SEISMIC ANALYSIS OF TRANSMISSION TOWER UNDER LOW TO MODERATE EARTHQUAKE LOADING

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

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JANUARY 2019

DEDICATION

This project report is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

ACKNOWLEDGEMENT

In preparing this project report, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Professor Dr. Azlan Adnan, for encouragement, guidance, critics and friendship. I am also very thankful to my co-supervisor Lecturer Mr. Mohd Zamri Ramli for their guidance, advices and motivation. Without their continued support and interest, this project report would not have been the same as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) for funding my Master study. Librarians at UTM, Cardiff University of Wales and the National University of Singapore also deserve special thanks for their assistance in supplying the relevant literatures.

My fellow postgraduate student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member.

ABSTRACT

In Malaysia, even though the country can be considered as a low seismic area, the structural safety under seismic load has not been studied. Therefore, seismic vulnerability assessment is needed to be performed, especially for the towers. The objectives of this study are to investigate the capacity of tower members, failure mode, determine seismic capacity, and to derive seismic fragility curve for towers in Malaysia when subjected to far-field earthquake. The numerical models of three different heights towers were established in non-linear FE software, namely SAP2000. Equivalent static and response spectrum analysis, Pushover analysis and time history analysis were performed to determine the capacity of the towers members, capacity and fragility of towers, respectively. Totally, 6 far-field earthquake records, which were scaled from 0.05g up to 0.6g, were used in an incremental dynamic analysis in order to obtain fragility curves. Result from this study revealed that plastic hinge formation occurred near the tower base. Capacity curve was proved that the capacity of the studied tower decreases when the height of tower increases, as the length of tower member increases. The result of fragility curves showed that the most vulnerable tower due to far-field earthquake was tower with tallest (63.33m) height, and the probability of damage has significantly increased for the peak ground acceleration (PGA) larger than 0.2g.

ABSTRAK

Di Malaysia, walaupun negara boleh dianggap sebagai kawasan seismik yang rendah, keselamatan struktur di bawah beban seismik tidak dipelajari. Oleh itu, penilaian kelemahan seismik diperlukan, terutamanya untuk menara. Objektif kajian ini adalah untuk menyiasat keupayaan menara, mod kegagalan, menentukan kapasiti seismik, dan memperoleh keluk kerapuhan seismik untuk menara di Malaysia apabila tertakluk kepada gempa bumi yang jauh. Model-model berangka dari tiga menara menara yang berbeza telah ditubuhkan dalam perisian FE linier, iaitu SAP2000. Analisis spektrum statik dan respon yang sama, analisis Pushover dan analisis sejarah masa telah dilakukan untuk menentukan kapasiti anggota menara, kapasiti dan kerapuhan menara, masing-masing. Secara amnya, 6 rekod gempa bumi yang jauh, yang berkisar dari 0.05g hingga 0.6g, digunakan dalam analisis dinamik incremental untuk mendapatkan keluk kerapuhan. Hasil daripada kajian ini menunjukkan bahawa pembentukan engsel plastik berlaku berhampiran pangkalan menara. Kurva kapasiti terbukti bahawa keupayaan menara yang dikaji berkurangan apabila ketinggian menara bertambah, karena panjang menara meningkat. Hasil kurva kerapuhan menunjukkan bahawa menara yang paling terdedah akibat gempa bumi jauh menara dengan ketinggian tertinggi (63.33m), dan kebarangkalian kerosakan telah meningkat dengan ketara untuk pecutan tanah puncak (PGA) lebih besar daripada 0.2g.

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Fu	-	Ultimate Stress of reinforcement
Fy	-	Yield stress of reinforcement
k	-	Stiffness
Φ	-	Standard normal cumulative distribution of PGA
Ϭ	-	standard deviation
Mw	-	Moment magnitude scale
m	-	metre
MPa	-	Mega pascal
kN	-	Kilo Newton
∆	-	Deflection

