Earthquake – Recognizing the Consequences and the Way Forward

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1. Introduction

Earthquakes do not kill people, but the buildings do. With the exception of tsunamis and landslides, most earthquake related fatalities are caused by the collapse of people's homes upon them or by fires following the earthquakes.

Earthquakes represent the largest potential source of casualties and damage for inhabited areas due to natural hazard. Although the location varies, the pattern is the same: an earthquake strikes without warning, leaving cities in rubble and killing tens to hundreds of thousands of people.

The death toll from the 6.9-magnitude earthquake that hit the Indonesian island of Lombok more on 9th August 2018 has surged to 436.

1. Introduction cont.

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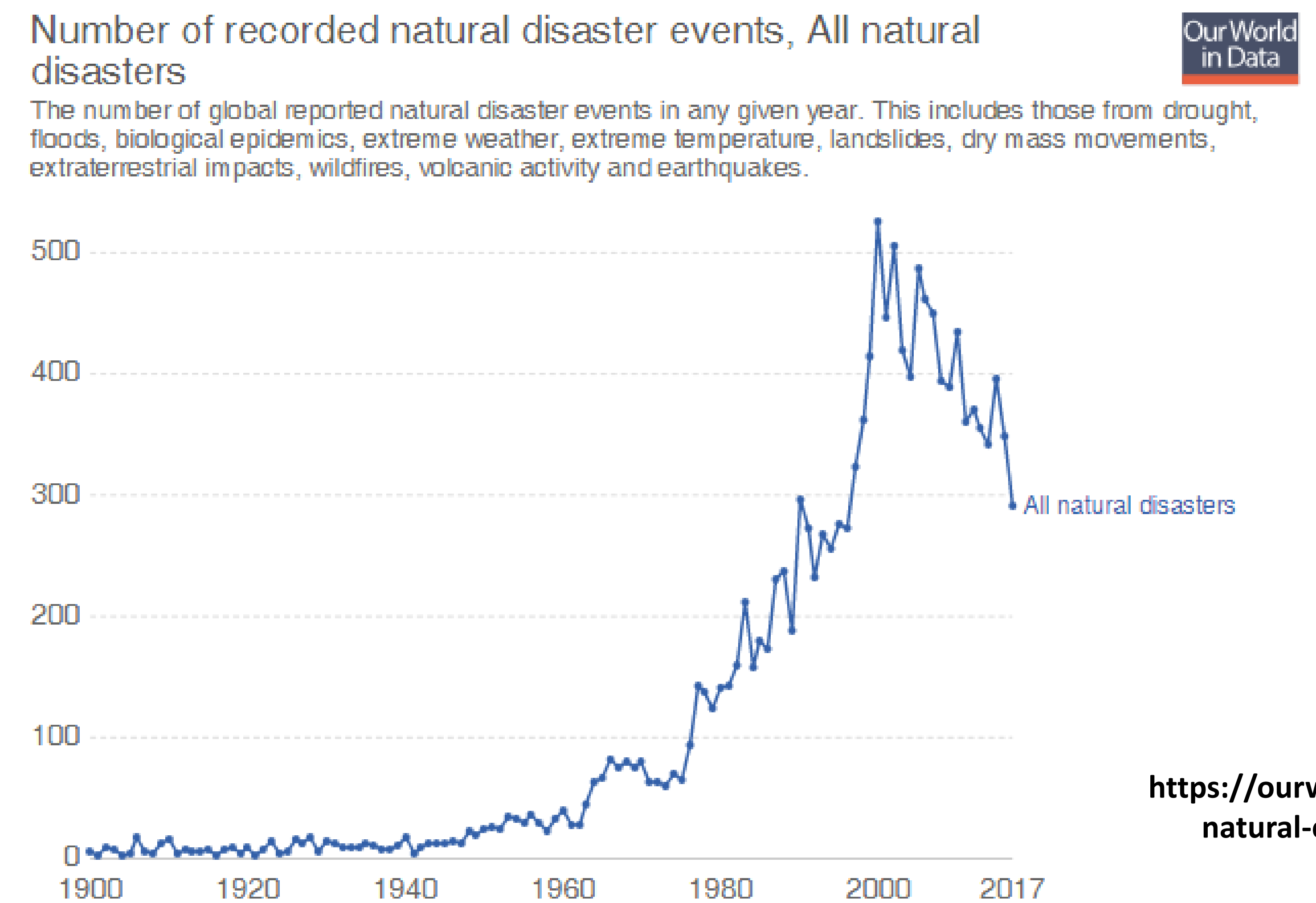
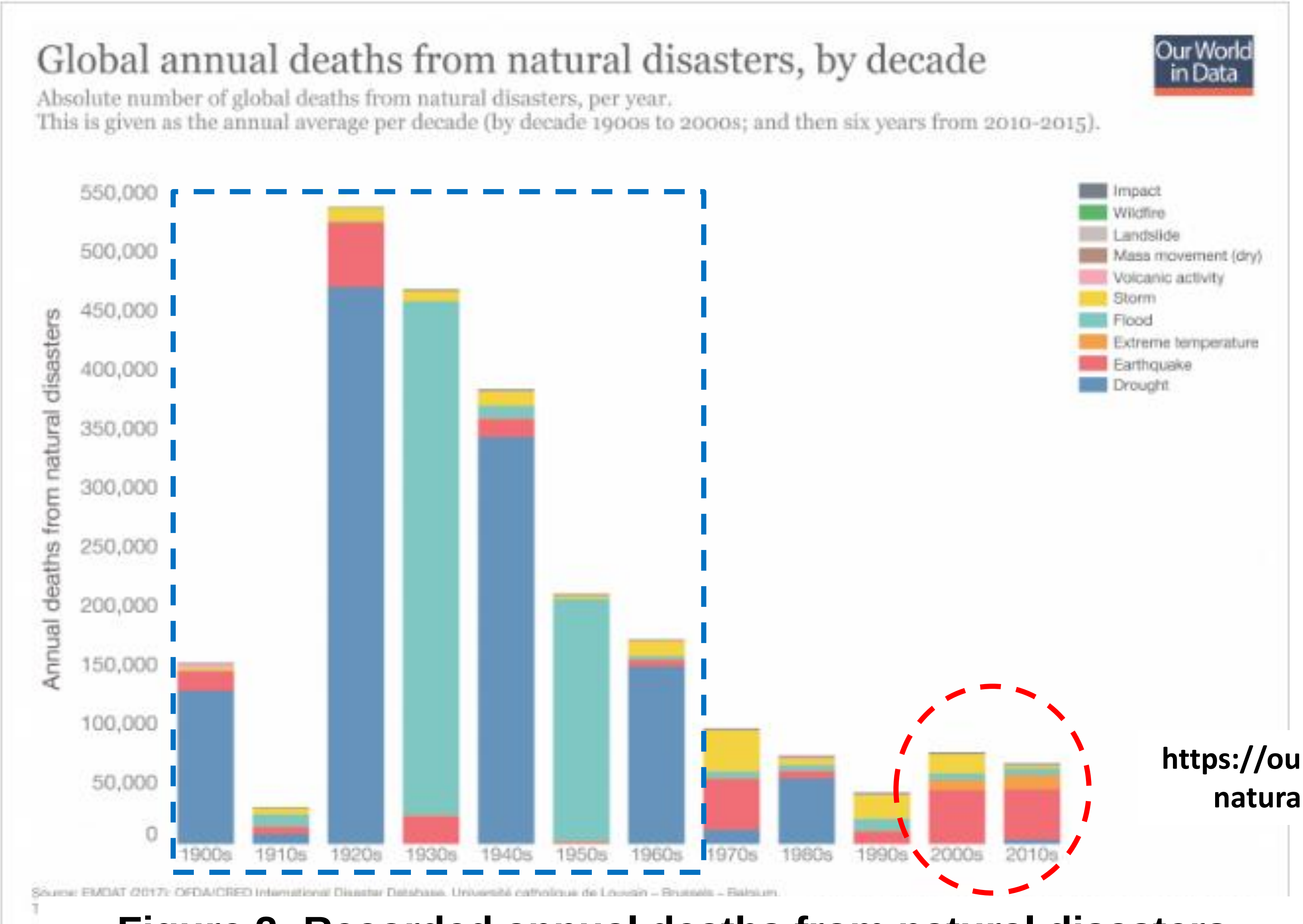


https://ourworldindata.org/natural-catastrophes

Figure 1: Recorded natural disaster events worldwide

1. Introduction cont.



https://ourworldindata.org/natural-catastrophes

Figure 2: Recorded annual deaths from natural disasters

1. Introduction cont.

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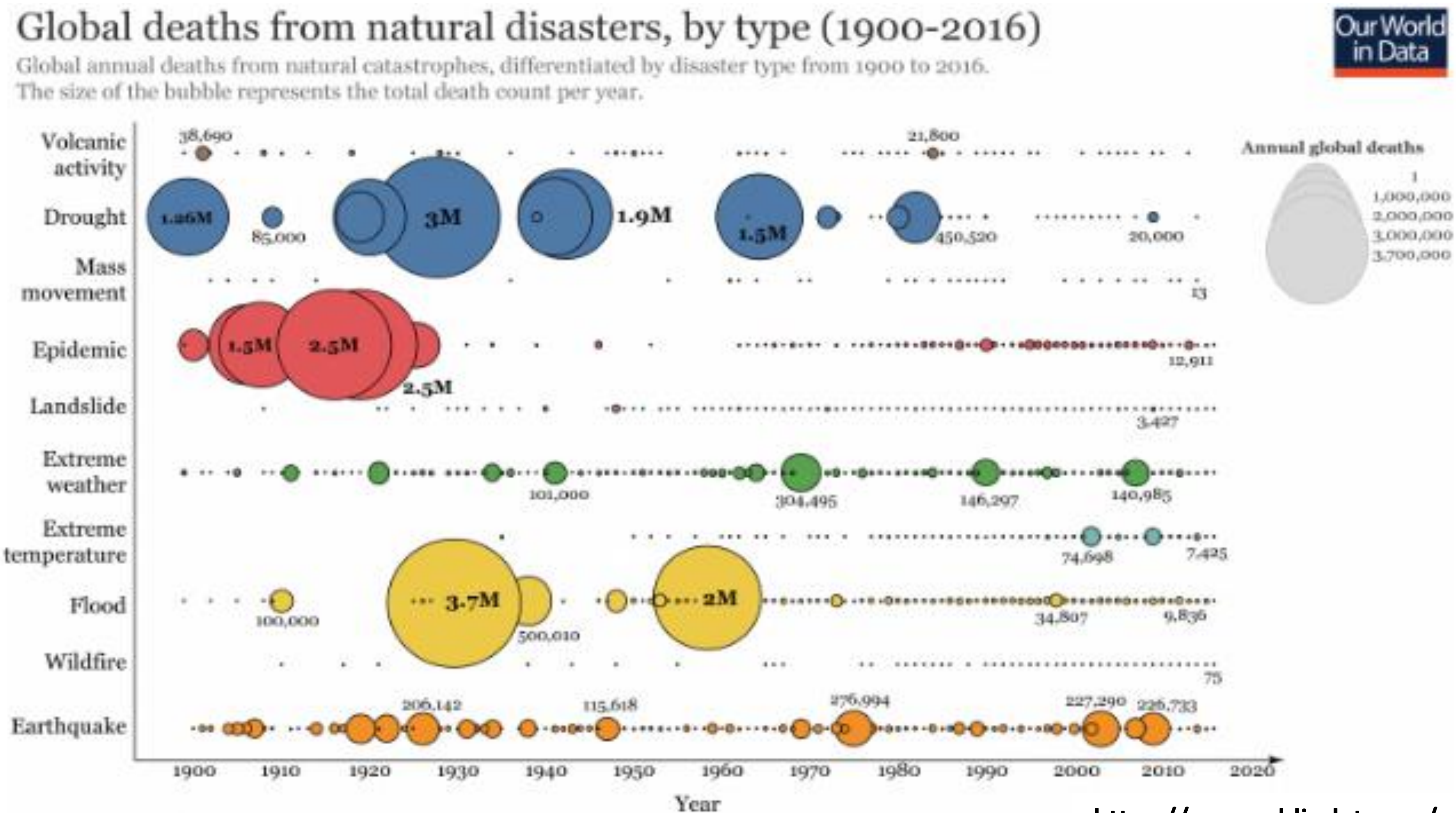


Figure 3: Global deaths from natural disasters

https://ourworldindata.org/natural-catastrophes

1. Introduction cont.

An earthquake is a phenomenon resulting from the sudden release of stored energy in the Earth's crust which creates seismic waves. Currently, the understanding of earthquake characteristics has considerably increased, due to the tragic experience from several recent earthquakes.

