

Jajarkot Earthquake: Impacts and Future Directions for Earthquake Resilient Reconstruction

2080/07/17 (2023/11/03)

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11 Nov. 2023 (2080/08/08)

Content

- Introduction
- Seismic setting of Nepal
- Impact of earthquake in buildings (Performance of buildings)
- Geotechnical hazards
- Future directions
- Recommendations

Introduction

- **On 03 Nov., 2023 (2080/07/17 at 23:47- midnight, an Earthquake of local magnitude (ML) 6.4 occurred around Ramidanda of Jajarkot district of Karnali Province (Source: NEMRC/SC/DMG)**
- Total number of Jajarkot earthquake aftershocks is **483** till **2080/07/23 12:00** (11>4 ML including 5.8ML on 2080/07/20)
- Government of Nepal, Ministry of **Urban Development** and **Nepal Engineer's Association**- mobilized a combined team to the Jajarkot Earthquake affected areas
- Provide report based on field observation and rapid visual damage assessment of earthquake affected areas
- Provide suggestions in the policy to be taken and the modality to be adopted for the future seismic resilient reconstruction

Team Members

- Ministry of Urban Development
 - Er. Lila Khatiwada (SDE), Coordinator
 - Er. Debendra Deb Khanal, Member
 - Er. Ram Krishna Acharya, Member
 - Er. Purna Prasad Sharma, Member
 - Er. Naresh Chandra Bhatta, Member
 - Er. Kishor Bickran Shahi, Member
- Nepal Engineer's Association
 - Prof. Er. Dr. Gokarna Bahadur Motra, IoE, Pulchowk Campus
 - Assoc. Prof. Er. Dr. Rajan Suwal, President- SEANep
 - Er. Rupendra Bar Dhoj Thapa, Executive Member- SEANep
- Field observation date: 6 Nov. 2023 to 10 Nov. 2023(2080/07/20 to 2080/0724)

Seismic Setting: Plate Tectonics

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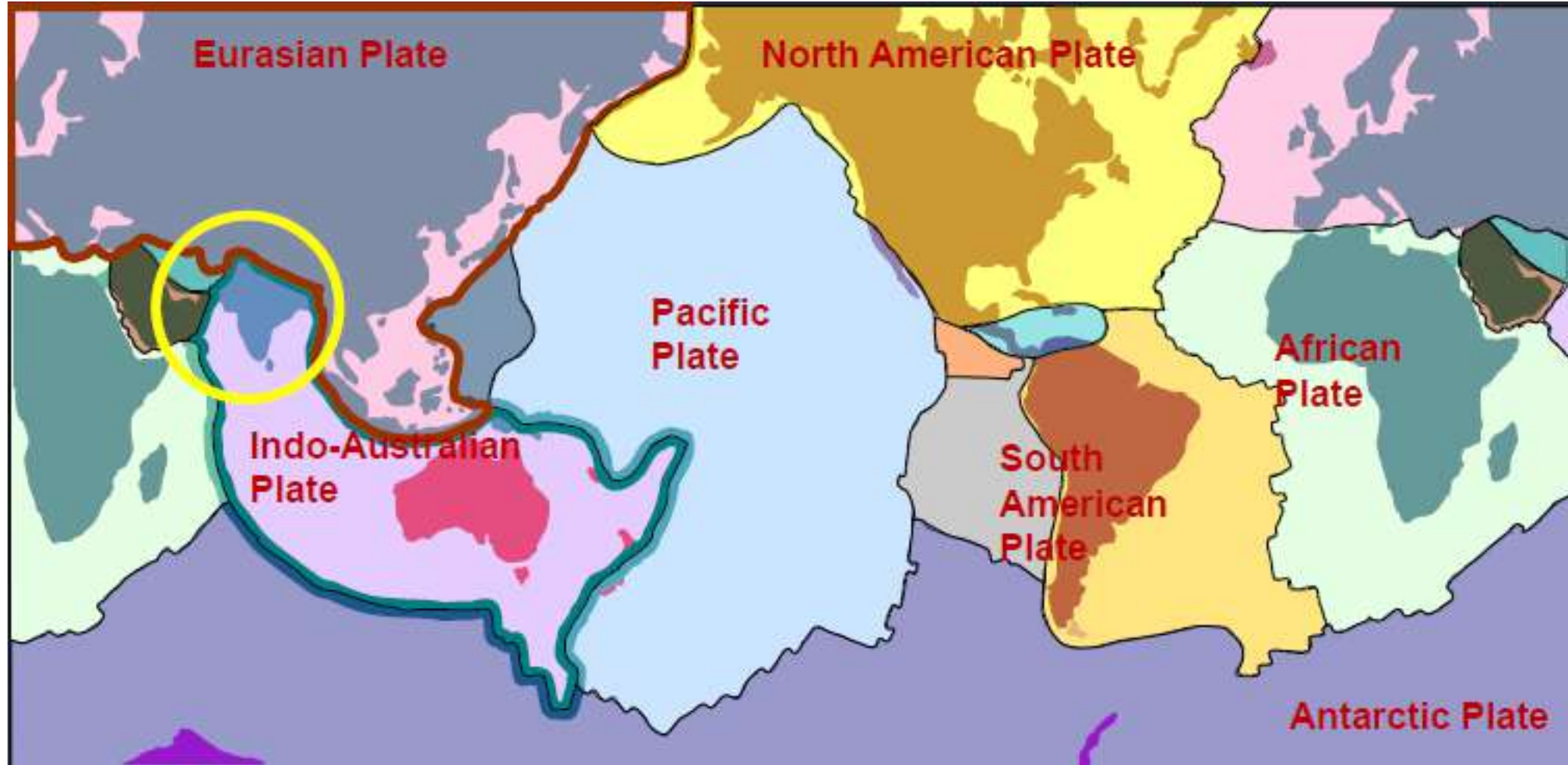
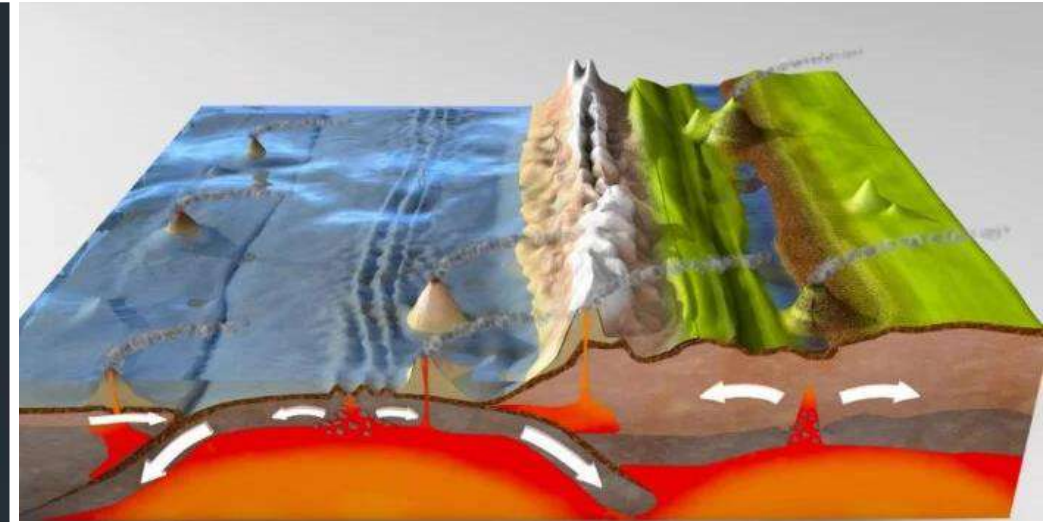
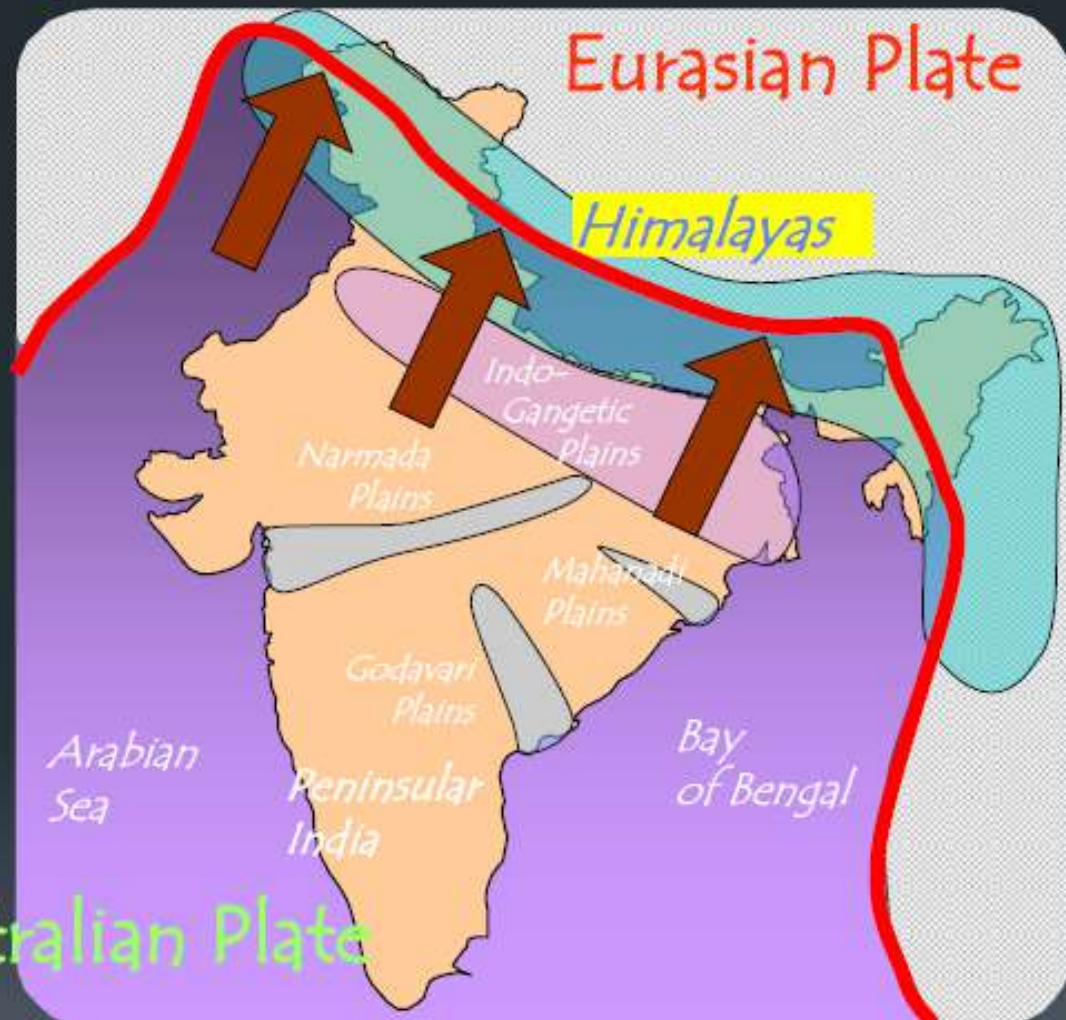


Fig.: Tectonics Plates

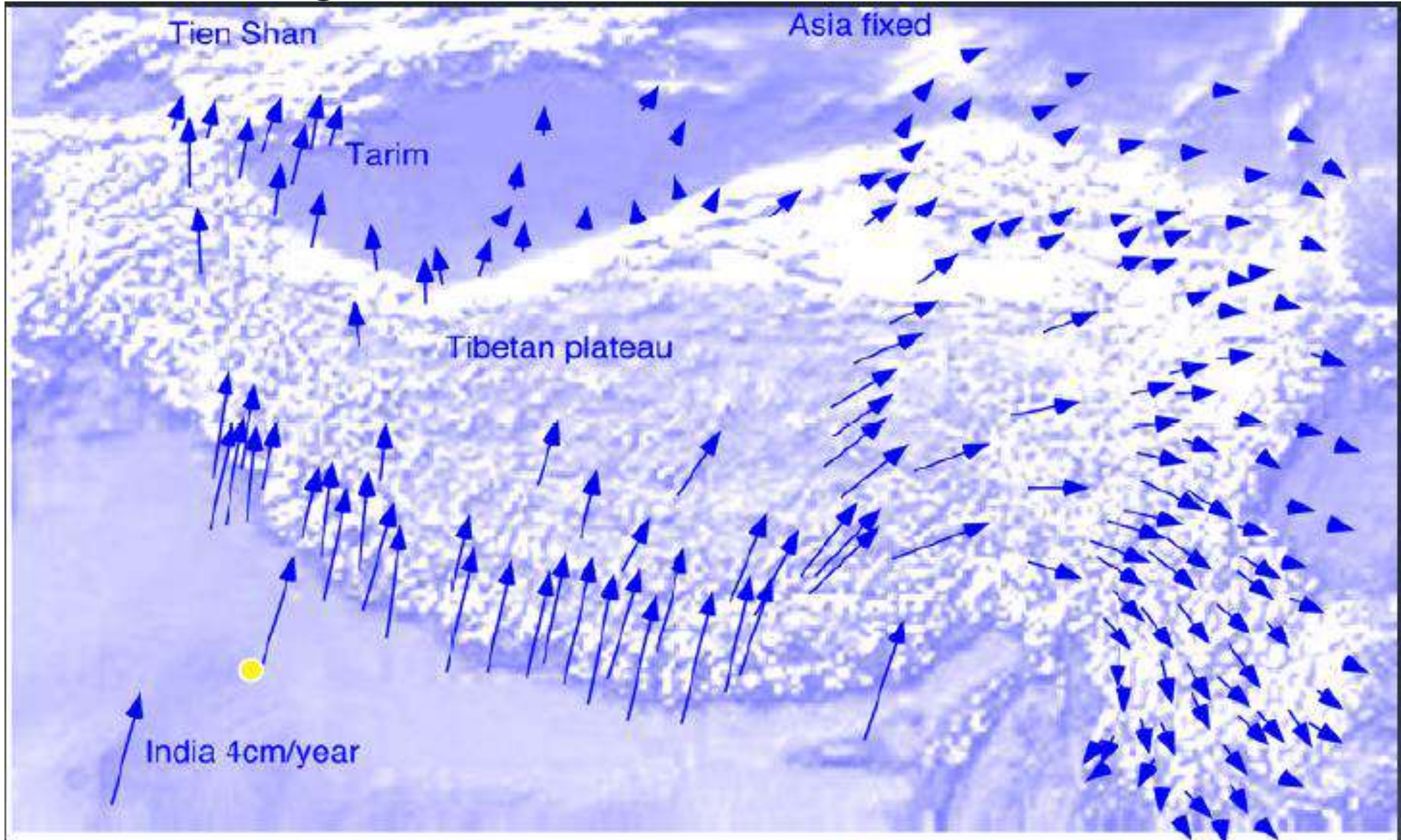
Plate Tectonics: Plate Boundaries



Michigan Tech

Seismic Setting: Plate Tectonics

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10 years of GPS

oleum
(Source:

Tectonic Activities along Himalaya Region

- Nepal is divided into **five** major tectonic zones: **Terai, Siwalik, Lesser Himalaya, Higher Himalaya** and **Trans-Himalayan** zones from south to north, respectively and extends parallel to its long dimension (Frank and Fuchs, 1970; Mitchell, 1979; Stöckl in, 1980; Windley, 1983).

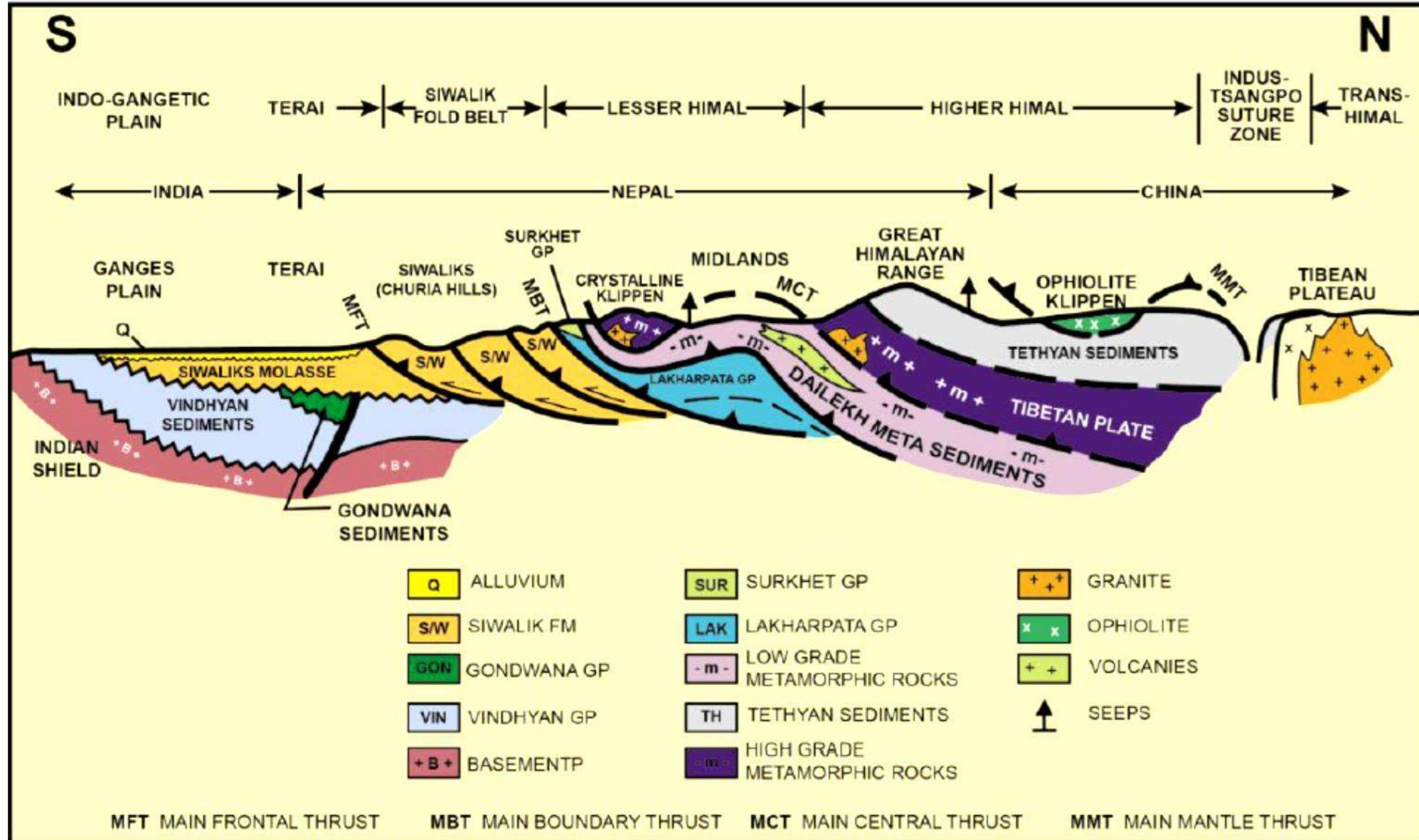
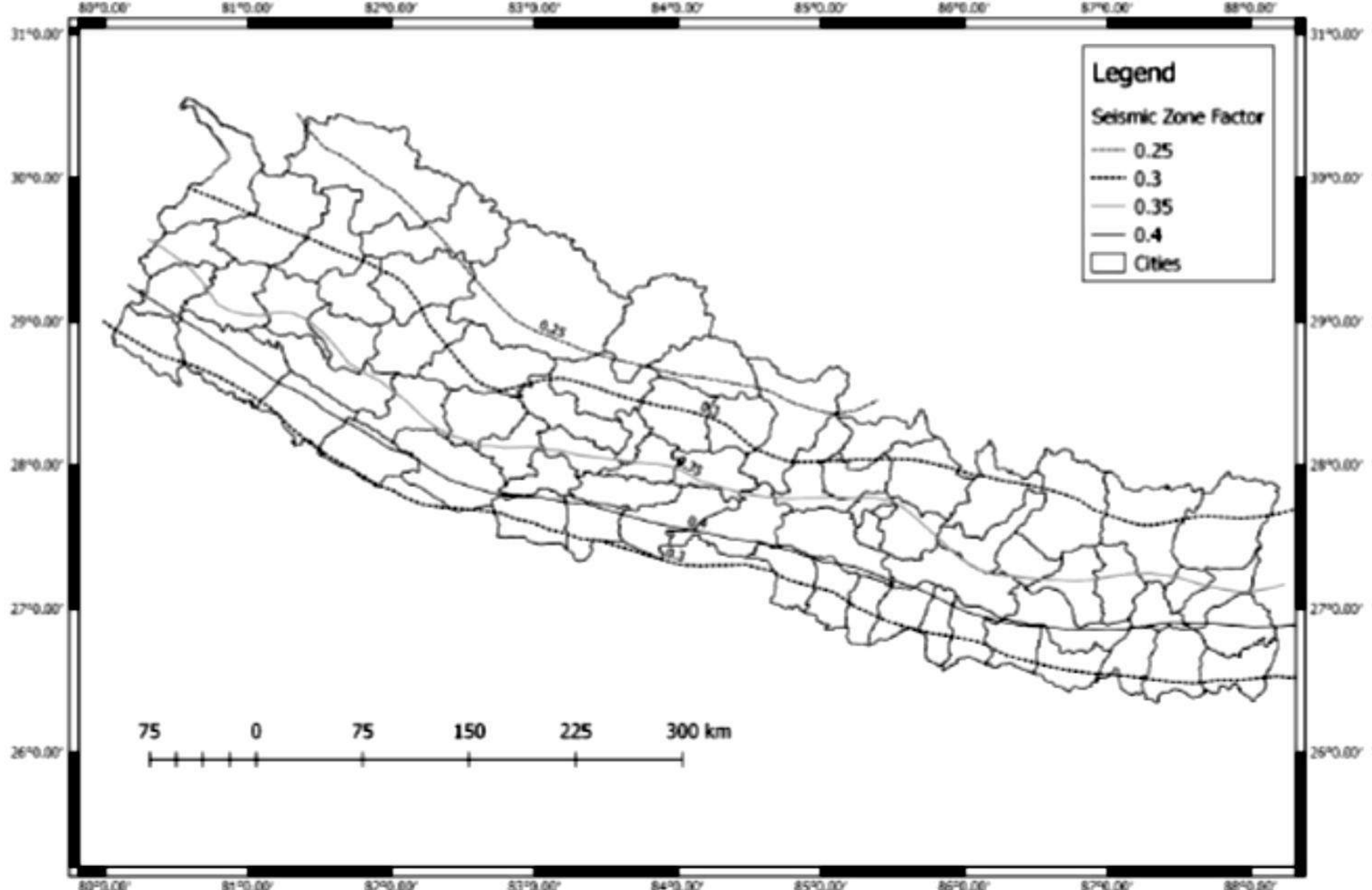


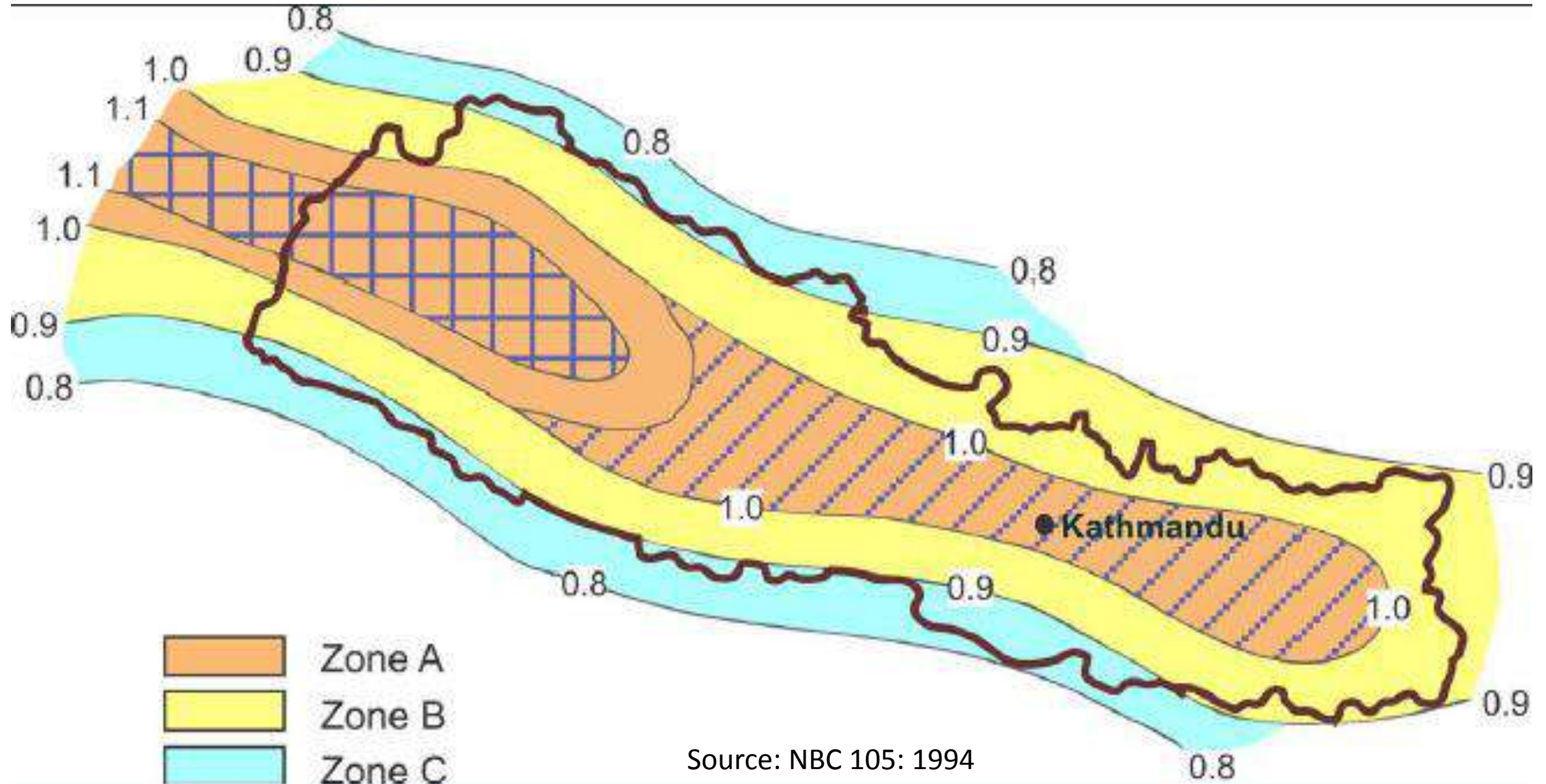
Fig.: Geological cross section at the longitude of Kathmandu prepared by Petroleum Exploration Project, Department of Mines and Geology, Government of Nepal (Source: <http://www.dmg.gov.np/>)

