UNDRR
UN Office for Disaster Risk Reduction

EARTHQUAKE HAZARD & RISK ASSESSMENT OF BANGLADESH

Technical Panel Session #3

Exposure, Seismic Vulnerability, Social Vulnerability

GLOBAL EARTHQUAKE MODEL FOUNDATION

30 November 2023

working together
to assess risk

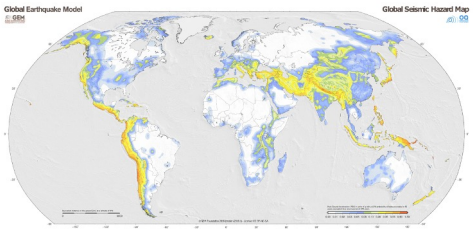
GEM
GLOBAL EARTHQUAKE MODEL

OQ
OPENQUAKE

Three components of seismic risk

Seismic Risk

The risk occurs when there is a spatial and temporal overlap of these three elements

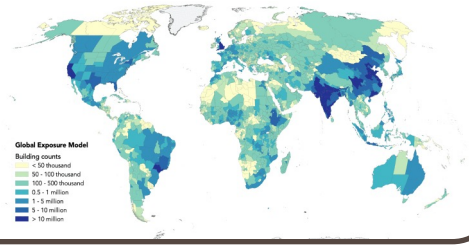


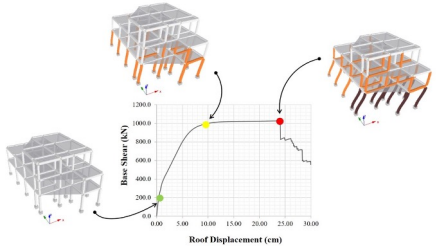
Hazard

Characterizing the potential locations, intensity or magnitude, frequency or probability of earthquakes

Exposure

Characterizing the built environment and people in hazard-prone areas

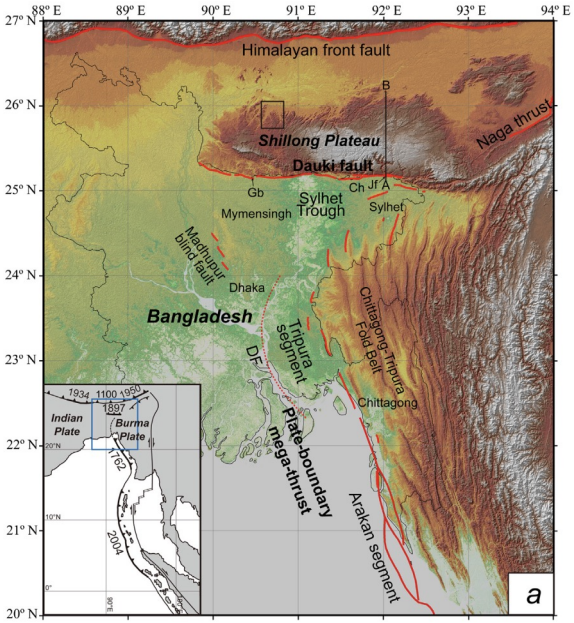




Vulnerability

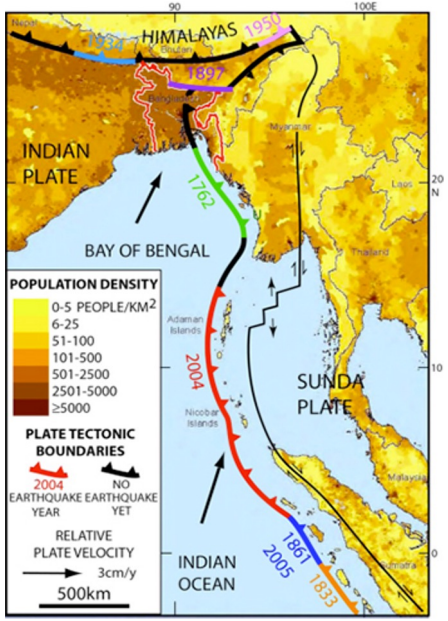
Factors which increase the susceptibility of an individual or assets to the impacts of hazards

Probabilistic seismic hazard assessment



Active fault map of Bangladesh

Morino et al. (2014). A paleo-seismological study of the Dauki fault at Jaflong, Sylhet, Bangladesh: Historical seismic events and an attempted rupture segmentation model. Journal of Asian Earth Sciences, 91, 218–226.

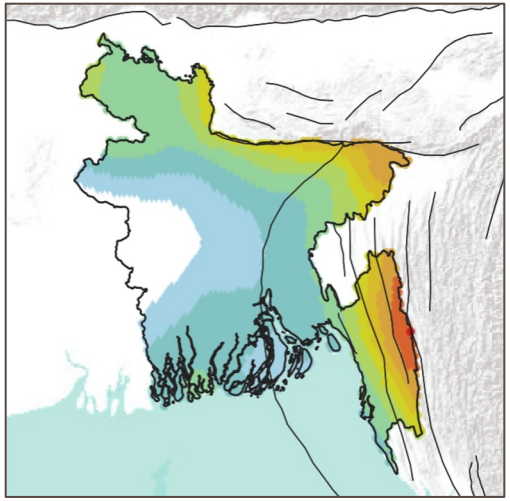


Subduction plate boundaries

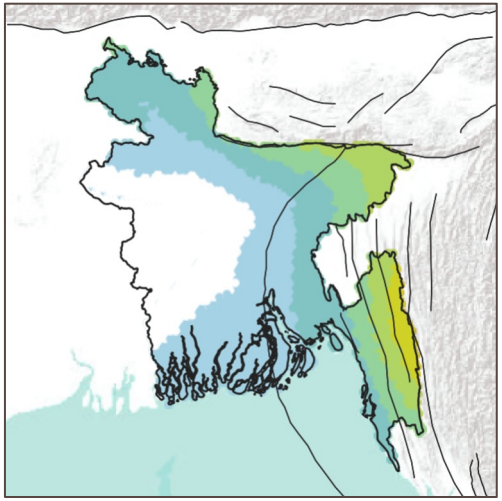
Source: Michael Steckler / Lamont-Doherty Earth Observatory

- Identification of active faults
- Historical earthquakes
- Hypothetical future scenarios
- Soil characterization using secondary data
- Ground motion model
- Probabilistic seismic hazard assessment

Probabilistic seismic hazard assessment



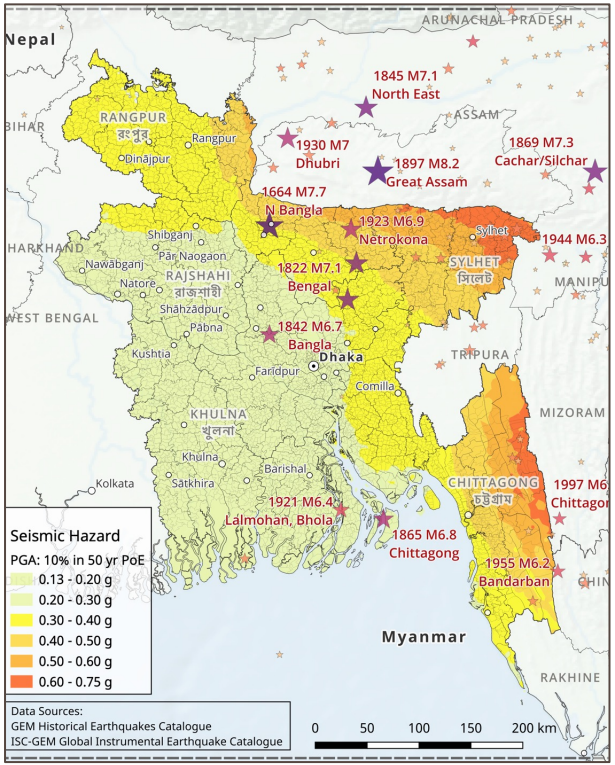
Nath & Thingbaijam (2012)



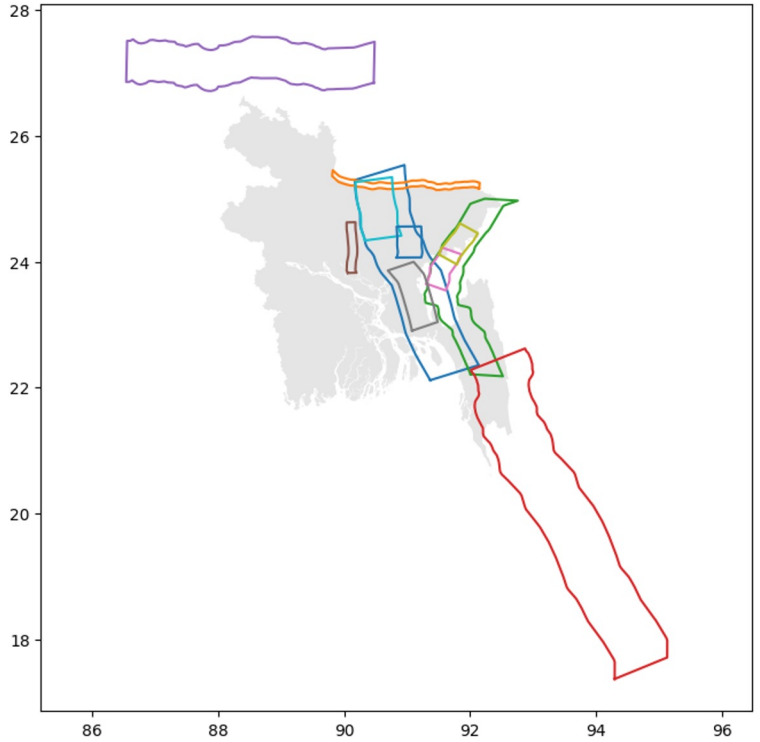
Updated model (GEM, 2023)

- Identification of active faults
- Historical earthquakes
- Hypothetical future scenarios
- Soil characterization using secondary data
- Ground motion model
- Probabilistic seismic hazard assessment

Earthquake scenario assessment



Historical earthquakes

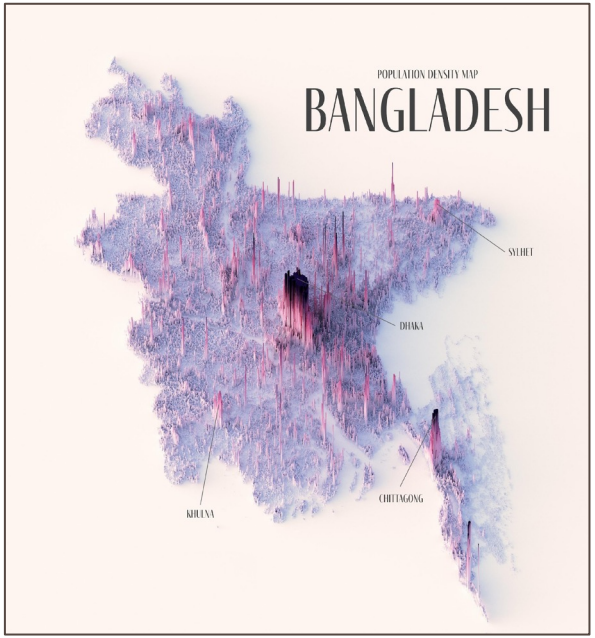


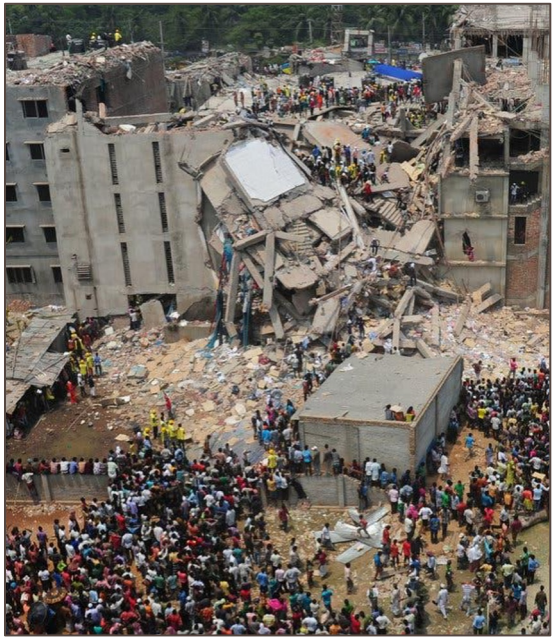
Modelled scenario ruptures

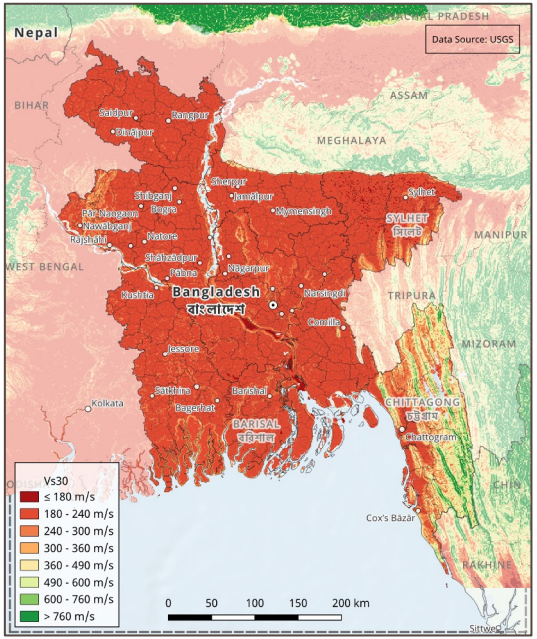
Exposure Model

BUILDINGS
POPULATION
INFRASTRUCTURE

Exposure – Context







High population across the country, with a particular concentration in Dhaka

Bangladesh population: 165 million (2022 census)
Dhaka metropolitan area: 22.5 million (2022 census)

