Fragility Curves for Reinforced Concrete Structures of Downtown Area in Yangon City

Nwe Ni Myint (Ph.D Student)[1] , **Kyaw Kyaw** (Associate Professor)[2]
[1 & 2]Civil Engineering Department, Yangon Technological University,
Yangon, Republic of the Union of Myanmar.
Email – nwenimyint28@gmail.com

Abstract: For seismic risk assessment of buildings, fragility curves play an important role and it is a step to determine appropriate risk reduction strategy. Fragility curve is an essential tool to assess the failure probability of structures. This paper proposes an analytical method for the development of fragility curves for existing reinforced concrete buildings in downtown area, especially for Latha Township, Yangon City. Most of the buildings in the selected area are mid-rise reinforced concrete buildings. Among them, the common and typical reinforced concrete buildings of 3 stories, 6 stories and 8 stories are considered to assess their probability of failure. In this study, a fully nonlinear soil model is used to evaluate nonlinear amplification of the surface strata, and pushover analysis is performed to determine the response of such structures due to earthquake excitation. The probability of failure is evaluated from the seismic response, and developed the fragility curves for the existing reinforced concrete buildings.

Key Words: fragility curve; analytical method; pushover analysis; seismic response.

1. INTRODUCTION:

Among the various disasters in the world, earthquakes have caused lots of losses and damage to structures and lifelines. Thus, evaluating the seismic responses of such structures is essential to disaster risk reduction programs. In disaster planning, buildings are the important structures which should be prepared with strongly resistance to earthquake. Myanmar is earthquake prone area and one of the major active faults is Sagaing fault which is known to have produced significant earthquakes in the past. The history of the region indicates that there was a strong possibility of major earthquakes occurrence and suffered immense losses of life and property.

Yangon, the biggest city in Myanmar, is located near Sagaing fault and many earthquakes with various intensities occurred frequently. Over the past three decades, urbanization in Yangon has been rapidly increasing and most of the buildings in congested downtown of Yangon is reinforced concrete buildings. These buildings are regular in plan and designed for gravity loads only. They are built with minimal consideration of building codes, sound construction and urban planning practices. These buildings have limited lateral resistance and are susceptible to story mechanisms during earthquake loading. Damage estimation is a vital part of the seismic performance evaluation of buildings and other structures with respect to multiple performance objectives.

In the congested downtown of Yangon, there are many different types of buildings depending on building age, building type, occupancy, number of stories, etc. but mid-rise reinforced concrete buildings are mostly occurred. Although the congested downtown is small, it has high population density, many households and the area is well developed in social and business. So, the area can be seriously effective in losses of life and property due to the failure of buildings if an earthquake disaster happens. Thus, it should be focused to estimate the seismic vulnerability of the buildings in congested downtown of Yangon. The important tool employed to assess the seismic performance of reinforced concrete buildings in the earthquake prone area is fragility curve and so, fragility curves for reinforced concrete structures of downtown area in Yangon City are presented in this study.

2. METHODOLOGY:

Fragility curves are the essential tools for seismic loss estimation in built environments. They represent the probability of exceeding a damage limit state for a given structure type subjected to a seismic excitation. Fragility curves can be developed by the four methods;

1. Empirical methods

This method constructed based on statistics of the observed damage from past earthquakes.

2. Expert opinion-based methods

This method depend on the judgment and the information of the experts.

3. Analytical methods

This method constructed starting from the statistical elaboration of damage distributions that are simulated from analyses of structural models under increasing earthquake intensity.

4. Hybrid methods

This method based on the combination of different methods for damage prediction.

For Yangon, there is no recorded damage data due to earthquake and so analytical method is used for this study. To develop the fragility curves, firstly it is required to estimate seismic hazard of the selected area and the seismic ground motion. The selected building data are essential for structural modelling and pushover analysis is performed and then the probability of failure is evaluated to generate the fragility curves. The flow chart for analytical method is as shown in figure1.

