

SEISMIC PERFORMANCE
OF HIGH-RISE BUILDING
UNDER DIFFERENT EXCITATION

CHEOK JIA WEI

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG



SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

A handwritten signature in black ink, consisting of a large loop and a long horizontal stroke, is written over a horizontal line.

(Supervisor's Signature)

Full Name : IR. TS. DR. HJ. SAFFUAN BIN WAN AHMAD

Position : SENIOR LECTURER

Date : JUNE 2023



STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

A handwritten signature in black ink, consisting of a stylized 'A' shape with a horizontal line extending to the left and a loop on the right.

(Student's Signature)

Full Name : CHEOK JIA WEI

ID Number : MAH21004

Date : JUNE 2023

SEISMIC PERFORMANCE
OF HIGH-RISE BUILDING
UNDER DIFFERENT EXCITATION

CHEOK JIAWEI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Civil Engineering Technology
UNIVERSITI MALAYSIA PAHANG

JUNE 2023

ACKNOWLEDGEMENTS

First and foremost, I would like to express deepest appreciation to my research supervisor, Ts. Ir. Dr. Hj. Saffuan Bin Wan Ahmad for giving me the opportunity to conduct this research and guide me in writing this thesis. Throughout the course of my graduate study, my supervisor has provided valuable guidance to enable me to complete this research. He has also shared with me the knowledge and methodology to carry out this research. It has been a great privilege and honor to study under his guidance. I would not have been able to successfully complete this research without his guidance and assistance. I am also very thankful to his wife for her understanding, cooperation and patience during the lengthy discussions and research meetings.

Secondly, I am grateful to my parents for their love and care in raising me and how much they have sacrificed in educating me to ensure that I would have a bright future. They have not only supported me throughout my life but also given me the much-needed encouragement without which I would not have been able to complete this research smoothly.

Last but not least, I thank my friends for helping me in this research. I have indeed gained valuable knowledge and learnt useful techniques. Their assistance and the knowledge shared have made my research an enjoyable experience and kept me motivated from start to finish. I have also learnt that teamwork is very important and that everyone has their own abilities and skills.