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CHAPTER 1

INTRODUCTION

1.1 Research Background

In this study, the seismic vulnerability of transmission tower is investigated by developing the fragility function curve to fare-field earthquake (low to moderate intestines). The typical type of tower that has discussed is the lattice steel equal angled transmission tower used in the many projects in Malaysia. According to the Tenaga National Berhad (TNB), The 500 kV transmission system is the single largest transmission in Malaysia. Begun in 1994, Phase 1 involved the design and construction of the 500kV overhead transmission lines from Gurun, Kedah, in the North along the west coast to Kapar, in the central region and from Pasir Gudang to Yong Peng in the south of Peninsular Malaysia. The total distance covered for the 500 kV transmission lines is 522 km and the 275 kV portion is 73 km. The National Grid; the Peninsula-wide transmission network which acts as a super-highway for electricity, plays a vital role in delivering the energy demand. It consists of approximately 18,812 circuit-km of overhead transmission lines, 740 circuit-km of underground transmission cables and 386 substations with transformation capacity of 83,808 MVA. During the period under review, thirty-two (32) power stations, made up of TNB power stations and Independent Power Producers (IPPs), are connected to the grid with 19,723 MW installed capacity and a maximum electricity demand of 14,007 MW recorded on 21 May 2008.

The transmission tower is the crucial, yet vital infrastructure of the electricity transportation network. The severe damage of this infrastructure will be affecting a huge loss, including economic impact, and need a significant time to repair. One of the possible hazards that may occur in future and also can contribute to major damage of typical transmission tower is the earthquake. To avoid that, important issues for a power transmission tower-line network, is to ensuring the seismic resistance of tower.

Developing a seismic fragility curves for tower is method to predict the risk of the structural system when subjected to the earthquake load. The terms of risk produced is the possibility that the tower severe damage or fully collapse due to excessive displacement, compression buckling or torsional twisting of tower element, also the damage of the tower will be severe while subjected to higher peak ground acceleration (PGA).

Beside to predict the possibility of failure, the seismic fragility of tower also can be used for damage prevention, guidance to periodical maintenance of the tower elements and retrofitting technique of infrastructure system that will be useful for both government and local shareholders to minimize the cost of maintenance. With knowing the capacity of the tower, it is also possible to estimate the total loss due to excessive lateral load.

The transmission tower is the main component of power supply and distribution system, so that it is important to assured that the structure will not collapse or experience an excessive deformation that might occur during seismic excitations. Beside possible to causing a huge economic loss, the failure of tower will also contribute an inconvenience to social life of inhabitants, since this is a vital structure that use by the communities.

The basic concept of the seismic fragility curves is a probability function, where there is an uncertainty factors that will affect the result of tower (elements) capacity. This uncertainty might come from material properties, construction errors, analytical uncertainties, and also a variance of peak ground acceleration that will be used to compute the failure probability function.

As a probabilistic approach, the seismic fragility curves play important roles for determining seismic risk assessment before or after earthquake strike. (Dipendra Gautam, 2017). This approach can be produced by the nonlinear analysis, using nonlinear software to determine how the tower will behave under the incremental static load and also dynamic load.

In this study, the effect of far field earthquake was performed. Although the location of Malaysia, can be consider as a non-seismic zone, the effect of far field earthquake should be consider when designing an engineering structures, because the far field earthquake that strikes from far epicentre, will create a resonance effect, that possible to increase the vulnerability of structures (tower).

The tower elements can be divided as a superstructures and substructures. The superstructures elements of the tower are the elements that directly receive the live load, while the substructures are elements below the superstructures. In this study, only superstructure have focused; superstructure elements are the lattice steel transmission tower, conductor lines and insulator which support the conductor and hanging over the cross arm of tower. While the substructures elements, which have not considered under this study; are the concrete footing making rigid connection to tower legs.

To state the damage stage of the tower, the limit states or performance level of structures was adopted. The performance level used was the one that recommended by the Federal Emergency Management Agency (FEMA) 273 guidelines for seismic rehabilitation of building and structures, namely immediate occupancy (IO), life safety (LS), and collapse prevention (CP). The damage criteria for each level is different, from the low damage, moderate, up to partial or total collapse of the structures. The damage states were measured according to the fragility curves associated to each component.

1.2 Problem Statement

Earthquake is a natural disaster that causing a tremor and violent shaking of the ground due to movement of earth crust or volcanic activities. The effect of earthquake or seismic activities is able to cause a great destruction for both structural and non-structural elements in building or infrastructure. As a civil and structural engineer, it is compulsory to design a structure to be stiff enough and resistant to earthquake lateral load.

