1. Seismic Codes and Relevant Data Layer for Hazard and Risk Assessment

1.1 Description of National Code Development

Indonesia has developed the earth quake code since 27 years ago. It had aim to improve the regulation of the earth quake resistance for building which was interpreted in the standard code (Design Method of Earth quake Resistance for Buildings). This code was proposed by Beca Carer Hollings, Ferner Ltd and Indonesian's expert engineers. The result of this investigation was published in "Indonesian Earth quake Studies" volume 1 until 7 at 1979. Based on this investigation, the hazard map was published for period 500 years. In the hazard map, the earth quake zone map of Indonesia is divided into 6 zones and it is classified by 2 (two) sub soil conditions type, stiff soil and soft soil.

Nowadays, there are many technologies and research to investigate the occurrences of earth quake much more details. The improving and developing of this research is published in the "Building Code" that must be fulfilled in order to generalize the design's calculation and give a safety factor for buildings and users. Indonesia is a one of dangerous locations in the world as it has a lot of earth quake occurrences; hence the Indonesia government makes a regulation and reference for engineers to design a building and infrastructure by using a code which is called Design Method of Earth quake Resistance for Buildings – Indonesia Standard National 1726-02. This standard is intended as a replacement of Indonesian National Standard (SNI-03-1726-1989).

Indonesia government has started a new code after Tsunami disaster which was occurred 5 years ago. We were aware that the current code is not relevant anymore to be implemented for designing of building. Many buildings and infrastructures were destroyed by earth quake and tsunami due to lack of quality and wrong construction method. This code is being accomplished by government which consider higher safety factor including construction method for housing and high building. This is necessary to give knowledge for engineers and architects to build a building as well as new code.

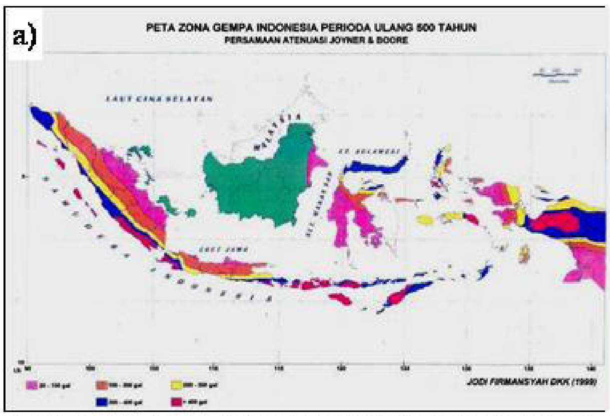
1.2 Recent code situation

1.2.1 Elaboration of National Seismic Zoning Maps

Currently, Indonesia has three earthquake hazard maps issued by Department of Public Works. The first map is Peak Ground Acceleration (PGA) map at bedrock for 500 years return period in the Standard for Earthquake Resilience Planning Structure Building (SNI 03-1726-2002). This hazard map is used for designing general buildings. The second is the hazard maps for designing waterworks (dam). This map was developed by Theo F. Najoan and published by Research centre for Waterworks Department of Public Works. The third map is used for designing bridge and road construction published by Research

Centre for Roads and Bridgeworks. This map is referred to the map developed by Theo F. Najoan with a return period of 50 and 100 years.

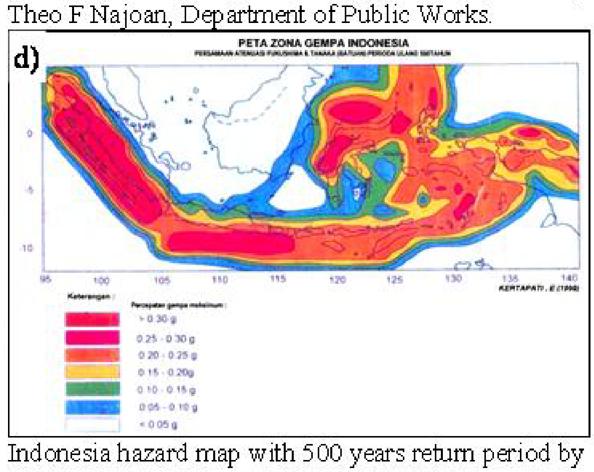
The map for PGA at bedrock in the SNI 03-1726-2002 (Figure 1e) was developing by averaging values from four seismic hazard maps developed by four different research groups in Indonesia(Figure 1a to 1d). This seismic hazard map was developed using total probability theorem (Cornel, 1968) and by applying area sources model (2-dimension model). This 2-dimension (2-D) model has some limitations in modeling the fault source geometries. Moreover, several great earthquake occurrences in Indonesia in the last two years inquire revision of seismic hazard parameters in SNI 03-1726-2002. These earthquake events must be considered in determining seismic hazard parameters especially maximum credible earthquake magnitude (MCE).



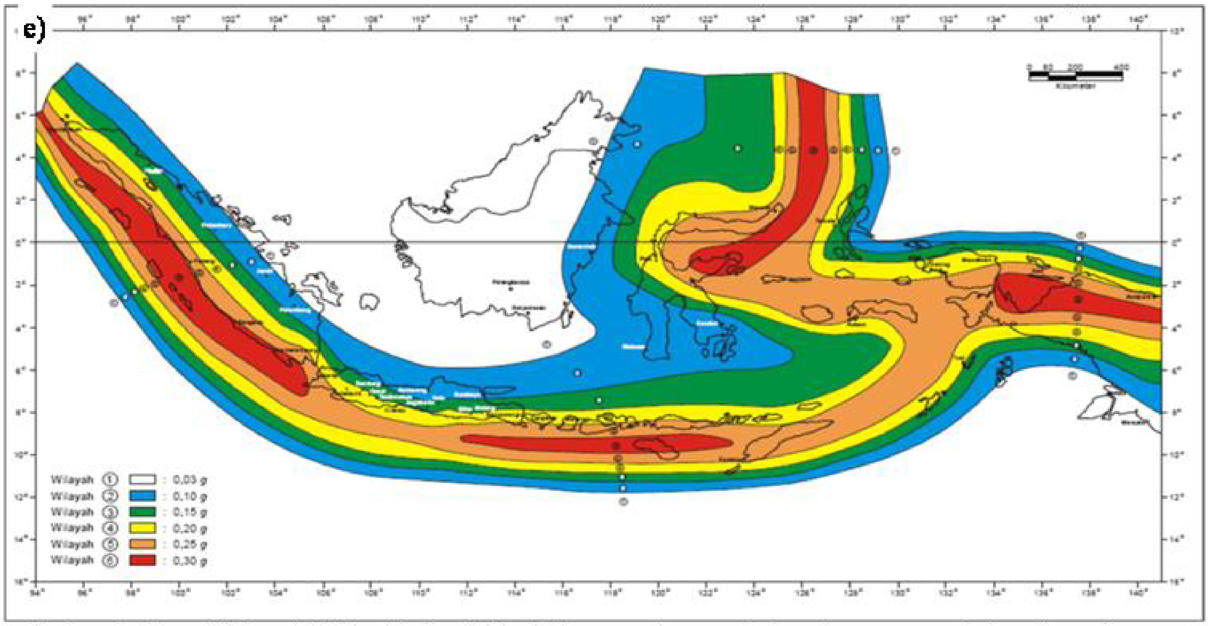
Indonesia hazard map with 500 years return period by Jodi Firmansyah and Irsyam, ITB.

Indonesia hazard map with variation return period by Theo F Najoan, Department of Public Works.

Indonesia hazard map with 500 years return period by Teddy Boen&Haresh Shah, university of Stanford.



Indonesia hazard map with 500 years return period by Engkon Kertapati, Dep. Mineral and Energy.



Indonesia Hazard Map of PGA at bedrock for 500 years return period on the average of above hazard map.

Figure 1. *Indonesia Hazard Map from four researches and as in SNI 03-1726-2002.*

1.2.2 Specification of Code Provisions

1.2.2.1. General Requirement.

This standard defines the effect of design earthquake that must be examined in the building structure design and various parts and components in general. Due to the effect of design earthquake, overall building structure must stay erected, albeit in near collapsing condition. The design earthquake is defined to have a reoccurrence period of 500 years, so its probability in the 50 years building life span is 10%.

The design requirements of earthquake resistant building structures defined in this standard do not apply for the following buildings:

- Building with uncommon structure system or buildings still requiring proving of their worthiness.
- Buildings using base isolation system to absorb earthquake effect on the upper structure.
- Civil Engineering Structures such as bridges, irrigation building, wall sand piers of harbor, off-shore oil structure, and other non-buildings.
- One storey house and other non-technical buildings.

This standard has a propose that the building structure which its earthquake resistance is designed conforming to this standard can function:

- To prevent human casualties by the collapse of building because of a strong earthquake

- To reduce building damage due to light to medium earthquake, so the building is repairable.
- To prevent tenant discomfort for building tenants during light to medium earthquakes.
- To maintain at all time vital services of building function.

1.2.2.2. Importance Factor

For various building categories, depending on the probability of building structure collapsing for the life and expected age of the building, the effect of design earthquake on it must be multiplied with a significance factor I (Importance Factor).

Building Category	**Significance Factor**		
	I_1	I_2	I (I1 x I2)
General building, such as for residential, trade and office	1.0	1.0	1.0
Monument and monumental buildings	1.0	1.6	1.6
Post earthquake important buildings such as hospital, clean water installation, power plant, emergency rescue center, radio and television facilities.	1.4	1.0	1.4
Buildings for storing dangerous goods such as gas, oil products, acid, toxic materials	1.6	1.0	1.6
Chimneys, towered tanks	1.5	1.0	1.5

Table 1. Importance factor

I_1 = the significant factor to adjust the reoccurrence period of the earthquake related to probability adjustment of the earthquake occurrence for the life of the building.
I_2 = Significant factor to adjust earthquake reoccurrence period related to the building age adjustment.

1.2.2.3. Regular and irregular building

A building structure is defined as a regular building under the following terms:

- Height of the building structure measured from lateral clamping level may not be more than 10 stories or 40 m.
- Shape of the building is rectangular without protrusion, if there is an protrusion, the length of the protrusion does not exceed 25% of the largest size of the building structure in the direction of the protrusion.
- The building structure map does not show any corner notch, if there is a notch, the length of the side of the notch does not exceed 15% of the largest size of the building structure in the notch side direction.
- The building structure system is formed by the lateral load bearer subsystems which direction is perpendicular to each other and parallel to orthogonal main axis of overall building structure map.
- The building structure system does not show a leap of the front plane, if a leap of the front plane, size of the structure map of the building protruding at each direction is no less than 75% of the largest size of structure map of

the lower building part. In this case, roof house structure which is less than 2 storeys tall is not necessarily considered to cause front plane leap.

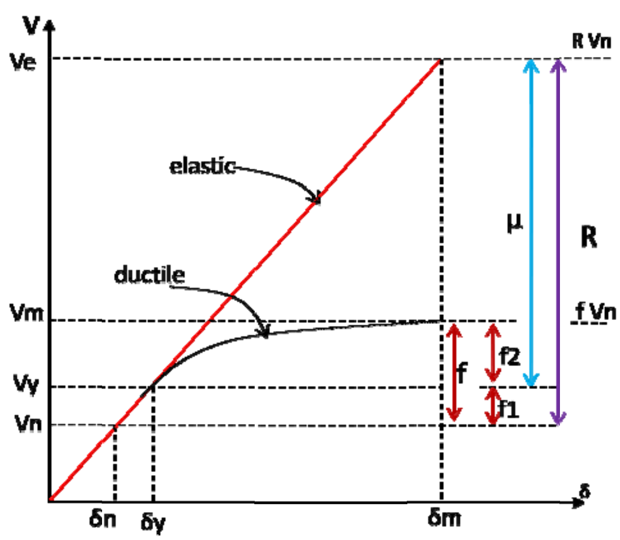
1.2.2.4. Ductility of the building structure and nominal earthquake loading

Building structure ductility factor (μ) is a ratio of maximum deflection to the building structure due to the effect of the design earthquake when reaching the condition of near collapsing (δ_m) and building structure deflection when the first yielding δ_y occurs, which is:

$$1.0 \le \mu = \frac{\delta_m}{\delta_y} \le \mu_m$$

Building structure performance Level	μ	R	f_2	f
Full Elastic	1,0	1,6	1	1.6
Partial Elastic	1,5 2,0 2,5 3,0 3,5 4,0 4,5 5,0	2,4 3,2 4,0 4,8 5,6 6,4 7,2 8,0	1.09 1.17 1.26 1.35 1.44 1.51 1.61 1.70	1.7 1.9 2.0 2.2 2.3 2.4 2.6 2.7
Full Ductile	5,3	8,5	1.75	2.8

Table 2. Ductility for each performance level



$$R = \mu . f_1 = \frac{V_e}{V_n}$$

$$\mu = \frac{V_e}{V_y} = \frac{\delta_m}{\delta_y}$$

$$f_2 = \frac{V_m}{V_y}$$

$$f_1 = \frac{V_y}{V_n}$$

$$f = f_1 . f_2 = \frac{V_m}{V_n}$$

Figure 2. Ductility curve

Where :

V_e = Maximum loading due to effect of design earthquake absorbable by a fully elastic building structure in the condition of near collapsing.
V_m = Maximum loading due to effect of design earthquake absorbable by a fully ductile building structure in the condition of near collapsing.
V_y = The loading that causes the first yielding in the building structure.
Vn = The nominal earthquake loading due to effect of design earthquake which must be examined in building structure design.
f_1 = the load and material extra strength factor included I the building structure, f1 = 1.6
f_2 = The structure extra strength factor
R = The earthquake reduction factor

1.2.2.5. Capacity Design

The earth quake code, which is called SNI 1726-02, explains the failure mechanism which is still in the safe zone due to earth quake load. This mechanism is called *Side Sway Mechanism* (picture 2) where the plastic-hinge only occurs on the edge of beams and columns. To reach this mechanism, the *strong column weak beam* must be fulfilled the capacity design. This concept explains that the columns must have nominal flexure capacity which is larger than beams. Side sway mechanism is expected in the design to prevent the collapse mechanism at the column where it is called as Soft Storey Mechanism (Picture 3).

