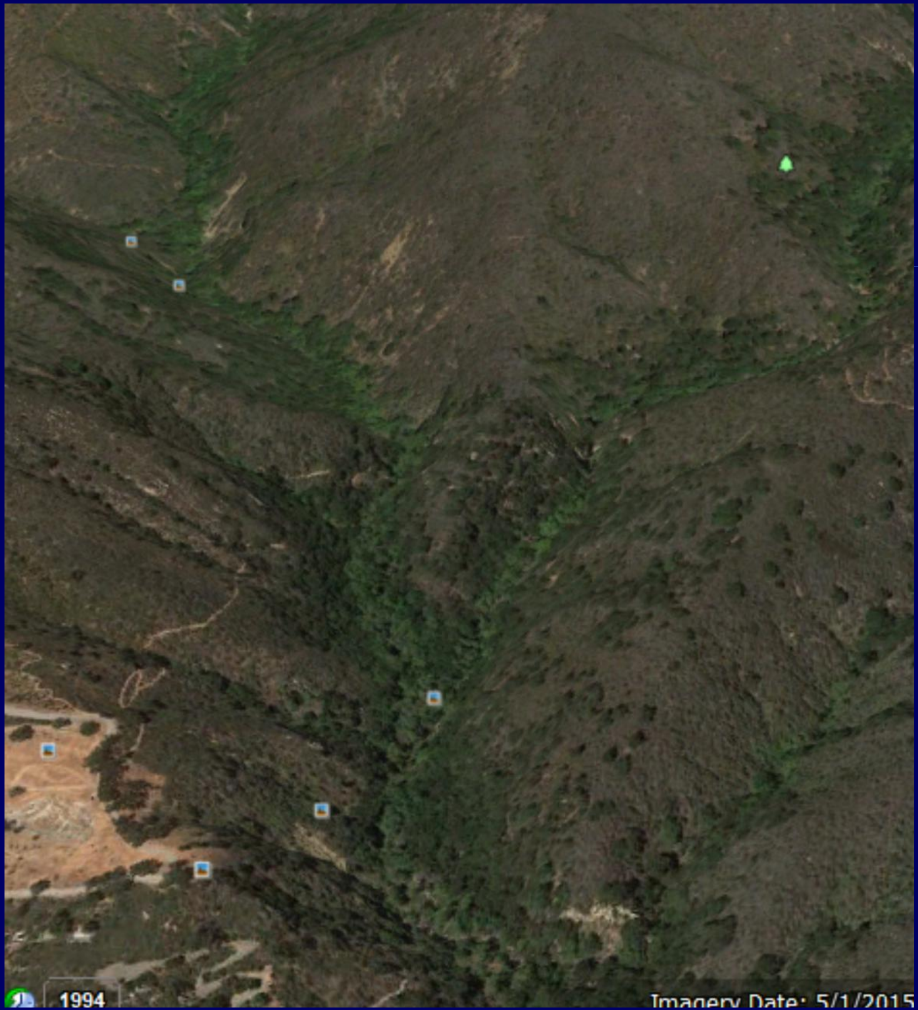
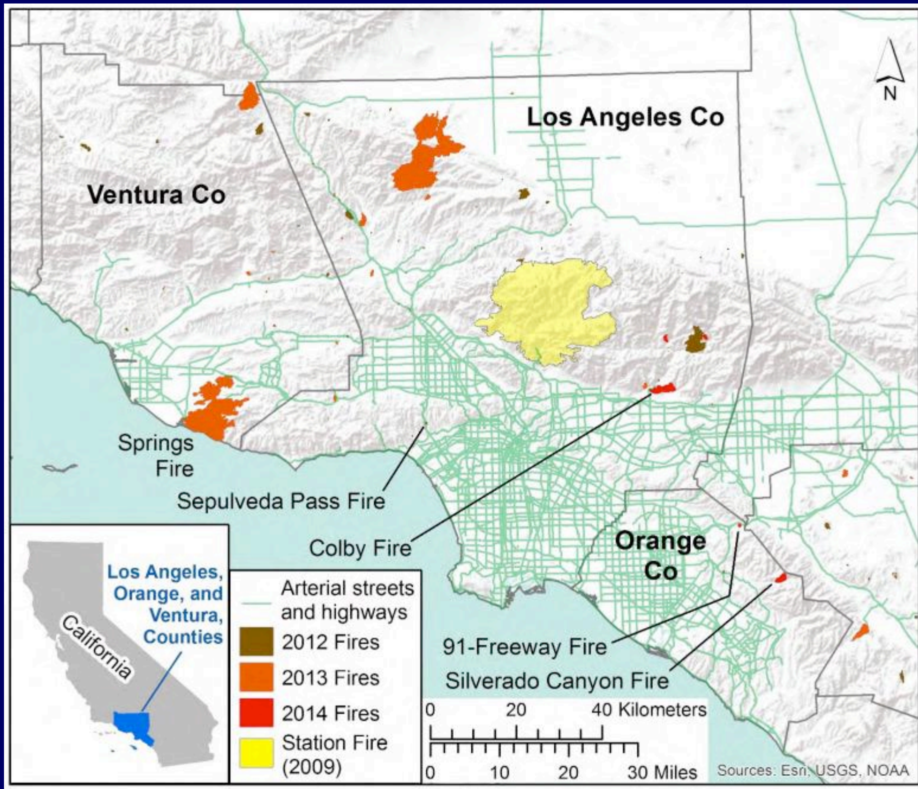

70000
60000
50000
40000
30000
20000
10000
0
Number of Landslides
0.0
0.5
1.0
1.5
2.0
2.5
Maximum PGA (g)
Moderate to Large Scale Landslides
All Landslides Triggered
Best-Fit Regression for Moderate to Large Scale Landslides
Best-Fit Regression for All Landslides
$N = 26967(PGA)^{1.41}$
$N = 2223.2(PGA)^{2.13}$
Tiwari, B., and Ajmera, B. 2017 Landslides Triggered by Earthquakes from 1920 to 2015, Fourth World Landslide Forum, Ljubljana, Slovenia, May 2017 (Key note Lecture), 2 (1), 5-15.

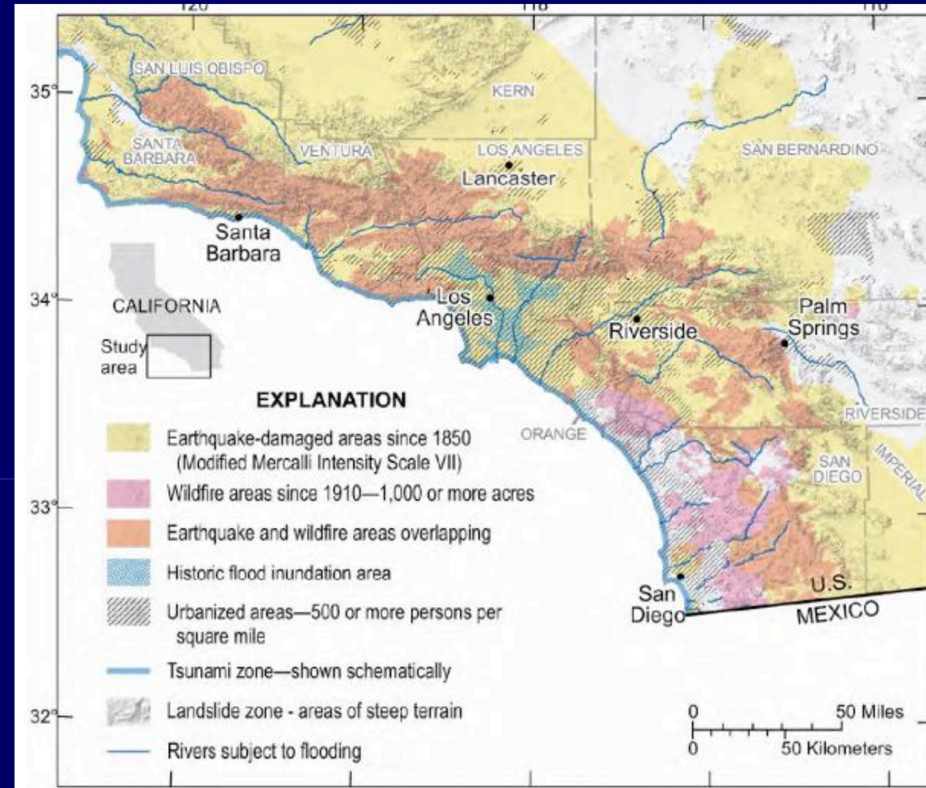
Pre and Post-earthquake Rainfall Induced Landslides



- **Anthropogenic Causes**
  - **Wildfire**







Keaton, J. R., Ajmera, B., Upadhyaya, S., **Tiwari, B**., Turner, B. Kwak, D. Y., and Brandenberg, S. J. 2015. DECEMBER 2014 STORM DAMAGEBELOW RECENTLY BURNED SLOPES, LOS ANGELES, ORANGE, AND VENTURA COUNTIES, CALIFORNIA, Geotechnical Extreme Event Reconnaissance GEER Association Report No. GEER- 042. Version 1 July 31, 2015. DOI: 10.18118/g66k56.

Reconnaissance – 2011 Tohoku Earthquake

Wartman, J., Dunham, L., Tiwari, B. and Pradel, D. 2013. Landslides in Eastern Honshu Induced by the 2011 Tōhoku Earthquake, *Bulletin of the Seismological Society of America*, 103 (2B), 1503-1521). doi: 10.1785/0120120128.

Tiwari, B., Wartman, J. and Pradel, D. 2013. Slope Stability Issues After Mw9.0 Tohoku Earthquake, *Geotechnical Special Publication*, ASCE, 231 (1), 1594-1601.

- M_w 9.0 ; March 11, 2011, at 14:46 local time
- Death - >20,000, injured - >5,000, displaced - >130,000
- Building damage - >332,000, Roads damaged - >2,000 , bridges damaged - > 56, and railway tracks - >26, Total damage - > $300 B
- The majority of the death toll was due to a devastating Tsunami; Death due to landslides - >20.
- Aftershocks - >1000, Larger than M_w 7.0 - 4.
- M_w 6.6 strong aftershock of April 11, 2011 hit Fukushima.

Rupture Surface

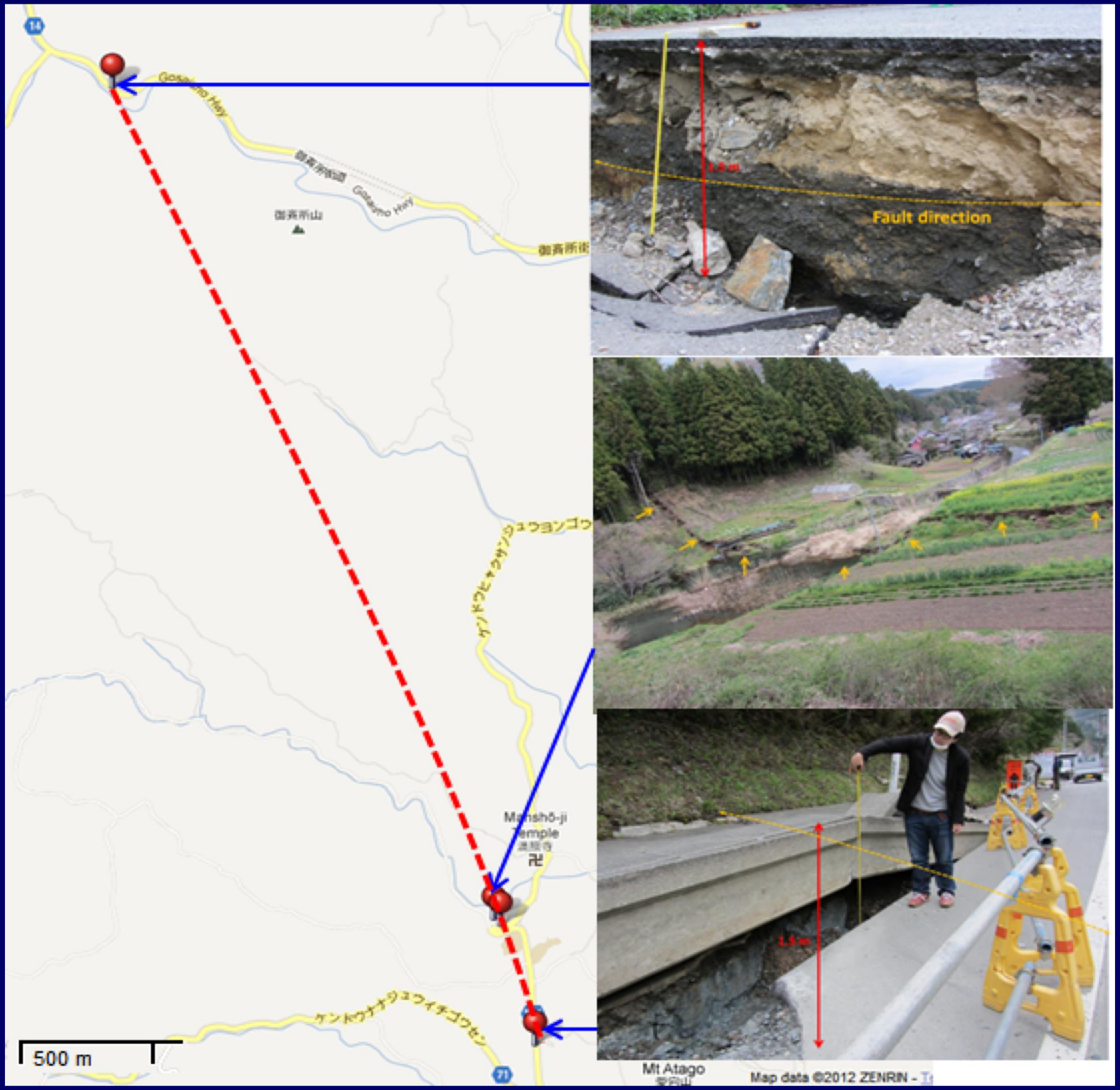

Fault direction
500 m
Mt Atago
Map data ©2012 ZENRIN

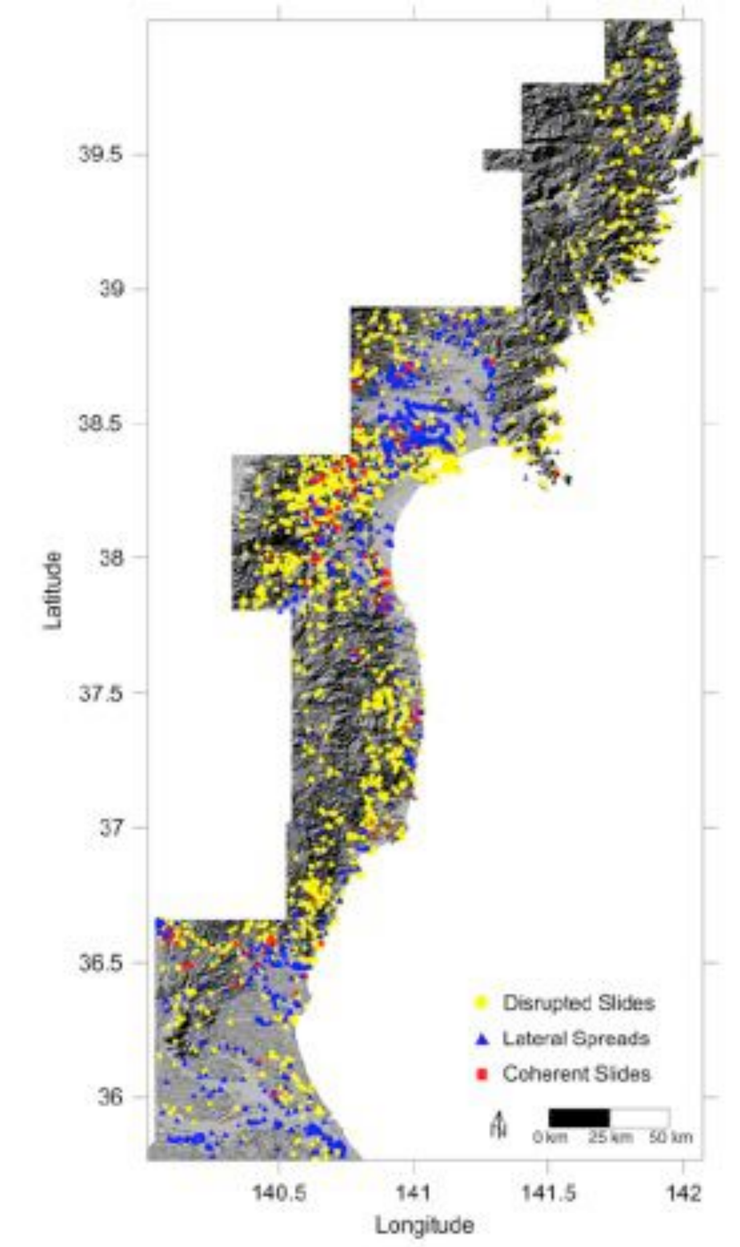

Photo 5/7/2010
75 m
Google earth
Photo 3/28/2011
75 m
Google earth


125 m
Image © 2012 GeoEye
Google earth


Photo 3/30/2009
72 m
Google earth
Photo 4/5/2011
72 m
Google earth

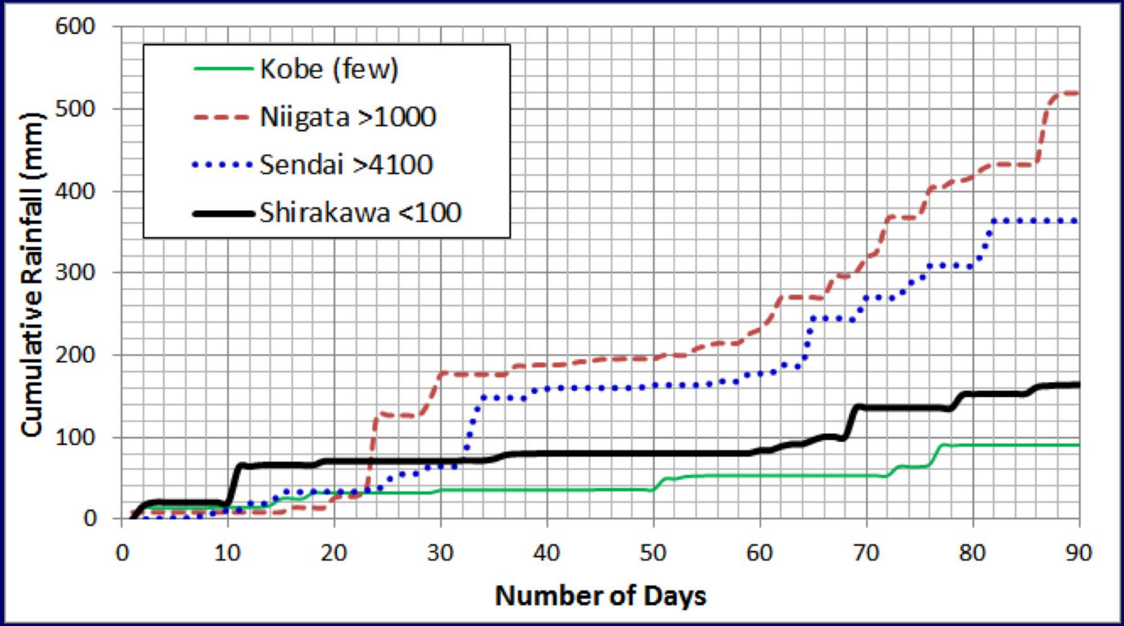
Wall Collapse

Dam Failure



Wartman, J., Dunham, L., **Tiwari, B.** and Pradel, D. 2013. Landslides in Eastern Honshu Induced by the 2011 Tōhoku Earthquake, *Bulletin of the Seismological Society of America*, 103 (2B), 1503-1521).

