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COMPARISON ON THE EFFECT OF EARTHQUAKE AND WIND LOADS ON THE PERFORMANCE OF REINFORCED CONCRETE BUILDINGS

SUHANA BINTI SURADI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Structures)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

DECEMBER 2007

We hereby declare that we have read this thesis and in
our opinion this thesis is sufficient in terms of scope and
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For my beloved mother and father

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ABSTRACT

In the year of 2004 and 2005, tremors from the Sumatran earthquakes had brought safety concerns to the publics, government authorities, engineers and researchers especially when the tremors are felt frequently in Malaysia and no earthquake design had been taken into practices. This study addresses the effects of earthquake and wind loads on the performance of reinforced concrete buildings in Malaysia by evaluating the adequacy of the building design capacity. This study investigated seven existing buildings from West and East Malaysia. The buildings were categorised as medium and high-rise reinforced concrete moment resisting frames. The UBC-97, CP3:1972 and the MS 1553:2002 are used as the design codes in determining the lateral loads from earthquake and wind. The design capacity calculation for the frames was based on BS 8110. There are five types of analyses adopted; (i) Free Vibration Analysis (FVA), (ii) Earthquake Static Equivalent Analysis (ESEA), (iii) Static Wind Analysis (SWA), (iv) Earthquake Dynamic Response Spectrum Analysis (EDRSA) and (v) Earthquake Dynamic Time History Analysis (EDTHA). Results from FVA showed that five out of seven buildings produced high dynamic amplification factor in the range of 2.01 to 5.16. These values show that local earthquake events produce dynamic effect to the buildings due to characteristic of the earthquake and the similarity between building's and earthquake's frequencies. From this study the ESEA normally produced larger lateral design load than that from the SWA and EDRSA. ESEA also result in larger base shear and deformation response includes greater lateral displacement and inter-storey drift in the buildings. However, the performances of buildings were generally deemed unsatisfactory under SWA, ESEA and EDRSA which design capacity of shear force at beam element and axial load at column element were exceeded. Based on storey drift response from ESEA and EDTHA, there are potential failures for the medium rise buildings at lower storey levels. While for high-rise buildings, the failures can potentially occur at higher storey levels. The inter-storey drifts indicator indicates that only the non-structural elements of the buildings would be possibly affected. However, based on Park and Ang Overall Damage Index, the results show that the maximum overall damage may reach up to 0.11 at 0.20g of earthquake intensity which indicates a moderate damage level where extensive large crack and spalling of concrete in weaker elements may occur.