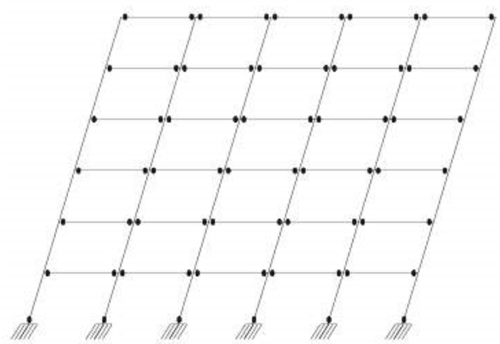


figure 3. Side Sway Mechanism

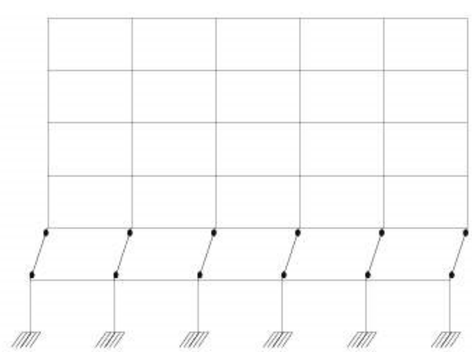


figure 4. Soft storey Mechanism

In the Strong column weak beam concept, the capacity design needs a multiplier to enlarge the column capacity against beam, which is called Over-strength factor (OF). This concept could be interpreted in equilibrium as below:

$$\sum M_c \geq OFx \sum M_g$$

Where:
$\sum M_c$ = Amount of column moments in the joint beam-column
$\sum M_g$ = Amount of beam moments in the joint beam-column
OF = Over-strength Factor value (6/5)

1.2.2.6. Type of soil and propagation of earthquake wave

Soil types are determined as hard soil, medium soil and soft soil. For the uppermost layer at a maximum thickness of 30 m, the requirement in the table is satisfied:

Soil Type	Average shear wave propagation speed	Average Standard Penetration Test Result N	Average Non Flowing shear strength Su (kPa)
Hard Soil	$Vs \geq 350$	$N \geq 50$	$S_u \geq 100$
Medium Soil	$175 \geq V_s \geq 350$	$15 \leq N < 50$	$50 \leq S_u < 100$
Soft Soil	$V_s < 175$	$N < 15$	$S_u < 50$
	Or, each profile with soft soil having total thickness of more than 3 m with PI > 20, $w_n \geq 40\%$, and $S_u < 25$ kPa		
Special Soil	Requires special evaluation at each location		

Table 3. Shear wave velocity

The effect of design earthquake on the soil surface must be determined from the analysis result of earthquake wave propagation from the depth of the base rock to soil surface by using input earthquake movement with peak acceleration for base rock.

Zone	Minimum PGA (g)	Ao (g) Rock	Ao (g) Stiff	Ao (g) soft
1	0.03	0.04	0.05	0.08
2	0.1	0.12	0.15	0.2
3	0.15	0.18	0.23	0.3
4	0.2	0.24	0.28	0.34
5	0.25	0.28	0.32	0.36
6	0.3	0.33	0.36	0.38

Table 4. Peak ground acceleration for each seismic zone

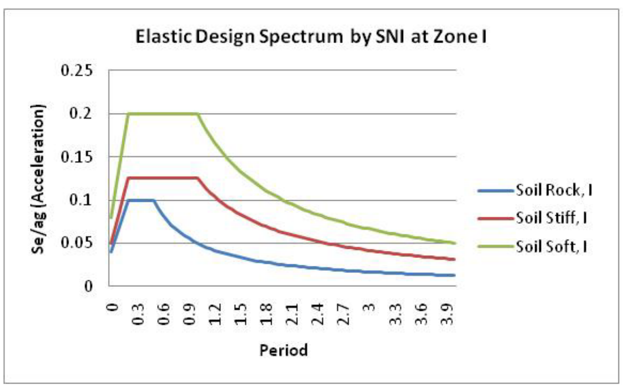
Considering the short natural frequency period of $0 \leq T \leq 0.2$ second, there is an uncertainty, both in soil movement characteristic or its structure ductility level, the earthquake response factor C is determined by the equation below:

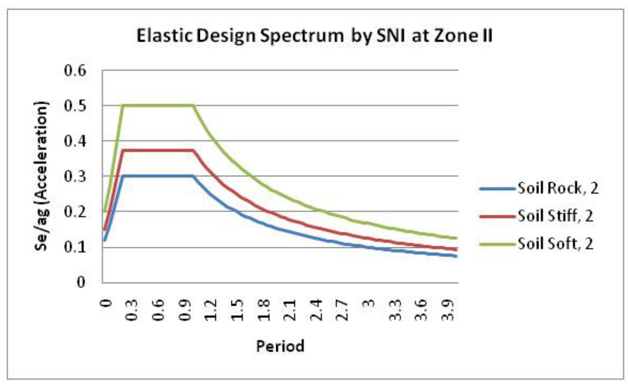
- For $T \leq T_c$; $C = A_m$
- For $T > T_c$; $C = A_r/T$

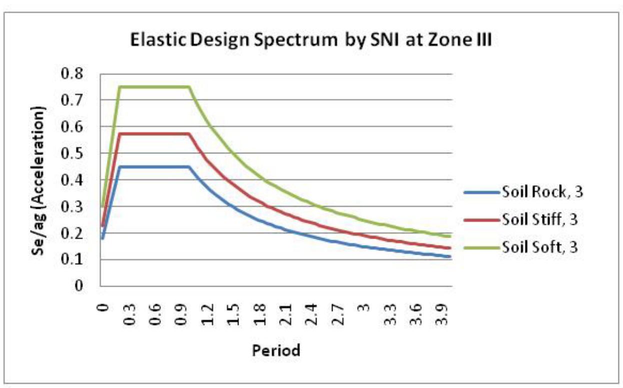
Where : $A_r = A_m.T_c$

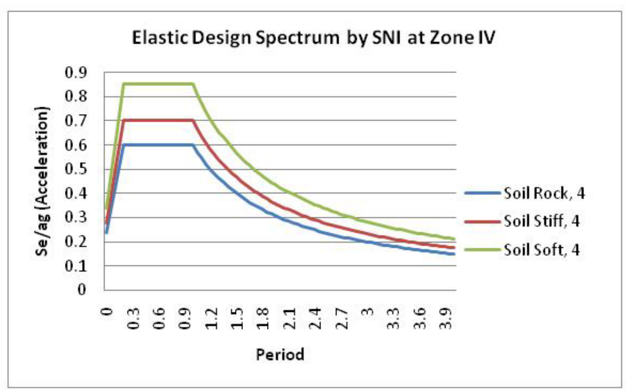
Zone	Hard Soil Tc = 0.5 sec		Medium Soil Tc = 0.6 sec		Soft Soil Tc = 1.0 sec	
	A_m	A_r	A_m	A_r	A_m	A_r
1	0.10	0.05	0.13	0.08	0.20	0.20
2	0.30	0.15	0.38	0.23	0.50	0.50
3	0.45	0.23	0.55	0.33	0.75	0.75
4	0.60	0.30	0.70	0.42	0.85	0.85
5	0.70	0.35	0.83	0.50	0.90	0.90
6	0.83	0.42	0.90	0.54	0.95	0.95

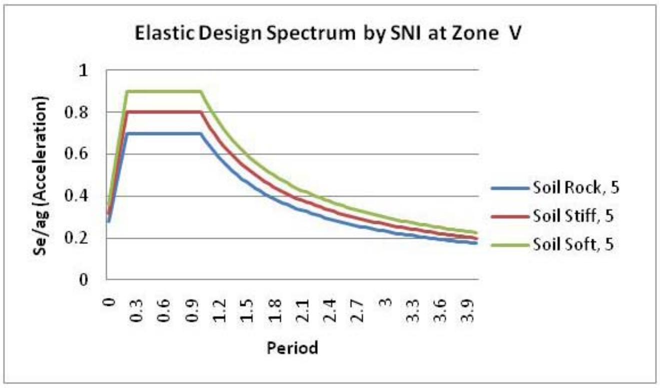
Table 5. Acceleration value for each soil type











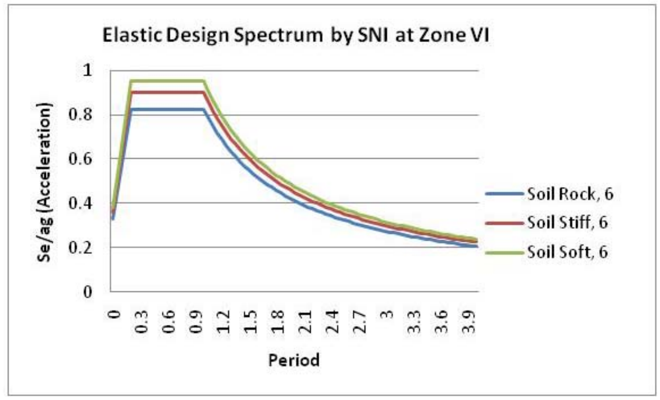


Figure 5. Response Spectra Graph for each zone

1.2.3 Basic Equation for Predicting the Equivalent Horizontal Forces

1.2.3.1. Limitation of fundamental natural frequency period

Fundamental period is basically able to be determined by using equation from UBC 97:
$T = 0.0853\ H^{3/4}$ (for steel frame)
$T = 0.0731\ H^{3/4}$ (for concrete frame)
$T = 0.0488\ H^{3/4}$ (for others frame)
Where H is total height of building
To prevent a usage of over flexible building structure, the fundamental natural frequency period T_1 of the building structure must be limited, depending on the coefficient ς for the Seismic zone where building is located and its storey total n is according to the equation.

$$T_1 < \varsigma\, n$$

Where the coefficient ς is defined according to table below:

Zone	Coeff. (ζ)
1	0.20
2	0.19
3	0.18
4	0.17
5	0.16
6	0.15

Table 6. multiplier of maximum natural period for each zone

According to the table above, it can be clearly seen that the critical zone (6) is expected to have lower period rather than other zones.

Fundamental natural frequency period of a regular building structure in each main axis direction can be determined using Rayleigh formula as follows:

$$T_1 = 6,3\sqrt{\frac{\sum_{i=1}^{n} W_i d_i^2}{g\sum_{i=1}^{n} F_i d_i}}$$

Where :

W_i = The floor weight of the ith including corresponding live load

F_i = Equivalent static nominal earthquake loads

d_i = The horizontal deflection of the ith floor

g = Gravitational acceleration (9.8 m/sec^2)

1.2.3.2. Eccentricity of center of gravity against the rotation center of storey floor

The center of gravity of storey floor of a building structure is the resultant point of dead load, including corresponding live load working at that floor. On the building structure design, the center of gravity is the resultant point of equivalent static load or dynamic earthquake force.

Storey level rotation center of a building structure is a point at the storey floor which if a horizontal load is working on it, the storey floor will not rotate, but only translates, while the other levels not experiencing horizontal load will all rotate and translate.

Between the center of gravity and the center of rotation, a designed eccentricity e_d must be examined. If the largest horizontal size of the building structure a storey floor, measured perpendicular to earthquake loading direction, is stated as **b**, the designed eccentricity e_d must be determined as follows:

- For $0 < e \leq 0.3$ b

  $e_d = 1.5e + 0.05b$ or $e_d = e-0.05d$

and selected between both which effect is the most determining for the examined building structure component or subsystem:

- For e> 0.3 b

  $E_d = 1.33e + 0.1b$ or $e_d = 1.17e – 0.1b$

1.2.3.3 Equivalent static nominal earthquake load

A regular building structure can be designed against nominal earthquake loading due to effect of design earthquake in the direction of each main axis of the structure map, in form of equivalent static nominal earthquake load.

The equivalent static nominal basic shear load V occurring at the base level can be calculated according to the equation:

$$V = \frac{C_1 I}{R} W_1$$

Where :	C_1	= The earthquake response factor
	I	= Importance factor
	W_1	= The total weight
	R	= earthquake reduction factor

Nominal basic shear load V must be distributed along the height of the building structure to be equivalent static nominal earthquake loads F_i working at the center of gravity at the i^{th} level according to equation:

$$F_i = \frac{W_i z_i}{\sum_{i=1}^{n} W_i z_i}$$

Where :

W_i = The floor weight of the i^{th} including corresponding live load

Z_i = The floor height of the i^{th} floor measured from lateral clamping level.

If the ratio between the height of the building structure and its map size in the earthquake loading direction equals or exceeding 3, then 0.1 V must be considered as a horizontal loads centralized at the center of gravity of the uppermost level, while the remaining 0.9 V must be distributed along the height of the building structure to be equivalent static nominal earthquake load.

1.2.3.4. Service Limit Performance

Service limit performance of a building structure is defined by the inter-level deflection due the effect of design earthquake which limit the occurrence of steel yield and excessive concrete cracking. To satisfy this requirement, inter-level deflection calculated from the building structure deflection may not exceed 0.03/R of height of the respective level or 30 mm.

1.2.3.5 Ultimate Limit Performance

The ultimate limit performance of the building structure is determined by the deflection and maximum inter-level deflection of the building structure due to effect of design earthquake when the building structure is near collapsing. To limit the occurrence possibility of building structure collapsing which can cause human casualties and to prevent dangerous collisions between buildings or between earthquake load parts separated by separation space (dilatation clearance).

- For regular building structure
  $\varsigma = 0.7$ R
- For irregular building structure

$$\xi = \frac{0.7R}{scale\_Factor}$$

Where R is earthquake reduction factor of the building structure.
To satisfy the building structure ultimate limit performance requirements, in all conditions, the inter-level deflection calculated from the building structure deflection may not exceed 0.02 of the respective storey height.

1.2.3.6 Response Spectrum Analysis by SRSS

This approach permits the multiple modes of response of a building to be taken into account (in the frequency domain). This is required in many building codes for all except for very simple or very complex structures. The response of a structure can be defined as a combination of many special shapes (modes) that in a vibrating string correspond to the "harmonics".

Combination methods include the following:

- absolute - peak values are added together
- square root of the sum of the squares (SRSS)
- complete quadratic combination (CQC) - a method that is an improvement on SRSS for closely spaced modes

In this report, I will compare the Equivalent static result with SRSS result.
The equilibrium of SRSS method is:

$$MPF_j = \frac{\sum_{k=1}^{N} m_k \phi_{kj}}{\sum_{k=1}^{N} m_k \phi_{kj}^2} \qquad \bar{\phi}_i = \sqrt{\sum_{j=1}^{N} \left(\phi_{ij} MPF_j\right)^2} \qquad F_i = \frac{m_i \bar{\phi}_i}{\sum_{k=1}^{N} m_k \bar{\phi}_k} V$$

1.3 Elaboration of Further Information

1.3.1 General Information

Indonesia, located in Southeast Asia, is a nation consiting of over 13,000 islands (some publications cite more than 17,000 islands). Only 6000 of these islands are inhabited. The islands spread between the Indian and Pacific oceans, linking the continent of Asia and Australia. The main islands are **Sumatera** (473,606 sq.km), **Kalimantan** (539,460 sq.km), **Sulawesi** (189,216 sq.km), **Irian Jaya** (421,981 sq.km), and **Java** (132,187 sq.km). Indonesia shares the islands of Kalimantan with Malaysian, and Irian with Papua New Guinea.

Indonesia is recognized as archipelago’s country which has more than ten thousand islands. 60% of population is concentrating in the Java Island and the rest are distributed in Sumatra, Kalimantan, Sulawesi and Irian Island.

Most of big cities in Indonesia have big potential to have earth quake due to the location is near to the tectonic plate and active mountain.

