Collapse Vulnerability of Reinforced Concrete Buildings Using Neural Networks

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ABSTRACT

In this study, an Artificial Neural Network (ANN) analytical method has been developed for evaluation the collapse vulnerability (earthquake performance) of reinforced concrete (RC) buildings . In this study, collected total of 260 reinforced concrete buildings with 4 storey, that were chosen to represent the existing RC buildings. The commercial program Sta4CAD is used for modeling and analysing these buildings. The performance analysis of these 260 RC buildings have been used for training neural networks. The parameters that affect on earthquake performance represent the input and the performance represent the output.

In this study 16 parameters have been thought to be effective on the performance of RC buildings were considered: Torsional Irregularity (A1), Slab Discontinuities (A2), Projections in Plan (A3), Weak Storey (B1), Soft Story (B2), Discontinuity of Vertical Structural Elements (B3), Weak Column – Strong Beam (C2), Stirrup Spacing (*cm*), Average Shear Wall Ratio, Average Column Ratio (CA) , Concrete Compression Strength (C), Type of Steel (Fy), Soil Type (Z), Turkish Earthquake Code (1975– 1997- 2007), Earthquake Zone (EZ) and Importance Factor (I). The output parameters are the Structural Performance (S1-S4) was obtained based on the 4 performance levels in Turkish Earthquake Code-2007 (TEC-2007). The performance analysis of RC buildings was performed according to both the linear performance analysis and nonlinear (static pushover analysis) procedures as specified in TEC-2007.

The effect of each parameter tested in this study had various affecting ratios on the earthquake performance of the structure. It was found that shear wall ratio is the most significant structural components that affect. The projections in plan and slab discontinuities were determined to be the least significant parameters. According to the study, the prediction accuracy of ANN has been found 90% accuracy for nonlinear (pushover analysis method) and about 89% accuracy for linear performance analysis method.

Keywords: Artificial neural network, collapse vulnerability, earthquake performance based design.

ÖZ

Bu çalışmada betonarme binaların deprem performanslarının değerlendirilmesi için yapay sinir ağları kullanılmıştır. Bu maksatla 4 katlı 260 betonarme bina seçilmiştir. Bu binalar Sta4CAD programı ile tasarlanmıştır. Binaların doğrusal elastik ve statik itme performans analiz sonuçları kullanılarak, yapay sinir ağı eğitilmiştir. Oluşturulan yapay sinir ağı sisteminde deprem performansını etkileyen parametreler girişi, yapı performans seviyesi ise çıkışı temsil etmektedir.

Bu çalışmada deprem performansını etkileyeceği düşünülen 16 parametre seçilmiştir. Bunlar: Burulma Düzensizliği (A1), Döşeme Süreksizliği (A2), Planda Çıkıntılar Bulunması (A3), Zayıf Kat (B1), Yumuşak Kat (B2), Taşıyıcı Sistem Düşey Elemanlarının Süreksizliği (B3), Güçlü Kolon-Zayıf Kiriş (C2), Etriye Aralığı (*cm*), Ortalama Perde Duvar Oranı, Ortalama Kolon Oranı (CA), Beton Basınç Dayanımı (C), Çelik Türü (F_y), Zemin Türü (Z), Türk Deprem Yönetmeliği (1975 – 1997 – 2007), Deprem Bölgesi (EZ) ve Bina Önem Katsayısı (I)'dır. Çıkış parametreleri ise 2007 Türk Deprem Şartnamasi'nde (TEC-2007) bulunan 4 bina performans seviyesidir (S1-S4). Performans analizleri deprem şartnamesinde mevcut olan doğrusal elastik ve statik itme performans analiz yöntemlerine göre yapılmıştır.

Bu çalışmada seçilen giriş parametreleri test edilmiş ve Ortalama Perde Duvar Oranının deprem performasında en önemli parametre olduğu saptanmıştır. Planda Çıkıntılar Bulunması ve Döşeme Süreksizliği parametreleri ise en az etkili parametreler olarak saptanmıştır. Bu çalışmanın sonucunda oluşturulan yapay sinir ağı sisteminde statik itme analizi yöntemi ile yapılan performans seviyesi

tahminlerinin doğruluk oranının % 90, lineer performans analiz yöntemine göre yapılan performans seviyesi tahminlerinin doğruluk oranının ise % 89 olduğu saptanmıştır.

Anahtar Kelimeler: Yapay sinir ağları, göçme riski, deprem performansına dayalı tasarım.

