# SEISMIC PERFORMANCE OF HIGH DUCTILE RC FRAME DESIGNED IN ACCORDANCE WITH MALAYSIA NATIONAL ANNEX TO EUROCODE 8

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## DEDICATION

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

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# ABSTRACT

A few decades dated back, Malaysia was deemed as an earthquake free zone. However, this perception was changed after the 2004 Indian Ocean Earthquake and Tsunami incident which happened in Sumatra Indonesia, as well as the 2015 Ranau Earthquake. The introduction of Malaysia Seismic National Annex to Eurocode 8 in 2017 has triggered awareness in the construction industry in Malaysia. The national seismic annex suggests that only for building with Important Class IV shall be checked with inter-storey drift limit with the return period of 475 years. Thus, an investigation on the need of drift limit checks onto the buildings in Class I to III shall be checked for the inter-storey drift. This is because most of the seismic pre-code buildings are designed and detailed without ductile detailing. Furthermore, those buildings have a soft-storey feature with open space ground floor. Such building type is highly vulnerable to seismic attack, causing significant inter-storey drift. Therefore, there is a need to investigate the failure mode and plastic hinge formation in the ground soft-story RC buildings designed in accordance with the Malaysian National Annex to Eurocode 8. Non-linear pushover analysis onto typical 4-, 7- and 10-storey buildings frame are carried out in this study, using ETABS software. The aforementioned buildings are modelled in 3D, and to be designed and detailed as a high ductile reinforced concrete frame. The soft-story feature is also considered in this study. The results reveal that the high ductile RC building, which is the 4-storey building (all cases) and 7-storeys building (only ground type D cases) cannot achieve life safety requirement as per ASCE 41 (2007). The formation of CP plastic hinges occurred before the target displacement and targets base shear. For the other cases (7-storeys building with ground type B and all 10-storeys building case) fulfil the life safety requirements)   Larger size of structural members is required in building with drift-controlled compare with the building without drift-controlled. Subsequently, the drift-controlled building is stiffer than the building without drift-control. As a result, the buildings have shorter target displacement and larger target base shear.

# ABSTRAK

Beberapa dekad yang lalu, Malaysia dianggap sebagai zon bebas gempa. Namun, persepsi ini berubah setelah kejadian Gempa dan Tsunami Lautan Hindi 2004 yang terjadi di Sumatera Indonesia, dan juga Gempa Bumi Ranau 2015. Pengenalan Lampiran Nasional Seismik Malaysia ke Eurocode 8 pada tahun 2017 telah mencetuskan kesedaran dalam industri pembinaan di Malaysia. Lampiran nasional seismik menunjukkan bahawa hanya untuk bangunan dengan Kelas Penting IV yang akan diperiksa dengan had drift antara tingkat dengan tempoh pengembalian 475 tahun. Oleh itu, siasatan mengenai keperluan pemeriksaan had drift ke bangunan di Kelas I hingga III hendaklah diperiksa untuk peralihan antara tingkat. Ini kerana kebanyakan bangunan pra-kod gempa dirancang dan diperincikan tanpa perincian mulur. Tambahan pula, bangunan-bangunan itu mempunyai ciri-ciri bertingkat-tingkat dengan ruang terbuka di tingkat bawah. Jenis bangunan seperti itu sangat rentan terhadap serangan seismik, menyebabkan pergeseran antara tingkat yang signifikan. Oleh itu, terdapat keperluan untuk menyiasat mod kegagalan dan pembentukan engsel plastik di bangunan RC lantai lembut yang direka sesuai dengan Lampiran Nasional Malaysia untuk Eurocode 8. Analisis tolakan nonlinear ke bangunan khas 4-, 7- dan 10 tingkat frame dijalankan dalam kajian ini, menggunakan perisian ETABS. Bangunan-bangunan di atas dimodelkan dalam bentuk 3D, dan akan dirancang dan diperincikan sebagai kerangka konkrit bertetulang mulur tinggi. Ciri cerita lembut juga dipertimbangkan dalam kajian ini. Hasilnya menunjukkan bahawa bangunan RC mulur tinggi, yang merupakan bangunan 4 tingkat (semua kes) dan bangunan 7 tingkat (hanya kes jenis D tanah) tidak dapat memenuhi syarat keselamatan nyawa seperti di ASCE 41 (2007). Pembentukan engsel plastik CP berlaku sebelum anjakan sasaran dan ricih dasar sasaran. Untuk kes-kes lain (bangunan 7 tingkat dengan jenis tanah B dan semua kes bangunan 10 tingkat) memenuhi syarat keselamatan nyawa b) Ukuran anggota struktur yang lebih besar diperlukan dalam bangunan dengan dikawal drift dibandingkan dengan bangunan tanpa dikawal drift. Seterusnya, bangunan yang dikendalikan drift lebih kaku daripada bangunan tanpa kawalan drift. Hasilnya, bangunan-bangunan tersebut memiliki anjakan sasaran yang lebih pendek dan ricih dasar sasaran yang lebih besar.

