LOW AND MEDIUM SEISMIC EFFECT TO PILOTIS STRUCTURE IN MALAYSIA

by

Jonathan Wong Sie Chuan

Dissertation submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Ibrisam B. Akbar)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY, 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

JONATHAN WONG SIE CHUAN

ABSTRACT

The current building structures which involve the design of pilotis system is having a potential of collapsing or failing due to seismic waves produce by earthquake. Pilotis system which does not have designed to suit with sustaining seismic waves can endanger people who are using it and cause damages to the surrounding. Some factors that seismic design was not considered in the pilotis system is that maybe during the time of construction, the particular region was not considered as a seismic active region. Due to changes in time, the moving of continental drift, a seismic inactive region might become active. Thus, buildings with pilotis system which was constructed during the old days need to be retrofitted and the risk of collapsing should be mitigated. Therefore, a modeling for pilotis frame is done to check for the suitability of the pilotis system in seismic region. The research is carried out by using SEISMOSTRUCT which aids in the model designing to analyze the post effect of pilotis structure subjected to cyclic loading. A 1 bay 2 storeys pilotis structure is constructed to verify the design usability. Then a 3 bays 3 storeys strengthened pilotis structure with concrete jacket at ground columns is modeled. The results showed that with concrete jacket, the ground column perform better due to higher compressive strength properties materials used in it. The column’s concrete jacket also serves as a protection layer to the column itself which is more invulnerable to the lateral loads. Some modifications on modifying the dimensions of concrete jacket are done and is proved that larger sizing concrete jacket does help in stabilizing structures. Thus, the retrofitting method of installing concrete jacket on ground column is able to withstand the seismic loading from low to medium level. It is also recommended that larger concrete jacket may be used for catering higher level seismic loading. Higher concrete and reinforcement bar compressive strength are also suggested to be use in concordance with larger concrete jacket.

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LIST OF ABBREVIATIONS

PGA	Peak Ground Acceleration
m	meter
m/s^2	meter per square second
T	oscillation time
f	frequency
K	stiffness of materials
M	mass of materials
Pa	Pascal
MPa	Mega Pascal

CHAPTER 1

INTRODUCTION

1.1 Background of Study

It is undeniable that either internal or external design of structural buildings had evolved through decades. From a simple square or rectangular shaped buildings, they had now evolved into different shaped for certain purposes. Some of the purposes are for attraction, energy saving, popularity, pleasant aesthetical view and many more. One of the building structures evolved is the pilotis system. Pilotis system consists of a soft first storey floor in which the loading on it is supported by columns. The columns sizes depend on the architectural design as well. It may have a long and big column. The purposes of integrating pilotis system to building structures are for aesthetical view and make use of ground floor spaces.

The pilotis system was developed by an architect, Le Corbusier in 1923. The idea is to present the view of structural buildings through modern architecture. This configuration enables large free spaces at ground floor to be easily and effectively arranged by a distributive point of view. This is the reason that most of the architects agreed with the pilotis configuration.

However, this configuration does have its disadvantage. The pilotis when subjected to seismic loading especially is weak. Thus, researchers had tried to simulate and experiment on different types of mitigation method which suits the best accordingly. Some pilotis are built and only the particular region is considered as a seismic prone region. Only physically retrofitting the pilotis, for instance, installation of jackets may help to reduce and mitigate the issue. Furthermore, the provided mitigation method shall also at the same time conserve the aesthetical expression of the building structure itself.

1.2 Problem Statement

The problem that arises in pilotis system is that it is vulnerable to lateral loadings, especially for seismic loadings. Before the acknowledgement of seismic considerations, previous pilotis system is built basically to cater for gravity loadings. Pilotis systems that existed 30 years ago which are still now in service are prone to upcoming seismic activities. This is because a region might not be considered as a seismic region decades ago can be considered as one now. For example, in Malaysia, previously was known as a place country which is free from natural disasters. However, in recent years, studies show that Malaysia was affected by earthquake from neighboring countries. This may probably due to the location of epicenter of the earthquake which is quite near to Malaysia. So, building structures are subjected to the waves. Due to this issue, Malaysia is now categorized under low to medium seismic region. Thus, mitigation plans shall be carried out in order to overcome the problem so that the structure can continue to serve the civilians.

1.3 Objectives

The aim of this project is:

- To simulate the low and medium seismic effect to pilotis structures and buildings using SEISMOSTRUCT
- To check on the after-effect of seismic loading on the pilotis structures and recommend enhancement

1.4 Scope of Study

The scope of study focuses on modeling pilotis frame system using SEISMOSTRUCT developed by SeismoSoft Company. The pilotis frame system will be modeled based on the modeled being verified. As in the construction industries in Malaysia, not many building design codes include the seismic design other than tall building structures. This is significant especially for building which involves the use of soft storey structures such as pilotis frame system. The pilotis frame system is basically withholding the gravity loads from the floors above it and it is vulnerable to any lateral loadings. Due to this, the pilotis structure eventually been modified to have better capabilities in dealing with either gravity or lateral loadings. The introduction of concrete jacket for the columns supporting soft storey had improve the overall pilotis structure's performance. It is foreseen that Malaysia is categorized as low and medium seismic region. Therefore, it is vital to include this design in Malaysia for the safety of public and image of the country. For this reason, this project is aimed to model and verify the improvised and strengthened pilotis frame.

1.5 Project Relevancy

The purpose of this project is to study on the strengthened pilotis frame system behavior under different scaled earthquake acceleration time history, using SEISMOSTRUCT.

The significant of this project to the society is:

- A proper pilotis frame system can be design based on its capability to withstand the seismic loading which is induced to it
- Older design used in the building structure which involves the use of pilotis type frame can be improvised to withstand seismic loading occurred in near future
- Newer building design can include the verified pilotis type frame without hesitation as it has been proven for the usage of such structure

1.6 Feasibility Studies

This project is mainly based on modeling. With given values from the research paper, it is able to make a comparison between the values obtained in the SEISMOSTRUCT modeling and the one in research paper. Most of the research time will be taken to model to modify the model, test with different level of earthquake intensity. This project is expected to be done within the planned time frame.

In terms of economically feasibility, it is necessary to carry out this research as it involve the safely occupancy of the building structure itself. If the structure is not designed to resist for seismic loadings, it might resulted in severe damage that the building has to stop its service and carry out maintenance. If it were an office building, a stop in servicing might halt the worker to work inside. This eventually can indirectly affect the economy of the country. A country’s image may also be spoilt if there are a lot of buildings consisting pilotis structure collapsed due to seismic waves.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Seismic, according to World English Dictionary, is a term related to or caused by earthquakes or artificially produced earth tremors [1]. Science Dictionary defined seismic as a term relating to earthquake or to other tremors of the Earth, such as those caused by large explosions. Seismic waves are waves created by tremors which travel through rock with different velocities. Seismic waves are categorized into 3 difference waves based on their velocities. The 3 different categories of waves are namely the longitudinal P-waves, transverse S-waves and surface waves [2]. It is also able to determine the location of the epicenter of earthquake based on the arrival time of the P-waves and S-waves to the station.

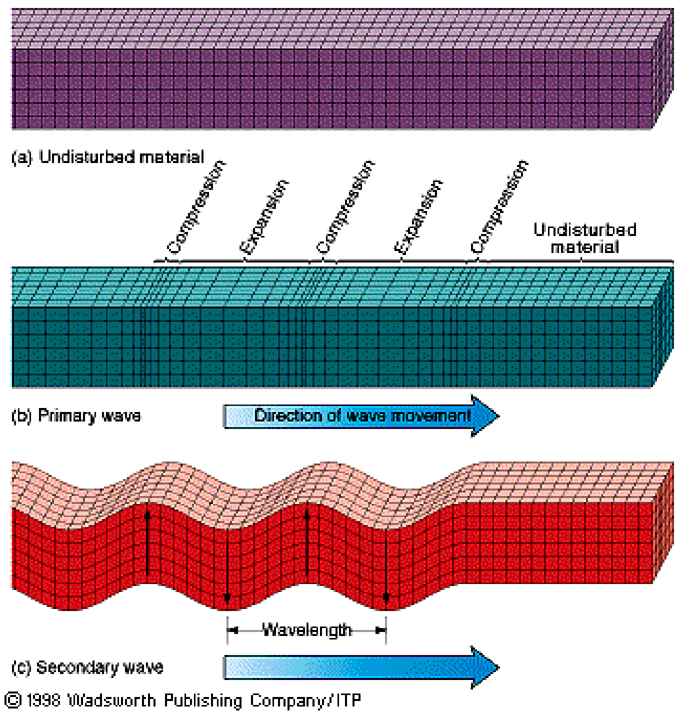


Figure 2.1: Primary Waves and Secondary Waves

A seismic zone refers to a region where the rate of seismic activity remains consistent [3]. Generally, the zones will be represented by different colours for different level of seismic activity. It may also be presented in numbering form where higher numbers represent the most at risk of seismic activity. The zoning of country into different seismic zones enables identification of areas which are at risk. Building construction in these regions will be taken into consideration by applying more stringent building codes in order for safer design of building structures.

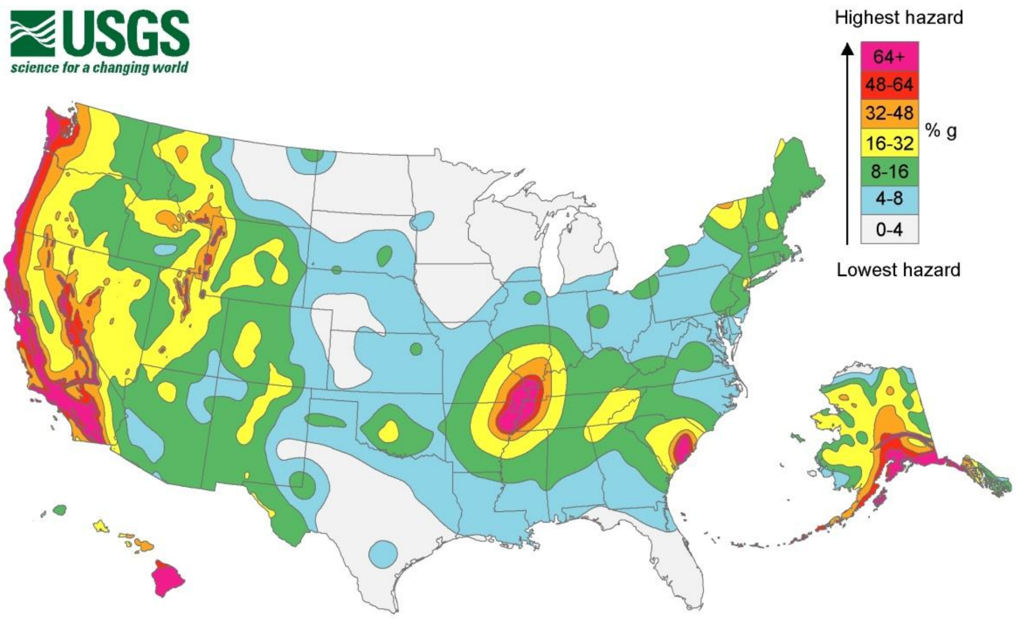


Figure 2.2: Region zoned based on different level of hazards

Each zone is given identified with its respective seismic hazard. Normal references to Richter scale and moment magnitude scales only make measurements about the magnitude and size of a seismic activity. Rather, it uses Mercalli intensity scale which measures the intensity of the seismic activity. The intensity here is defined as the ground motion on how intense the earth shakes in the particular geographical area. This is also known as the measurement of peak ground acceleration (PGA). It is however PGA is more suitable to determine the damage in moderate earthquakes. Peak ground velocity will be a better damage determinant for severe earthquakes. Thus, the measurement of the intensity of seismic hazard for a particular region is based on the percentage of gravity, g. ($1g=9.81m/s^2$) [4]. The higher the value for seismic hazard, the more should the professionals concern when carrying out project in these areas. Considerations of risk, safely, and building design codes will be taken. In a research paper, The Seismic Analysis of Malaysia Bridges, it is stated that Malaysia is categorized in low intensity ground acceleration area of around 0.15g in Penisular Malaysia and 0.20g in Sabah and Sarawak [5]. In a research paper, Seismic Considerations of Circuit Breakers, it stated that there are three seismic qualification levels for earthquakes, which are:

- Low seismic region– 0.1g or less.
- Moderate seismic region – 0.25g.
- High seismic region – 0.5g

2.2 Malaysia Seismic Condition

A research paper, Development of Design Response Spectra Based on Various Attenuation Relationships at Specific Location, stated that Penisular Malaysia is located in a low seismic region [6]. This is also stated in a technical paper, Seismic Hazard of Singapore and Malaysia, that Singapore and Malaysia are of low to moderate seismic regions. Although Malaysia is located approximately 350km away from Sumatran seismic zones and on a stable region, building structures in Malaysia can feel the tremor generated from Sumatran seismic zones even though the magnitude of the earthquake is only 5.0. This is probably due to the buildings which are constructed on top of soft soil. The low frequency waves from the earthquake are able to travel long distances and are more to energy dissipation. Long waves reaching Malaysia are being amplified due to resonance where the natural period is close to the period on site. Thus, residents in Malaysia can feel the tremor [7].

