TELECOMMUNICATION TOWERS ASSESSMENT SYSTEM IN CONSIDERATION OF EARTHQUAKES EFFECTS IN MALAYSIA

ZAWIYAH BINTI ABDUL RAZAK

UNIVERSITI TEKNOLOGI MALAYSIA

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ZAWIYAH BINTI ABDUL RAZAK

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DEDICATION

Undertaking a study of this nature cannot be sustained without the support of the dearly people in my life. I dedicate this work firstly to the following two persons who have touched my life in significant ways, more than they'll ever know – my beloved parents, Tn. Haji Abdul Razak B. Mohamed Ali and Pn. Hajah Nooriah Bt. Mohamed Basir; for their simplicity and thrift, ALLAH bless them with good health. Secondly, to my boy Zubair, who have been very patience, cherish my life and have helped in various ways, my heartfelt thanks. Also to all my brothers, sisters and families for their invaluable support and understanding, for their forbearance over the past few years, may ALLAH bless them with self-fulfilment, good cheer and happy lives.

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ABSTRACT

The main objectives of the study are to produce standard visual inspection procedure for telecommunication tower structures, secondly to evaluate the structural integrity of the existing towers and finally, to develop Telecommunication Tower Assessment System (TTAS). In order to produce the standard visual inspection procedure a meticulous strategy was implemented. Five phases of work included planning, site survey, development, evaluation and finally the application phase were carried out. Moreover, the integrity of existing towers was evaluated through seismic analysis of four (4) legged self-supporting steel towers with different geometrical cross sections and variable heights using International Building Code (IBC2000) and Eurocode (EC8) and SAP 2000 software. Seismic base shears, maximum joint displacements, and axial force of critical elements were calculated and were compared with allowable values. Besides that, a map locating all the towers was also produced on the seismic map considering 500 year return period for both Peninsular and East Malaysia. Both TTAS and map was later evaluated, verified and validated by subject matter experts. The study has developed a complete telecommunication tower's assessment system that includes types of damages and severity inflicted to the towers and also matters related to it. This classification will make assessment easier and standardised for all inspection works carried out. With the aid of the seismic map, Telekom Malaysia will be able to further define priorities and establish programmes to apply available resources to the most critical towers nationwide. In short, the outcomes of this research helps to promote a uniform standard of practice among tower owners and related parties besides assessing relevant authorities to be more prepared and alert in terms of emergency management and hazard-preparedness due to the effect of earthquake events.

ABSTRAK

Objektif utama kajian adalah untuk menghasilkan prosedur setara pemeriksaan bagi struktur menara telekomunikasi, keduanya untuk menilai keupayaan dan kekukuhan struktur sediada, dan akhir sekali untuk membangunkan satu Sistem Penilaian Menara Telekomunikasi (SPMT). Bagi menghasilkan prosidur tersebut, strategi yang teliti telah diimplentasikan. Lima fasa merangkumi perancangan, kajian lapangan pembangunan, penilaian dan akhirnya fasa aplikasi telah dilakukan. Kekukuhan menara sediada turut dikaji melalui analisa seismik terhadap menara besi berkaki empat (4) dengan berbagai keratan geometri dan ketinggian menggunakan International Building Code (IBC 2000) dan Eurocode (EC8) serta perisian SAP2000. Ricihan tapak seismik, perubahan sambungan maksima dan daya paksian bagi elemen kritikal telah dikira dan dibandingkan dengan nilai yang dibenarkan. Sebuah peta seismik yang mengandungi semua menara telah dihasilkan yang mengambilkira ulangan gempa selama 500 tahun bagi Semenanjung dan Malaysia Timur. Kedua-dua SPMT dan peta yang dihasilkan telah dinilai, sahkan dan dimuktamadkan oleh pakar bidang berkaitan. Kajian ini berjaya membangunkan satu sistem penilaian penyelengaraan yang menyeluruh termasuk mengenalpasti jenis-jenis dan tahap kerosakan yang dialami oleh menara telekomunikasi dan perkara yang berkaitan dengannya. Klasifikasi ini akan membuat penilaian struktur lebih mudah dan setara. Peta seismik yang dihasilkan akan memudahkan pihak Telekom Malaysia menetapkan keutamaan dan mewujudkan program untuk menyediakan peruntukan bagi menara yang kritikal di seluruh negara. Dalam ertikata lain, kajian ini telah berjaya membangunkan satu sistem setara yang diharap dapat membantu menyelaraskan pemeriksaan antara pemilik menara dan pihak lain yang terbabit serta membantu pihak berkuasa dalam membuat persiapan pengurusan kecemasan dan persediaan menghadapi kesan akibat kejadian gempa bumi.

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LIST OF SYMBOLS

a_g	-	Design ground acceleration
B	-	Ratio of shear demand or lower bound factor for the horizontal design spectrum
C_d	-	Deflection amplification factor
C_s	-	Seismic response coefficient
C_u	-	Upper limit on calculated period
C_{vx}	-	Vertical distribution vector
D	-	Dead load of structure and appurtenances, excluding guy assemblies
D_g	-	Dead load of guy assemblies;
D_1	-	Weight of ice due to factored ice thickness;
E	-	Earthquake load
F	-	Seismic force
F_a	-	Acceleration-based site coefficient based on site class and spectral response acceleration at short periods.
F_v	-	Velocity-based site coefficient based on site class and spectral response acceleration at short periods.
h_n	-	Structural height
I_e	-	Seismic importance factor
I_i	-	Ice importance factor thickness I_i
I_s	-	Snow importance factor
I_w	-	Ice importance factor thickness I_w
m	-	Total mass of the building
$\overline{N}$	-	Standard penetration resistance
P_x	-	The vertical design load at and above level x
q	-	Behaviour factor
β	-	The lower bound factor for the horizontal design spectrum
R	-	Response modification factor

