SEISMIC PERFORMANCE OF A DOUBLE-STOREY PREFABRICATED COLD-FORMED STEEL STRUCTURE AS POST-DISASTER TEMPORARY HOUSING

WONG JIA HUI

SCHOOL OF CIVIL ENGINEERING
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by

WONG JIA HUI

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Name of Student: Wong Jia Hui

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

Signature:

Albert Wong

Date : 02/08/2021

Endorsed by:

Ir. Dr. LAU TZE LIANG
ASSOCIATE PROFESSOR
SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA

(Signature of Supervisor)

Name of Supervisor:
Assoc. Prof. Ir. Dr. Lau Tze Liang
Date: 2/8/2021

Approved by:

(Signature of Examiner)

Name of Examiner:
Prof. Ir. Dr. Choong Kok Keong
Date: 2/8/2021

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ABSTRAK

Risiko gempa bumi di Semenanjung Malaysia sering diabaikan oleh masyarakat kerana negara ini terletak jauh dari Lingkaran Api Pasifik. Oleh itu, reka bentuk seismik jarang dipertimbangkan dan ini menyebabkan kekurangan kajian penyelidikan dalam pembangunan tempat perlindungan kecemasan atau sistem perumahan pasca bencana yang berkesan. Oleh itu, kajian ini mencadangkan reka bentuk rumah keluli prefabrikasi dua tingkat yang siap dibina sebagai penyelesaian perumahan sementara yang mampan semasa berlaku gempa bumi. Dalam kajian ini, analisis berangka terhadap model berskala 1:2 digunakan untuk menganalisa prestasi seismiknya dengan memasukkan sejarah waktu pecutan sebanyak 0.09g, 0.12g, dan 0.16g yang direkodkan di stesen seismik KKM semasa gempa bumi Ranau pada tahun 2015 melalui perisian ETABS. Dua jenis model telah disimulasikan iaitu model tanpa dinding dan model dengan dinding untuk mengenal pasti pengaruh dinding terhadap prestasi gempa struktur. Keputusan daripada analisis menunjukkan penggunaan dinding dapat mengurangkan pecutan struktur dengan purata 74%, sementara itu mengurangkan anjakan sambungan dengan peratusan 7.5% (tingkat satu) dan 34% (bumbung bawah dan bumbung atas). Walau bagaimanapun, reka bentuk model yang dicadangkan melebihi had untuk jumlah hanyut tingkat dan hanyut antara tingkat. Oleh itu, tiga kaedah pengukuhan yang berbeza telah dicadangkan, dan kaedah yang paling berkesan untuk meningkatkan prestasi struktur seismic adalah pemasangan perimbatan pepenjuru di tingkat bawah untuk menghubungkan tingkat satu dan dasar struktur antara dua ruang kerangka portal dengan rentang yang pendek dalam arah gegaran.

ABSTRACT

The community often neglects the risk of earthquake occurring in Peninsular Malaysia as the country is located away from the Ring of Fire zone. Therefore, seismic design is seldom considered during building design. Furthermore, there is a lack of research in developing a good emergency relief shelter or post-disaster housing system. Therefore, this study proposes a design of a double-storey prefabricated cold-formed steel house as a sustainable post-disaster temporary housing solution for an earthquake event. In this study, a numerical analysis of 1:2 scaled models is used to analyse their seismic performance by inputting the acceleration time history of 0.09g, 0.12g, and 0.16g recorded by KKM Seismic Station during the 2015 Ranau earthquake via ETABS software. Furthermore, two types of models were simulated, i.e., model without wall panels and model with wall panels to identify the influence of the wall panels on the structure's seismic performance. The results show that the inclusion of wall panels reduces the joint acceleration of the structure by an average of 74 %. In addition, it also reduces the joint displacement by a percentage of 7.5% (storey one) and 34% (lower roof and upper roof). However, the proposed model’s design exceeded the limit for total storey drift and inter-storey drift. Therefore, three different strengthening methods were proposed, and the most effective way to enhance the structural seismic performance is by adding two pairs of diagonal bracing at the ground floor connecting the first floor and the base of the structure in the two bays of portal frame with shorter span in the shaking direction.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

AFC	Asymmetric Friction Connections
BB	Buckling Brace
BRB	Buckling Restrained Brace
CFS	Cold-formed steel
CMU	Concrete Masonry Units
CBSBF	the Concentric BRB-Strong Braced Frame
CBF	Concentrically Braced Frames
DfD	Design of Deconstruction
DL	Dead Load
EQ_y	Seismic Load
GB	Gapping Brace
IBC	International Building Code
IBS	Industrialised Building System
ISDR	Inter-Storey Drift Ratio
KKM	Kota Kinabalu Seismic Station
LSF	Lightweight Steel Framing
LL	Live Load
M_{no_wall}	Model without wall panels
M_{wall}	Model with wall panels
$M_{str,1}$	Model with first proposed strengthening method
$M_{str,2}$	Model with second proposed strengthening method
$M_{str,3}$	Model with third proposed strengthening method
MDOF	Multiple Degree of Freedom

MCE	Maximum Considered Earthquakes
NNE	North-Northeast
NW	North-West
NE	North-East
NADMA	National Disaster Management Agency
NSC	National Security Council
NB	No Brace
OXFAM	Oxford Committee for Famine Relief
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
PGD	Peak Ground Displacement
RB	Ratcheting Brace
RHS	Rectangular Hollow Section
RHCF	Rectangular Hollow Cold-Formed
RSFJ	Resilient Slip Friction Joint
SB	Strong Brace
SHS	Square Hollow Section
SHCF	Square Hollow Cold-Formed
SCM	Supply Chain Management
SDOF	Single Degree of Freedom
UNCHR	United Nations High Commissioner for Refugee

CHAPTER 1

INTRODUCTION

1.1 Background study

Peninsular Malaysia is well-known as a country safe from seismic and volcanic activities due to its strategic location, which falls outside the Ring of Fire zone. However, in reality, this statement is questionable as numerous moderate seismic activities has been recorded in Malaysia starting from the earliest on 7th February 1922 between Batu Pahat and Kota Tinggi in the southern state of Peninsular Malaysia, Johor (Martin et al., 2020) and to the latest on 5th June 2015 in Ranau, Sabah. In addition to that, the Sabah regions such as Lahad Datu, Tawau and Ranau are predicted to reencounter seismic activity from the year 2015 to the year 2022 (Cheng, 2016). The reactivation of fault lines due to frequent high intensities and frequencies seismic activities around Peninsular Malaysia (Muiz et al., 2018), primarily from the Sumatra Subduction Zone and Sumatra Transform Zone (Marto et al., 2013) causes potential earthquake risk in Peninsular Malaysia.