Province	Population Density (in thousand [1000])				
	1971	1980	1990	1995	2000
Jawa Barat	21624	27454	35384	39207	35730
Jawa Timur	25517	29189	32504	33844	34784
Jawa Tengah	21877	25373	28521	29653	31229
Sumatera Utara	6622	8361	10256	11115	11650
DKI Jakarta	4579	6503	8259	9113	8389
Banten					8099
Sulawesi Selatan	5181	6062	6982	7558	8060
Sumatera Selatan	3441	4630	6313	7208	6900
Lampung	2777	4625	6018	6658	6741
Riau	1642	2169	3304	3901	4958
Sumatera Barat	2793	3407	4000	4323	4249
Kalimantan Barat	2020	2486	3229	3636	4034
NTB	2203	2725	3370	3646	4009
NTT	2295	2737	3269	3577	3952
NAD	2009	2611	3416	3848	3931
Bali	2120	2470	2778	2896	3151
DI Yogyakarta	2489	2751	2913	2917	3122
Kalimantan Selatan	1699	2065	2598	2893	2985
Kalimantan Timur	734	1218	1877	2314	2455
Jambi	1006	1446	2021	2370	2414
Papua	92	1174	1649	1943	2221
Sulawesi Tengah	914	1290	1711	1938	2218
Sulawesi Utara	1719	2115	2478	2649	2012
Kalimantan Tengah	702	954	1396	1627	1857
Sulawesi Tenggara		942	1350	1587	1821
Bengkulu	519	768	1179	1409	1567
Maluku	1090	1411	1858	2087	1206
Belitung					900
Gorontalo					835
Maluku Utara					785
INDONESIA	117663	146935	178631	193915	206265

Figure 6.population density in Indonesia

1.3.2 Geological and topographical maps

The maps below are drawing the geological and topographical condition in Indonesia. It is consisted of several of soil types for instance, metamorphic rock, Mesozoic formation and volcanic formation. It is caused by many active volcanos and many tectonic plates in Indonesia.

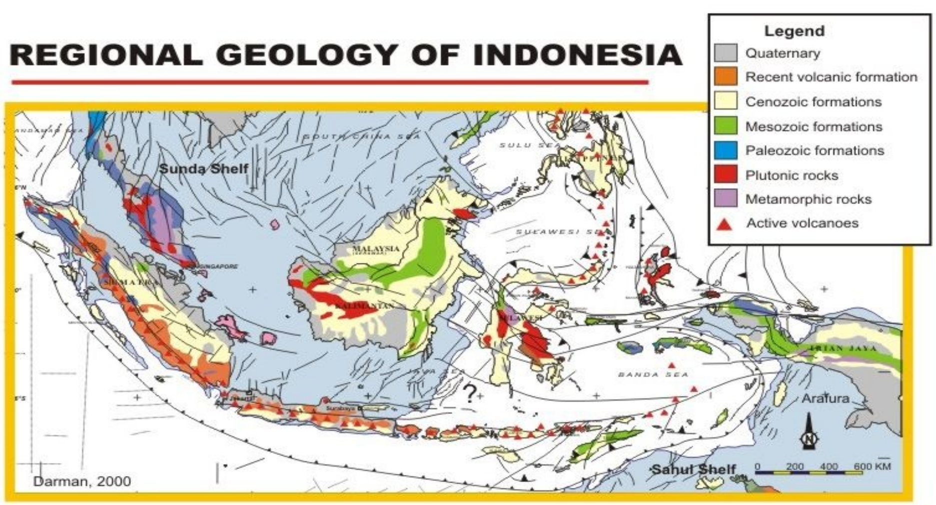


Figure 7. Geology map of Indonesia

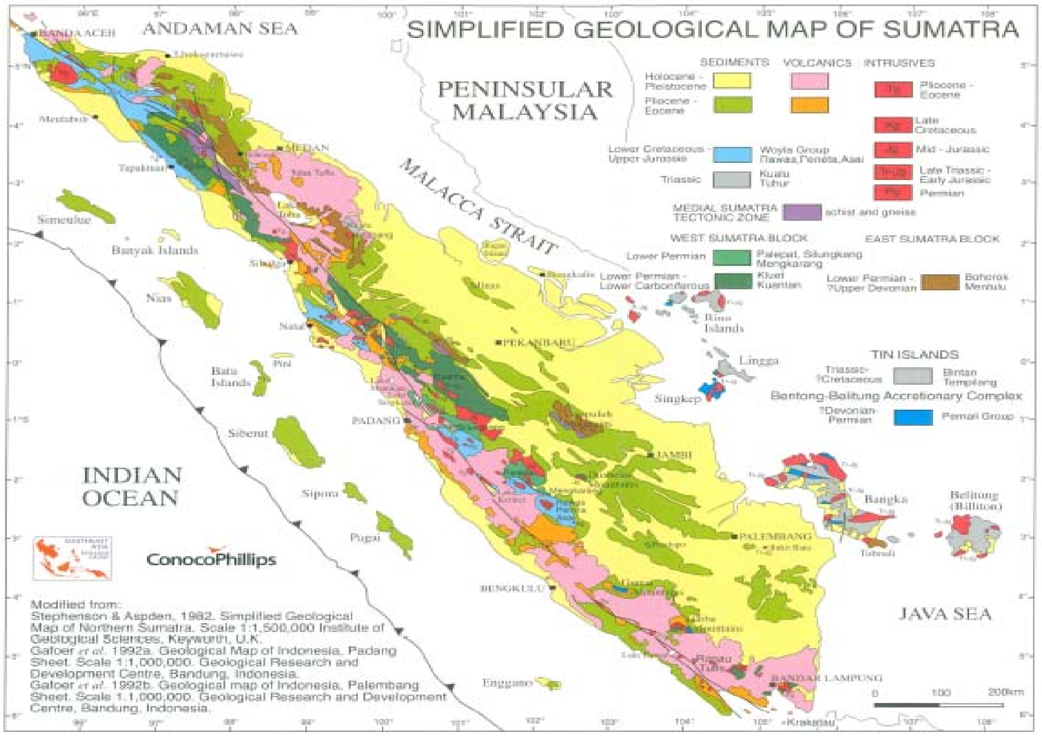


Figure 8. Geology map of Sumatera Island

1.3.3 Government and Political conditions

Indonesia is a republic based on the 1945 constitution providing for a separation of executive, legislative, and judicial power. Substantial restructuring has occurred since President Suharto's resignation in 1998 and the short, transitional Habibie administration in 1998 and 1999. The Habibie government established political reform legislation that formally set up new rules for the electoral system, the House of Representatives (DPR), the People's Consultative Assembly (MPR), and political parties without changing the 1945 Indonesian constitution. After these reforms, the constitution now limits the president to two terms in office.

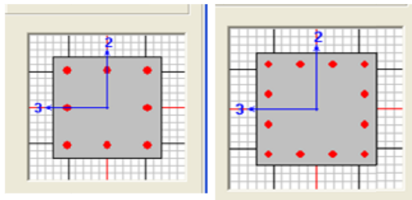
2 Seismic Forces for an Idealized RC Frame System

2.1 Analysis of concrete frame

2.1.1 Model of Structure

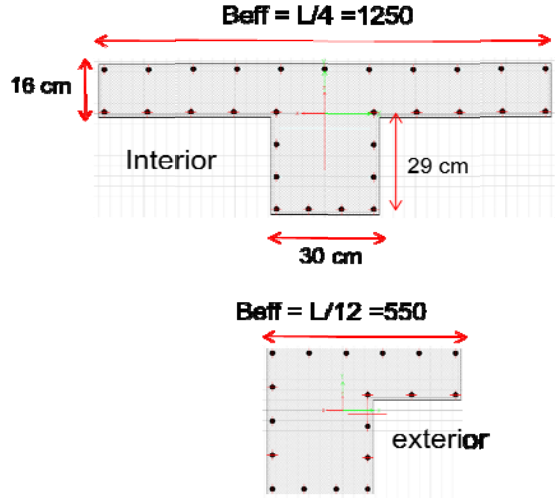
In this yellow project, the typical structure given for designing is a 4-storey building which is constructed by Reinforced concrete. The analysis uses a structure’s software (ETABS v.9.0.9). The dimension of frame elements and layout are explained as follows:

1. Column



300x300 mm 400x400 mm

2. Beam



3. Slab

Slab is 16 cm

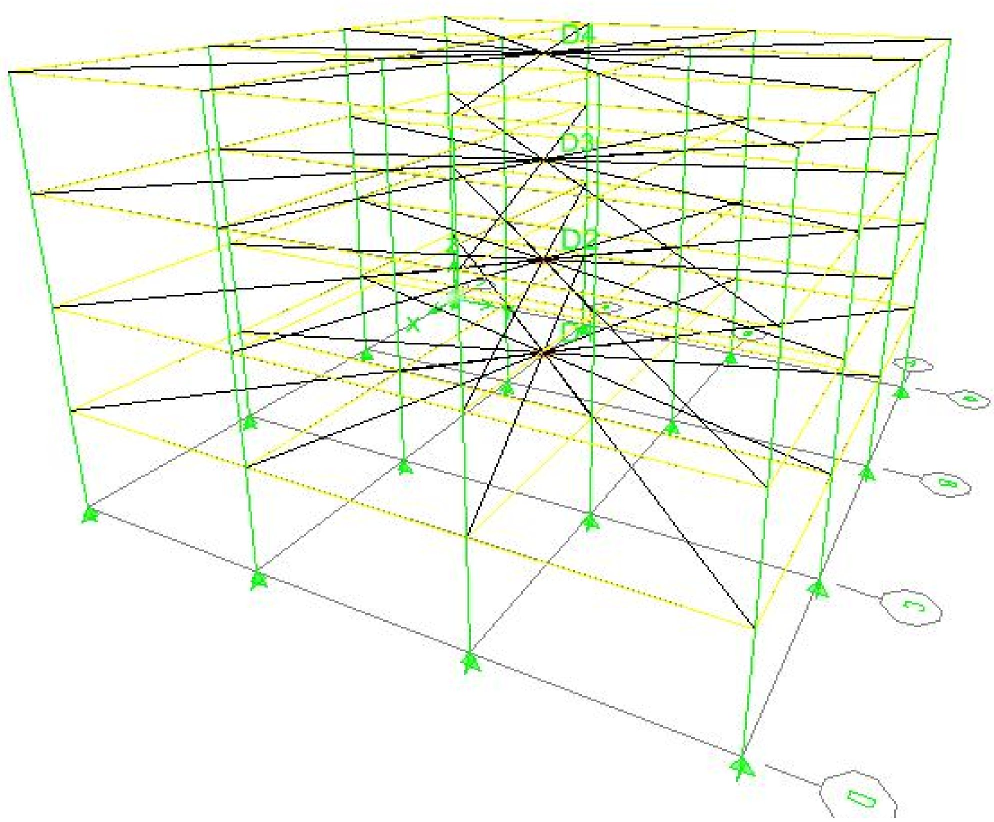


Figure 9. Layout of building structure

2.1.2. Material Properties

In the etabs software, we could apply the material properties such as below:

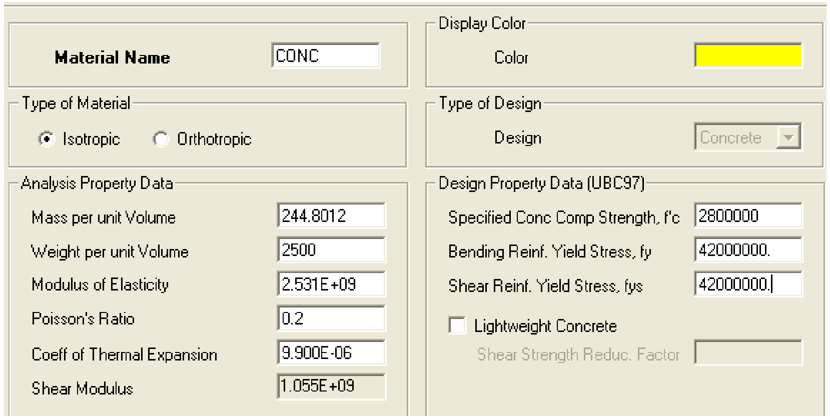


Figure 10. Material properties

According to picture above,

- concrete density is 2500 kg/m3
- concrete Compression Strength is 2800000 kg/m^2
- Reinforcement yield stress is 42000000 kg/m^2

2.1.3 Load Cases

There are several load cases which are applied into account. These load cases are Dead Load (DL), Live Load (LL) and Earthquake Load (E).

The detail of each load case is calculated in the table below:

	kN/m^2	γ_c	h	b	L_1	Load
Load		[kN/m^3]	[m]	[m]	[m]	[kN/m]
Dead Load						
Slab		25	0.16		5	20
Plastering	1.25				5	6.25
Partitions	1.25				5	6.25
Superimposed Load						32.5
Roof	5.75				5	28.75
Live Load	2				5	10
Frame Load						
Column 300 mm x 300 mm		25	0.3	0.3		2.25
Column 400 mm x 400 mm		25	0.4	0.4		4
Beam 300 mm x 450 mm		25	0.45	0.3		3.375

Table 7. Load Cases calculation

2.1.4 Equivalent static nominal earthquake load Calculation

Before calculating the shear force, we have to determine the weight at each storey which is calculated as table below:

Weight each Storey									
	h_1	h_2	h_3	h_4	n-slab	L_2	n-beam	n-column	Sub Total (KN)
	[m]	[m]	[m]	[m]		[m]			
w_4				3.2	3	5	24	16	893.85
w_3			3.2		3	5	24	16	1101.45
w_2		3.2			3	5	24	16	1191.05
w_1	3.05				3	5	24	16	1186.25
									4372.6

Table 8. Weight distribution for each storey

According to the equivalent static equilibrium, the base shear for each seismic zone is

Storey	Wi	zi	Wi*zi
	[kN]	[m]	[kN.m]
4	893.85	12.65	11307.20
3	1101.45	9.45	10408.70
2	1191.05	6.25	7444.06
1	1186.25	3.05	3618.06
	4372.60		32778.03

Table 9. Equivalent static distribution

Zone		zone 1			zone 2			zone 3			zone 4			zone 5			zone 6		
C_v		0.2	0.08	0.05	0.5	0.23	0.15	0.75	0.33	0.23	0.85	0.42	0.3	0.9	0.5	0.35	0.95	0.54	0.42
		hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil
Base Shear (kN)		218.63	87.45	54.66	546.58	251.42	163.97	819.86	360.74	251.42	929.18	459.12	327.95	983.84	546.58	382.60	1038.49	590.30	459.12
Storey	4	75.42	30.17	18.85	188.55	86.73	56.56	282.82	124.44	86.73	320.53	158.38	113.13	339.39	188.55	131.98	358.24	203.63	158.38
	3	69.43	27.77	17.36	173.57	79.84	52.07	260.35	114.55	79.84	295.06	145.80	104.14	312.42	173.57	121.50	329.77	187.45	145.80
	2	49.65	19.86	12.41	124.13	57.10	37.24	186.20	81.93	57.10	211.02	104.27	74.48	223.43	124.13	86.89	235.85	134.06	104.27
	1	24.13	9.65	6.03	60.33	27.75	18.10	90.50	39.82	27.75	102.56	50.68	36.20	108.60	60.33	42.23	114.63	65.16	50.68
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		218.63	87.45	54.66	546.58	251.42	163.97	819.86	360.74	251.42	929.18	459.12	327.95	983.84	546.58	382.60	1038.49	590.30	459.12