ABSTRAK

Malaysia dianggap terletak di lokasi yang selamat daripada bahaya seismik dan jauh dari kawasan lingkaran gunung berapi Pasifik. Namun begitu, kejadian gempa bumi di Ranau pada tahun 2015 telah menjadi amaran bahawa Malaysia tidak lagi kebal daripada ancaman bencana seismik. Pada masa lalu, kebanyakan bangunan di Malaysia dibina tanpa mengambil kira faktor ketahanan terhadap beban seismik. Hal ini mewujudkan cabaran yang perlu diatasi dan bahaya kepada masyarakat tempatan. Oleh itu, kerja-kerja pembinaan dalam sektor kejuruteraan awam di Malaysia juga sewajarnya memberi perhatian yang lebih terhadap kemungkinan bahaya gempa bumi. Maka, bangunan khususnya bangunan yang tinggi di kawasan kediaman berkemungkinan akan berhadapan dengan kemusnahan yang teruk akibat gegaran gempa bumi jika penilaian tidak dibuat ke atas bangunan tersebut dan seterusnya meningkatkan ketahanan strukturnya. Penyelidikan ini bertujuan menentukan kerentanan dan ciri-ciri kelakuan bangunan tinggi yang sedia ada dalam pengujian berbeza dan juga menilai implikasi kos yang timbul. Bangunan tinggi konkrit bertetulang 50 tingkat di Kuala Lumpur digunakan sebagai sampel dalam kajian ini untuk menganalisis prestasi seismik dalam keadaan pengujian gempa bumi yang berbeza dengan menggunakan perisian unsur terhingga Etabs. Beban seismik yang berbeza dalam setiap kes berikut telah diuji dalam analisis simulasi untuk mencapai objektif-objektif kajian ini: STATIC EQ, RSA, THA-ACEH, THA-RAPIDKL, THA-ELCENTRO, THA-YERMO dan THA-ALDATENA. Keputusan analisis getaran bebas menunjukkan tempoh tabii bangunan yang diuji mencatat 5.942 saat. Iaitu menghampiri petua yang membuat anggaran dengan membahagikan jumlah tingkat di dalam bangunan dengan 10. Hasil kajian juga menunjukkan bahawa bangunan yang tak sebetulnya cenderung untuk memiliki kilasan pada tiga bentuk ragam yang pertama disebabkan oleh wujudnya ciri-ciri asimetri. Tambahan pula, ciri-ciri kelakuan dan tahap prestasi struktur bangunan dinilai berdasarkan komponen-komponen global dan tempatan dengan membandingkan hasil output yang berbeza. Kesimpulannya, pengujian berbeza telah mempengaruhi kelakuan dan prestasi bangunan yang mempunyai pola beban yang berbeza. Gempa bumi tempatan dengan nilai *peak ground acceleration* (PGA) yang tinggi didapati turut menghasilkan nisbah hanyut keseluruhan yang tinggi dan menyebabkan bangunan perlu menahan rintangan daya sisi yang lebih tinggi. Dalam kes beban seismik yang jauh puncanya, kemusnahan yang berlaku pada bangunan berada pada tahap yang tidak begitu teruk oleh kerana tenaga seismik akan berkurangan semasa gegaran berada dalam jarak perjalanannya dari punca asal. Pesongan didapati meningkat dengan peningkatan ketinggian bangunan. Hal ini menunjukkan bahawa bangunan tinggi didapati lebih sensitif terhadap beban sisi. Model Etabs yang dibina telah sekaligus menunjukkan bahawa sampel bangunan sedia ada berupaya menahan rintangan STATIC EQ, RSA, THA-ACEH, dan THA-RAPIDKL dengan tahap prestasi *Immediate Occupancy* (IO), manakala dikategorikan sebagai *Life Safety* (LS) apabila tertakluk kepada THA-ELCENTRO berdasarkan garis panduan FEMA 356. Walau bagaimanapun, sampel gagal melepasi beban seismik apabila diuji dengan THA-YERMO dan THA-ALDATENA. Di samping itu, implikasi kos turut meningkat dengan peningkatan PGA seismik yang juga menunjukkan bahawa elemen-elemen dalam struktur bangunan memerlukan tetulang yang lebih bagi menambah kapasiti bangunan untuk menahan rintangan beban sisi. Hasil analisis terhadap sampel bangunan sedia ada membuktikan keupayaan menahan rintangan lima bebanan seismik dalam julat yang boleh diterima dengan kos tambahan yang perlu ditanggung.

ABSTRACT

The location of Malaysia is considered safe from seismic and not within the Pacific Ring of Fire but the Ranau's earthquake in 2015 warned that Malaysia is no longer immune from seismic disasters. In the past, most of the buildings were not designed to resist seismic loadings and so created challenges and hazards for people in Malaysia. Most Malaysian perceive that they are free from the life-threatening seismic crisis but they are wrong. Structural performances and life safety of any civil engineering work in Malaysia were paid more concern and attention due to the significant hazard occur in this earthquake. Thus, buildings especially high-rise residential expected to be subject to substantial damages caused by earthquake tremors if the building's structures are not assessed and eventually strengthened. This research aims to determine the vulnerability and behaviour of existing high-rise buildings under excitation. Furthermore, the cost implication of structural design to resist seismic can be evaluated. A 50-storey reinforced concrete high-rise building in Kuala Lumpur was used as an example in this study to demonstrate the seismic performance under different excitation by using Etabs finite element software. Different seismic load cases were applied in this simulation analysis to achieve the main objectives, which are STATIC EQ, RSA, THA-ACEH, THA-RAPIDKL, THA-ELCENTRO, THA-YERMO, and THA-ALDATENA. According to the findings of free vibration analysis, the natural period of the buildings was 5.942 sec. The result of the natural period for this research was close to the rule of thumb, which is the number of stories divided by 10 usually used to estimate the natural periods for the buildings. The results showed that buildings with irregular shapes tend to be torsional for the first three mode shapes due to asymmetry characteristics. Moreover, the behaviours and performances of the building's structure are assessed in global and local components through compared the different output results. The results obtained have shown that different excitation influenced the behaviours and performance of the building with different load patterns. If seismic types are classified as local earthquakes and with higher peak ground acceleration, a higher total drift ratio will be produced as the building is required to resist higher lateral forces. For the distant seismic load cases, lesser damages caused to buildings due to seismic energy have reduced during travel for a distance. Besides, results showed that deflection increased with the height of the buildings indicated that higher buildings tend to be more sensitive toward lateral loads. The developed Etabs model showed that the existing building capable to resist STATIC EQ, RSA, THA-ACEH, and THA-RAPIDKL under performance level of Immediate Occupancy (IO), while categorized as Life Safety (LS) when subjected to THA-ELCENTRO, by referred to the FEMA 356 guideline. Meanwhile, the buildings failed to resist the seismic load when subject to THA-YERMO and THA-ALDATENA. It also found that the cost of implication increased as the peak ground acceleration of seismic increased, where the structural elements required more reinforcements to provide capacity for resisting lateral loads. The analysis outcome of the existing building can resist 5 seismic loads within the acceptable range with additional cost imposed on the building.