The reactivation of the dormant fault line has raised the attention towards the safety of building structure in Peninsular Malaysia due to structural failure lead to high fatality rate and injuries (Muiz et al., 2018). Most of the structural buildings in Peninsular Malaysia are not designed for seismic resistance due to the misbelief of Peninsular Malaysia is located outside of the Ring of Fire zone (Adiyanto et al., 2019). In addition, Malaysia's construction industries do not widely practise the building codes related to seismic design such as BS EN 1998, or International Building Code (IBC). It is further proven when Sabah started introducing a new set of earthquake resistance building codes for all newly proposed infrastructures and buildings only after the Ranau earthquake incident in 2015.

Malaysia experienced its first-ever tsunami disaster due to the magnitude 9.0 earthquake at Indonesia's Sumatra Island coast on 26th December 2004. The tsunami has destroyed more than 40 villages and affected the lives of more than 4000 people (Ling et al., 2006). Next, on 5th June 2015, a magnitude 6.0 earthquake struck the Ranau District of Sabah, Malaysia. The earthquake has caused physical damage to infrastructure, public buildings and private buildings around Ranau and Kundasang areas. The earthquake induced rockfalls and landslides have caused severe damage to public and private buildings (Tongkul, 2015). Based on the stated scenarios, it is essential to have a proper post-disaster temporary housing system considering affordability, speedy construction, and sustainability to incubate the affected people immediately.

Hence, this study proposes a double-storey prefabricated cold-formed steel (CFS) house as a post-disaster temporary house and investigates its structural performance when exposed to earthquake excitation. The modular steel construction of building structure has slowly gained its popularity from the construction industry. It poses many advantages over traditional construction in terms of economic, environmental and social (Ferdous et al., 2019). As examples, faster construction speed, safer construction method, environmental-friendly material and fewer labours on site. Therefore, its characteristics are suitable for constructing permanent housing or temporary housing in moderate to high seismic activity areas.

In this project, numerical analysis is carried out to investigate the double-storey prefabricated cold-formed steel house's seismic performance. The simulation is conducted using ETABS software. For the second part of the research, strengthening methods are proposed to improve the building's seismic performance.

1.2 Problem statement

Numerous earthquakes have been recorded in Malaysia since the year 1922 until the latest in the year 2018 primarily from the Sumatra Subduction Zone and Sumatra Transform Zone. Therefore, it has raised the attention of the possibility of an earthquake happening in Malaysia. Since most of Malaysia's buildings are not designed as seismic resistant buildings, any occurrence of a large magnitude earthquake might lead to disastrous impacts. Although Malaysia has a disaster managing system equivalent to a developed country, but we have a developing country's implementation capacity (Roosli & O'Keefe, 2013) especially in emergency shelter relief or temporary post-disaster housing construction. Therefore, this study focuses on proposing a suitable double-storey prefabricated cold-formed steel house as a post-disaster temporary shelter with sufficient earthquake resistance.

Besides, there is a lack of research on studying the influence of wall panels on a cold-formed steel structure's seismic performance in Malaysia compared to the main structural members. Most of the existing studies related to the seismic behaviour of steel modular structures do not consider the effects of non-structural components such as wall panels and wall partition. Therefore, this study helps to fill up the knowledge gap of the seismic behaviour between structural components and non-structural components in a cold-formed steel structure.

1.3 Objectives

The objectives of this project are: -

i) To study the seismic performance of a double-storey prefabricated cold-formed steel house when subjected to earthquake excitation.

ii) To determine the influence of wall panels on the seismic performance of a double-storey prefabricated cold-formed steel house.

iii) To propose an affordable and effective post-disaster temporary housing with required seismic resistance.

1.4 Scope of works

The original scope of the study includes experimental analysis using shaking table test and numerical modelling. However, due to the sudden surge of Covid-19 cases and the implementation of Full Movement Control Order (total lockdown), the experimental analysis must be halted. Therefore, only numerical analysis is conducted for this research study.

The focus area of this study is the places prone to the earthquake disaster in Malaysia. The double-storey prefabricated cold-formed steel house in this research is designed with reference from a product of a CFS manufacturer. The length dimensions of the prototype are downscaled to half of its original size in order to suit the shake table facility at USM in the original plan. Some alterations are made on the prototype to fit for the usage as post-disaster temporary housing. In this study, the computational analysis is conducted to study the double-storey prefabricated cold-formed steel house's seismic behaviour. The numerical analysis is carried out to compare the seismic performance between a bare structure and structure with wall panels included. The peak ground accelerations tested on the model during the numerical analysis are 0.09g, 0.12g and 0.16g scaled from the ground motion recorded in the KKM Seismic Station during the 2015 Ranau earthquake. Based on the results, strengthening methods are suggested to enhance the seismic resistivity further. At the end of this study, an affordable and effective post-disaster temporary house with seismic resistance is proposed.

1.5 Dissertation structure

There is a total of five chapters in this dissertation, which are: -

Chapter 1 is an introduction to provide the reader with a clear understanding of the overall research purpose. It consists of the background study, problem statement, research's objectives, scope of the study, dissertation structure and the projects' significance.

Chapter 2 consists of the literature review, which involves the background study of Malaysia's seismic activity and related studies on the industrialized building system (IBS) and the prefabricated CFS properties. Besides, past studies related to the experimental and numerical analyse for determining the seismic performance of cold-formed steel structure are reviewed.