Seismic Hazard of Nepal

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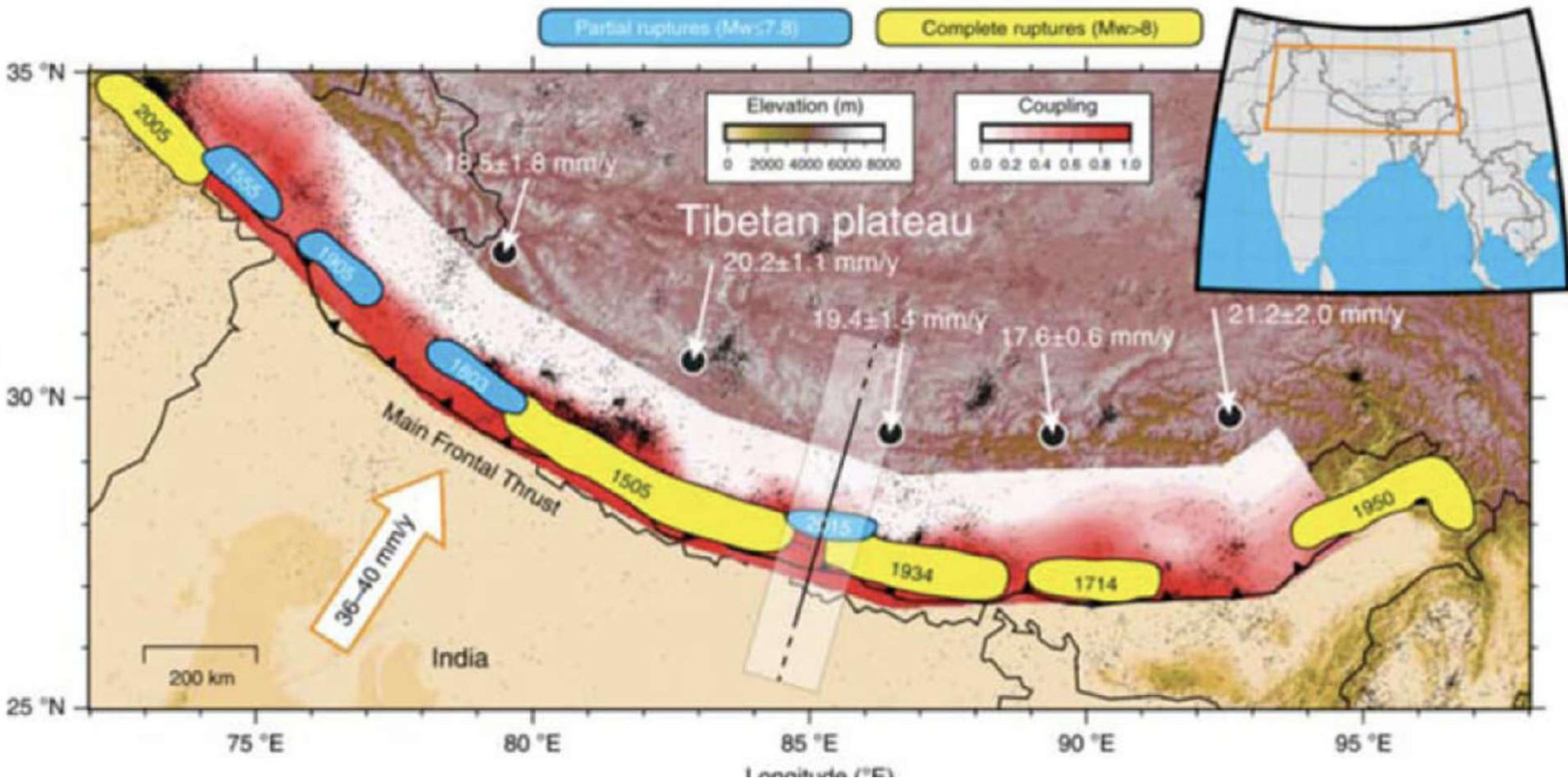


Seismic Hazard of Nepal



Tectonic Activities in Himalayas

- Nepal is located on a **major fault-line** that divides the Indian and Eurasian tectonic plates
- Collisions between Indian and Eurasian plates (massive regions which created the Himalayas millions of years ago) have made the region world's most **seismic active region**.
- Nepal is one of the world's most **quake-prone** countries
- The Indian plate is sliding under the Tibetan plateau at a **rate of 60 mm/year**, causing a build-up of stress over time
- Over time, the **pressure accumulates** along the boundary of the two plates
- When the pressure **exceeds capacity** of the plate materials, causes potentially destructive EQs

a

Tectonic Activities in Himalayas

- R. Bilham (2019) analyzed the past 1000 years of earthquakes in the Himalaya region using geodetic, historical and seismological data, and identified segments of the Himalaya that remain unruptured.
- Seismic threat along western part of Nepal

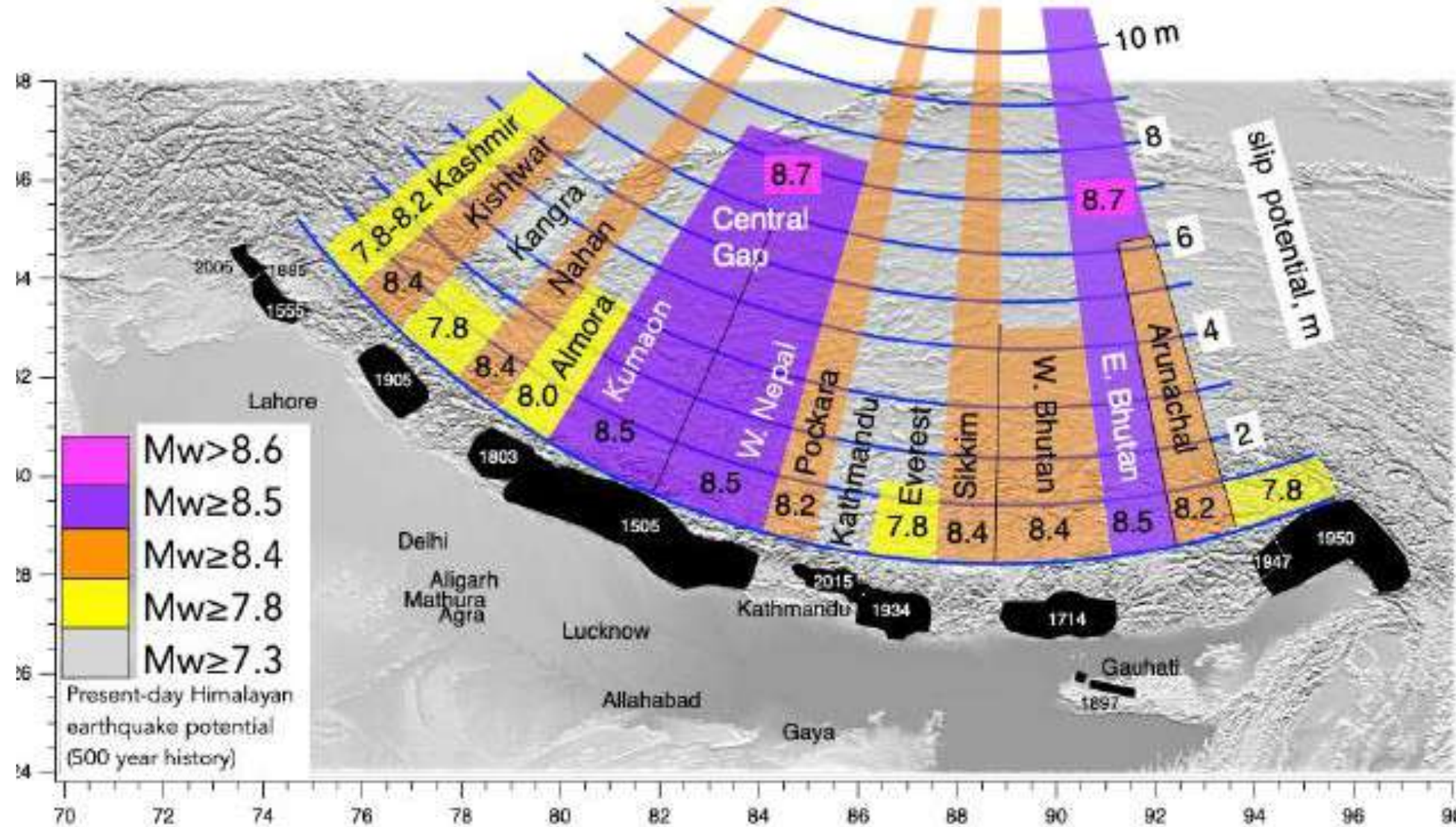


Fig.: Possible segments along the Himalaya and their potential magnitudes at present (R. Bilham, 2019)

Historical Earthquakes

- Kathmandu has been struck by numerous very large earthquakes throughout historical time (Rana, 1935; Pant, 2002).
- Damaging EQs to Nepal were reported in the years 1100, 1223, 1225, 1344, 1408, 1505, 1555, 1681, 1724, 1803, 1833, 1934, (Bilham et al., 2001; Avouac, 2003; Bilham, 2004, 2009)
- 25 April, 2015 Gorkha Earthquake, 3 Nov., 2023 Jajarkot Earthquake, Dipyal, Bhajang Earthquakes
- One large earthquake in 70-80 years