As a consequence of the direct observations and subsequent studies, now it is possible to quantitatively predict strong motions for dangerous earthquakes, provided that the source mechanism, wave travel path and site geological conditions are correctly modeled (Huang, 1983, Kawase, 2004).

1. Introduction cont.

Seismic waves are the wave of energy caused by the sudden breaking of rocks within the Earth. Seismic waves radiating from the fault break to the site are of two main types namely, body (P and S) and surface (L and R) waves as shown in Figure 4.

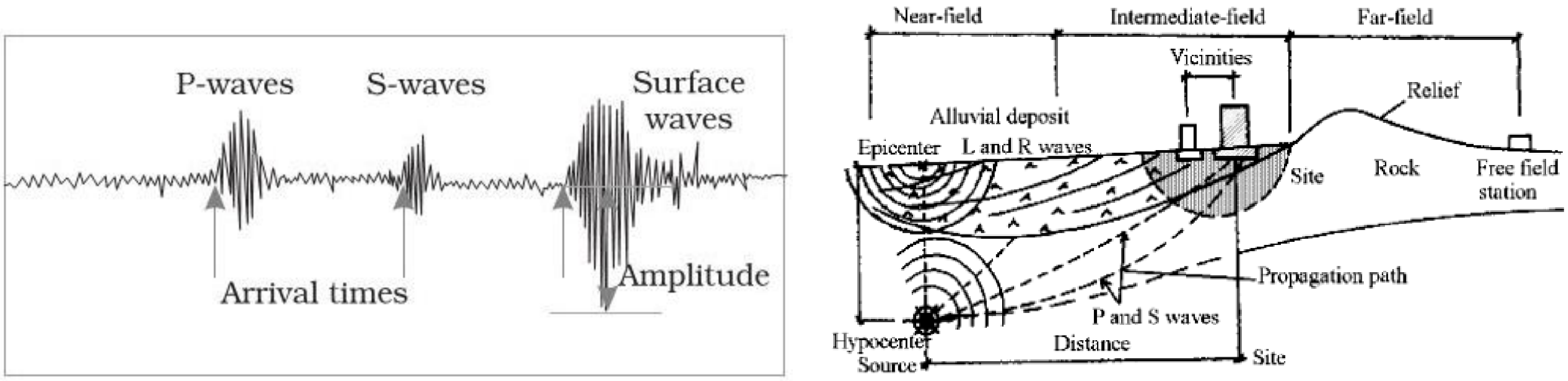
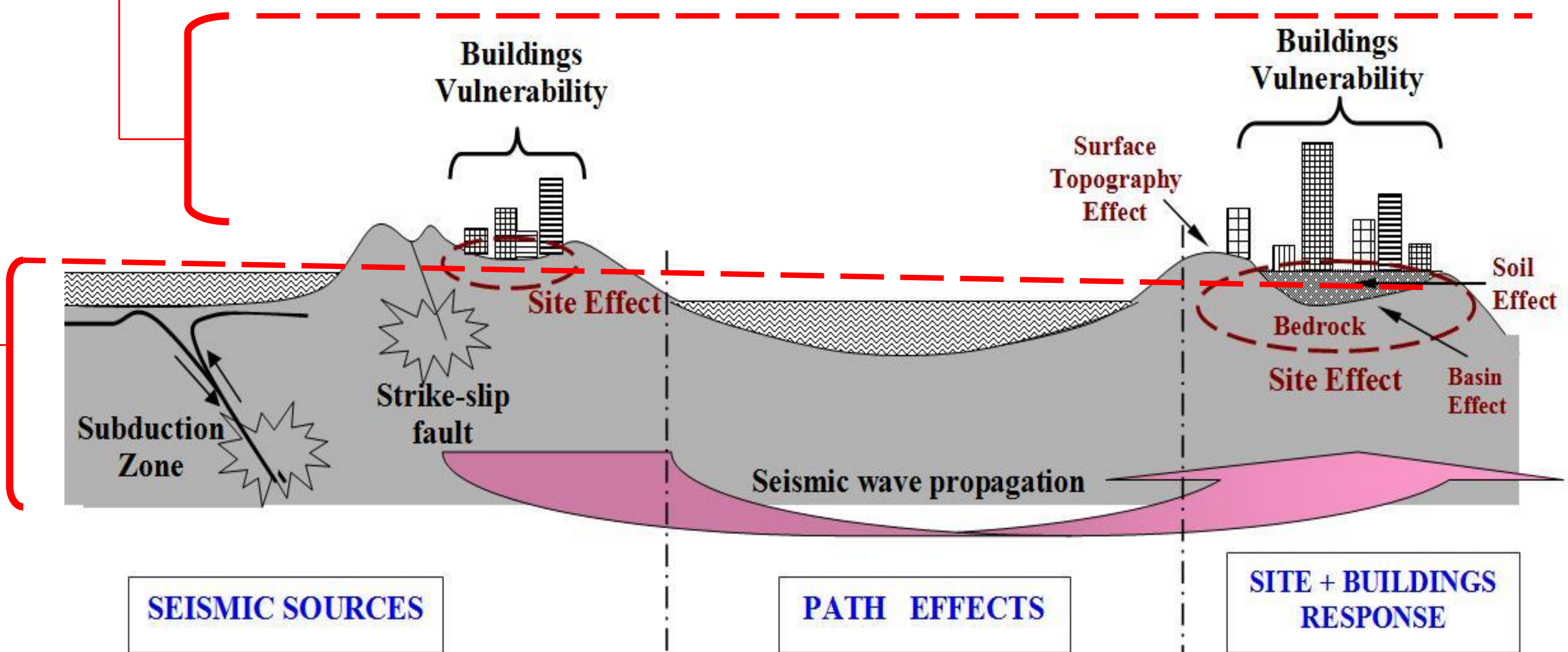


Figure 4: Seismic waves propagate during earthquake (Gioncu & Mazzolani, 2010)

1. Introduction cont.

Engineering Seismology

Earthquake Engineering



- Magnitude
- Depth & Source-site Distance
- Earthquake faulting
- Rupture propagation

- Attenuation
- Geologic type
- etc.

- Soil effect
- Basin Effect
- Surface topography Effect

Figure 5: Engineering Seismology versus Earthquake Engineering

2. Earthquakes in Malaysia

Peninsula Malaysia is located near the Sumatra Island, which it is situated in the Ring of Fire. On the other hand, Sabah is located at the intersection of three major tectonic plates, the Eurasian Plate to the North, the Indian-Australian plate to the West and South and Pacific-Philippine Sea Plate to the East as illustrated in Figure 6-7. Peninsula Malaysia will experience the tremor when a major earthquake hits the Sumatra region.

Generally, Malaysia is known as a safe country from earthquake. However, this statement is overruled due to the recent earthquakes activities occurred mainly in East Malaysia.

2. Earthquakes in Malaysia cont.

GLOBAL SEISMIC HAZARD MAP

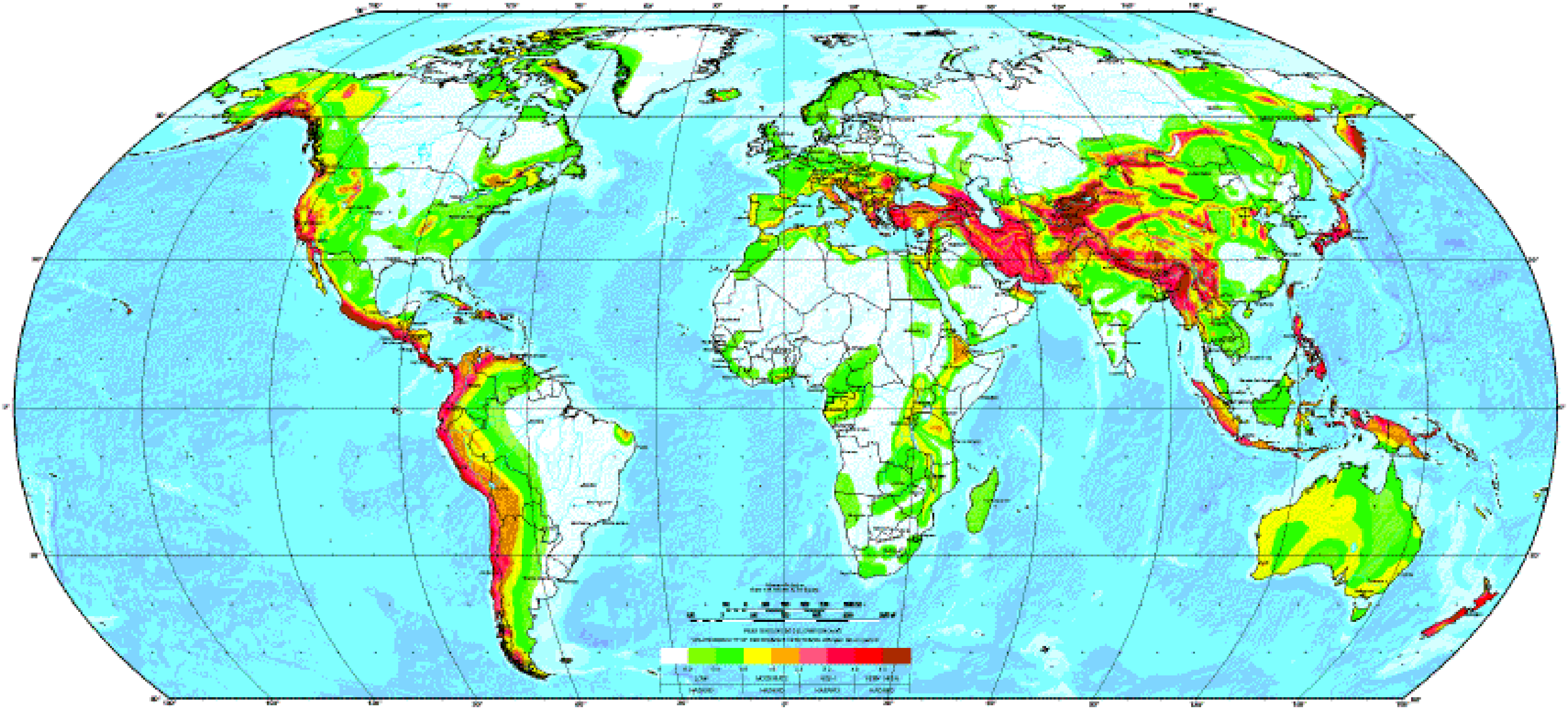


Figure 6: Global seismic hazard map (https://www.gfz-potsdam.de/en/GSHAP/)