S	-	Soil factor
S_1	-	1 Seconds spectral acceleration
S_{D1}	-	Design spectral response acceleration at a period of 1.0 second
S_{DS}	-	Design spectral response acceleration parameter in the short period range
$S_d(T)$	-	Design spectrum
$S_E(T)$	-	The elastic response spectrum
S_S	-	0.2 Seconds spectral acceleration
$\bar{s}_u$	-	Soil undrained shear strength
T	-	Vibration period of a linear single-degree-of-freedom system
T_a	-	Fundamental period
T_1	-	Load effects due to temperature
T_1	-	Fundamental period of vibration of the building for lateral motion in the directional considered
T_B	-	The lower limit of the period of the constant spectral acceleration branch
T_C	-	The upper limit of the period of the constant spectral acceleration branch
T_D	-	The value of defining the beginning of the constant displacement response range of the spectrum
V	-	Total design lateral force or seismic base shear of the structure
V_x	-	Seismic shear force acting between level x and x-1
W	-	Effective seismic weight
W_o	-	Wind load without ice;
W_1	-	Concurrent wind load with factored ice thickness.
η	-	Damping correction factor with reference value of η=1 for 5% viscous damping
Ω	-	System Overstrength
Θ	-	Stability coefficient
θ_{max}	-	Maximum stability coefficient
Δ	-	The design story drift
Δ_a	-	The allowable story drift, Δ_a
λ	-	The correction factor

δ_x - Deflection at level x

LIST OF ABBREVIATIONS

AAG	-	Asia America Gateway
AASHTO	-	American Association of State Highway and Transportation Officials
AEIC	-	ASEAN Earthquake Information Centre
AGCA	-	Associated General Contractors of America (AGCA)
ALI	-	Automatic Location Identification
AM	-	Amplitude modulation
ASE	-	Asia Submarine Cable Express Cable System
ATC	-	Applied Technology Council
CATV	-	Consumer Access Television
CIDB	-	Construction Industry and Development Board
DWDM	-	Dense Wavelength Division Multiplexing
EC	-	European code
EENA	-	European Emergency Number Association
EIA	-	Electronic Industry Association
EN	-	European standards
ETP	-	Economic Transformation Program
FM	-	Frequency modulation
GIS	-	Geographical information system
GNP	-	Gross National Product
GTP	-	Government Transformation program
HERP	-	Headquarters for Earthquake Research Promotion
HSBB	-	High Speed Broad Band
IAEA	-	International Atomic Energy Association
IBC	-	International Building Code
ICC	-	International Code Council
IP	-	Internet protocol

IPTV	-	Internet Protocol Television
ITU	-	International Telecommunication Union
JSHIS	-	Japan Seismic Hazard Information Station
JSCE	-	Japan Seismic Centre for Earthquake
JTM	-	Jabatan Telekom Malaysia
JUCN	-	Japan-United States Cable Network
MCMC	-	Malaysian Communication and Multimedia Commission
MERS	-	Malaysian Emergency Response System
MM	-	Modified Mercalli
MMS	-	Malaysian Metrological Services
NEM	-	New Economic Model
NENA	-	National Emergency Number Association
NGN	-	Next Generation Network
NKRAs	-	National Key Result Areas
NBI	-	National Broadband Initiatives
NRCC	-	National Research Council Canada
NTT	-	Nippon Telegraph and Telephone
NTTComm	-	Nippon Telegraph and Telecom Communications
PCS	-	Personal Communication Service
PGA	-	Peak ground acceleration
PSP	-	Philippine Sea plate
PWD	-	Public Works Department
SMW3	-	South-East Asia-Middle-Western Europe 3
TeAMS	-	Telekom Asset Management System
TIA	-	Telecommunciation Industry Association
TM	-	Telekom Malaysia Berhad
TTAS	-	Telecommunication Towers Assessment System
TNB	-	Tenaga Nasional Berhad
UBC	-	Uniform Building Code
UHF	-	Ultra high frequency
USGS	-	United States Geogical Survey
VHF	-	Very High Frequency
WHO	-	World Health Organisation
www	-	World wide web

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Since its independence over the past 55 years, in parallel with the strong emergence of the telecommunication industry a large number of self supporting towers have been erected throughout Malaysia. With the divergence of the high speed broadband projects initiated by the Malaysian government in mid 2008, more telecommunication towers are being and erected to cater for the country's needs. Furthermore with the Government Transformation Programme (GTP) which has been launched by the Prime Minister in 2010 is an ambitious, broad based initiative aimed at addressing key areas of concern to the people while supporting Malaysia's transformation into a developed and high-income nation as per Vision 2020 have been actively participated by everyone in the country.

The GTP is aligned to the New Economic Model (NEM) and the Tenth Malaysia Plan (10MP) and should be viewed together with these initiatives as part of one cohesive effort to transform Malaysia into a progressive, harmonious and high-income nation by 2020 (PEMANDU, 2010). The roadmap of the National Broadband Initiatives (NBI) is illustrated in Figure 1.1.

