A STUDY ON FATIGUE BEHAVIOR OF BEAM COLUMN JOINT UNDER MODERATE EARTHQUAKE LOADING

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CERTIFICATION OF APPROVAL

A Study on Fatigue Behaviour of Beam Column Joint Under Moderate Earthquake Loading

by

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July 2009

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 that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(MUHAMMAD KHAIRUL AMRI BIN MAHAT)

ABSTRACT

On 26 December 2004, Malaysia was affected by the Indian Ocean earthquake. Despite its proximity to the epicenter of the earthquake, Malaysia escaped the kind of damage that struck countries thousands of miles further away. Since the epicenter was on the western coast of Sumatra, the island largely shielded the country from the worst of the tsunami. Structures and buildings in Malaysia are design in accordance to British Standard (BS) which neglect seismic loading. This research aims to estimate the fatigue life of reinforced concrete beam-column joint under moderate earthquake loading. A case study is chosen base on existing structure which is a school. Lightly reinforced concrete beam-column joint is selected and 5 samples were constructed. Samples are put under seismic loading and investigations on load and deflection were conducted. Theoretical study was conducted using STAAD Pro by modeling the whole structure undergoing seismic load in the form of time-history data, obtained from Siukuai Island, Indonesia. The result of displacement response is later used to calculate the stress of structure during earthquake. It was observed that the maximum displacement of the structure under the earthquake load is 5.45 mm, while the fatigue damage of the structure due to the equivalent cyclic loading is 28%. Hence, a structure in Malaysia undergone an earthquake with VI MMI will have 72% of fatigue life remaining.

ACKNOWLEDGEMENT

This project, conducted in the Civil Engineering Department of Universiti Teknologi PETRONAS, was done with the help and support of many people whom I would like to thank.

Firstly, I would like to express my sincerest gratitude to my Final Year Project supervisor, Ms Nabilah Bt. Abu Bakar. Her continuous support and motivation to this project has made it more meaningful and worthwhile. While maintaining her professionalism as a lecturer and supervisor, she also made effort to understand the difficulties and help to overcome problems which I encountered.

In conducting this study, a lot of manpower was required. The experiment that I've done for this project could not be done successfully without the help and expertise of the laboratory technician of Civil Engineering Department who have been very helpful, unconditionally. I would like to take this opportunity to sincerely thank Mr. Johan, Mr. Idris, Mr. Meor, Mr. Iskandar, Mr. Zaaba and Mr. Hafiz.

Undertaking this project has been a great challenge, physically and mentally. My friends have been there to provide support and help. I would like to personally convey my appreciation to Zuraimi, and others who have contributed directly and indirectly to the completion of this project.

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CHAPTER 1

INTRODUCTION

This chapter will elaborate in details about the background that lead on to this study, problem statement and objective and scope of this study.

1.1 Background of Study

Malaysia is close to the two most seismically active plate boundaries, the inter-plate boundary between the Indo-Australian and Eurasian Plates on the west and the inter-plate boundary between the Eurasian and Philippines Sea Plates on the east. Major earthquakes originating from these plate boundaries have been felt in Malaysia.

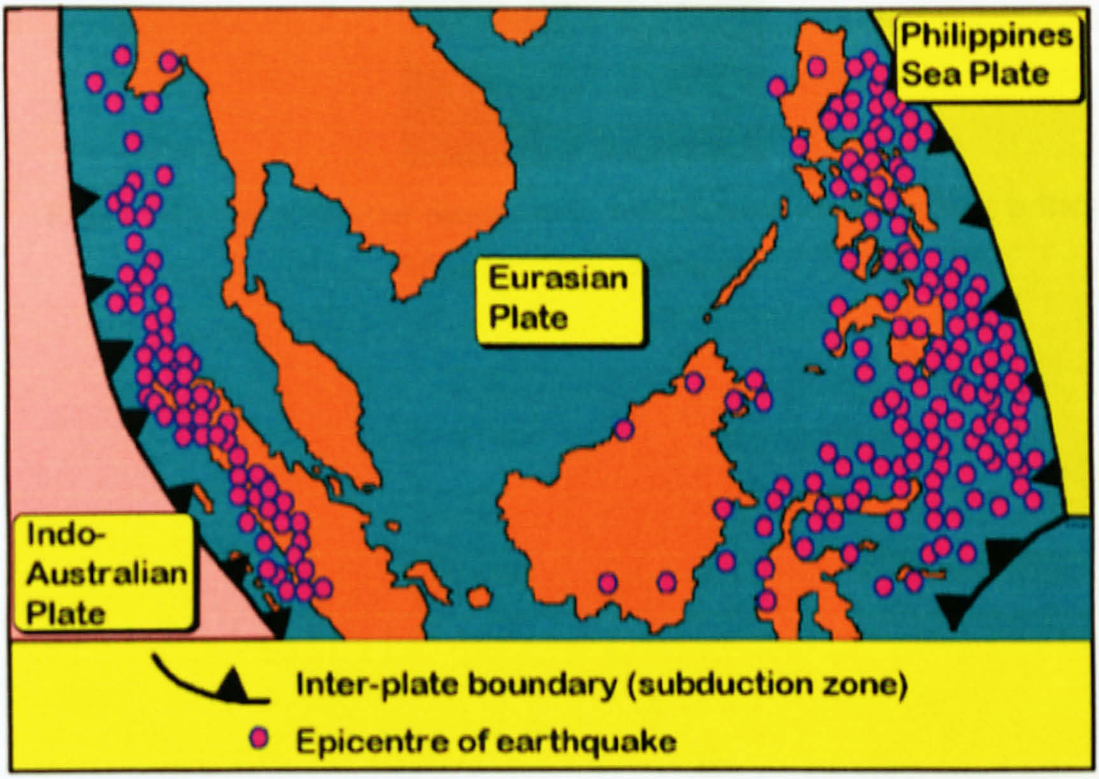

Figure 1.1 Plate boundaries and epicenter distribution

Tremors felt along the west coast of Peninsular Malaysia are originating from large earthquakes in the active seismic areas of Sumatra and Andaman Sea. East Malaysia has experienced earthquakes of local origin. Several possible active faults have been delineated and local earthquakes in East Malaysia appear to be related to some of them.