Rapid urbanization coupled with poor quality RC construction & slums

Collapse of Rana Plaza in Savar, Dhaka led to 1,134 fatalities and around 2,500 injuries

80% of the country is a river delta – deep deposits of soft clay & silt

Potential for significant amplification of ground motions and liquefaction

Exposure – Structural and physical attributes

It is necessary to identify the physical characteristics of the built environment, to classify each exposed element according to its seismic fragility and vulnerability



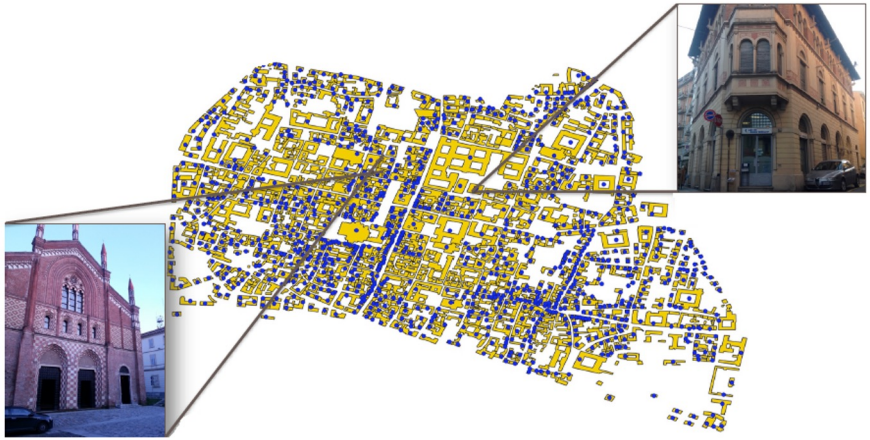

Some of the main attributes that need to be identified are:
construction material, structural system, height, and code compliance

Exposure – Conceptual framework

https://zagreb.gdi.net/zg3d/

Exposure – Small scale building inventory compilation

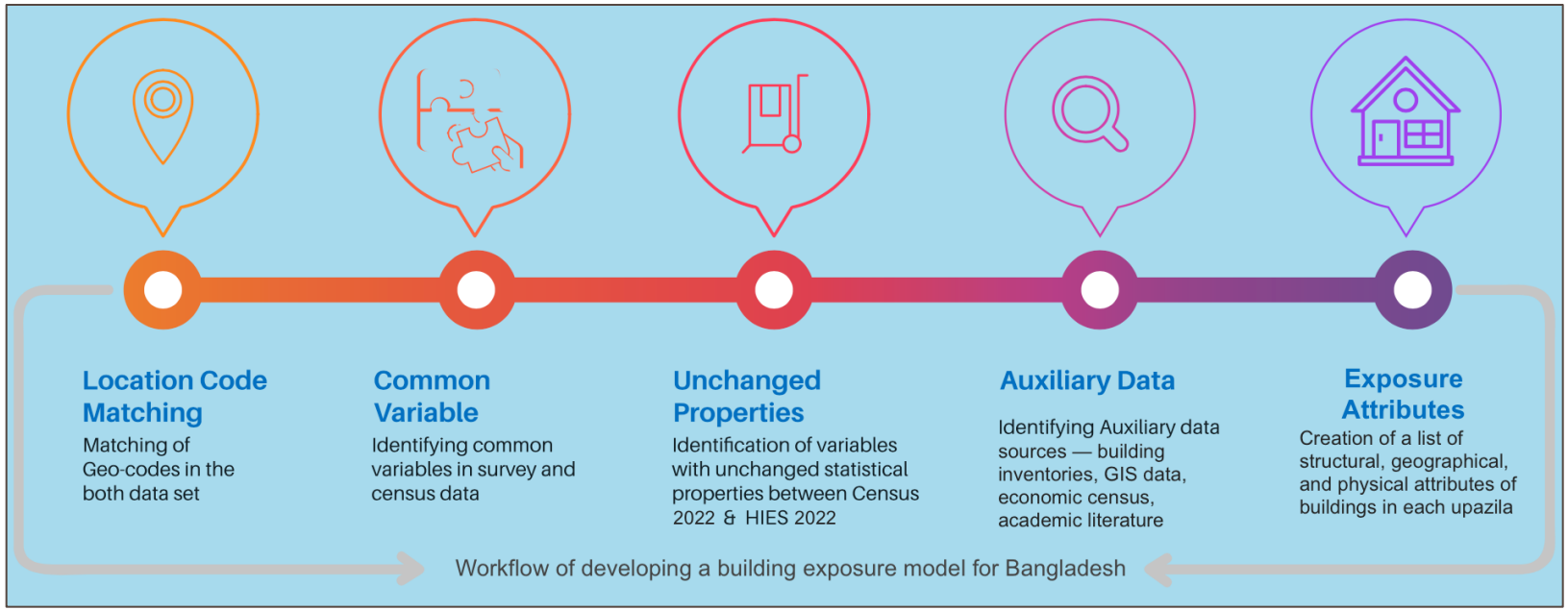
Building by building capture tool



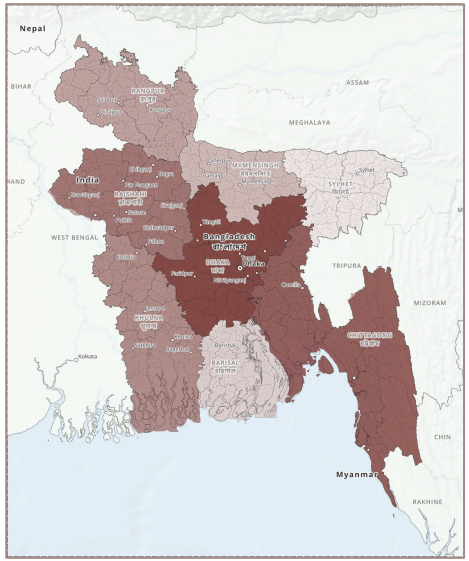
Urban exposure models

Android App: IDCT Direct Observation Survey
https://play.google.com/store/apps/details?id=org.globalquakemodel.org.idctdo&hl=en

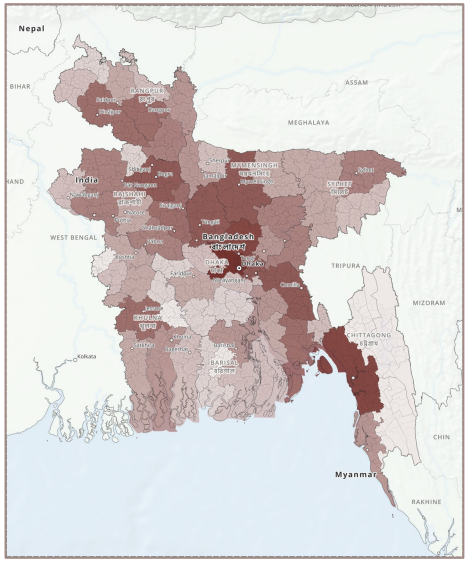
Exposure – Model development workflow at national scale



Exposure – GEM's existing coverage for Bangladesh



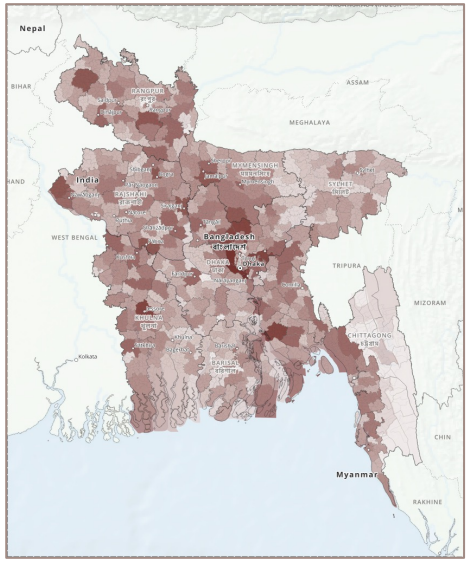
Residential Exposure (2018)
2011 Census
Admin Level 1 – Division (8)



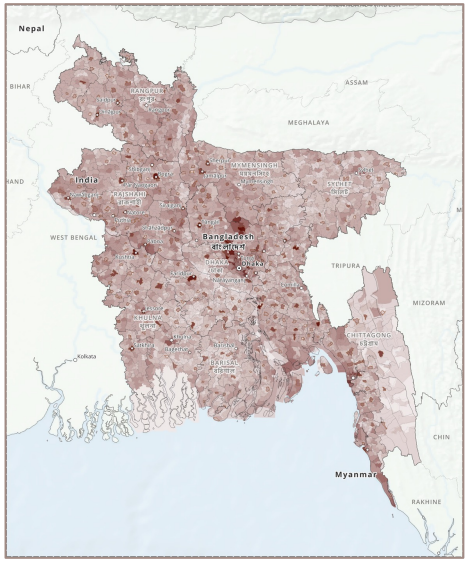
Residential Exposure (2023)
2011 Census
Admin Level 2 – Zila (64)

- **Buildings**
  - Residential
  - Commercial
  - Industrial
- **Infrastructure**
- **Attributes**
  - Location
  - Typology
  - Valuation
  - (Height)
  - Age
- **Population**
  - 2011 Census

Exposure – Additional coverage and improvements



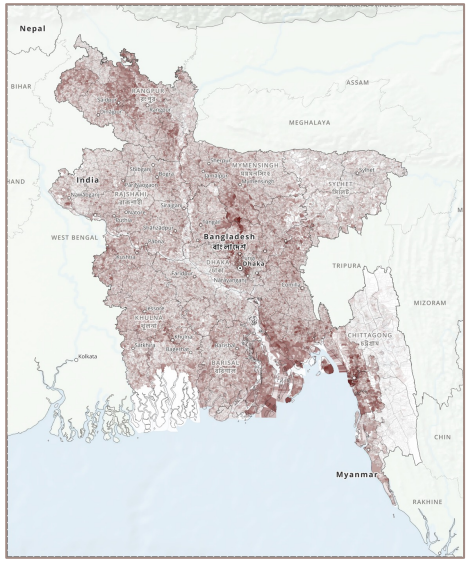
Residential Exposure (2024)
2022 Census
Admin Level 3 – Upazila



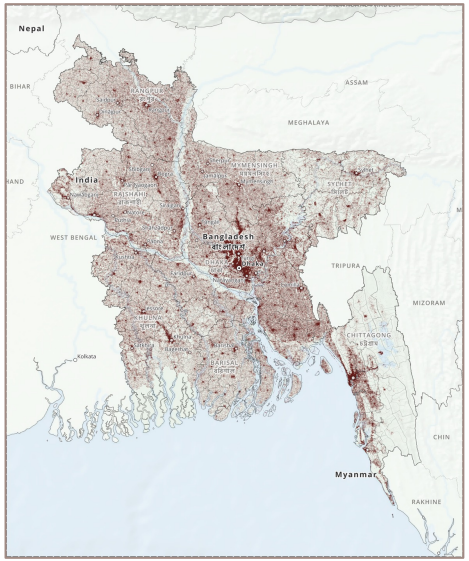
Residential Exposure (2024)
2022 Census
Admin Level 4 – Union/Paurashava

- **Buildings**
  - Residential
  - Commercial
  - Industrial
  - Healthcare
  - Education
- **Infrastructure**
  - Roads
  - Railways
- **Attributes**
  - Location
  - Typology
  - Valuation
  - Height
  - Age
- **Population**
  - 2022 Census

Exposure – Enhanced spatial resolution for flood risk



Residential Exposure (2024)
2022 Census
Admin Level 5 – Villages



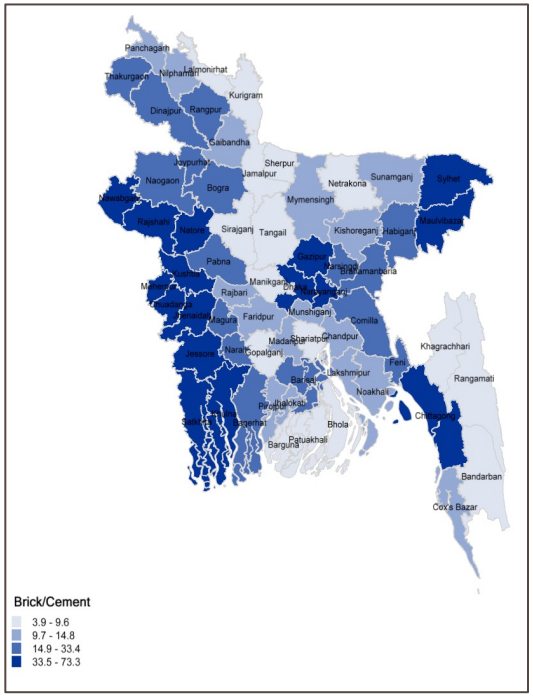
Residential Exposure (2024)
2022 Census
Admin Level 6 – Enumeration Areas

- **Buildings**
  - Residential
  - Commercial
  - Industrial
  - Healthcare
  - Education
- **Infrastructure**
  - Roads
  - Railways
- **Attributes**
  - Location
  - Typology
  - Valuation
  - Height
  - Age
- **Population**
  - 2022 Census

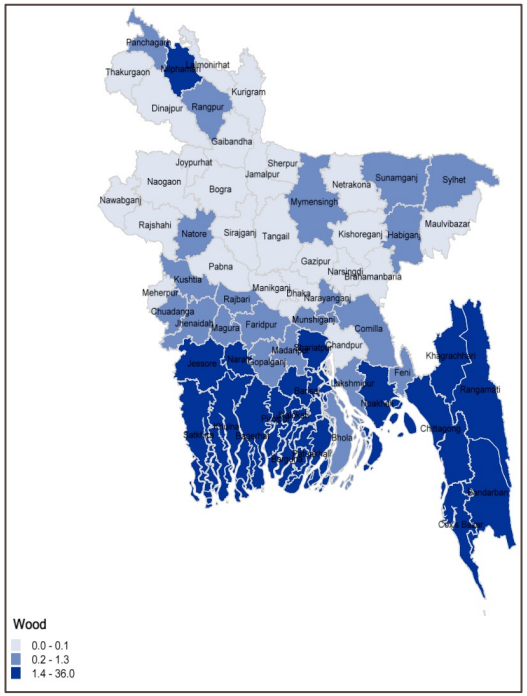
Exposure – Inferring construction type from wall, roof, floor