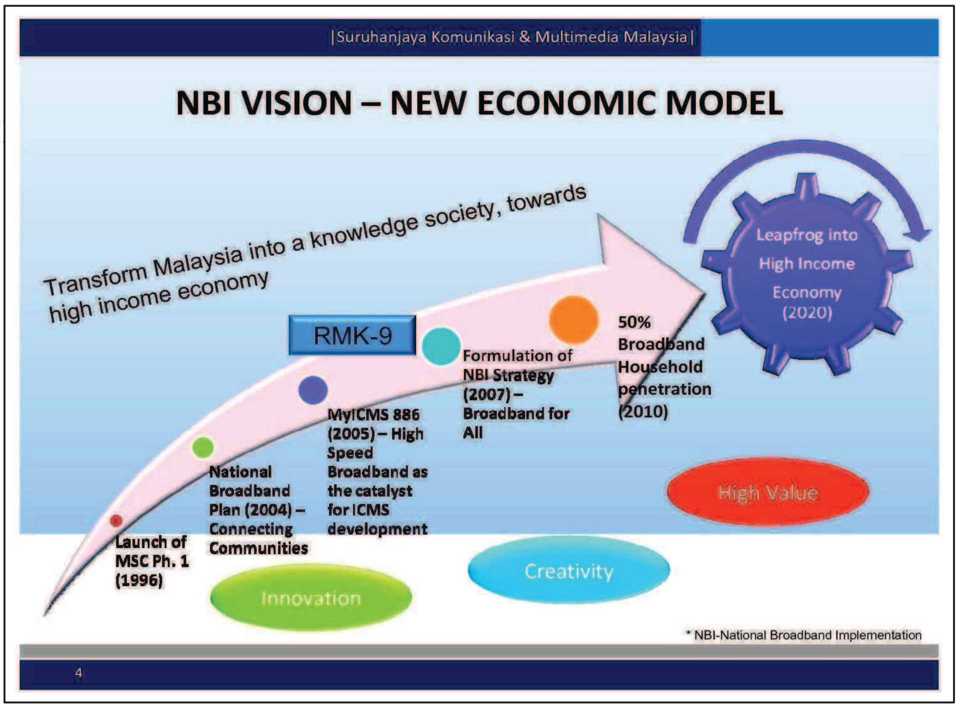

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Figure 1.1 National Broadband Initiatives Vision – New Economic Model (PEMANDU, 2010)

With this National Key Result Areas (NKRAs) targets, more telecommunication towers will need to be erected throughout the country. These specifically light and slender tower structures are particularly sensitive to the environmental loads and also to ground movements. Cantuniar (2011) has expressed that globally the need for speed is becoming pronounced and urgent. Consumer appetite for on the move data consumption via mobile broadband shows no signs of being sated in the face of smart phone and tablet growth. Home and business demand for high-speed internet access is also growing, while the scrutiny on broadband providers is under from watchdogs, home regulators and the commission continues.

Being the country's biggest telecommunication infrastructure planner and service provider, Telekom Malaysia (TM) has to keep up at par with the current needs and trends not only locally but globally besides maintaining the efficiency of its facilities. Telecommunication plays an important role in our daily life. It is primarily concerned with people. Any telecommunications administration must be judged not by its equipment, but on how well it meets the needs and the aspirations of the people it serves. Zamzairani (2011) has pointed out that one of the driving forces for people at TM is that whatever they do there is of prime importance to the country. The feeling of wanting to contribute to the nation's development is what matters most.

Malaysia is situated on the southern edge of the Eurasian plate. It is close to the two most seismically active plate boundaries, the inter plate boundary between the Indo-Australian and Eurasian plates on the west and the inter-plate boundary between the Eurasian and Philippines plates on the east as seen in Figure 1.2.

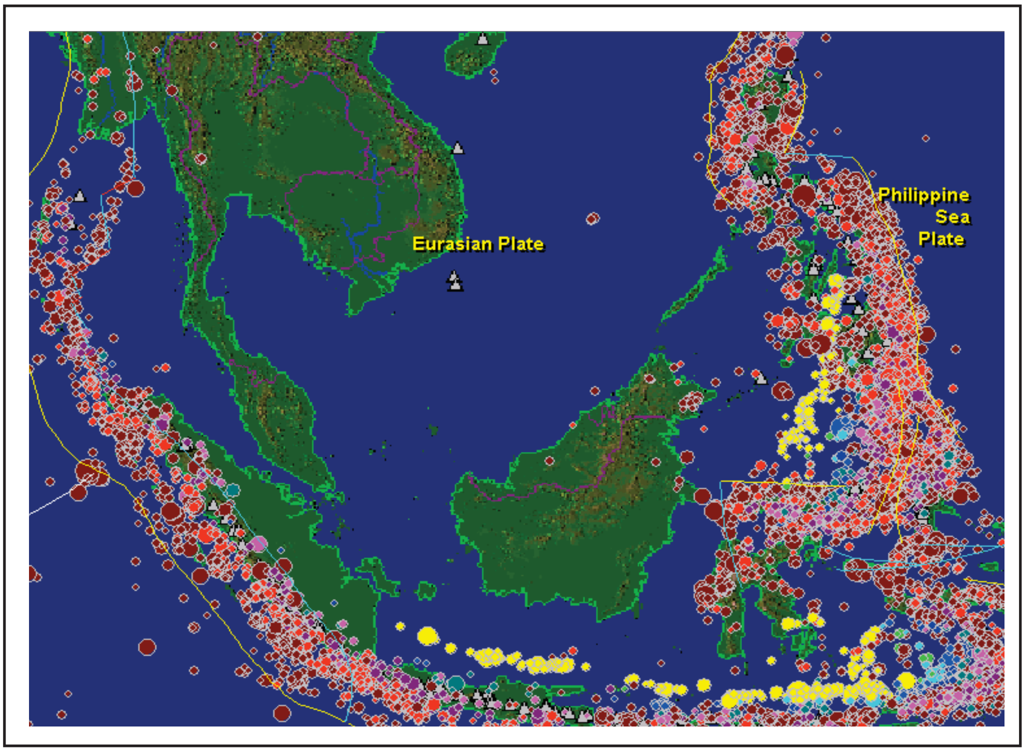

Figure 1.2 Location of plates (Adnan. A, 2006)

Major earthquake originating from these plate boundaries has been felt in Malaysia. Peninsular Malaysia is classified as a seismically stable area. As reported in the ASEAN Earthquake Information Center (2009) there have been no known local earthquakes so far except for those occurred in reservoirs such as those occurring at the Kenyir Dam area in Terengganu between 1984 to 1986. However the west of peninsular Malaysia is affected by tremors originating from large

Sumatran earthquakes on the average of 1.5 to 2 tremors a year with maximum intensity of V observed base on the Modified Mercalli (MM) scale. Several possible active faults have been delineated and the local earthquakes in East Malaysia appear to be related to some of them. Based on earthquakes with body wave magnitude of 4 and above located within a radius of 450 kilometer of the island during the period 1976 to 1990, the return periods for different magnitudes were found to be as tabulated in Table 1.1 below.