TABLE OF CONTENT

DECLARATION	
TITLE PAGE	
ACKNOWLEDGEMENTS	ii
ABSTRAK	iii
ABSTRACT	iv
TABLE OF CONTENT	v
LIST OF SYMBOLS	xii
LIST OF ABBREVIATIONS	xv
LIST OF APPENDICES	xvi
CHAPTER 1 INTRODUCTION	1
1.1 Background of the study	1
1.2 Problem statement	2
1.3 Research objective	3
1.4 Scope of the study	4
1.5 Significance of the study	4
1.6 Structure of the thesis	5
CHAPTER 2 LITERATURE REVIEW	6
2.1 Introduction	6
2.2 Earthquake	6
2.2.1 Fault	7
2.2.2 Seismic wave	8
2.3 Measurement parameters for earthquake	9
2.3.1 Magnitude	10

2.3.2	Intensity	10
2.4	Ground motion in Malaysia	12
2.4.1	Earthquake in Malaysia	13
2.5	Seismic response spectrum	14
2.6	Seismic actions on different types of soil	17
2.7	Performance level of buildings	20
2.8	High rise buildings in Malaysia	22
2.8.1	Design concept of high-rise buildings	23
2.8.2	Design practice of high-rise buildings in Malaysia	24
2.8.3	Seismic damages on building structures	25
2.9	Research gaps	28
 CHAPTER 3 METHODOLOGY		 31
3.1	Introduction	31
3.2	Overall research methodology	31
3.3	Selection of buildings for analysis	33
3.3.1	Building structural description	33
3.4	Dead load and live load (vertical loads)	35
3.5	Seismic load (horizontal loads)	36
3.6	Wind load (horizontal load)	37
3.7	Cost of materials	41
3.8	Modelling analysis	42
3.8.1	Etabs software simulation	45
3.8.2	Elastic model for wind load	47
3.8.3	Response spectrum analysis	50
3.8.4	Time history analysis	54

3.9	Spreadsheet calculation for drift ratio	56
3.9.1	Drift limit for wind loads (MS1553:2002)	56
3.9.2	Drift limit for seismic load (FEMA 356)	57
3.9.3	Microsoft Excel spreadsheet calculation for drift limit	57
3.10	Comparison and validation of software simulation	59
3.11	Summary	59
 CHAPTER 4 RESULTS AND DISCUSSION		60
4.1	Introduction	60
4.2	Modal periods and mode shape	60
4.3	Static analysis for wind load	69
4.4	Static and dynamic analysis for earthquake loads	75
4.5	Performance level of building under different seismic analysis	80
4.6	Comparison for vertical members	82
4.7	Comparing the cost for structural under different seismic loads	85
4.8	Summary	92
 CHAPTER 5 CONCLUSION AND RECOMMENDATION		93
5.1	Introduction	93
5.2	Overall conclusion	93
5.2.1	Research objective 1	94
5.2.2	Research objective 2	94
5.2.3	Research objective 3	95
5.3	Recommendations for future work	95
 REFERENCES		96

