ASSESSMENT OF SEISMIC SCENARIO-STRUCTURE-BASED LIMIT STATE CRITERIA FOR 23-STOREY OF RC HIGH-RISE BUILDING

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By

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I hereby declare that all corrections and comments made by the supervisor(s) and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Isu-isu berkaitan untuk konkrit bertetulang bertingkat tinggi bangunan adalah berbeza scenario seismik seperti gempa bumi jarak jauh dan jarak dekat boleh menyebabkan perbezaan tahap dan lebih kompleks struktur gunung berapi senario yang berkaitan dengan kerosakan global. Objektif kajian ini adalah untuk menilai struktur gempa bumi senario untuk 23 tingkat bangunan konkrit bertetulang bertingkat tinggi berdasarkan perbezaan ukuran dan membangunkan lengkung kerapuhan dengan kriteria keadaan had yang berbeza. Dalam kajian ini, 23-tingkat, 83.95m tinggi, struktur konkrit bertetulang dipilih sebagai sebuah bangunan wakil sampel untuk menilai struktur gempa bumi senario. Enam rekod pergerakan tanah dipilih mewakili dua senario gempa bumi. Bangunan berasaskan senario seismik respon global meningkatkan mengukur keamatan gempa bumi telah dibuat menggunakan analisis dinamik tambahan. IDA lengkung dan anjakan antara tingkat adalah kajian berparameter. Prestasi struktur dan kerosakan ukuran RC bangunan tinggi telah dinilai dengan keadaan had prestasi berasaskan Prestasi Berdasarkan Rekabentuk Seismik (PBSD). ATC-43 (1998), mencadangkan empat tahap prestasi: Prestasi Operasi (OP), Penghunian Serta-Merta (IO), Keselamatan Hidup (LS) dan Pencegahan Kejatuhan (CP). Berdasarkan lengkung IDA, ia menunjukkan bahawa kesan gempa bumi jarak dekat mempunyai frekuensi tinggi yang memberi kesan pada awal keamatan ukuran pada bangunan runtuh berbanding kesan gempa bumi jarak jauh. Sementara itu, hasil anjakan antara tingkat menunjukkan bahawa kesan gempa bumi jarak dekat mempunyai kesan ketara yang besar ke arah kerosakan bangunan berbanding kesan gempa bumi jarak jauh. Mengenai kerapuhan lengkung, kesan gempa bumi jarak jauh mempunyai kesan yang sangat tinggi ke arah kerosakan struktur berbanding kesan gempa bumi jarak dekat.

ABSTRACT

Issues regarding to RC high-rise building is different seismic scenario such as near and far-field earthquake can result in difference levels and more complex of seismic scenario structure related to global damage. The objectives of this study are to evaluate the seismic scenario structure for 23-storey of RC high-rise building based on different damage measure and to develop the fragility curve with different limit state criteria. In this study, a 23-storey, 83.95m in height, RC structure is selected as a representative sample building to evaluate the seismic scenario structure. Six ground motions are selected representing two seismic scenarios. Seismic scenario-based building global response at increasing earthquake intensities measure is adopted using Incremental Dynamic Analysis. IDA curves and interstorey drift are the parametric study. The structural performance and damage measure of RC high-rise building were evaluated with the Performance Based Seismic Design (PBSD) limit state. ATC-43 (1998), proposed four performance levels: operational performance (OP), immediate occupancy (IO), life safety (LS), and collapse prevention (CP). Based on the IDA curves, it shows that near field effect has high frequency that gives impact at early intensities measure on building collapsed compared to far field effect. Meanwhile, interstorey drift result indicates that the near field effect has large effect towards the building damage compared to the far field effect. Regarding fragility curves, far field earthquake has larger effect towards the structural damage compared to the near field.