Housing Materials	Settlement Type				Division							
	Total	Rural	City Corporation	Pourashava / Other Urban	Barisal	Chittagong	Dhaka	Khulna	Mymensingh	Rajshahi	Rangpur	Sylhet
Floor Materials												
Mud / Sand	52.30	63.12	3.25	27.20	70.71	49.75	29.76	53.79	69.14	65.45	70.00	55.46
Cement / Concrete / Brick / Burnt mud	41.42	33.13	72.77	63.95	25.04	40.77	59.28	42.16	27.81	32.41	27.89	41.03
Tiles / Mosaic / Marble / Granite / Furnish wood	4.34	1.54	22.88	7.79	2.06	4.35	8.75	3.77	1.43	1.70	1.54	2.84
Wood / Bamboo / Mat / Palm-betelnut bole	1.74	1.99	1.00	1.00	2.00	4.54	2.14	0.25	1.04	0.40	0.55	0.63
Others	0.19	0.23	0.10	0.06	0.18	0.60	0.07	0.03	0.58	0.05	0.02	0.03
Total	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*
Wall Materials												
Cement / Concrete / Brick / Burnt mud	43.63	34.52	86.89	63.70	24.79	35.56	51.49	59.72	26.43	42.46	38.52	53.35
Metal sheet / CI sheet	42.86	49.47	9.58	29.27	67.71	43.00	45.44	22.26	67.63	32.82	46.44	32.15
Mud / Soil	8.01	9.97	0.17	2.94	0.77	8.24	2.21	9.89	3.81	22.29	7.32	9.92
Wood / Bamboo / Mat / Palm-betelnut bole	4.76	5.39	1.65	3.41	6.02	12.25	0.18	7.20	1.64	1.66	7.22	3.79
Ceramic tiles / Furnish wood	0.47	0.31	1.62	0.57	0.47	0.69	0.58	0.45	0.29	0.24	0.27	0.45
Straw / Chaff / Gal leaves / Palm leaves / Bic	0.19	0.24	0.04	0.05	0.17	0.15	0.05	0.31	0.13	0.41	0.18	0.30
Other materials	0.05	0.06	0.03	0.04	0.05	0.02	0.04	0.15	0.01	0.11	0.02	0.02
No wall at all	0.03	0.03	0.01	0.02	0.02	0.08	0.01	0.02	0.05	0.02	0.01	0.02
Total	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*
Roof Materials												
Metal sheet / CI sheet / Tin	79.35	86.89	34.96	67.21	87.08	77.49	68.93	68.21	92.71	86.38	94.29	84.58
Cement / Concrete	18.96	11.32	63.66	31.40	11.88	20.37	30.55	25.57	5.80	12.77	4.77	14.48
Wood / Bamboo / Mat / Golpata / Palm leaf / Polythene	0.79	0.86	0.33	0.71	0.53	1.87	0.16	1.28	1.36	0.18	0.64	0.76
Handmade tiles / Tali	0.38	0.46	0.04	0.17	0.01	0.03	0.01	3.05	0.01	0.11	0.02	0.00
Others	0.02	0.02	0.03	0.02	0.01	0.03	0.01	0.02	0.02	0.03	0.01	0.02
No roof at all	0.50	0.44	0.99	0.49	0.48	0.21	0.34	1.87	0.11	0.54	0.27	0.16
Total	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*

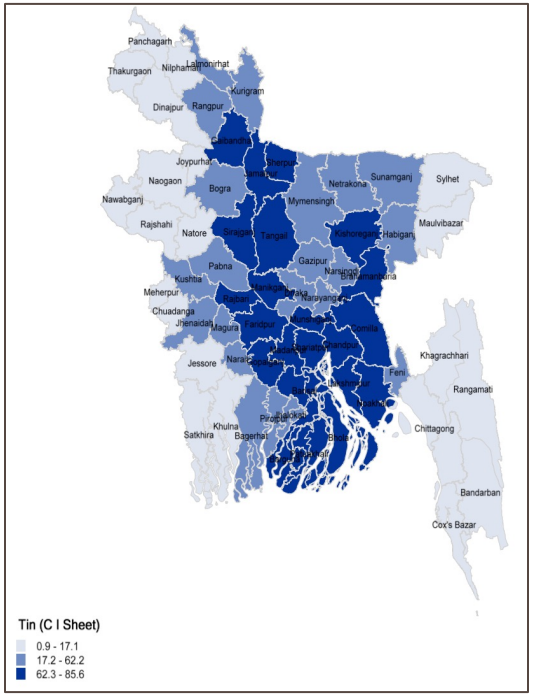
Exposure – Wall material geographical variation (2011)



Brick / Cement
2011 Census
Zila Level

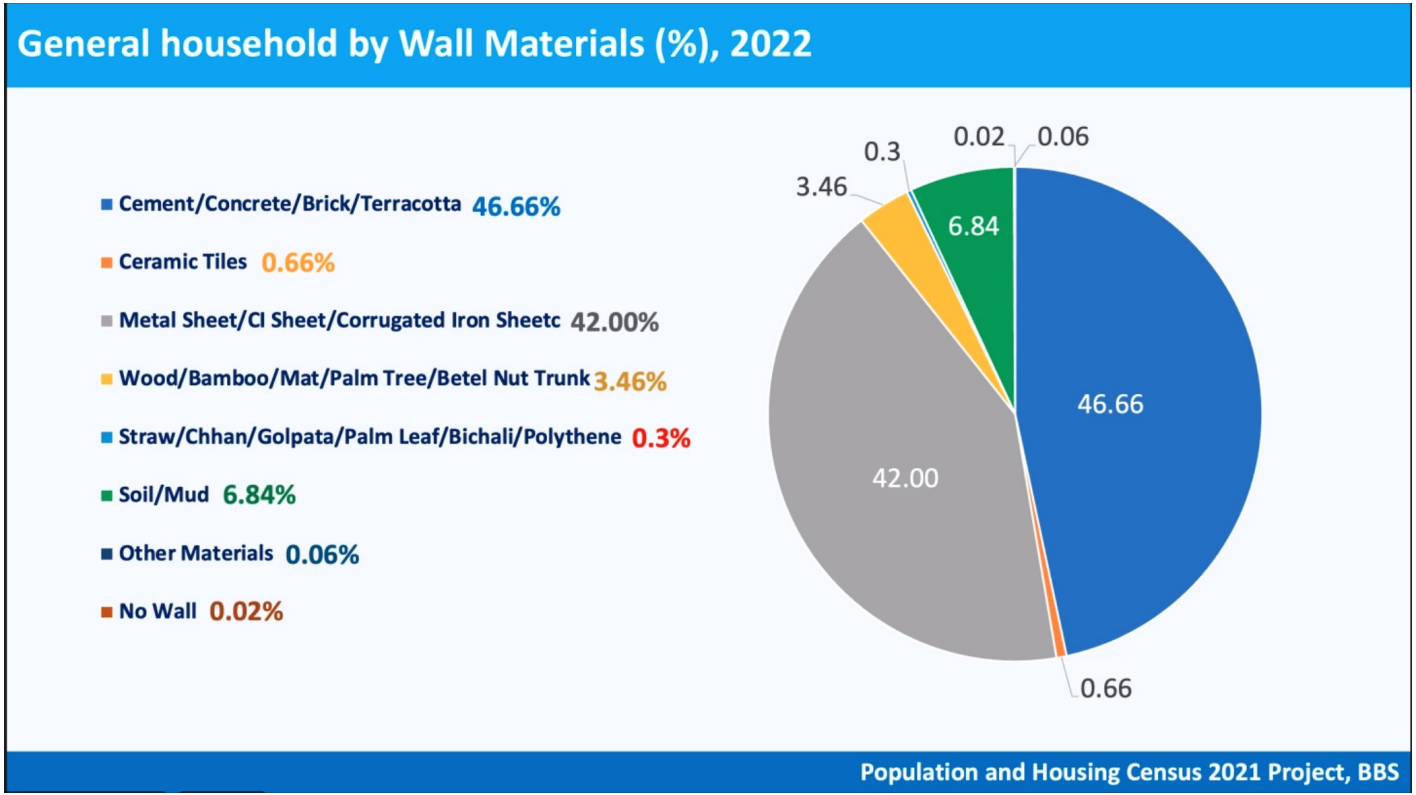


Wood / Bamboo
2011 Census
Zila Level



Tin / CI Sheet
2011 Census
Zila Level

Exposure – Wall materials (2022)



Source: Population and Housing Census 2022, BBS. Courtesy: Md. Dilder Hossain

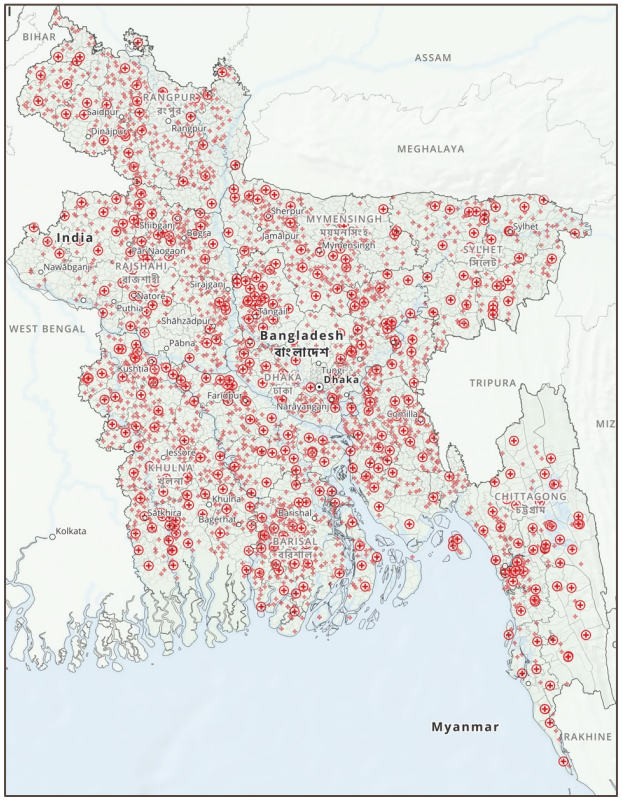
Exposure – Slum dwellings and floating population

Type of dwelling unit	Slum Census 2014		Slum Census 1997	
	Household	Percentage	Household	Percentage
Jhupri	36875	6.20	142476	42.61
Katcha/Tin	371485	62.45	178586	53.40
Semi-pucca	157243	26.43	10319	3.08
Pucca	24169	4.06	3050	0.91
Others	5089	0.86	NA	NA
National	**594861**	**100.00**	**334431**	**100.00**

NB: Tong, Chhai etc. included in katcha structure.

Source: Census of Slum Areas and Floating Population 2014, BBS

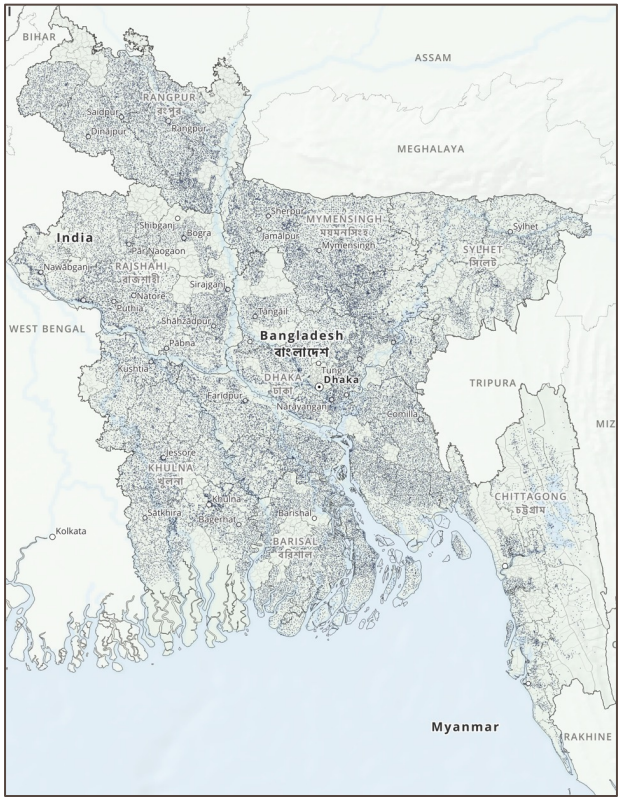
Exposure – Healthcare facilities



Primary data source:

- Hospitals & Clinics Management Section, Directorate General of Health Services (DGHS)