Table 1.1: Magnitude and Return Period of Earthquakes Events (ASEAN Earthquake Information Centre, 2009).

Magnitude(Richter)	4.0	5.0	5.5	6.0	6.5	7.0
Return Period (year)	0.3	1.01	2.07	3.95	7.52	14.30

East Malaysia is classified as a moderately active in seismicity mainly in Sabah. In addition to the local earthquakes, East Malaysia is also experiencing tremors originating from large earthquakes located over southern Philippines and in the Straits of Makassar, Sulu Sea and Celebes. These areas have experienced earthquake origin with magnitudes of up to 5.8 on the Richter scale. Some of these resulted in some damages on properties. The maximum intensity observed so far was VI on the MM scale.

Tjia (1983) mentioned that in Sabah and Sarawak historical and instrumental seismicity recorded the presence of several earthquake epicenters that reflect their present-day tectonic setting. Lim (1985) claimed that on-shore Sabah, the epicenters mark earthquakes of moderate magnitudes that are mostly found in and close to, the Dent and Semporna Peninsulas, where they demarcate a broad zone of mainly shallow foci between the Sulu Trench and Sulu Volcanic Arc. Lim (1986) and Raj (1996) mentioned that in the west of Sabah and Sarawak the epicenters in the South China Sea may represent renewed fault movements, whilst other epicenters particularly in Sarawak show no clear relationship with the tectonic setting. Due to its strategic location, Malaysia is generally spared from any major active seismic activities. However, when earthquakes occur in neighbouring countries, the effects can be felt locally even though the epicenter of the earthquake is hundreds of kilometers away. Again Lim (1977) and Godwin (1992) both claimed that substantial damage to buildings have been reported on July 26, 1976 and on May 26, 1991 in Tawau, Lahad Datu and Ranau, Sabah, respectively. While Adnan et al. (2005) in their study which included several items such as the tectonic setting of Sumatra, location, mechanism and size of the recent earthquake and also analysis of ground at bedrock for Penang and Kuala Lumpur using several appropriate attenuation relationships has shown that the Sumatra Earthquake did have some effect to the Malaysian Peninsular. In 2007, the inhabitants of Bukit Tinggi, Pahang have experienced tremors due to minor movements from the earth. Although there were no reports of major structural damage, the incident has raised several questions. As reported in the Jurutera Bulletin (2008); one of the major concerns is this; "Are existing high rise buildings in Malaysia able to withstand such tremors and should future developments be designed for seismic effects?" Again, on September 30, 2009, another earthquake measuring 7.6 Magnitude location of epicenter at 60 km southwest of Padang Sumatera, followed by subsequent moderate magnitude 6.6 quake occurred at the same spot about 20 minutes later have caused great fear to our locals especially in the Peninsular Malaysia (USGS). Thousands of workers in several cities in the country fled their high rise offices and homes as tremors shook the buildings. Reports on calls and complaints by the public were made to the Fire Department in most of the states due to the tremors felt and the concern of their safety on their dwellings and offices. These were documented in the Executive Report on Typhoon and Earthquake Disaster (2009) by the Fire Department of Malaysia.

Similar question arose indicating one of the major concerns in regards to the existing buildings and structures in the country being able to withstand earthquake events in future. If not, what are the actions and necessary steps to be taken to mitigate this disaster? After the 2004 tsunami disaster that struck Aceh, the Malaysian government under the National Security Council has taken early initiatives to look into the impact of earthquake events originating from our neighbours. The Standard Operating Procedure (SOP) for Managing Earthquake

Disaster (2007) which rules out the guidelines and the responsibilities of all relevant departments and agencies in handling and managing such disaster has been drafted. This is to ensure that the operations will runs smoothly and systematically in facing such events. Further discussions on this are made in the proceeding chapters.

Important buildings and sensitive structures such as telecommunication towers are among the most crucial to be looked upon. This is because tower structures play an important role in enabling communication during disaster to be broadcasted to the public without any failure. Lomnitz (1974) mentioned that it is important to be noted that earthquakes do not need to be of large magnitude to produce severe damage, because the degree of damage depends not only on the physical size of an earthquake but also on other factors such as where and when an earthquake occurs, the population density in the area and secondary related events such as fire.

Managing telecommunication structures is of utmost importance to ensure that services are uninterruptable and can be delivered during these hard times. Communication needs during disaster are unique and critical. It becomes more crucial when disaster such as flood, typhoon, hurricane and earthquakes events happen. According to Kramer (1992), in a major emergency caused by an earthquake it is likely that telephone lines may be down, other alarm and telecommunications facilities are adversely affected, and a vast increase in the work load imposed upon personnel and equipment in the control centre. One distinguishing characteristics is the dramatic increase in the number of people who must make use and communicate among them. The malfunction of the communication facilities immediately after an earthquake struck other countries should be a lesson learned especially for telecommunication service providers.