2. Earthquakes in Malaysia cont.

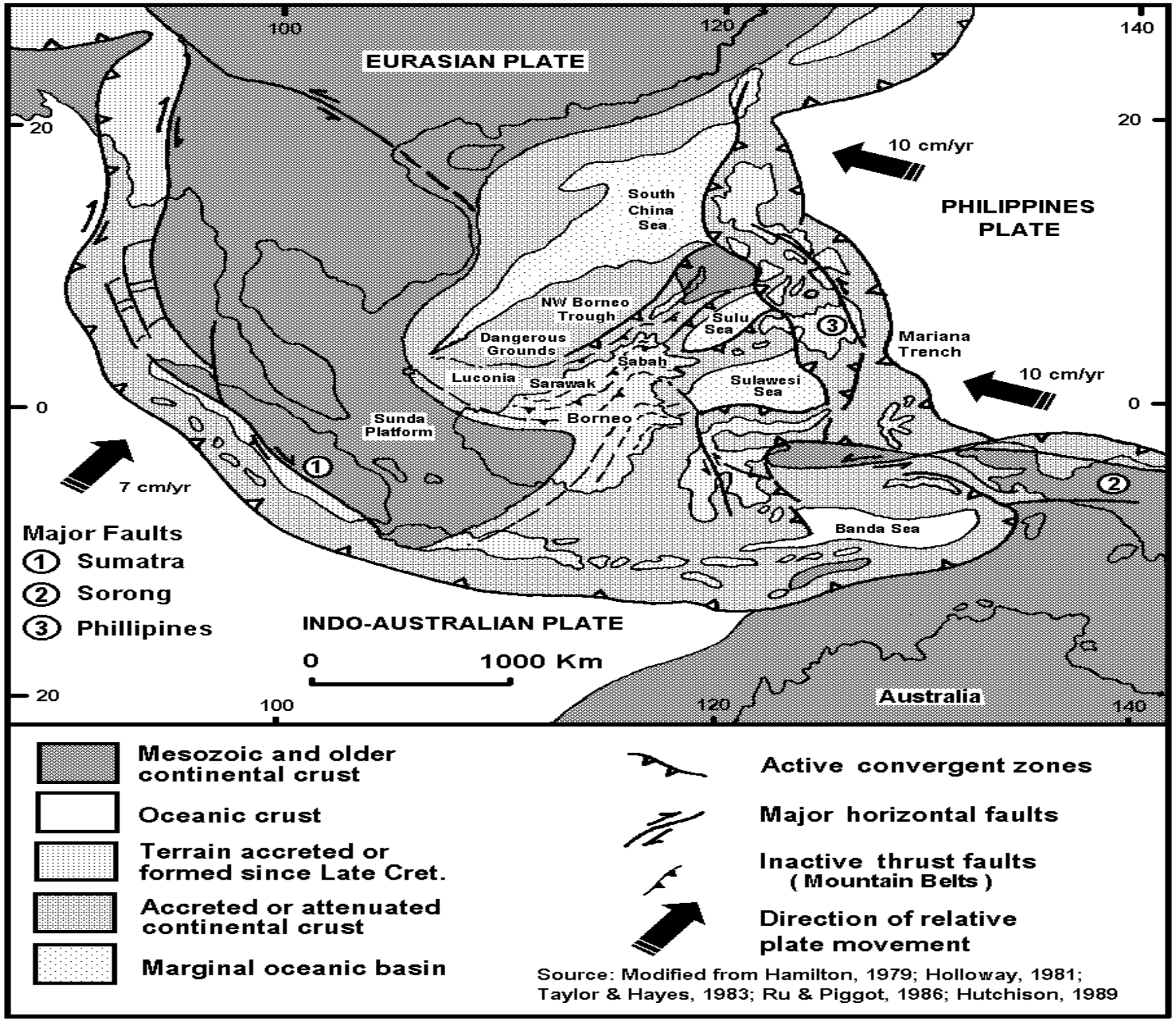


Figure 7: Major tectonic in Malaysia (Tongkul, 1999)

2. Earthquakes in Malaysia cont.

Seismic threat in Peninsular Malaysia:

1. Far-field earthquake:
    - Sumatra fault
    - Subduction zone

2. Local faults:
    - Kuala Pilah
    - Manjung
    - Bukit Tinggi, Pahang
    - Temengor
    - Kenyir

2. Earthquakes in Malaysia cont.

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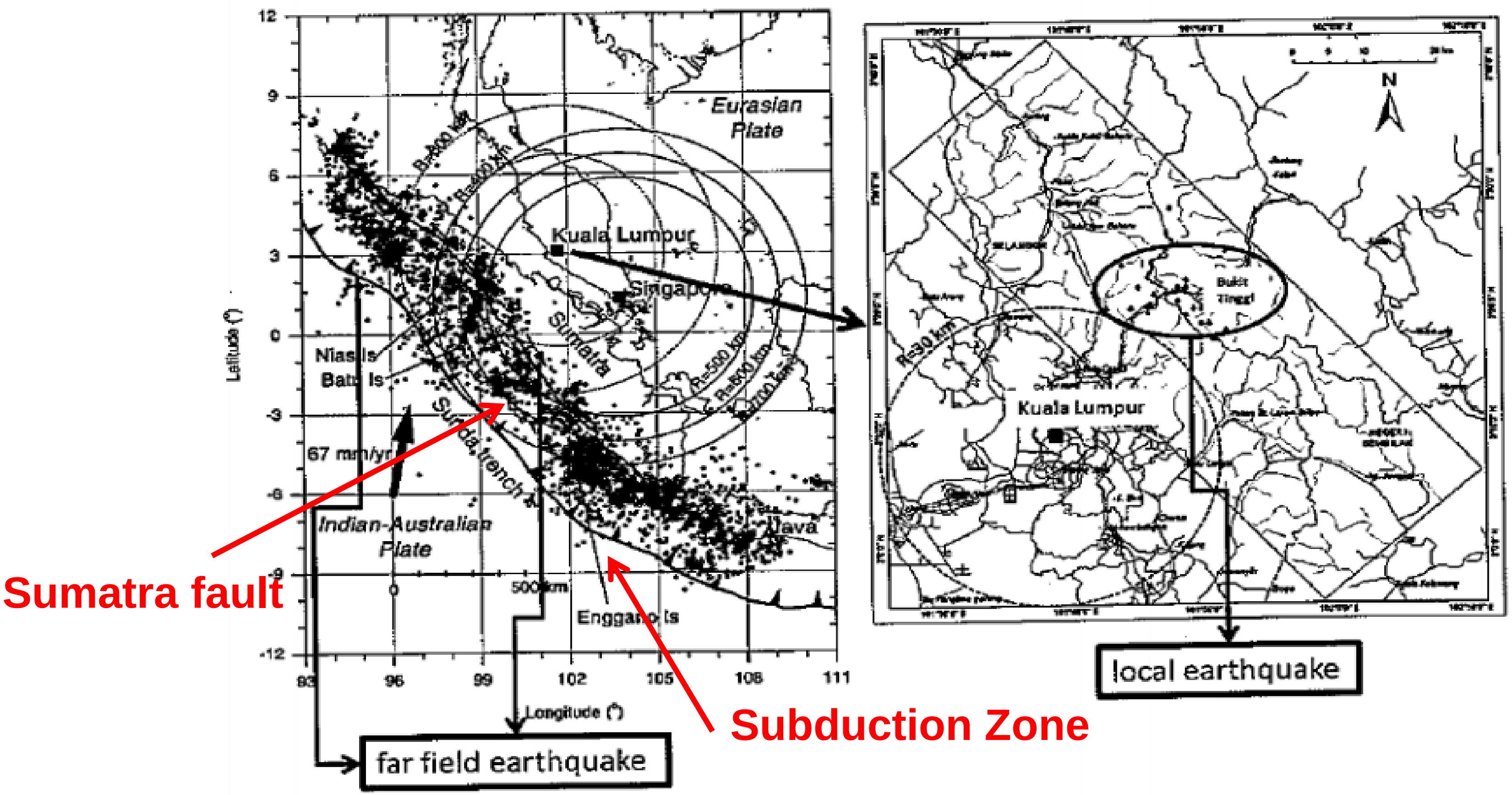

Figure 8: Potential earthquake threat to Peninsular Malaysia (Shakri and Sanjery, 2015)

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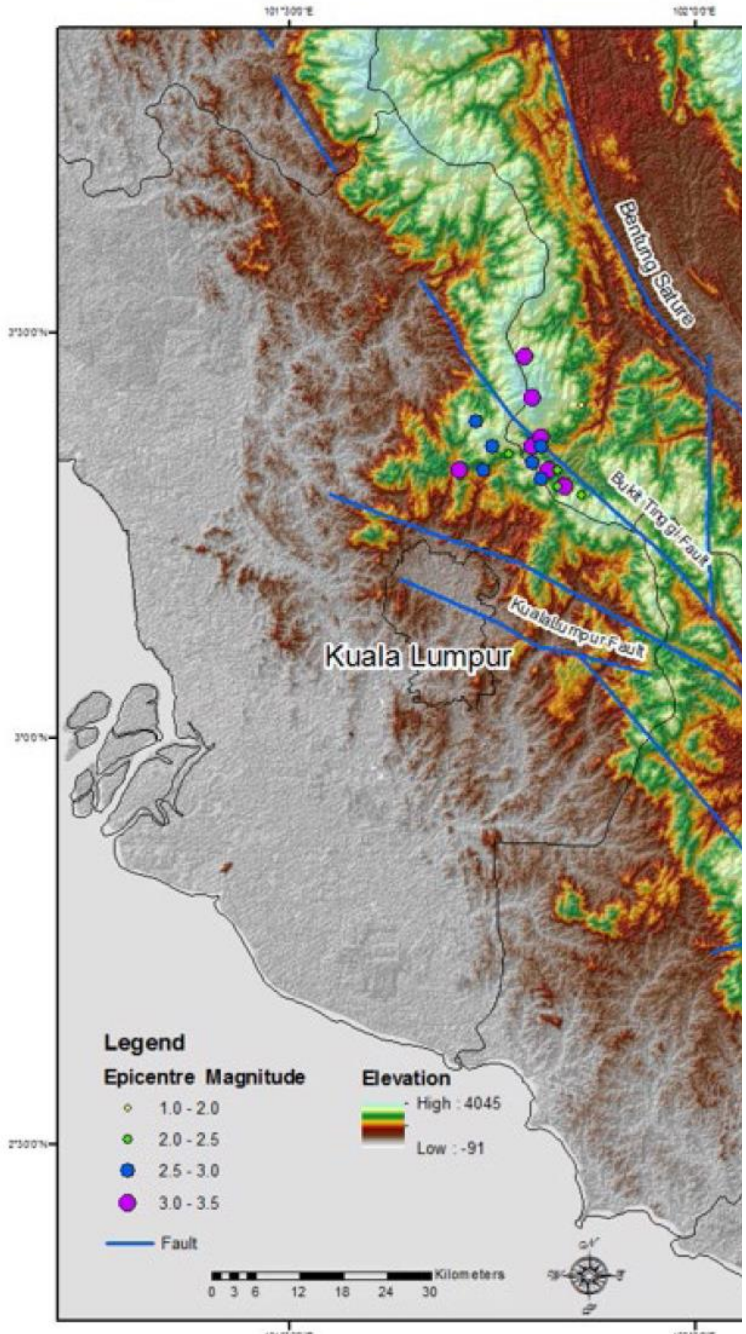