Earthquake	Day	Month	Year	Depth (Km)	Magnitude	Max. PGA (x g)	Number of landslides	Number of Landslide Dams
Hyogoken Nanbu	17	January	1995	17	6.8	0.8	few	0
Niigata	23	Oct.	2004	16	6.8	1.02	>1000	>50
Iwate-Miyagi	14	June	2008	10	6.9	1.02	>4100	>3
Tohoku	11	March	2011	30	9.0	2.93	> 3400	1

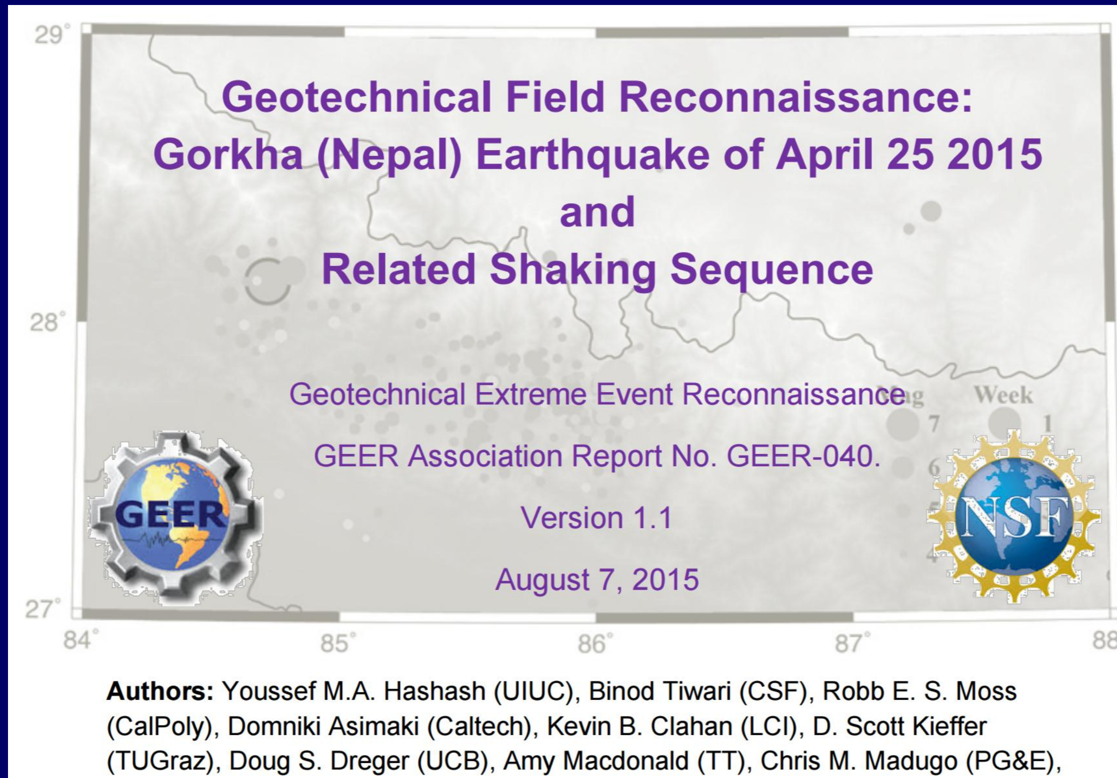


2015 Gorkha Nepal Earthquake

Nepal Partners

Aerial Recon

Ground Recon



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

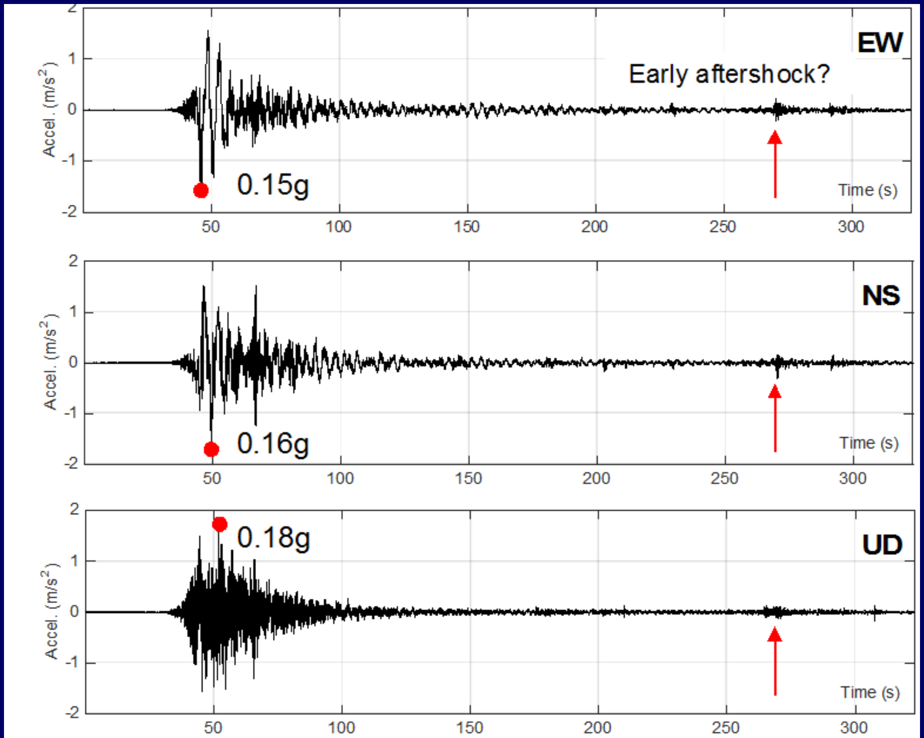
August 7, 2015

Authors: Youssef M.A. Hashash (UIUC), Binod Tiwari (CSF), Robb E. S. Moss (CalPoly), Domniki Asimaki (Caltech), Kevin B. Clahan (LCI), D. Scott Kieffer (TUGraz), Doug S. Dreger (UCB), Amy Macdonald (TT), Chris M. Madugo (PG&E),

Hashash, Y. M.A., **Tiwari, B**., Moss, R. E. S., Asimaki, D., Clahan, K. B., Kieffer, D. S., Dreger, D. S., Macdonald, A., Madugo, C. M., Mason, H. B., Pehlivan, M., Rayamajhi, D., Acharya, I., and Adhikari, B. 2015. ***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 August 7, 2015.

Features

- 25 April 2015, 11:56:26
- 7.8 Mw, 8.1 Ms, MMI IX
- 8.2 km
- 7.3 Mw May 12th , 6.7 Mw April 26th , over 410 aftershocks
- $5 billion (about 25% of GDP)
- Over 9,000 dead and 22,000 injured

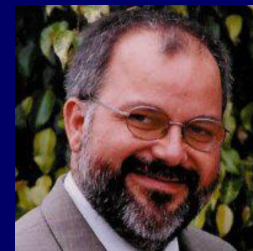


Landslides - 2015 Gorkha Nepal Earthquake

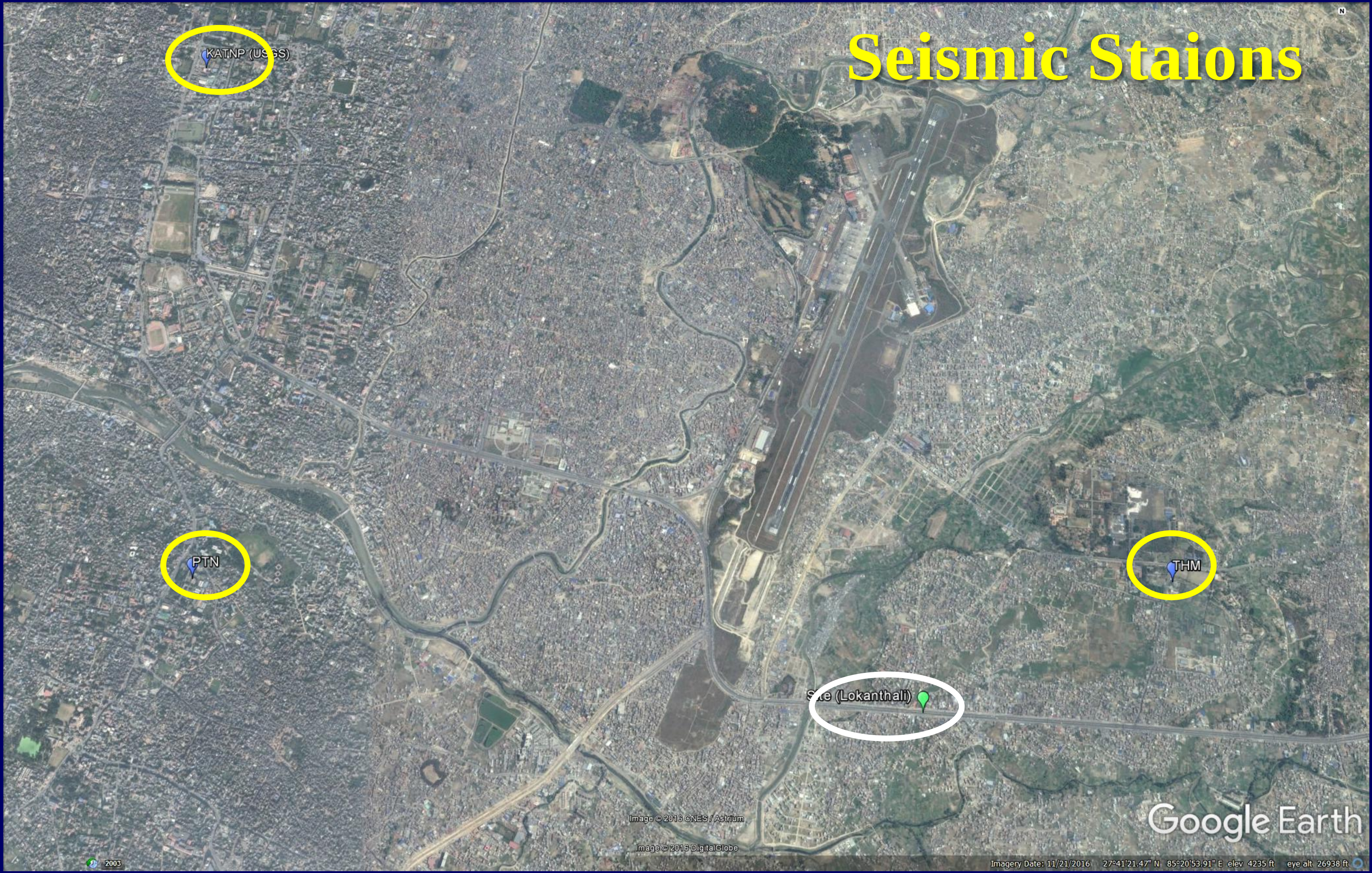
Tiwari, B., **Pradel, D., Ajmera, B., Yamashiro, B., and Diwakar, K. (2018) "Landslide Movement at Lokanthali during the 2015 Earthquake in Gorkha, Nepal,"** ***Journal of Geotechnical and Geoenvironmental Engineering*****, 144(3), 05018001 1-12**.

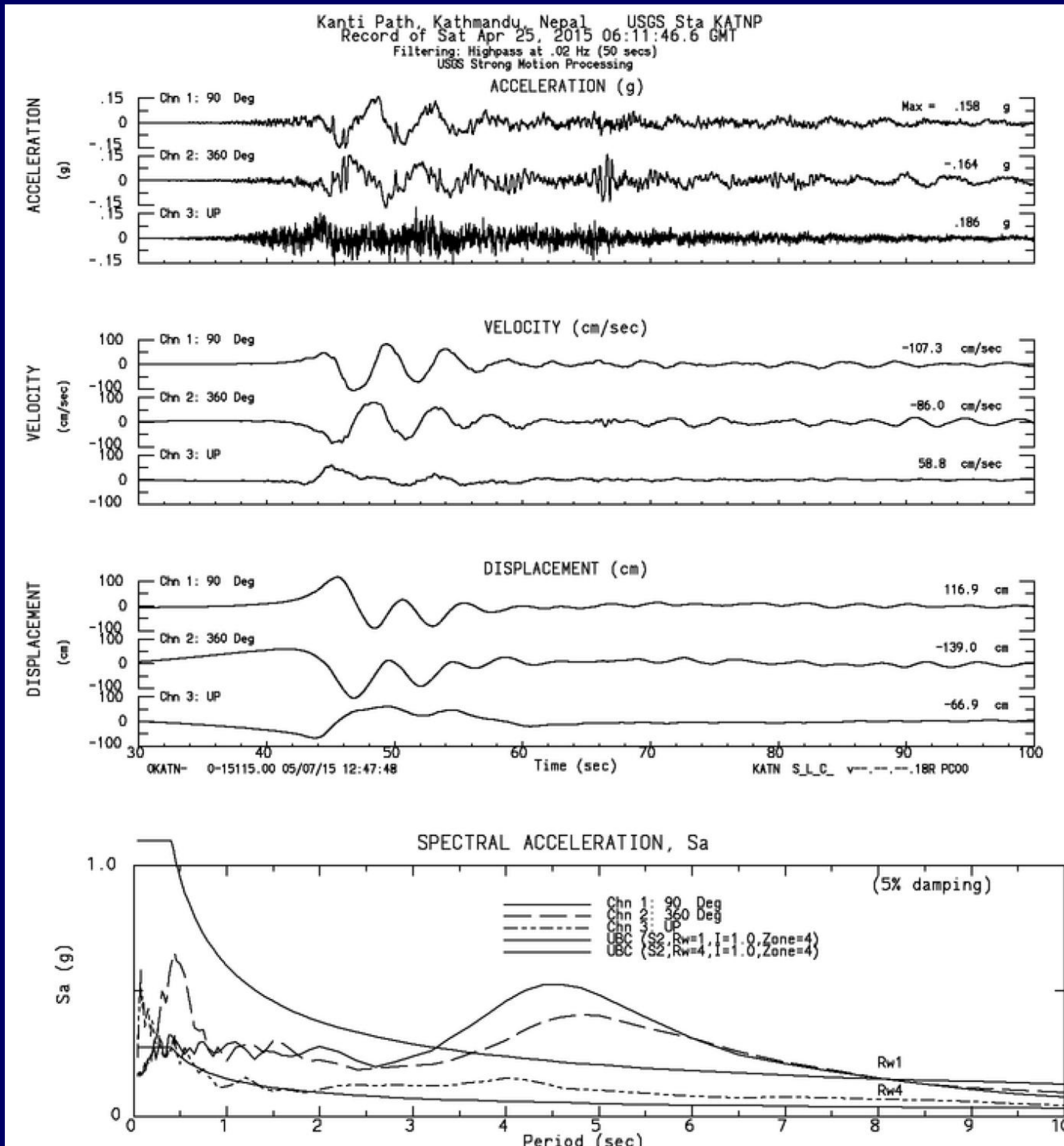
Tiwari, B., Ajmera, B., and *Dhital, S.,* CHARACTERISTICS OF MODERATE TO LARGE SCALE LANDSLIDES TRIGGERED BY THE Mw 7.8 2015 GORKHA EARTHQUAKE AND ITS AFTERSHOCKS, *Landslides*, 14 (4), 1297-1318).

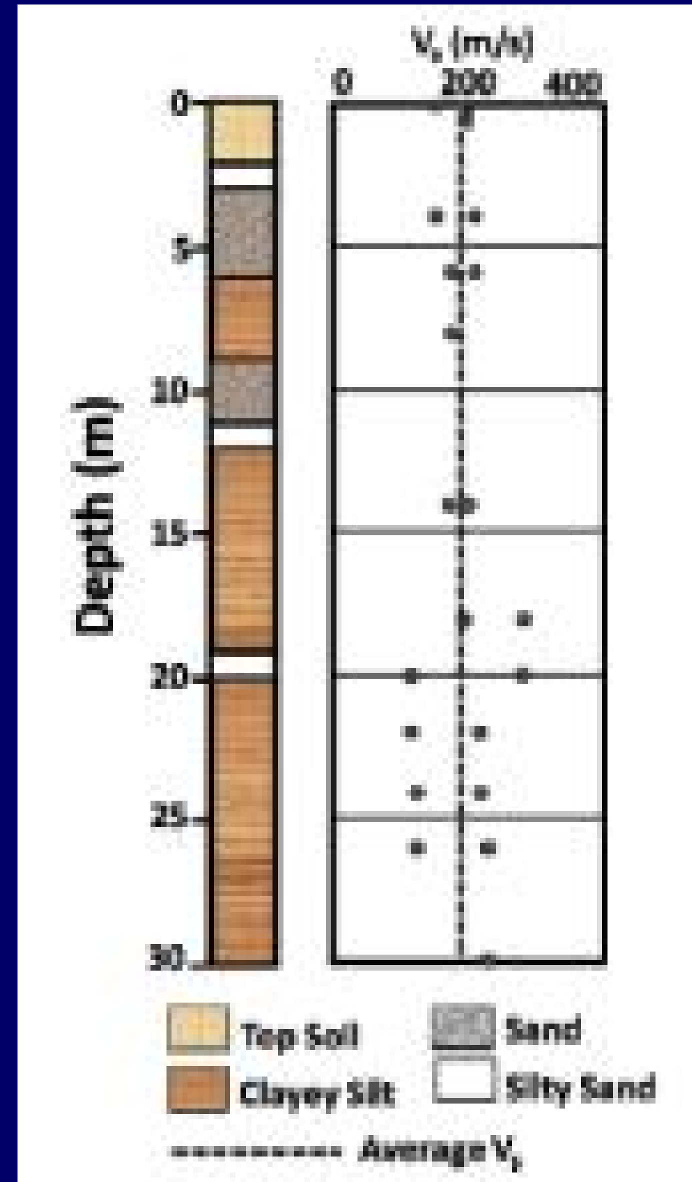
Hashash, Y. M.A., **Tiwari, B.**, Moss, R. E. S., Asimaki, D., Clahan, K. B., Kieffer, D. S., Dreger, D. S., Macdonald, A., Madugo, C. M., Mason, H. B., Pehlivan, M., Rayamajhi, D., Acharya, I., and Adhikari, B. 2015. ***Geotechnical Field Reconnaissance: Gorkha (Nepal) Earthquake of April 25 2015 and Related Shaking Sequence***, Geotechnical Extreme Event Reconnaissance GEER Association Report No. GEER-040. Version 1.1 August 7, 2015.



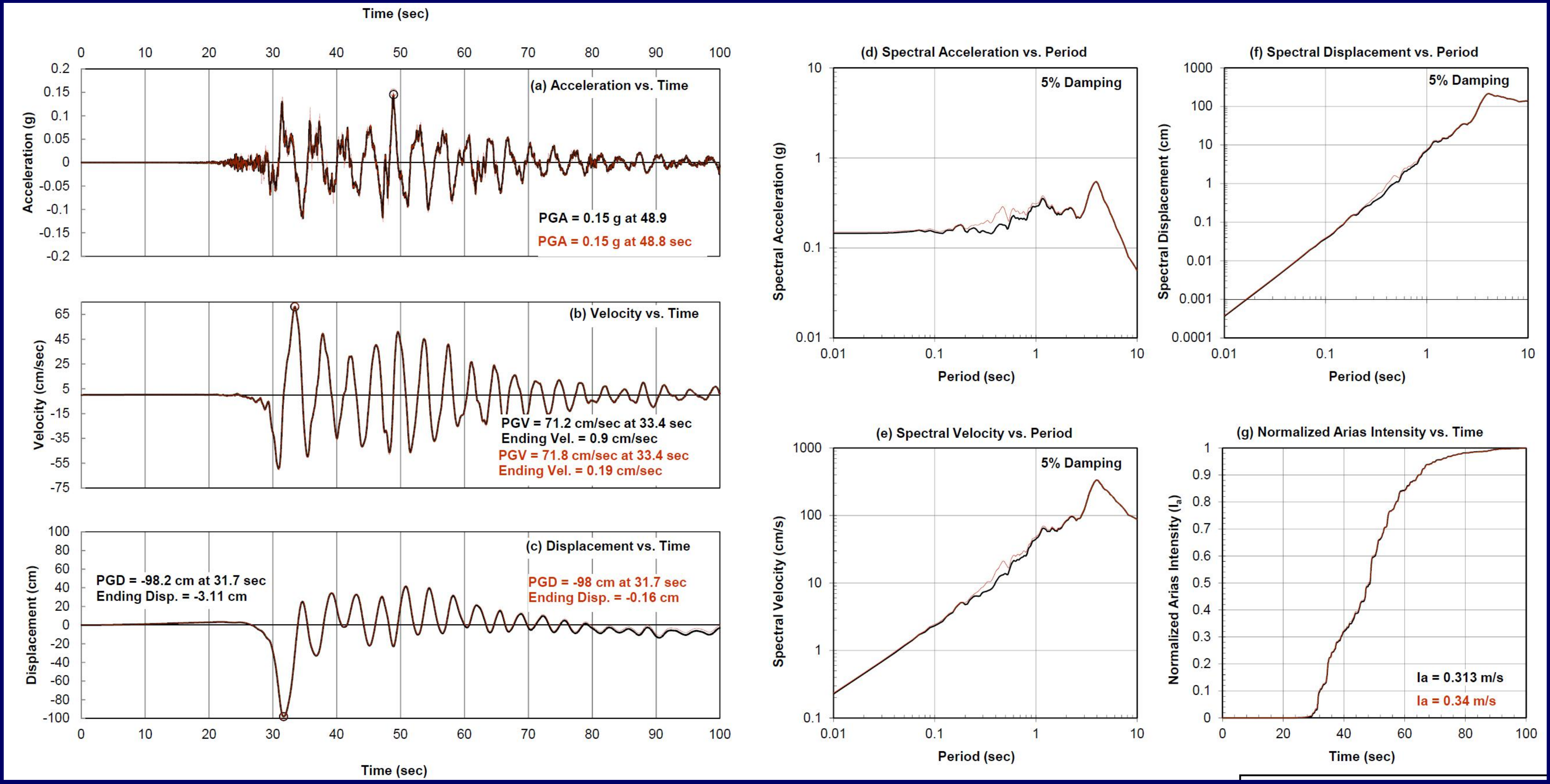
Tiwari, B., Pradel, D., Ajmera, B., Yamashiro, B., and Diwakar, K. (2018) "Landslide Movement at Lokanthali during the 2015 Earthquake in Gorkha, Nepal," ***Journal of Geotechnical and Geoenvironmental Engineering*****, 144(3), 05018001 1-12**.