Chapter 3 presents this project's methodology, which covers desk study, design concept, model development, process of numerical analysis, data analysis and strengthening methods.

Chapter 4 presents the results obtained from the numerical analysis via ETABs software. A discussion is then carried out to investigate the seismic performance of the structure in terms of joint acceleration, joint displacement, total storey drift, inter-storey drift, global deformation and the effect of strengthening methods on the double-storey prefabricated cold-formed steel house's seismic performance.

Chapter 5 concludes the findings of this research on the seismic performance of the double-storey prefabricated cold-formed steel house, the influence of wall panels on the structure's seismic performance and the most suitable strengthening method in improving the seismic performance of the double-storey prefabricated cold-formed steel house. A list of references and appendices are attached in the final part of the dissertation.

1.6 Significance of the study

The main contribution from this study is to promote a fast construction of post-disaster temporary housing through the material usage like prefabricated cold-formed steel components. The speedy construction of post-disaster housing allows to incubate victims who suffered from an earthquake disaster and accelerates the rehabilitation and recovery phases. By carrying out the computational analysis on the designed model, it helps us to understand the seismic performance of the developed prototype during an earthquake ground motion. Furthermore, suitable strengthening measures can be carried out immediately to determine the level of improvement on the house's seismic resistivity. With better seismic resistivity, the post-disaster temporary house can remain service and keep the victims safe from any aftershocks. Overall, this study proposes a design of a sustainable post-disaster temporary housing solution for an earthquake event.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This final year project offers an idea of constructing a seismic resistant double-storey temporary housing by using prefabricated cold-formed steel components. Besides, it provides understanding on the seismic resistance of the proposed temporary housing and determining the influence of the wall panels on the seismic performance of the house.

According to Chan (2012), Malaysia is located in a geographically stable region, which is generally free from most natural disasters. Still, it is affected by landslides, haze, flooding, and other human-made disasters. However, Malaysia is also prone to earthquake disaster as according to Muiz et al.(2018), it is suspected that the frequent high intensities and frequencies of seismic event around Peninsular Malaysia primary from the Sumatra Subduction Zone and Sumatra Transform Zone have led to the reactivation of the fault lines in Malaysia. Besides, Jainih & Harith (2020) has stated that Sabah has a higher possibility of earthquake occurrence than other states in Malaysia. Due to the neglect of the earthquake disaster risk, most of the buildings constructed in Malaysia are not designed with seismic resistance.

One of the primary considerations to be considered in the Malaysia disaster management system is post-disaster temporary housing. If a high magnitude of earthquake occurred in any major cities in Malaysia, the community requires enough temporary housing to be constructed under a short period to accommodate the affected victims. Prefabricated cold-formed steel components are the suitable materials to be selected for the temporary housing due to its sustainability, speedy construction and the ability to mass production.

A review of the literature relating to the post-disaster housing in Malaysia shows that the research in developing a seismic resistant temporary housing with prefabricated cold-formed steel components is a new topic in Malaysia and that studying the influence of wall panels toward the seismic performance of a cold-formed steel structure does not yet exist. The results of the present study will then fill these knowledge gaps.

This chapter covers topics related to the background study of Malaysia's seismic activity, related studies on the industrialized building system (IBS) and the prefabricated CFS properties. Besides, literature related to the experimental and numerical analyse conducted to determine seismic performance of cold-formed steel structure is also included.

2.2 Malaysia earthquake source

Malaysia is well-known for its strategic location as it is located away from the Ring of Fire zone and not affected by the earthquake disaster. This statement has provided false information that Malaysia has no potential earthquake risk, and the earthquake risk is negligible. Based on Figure 2.1, a comparison can be made between Australia and Malaysia as both countries are away from the Ring of Fire zone. However, Australia has recorded an average of 100 earthquakes of magnitude three or more each year, but Malaysia does not have a similar rate of occurring. Therefore, the reason for Malaysia not having the similar rate of earthquake occurring as Australia is due to the smaller landmass of Malaysia which result in lower chance of encountering an earthquake incident. Hence, it is incorrect to consider Malaysia as an earthquake disaster free country and buildings should be designed with seismic resistance.