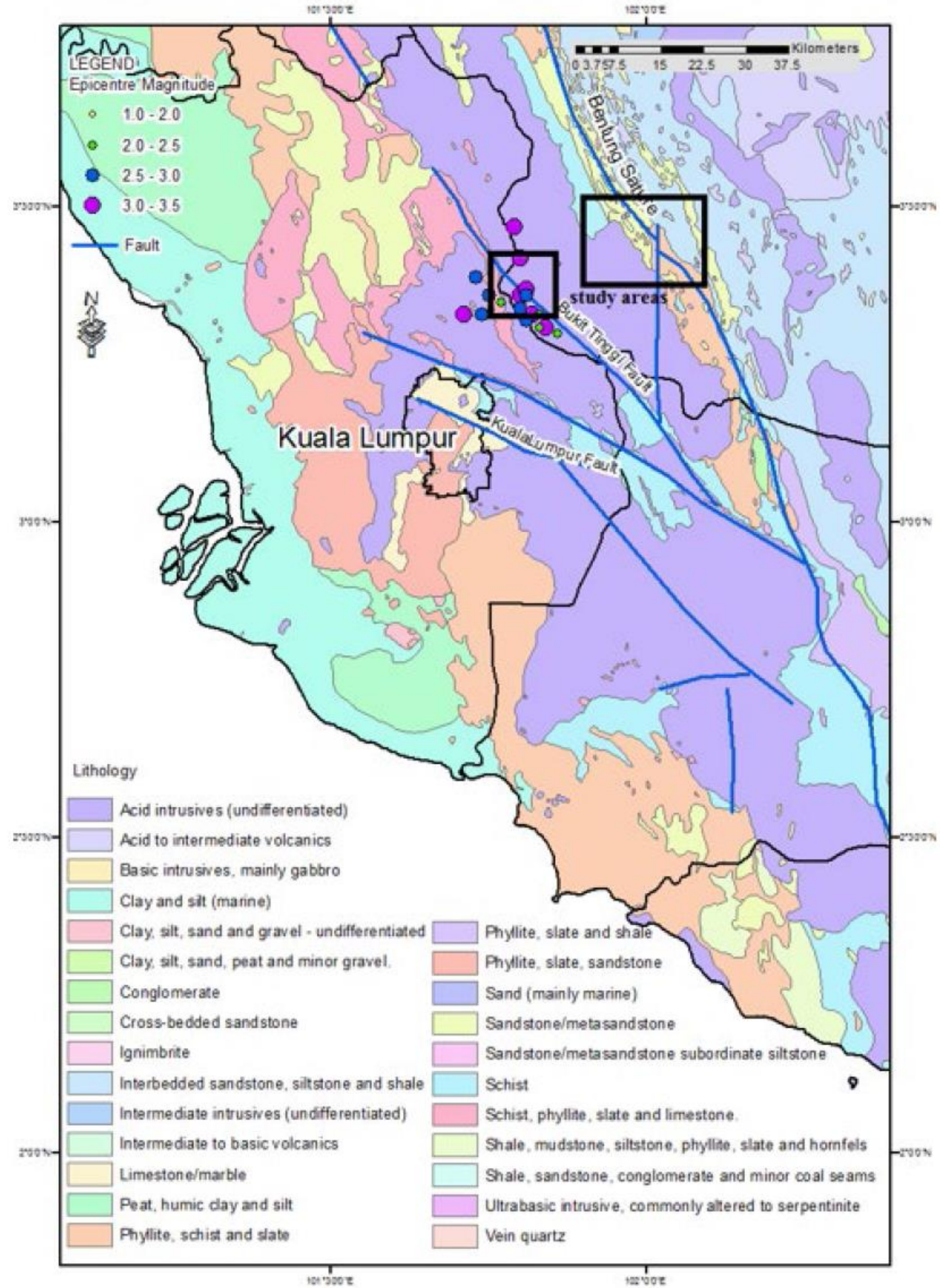

(Mustaffa et al., 2017) **Figure 9:**

2. Earthquakes in Malaysia cont.

A devastating earthquake event occurred on 26th December 2004 with magnitude 9.0Mw originated from West Aceh, Sumatra, Indonesia. The tremors were felt along the west coastal areas in Peninsular Malaysia and triggered panic to the public. This event has put an alarm to the effect of earthquake from Indonesia that can be disastrous to the public safety and the existing structures.

On **26 May 1991**, an earthquake with the magnitude of 5Mw damaged several columns of a school structure in Ranau. A weak earthquake of 3.5Mw magnitude triggered in Sandakan at 12.23 pm on 14 October 2010. This earthquake epicentre is located at 5.3 North latitude and 117.3 East longitudes, 108 km southwest of Sandakan, Sabah and was triggered from local fault.

2. Earthquakes in Malaysia cont.

On 5th June 2015, a moderate earthquake with magnitude 5.9Mw hit Sabah at 16 km northwest from Ranau. The tremors were also felt in Kundasang, Ranau, Tambunan, Pedalaman, Tuaran, Kota Kinabalu, and Kota Belud.

Moreover, several buildings suffered some form of damage due to this event. It is very important to observe the structural performance (damage) shortly after the earthquake (Ates et al., 2013).

The time-history of Ranau earthquake in 2015 is shown in Figure 10. This earthquake had damaged several buildings (Figure 11- Figure 14) due to the fact that the previous design only considered gravity and wind loading. Obviously, no seismic type of detailing was used in the design.

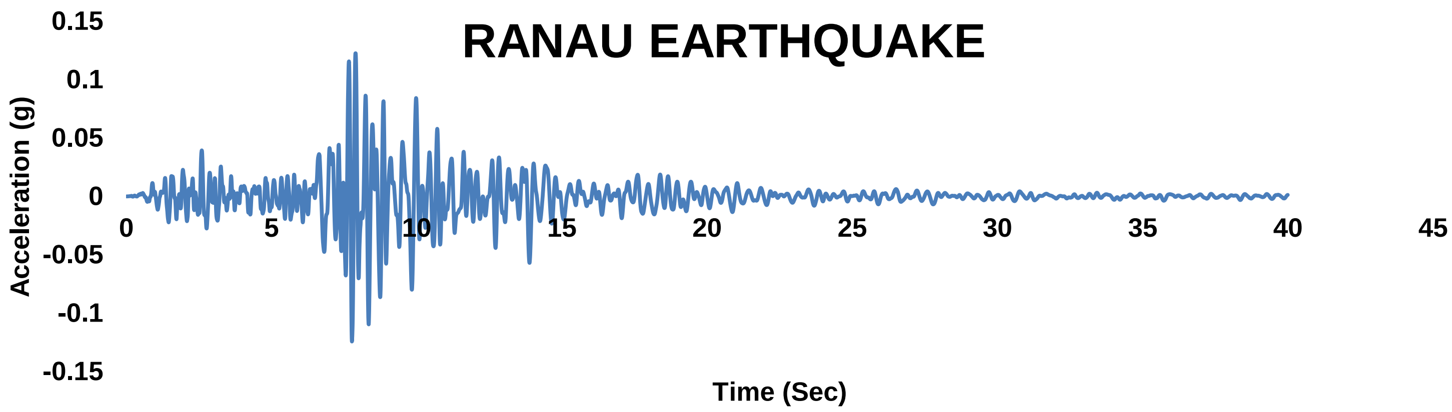

Figure 10: Ranau earthquake

2. Earthquakes in Malaysia cont.

Figure 11: Observed damages in Ranau town (Roslee and Tongkul, 2018)

2. Earthquakes in Malaysia cont.

Masjid Ranau

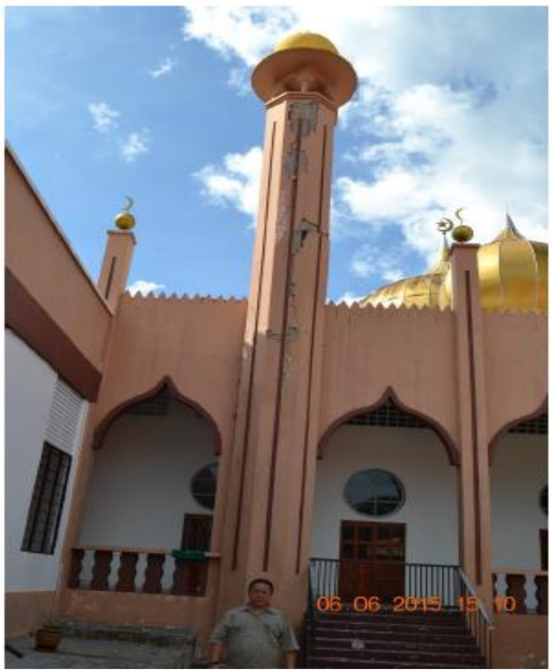

Figure 12: External and internal damage of a local mosque (Roslee and Tongkul, 2018)

2. Earthquakes in Malaysia cont.

Figure 13: Damaged and cracked walls (Roslee and Tongkul, 2018)

2. Earthquakes in Malaysia cont.

SMK Ranau

Figure 14: Damaged column (Roslee and Tongkul, 2018)

2. Earthquakes in Malaysia cont.

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Table 1: List of local earthquake in Malaysia (MMD, 2015)

No	Location	Date	Epicenter Coordinate (°)	Magnitude
1	Kudat, Sabah	16 Aug 2016	6.69, 116.87	3.5
		23 July 2013	6.80, 117.10	4.2
2	Ranau, Sabah	30 Dec 2015	6.00, 116.60	3.2
		19 Oct 2015	6.00, 116.60	3.4
		8 Sept 2015	6.10, 116.60	3.8
		28 Aug 2015	5.90, 116.60	3.6
		27 July 2015	6.00, 116.60	4.4
		23 June 2015	6.10, 116.50	4.3
		23 June 2015	6.00, 116.50	3.5
		18 June 2015	6.00, 116.60	4.0
		13 June 2015	6.20, 116.50	5.1
		13 June 2015	6.10, 116.60	3.9
		11 June 2015	6.10, 116.50	3.7
		7 June 2015	6.10, 116.60	3.7
		5 June 2015	6.10, 116.50	4.0
		5 June 2015	6.10, 116.50	3.8
		5 June 2015	6.10, 116.60	6.0
3	Kunak, Sabah	5 Sept 2014	4.60, 118.30	4.0
4	Tasik Temenggor, Perak	20 Aug 2013	5.40, 101.40	4.1
5	Bukit Tinggi	7 Oct 2009	3.40, 101.80	4.2
		14 Jan 2008	3.40, 101.80	3.4
		12 Dec 2007	3.20, 101.80	3.4
		30 Nov 2007	3.40, 101.80	3.4

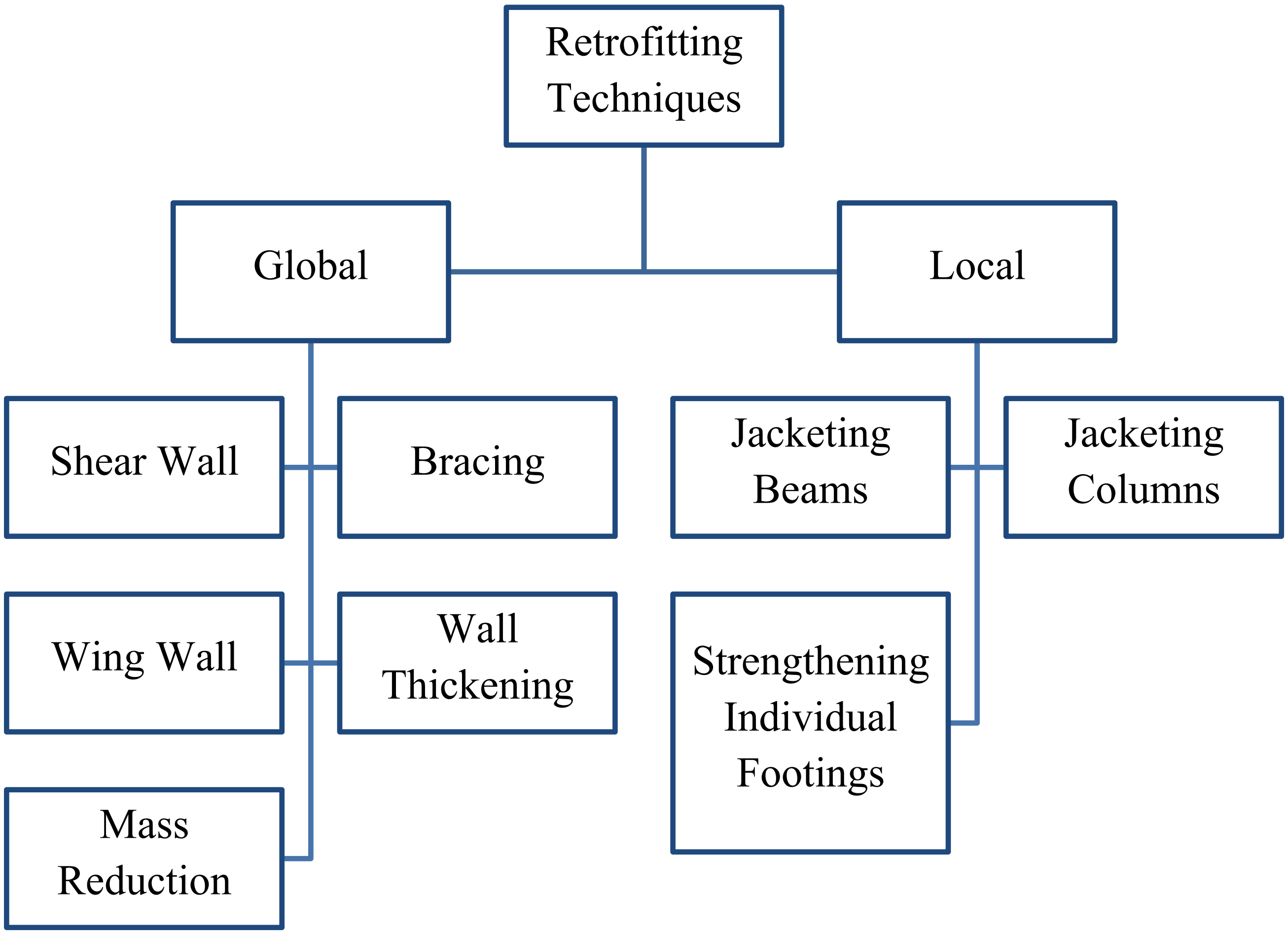
3. Building Vulnerability

Urban vulnerability to natural hazards such as earthquakes is a function of human behavior. It describes the degree to which socioeconomic systems and physical assets in urban areas are either susceptible or resilient to the impact of natural hazards.