DEDICATION

I dedicate this thesis to my family whom they supported me throughout my study.

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First of all, I would like to thank Allah for giving me this chance to get master degree. Secondly, I would like to thank my supervisor Asst. Prof. Dr. Giray Özay for his continuous support and guidance in the preparation of this study. Without his invaluable supervision, all my efforts could have been short-sighted.

I owe quite a lot to my family who supported me all throughout my studies. I would like to dedicate this study to them as an indication of their significance in this study as well as in my life.

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LIST OF ABBREVIATIONS

ATC	American Technology Council
FEMA	Federal Emergency Management Agency
RVS	Rapid Visual Screening
SSSM	Seismic Safety Screening Method
TRNC	Turkish Republic of Northern Cyprus
TS-500	Requirements for Design and Construction of Reinforced Concrete Buildings
TEC-2007	Turkish Earthquake Code 2007

LIST OF SYMBOLS

$A(T)$	Spectral acceleration coefficient.
A_0	Effective ground acceleration coefficient.
A_b	Total area of openings.
A	Gross floor area.
a_y, a_x	Length of re-enter corners in x, y direction.
A_e	Effective shear area.
A_w	Effective of web area of column cross sections.
A_g	Section areas of structural elements at any storey.
A_k	Infill wall areas.
A_c	Column cross-section area.
$(A_{tsw})_x$	Total cross-sectional area of shear walls in x direction.
$(A_{tsw})_y$	Total cross-sectional area of shear walls in y direction.
$(A_{tmw})_x$	Total cross-sectional area of masonary walls in x direction.
$(A_{tmw})_y$	Total cross-sectional area of masonary walls in y direction.
A_{nf}	Normal floor area.
A_{tc}	Total cross-sectional area of columns.
A_{sw}	Total cross-sectional area of shear walls at the base level (m^2).
Amw	Total cross-sectional area of masonry walls at the base level (m^2).
A_f	Total floor area above base (m^2).
Ace	Effective cross-sectional area of columns above base level (m^2).
Acol	Total cross-sectional area of columns at the base level (m^2).
A_{nf}	Normal floor area.

*B*w	Width of primary seismic beam.
CI	Column Index.
D	Effective beam and column height.
Ed	Load Combinations.
E_x, E_y	Earthquake in direction to *n*.
ΔFN	Additional equivalent seismic load acting on the N'th storey (top) of building.
f_{ctm}	Tensile strength of the existing concrete.
f_c	Concrete pressure stress in coated concrete.
G	Dead load.
g	Gravity coefficient.
*g*i	Total live load at i,th story of the building.
*h*i	Height of i,th storey of building [m].
hw	Height of wall or cross-sectional depth of beam.
h	Width of compression flange.
*h*w	Depth of beam.
Hi	Height of i'th storey of building measured from the top foundation level
Hw	Total height of the wall.
*h*wall	Height of the filling wall (mm).
hji	Storey height of the j'th column or curtain in i'th storey.
h	Effective height of the section.
I	Building importance factor.
Lmax	Larger dimension in plan of the building.
Lmin	Smaller dimension in plan of the building.

Lx, Ly	Length of the building at x, y direction.
l_c	Length of the column.
l_w	Long side of the rectangular wall section.
ℓ_w	Length of partition or piece of strap partition on plan.
L_p	Length of plastic hinge.
N	Number of stories in the structure.
n	Live load participation factor.
N_K	Axial power correspond to cross section moment capacity.
PI	Priority Index.
Q	Live load.
qi	Total dead load at i,th story of the building.
R	Structural Behavior Factor.
Ra	Inhibition Coefficient of the Power of Earthquake.
Ra(T)	Seismic Load Reduction Factor.
r	Ratio of exposure/capacity.
S	Soil factor.
$S_{ae}(T)$	Elastic spectral acceleration.
$S_e(T)$	Elastic response spectrum.
$S_d(T)$	Design spectrum (for elastic analysis).
S(T)	Spectrum coefficient.
T	Vibration period of a linear single degree of freedom system.
TB	Lower limit of the period of the constant spectral acceleration branch.
T_A, T_B	Spectrum characteristic periods.
Ve	Shear force taken into account for the calculation of transverse reinforcement of column, beam or wall.