Telecommunication towers are categorised among the tallest man-made structures and can be found standing high on every part of the globe with different heights and purposes. McClure (1999) quoted a survey of the earthquake performance of communication structures that summarised documented reports of 16 instances of structural damage related to seven important earthquakes between 1949 to 1998, none of which were a direct threat to life safety. However, several towers may have been damaged or have become unserviceable without having collapsed or suffered damage visible from the ground during post earthquake inspections. Many strong earthquakes have happened since then and more damage has been reported as more telecommunication equipment is deployed worldwide. Indonesia, the country that lies in the Ring of Fire area has witnessed many of its telecommunication towers failed during earthquakes events. This can be seen in Figure 1.3.

Figure 1.3 Collapsed of tower structure after an earthquake event in Indonesia (PT. XL Axiata Tbk., Indonesia 2011).

Also Bahme et al. (1992) highlighted that in any disaster scenario quality decisions require the communication of timely, valid, and usable information among a very large number of individuals and agencies during this event. Information that needs to be communicated generally involves guidance, direction, requests for assistance, status reports on the incident and updates on resources and operations. According to Faridafshin et al. (2008) the preservation of serviceable communication infrastructure as critical links of communication or post disaster networks is essential in the event of an earthquake. The January, 1995 Kobe earthquake is a good example where communication facilities malfunction has given a big impact where this event was said to have prevented local governments from knowing the level and the scope of casualties caused by the disaster. Their poor reaction has increased the number of the fatalities affected (Smith, 2007). The same scenario happened in most of the world's earthquake prone countries like Indonesia, Haiti, New Zealand and others. The failure of communication has worsened the disaster effects to the victim. As has been reported in the Mainichi Shimbun (2011) in the March 11, 2011 Tohoku earthquake, communications were badly broken, with cell phone service largely knocked out; many residents had to rely on the small number of surviving pay phones. Undoubtedly, the preservation of serviceable communication infrastructure as critical links of communication or post disaster networks is essential in the event of a severe earthquake and this issue requires attention in not only the seismic-prone regions of the world but also areas that felt earthquake effects. This can no longer be compromised.

Telecommunication towers are exposed to numerous environmental loads and imposed live loads which increase from time to time and also due to rugged site locations. These can cause a reduction in overall strength and will lead to eventual failure of the towers. Bai et al. (2010) who conducted a study on transmission towers and power lines have proven that seismic responses are amplified to these structures when considering the local site effect. Telecommunication towers are also expected to have experienced the same effects on its structures. As mentioned by Bahme (1992), successful communication in information management for disaster control requires a good organisation that includes proper managing of its structures that will not affect transmission or news broadcasting during disaster.

Since TM possesses many high structures including hundreds of telecommunication towers nationwide, therefore it is of vital importance to understand and monitor the safety of all its structures. Assessing the condition of the structures by taking earthquake effects into consideration is deemed necessary to determine its structural integrity, safety and reliability.

1.2 Problem Statement

Currently towers are evaluated only through visual observation and inspections. The major problem with visual inspection is the inherent variability that occurs naturally when subjective observations are carried out without proper guidance. Telecommunication tower evaluation method may vary according to personal judgment. Thus, large uncertainties exist in the interpretation of inspection data. Besides there is no such standardised assessment system yet in TM or other operators in managing its telecommunication towers nationwide. If there were, the inspection requirement would differ from one operator to another and would not cover all aspects of the tower structures including its surrounding conditions.

Local authorities too like the Kuala Lumpur City Hall and also major players in the construction industry like the Public Works Department (PWD) and also Construction Industry and Development Board (CIDB) do not have such guidelines yet especially in inspection of their building structures. Different agencies have different guidelines to be followed but not implemented as an act by the government. In the event of an earthquake, the Fire Department is called upon to check and ensure the safety of the building before tenants are allowed to go back to their homes or offices. The fireman could not check the connections as they are covered. They don't have the expertise in this field to properly justify the safety of the structures and rely on other parties for evaluation. By the time the evaluation is completed, it might already be too late for taking any preventive measures?

To date there is no specific study or research that has been made or carried out in TM or in the country specifically related to the issues and areas addressed. As for TM's practices, only normal visual inspections have been carried out in its maintenance program for its tower structures and if defects are encountered it will only be rectified based on request and urgency. Specifically, earthquake related scenario has not been considered and nothing has been carried out so far.

As mentioned earlier, Malaysia is now being exposed to earthquake effects though it is located far away from its epicenter. As has been reported in the

Executive Report on Typhoon and Earthquake Disaster (2009), that Malaysia emerged relatively unscratched from the September 2009 disaster with only a dozen buildings reporting cracks compared to 2600 buildings damaged or destroyed in Padang including thousands trapped under collapsed buildings. Since our buildings are generally not designed to withstand earthquake loads, it is better to prevent huge losses to assets and life rather than 'curing' it later. According to Kramer (1992) disaster such as earthquake will affect the economy and development of the nation, destroying means of production, distribution, and transportation of commercial products, and disruption of communications and public utility services. This is noticeably true. The triple catastrophe in Fukushima 2011 has proven this and causing Japan to face a downturn in its economic. As reported in the International Business Times (2012), exports fell 9.3 percent because of the disruption of supply-chain processes due to Thai floods, slower growth in China's economy and a weakening euro that made Japanese products more expensive. Imports fell 9.8 percent because of increased demand for energy imports in a country whose nuclear power production levels have yet to recover from the devastating tsunami and earthquakes. Prior to 2011, Japan had not run a trade deficit in 31 years.