According to a research paper, Preventing Earthquake Disaster, posted by the National Research Council, the occurrence of an earthquake is the result of sudden displacements across a fault within the earth. People who stay in a seismically active region are exposed to the inevitable risk from earthquakes. Since the advance of technology nowadays, it could be one of elements for earthquake disaster prevention [8].

In Malaysia history, the earthquake has not inflicted either severe property damage or casualty until the Sumatra-Andaman Earthquake which stroked on 26th December 2004, generated a moment magnitude of 9.15. Some areas in Malaysia where received the hardest hit from the wave includes Penang, Perak, Kedah and Perlis. A significant number of deaths in Malaysia were reported to be more than 50. From this incident, Malaysia is said to locate at an earthquake region. However, Malaysia is considered as a low seismic region as earthquake origin is far from Malaysia.

2.3 Pilotis Structures Framing System

Pilotis is a structural framing system which is commonly used in upcoming structural buildings and existing building. The idea of pilotis structure configuration is developed by an architect Le Corbusier and is expressed in its opera Vers une architecture on 1923 [9]. Commonly, it is found out that the pilotis structure comes with a soft first storey configuration. In which it means that from physical view, the building seems to be lifted from the ground using reinforced concrete columns. Due to this configuration, it allows a great ample space for use at the ground floor.

On the other hand, the design of the structure has found out to be dangerous from the view of seismic analysts. When there is seismic activity, the whole building other than the first storey behaves as a rigid body. The first storey is subjected to lateral loadings from the seismic activity. The problem arises now is that most of the structures which uses the application of pilotis system do not resist to lateral loads from earthquake. Also, current pilotis system presents various types of weaknesses.

2.4 Current Available Retrofitting Methods

According to a technical paper, Investigation of Seismic Retrofit For Pilotis Frames Utilizing Extremely Thick Hybrid Walls, it stated that pilotis structures designed with both older or updated codes had suffered from extensive structural and non structural damages. The damages are mostly concentrated on first storey due to the changes in lateral strength and stiffness. Thus, a retrofitting method is required to be carried out before the remaining buildings still upright intact with the earth collapse. Some retrofitting method had been carried out to improvise their strength against lateral load in a way that to preserve the aesthetical expression of the structure [10].

There are also methods on retrofitting the pilotis structure through the implementation of opening type extremely think hybrid walls as stated in the technical paper, Investigation of Seismic Retrofit for Pilotis Frames Utilizing

Extremely Thick Hybrid Walls. The hybrid walls will serve as an element which can improve both lateral force resistance capacity and ductility of the first storey.

Among the modification method available now are dissipating bracing strategy, synergetic dissipation strategy and base isolation strategy. Dissipating bracing strategy make use of braces to absorb extra energy induced from the earthquake and thus strengthening the pilotis frame. Synergetic dissipation strategy is more suitable for works in basement pilotis storey. It involves the insertion of new energy dissipating bracing elements in frame grids and improves the dissipating capacity of the columns. Base isolation strategy is also more to basement retrofitting. It involves the use of concrete jacketing at the basement column, dampers for resisting lateral displacement and gap connection between building and platform.

Among the improving method or modification method is by strengthening the column which connects the ground and the first soft storey. A specifically design reinforced concrete jacket is constructed to fill up the outer layer of the column itself. This causes the ground column to look bigger and steadier than the upper columns. With the increase in size of column, additional reinforcement bars with better tensile strength are able to withstand lateral forces from the earthquake.

From the research paper, Enhancing the Seismic Performance of Existing Pilotis Configuration, the building structures in Italy was not design to resist earthquake as during 30 years ago, Italy was not considered as a seismic area and now it is consider as medium intensity seismic zone. It is also found out that using different retrofitting solutions through the application of innovative seismic protection system based on energy dissipation and base isolation concepts, allows the old building structures to be effectively enhance in overall building performance [9].

However, it is a concern that whether the enhancing method is suitable for use in a region considered as low seismic or medium seismic or high seismic region is a huge concern. This is because some methods are more expensive for retrofitting. Hence, the method used shall be feasible economically.

2.5 Seismic Analysis Software

Experiments on pilotis frame system were carried out to prove it usability. However, experiments require work force and time as well as finance. Thus, developed modeling software can assist in modeling the structures to enable work done with higher efficiency. Notably, the software can be used is DRAIN-2DX and SEISMOSTRUCT. SEISMOSTRUCT is software which uses finite element analysis. It is able to predict the large displacement behavior of space frames under static or dynamic loading. The program had also been extensively checked and validated for its usability. From previous research done, SEISMOSTRUCT had been used in modeling bridge bents using nonlinear static and dynamic time-history analyses. Besides, a nonlinear dynamic analysis was also carried out with SEISMOSTRUCT (SeismoSoft, 2011) for steel frame analysis. In the research paper, Seismic Response of A Pilotis System, SEISMOSTRUCT was used to modeled pilotis frame structure and the result obtained is compared directly to a result obtained from DRAIN-2DX [12]. Hence, it is confirmed that SEISMOSTRUCT software is able to model for pilotis frame system which is the main software used in this research.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The research methodology on this project will be fully based on trial and error method. The information of full geometrical and material properties for concrete, reinforcement, and loading type as well as analysis type can be obtain from the research paper done by previous researchers.

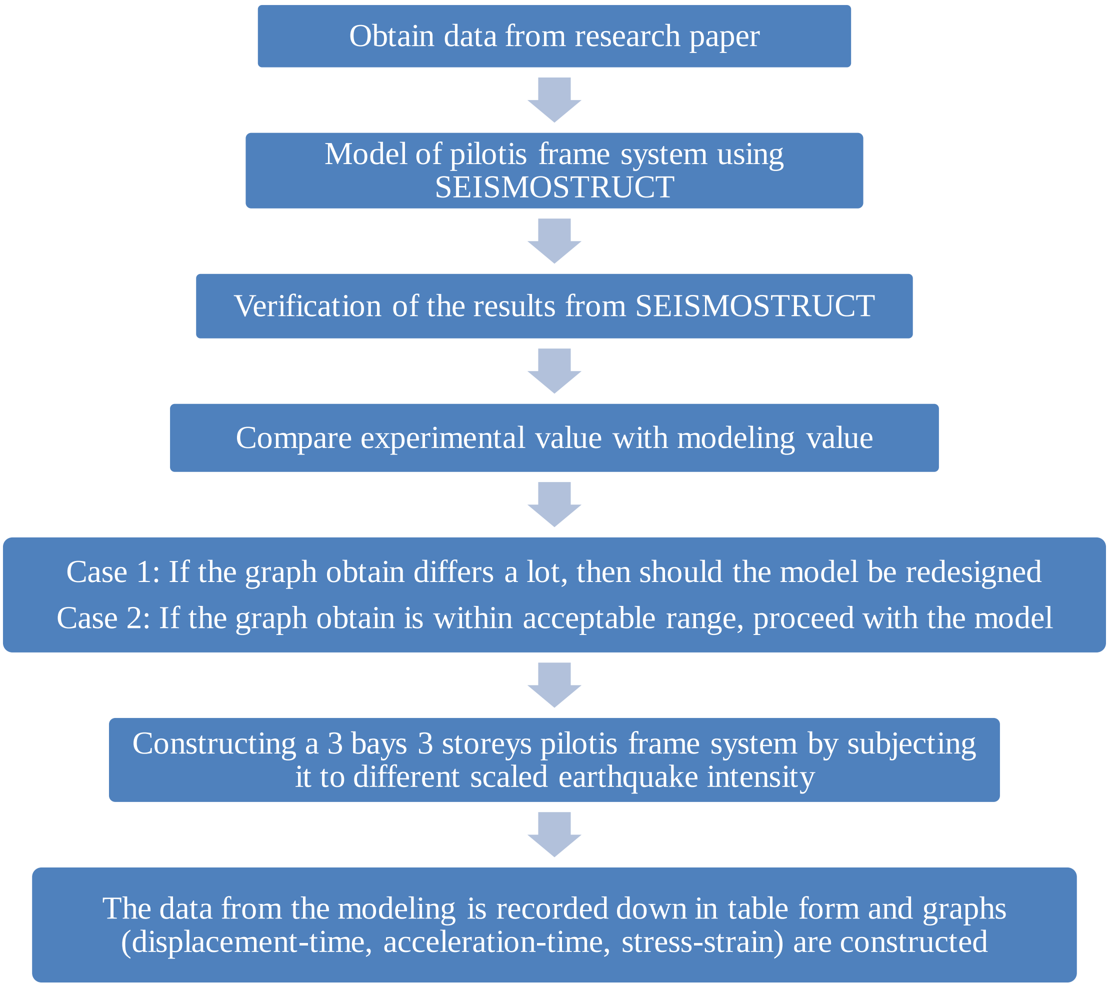


Figure 3.1: Standard flow of trial and error method

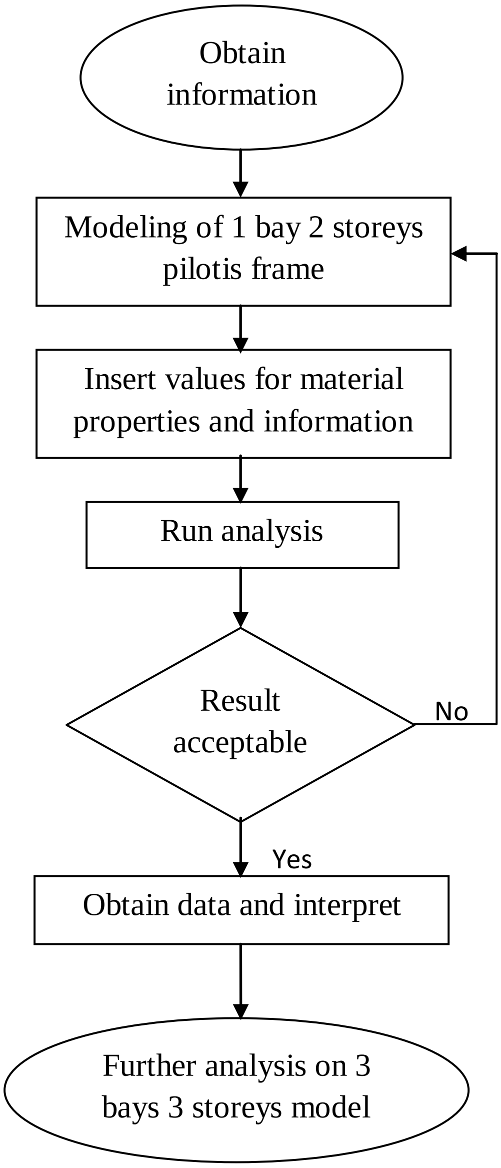


Figure 3.2: Typical flowchart for the modeling process

This research is based more on trial and error as it consisted of modeling. By referencing to a particular paper which provides the details of the model, a 1 bay 2 storey pilotis frame is modeled using SEISMOSTRUCT. The 1 bay 2 storey pilotis frame is created using the wizard option from SEISMOSTRUCT. By entering the particulars and type of analysis with types of loading, the model is generated. Once the model is done, the materials properties are edited to be the same with the details obtained from the paper. Other details which are not provided are to remain default. Time history curve is loaded to the applied load to generate the real time earthquake load on the system. The earthquake data that is used is Griva 1990. The analysis is then processed to view the results. It can be in graph, table or real time processing form. The processing results are generated into graphs and values form. The results are then interpreted to check the response of the pilotis frame system toward the induced load. The lateral drift is based on the displacement time graph obtained. The concrete crushing and steel yielding however can be determined from the stress strain diagram. Once the model is being verified, a 3 bays 3 storeys pilotis frame system is modeled using the same methodology.

