SEISMIC FRAGILITY OF CONCRETE BUILDING IN MALAYSIA CONSIDERING THE EFFECTS OF INADEQUATE LAP SPLICE LENGTH

MAHESAN BAVAN

A project report submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Structure)

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JULY 2020

ACKNOWLEDGEMENT

First of all, I would like to express my greatest gratitude to my supervisors, DR. Mohammadreza Vafaei and DR. Sophia C. Alih. Their kind guidance, patience, and valuable suggestions and advices have been a great help to me throughout the preparation and completion of this project as well as my dissertation writing.

In addition, deepest appreciation is expressed to my parents, families and friends because of their warmest support and encouragement all the time. Lastly, would like to thank those who had contributed, either directly or indirectly, for the completion and success of this study.

ABSTRACT

The tremors due to Sumatra earthquake have been reported recently with low to moderate seismic activity level, which have been causing fear to people who are in Peninsula Malaysia. Those, that the new structure should be built or partially built with retrofitting of the existing structure, are the major questions to design globe, which lead essential seismic hazard assessment is necessary to ground motion scenarios due to potential earthquakes. A gap in the previous studies was identified that the inadequate lap splice length in column may give higher probability of exceedance in the seismic design. Accordingly, the seismic fragility curve development is useful in contributing further insight to the continuing evolution of low ductile reinforced concrete frame subjected to far field ground motions with studying the effects of inadequate lap splice length. Three models such as three-, six- and nine- storeys, in low ductile bare reinforced concrete frames developed through ETABS, were included in this study. In order to develop the adequate lap splice lengths to RC frame in ETABS, the P-M2-M3 hinges were assigned to all joints in column with "controlled" dynamic lap splice lengths under column behaviour while all hinges in beam and columns were developed with the behaviours based on American Society of Civil Engineers, ASCE 41-13, standard of seismic evaluation and retrofit of existing buildings. Subsequently, all RC frame models were subjected to analyses such as static pushover, push over with first mode and push over with dynamic mode, the observation of the plastic hinges formation in terms of the damage levels of IO, LS and CP were predicted, and finally, the maximum storey drifts of each damage level were projected to determine as capacity of RC frame in the development of fragility assessment. In addition, the performance of all models was studied by a series of Incremental Dynamic Collapse Analysis (IDA) by means of incremental of 0.05g until 0.50g, which were subjected to 15 far-field ground motions. Based on maximum storey drifts in each analysis from IDA, the median, standard deviation and standard error corresponding to Peak Ground Acceleration (PGA) value were attained as demand of the fragility assessment. Finally, according to the predicted capacity and demand, the fragility curves were presented to the frames of 3-storey, 6-storey and 9-storey with column behaviour consisted of controlling inadequate development or splicing subjected to far-field earthquake excitations. By providing adequate lap splice lengths in columns, the push over analysis showed that there were no damages in columns near foundation while the columns near foundation showed the damage levels of IO, LS and CP when they do have inadequate lap splice lengths. In capacity assessment by push over analysis, maximum storey drifts in all cases were increased by providing adequate lap splice lengths, which this trend brought to be stated that the columns were improved in strength to bear horizontal loads against horizontal displacement. Also, based on the observation of plastic hinge formations at all levels, the damage levels were postponed by providing adequate lap splice lengths to columns and this is a very convenient representation to avoid column failure and postpone the damaged states. Based on the predicted maximum storey drifts from IDA, the storey drifts were lower in all cases due to providing adequate lap splice lengths to columns, which this study brought that the parameter of inadequate lap splice length will be super imposition parameter in controlling the drifts and avoiding structural damages. Developed fragility curves can be a statistical tool in representing the probability of exceeding against PGA and for estimating a specific damage measure in design practice.