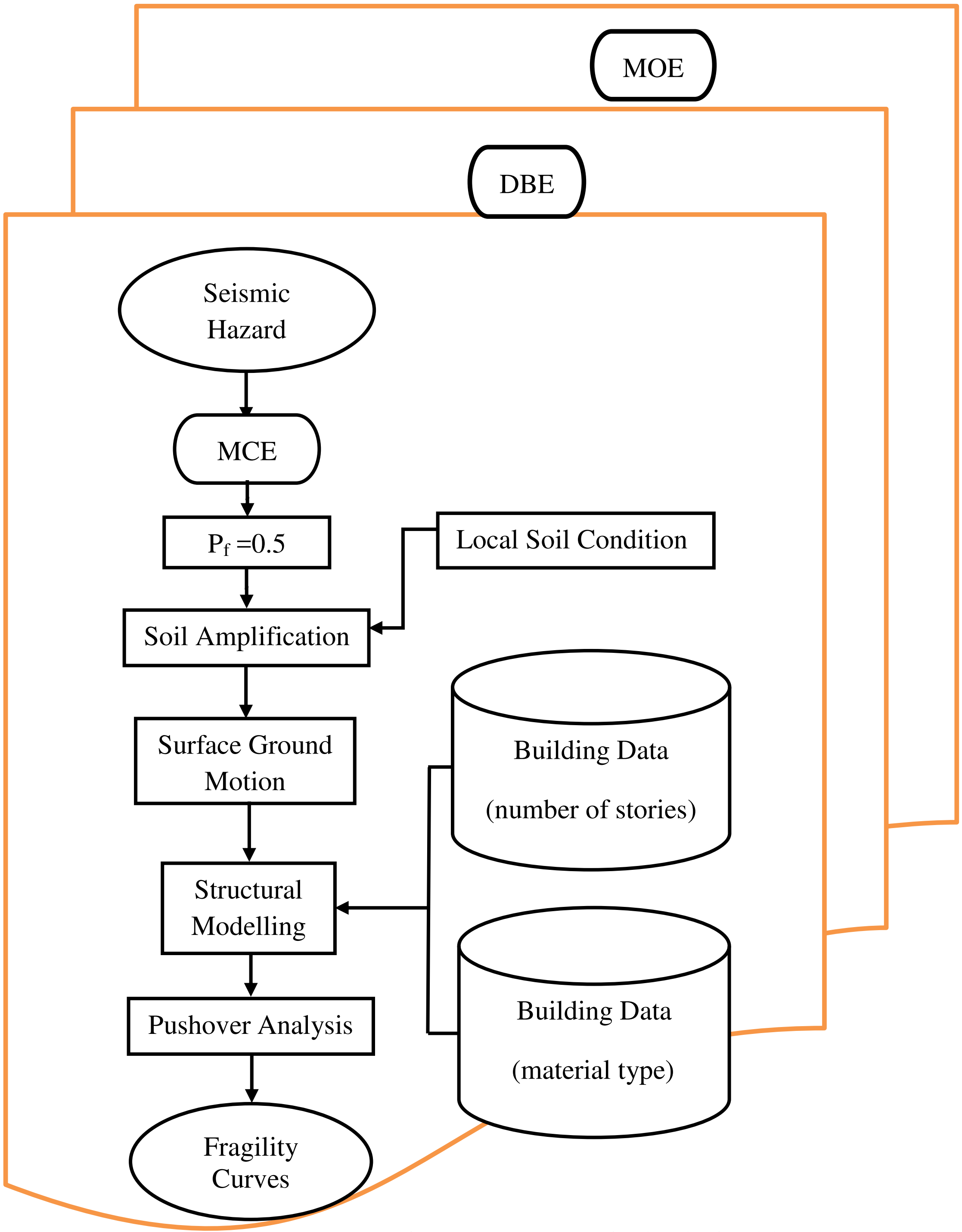


Figure 1: Flow chart for development of seismic fragility curve

3. PROPOSED AREA:

3.1. Geographical location, area and population

Latha, the selected area, is a township in congested downtown of Yangon. It is in the southern part of Yangon city and near the bank of Yangon River. It has an area of 604770 sq. meters and the area is divided into ten wards. According to 2012 provincial data, the total number of population is 27805.