V_r	Shearing strength of the column, beam and curtain cross section.
V_t	Total seismic load acting on a building.
WI	Wall Index.
Δ_i	Storey drift of i,th storey of the building.
$(\Delta_i)_{ort}$	Average storey drift of i,th storey of the building.
$(\Delta_i)_{max}$	Maximum storey drift of i'th storey of the building.
$(\Delta_i)_{min}$	Minimum storey drift of i,th storey of the building.
η	Damping correction factor with a reference value of η =1 .
η_{bi}	Torsionally irregularity factor defined at i'th storey of the building.
η_{ci}	Strength Irregularity Factor defined at i'th storey of building.
η_{ki}	Stiffness irregularity factor defined at i,th storey of the building.
ρ	Tension reinforcement ratio.
ρ'	Compression steel ratio in beams.
ρ'	Pressure reinforcement ratio.
ρ_b	Balanced reinforcement ratio.
ρ_{min}	Minimum tension reinforcement ratio.
ρ_{max}	Maximum tension reinforcement ratio.
ρ_w	Shear reinforcement ratio.
λ	Equivalent Earthquake Power Derogation Factor.
λ	Slenderness ratio of steel columns.

Chapter 1

INTRODUCTION

1.1 General

Earthquakes are considered one of the most important threat all over the world and most of their hazards can be prevented. And controlled with recent invation most of the new structural buildings are design based on set of regulations and standard but the older ones still need to be evaluated from the seismic performance point of view. Therefore the existing buildings need to be examined if they resist earthquakes or not. Analysis and evaluation of the seismic performance of all the buildings by the traditional methods is very difficult because it requires time, great effort and economy. For this reason, in recent years, researchers have developed and continue to improve quick assessment methods to evaluate the earthquake performance of RC buildings. The figure below shows the different levels of seismic activitis in the world.

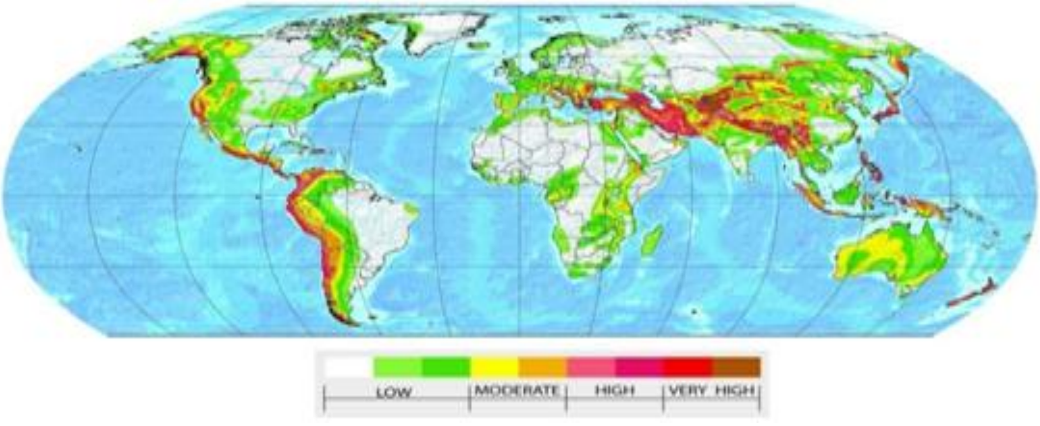


Figure 1.1 Map of Global Seismic Hazard [1].

1.2 Previous Studies on Rapid Assessment Methods for Seismic Vulnerability of Existing Reinforced Concrete Buildings

1.2.1 P25 Rapid Screening Method

The P25 Method was initially suggested by Bal (2005) [2]. Then it was developed and calibrated in relation to many heavily, moderately, slightly or completely undamaged buildings that endured the different past earthquakes happened in Turkey.

The P25 is considered as the primary method of calculation for ratios related to the cross-sectional characteristics of structural members, and observing well as scoring the most important of structural parameters which affect the seismic response of buildings.

1.2.2 Seismic Safety Screening Method (SSSM)

The Seismic Index Method (Ohkubo 1990) [3]. It has been modified and calibrated and it is one of the main rapid assessment methods, it is also known as 'Seismic Safety Screening Method: (SSSM)' by Boduroglu (2004) [4]. The Seismic Index method is used for the rapid seismic safety evaluation of RC structures of 7 stories or less. It is also applied to buildings that have an unusual geometry or too low quality materials.

The first step in investigation is the examination of the structural system, year of construction and the condition of the building. After that, calculate the performance index of the existing building "Is"and demand index" Iso" .