Over the past two decades, vulnerability has come to represent an essential concept in hazards research and in the development of mitigation strategies at the local, national, and international levels (White and Haas 1975, Hewitt 1997, Mileti 1999, Alexander 2000).

Therefore, the earthquake vulnerability of building structures has remained a key area for the researchers in order to minimize the hazards of earthquake as much as possible. One of the possible ways to re-strengthen the existing buildings is using seismic retrofitting technique (Figure 15) but the building should be seismically evaluated in the first place. If a building is not seismically evaluated, in that case the application of retrofitting is of no use (Alam et al., 2013).

3. Building Vulnerability cont.



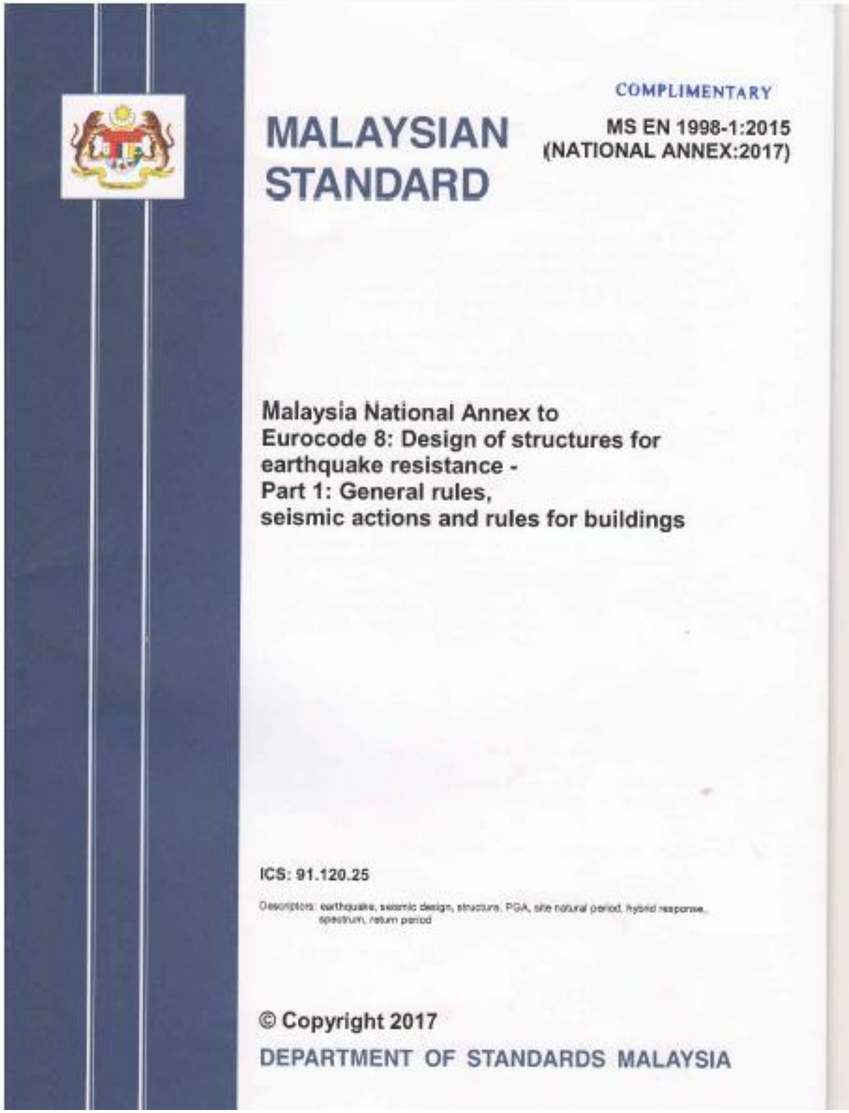
Existing RC building without any seismic consideration have nonetheless some inherent capacity to resist earthquake actions of some intensity ranging from 1% - 20% [Low rise is between 15-20%](Kim and Kim , 2004)

Figure 15: Retrofitting technique for existing structures (https://theconstructor.org)

3. Building Vulnerability cont.

It is apparent that earthquakes tends to damaged structures mainly the existing structures designed without considering seismic loading.

Therefore, Malaysia National Annex is developed a national annex for allowing Seismic loading is taken into consideration in designing.



COMPLIMENTARY

MALAYSIAN STANDARD

MS EN 1998-1:2015 (NATIONAL ANNEX:2017)

Malaysia National Annex to Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings

ICS: 91.120.25

Descriptors: earthquake, seismic design, structure, PGA, site natural period, hybrid response, spectrum, return period

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DEPARTMENT OF STANDARDS MALAYSIA

3. Building Vulnerability cont.

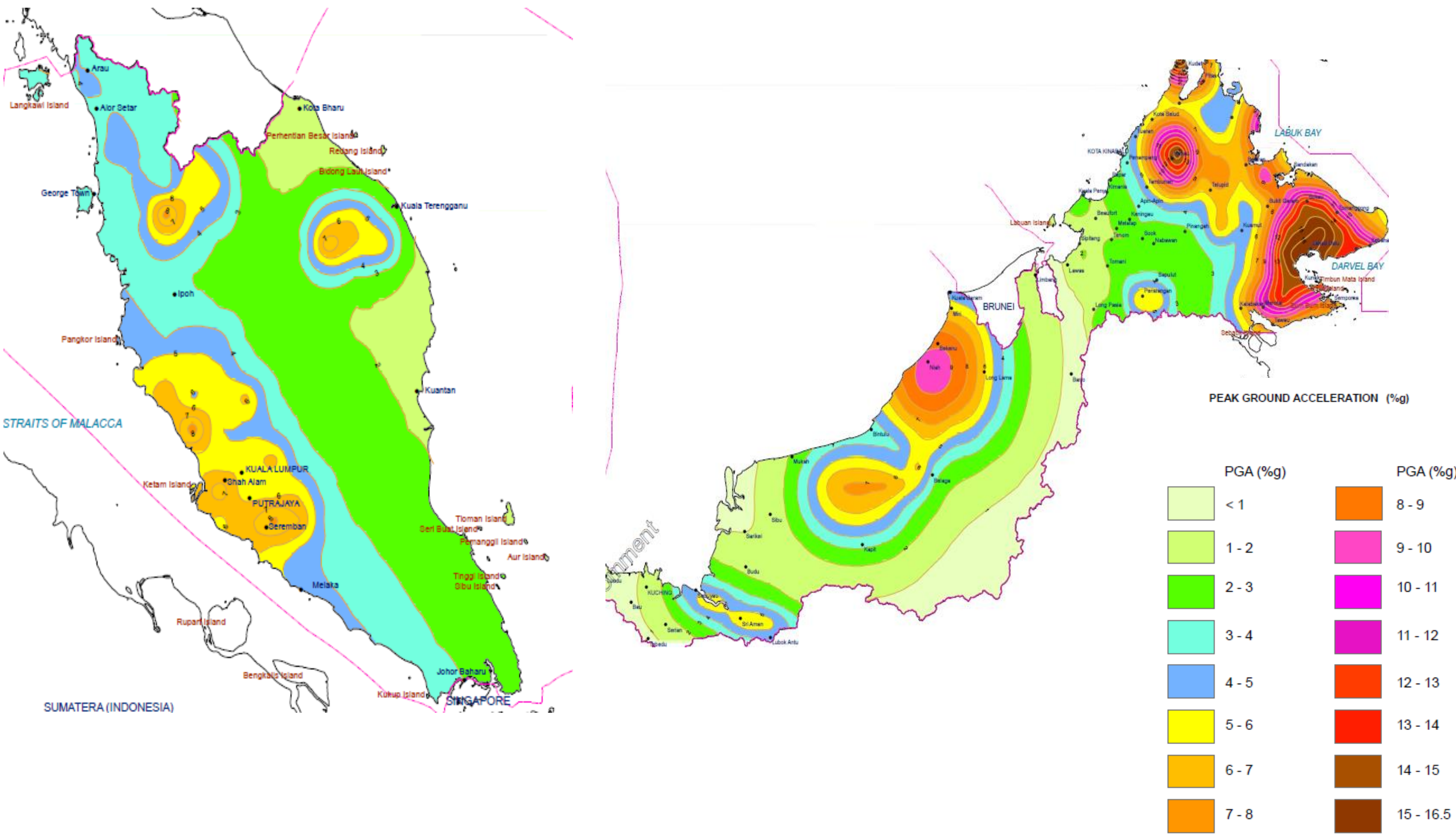
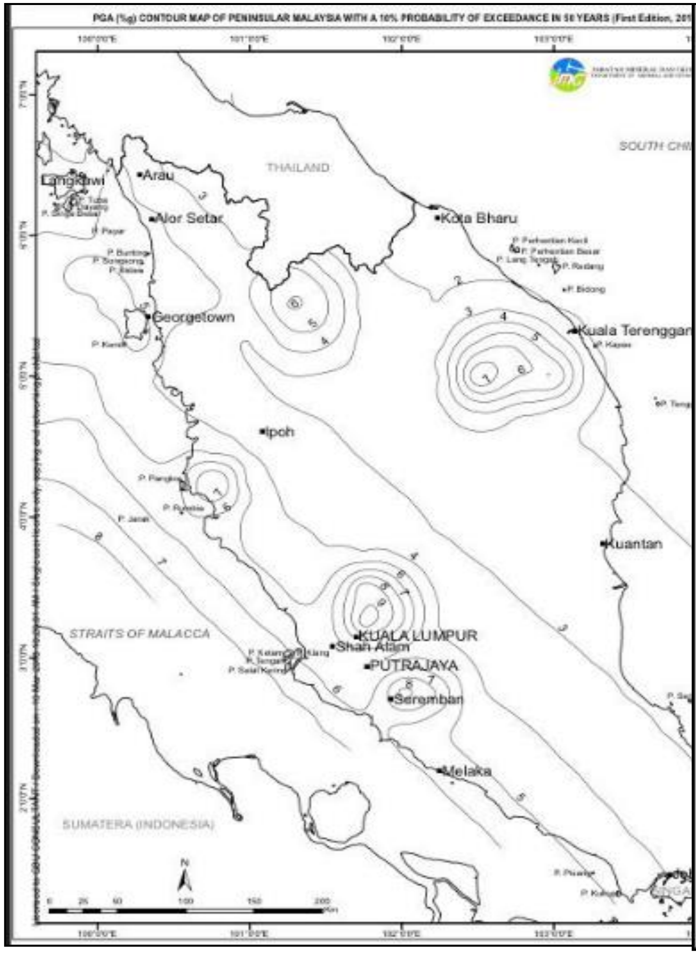


Figure 16: Seismic Hazard Map of Malaysia

3. Building Vulnerability cont.

Malaysian National Annex (MS EN 1998-1, 2017).