Position of Malaysia in geological form is located in sunda shelf, except for eastern part of Malaysia where Sabah and Sarawak consider within the indo-Australian plate. The peninsular of Malaysia, can be consider as a low seismic activity region since it is located far enough from the joint of the plate, so normally the earthquake that might happened to peninsular Malaysia is consider as a low seismic. Because of this, generally the typical building such as single story or multi story residential house, office, apartment, hospital etc., and infrastructure such as transmission tower, water tank, sewage, or electric pole etc. are designed based on dead load and imposed loads.

Peninsular Malaysia, even though can be consider as a low seismic area, does not rule out the possibility that the building and infrastructure will safe and resistant during earthquake, since it is possible that far earthquake effect able to produce the resonance effect to the structures. Based on this condition, it is necessary to predict how the structure will behave and determine the capacity and probability of structure due to lateral load that will be useful for further action.

Seismic fragility curves was needed to be constructed for important structures such as transmission tower in Malaysia, in order to determine the probability of tower failures due to seismic excitations. This information from fragility curves can be used to establish a proper seismic risk management for transmission tower-line system, And also to design a new earthquake resistant structures or retrofitting techniques to existing structures of towers system.

Another reason why this study needed to be done was because there had been no comprehensive study about seismic fragility curves or vulnerability assessment of the overhead electricity transmission tower in Malaysia. The previous study that has the same concept is applied the vulnerability assessment for material in moment resisting concrete frame, typically can be found in the normal building. The result of this study hope can be used as tools for predicting seismic loss that can be apply to the tower in Malaysia, especially in lattice steel transmission towers.

1.3 Objectives of Research

This study is design to aim the following objectives:

1. To determine the capacity of tower member to the internal forces generate by earthquake according to Malaysia national annex to euro code 8.
2. To investigate failure mode of transmission tower when subjected to far field earthquake by numerical, 3D modelling in FE software SAP2000.
3. To determine seismic capacity of transmission tower subjected to earthquake through static and dynamic incremental analysis (pushover analysis and time history analysis).
4. To derive seismic fragility curve for transmission tower when subjected to far field earthquake considering different tower height.
5. Performance limits at different damage stages; fine, minor damage, major damage and collapse, based on fragility curve will be determined for each type of tower.

1.4 Scopes of Research

This study is limited and constraint by the following scopes:

1. Seismic fragility curves for equal angled lattice steel HV overhead power transmission tower of different height in Malaysia.
2. The tower model and analysis based on the actual design drawing of 275kv and 500kv electricity supply tower available from Tenaga National Berhad (TNB), Malaysia.

3. Three different heights of tower 42.51m, 52.77m and 63.33m representing the most typical heights of tower in Malaysia were considered.

4. The seismic fragility curves developed using set of similar tower height.

5. The transmission towers are made of mild steel with yield strength Fy; 440 MPa to 275 MPa, Ultimate strength Fu; 510 MPa to 430 MPa and Young's modulus of 210 GPa.

6. Truss elements are used to model the structural primary members (legs diagonal bracings and horizontal bracing) and secondary bracing (redundant).

7. For simplicity of tower numerical modeling, the coupled tower-cable interaction of tower-line system was not considered in this study.

8. The mass of the cables and the wind loads effects on cables as well as tower body were applied as nodal load to the cross arms of tower at the point cable attached to the cross arm.

9. The legs of the transmission tower were fully fixed to the ground through the cast-in-situ concrete footings.

10. The soil condition interaction was not considered in this study.

11. Different loads calculations, applied to the towers were based on the actual drawings calculations available from TNB, Malaysia.

12. The analysis and design considerations were based on Euro code 3 (EN 1993-3-1)

13. 6 Earthquake records were used to perform Incremental Dynamic Collapse Analysis (IDA).