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LIST OF ABBREVIATIONS

RC/RCC	**R**einforced **C**oncrete
EDP	**E**ngineering **D**emand **P**arameter
DM	**D**amage **M**easure
IDA	**I**ncremental **D**ynamic **A**nalysis
MRIDA	**M**ulti **I**ncremental **D**ynami**c** **A**nalysis
EC8	**E**urocode 8
IM	**I**ntensity **M**easure
PLS	**P**erformanc**e** **L**imit **S**tate
ASFR	**A**nalytical **S**eismic **F**ragility **R**elation
PGV	**P**eak **G**round **V**elocity
PI	**P**ulse **I**ndex
OP	**O**peration **P**erformance
IO	**I**mmediate **O**ccupancy
LS	**L**ife **S**afety
CP	**C**ollapse **P**revention
TISD	**T**otal **I**nter**-S**tory **D**rift
NISD	**N**et **I**nter**-S**tory **D**rift
PEER	**P**acific **E**arthquake **E**ngineerin**g** **R**esearch
FF	**F**ar **F**ield
NF	**N**ear **F**ield
PGA	**P**eak **G**round **M**otion
3D	**3 D**imension

CHAPTER 1

INTRODUCTION

1.1 Background

Earthquake is a natural phenomenon that can happen anytime or anywhere. Earthquake happened because when the stress is increases within the rocks of the earth`s crust is released in a sudden push. This result in rocks to crack and slip past each other that causes vibration of the ground surface. Faults which are cracks along the rocks slip can break through the ground surface or deep within the earth. Focus where the first clip occurs is directly position above it on the ground surface is called as the epicentre (Adagunodo and Sunmonu, 2015).

All over the world, there is a high demand for construction of high rise buildings due to increasing urbanization and increase rapidly in population. Earthquake phenomenon can cause the greatest damages to high-rise structures. Furthermore, earthquake forces are random in nature and unpredictable that needed for engineering tools to be enhanced for analyzing structures under the action of these forces. Therefore, earthquake loads are required to be carefully modelled so as to determine the real behaviour of structure with a clear understanding that damage is expected but it should be managed. Analyzing the structure with different earthquake intensities and checking for multiple criteria at each level has become an essential exercise for the last couple of decades (Mohan and Prabha, 2011; Juni et al., 2017).

Many researched have been carried out to study the behaviour of the structure towards the earthquake scenario. Thus, it is essential to understand the structure performance under multi-hazard loadings in order to apply such knowledge to design.

Furthermore, according to Mwafy et al. (2006), there is a significant increase in attention to understand complex behaviour of the high-rise building particularly under seismic loading. Regions subjected to low-to-moderate seismic hazard are not risk from powerful earthquakes and therefore, it is more economical to construct high-rise buildings. An example of such regions is Dubai, United Arab Emirates, where the increasing number of high-rise buildings currently under construction is more noticeable. One of the most important earthquake scenarios for such a region would be for severe earthquakes generated in neighbour regions. Such earthquakes would generate low levels of ground motion acceleration at the site and therefore often overlooked.

Earthquake phenomenon can result in immediate destruction such as collapsed building, dam failures, landslides, flooding and etc. Destruction of property may have a serious impact on shelter needs, economic production and living standards of local populations. Depending on the vulnerability of the affected community, large numbers of people may be homeless after the earthquake happened. According to Ibarra and Krawinkler (2005), protection against collapse has always been a major objective of seismic design. In terms of earthquake engineering, collapse indicates to the loss of ability of a structure system to resist gravity loads in the presence of seismic effects. Collapse can be either local or global. The local damage indicates stiffness and strength decrease. Meanwhile, a global damage can be defined as the overall damage state and serviceability of the structure.

Figure 1.1: Mexico City building collapsed with 7.1 magnitude earthquake (https://finance-commerce.com/2017/09/mexico-assesses-quake-damage-to-economy/)

1.2 Problem Statement

Nowadays, the numbers of high-rise building have expanded rapidly because of the changing socioeconomic conditions, rapid population growth and urbanization. The expansion of high-rise building spread to the cities that subjected to multiple-scenario earthquake-prone regions. Recently, development of commercial high-strength concrete and new advances in construction technologies influence developments of RC high-rise building. This increases the exposure to seismic risk that need to be accurately quantified and appropriate mitigated the hazard and vulnerability of RC high-rise building (Moon, 2007; W Alwaeli et al., 2014; Alwaeli et al., 2017a; Alwaeli et al., 2017b).