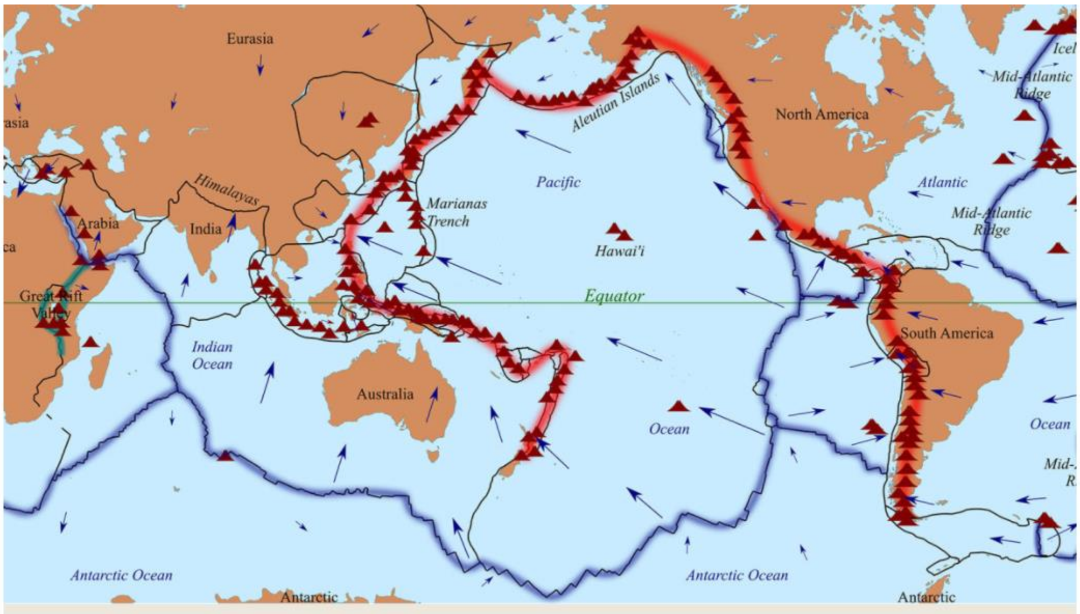


Figure 2.1 The location of Ring of Fire zone

According to Naraghiaraghi et al.(2014), most of the earthquakes that occurred in West Malaysia are influenced by two major faults namely the Sumatran subduction zone and the Sumatran strike-slip fault. The Sumatran subduction zone (Refer to Figure 2.2) is located about 400 km away from the West Coast of Malaysia. It is formed due to the subduction of the India-Australian plate under the Eurasian plate. The slip rate of the Sumatran subduction zone is recorded to be 67 mm each year. The Sumatran strike-slip fault (Refer to Figure 2.2) is located about 260 km away from Malaysia's West Coast and has a total length of 1500 km, which can be further divided into 20 major sections. The Sumatran strike-slip fault has a different slip rate for each section, but it is recorded that the southern segments (20 mm/year) have a slower rate than the northern segment (37 mm/ year).

For East Malaysia, Sabah has the most seismic activities if compared to other states of Malaysia. According to Tongkul (2017) Sabah is located near the most seismically active plate boundaries between the Eurasian Plate in the west and Indian-Australian Plate and between Philippine Plate in the east. The convergence between these three main plates results in the formation of active subduction zones and strike-slip faults, which lead to the occurrence of numerous earthquakes in Sabah. The plate movement for the Eurasian Plate, Indian-Australian Plate and Philippine Sea-Pacific Plate is estimated to be about 40 mm/year to the southeast, 70 mm/year to the north and 100 mm/year to the west as shown in Figure 2.2.

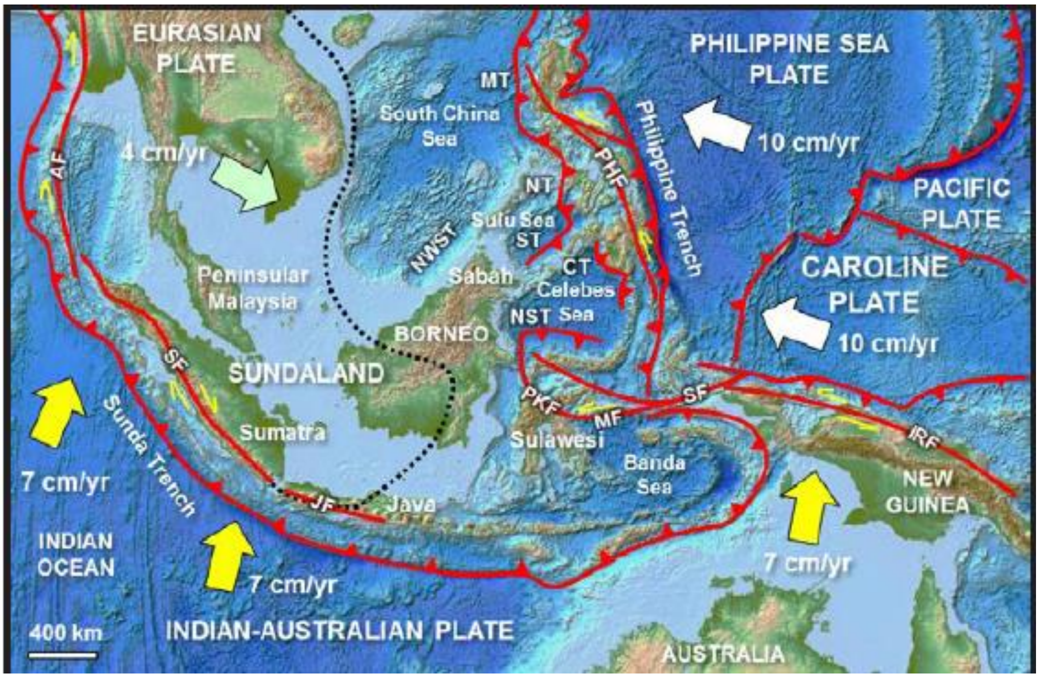


Figure 2.2 The plate boundaries in and around Southeast Asia (Tongkul, 2015)

2.3 Historical earthquake event in Malaysia

According to Martin et al.(2020), Peninsular Malaysia has experienced the largest earthquake on the 31st January 1922 and 7th February 1922, with an average magnitude of about 5.4 and 5.0. A broad region has felt the earthquake that occurred on the 31st of January 1922 with an estimated 500 km from Taiping in the north to Singapore in the south. On the 7th of February 1922, another earthquake occurred in the southern Johor state between Kota Tinggi and Batu Pahat. Besides, there are numerous other local earthquakes occurred in Peninsular Malaysia in between the year of 2007 to 2012 as shown in Table 2.1. Peninsular Malaysia is also heavily affected by the far-field earthquakes, which are originated from the Sumatra subduction zone and the Sumatra fault that is running through the entire Sumatra Island (Marto et al., 2013). A list of the far-field earthquakes which affected Peninsular Malaysia is shown in Table 2.2.

Table 2.1 Local earthquake occurrences in Peninsular Malaysia (Marto et al., 2013)

Date	Case	Location
2007 – 2009	24	Bukit Tinggi, Kuala Lumpur
2009	4	Kuala Pilah, Perak
2009	1	Jerantut, Pahang
2009	1	Manjung, Perak
2010	1	Kenyir Dam, Terengganu
2012	1	Mersing, Johor

Table 2.2 Far-field earthquakes that affected Peninsular Malaysia (Marto et al., 2013)