Tectonic Activities along Himalaya Region

- Active Seismic Region

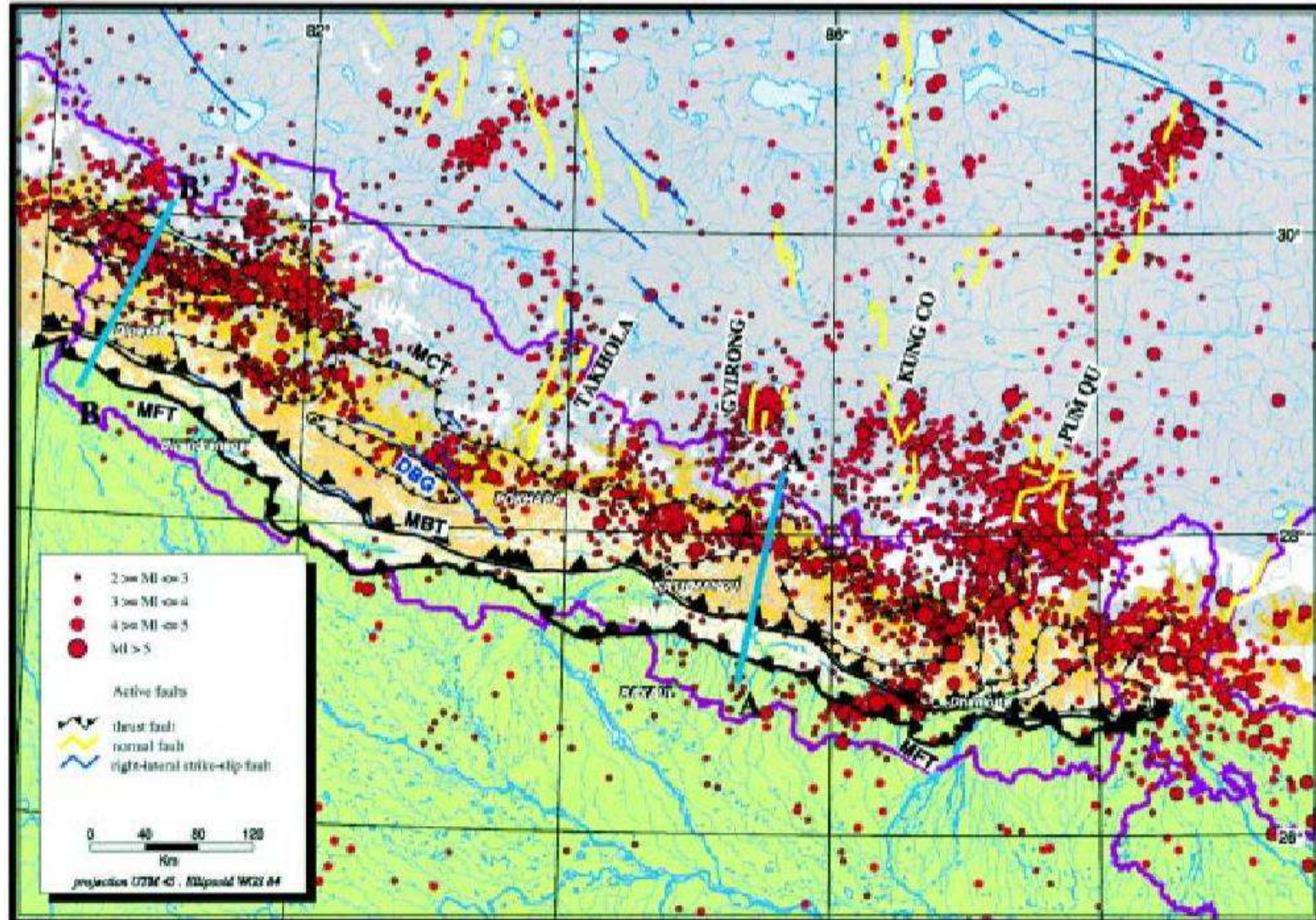
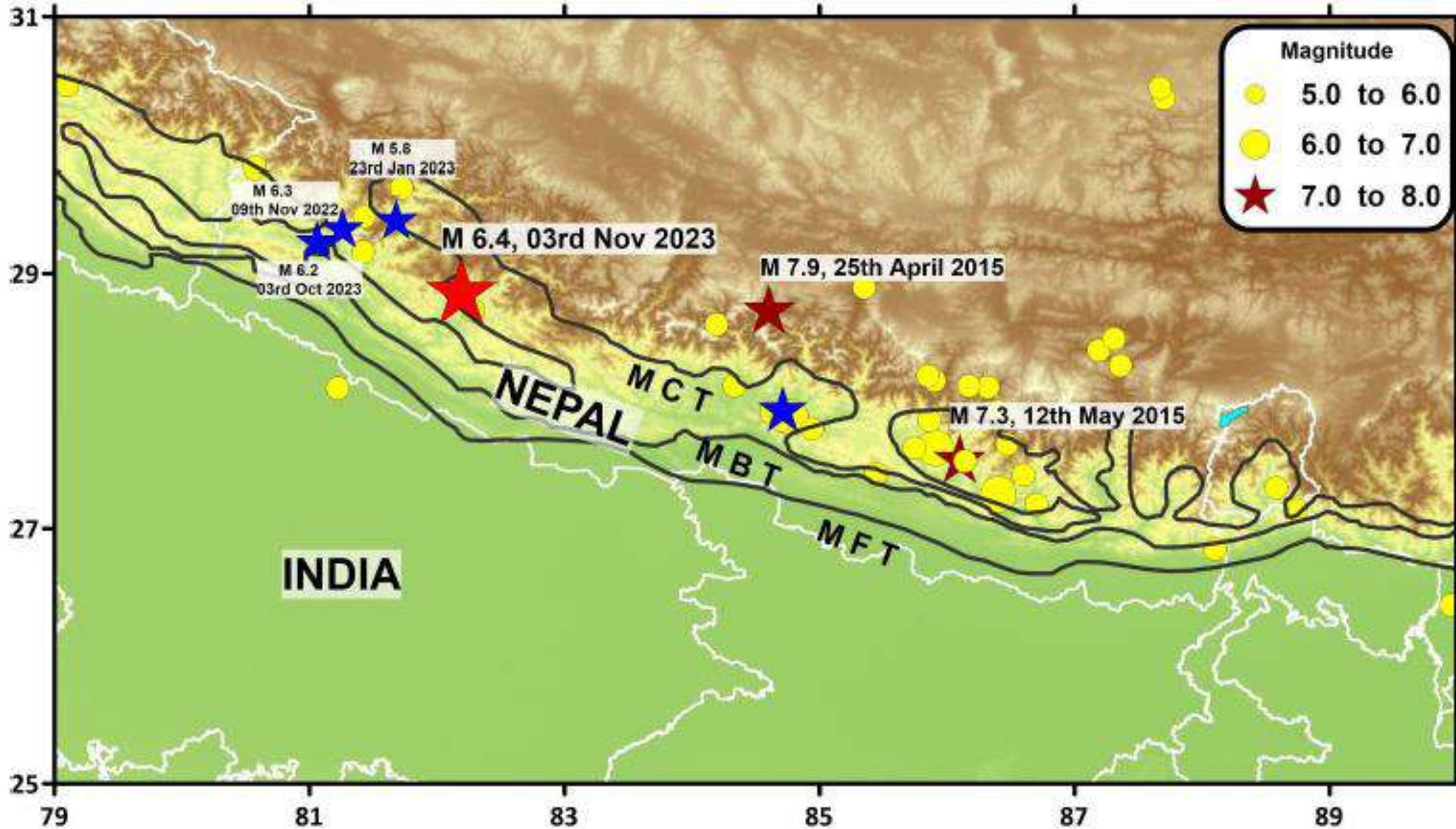


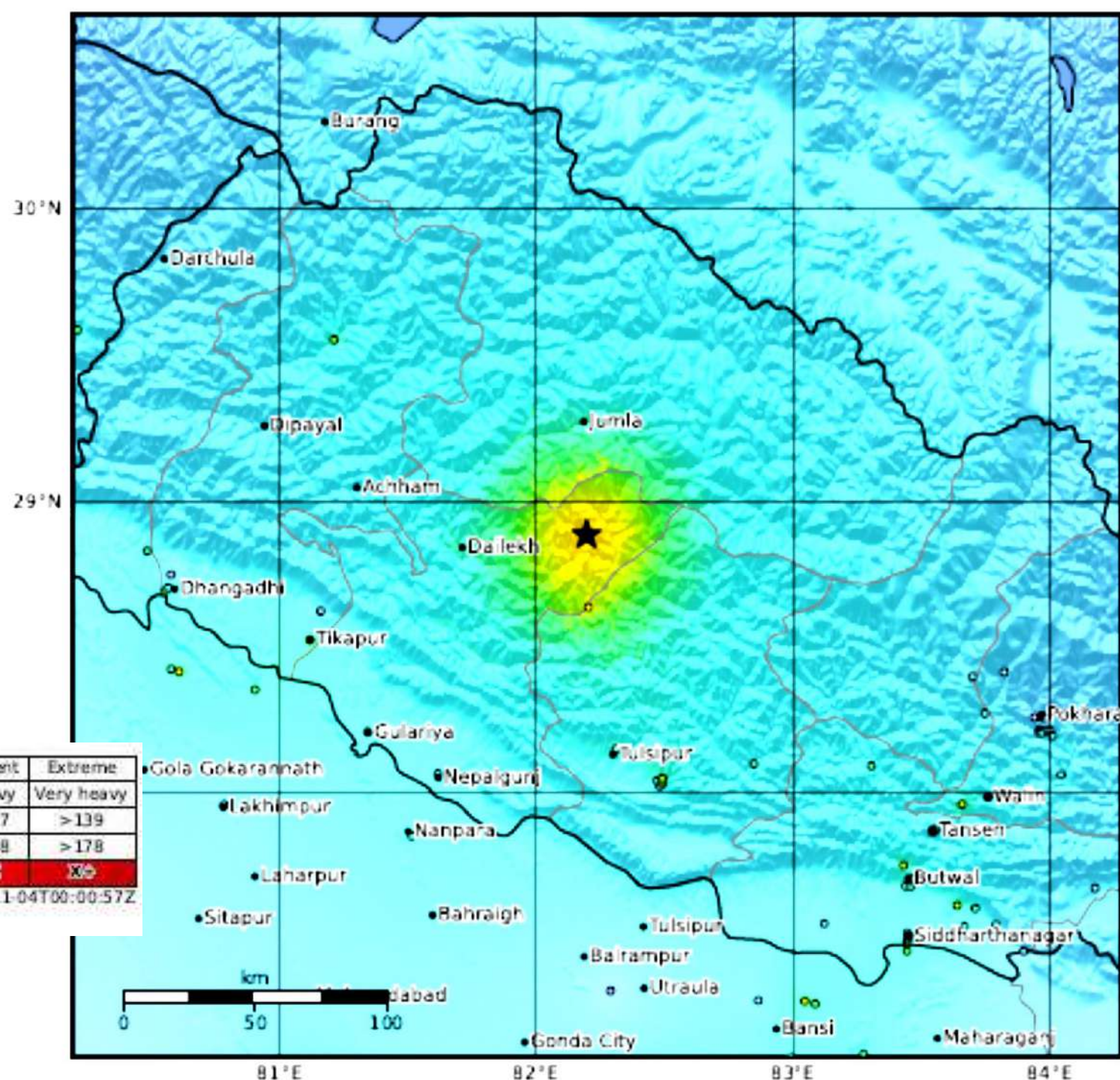
Fig.: Seismicity map of Nepal (Pandey *et al.*, 1999).

Tectonic Activities along Himalaya Region

- Three prominent events recorded on 09th Nov. 2022 of M 6.3, 23th Jan. 2023 of M 5.8 and 3rd Oct. 2023 of M 6.2 occurred Northwest of the recent event.



Intensity Map



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X

Scale based on Worden et al. (2012)

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▲ Seismic Instrument ○ Reported Intensity

★ Epicenter

Source: USGS

Human Casualty and Building Damage as of 2080/08/02

SN	District	Human Casualty		Buildings Damage		Office Buildings		Remarks
		Death	Injury	Comp.	Partly	Comp.	Partly	
1	Jajarkot	101	145	9794	24707			
2	Rukum W.	53	202	16570	9961	16	21	
3	Rukum E.	0	0	9	148		4	
4	Salyan	0	2	151	512			
5	Rolpa	0	1	25	87		1	
6	Nawalparasi E.	0	0		1			
7	Dailekh	0	3	1	1			
8	Dang	0	0		7			Source: http://drrportal.gov.np
9	Baitadi	0	3	1				
10	Jumla	0	6	5			1	
11	Kalikot	0	1	1				
12	Pyuthan	0	3		31		1	
13	Accham	0	0				6	
Total		154	366	26557	35455	16	34	

Building Stock of Nepal as of Census Data 2021

Number of private households by type of materials used for outer walls of housing unit as per Censuses 2021

Area	Total	Type of Material for outer walls (Source: GoN, Dept. of Statistics)							
		Mud in Bricks/Stones	Cement in Bricks/Stones	Woods/ Planks	Bamboo	Unbaked Bricks	Galvanized Sheets	Pre-fabricated Sheets	Other
Nepal	6660841	2042978	3474957	210694	779922	28141	80989	2064	41096
Urban/Rural									
Urban Municipality	4474699	927269	2804054	140434	494568	19120	60455	1578	27221
Rural Municipality	2186142	1115709	670903	70260	285354	9021	20534	468	13875
Ecological Belt									
Mountain	409260	287909	100574	5633	6821	493	7078	216	536
Hill	2945030	1322366	1451311	54312	53535	5165	50624	1110	6607
Terai	3306551	432703	1923072	150749	719566	22483	23287	738	33953
Province									
Koshi	1190755	345610	505454	60716	237981	2052	34350	206	4386
Madhesh	1156383	113761	552229	41402	436375	2226	2065	177	8148
Bagmati	1567919	316144	1165039	24525	16356	2443	37045	1053	5312
Gandaki	661632	270675	375767	5856	3335	1221	2785	193	1800
Lumbini	1141345	433174	608553	18824	51154	15563	1932	205	11940
Karnali	366037	293784	62956	6549	809	671	758	158	352
Sudur Paschim	576772	269830	204959	52822	33912	3965	2054	72	9158

Building Stock of Nepal as of Census Data 2021

Number of households by type of materials used for outer walls of housing unit as per Censes 2021

Area	Total	Type of Material for outer walls							
		Mud in Bricks/Stones	Cement in Bricks/Stones	Woods/ Planks	Bamboo	Unbaked Bricks	Galvanized Sheets	Pre-fabricated Sheets	Other
Mugu	12430	11406	718	155	2	3	102	34	10
Humla	11204	11041	92	26	2	0	19	22	2
Dolpa	9380	8839	371	118	3	1	24	14	10
Jumla	24422	22357	1821	79	2	2	98	47	16
Kalikot	26770	24828	1713	59	6	33	108	9	14
Dailekh	54594	50138	4018	126	52	181	59	12	8
Jajarkot	37453	34854	2196	93	50	167	72	4	17
Rukum (West)	37290	31963	5138	47	15	54	62	2	9
Salyan	54672	48315	5992	190	33	28	26	7	81
Surkhet	97822	50043	40897	5656	644	202	188	7	185