Issues regarding to RC high-rise building is different seismic scenario such as near and far-field earthquake can result in difference levels and more complex of seismic scenario structure related to global damage. Engineering Demand Parameters (EDPs) for buildings are such as inter-story drift ratio, inelastic component structure deformations such as plastic hinge rotations and floor accelerations which can be defined from inelastic time history. The structural element performance results from analyses were used to link EDP to Damage Measure. Damage Measures (DMs) describe the physical condition of the structure including effective descriptions of damage to characterize the performance limit state criteria (Ghobarah, 2004; Dantanarayana et al., 2012; W Alwaeli et al., 2014). Therefore, a study of the behaviour of the structure of the RC high-rise building is needed where suitable DMs need to be considered.

Regarding to Ghobarah (2004), the limit states of the structure are selected based on damage levels related to the performance objectives. Difference limit states will develop difference fragility curve that represent probability of damage occur. On that account, it is necessary to create fragility curve with different limit states criteria where it represents the global response for RC high-rise building.

1.3 Objectives

Two of the major objectives of this research are listed below:

1. To evaluate the seismic scenario structure for 23-storey of RC high-rise building based on different damage measure.
2. To develop the fragility curve for 23-storey of RC high-rise building with different limit state criteria.

1.4 Organization and Outline

Chapter 1 gives an introduction on what is an earthquake and how does it happen. This chapter also explained development of the structure building as well as the RC high-rise building widely being used. The problem related to the RC high-rise building and objectives for this study are well defined.

Chapter 2 describes the review from the researcher to have a better understanding for this study. Study regarding RC high-rise building is important to understand the behaviour of the structure.

Chapter 3 explains the methodology for this study including with a flow chart. In this chapter, the details regarding of sample building is well defined. Other than that, selection of ground motion by considering far and near field seismic scenario is well discussed.

Chapter 4 discusses the results obtained from the nonlinear dynamic analysis done by using the software. Based on the results obtained, IDA curves, interstorey drifts and fragility curves are developed. By comparing between far and near field effects, all the parameters are discussed in this chapter.

Chapter 5 concludes the result from this study and proposed suggestions for further study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, review from the past researcher about this study to have a better understanding. Nonlinear Dynamic Analysis which is Incremental Dynamic Analysis (IDA) is a very important section covered in this study. This is because to complete the analysis, this analysis must be done to come out with the result of the structural performance. Other than that, ground motion which is near and far-field are applied during the analysis. Engineering Demand Parameters (EDPs) are the parameters of the Damage Measure (DM) that will be discussed in chapter 4.

2.2 High-Rise Building

Recent years, a massive increase in high-rise buildings spread to the cities and multiple-scenario earthquake-prone region resulting in exposure to seismic risk because of the changing socioeconomic conditions, rapid population growth and urbanisation (W Alwaeli et al., 2014; Alwaeli et al., 2017a; Alwaeli et al., 2017b).

According to Wood et al. (2008), high-rise building is defined as a building with height exceed 50m. However, performance-based assessments are required in some countries such as Japan and China because of the active regions. In China`s highest seismic zone, the maximum height for code-designed reinforced concrete structures is 80m where the height limitation depend on the seismic zone, the structural material and the structural systems adopted. For buildings with exceeding limitation, a performance-based approach is needed to signify adequate seismic performance and the design must passing an expert panel review. Meanwhile in Japan, a consistent performance based philosophy with the best international practice is required by regulatory authorities for buildings exceeding 60m.

Based on Ji et al. (2009), there are two important parameters when assessing the seismic performance of high-rise buildings. Firstly is wide range frequency content in real ground motion stimulate both lower and higher modes and result in very complex seismic demands. Secondly is the imposed displacements in earthquake may be very substantial since the standard earthquake displacement spectrum peaks in the period of 3-6s which corresponds to the fundamental modes of many RC high-rise structures, especially when responding in the inelastic range.

Determination of seismic vulnerability of high-rise buildings has limited information because there has no effective procedure for conducting such assessments. The assessment of seismic risk is continued through the use of fragility relationships developed under different classification of structures. There are several challenges identified to develop fragility relationships for RC high-rise buildings which are complex nonlinear behaviour of structural concrete members and computation time consuming for conducting large amount of simulation.

Based on Mwafy et al. (2006), it is important to insistence that the response of the investigated structure, which has observable reserve strength, distressing under the severe distant records and reflects the need for considering this seismic scenario for similar structures and sites. The characteristic difference in earthquake induced response due to large distant events and moderate close earthquake is predicted from their response spectra and the uncracked periods of vibration. The global response from the severe distant earthquake shows the response is slightly beyond the yield limit state while under moderate close records, the response is entirely elastic.