ABSTRAK

Gegaran akibat gempa di Sumatera yang dilaporkan baru-baru ini dengan tahap aktiviti seismik berintensiti rendah hingga sederhana, telah menimbulkan ketakutan kepada orang-orang yang berada di Semenanjung Malaysia. Maka timbul keperluan untuk struktur baru di reka dengan beban gempa dan struktur lama di ubah suai untuk meningkatkan daya tahan terhadap gempa bumi. Kekangan dalam kajian terdahulu dikenal pasti bahawa panjang sambungan putaran yang tidak mencukupi dalam lajur dapat memberikan risiko lebih tinggi dalam reka bentuk seismik. Oleh yang demikian, pengembangan lengkung kerapuhan seismik berguna dalam memberikan gambaran lebih lanjut mengenai evolusi berterusan kerangka konkrit bertetulang mulur rendah yang dikenakan gerakan tanah jarak jauh dengan mengkaji kesan panjang sambungan putaran yang tidak mencukupi. Tiga model bangunan; tiga-, enam- dan sembilan tingkat, dalam kerangka konkrit bertulang rendah mulur yang dikembangkan melalui ETABS, dianalisa dalam kajian ini. Untuk mengembangkan panjang penyambungan putaran yang mencukupi ke bingkai RC di ETABS, engsel P-M2-M3 ditugaskan ke semua sendi dalam lajur dengan panjang sambungan putaran dinamik "terkawal" di bawah tingkah laku lajur sementara. Semua engsel pada rasuk dan lajur dikembangkan dengan tingkah laku berdasarkan American Society of Civil Engineers, ASCE 41-13, standard penilaian seismik dan retrofit bangunan yang ada. Selanjutnya, semua model bingkai RC di analisis menggunakan pushover statik, dengan mode pertama dan push over dengan mode dinamik, pemerhatian pembentukan engsel plastik dari segi tahap kerosakan IO, LS dan CP diramalkan, dan akhirnya, drift tingkat maksimum setiap tahap kerosakan di analisis untuk menentukan kapasiti kerangka RC dalam pengembangan penilaian kerapuhan. Di samping itu, prestasi semua model dikaji oleh satu siri Analisis Keruntuhan Dinamik Peningkatan (IDA) dengan kenaikan 0,05g hingga 0,50g, yang dikenakan 15 gerakan tanah dari jarak jauh. Berdasarkan drift tingkat maksimum dalam setiap analisis dari IDA, median, sisihan piawai dan ralat piawai yang sepadan dengan nilai Puncak Tanah Puncak (PGA) dicapai sebagai permintaan penilaian kerapuhan. Akhirnya, mengikut kapasiti dan permintaan yang diramalkan, lengkung kerapuhan ditunjukkan pada kerangka 3 tingkat, 6 tingkat dan 9 tingkat dengan tingkah laku lajur yang terdiri daripada mengawal pembangunan atau penyambungan yang tidak mencukupi dan terkena rangsangan gempa di medan jauh. Dengan memberikan panjang penyambungan putaran yang mencukupi pada lajur, analisis push over menunjukkan bahawa tidak ada kerosakan pada lajur berhampiran landasan sementara lajur di dekat landasan menunjukkan tahap kerosakan IO, LS dan CP ketika mereka mempunyai panjang sambungan putaran yang tidak mencukupi. Dalam penilaian kapasiti dengan analisis push over, drift tingkat maksimum dalam semua kes dinaikkan dengan memberikan panjang sambaran putaran yang mencukupi, yang ditunjukkan oleh trend ini bahawa tiang ditingkatkan kekuatannya untuk menanggung beban mendatar terhadap anjakan mendatar. Juga, berdasarkan pengamatan formasi engsel plastik di semua peringkat, tahap kerosakan ditangguhkan dengan memberikan panjang sambungan putaran yang mencukupi ke lajur dan ini adalah perwakilan yang sangat sesuai untuk mengelakkan kegagalan lajur dan menangguhkan keadaan yang rosak. Berdasarkan drift tingkat maksimum yang diramalkan dari IDA, drift tingkat lebih rendah dalam semua kes kerana memberikan panjang sambungan putaran yang mencukupi ke lajur, yang mana kajian ini membawa parameter panjang sambungan putaran yang tidak mencukupi akan menjadi parameter pengenaan super dalam mengawal drift dan mengelakkan kerosakan struktur. Keluk kerapuhan yang dikembangkan dapat menjadi alat statistik untuk mewakili kebarangkalian melampaui PGA dan untuk mengira ukuran kerosakan tertentu dalam reka bentuk.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CP	-	Collapse Prevention
EC2	-	Eurocode 2
EC8	-	Eurocode 8
FE	-	Finite Element
IDA	-	Incremental Dynamic Analysis
IBS	-	International Building Standard
LS	-	Life Safety
RC	-	Reinforced Concrete
IO	-	Immediate Occupancy
UTM	-	Universiti Teknologi Malaysia
PGA	-	Peak Ground Acceleration
3D	-	Three dimensional
2D	-	Two dimensional
P-Wave	-	Primary Wave
S-Wave	-	Secondary Wave

LIST OF SYMBOLS

D	-	Damage
Φ	-	Standard normal cumulative distribution
μ	-	Mean
σ	-	Standard deviation of natural logarithm of PGA
fck	-	Characteristics strength of conc ete
fyk	-	Characteristics strength of steel
Ecm	-	Concrete Young Modulus
Es	-	Steel Young Modulus
SE2	-	Standard error of demand drift
DS	-	Damage state
SI	-	Seismic intensity
Φ	-	Standard normal distribution
λc	-	Natural logarithm of the median of drift capacities for particular damage state
λD/SI	-	Natural logarithm of the median demand drift given the seismic intensity from the best fit power law
βcβm	-	Uncertainties related to capacity and modelling ≈0.3 (Mwafy, 2012).