In The Street, Drainage and Building Act (1984) it is clearly stated that buildings or structures reaching the age of five to twelve years need a thorough inspection to determine its durability, integrity besides its safety for occupants. Besides that clause 5.1 and Clause 5.2, 'Actions After Construction' as stated in the Guide for Construction of Towers and Telecommunication Broadcasting Structures Systems Under Local Authority (Ministry of Housing and Local Government, 2002) clearly states the "requirements that needed to be complied by developers or networks services provider to ensure that all structures after erection need to be properly maintained but also to ensure the safety of the property and also the public at large. Scheduled inspection should be carried out regularly but not less than once in every twelve months after the date of certificate of fitness have being issued by the local authority".

In Malaysia, most of the existing telecommunication towers were erected way back before the 1950's especially for those structures meant for carrying microwave purposes. The British and Japanese erected it earlier during their occupation in Malaya and all are still operational today. During those days, the towers are designed only to cater for the normal loads and no additional factors or specific considerations of seismic events were considered. Generally these tower structures are more than ten years of age while some reaching almost sixty years of service life and no thorough assessment have been carried out on them. Most of these structures are located on highland areas which are also suspected to have experienced some effects due to earthquake events and movements of faults lines besides ground motions. Due to their tall and tapered shape and being exposed to environmental factors daily, it is of outmost importance to investigate the safety, reliability and structural integrity of these tower by taking into consideration earthquake effects in the country.

1.3 Aim of Research

The main aim of this research work is to develop a telecommunication tower assessment system by considering earthquakes effects in Malaysia which can serve as a national guide for all tower owners and operators in the country, thus helps to promote a uniform standard of practice among various parties.

1.4 Objectives of Research

To achieve such aim the following objectives have been considered for the research work:

i. To produce standard visual inspection procedures for telecommunication tower structures by considering earthquake effects.

ii. To evaluate the structural integrity of the existing telecommunication tower structures due to the effects of earthquakes.

iii. To develop a Telecommunication Tower Assessment System by considering earthquakes effects in the country.

To achieve the above objectives, a specific research methodology has been carried out and explained in detail in Chapter 4 of this thesis and also as simplified in Figure 1.4 below.

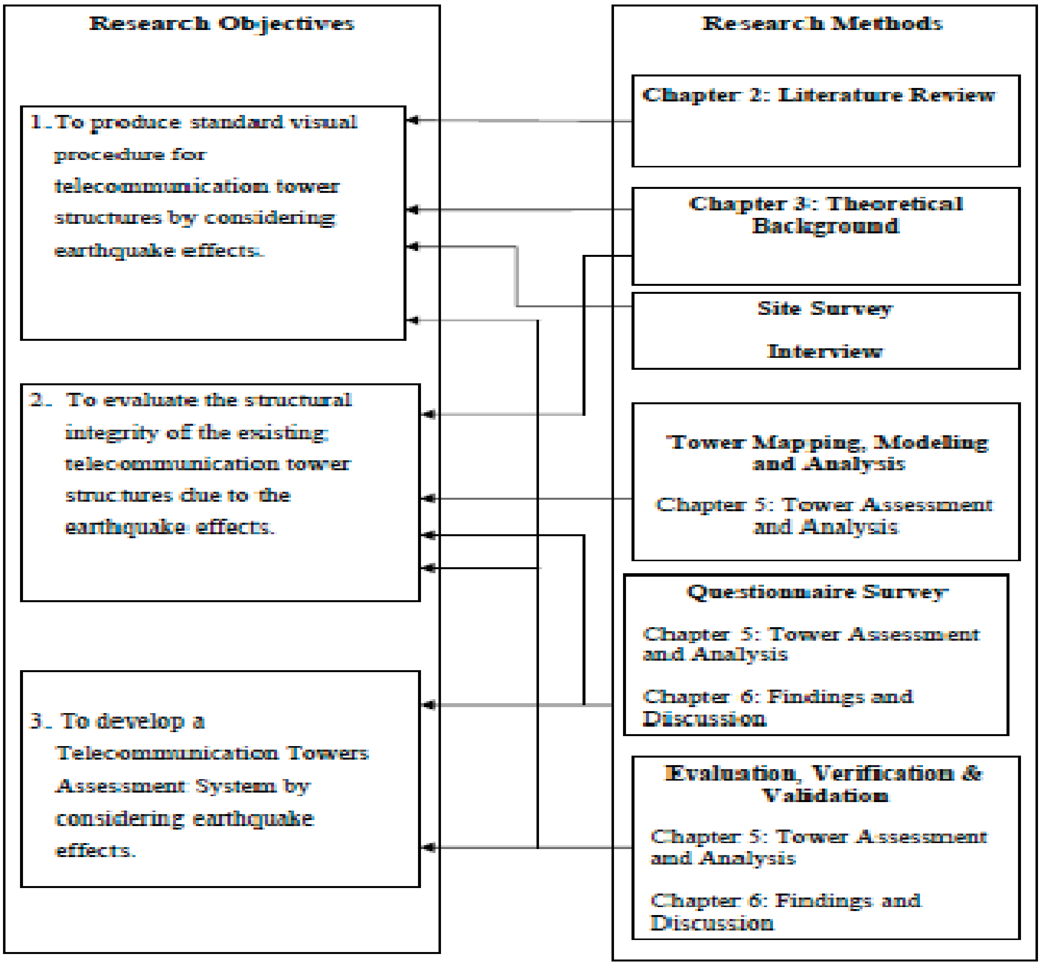

Figure 1.4 Research objectives and methodology

1.5 Scope of Research

The focus of this research has been narrowed down to only on structural related issues for assessment on four (4) legged self-supporting steel towers. Due to the huge numbers of four (4) legged self-supporting steel towers type being erected, it is most important to prioritise due to its importance in the telecommunication purposes. Several steel telecommunication towers of different height categories have been selected for this purpose. The research work includes investigating, accessing, analysing and evaluating, including modeling the selected towers located in various seismic zones in the country.