Below shows the description on the analytical models:

a) Bared frame
b) Pilotis frame
c) Strengthened pilotis frame

Dimensions of the bay = 3.05m

Storey height = 3m

Numbers of storey = 2

Square column of 0.25m X 0.25m and T-beam is used

Foundation tie beams of 0.30m X 0.40m is used

For pilotis frame,

- has an infill panel
- compressive strength for brick, f_b=15MPa
- compressive strength for mortar, f_m=3.8Mpa

For strengthened pilotis frame,

- same geometry with pilotis frame
- ground column is strengthened with RC jackets of 7.5cm thick

Compressive strength of concrete, f_c=16Mpa

Compressive strength of concrete jacket, f_s=20Mpa

Compressive strength of reinforcement bar in frame, f_s=220Mpa

Compressive strength of reinforcement bar in concrete jacket, f_s=500Mpa

4 bays 3 storey pilotis frame system is based on the strengthened pilotis frame.

3.2 Project Activities

- A related research paper or technical paper is found and materials information as well as properties of the pilotis frame system
- According to the model in the research paper, a similar model is constructed using the information given and SEISMOSTRUCT
- Process the graph of displacement-time graph, acceleration-time graph, and stress-strain diagram
- Verify the values obtained with the values provided
- If the model is verified, a 3 bays 3 storeys pilotis frame shall be modeled using the same methodology
- The 3 bays 3 storeys pilotis frame will be subjected to different scales of earthquake intensity
- Graph of displacement-time graph, acceleration-time graph and stress-strain diagram is processed
- Interpret the results of the graph

3.3 Key Milestone and Gantt Chart

Duration of key milestone and Gantt Chart is set within June 2013 to August 2013, starting from week 1 till week 15.

No.	Activities/ Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Preparation for FYP2	■														
2	Modeling of pilotis frames		■	■	■	■	■	■	■	■	■					
3	Verification of model		■	■	■											
4	Modeling of modified pilotis frames				■	■	■	■								
5	Progress Report Submission								■							
6	Analyse the results obtained from modeling									■	■					
7	Pre-Sedex											■				
8	Submission of draft report												■			
9	Submission of technical report and dissertation													■		
10	Oral Presentation														■	
11	Submission of hardbound dissertation															■

Figure 3.3: Gantt Chart

3.4 Tools

SEISMOSTRUCT V6

- Used to model pilotis frames and run analysis

Microsoft Excel 2003

- Used to extract data
- Modify and scale raw data
- Record values for graphs

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Introduction

In this chapter, modeling results from SEISMOSTRUCT on 1 bay 2 storeys and 3 bays 3 storeys pilotis frame will be discussed. First it will be a results and discussion on the verification of model to verify the design methodology based on eigenvalue analysis and seismic analysis for elastic behavior. The significant of verifying the model is to check on the model whether it reacted the same way as been stated in the research paper, Seismic Response of A Pilotis System. This is to prove that the design methodology is correct and only then modeling and analysis of 3 bays 3 storeys pilotis frame can be carried out based on the same design methodology of 1 bay 2 storeys pilotis frame.

4.2. Verification of Model

The verification of model was done by comparing the results of analysis with the analysis results from the research paper. Two types of analysis were carried out to verify the design methodology of the model, which are Eigenvalue analysis and seismic analysis for elastic behavior. 3 models as shown in Figure 4.1 were designed to verify under Eigenvalue analysis, which are, bare frame, pilotis type frame and strengthened pilotis type frame. However, only strengthened pilotis type frame is verified for the seismic analysis for elastic behavior. Figure 4.1 showed the model output of a bare frame, followed by pilotis type frame and strengthened pilotis type frame. A bare frame is just a frame which consisted of beams and columns. A pilotis type frame is a frame but with additional wall which imposed a loading to it. A strengthened pilotis type frame is the same with pilotis type frame in all way, but it has a strengthened ground column.

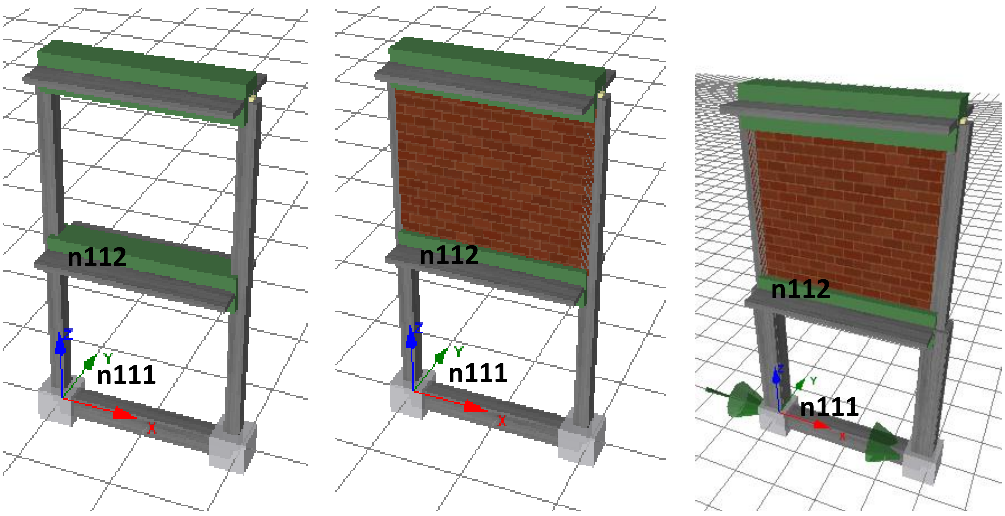


Figure 4.1: (a) Bare Frame, (b) Pilotis Type Frame, (c) Strengthened Pilotis Type Frame

4.2.1. Eigenvalue Analysis

The 3 models of frames are being analyzed under Eigenvalue analysis. Eigenvalue analysis is carried out to determine the Eigenperiod. Eigen analysis seeks to find a coordinate system, in which the solution to an applied problem has a simple expression. Thus, Eigen analysis in other term may be defined as method of simplifying coordinates. Eigenperiod is also known as Eigen frequency. Eigen frequency refers to a natural frequency of a vibrating system at which it will vibrate after a nonrecurring excitation. Eigen frequency will decrease due to damping. In other way to say, if damping is excluded in consideration, Eigen frequency and resonance frequency will be the same. Eigen frequency may be influenced by several factors. Among the factors include:

- change in stiffness
  - material properties
  - dimensions
  - structures
- change in mass
  - specific weight
  - density
  - porosity
  - disruption

It is known that frequency, f = speed/ wavelength. The significant of taking in consideration of Eigen frequency is that if a system is subjected to external excitation at a frequency which coincides with its natural frequency, the whole system will eventually vibrate at higher frequency, also known as resonance. As it vibrates more vigorously, it might contribute more damage to the particular building structure which might overly vibrate more than the designed standard. It is known that every structure has its own specific dynamic behavior. The frequency, f, mentioned is the reciprocal of the oscillation time, T (f = 1/T). Shorter time taken results in higher frequency. Each structure has many natural frequencies and associated mode shapes. However, most of the time only the first natural frequency that is on the lowest energy level is most likely to be activated. The equation for natural frequency of a single degree of freedom system is as shown below:

$$f = \frac{1}{2\pi}\sqrt{\frac{K}{M}}$$

where *K*=stiffness, *M* is the mass

Therefore, the manipulating factors for the Eigen value will be the stiffness of the materials as well as the overall mass which is affected by the weight of materials used.

For the data from research paper, Seismic Response of A Pilotis System, the first Eigenperiod for the bare frame, pilotis type frame, and strengthened pilotis type frame is provided and is shown in Table 4.1. These values will be compared with 1^{st} Eigenperiod values obtained from SEISMOSTRUCT analysis shown in Table 4.2.

Table 4.1: First Eigenperiod of the frames

Frames	1^{st} Eigenperiod (sec)
Bare Frame	0.384
Pilotis Type Frame	0.351
Strengthened Pilotis Type Frame	0.152

From the SEISMOSTRUCT analysis, the first Eigenperiod for the 3 frames is summarized in Table 4.2.

Mode	Period (sec)
1	0.35209028
2	0.12737834
3	0.05751431
4	0.03892154
5	0.03627612
6	0.02683702
7	0.02389563
8	0.01041929

Mode	Period (sec)
1	0.31167973
2	0.06480987
3	0.05450408
4	0.04804459
5	0.03609669
6	0.02808895
7	0.02597029
8	0.01088050

Mode	Period (sec)
1	0.16354138
2	0.06019872
3	0.05344540
4	0.03734638
5	0.03338750
6	0.02781445
7	0.02109871
8	0.00918589

Figure 4.2: (a) Bare Frame, (b) Pilotis Type Frame, (c) Strengthened Pilotis Type Frame

There are eight modes in the results obtained in which only the first eigenperiod will be used for verification. The first eigenperiod will represent the structures responds under eigenanalysis. The second eigenperiod till the eighth eigenperiod, which is represented by Mode 2 to Mode 8 is a derivation from the first eigenperiod. Thus, second eigenperiod and till eighth eigenperiod will not be used. In Table 4.2 summarizes the First Eigenperiods for bare frame, pilotis type frame, and strengthened pilotis type frame, which are represented by Mode 1 in the analysis result. These values will be compared with the 1st Eigenperiod values obtained from the research paper, Seismic Response of A Pilotis System, which is shown in Table 4.1.

Table 4.2: First Eigenperiod of the frames

Frames	1st Eigenperiod (sec)
Bare Frame	0.352
Pilotis Type Frame	0.311
Strengthened Pilotis Type Frame	0.164

The results obtain from SEISMOSTRUCT is acceptable due to small deviations in the values. Below showed the calculations that have been down for the percentage calculation deviation in each frames:

Percentage deviation in bare frame,

= (0.384-0.352)/0.384 X 100%

= 8.333%

Percentage deviation in pilotis type frame,

= (0.351-0.311)/0.351 X 100%

= 11.396%

Percentage deviation in Strengthened pilotis type frame,

= (0.164-0.152)/0.152 X 100%

= 7.895%

The difference of the values might come from the difference in the modeling method as some of the properties are not clearly specified. As aforementioned, Eigenvalue may be affected by the changes in stiffness and masses. Since the deviation is relatively small, it is confirmed that the frame design methodology used in SEISMOSTRUCT is accepted and this brings the model one step closer to the verification stage.

4.2.2. Seismic Analysis for Elastic Behavior

Another verification carried out is verified through seismic analysis for elastic behavior. Elastic behavior of an object means that the object can still return back to its original position once the load upon it is unloaded. This also means that if another same force applied to it, it still can exhibit in the same behavior as the previous loads. If an object were unloaded and unable to get back to the original state or position, this means that the object has reached its limit state and had undergone a plastic behavior. The frame is subjected to dynamic load to analyze for its response. Table 4.3 showed the maximum and minimum values of first storey drifts and acceleration obtained by SEISMOSTRUCT codes from the research paper, Seismic Response of A Pilotis System. A maximum and minimum value in 1st storey drift indicates the direction of the drifting subjected by seismic loading. The negative values indicate the drifting is in opposite direction. The values indicate the maximum storey drift occurred when subjected to seismic loading. As for maximum and minimum values of 1st storey acceleration, the negative sign indicate opposite direction acceleration. The values however indicate that the maximum or minimum storey acceleration occur in the structure when subjected to seismic loading.

Table 4.3: Maximum and minimum values of first storey drifts and acceleration obtained by SEISMOSTRUCT codes from the research paper

	Maximum Values	Minimum Values
1st Storey Drift (cm)	0.38	-0.34
1st Storey Acceleration (m/s^2)	1.08	-1.14

Simulation is carried out using the same software coding from SEISMOSTRUCT.

For seismic analysis for elastic behavior, an acceleration time graph of Griva 1990 earthquake is used. It is an earthquake with M=5.9 magnitude and a peak horizontal acceleration of 0.10 g. The acceleration time graph data is obtained from PEER Strong Motion Database. When inputted into SEISMOSTRUCT, the acceleration time graph of Griva 1990 is as shown in Figure 4.3.