In addition to the local earthquakes, East Malaysia is also affected by tremors originating from large earthquakes located over Southern Philippines and Northern Sulawesi. Figure 2 show the damages caused by the earthquakes of 26 May 1991.

Figure 1.2 Massive structure damage to the rubbish chute wall of a school in Ranau, Sabah on 26/5/91 earthquake.

Table 1.1 shows the frequencies of eartquake happened in Malaysia and the maximum Modified Mercalli Scale observed for each state. From this table maximum intensity of VII was observed in Perak, Selangor and Sabah. Sabah can felt an earthquake with an intensity of VII because it is located near to Philippine Sea Plate. For Selangor and Perak, the states are located near to Indo-Australian Plate which is also an active plate. According to Modified Mercalli Intensity Scale, VII type of earthquake can be felt and cause slight to moderate damage to structure.

Table 1.1 Earthquake intensity in Malaysia

State	Frequencies	Maximum Intensity Observed (Modified Mercalli Scale)
Peninsular Malaysia (1909 - June 2009)		
Perlis	3	V
Kedah	15	V
Penang	37	VI
Perak	22	VII
Selangor	43	VII
Negeri Sembilan	8	V
Malacca	16	V
Johor	29	VI
Pahang	25	III
Terengganu	2	IV
Kelantan	3	IV
Kuala Lumpur / Putrajaya	31	VI
Sabah (1897 - June 2009)		
Sabah	37	VII
Sarawak (1874 - 2008)		
Sarawak	16	VI

(Source: Malaysian Meteorological Department website)

1.2 Problem Statement

The seismic design philosophy relies on providing sufficient ductility to the structure by which the structure can dissipate seismic energy. The structural ductility essentially comes from the member ductility wherein the latter is achieved in the form of inelastic rotations. In reinforced concrete members, the inelastic rotations spread over definite regions called as plastic hinges. During inelastic deformations, the actual material properties are beyond elastic range and hence damages in these regions are obvious.

Most structures and buildings in Malaysia are made from concrete and design in accordance to BS code. Unfortunately the design of buildings in Malaysia does not include any seismic provision and are vulnerable to earthquake. Studies done by Prof. A. Meher Prasad (2006) suggest that joint should have adequate strength and stiffness especially under seismic loading. In order for structures and buildings to withstand seismic loading, focus on joints are crucial and should be oriented towards Malaysian earthquake scenario.

1.3 Objectives and Scope of Study

Objective for this study:-

- Investigating the deflection of a beam-column joint under horizontal loading.
- Analyzing reinforced concrete building in Malaysia against moderate earthquake using STAAD PRO.
- Estimating the remaining fatigue life for reinforced concrete structure under repetitive earthquake loading.

The scope of study would cover the following:-

- Investigating the effect of simulated earthquake loading on joint samples that are considered 'lightly reinforced'.
- Testing the joint samples until failure to investigate the extent of damages.
- Analyzing only on one type of beam-column joint.
- Collecting and analyzing data base on five sample of beam-column joint.

CHAPTER 2
LITERATURE REVIEW

This chapter will provide detail on types of joint, force imposed on beam-column joint, and description on earthquake.

2.1 Types of Joints in Frames

The joint is defined as the portion of the column within the depth of the deepest beam that frames into the column. In a moment resisting frame, three types of joints can be identified interior joint, exterior joint and corner joint. When four beams frame into the vertical faces of a column, the joint is called as an interior joint. When one beam frames into a vertical face of the column and two other beams frame from perpendicular directions into the joint, then the joint is called as an exterior joint. When a beam each frames into two adjacent vertical faces of a column, then the joint is called as a corner joint. The severity of forces and demands on the performance of these joints calls for greater understanding of their seismic behavior. These forces develop complex mechanisms involving bond and shear within the joint. The objective of the paper is to review and discuss the well postulated theories for seismic behavior of joints in reinforced concrete moment resisting frames.

2.2 Force Imposed on Beam-Column Joint

Under the action of lateral earthquake loading, a moment resisting multi-storey multi-bay frame will deflect horizontally with points of contra flexure located roughly at the mid-length of the members. Figure 3(a) shows the deformation of a typical interior beam–column assembly. A typical interior beam–column joint is usually subjected to large shear forces due to lateral earthquake loading, as shown in Figure 4. The bending moments and shear forces acting on the joint give rise to both horizontal and vertical shear forces at the joint core. The situation becomes critical under large cyclic reversals of ground shaking, possibly causing extensive damage to the joints.

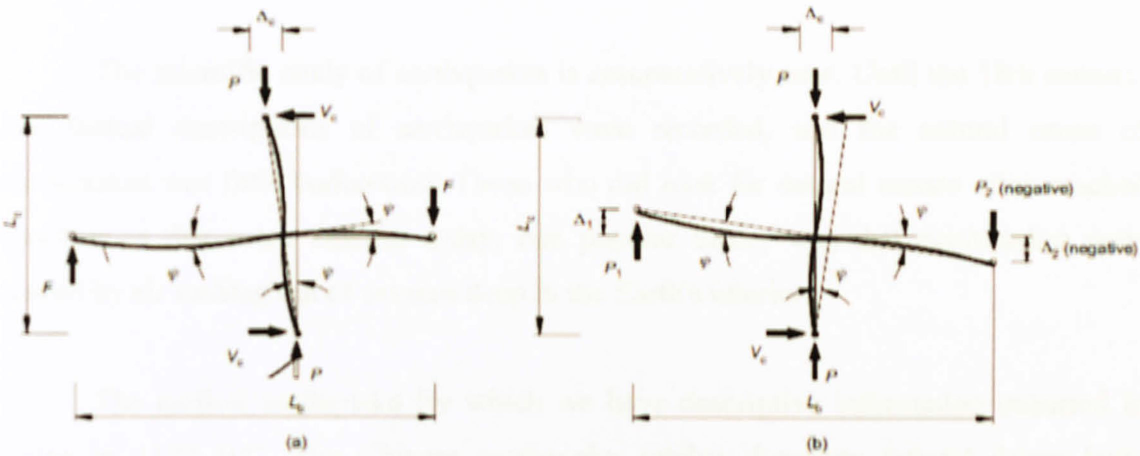

Figure 2.1 Simulation of interior beam-column joint. a) Deformation of a typical interior beam-column joint assembly under lateral load. b) Assembly in loading ring