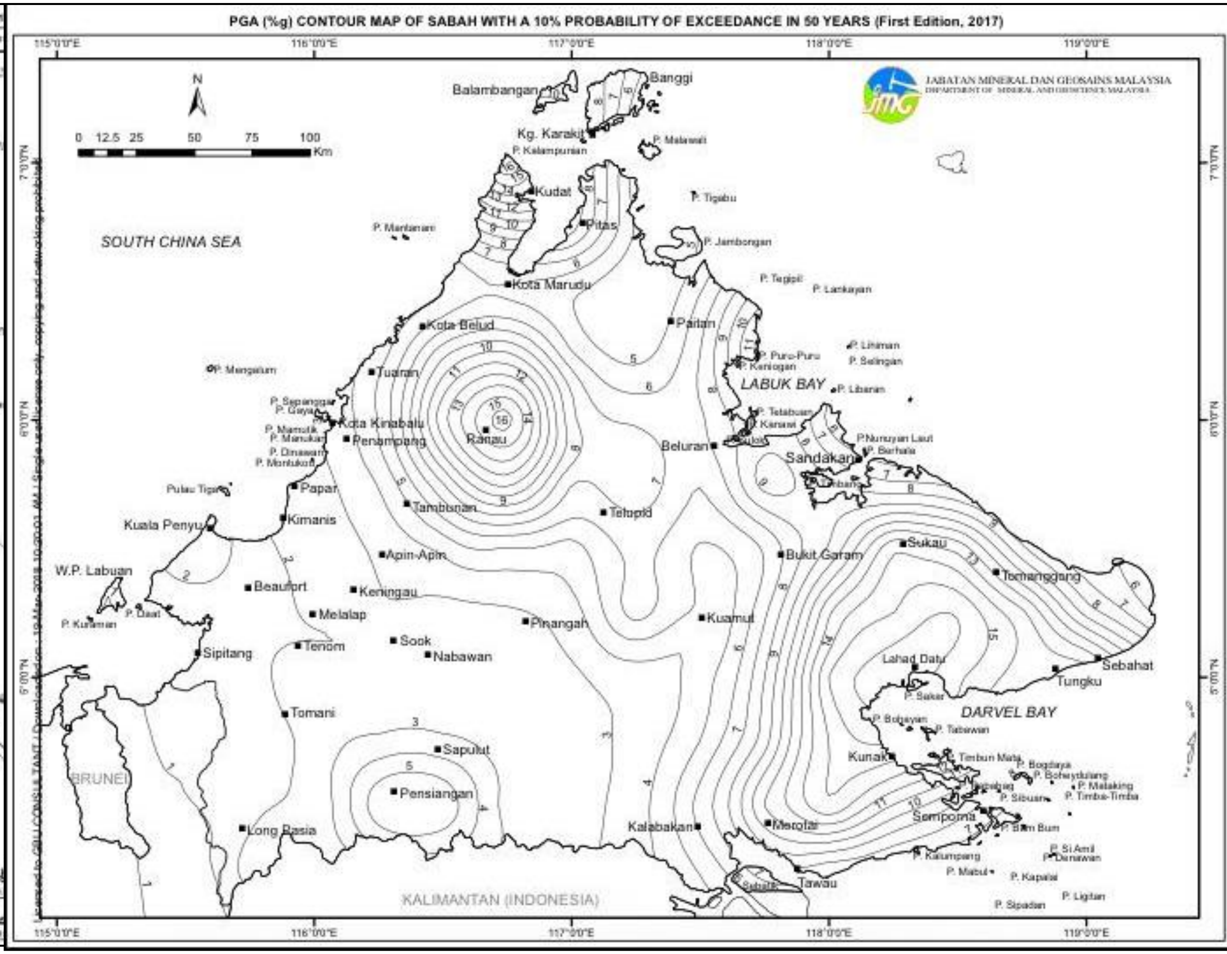


Figure 17: PGA (%) contour map of Peninsular Malaysia and Sabah

4. Cost Analyses for RC Building

Scope of Study

Each building model will be designed in accordance to Eurocode 2 and Malaysian National Annex (NA) to Eurocode 8

2D model will be considered in the analysis

Three building models having 5, 10 and 20 stories representing low, medium and high rise structure will be adopted

The wind load will be derived in accordance to MS 1553 Code Malaysian Standard

Modal response spectrum analysis will be used to determine the seismic effect

Only focus on the change in the concrete volume and reinforcement tonnage for columns and beams

The percentage of increase in the material cost will be calculated and analysed for seismic design in comparison with the conventional design.

(Theivigaa and Shaharudin, 2018)

4. Cost Analyses for RC Building

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Ductility Class

- Eurocode 8 suggested that reinforced concrete buildings can be designed based on 3 ductility classes namely, DCL, DCM and DCH based on the seismicity cases.
- The requirement for reinforcement increases as the ductility class increases from low to medium, thus cost of construction become more expensive.
- The total stiffness of the building increases with increase in column size in higher ductility class
- Increment in reinforcement requirement of the ductility class causes enlargement of column

Source: Ramli (2017)

Ductility Class	Quantity of Reinforcement (Tonne)			Increment (%)
	Beam	Column	Total	
EC2	117.0	8.6	125.6	-
EC8 DCL0.06g	127.5	11.0	138.5	+10.2
EC8 DCM 0.08g	154.0	31.8	185.8	+32.4
EC8 DCM 0.14g	155.9	32.1	188.0	+33.2

Reinforcement required for non-seismic and seismic design of 5 stories building

(Theivigaa and Shaharudin, 2018)

(Ramli, 2018)

4. Cost Analyses for RC Building

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The percentage Increase in Cost of Construction for Earthquake Resistant Building Compared to Conventional Building

Author	Increase in Cost (%)		
	Low Rise	Medium Rise	High Rise
Awaludin(2016)	13	36	-
Hee (2016)	4.4	8.1	4.3
Ramli, (2017)	33.2	61.8	-

(Theivigaa and Shaharudin, 2018)

4. Cost Analyses for RC Building

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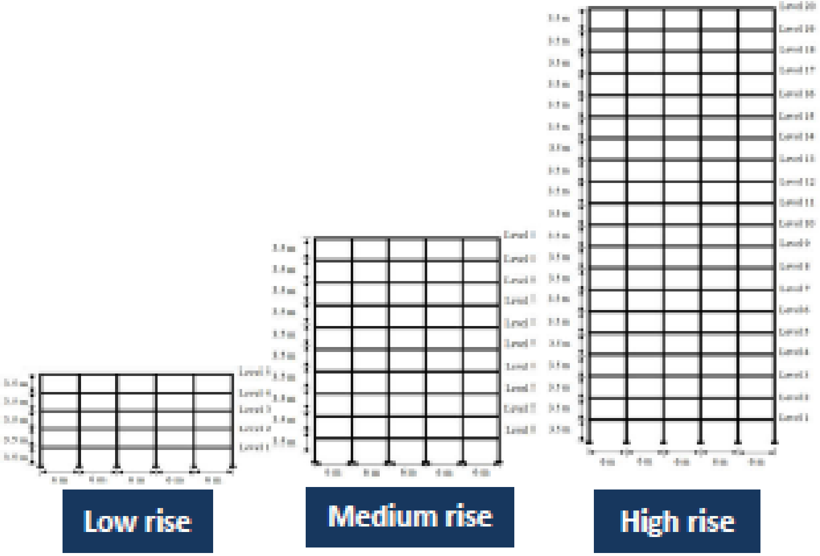
Modelling

- 3 types of reinforced concrete frame models were used in analysis
- The 2D frames have a typical storey height of 3.5 m with five equal bays of 6.0 m
- The frame models were categorised as low-rise, medium-rise and high-rise with 5 stories, 10 stories and 20 stories, respectively.
- Hee (2016) have used similar frames and studied the cost implication for using earthquake design in Malaysia.
- The frame models were designed for gravitational and wind load based on Eurocode 2 and MS 1553: 2002 to represent the current design practice in Malaysia.
- The same frame models were redesigned by considering seismic action based on Eurocode 8 and National Annex MS EN 1998-1: 2015.



- concrete grade of C30/37
- compressive strength of concrete, fcu = 30 N/mm2
- yield strength of steel, fy = 460 N/mm2

(Theivigaa and Shaharudin, 2018)

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Loading

The permanent load for the beams and columns were auto generated by the software (given the member sizes and concrete density)

The calculated imposed load was assigned as a uniformly distributed load on the beam of the 2D frame model

The highest PGA selected in the analysis as the reference peak ground acceleration, *agR* was set to be 0.165g

In this study the calculated *q* was found to be 3.9 for the reinforced concrete frame system.

The response spectrum compatible with Soil D was used in the analysis (Eurocode 8, 2004) following the work by Majid (2013) and Ramli (2017).

The seismic load assigned to the 2D frame model in SAP2000 software by defining a response spectrum function

The frame was designed for ductility class medium (DCM)

(Theivigaa and Shaharudin, 2018)

4. Cost Analyses for RC Building

Load Combination

$LC\ 1 = 1.35G_k + 1.5Q_k$

$LC\ 2 = 1.0G_k + 1.5W_L$

$LC\ 3 = 1.35G_k + 1.50Q_k + 0.9W_L$

Source: Eurocode 2 (2004) ; Eurocode 1 (2002)

$LC\ 4 = 1.0G_k + \psi_2 Q_k + 1.0E_L$

$LC\ 5 = 1.0G_k + \psi_2 Q_k - 1.0E_L$

$LC\ 6 = 1.35G_k + 1.50Q_k$

Source: Eurocode 8 (2004) ;Eurocode 1 (2002); Majid (2013)

4. Cost Analyses for RC Building

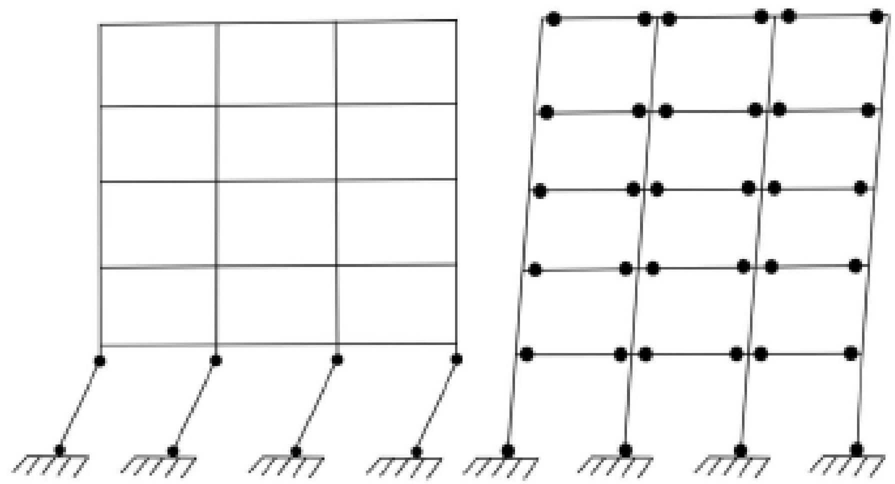
Strong Column - Weak Beam Mechanism

Design concept where the capacity of column is greater than beam.

Enable the formation of an internal plastic hinge within the seismic beam by attracting high stresses and allowing beam rotations.