Seismic Staions
KATNP (USGS)
PTN
THM
Site (Lokanthali)
Image © 2016 CNES / Astrium
Image © 2016 DigitalGlobe
Google Earth
Imagery Date: 11/21/2016 27°41'21.47" N 85°20'53.91" E elev 4235 ft eye alt 26938 ft

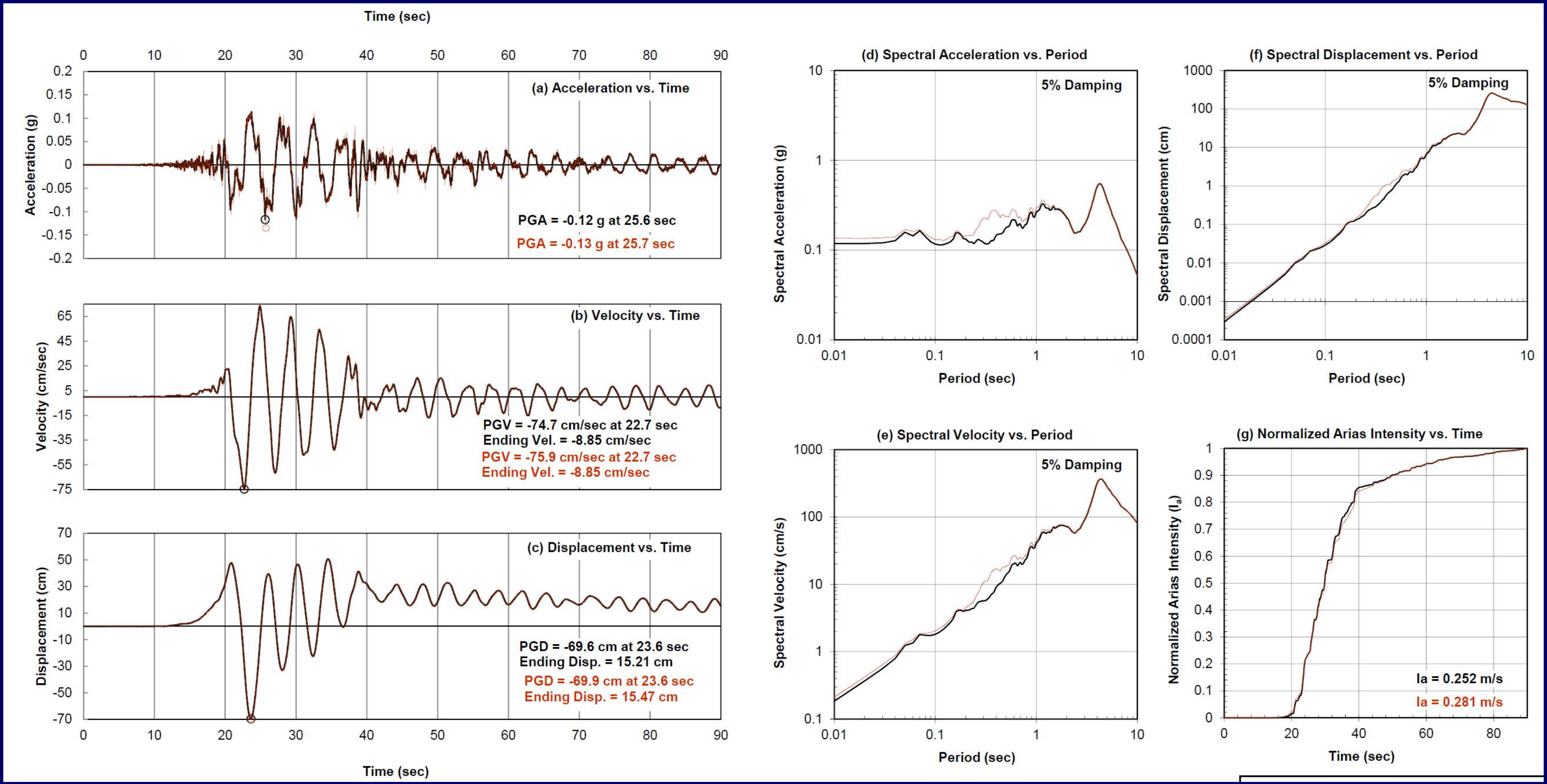

Kanti Path, Kathmandu, Nepal USGS Sta KATNP
Record of Sat Apr 25, 2015 06:11:46.6 GMT
Filtering: Highpass at .02 Hz (50 secs)
USGS Strong Motion Processing
ACCELERATION (g)
Chn 1: 90 Deg
Max = .158 g
Chn 2: 360 Deg
-.164 g
Chn 3: UP
.186 g
ACCELERATION (g)
VELOCITY (cm/sec)
-107.3 cm/sec
-86.0 cm/sec
58.8 cm/sec
VELOCITY (cm/sec)
DISPLACEMENT (cm)
116.9 cm
-139.0 cm
-66.9 cm
DISPLACEMENT (cm)
Time (sec)
0KATN- 0-15115.00 05/07/15 12:47:48
KATN S_L_C_ v--.--.--.18R PC00
SPECTRAL ACCELERATION, Sa
(5% damping)
Chn 1: 90 Deg
Chn 2: 360 Deg
Chn 3: UP
UBC (S2,Rw=1,I=1.0,Zone=4)
UBC (S2,Rw=4,I=1.0,Zone=4)
Rw1
Rw4
Sa (g)
Period (sec)


Vs (m/s)
0
200
400
Depth (m)
Top Soil
Sand
Clayey Silt
Silty Sand
Average Vs

NS ground motions at THM station including propagated motions after deconvolution



EW ground motions at THM station including propagated motions after deconvolution



2003 October

2010 January

2012 April

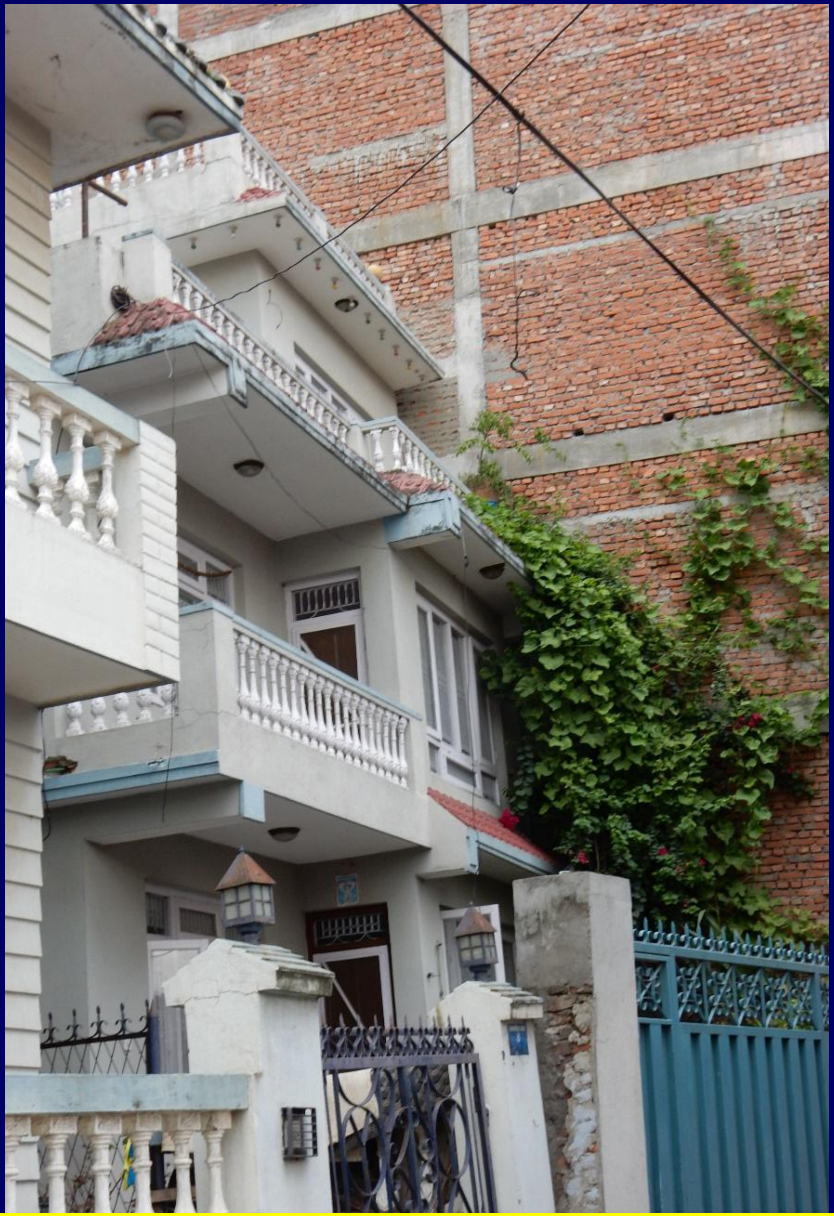
2015 March (Before)

2015 May (after)


A
WAVE
PHYSICAL FITNESS

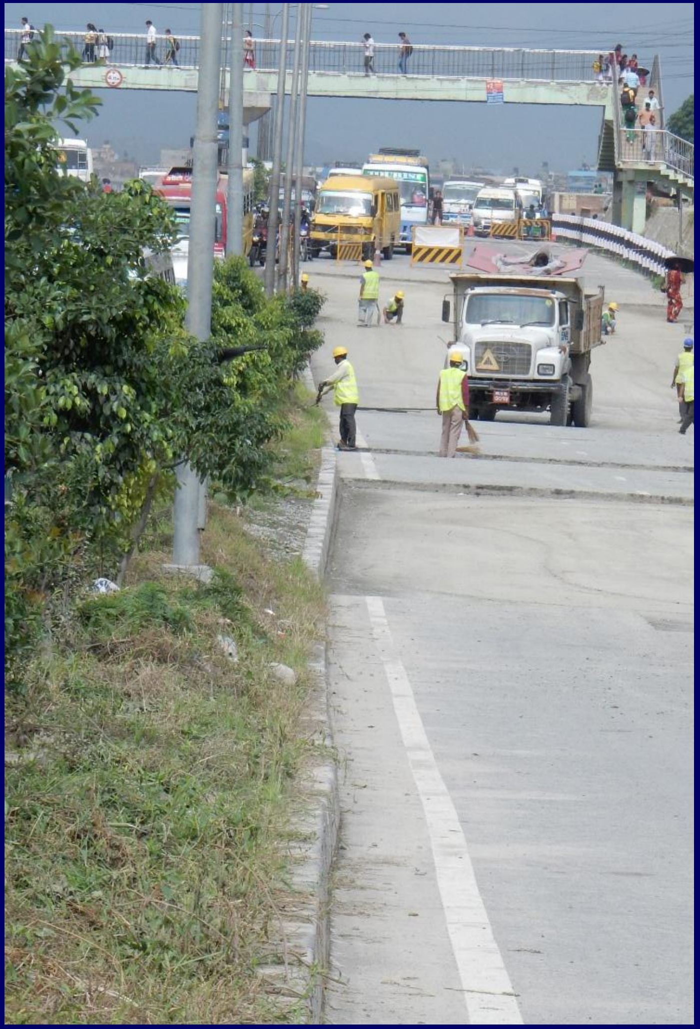

ZENITH TRADING CONCERN

2015 May (after)



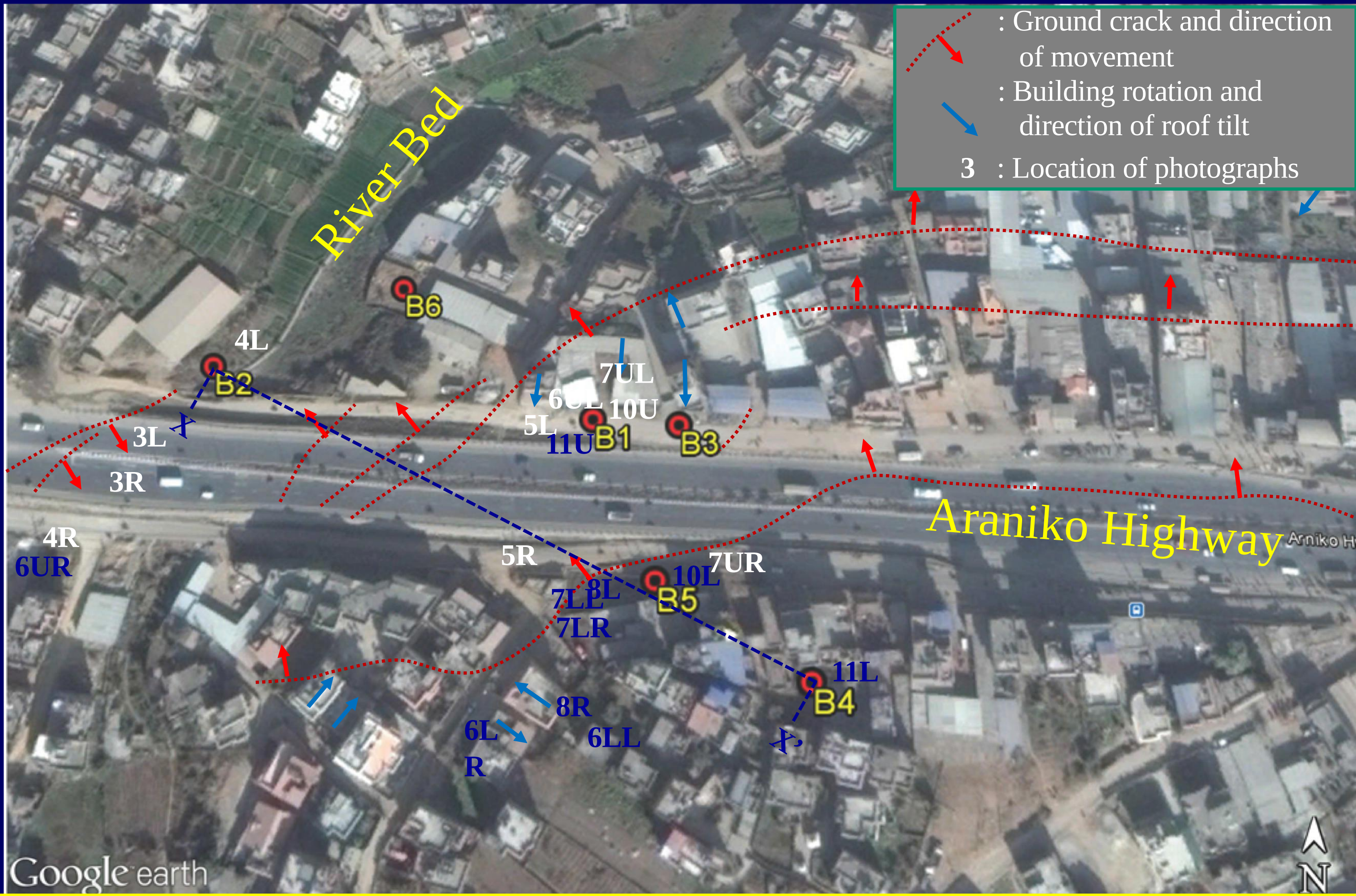
2015 May (after)

2015 May (after)

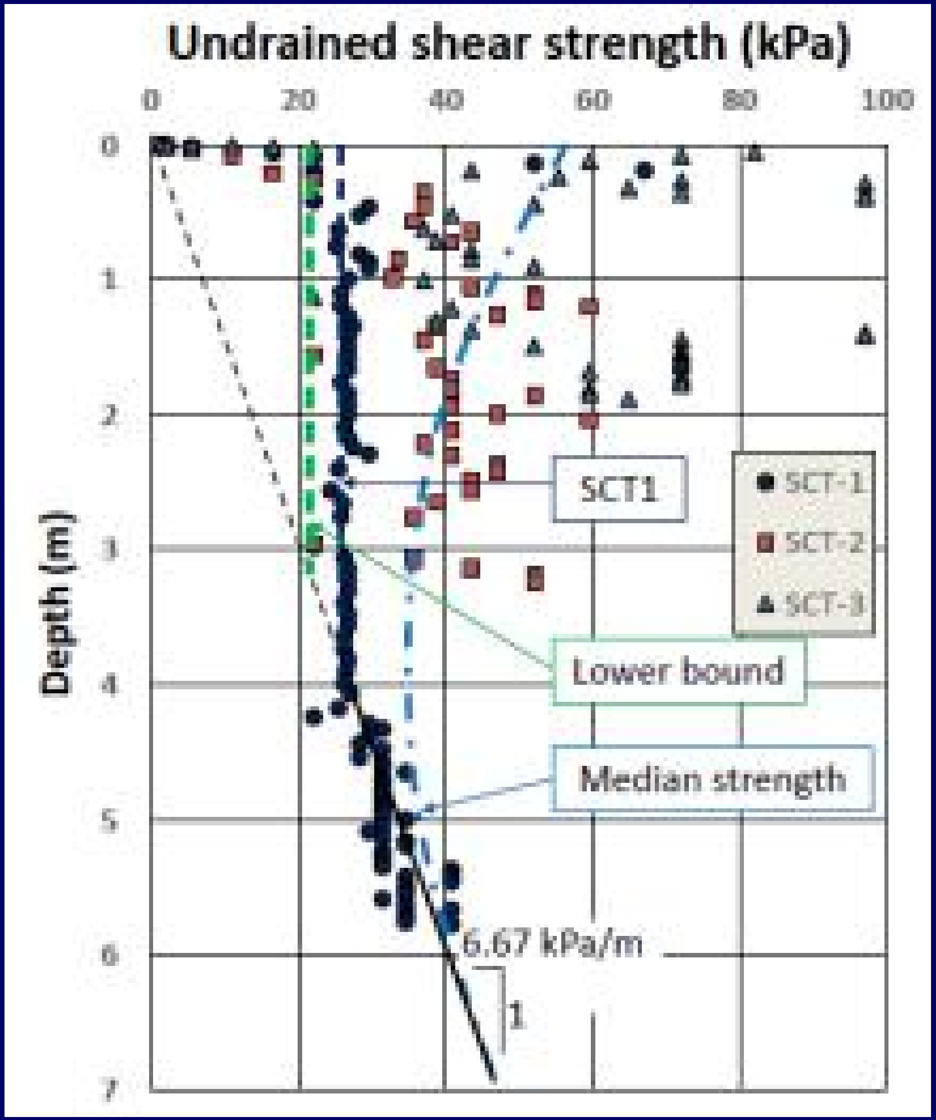


Postulated causes of movement

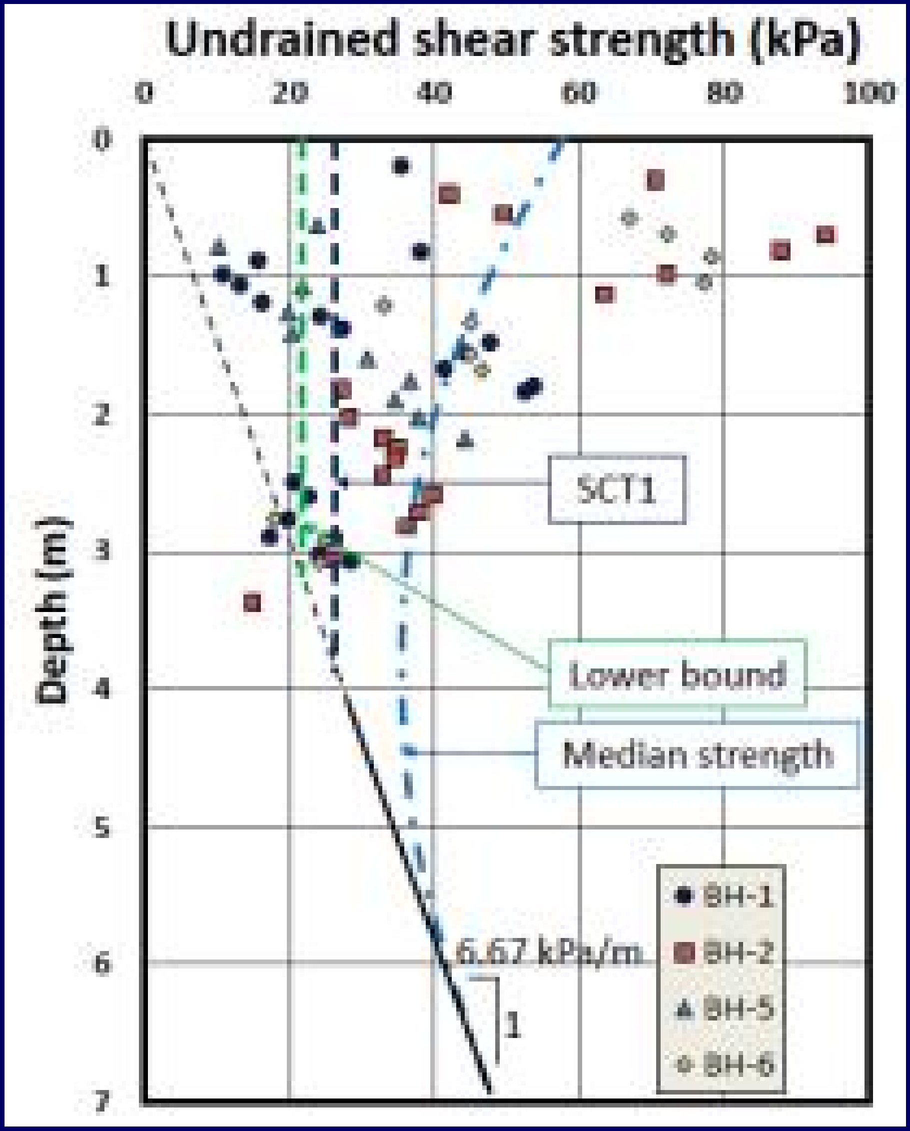
- Faulting
- Seismic compression
- Liquefaction induced lateral spreading
- Cyclic slope instability/ landsliding