Table 10. Shear force result for all zones

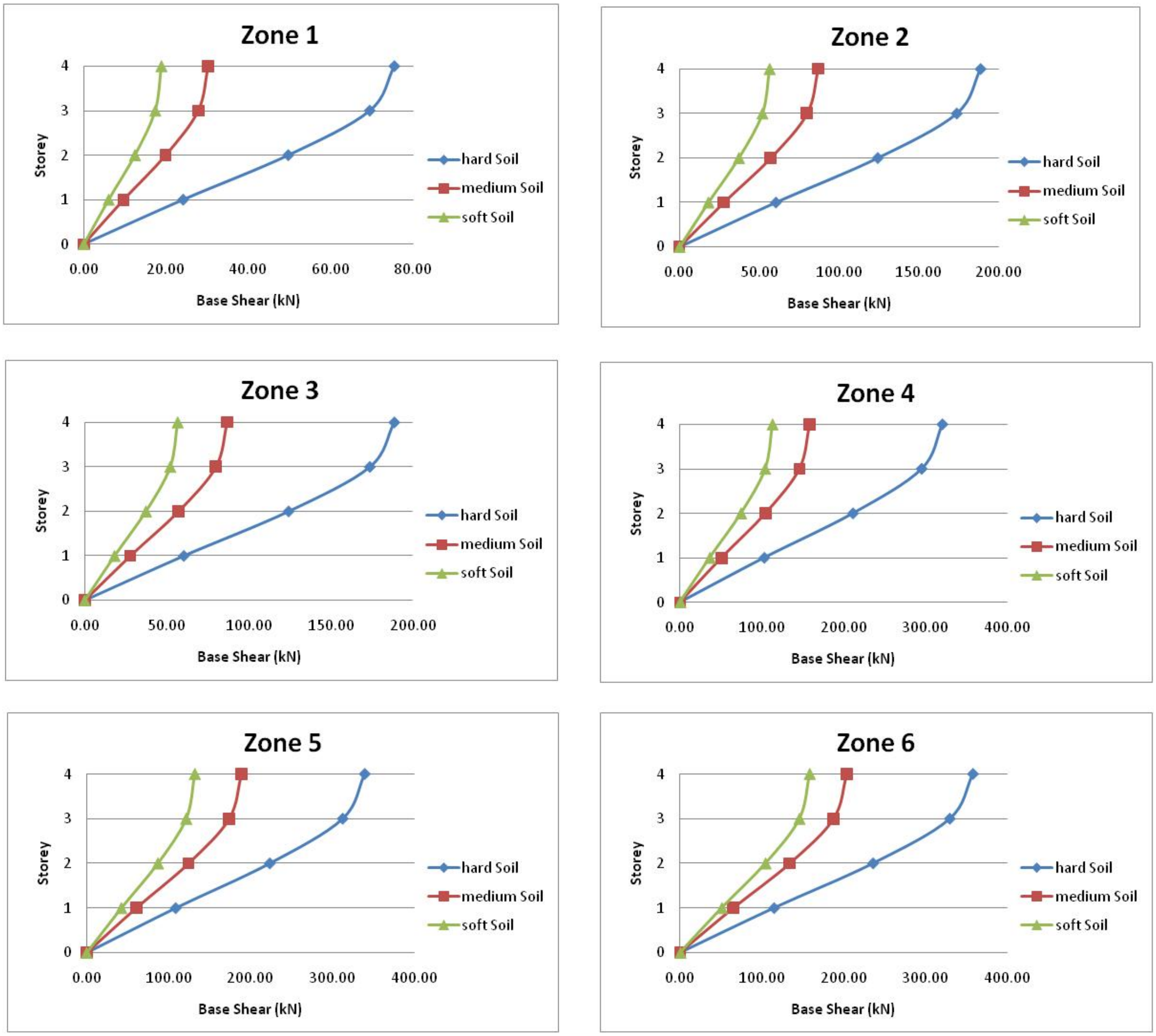


Figure 11. base Shear force distribution for each zone

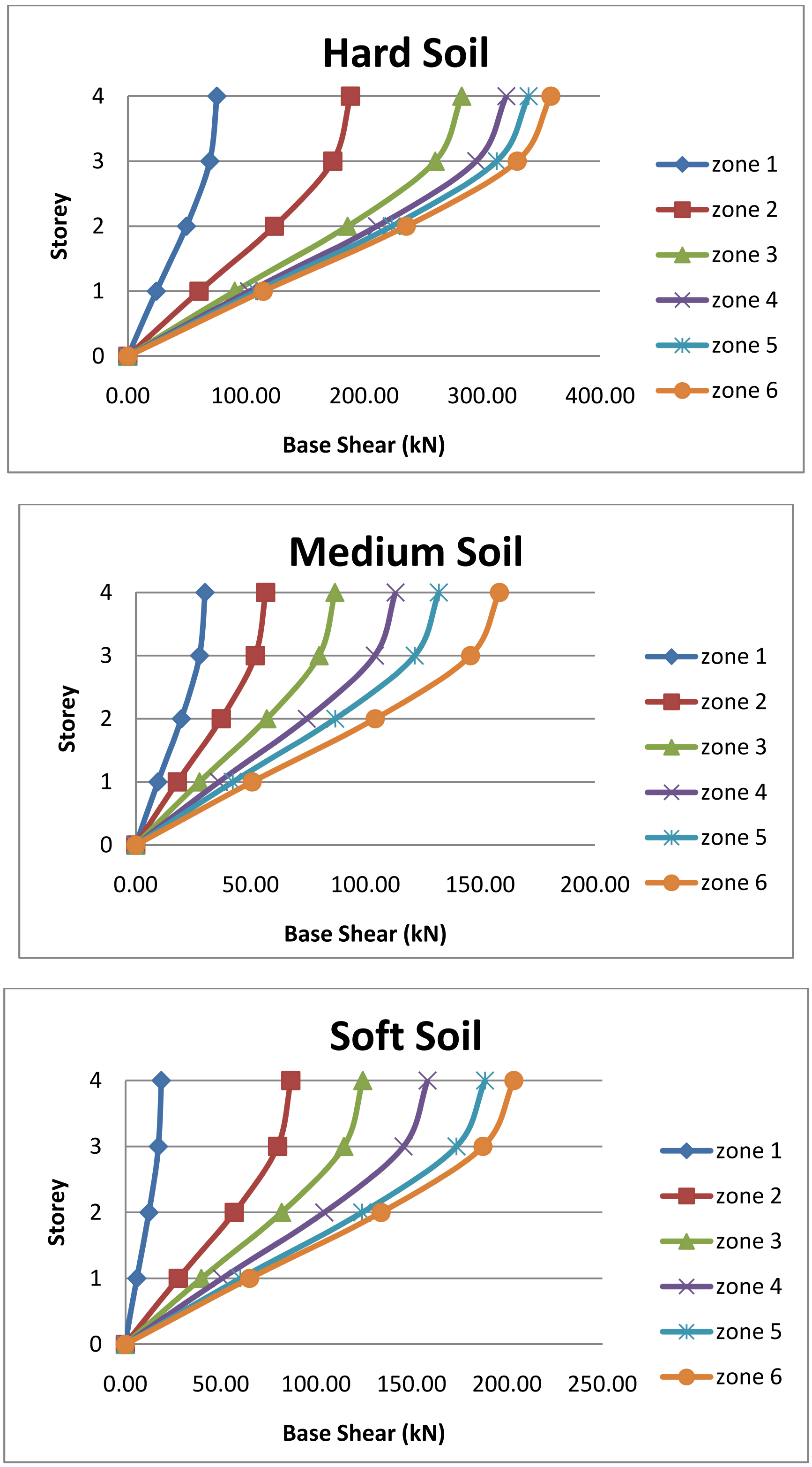
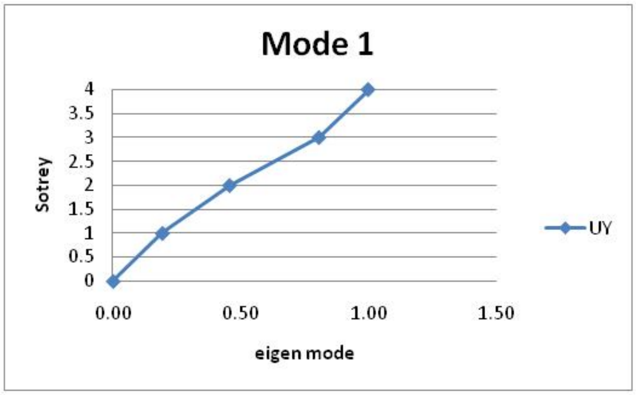


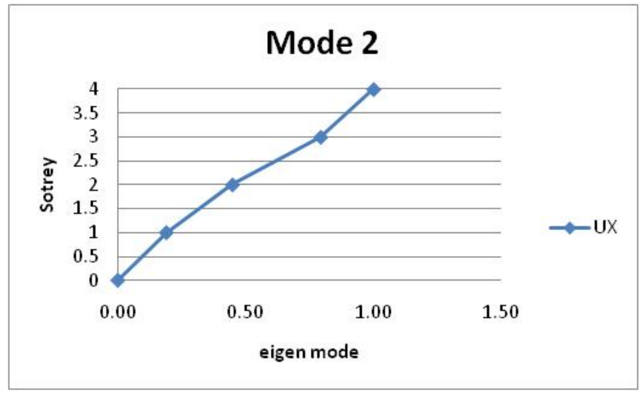
Figure 12. Base Shear Force for each soil type

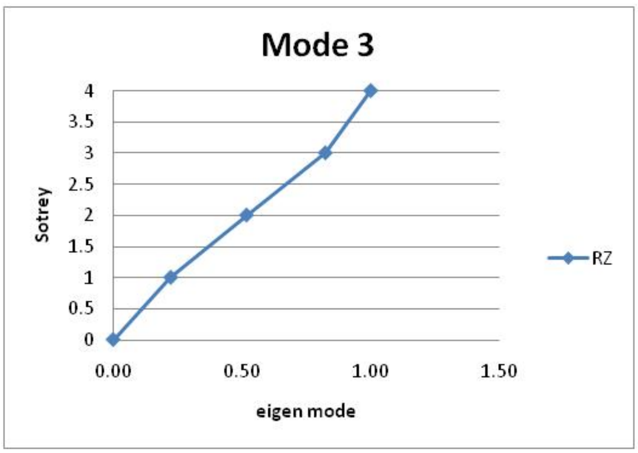
	1	2	3	4	5	6	7	8	9	10	11	12
	UY	UX	RZ	UY	UX	RZ	UY	UX	RZ	UY	UX	RZ
STORY4	-0.0057	0.0058	-0.00085	-0.0045	0.0044	-0.00069	-0.0032	-0.0032	-0.00052	-0.0004	-0.0004	0.0001
STORY3	-0.0046	0.0046	-0.0007	0.0015	-0.0015	0.00015	0.0059	0.006	0.00088	0.0016	0.0016	-0.00034
STORY2	-0.0026	0.0026	-0.00044	0.0053	-0.0053	0.0008	-0.0021	-0.0021	-0.00021	-0.0046	-0.0046	0.00073
STORY1	-0.0011	0.0011	-0.00019	0.0033	-0.0033	0.00053	-0.0034	-0.0033	-0.00057	0.006	0.0061	-0.00086

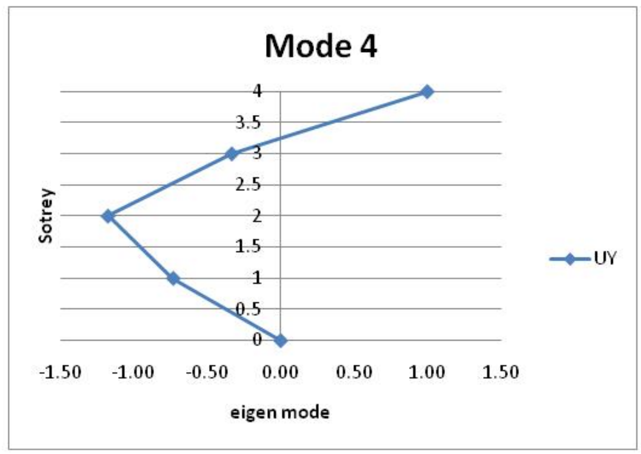
normalization												
	1	2	3	4	5	6	7	8	9	10	11	12
	UY	UX	RZ	UY	UX	RZ	UY	UX	RZ	UY	UX	RZ
4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3	0.81	0.79	0.82	-0.33	-0.34	-0.22	-1.84	-1.88	-1.69	-4.00	-4.00	-3.40
2	0.46	0.45	0.52	-1.18	-1.20	-1.16	0.66	0.66	0.40	11.50	11.50	7.30
1	0.19	0.19	0.22	-0.73	-0.75	-0.77	1.06	1.03	1.10	-15.00	-15.25	-8.60
base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

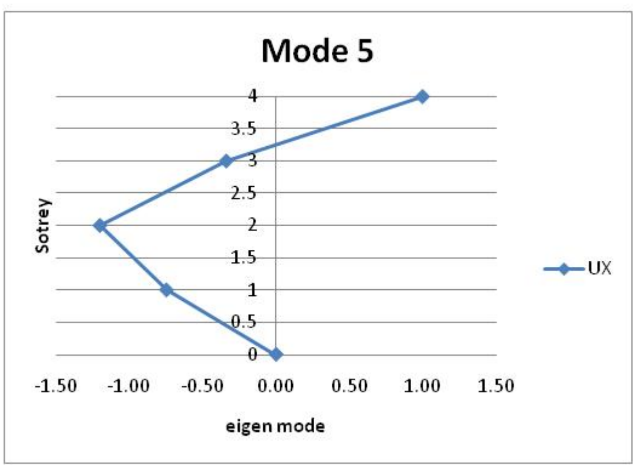
Table 11. eigen mode for each storey

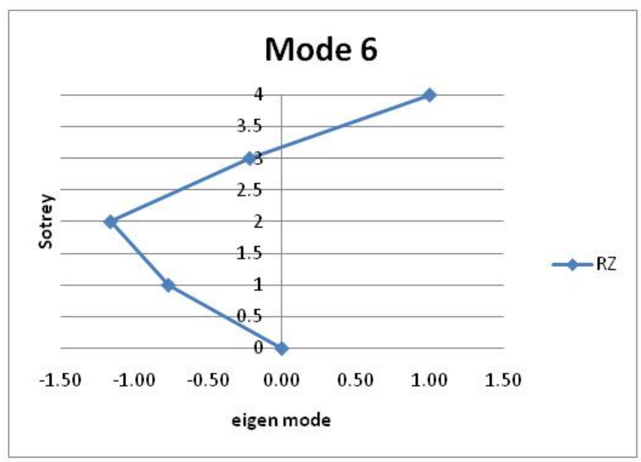

Mode 1
Sotrey
eigen mode
UY
0
0.5
1
1.5
2
2.5
3
3.5
4
0.00
0.50
1.00
1.50


Mode 2
Sotrey
eigen mode
UX
0
0.5
1
1.5
2
2.5
3
3.5
4
0.00
0.50
1.00
1.50


Mode 3
Sotrey
eigen mode
RZ
0
0.5
1
1.5
2
2.5
3
3.5
4
0.00
0.50
1.00
1.50


Mode 4
Sotrey
eigen mode
UY
0
0.5
1
1.5
2
2.5
3
3.5
4
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50


Mode 5
Sotrey
eigen mode
UX
0
0.5
1
1.5
2
2.5
3
3.5
4
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50


Mode 6
Sotrey
eigen mode
RZ
0
0.5
1
1.5
2
2.5
3
3.5
4
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50