Exposure – Educational facilities



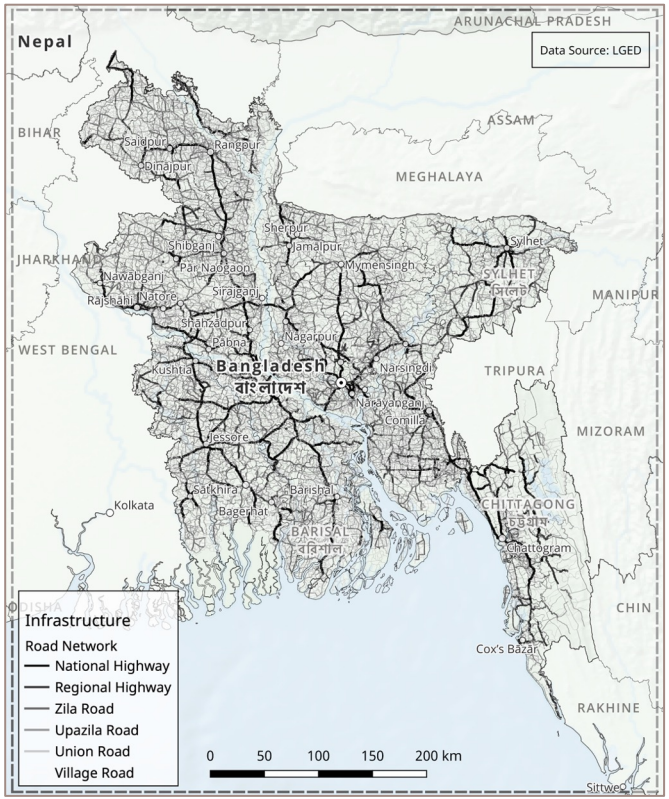
Primary data sources:

- Bangladesh Bureau of Educational Information and Statistics (BANBEIS), Ministry of Education
- Bangladesh Primary Education Statistics & Annual Primary School Census 2021, Ministry of Primary and Mass Education

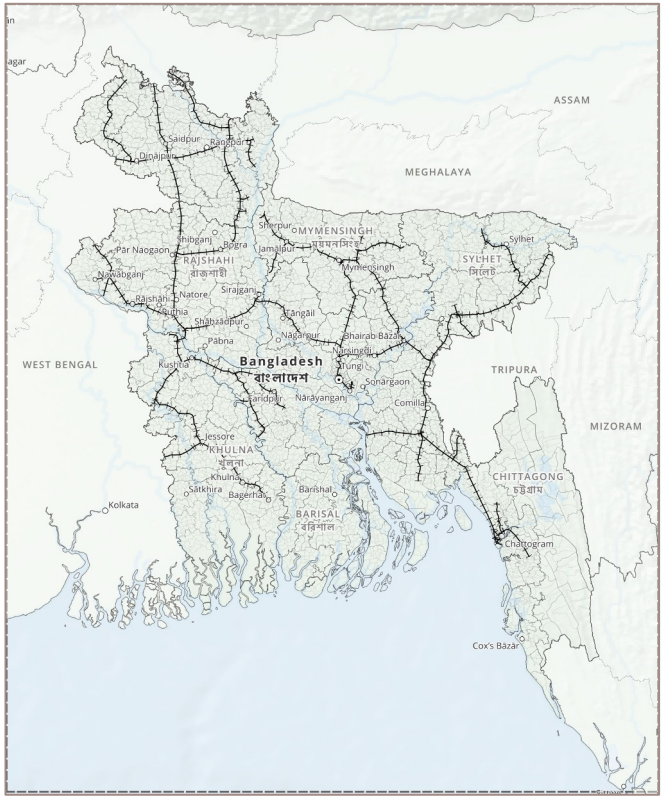
Key Statistics (public)

18,907 (627)	Secondary Education
137	English Medium School
1,446 (64)	School & College
3,301 (637)	College Education
9,268 (3)	Madrasah Education
2,547 (322)	Technical-Vocational (Independent)
826 (129)	Professional Education
209 (94)	Teacher Education
164 (53)	University Education
5,272 (369)	Attached Vocational
118,891 (65,566)	Primary Schools

Exposure – linear infrastructure networks



Road network



Railway network

Primary data sources:

- Local Government Engineering Dept (LGED)
- OpenStreetMap (OSM)

Seismic Vulnerability Model

DAMAGE

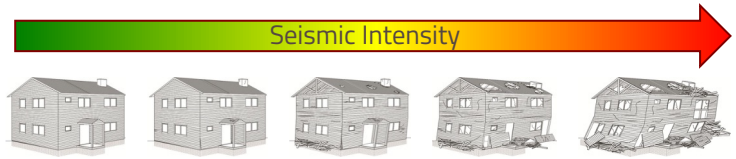
ECONOMIC LOSS

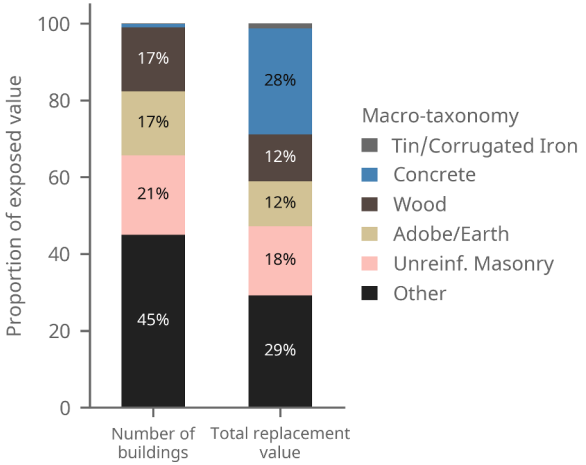
FATALITIES, INJURIES & DISPLACEMENT

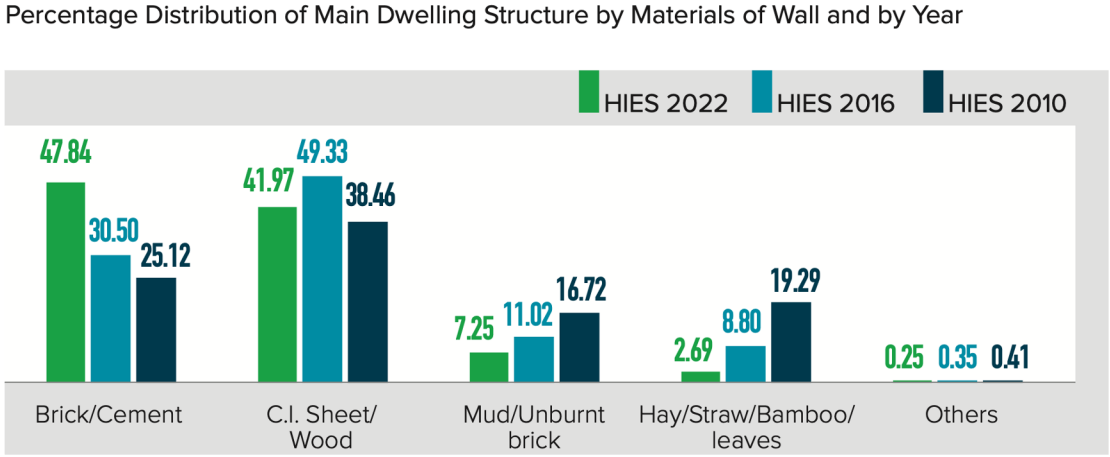
Seismic fragility and vulnerability

Seismic *fragility* represents the likelihood of an element exposed to seismic hazard to suffer *damage* due to ground shaking. Similarly, seismic *vulnerability* represents the likelihood of an element exposed to seismic hazard to suffer *losses* due to ground shaking

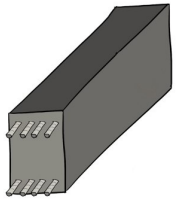
Seismic vulnerability analysis



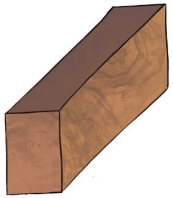




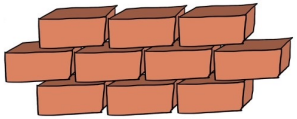
Factors affecting damage level – construction factors



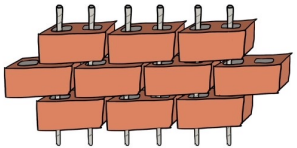
Reinforced concrete



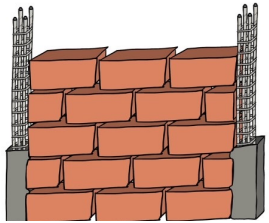
Wood



Unreinforced masonry



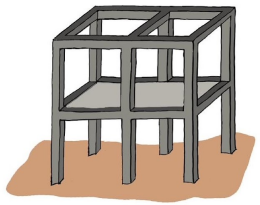
Reinforced masonry



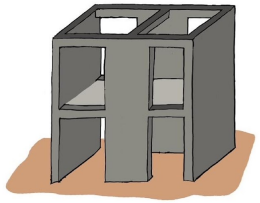
Confined masonry

Main material of construction

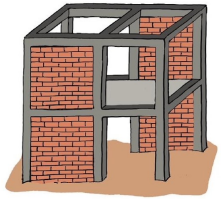
Factors affecting damage level – construction factors



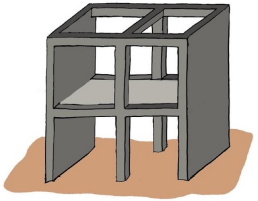
Moment frames



Walls



Infilled moment frames



Dual systems (Moment frames and walls)

Lateral load resisting system (LLRS)

Factors affecting damage level – construction factors

Number of stories

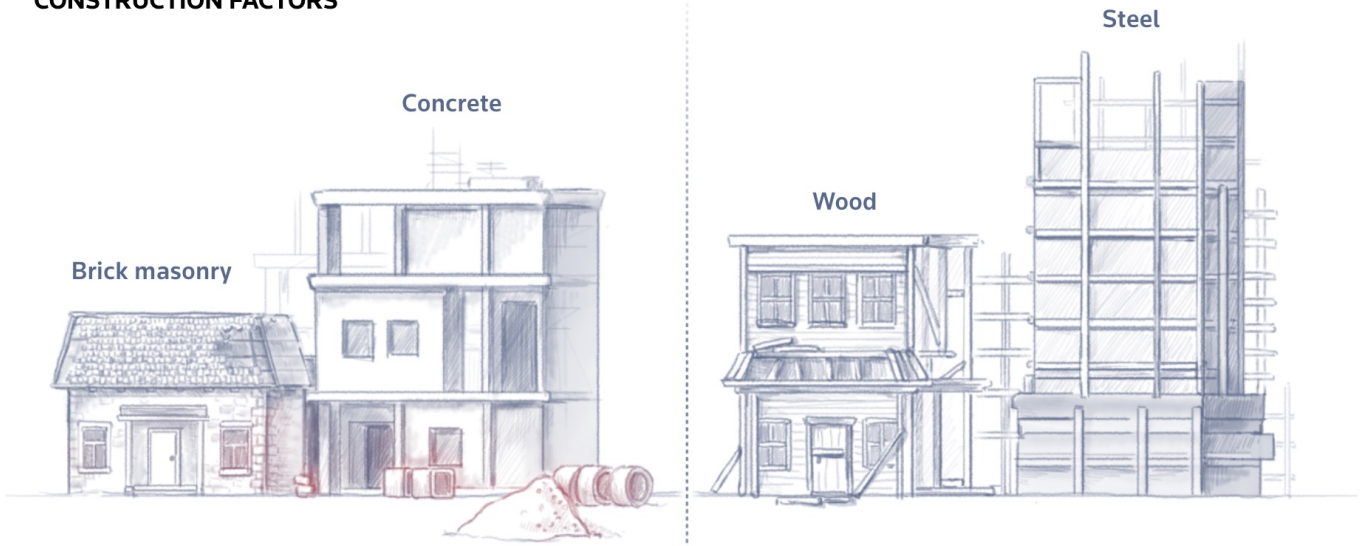
Height

Building code complaince

Ductility level

Factors affecting damage level – construction factors

CONSTRUCTION FACTORS

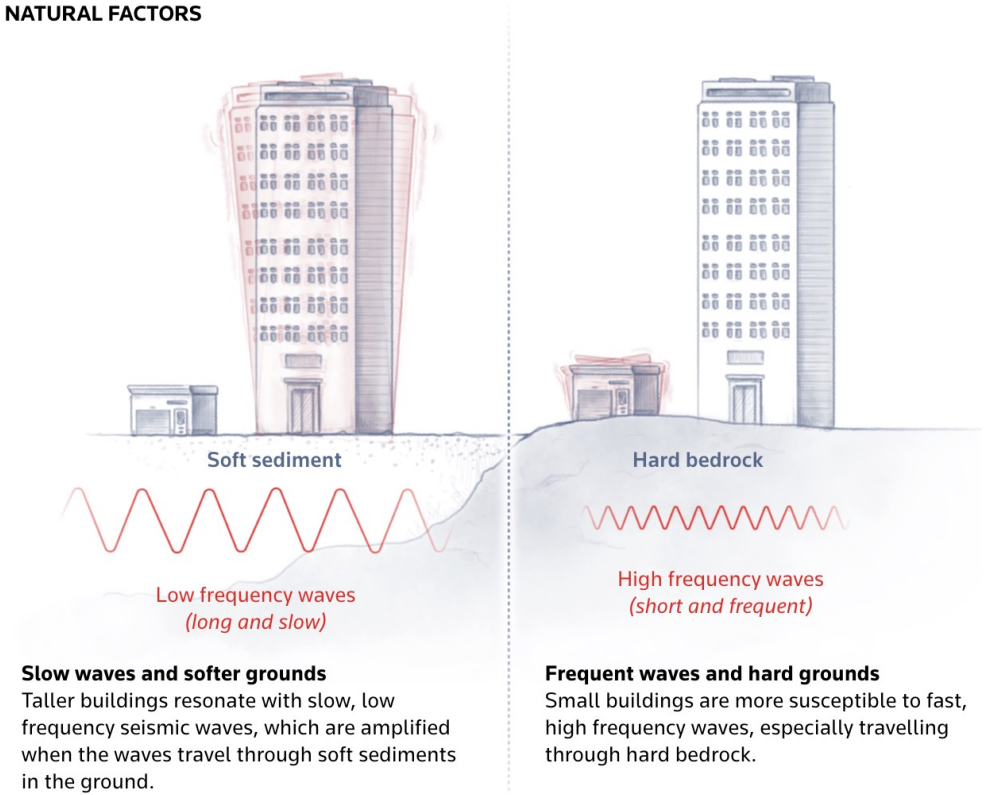


Too stiff to sway
Brick masonry and concrete structures are rigid, which hinders their ability to absorb the energy from seismic waves. Steel is often used to reinforce these buildings, but they may still collapse during major earthquakes.