LIST OF TABLES

Table 3.1 Details of the selected buildings in the present research	33
Table 3.2 Slab details	34
Table 3.3 Beam details	34
Table 3.4 Column and shearwall details	35
Table 3.5 Table of dead load and live load	35
Table 3.6 Details for wind load input	37
Table 3.7 Material cost table list	42
Table 3.8 Drift limit for wind load	57
Table 3.9 Drift limit for seismic load	57
Table 4.1 Modal periods and modal frequencies	61
Table 4.2 Mass participation ratio	62
Table 4.3 Mode shape of buildings	68
Table 4.4 Total drift ratio under (50YRS) wind load for both directions	69
Table 4.5 Interstorey drift ratio under (5YRS) wind loads for both directions	71
Table 4.6 Load case and combination for different seismic analysis	75
Table 4.7 Deflection of buildings under different type of seismic analysis	79
Table 4.8 Performance level of building under different seismic analysis	81
Table 4.9 Critical vertical structural elements under different seismic analysis	84
Table 4.10 Concrete volume and reinforcement for vertical elements	85
Table 4.11 Different of reinforcement for vertical elements	85
Table 4.12 Concrete volume and reinforcement for beam elements	87
Table 4.13 Different of reinforcement for beam elements	88
Table 4.14 Concrete volume and reinforcement of slab	90
Table 4.15 Total of existing building structural cost	91
Table 4.16 Total structural cost under different seismic analysis	91

LIST OF FIGURES

Figure 2.1 Dip-slip and Strike slip of earthquake	8
Figure 2.2 Types of seismic waves	9
Figure 2.3 Intensity of earthquake (European Macroseismic Scale)	11
Figure 2.4 Regional tectonic setting of Malaysia	13
Figure 2.5 Example of response spectrum graph	17
Figure 2.6 Illustration of performance-based design	21
Figure 2.7 Structural layout of high-rise buildings	23
Figure 2.8 Soft-storey mechanism and beam – column failure due Ranau earthquake	26
Figure 2.9 Damages on Box up brick after Ranau earthquake	27
Figure 2.10 Significant damages on RC column after Ranau earthquake	28
Figure 3.1 Flow chart of the research	32
Figure 3.2 Time history earthquake data of El Centro	36
Figure 3.3 Time history earthquake data of Aceh	36
Figure 3.4 Time history earthquake data of RapidKL	37
Figure 3.5 Upwind distance from sea to site in google map	38
Figure 3.6 Elevation of the buildings	39
Figure 3.7 Spreadsheet calculation use for wind load – Part 1	40
Figure 3.8 Spreadsheet calculation use for wind load – Part 2	41
Figure 3.9 3D view of buildings modelling	43
Figure 3.10 3D view of buildings modelling	43
Figure 3.11 Plan view of typical unit floor	44
Figure 3.12 Plan view of podium	44
Figure 3.13 Result of maximum story displacement graph in Etabs	45
Figure 3.14 Result of story shears graph in Etabs	46
Figure 3.15 Result of maximum story drift in Etabs	46
Figure 3.16 Results of mode shape periods and frequencies in Etabs	47
Figure 3.17 Define load patterns of wind load	48
Figure 3.18 Input data for 50 years wind loads in x-direction	48
Figure 3.19 Input data for 5 years wind loads in x-direction	48
Figure 3.20 Input data for 1 year wind loads in x-direction	49
Figure 3.21 Input data for 50 years wind loads in y-direction	49
Figure 3.22 Input data for 5 years wind loads in y-direction	49

Figure 3.23 Input data for 1 year wind loads in y-direction	50
Figure 3.24 Mass source data of the modelling	51
Figure 3.25 Modal analysis load cases settings	51
Figure 3.26 Define the static seismic load pattern in X and Y direction	52
Figure 3.27 Input data for EQ in X-direction	52
Figure 3.28 Input data for EQ in Y-direction	52
Figure 3.29 Input data for response spectrum function	53
Figure 3.30 Load cases data for response spectrum analysis	53
Figure 3.31 Time history function of El-centro	54
Figure 3.32 Time history function of Aceh	55
Figure 3.33 Time history of RapidKL	55
Figure 3.34 Matched response spectrum for time history	56
Figure 3.35 Spreadsheet for wind load total drift ratio	58
Figure 3.36 Spreadsheet for wind load interstorey drift ratio	58
Figure 3.37 Spreadsheet for wind load acceleration check	59
Figure 4.1 Comparison of modal periods vs mode shape	61
Figure 4.2 Building height vs total drift ratio under WLX (50YRS)-BS-0D	74
Figure 4.3 Building height vs total drift ratio under WLY (50YRS)-BS-90D	74
Figure 4.4 Interstorey drift ratio under wind load (5YRS) for both directions	75
Figure 4.5 Building height vs deflection under different seismic analysis	80
Figure 4.6 Performance level of building under different seismic analysis	81
Figure 4.7 Weight of reinforcement for vertical elements under different seismic loads	85
Figure 4.8 Increment of reinforcement for vertical elements for different seismic loads	85
Figure 4.9 Weight of reinforcement for beam elements under different seismic loads	87
Figure 4.10 Increment of reinforcement for beam elements for different seismic loads	88
Figure 4.11 Total cost increase in terms of percentage under different excitation	92