Based on Asgarian et al. (2010), for high-rise building, the higher modes typically contribute significantly to the seismic response at least in the elastic range. Therefore, global drift ratio is less effective for high-rise buildings than it is for a shorter building which response is dominated by the fundamental mode. Figure 2.1 shows that the global drift is approximately zero but the structure experienced significant damage.

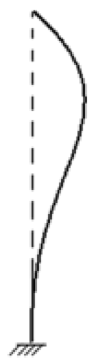

Figure 2.1: Global drift ratio inefficiency

Table 2.1 shows the study regarding high-rise RC building with various type of scheme. This showed that many research has been done regarding high-rise RC building with so many approach and objectives.

Table 2.1: Case Study of RC high-rise building

Author	Type of High Rise Building	Scope of Study
Juni et al. (2017)	23-storey RCC residential building.	Using five different nonlinear dynamic time history analysis considering different seismic intensities to develop the relationship between seismic intensities and seismic responses.
Ji et al. (2009)	54-storey RC high-rise building with a dual core wall system.	Using thirty strong ground motion records for nonlinear dynamic analyses to produce appropriate range in structural response characteristics due to variation in magnitude, distance and site condition.
W. Alwaeli et al. (2017)	30-storey RC high-rise wall building.	Using incremental dynamic analyses (IDAs) method with improved intensity measure (IM) to develop the fragility relations for RC high-rise wall structures based on defined performance limit states (PLSs).
Archila and Ventura (2012)	44-storey RC high-rise building located at downtown Vancouver, British Columbia, Canada with a core all, perimeter columns and flat plate slabs.	Demonstrates the sensitivity of the calculated nonlinear dynamic response towards horizontal ground motion directionality.
Alwaeli et al. (2017b)	30-storey RC high-rise wall building located at multi-seismic scenario.	The study is to propose the methodology at a reliable definition of limit state criteria for an inventory of RC high-rise wall buildings under multiple earthquake scenarios.
Alwaeli et al. (2014)	30-storey RC high-rise wall building located at Emirate of Dubai (United Arab Emirates).	This study presents a framework and model application for the development of reliable analytical seismic fragility relations (ASFRs) for code-compliant, reinforced-concrete (RC) high-rise wall structures.
Mwafy et al. (2006)	187m high-rise tower with a specific site hazard study, city of Dubai, UAE.	The study presents comprehensive hazard and vulnerability study for the selected test case and conclusions about performance of the high-rise building when subjected to large-distant and small-close earthquakes.

2.3 Seismic Behaviour of Soft Story Building

A soft story is defined as a story in a building that has essentially less resistance or stiffness or inadequate ductility in terms of energy absorption capacity to resist the earthquake induced building stresses. Soft story buildings known as weak story buildings are identified by having a story which has a lot of open space or large retail spaces or floors with a lot of windows such as parking garages. Figure 2.2 shows the cross section of a soft story building.

Besides, soft story creates a major weak point in an earthquake and since soft stories are associated with retail spaces and parking garages, they are often on the lower stories of a building. This indicates that when they collapse, they can take the whole building down with them and causing serious structural damage which may contribute the structure totally unstable (Hejazi et al., 2011).

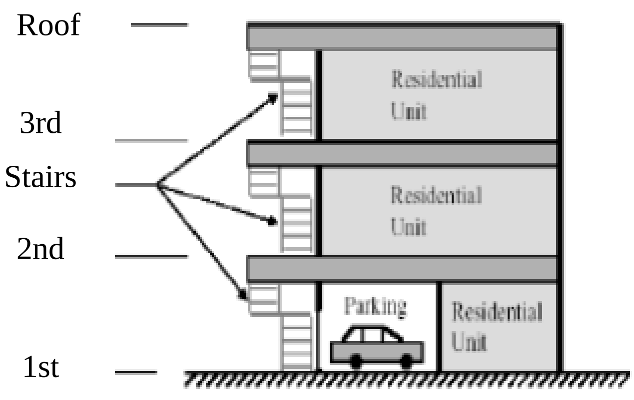

Figure 2.2: Cross Section of a Soft Story Building. (Hejazi et al., 2011)

As studied by Nirkhe et al. (2016), in India almost all multi-story buildings consists of soft storey because of fist storey get accommodated for parking or reception and the second storey used for brick wall construction. Accordingly, in soft storey building, the upper storey being stiff and undergo small interstorey drifts. However, the interstorey drift in the soft first storey is large. This shows that the strength demands on the columns in the first storey for third buildings are also large, as the maximum shear in the first storey. Regarding the upper storey, the forces in the columns are effectively reduced because of the uneven lateral force distribution along the height that results in stress concentration. Figure 2.3 shows the nominal damages occurs at Ajanta apartment`s buildings.