Flexible and strong
Flexibility is key to absorbing quake energy without collapsing. Wood can flex without breaking, while steel can expand and retract, making them effective quake-resistant materials when used correctly.

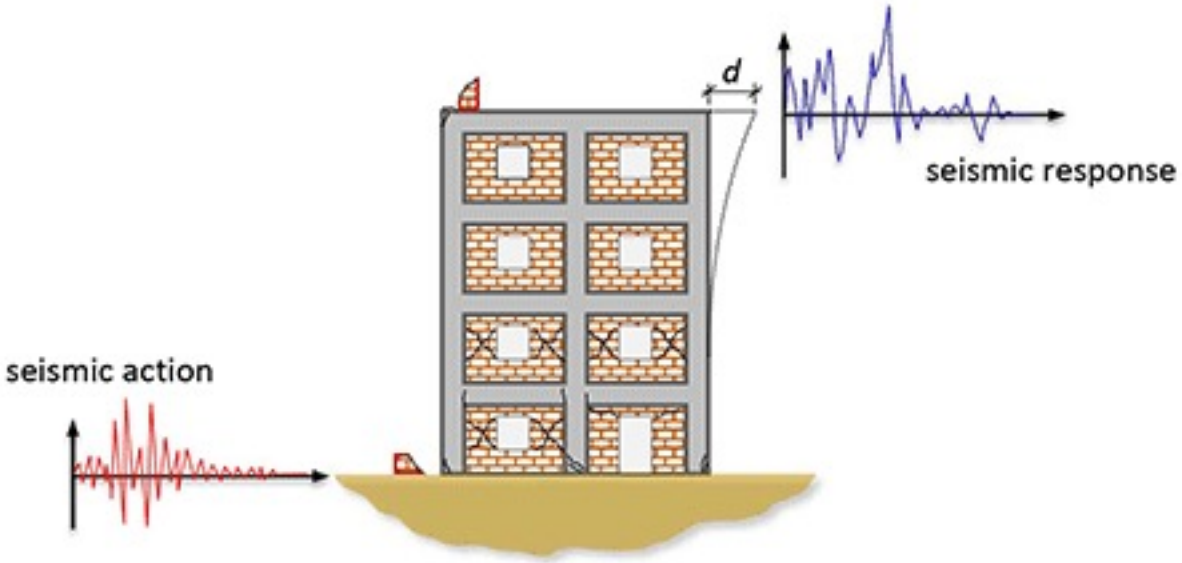
https://www.reuters.com/graphics/TURKEY-QUAKE/zdvxdngmzvx/

Factors affecting damage level – natural factors



https://www.reuters.com/graphics/TURKEY-QUAKE/zdvxdngmzvx/

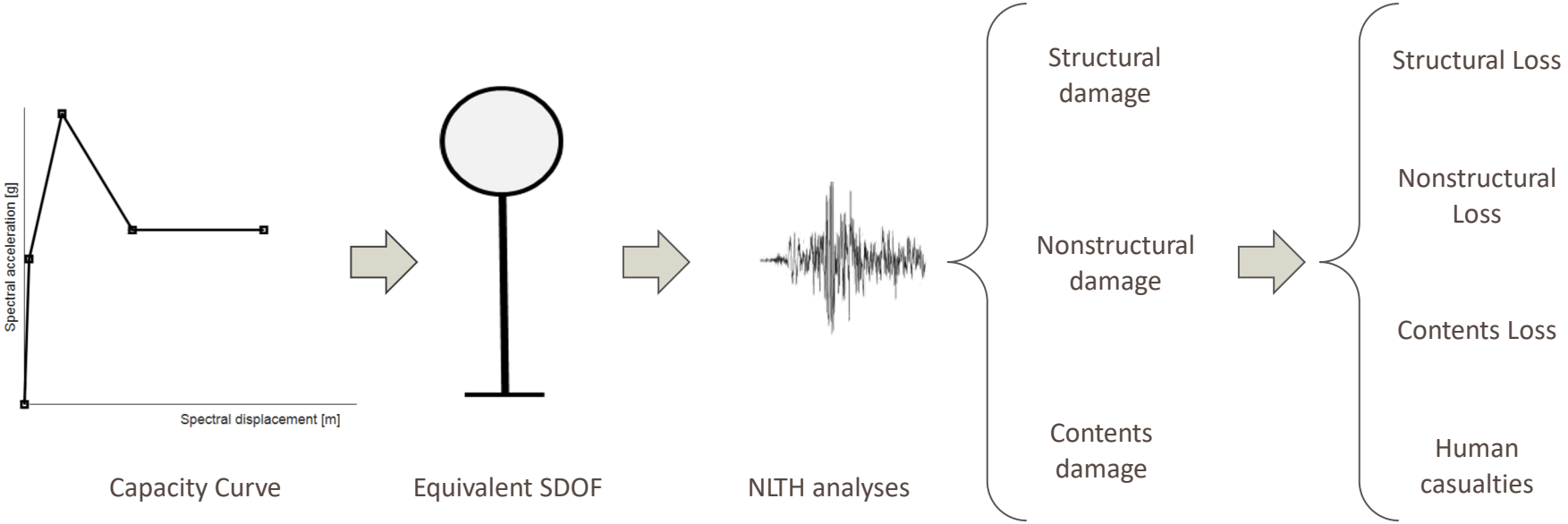
Structural response to ground shaking



Meslem, A., & Lang, D. H. (2017). Physical Vulnerability in Earthquake Risk Assessment. *Oxford Research Encyclopedia of Natural Hazard Science*. Oxford Research Encyclopedias. https://doi.org/10.1093/acrefore/9780199389407.013.71

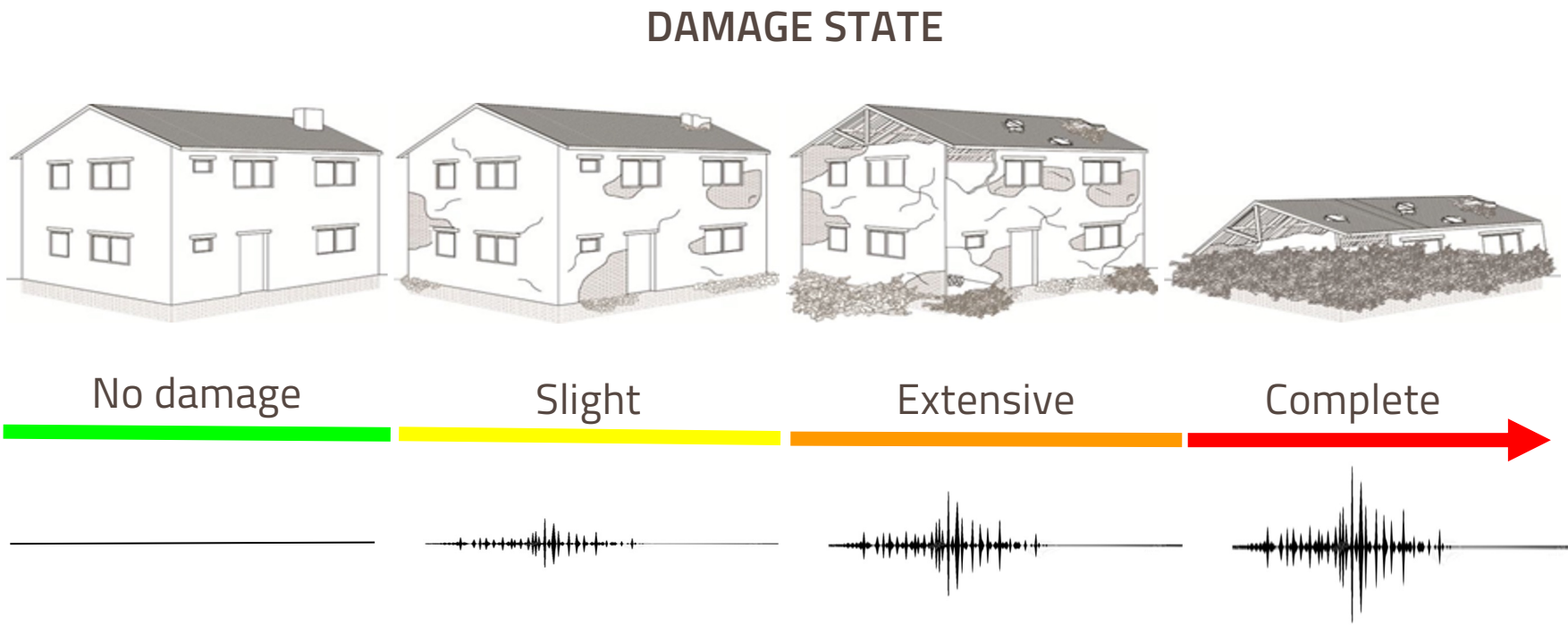
Structural response to ground shaking

Structural response to ground shaking

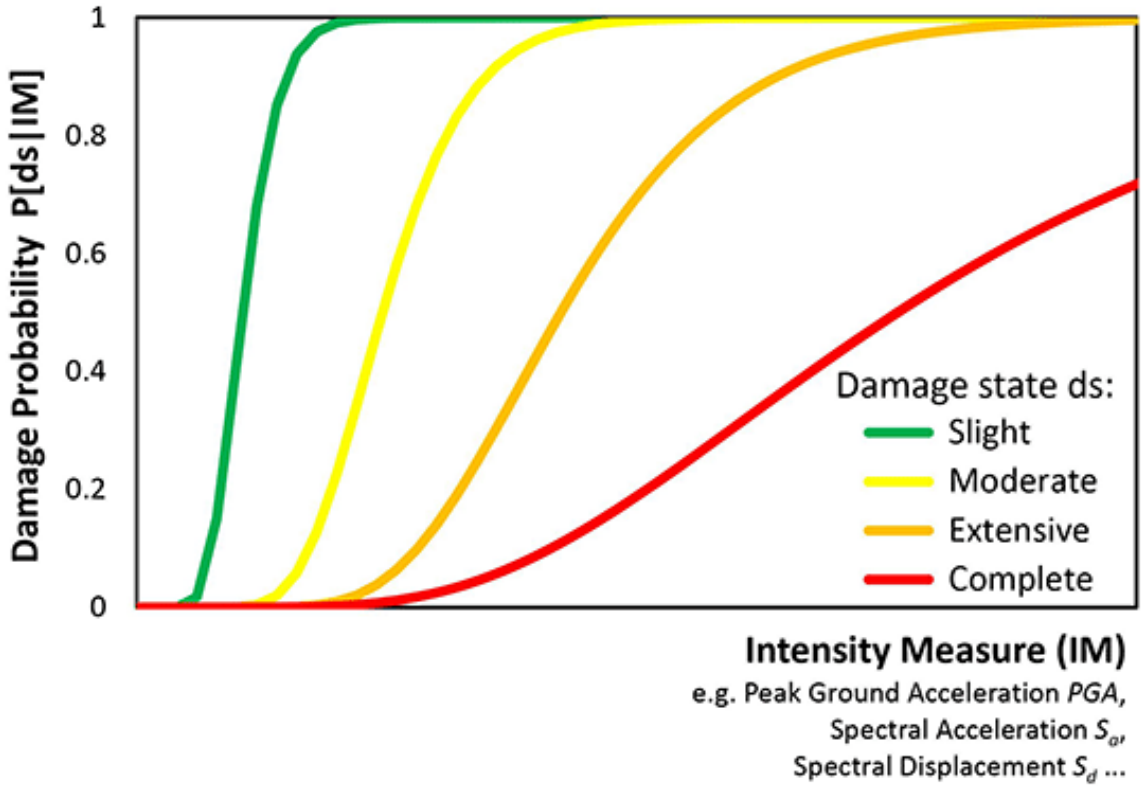


* A complete description of the framework is available through the documentation page at
https://docs.openquake.org/vulnerability/vulnerability_methodology_summary/vulnerability_methodology_summary.html

Structural response to ground shaking



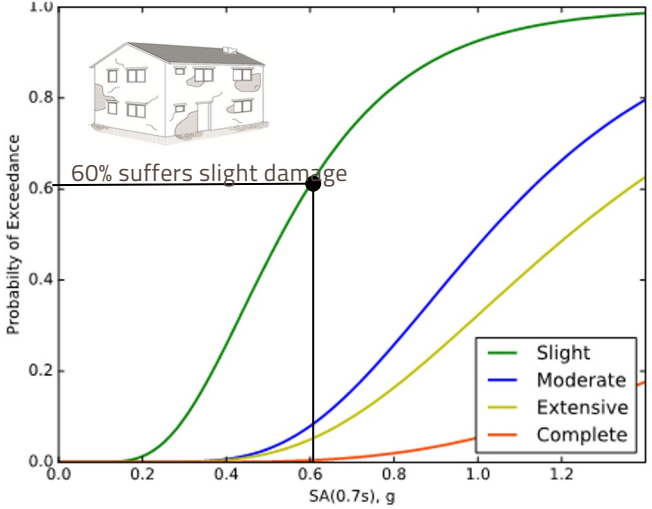
Seismic fragility functions



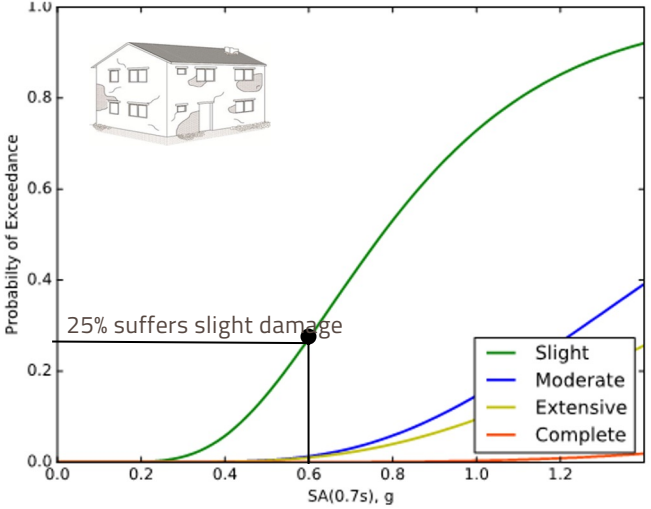
Meslem, A., & Lang, D. H. (2017). Physical Vulnerability in Earthquake Risk Assessment. *Oxford Research Encyclopedia of Natural Hazard Science*. Oxford Research Encyclopedias. https://doi.org/10.1093/acrefore/9780199389407.013.71