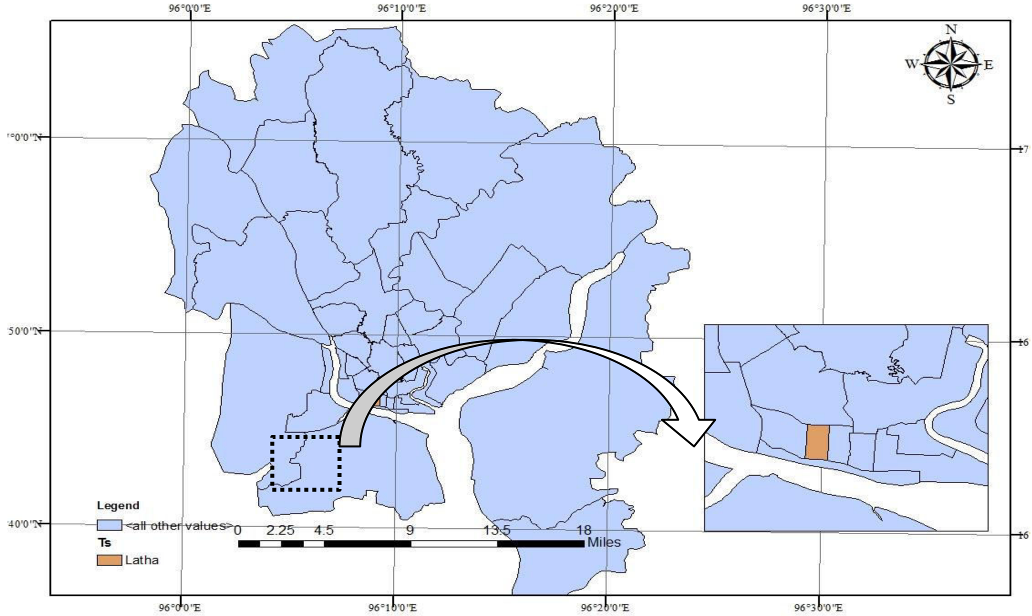


Figure 2: Location of proposed area

3.2. Nonlinear soil amplifications of surface strata

Both the non-linearity of the surface strata and the soil amplification between surface strata and the underlying bedrock affect the seismic response during the earthquake. To estimate the surface ground motion, the soil amplification factor is the important one to evaluate. So, it is needed to know the local soil data and soil profile of the selected area.The proposed area is divided into 4 grids presented in figure 3 and the bore hole data for each grid is collected from the soil test reports submitted to Yangon City Development Committee (YCDC) for building construction approvals. The soil profile for the selected area, Latha, Yangon is shown in figure 4. In the proposed area, most of the soil layers are composed with silty clay and silty sand.

Figure 3: Grid ID map for proposed area

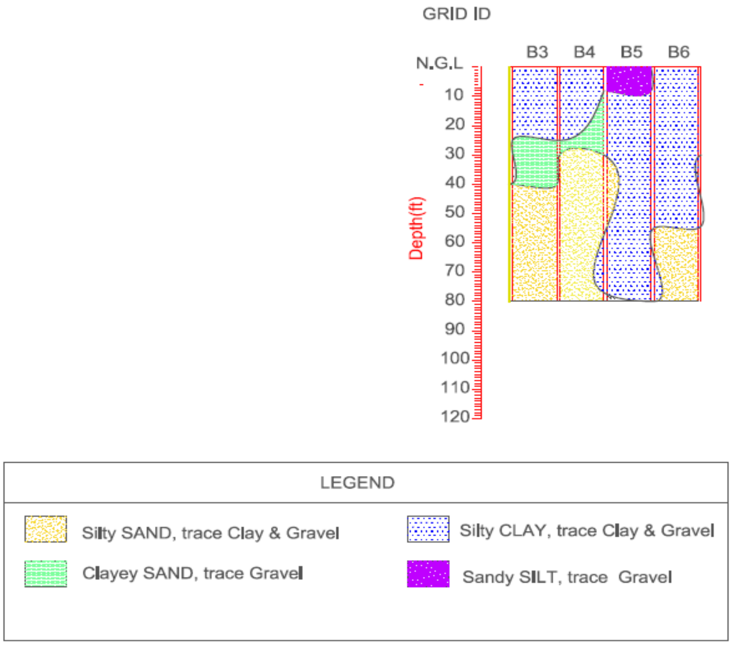


Figure 4: Soil Profile of Latha, Yangon

Table 1: Shear velocity from SPT or N-value
(Reference: JWWA Water Pipeline Seismic Design Guideline)

Geology	Soil	Shear Velocity (m/sec)		
		MCE	DBE	MOE
Delluvial Layer	Clay	$129N^{0.183}$	$156N^{0.183}$	$172N^{0.183}$
	Sand	$123N^{0.125}$	$200N^{0.125}$	$205N^{0.125}$
Alluvial Layer	Clay	$122N^{0.0777}$	$142N^{0.0777}$	$143N^{0.0777}$
	Sand	$61.8N^{0.211}$	$90N^{0.211}$	$103N^{0.211}$

Where N = SPT value and V_s = shear velocity (m/sec)

The acceleration response spectrum on the ground surface is simplified by using the method of INOUE et al.

$$G_S(T) = \frac{S_{A_S}(T)}{S_{A_B}(T)} \qquad (1)$$

$G_s\ (T)$ = soil amplification ratio

S_{A_S} = spectral acceleration at ground surface

S_{A_B} = Spectral Acceleration at base rock

$$G_s\ (T) = G_{s2} \times \frac{T}{0.8\ T_2} \qquad (T \le 0.8\ T_2) \qquad (2)$$

$$G_s\ (T) = \frac{G_{s1} - G_{s2}}{0.8\,(T_1 - T_2)}\ T + G_{s2} - 0.8\ \frac{G_{s1} - G_{s2}}{0.8\ (T_1 - T_2)}\ T_2 \qquad (0.8T_2 < T \le 0.8\ T_1) \qquad (3)$$

$$G_s\ (T) = G_{s1} \qquad (0.8\ T_1 < T \le 1.2T_1) \qquad (4)$$

$$G_s\ (T) = \frac{G_{s1} - 1}{\frac{1}{1.2\ T_1} - 0.1} \cdot \frac{1}{T} + G_{s1} - \frac{G_{s1} - 1}{\frac{1}{1.2\ T_1} - 0.1} \cdot \frac{1}{1.2\ T_1} \qquad (1.2\ T_1 < T) \qquad (5)$$

From the above equations, the soil amplification factor for each grid is calculated according to the earthquake and the calculated factors are presented in figure 5. From the figure, it can observe that the factor varies from1.2 to 2.5 with respect to the soil properties and earthquake intensity. Since the soil layer of grid B2 is mostly composed with silty clay and the soil amplification factor is highest in the selected area.