Figure 2.3: Collapse of multi-storey building due to soft storey. (Nirkhe et al., 2016)

Meanwhile, based on studied by By and By (2017), they found out that as the level of the soft storey increase the value of displacement decrease and as the level of soft storey decreases the value of time period increases. In order to reduce the displacement, they suggested to provide soft storey at highet levels and provide shear wall to reduce the earthquake effect in soft storey.

2.4 Nonlinear Dynamic Analysis

Nonlinear Dynamic Analysis or Time History Analysis is the only universally appropriate method to demonstrate the performance of structures and attempts to fully represent the seismic response of buildings without any of these major simplifying assumptions (Chambers and Kelly, 2004; Wilkinson and Hiley, 2006; Patil and Kumbhar, 2013).

The objectives of IDA are:-

1. Understand the range of response versus the range of potential levels of a ground motion record,
2. Understand structural implications of severe ground motion levels,
3. Good understanding regarding changes in the nature of the structural response as the intensity of ground motion increases,
4. Produce estimation of the dynamic capacity of the global structural system and
5. Based on a multi-record of IDA, able to understand how the variables are stable from one ground motion to another (Vamvatsikos and Cornell, 2002).

Nonlinear Dynamic Analysis is practical to be used for tall building and many structural engineers used the analysis for earthquake resistant design. Based on Powell (2006), Nonlinear Dynamic Analysis required step-by-step integration that applied for nonlinear behaviour. Other than that, in nonlinear dynamic analysis, inelastic deformation also calculated such as the rotation at a plastic hinge. Based on ATC-43 (1998), Nonlinear Dynamic Analysis must be performed with at least three data sets of appropriate ground motion time histories that must be selected and scaled from at least three recorded events.

Nonlinear dynamic analysis which is incremental dynamic analysis (IDA) is a parametric analysis method that has been enhanced in several forms to estimate more thoroughly structural performance under seismic loads. The IDA involves one or more ground motion records, each scaled to multiple levels of intensity (example 0.1g) subjected to a structural model that produced one or more curves of response parameterized versus intensity level (Vamvatsikos and Cornell, 2002).

A single-record IDA study cannot fully estimate the behaviour of a building thus, sufficient number of records is needed to cover the full of responses. Multi-Record Incremental Dynamic Analysis (MRIDAs) is a collection of single-record IDA studies of the same structural model, under different acceleration ground during an earthquake.

Based on Asgarian et al. (2010), IDA was well documented and introduced by Vamvatsikos and Cornell (2002) but the concept of seismic load scalling had been formerly used by several authors to assess the performance of structural frames in builldings. However, beyond its advantages, IDA had created challenges that need to be overcome. In conjunction to have an accurate IDA curve, sufficient amount of nonlinear time history analyses are needed and in order to provide sufficient accuracy in the estimation of seismic demands, several records need to be applied. Other than that, it is important to the analysis is the post processing of the resulting data and the most important issues is selecting a suitable Intensity Measure (IM) and EDP. As nonlinear dynamic analysis to become more commanly used procedure for evaluating the demand on a structure due to earthquake, it is increasingly important to understand which properties of a recorded ground motion are most strongly related to the response caused in the structure.

Therefore, a value should be defined to quantify the effect of a record on a structure that is IM. Other than that, in process performing the analysis, once the model has been formed and the ground motion records have been selected, a fast and automated way are needed to perform the actual dynamic analyses for IDA. This required suitable scalling each record to cover the entire range of structual response, from elasticity to yielding and finally to global dynamic instability. Analyses are performed at rapidly increasing levels of IM until signalling global dynamic instability while additional analyses are run at immediate IM levels to sufficiently bracket the global collapse and increase the accuracy at lower IM. Concerning the computational cost, it is obviously that the more analyses per record, the better accuracy and the longer time needed for IDA to complete.