Seismic fragility functions

Wooden building (W1)
Prior to building code

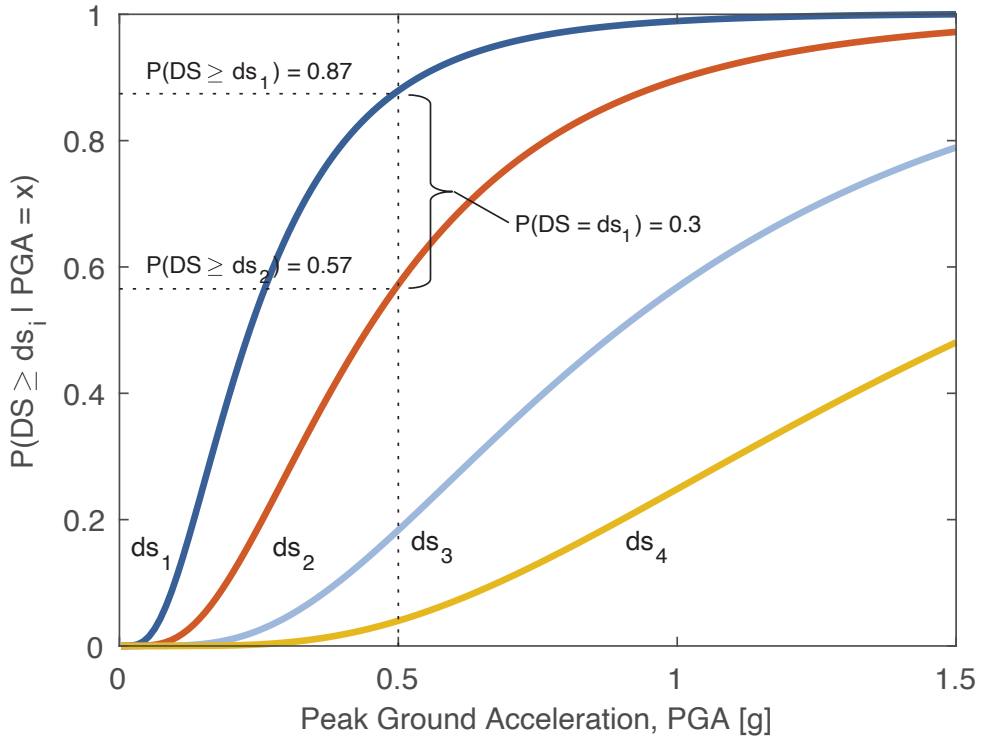


Wooden building (W2)
Building code complaint



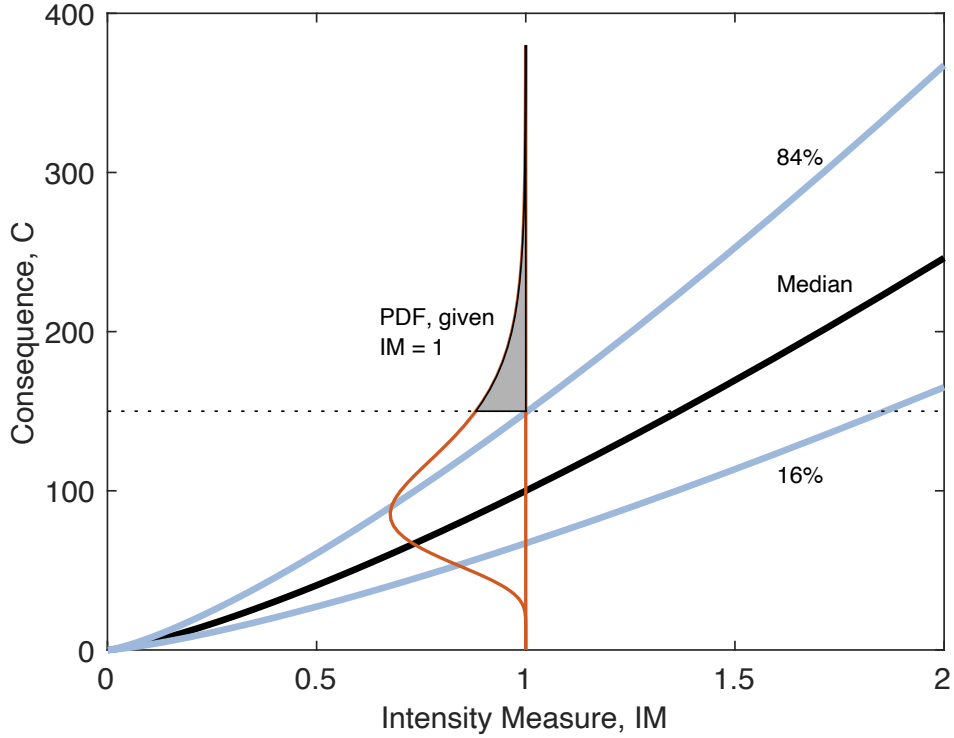
The structural attributes of a building (e.g. construction material, construction system, height, design regulations) directly influence its fragility, making it more or less vulnerable to ground agitation.

Seismic fragility functions



Baker, J. W., Bradley, B. A., & Stafford, P. J. (2021). Seismic hazard and risk analysis. Cambridge University Press. https://doi.org/10.1017/9781108425056

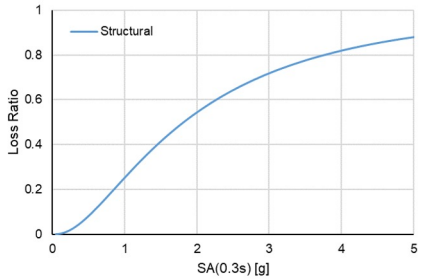
Seismic vulnerability functions



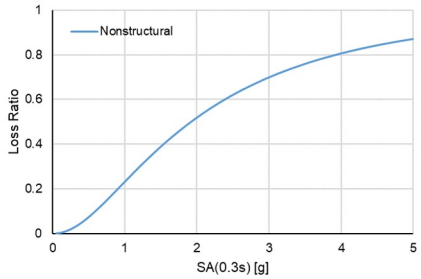
Baker, J. W., Bradley, B. A., & Stafford, P. J. (2021). Seismic hazard and risk analysis. Cambridge University Press. https://doi.org/10.1017/9781108425056

Structural, nonstructural, and contents vulnerability

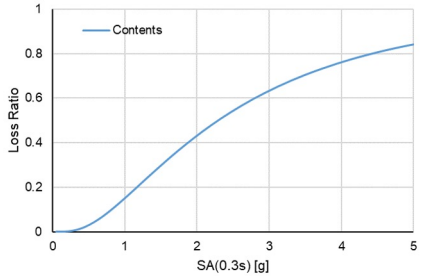
Structural



Non-structural

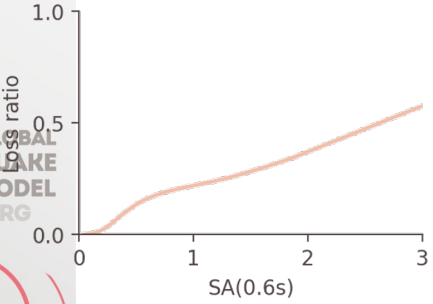


Contents

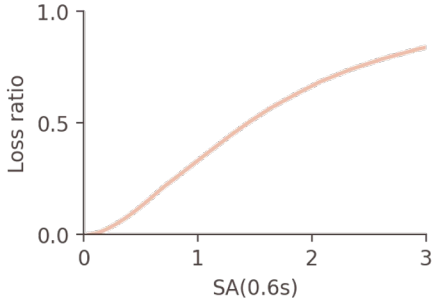


GEM's vulnerability database → Economic losses

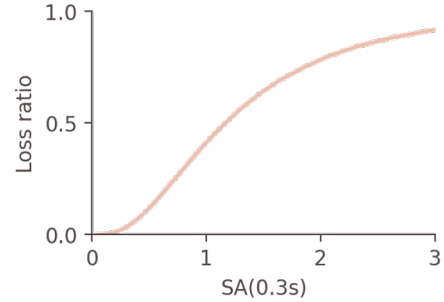
Bamboo houses



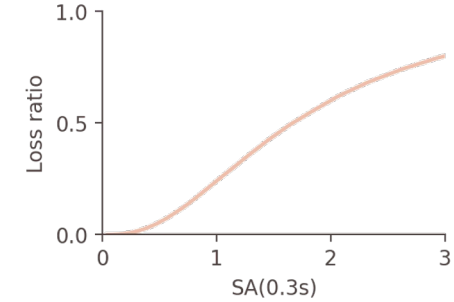
Reinforced concrete buildings



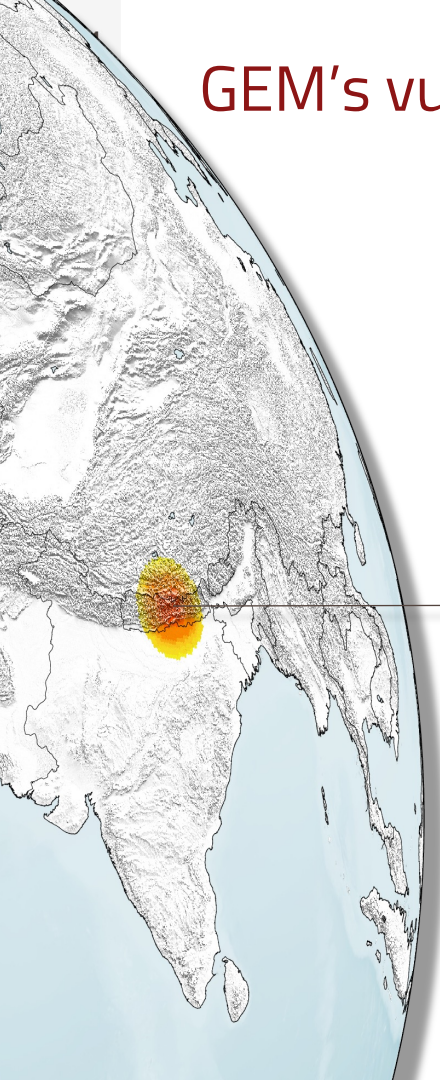
Rubble stone masonry

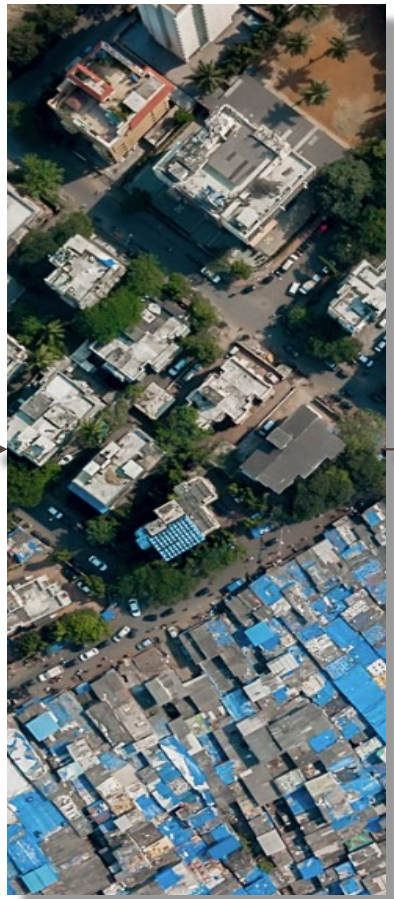


Clay brick masonry



GEM's vulnerability database → Human impact





High fatality rates (Concrete)

Moderate fatality rates (Masonry)

Low fatality rates (Wood)

Risk metrics covered by GEM's vulnerability database

Exposure

Consequences

- Buildings lost
- Area lost (m^2)
- Economic loss (USD)
- Fatalities
- Severe injuries
- Displaced

Social Vulnerability Model

MOTIVATION

SOVI METHODOLOGY

SOCIO-ECONOMIC VARIABLES

Disparate impacts on different groups

WORLD NEWS

More than 90% of people killed by western Afghanistan quake were women and children, UN says

AP

6 of 7 | Afghan women sit in front of their houses that were destroyed by the earthquake in Zenda Jan district in Herat province, western of Afghanistan, Wednesday, Oct. 11, 2023. Another strong earthquake shook western Afghanistan on Wednesday morning after an earlier one killed more than 2,000 people and flattened whole villages in Herat province in what was one of the most destructive quakes in the country's recent history. (AP Photo/Ebrahim Noroozi)

BY RIAZAT BUTT

Updated 1:09 AM GMT+5:30, October 13, 2023

ISLAMABAD (AP) — **More than 90% of the people killed by a 6.3-magnitude earthquake in western Afghanistan last weekend were women and children**, U.N. officials reported Thursday.

...