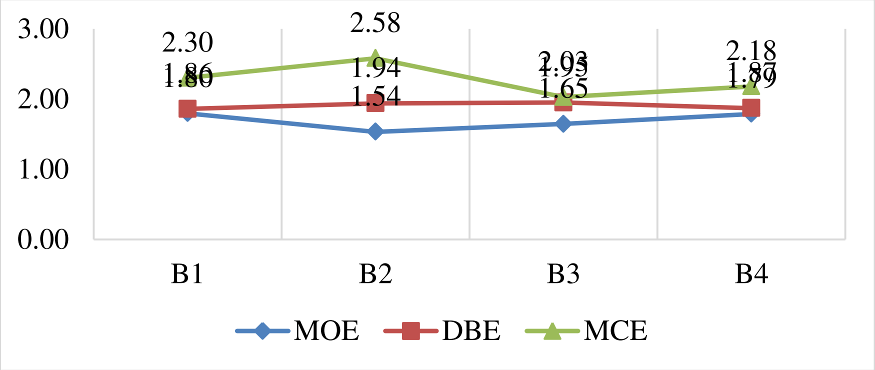


Figure 5: Soil amplification according to earthquake intensity

3.3. Ground Motion

Based on the recorded earthquake and seismicity, the selected area can be assumed as in the region of low to medium seismicity. Most of the earthquakes occurred around the region are shallow focus earthquakes especially within about 250 km in radius. Most earthquakes are related with Sagaing fault, one of the major active faults in Myanmar. Some of the active faults in Yangon region are shown in figure 6.

For this study, three types of earthquake levels are considered such as Maximum Operational Earthquake (MOE), Design Basic Earthquake (DBE), and Maximum Considered Earthquake (MCE). Each earthquake level is characterized by probability of exceedance (P), return period (T_R) and design life cycle (T_D) taken as 50years. MOE is specified for 50% probability, DBE is specified for 10% probability and MCE is specified for 2% probability in 50years. Gutenberg-Richter relation for the Sagaing fault by Myo Thant et al, 2012 is as follow:

$$\ln(PGA) = -0.152+0.859M_w-1.803\ln(R+25) \quad (3)$$

Where PGA is peak ground acceleration in g, M_w is the moment magnitude, and R is closest horizontal distance to the surface projection of the rupture plane (km). Based on the soil amplification, ground accelerations at the base rock are generated to the surface ground motions and the results are presented in table 3.

Table 2: Calculation of seismic ground motion at the base rock

Earthquake	Occurrence Probability, P	Return Period, T_R(years)	Magnitude, M_w	Acceleration at the Base rock, A_B(m/s^2)
MOE	0.5	73	6.4	0.1
DBE	0.1	475	6.8	0.14
MCE	0.02	2475	7.3	0.21

Table 3: Calculation of surface ground motion

Grid	Earthquake	Acceleration at the Base rock ,A_B	Amplification factor at the surface layer ,C_g	Acceleration at the Ground Surface ,A_s
		m/s^2		m/s^2

B1	MOE	0.10	1.857	0.18
	DBE	0.14	1.803	0.25
	MCE	0.21	2.304	0.49
B2	MOE	0.10	1.535	0.15
	DBE	0.14	1.941	0.27
	MCE	0.21	2.583	0.55
B3	MOE	0.10	1.647	0.16
	DBE	0.14	1.951	0.27
	MCE	0.21	2.028	0.43
B4	MOE	0.10	1.791	0.18
	DBE	0.14	1.872	0.26
	MCE	0.21	2.183	0.47