Field Reconnaissance: Damage Observation

- Khalanga, Jajarkot



Performance of Buildings

Stone Masonry Buildings

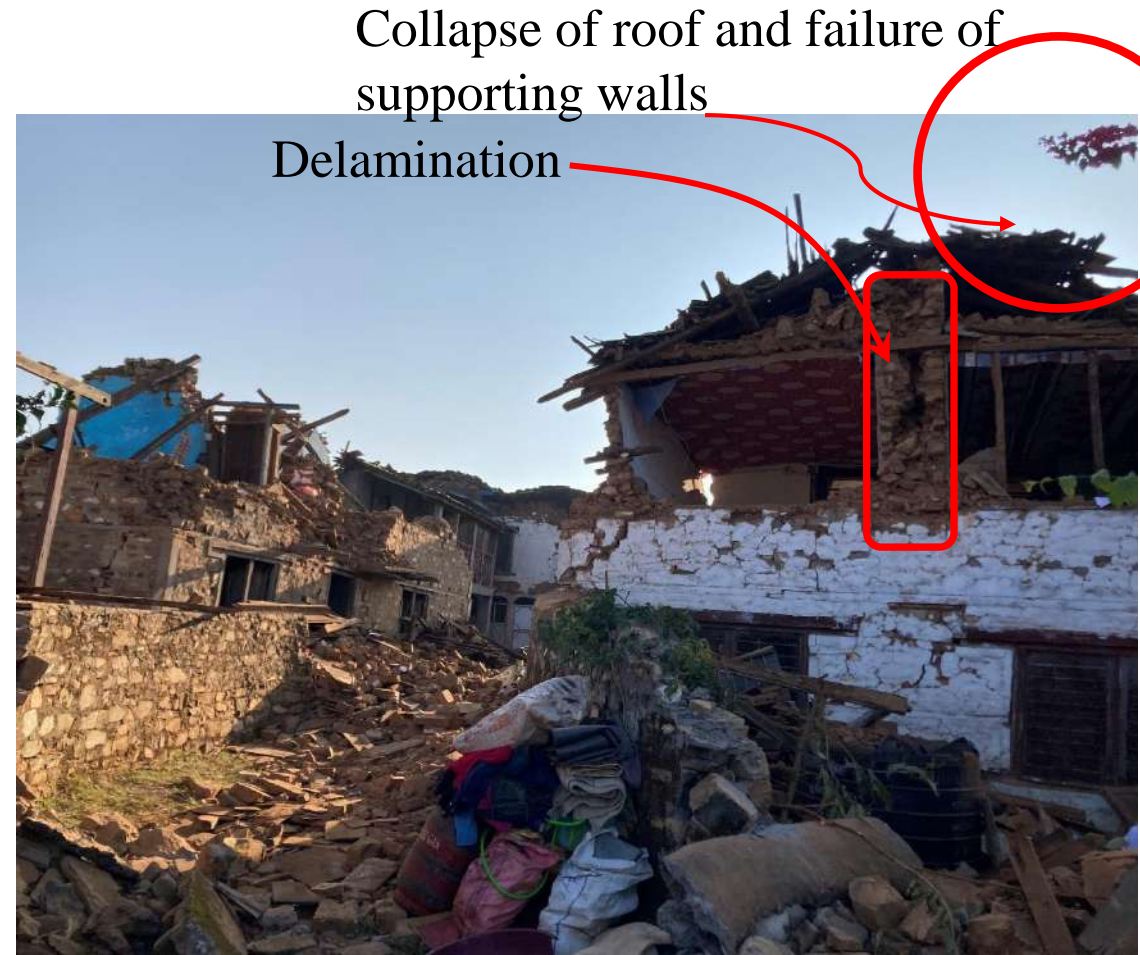
Quarry Stones

River Boulders

“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)

Damage Observation: Performance of URM Buildings



Collapse of Stone Masonry Building in Mud Mortar at Khalanga, Jajarkot

Field Reconnaissance: Damage Observation

- Khalanga, Jajarkot

Out-of-plane failure of Stone Masonry



Collapse of roof and failure of supporting walls



Typical out-of-plane failure of URM walls

- Widely observed out-of-plane collapse of load bearing masonry walls of old buildings- common deficiency
- Poor connection between the diaphragm and cross walls led to such collapse

Field Reconnaissance: Damage Observation

- Khalanga, Jajarkot



Field Reconnaissance: Damage Observation

- Khalanga, Jajarkot



Complete collapse of Stone Masonry Building in Mud Mortar at Khalanga, Jajarkot

Field Reconnaissance: Damage Observation

- Khalanga, Jajarkot



- Old unreinforced masonry buildings suffered extensive damage due to low strength of masonry via material deterioration over the years
- Debate among professionals: can it be made earthquake resistant or not?
- Collapse of the roof and failure of supporting walls
- Weak diaphragms and their poor connection with the masonry wall caused collapse of floor as well as failure of supporting walls

Field Reconnaissance: Damage Observation

- Khalanga, Jajarkot



Formation of cracks at the corners of the URM buildings
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



Stone masonry buildings with timber bands survived

Field Reconnaissance: Damage Observation



Collapse of roof and failure of supporting walls



Collapse of roof and failure of supporting walls

- Heavy roof collapse and out of plane failure of supporting walls
- Typical out-of-plane failure of URM walls

Field Reconnaissance: Damage Observation

Diagonal shear cracks



- Heavy roof collapse and failure of supporting walls in out-of-plane
- Diagonal shear crack in shear walls

Field Reconnaissance: Damage Observation

Khalanga, Jajarkot



Complete collapse



Field Reconnaissance: Damage Observation

Lack of bonding stones



Wall failure at corner



Field Reconnaissance: Damage Observation

Wall pier diagonal cracking



- Flexible floor- holding one direction walls only
- Formation of vertical cracks at the corners of the building reduce the out-of-plane stability of the walls drastically that leads to strength loss significantly.

Field Reconnaissance: Damage Observation



Wall pier diagonal cracking

Field Reconnaissance: Damage Observation



- In old masonry buildings, out-of-plane collapse of load bearing walls was widely observed in Jajarkot.
- Poor connection with the diaphragm and cross walls led to such collapse.

Field Reconnaissance: Damage Observation

Collapse of roof and failure of supporting walls



Complete collapse



Field Reconnaissance: Damage Observation



- Building typology at Khalanga, Jajarkot

Field Reconnaissance: Damage Observation



Corner separation, collapse of roof and failure of supporting walls







Formation of cracks at the corners

Formation of vertical cracks at the corners of the building reduce the out-of-plane stability of the walls drastically leading to loss of strength of URM walls significantly.

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Absence of gable band and heavy roof lead to the formation of cracks at the corners and diagonal cracks in the URM walls leading to collapse



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



Failure of supporting wall

Out-of-plane failure of URM walls



Weak diaphragms, their poor connection with the masonry wall and lack of connection in shorter wall caused out-of-plane collapse of supporting walls

Topographical Effect along the Ridge

- After Earthquakes, many field investigations were conducted considering local site conditions to seismic damage, such as the 1989 $M_w = 6.9$ Loma Prieta earthquake, the 1999 $M_w = 7.7$ Chi-Chi earthquake, the 2008 $M_w = 7.9$ Wenchuan earthquake, the 2009 $M_w = 6.3$ L'Aquila earthquake in Italy and the 2010 $M_w = 7.0$ Haiti earthquake [1–7]. These earthquakes triggered numerous landslides associated with site effects due to topographic or geological conditions.
- During the 1994 Northridge, California, earthquake, a very high horizontal acceleration peak of 1.58 g was recorded by an analog accelerograph installed at a ridge near the Pacoima Dam, while the peak accelerations recorded by accelerographs in the surrounding areas were under 0.5 g [9]. A similar observation was made during the destructive Haiti earthquake [10].

Topographical Effect along the Ridge



Topographical Effect along the Ridge



Roof collapse and failure
of supporting walls



Collapse of the roof and failure of supporting wall

- Collapse of buildings along the ridge

Topographical Effect along the Ridge

Complete collapse



- Building damage along the ridge line

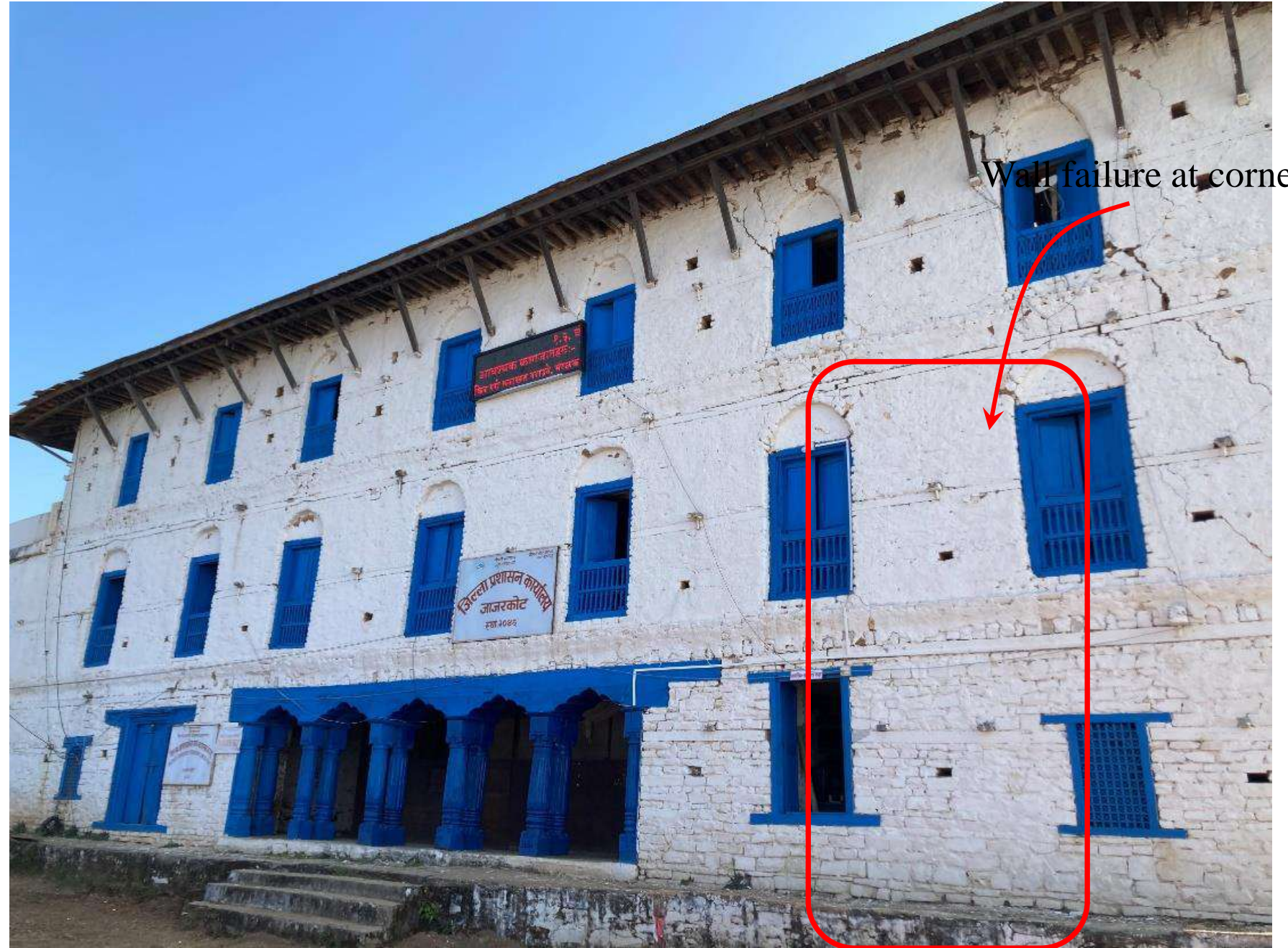
Performance of Heritage Structures

Jajarkot Durbar, Khalanga

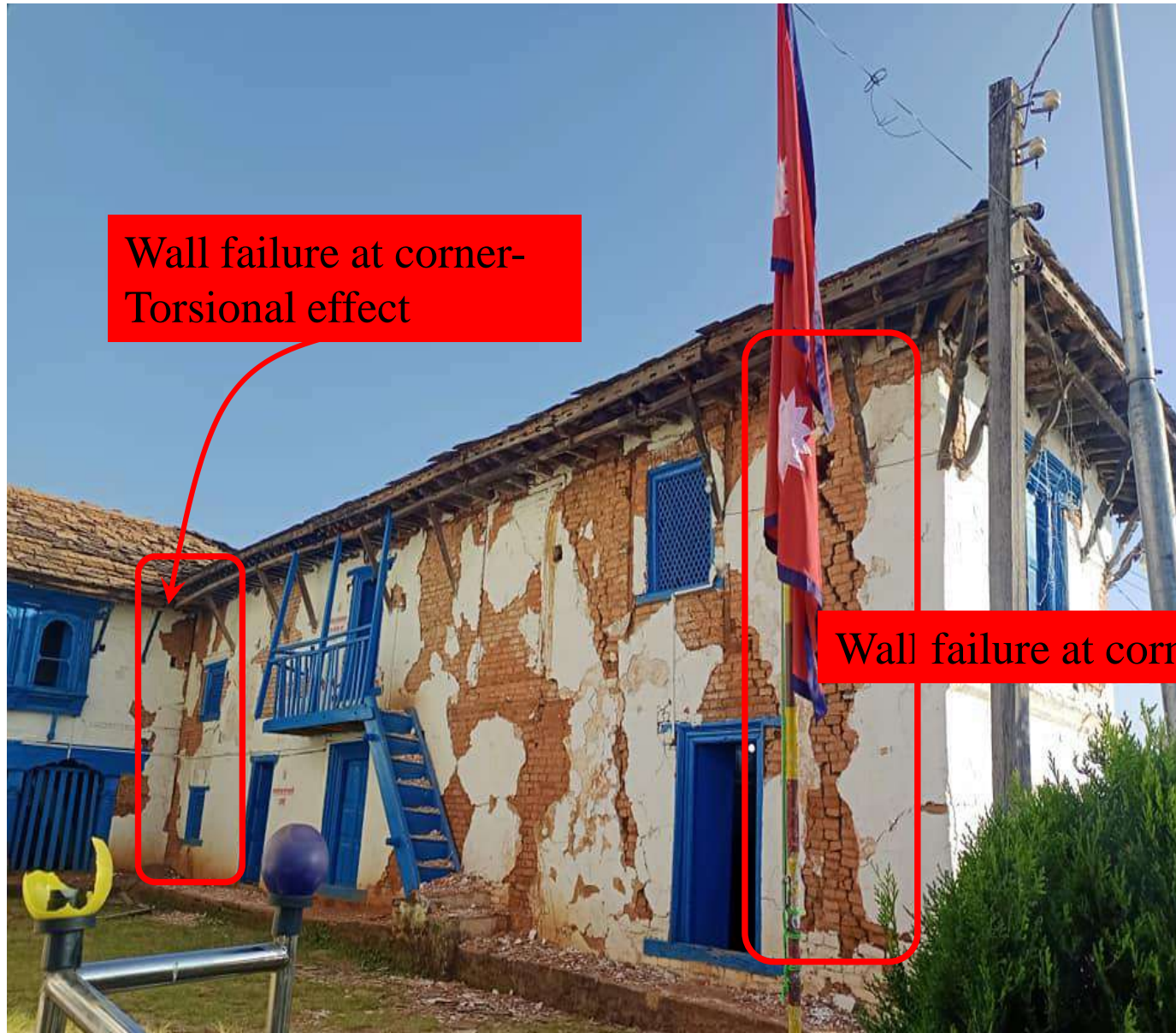
Performance of Unreinforced Brick Masonry (UBM) Buildings