To prevent the formation of soft storey mechanism,

$\sum MRc \geq 1.3 \sum MRb$

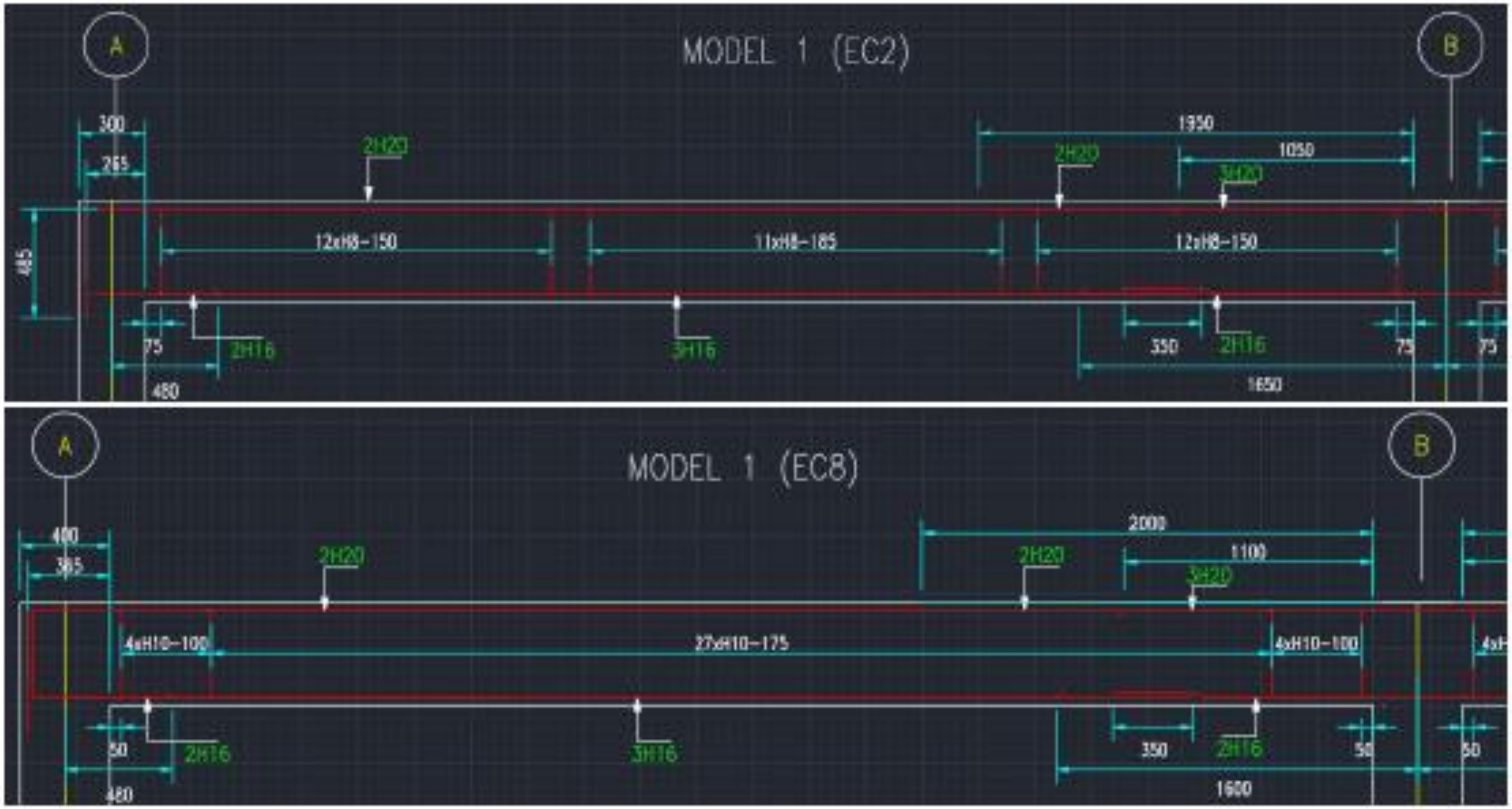


First soft-story failure versus “weak beam-strong column” mechanism

Source: Eurocode 8 (2004); Majid (2013); Tsavdaridis (2016)

4. Cost Analyses for RC Building

Detailing of Structural Member (Beam)

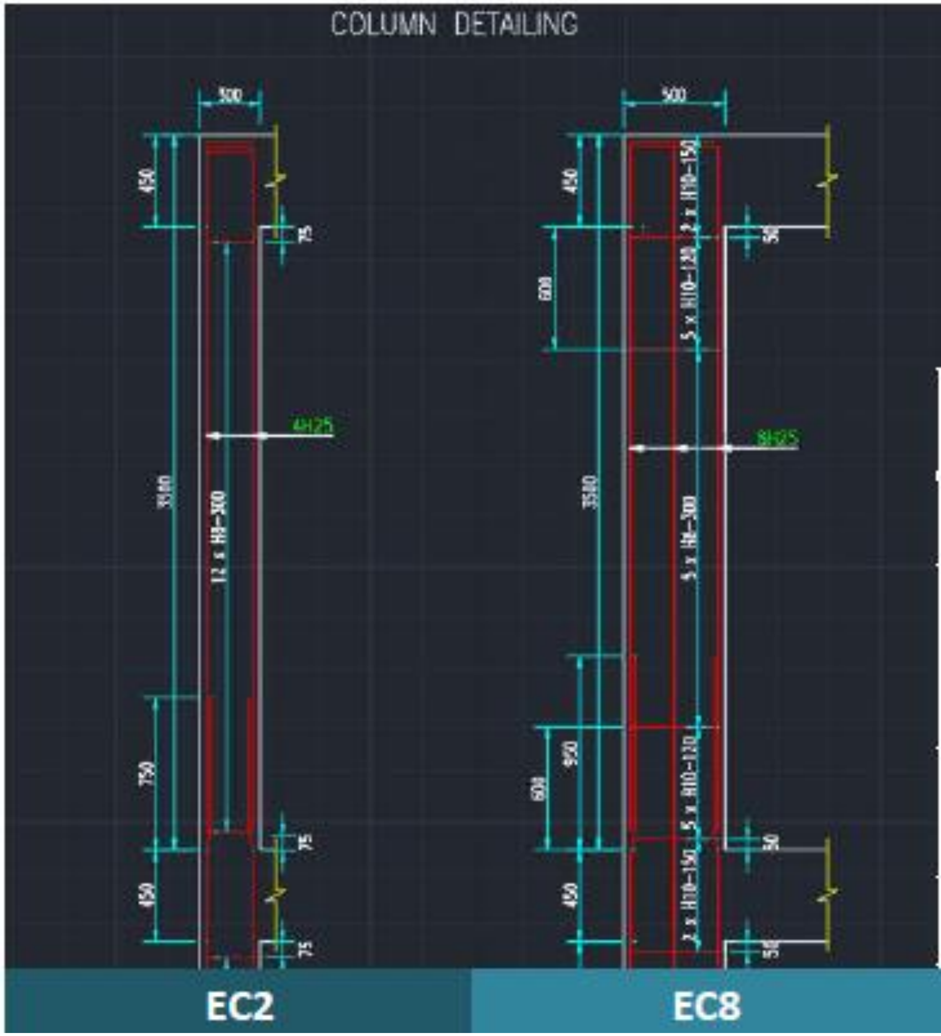


(Theivigaa and Shaharudin, 2018)

4. Cost Analyses for RC Building

Detailing of Structural Member

EC2	EC8
0.002Ac < As< 0.04 Ac	0.01Ac < As< 0.04 Ac
Larger dimension, h < 4 times the smaller dimension, b	symmetrical cross-sections symmetrical reinforcement
Not required	At least one intermediate bar
Φmin > 8mm	Φmin > 8mm



(Theivigaa and Shaharudin, 2018)

4. Cost Analyses for RC Building

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Taking Off and Cost Analysis

The taking off process was conducted after the member sizes, longitudinal and shear reinforcement had satisfied all the design and detailing requirements.

The volume of concrete was determined by multiplying the member dimensions, while the volume of steel bar was determined by multiplying the total length of the bar to its area of steel provided.

Next, the weight of steel reinforcement was calculated by multiplying the total volume of steel bar to its density.

Finally the materials cost were calculated by referring to the Building Material Prices in Kota Kinabalu for 2017 established by Construction Industry Development Board (CIDB, 2017).

Source: CIDB (2017)

(Theivigaa and Shaharudin, 2018)

4. Cost Analyses for RC Building

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Results

Beam and Column Size for Eurocode 2 and Eurocode 8 design for different model.of Structural Member

Type of Model	Element	EC2	EC8
5-storey (low-rise)	Beam size (mm)	450 x 250	450 x 250
	Column size (mm)	300 x 300	400 x 400
10-storey (medium-rise)	Beam size (mm)	450 x 250	450 x 250
	Column size (mm)	400 x 400	400 x 400
20-storey (high-rise)	Beam size (mm)	450 x 250	450 x 250
	Column size (mm)	500 x 500	500 x 500

(Theivigaa and Shaharudin, 2018)

4. Cost Analyses for RC Building

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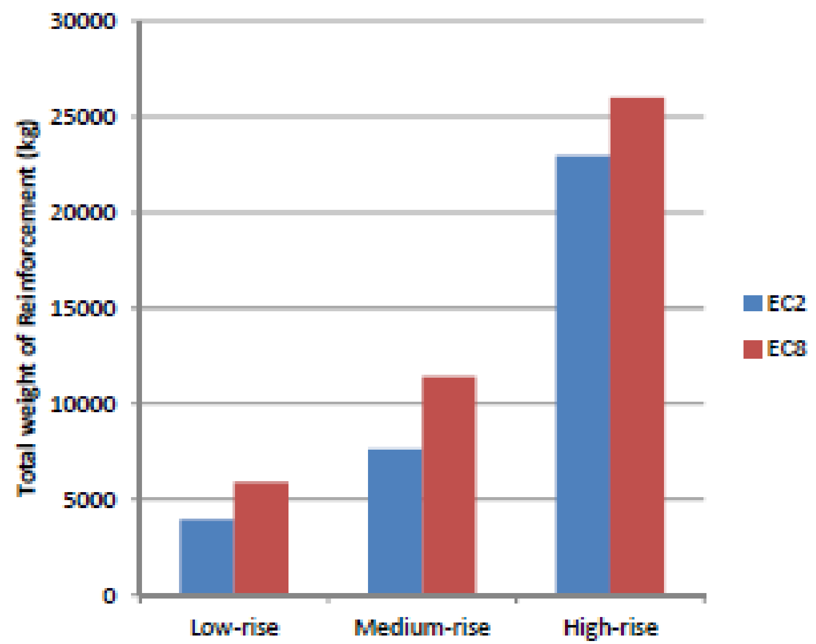
Results

The steel reinforcement affected the increment in cost when different design codes were used.

Based on the chart, the increase was calculated to be 49%, 54% and 13% for low rise, medium rise and high rise, respectively.

The fact that the minimum area of longitudinal reinforcement is 1% of the column cross section area for the design in accordance to EC 8 while, using EC 2, the value of minimum longitudinal reinforcement can be 0.2% is the reason for the material cost increments.

For column in EC 8, higher amount of link need to be provided especially along the critical regions which on the both end section of column. On the other hand, for EC 2, the transverse reinforcement need to be provided with a uniform distance in between them along the column.