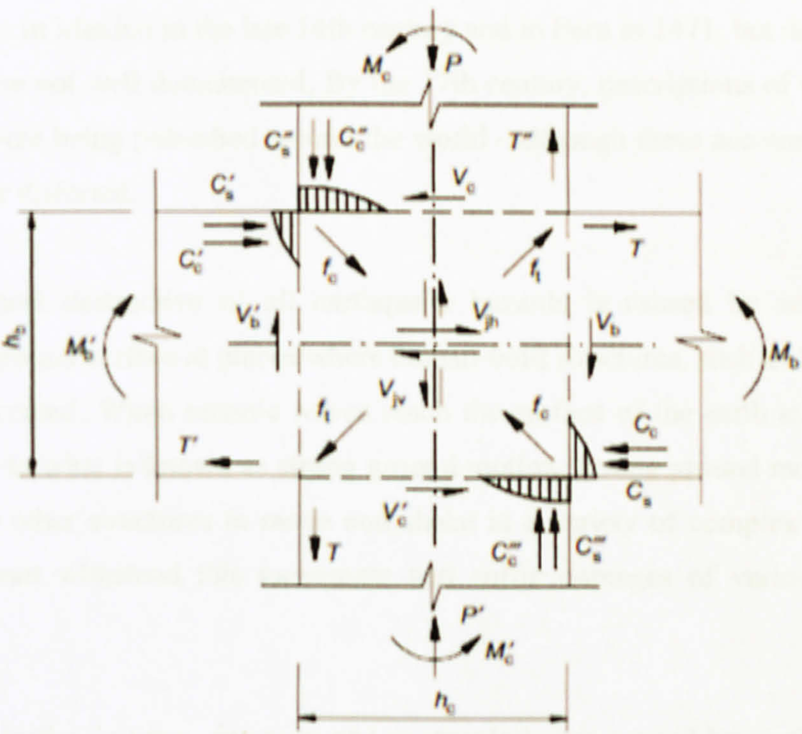

Figure 2.2 Force acting on beam-column joint under seismic action.

2.3 Earthquake

The scientific study of earthquakes is comparatively new. Until the 18th century, few factual descriptions of earthquakes were recorded, and the natural cause of earthquakes was little understood. Those who did look for natural causes often reached conclusions that seem fanciful today; one popular theory was that earthquakes were caused by air rushing out of caverns deep in the Earth's interior.

The earliest earthquake for which we have descriptive information occurred in China in 1177 B.C. The Chinese earthquake catalog describes several dozen large earthquakes in China during the next few thousand years. Earthquakes in Europe are mentioned as early as 580 B.C., but the earliest for which we have some descriptive information occurred in the mid-16th century. The earliest known earthquakes in the Americas were in Mexico in the late 14th century and in Peru in 1471, but descriptions of the effects were not well documented. By the 17th century, descriptions of the effects of earthquakes were being published around the world - although these accounts were often exaggerated or distorted.

The most destructive of all earthquake hazards is caused by seismic waves reaching the ground surface at places where human-built structures, such as buildings and bridges, are located. When seismic waves reach the surface of the earth at such places, they give rise to what is known as strong ground motion. Strong ground motions cause's buildings and other structures to move and shake in a variety of complex ways. Many buildings cannot withstand this movement and suffer damages of various kinds and degrees.

Most deaths, injuries, damages and economic losses caused by earthquake result from ground motion acting on buildings and other manmade structures not capable of withstanding such movement.

2.4 The Modified Mercalli Intensity

The effect of an earthquake on the Earth's surface is called the intensity. The intensity scale consists of a series of certain key responses such as people awakening, movement of furniture, damage to chimneys, and finally - total destruction. Although numerous intensity scales have been developed over the last several hundred years to evaluate the effects of earthquakes, the one currently used in the United States is the Modified Mercalli Intensity Scale. It was developed in 1931 by the American seismologists Harry Wood and Frank Neumann. This scale, composed of 12 increasing levels of intensity that ranges from imperceptible shaking to catastrophic destruction, is designated by Roman numerals. It does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects.

The Modified Mercalli Intensity value assigned to a specific site after an earthquake has a more meaningful measure of severity to the nonscientist than the magnitude because intensity refers to the effects actually experienced at that place.

The lower numbers of the intensity scale generally deal with the manner in which the earthquake is felt by people. The higher numbers of the scale are based on observed structural damage. Structural engineers usually contribute information for assigning intensity values of VIII or above.

2.5 Fatigue

Fatigue cracking is one of the primary damage mechanisms of structural components. Fatigue cracking results from cyclic stresses that are below the ultimate tensile stress, or even the yield stress of the material. The name "fatigue" is based on the concept that a material becomes "tired" and fails at a stress level below the nominal strength of the material. The facts that the original bulk design strengths are not exceeded and the only warning sign of an impending fracture is an often hard to see crack, makes fatigue damage especially dangerous.

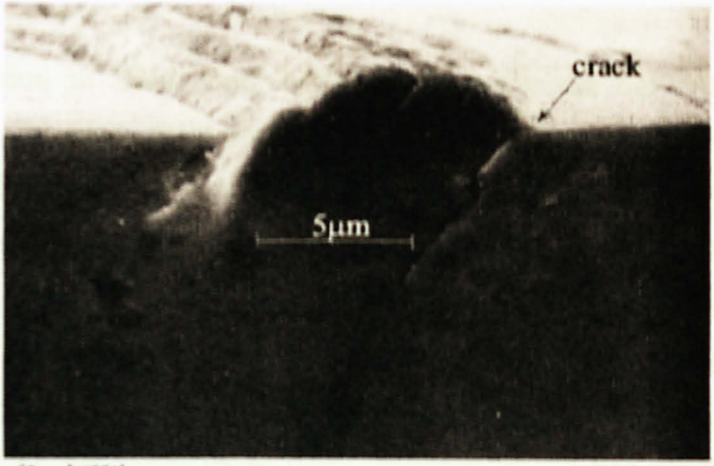

Figure 2.3 Image of a crack taken with a scanning electron microscope

2.6 Factor Affecting Fatigue Life

In order for fatigue cracks to initiate, three basic factors are necessary. First, the loading pattern must contain minimum and maximum peak values with large enough variation or fluctuation. The peak values may be in tension or compression and may change over time but the reverse loading cycle must be sufficiently great for fatigue crack initiation. Secondly, the peak stress levels must be of sufficiently high value. If the peak stresses are too low, no crack initiation will occur. Thirdly, the material must experience a sufficiently large number of cycles of the applied stress. The number of cycles required to initiate and grow a crack is largely dependent on the first to factors.