Scopes of work are listed below:

i) Types

4 legged Self Supporting steel towers were selected. Several towers of different heights that are categorised in the medium rise and high rise structures were selected.

The medium rise category was considered when the height of the tower lies within 19.81 meters and 73.15 meters while for the high rise category was considered when the height is above 73.15 meters (UBC,1994). No low rise category was carried out since tower under this height are located on building roof tops.

For medium rise category, two towers of height 30 meters and 45 meters were selected for modeling and analysis, while for high rise category four towers of height 90 meters, 120 meters and 140 meters were selected. The categories of the towers are tabulated in Table 1.2.

Table 1.2: Heights of Towers for Modeling and Analysis

Tower Categories	Height of Tower (meter)
Lower Rise (< 19.81 meter)	Nil (No tower in this category)
Medium Rise ($19.81 \leq H \leq 73.15$)	30 45
High Rise (H> 73.15)	90 120 140

ii) Location

The selected towers are located in the various seismic zones as indicated in the CIDB 500 Years Return Period map for Peninsular and the PWD 500 Years Return Period for East Malaysia map as tabulated in Table1.3. This table shows that for Peninsular Malaysia, the maximum of peak ground acceleration for a Year Return of 500 years is less than 100 gals while for East Malaysia is less than 120 gals and in various seismic zones. This follows accordingly as in seismic map in Figure 5.6 and 5.7 in Chapter 5.

Table 1.3: 500 Year Return Period Based on CIDB for Peninsular Malaysia and PWD for East Malaysia

500 Year Return Period Based on CIDB for Peninsular Malaysia	Seismic Zone	500 Year Return Period Based on PWD for East Malaysia	Seismic Zone
20 - 40 gals	0	60 - 80 gals	1
40 - 60 gals	1	80 - 100 gals	2A
60 - 80 gals	1	100 - 120 gals	2B
80 - 100 gals	2A	-	

iii) Seismic zone

The study was carried out in various zones. The zones are Zone 1, Zone 2A and Zone 2B. Table 1.4 summarises the seismic zones identified in Malaysia ranging from Zone 0 to Zone 4 (Refer Table 1.4).

Table 1.4: Seismic Zones in Malaysia

Peak Ground Acceleration (gals)	**Seismic Zone**	**Seismic Zone Factor (Z)**
0 - 40	0	0.0
41 - 80	1	0.075
81 - 100	2A	0.15
101 - 150	2B	0.20
151 - 300	3	0.30
301 - 500	4	0.40

iv) Peak Ground Acceleration

In the design codes like IBC and Euro Code, Design Base Earthquake (DBE) is considered to have a return period of 475 years. Therefore, following these codes, if we want to design structures the DBE must be in reference for the calculation of the earthquake load.

The 500 year return period is preferably to be used in the research work is because in Malaysia the DBE is also the commonly used return period for the design of structures against earthquake loads.

Various values of peak ground acceleration were selected for the purpose of analysis. Since the study was carried out in the 500 year return period, three (3) ground accelerations in Zone 1 and three (3) in Zone 2. (Refer Table 1.5) This table shows the peak ground acceleration (pga) that has been selected and categorised meant for tower analysis. The zones are breakdown into various pga's within each dedicated range to enable a more specific pga value to be used for analysis purposes.

Table 1.5: Peak Ground Acceleration for Tower Analysis

No	Seismic Zone	Peak Ground Acceleration (gals)
1	Zone 1	0.04
2	Zone 1	0.06
3	Zone 1	0.08
4	Zone 2	0.08
5	Zone 2	0.10
6	Zone 2	0.12

(v) Selection of Analysed Towers

From structural point of view, since the study is concerning on the seismic behavior of 4 legged self-supporting towers and the scope carried out includes the different tower height ranges in the medium and high rise category; not the geometry of the towers.

For this study, two numbers of 4 legged self supporting steel tower from medium rise category and 4 numbers from high rise category are selected. There are six (6) numbers of towers in the respective category to be modeled in four (4) types of ground conditions and analysed on the different seismic zones.

These tower samples that are studied cover all of the current existing heights of towers in the country. They are anlaysed in different types of parameters such as the different seismic zones, peak ground acceleration and also ground types. These samples of tower are enough for the scope of the study on seismic behavior of the towers considering earthquake effects in Malaysia.

The summary is as tabulated in Table 1.6 below. The total numbers of analyses carried out were ninety six (96).

Table 1.6: Heights of Towers for Modeling and Analysis

Tower Category	**Tower Id**	**Height of Tower (meter)**
Medium Rise	T30	30
	T45	45
High Rise	T90a	90
	T90b	90
	T120	120
	T140	140

(vi) Ground Type

For this study various ground types were selected for each seismic zone for all the towers. These ground types that fall under the normal Malaysian condition were considered and used in the analysis work where the ground condition that has been applied in Euro Standards (EC8) and International Building Code (IBC) were referred. (Refer Table 1.7 for EC ground types and Table 1.8 for IBC ground types).

In EC8, Ground types A, B, C, D, and E, are described by the stratigraphic profiles and parameters given in Table 1.7 and described herein, were used to account for the influence of local ground conditions on the seismic action. This was done by additionally taking into account the influence of deep geology on the seismic action.