Total weight of reinforcement for different model designed according to EC 2 compared with EC 8

(Theivigaa and Shaharudin, 2018)

4. Cost Analyses for RC Building

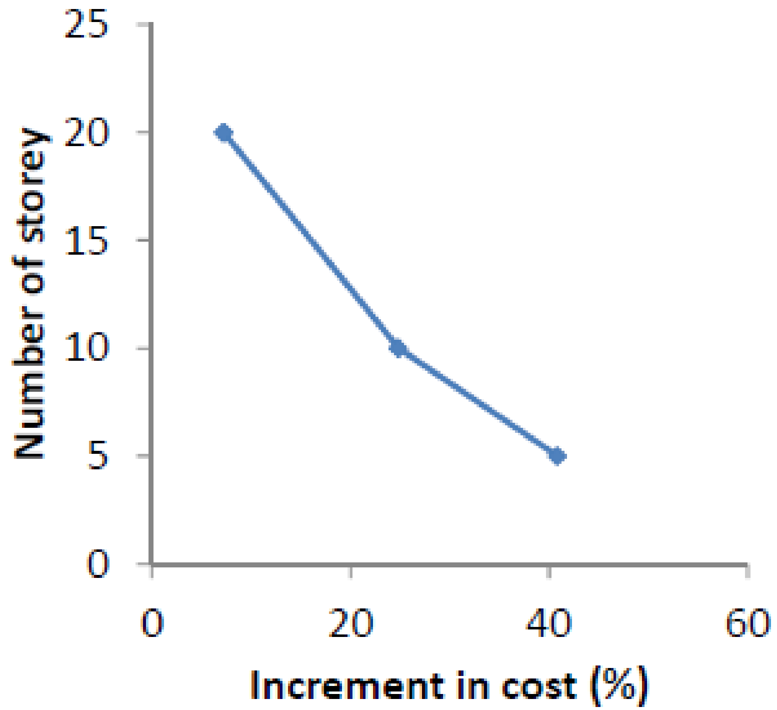
Results

The percentage of cost increment was found to be 41%, 25% and 7% for low-rise, medium-rise and high-rise, respectively.

Adopting EC 8 design requirements have resulted in having larger column order to achieve the strong column.

This strong column can be achieved without increasing the column size in high-rise building for EC 8 design compared to EC 2 design requirements.

Whereas, in low-rise buildings the columns designed in accordance to EC 2 were smaller due to lower axial load.



(Theivigaa and Shaharudin, 2018)

4. Cost Analyses for RC Building

Results

Cost versus number of storey from previous study presented in the table.

It can be seen that the trend of the relationship between the cost and the number of storey contradicts with the finding from other research work.

In this study, as the storey height increased, the increase in the material cost for beams and columns decreased.

However, similar trend was noted from the work of Hee (2016). Reduction trend in cost between medium rise and high rise buildings although Hee (2016) only showed a small reduction of 3.8% compared to 18% obtained from this study.

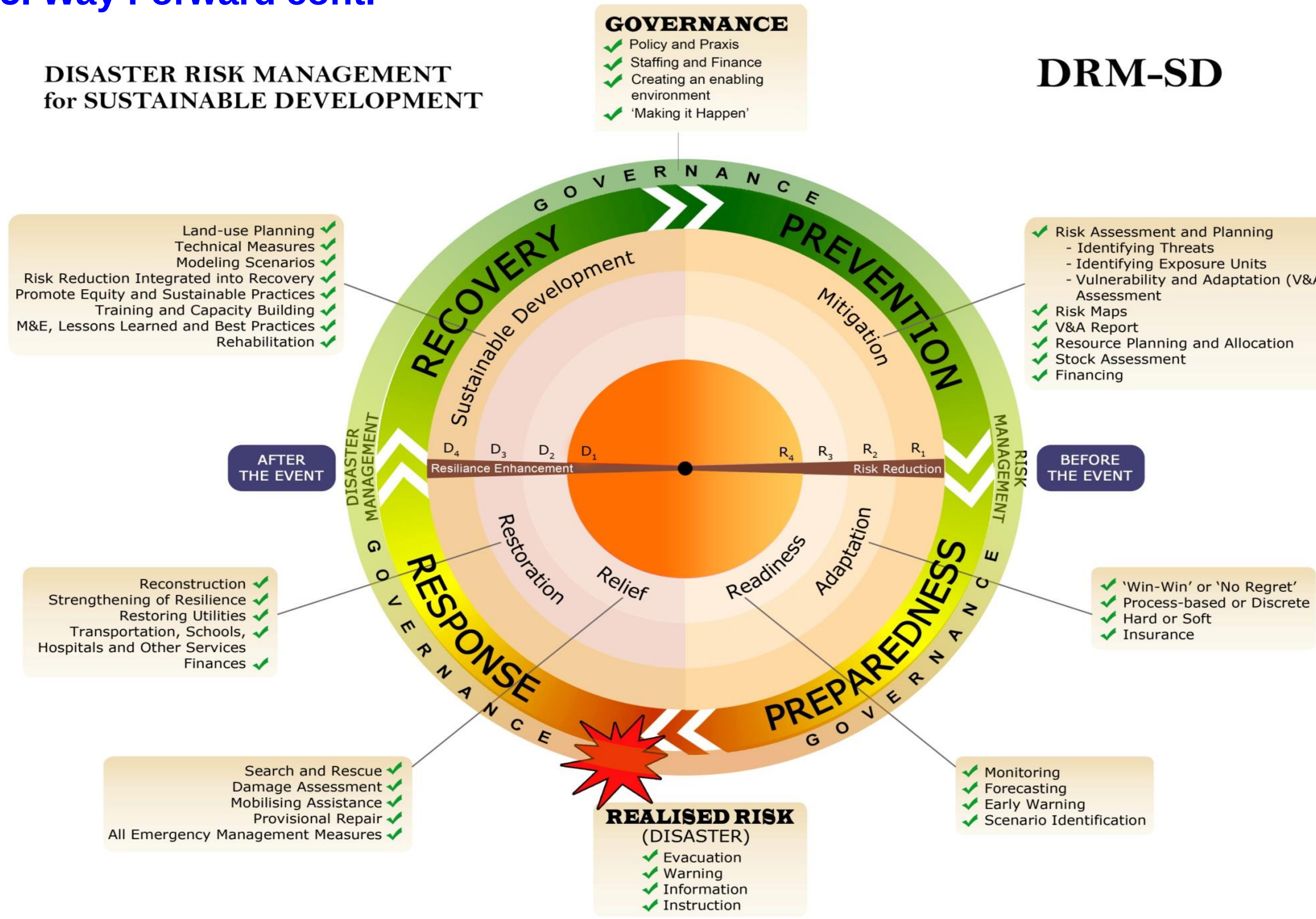
Author	Increase in Cost (%)		
	Low Rise	Medium Rise	High Rise
Awaludin(2016)	13	36	-
Hee (2016)	4.4	8.1	4.3
Ramli, (2017)	33.2	61.8	-
This study	41.0	25.0	7.0

(Theivigaa and Shaharudin, 2018)

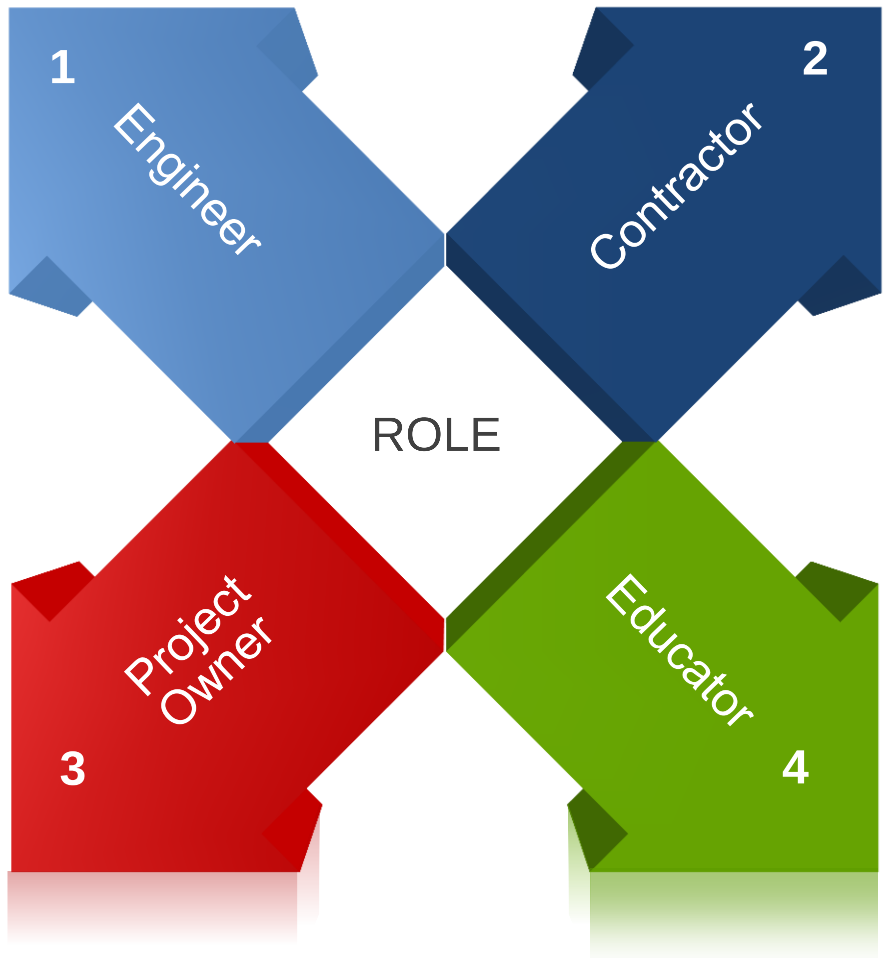
5. Way Forward

1. Improve earthquake monitoring.
2. Improve understanding of earthquake occurrence.
3. Improve fundamental knowledge of earthquake effects.
4. Improve the seismic design of structures.

5. Way Forward cont.



5. Way Forward cont.



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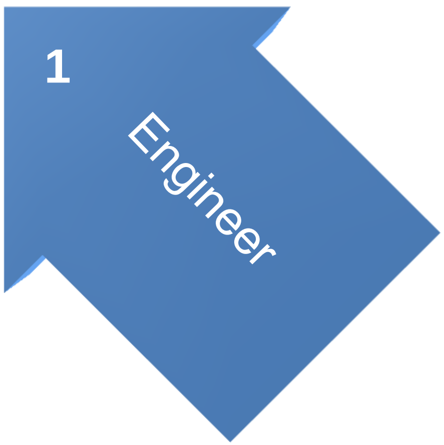
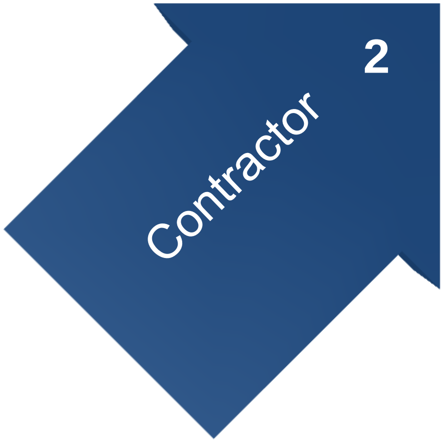


1. Awareness Courses
2. 2D frame analysis and design – not suitable for irregular floor and high rise structures
3. 3D design – time consuming, may need bidirectional earthquake analysis
4. Choice of Analysis - Linear Elastic / Non Linear Elastic
5. Software as a tools – commercial software is available in the market

5. Way Forward cont.



1. Familiar with special detailing such as the construction details at column-beam connection

2. New detailing and closely spaced links

3. Competent seismic retrofit Contractor – training & courses

5. Way Forward cont.

Project Owner

3

1. Implementation of Seismic Code

2. Cost for budgeting purposes – the anticipated increase in the cost for adopting seismic loading

3. The rise in the market price for incorporating Seismic Code – sales and rentals

4. Others – the appropriate calculation for insurance rates/fees, public versus private buildings

5. Way Forward cont.

Disaster Research Nexus

1. Most of the structural design employ “conventional” design for RC (EC2) and Steel (EC3)

2. No stand alone and compulsory courses to include seismic design & detailing in the current syllabus

3. Initiative at FYP level introducing seismic-related design topics

4. Master program

6. Conclusion

1. Data on cost implication for projects incorporating seismic loading is still lacking. A thorough study is needed in order to provide more realistic project cost estimation to many relevant agencies
2. Klang Valley is categorized as low to moderate seismicity. Generally, the construction practices in Malaysia follow proper regulation and posses good workmanship compared to poor country with uncontrolled growth of megacities such that even small earthquakes may turn into catastrophic failure.
3. The role and contribution of various stake holders such as engineer, contractor, project owner and educators in shaping the seismic resistant structure in the future should be synchronized with the implementation of the Malaysian National Annex (MS EN 1998-1, 2017).

Thank You

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