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| | | |
|---|---|---|
| NDPs | - | Nationally determined parameters |
| RC | - | Reinforced Concrete |
| IO | - | Immediate Occupancy |
| LS | - | Life Safety |
| CP | - | Collapse Prevention |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $v$ | - | Reduction factor |
| $d_r$ | - | Design interstorey drift |
| $d_s$ | - | Displacement of a point of the structural system induced by the designed seismic action |

# CHAPTER 1

# INTRODUCTION

## 1.1 Problem Background

A few decades dated back, Malaysia was deemed as an earthquake free zone. However, this perception was changed after the 2004 Indian Ocean Earthquake and Tsunami incident which happened in Sumatra Indonesia. Hereafter, Malaysian, especially who are from Kuala Lumpur area, also have experienced several times of earthquake-induced tremor, which was mainly caused by the seismic source from Sumatra(Shoushtari et al., 2018).

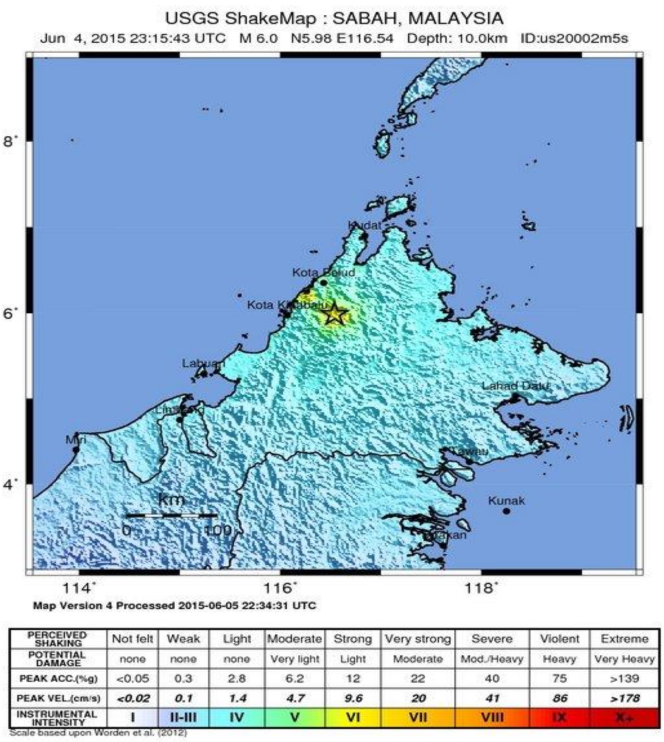


Figure 1.1 USGS ShakeMap for the event(USGS, 2015)

In 2015, an earthquake with a moment magnitude of 6.0 struck Ranau, Sabah. This was the strongest and worst earthquake that has ever-affected Malaysia since 1976 Sabah earthquake (Adnan and Harith, 2017). Although the moment scale of Ranau earthquake was smaller than the 1976 Sabah earthquake, it brought more significant damage to the infrastructure and building compared to 1976 Sabah earthquake. This earthquake also caused 18 people dead(Yeong, 2015), which was the lethal earthquake happened in Malaysia. Figure 1.1 shows the epicentre of the Ranau earthquake, and Figure 1.2 shows the crack of the column of the school building after the quake.


Figure 1.2 Crack of columns of a building after the earthquake (Vanar, 2015)

On top of that, a massive earthquake of $M_w$7.5 with shallow focus depth has been recorded in Minahasa Peninsula, Indonesia, in September 2018 (Hui et al., 2018). Although the epicentre of the earthquake has more than 500km from Tawau, the residents at Tawau still can feel the movement of the ground. These incidents show that Malaysia has the potential to be affected by the earthquake-induced long-period ground motion from our neighbour country.