Jajarkot Durbar

- The then King Gajendra Narayan Shah build the Durbar in 1400BC.
- Rebuilt by the King of Jajarkot [Hari Shah](#) in 1825 BC using burnt bricks.
- The palace was originally seven storeys
- Reduced to four storeys by the 1934 [Earthquake](#).
- The [25th April 2015 Nepal Earthquake](#) further damaged the building.
- Timber band at lintels and roof saved the building



Performance of Unreinforced Brick Masonry (UBM) Buildings

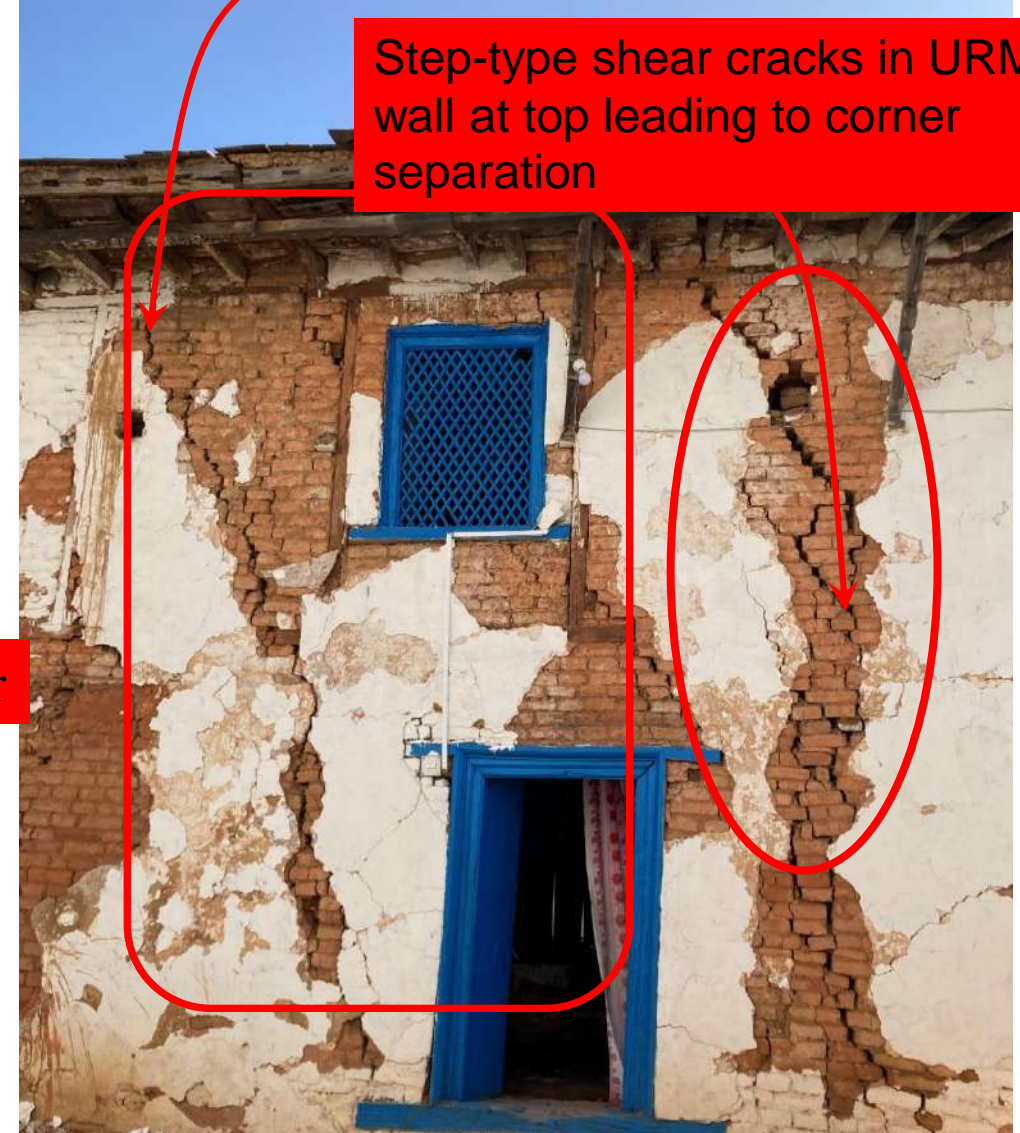


Wall failure at corner-
Torsional effect

Wall failure at corner

Step-type shear cracks in URM walls

Step-type shear cracks in URM
wall at top leading to corner
separation



Performance of Unreinforced Brick Masonry (UBM) Buildings



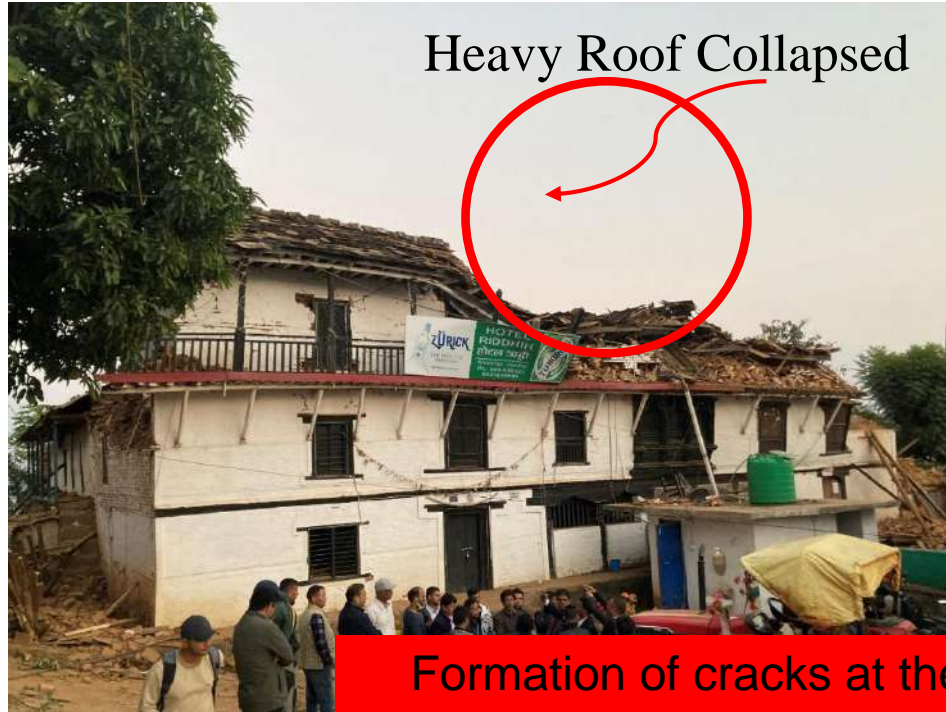
Out-of-plane failure of gable and supporting walls



Flat bricks on flexible floor base

- Unsupported gable wall failure in the absence of band at gable
- Flexible floor is not supported on the short wall

Performance of Unreinforced Brick Masonry (UBM) Buildings



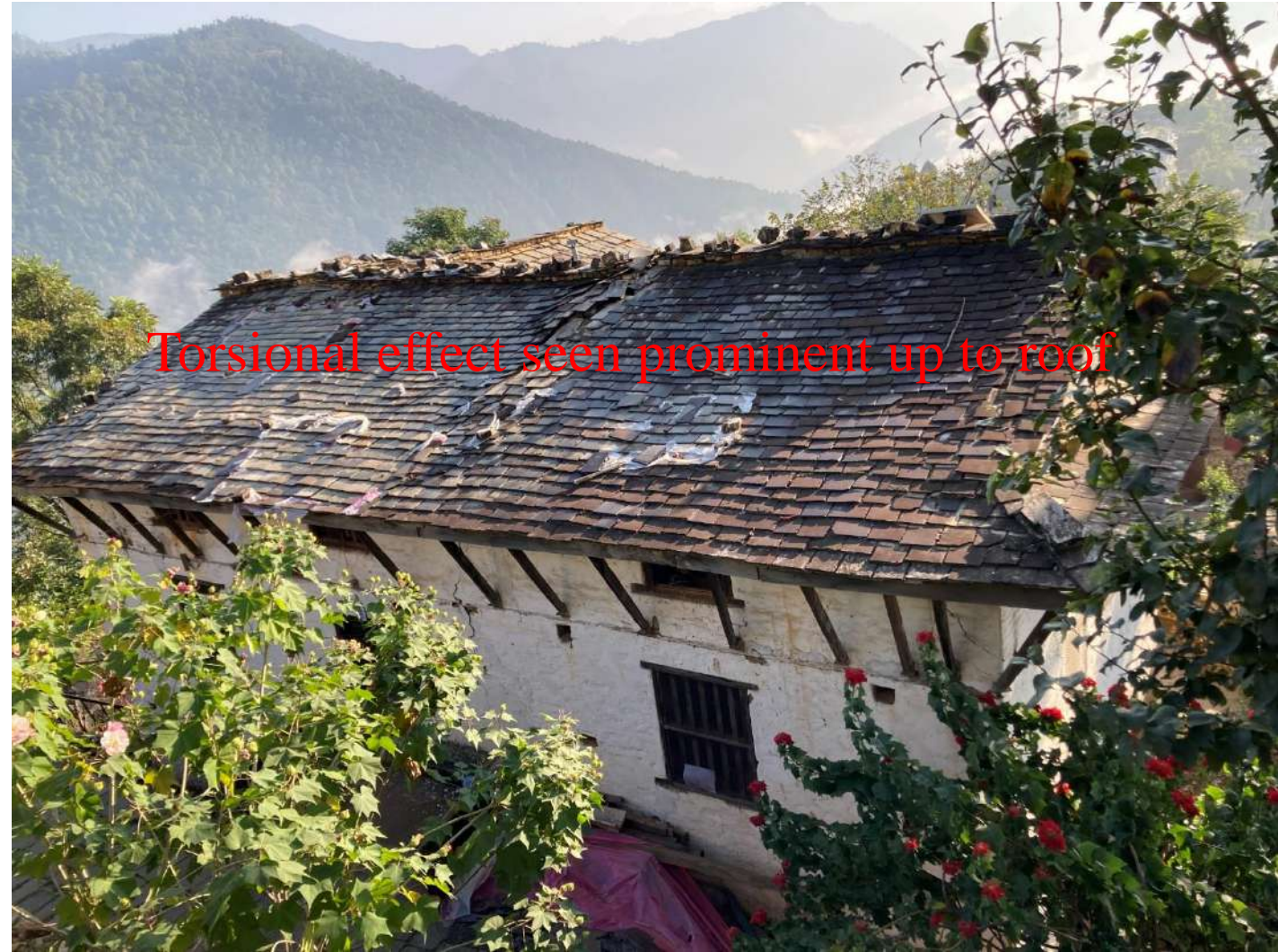
- Poor connection with the diaphragm and cross walls led to the out-of-plane collapse of old load bearing masonry walls at Khalanga, Jajarkot.

Performance of Unreinforced Brick Masonry (UBM) Buildings



Roof collapse, corner separation
and out-of-plane failure

Torsional Effect in Irregular Buildings



Torsional Effect in Irregular Buildings



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Horizontal shear sliding

Torsional effect is prominent in L-, T-shape buildings, leading to cracks at the junction

RCC Structure in Steep Slope



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Buildings along Veri River



River picked boulders are unstable units. Absence of bands in the walls and heavy roof load during shaking need to transfer from in-plane wall action to out-of-plane wall. Absence of bands cause initiation of vertical cracks at the corners reducing the out-of-plane stability of the walls drastically leading to out-of-plane failure of the walls.