The seismic safety of the buildings can be determined by comparing the performance index Is, with the adequate reference or the demand index Iso. This comparison must be repeated for all critical stories and for two main directions.

In the second step of the investigation, the carrying capacity and the ductility levels of columns and shear-walls are calculated.

1.2.3 Hassan and Sozen

Hassan and Sozen in 1997 suggested a simplified method for seismic vulnerability assessment of low-rise monolithic buildings in a given region. The method aims to identify the buildings with high probability of severe damage. The required parameters are total floor area, cross-sectional areas of columns, shear walls and masonry walls. In order to rank the buildings, so called “wall index” and “column index” values are calculated for both directions [5]. These indices are given as follows,

$$\text{Wall Index (WI)} = (\text{Asw}+\text{Amw}/10)*100/\text{Af} \tag{1.1}$$

$$\text{Column Index (CI)} = (\text{Ace})*100/\text{Af} \tag{1.2}$$

$$\text{Ace} = \text{Acol}/2 \tag{1.3}$$

$$\text{Priority Index (PI)} = \text{WI} + \text{CI} \tag{1.4}$$

where;

Asw: total cross-sectional area of shear walls at the base level (m^2)

Amw: is total cross-sectional area of masonry walls at the base level (m^2)

Af: total floor area above the base level (m^2)

Ace: effective cross-sectional area of columns above base level (m^2)

Acol: total cross-sectional area of columns at the base level (m^2)

1.2.4 FEMA The Rapid Visual Screening

The rapid visual screening (RVS) method was first proposed with ATC 21 in 1988 and the new versions were also issued by FEMA in 2002, [6] . The (RVS) procedure has been mainly developed for the identification of inventory, and screen buildings that may potentially seismic hazardus.

The methodology used in this procedure is based on the sidewalk surveys of a building and the data collection form.

1.3 Previous Studies on Seismic Vulnerability Assessment using ANNs

Arslan [7] used neural networks to evaluate the effective design parameters on earthquake performance of RC buildings. The related structural parameters that have been considered in this study are: The ultimate and the yield strength of steel, the compressive strength of concrete, the short column, the infill walls ratio, the transverse reinforcement , the shear walls ratio and the weak beam– strong column . 256 RC buildings between 4 and 7 floors were modeled and the pushover analysis method was then applied to each of them in order to obtain capacity curves of the building. However, the load-bearing system with irregularities, the ground effect and the overhangs were not covered in the study.

This study was carried out for 4 and 7 story regular frame RC buildings. There are 5 axles in the *x* direction and 5 axles in the *y* direction. The distance between each axle is 4 meters: The plans for all selected buildings models are symmetrical and there is no any type of irregularity.

According to Arslan [7] shear walls are of utmost importance and significantly affect on structural performance. Buildings that have sufficient shear walls and do not have short columns in the ground story, display good performance in resisting the effect of lateral loads, the increasing strength of the steel reinforcement increases the strength of the system. Furthermore, stirrup spacing and concrete quality are the least influence on the level of performance. Weak Beam–Strong Column formation also has less impact on the earthquake performance for structures when compared to shear walls or short columns.

In a study conducted by Arslan, Ceylan and Koyuncu [8] analytical method developed for analyzing the earthquake performances of RC buildings by Neural Network, where 66 RC buildings with 4-10 storey, were modeled by using the commercial software (IDEStatik V.6.0053), according to the linear analysis method in TEC-2007.

In this study, the performance of the reinforced concrete buildings under earthquake loads was determined with 64.26% accuracy. Table 1.1 indicates the variation intervals of the parameters for the selected 66 buildings.

Table 1.1. The variation intervals of Arslan's parameters [8]

USED DATA RANGE

Parameter	Minimum Value	Maximum Value
Number of Storey (NS)	4	10
Building project year (PY)	0	1
Average Column Ratio (ρ_{CA})	0.008197	0.024721
Average Shear Wall Ratio (ρ_{SWA})	0	0.011725
Average Longitudinal Bar Ratio in Columns ($\rho_{\ell\ col}$)	0.00843	0.012828
Average Longitudinal Bar Ratio in SW ($\rho_{\ell\ sw}$)	0	0.010643
Steel Tension Strength (S)	220	420
Concrete Compression Strength (C)	16	20
Average Inertia of Beams (IB)	0.001092	0.0045
Importance Factor (I)	1	1.5
Soil Type (Z)	1	4
Earthquake zone (EZ),	1	4
Earthquake Reduction Coefficient (R)	4	7
Living Load Reduction Coefficient (n)	0.3	0.6
Structural Performance (S_1-S_4)	1	4
Slab types (ST)	1	3

1.4 General Objective

This study is aimed to develop a quick and easy method to evaluate the existing reinforced concrete buildings for their earthquake performance using Artificial Neural Networks (ANN).