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Past case histories are giving diverse information apart from the common belief in Malaysia that Peninsular Malaysia is under seismic free zone, there are drastic changes that there is a growing trend in earthquake engineering studies due to the seismic impact in Peninsular Malaysia. There are considerable earthquakes recently in Peninsular Malaysia, which were originated from the Sumatra Subduction Zone and the Sumatra Transform Zone. Seismic vulnerability evaluation of existing buildings considering the effect of inadequate lap splice length is dealt in this study using fragility graph to provide improved prediction of damaged structure in Malaysia and also the study was extended considering physical damage, loss of life and the economic impact of future seismic events with application of adequate retrofitting solutions. There are different approaches in the development of the fragility graph such as empirical, judgemental, analytical and hybrid method (Tan, et al., 2014). Fragility graphs in the probability of exceeding a certain level of damage for a various range of ground motions intensities were included in prediction such that the analytical approaches were used in this study, which can be applicable to different structural types such as to analyse existing buildings, essential facilities, and lifelines structures and geographical area where damage records are inadequate.

The probability of exceeding a given performance and damage state can be predicted well by fragility graph, which is a statistical implement representation, based on a function with engineering parameters, which the parameters will be represented the ground motion correspondingly preferable spectral displacement at a given each frequency. In addition, this tool of fragility graph can be a useful tool to estimate the entire risk of structural components or whole structure in terms of predicting the economic impact of earthquake occurred or potential future earthquakes. Likewise, the fragility graphs can be useful to study using a maximum likelihood method in determination of damage probabilities correspondingly to a specific damage level with a parameter of different inundation heights (Foytong, et al., 2016). Another importance of fragility graph is determination of emergency response and damage planning that can be evaluated for the necessity of national authority and insurance companies to estimate the overall damage loss after earthquake strike (Papailia, 2011). In addition, by estimating costs and benefit of the studies for a structural scheme, retrofitting schemes can be determined for continuous structural use. Further, another aspect of fragility graph also benefits in the determination of damages, estimation to avoid such damages and amending the established seismic codes on designing new buildings, which will mitigate the additional cost to cater the requirements of structural components for the seismic resistance in designing the structure at design stage.

In this study, the seismic fragility of concrete buildings in Malaysia considering the effects of inadequate lap splice length was presented by considering the parameters of low, mid- and high-rise buildings included with low ductile bare RC frame. In order to develop the frame models, while IBS code was used to design the frames, finite element software ETABS was used for developing various categorised frames three, six, and nine storey frame structures. With consideration categories of far fault earthquake, including scaling of increasing the peak ground acceleration, Incremental dynamic analysis (IDA) was conducted under 45 sets of ground motion. In terms of seismic design, three levels of performance such as immediate occupancy (IO), life safety (LS) and collapse prevention (CP) were also studied for prediction of structural performance. Finally, seismic fragility graphs were developed for structural models with parameters of different seismic motion under far fault regions to study the influence of the effects of inadequate lap splice length.

Malaysia Peninsula is considered seismically stable by means of a certain modern history of volcanic activity, which those are being located on the Sunda tectonic plate, between two main boundaries of the Australian plate and Eurasian plate in the west of Malaysia, and the Philippine Sea Plate and Eurasian Plate at Bornean Malaysia. In addition, the Sabah earthquake is notable, which will be strongest in affecting Malaysia from the year of 1976, and the Sabah earthquake in 2015 was in struck whole Ranau, Sabah, Malaysia with a moment magnitude of 6.0. The western coast of Peninsular Malaysia was basically isolated by the Sumatran island by the influences of waves, which generated because of earthquake. The deflected tsunami waves had created damages and casualties along the north-western coast of Peninsular Malaysia such as coastal Perlis, Kedah, Penang and Perak. These disasters also can be highlighted the risk of upcoming tsunamis that may be damaged the coasts line of undersea faults, which will be around the South China Sea.

1.2 Problem Statement

Aminaton *et al.* (2013) have presented about seismic impact in peninsular Malaysia considering earthquakes, which affected Peninsular Malaysia. They noted that earthquakes originated from Sumatra, particularly from the Sumatra Subduction Zone and the Sumatra Transform Zone are acting with reactivation of ancient, inactive faults within Peninsular Malaysia, which must be taken into consideration especially after the initiation of the local originating earthquake. Daniel *et al*. (2018) investigated on revisiting seismic hazard assessment for Peninsular Malaysia using deterministic and probabilistic approaches and they concluded that the central western cities of Peninsular Malaysia are most vulnerable to high peak ground acceleration, due to neighbouring active Sumatran sources such as Sumatran fault zone and Sumatran subduction zone. However, the current design practice in Malaysia is commonly while gravity and wind loads are adopted, but, seismic loads are not being considered. Even the recent earthquake record shows that the structures in Malaysia are affected by a number of near and far field earthquakes, existing code of practices in Malaysia does not cover the design of vulnerability of existing structures in Malaysia due to not being designed for seismic forces. The common practice is existed in a good loss model, which can be given a total damage and thus, the optimum cost and economical design for the retrofitting can be determined. In terms of this, the seismic fragility graphs were described for RC buildings and bridges in Thessaloniki by Tsionis *et al*. (2014) for using in the systemic seismic vulnerability and risk analysis of the urban area. Their fragility graphs have revealed that buildings may affect to minor damage for the design of earthquake and that there is a safety margin before severe damage appears.