Women and children were more likely to have been at home when the quake struck in the morning, said Siddig Ibrahim, the chief of the UNICEF field office in Herat. "When the first earthquake hit, people thought it was an explosion, and they ran into their homes," he said.

Hundreds of people, mostly women, remain missing in Zenda Jan.

Social vulnerability index

SoVI methodology established by Susan Cutter et al.

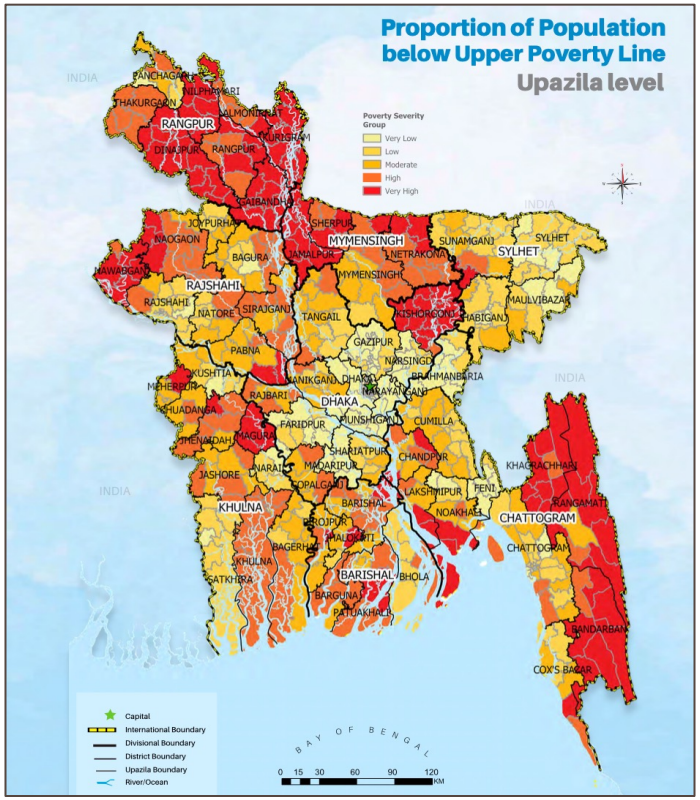
Concept	SoVI® variables
Socioeconomic status	Extreme poverty
	Overcrowded households
	No phone
Gender	% of females
	Females in work force
	Ratio F/M income
Religion and ethnicity	% by ethnicity
Age	Median age
Employment lost	Single sector reliance
Urban/Rural	% urban population
	Population density
Renters	% of renters
Occupation	Legally registered
	Not legal register
	Subsistence workers

Concept	SoVI® variables
Family structure	% Female headed households
	People per household
Education	% illiterates over 15
	Population incompleted highschool
	Complete college degree
Population change	Population change within the decade
Medical services & access	Labor force working in health
	Health coverage
Social dependency	# of Benefits granted
Special needs population	% population with disability
	% population high deficiency
Quality of the built environment	Households no water
	Households no sewer
	Households no garbage
	Households no electricity

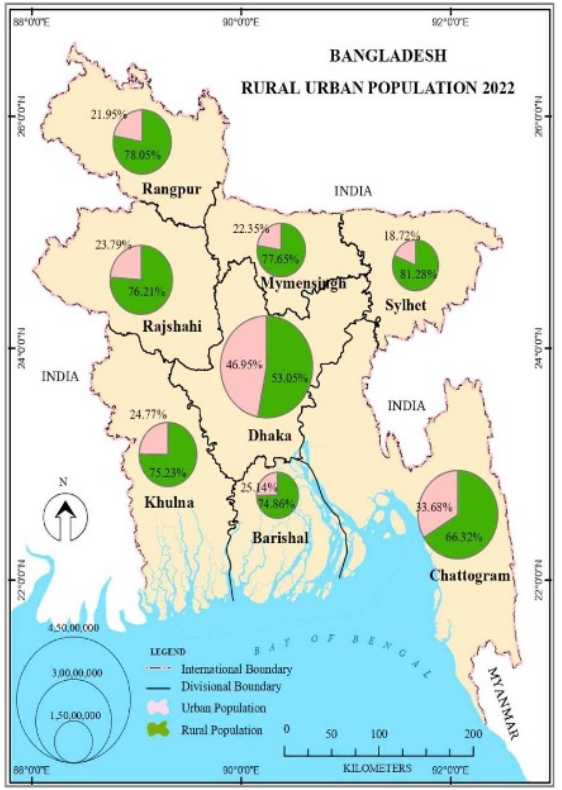
Roncancio, D. J., Cutter, S. L., & Nardocci, A. C. (2020). Social vulnerability in Colombia. *International Journal of Disaster Risk Reduction*, *50*(September), 101872. https://doi.org/10.1016/j.ijdrr.2020.101872

de Loyola Hummell, B. M., Cutter, S. L., & Emrich, C. T. (2016). Social Vulnerability to Natural Hazards in Brazil. *International Journal of Disaster Risk Science*, *7*(2), 111–122. https://doi.org/10.1007/s13753-016-0090-9

Drivers of social vulnerability: Poverty level & urban/rural



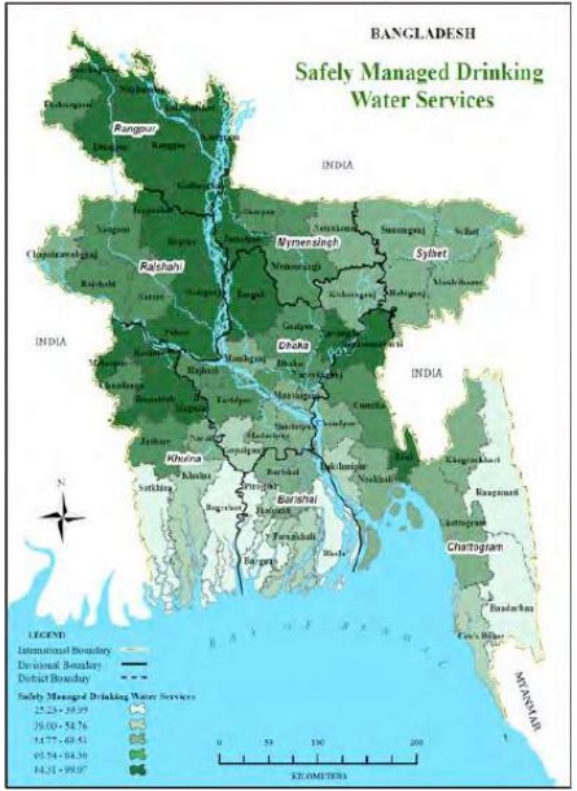
2016 Poverty Maps of Bangladesh



2022 Population & Housing Census

Drivers of social vulnerability: Sanitation and clean water

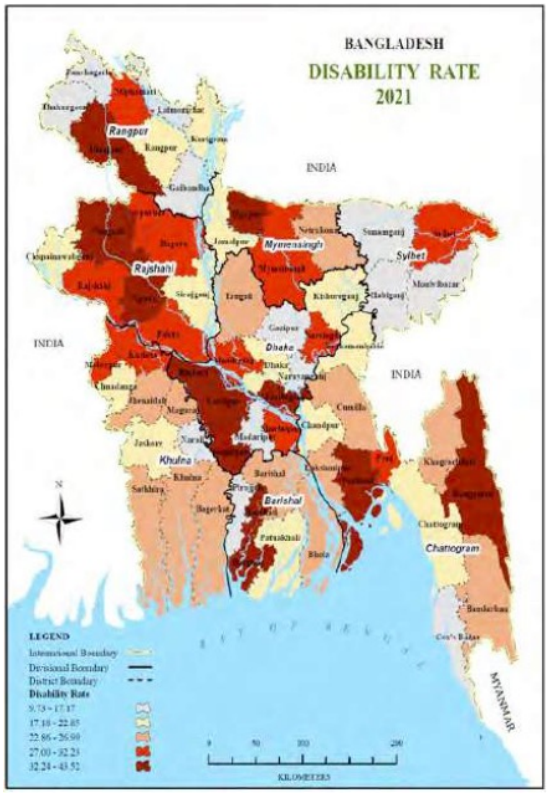
2021 Bangladesh Sample Vital Statistics



2021 Bangladesh Sample Vital Statistics

Drivers of social vulnerability: Adult literacy and disability

2021 Bangladesh Sample Vital Statistics



2021 Bangladesh Sample Vital Statistics

Components, drivers, and direction of influence

Components, drivers, and their direction of influence (cardinality) on social vulnerability according to SoVI® Colombia.

Component name	Cardinality	Drivers	Factor correlation*
Under-development	+	QNOWATER	,731
		SSBENPC	,713
		EMPLOY	-,692
		QILLIT	,669
		QBORNOD	-,596
		QOVERC	,587
		Q_FEMLF	-,569
		QNOSEWER	,568
Urban educated female population	-	QFEMALE	,772
		QURBAN	,772
		QCOLLEGE	,709
		QFHH	,677
		NOGARB	-,666
		QED12LESS	,533
Indian population	+	QINDIAN	,811
		QFHOUSE	-,648
		QNOELEC	,576
		QFORBORN	,509
Recent migration and violence displacement	+	POPMIG	,872
		QDESVIOL	,841
		RENTER	,716
Low percentage of special needs population and extreme poverty.	-	QSPCHIGH	-,669
		QEXPOV	-,620
Age dependency	||	QAGEDEP	,773
		PPUNIT	-,715
		QHSREG	,633
Black population and ethnic minorities	+	QBLACK	,758
		WHITE	-,555
		QMINOR	,514

*Only correlations >0,500 are listed in the table.

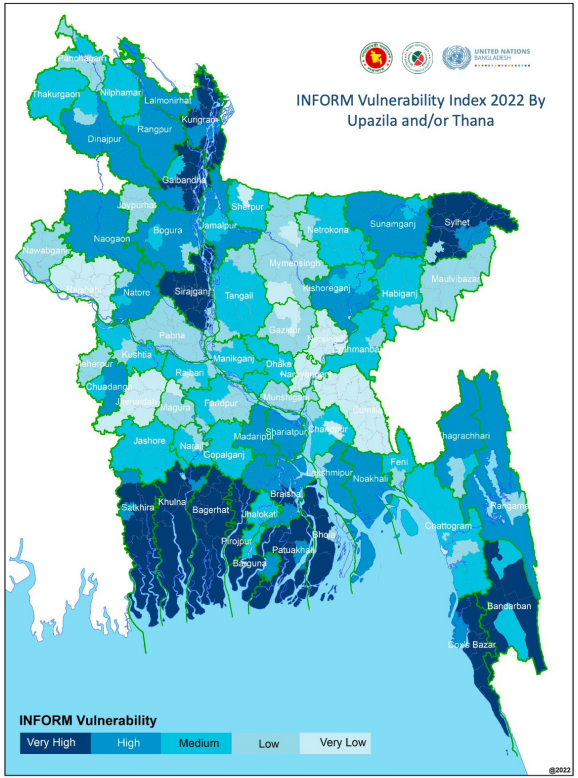
SoVI methodology

- Multicollinearity test to reduce variables
- Factor analysis using principal component analysis (PCA)
- Identify most significant indicators (correlation >0.5 and >-0.5) driving each component
- Cardinality (±) is decided according to the influence of the factor on the general social vulnerability
- SoVI® is calculated as the sum of the scores of the components for each upazila

INFORM Index

INFORM INDEX FOR RISK MANAGEMENT SUBNATIONAL Bangladesh

INFORM Vulnerability: Upazila and/or Thana Map



The depiction and use of boundaries are not warranted to be error-free, nor do they necessarily imply official endorsement or acceptance by the United Nations.

INFORM INDEX FOR RISK MANAGEMENT SUBNATIONAL Bangladesh

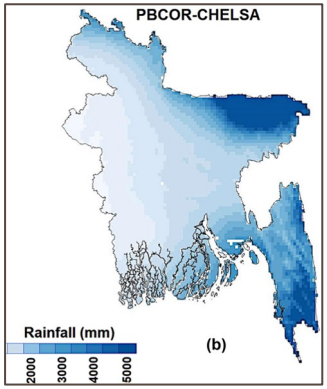
Vulnerability: Indicators (32)

Categories	Component	Indicators	Source
Socio-Economic	Poverty and Development (4)	• Score in Human Development Index (HDI) in 2016 • Percentage of poor households in 2017 • Percentage of extreme poor households in 2017 • Percentage of households are dependent on daily wage labour (unsustainable livelihoods)	BBS, WB
	Economic Dependence (5)	• Percentage of unemployed people in 2017 • Percentage of EGPP coverage among the poor in 2020 • Per capita public aid (in USD) in 2019 • Net ODA received as a percentage of GNI in 2020 • Volume of remittances (in USD) as a proportion of total GDP	MoDMR, BARC
	Inequality (4)	• Ratio of Gini coefficient from income distribution in 2020 • Gender parity index (GPI) for primary school adjusted net attendance ratio (NAR) in 2019 • Gender parity index (GPI) for lower secondary school adjusted net attendance ratio (NAR) in 2019 • Gender parity index (GPI) for upper secondary school adjusted net attendance ratio (NAR) in 2019	BBS, BARC
Vulnerable Group	Uprooted People (3)	• Percentage of floating population in 2020 • Number of annual average disaster induced Internal Displaced Population (IDP) per 100,000 during 2014-2020 • Number of asylum seeker/refugee in 2021	BBS, NDRCC, RRRC
	Recent Shocks (3)	• Annual average affected population (per 10,000) by flood and cyclone during 2014-2020 • Number of fully damaged houses by cyclone and flood during 2014-2020 • Number of partially damaged houses by cyclone and flood during 2014-2020	NDRCC
	Food Security (2)	• Percentage of households with poor dietary diversity (Food group <=4) in 2021 • Percentage of population in IPC level 4 (Food scarcity on terms of quality) in 2022	IPC-FAO and FPMU
	Other Vulnerable Group (7)	• Percentage of child labour (children age 5- 17) in 2019 • Percentage of women (age 15-49 years) reported domestic violence by male partner in 2017 • Percentage of women headed households in 2019 • Percentage of population with disability in 2020 • Percentage of elderly population (age >65) in 2020 • Percentage of tribal population in 2020 • Percentage of households living in jhupri and kutcha house in 2020	BBS
	Children Under 5 (2)	• Under 5 children mortality rate per 1,000 in 2020 • Underweight prevalence (severe) <-3 SD in 2019 • Stunting prevalence (severe)<-3 SD in 2019 • Insufficient early child development index (% of 36-59 months child) in 2019	BBS