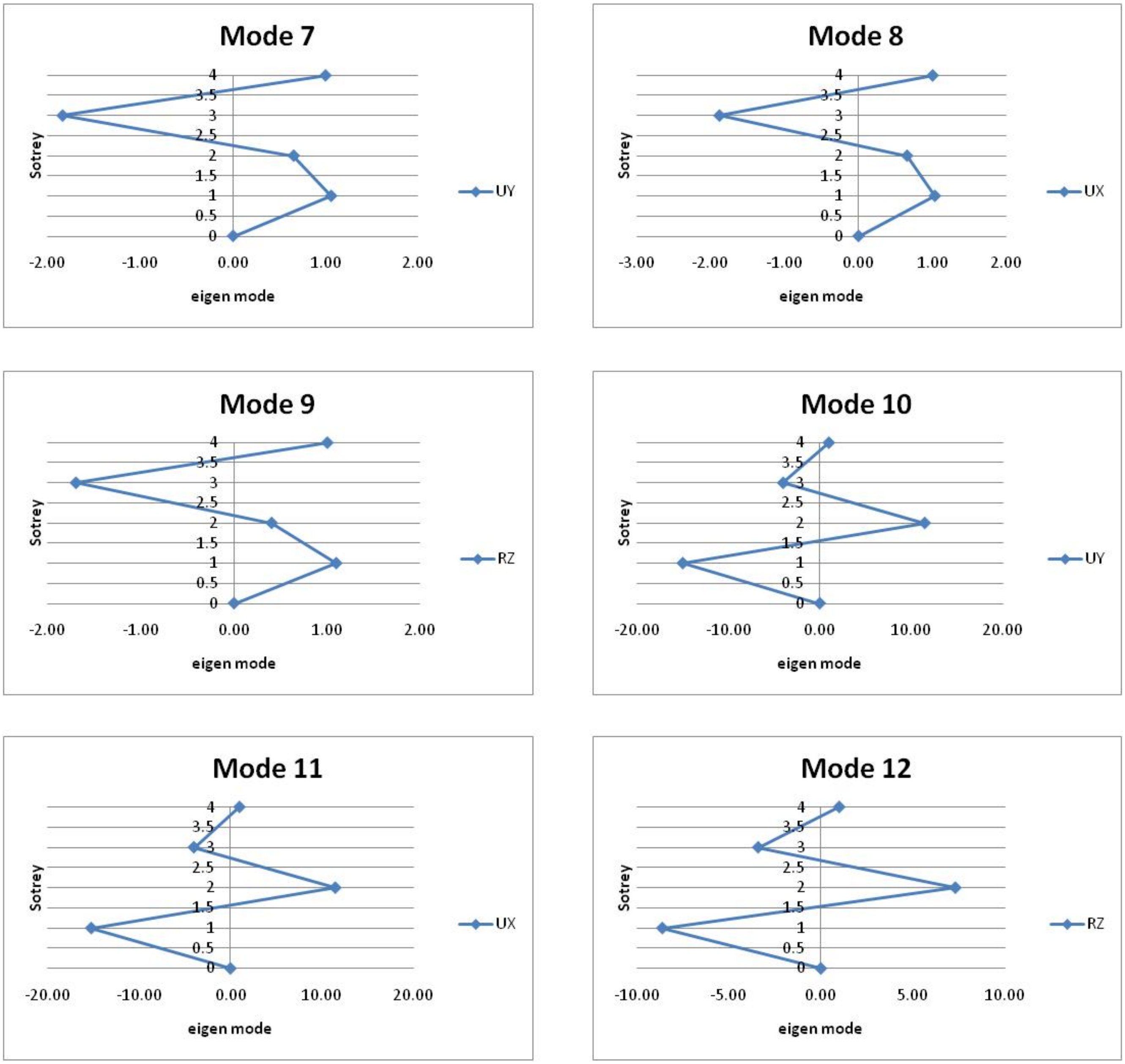


Figure 13. mode shape for each mode

		1		2		3		4		5		6	
		UY		UX		RZ		UY		UX		RZ	
4	893.85	893.85	893.85	893.85	893.85	893.85	893.85	893.85	893.85	893.85	893.85	893.85	893.85
3	1101.45	888.89	717.35	873.56	692.83	907.08	747.00	-367.15	122.38	-375.49	128.01	-239.45	52.05
2	1191.05	543.29	247.81	533.92	239.34	616.54	319.15	-1402.79	1652.18	-1434.67	1728.13	-1380.93	1601.08
1	1186.25	228.93	44.18	224.98	42.67	265.16	59.27	-869.92	637.94	-889.69	667.27	-911.18	699.89
		2554.95	1903.19	2526.31	1868.69	2682.63	2019.28	-1746.01	3306.35	-1806.01	3417.25	-1637.70	3246.87
	MPF	1.34		1.35		1.33		-0.53		-0.53		-0.50	

7		8		9		10		11		12	
UY		UX		RZ		UY		UX		RZ	
893.85	893.85	893.85	893.85	893.85	893.85	893.85	893.85	893.85	893.85	893.85	893.85
-2030.80	3744.28	-2065.22	3872.29	-1863.99	3154.45	-4405.80	17623.20	-4405.80	17623.20	-3744.93	12732.76
781.63	512.94	781.63	512.94	481.00	194.25	13697.08	157516.36	13697.08	157516.36	8694.67	63471.05
1260.39	1339.17	1223.32	1261.55	1300.31	1425.34	-17793.75	266906.25	-18090.31	275877.27	-10201.75	87735.05
905.07	6490.24	833.58	6540.63	811.17	5667.89	-7608.63	442939.66	-7905.19	451910.68	-4358.17	164832.72
0.14		0.13		0.14		-0.02		-0.02		-0.03	

	Φ_1	Φ_2	Φ_3	Φ_4	Φ_5	Φ_6	Φ_7	Φ_8	Φ_9	Φ_{10}	Φ_{11}	Φ_{12}
MPF	1.34	1.35	1.33	-0.53	-0.53	-0.50	0.14	0.13	0.14	-0.02	-0.02	-0.03
4	1.80	1.83	1.76	0.28	0.28	0.25	0.02	0.02	0.02	0.00	0.00	0.00
3	1.17	1.15	1.20	0.03	0.03	0.01	0.07	0.06	0.06	0.00	0.00	0.01
2	0.37	0.37	0.47	0.39	0.41	0.34	0.01	0.01	0.00	0.04	0.04	0.04
1	0.07	0.07	0.09	0.15	0.16	0.15	0.02	0.02	0.02	0.07	0.07	0.05
	3.42	3.41	3.52	0.85	0.87	0.76	0.12	0.10	0.11	0.11	0.12	0.10
	1.85	1.85	1.88	0.92	0.93	0.87	0.34	0.31	0.33	0.33	0.34	0.31

	$m_i\Phi_i$ UY	$m_i\Phi_i$ UY	$m_i\Phi_i$ RZ
4	1652.53	1650.68	1677.74
3	1013.48	1029.80	959.30
2	405.45	372.12	389.77
1	394.20	405.47	370.86
$\sum m_i\Phi_i$	3465.67	3458.08	3397.66

Table 12. SRSS calculation

Zone		zone 1			zone 2			zone 3			zone 4			zone 5			zone 6		
C_v		0.2	0.08	0.05	0.5	0.23	0.15	0.75	0.33	0.23	0.85	0.42	0.3	0.9	0.5	0.35	0.95	0.54	0.42
		hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil
Base Shear (kN)		218.63	87.45	54.66	546.58	251.42	163.97	819.86	360.74	251.42	929.18	459.12	327.95	983.84	546.58	382.60	1038.49	590.30	459.12
Storey	4	104.25	41.70	26.06	260.62	119.89	78.19	390.93	172.01	119.89	443.06	218.92	156.37	469.12	260.62	182.44	495.18	281.47	218.92
	3	63.94	25.57	15.98	159.84	73.53	47.95	239.76	105.49	73.53	271.72	134.26	95.90	287.71	159.84	111.89	303.69	172.62	134.26
	2	25.58	10.23	6.39	63.94	29.41	19.18	95.92	42.20	29.41	108.70	53.71	38.37	115.10	63.94	44.76	121.49	69.06	53.71
	1	24.87	9.95	6.22	62.17	28.60	18.65	93.26	41.03	28.60	105.69	52.22	37.30	111.91	62.17	43.52	118.12	67.14	52.22
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Zone		zone 1			zone 2			zone 3			zone 4			zone 5			zone 6		
C_v		0.2	0.08	0.05	0.5	0.23	0.15	0.75	0.33	0.23	0.85	0.42	0.3	0.9	0.5	0.35	0.95	0.54	0.42
		hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil
Base Shear (kN)		218.63	87.45	54.66	546.58	251.42	163.97	819.86	360.74	251.42	929.18	459.12	327.95	983.84	546.58	382.60	1038.49	590.30	459.12
Storey	4	104.36	41.74	26.09	260.90	120.02	78.27	391.35	172.20	120.02	443.53	219.16	156.54	469.62	260.90	182.63	495.71	281.77	219.16
	3	65.11	26.04	16.28	162.77	74.87	48.83	244.15	107.43	74.87	276.71	136.73	97.66	292.98	162.77	113.94	309.26	175.79	136.73
	2	23.53	9.41	5.88	58.82	27.06	17.65	88.23	38.82	27.06	99.99	49.41	35.29	105.87	58.82	41.17	111.75	63.52	49.41
	1	25.64	10.25	6.41	64.09	29.48	19.23	96.13	42.30	29.48	108.95	53.83	38.45	115.36	64.09	44.86	121.77	69.21	53.83
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Zone		zone 1			zone 2			zone 3			zone 4			zone 5			zone 6		
C_v		0.2	0.08	0.05	0.5	0.23	0.15	0.75	0.33	0.23	0.85	0.42	0.3	0.9	0.5	0.35	0.95	0.54	0.42
		hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil	hard Soil	medium Soil	soft Soil
Base Shear (kN)		218.63	87.45	54.66	546.58	251.42	163.97	819.86	360.74	251.42	929.18	459.12	327.95	983.84	546.58	382.60	1038.49	590.30	459.12
Storey	4	107.96	43.18	26.99	269.89	124.15	80.97	404.84	178.13	124.15	458.82	226.71	161.94	485.81	269.89	188.93	512.80	291.49	226.71
	3	61.73	24.69	15.43	154.32	70.99	46.30	231.48	101.85	70.99	262.34	129.63	92.59	277.78	154.32	108.02	293.21	166.67	129.63
	2	25.08	10.03	6.27	62.70	28.84	18.81	94.05	41.38	28.84	106.59	52.67	37.62	112.86	62.70	43.89	119.13	67.72	52.67
	1	23.86	9.55	5.97	59.66	27.44	17.90	89.49	39.37	27.44	101.42	50.11	35.80	107.39	59.66	41.76	113.35	64.43	50.11
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 13. Base shear force based on SRSS

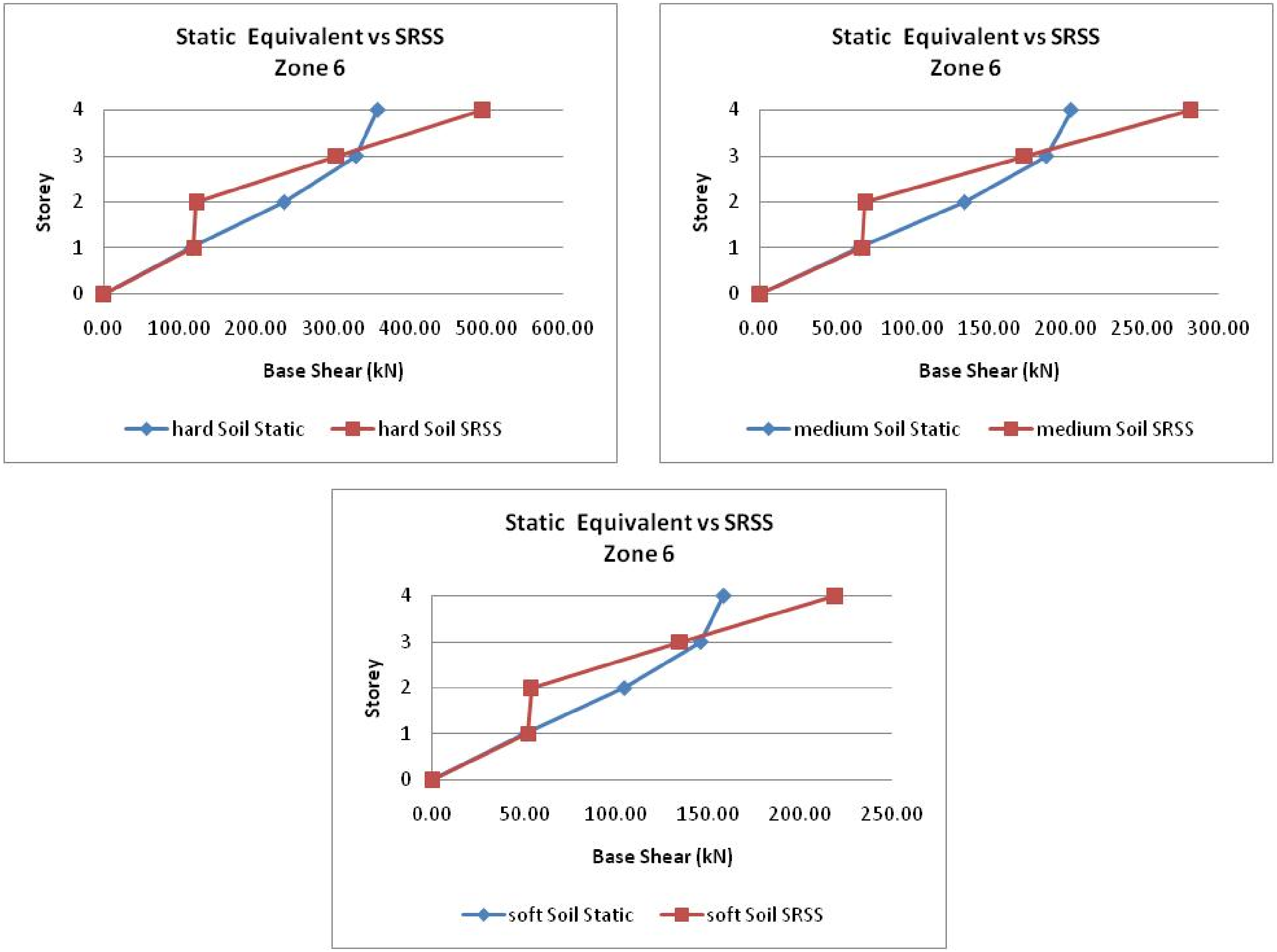


Figure 14. Base shear Force for zone 6

2.1.5 Axial Force, Shear Force and Bending Moment Diagram

According to the result from ETABS software, the forces and moment diagram are given as follows:

a. Dead Load (DL)