Aware of the seriousness of the earthquake incidents in the past few decades, the technical committee on earthquake under the authority of the Industry Standard Committee on Building, Construction and Civil Engineering has developed earthquake resistance design standard which is the "Malaysia National Annex to Eurocode 8: Design of structure for earthquake resistance - Part 1: General rules, seismic actions and rule for building (MS EN1998-1:2017 (National Annex to Eurocode)". This national annex applied to the design and construction of buildings in seismic regions (Azudin, 2018). The objective of the MS EN1998-1: 2017 is to ensure that during the event of an earthquake, the damage of structure is limited, human life is protected, and the vital structure can remain operational.

According to Azudin (2018), Engineering Director (Structure Expert) of Public Works Department Malaysia, the national annexe provides the information for parameters that are left open by Eurocode 8 for national choice, which is also known as Nationally Determined Parameters (NDPs). The NDPs has taken into account the differences in geological and geographical conditions such as Peak Ground Acceleration Map (PGA Maps). Besides, the NDPs also consider the different design cultures and the structural analysis produced between Malaysia, British and European. There are about 56 of NDPs which were decided by the Technical Committee to suit Malaysia seismic design condition.

## 1.2 Problem Statement

In Malaysia, the majority of low-rise building use infilled masonry, whereby this type of wall is designed to resist permanent action (dead load) only. In addition, there are also some of the apartment building designed with partially infilled masonry, whereby the ground level of these kinds of buildings consist only of beam, slab and column without masonry covered for parking areas purpose. In this situation, the basement floor is defined as a soft storey. During an earthquake event, the distribution of seismic forces is dependent on the stiffness distribution and mass of the building, as well as with the height. For those building with soft storeys, the inter- storey drift above the soft storey is small, but for the soft storey itself, the inter-storey drift is much more significant. Figure 1.3 shows the inter- storey drift pattern for the soft storey of building in an earthquake (Singh and Babulal, 2015).

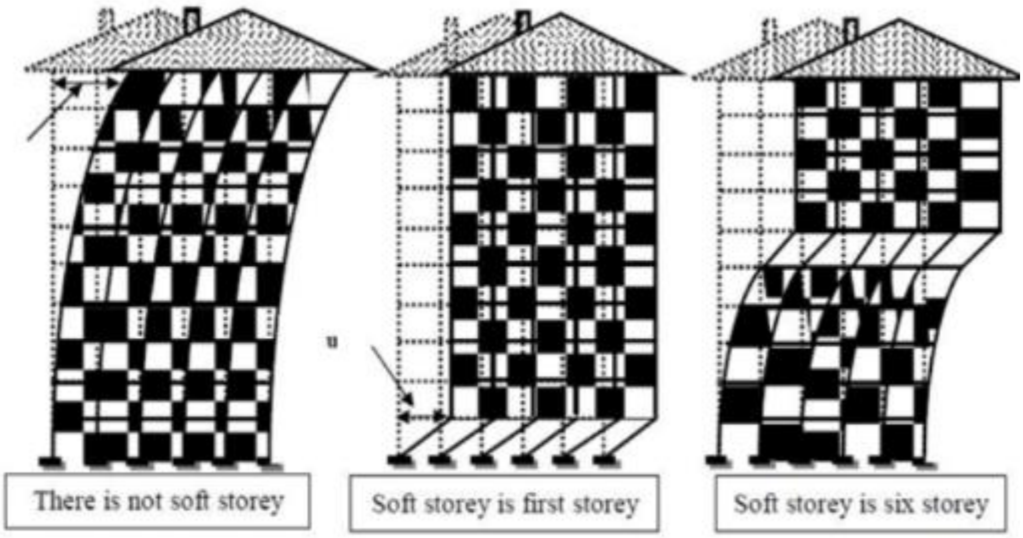


Figure 1.3 Inter-storey drift pattern for the soft storey of building in an earthquake(Singh and Babulal, 2015)

Based on the research conducted by Institute of Geological and Nuclear Science Limited, the result shows that the inelastic inter-storey drift for the reinforced concrete building is much higher than steel structures (Uma et al., 2009). Thus, it is believed that most of the multi-storey building with soft storeys in Malaysia will experience massive displacement drift at the soft storey floor when the earthquake happened.