ABSTRAK

Pada tahun 2004 dan 2005 gegaran daripada gempa bumi di Sumatera telah meningkatkan tahap kesedaran orang ramai, pihak kerajaan, para jurutera dan para penyelidik tentang tahap keselamatan bangunan di Malaysia terutamanya apabila gegaran tersebut kian dirasai dan beban gempa bumi belum pernah diambil kira dalam reka bentuk. Kajian ini tertumpu kepada kesan beban gempa bumi dan beban angin terhadap prestasi bangunan konkrit bertetulang di Malaysia dengan mengenalpasti tahap keupayaan rekabentuk bangunan yang selamat. Kajian ini melibatkan tujuh buah bangunan termasuk di Malaysia Barat dan Timur. Bangunan-bangunan ini dikategorikan sebagai bangunan sederhana tinggi dan bangunan tinggi jenis kerangka rintangan momen konkrit bertetulang. Kod amalan rekabentuk UBC-97, CP3:1972 dan MS 1553: 2002 digunakan dalam menentukan beban rekabentuk gempa bumi dan angin. Pengiraan keupayaan rekabentuk untuk setiap kerangka bangunan adalah berdasarkan BS 8110. Terdapat lima jenis analisis yang digunakan iaitu (i) Analisis Getaran Bebas (AGB), (ii) Analisis Gempa Bumi Statik (AGS), (iii) Analisis Angin Statik (AAS), (iv) Analisis Spektra Gerak Balas Dinamik (ASGD), dan (v) Analisis Sejarah Masa Dinamik (ASMD). Keputusan daripada AGB menunjukkan lima daripada tujuh bangunan menghasilkan faktor pembesaran dinamik yang tinggi iaitu antara 2.01 hingga 5.16. Nilai ini menunjukkan bahawa siri gempa bumi tempatan menghasilkan kesan dinamik kepada bangunan-bangunan tersebut kesan dari prilaku gempa bumi dan kesamaaan antara frequensi bangunan dan gempa bumi tersebut. Hasil kajian ini menunjukkan bahawa AGS biasanya menghasilkan beban sisi rekabentuk yang lebih besar berbanding AAS dan ASGD. AGS juga menghasilkan ricih asas dan gerak balas ubah bentuk yang lebih besar termasuk anjakan sisi dan anjakan nisbi antara aras bangunan. Walau bagaimanapun, prestasi bangunan-bangunan tersebut secara keseluruhannya tidak selamat di bawah AGS, AAS dan ASGD dimana nilai daya ricih di rasuk dan daya paksi di tiang telah melebihi keupayaan rekabentuk elemen tersebut. Berdasarkan parameter anjakan nisbi antara aras untuk AGS dan ASMD menunjukkan bahawa potensi berlaku kegagalan struktur untuk bangunan sederhana tinggi adalah di aras bangunan yang lebih rendah manakala untuk bangunan tinggi potensi kegagalan akan berlaku di aras bangunan yang lebih tinggi. Keputusan ini menunjukkan bahawa hanya elemen bukan struktur akan mengalami kesan kerosakan. Walau bagaimanapun, berdasarkan Indeks Kerosakan Keseluruhan Park dan Ang, hasil kajian menunjukkan bahawa tahap kerosakan keseluruhan maksimum boleh mencecah sehingga 0.11 pada gempa bumi berintensiti 0.20g. Tahap kerosakan ini adalah sederhana yang mana keretakan besar secara menyeluruh dan kekopakkan konkrit di kawasan elemen yang lemah akan berlaku.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A_c	-	Area of the compressive reinforcing bars
A_t	-	Area of the tensile reinforcing bars
b	-	Clearance in window frame
β	-	Model constant parameter
β	-	Frequency ratio
C	-	Proportional damping matrix
C	-	Structural damping
$[C]$	-	Viscous matrix of the structure
c	-	Factor to amplify the curvature due to inelasticity of the concrete
C_a	-	Seismic coefficient depend on soil region
c_{corr}	-	Correction coefficient (usually taken as one)
Cr	-	Critical damping
C_v	-	Seismic coefficient depend on soil region
D	-	Dynamic magnification factor
d	-	Shear drift
d	-	Depth to rebar in inches.
d_c	-	Cover depth for compression bars
δ	-	Inter-storey drift index

δi	-	Static lateral displacement at level i due to the forces F_i computed on a linear elastic basis
δm	-	Maximum experienced deformation
δu	-	Ultimate deformation of the element
Δ_a	-	Allowable inelastic storey displacement
Δ_i	-	Lateral displacement
Δ_{top}	-	Overall drift
$\{\Delta F\}$	-	Vector of applied load increments
$\{\Delta F_{err}\}$	-	Vector with the unbalanced forces in the structure
$\{\Delta P_V\}$, $\{\Delta P_{FR}\}$, $\{\Delta P_{HY}\}$, and $\{\Delta P_{IW}\}$	-	Restoring forces from viscous dampers, friction dampers, Hysteretic dampers and infill panels respectively
$\{\Delta_u\}$	-	Vector of unknown nodal displacement increments
$\{\Delta u\}$, $\{\Delta \dot{u}\}$, and $\{\Delta \ddot{u}\}$	-	Incremental vectors of displacement velocity and acceleration in the structure respectively
$\Delta\ddot{x}_{gh}$ and $\Delta\ddot{x}_{gv}$	-	Increment in the horizontal and vertical ground accelerations
ε_c and $\varepsilon_c^{'}$	-	Maximum compression and tension strains in the concrete
ε_0	-	Strain at maximum strength of the concrete
ε_y	-	Strain at yield stress of steel
$f_c^{'}$	-	Concrete strength in ksi
Fi	-	Seismic lateral force at Level i

F_t	-	Force at the top
F_x	-	Lateral force at level *x*
f_{xn}, f_{yn}, f_{zn}	-	The participation factors
Φ	-	Matrix of corresponding eigenvectors
g	-	Acceleration due to gravity
H		Height of building
h	-	Height of wall or cladding unit
h	-	Overall height of structure
h	-	Height of the section
HBD	-	Ductility-based strength degradation
HBE	-	Energy control strength
HC	-	Stiffness degradation
h_i	-	Floor to floor of the structure
HS	-	Slip or crack closing parameter
h_x, h_i	-	Height in feet above the base at level *x* and *i* respectively
I	-	Seismic importance factor
I_g	-	Gross section
IBILINEAR	-	Vertex oriented model
φ_n or ϕ_n	-	Mode shape
K	-	Stiffness matrix
k	-	Coefficient for various units in the code of CP3: Chapter 5
k'	-	Neutral axis parameter (similar to *k*).
$[K_t]$	-	Tangent stiffness matrix