Tan *et al*. (2018) focused on seismic probability assessment of RC buildings, which have been designed for gravity loads and they developed fragility graphs for a 3-storey RC building categorised as office frame building and a 4-storey RC building categorised as school building included with unreinforced masonry infill walls typically adopted in Malaysian Peninsula. Their fragility assessment shows that the seismic performance of the structures they studied can be met the necessary performance level recommended by the existing seismic codes, and also, they showed that they were with low vulnerability of the structures in Malaysian Peninsula. Vfaei *et al*. (2016) investigated the low-ductile moment resisting frames subjected to far field earthquake excitations and they discussed that seismic excitation effects are not considered in the designing of most of current Malaysian's structures. They were determined that that the vulnerability of the typical RC is soft-storey phenomenon and clarified that seismic retrofit for such structures is necessary. Fazilan *et al*. (2018) has illustrated on seismic fragility of low ductile RC frame in Malaysia. They presented seismic fragility graphs from a set of earthquake record, in terms of assessing the vulnerability of low-ductile RC frame subjected to earthquake loads. The results further brought that earthquake records consisted of low PGA/PGV ratios, which can be represented far-field earthquakes, trend to induce the highest level of damage to the low ductile RC frames. Further, their analysis showed that three and 9-stories RC frames, which had been constructed in the East Malaysia, had not satisfied the collapse requirements states, which should be necessary for retrofitting. Nazri *el al*. (2019) examined the structural pounding, in terms of probabilistic estimation, on adjacent structural buildings subjected to repeated seismic excitations. They developed fragility graphs in terms of different performance levels to represent the capacity of the adjacent structural buildings. In addition, they found that the damage occurred in irregular frames was concentrated on top and bottom storey beams and also in ground floor columns. They have suggested in terms of moderate seismic events that their findings were valuable and those should be included in the seismic codes in terms of reducing damage in adjacent structural buildings during.

Based on the recent literatures, there are limited researches in fragility graph development for bare RC frame in Malaysia, studied with limited parameters, and previous studies on seismic fragility graphs for RC frames have not been considered the effect of inadequate lap splice length. However, columns with inadequate lap-splice length show significant lower deformation capacity and this can increase the probability of damage to RC frames. Accordingly, there is a gap found form the existing literatures and it is important to carry out this study on seismic fragility graphs to study the effects of inadequate lap splice length.

1.3 Research Objectives

The research study carried out in this thesis is to analyse and study the issues discussed in problem statement so as to understand the further on those issues. The main objectives and contributions to be derived from this thesis are outlined as follows:

(a) To investigate the failure mechanism of bare low ductile RC frame subjected to far field ground motions.

(b) To evaluate inter-story drift demand and capacity of bare low ductile RC frame subjected to far field ground motions.

(c) To develop seismic fragility graphs for the effects on inadequate lap splice length.

1.4 Research Scope

In order to investigate the designed objectives, the scopes of the study are extended, which is as follows:

(1) Development of the nonlinear finite element model using ETABS for Low ductile bare RC frames with three types of structural frames, such as three, six and nine-storey frames in order to represent typical buildings in Malaysia, considering that four 6m bays and 3m storey height except the base height which is 4m.

(2) Development of the material models such that the compressive strength of concrete 20MPa, and yield and ultimate stress of the reinforcement steel bar 300 N/mm2 and 420 N/mm2, respectively.

(3) Design of frames with dead load of 31.08kNm and live load of 12kNm using code of EC2.

(4) Conduction of parametric studies based on incremental dynamic collapse analysis (IDA) using software ETABS2015 to all frames subjected to 15 far field sets of ground motion records.

(5) Three performance levels inclusive of immediate occupancy (IO), life safety (LS) and collapse prevention (CP) will be used for the derivation of seismic fragility graphs.

REFERENCES

Abas, M. R. C., (2001). *Earthquake Monitoring in Malaysia*, Petaling Jaya Selangor: Seismological Division Malaysian Meteorological Service.

Adhikari, R., & Gautam, D. (2019). Component level seismic fragility functions and damage probability matrices for Nepali school buildings. *Soil Dynamics and Earthquake Engineering*, pp. 316-319.

Adnan, A. & Suradi, S., (2008). Comparison on the effect of earthquake and winds loads on the perfomance on reinforced concrete buildings. Beijing , China.

Adnan, A., Hendriyawan, Marto, A. & Irsyam, M., (2005). Seismic Hazard Assessment for Peninsular Malaysia using Gumbel Distribution Method. *Jurnal Teknologi*, 42(B), pp. 57-73.

Amadio, C., Bedon, C., & Fasan, M., (2017). Numerical assessment of slab-interaction effects on the behaviour of steel-concrete composite joints. *Journal of Construction Steel Research*, pp. 397-410.

American Society of Civil Engineers (ASCE) 2013 ASCE/SEI 41-13, Seismic Evaluation And Retrofit of Existing Buildings (Virginia, USA: American Society of Civil Engineering.