: Ground crack and direction of movement
: Building rotation and direction of roof tilt
3 : Location of photographs
River Bed
Araniko Highway
B1
B2
B3
B4
B5
B6
X
X'
3L
3R
4L
4R
5L
5R
6UR
6UL
7UL
10U
11U
7UR
10L
8L
7LL
7LR
8R
6LL
6L
R
11L
Google earth
Image © 2016 DigitalGlobe
N


GEOTECHNICS
VANE
1626
MADE IN

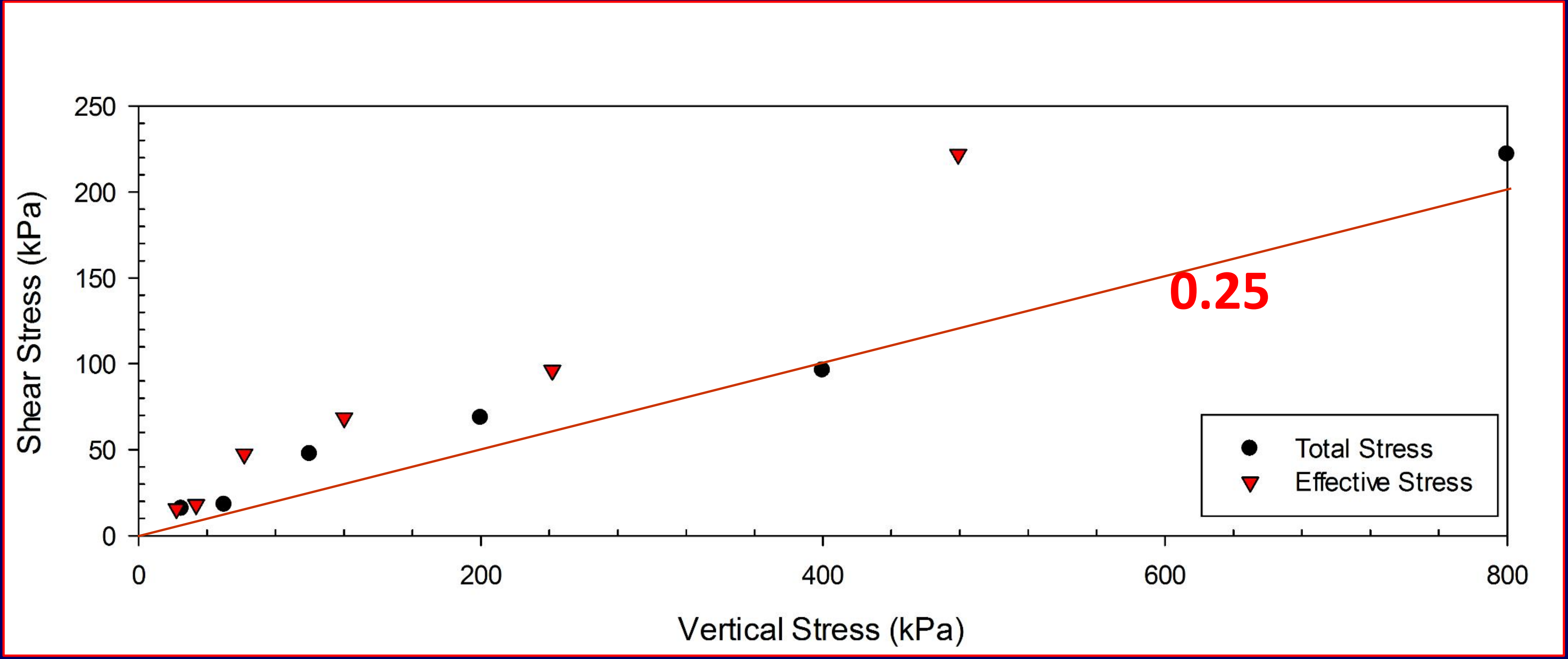


Undrained shear strength (kPa)
0
20
40
60
80
100
Depth (m)
SCT1
Lower bound
Median strength
6.67 kPa/m
1
SCT-1
SCT-2
SCT-3

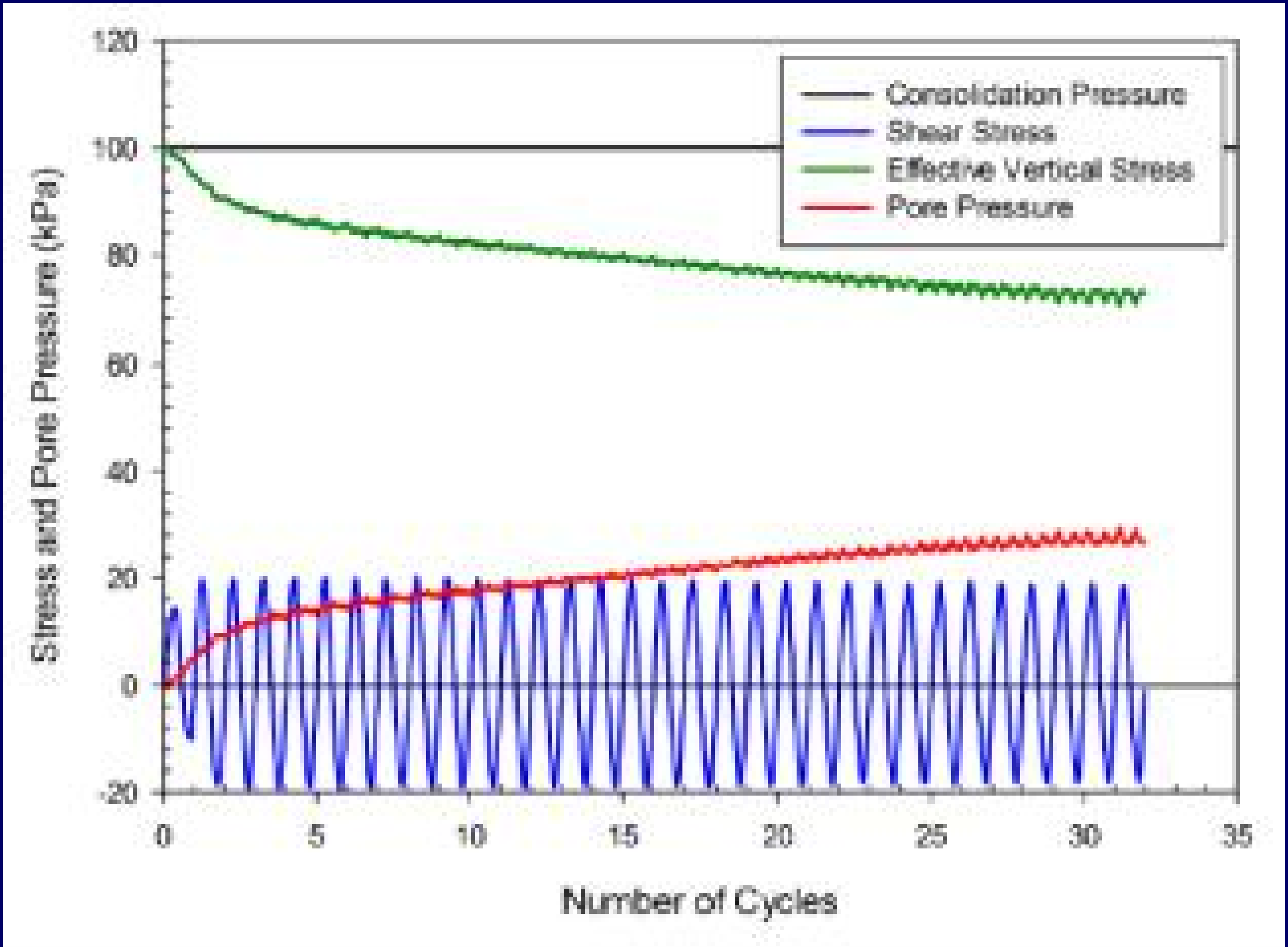


Undrained shear strength (kPa)
0
20
40
60
80
100
Depth (m)
SCT1
Lower bound
Median strength
6.67 kPa/m
1
BH-1
BH-2
BH-5
BH-6

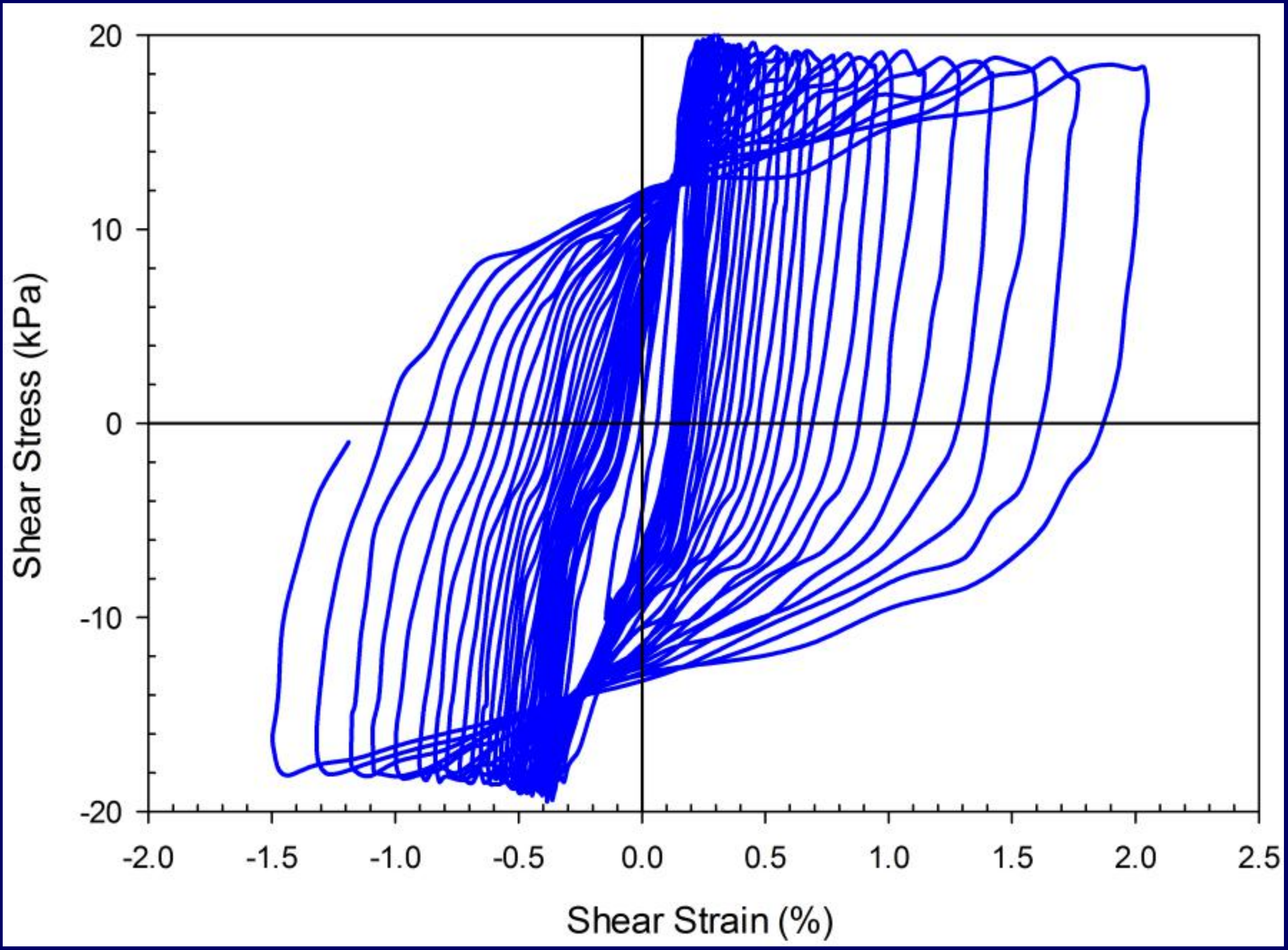
Monotonic Simple Shear

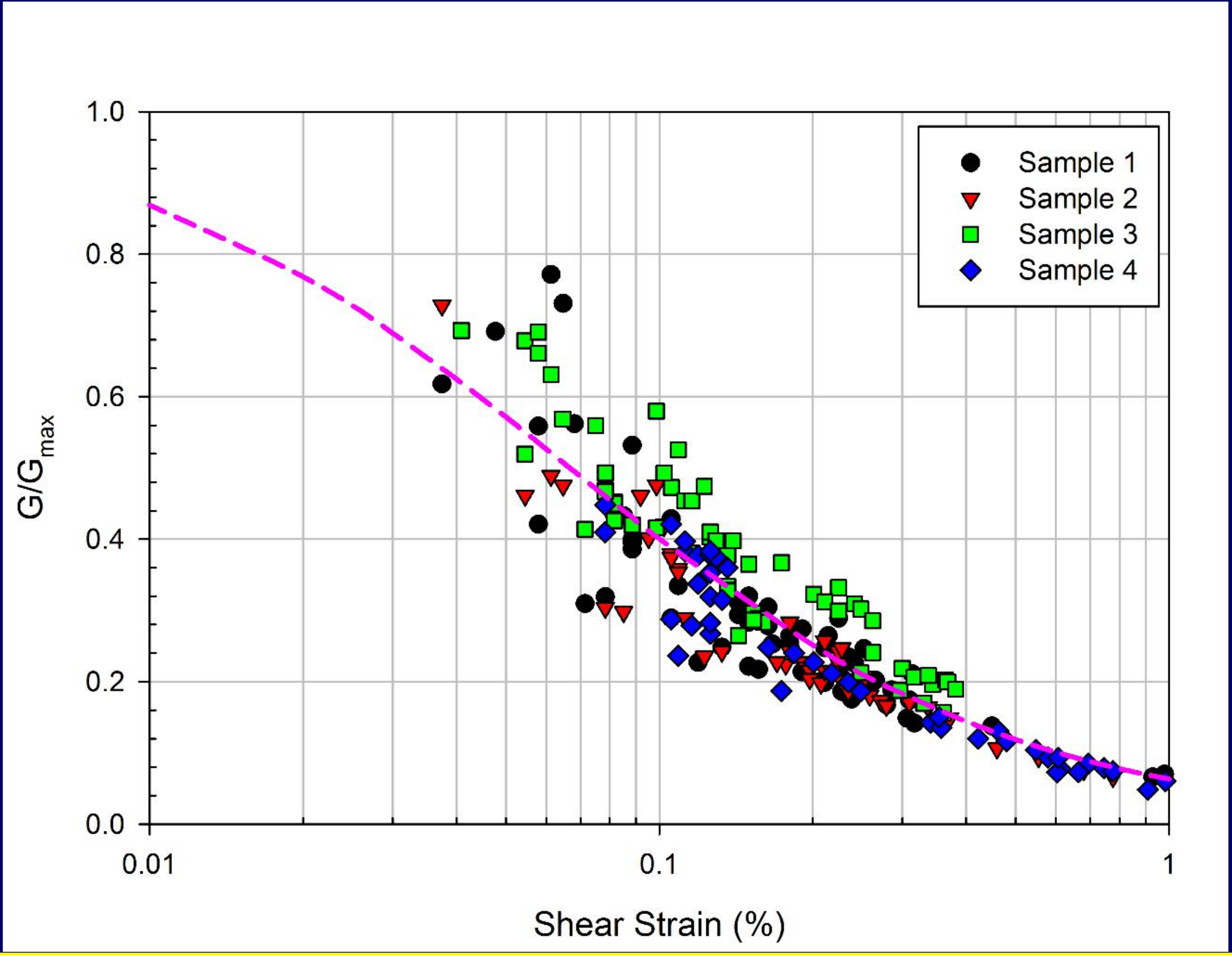


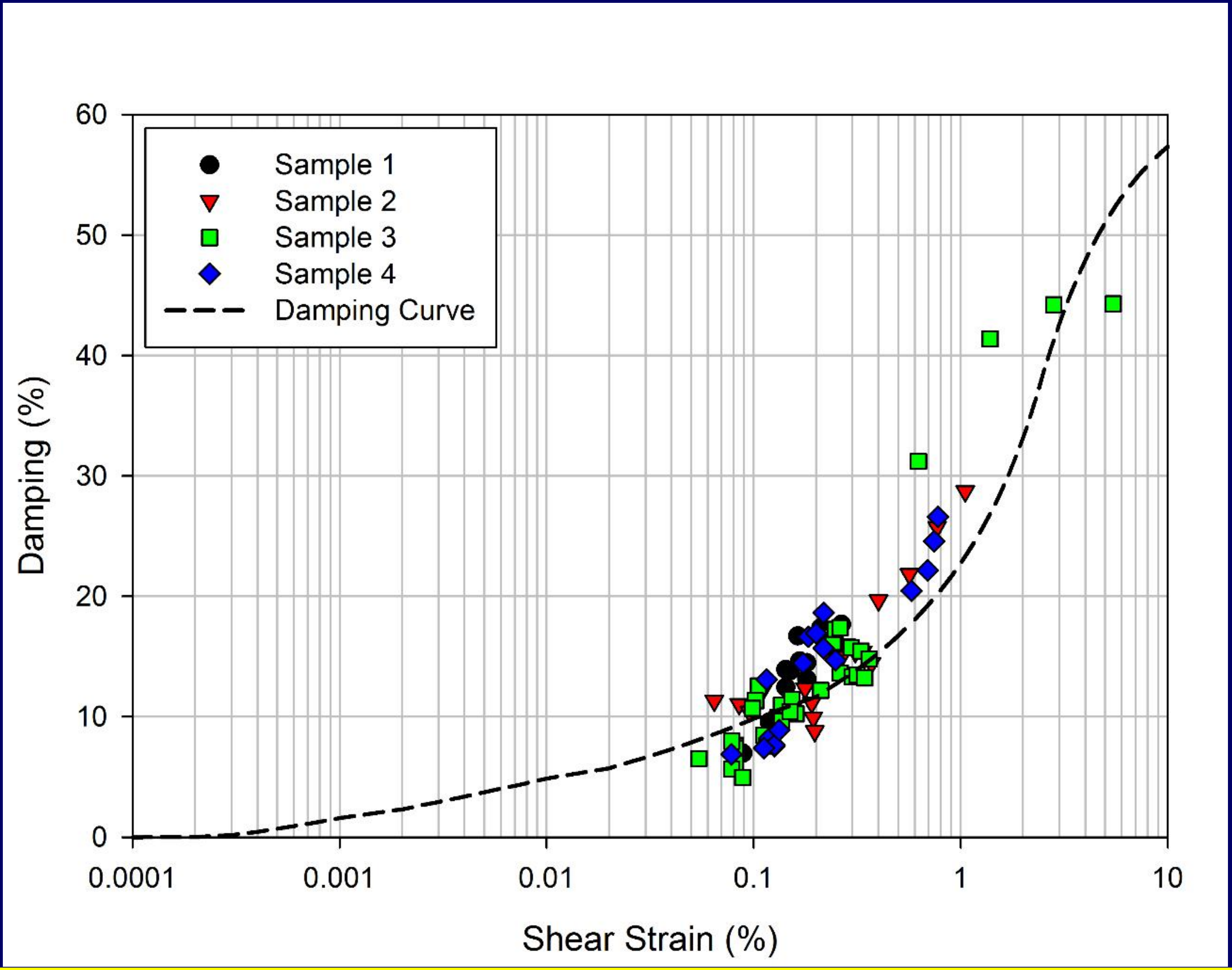
USR = 0.25 – 0.40 **ϕ'_{fs} = 24° (average)**