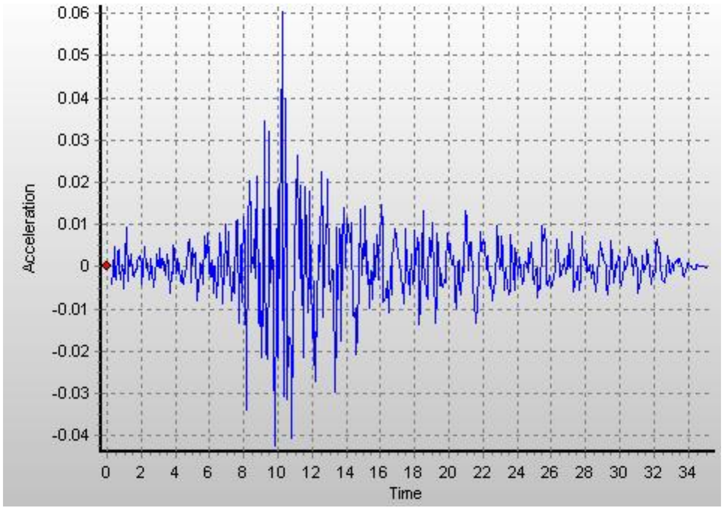


Figure 4.3: Acceleration Time Graph for Griva 1990

The results obtain is shown below in Figure 4.4. Y-axis will represent Structural Displacement of Node 112 with reference to Node 111 in unit of meter, while X-axis will represent the time in seconds.

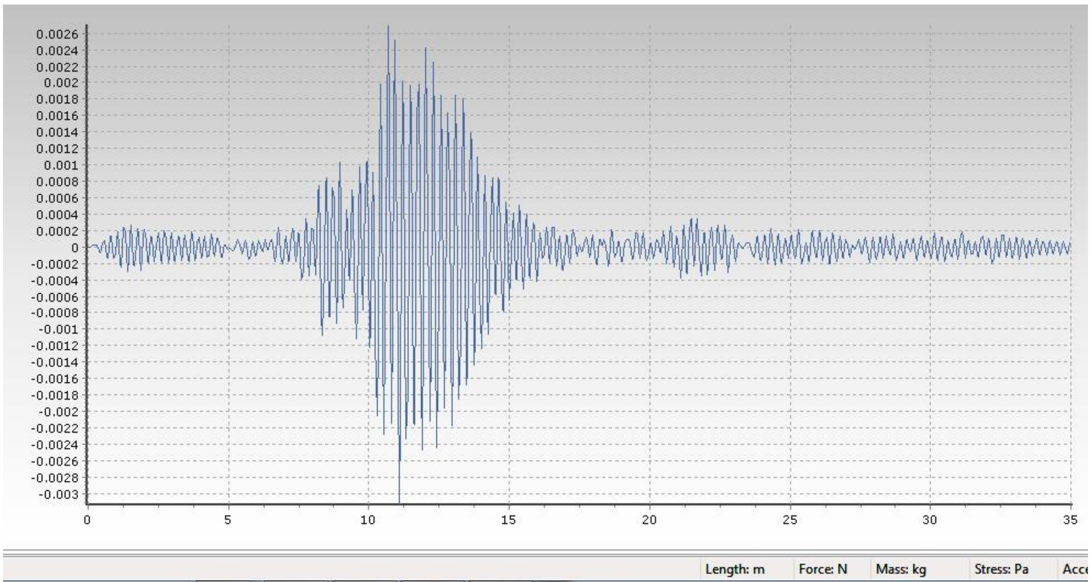


Figure 4.4: 1^{st} Storey Displacement Time Graph

From the graph, the maximum and minimum structural displacement is determined and as shown in Table 4.4. Comparing the maximum and minimum value for 1^{st} storey drift in Table 4.4 with Table 4.3, the values are near. This indicates that the model pilotis frames are responding in a way same as the one stated in the research paper, Seismic Response of A Pilotis System.

Table 4.4: Maximum and minimum value for 1st storey drift

	Maximum Value	Minimum Value
1st Storey Drift (cm)	0.269	-0.313

Figure 4.5 shows 1st Storey Acceleration Time Graph, where the Y-axis represents acceleration in unit of m/s^2; X-axis represents time in seconds. From the graph, the maximum and minimum value for acceleration is tabulated in Table 4.5.

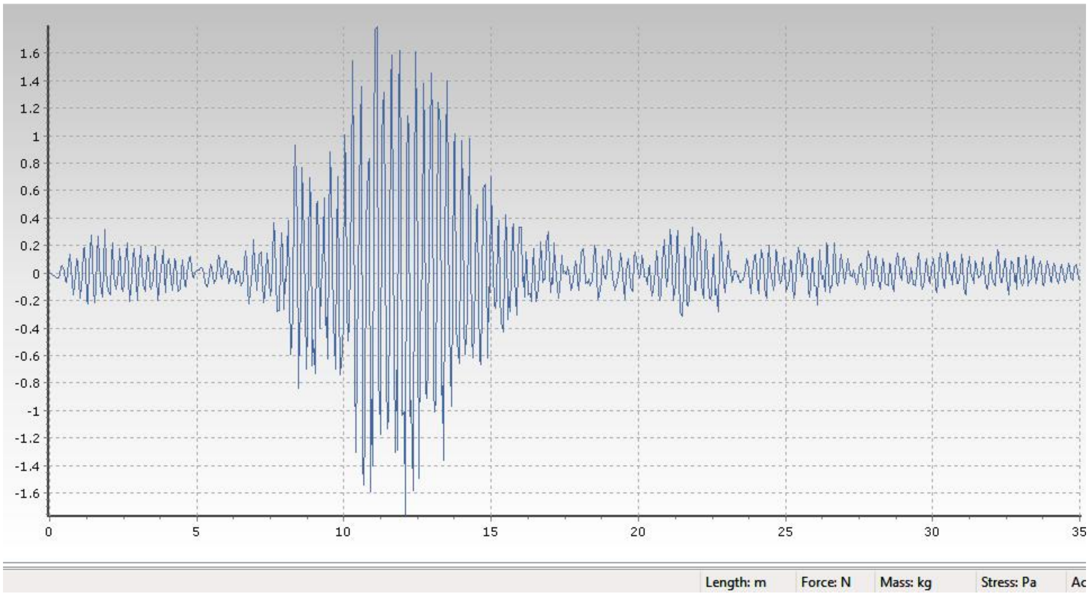


Figure 4.5: 1st Storey Acceleration Time Graph

Table 4.5 showed the obtained values of 1st storey acceleration from SEISMOSTRUCT analysis. Comparing values in Table 4.5 with Table 4.3, the values might differ with the reason that there might have some difference in materials assigned or design methodology. However, the difference is still within allowable area.

Table 4.5: Maximum and minimum value for 1st storey acceleration

	Maximum	Minimum
1st Storey Acceleration (m/s^2)	1.79	-1.76

From the results obtained, it is obvious that the values differ from the values given in the research paper, Seismic Response of A Pilotis System. However, the obtained value is within the acceptable range in which the model is confirmed to be verified. The 1st storey acceleration and displacement do not affect much on the pilotis structure and still within limit. Thus, no maintenance is required. Other models can be design in such a way that following the methodology same as the one used for the verified model.

4.3 3 Bays 3 Storeys Pilotis Frame Model

The 3 bays 3 storeys pilotis frame model which is constructed based on the methodology of 1 bay 2 storeys model had been subjected to 6 different scaled acceleration time histories. All the acceleration time histories are scaled based on Griva 1990 Earthquake of 5.9 in magnitude and has a sinusoidal shape with predominant period of about 0.6 sec and peak horizontal acceleration of 0.10g. The 3 bays 3 storeys pilotis model had undergone dynamic response to experiment for its capability of withstanding the magnitude of earthquake.

After the verification of the 1 bay 2 storeys model, it is suggested that a model frame of 3 bays 3 storeys pilotis frame as show in Figure 4.6 can be modeled using the same methodology. The 3 bays 3 storeys model is tested under several acceleration time histories of Griva 1990 which are scaled and the response to each acceleration time histories are recorded.

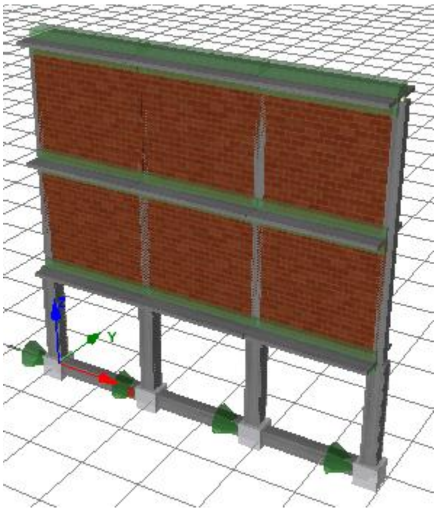


Figure 4.6: Strengthened 3 Bays 3 Storeys Pilotis Type Frame

Figure 4.7 showed the wired frame view of strengthened 3 bays 3 storeys pilotis type frame for the ease of viewing nodes and elements label.

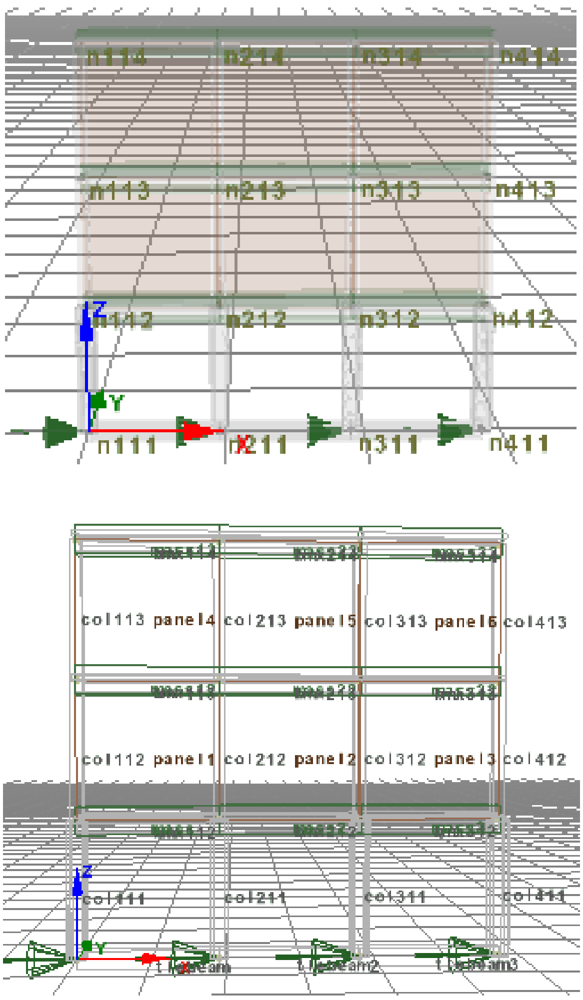


Figure 4.7: Wired Frame View of Strengthened 3 Bays 3 Storeys Pilotis Type Frame

The following acceleration time history analyses shown in Table 4.6 are all analyzed at n112 relative to n111. The reason that the values of acceleration time history data is scaled to this value is to suit with the scaled acceleration time history as provided in the research paper, Seismic Response of A Pilotis System. The 3 bays 3 storeys pilotis type frame will be subjected to each of these scaled acceleration time history loading.

Table 4.6: Scaled acceleration time history

Analysis	1	2	3	4	5	6
Scale to (m/s^2)	0.060	1.125	2.000	2.550	3.050	4.875

The following of the result and discussion part displayed the result graphs of 3 bays 3 storeys pilotis frame subjected to different scaled acceleration time history loading. The results of the analysis are shown in the graph so as to give an idea on the particular time period where the model react the most or the less throughout the analysis time frame. For 1st storey displacement time graph, Y axis will represent the displacement of n211 relative to n111 in units of meter, while X axis will represent the time period of whole analysis in seconds. For 1st storey acceleration time graph, Y axis will represent the 1st storey acceleration of n211 relative to n11 in units of meter per squared second (m/s^2) while X axis will represent time period of whole analysis in seconds.