In addition to these three basic factors, there are variables, such as stress concentration, corrosion, temperature, overload, metallurgical structure, and residual stresses which can affect the propensity for fatigue. Since fatigue cracks generally initiate at a surface, the surface condition of the component being loaded will have an effect on its fatigue life. Surface roughness is important because it is directly related to the level and number of stress concentrations on the surface. The higher the stress concentration the more likely a crack is to nucleate. Smooth surfaces increase the time to nucleation. Notches, scratches, and other stress risers decrease fatigue life. Surface residual stress will also have a significant effect on fatigue life.

2.7 Rainflow Counting Method

The rainflow counting algorithm (also known as the "rain-flow counting method") is used in the analysis of fatigue data in order to reduce a spectrum of varying stress into a set of simple stress reversals. Its importance is that it allows the application of Miner's rule in order to assess the fatigue life of a structure subject to complex loading. The algorithm was developed by Tatsua Endo and M. Matsuiki in 1968. Though there are number of cycle-counting algorithms for such application, the rainflow method is the most popular.

Downing and Socie created one of the more widely referenced and utilized rainflow cycle-counting algorithms in 1982, which was included as one of many cycle-counting algorithms in ASTM E1049-85. This algorithm is used in Sandia National Laboratories LIFE2 code for fatigue analysis of wind turbine components.

2.8 Palmgren-Miner Rules

Suppose a body can tolerate only certain amount of damage, D. If that body experiences damages D_i (i=1, 2, N) from N source, then failure will occur if

$$\sum_{i=1}^{N} D_i = D$$

Or equivalently

$$\sum_{i=1}^{N} \frac{D_i}{D} = 1$$

This linear damage concept can be use in fatigue setting by considering the situation where a component is subjected to n_1 cycles at alternating stress σ_1, n_2 cycles at stress σ_2, n_N cycles at σ_N. From the S-N curve for this material, number of cycles to failure can be determined.

CHAPTER 3
METHODOLOGY

This chapter will provide details on project workflow, experiment procedure, and data collection and analysis.

3.1 Project Workflow

This project is divided into two stages which are pre-experimental and experimental. During pre-experimental stage literature review and data gathering are done in order to get better understanding about this project. After that the procedures for this experiment are develop and method to collect data are suggested. Figure 3.1 shows summary of project flow.

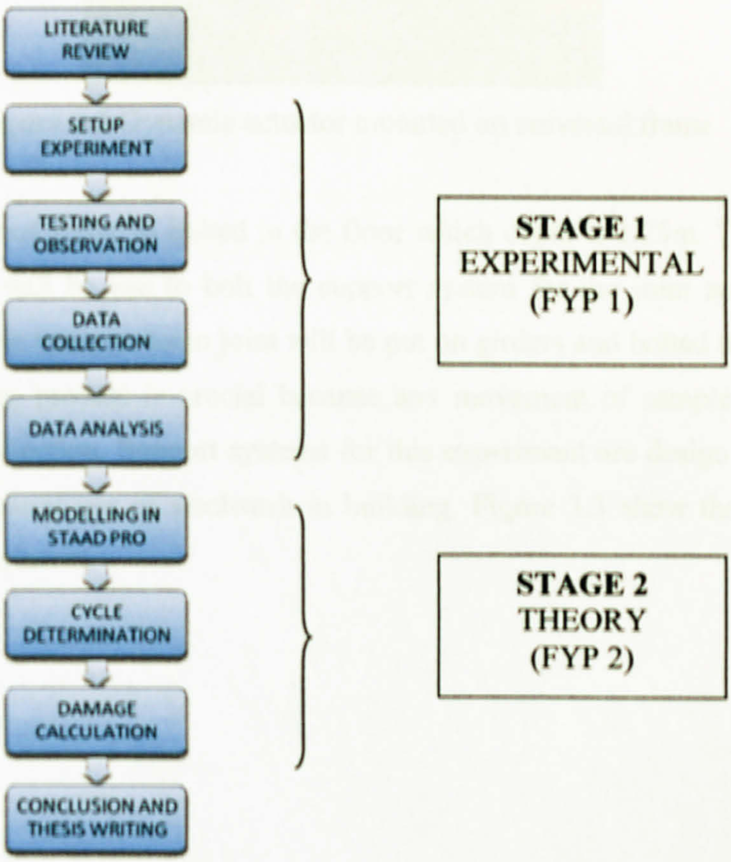

Figure 3.1 Summary of project flow

3.2 Experimental Setup

Dynamic actuator with the capacity of 2000kN is used for this experiment.

Figure 3.2 Dynamic actuator mounted on universal frame

The universal frame is bolted to the floor which depth is 1.25m. There are voids on the floor that will be use to bolt the support system for the joint sample onto the ground. The sample beam-column joint will be put on girders and bolted to prevent from movement. Bolting process is crucial because any movement of sample will result in inaccurate data collection. Support systems for this experiment are design in accordance to BS 5950: structural use of steelwork in building. Figure 3.3 show the experimental setup for this experiment.