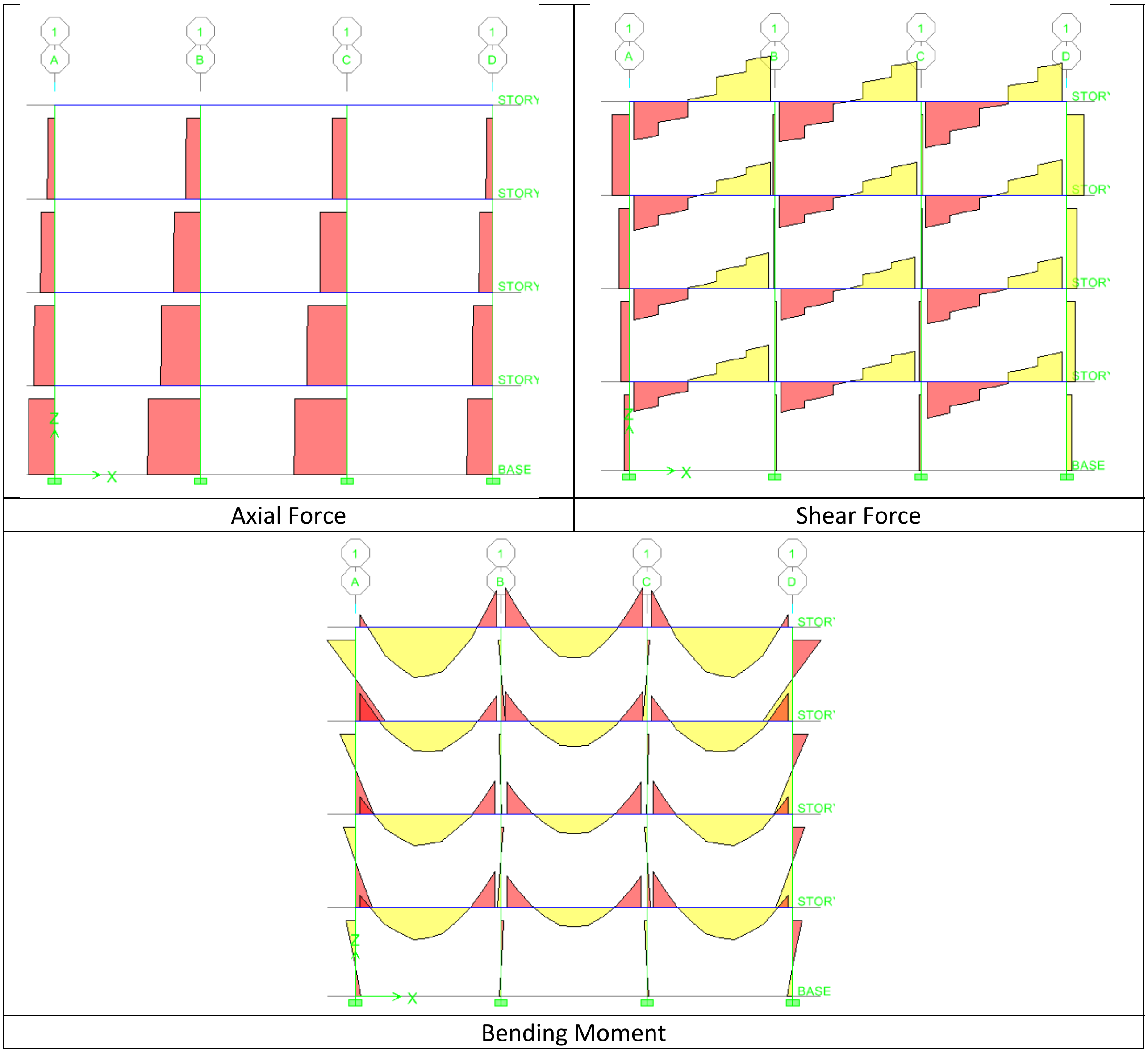


Figure 15. Load diagrams for Dead Load

b. Live Load (LL)

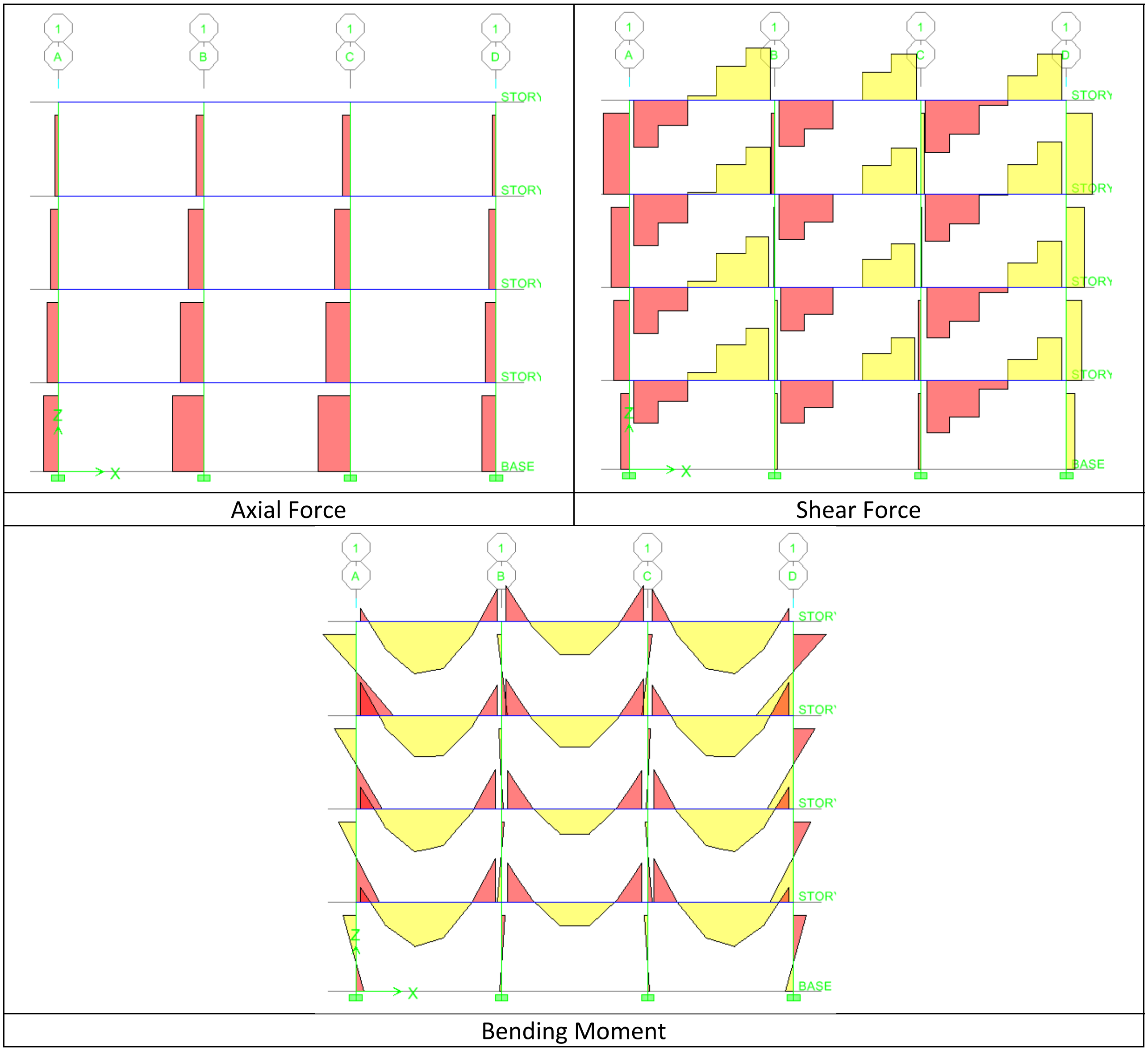


Figure 16. Load diagrams for Live Load

c. Earthquake Force

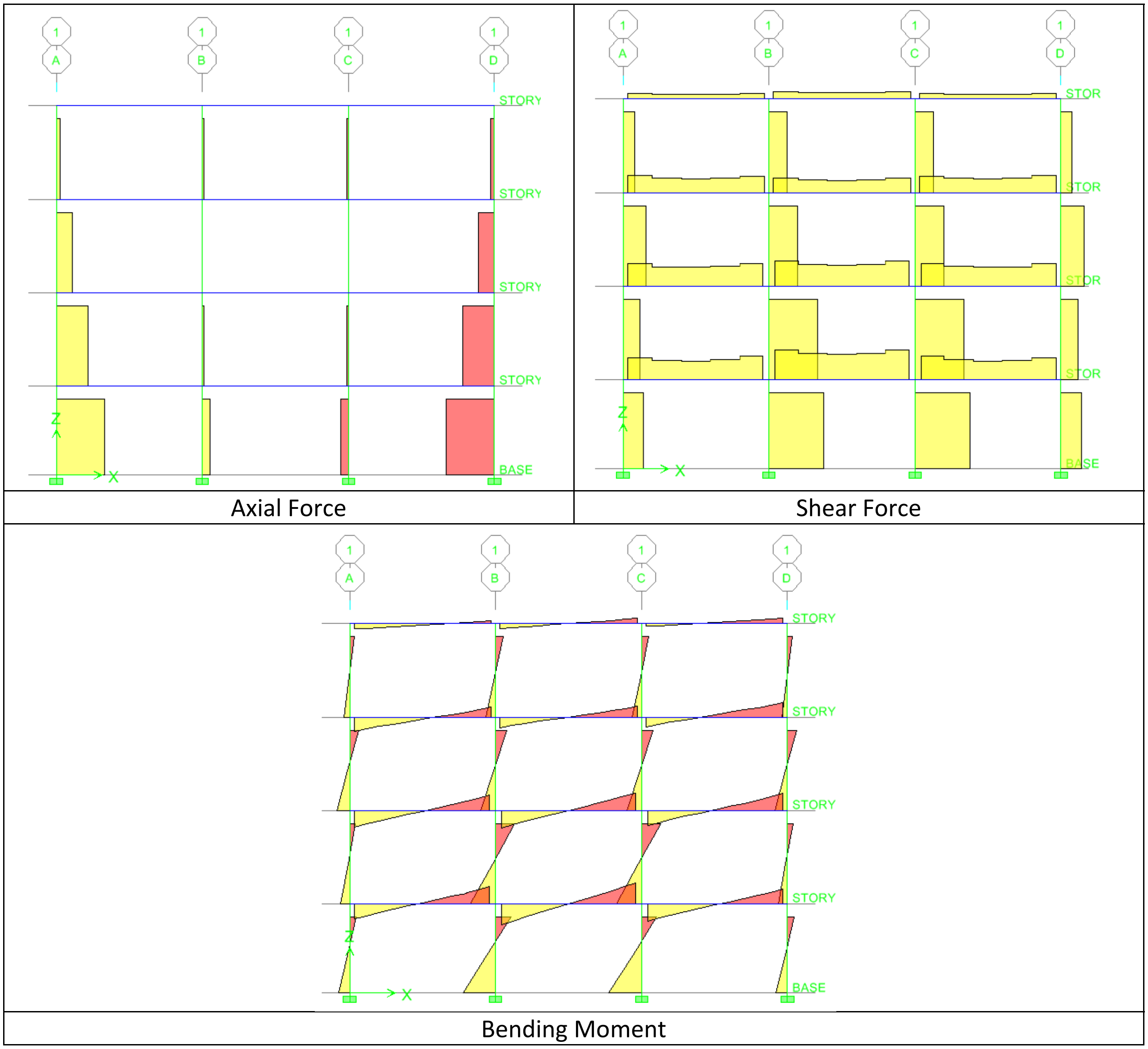


Figure 17. Load diagrams for Earthquake Load

3. Behavior of Building Types During Recent Earthquake

3.1 Recent Earthquakes

In this recent century, Indonesia has been impacted by a lot of Earthquakes every year. Most of big islands and cities in Indonesia have earth quake occurrences which cause small and big damage. There are many historical earth quake including magnitudes and intensities which were recorded by geologists.

	Date	Location	Magnitude	Fatalities	Description
1	1797 02 10	Sumatra	8.4	>300	There was Tsunami that was particularly severe near Padang
2	1833 11 25	Sumatra	8.8-9.2	'numerous'	a large tsunami that flooded the southwestern coast of the island There are no reliable records of the loss of life
3	1861 02 16	Sumatra	8.5	'several thousand'	a devastating tsunami which led to several thousand fatalities. The earthquake was felt as far away as the Malay peninsula and the eastern part of Java
4	1917 01 20	Bali		1,500	
5	1938 02 01	Banda Sea	8.5		it was the ninth largest earthquake in the 20th century It generated Tsunamis of up to 1.5 metres, but no human lives appear to have been lost.
6	1976 06 25	Papua	7.1	5,000	
7	1992 12 12	Flores Region	7.8	2,500	
8	2000 06 04	Southern Sumatra	7.9	103	
9	2002 10 10	Western New Guinea	7.6	8	
10	2002 11 02	Northern Sumatra	7.4	3	
11	2003 05 26	Halmahera	7	1	
12	2004 01 28	Seram	6.7		
13	2004 02 05	Western New Guinea	7	37	
14	2004 02 07	Western New Guinea	7.3		
15	2004 07 25	Southern Sumatra	7.3		
16	2004 11 11	Kepulauan Alor	7.5	34	
17	2004 11 26	Papua	7.1	32	
18	2004 12 26	Sumatra-Andaman Islands	9.3	283,106	inundating coastal communities with waves up to 30 meters (100 feet) high
19	2005 01 01	Off the West Coast of Northern Sumatra	6.7		
20	2005 02 19	Sulawesi	6.5		
21	2005 02 26	Simeulue	6.8		
22	2005 03 02	Banda Sea	7.1		approximately 500 km from East Timor on March 2, 2005. Residents of Darwin, Australia felt the impact quite strongly, despite the epicenter being located approximately 140 km away

23	2005 03 28	Northern Sumatra	8.6	1,313	mostly on the island of Nias
24	2005 04 10	Kepulauan Mentawai Region	6.7		
25	2005 05 14	Nias Region	6.7		
26	2005 05 19	Nias Region	6.9		
27	2005 07 05	Nias Region	6.7		
28	2005 11 19	Simeulue	6.5		
29	2006 01 27	Banda Sea	7.6		The location was 200 km south of Ambon Island
30	2006 03 14	Seram	6.7	4	
31	2006 05 16	Nias Region	6.8		
32	2006 05 26	Java	6.3	5,749	36,299 people were injured, 135,000 houses damaged, and an estimated 1.5 million left homeless
33	2006 07 17	Java	7.7	730	its hypocentre at a depth of 48.6 km below the seabed
34	2006 07 23	Sulawesi	6.1		its hypocenter at a depth of 86.2 km
35	2006 12 18	North Sumatra	5.8	7	
36	2007 01 21	Molucca Sea	7.5	4	
37	2007 03 06	Sumatra	6.4, 6.3	68	hit near the northern end of Lake Singkarak in Sumatra, Indonesia, Over 60 fatalities and 460 serious injuries have been reported
38	2007 08 09	Java	7.5[2]		The quake was located 70 miles (110 km) east-northeast of Jakarta, at a depth of 175 miles (282 km).[3]
39	2007 09 12	Sumatra	8.5, 7.9, 7.1	23	It caused buildings to sway in Jakarta, and some buildings were reported to have collapsed in the city of Bengkulu
40	2008 02 20	Simeulue	7.4	3	
41	2008 02 25	Kepulauan Mentawai Region	7.0, 6.4, 6.6		
42	2008 11 16	Sulawesi	7.5, 5.6	4	Four people were killed in the quake and 59 injured
43	2009 01 04	West Papua	7.6	4	ten buildings had been totally destroyed, including several hotels and the house of a government official
44	2009 08 16	Siberut, Mentawai Islands	6.7		The epicentre of the quake was located 43 kilometres (29 miles) southeast of Siberut Island off western Sumatra
45	2009 09 02	Java	7	15	killing at least 79 people, injuring over 1,250, and displacing over 210,000
46	2009 09 30	Sumatra	7.6	1,117	around 135,000 houses were severely damaged, 65,000 houses were moderately damaged and 79,000 houses were slightly damaged
47	2010 05 19	Sumatra	7.2	Unreported	It was one of a sequence of large earthquakes along the Sunda megathrust in 2000s

Table 14. Maximum earthquake in Indonesia

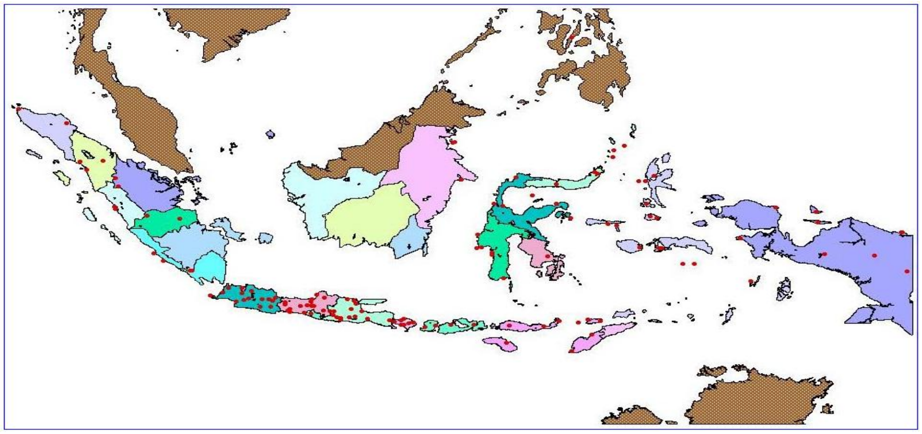


Figure 18. Maximum Earthquake distribution map in Indonesia

3.2 Damage cases on 26 December 2004

There are some damage cases affected by earthquake in Indonesia. It is dependent on building stocks and vulnerability classes. In this report, I will describe some earthquake cases which occur several years ago.