Acceleration time history scaled to 0.060 m/s^2,

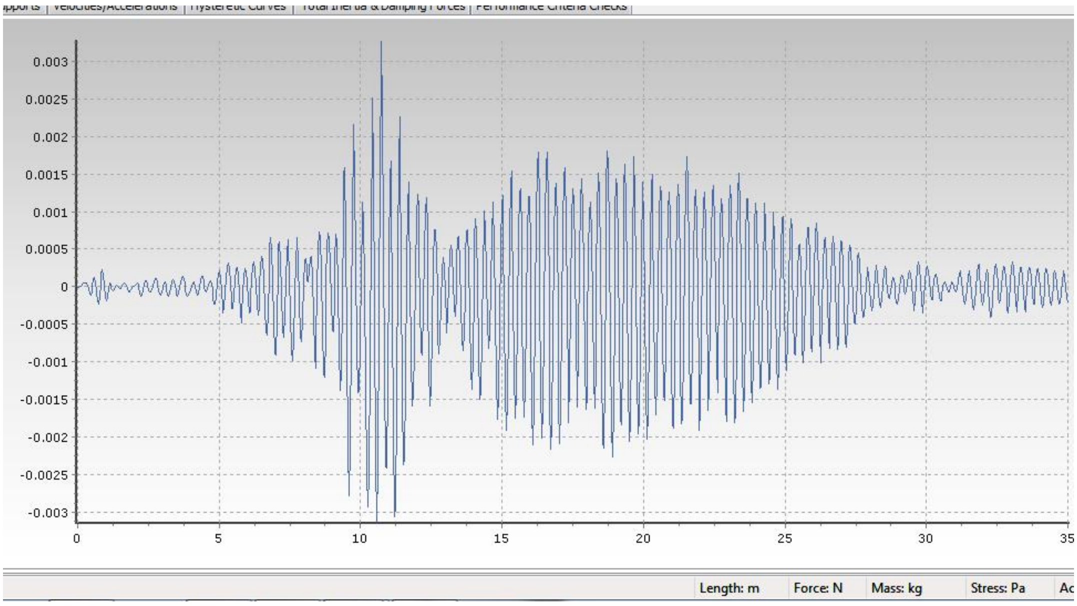


Figure 4.8: 1st Storey Displacement Time Graph (0.060 m/s^2)

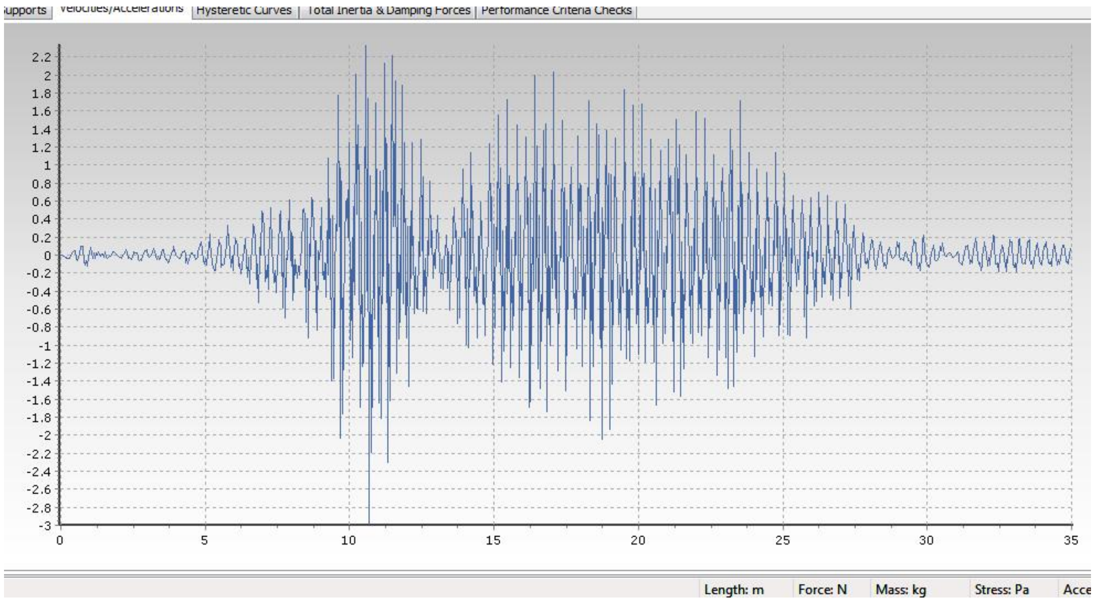


Figure 4.9: 1st Storey Acceleration Time Graph (0.060 m/s^2)

Acceleration time history scaled to 1.125 m/s^2,

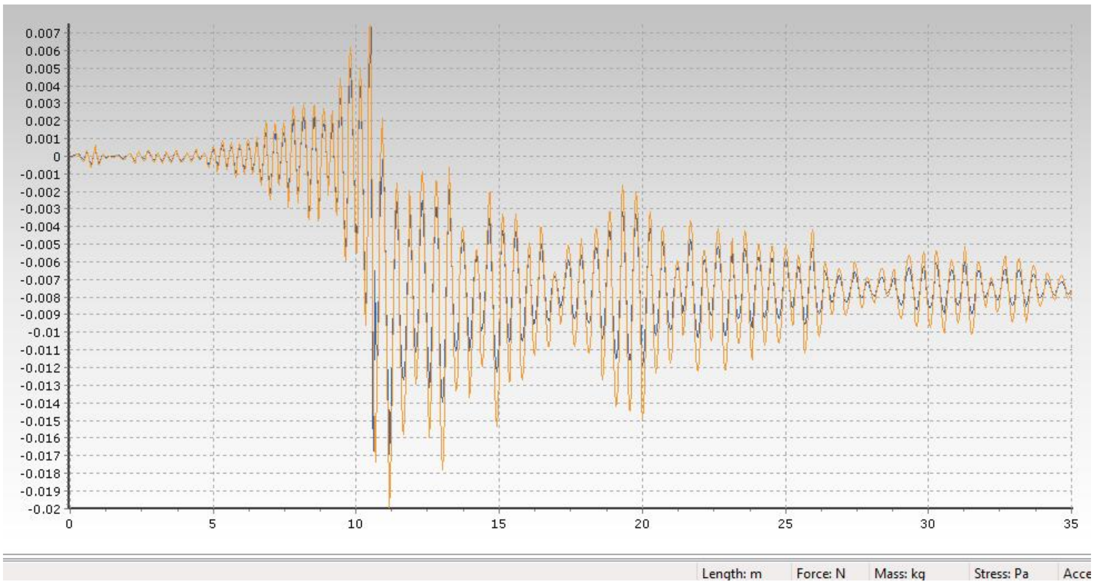


Figure 4.10: 1st Storey Displacement Time Graph (1.125 m/s^2)

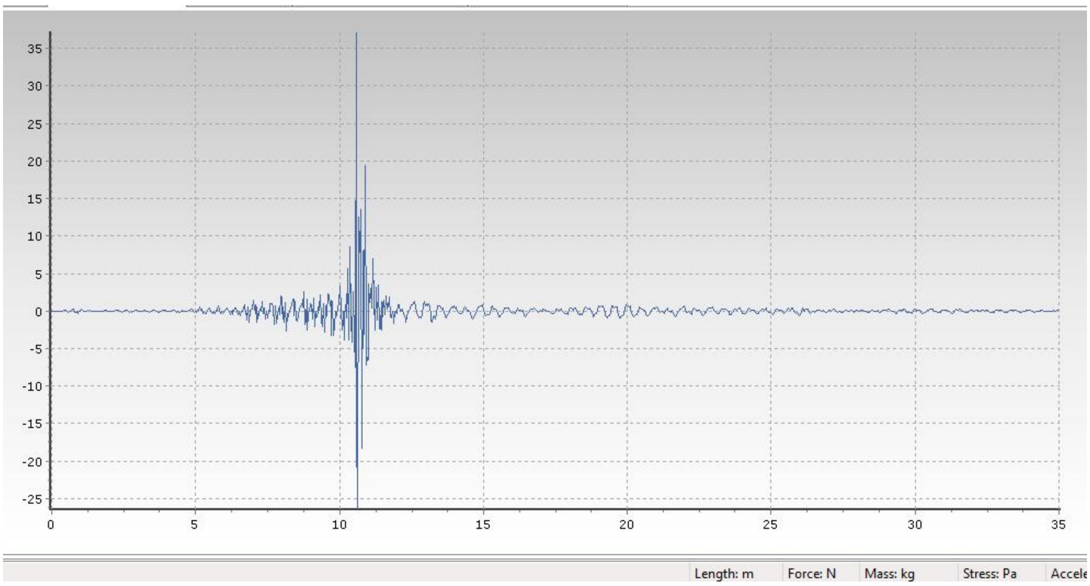


Figure 4.11: 1st Storey Acceleration Time Graph (1.125 m/s^2)

Acceleration time history scaled to 2.000 m/s^2,

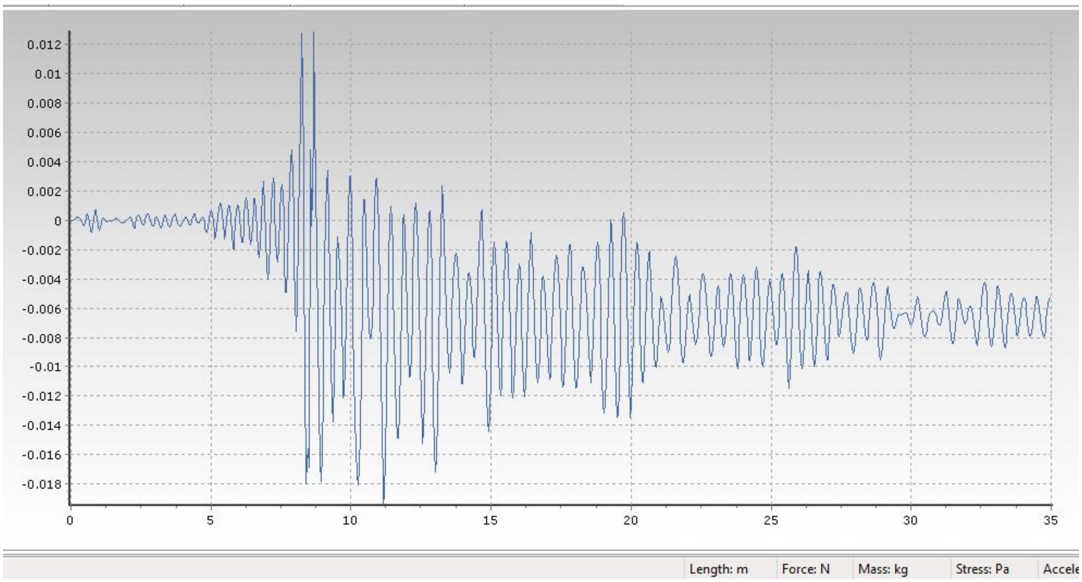


Figure 4.12: 1st Storey Displacement Time Graph (2.000 m/s^2)

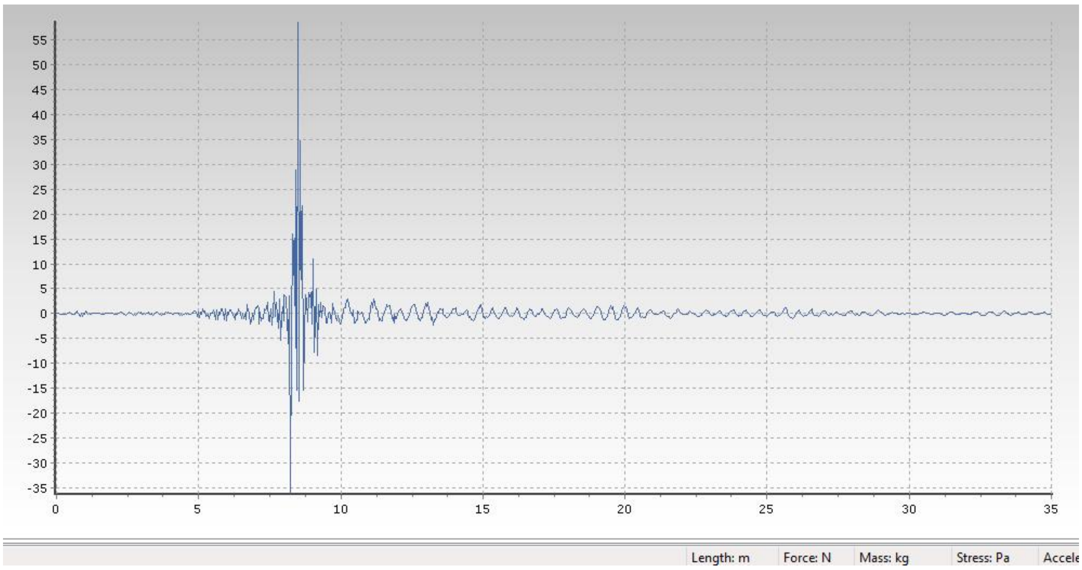


Figure 4.13: 1st Storey Acceleration Time Graph (2.000 m/s^2)