LIST OF SYMBOLS

mm	Millimeter
mm ²	Millimeter square
cm	centimeter
km	Kilometer
s	Second
kg	Kilogram
kg/m ³	Kilogram per meter cube
N	Newton
kN	Kilo newton
MN	Mega Newton
N/m	Newton per meter
N/mm ²	Newton per millimeter square
kN/m ²	Kilo newton per meter square
kN/m ³	Kilo newton meter cube
kNm	Kilo newton meter
m/s	Meter per second
kPa	Kilo pascal
g	Acceleration of gravity
f _{ck}	Concrete compressive strength
f _{yk}	Yield strength of steel
g _k	Dead load
q _k	Live load
P	Design wind pressure

ρ_{air}	Density of air
V_{des}	Design wind speed
I	Importance factor
C_{fig}	Aerodynamic shape factor
C_{dyn}	Dynamic response factor
$C_{\text{p,e}}$	External pressure coefficient
K_{a}	Area reduction factor
K_{c}	Combination factor
K_{l}	Local pressure factor
K_{p}	Porous factor
V_{sit}	Site wind speed
V_{s}	Wind speed
M_{d}	Wind direction multiplier
$M_{\text{z,cat}}$	Terrain or height multiplier
M_{h}	Hill shape multiplier
M_{s}	Shielding multiplier
T_{l}	Fundamental period of vibration
C_{t}	Coefficient of structural system
H	Height of building from the foundation or from the top of rigid basement
$S_{\text{d}}(T)$	Design spectrum
a_{g}	Design ground acceleration on type A ground
S	Soil factor
T_{B}	Lower limit of the period of the constant spectral acceleration branch
T_{C}	Upper limit of the period of the constant spectral acceleration branch
T_{D}	Value defining the beginning of the period of the constant displacement response range of the spectrum

q	Behaviour factor
β	Lower bound factor for horizontal design spectrum
q_0	Basic value of the behaviour factor
k_w	Factor reflecting the prevailing failure mode in structural systems with walls
α_u	Multiplier of horizontal seismic design action at formation of global plastic mechanism
α_l	Multiplier of horizontal design seismic action at formation of first plastic hinge in the system
$v_{s,30}$	Average shear wave velocity
h_i	Thickness (in meters) of the i -th formation or layer in a total of N , existing in the top 30 m
v_i	Shear-wave velocity (at a shear strain level of 10^{-5} or less) of the i -th formation or layer in a total of N , existing in the top 30 m
C_u	Undrained shear strength of soil
N_{SPT}	Standard Penetration Test blow-count
γ_1	Importance factor
a_{gR}	Reference peak ground acceleration

LIST OF ABBREVIATIONS

MMI	Modified Mercalli Intensity
JKR	Public Work Department
RC	Reinforced Concrete
DCL	Ductility Class Low
DCM	Ductility Class Medium
DCH	Ductility Class High

LIST OF APPENDICES

Appendix A: Code of practise for wind load (MS 1553:2002)	101
Appendix B: Code of practise for seismic (EN199801:2005)	109
Appendix C: Keyplan layout of structural buildings	120
Appendix D: Total deflection of buildings under wind load	122
Appendix E: Input for response spectrum analysis	127
Appendix F: List of Publication	128