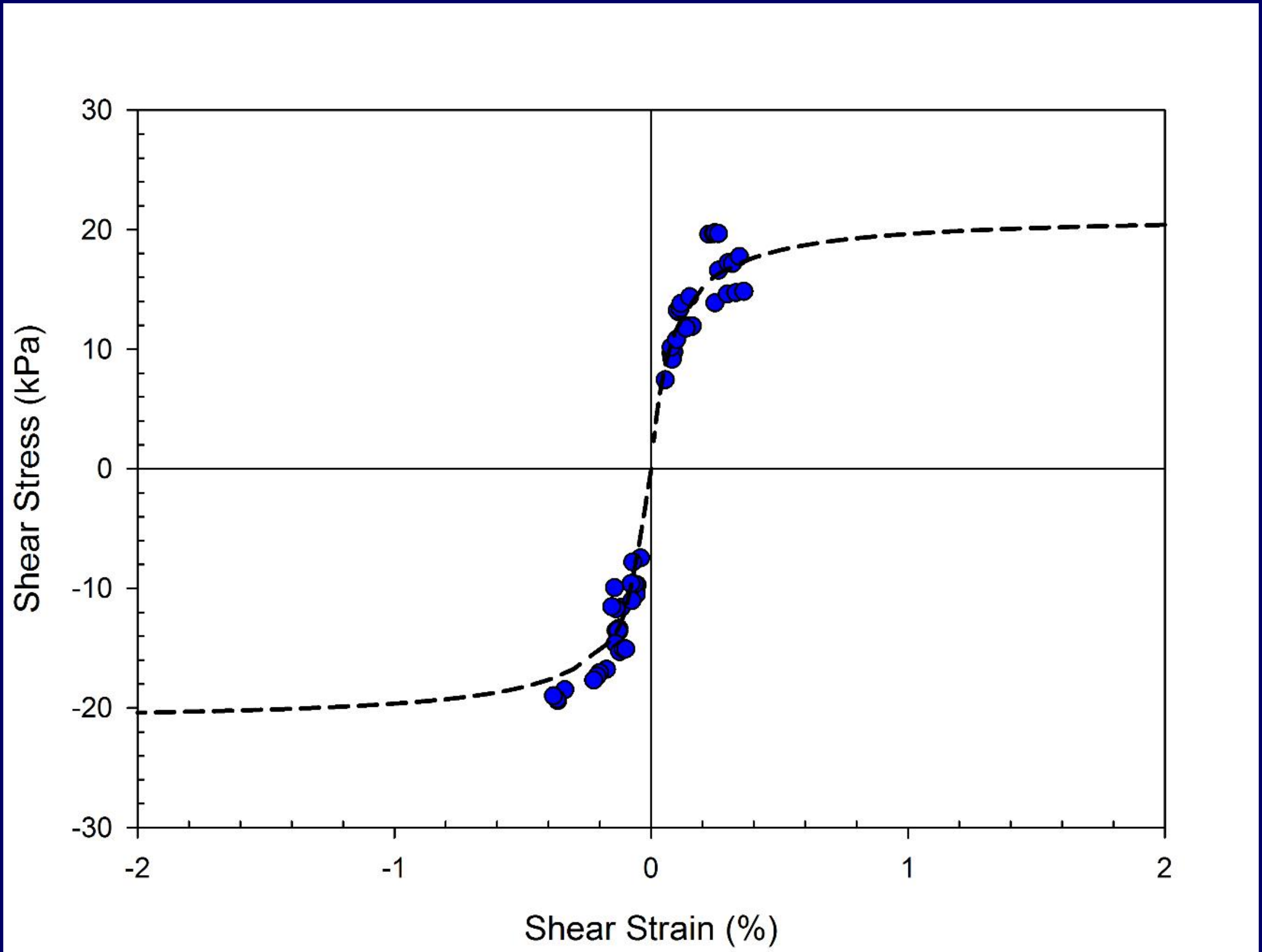

Consolidation Pressure
Shear Stress
Effective Vertical Stress
Pore Pressure
Stress and Pore Pressure (kPa)
120
100
80
60
40
20
0
-20
0
5
10
15
20
25
30
35
Number of Cycles

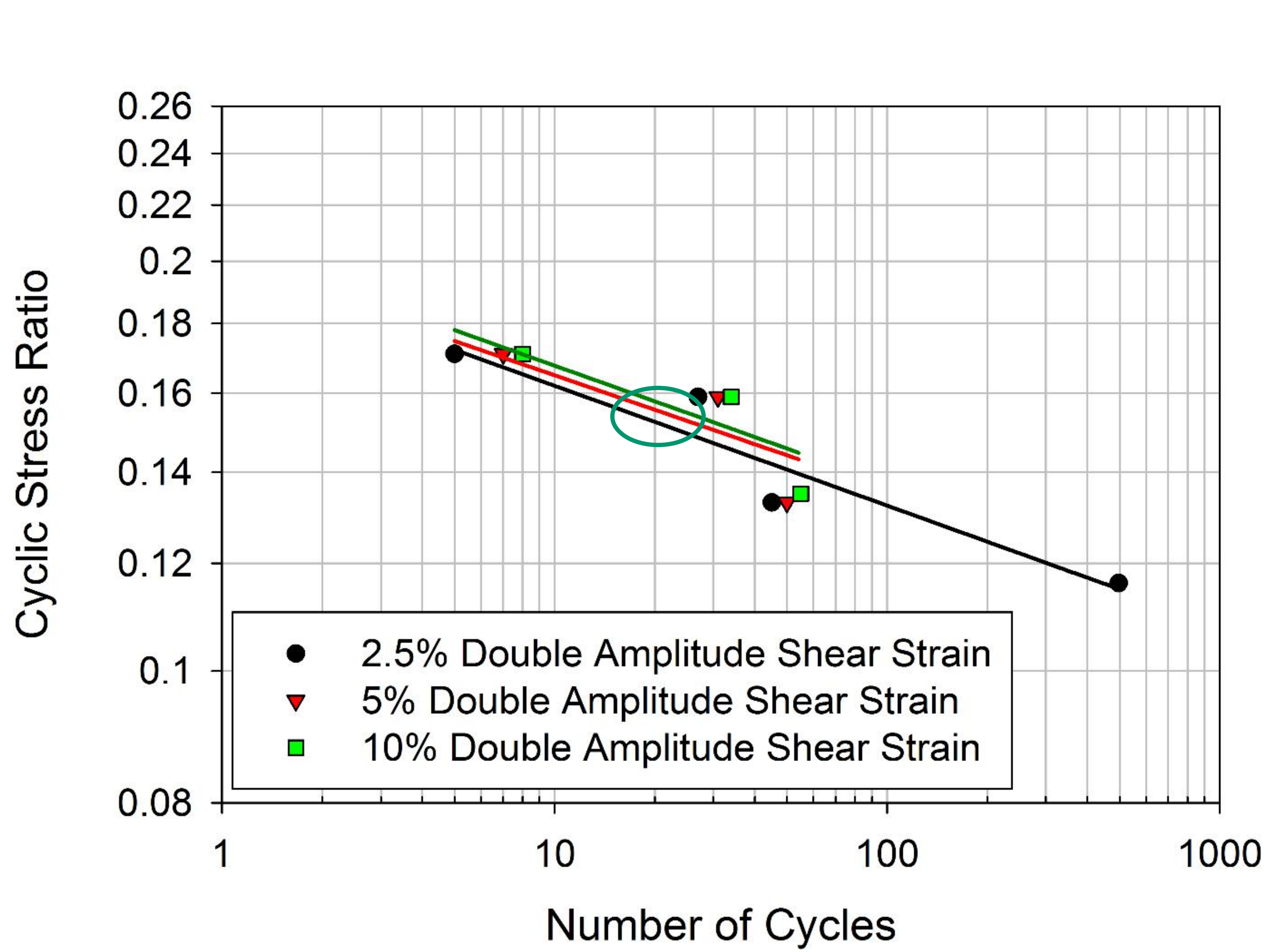
Cyclic Simple Shear



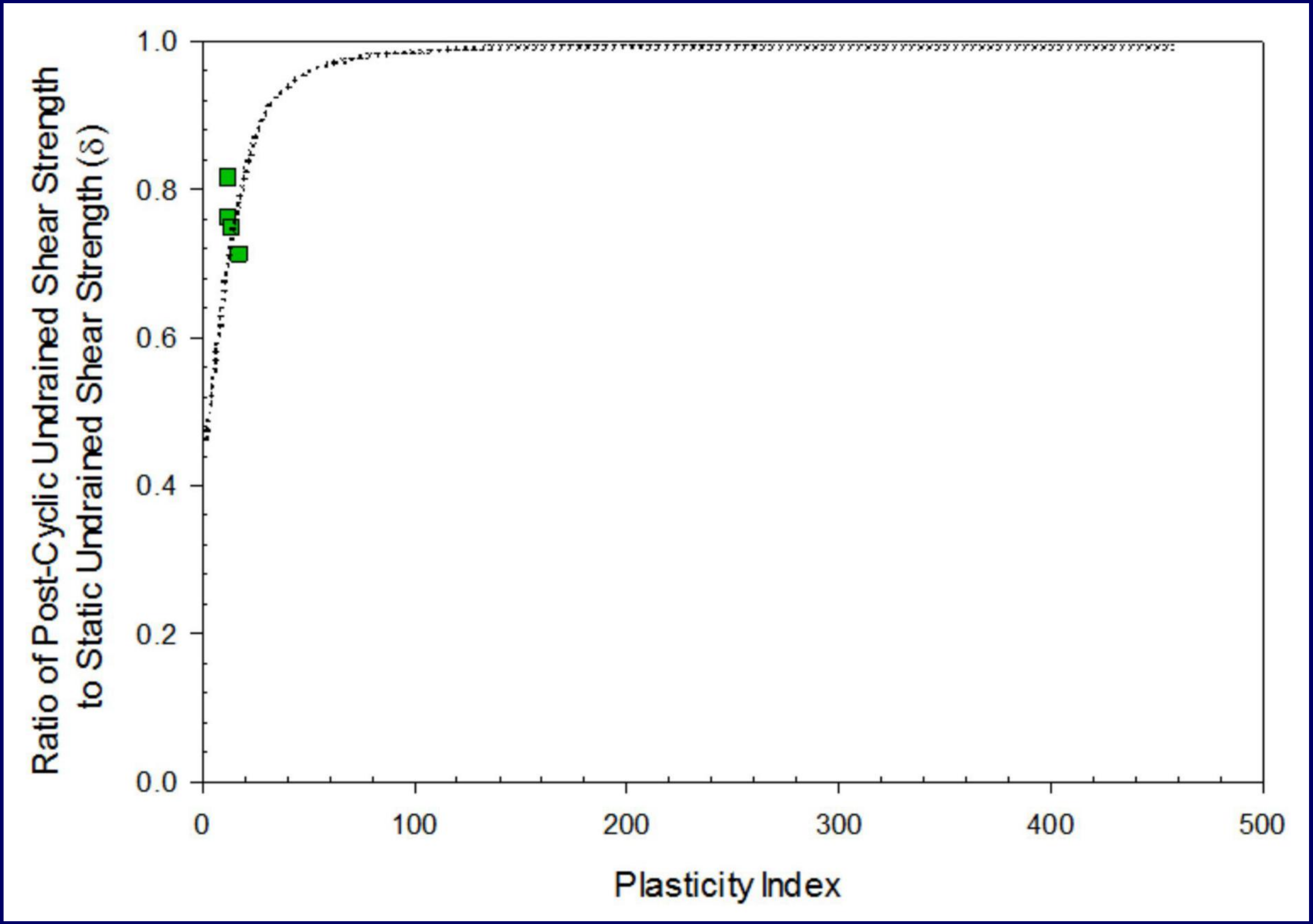

1.0
0.8
0.6
0.4
0.2
0.0
G/G max
0.01
0.1
1
Shear Strain (%)
Sample 1
Sample 2
Sample 3
Sample 4


60
50
40
30
20
10
0
Damping (%)
Sample 1
Sample 2
Sample 3
Sample 4
Damping Curve
0.0001
0.001
0.01
0.1
1
10
Shear Strain (%)

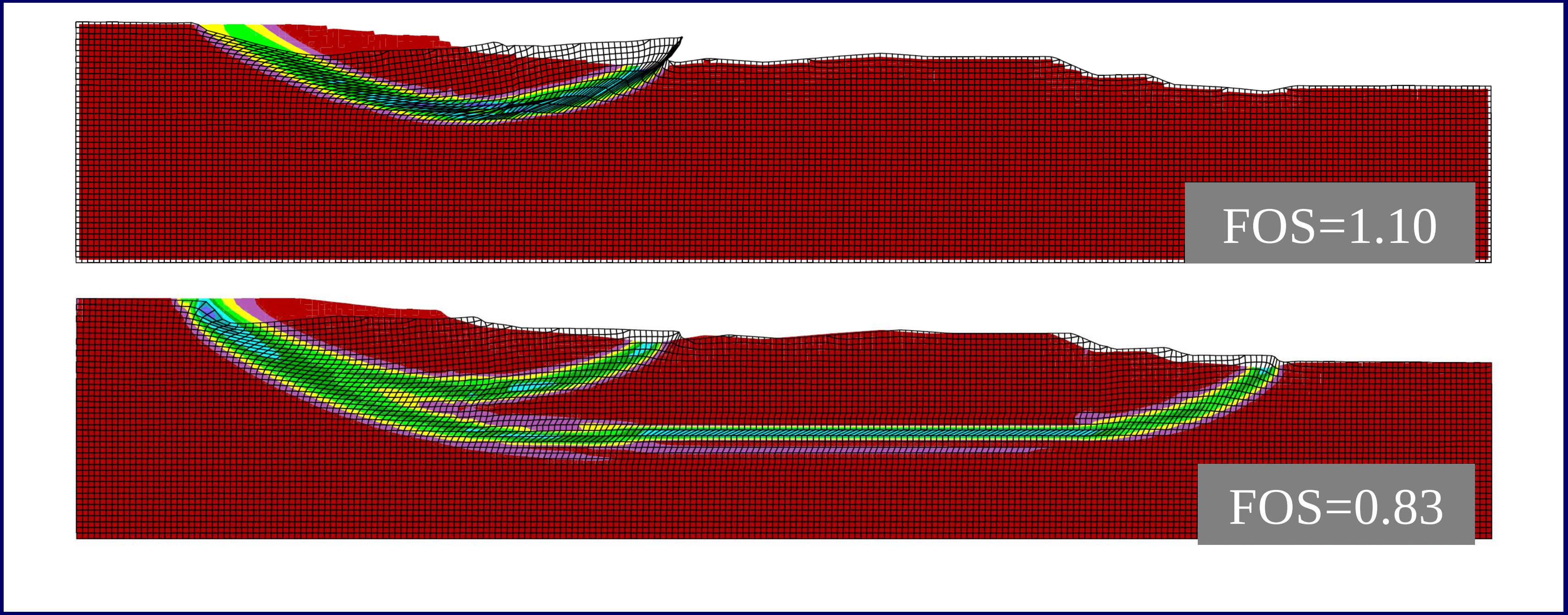

Shear Stress (kPa)
30
20
10
0
-10
-20
-30
-2
-1
0
1
2
Shear Strain (%)



Cyclic Stress Ratio
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
1
10
100
1000
Number of Cycles
2.5% Double Amplitude Shear Strain
5% Double Amplitude Shear Strain
10% Double Amplitude Shear Strain


Ratio of Post-Cyclic Undrained Shear Strength to Static Undrained Shear Strength (δ)
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
Plasticity Index

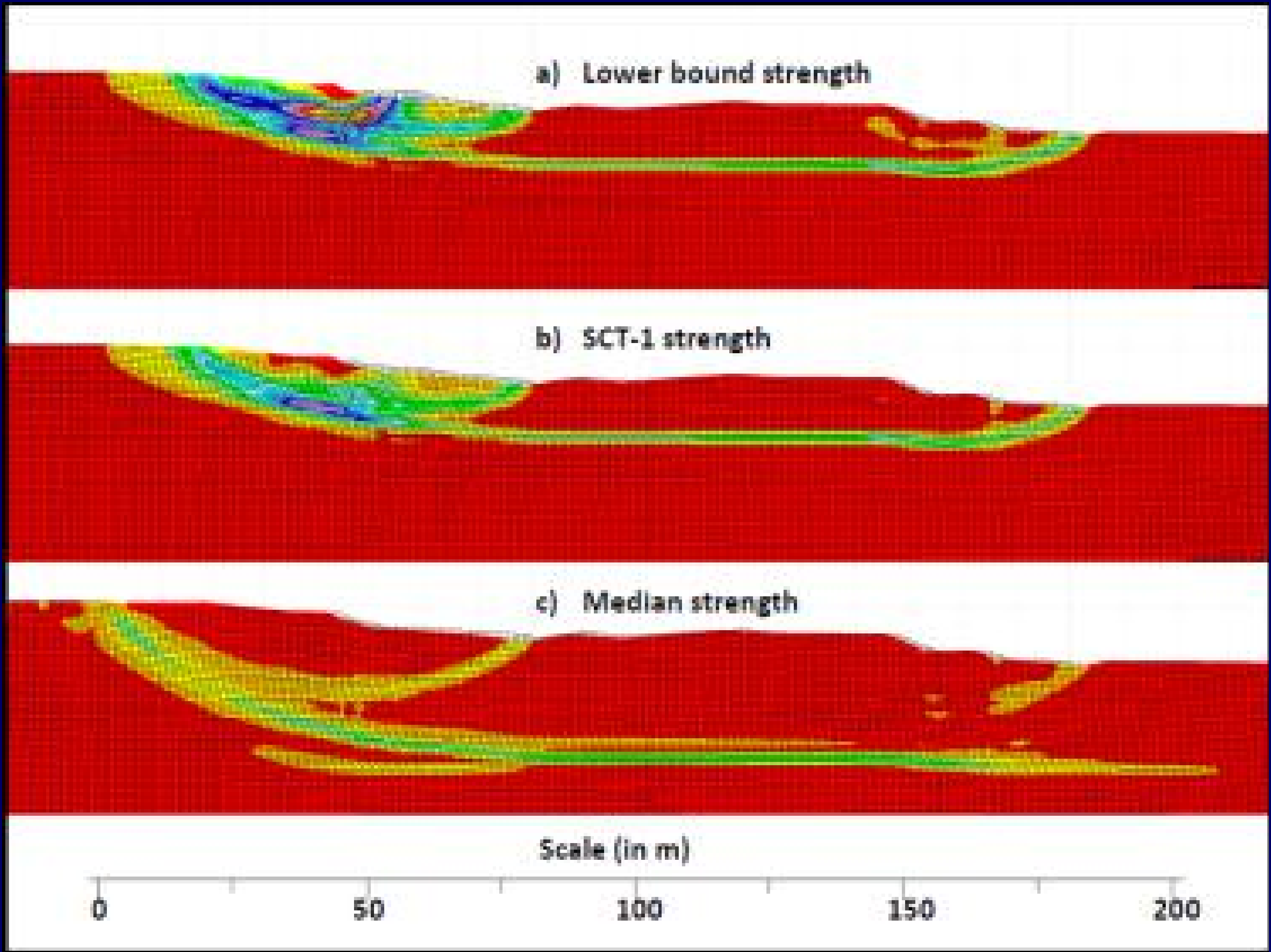
Critical pseudostatic failure mode obtained by the strength reduction method for 0.2g (top) and 0.3g (bottom)



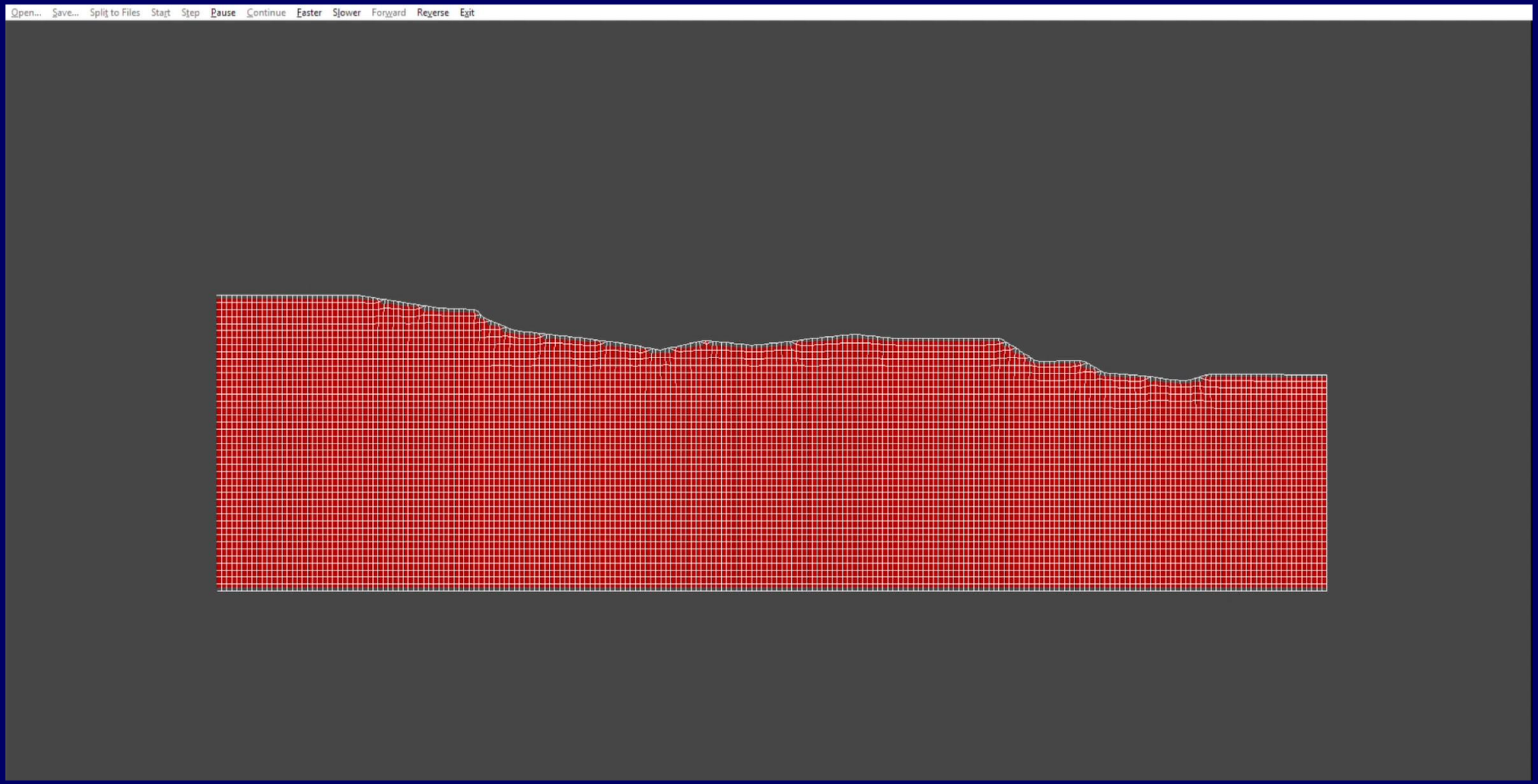
Note: mesh is 1 x 1 m

Dynamic Analysis (FLAC)