Date	Epicentre	Magnitude	Effect on Malaysia
1984/08/27	Northern Sumatera	5.2	Kuala Lumpur, Penang
1987/04/25	Northern Sumatera	6.3	Kuala Lumpur
1990/11/15	Northern Sumatera	6.9	Ipoh, Kuala Lumpur, Penang, Taiping
1994/10/11	Northern Sumatera	6.5	Southern Malaysia
1997/08/20	Northern Sumatera	6.0	Alor Setar, Petaling Jaya, Penang
1998/04/01	Padang	6.9	Kuala Lumpur
2000/05/04	Sulawesi	7.4	Tawau
2000/06/04	Southern Sumatera	7.7	Johor, Kuala Lumpur, Port Kelang
2002/11/02	Simeulue	7.4	Kuala Lumpur, Port Kelang
2004/07/25	Southern Sumatera	7.3	Southern Johor
2004/12/26	Northern Sumatera	9.0	Penang, Langkawi, Kedah
2005/02/12	Sulawesi	7.0	Kota Kinabalu
2005/03/28	Northern Sumatera	8.6	West coast Peninsular Malaysia
2005/04/10	Mentawai	6.7	Kuala Lumpur
2005/04/10	Mentawai	6.5	Kuala Lumpur
2005/05/19	Nias	6.9	Penang, Kuiala Lumpur, Sungai Ara, Tanjung Tokong
2005/07/05	Nias	6.7	Kelang, Kuala Lumpur, Petaling Jaya, Sungai Ara

Table 2.2 Continued

Date	Epicentre	Magnitude	Effect on Malaysia
2005/07/24	Nicobar Islands	7.2	George Town
2005/11/19	Simeulue	6.5	Ayer Itam
2006/12/17	Northern Sumatera	5.8	Kuala Lumpur
2007/03/06	Southern Sumatera	6.4	Johor, Kuala Lumpur, Port Dickson, Skudqai
2007/08/08	Jawa	7.5	Kuala Lumpur, Petawling Jaya, Sungai Ara
2007/09/12	Southern Sumatera	8.4	Setapak, Cheras, Pudu, Langkawi, Johor, Melacca
2009/08/16	Southern Sumatera	6.3	Kuala Lumpuir, Penang, Johor
2009/09/30	Padang	7.9	Kuala Lumpur, Putrajaya, George Town, Johor
2010/05/09	Northern Sumatera	7.2	Sungai Dua, Penang
2011/06/14	Northern Sumatera	5.6	Selangor, Melacca, Perak, Putrajaya, Negeri Sembilan
2012/04/11	Northern Sumatera	8.2	Penang, Kuala Lumpur
2012/06/24	Northern Sumatera	6.5	Kedah, Perak, Selangor, Negeri Sembilan, Putrajaya
2012/07/25	Northern Sumatera	6.6	West coast Peninsular Malaysia

For East Malaysia, Sabah is known as the most seismic active states. Based on the United States Geological Survey (USGS) database, about 65 local light to moderate earthquakes occurred onshore Sabah or around its surroundings from 1973 to December 2015 (Tongkul, 2015). Out of the 65 local earthquakes, there are only three of them which resulted in damage to infrastructure and buildings, i.e., the Lahad Datu earthquake in 1976 (magnitude 6.2), Ranau earthquake in 1991 (magnitude 5.1) and Ranau earthquake in 2015 (magnitude 6.0). Based on the most recent Sabah earthquake in the Ranau area, its epicentre is located about 7 km NNE of Kundasang town, 13 km NW of Ranau town and 60 km NE Kota Kinabalu city as shown in Figure 2.3 (Tongkul, 2015). The incident has caused several impacts on the Ranau area such as physical damage on building due to vertical and lateral surface movement, liquefactions, rockfalls and landslides.

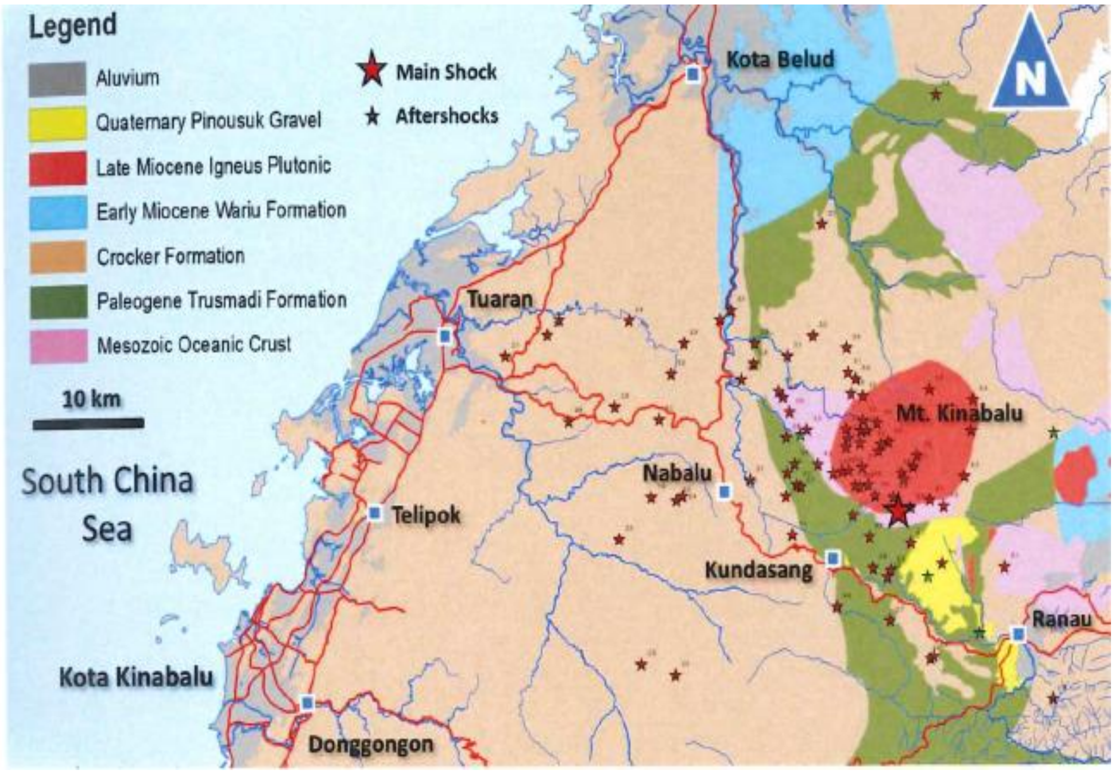


Figure 2.3 Location of mainshock and aftershocks (Tongkul, 2015)

