SEISMIC PERFORMANCE
OF HIGH-RISE BUILDING
UNDER DIFFERENT EXCITATION

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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.

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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.

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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 pengujaan 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 pengujaan 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 sebentuk 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, pengujaan 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.

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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
$C_{p,e}$	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
$M_{z,cat}$	Terrain or height multiplier
M_h	Hill shape multiplier
M_s	Shielding multiplier
T_1	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_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_o	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
$\nu_{s,30}$	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
ν_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

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