14. The numerical models of towers were based on using nonlinear finite element software SAP2000

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Appendix A Demand Drift for 42.51m Tower

Table 1: SCALLING FACTOR							
Time History	Name	OPACO	ElCentro	POMONA	KKM	KDM	SPM
	PGA (g)	1.17	0.3075	0.1646	0.1325	0.0032	0.0049
PGA (g)	0	0	0	0	0	0	0
	0.05	0.41923	1.595122	2.979951	3.70189	151.58	100.7
	0.1	0.83846	3.190244	5.959903	7.40377	303.15	201.4
	0.15	1.25769	4.785366	8.939854	11.1057	454.73	302.09
	0.2	1.67692	6.380488	11.91981	14.8075	606.3	402.79
	0.25	2.09615	7.97561	14.89976	18.5094	757.88	503.49
	0.3	2.51538	9.570732	17.87971	22.2113	909.46	604.19
	0.35	2.93462	11.16585	20.85966	25.9132	1061	704.89
	0.4	3.35385	12.76098	23.83961	29.6151	1212.6	805.58
	0.45	3.77308	14.3561	26.81956	33.317	1364.2	906.28
	0.5	4.19231	15.95122	29.79951	37.0189	1515.8	1007
	0.55	4.61154	17.54634	32.77947	40.7208	1667.3	1107.7
	0.6	5.03077	19.14146	35.75942	44.4226	1818.9	1208.4

42.51m Tower Drift Division		
Performance Level	Displacement (mm)	Drift (%)
OP	19	0.050304
IO	35	0.092666
DC	56	0.148266
LS	80	0.211808
CP	98	0.259465

Table 3: RESULT DRIFT OF (%) 42.51M TOWER							
Time History	Name	OPACO	ElCentro	POMONA	KKM	KDM	SPM
	PGA (g)	1.17	0.3075	0.1646	0.1325	0.003	0.005
PGA (g)	0	0	0	0	0	0	0
	0.05	0.00533	0.008125	0.0094202	0.0085	0.003	0.003
	0.1	0.01066	0.016251	0.018843	0.0171	0.006	0.007
	0.15	0.01599	0.024376	0.0282658	0.0256	0.009	0.01
	0.2	0.02132	0.032502	0.0376886	0.0342	0.012	0.013
	0.25	0.02666	0.040627	0.0471115	0.0427	0.015	0.017
	0.3	0.03199	0.048753	0.0565369	0.0513	0.018	0.02
	0.35	0.03732	0.056878	0.0659598	0.0598	0.021	0.023
	0.4	0.04264	0.065001	0.0753826	0.0684	0.023	0.027
	0.45	0.04799	0.073132	0.0848054	0.0769	0.026	0.03
	0.5	0.05331	0.081258	0.0942282	0.0862	0.029	0.033
	0.55	0.05864	0.089383	0.103651	0.094	0.032	0.037
	0.6	0.06397	0.097509	0.1130739	0.1026	0.035	0.04

Appendix B Demand Drift for 52.77m Tower

Table 1: SCALLING FACTOR							
Time History	Name	OPACO	ElCentro	POMONA	KKM	KDM	SPM
	PGA (g)	1.17	0.3075	0.1646	0.1325	0.0032	0.0049
PGA (g)	0	0	0	0	0	0	0
	0.05	0.41923	1.595122	2.979951	3.70189	151.58	100.7
	0.1	0.83846	3.190244	5.959903	7.40377	303.15	201.4
	0.15	1.25769	4.785366	8.939854	11.1057	454.73	302.09
	0.2	1.67692	6.380488	11.91981	14.8075	606.3	402.79
	0.25	2.09615	7.97561	14.89976	18.5094	757.88	503.49
	0.3	2.51538	9.570732	17.87971	22.2113	909.46	604.19
	0.35	2.93462	11.16585	20.85966	25.9132	1061	704.89
	0.4	3.35385	12.76098	23.83961	29.6151	1212.6	805.58
	0.45	3.77308	14.3561	26.81956	33.317	1364.2	906.28
	0.5	4.19231	15.95122	29.79951	37.0189	1515.8	1007
	0.55	4.61154	17.54634	32.77947	40.7208	1667.3	1107.7
	0.6	5.03077	19.14146	35.75942	44.4226	1818.9	1208.4

52.77m Tower Drift Division		
Performance Level	Displacement (mm)	Drift (%)
OP	19	0.044695
IO	35	0.082334
DC	56	0.131734
LS	80	0.188191
CP	98	0.230534