2.4 Emergency housing and post-disaster housing in Malaysia

Malaysia has a disaster management system based on top-down and bottom-up approaches, which have been established over the years and integrated into the disaster risk management area. At the very top, the National Disaster Management Agency (NADMA), under the Prime Minister's Department is the head of the disaster management agency for regional and international disaster management efforts. The disaster management system is regulated by the National Security Council (NSC) Directive No. 20, under the guidance of NADMA. The disaster management system structures can be divided into three levels, specifically federal, state and district. The purpose of Directive No. 20 is to outline the policy related to disaster and relief management based on the complexity of disaster and to establish the roles and responsibilities of the various agencies at different disaster management tiers (Chan, 2012). Under Directive No. 20, Malaysia's disaster management cycle consists of five stages which are prevention, mitigation, preparedness, response and recovery.

The construction of post-disaster housing is one of the essential activities under the recovery phase. It helps to recover the infrastructure systems to minimize operating standards and return life to normal or improved levels after a disaster. According to Roosli & O’Keefe (2013), Malaysia has a developed country approach in disaster management policy but with a developing country's implementation capacity. International agencies such as the Oxford Committee for Famine Relief (OXFAM), Sphere Project and United Nations High Commissioner for Refugees (UNCHR) will be used as references when the federal government deals with managing housing and urban sprawl after disaster strikes. However, in Malaysia, those international guidelines are only used as the legal context for implementing emergency housing and bind with any laws.

Malaysia has experienced the first tsunami disaster on 26th December 2004 due to the magnitude 9.0 earthquake, which occurred 160 km away from the coast of Indonesia’s Sumatra Island. According to Ling et al.(2006), this was the first time in Malaysia's history that the government was forced to manage such a great disaster and construct large scale post-disaster temporary houses to the victims. This is justified in the study conducted by Zahari & Hashim (2018), where during a disastrous event, the victims were relocated to relief shelter like mosque, public halls and schools. The impacts of the tsunami disaster have caused 104 affected families from 1f3 different fishing villages to be relocated to post-disaster temporary housings while waiting for the permanent housing to be constructed. A total of 120 units of temporary hybrid (timber and steel) longhouses were erected to accommodate the affected families, and the remaining units were used as a community room, management office, prayer room and storage room (Ling et al., 2006). A picture of the temporary longhouses and typical floor plan is shown in Figure 2.4. Besides, a questionnaire survey was carried on the affected families to evaluate the community response towards the recovery measures. One of the evaluation factors was about the living conditions in the temporary longhouses. Eighty-five per cent of the respondents agreed that the timber structure has poor water resistance and 80% of the respondents mentioned the temporary longhouses would not last for two years due to the non-durable materials used (Ling et al., 2006). Therefore, there are still improvements to be made to the Malaysia disaster management system, especially in terms of emergency relief and post-disaster temporary housing during the recovery phase.

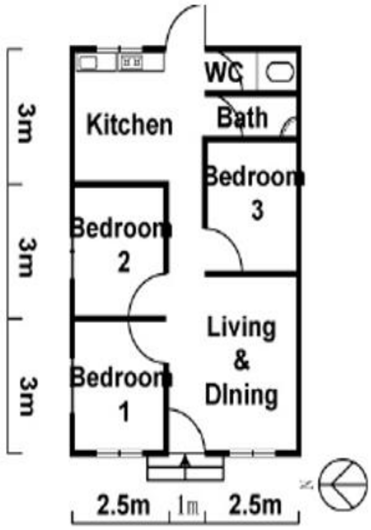


Figure 2.4 Temporary longhouses and typical floor plan (Ling et al., 2006)

2.5 Industrialised Building Systems (IBS) in Malaysia

Industrialised Building Systems (IBS) in Malaysia has been introduced since the 1960s with the purpose to speed up the construction time of the project and to fulfil the demand for houses in Malaysia (Musa et al., 2015; Mohammad et al., 2016; Mohd Fateh et al., 2020) . The definition of IBS from 2003 until the present is shown in Table 2.3.

Table 2.3 Definition of Industrialised Building System (IBS)

Definitions	Authors
An Industrialised Building System (IBS) may be defined as all building components such as the wall, floor slab, beam, column, and staircase mass-produced either in a factory or at the site under strict quality control and minimal on-site activities.	Thanoon et al.(2003)
Industrialised Building System (IBS) is a construction process that uses standardised building components mass-produced in a factory or on-site, then transported and assembled into a structure using appropriate machinery and equipment with minimal workers on-site with proper planning and integration.	Musa et al.(2015)
IBS is defined as a construction technique in which components are manufactured in a controlled environment (on or off-site), transported, positioned and assembled into a structure with minimal additional site work.	Din et al.(2012); Mohammad et al.(2016)
Industrialised Building System (IBS) can be generally interpreted as the process in which all buildings components are produced either in a factory or at the site.	Alzahri et al.(2020)

Although the introduction of IBS in Malaysia is about 60 years, the implementation of IBS in the construction field is not widely practised yet. According to Din et al.(2012), the slow adoption of IBS in Malaysia is due to the lack of IBS incentives, cheap labour fees and the inadequacy of market size. Besides, the adopters require a huge amount of work to break even on the investment, low standardisation of components, limitation in mass production and lack of understanding of the Supply Chain Management (SCM) and partnering concept. If the advantages of IBS can be fully understood and adopted in Malaysia's construction field, it is beneficial to a project timeline due to its speedy construction and mass production rate. Therefore, the IBS is essential in constructing post-disaster housing to recover the affected community to its original state or better in a short time.

2.5.1 Advantages of IBS

According to CIDB (2016), it is proven that the IBS can speed out the delivery time of a project, and the quality of work delivered is much better than the conventional methods as the components are manufactured and monitored under a strictly controlled environment. In relation to that, the labour cost will be reduced as fewer workers are required on-site and not subjected to downtime due to adverse weather condition. Besides, the IBS is also known as the greener building materials due to lower carbon emission when compared with the conventional building methods. The advantages of IBS are categorized and presented in Table 2.4.