$\{L_h\}$ and $\{L_v\}$	-	Allocation vectors for the horizontal and vertical ground accelerations
λi	-	Energy weighting factors
M	-	Diagonal mass matrix
$[M]$	-	Lumped mass matrix of the structure
M_{cr}^{+} and M_{cr}^{-}	-	Positive and negative cracking moments
M_{u}^{+} and M_{u}^{-}	-	Positive and negative ultimate moments
m_x, m_y, m_z	-	Unit acceleration loads
M_x, M_y, M_z	-	Total unrestrained masses acting in the X, Y and Z direction
M_y	-	Yield moment
M_{y}^{+} and M_{y}^{-}	-	Positive and negative yield moments
N	-	Numbers of stories
N	-	Axial load in kips
n	-	Number of floors
N_a	-	Near sources factor
N_v	-	Near sources factor
Ω^2	-	Diagonal matrix of eigenvalues
P_y	-	Yield strength of the element
q	-	Dynamic wind pressure
θr	-	Recoverable rotation when unloading
θu	-	Ultimate rotation capacity of the section
θ_M	-	Maximum rotation attained during the loading history

S_1	-	Design wind speed factors (topography factor)
S_1	-	Maximum considered earthquake spectra response acceleration at a 1 second period
S_2	-	Design wind speed factors (ground roughness, building size and height above ground)
S_3	-	Design wind speed factors (statistical factor)
S_{D1}	-	Design spectral response at a 1.0 second period
S_{DS}	-	Design spectral acceleration in the short period range
$\int dEh$	-	Hysteretic energy absorbed by the element during the response history
T	-	Fundamental period of the structure
T_1	-	Fundamental period
u	-	The relative displacement
$\dot{u}$	-	Velocities
$\ddot{u}$	-	Acceleration with respect to the ground
$\ddot{u}_{gx}, \ddot{u}_{gy}, \ddot{u}_{gz}$	-	Component of uniform ground acceleration
V	-	Basic wind speed
V	-	Design base shear
V_s	-	Design wind speed
W	-	Seismic dead load
ω	-	Circular frequency
ϖ	-	Frequency of earthquake excitation
w_i	-	The seismic weight assigned in Level i
w_x, w_i	-	Portion of w located at level *x* and *i* respectively

$\overline{x}$	-	Distance from the base to the centroid of the section
ξ	-	Damping ratio
Z	-	Seismic zone factor
Z_e	-	Section modulus in in^3

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 General

Public building structures in Malaysia which include offices, apartment and hospitals are heavily developed in many states. This corresponds to the needs of quality life and increasing population. The public buildings in Malaysia are usually categorised as reinforced concrete buildings. These buildings are designed to resist gravity loads, wind loads and notional horizontal loads in accordance with the British code BS 8110, which does not have any special provision for seismic loads. However due to far-field effects of earthquake in Sumatra, these buildings are occasionally subjected to tremors.

In year of 2004 and 2005, repeated tremors from the Sumatran earthquakes had brought concerns to the public, government authorities, engineers and researchers on safety especially when no earthquake design practice had been taken into consideration for our buildings. As part of the responsibility to the public, this study concerns the safety aspect of public buildings due to seismic effects.

On 26 December 2004, the most powerful earthquake in 40 years triggered massive tidal waves that slammed into coastline across Asia which killed almost 100,000 people in the affected country. The havoc that happened in the aftermath of this wave should be taken as an early sign and lessons for the respective authority. The tsunami hit Penang, Kedah and Perlis and caused major damages and loss of lives. The 8.9 magnitude earthquake centered off the west coast of the Indonesian Island of Sumatra had caused tremors in Klang Valley, Selangor and other parts of the East Cost like Terengganu and Kelantan. Hundreds of civilians and patients were evacuated from hospitals, police stations, hotels, and apartments, until the vibrations that lasted for more than five minutes stopped.

This is only one of the scenarios that we have experienced at the end of year 2004 as reported in the media. Eventually many earthquake events from Sumatra's earthquakes since 1998 to 2007 have been reported repeatedly. The assumptions saying that Malaysia is free from earthquake an effect has changed since most of the tremors are felt, especially at medium and high-rise buildings. Thus the structure's safety and adequacy in resisting earthquake effects have been questioned. Detailed inspection and research should be conducted in the future to determine the exact performance of the building before and after each earthquake.