Aminaton, M., Tan, C. S., Fauzia, K. and Zurairahetty, M. Y. P. (2013). Seismic impact in Peninsular Malaysia, Proc. 5th International Geotechnical Symposium-Incheon.

Anon., (2013). *Manual for design and detailing of reinforced concrete to the code of practice for structural use of concrete 2013.* [Online] Available at: file:///C:/Users/welcome/Downloads/DUCTILITY%20REQUIREMENTS%20FOR%20BUILDINGS%20(1).pdf

Anon., 2010-2016. *Soft Story Retrofit Program.* [Online] Available at: http://www.ladbs.org/services/core-services/plan-check-permit/plan-check-permit-special-assistance/mandatory-retrofit-programs/soft-story-retrofit-program

Asamoah M. A, Osei J, B, Asamoah A, Osei, (2018), A comparative seismic fragility analysis of a multi and single component beam-column joint models Cogent Engineering.

Attari, N., Youcef, Y. S., & Amziane, S. (2019). Seismic performance of reinforced concrete beam–column joint strengthening by FRP sheets. *Journal of Structures*, pp. 353-364.

Bakhshi, & Asadi, P. (2013). Probabilistic Evaluation of Seismic Desig Paramaters of RC Frames based on Fragility Curves. Scientia Iranica, pp. 231-241.

Barkhordary, M., & Tariverdilo, S. (2011), Vulnerability of ordinary moment resistant concrete frames, Earthquake Engineering and Engineering Vibration.

Bezerra, L. M., Wallison, C.S., Bonilla, B. J., & Cavalcante, O. R. (2018). Truss-type shear connector for composite steel-concrete beams. *Journal of Construction and Building Materials*, pp. 757-767.

Booth, E. & Key, D., (2008). *Earthquake design practice for buildings.* 2nd ed. s.l.:Thomas Telford Publising.

Borjigin, S., Kim, C. W., Chang, K. C. & Sugiura, K. (2018). Nonlinear dynamic response analysis of vehicle–bridge interactive system under strong earthquakes. *Engineering Structures*, pp. 500-521.

Bovo, M., & Buratti, N. (2019). Evaluation of the variability contribution due to epistemic uncertainty on constitutive models in the definition of fragility curves of RC frames. *Journal of Engineering Structures*, pp. 700-716.

British Standard Institution (BSI) 1997 BS 8110-1: Structural Use of Concrete – Part 1: Code of Practice for Design and Construction, British Standard.

Calvi, G. M. (2006). Development of Seismic Vulnerability Assessment Methodologies over the past 30 years. *Earthquake Technology*, 43(3), pp. 75-104.

Cao, X. Y., Feng, D. C., & Wu, G. (2019). Seismic performance upgrade of RC frame buildings using precast boltconnected steel-plate reinforced concrete frame-braces. *Engineering Structures*, pp. 382-399.

Caruso, C., Bento, R., & Castro, J. R., (2019). A contribution to the seismic performance and loss assessment of old RC wall-frame buildings. *Journal of Engineering Structures* (197). Pp 1 -14.

Chiorean, C. G., & Buru, S. M., (2017). Practical nonlinear inelastic analysis method of composite steel-concrete beams with partial composite action. *Journal of Engineering Structures*, pp. 74-106.

Choua, C. C. & Wu, S. C. (2019). Cyclic lateral load test and finite element analysis of high-strength concretefilled steel box columns under high axial compression. *Journal of Engineering Structures*, pp. 89-99.

Choudhury, T., & Kaushik, H. B., (2019). Treatment of uncertainties in seismic fragility assessment of RC frames with masonry infill walls. *Soil Dynamics and Earthquake Engineering*.

Corigliano, M., Scandella, L., Lai, C. & Paolucci, R., (2011). Seismic Analysis of Deep Tunnel in near fault conditions: a case study in Southern Italy. *Bull Earthuake Engineering.*

CSI Analysis Reference Manual, Computers and Structures, 2020.

Dahlgren, A. & Svensson, L., (2013). *Guidelines and rules for detailing of reinforcement in concrete structures,* Sweden: s.n.

Daniel, W. L., Mavinakere, E. R. and Varghese, S. J. (2018). Revisiting seismic hazard assessment for Peninsular Malaysia using deterministic and probabilistic approaches. J. Nat. Hazards Earth Syst. Sci.18, pp 2387–2408.

Davoodi, M., Sadjadi, M., Goljahani P., & Kamalian, M. (2012). *Effect of Near-Field and Far-Field Earthquakes on Seismic Response of SDOF System Considering Soil Structures Interaction.* Lisbon ,Portugal, s.n.

Deng, K., Wang, T., Kurata, M., Zhao, C., & Wang, K. (2018). Numerical study on a fully-prefabricated damage-tolerant beam to column connection for an earthquake-resilient frame. *Journal of Engineering Structures*, pp. 320-331.

Deng, W., Xiong, Y., Liu, D. & Zhang, J. (2019). Static and fatigue behavior of shear connectors for a steel-concrete composite girder. *Journal of Constructional Steel Research*, pp. 134-146.