Buildings along Veri River



Epicenter: Ramidada, Barekot Rural Municipality



Sherpa Village

Epicenter: Ramidada, Barekot Rural Municipality



Out-of-plane failure of gable and supporting walls



Out-of-plane failure of gable and supporting walls

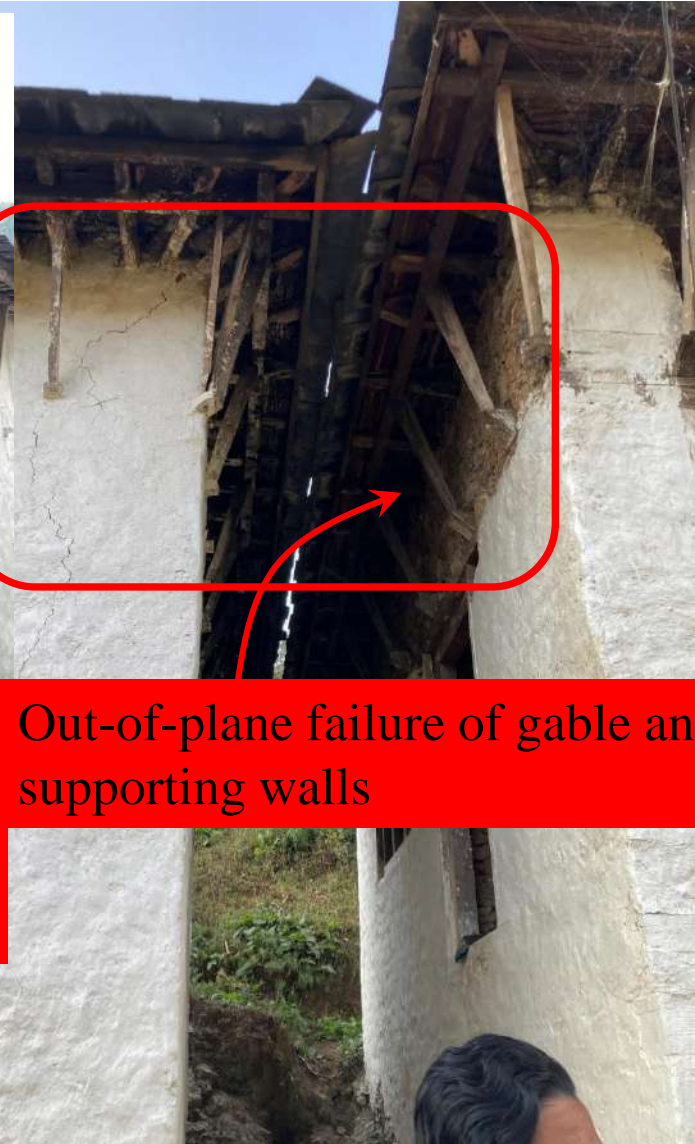
Epicenter: Ramidada, Barekot Rural Municipality



Out-of-plane failure of gable and supporting walls



Out-of-plane failure of gable and supporting walls



Out-of-plane failure of gable and supporting walls

Epicenter: Ramidada, Barekot Rural Municipality



Out-of-plane failure of gable and supporting walls



Epicenter: Ramidada, Barekot Rural Municipality



Barekot Rural Municipality



Aathbishkot Municipality



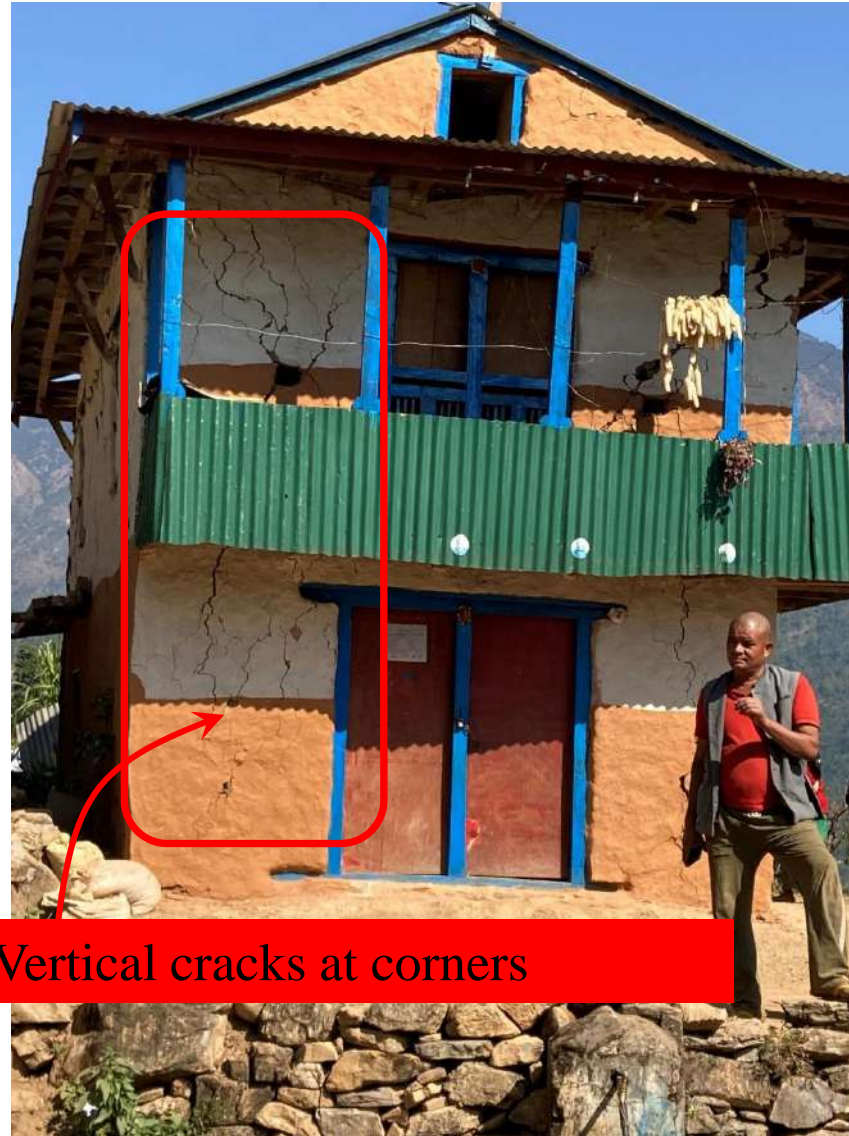
Hospital Building at Aathbishkot Municipality