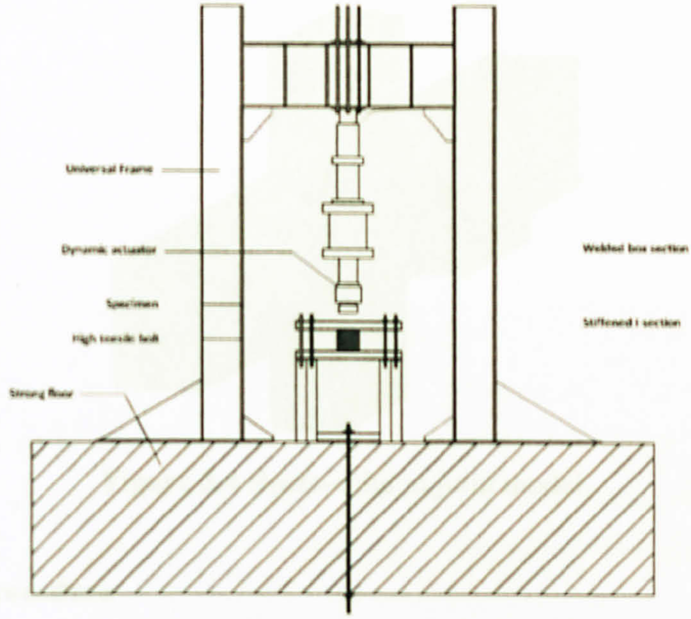

Figure 3.3 Experimental setup

3.3 Beam-Column Joint Model Selection

Beam-column joint sample for this study was taken from a school building design. The building was originally designed by Malaysia Public Work Department in 1991. A design of school building was taken because this type of building was design to support high live load. Any structure defect cause by earthquake could result in high casualties and could be life threatening. So this study is done to ensure that the building is safe for usage. An external beam-column joint was chosen because this type of beam-column joint has high possibility to defect if earthquake occur. Figure 3.4 show the beam-column joint model.

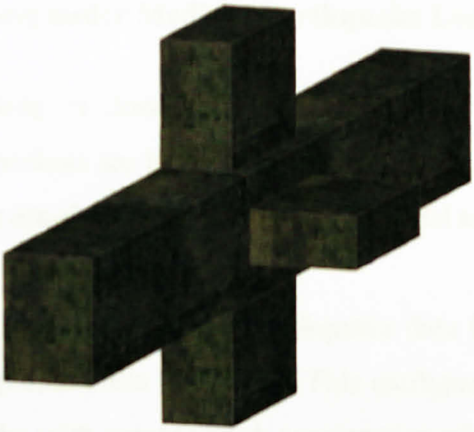

Figure 3.4 Beam-column joint model

3.4 Testing Procedure

Dynamic actuator will apply pushing and pulling force repetitively until there are cracking and failures. This repetitive pushing and pulling force will simulate the actual earthquake. In order to get the average beam curvature LVDTs will also be installed in pairs both above and below the beam. The two pairs of LVDTs adjacent to each column face enable the estimation of crack width at the beam–column interface. In addition, two LVDTs were positioned diagonally on the rear face of the joint to detect the shear distortion. Electrical resistance strain gauges were used to monitor strain variation along selected reinforcing bars. All strain gauges were stuck along the centerline of the reinforcing bar such that the local bending effect could be eliminated. All the LVDTs and strain gauges were connected to a logger for data acquisition.

3.5 Modeling of Building under Medium Earthquake Loading Using Staad Pro

Modeling of building is done using data given by Malaysia Public Work Department. Building dimensions are in accordance with actual design and specification. Dead loads for the building are also implemented in the model to get accurate data.

After modeling of building are made, earthquake data for average peak velocity from Sikuai Island is incorporated into the design. This earthquake is chosen because it is a medium type of earthquake with average peak acceleration of $40cm/s^2$. Under Modified Mercalli Intensity, this kind of earthquake is classified as type VI. According to Modified Mercalli Intensity, earthquake of type VI can cause slight damage on structure and can be felt by all.

3.6 Cycle Determination

Unlike mechanical vibrations, seismic load do not impose constant amplitude, or even complete, cycles on a structure. This makes the concept of cycles problematic and complicates application for Palmgren-Miner rule. Typical seismic response time histories exhibit varying amplitude cycles. The rainflow method most commonly used for converting random measurements to cycles and has been standardized.

The rainflow procedure operates by defining half-cycles where significant changes in response direction occur. These half-cycles are then matched to produce full cycles. The output is a series of cycles with calculated mean values, not necessarily zero, and amplitudes.

All stress data are inputted into software called STOFLO 9.08. This software is used to filter non peak data and perform rainflow cycle counting method. Result of rainflow counting method would be the frequency of stress occurs during earthquake period.

3.7 Damage Calculation

Calculation of damage due to repeated cyclic loads is a well establish methodology in some fields of engineering. In particular, mechanical engineers regularly use fatigue damage calculation as part of the design process. With mechanical equipment the cycle amplitudes are generally constant and known and the fatigue limit is directly determined from experiment. However seismic loads are not made up of complete, consistent cycles. In this case, Palmgren-Miner rule is used to predict the damage per cycle. Assuming no recovery between loading events, the remaining fraction of the fatigue capacity after an event is 1-*FDI.* Thus if the *FDI* is equal to 0.60, approximately 40% of the element fatigue remains available for the future events.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter will provide detail on the result of cube test and static test. Dynamic test data have not been process so there will no data on dynamic test.

4.1 Cube Test

Compressive strength tests have been conducted on the cube samples for 8 days and 14 days to verify the designed concrete strength. Concrete of grade 30 with dimension of 150mm x 150mm x 150mm are used for this test. The loading rate is 6.8kN/s. The following Table 1 shows the results of the cube tests.

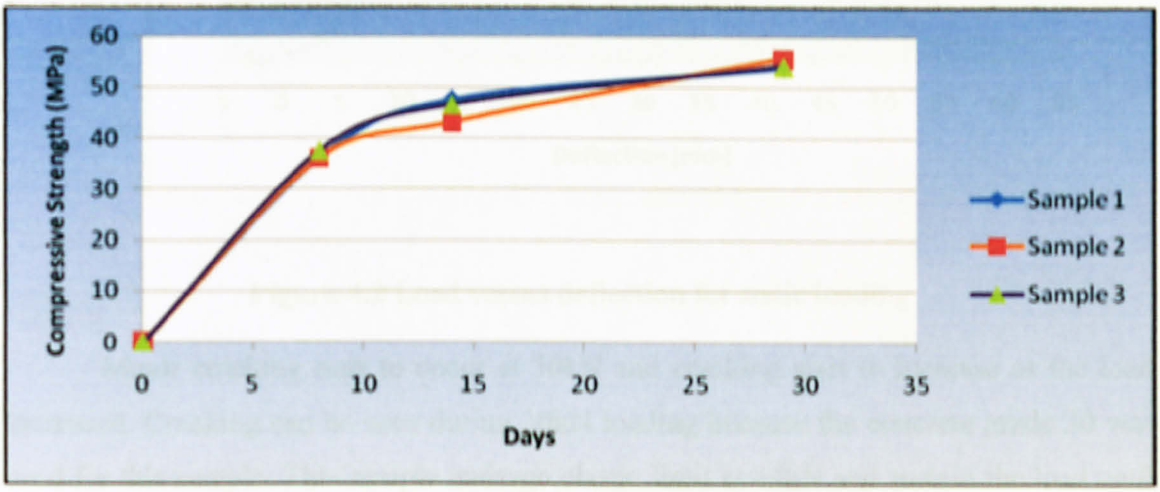

Figure 4.1 Compressive strength versus days

Figure 4.1 shows that the strength of concrete increase by time and reach an average value of 54Mpa during 28th day. Increments of strength are high from day 1 to day 8 but slowly increase afterward.