2.5 Selection of Ground Motion

Many sites around the world can be exposed to near and far field earthquake events. The two scenarios have different impacts on high-rise buildings that need to be studied Mwafy et al. (2006). The near field distance generally affects the ground motion at the site through path attenuation and high-frequency filtration. By depends on the characteristic of the site soil strata, the seismic wave can be identified as amplified or dissipated while travel from the bedrock to the ground level that results in dynamic behaviour of wide frequency-sensitive high-rise buildings. A distant large-magnitude earthquake imposes, however, potentially very large displacement demands as well as excited long period (usually fundamental period) modes (Alwaeli et al., 2017a).

According to Baker (2007), there are three quantitative criteria to identify near-field ground motion which are the velocity pulse appears at the beginning of the record, recorded PGV is larger than 30cm/s and pulse index (PI) is larger than 0.85. However, based on Kumar et al. (2011), the boundaries to define near-field and far-field based on period records were not clearly identified. Meanwhile, it depends on the parameters such as shaking intensity and structural characteristics.

According to Alwaeli et al. (2017a), the ratio ground motion acceleration to velocity ratio (a/v) develop an important measure to the magnitude, frequency content and site-to-source distance of the earthquake scenario. High ratio of a/v which is greater than 1.2 g/ms^{-1} indicates the scenario with high dominant frequencies, medium-to-small magnitude, short site-to-source distances and short duration periods. Meanwhile, low ratio of a/v which is less than 0.8 g/ms^{-1} indicates the scenario with low dominant frequencies, high-to-medium magnitude, long site-to-source distances and long duration periods.

2.6 Performance Based Seismic Design

Performance based seismic design basic concept is to present engineers with the potential to design buildings that have a predictable and reliable performance in earthquake and to select a level of performance that satisfy their needs while retaining a basic level of safety. The objective is the specification of an acceptable level of damage to a building if it experiences an earthquake (ATC-43, 1998).

Based on Wood et al. (2008), performance objective relevant for high-rise buildings are based on performance expectations from most of the building design codes. Seismic design procedures of American, Japanese, Chinese, New Zealand codes and Eurocode 8 are expect that a building designed will resist a minor level of earthquake ground shaking without damage, resist the design level of earthquake ground shaking with damage but without causing extensive loss of life and resist the strongest earthquake shaking expected at the site without total collapsed but potentially with extreme damage. These performance objectives have formed the fundamental of structural design of countless high-rise buildings.

Performance level is condition of a building after experience an earthquake by measure the damage occurs towards the building. A building performance level is combination of a structural performance level and a non-structural performance level to describe of an overall damage level.

The structural performance levels are Operational Performance (OP), Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) as shown in Figure 2.4.

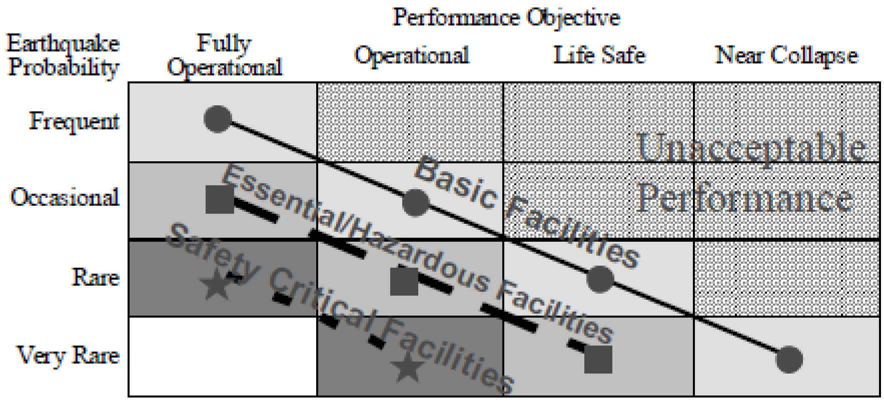

Figure 2.4: The Structural Performance Levels (http://peer.berkeley.edu/course_modules/eqrd/index.htm?c227top.htm&227cont.htm&DesPhil/desphil5.htm)

i. Operational Performance (OP):

All the systems important to normal operation are still functional. There is no permanent drift and very light damage with lower risk. The structure substantially remains at original strength and stiffness. This scenario usually occurs at drift ratio 0.5%.