- Conducted non-linear dynamic geo-mechanical analysis using the deconvoluted ground motions from the recordings at the three nearby stations
- A quiet absorbing (viscous) boundary was used along the base of the model and free-field boundaries were placed along the edges to minimize wave reflections at model boundaries.
- SHAKE2000 was used to deconvolute the recorded ground motion and obtain input base velocities
- Laboratory based hysteresis loops were used for input damping characteristics.


a) Lower bound strength
b) SCT-1 strength
c) Median strength
Scale (in m)
0
50
100
150
200

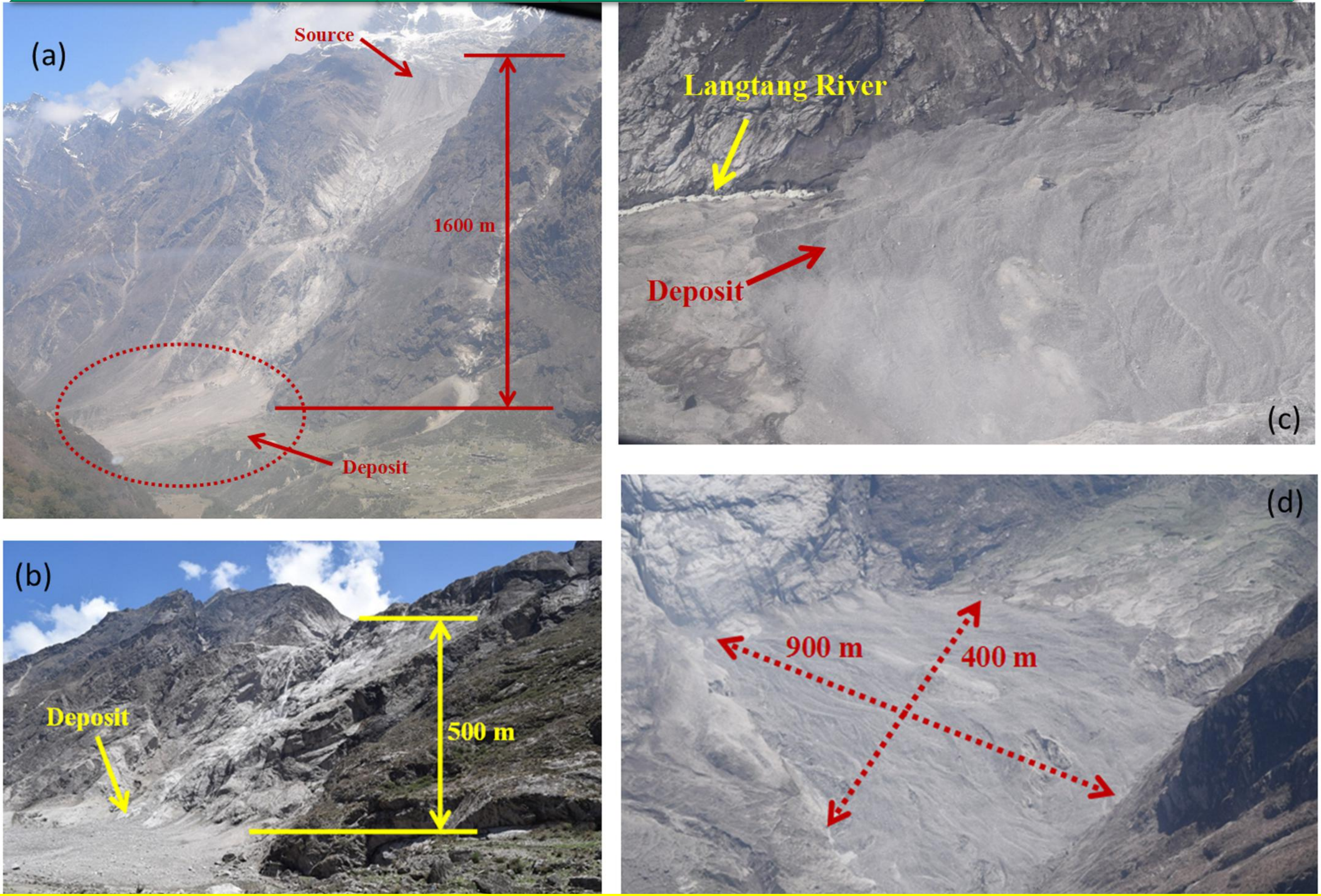
Simulation Result



Slope Stability and Landslides

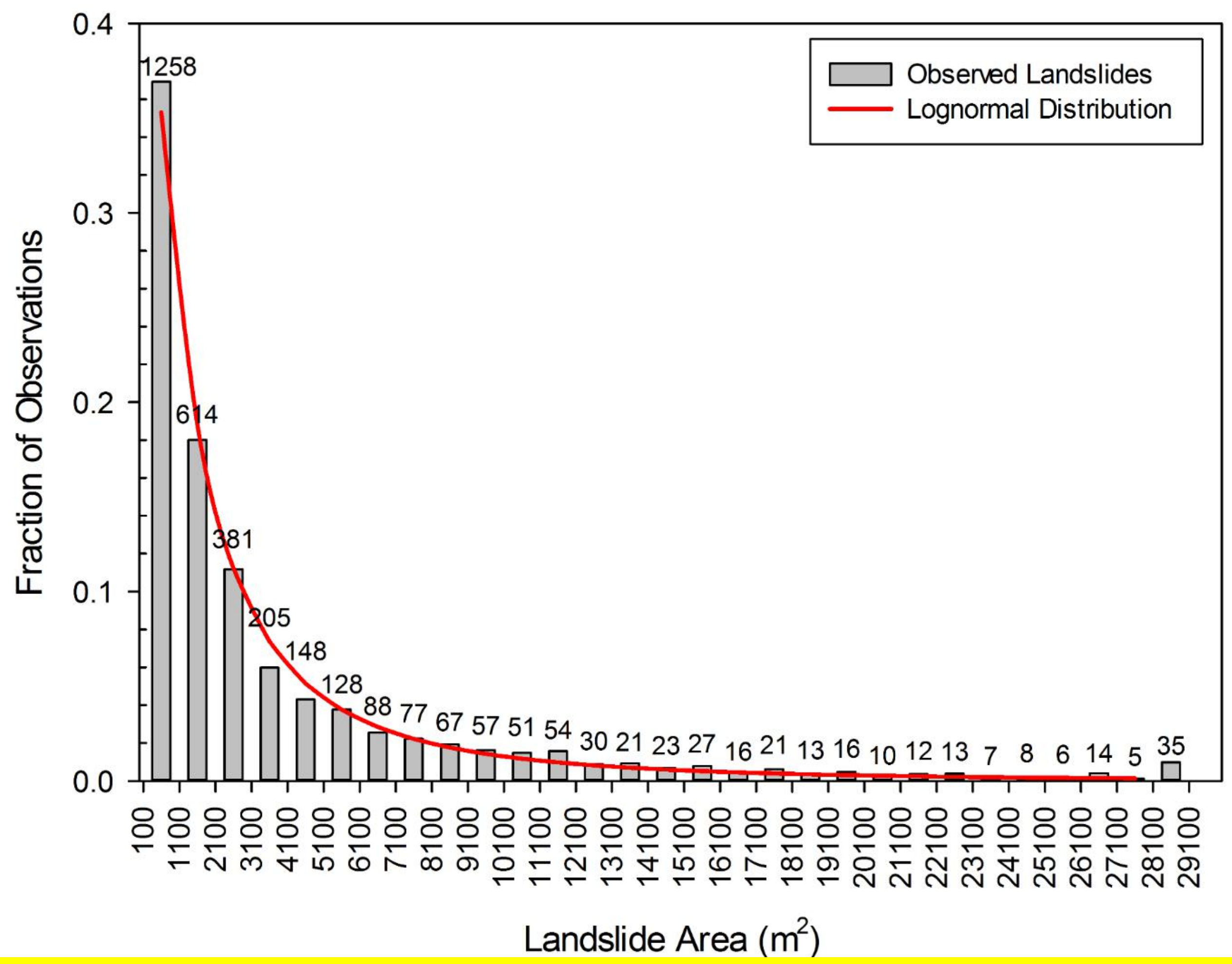
A total of 15,000 (3,500 larger than 100 m^2) post-earthquake landslides were detected by aerial photo interpolation

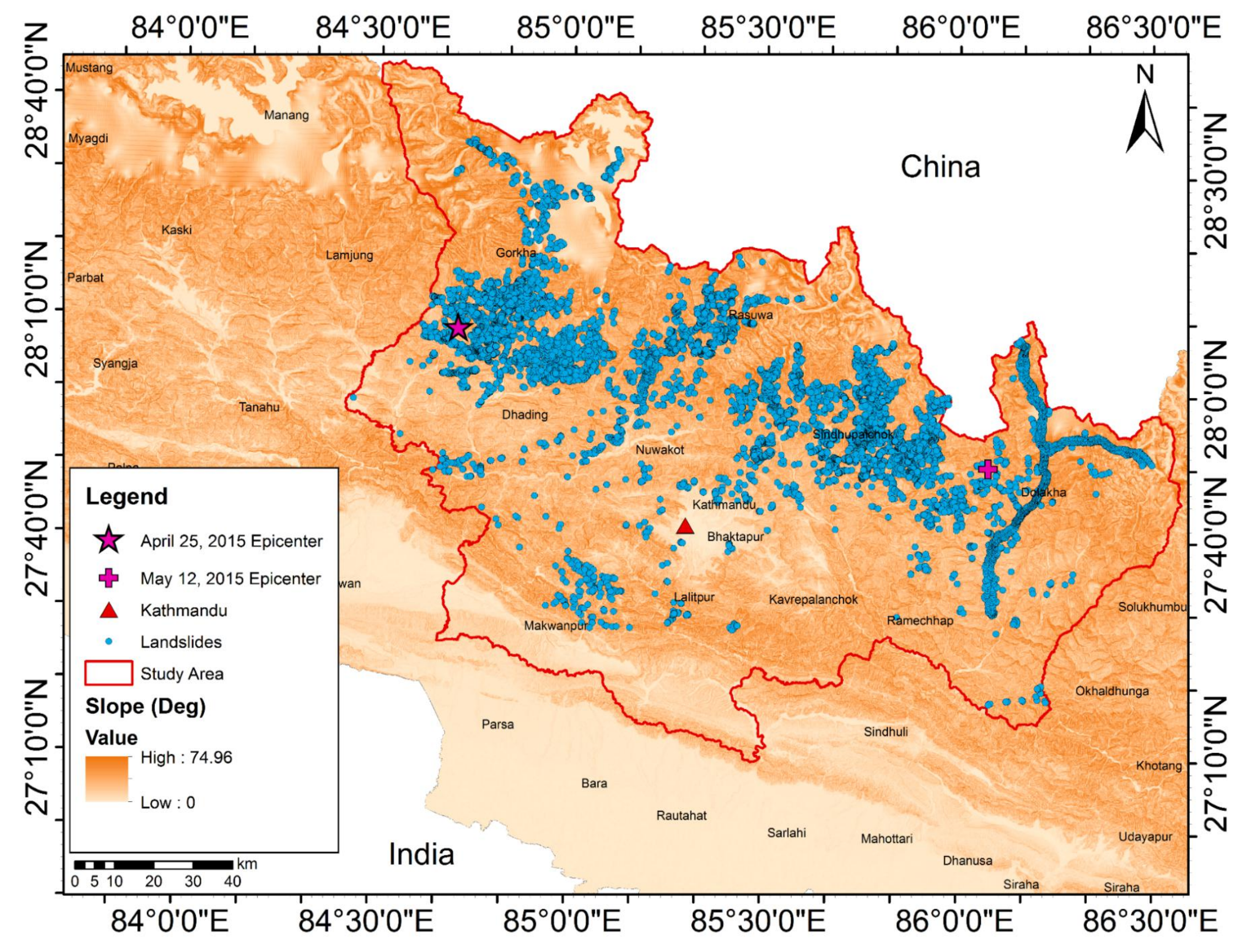
Tiwari, B., Ajmera, B., and *Dhital, S.,* CHARACTERISTICS OF MODERATE TO LARGE SCALE LANDSLIDES TRIGGERED BY THE Mw 7.8 2015 GORKHA EARTHQUAKE AND ITS AFTERSHOCKS, *Landslides*, 14 (4), 1297-1318).


(a)
Source
1600 m
Deposit
(c)
Langtang River
Deposit
(b)
Deposit
500 m
(d)
900 m
400 m

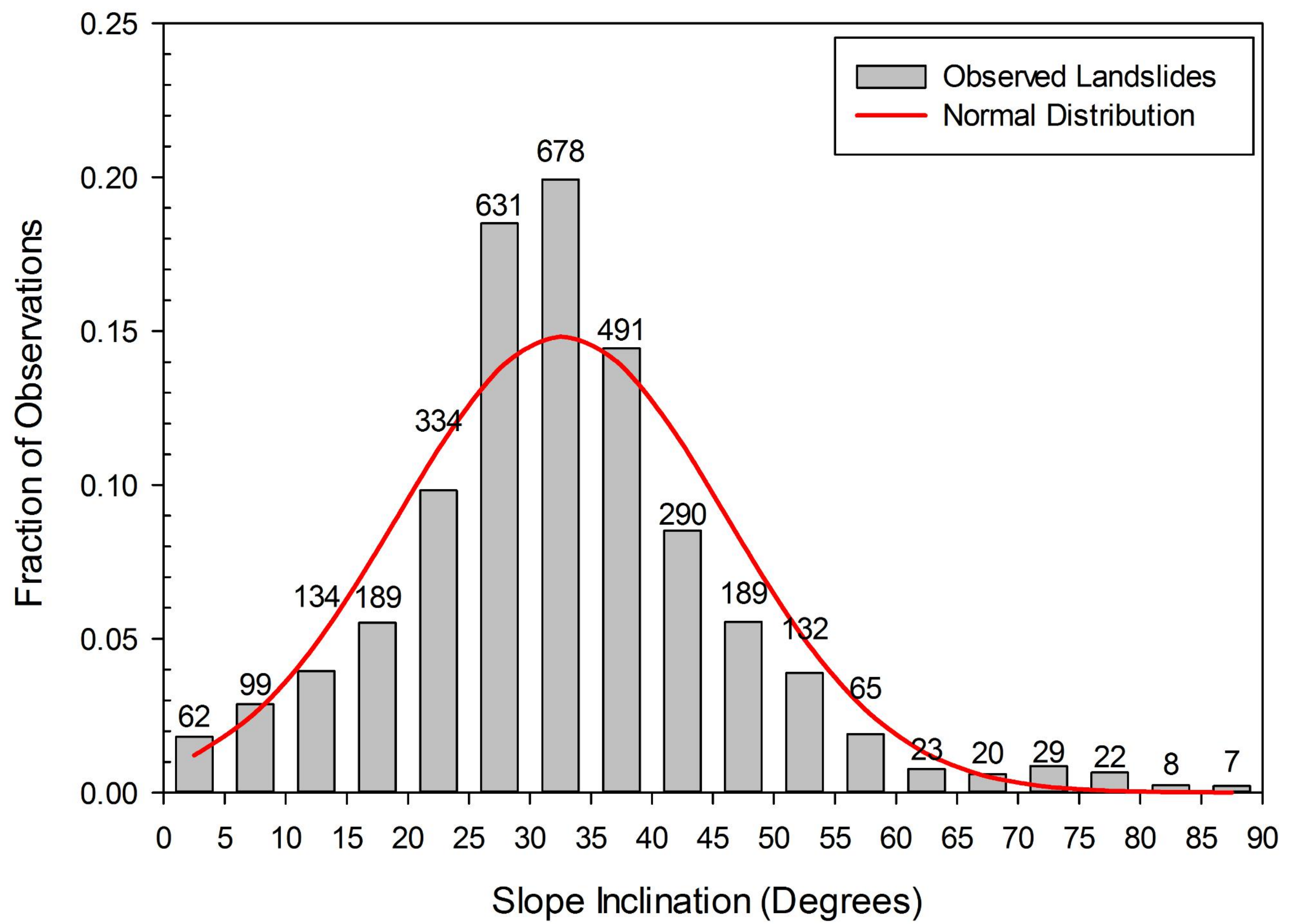
Characteristics of Co-seismic Landslides

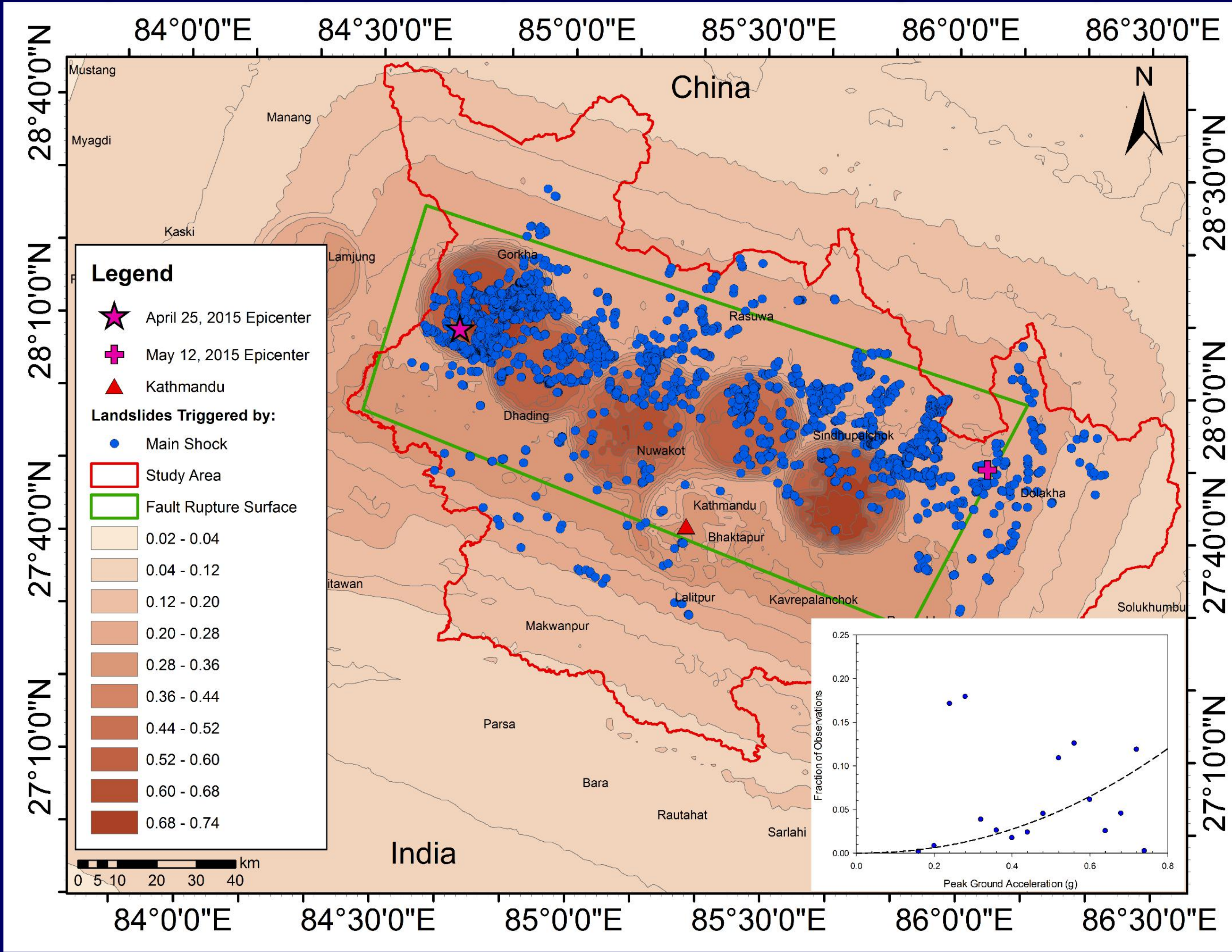
- Total landslides identified: 14,670
- Total number with areas larger than 100 m^2: 3403