2.5.2 Types of IBS

The Industrialised Building System (IBS) in Malaysia can be classified into five major groups, namely pre-cast concrete framing, panel and box systems, steel formwork systems, steel framing systems, prefabricated timber framing systems and block work systems. The detail of the classification is shown in Table 2.5.

Table 2.4 The advantages of IBS

No.	Advantages	Findings	Source
1	Reduction of project delivery time	The preparation and construction of the modules can be carried out simultaneously, thus reducing the time of construction.	Navaratnam et al.(2019)
2	Better quality control	The quality of building finishes was also found to be better than the conventional construction method.	Thanoon et al.(2003)
3	Cost reduction	Based on the cost evaluation made, it can be concluded that IBS has shown the advantages in the cost reduction on slab structure of the school construction project.	Ramli et al.(2016)
4	Lower carbon emission	It is found that the IBS construction method has a lower carbon emission compared to Project B using the conventional system by 35.93%	Ibrahim et al.(2018)
5	Sustainability	IBS contributes to sustainability by producing less waste, less volume of construction materials, increased environmental and construction site cleanliness, better quality control and promote safer and organised construction site.	Musa et al.(2015)
6.	Reduction of labour workforce	IBS construction approaches are to resolve the foreign labour workforce issues, improve the project's quality, and minimise the volume of material consumed in finishing the projects.	Kamaruddin et al.(2013)
7.	Reduction of waste materials	Up to 80% of prefabricated construction system is typically conducted at factories with consistent quality control, and any waste materials found will be recycled or reused.	Navaratnam et al.(2019)

Table 2.5 Classification of IBS in Malaysia

Group	Description
Pre-cast Concrete Framing, Panel and Box Systems	The concrete structural components are pre-casted off-site. The common pre-cast concrete elements found are columns, slabs, beams, 3D components, permanent concrete formwork, and lightweight pre-cast concrete (Din et al., 2012; Musa et al., 2015).
Steel Formwork Systems	The formworks are made of prefabricated steel sections (Taher Ahmed et al., 2014).
Steel Framing Systems	One of the favourite choices is extensively used in the fast-track construction of skyscrapers. This system's development is currently focusing on increasing the usage of lightweight steel and steel portal frame systems (Din et al., 2012; Musa et al., 2015).
Prefabricated Timber Framing Systems	The construction of roof trusses and building frames is done by using prefabricated timber components. (Din et al., 2012; Musa et al., 2015).
Block Work Systems	Interlocking concrete masonry units (CMU) or lightweight concrete blocks are used as alternatives to the time-consuming conventional brickworks (Din et al., 2012; Musa et al., 2015).

2.6 Prefabricated cold-formed steel construction

According to Tahir et al.(2006), the introduction of light steel framing system with cold-formed steel is one of the focused developments in the lightweight material to promote the implementation of Industrialised Building System (IBS) in Malaysia construction industries. Light steel framing is commonly made up of cold-formed steel with C-shaped sections or Z-shaped sections. A few figures of the typical cold-formed steel sections used in light steel framing systems are shown in Figure 2.5 and Figure 2.6. There are differences between the steel framing systems constructed by prefabricated cold-formed steel and hot-rolled steel. Gardner et al.(2010) has stated that the cold-formed steel sections are manufactured at the ambient temperature following EN 10219-2 (2006), and it will experience plastic deformation during the rolling process. However, the hot-rolled steel is produced at a temperature above the recrystallisation temperature of itself following EN 10210-1 (2006). As a result, the cold-formed steel has better strength but lower ductility when compared to the hot-rolled steel.

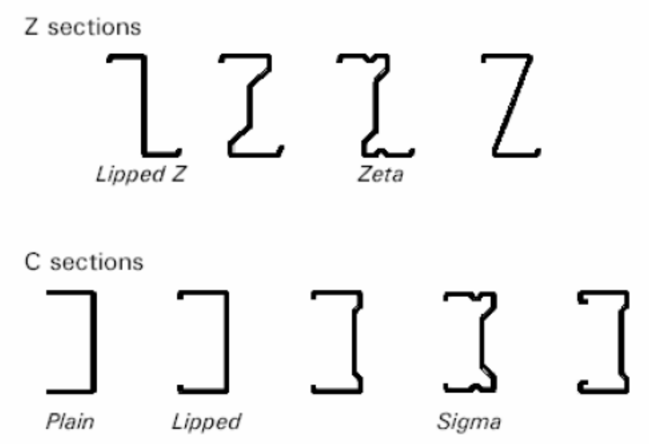


Figure 2.5 Typical cold-formed steel sections (Ling et al., 2006)

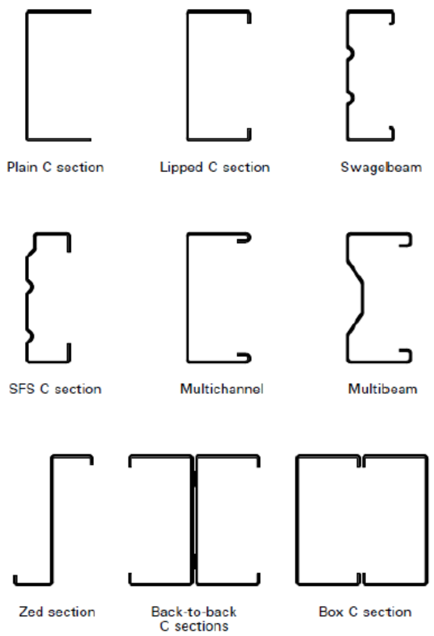


Figure 2.6 Typical cold-formed steel sections (Jing, 2016)

2.6.1 Application of cold-formed steel in construction field

Schafer et al.(2016) have stated that cold-formed steel usage can be found in both non-structural and structural applications. For the non-structural applications, the cold-formed steel can be used as interior partition walls and curtain walls. In contrast, the cold-formed steel is also applicable in using as the girts and purlins of a steel building, mimicking wood construction, constructing residential housing and mid-rise structures in North America.