Table 1.7: Ground Types in European Standards (Standard EN-1:2003)

Ground Type	**Description of stratigraphic profile**	**Parameters**		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	-	-
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360-800	>50	>250
C	Deep deposits of dense or mediumdense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180-360	15-50	70-250
D	Deposits of loose-to-medium cohesionless soil (with or without some	<180	<15	<70

	soft cohesive layers), or of predominantly soft-to-firm cohesive soil			
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with v_s > 800 m/s.			
S_1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index (PI > 40) and high water content	< 100 (indicative)	-	10-20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S_1			

Table 1.8: Ground Types in International Building Code (IBC: 2009)

SITE CLASS	SOIL PROFILE NAME	AVERAGE PROPERTIES IN TOP 100 feet		
		Soil shear wave velocity, $\bar{v}$, (ft/s)	Standard penetration resistance, $\bar{N}$	Soil undrained shear strength, $\bar{s}_u$, (psf)
A	Hard Rock	$\bar{v}_s > 5{,}000$	N/A	N/A
B	Rock	$2{,}500\ \bar{v}_s \leq 5{,}000$	N/A	N/A
C	Very dense soil and soft rock	$1{,}200 < \bar{v}_s \leq 2{,}500$	$\bar{N} > 50$	$\bar{s}_u \geq 2{,}000$
D	Stiff soil profile	$600 \leq \bar{v}_s \leq 1{,}200$	$15 \leq \bar{N} \leq 50$	$1{,}000 \leq \bar{s}_u \leq 2{,}000$
E	Stiff soil profile	$\bar{v}_s < 600$	$\bar{N} < 15$	$\bar{s}_u < 1{,}000$
E	-	Any profile with more than 10 feet of soil having the following characteristics: 1. Plasticity index $PI > 20$,		

		2. Moisture content $w \geq 40\%$, and 3. Undrained shear strength $\bar{s}_u < 500$ psf
F	-	Any profile containing soils having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. 2. Peats and/or highly organic clays ($H > 10$ feet of peat and/or highly organic clay where H = thickness of soil) 3. Very high plasticity clays ($H > 25$ feet with plasticity index $PI > 75$) 4. Very thick soft/medium stiff clays ($H > 120$ feet)

1.6 Significance of the Research

This research considers earthquake effects on telecommunication tower structures mainly for the 4 legged types which are mostly found in the country. The researcher has managed to locate all the towers owned by TM on the 500 year return period seismic map. This map will enable TM to identify the location of the most critical towers in the various seismic zones that may have great exposure from earthquakes events.

The study is the pioneer in its field because this is the first time that an assessment system for 4 legged self supporting towers by considering earthquakes effects in the country is prepared. The tower assessment system consists all of the important attributes for inspection purposes, types of damages and also damage criterion not only for the tower structures but also related to the surrounding conditions.

The research is also able to determine the integrity of selected tower samples under various seismic zones in response to different peak ground accelerations and different ground types acted on it. This helps to understand the seismic behavior experienced by these towers.

The developed system thus helps to promote a uniform standard of practice among various parties besides assisting the relevant authority in making preparation from an emergency-management and hazard-preparedness perspective.

1.7 Contribution of the Research

The contribution of this research is to prove that the telecommunication tower assessment system considering earthquake effects in Malaysia will help to improve the capability of the industry in facing such situation and can be seen in terms of benefits gained by both the TM Group and the nation too in addressing such issues.

In addition, the tower distribution located in the seismic map prepared for TM covers all the 4 legged self supporting towers and can be used to predict the probability of imposed damage experienced by far fields effects of earthquakes especially related to ground movements. Moreover this helps the management to further prioritise resources in their yearly budget planning for maintenance work. The impact of the research on the New Economic Model is that it will help to promote a systematic and continuous interaction between the **Knowledge Triangle – Higher Education, Research in Industry and Innovation**. This will further improve the capability of the industry in facing such situations and can be seen in terms of benefits gained by both the TM Group and the nation. The research will help us to understand the impact and be able to mitigate besides prevent huge losses to assets and life caused by disaster such as earthquake events which will affect the economy and development of the nation, destroying means of production, distribution, and transportation of commercial products, and disruption of communications and public utility services. It will also help to boost the economic development especially in providing the best telecommunication services and also to transform Malaysia into a competitive, knowledge-based and innovative that will drive the country towards economic prosperity.

1.8 Organisation of Thesis

The organisation of the thesis can be described briefly as follows:

- Chapter 1 is the Introduction, which explains on the background, the aim, objectives, scope of research and limitations of the research.

- Chapter 2 is on Literature Review which explains the telecommunication facilities, infrastructure and society, the company overview where the research has been carried out, matters related to policy and ethics practiced in Telekom Malaysia (TM), its responsibility in the nation's telecommunication infrastructure and development in providing services to the nation. Overview of the importance of telecommunication towers and matters on maintenance cultures related to structures in Malaysia are also discussed here. Discussion on earthquakes matters; its effects and impacts, overview of the Malaysian authorities' actions on earthquakes effects including reviews of current engineering design and construction standards are also included. The importance of seismic mapping for the country is also discussed.

- Chapter 3 presents the theoretical background of linear analysis besides earthquake consideration in tower analysis using both EC and IBC codes besides other such as American Society of Civil Engineer (ASCE), Electronic Industry Association (EIA) and Telecommunication Industry Association (TIA).

- Chapter 4 is Research Methodology which explains the methodology to complete the research besides the data collection and analysis technique used in the study.

- Chapter 5 is on Model Development which details out the development of the tower assessment list, seismic mapping of telecommunication towers in the 500 year return period map, modeling and analysis works using SAP 2000 software carried out on the samples of selected structures.

- Chapter 6 is on Results and Discussion that discusses the highlights of the research where the results and analysis of towers are detailed out. Statistical analyses of feedbacks on questionnaires obtained from selected respondents are also discussed in detailed at the later part of the chapter.

- Chapter 7 is on Conclusion and Recommendations which explains the significance of the research findings including recommendation or suggestion and benefit of the research for future comparative study.

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