4.2 Static Loading Test

Static loading test have been conduct on 21st July 2009 to determine the maximum loading capacity of the beam. This test is crucial because the maximum value from this experiment will be use as reference during dynamic test. The following Table 2 shows the results of static test.

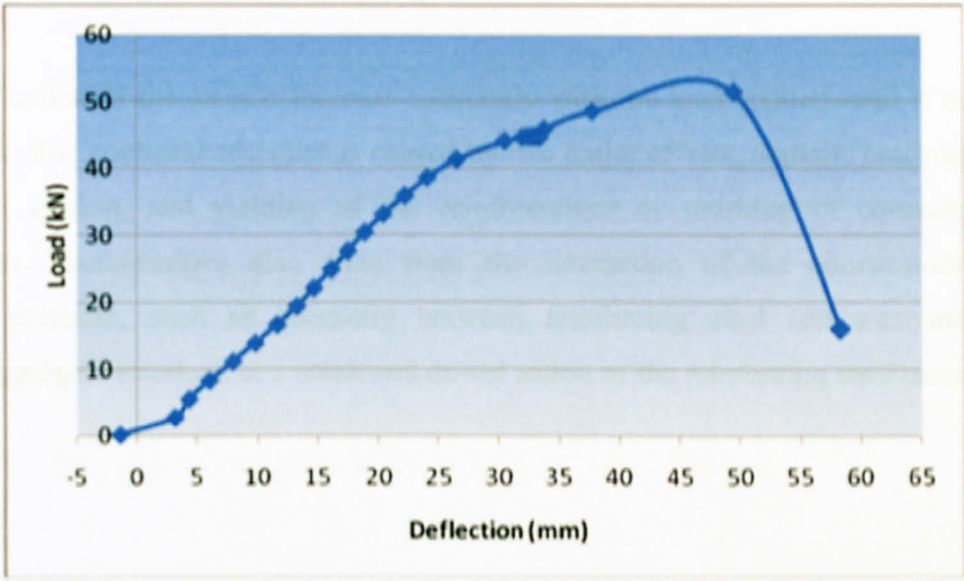

Figure 4.2 Load versus deflection for static loading

Minor cracking start to occur at 30kN and cracking start to increase as the load increased. Cracking can be seen during 30kN loading because the concrete grade 30 was used for this sample. This sample undergo elastic limit at 44kN and sustain the load until it reach its limit at 52kN. Maximum capacity that this sample can handle is 52kN before its rupture.

Reinforced concrete structures are made up of two materials with different characteristics, namely, concrete and steel. Steel can be considered a homogeneous material and its material properties are generally well defined. Concrete is, on the other hand, a heterogeneous material made up of cement, mortar and aggregates. Its mechanical properties scatter more widely and cannot be defined easily. For the convenience of analysis and design, however, concrete is often considered a homogeneous material in the macroscopic sense.

Deflection of the sample increase constantly with the load applied until it reach plastic limit. The nonlinear response is caused by two major effects, namely, cracking of concrete in tension, and yielding of the reinforcement or crushing of concrete in compression. Nonlinearities also arise from the interaction of the constituents of reinforced concrete, such as bond-slip between reinforcing steel and surrounding concrete, aggregate interlock at a crack and dowel action of the reinforcing steel crossing a crack.

4.3 Stresses under Seismic Loading

4.3.1 Earthquake Data

Earthquake data is taken from Siukuai Island, Indonesia. Siukuai Island is located at west of Sumatera which is near to inter-plate boundary of Indo-Australian Plate and Eurasian Plate. This location is a strategic location for earthquake to occur and plenty of earthquakes can be felt. One of the earthquake recorded have an average peak acceleration of $40cm/s^2$. This earthquake data was taken from COSMOS and used in this research.

In order to have a better understanding on the intensity of this earthquake, Modified Mercalli Intensity Scale (MMIS) is used. According to Modified Mercalli Intensity Scale (MMIS), earthquake with an average peak acceleration of $40cm/s^2$ is classified as type VI. This earthquake was chosen because it is a moderate earthquake and there are possibilities for this type of earthquake to occur in Malaysia.

According to Malaysian Meteorological Department, there were many earthquakes with intensity of VI or more occurred in Malaysia. West coast of Peninsular Malaysia showing a 'trend' of higher earthquakes frequencies compare to east Peninsular Malaysia. It would be a bad situation if an earthquake with intensity of VI or higher do occur. This is because many structures can be found in west Peninsular compare to east Peninsular.

4.3.2 Response of Structure

In order to analyze the effects of medium earthquake toward structure, a critical joint must be chosen. Joint 171 was chosen because of the assumption made during the calculations. Beam is assumed to be supported at both ends and a point load is located at the middle of the beam. This assumption made the calculation a lot easier but it would cause the smaller deflection for the same value of force. Joint 171 is located at level 3 and marked in figure 4.3