REFERENCES

- Abdullah, K., Tan, K. S., & Ghazali, N.H, M. (2005). NO MORE IN THE COMFORT ZONE – Malaysia’s Response to the December 2004 Tsunami A Tsunami hits Malaysia. *Response, December 2004*, 3–7.
- Adiyanto, M. I., & Majid, T. A. (2014). Seismic design of two storey reinforced concrete building in Malaysia with low class ductility. *Journal of Engineering Science and Technology*, 9(1), 27–46.
- Adiyanto, M. I., Majid, T. A., & Mustapa, S. A. H. S. (2020). *COST EVALUATION OF RC SCHOOL BUILDING CONSIDERING SEISMIC DESIGN BASED ON MALAYSIA NATIONAL ANNEX TO EC8*.
- Adnan, A., Hendriyawan, H., & Irsyam, M. (2002). The effect of the latest Sumatra earthquake to Malaysian Peninsular. *Malaysian Journal of Civil Engineering*, 14, 1.
- Adnan, A., Hendriyawan, H., Marto, A., & Irsyam, M. (2005). Seismic Hazard Assessment For Peninsular Malaysia Using Gumbel Distribution Method. *Jurnal Teknologi B*, 42(42B), 57–73. <https://doi.org/10.11113/jt.v42.741>
- Ahmed, M. M. M., Abdel Raheem, S. E., Ahmed, M. M., & Abdel Shafy, A. G. A. (2016). Irregularity Effects on the Seismic Performance of L-Shaped Multi-Story Buildings. *JES. Journal of Engineering Sciences*, 44(5), 513–536. <https://doi.org/10.21608/jesaun.2016.111440>
- Andrew Alden. (2020). *Reverse, Strike-Slip, Oblique, and Normal Faults*. Geology Basics: Types of Faults. <https://www.thoughtco.com/fault-types-with-diagrams-3879102>
- Işik, E., Büyüksaraç, A., & Aydin, M. C. (2016). Effects of local soil conditions on earthquake damages.
- Badami, S., & Suresh, M. R. (2014). A Study on Behavior of Structural Systems for Tall Buildings Subjected To Lateral Loads. *International Journal of Engineering Research & Technology (IJERT)*, 3(7, JULY 2014), P989-994. www.ijert.org
- Binti Harith, N. S. H., & Adnan, A. (2017). Estimation of peak ground acceleration of ranau based on recent earthquake databases. *Malaysian Journal Geosciences*, 1(2), 06–09. <https://doi.org/10.26480/mjg.02.2017.06.09>
- Bommer, J. J., Crowley, H., & Pinho, R. (2015). A risk-mitigation approach to the management of induced seismicity. *Journal of Seismology*, 19(2), 623–646. <https://doi.org/10.1007/s10950-015-9478-z>
- Bormann, P. (2020). *Earthquake, Magnitude*. 1–12. https://doi.org/10.1007/978-3-030-10475-7_3-1
- CSI. (2020). *Etabs Buildings Analysis and Design*. <https://www.csiamerica.com/products/etabs>
- Elnashai, A. S., & Sarno, L. Di. (2008). Fundamentals of Earthquake Earthquake. *John Wiley & Sons Ltd*, 337.

- Emporis. (2021). *Buildings in Kuala Lumpur 2000-2021*.
<https://www.emporis.com/city/100354/kuala-lumpur-malaysia>
- Gill, J., Shariff, N. S., Omar, K., & Amin, Z. M. (2015). TECTONIC MOTION of Malaysia: ANALYSIS from YEARS 2001 to 2013. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 2(2W2), 199–206.
<https://doi.org/10.5194/isprsannals-II-2-W2-199-2015>
- Kar, S., & Sadhu, T. (2021). Seismic analysis of RC framed tall structures with plan irregularity. In *Recent Developments in Sustainable Infrastructure: Select Proceedings of ICDSI 2019* (pp. 265-277). Springer Singapore.
- Khalil, A. E., Abir, I. A., Ginsos, H., Hafiez, H. E. A., & Khan, S. (2018). Probabilistic seismic hazard assessments of Sabah, east Malaysia: Accounting for local earthquake activity near Ranau. *Journal of Geophysics and Engineering*, 15(1), 13–25.
<https://doi.org/10.1088/1742-2140/aa8d51>
- Khan, A. A., Abdullah, W. H., Hassan, M. H., & Iskandar, K. (2017). Tectonics and sedimentation of SW Sarawak basin, Malaysia, NW Borneo. *Journal of the Geological Society of India*, 89(2), 197–208. <https://doi.org/10.1007/s12594-017-0584-0>
- Khan, Z. (2010). *EVALUATION OF EFFECTS OF RESPONSE SPECTRUM ANALYSIS ON 2 . Requirement of Dynamic analysis. December*, 13–14.
- Khoiry, M. A., Hamzah, N., Osman, S. A., Mutalib, A. A., & Hamid, R. (2018). Physical damages effect on residential houses caused by the earthquake at Ranau, Sabah Malaysia. *International Journal of Engineering and Technology*, 10(5), 414-418.
- Lam, N. (2002). *Analysis of long-distance earthquake tremors and base shear demand for buildings in Singapore*. 0296(January). [https://doi.org/10.1016/S0141-0296\(01\)00065-7](https://doi.org/10.1016/S0141-0296(01)00065-7)
- Liel, A. B., & Deierlein, G. G. (2013). Cost-benefit evaluation of seismic risk mitigation alternatives for older concrete frame buildings. *Earthquake Spectra*, 29(4), 1391–1411.
<https://doi.org/10.1193/030911EQS040M>
- Looi, D. T. W.; Chiang, J. C. L.; Tsang, H. H.; Lam, N. T. K. (2020). Potential Issues Faced on Reservoir-Triggered Earthquakes in Malaysia. *Proceedings of the 1st International Conference on Dam Safety Management and Engineering, "ICDSME 2019", Penang, Malaysia, 19-21 November 2019 / Lariyah Mohd Sidek, Gasim Hayder Ahmed Salih, Mohd Hariffin Boosroh (Eds.), Pp. 158-166*.
- MalayMail. (2015). *Sabah earthquake a 2015 shock for the nation*.
<https://www.malaymail.com/news/malaysia/2015/12/24/sabah-earthquake-a-2015-shock-for-the-nation/1029201>
- Department of Statistics Malaysia. (2020). Current population estimates, Malaysia, 2020. , Population and Demography.
https://www.dosm.gov.my/v1/index.php?r=column/cthemByCat&cat=155&bul_id=OVByWjg5YkQ3MWFZRTN5bDJiaEVhZz09&menu_id=L0pheU43NWJwRWVVSZklWdzQ4TlhUUT09
- Marto, A., Tan, C. S., Kasim, F., & Mohd Yunus, N. Z. (2013, May). Seismic impact in peninsular Malaysia. In *Proceedings of the 5th International Geotechnical Symposium-*