Ding, F., Yina, G., Jiang, L., & Baib, Y. (2018). Composite frame of circular CFST column to steel-concrete composite beam under lateral cyclic loading. *Journal of Thin-Walled Structures*, pp. 137-146.

Dohare, D. & Maru, D., (2014). Seismic Behavior of Soft Storey Building : A Critical Review. *International Journal of Engineering Research and General Science* , pp. 35-39.

Elmy, M. H., & Nakamura, S. (2017). Static and seismic behaviours of innovative hybrid steel reinforced concrete bridge. *Journal of Constructional Steel Research*, pp. 701-713.

EN 1998-1. Eurocode 8, Design of Structures for Earthquake Resistance. Part 1.3: General Rules-Specific Rules for Various Materials and Elements. Brussels: Commission of the European Communities; 2005.

Faisala, A., Majid, T. A., and Hatzigeorgiouc, G. D., (2013). 'Investigation of story ductility demands of inelastic concrete frames subjected to repeated earthquake'. *Journal of Soil Dynamics and Earthquake Engineering,* pp. 42-53.

Faleschini, F., Zanini, M., A., & Toska, K., (2019). Seismic reliability assessment of code-conforming reinforced concrete buildings made with electric arc furnace slag aggregates. *Journal of Engineering Structures*, pp. 324-339.

Fattahi, F. & Gholizadeh, S., (2019). Seismic fragility assessment of optimally designed steel moment frames. *Journal of Engineering Structures,* pp. 37-51.

Fazilan, N. N., Rosman, N. A., Anuar, N. A., & Sophia, S. C. J. (2018). Seismic fragility of low ductile reinforced concrete frame in Malaysia. *International Journal of Civil Engineering and Technology* 9(4). Pp 1559-1571.

Foti, D., (2015). Local Ground effects in near-field and far-field areas on seismically protected buildings. *Soil Dynamics and Earthquake Engineeing,* pp. 14-24.

Foytong, P., & Ornthammarath, T. (2019). Empirical seismic fragility functions based on field survey data after the 5 May 2014 Mae Lao (Northern Thailand) earthquake. *International Journal of Disaster Risk Reduction*.

Frigui, F., Faye, J. P, Martin, C., Dalverny, O, Peres, F, & Judenherc, S. (2018). Global methodology for damage detection and localization in civil engineering structures. *Journal of Engineering Structures*, pp. 686-695.

Gholizad, A., & Safari, H,. (2014). Seismic fragility curves for mid-rise rc frames designed according to Iranian seismic code. *Asian Journal of Civil Engineering (BHRC),* pp. 803-815.

Goksu, C., Yilmaz, H., Chowdhury, S. R., Orakcal, K., & Ilki, A. (2016), The Effect of Lap Splice Length on the Cyclic Lateral Load Behavior of RC Members with Low-Strength Concrete and Plain Bars, Advances in Structural Engineering.

Guo, L., Wang, Y., & Zhang, S. (2018). Experimental study of rectangular multi-partition steel-concrete composite shear walls. *Journal of Thin-Walled Structures,* pp. 577-592.

Hajimehrabi, H., Behnamfar, F., Samani, A. B., & Goudarzi, M. A., (2019). Fragility curves for baffled concrete cylindrical liquid-storage tanks. *Journal of Soil Dynamics and Earthquake Engineering*, pp. 187-195.

Hazus, (1997). *Earhquake loss estimation methodology ,in Technical Manual*, Washington, D.C: National Institute of Building for the Federal Emergency Management Agency.

Heydari, M. & Mousavi, M., (2015). The Comparison of Seismic Effects of Near-Field and Far-Field Earthquake on Relative Displacement of Seven Storey Concrete Building with Shear Wall. *Current World Environment*, pp. 40-46.

Hu, B., Heng-Lin, & Kundu, T. (2019). Experimental study on seismic behavior of reinforced concrete frame in primary and middle schools with different strengthening methods. *Journal of Construction and Building Materials*, pp. 473-486.

Hu, Y. Zhao, J., Zhang, D., & Chen, Y. (2019). Seismic behavior of concrete-filled double-skin steel tube/moment-resisting frames with beam-only-connected precast reinforced concrete shear walls. Archives of Civil and Mechanical Engineering, pp. 967-980.

Jelinek, T., Zania, V. & Giuliani, L. (2017). Post-earthquake fire resistance of steel buildings. *Journal of Constructional Steel Research*, pp. 774-782.

Jiang, Z., Dou, C., Zhang, A., Wang, Q., & Wu, Y. (2019). Experimental study on earthquake-resilient prefabricated cross joints with Lshaped plates. *Engineering Structures*, pp. 74-84.

Juntanalikit, P., Jirawattanasomku, T. & Pimanmasa, A., (2016) Experimental and numerical study of strengthening non-ductile RC columns with and without lap splice by Carbon Fiber Reinforced Polymer (CFRP) jacketing, Engineering Structures V.125, Pp 400-418.