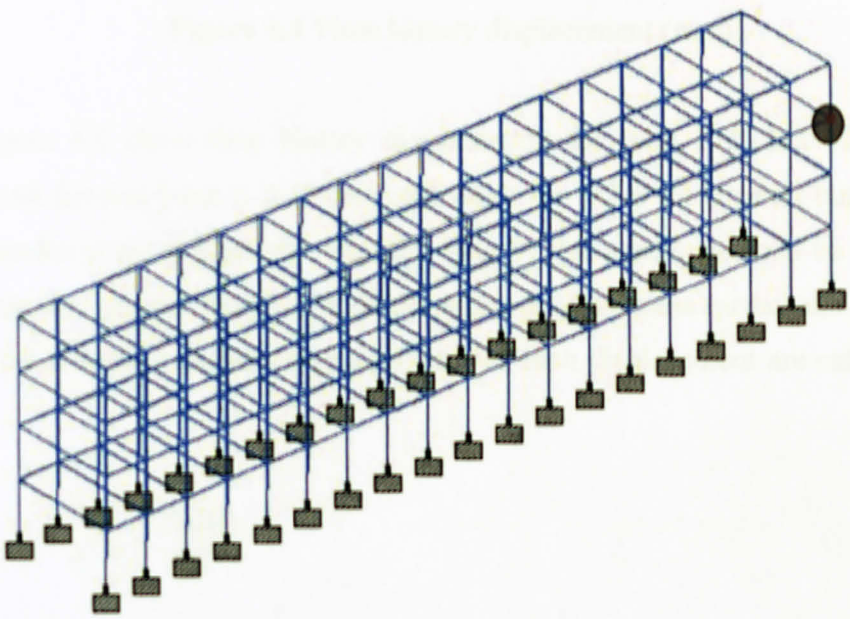

Figure 4.3 Selected Joint

Using earthquake data from Siukuai Island, analysis were done to get time history displacement. These values are needed to calculate the values of stresses occurred at joint 171 during the earthquake.

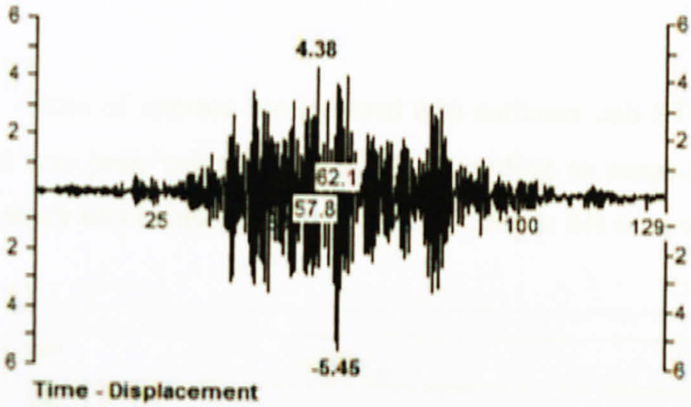

Figure 4.4 Time history displacement (mm)

Figure 4.4 show time history displacement for joint 171. Maximum value of displacement for this joint is 5.45 mm. Although the value seem small but the affect of this earthquake is not negligable. Damage done by this earthquake can be calculated by determining the value of stress for each displacement during the earthquake period. Using data from time history displacement, stresses for each displacement are calculated using equation:

$$\sigma = \frac{12\delta E y}{L^2}$$

Where:

σ = stress, (pa)

y = perpendicular distance from neutral axis, (m)

L = length of beam, (m)

δ = deflection, (m)

E = modulus of elasticity, (pa)

4.4 Rainflow Counting Method

Calculated values of stresses are inputted into software call STOFLO 9.08. This software will filter non peak value and sort data according to range and frequency of stresses. This frequency will be use in determining the fatigue life time of the structure.

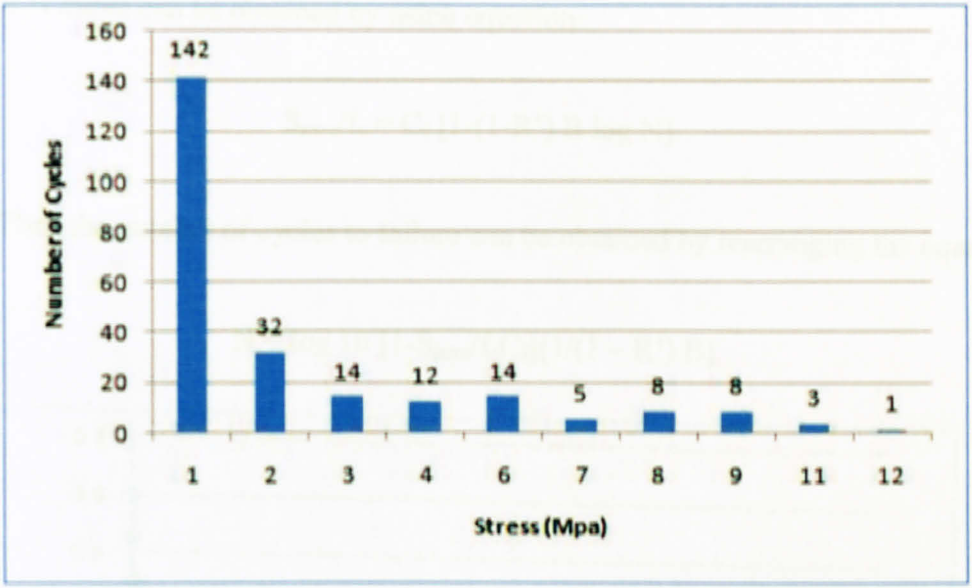

Figure 4.5 Number of cycle versus Stress (Mpa)

Figure 4.5 show number of complete cycles for each stress range. Small stress value appear frequently compare to higher stress value. Stress range from 0 to 1 Mpa occur most frenquently with 142 complete cycles. Highest stress occur during this earthquake is about 12 Mpa but only occur once. This results are then used to plot S-N curve. From S-N curve fatigue life of a structure can be determine.

4.5 S-N Curve

In order to determine fatigue life of a structure, S-N curve is used along with Palmgren-Miner rule. Stresses (Mpa), are divided with maximum stress capacity, f_c. If the values are >1 the structure will fail.