ii. Immediate Occupancy (IO):

Minor cracking occurs but the structure substantially still remains at original strength and stiffness. No permanent drift and light damage with lower risk. This scenario usually occurs at drift ratio 1%.

iii. Life Safety (LS):

Damage is moderate but the structure still remains stable. Some of the elements structure or contents might be protected from damage. Life safety is generally protected. Repair is possible but economically impractical. This scenario usually occurs at drift ratio 1.5%.

iv. Collapse Prevention (CP):

Damage is severe but structural collapse prevented. Non structural elements might fall. Large permanent drift and building is near collapse. This scenario usually occurs at drift ratio 2.5%.

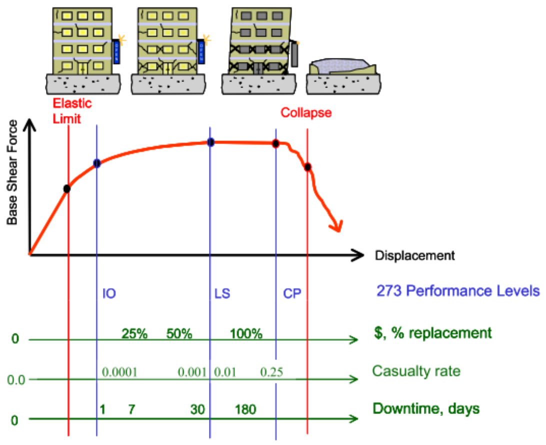

Figure 2.5: Illustration of performance based-earthquake engineering. (Whittaker et al., 2004)

Figure 2.5 shows the behaviour of the structure at each of the limit states. A building is loaded by earthquake-induced lateral forces that produce nonlinear response or damage in structural components. Connection between structural response such as interstorey drift, inelastic member deformations and member forces and performance oriented descriptions such as Immediate Occupancy (IO), Life Safety (LS), and Collapse

Prevention (CP) (Whittaker et al., 2004). Meanwhile Table 2.2 shows the drift limit (%) for each of the performance level.

Table 2.2: Drift (%) for each of the performance level. (ATC-43, 1998)

Performance Level	Drift (%)
Operational Performance (OP)	0.5%
Immediate Occupancy (IO)	1.0%
Life Safety (LS)	1.5%

2.7 Engineering Demand Parameter

Engineering Demand Parameters, EDPs are structural response quantities that can be used to estimate the amount of damage to structural and non-structural components and systems. A few individual researchers have explored that EDPs could be used to improve performance estimation and reliability. EDPs can be categorized into two which is direct and processed. Direct EDPs are EDPs calculated from analysis software such as interstory drift while processed EDPs can be consider as DM that served to characterized limit state of damage and structural performance such as damage index (Whittaker et al., 2004; Dantanarayana et al., 2012) .

Based on case study by Alwaeli et al. (2017a), the researcher found out that Total Inter-Story Drift (TISD) can be responsible for non-structural damage in high-rise building and inconvenience of the occupants. Therefore, it is important that at least to evaluate the performance of high-rise buildings at serviceability level. The researcher also conclude that to implement Net Inter-Story Drift (NISD) as the global damage measure because of its structural significance, its correlation with local response and its consistency in buildings with varying heights.

Meanwhile based on case study by Dantanarayana et al. (2012), frame structures were observed to have a maximum interstorey drift at the base of the structure and for the wall structures occurred at the top level of the structure. Maximum interstorey drift increased with increasing design ductility. The acceleration of demands was found to stop with increasing design target drift and ductility. This is because of the reduction in stiffness as the structure undergoes larger displacements that results in attraction of lower floor accelerations. Floor accelerations were found to become more uniform as the height of the structure increases.

The relation between roof drift and storey drift also has been studied by Gupta and Krawinkler (2000). The distribution of storey drifts over the height of the structure and therefore the relationship between storey drifts and roof drift is strongly dependent on the ground motion and structure characteristics. Other than that, maximum storey drift refers to the maximum drift over the height of the structure. This indicates different maximum drift can occurs in different stores under different ground motion. Meanwhile, for the structures that undergo maximum storey drift at the upper stories cases is generally affected by higher mode effects and in lower stories cases is controlled by P-delta effects.