The 2004 Indian Ocean earthquake was an undersea mega-thrust earthquake that occurred at 00:58:53 UTC on December 26, 2004, with an epicenter off the west coast of Sumatra, Indonesia. The quake itself is known by the scientific community as the Sumatra-Andaman earthquake.

The earthquake was caused by subduction and triggered a series of devastating tsunamis along the coasts of most landmasses bordering the Indian Ocean, killing over 230,000 people in fourteen countries, and inundating coastal communities with waves up to 30 meters high. It was one of the deadliest natural disasters in recorded history. Indonesia was the hardest hit, followed by Sri Lanka, India, and Thailand.
USGS recorded this event where we could find it in the USGS website as following below:

Magnitude	9.1
Date-Time	**Sunday, December 26, 2004 at 00:58:53 (UTC)**
	Sunday, December 26, 2004 at 7:58:53 AM
	Time of Earthquake in other Time Zones
Location	3.316°N, 95.854°E
Depth	30 km (18.6 miles) set by location program
Region	OFF THE WEST COAST OF NORTHERN SUMATRA
Distances	250 km (155 miles) SSE of **Banda Aceh, Sumatra, Indonesia**
	300 km (185 miles) W of **Medan, Sumatra, Indonesia**
	1260 km (780 miles) SSW of **BANGKOK, Thailand**
	1590 km (990 miles) NW of **JAKARTA, Java, Indonesia**
Location Uncertainty	horizontal +/- 5.6 km (3.5 miles); depth fixed by location program
Parameters	Nst=276, Nph=276, Dmin=654.9 km, Rmss=1.04 sec, Gp= 29°,

Table 15. Earthquake on 26 December 2004

Numerous aftershocks were reported off the Andaman Islands, the Nicobar Islands and the region of the original epicenter in the hours and days that followed. The largest aftershock, which originated off the coast of the Sumatran island of Nias, registered a magnitude of 8.7.

The earthquake that generated the great Indian Ocean tsunami of 2004 is estimated to have released the energy of 23,000 Hiroshima-type atomic bombs, according to the U.S. Geological Survey (USGS).

The earthquake was the result of the sliding of the portion of the Earth's crust known as the India plate under the section called the Burma plate. The process has been going on for millennia, one plate pushing against the other until something has to give. The result on December 26 was a rupture the USGS estimates was more than 600 miles (1,000 kilometers) long, displacing the seafloor above the rupture by perhaps 10 yards (about 10 meters) horizontally and several yards vertically. That doesn't sound like much, but the trillions of tons of rock that were moved along hundreds of miles caused the planet to shudder with the largest magnitude earthquake in 40 years.

There are two types of damage cases over buildings and infrastructures due to earthquake and tsunami on 26 December 2004, which is:

a. Structural (Engineered) buildings.
b. Non structural (non-engineered) buildings.
c. Road Access
d. Port
e. Power supply
f. Telecommunication
g. Water Supply
h. Industrial

3.2.1 Structural (Engineered) buildings.

The causes of typical damage of reinforced concrete engineered buildings during the Sumatra earthquake in Banda Aceh were mostly due to vertical irregularities in certain RC buildings creating abrupt changes in stiffness and strength that may concentrate forces in an undesirable way. Also poor quality of concrete and detailing contributed to the collapse of those engineered buildings.

Figure 19. The most obvious damage occurred to Kuala Tripa hotel, a 5 story RC building. It suffered a "first soft story" collapse. The second and third floor was severely damaged because of the impact but the building as a whole did not collapse. The collapse was caused by poor detailing.

Figure 20. Another visible collapse was a three story supermarket, the Pante Pirak. The collapse was due to poor quality of construction.

Figure 21. Another building that partially collapsed was the office of the department of finance. One of the wings suffered a pancake type of collapse. From the damaged columns it can be seen that the detailing was poor.

3.2.2 Non structural (non-engineered) buildings

The majority of the buildings that collapsed in Banda Aceh city, and villages in Lhok Nga, Krueng Raya, and Meulaboh city, are non engineered buildings consisting of two types. The first type is a one or two stories buildings made of burnt brick confined masonry using sand and Portland cement mortar. The roof mostly consists of galvanized iron sheets. All those buildings used RC "practical" columns and beams as confinement. The second type is timber construction consisting of a timber frame and also timber planks walls and usually use galvanized iron sheets as roof.

Almost none of the people's housing, one to two story masonry buildings collapsed by the shaking, even though some had cracks in the walls. **The destruction was caused by the tsunami forces.**

Most of the buildings in the coastal areas consist of non-engineered timber structures and confined masonry structures. The ratio of those two types of structures is estimated to be 30 % to 70 %.

Figure 22. burnt brick confined masonry

Figure 23. timber construction

3.2.3 Road Access

Some roads in Banda Aceh were scoured by tsunami but the majority was still in tact. Most of the main roads in zone 1 were covered by huge amount of tsunami debris. Several parts of the road from Banda Aceh to Meulaboh were washed away by tsunami.

Figure 24. Some of the Damage of Roads and Bridges from Banda Aceh to Meulaboh

Figure 25. Ulhue Lhe beach

Figure 26. Lhok nga Beach

Figure 27. Ulhue Lhe beach

3.2.4 Bridges

In Banda Aceh, several bridges were destroyed, the one at Jl Iskandar Muda and the one leading to Lhok Nga. The Lhok Nga Bridge has a main span of 20 m and secondary span of 10 m made of galvanized steel frames. Both were dumped into the river. Along the road from Banda Aceh to Meulaboh (distance approx 270 km), several bridges were washed away by tsunami.

Figure 28. The Lhok Nga Bridge

3.2.5 Ports

Generally, jetties and wharf of ports in Banda Aceh and in Kreung Raya as well as the jetty of the cement factory Lhok Nga were slightly damaged but could still function. Part of the platform of the jetty in Meulaboh was washed away by tsunami, but the supports were still in tact. The main building of the Ulhue Lhe harbor in Banda Aceh was damaged and only the frame remained.

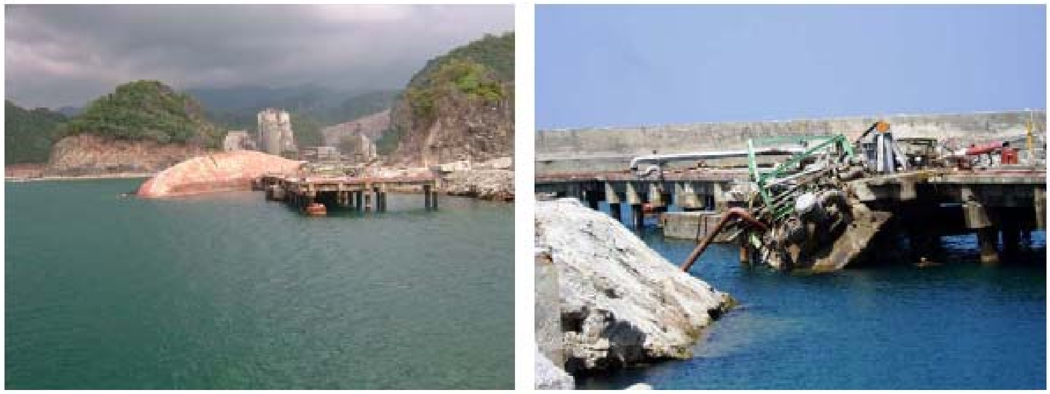


Figure 29. Lhok Nga Cement Factory Jetty

3.2.6 Power supply

Main Power generating plant in Banda Aceh was not affected by the shaking or tsunami. However, many distribution poles and wires in devastated areas collapsed.

Figure 30. Main Power generating plant in Banda Aceh

3.2.7 Telecommunication

Some mobile phone antennas towers were dismantled by the tsunami and dragged up to 2 km from its foundations. Many telephone junction boxes were practically destroyed.

Figure 31. mobile phone antennas towers

3.2.8 Water supply

Water Treatment plant in Banda Aceh was not affected by neither the shaking nor the tsunami, however, the piping systems were destroyed by scouring of the tsunami.

Figure 32. Water Treatment plant in Banda Aceh

3.2.9 Industrial

Figure 33. Cement Factory, Lhok Nga

Figure 34. Pertamina Oil Depot, Krueng Raya

3.3 Building Code Before and After the Earthquake

The latest standard code used for earthquake is SNI 1726-2002 where it was published base on some references, which is:

1. SNI – 03-1726-1989, "Earthquake Resistance Design Method for Houses and Buildings". It was published by the Office of the State Minister of Civil Works, The Directorate of the Technology Education and the Directorate General of Cipta Karya in 1997.
2. National Earthquake Hazards Reduction Program (NEHERP). This was proposed for Seismic Regulation for New Buildings and Other Structures in 1997, and FEMA 302 in 1998.
3. Uniform Building Code (UBC) 1997, Volume 2, for Structural Engineering Design Provisions, International Conference of Building Officials, April 1997.

In 2010, Indonesian Government has introduced a revised code which was developed by a team of Indonesian scientists in recognition of the serious earthquake risk Indonesia is prone to. It estimates the chances of ground shaking caused by earthquakes across Indonesia and revises national building standards to ensure that buildings and infrastructure are resilient to earthquakes in order to reduce the number of fatalities.

The new hazard map incorporates the lessons learnt from recent deadly earthquakes in Indonesia such as those in Sumatra and Java. It has been developed using better information and more advanced methodologies than previous earthquake hazard maps. It aims to support building standards, to be used to educate people about the earthquake risks that they face, and to help them to better protect themselves and their families from future earthquakes.
This code is being developed by expert teams. It will be accomplished soon as a new hazard map which considers all earthquake occurrences.

4. Elaborations of the Typical National Building Types and its Vulnerability Classes

4.1 Typical Building Types

Indonesia has a lot of building types which are still exist in every location even it is allocated in the critical earthquake zone. These building types are associated in some categories, which are:

1) Masonry
    a. Adobes
    b. Temples
    c. Unreinforced with RC Floors
    d. Reinforced or Confined
2) Reinforced Concrete
    a. Frame with Moderate Level of Earthquake Resistant Design
    b. Walls with Moderate Level of Earthquake Resistant Design
3) Steel
    a. Steel Structures
    b. LGS structures
4) Wood

a. Timber Structures
b. Bamboo Structures

4.2 Macroseismic Intensity Scale

The building types above are comparable with macroseismic intensity scale which is generated by EMS (European Macroseismic Scale)'98 and the world housing encyclopedia from EERI (Earthquake Engineering Research Institute).

This is a table for vulnerability class from EMS:

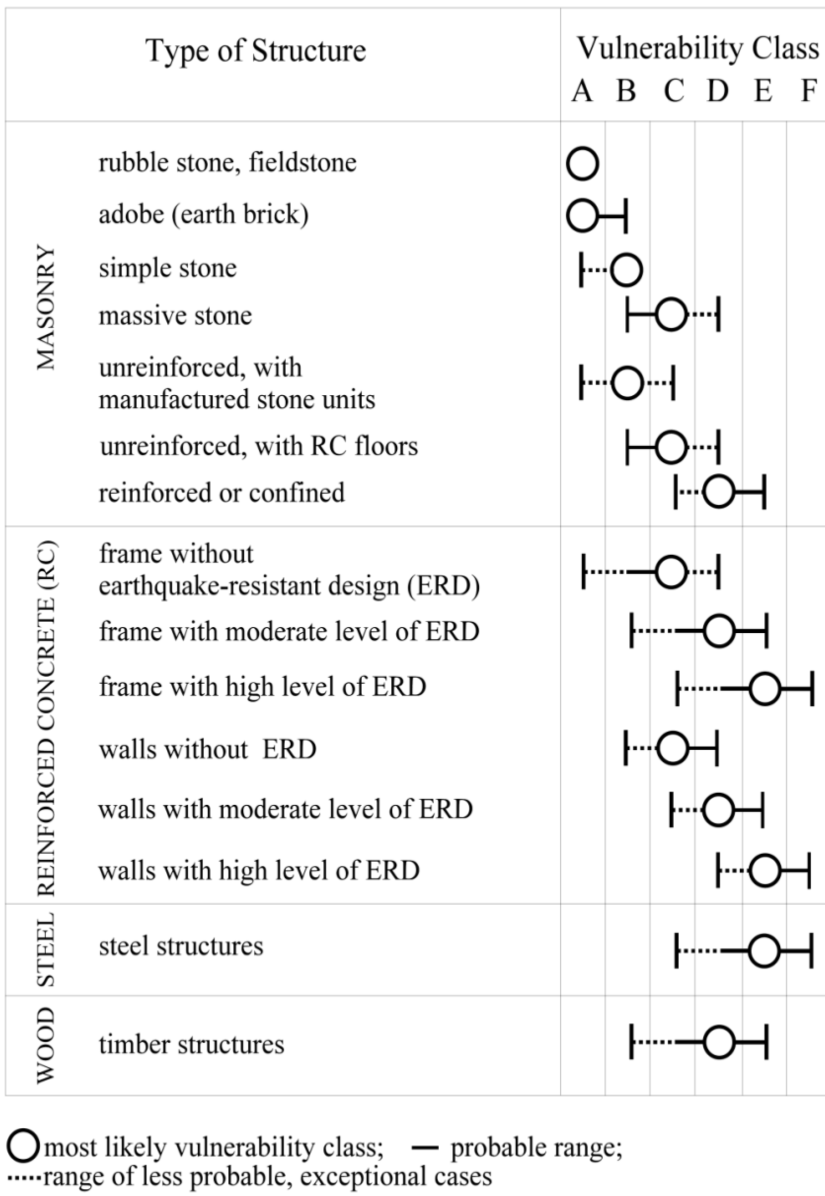


Figure 35. EMS (European Macroseismic Scale)'98

4.3 Vulnerability Class

4.3.1 Masonry

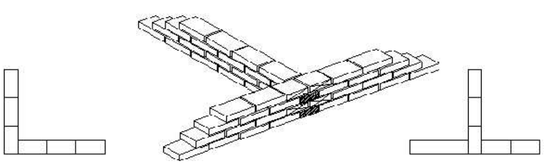
Most of buildings/housings in Indonesia are constructed by masonry. There are some pictures which describe typical masonry building in Indonesia.