Incheon, Seoul, Korea.

- Masjuki, S. A. (2017). Assessment and retrofitting of reinforced concrete buildings with shear walls subject to earthquake loading.
- Megawati, K., Pan, T. C., & Koketsu, K. (2005). *Response spectral attenuation relationships for Sumatran-subduction earthquakes and the seismic hazard implications to Singapore and Kuala Lumpur*.
- Memon, S. A., Zain, M., Zhang, D., Rehman, S. K. U., Usman, M., & Lee, D. (2020). Emerging trends in the growth of structural systems for tall buildings. *Journal of Structural Integrity and Maintenance*, 5(3), 155-170.
- Mokhafaf. (2018). *What is EMS?* <https://www.mokhafaf.com/en/units/4892-EMS.html>
- National Geographic. (2020). *Earthquake*. <https://kids.nationalgeographic.com/science/article/earthquake>
- Ngu, K. (2005). Earthquake Hazard and Basic Concept of Seismic Resistant Design of Structure. *Earthquake Hazard and Basic Concept of Seismic Resistant Design of Structure. Master Builders 4th Quarter*, 90-95.
- Nizamani, Z., Seng, S. K., Nakayama, A., Khan, M. S. B. O., & Bilal, H. (2018). Seismic Effects on a Horizontally Unsymmetrical Building using Response Spectrum Analysis. *MATEC Web of Conferences*, 203, 0–8. <https://doi.org/10.1051/mateconf/201820306014>
- Noorliza Lat, C. H. E., & Ibrahim, A. T. (2009). Bukit tinggi earthquakes: November 2007 - January 2008. *Bulletin of the Geological Society of Malaysia*, 55(55), 81–86. <https://doi.org/10.7186/bgsm55200913>
- Adiyanto, M. I., Majid, T. A., & Nazri, F. M. (2017, July). Nonstructural damages of reinforced concrete buildings due to 2015 Ranau earthquake. In AIP Conference Proceedings (Vol. 1865, No. 1, p. 090002). AIP Publishing LLC.
- Petersen, M. D., Dewey, J., Hartzell, S., Mueller, C., Harmsen, S., Frankel, A. D., & Rukstales, K. (2004). Probabilistic seismic hazard analysis for Sumatra, Indonesia and across the Southern Malaysian Peninsula. *Tectonophysics*, 390(1–4), 141–158. <https://doi.org/10.1016/j.tecto.2004.03.026>
- Pindexter, G. (2016). *Earthquake in Malaysia near 165-MW Sultan Mahmud hydroelectric facility*. <https://www.hydroreview.com/world-regions/earthquake-in-malaysia-near-165-mw-sultan-mahmud-hydroelectric-facility/#gref>
- Raheem, S. E. A. (2013). *Evaluation of Egyptian code provisions for seismic design of moment-resisting-frame multi-story buildings*. 1–18.
- Razak, J., Rambat, S., Che Ros, F., Shi, Z., & Mazlan, S. (2021). Seismic vulnerability assessment in Ranau, Sabah, using two different models. *Int. J. Geo-Inf*, 10, 1-25.
- Redzuan, M., & Abdul, B. (2012). *Analysis of Existing High-Rise Reinforced Concrete Structures in Malaysia Subjected to Earthquake and Wind Loadings by Dissertation submitted in partial fulfilment of The requirement for the Bachelor of Engineering (Hons) (Civil Engineering) SEPT 2012. 12027*.