Acceleration time history scaled to 2.550 m/s^2,

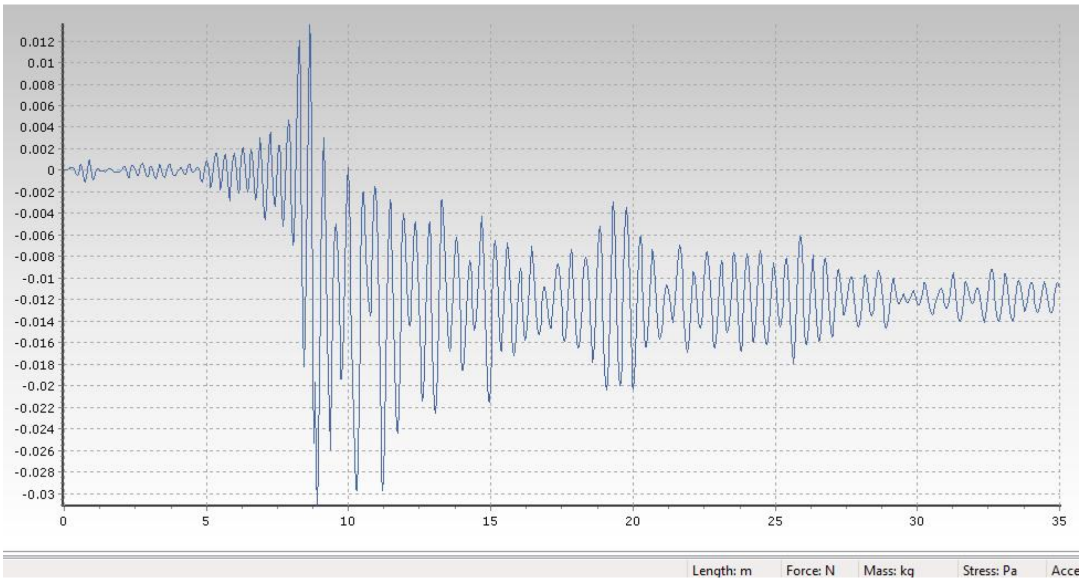


Figure 4.14: 1st Storey Displacement Time Graph (2.550 m/s^2)

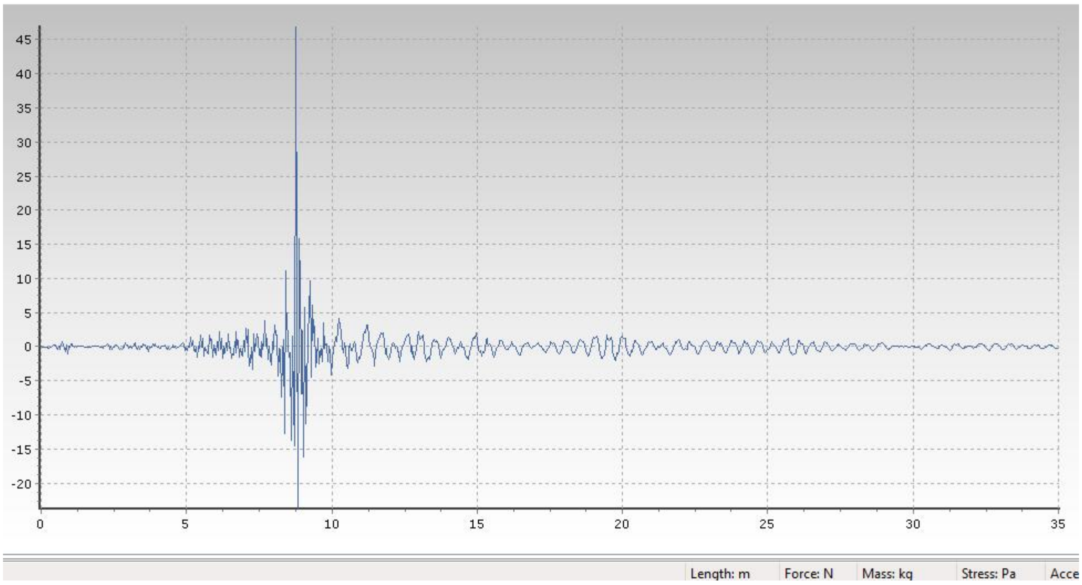


Figure 4.15: 1st Storey Acceleration Time Graph (2.550 m/s^2)

Acceleration time history scaled to 3.050 m/s^2,

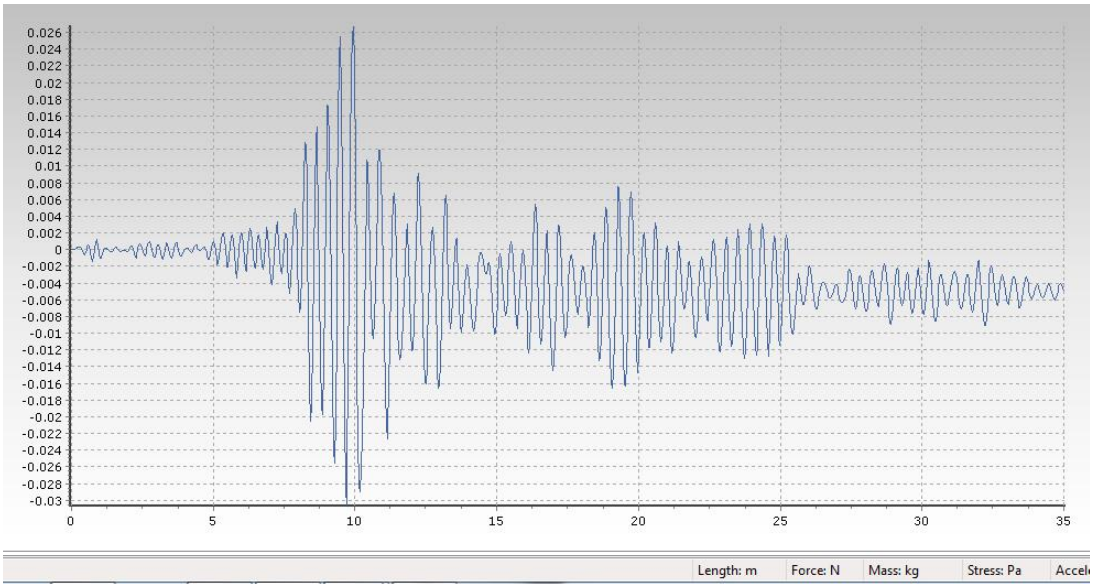


Figure 4.16: 1st Storey Displacement Time Graph (3.050 m/s^2)

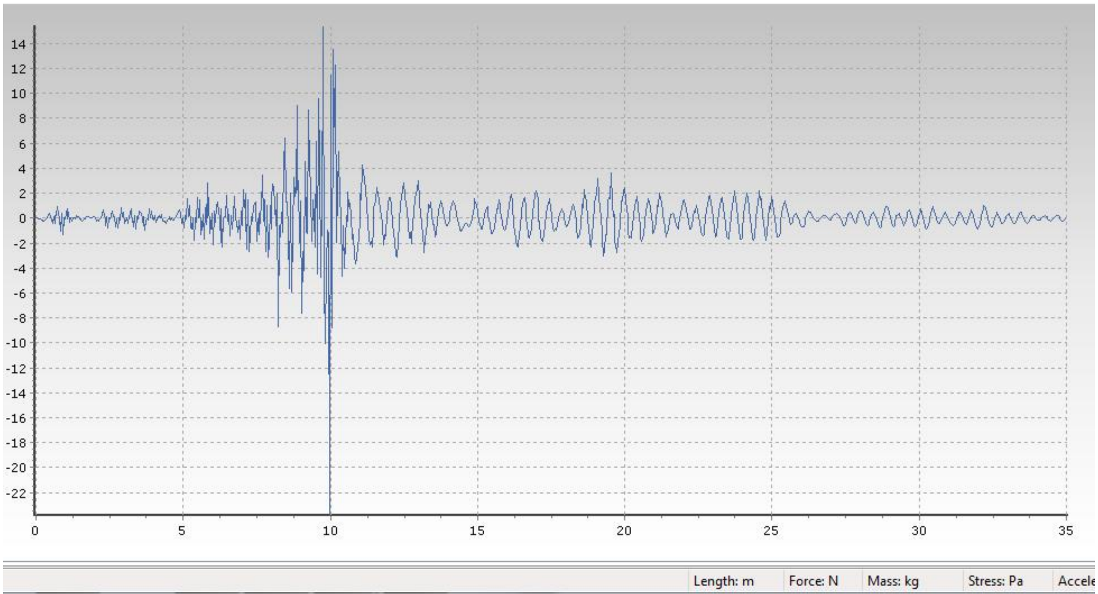


Figure 4.17: 1st Storey Acceleration Time Graph (3.050 m/s^2)

Acceleration time history scaled to 4.875 m/s^2,

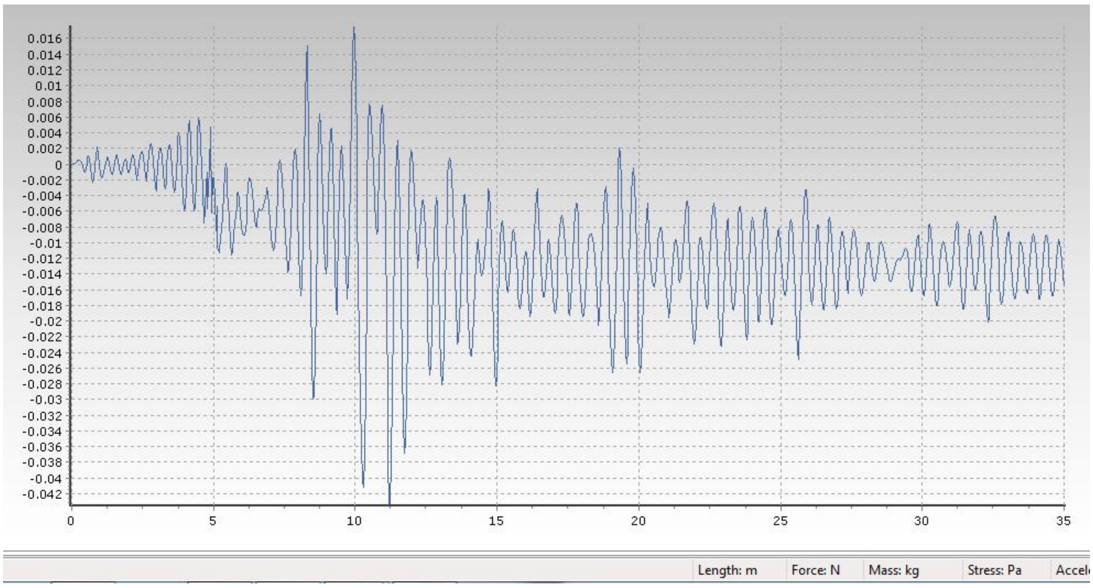


Figure 4.18: 1st Storey Displacement Time Graph (4.875 m/s^2)

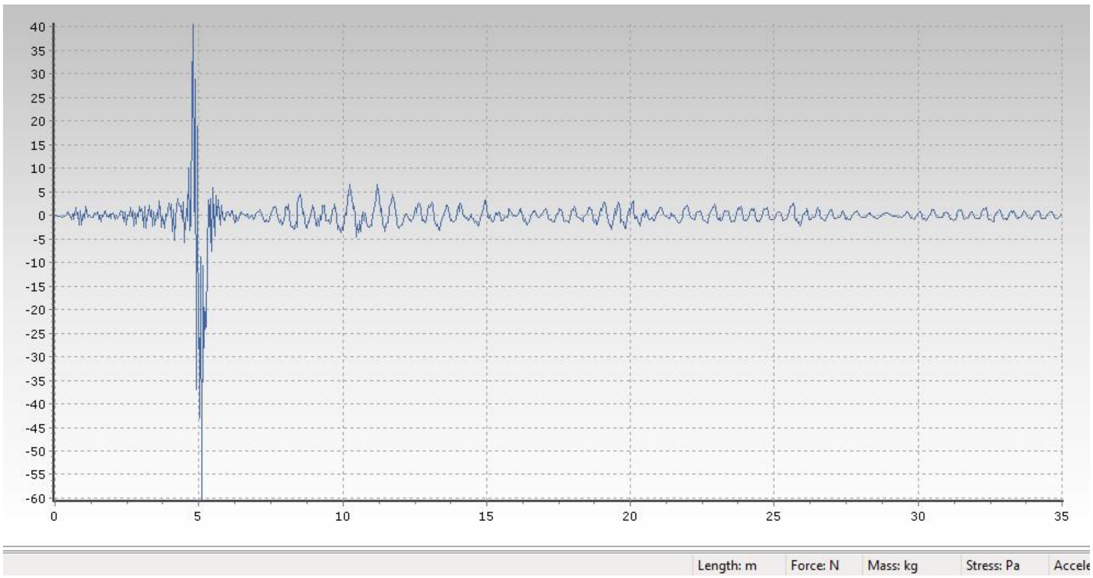


Figure 4.19: 1st Storey Acceleration Time Graph (4.875 m/s^2)

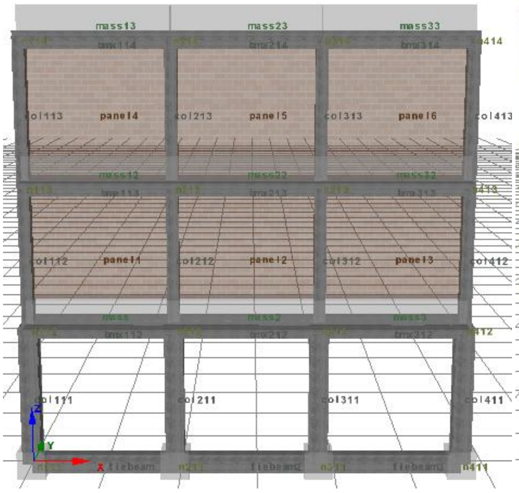
Based on the graphs obtained, the 3 bays 3 storeys pilotis frame model react the most between a time period of 5-15 seconds. This means that the maximum and minimum values of structural displacement and acceleration occurred within this time period. From the graph and data shown, the maximum and minimum values of the graph are tabulated in Table 4.7.