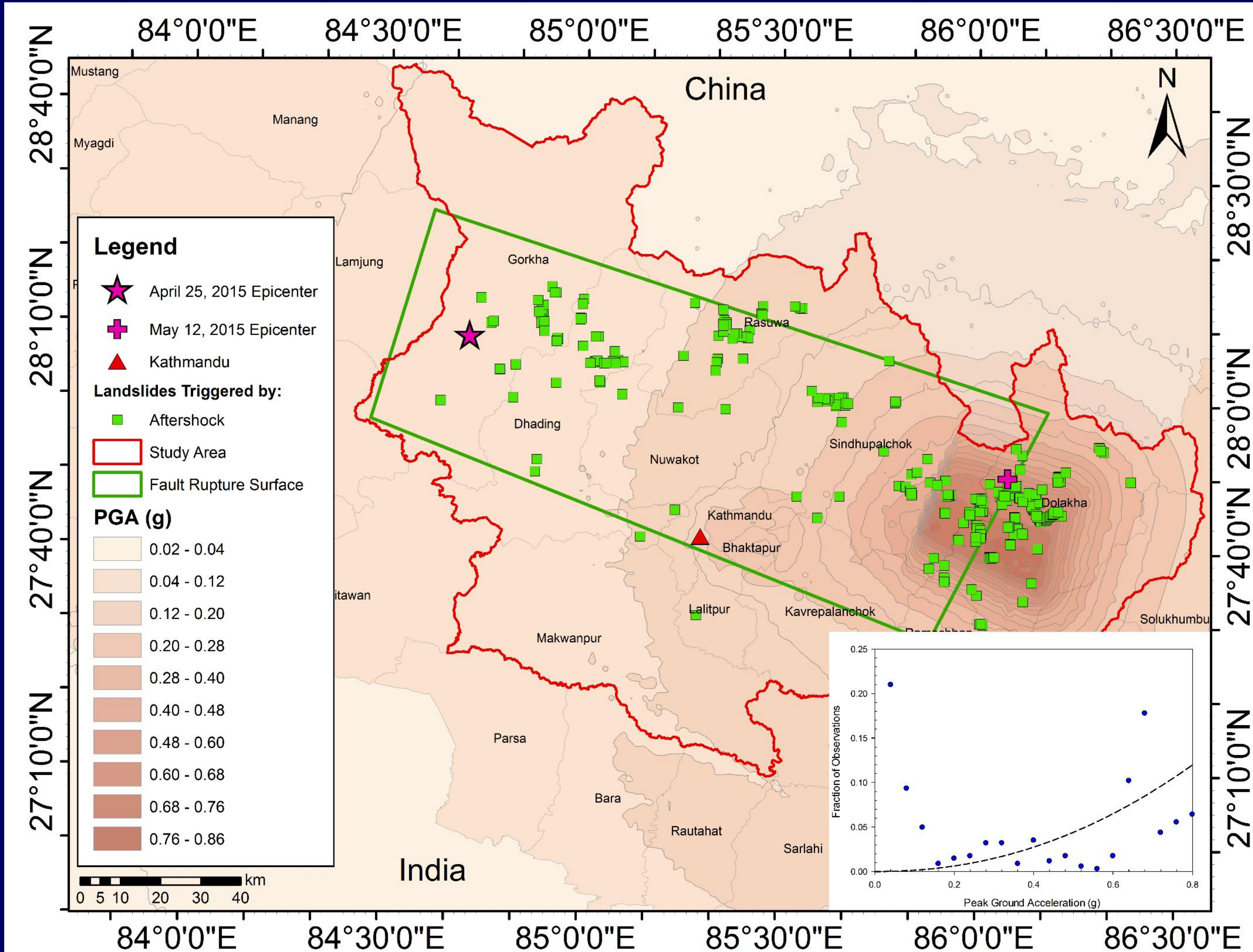


84°0'0"E
84°30'0"E
85°0'0"E
85°30'0"E
86°0'0"E
86°30'0"E
28°40'0"N
28°10'0"N
27°40'0"N
27°10'0"N
28°30'0"N
28°0'0"N
N
China
India
Mustang
Manang
Myagdi
Kaski
Lamjung
Gorkha
Parbat
Rasuwa
Syangja
Tanahu
Dhading
Sindhupalchok
Nuwakot
Dolakha
Kathmandu
Bhaktapur
Lalitpur
Kavrepalanchok
Solukhumbu
Makwanpur
Ramechhap
Okhaldhunga
Parsa
Sindhuli
Khotang
Bara
Rautahat
Sarlahi
Mahottari
Udayapur
Dhanusa
Siraha
Legend
April 25, 2015 Epicenter
May 12, 2015 Epicenter
Kathmandu
Landslides
Study Area
Slope (Deg)
Value
High : 74.96
Low : 0
km
0 5 10 20 30 40


Observed Landslides
Normal Distribution
Fraction of Observations
Slope Inclination (Degrees)
0.25
0.20
0.15
0.10
0.05
0.00
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
62
99
134
189
334
631
678
491
290
189
132
65
23
20
29
22
8
7



84°0'0"E
84°30'0"E
85°0'0"E
85°30'0"E
86°0'0"E
86°30'0"E
28°40'0"N
28°30'0"N
28°10'0"N
28°0'0"N
27°40'0"N
27°10'0"N
China
India
N
Mustang
Manang
Myagdi
Kaski
Lamjung
Gorkha
Rasuwa
Dhading
Nuwakot
Sindhupalchok
Dolakha
Kathmandu
Bhaktapur
Lalitpur
Kavrepalanchok
Makwanpur
Solukhumbu
Parsa
Bara
Rautahat
Sarlahi
Legend
April 25, 2015 Epicenter
May 12, 2015 Epicenter
Kathmandu
Landslides Triggered by:
Main Shock
Study Area
Fault Rupture Surface
0.02 - 0.04
0.04 - 0.12
0.12 - 0.20
0.20 - 0.28
0.28 - 0.36
0.36 - 0.44
0.44 - 0.52
0.52 - 0.60
0.60 - 0.68
0.68 - 0.74
0 5 10 20 30 40 km
Fraction of Observations
Peak Ground Acceleration (g)
0.00
0.05
0.10
0.15
0.20
0.25
0.0
0.2
0.4
0.6
0.8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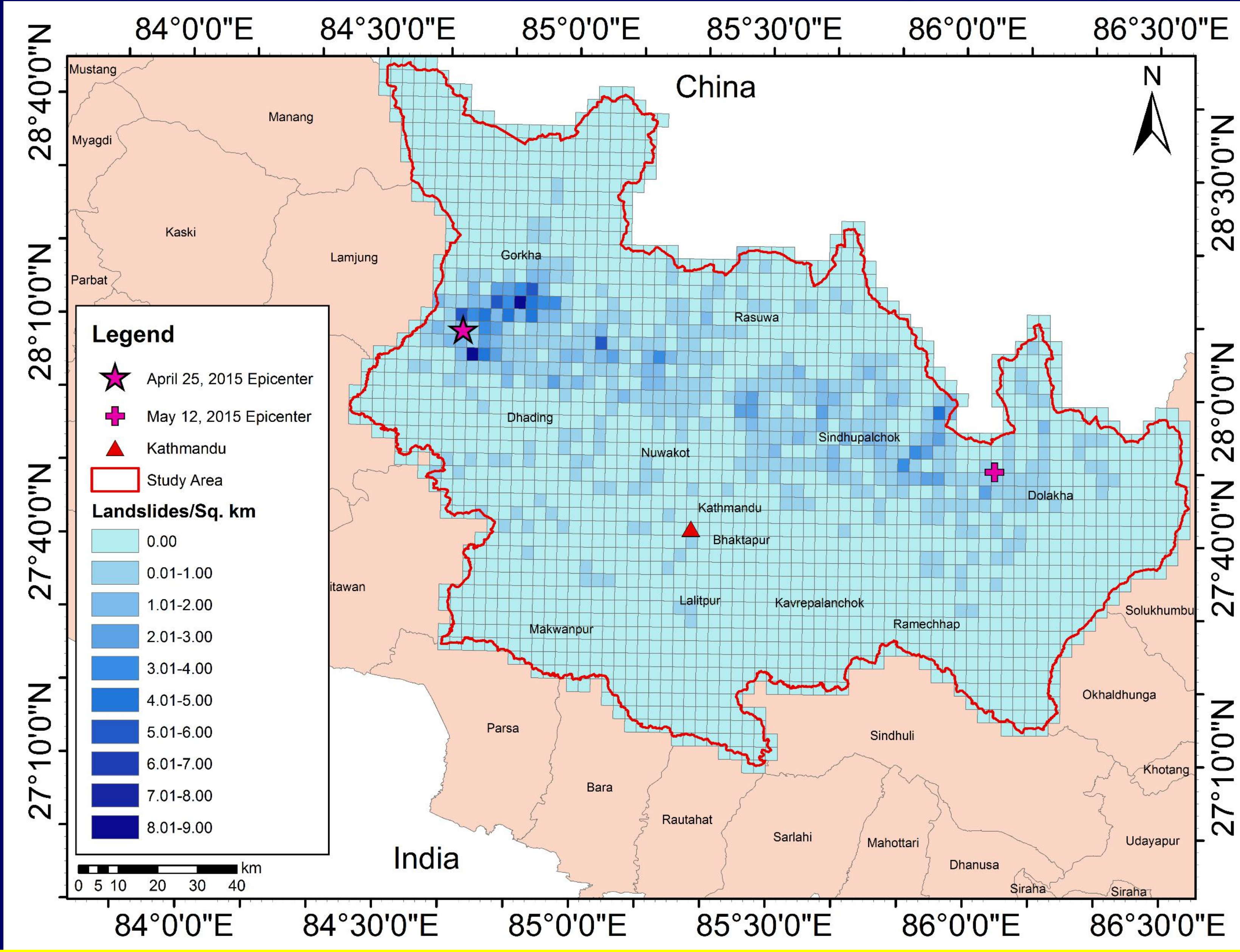
86°30'0"E
28°40'0"N
28°30'0"N
28°10'0"N
28°0'0"N
27°40'0"N
27°10'0"N
China
India
N
Mustang
Manang
Myagdi
Lamjung
Gorkha
Rasuwa
Dhading
Nuwakot
Sindhupalchok
Dolakha
Kathmandu
Bhaktapur
Lalitpur
Kavrepalanchok
Makwanpur
Parsa
Bara
Rautahat
Sarlahi
Solukhumbu
itawan
Legend
April 25, 2015 Epicenter
May 12, 2015 Epicenter
Kathmandu
Landslides Triggered by:
Aftershock
Study Area
Fault Rupture Surface
PGA (g)
0.02 - 0.04
0.04 - 0.12
0.12 - 0.20
0.20 - 0.28
0.28 - 0.40
0.40 - 0.48
0.48 - 0.60
0.60 - 0.68
0.68 - 0.76
0.76 - 0.86
0 5 10 20 30 40 km
Fraction of Observations
Peak Ground Acceleration (g)
0.00
0.05
0.10
0.15
0.20
0.25
0.0
0.2
0.4
0.6
0.8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86°30'0"E
28°40'0"N
28°30'0"N
28°10'0"N
28°0'0"N
27°40'0"N
27°10'0"N
China
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Lamjung
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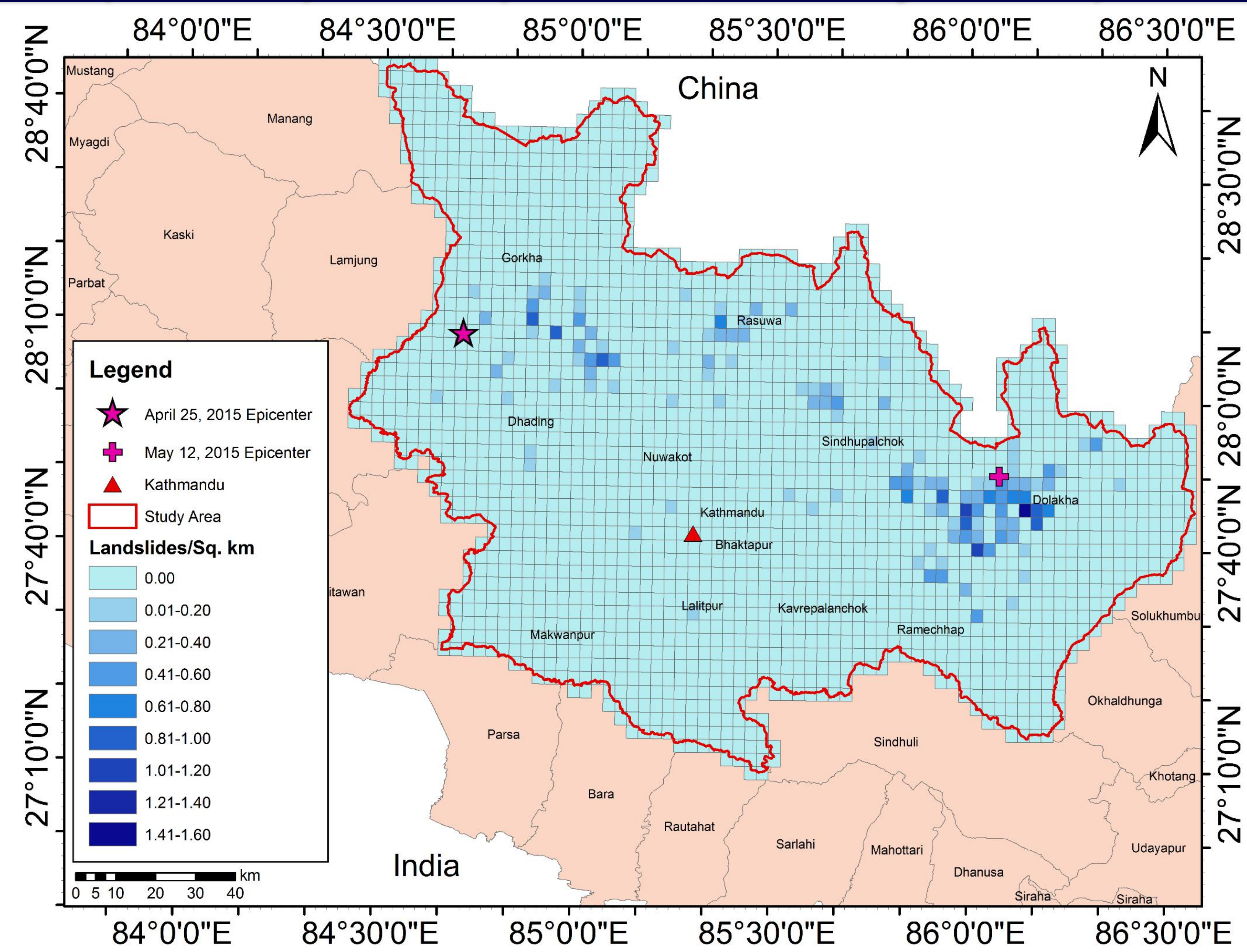
Rasuwa
Dhading
Nuwakot
Sindhupalchok
Dolakha
Kathmandu
Bhaktapur
Lalitpur
Kavrepalanchok
Makwanpur
Ramechhap
Solukhumbu
Okhaldhunga
Parsa
Bara
Rautahat
Sarlahi
Mahottari
Dhanusa
Siraha
Sindhuli
Khotang
Udayapur
itawan
Legend
April 25, 2015 Epicenter
May 12, 2015 Epicenter
Kathmandu
Study Area
Landslides/Sq. km
0.00
0.01-1.00
1.01-2.00
2.01-3.00
3.01-4.00
4.01-5.00
5.01-6.00
6.01-7.00
7.01-8.00
8.01-9.00
km
0 5 10 20 30 40



84°0'0"E
84°30'0"E
85°0'0"E
85°30'0"E
86°0'0"E
86°30'0"E
28°40'0"N
28°10'0"N
27°40'0"N
27°10'0"N
28°30'0"N
28°0'0"N
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Bhaktapur
Lalitpur
Kavrepalanchok
Ramechhap
Makwanpur
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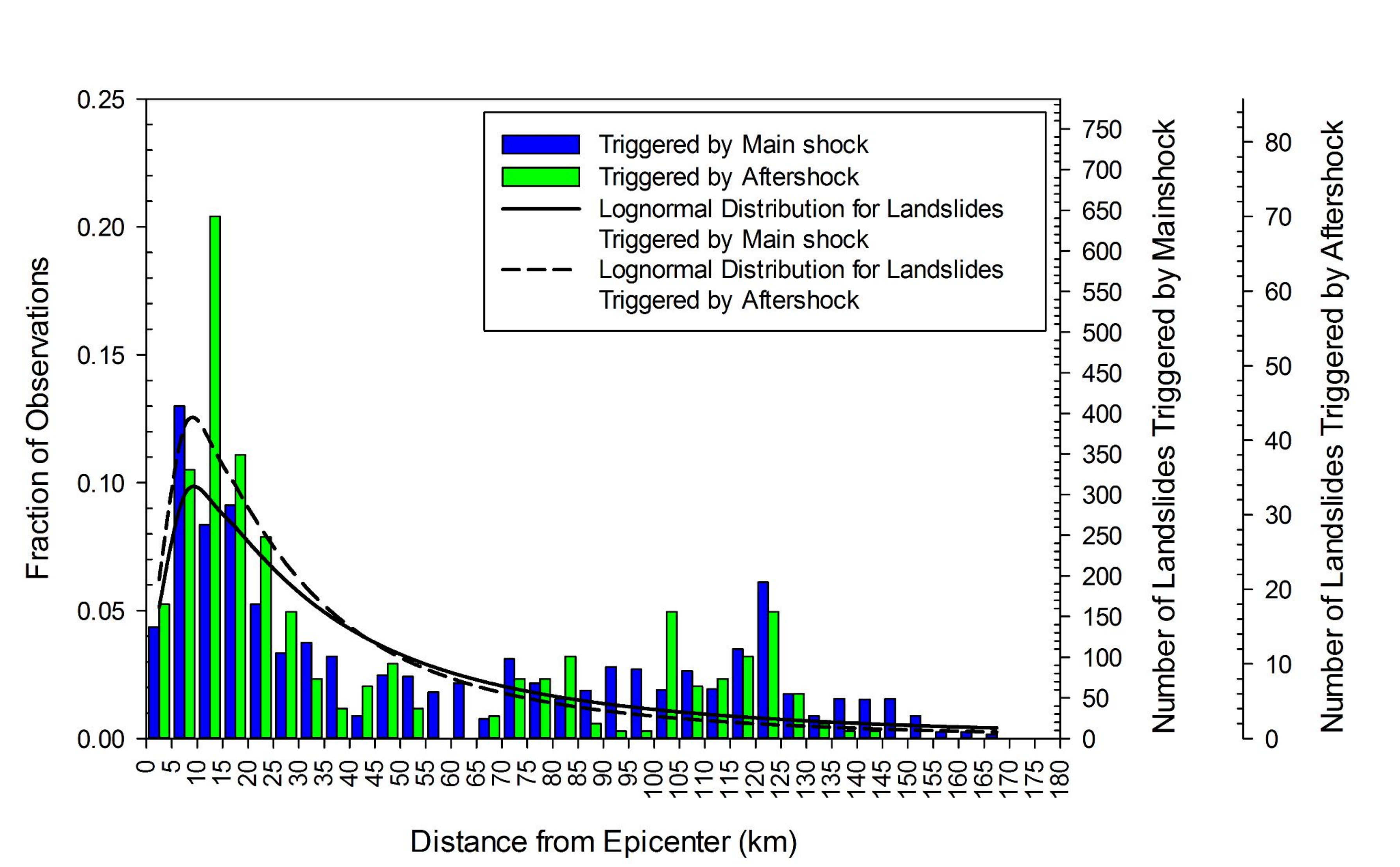
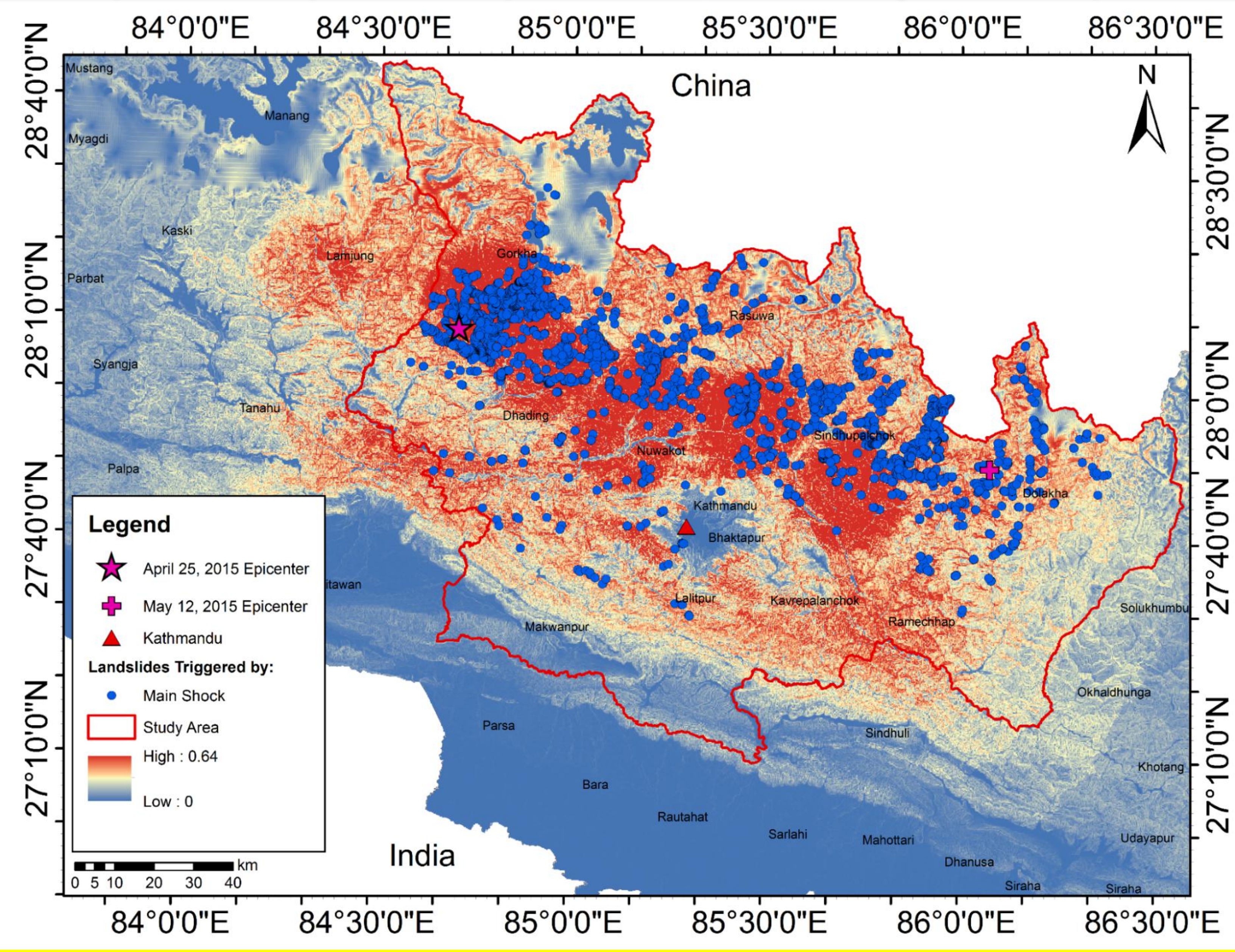
Okhaldhunga
Parsa
Sindhuli
Khotang
Bara
Rautahat
Sarlahi
Mahottari
Dhanusa
Udayapur
Siraha
Legend
April 25, 2015 Epicenter
May 12, 2015 Epicenter
Kathmandu
Study Area
Landslides/Sq. km
0.00
0.01-0.20
0.21-0.40
0.41-0.60
0.61-0.80
0.81-1.00
1.01-1.20
1.21-1.40
1.41-1.60
km
0 5 10 20 30 40