- Roslan, H. A., Adiyanto, M. I., Harith, N. S. H., Faisal, A., & Razak, S. M. S. A. (2021). Impact of seismic design on cost of structural materials for two storey hostel building in Sabah. *IOP Conference Series: Earth and Environmental Science*, 682(1). <https://doi.org/10.1088/1755-1315/682/1/012024>
- Roumelioti, Z., Hollender, F., & Guéguen, P. (2020). Rainfall-induced variation of seismic waves velocity in soil and implications for soil response: What the argonet (cephalonia, Greece) vertical array data reveal. *Bulletin of the Seismological Society of America*, 110(2), 441–451. <https://doi.org/10.1785/0120190183>
- Rozaina, I., Azmi, I., & Norhazlila, R. (2017). Vulnerability study of public buildings subjected to earthquake event. In *MATEC Web of Conferences* (Vol. 103, p. 02023). EDP Sciences.
- Sato, H., & Fehler, M. C. (2009). Seismic Wave Propagation and Scattering in the Heterogeneous Earth. In *Seismic Wave Propagation and Scattering in the Heterogeneous Earth*. <https://doi.org/10.1007/978-3-540-89623-4>
- Standard, M. (1998). Malaysia national annex to eurocode 8: design of structures for earthquake resistance-part 1: general rules, seismic action and rules for buildings. MS EN, 1, 2015.
- Su, R. K. L., Looi, T. W., Tang, O., & Law, C. W. (2014). AnnualSeminar_proceeding_Part3_Paper7_RaySU_R3. *Performance Based Seismic Design for Tall Buildings in Hong Kong*. In *Proceedings of Advances in Seismic Engineering: Joint Structural Division Annual Seminar 2014*.
- Surana, M., Singh, Y., & Lang, D. H. (2018). Effect of strong-column weak-beam design provision on the seismic fragility of RC frame buildings. *International Journal of Advanced Structural Engineering*, 10(2), 131–141. <https://doi.org/10.1007/s40091-018-0187-z>
- Szolomicki, J., & Golasz-Szolomicka, H. (2019). Technological advances and trends in modern high-rise buildings. *Buildings*, 9(9). <https://doi.org/10.3390/buildings9090193>
- Taranath, B. S. (2016). Earthquake Effects on Buildings. In *Tall Building Design* (pp. 69–221). CRC Press. <https://doi.org/10.1201/9781315374468-4>
- Tromp, J. (2020). Seismic wavefield imaging of Earth's interior across scales. *Nature Reviews Earth and Environment*, 1(1), 40–53. <https://doi.org/10.1038/s43017-019-0003-8>
- Weijie Loi, D., Eshwaraiyah Raghunandan, M., & Swamy, V. (2018). Revisiting seismic hazard assessment for Peninsular Malaysia using deterministic and probabilistic approaches. *Natural Hazards and Earth System Sciences*, 18(9), 2387–2408. <https://doi.org/10.5194/nhess-18-2387-2018>
- William Spence, Stuart A. Sipkin, and G. L. C. (1989). *Determining the Depth of an Earthquake*. Earthquakes and Volcanoes. <https://www.usgs.gov/programs/earthquake-hazards/determining-depth-earthquake>
- Zhu, H., Sun, Y., Zhao, W., Zhuang, F., Wang, B., & Xiong, H. (2020). Rapid Learning of Earthquake Felt Area and Intensity Distribution with Real-time Search Engine Queries. *Scientific Reports*, 10(1), 1–9. <https://doi.org/10.1038/s41598-020-62114-8>