Li, C., Bi K., & Hao, K. (2019). Seismic performances of precast segmental column under bidirectional earthquake motions: Shake table and numerical evaluation. *Journal of Engineering Structures*, pp. 314-328.

Li, S., Yu, X., Zhang, Y. & Zhai, C. (2018). A numerical simulation strategy on occupant evacuation behaviors and casualty prediction in a building during earthquakes. Physica A, pp. 1238-1250.

Liu, K., Yan, J., Alam, M. S. & Zou, C. (2019). Seismic fragility analysis of deteriorating recycled aggregate concrete bridge columns subjected to freeze-thaw cycles. *Journal of Engineering Structures,* pp. 1-15.

Luca, A. D., Mele, E. & Grande, E., Ductile design of CBF steel structures.

Mail, T. M., (2015). *Sabah earthquake : Damage to public assests and infrastructure worth RM9.4m.* [Online] Available at: http://www.themalaymailonline.com/malaysia/article/sabah-earthquake-damages-to-public-assets-and-infrastructure-worth-rm94.8m

Malysia Standard 2017 MS EN 1998-1 Malaysia National Annex to Eurocode 8: Design of Structures for Earthquake Resistant – Part 1: General Rules, Seismic Actions and Rules for Buildings, Department of Standard Malaysia.

Memari, M. & Mahmoud, H. (2018). Framework for a performance-based analysis of fires following earthquakes. *Journal of Engineering Structures,* pp. 794-805.

Minas, S., & Galasso, C. (2019). Accounting for spectral shape in simplified fragility analysis of case-study reinforced concrete frames. *Soil Dynamics and Earthquake Engineering*, pp. 91-103.

Mwafy, A., (2012). Analytically derived fragility relationship for the modern high-rise buildings in the UAE. *The Structural Design of Tall and Special Buildings,* pp. 824-843.

Nagaraju, D., Lakshmaiah, K., & Yadav, B. M., (2016). Seismic Analysis of Multistorey Building with Bare Frame, Bare Frame with Slab Element and Soft Storey at Different Levels of the Building for Seismic Zone II. *International Journal of Research in Engineering and Technology,* pp. 307-312.

Navarro-Gómez, A. & Bonet, J. L., (2019). 'Improving the seismic behaviour of reinforced concrete moment resisting frames by means of SMA bars and ultra-high performance concrete'. *Journal of Engineering Structures* 197, pp 01-20.

Nazri, F. M., Ahmadi, R., Pilakoutas, K., Mulyani, R. & Hajirasouliha, I. (2014) Seismic Vulnerability Assessment of an Industrial Building in Peninsular Malaysia, *5th Brunei International Conference on Engineering and Technology* (BICET 2014), Institution of Engineering and Technology, pp 3.07 (6 .)-3.07 (6 .).

NDTV, 2015. *Last 2 missing in Malaysian Earthquake confirmed dead.* [Online] Available at: http://www.ndtv.com/world-news/last-2-missing-in-malaysian-earthquake-confirmed-dead-770342

Nguyen, N. H., & Whittaker, A. S. (2017). Numerical modelling of steel-plate concrete composite shear walls. *Engineering Structures*, pp. 1-11.

Nie, X., Wang, W., Wang, Y. H., Yu, J., & Hou, C. (2019). Ultimate torsional capacity of steel tube confined reinforced concrete columns. *Journal of Constructional Steel Research*, pp. 207-222.

Pang, Y., Cai, L., Ouyang, H. & Zhou, X. (2019). Seismic performance assessment of different fibers reinforced concrete columns using incremental dynamic analysis. *Construction and Building Materials*, pp. 241-257.

Papailia, (2011). Seismic Fragility Curves for Reinforced Concrete Buildings. *Earthquake Engineering.*

Pavel, F., & Carale, G., (2019). Seismic assessment for typical soft-storey reinforced concrete structures in Bucharest, Romania. *International Journal of Disaster Risk Reduction*.

Peng, S., Xu, C., Lu, M. & Yang, J. (2018). Experimental research and finite element analysis on seismic behavior of CFRP-strengthened seismic-damaged composite steel-concrete frame columns. *Engineering Structures*, pp. 50-60.

Pnevmatikos, N. G., Papagiannopoulos, G. A., & Papavasileiou, G. S., (2019). Fragility curves for mixed concrete/steel frames subjected to seismic excitation. *Soil Dynamics and Earthquake Engineering*, pp. 709-713.

Potty, N. S. & Ahmad Sohaimi, A. F., (2013). Ultimate strength assessment for fixed steel offshore platform. *Malaysian Journal of Civil Engineering*, 25(2), pp. 128-153.

Rave-Arangoa, J., Carlos, A., José, B., Restrepo, I. & Carmonac, F. (2018) Seismic performance of precast concrete column-to-column lap-splice connections, Engineering Structures, V.172, pp 687-699.

Salami, M. R., Kashani, M. M., & Goda, K., (2019). Influence of advanced structural modeling technique, mainshock-aftershock sequences, and ground-motion types on seismic fragility of low-rise RC structures. *Soil Dynamics and Earthquake Engineering*, pp. 263-279.