1.2 Objective

The objectives of the research are:

1). To identify the design base shear force for buildings in Malaysia by performing wind and earthquake static equivalent analyses.

2). To identify the design capacity level of buildings and the maximum allowable lateral load based on shear coefficients of wind and earthquake loadings by performing earthquake linear static and dynamic analyses.

3). To specify the damage level of buildings by performing earthquake non-linear dynamic analysis

Considerations on seismic effect on structural building design have not been practiced in Malaysia, because there are currently no design guidelines for seismic loads. Even though the development of the design guideline is on going, it may take time to publish. Therefore this study contributes to the development process for seismic loads especially for the reinforced concrete buildings.

1.3 Scope of Work

The scope of research covers some aspects mentioned below:

1). Seven public buildings were chosen from different locations in the Peninsular and East Malaysia which were categorized as medium-rise and high-rise buildings. All buildings are reinforced concrete moment resisting frame type. These buildings were chosen based on the typical existing building in Malaysia, varies of location, occupancy and varies of height level.

2). Finite Element Modeling was used in structural analysis, which consist of liner and non-linear analysis. The computer software, SAP 2000 was used in static and dynamic linear analysis, while IDARC 2D was used in dynamic non-linear analysis.

3). Various earthquake ground accelerations (0.05g, 0.10g, 0.15g, and 0.20g) were used in earthquake Static Equivalent, Response Spectrum and Time History Analysis. The ground motions were scaled to 5% damped spectral acceleration at the fundamental frequency of the structure. Therefore various wind velocities (20m/s, 30m/s, 40m/s, 50m/s) were used in the Wind Static Analysis.

4). UBC-97 and CP3:1972 were used as the design codes in determining the lateral load from earthquake and wind respectively. In order to identify the design capacity in each element of reinforced concrete building frames, the BS 8110 design code was referred.

1.4 Research Methodology

The steps for a comparative study of earthquake and wind loads on the performance of reinforced concrete buildings in Malaysia are shown in Figure 1.1. The chronological steps taken in the study are described below.

Step 1: Literature, Collecting Data and Design Specifications for Reinforced Concrete Buildings

The collection of related information on potential seismic risks in the region as well as the related research work done by others researchers was emphasized in this stage. Background studies of existing buildings in Malaysia that did not consider seismic effects were reviewed. The current practice of wind design in Malaysia was reviewed. Selected building data for modeling analysis were collected from the government authorities. Then, design specifications for each building were identified.

Step 2: Technique for Finite Element Modeling and Analysis Design

To study the performance of buildings, Finite Element Modeling was used in structural analyses, which consist of linear and non-linear analysis. The computer software, SAP 2000 was used in static and dynamic linear analysis, while IDARC 2D was used in dynamic non-linear analysis. Under the static equivalent linear analysis, buildings performances under wind and earthquake load were compared. Dynamic analysis (e.g. free vibration analysis, time history analysis and response spectrum analysis) were used for further study of seismic load effects.

Step 3: Performance of Reinforced Concrete Buildings

The response obtained from static wind analyses, and both static and dynamic seismic analyses which were conducted in previous step were used for subsequent comparison. Thus, the governing parameter (wind or earthquake) were determined. In addition, the responses of buildings were evaluated to check whether the component forces and deformation meet the criteria requirements. Other parameters such as base shear and moment base capacities of buildings were compared to identify the optimum acceleration levels that can cause failures to the building structures under the various intensities of earthquake. Therefore to evaluate the expected damage, appropriate structural response parameters such as inter-storey drift, and damage index were used.

Step 4: Discussion and Conclusion

The final step presented the summary and conclusion of the whole study, which includes discussion and recommendations of the study to improve the research.

1.5 Organisation of Thesis

The thesis is divided into six chapters, as shown in Figure 1.1. Chapter 1 outlines the general introduction, objective of the study, scope of work and the methodology used. Detail literature reviews are presented in Chapter 2. In this chapter current Malaysia practice of wind and seismic design and potential of seismic activities in Malaysia are discussed. The performances of the reinforced concrete buildings from previous studies are also discussed. Chapter 3 outlines the theoretical background which includes the static linear analysis for wind and earthquake. Besides further analysis in earthquake dynamic linear and non-linear is also emphasized in this chapter. The modeling techniques applied for finite element analysis are shown in Chapter 4. This chapter also highlights the earthquake dynamic analysis method which includes free vibration, response spectrum and time history analysis. Chapter 5 presents the results of modeled analyses in terms of the performance of reinforced concrete buildings. This includes dynamic response of structure, maximum stress, maximum response and damage analysis. Chapter 6 summarizes the findings of this study and the conclusions from this research. Recommendations are listed in this chapter to improve the research for the betterment of the next generation.