S-N curve can be obtained by using equation:

$$S_{max}/f_c = C_f\,[1-(1-R')\,B \log N]$$

Then the number of cycles to failure can be obtained by rearranging the equation

$$N = \log 10\,[1-S_{max}/f_cC_f][1/(1-R')\,B]$$

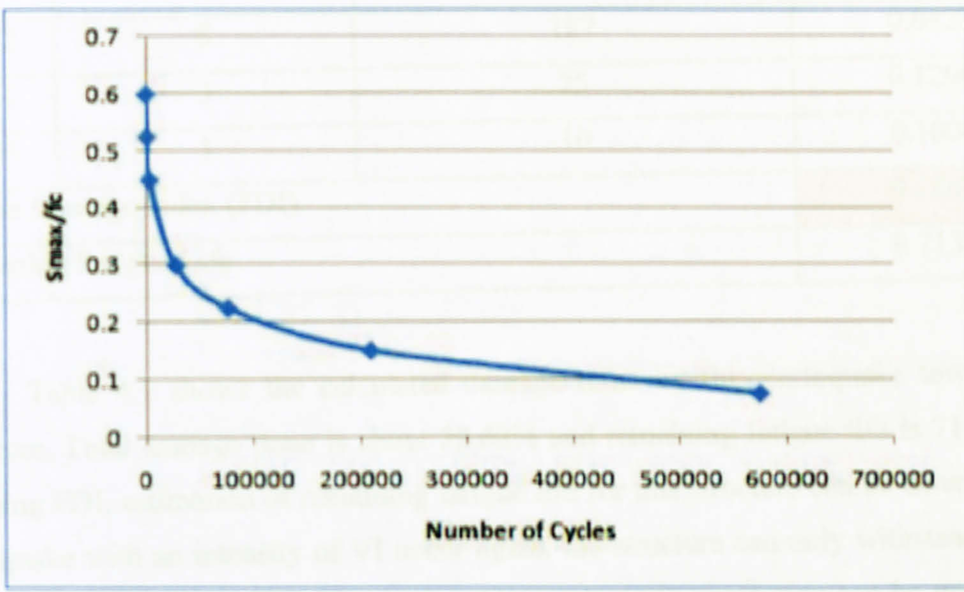

Figure 4.6 S-N curve

4.6 Damage Calculation

Total damage is calculated by dividing the number of cycles found in the time domain for each stresses to the number of cycles found from S-N curve.

Table 4.1 Damage calculation

S_{max}/f_c	Number of cycle, N_i	Number of cycle to failure, N_f	Damage, N_i/N_f
0.075	142	575124	0.00025
0.149	32	210632	0.00015
0.224	14	77141	0.00018
0.299	12	28252	0.00042
0.448	14	3790	0.00369
0.522	5	1388	0.00360
0.597	8	509	0.01572
0.672	8	187	0.04278
0.821	3	25	0.12000
0.896	1	10	0.10000
Fatigue Damage Index (FDI)			0.28679
Remaining Fatigue Life			0.71321

Table 4.1 shows the calculated damage done by this earthquake towards this structure. Total damage done is about 28.68% and remaining fatigue life is 71.32%. So by using FDI, estimation of remaining fatigue life for this structure can be determined. If earthquake with an intensity of VI occur again, the structure can only withstand another three times before its collapse. By using this result, early precaution can be taken if this type of earthquake repeats and casualties can be hinder.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

Static and dynamic loading test have been conduct for this project. Base on data gathered from experiment, it can be concluded that the samples are able to withstand force up to 50kN. Cracking appear mostly around critical area which is near to the joint. When cyclic loading of 20kN was applied, sample show no sign of cracking or failure even after 150000 cycles.

Theoretical displacement values for this earthquake are gathered by modeling the whole structure in STAAD Pro. Maximum displacement archive for this earthquake is about 5.45mm. Experiment shows that maximum deflection for this sample before its collapse is 52mm.

In the event of earthquake, structures will experience a higher frequency of low stresses compared to the larger stress levels. Small stresses (under 1Mpa) should not be neglected due to high occurrences and are included in the damage calculation.

Calculated value of FDI for 40cm/s^2 average peak acceleration from Siukuai Island is 28%. This indicates that the structure is 28% damaged and only have 72% fatigue life remaining. Precaution should be taken if this magnitude of earthquake does strike Malaysia. Thorough investigation need to be done to avoid any unwanted casualties.

This research shows that structure in Malaysia should have included earthquake factor in design. It is important especially to public structure or facilities which contain huge number of people. State such as Selangor should implement earthquake design because of rapid development and high MMI recorded happened in the past.

In order for this kind of project to run smoothly in the future, there are few matters that need to be considered:

1) UTP need to do maintenance of equipment regularly to prevent any problem during experiment.
2) Staffs should be well trained and capable of handling two or three equipments. This would overcome the problem of too dependent to certain staff in order to run specified equipment.

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APPENDIX A

Table A-1. Modified Mercalli Intensity Scale

Intensity Value	Description	Average Peak Acceleration (cm/s^2)
I	Not felt except by a very few under especially favorable circumstance	
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.	
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated.	
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably.	14.7 – 19.6
V	Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.	29.4 – 39.2
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight.	58.8 – 68.6
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate damage in well-built ordinary structures; considerable in	98.0 – 147.0

	poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars.	
VIII	Damage slight in specially designed structures, considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structure. Chimneys, factory stacks, columns, monuments, walls may fall. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed.	245.0 – 294.0
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.	490.0 – 539.0
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks.	More than 588.0
XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.	
XII	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.	

Table A-2. Richter Scale

Richter Magnitudes	Description	Earthquake Effects	Frequency of Occurrence
Less than 2.0	Micro	Microearthquakes, not felt.	About 8,000 per day
2.0-2.9	Minor	Generally not felt, but recorded.	About 1,000 per day
3.0-3.9	Minor	Often felt, but rarely causes damage.	49,000 per year (est.)
4.0-4.9	Light	Noticeable shaking of indoor items, rattling noises. Significant damage unlikely.	6,200 per year (est.)
5.0-5.9	Moderate	Can cause major damage to poorly constructed buildings over small regions. At most slight damage to well-designed buildings.	800 per year
6.0-6.9	Strong	Can be destructive in areas up to about 160 kilometres (100 mi) across in populated areas.	120 per year
7.0-7.9	Major	Can cause serious damage over larger areas.	18 per year
8.0-8.9	Great	Can cause serious damage in areas several hundred miles across.	1 per year
9.0-9.9	Great	Devastating in areas several thousand miles across.	1 per 20 years
10.0+	Epic	Never recorded; see below for equivalent seismic energy yield.	Extremely rare (Unknown)

Table A-3. Non-Numerical Comparison Between Mercalli Intensity Scale And Richter Scale

Mercalli Intensity Scale	Richter Scale
I	<3.5
II	3.5
III	4.2
IV	4.5
V	4.8
VI	5.4
VII	6.1
VIII	6.5
IX	6.9
X	7.3
XI	8.1
XII	>8.1

APPENDIX B

Sample delivered from casting site

Support system fabricated at Pusing

Support System was setup and bolted to the ground

Sample setup on support system and ready to be tested