According to MS EN 1998-1: 2015, it suggests checking the inter-storey drift for all types of building.

a) For the building have non-structural elements of brittle materials attached to the structure the formula is: $d_r v \leq 0.005h$.
b) For the building have ductile non-structural elements the formula is: $d_r v \leq 0.0075h$.
c) For the building have ductile non-structural elements fixed in the way so as not to interface with structural deformation, or without non- structural element the formula is: $d_r v \leq 0.01h$.

where for Class I and II building, the reduction factor, $v$ is 0.5 and for Class III and IV building the reduction factor, $v$ is 0.4

Clause 4.4.2.2(2) states that the designed inter-storey drift shall be evaluated as the difference of the average lateral displacement $d_s$ at the top and bottom of the storey under consideration and calculated based on displacement calculation in clause 4.3.4. MS EN 1998-1: 2015 has also specified all building class shall be designed complying with the inter-storey drift limit according to clause 4.4.3.2 with displacement reduction factor, $v$ value at damage limit state accordingly. However, Malaysia NDPs state that only the important building (Class IV) such as hospital and police station shall need to check for the displacement at damage limit state based on the 475 years return period with the $v$ value of 0.5.

Based on the previous earthquake incident happened in Ranau, the RC building with "pilotis" configuration are among the most damaged structure. Figure 1.4 shows the RC building with "pilotis" configuration in the affected area. Therefore, it is highly recommended that the Class I to Class III buildings stated in MS EN 1998-1: 2015, shall be checked with the inter-storey drift. This is because buildings with the soft-storey feature can induce building displacement and drift compared with other typical storeys.

Figure 1.4 RC building with "pilotis" configuration in the affected area. (Alih & Vafaei, 2019)

It is believed that inter-storey drift displacement of the soft-storey of the building might cause the formation of plastic hinges on the ground soft-storey of the RC building and causes the building collapse during an earthquake. Therefore, the aforementioned condition has initiated the study to investigate the failure mode and plastic hinge formation in the ground soft-story RC buildings designed in accordance with the Malaysian National Annex to Eurocode 8.

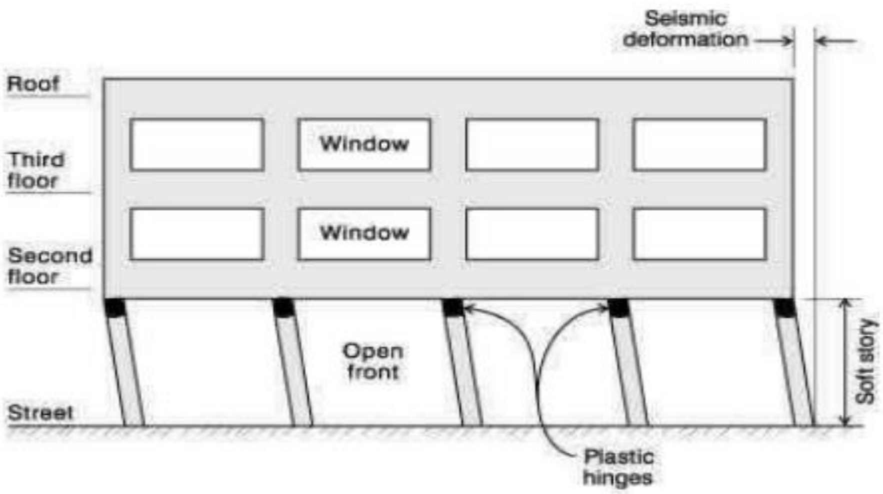


Figure 1.5 Formation of the plastic hinge on the soft storey. (Anuar, 2017)

## 1.3 Research Goal

### 1.3.1 Research Objectives

a) To investigate the failure mode and plastic hinge formation in the ground soft-story RC buildings designed in accordance with the Malaysian National Annex to Eurocode 8.

b) To calculate the drift demand and capacity of ground soft-story RC buildings designed in accordance with Malaysian National Annex to Eurocode 8 and compare it with Eurocode 8.

c) To establish a seismic design recommendation for ground soft-story buildings designed in accordance with the Malaysian National Annex to Eurocode 8.

## 1.4 Scope of the Research

a) Understand the current practice of partial infill frame structure in Malaysia.

b) Understand the non-linear pushover analysis theory to determine the displacement drift of the building.

c) Construct a numerical building model and validate the numerical building model

d) To conduct non- linear pushover analysis on the model and analyse the data obtained.

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