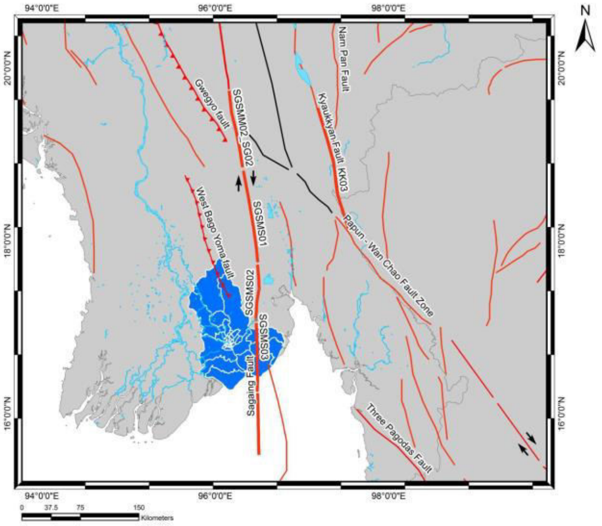


Figure 6: Seismic faults around Yangon region

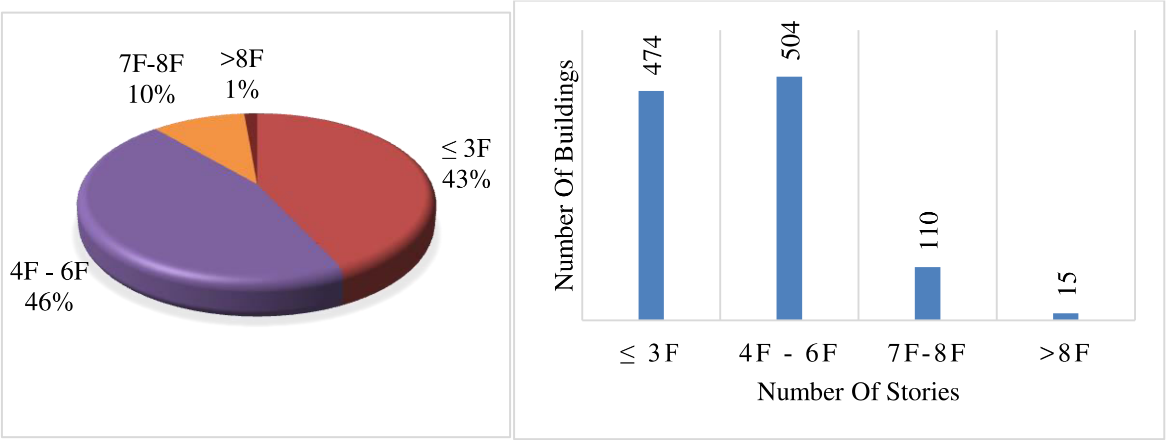
3.4. Building Information

The collected number of buildings is totally 1103. There are many different types of buildings depend on building age, structure, building material, occupancy, number of stories, etc. Most of the building in the congested downtown are mid-rise reinforced concrete buildings. In the selected area, the layouts of the buildings are rectangular in shape and the floor plans are symmetrical for 2 units apartments in one floor and unsymmetrical for 1 unit apartment in one floor. So, the common and typical type of the existing 3, 6 and 8 storeyed R.C buildings are proposed to assess the seismic vulnerability.

Figure 7: Buildings in Latha

3.4.1. Number of storeys

In this study, the building data are grouped according to the study cases and classifications of number of stories are as shown in figure 8. The maximum occurred class is 4 to 6 storeyed buildings and it is nearly 46% of the total number of buildings. Some high rise buildings are also located in the selected area and the amount is too little to study and the building types are not typical.

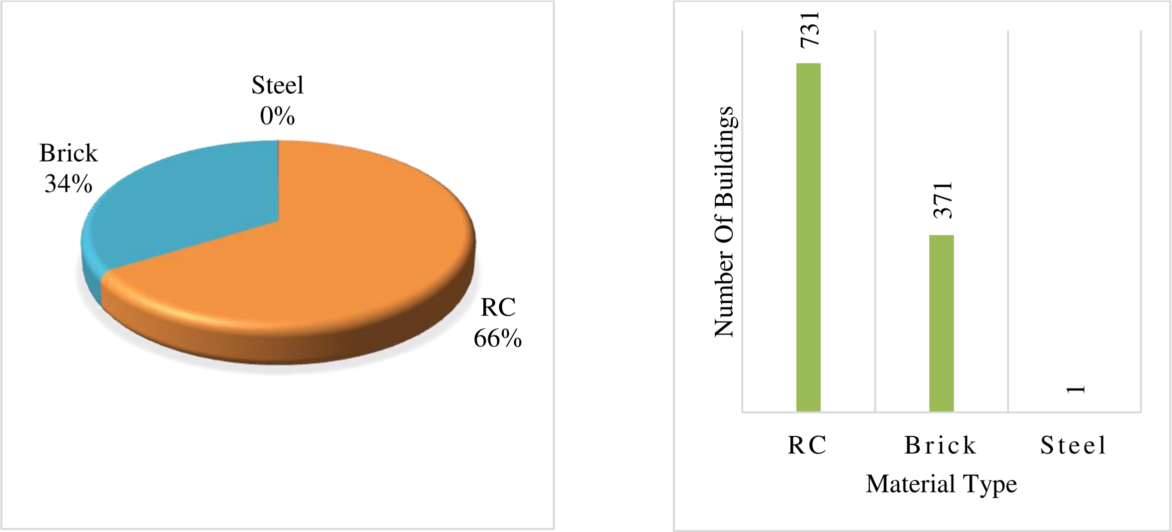


(a) (b)

Figure 8: Floor volume in proposed area (a) percentage and (b) number of buildings

3.4.2. Building Material

In the selected area, the principal building system consists of framed structure built up of RC columns and beams as structural elements with masonry wall. Steel buildings are the least occurred buildings in the selected area. The building material for each building in the selected area is shown in figure and the percentage and number of the buildings are shown in figure 9. The most commonly occurred building material is R.C and it covers 66% of the total buildings.