Adobe

	Type of Structure	A	B	C	D	E	F
M	unreinforced, with manufactured stone units	├	O	┤			

Stone building in Bali

	Type of Structure	A	B	C	D	E	F
SO	massive stone	├	O	┤			



Unreinforced building

Type of Structure	A	B	C	D	E	F
unreinforced, with RC floors		├	O	┤		

Reinforced building

Type of Structure	A	B	C	D	E	F
reinforced or confined			├	O	┤	

Figure 36. Vulnerability Class for masonry

If it is compared with world housing encyclopedia from EERI, the Seismic Vulnerability of Unreinforced Masonry Building is:

Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		TRUE	FALSE	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☐	☑	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☐	☐	☑
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☐	☑	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☐	☑	☐
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☐	☐	☑
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☐	☑
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☐	☑	☐
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☑	☐
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☐	☑	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Other		☐	☑	☐

Table 16. Structural and Architectural Features

Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	1. Clay-brick with very low compressive strength 2. The quality of clay-brick varies depends on the local clay-soil material 3. The clay-brick material is very brittle and doesn't have any ductility.		Shear crack, flexure crack or combination of both in clay brick walls.
Frame (columns, beams)			
Roof and floors	Timber truss system for roofing without any special connection with the clay brick walls.		The roof sliding off from the clay brick walls.

Table 17. Seismic Features

Overall Seismic Vulnerability Rating

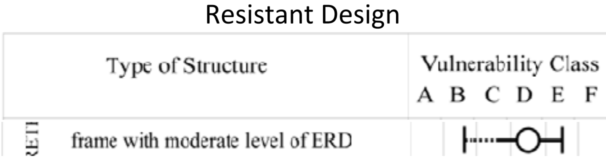
Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☑	☐	☑	☐	☐	☐

Table 18. Overall Seismic Vulnerability Rating

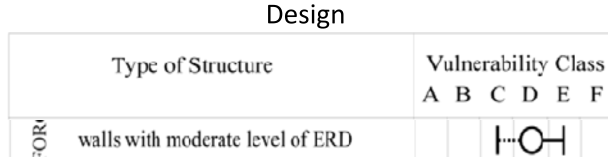
4.3.2 Reinforced Concrete

Frame with Moderate Level of Earthquake Resistant Design

Wall with Moderate Level of Earthquake Resistant Design



Type of Structure	Vulnerability Class A B C D E F
frame with moderate level of ERD	



Type of Structure	Vulnerability Class A B C D E F
walls with moderate level of ERD	

Figure 37. Vulnerability Class for Reinforced Concrete

4.3.3 Steel Structure

Steel Structure

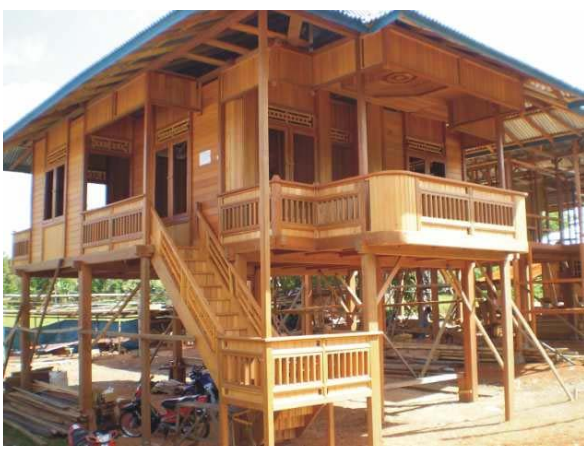
LGS (Light Gauge Steel) structure

	Type of Structure	A	B	C	D	E	F
STEEL	steel structures			├┈┈	┈┈	─○─	┤

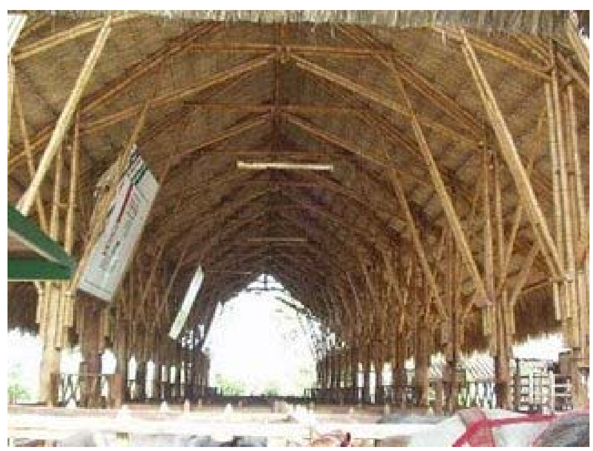
	Type of Structure	A	B	C	D	E	F
ꓤETI	frame with moderate level of ERD		├┈┈	┈┈	─○─	┤	

Figure 38. Vulnerability Class for Steel

4.3.4 Timber Building



Timber structure



Bamboo Structure

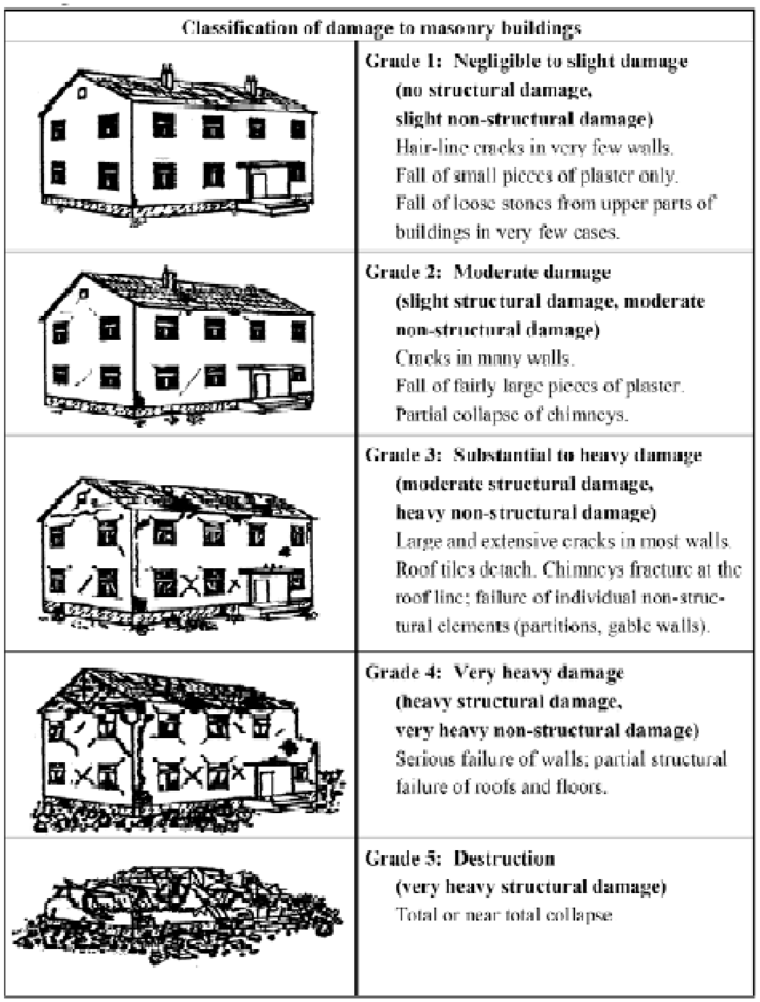
	Type of Structure	A	B	C	D	E	F
WOOD	timber structures		├┈┈	┈┈	─○─	┤	

	Type of Structure	A	B	C	D	E	F
WOOD	timber structures		├┈┈	┈┈	─○─	┤	

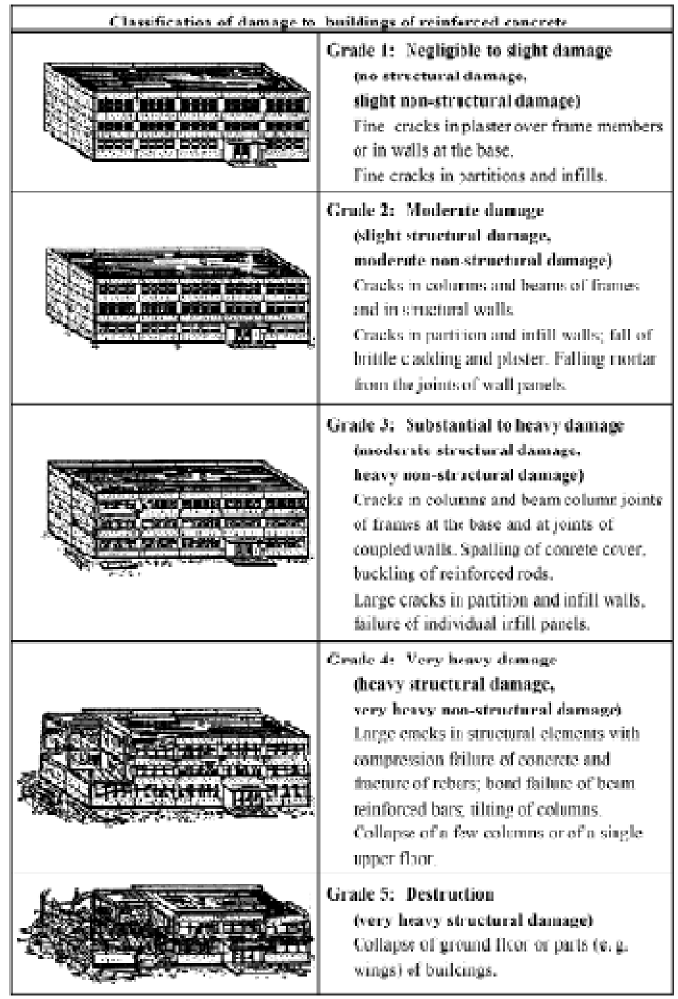
Figure 39. Vulnerability Class for Timber

4.4 Damage Grades

According to EMS’98, there are some damage grades which are used to investigate the certain condition of buildings after earthquake occurrences.



Classification of damage to masonry buildings	
	Grade 1: Negligible to slight damage **(no structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	Grade 2: Moderate damage **(slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	Grade 3: Substantial to heavy damage **(moderate structural damage, heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	Grade 4: Very heavy damage **(heavy structural damage, very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.
	Grade 5: Destruction **(very heavy structural damage)** Total or near total collapse.



Classification of damage to buildings of reinforced concrete	
	Grade 1: Negligible to slight damage **(no structural damage, slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	Grade 2: Moderate damage **(slight structural damage, moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	Grade 3: Substantial to heavy damage **(moderate structural damage, heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	Grade 4: Very heavy damage **(heavy structural damage, very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebers; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	Grade 5: Destruction **(very heavy structural damage)** Collapse of ground floor or parts (e.g. wings) of builcings.

Figure 40. Damage Grades according to EMS’98

4.4.1 Masonry

After earthquake occurrence, some buildings were devastated and destroyed by earthquake over some masonry buildings and historical buildings. These are some documentation which explains some damage cases in the masonry building types.

Adobe

Damage Grade				
1	2	3	4	5
				√

Unreinforced building

Damage Grade				
1	2	3	4	5
		√		

Stone building (temple)

Damage Grade				
1	2	3	4	5
			√	

Reinforced building

Damage Grade				
1	2	3	4	5
	√			

Figure 41. Damage grades for masonry

4.4.2 Reinforced Concrete

Frame with Moderate Level of Earthquake Resistant Design

Damage Grade				
1	2	3	4	5
				√

Figure 41. Damage grades for Reinforced Concrete

4.4.3 Steel

Steel Structure

Damage Grade				
1	2	3	4	5
	√			

LGS Structure

Damage Grade				
1	2	3	4	5
				√

Figure 42. Damage grades for Steel

4.4.4 Timber

Timber house

Damage Grade				
1	2	3	4	5
				√

Bamboo house

Damage Grade				
1	2	3	4	5
		√		

Figure 43. Damage grades for Timber

4.5 After Earthquake

4.5.1 Masonry

Some International Organizations and countries donated some money to help reconstruction and retrofit program in Indonesia after Earthquake disaster. They just consider constructing a reinforced building for houses as it is usable for long time and the materials have to be provided by local area to make it much easier to build. The type of building has to be easy improved if the house's owner needs to expand the size of house. These are some documentation of buildings which were reconstructed after earthquake and tsunami disaster.

Figure 44. Reinforced Concrete for houses from Germany Government

4.5.2 Reinforced Concrete

Figure 45. Frame with Moderate Level of Earthquake Resistant Design

4.5.3 Steel

Figure 46. LGS structure for houses

4.5.4 Timber

Figure 47. Building Stock is still exist due to bracing

Figure 48. Timber houses

5. Conclusions

According to descriptions above, we could conclude some recommendations, which are:

1) New Earthquake and Tsunami Code are being developed by expert team who is responsible to conclude it accordance with occurrence of these catastrophes.
2) Shear forces distribution from SRSS has inclination to be soft storey at 2nd floor. It is different from Shear forces distribution from equivalent static inclination.
3) Mode shapes for each direction are relatively similar as the shape of building is rectangular and position of elements is symmetric.
4) Base on figure 11, shear force distribution for hard is relatively higher compare to medium and soft soil at zone 3, 4, 5 and 6.
5) Base on figure 12, it can be clearly seen that shear force distribution for hard, medium and soft soil at zone 3, 4, 5 and 6 have the same inclination, where as zone 1 and 2 is relatively different inclination compare to other zones.
6) Vulnerability class is important to be developed in each country where it has a lot of earthquake occurrences.
7) Bracing elements are really important to be constructed in simple (traditional) house which is used to resist earthquake load.
8) Routine maintenance for steel building should be done to investigate the construction element from crack or collapse due to earthquake occurrences. This is important as the steel elements are covered by concrete which is not visually seen.
9) For building which is near to Tsunami region, we should design it by considering minimum two storey building where the people could escape from low tsunami. At least, the high of the first storey is higher than maximum flood level.
10) LGS (Light Gauge Steel) elements are used as main frame of building as long as the type of building is simple structure and it has rigid foundation.
11) Quality and quantity of shear reinforcement should be improved for residential building and high rise building.
12) Additional beam and column are needed to install near to the opening section to enlarge the building capacity.
13) For ancient building (temple) should be conducted a retrofit treatment to increase the building capacity for long period.

6. References

1. Indonesia National Standard for earthquake 1726-2002.
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4. Uniform Building Code (UBC) 1997
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