Construction of new block of Hospital Building at Aathbishkot Municipality

Performance of Stone Buildings



Corner separation – leading of out-of-plane failure

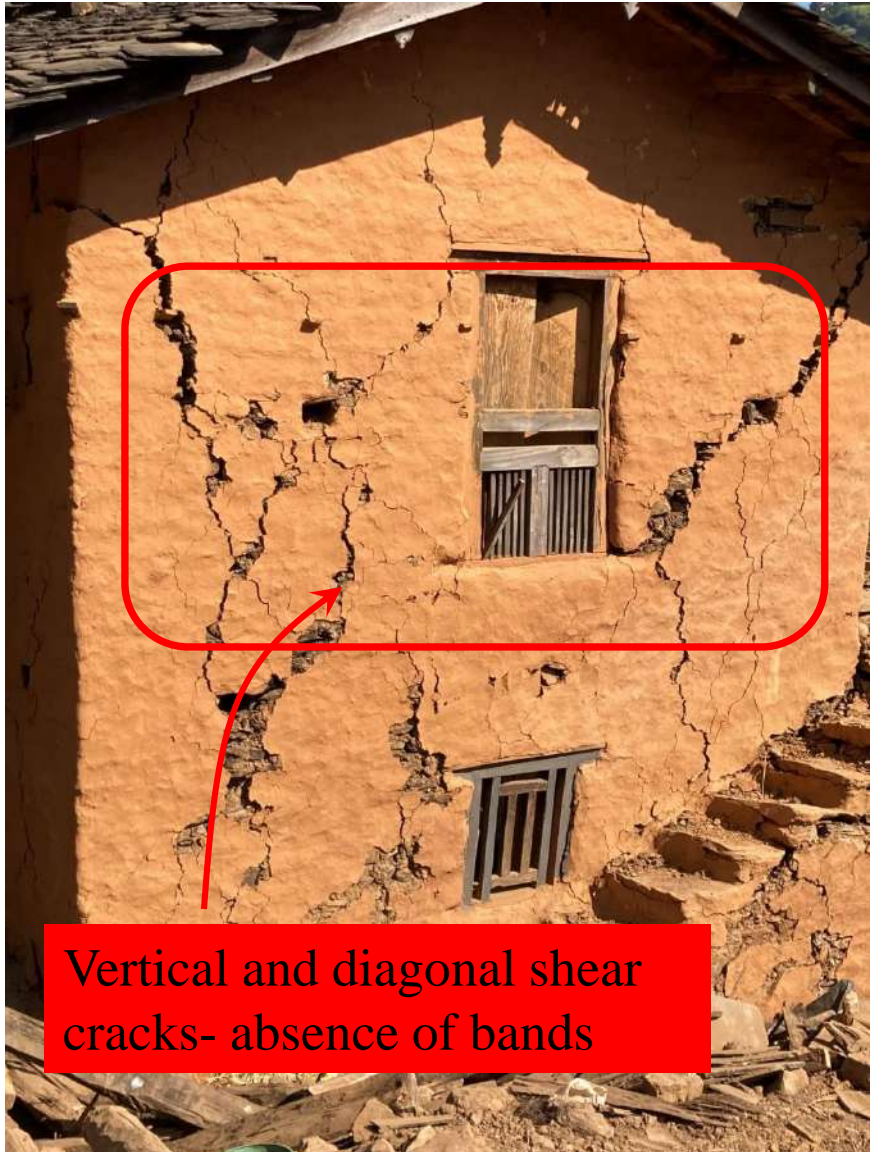


Vertical cracks at corners



Out-of-plane failure of SMM wall- absence of roof band

Nalgad Rural Municipality, Chiyaure



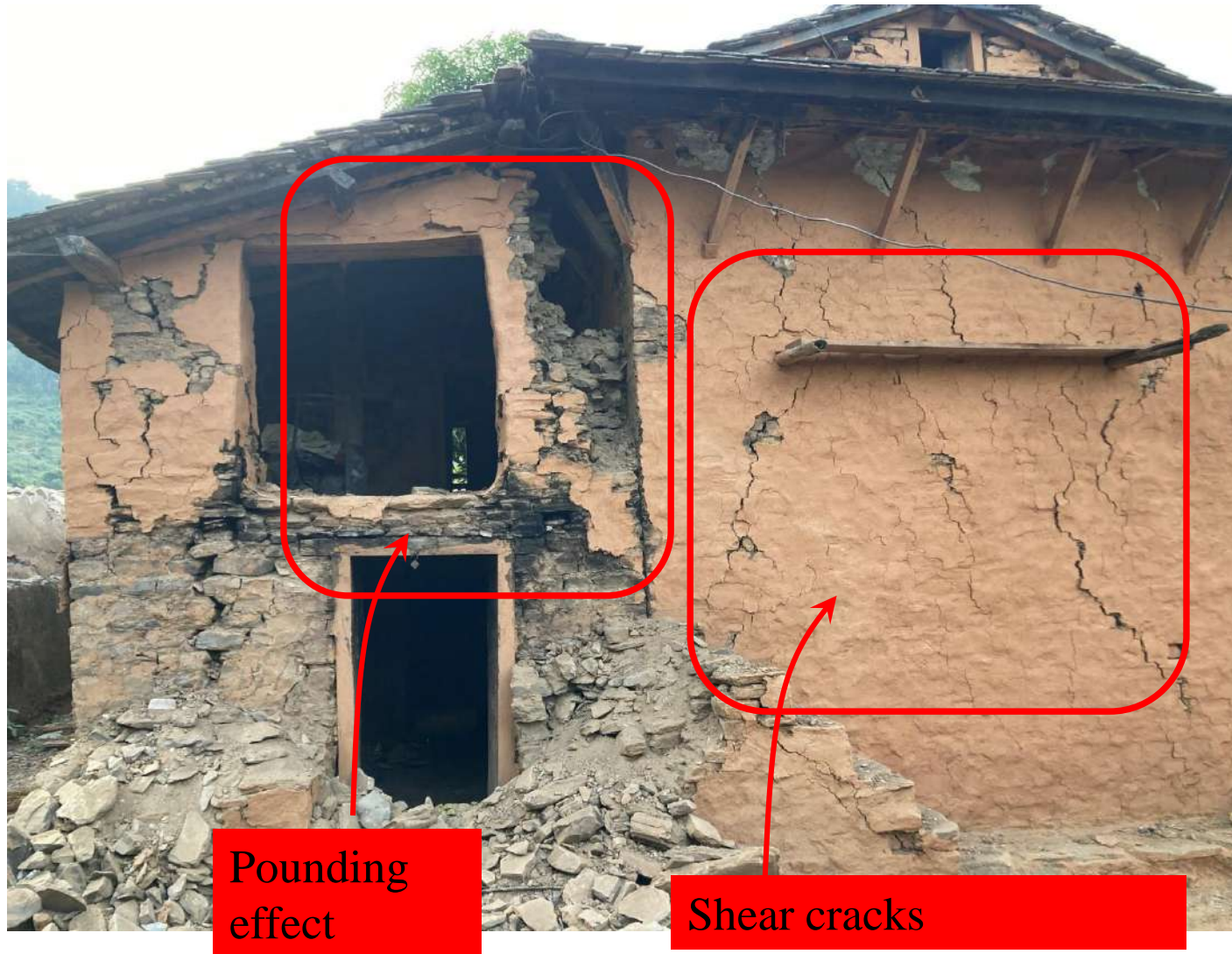
Nalgad Rural Municipality Building



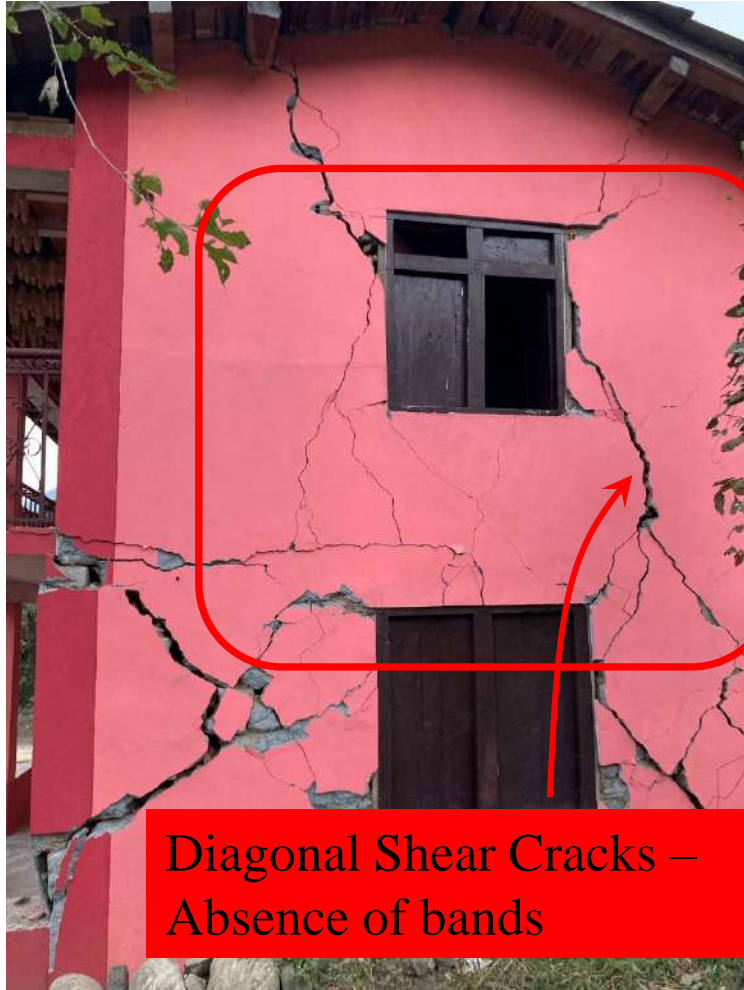
Pounding Effect



Pounding Effect



Performance of Masonry Structures



Diagonal Shear Cracks –
Absence of bands

Salyan- Darma Rural Municipality-3



Out-of-plane failure – Free standing walls and absence of bands

Geological Hazards

- Damage in Mid-Mountain Highway- Musikot to Cahurjhari Rukum (West)



Geological Hazards

- Damage in Madhya Pahadi Rajmarg- near China Bazar way to Cahurjhari Rukum (West)
- Land slides
- Minor damage in bridge



Geotechnical Failures



Future Directions for Earthquake Resilient Reconstruction

- Common deficiencies in stone masonry buildings

Tectonic Activities in Himalayas

- R. Bilham (2019) analyzed the past 1000 years of earthquakes in the Himalaya region using geodetic, historical and seismological data, and identified segments of the Himalaya that remain unruptured.
- Seismic threat along western part of Nepal

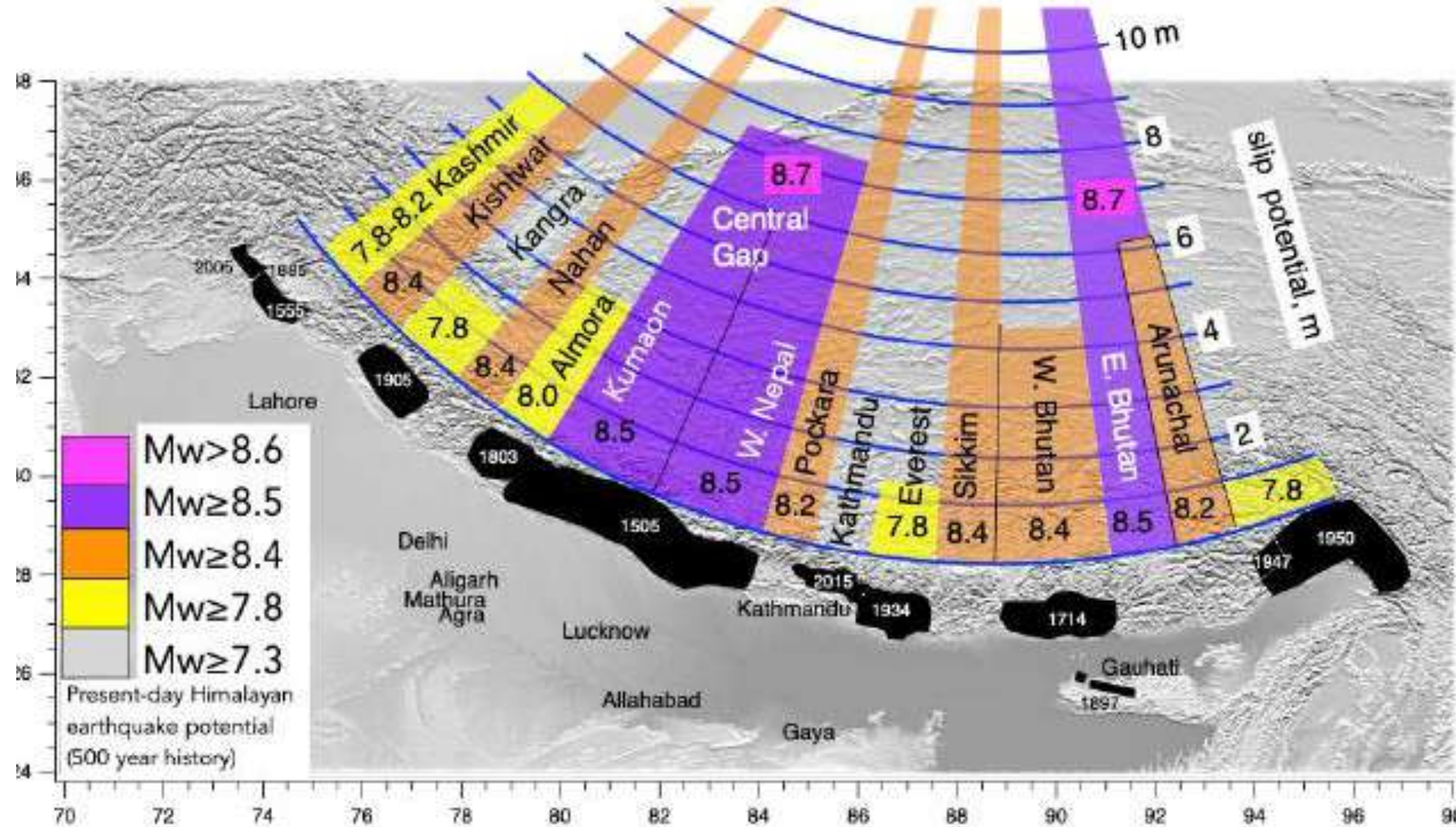


Fig.: Possible segments along the Himalaya and their potential magnitudes at present (R. Bilham, 2019)

Seismic Deficiencies in Stone Masonry Buildings

- Vulnerable to **moderate earthquakes** due to thick walls with heavy flexible floors and roofs - **higher seismic weights**.
- Higher inertial force during earthquakes, i.e., **large earthquake force** (base shear)
- Stone is strong in compression compared to bricks, blocks etc.
- Round, rubble (unshaped) stones and low-strength mortar, unskilled manpower (artisan skills) - the stone structures are **extremely vulnerable**.
- Unsafe practices are the result of economic constraints, lack of knowledge and lack of trained masons.

Findings of Field Visit: Seismic Deficiencies in Stone Masonry Buildings

- Lack of structural integrity- lack of connections betⁿ walls and ...
- Collapse of heavy roof and gable wall due to higher EQ force
- Delamination of wall wythes due to weak mortar and absence of bond stones
- Out-of-plane wall collapse
- In-plane shear cracking
- Load path discontinuity
- Poor quality of construction materials
- Foundation problems
- Age of building

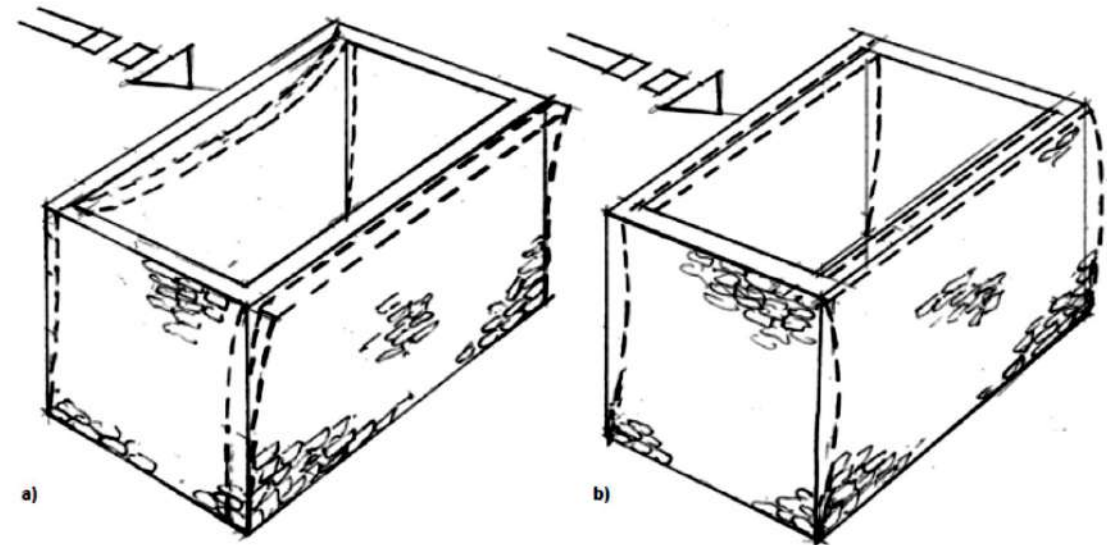


Fig. Masonry building during earthquake shaking: a) loosely connected walls without slab at the roof level, and b) a building with well connected walls and a roof slab (source: Tomazevic 1999)

Seismic Deficiencies in Stone Masonry Buildings

- Lack of bracing-walls, floors, roofs
- Construction and structural deficiencies
- Issues in materials



Findings of Field Visit: Seismic Deficiencies in Masonry Buildings

- Absence of key stones, through stones, bands
 - Absence of EQ force resistive elements
 - Absence of the provisions mentioned in masonry guidelines, NBC and ...
-
- Office buildings of all Municipalities are of RCC Frame Structures
 - Even poor RCC buildings survived the EQ shaking
 - **Distractions and misconceptions to masonry buildings among users**
 - Technical manpower at municipalities need trainings to implement NBC

Recommendations

- Lessons learned from the 2015 Gorkha Earthquake should be fully utilized in the **reconstruction of 2023 Jajarkot Earthquake**.
- Reconstruction work should move forward in the coordination with Local, Provincial and Central Level Governments.
- Difficult in the procurement process from prevailing acts, so necessary amendments required to have speedy procurement with assurance of quality.
- In private housing reconstruction, local/provincial level manpower should be mobilized with proper trainings
- Local materials should be used in the reconstruction with minimum imported ones.
- Innovative materials and technologies should be utilized

Recommendations

- Some modifications in the usage of river boulders in necessary
- Implementation of **Nepal Building Code, guidelines and bye-laws**
- For reconstruction of Government Offices/Infrastructures, Central Government should have important responsibility

Immediate Actions

- Construction of temporary shelters to save EQ victims from cold

Recommendations

Damage Assessment Survey

- While collecting social, economic data, survey tool should be based on the family size, shape and size of building
- In the construction of infrastructures like roads, hydropower, irrigation channels etc., appropriate questionnaires should be added to ease land acquisition.
- Separate questionnaires to vulnerable population

Recommendations

Damage Assessment Survey...

- Questions regarding authoritative documents to accommodate two families in a single house so as eliminate duplication
- Multiple ownership in residencies should be addressed in Survey Tool
- Issues of multiple houses of a single owner should be mentioned clearly

Recommendations

Reconstruction of Private Housing

- Cultural vernacularism suitable to the local geography and necessity of users (family size) should be addressed
- Use lessons learned during reconstruction of Private Housing after 2015 Gorkha EQ
- Proper design with SMM, BMM, SMC, BMC, RCC etc. as per geography, availability of local materials and cultural values
- Use of quarry flat stones and wood with proper bands utilizing NBC provisions/MRT guidelines
- Along river side, appropriate technology should be used without using river boulders in housing
- Local manpower should be trained to use EQ resistive technology using local materials before reconstruction.

Recommendations

Reconstruction of Private Housing...

- Necessity of differently able people should be addressed in the reconstruction
- Use of local manpower in owner driven or any other modality of reconstruction to ensure resiliency.
- In landslide prone and other vulnerable areas team of experts should be mobilized to identify the risk.
- Adopt appropriate modality for subsidy based on lessons learned from 2015 EQ. It should assure compliance of NBC and control of quality in the reconstruction

Recommendations

Long Term Recommendations

- Need to amend building bye-laws to address local topographical conditions
- Implementations of NBC by the local government
- Retrofit of old-deficient buildings through appropriate policy
- Local levels should be prepared for future earthquakes via resilient construction.
- Up to date emergency response team at local level
- Identification of landslide prone-vulnerable locations and if needed resettlement planning for vulnerable settlements.
- Additional subsidy for vulnerable population to reconstruct/retrofit buildings

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Thank you!