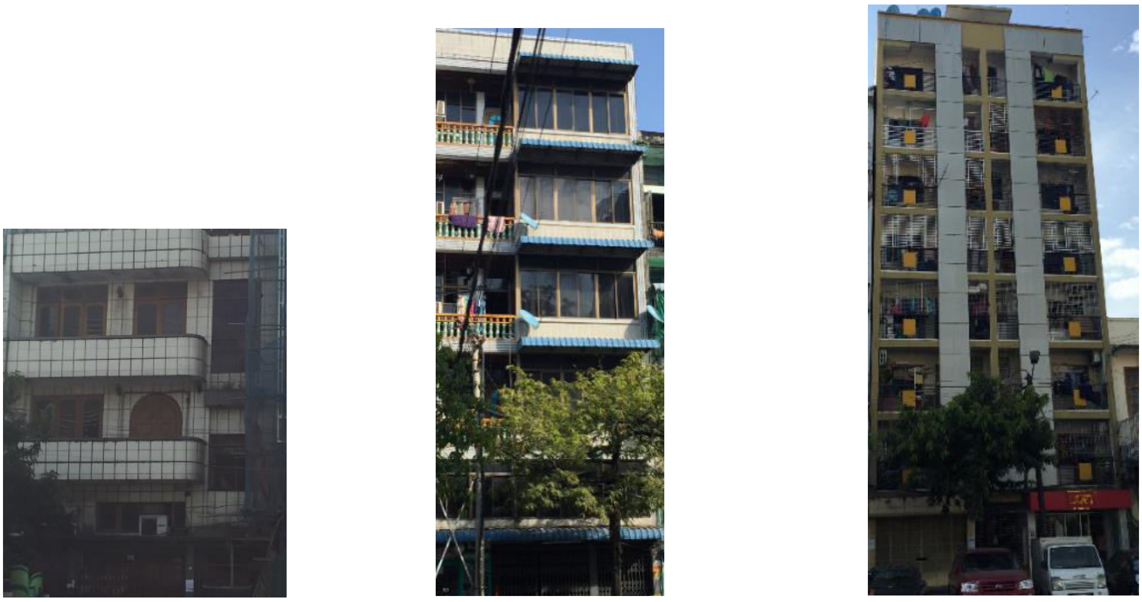
(a) (b)

Figure 9: Building material type in proposed area (a) percentage and (b) number of buildings

4. DEVELOPMENT OF FRAGILITY CURVES:

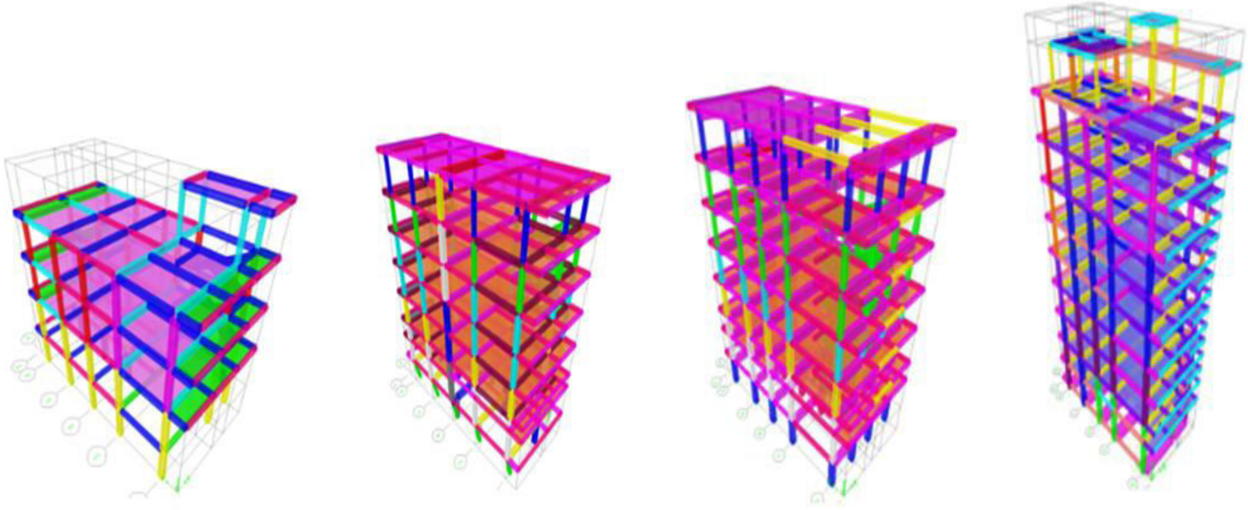
4.1. Pushover Analysis

In this paper, pushover analyses are performed using ETABS software (V.9.7.1). The shapes of the building are rectangular and the dimensions are 25ft x 50ft. The floor to floor height of proposed building is 9ft for typical floor and 10ft for ground floor.