Table 3: RESULT DRIFT OF (%) 52.77M TOWER							
Time History	Name	OPACO	ElCentro	POMONA	KKM	KDM	SPM
	PGA (g)	1.17	0.3075	0.1646	0.1325	0.003	0.005
PGA (g)	0	0	0	0	0	0	0
	0.05	0.00572	0.008589	0.0104728	0.0144	0.005	0.004
	0.1	0.01143	0.017179	0.020948	0.0288	0.011	0.008
	0.15	0.01715	0.025768	0.0314232	0.0432	0.016	0.013
	0.2	0.02287	0.034359	0.0418984	0.0576	0.022	0.017
	0.25	0.0286	0.042948	0.0523736	0.072	0.027	0.021
	0.3	0.03431	0.051538	0.0628511	0.0864	0.033	0.025
	0.35	0.04003	0.060127	0.0733263	0.1008	0.038	0.03
	0.4	0.04574	0.068718	0.0838015	0.1152	0.043	0.034
	0.45	0.05147	0.077314	0.0942766	0.1296	0.049	0.038
	0.5	0.05719	0.085902	0.1047518	0.144	0.054	0.042
	0.55	0.06291	0.094491	0.115227	0.1584	0.06	0.047
	0.6	0.06862	0.103082	0.1257045	0.1728	0.065	0.051

Appendix C Demand Drift for 63.33m Tower

Table 1: SCALLING FACTOR							
Time History	Name	OPACO	ElCentro	POMONA	KKM	KDM	SPM
	PGA (g)	1.17	0.3075	0.1646	0.1325	0.0032	0.0049
PGA (g)	0	0	0	0	0	0	0
	0.05	0.41923	1.595122	2.979951	3.70189	151.58	100.7
	0.1	0.83846	3.190244	5.959903	7.40377	303.15	201.4
	0.15	1.25769	4.785366	8.939854	11.1057	454.73	302.09
	0.2	1.67692	6.380488	11.91981	14.8075	606.3	402.79
	0.25	2.09615	7.97561	14.89976	18.5094	757.88	503.49
	0.3	2.51538	9.570732	17.87971	22.2113	909.46	604.19
	0.35	2.93462	11.16585	20.85966	25.9132	1061	704.89
	0.4	3.35385	12.76098	23.83961	29.6151	1212.6	805.58
	0.45	3.77308	14.3561	26.81956	33.317	1364.2	906.28
	0.5	4.19231	15.95122	29.79951	37.0189	1515.8	1007
	0.55	4.61154	17.54634	32.77947	40.7208	1667.3	1107.7
	0.6	5.03077	19.14146	35.75942	44.4226	1818.9	1208.4

63.33m Tower Drift Division		
Performance Level	Displacement (mm)	Drift (%)
OP	19	0.030016
IO	35	0.055292
DC	56	0.088468
LS	80	0.126382
CP	98	0.154818

Table 3: RESULT DRIFT (%) OF 63.33M TOWER							
Time History	Name	OPACO	ElCentro	POMONA	KKM	KDM	SPM
	PGA (g)	1.17	0.3075	0.1646	0.1325	0.003	0.005
PGA (g)	0	0	0	0	0	0	0
	0.05	0.013	0.010071	0.0202796	0.0081	0.015	0.008
	0.1	0.02599	0.020142	0.0405671	0.0163	0.03	0.016
	0.15	0.03899	0.030213	0.0608547	0.0244	0.046	0.025
	0.2	0.05198	0.040286	0.0811422	0.0325	0.061	0.033
	0.25	0.06501	0.050357	0.1014297	0.0407	0.076	0.041
	0.3	0.078	0.060428	0.1217156	0.0488	0.091	0.049
	0.35	0.091	0.070499	0.1420032	0.0569	0.106	0.057
	0.4	0.104	0.08057	0.1622907	0.0651	0.122	0.066
	0.45	0.11702	0.090648	0.1825782	0.0732	0.137	0.074
	0.5	0.13002	0.100719	0.2028641	0.0813	0.152	0.082
	0.55	0.14302	0.11079	0.2231517	0.0895	0.167	0.09
	0.6	0.15601	0.120863	0.2434392	0.0976	0.182	0.099