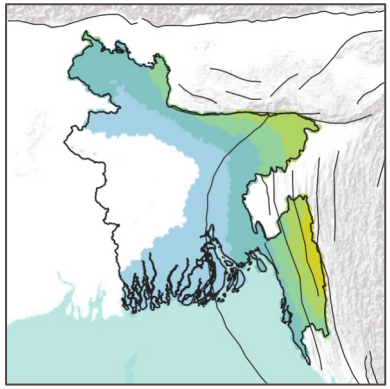
Preview of Final Technical Panel Session (Jan 2024)

LIQUEFACTION ASSESSMENT
SEISMIC RISK ASSESSMENT
EARTHQUAKE SCENARIOS
SEISMIC RISK PROFILES

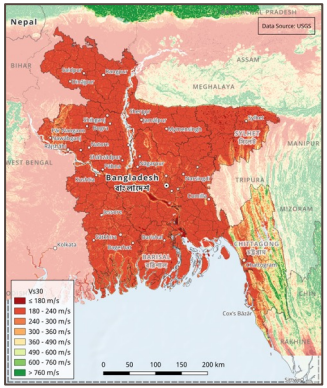
Probabilistic seismic liquefaction assessment



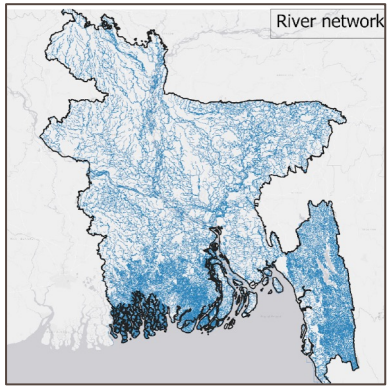
Average annual precipitation



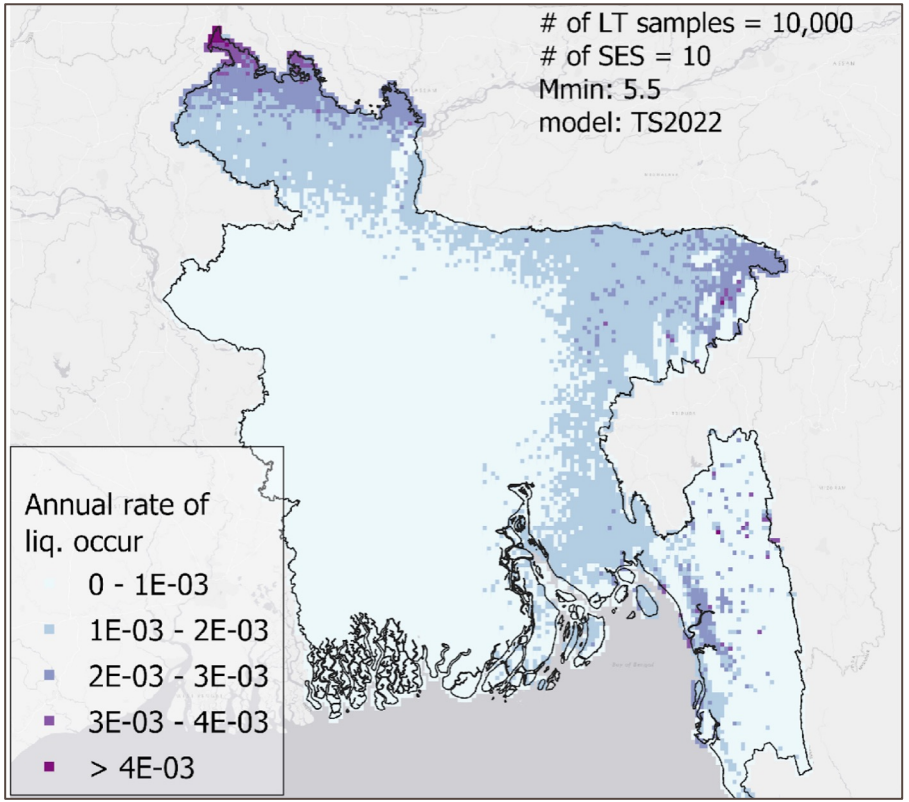
PGV, PGA



Vs_{30}



Distance to river / coast

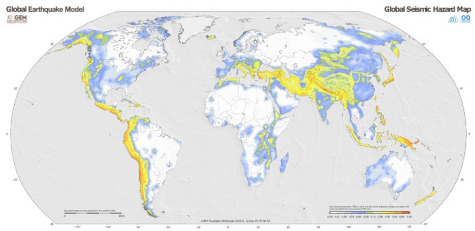


Average annual rate of liquefaction occurrence

Probabilistic seismic risk assessment

Seismic Risk

The risk occurs when there is a spatial and temporal overlap of these three elements

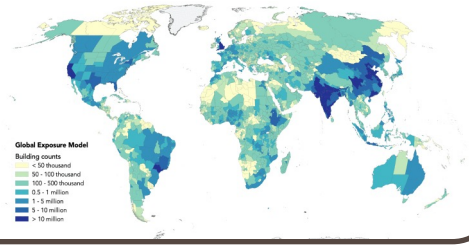


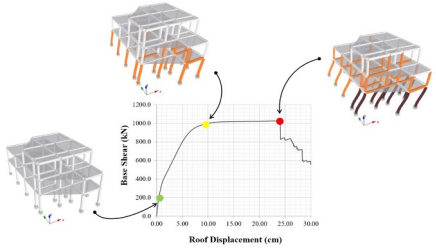
Hazard

Characterizing the potential locations, intensity or magnitude, frequency or probability of earthquakes

Exposure

Characterizing the built environment and people in hazard-prone areas

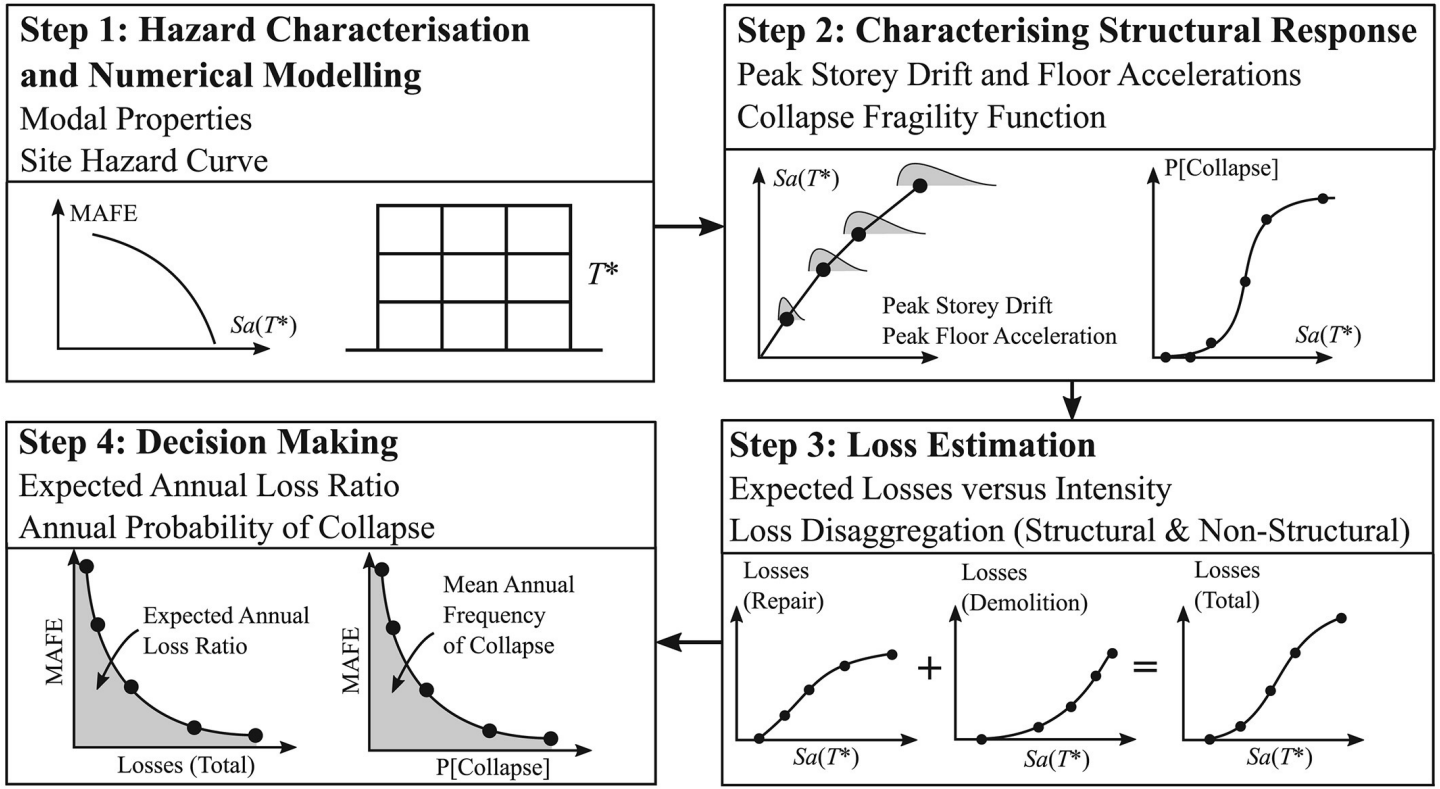




Vulnerability

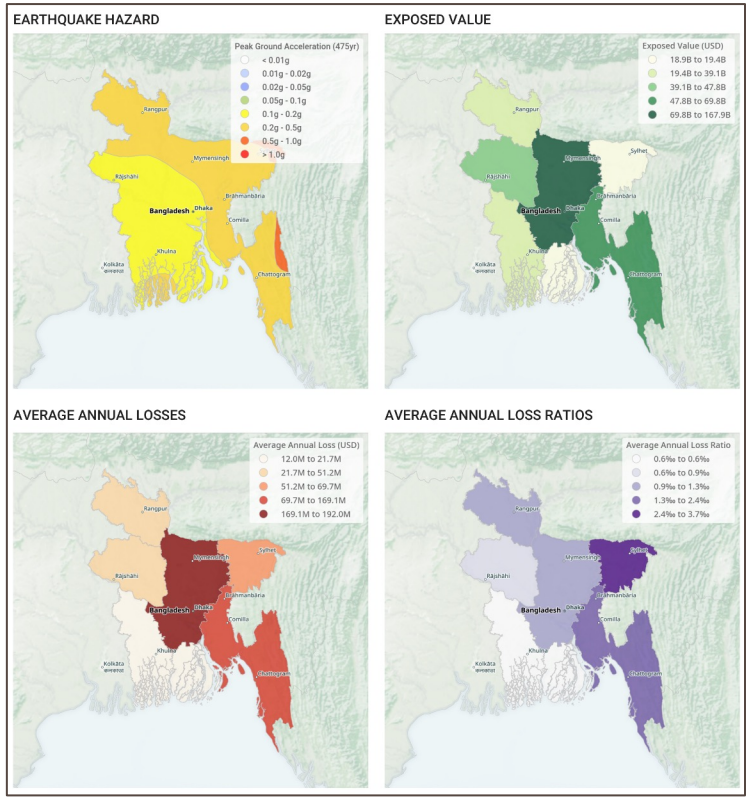
Factors which increase the susceptibility of an individual or assets to the impacts of hazards

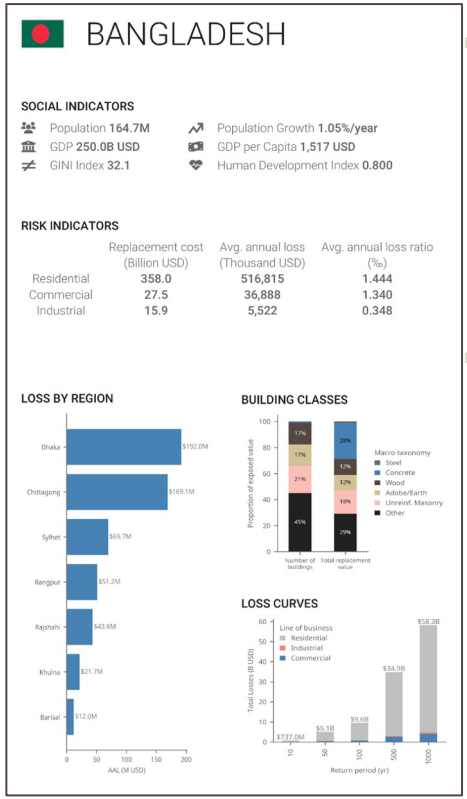
Performance based earthquake engineering framework



O'Reilly, G. J., & Calvi, G. M. (2019). Conceptual seismic design in performance-based earthquake engineering. Earthquake Engineering and Structural Dynamics, 48(4), 389–411. https://doi.org/10.1002/eqe.3141

Seismic risk profiles at the upazila level





- GEM has published division-level maps of seismic hazard, exposure, and risk for Bangladesh
- The spatial resolution will be improved to upazila level in this project

Thank you!

Please attribute to the GEM Foundation with a link to:
https://www.globalquakemodel.org