(a) (b) (c)

Figure 10: Photos of typical RC buildings (a) 3 stories (b) 1unit 6 stories (c) 8 stories



(a) (b) (c) (d)

Figure 11: 3D Views of Structural Models (a) 3 stories (b) unsymmetrical 6 stories (c) symmetrical 6 stories (c) 8 stories

The material strengths are 2500 psi for concrete and 40000 psi for steel. For loadings, live load is 40 psf for occupants and 20 psf for roof and also finishing load is 15 psf. Seismic Load data are according to UBC-97. The pushover analysis and design are according to Uniform Building Code 1997 and ACI 318-02.

Pushover analysis is performed for MOE, DBE and MCE. From the pushover curve, the yield displacement, u_y and the maximum displacement, u_{max} and period, T according the seismic excitation are evaluated.

4.2. Fragility curves

Fragility curve is a statistical tool representing the probability of exceeding a damage limit state for a given structure type subjected to a seismic excitation (Shinozuka et al., 1999).In this paper, the probability of failure is evaluated based on the maximum displacement obtained from the pushover analysis and the critical displacement according to Federal Emergency Management Agency (FEMA 356). A simplified equation is developed to estimate the probability of failure and some deviations in displacement are also considered.

Probability of failure, $p_f = P[Z < 0 | EQ]$

Then $$p_f = \left[\frac{E[u_{cr}] - E[u_{max}]}{\delta} < 0 \,|\, EQ \right]$$

$$p_f = 1 - \Phi \left[\frac{E[u_{cr}] - E[u_{max}]}{\sqrt{\sigma^2{}_{u_{cr}} + \sigma^2{}_{u}}} \right] \tag{4}$$

$\mu_{\mu cr}$ = critical displacement

μ_{μ} = maximum displacement
σ = variance

Performance levels or limit states for both structural and non-structural systems are defined as the point in which the system is no longer capable of satisfying a desired function. FEMA 356 has the most comprehensive documentation on performance levels as described below.

(1) Immediate Occupancy (IO) - occupants are allowed immediate access into the structure following the earthquake and the pre-earthquake design strength and stiffness are retained;

(2) Life Safety (LS) - building occupants are protected from loss of life with a significant margin against the onset of partial or total structural collapse;

(3) Collapse Prevention (CP) – building continues to support gravity loading, but retains no margin against collapse.