Triggered by Main shock
Triggered by Aftershock
Lognormal Distribution for Landslides Triggered by Main shock
Lognormal Distribution for Landslides Triggered by Aftershock
Fraction of Observations
0.25
0.20
0.15
0.10
0.05
0.00
Number of Landslides Triggered by Mainshock
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Number of Landslides Triggered by Aftershock
80
70
60
50
40
30
20
10
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180
Distance from Epicenter (km)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86°0'0"E
86°30'0"E
28°40'0"N
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Okhaldhunga
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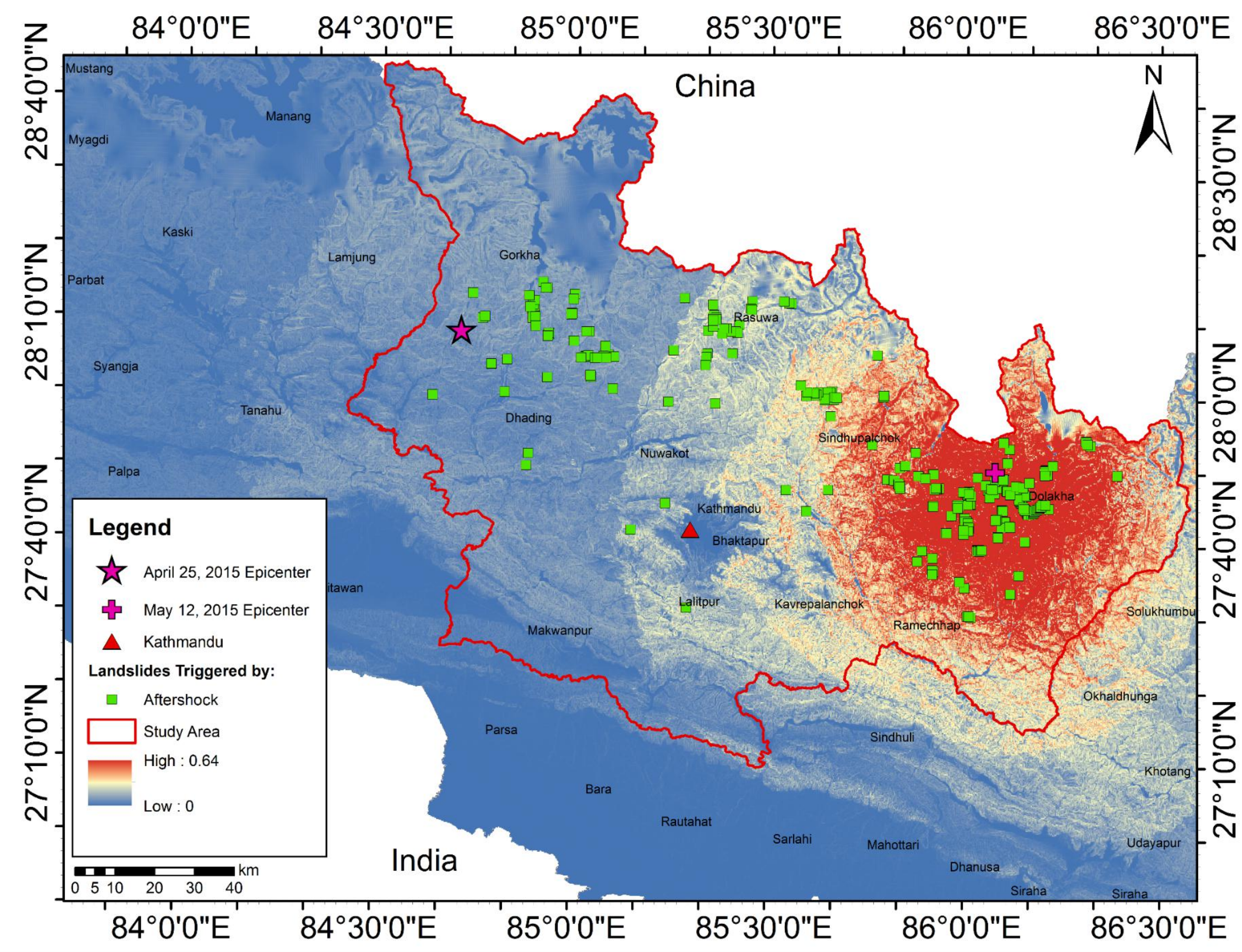
Khotang
Bara
Rautahat
Sarlahi
Mahottari
Udayapur
Dhanusa
Siraha
Legend
April 25, 2015 Epicenter
May 12, 2015 Epicenter
Kathmandu
Landslides Triggered by:
Main Shock
Study Area
High : 0.64
Low : 0
km
0 5 10 20 30 40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28°10'0"N
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27°10'0"N
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Dhanusa
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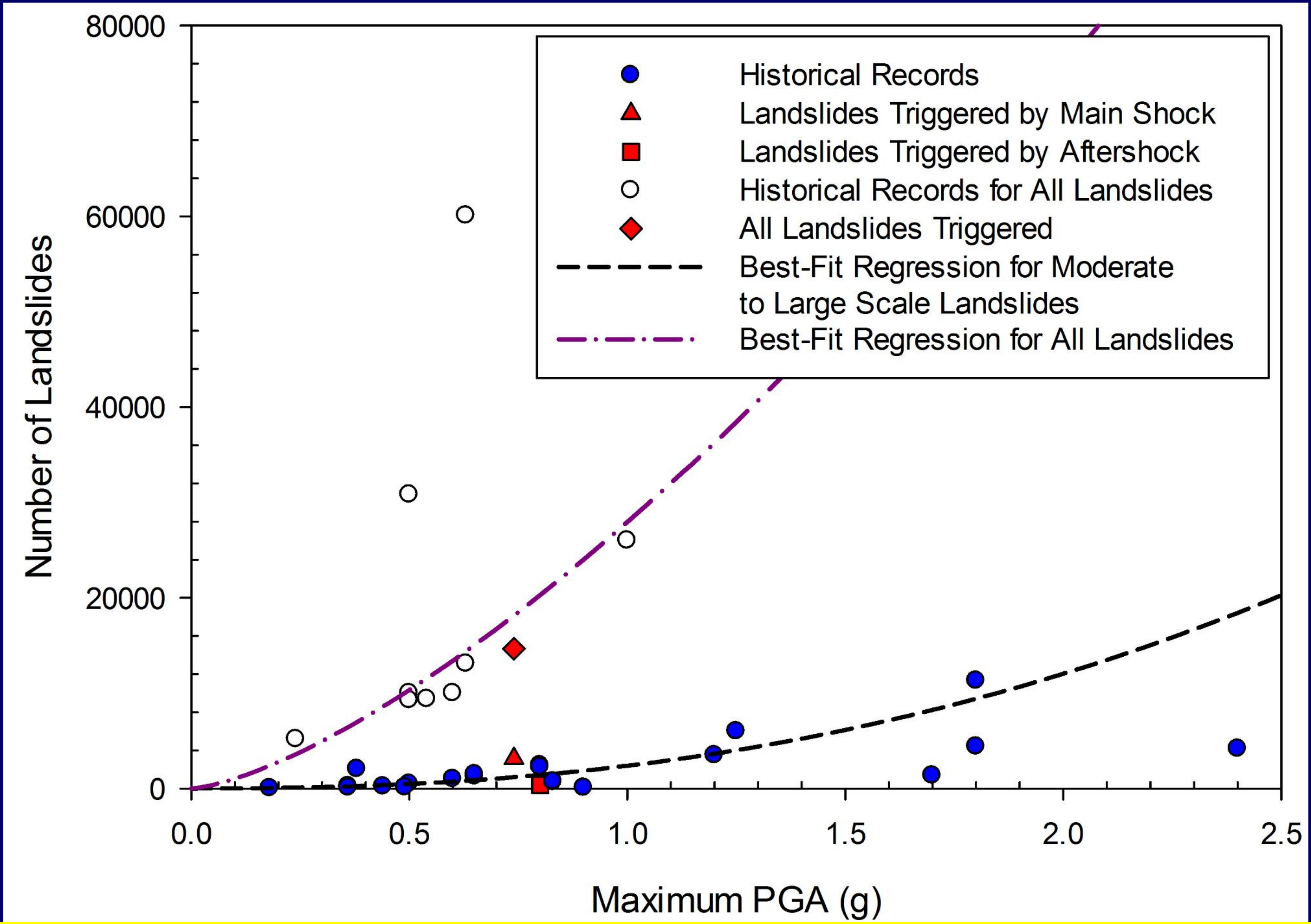
Legend
April 25, 2015 Epicenter
May 12, 2015 Epicenter
Kathmandu
Landslides Triggered by:
Aftershock
Study Area
High : 0.64
Low : 0
km
0 5 10 20 30 40



80000
60000
40000
20000
0
Number of Landslides
0.0
0.5
1.0
1.5
2.0
2.5
Maximum PGA (g)
Historical Records
Landslides Triggered by Main Shock
Landslides Triggered by Aftershock
Historical Records for All Landslides
All Landslides Triggered
Best-Fit Regression for Moderate to Large Scale Landslides
Best-Fit Regression for All Landslides

$$LC = a_1 d + a_2 \beta + a_3 (PGA) + b$$

	All cells in study area		Only cells with landslides	
Term	Value	P value	Value	P value
Main shock				
a_1	-9.665×10^{-4}	3.146×10^{-4}	-0.003	0.004
a_2	0.013	2.094×10^{-16}	0.050	6.240×10^{-7}
a_3	1.092	7.259×10^{-21}	1.580	5.731×10^{-4}
b	-0.377	1.290×10^{-12}	-0.984	0.006
Aftershock				
a_1	-3.335×10^{-4}	1.031×10^{-3}	0.258	0.087
a_2	0.001	1.089×10^{-4}	-0.002	0.066
a_3	0.015	0.343	0.333	0.687
b	0.017	0.034	0.258	0.087

Hydropower Project

Martin, R. and Tiwari, B. "NEPAL HYDRO PROJECT POST-EARTHQUAKE EVALUATION", *Proc. Dam Safety 2016*, Philadelphia, PA, 1-10.


Ancient Landslide Dam


Settlement
Flow

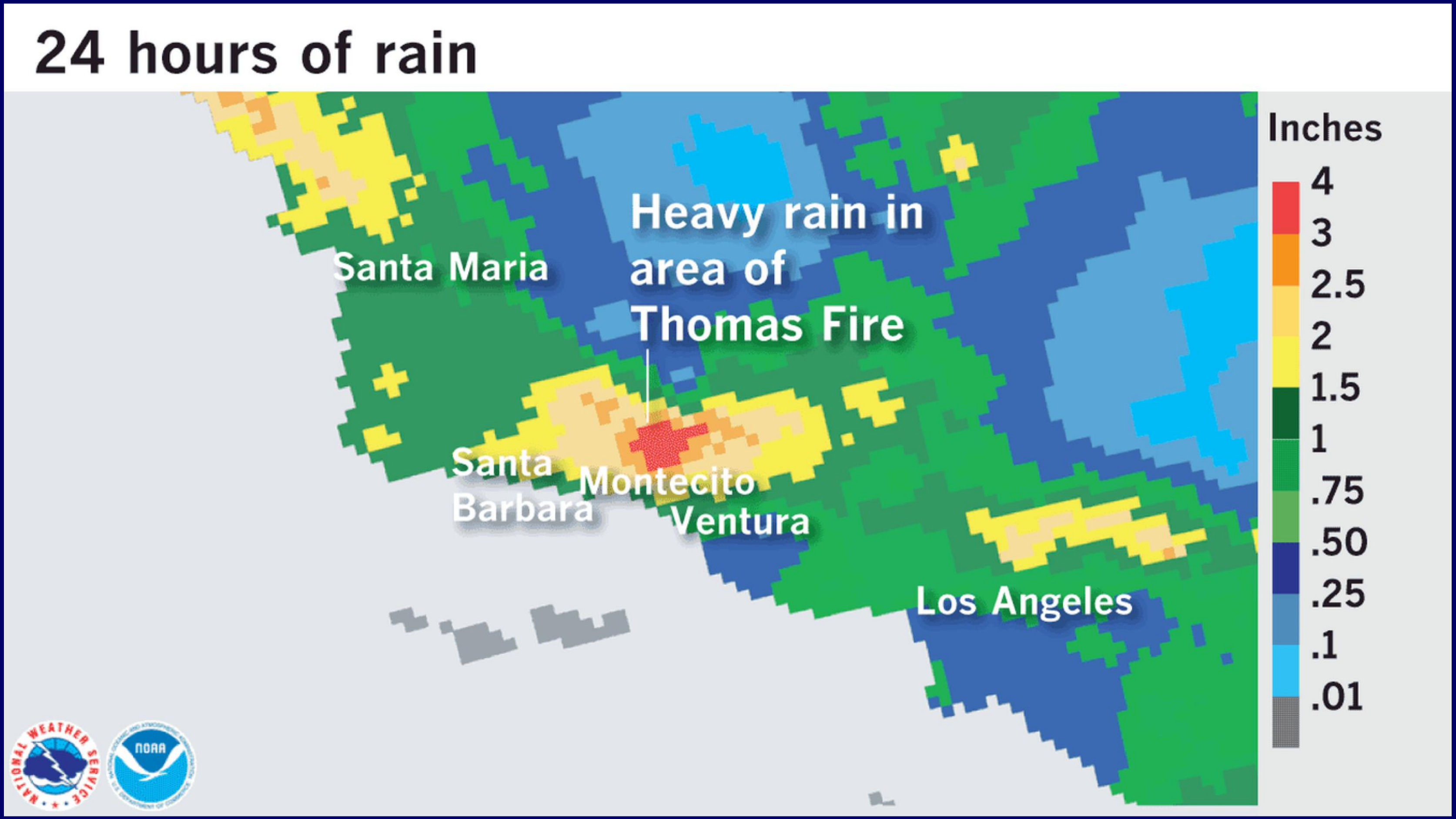

Intake tunnel


Parapet

Montecito Debris Flow

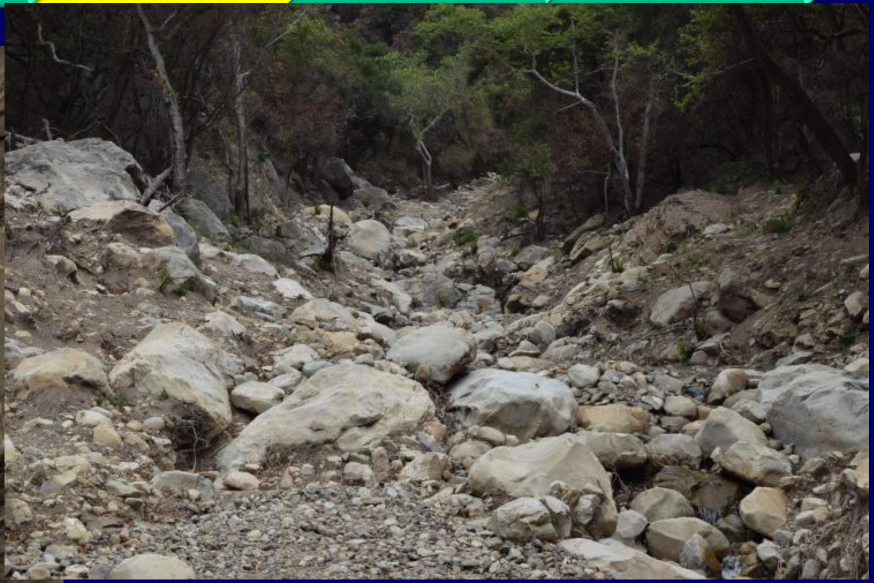
Montecito Debris Flow

Estimated intensity – 12.5 mm/hr; Total 24 hour rain fall – 125 mm



Source: LA Times


Image © 2018 DigitalGlobe




Montecito Montecito
Romero Reservoir
Ortega Reservoir
Summerland


CAT

Photo Courtesy: Chris Doolittle

Similarities between Earthquake and Rainfall Induced Landslides

Similarities

- Cause – magnitude vs intensity; Geology; Gradient; Landuse
- Size – aerial extent
- Depth – sliding surface depth
- Damages – nature and extent of damage

Differences

- Cause – magnitude vs intensity; Geology; Gradient; Landuse
- Size – aerial extent
- Depth – sliding surface depth
- Damages – nature and extent of damage

SUMMARY AND CONCLUSION

- **Natural disasters are affecting our infrastructure and community almost every year; just location and type differs.**

- **Each country has potential of specific types of natural disasters depending on their geographic, climatic, topographic and geologic conditions and associated risks.**

- **Earthquakes and rainfall have much more influence in triggering landslides.**

- **There are many similarities as well as differences between the landslides triggered by earthquakes and rainfall.**


TERIMA KASIH
GRACIAS
MERCI
TAKK
SALAMAT
OBRIGADO
GRAZIE
謝謝
KIITOS
THANK YOU
БЛАГОДАРЯ
DZIĘKUJĘ
감사합니다
DANK U
DANKIE
TƏŞƏKKÜR
DĚKUJI
СПАСИБО
DANKE
FALEMNDERIT
ありがとう
MULȚUMESC
TACK
ÞAKKA ÞÉR
motionelements