Table 4.7: Maximum and minimum values of acceleration time history graphs

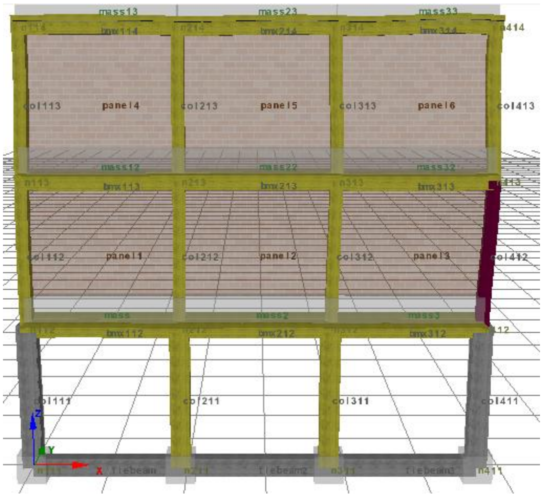
Acceleration time history scaled to (m/s^2)	Structural Displacement (m)		Acceleration (m/s^2)	
	Max.	Min.	Max.	Min.
0.060	0.00326	-0.00313	2.33	-2.99
1.125	0.00731	-0.0169	37.0	-26.3
2.000	0.0128	-0.0194	58.5	-36.1
2.550	0.0135	-0.0311	46.9	-23.6
3.050	0.0267	-0.0305	15.3	-23.8
4.875	0.0175	-0.0434	40.6	-60.5

It is found out that the 3 bays 3 storeys model can withstand up to an earthquake with a acceleration of 4.875m/s^2. A further increase in acceleration of the earthquake till 6.5m/s^2 resulted in the SEISMOSTRUCT unable to process the model. It is expected that the software cannot process the model due to the failure in the 3 bays 3 storeys model. From Table 4.7, from acceleration time history which is scaled from 0.060m/s^2 to 2.550m/s^2, the structural displacement and acceleration of 1st storey of the model increased gradually. However, the structure started to behave abnormally when subjected to acceleration time history scaled loading of 3.050m/s^2 onwards. This might probably due to the internal materials of the structural members unable to withstand more of the loading from higher seismic loading. It is expected that most of the reinforcement bars are yielded and a crushing of concrete had occurred.

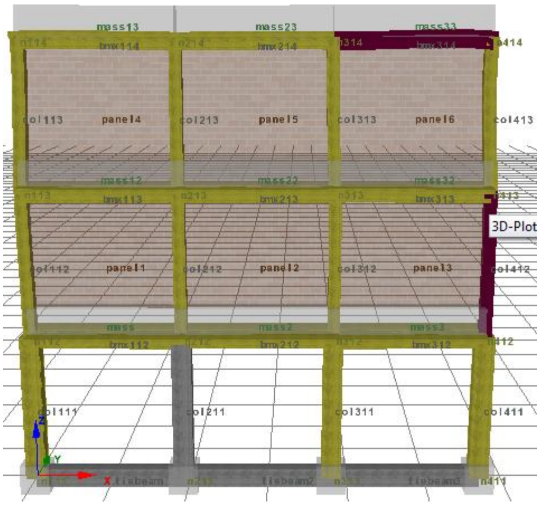
The defection of members on the pilotis structure after a 35 seconds period of time is also processed as shown in Figure 4.20 in order to identify which member defects the most during the period of time.



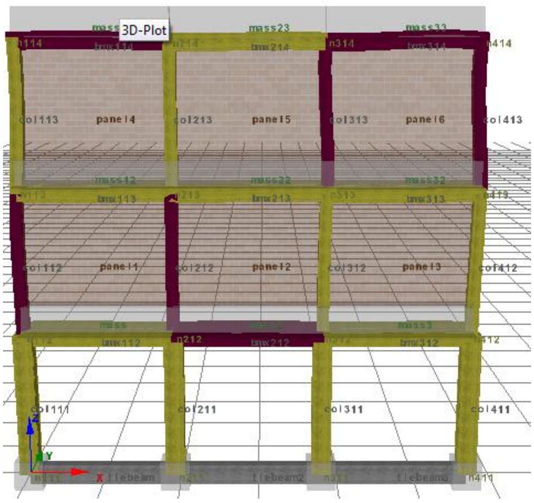
(a)



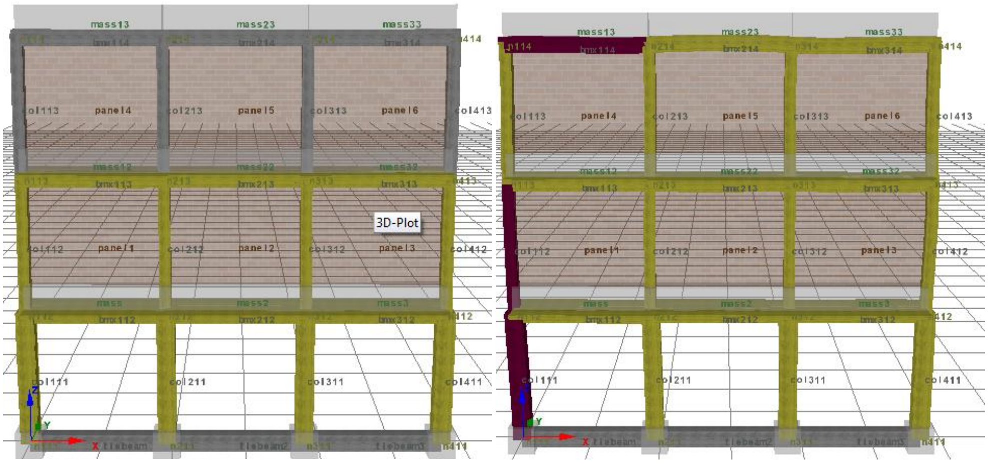
(b)



(c)



(d)



(e) (f)

Figure 4.20: The after effect of the pilotis structure subjected to acceleration time history scaled to (a) 0.060 m/s^2 (b) 1.125 m/s^2 (c) 2.000 m/s^2 (d) 2.550 m/s^2 (e) 3.050 m/s^2 (f) 4.875 m/s^2

From Figure 4.20, the yellow colour in the figure represents the yielding of steel reinforcement bar in the members while purple colour represents the crushing of concrete in unconfined region. It could be seen that most of the steel reached the yielding stress in the end of the processing. A few concrete columns and beams eventually crushed in the unconfined region. However, it is shown that the crushing of concrete occurs more in the upper section of the frame system instead of the retrofitted columns on ground floor. The main reason for this is because the ground floor column is retrofitted with a column jacket. The column jacket acts as an add-on to the current pilotis column by surrounding the outer layer of the column. The presence of column jacket strengthened the legs of the pilotis system. This can be determined from the section of the column itself. The columns with jacket make use of more reinforcement steel bars with higher compressive strength and using stronger concrete with larger compressive strength. This enables the stiffness of the base of pilotis structure to become stronger. Compared with the column jackets, other columns are much smaller and less reinforcement bar act as energy dissipation. Thus, it can be observed from the processing that the upper columns experience crushing in unconfined region more compares to the ground floor columns.

Furthermore, a study of stress and strain analysis at a particular point in the pilotis structure system was carried out. The unit for stress used in the analysis is in Pascal

(Pa). Stress is the product of force per unit area. It acts perpendicular to a surface, either compression of tension. On the other hand, strain is the amount of deformation an object experiences compared to its original size and shape. Strain is a dimensionless parameter.

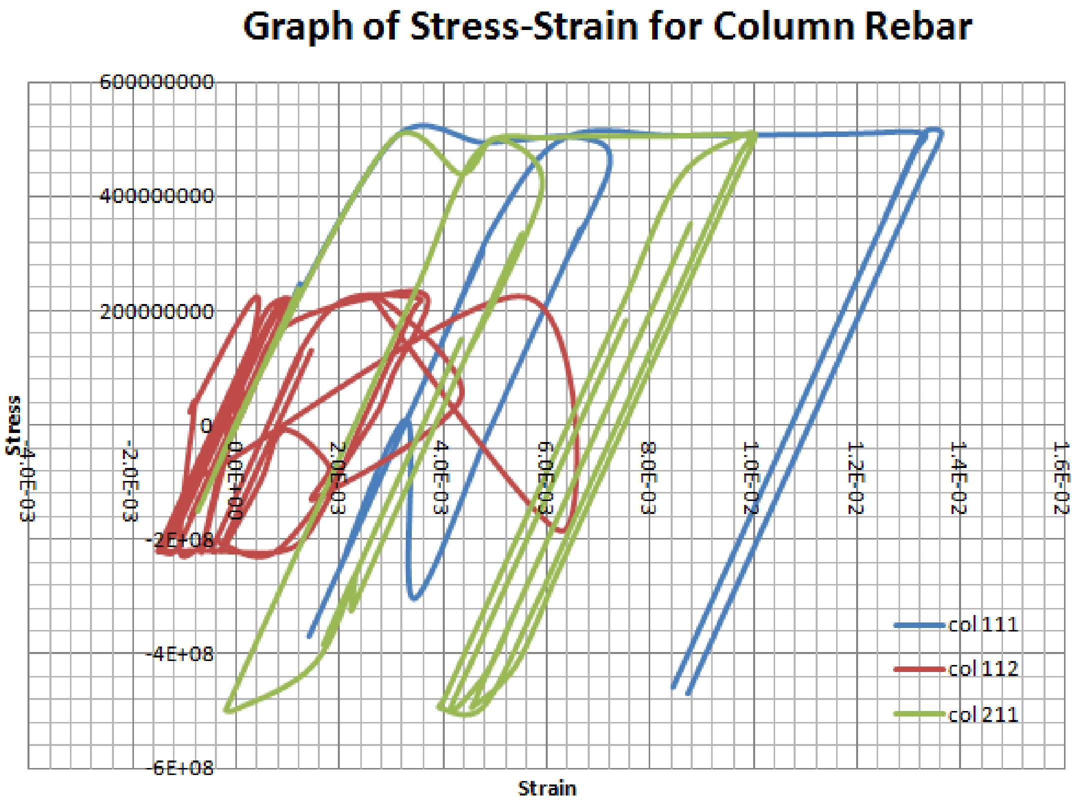


Figure 4.21: Graph of stress-strain for column rebar for pilotis structure subjected to 4.875 m/s^2 scaled acceleration time history loading