According to Sharafi et al.(2018), the lightweight steel framing (LSF) made up of cold-formed steel can be shaped into various structural elements such as walls, roof trusses and joists. The usage of LSF in low-rise buildings is having an increase in demand, and it is gradually penetrating to the mid-rise structure's construction. Besides, in the non-structural architectural systems such as drywall systems, the lightweight steel framed systems constructed from cold-formed steel can be made into products like non-loading bearing partitions, façades and suspended ceilings. The non-loading bearing partitions are a type of frames made up of the prefabricated cold-formed C-shaped and U-shaped steel sections with a thickness of 0.6mm usually (Landolfo, 2019).

Modular construction with cold-formed steel framing has various applications due to its benefits like speedy construction, sustainable and safer construction methods. The modular construction applications consist of constructing hotels and apartments, student accommodation, school, sheltered accommodation, toilet, serviced units, roof extensions from buildings, restaurants and service stations and temporary buildings (Jing, 2016). According to Gunawardena (2016), prefabricated modules is widely used as a temporary housing solution for different scenarios. For example, the prefabricated modules are used as temporary housing for tsunami victims in Japan in 2012. It can also be deployed as a temporary office unit at the construction site.

2.6.2 Connections and joints in CFS structure

According to EN 1993-1-8 (2005), a connection refers to the point where two connected members or elements meet. A joint is referred as the interconnectedness of the connected members at a particular area. In Lu (2016) study, it states that the design of connection and joints used in CFS construction commonly follows the principles of design of deconstruction (DfD). In addition to that, the typical CFS connections used are screwing, bolting, riveting, joining with shot-fired pins, nailing and welding (Yu & LaBoube, 2010; Lee et al., 2014). However, in the CFS modular building, the welding connection or rigid connection is less preferable than the semi rigid connection as the CFS components' fabrication speed might be affected (Gatheeshgar et al., 2021).

John (2016) mentions two types of connections present during the CFS modular construction which are factory-made connections between CFS members and on-site connection between modules. Furthermore, the common type of connection methods used in prefabrication members, ceiling and wall panels are screwing, welding, clinching and riveting (Lawson et al., 1999) as presented in Table 2.6.

The principle of DfD for connections and joints (Lu, 2016) are:

1. Connections considered in structure should be reversible.
2. Promote the usage of removable fasteners and avoid using adhesives.
3. Ease of accessing the connection location during deconstruction.
4. The connection should follow the market standard sizing and shapes.
5. The connection details should be simplified and standardized.
6. The connection is easily accommodated by few connecting elements.
7. Minimize the number of members with different sizing.

Table 2.6 The type of cold-formed steel connections

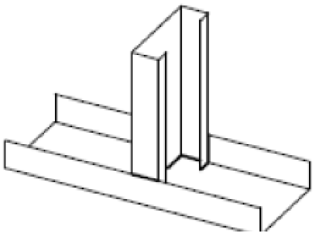
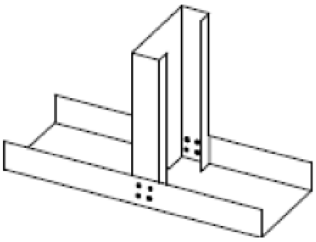
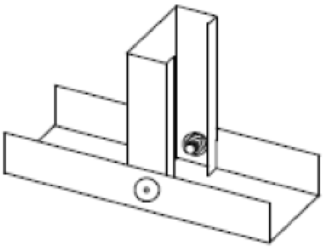
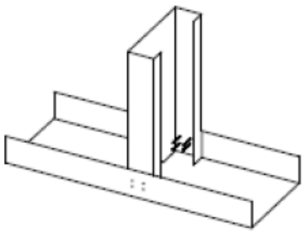
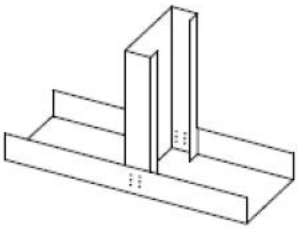
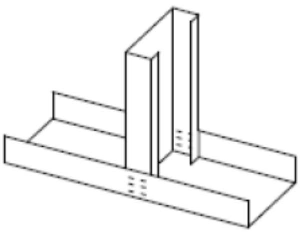
Connection Illustration	Description and Comments
	<u>Continuous MIG Welding:</u> Cautions should be taken while welding as they might damage the thin members. Welded area should be covered with zinc-rich paint for preventing corrosion
	<u>Spot Welding:</u> It is used in workshop fabrication and a minimum of three spot welds per connection
	<u>Bolting:</u> Bolting is commonly used as the holes can be punched through easily during the manufacturing process. The strength of the connection is limited by the strength bearing capacity of the thin steel sections
	<u>Screwing:</u> A common connections method used in connecting steel members. The screws consist of a drill and tapping part. A hole is drilled while the thread is established with the tapping part. A minimum of two screws are needed per connection.

Table 2.6 Continued

 	<u>Riveting:</u> Riveting can be divided into blind riveting and self-piercing riveting. Blind riveting requires pre-drilled holes on the steel members, and the rivets are inserted and then expanded in the holes. Self-piercing riveting requires no pre-drilled holes as the hole and permanent fastening are established in only one operation.
	<u>Clinching:</u> Clinching is a type of mechanical fastening connection method which requires no additional connecting elements. Clinching do not require any pre-drilled holes, and it is conducted in a single operation.

2.6.3 Exterior wall cladding of steel structure

The exterior wall cladding refers to the materials used to enclose or attach to the steel structure's opening surface to act as a protective layer. The installation of exterior wall cladding of a steel structure can be done either on-site or off-site in the factory. The common type of exterior wall claddings used in a steel structure is brickwork, polymer modified render on rigid insulation, metallic profiled panels, composite insulated cladding panels, hanging tiles and timber boards (Lawson et al., 1999; Gorgolewski et al., 2001;). The figures for each type of exterior wall cladding are illustrated by Figure 2.7 to Figure 2.12. According to John (2016), brickwork cladding