Samadian, D., Ashtiany, M. G., Naderpour, H., & Eghbali, M. (2019). Seismic resilience evaluation based on vulnerability curves for existing and retrofitted typical RC school buildings. *Journal of Soil Dynamics and Earthquake Engineering*.

Saruddin, S. N. A. & Mohamed Nazri, F., (2015). Fragility curves for low and mid rise buildings in Malaysia. *Procedia Engineering,* pp. 873-878.

SCEEP, (2002). *Locating, Measuring And Predicting Earthquakes.* [Online] Available at: http://scearthquakes.cofc.edu/?page=locatingeqs

Seifi, M., Noorzaei, J., Jaafar, M. S. & Panah, E., (2008). *Nonlinear Static Pushover Analysis in Earthquake Engineering : State of Development.* Kuala Lumpur, s.n., pp. 69-80.

Selna, R., (2008). *S.F leaders ignore weak buildings' quake risk.Classic structures abound - many on unstable ground..* [Online] Available at: http://www.sfgate.com/news/article/S-F-leaders-ignore-weak-buildings-quake-risk-3208142.php

Shah, S. D., (2015). *A simple disclosure norm that can lead to bankruptcy.* [Online] Available at: http://realty.economictimes.indiatimes.com/realty-check/a-simple-disclosure-norm-that-can-lead-to-bankruptcy/670

Singhal, A,. & Kiremidjian, A., (1996). Method for Probabilistic Evaluation of Seismic Structural Damage. *Structural Engineering,* 122(12), pp. 1459-1467.

Suwondo, R., Cunningham, L., Gillie, M. & Bailey, C. (2019). Progressive collapse analysis of composite steel frames subject to fire following earthquake. *Fire Safety Journal*, pp. 49-58.

Suwondo, R., Cunningham, L., Gillie, M., & Bailey, C., (2018). Improving the performance of composite floors subjected to post-earthquake fire. *Fire Safety Journal,* pp. 18-26.

Talebi, E., Korzen, M., & Hothan, S. (2018). The performance of concrete filled steel tube columns under postearthquake fires. *Journal of Constructional Steel Research,* pp. 115-128.

Tan, C.G., Majid, T. A., Ariffin, K. S. & Bunnori, N. M., (2014). The Effect of Site Classification on Incremental Dynamic Analysis for RC Buildings without Seismic Provision in Penang. *Journal of Civil Engineering Research,* pp. 154-158.

Tariverdilo, S., Farjadi, A., & Barkhordary, M. (2009), Fragility curves for reinforced concrete frames with lap-spliced columns.

Times, T. S., (2016). *4.0 Magnitude earthquake hits Malaysia's Mount Kinabalu.* [Online] Available at: http://www.straitstimes.com/asia/se-asia/40-magnitude-earthquake-hits-malaysias-mount-kinabalu

Tomasin, M., Domaneschi, M., Guerini, C., Martinelli, L. & Perotti, F. (2018). A comprehensive approach to small and large-scale effects of earthquake motion variability. *Journal of Computers and Structures*, pp. 155-170.

Tso, W., Zhu, T. & Heidebrecht, A., (1992). Engineering implication of ground motion A/V ratio.. *Soil Dynamics and Earthquake Engineering,* pp. 133-144.

Uy, B., Patel, V., Li, D., & Aslani, F. (2017). Behaviour and Design of Connections for Demountable, *Journal of Steel and Composite Structures*, pp. 1-12.

Vafaei, M., Alih, S. C. and Rahman, Q. A. J (2016), Drift demands of low-ductile moment resistance frames (MRF) under far field earthquake excitations, *J. Jurnal Teknologi* 78, pp 83-92.

Warning, S. T., 2011. *Mercalli Scale*. [Online] Available at: http://www.sms-tsunami-warning.com/pages/mercalli-scale#.WUJZy2iGPIU

Wu, R. Y., & Pantelides, C. P. (2017). Rapid repair and replacement of earthquake-damaged concrete columns using plastic hinge relocation. *Composite Structures,* pp. 467-483.

Xiang, N., & Alam, M. S., (2019). Displacement-based seismic design of bridge bents retrofitted with various bracing devices and their seismic fragility assessment under near-fault and far-field ground motions. *Soil Dynamics and Earthquake Engineering*, pp. 75-90.

Xu, C. Z., Peng, S., Deng, J., & Wan, C., (2018). Study on seismic behavior of encased steel jacket-strengthened earthquakedamaged composite steel-concrete columns. *Journal of Building Engineering*, pp. 154-166.

Xu, T., Zheng, D., Yang, C., & Deng, K. (2018). Seismic performance evaluation of damage tolerant steel frame with composite steel-UHPC joint. Journal of Constructional Steel Research, pp. 457-468.

Zhang, A., Wang, Q., Jianga, Z., Yang, X. F., & Zhang, H., (2019). Experimental study of earthquake-resilient prefabricated steel beam-column joints with different connection forms. *Journal of Engineering Structures*, pp. 299-313.