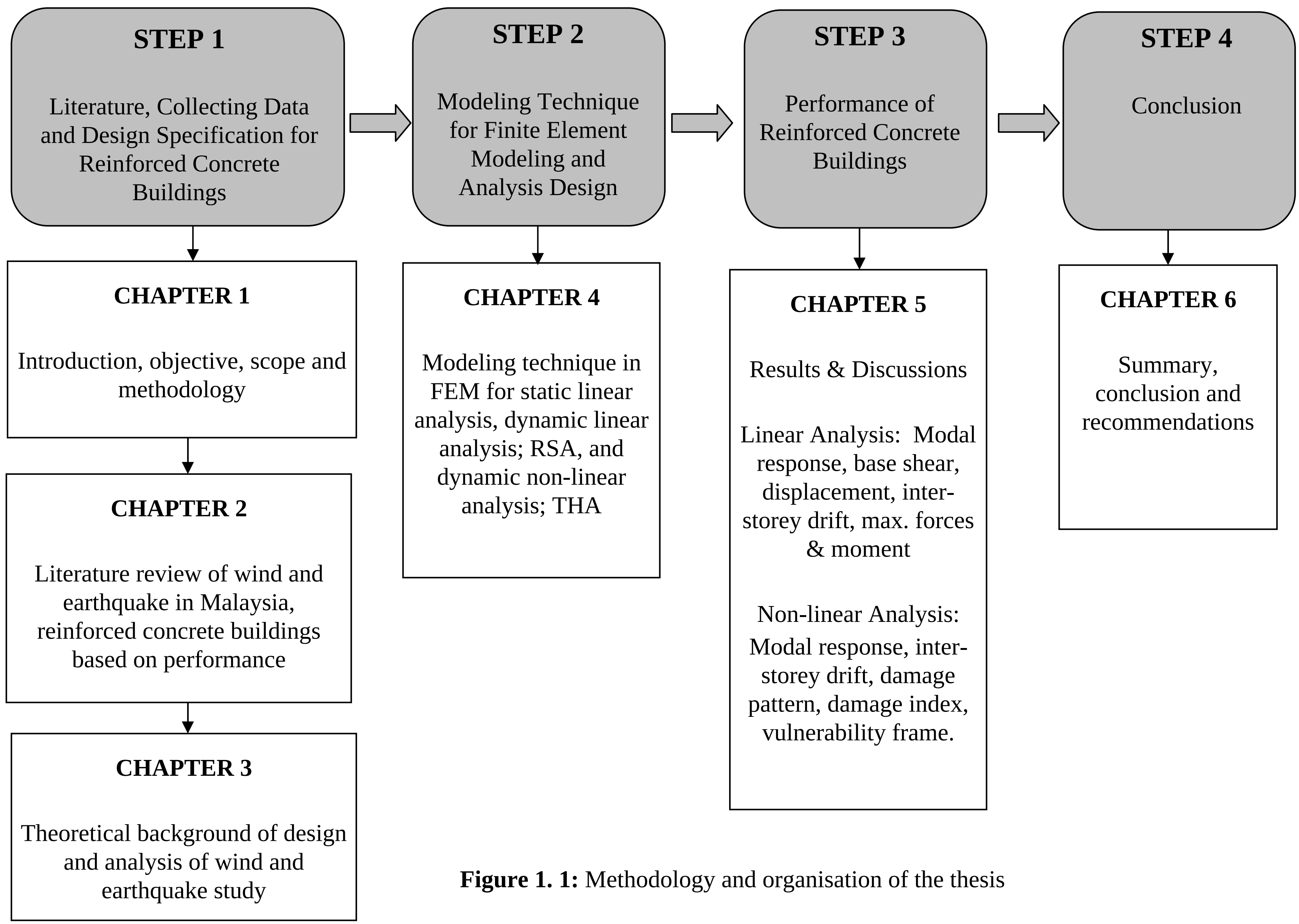

Figure 1. 1: Methodology and organisation of the thesis