4.3. Development of fragility curves

(1) 3 stories building

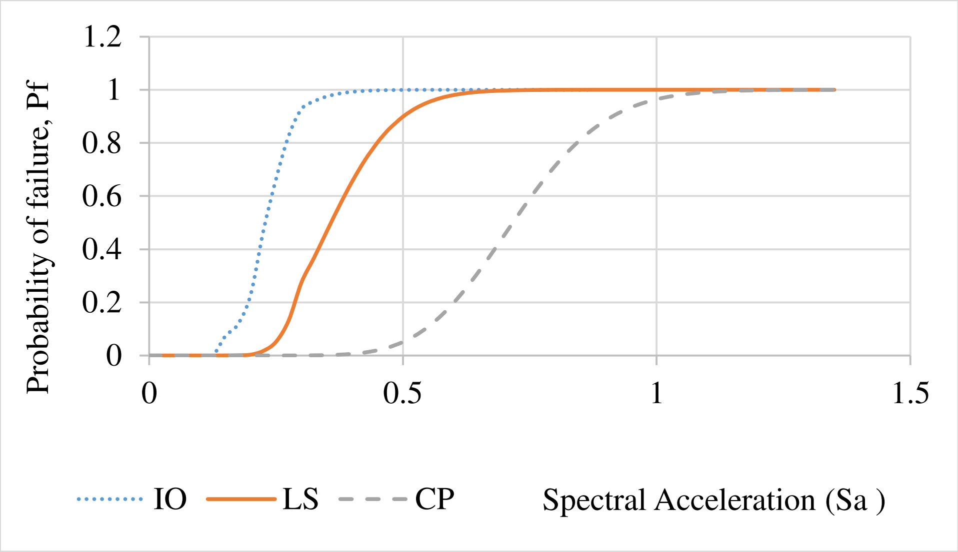


Figure 12: Fragility curves for 3 storied building

(2) Unsymmetrical 6 stories building

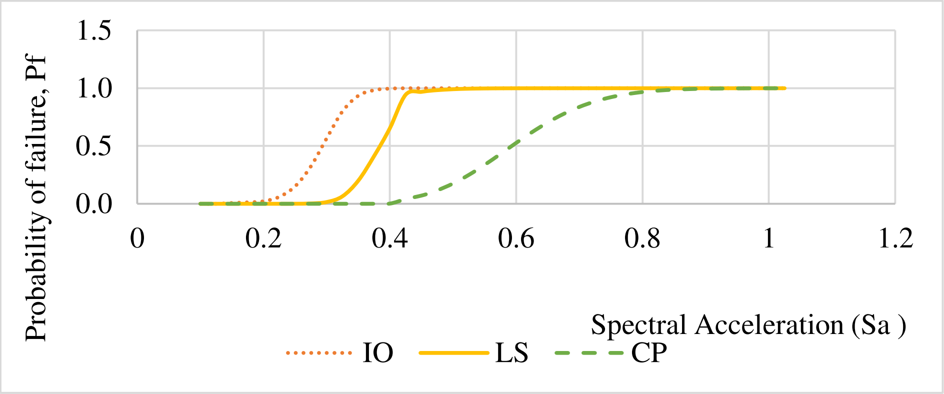


Figure 13: Fragility curves for 1unit 6 storied building

(3) Symmetrical 6 stories building

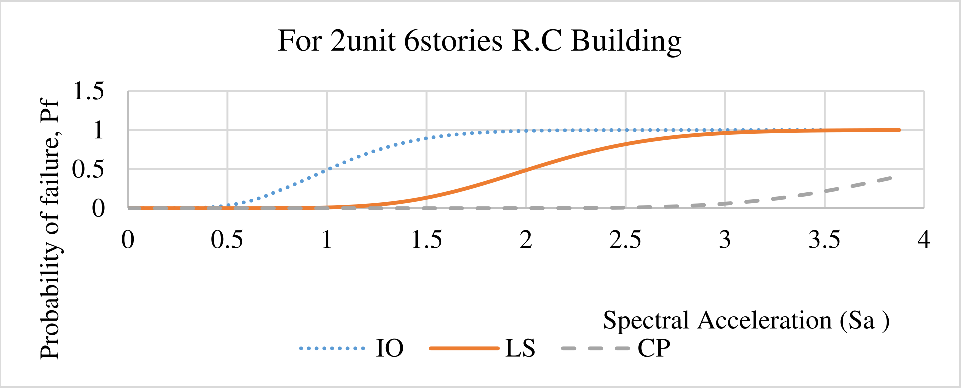


Figure 14: Fragility curves for 2 units 6 storied buildings

(4) 8 stories building

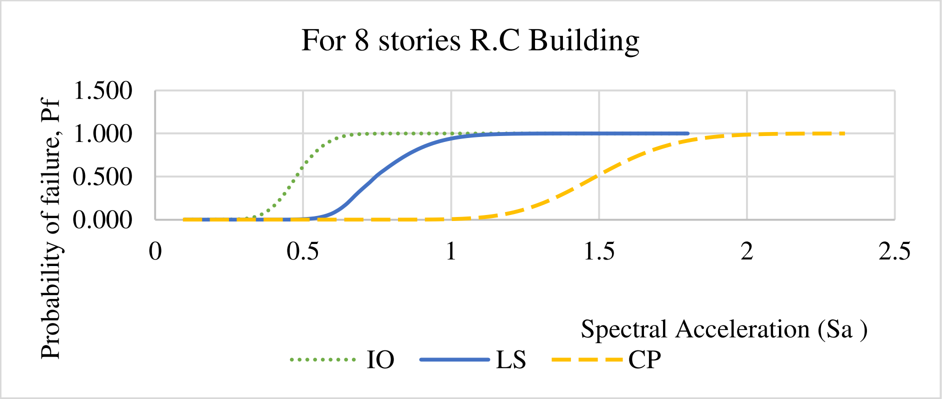


Figure 15: Fragility curves for 8 storied buildings

5. DISCUSSION AND CONCLUSION:

This paper is intended to propose an analytical and simplified methodology to derive fragility curves. The equations used to estimate soil amplification factors are compatible for local soils in Yangon. In this method, the maximum roof displacement is compared with critical displacement by FEMA356 to evaluate the probability of failure. The approach was elaborated to be used in the regions with moderate seismic hazard; therefore, the knowledge about earthquakes and the estimation of damage on structures in Yangon region will be improved. From the basic structural types identified, the concrete frame buildings are predominant in the township, and the more important modification factors detected were plan irregularity for each of these structural types.

From this study, the following conclusions can be made.

(1) The buildings with unsymmetrical structural plans are more vulnerable than symmetrical structural plans.
(2) 3 storied buildings are the most vulnerable buildings in the selected area.
(3) For 6 storied buildings, 2 units type buildings has more resistant to earthquake than 1 unit type buildings.
(4) Buildings considered for lateral load in structural analysis, 7 and 8 stories buildings, are more resistant to seismic load than other buildings designed only for gravity load.

Thus the probability of failure of the buildings for various seismic intensities can be evaluated by the proposed method. The proposed methodology could apply to plan strategies of replacement and retrofitting of an existing building stock, to investigate the seismic resistance of some reinforced concrete buildings, and to support information for disaster risk reduction system and city planning in Yangon City.

ACKNOWLEDGEMENT:

The author would like to express her special thanks to Dr. Takeshi Koike, Academic Adviser of JICA EEHE project, for his encouragement, guidance, support, and suggestions. The author is also deeply grateful to U Than Htay, Head of Department, and the engineers from YCDC for supporting building data and soil data in preparation of this paper. The authors would like to say special thanks to my family and friends who kindly help during data collection.

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