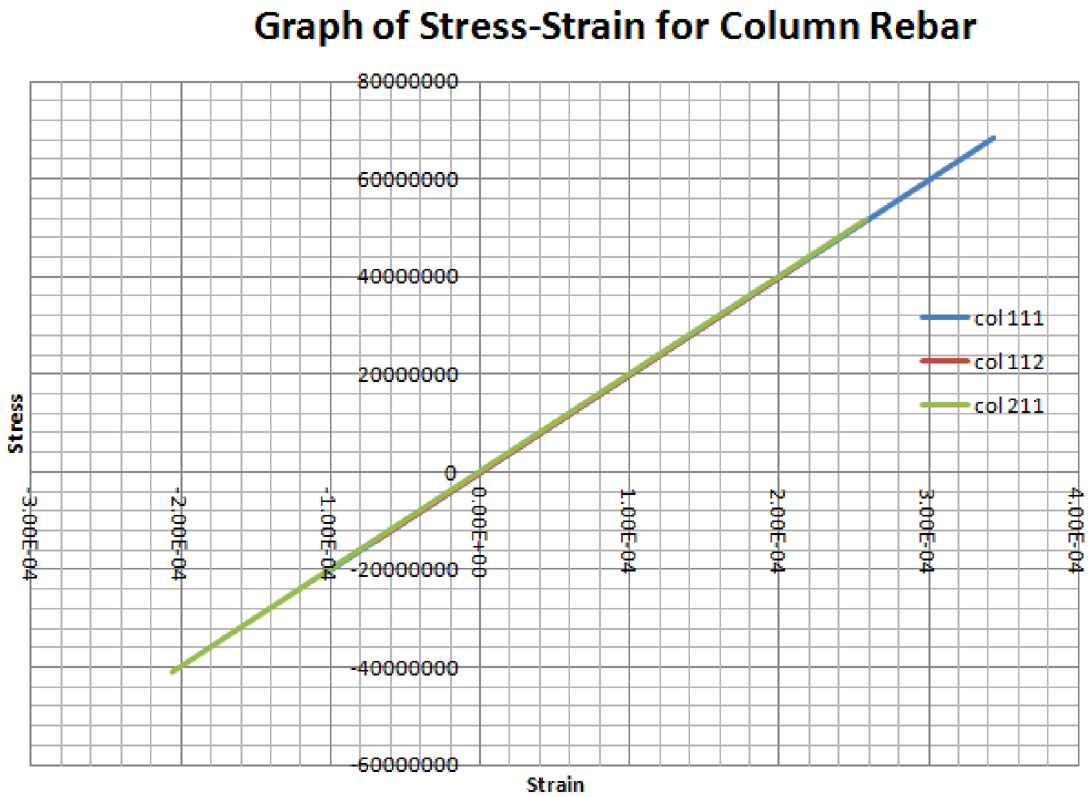


Figure 4.22: Graph of stress-strain for column rebar under elastic limit

From both of the graphs in Figure 4.21 and Figure 4.22, it shows the behavior of the column rebar over the elastic limit and under elastic limit respectively. 3 columns which are col 111, col 112 and col 211 were analyzed to check for the performance of rebar subjected under cyclic loading of 4.875 m/s^2 acceleration time history. Under normal loading which is within the elastic limit, the rebar can maintain its stress-strain behavior linearly. The cyclic loading magnitude is the greatest during the 8-14s of the total loading period. When it reaches its limit which is the yielding limit, it undergoes inelastic manner. During this stage, when the applied load is removed from the rebar, it is unable to behave linearly and would not be able to get back to its original position.

From the 3 tested columns, one of them is normal column, another two of them are columns with jackets. col 112 with minimal steel reinforcement is unable to sustain the loading from the earthquake. It reached its yielding point faster than the other two columns. Due to reinforcement bars reaching the yielding point, it has a higher possibility that the column malfunctions and transfers the weight it carried to other members. In this case, the reinforcement bar yielded and the concrete in unconfined region was crushed, but still in service.

For col 111, it also undergoes till the crushing of concrete in unconfined region. However, the failure occurs later than col 112. This is due to the extra reinforcement bars with higher compressive strength in the column jacket, adding extra strength to the column itself. The loading from earthquake is distributed to more reinforcement bars. Reinforcement bars with higher compressive strength can sustain more energy from the loading. Thus, stabilizing the ground column.

Another ground column, col 211 did not encounter any concrete crushing, but the column rebar does reach its limit state. col 211 did not have much defect compare with col 111. This might be due to the failing of col 112 which is directly above col 111. The failure of col 112 causing the load from above cannot be distributed well throughout the load distribution system.

From both of the graphs, it can be interpreted that columns with more reinforcement bars can withstand more forces. Comparing 4 with 12 reinforcement bars, the one with 12 bars will have the advantage as when the loads are applied, the forces acting on it is distributed equally among the 12 reinforcement bars. This can be proved from the stress strain graph as shown in the figure.

It is also due to the higher compressive strength of the reinforcement bar used in the concrete jacket. Although the inner column is still using reinforcement bar with compressive strength of 220MPa, the outer concrete jacket with its reinforcement bar of 500MPa of compressive strength is able to resist higher seismic loading subjected to it.

A further investigation is made based some of the recommendations – increasing the size of the ground column jacket. The original column jacket sizing is 0.40m. From the modeling carried out, it is found out that the increasing in sizing of the column jacket does assist in maintaining the stability of the structure when subjected to a low and medium seismic wave. The after effect is as shown in Figure 4.23 and Figure 4.24.

4.4 Modifications on 3 Bays 3 Storeys Pilotis Frame Model

3 bays 3 storeys pilotis frame with 0.48m strengthened ground column

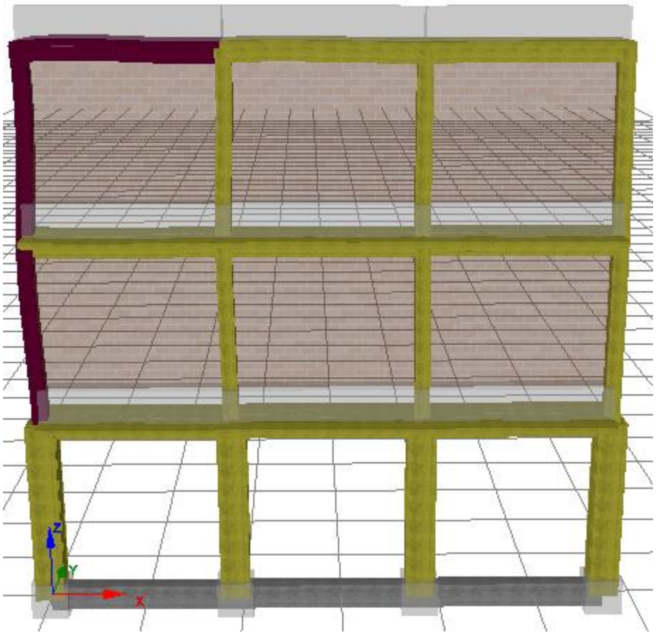


Figure 4.23: The after effect of 3 bays 3 storeys pilotis frame with 0.48m strengthened ground column

3 bays 3 storeys pilotis frame with 0.70m strengthened ground column

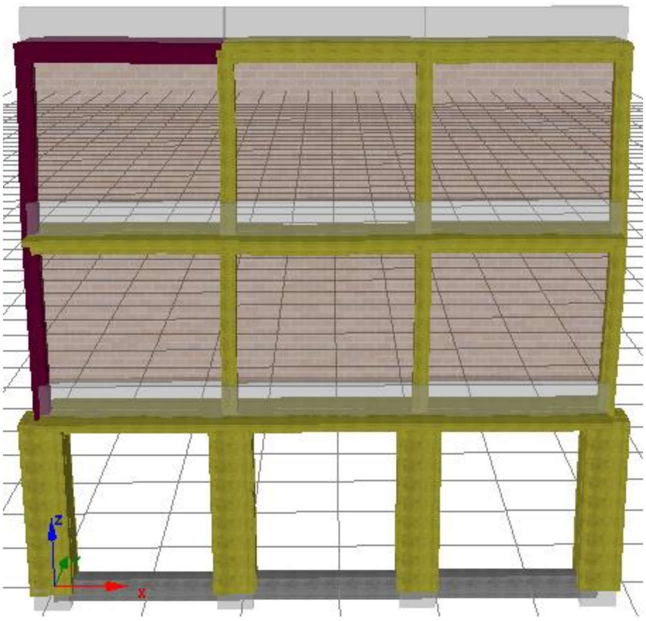


Figure 4.24: The after effect of 3 bays 3 storeys pilotis frame with 0.70m strengthened ground column

From the two modification of the ground column jacket shown in Figure 4.23 and Figure 4.24, it can be seen that there are no crushing of the concrete in unconfined region in the columns. This may indicated that with larger dimension of column jacket can help in stabilizing the structure. A wider base indicates more base area. Loading from upper building structure can distribute evenly on the increased area. The bigger the area of the base, the smaller forces is distributed evenly across the area. An increase in size of column jacket to 0.48m and 0.70m produces nearly the same after effect. Therefore, it is expected that a further increase in size of the column jacket does not help much in retaining the structure which is subjected to higher loading. In other way, it means that there is an optimal sizing for the column jacket for maintaining the stability. From this point, in order to make the column more economically feasible and provide the optimal stability, a column jacket with 0.48m in width and breadth respectively, is suggested.

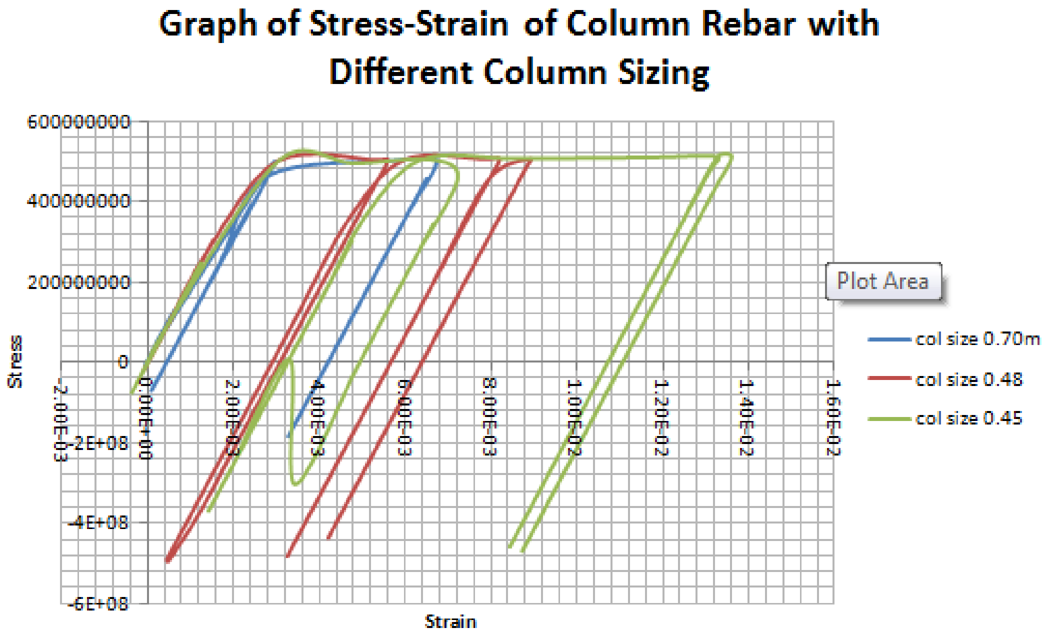


Figure 4.25: Graph of Stress-Strain of Column Rebar with Different Column Sizing

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In a nutshell, it is concluded that the objective of this research is achieved. The low and medium seismic effect to pilotis structures and buildings is able to be simulated using SEISMOSTRUCT. This can be done through the input of real time acceleration time history data from strong motion database from the internet. The effect from the seismic can also be processed from the SEISMOSTRUCT. It is also able to determine which member of the structure fails in the end of the process. From obtained results, the 3X3 pilotis frame can sustain up to an acceleration of 2.000m/s^2. This means that the peak acceleration in terms of ‘g’ is 0.26g. This is categorized within medium seismic region. Thus, it can be concluded that the 3X3 pilotis frame system is suitable for use in low to medium seismic region. The pilotis frame is able to withstand bigger seismic loadings with retrofitted concrete jacket at the ground floor column. This is mainly due to the number of reinforcement bars used in the concrete jacket. Another factor is due to its larger base as the surrounding concrete jacket which directly improve the structure overall stability.

Some recommendations are suggested to further improve on the performance of the pilotis system. A larger concrete jacket system may be introduced to further stabilize the structure. A maximum of 20% of the original sizing may be used. In this case, larger concrete jacket system utilizes more reinforcement bars to cater for the seismic loadings. Another recommendation is to use reinforcement bar with higher yielding limit. With the usage of higher yielding limit reinforcement bar, a higher loading from earthquake it can sustain. To acquire higher yielding limit, higher compressive strength steel shall be used. Hence, it improves the overall performance. However, the modeling of using higher compressive strength of steel will not be done and discussed in under this topic. In terms of economic, less defects in after-effect reduces the maintenance cost fee. In terms of safety, with the pilotis system designed to resist low and medium seismic load, users of the building can occupy the building without much hesitation that the structure might collapse.

Hence, it is concluded that the pilotis frame undergone retrofitting method is able to sustain a designed amount of loadings specified.

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