2.8 Summary

Based on literature review done, RC high-rise buildings are widely applied and construct. The behaviours of the RC high-rise buildings are well defined. Nonlinear dynamic analysis is a very important analysis in this study to study the performance of the building. Meanwhile the EDP is the parameter to express the performance damage of the structure. Reviews from researcher helps to gain knowledge and understanding in this study.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter briefly explained the methodology for this study. All the details about RC high-rise building are well defined in this chapter. SAP2000 is the software that is being used for nonlinear modelling and to run the analysis. Briefly, after the analysis done, the IDA curves were plotted until achieved the limit state based on the performance limit state criteria. Fragility curve were plotted based on the different limit state. The behaviour of the building sample was being observed based on different damage measure.

3.2 Flow Chart of Research Methodology

Figure 3.1 shows the flow chart of research methodology. The methodology is demonstrated on a 23-storey RC high-rise building. Six ground motion under far and near field ground motion are downloaded via PEER database. 3D model of sample building is formed and IDA was performed by using SAP2000. The results from IDA are evaluated based on the different seismic scenario.

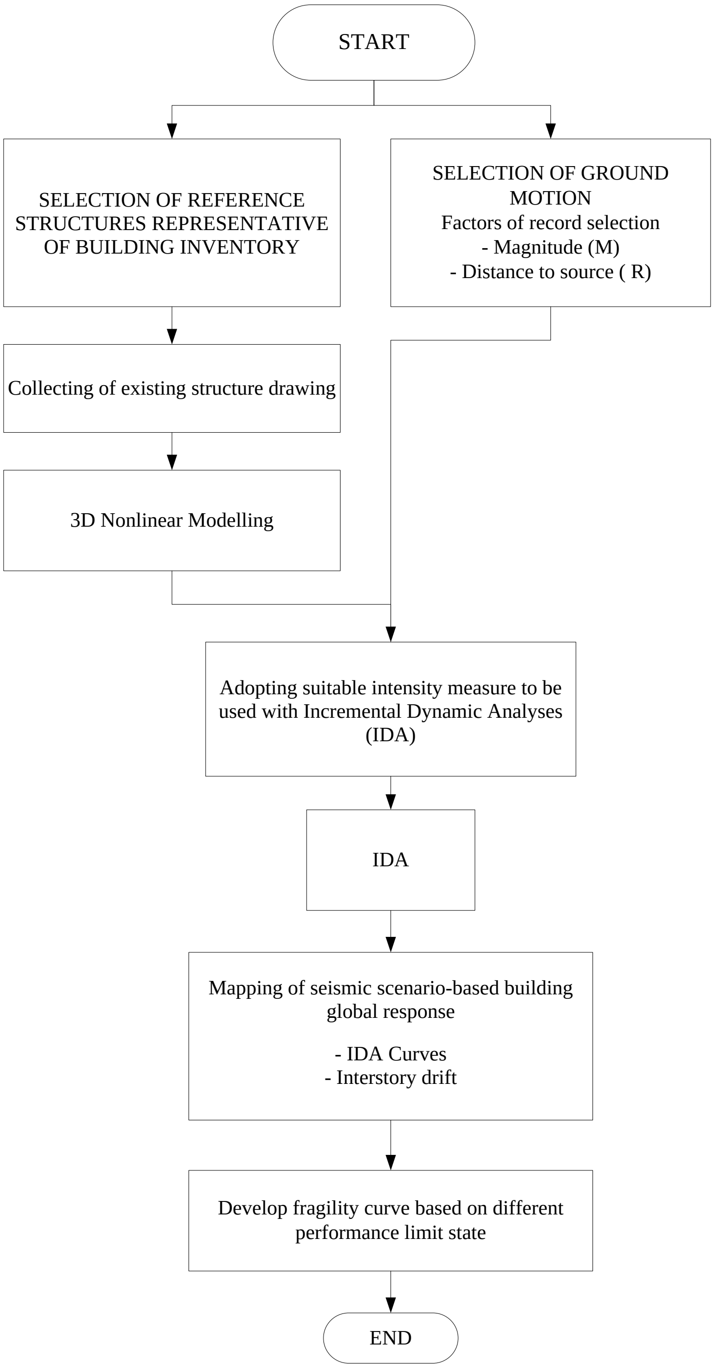

Figure 3.1: Flow chart of the research methodology.