1.5 Specific Objectives

1) Develop a neural network model which can predict earthquake performance for reinforced concrete buildings.

2) Carry out a parametric study using the trained neural network to obtain the significance of each parameters affecting the resistant of buildings for earthquakes.

1.6 Scope of Study

This study is concerned only with concrete buildings. Structural steel buildings need further studies.

1.7 Research Methodology

The following methodology will be adopted to achieve the objective:

1-Literature review will be carried out on the performance analysis and Artificial Neural Networks.

2- Dozens of models of buildings will be carried out for getting database which then be used for training the neural network then testing the results.

3- Effective parameters on earthquake performance will be investigated using Artificial Neural Network (ANN) and then it will be sorted according to the significance.

4- ANN modelling will be considered for assessment earthquake performance of RC buildings.

1.8 Structure of the Thesis

This study consists of six main chapters as followings:

- Chapter 1- includes general information on the purpose of the study, previous studies on seismic vulnerability assessment, previous studies on seismic vulnerability assessment using ANNs, general objective, specific objectives, scope of study, research methodology and structure of the Thesis.
- Chapter 2 – details earthquake analysis methods and performance analysis methods according to TEC-2007.
- Chapter 3 - includes the fundamentals of ANN showing their definition, the terminology used, as well as the advantages and disadvantages of them. The mechanism of ANN, their architecture types, algorithms used for training them are also reviewed.

- Chapter 4 - explains the modeling of the collapse vulnerability using artificial neural networks. This chapter also discusses the collection stage of the analytical data, pre processing of the training data, training and the performance of the developed model.
- Chapter 5- presents a parametric study in which the influence of each parameter on the earthquake performance for RC buildings.
- Chapter 6 - presents conclusions and recommendations for future work.

Chapter 2

GENERAL PRINCIPLES AND RULES OF EARTHQUAKE DESIGN

2.1. Introduction

The earthquake analysis methods and the performance analysis methods according to TEC-2007 were summarized below .

2.2. Earthquake Analysis According to TEC 2007

2.2.1 Building Importance Factor

Preventing structural and non-structural elements of buildings from damage is the basic principle of earthquake resistant design, if limits the damage in the buildings (structural and non-structural elements) to repairable levels in medium-intensity earthquakes, and in high intensity earthquake to prevent the comprehensive or partial collapse in the building to avoiding losing life.

According to Table 2.1, buildings that have Importance Factor I=1, implies the probability of exceedance of the design earthquake is 10% in a period of 50 years .

Table 2.1. Buildings Importance Factor [9].

Purpose of Occupancy or Type of Building	Importance Factor (I)
1. Buildings required to be utilized after the earthquake and buildings containing hazardous materials a) Buildings required to be utilized immediately after the earthquake (Hospitals, dispensaries, health wards, firefighting buildings and facilities, PTT and other telecommunication facilities, transportation stations and terminals, power generation and distribution facilities; governorate, county and municipality administration buildings, first aid and emergency planning stations) b) Buildings containing or storing toxic, explosive and flammable materials, etc.	1.5
2. Intensively and long-term occupied buildings and buildings preserving valuable goods a) Schools, other educational buildings and facilities, dormitories and hostels, military barracks, prisons, etc. b) Museums	1.4
3. Intensively but short-term occupied buildings Sport facilities, cinema, theatre and concert halls, etc.	1.2
4. Other buildings Buildings other than above defined buildings. (Residential and office buildings, hotels, building-like industrial structures, etc.)	1.0

2.2.2 Ground Conditions

Table 2.3. details the soil types in TEC-2007 that represent the most common local soil conditions. Table 2.2. details the local site classes that shall be considered as the bases of determination of local soil conditions.

Table 2.2. Local Site Classes [9].

Local Site Class	***Soil Group according to Table 6.1 and Topmost Soil Layer Thickness*** **(h_1)**
Z1	Group **(A)** soils Group **(B)** soils with $h_1 \leq 15$ m
Z2	Group **(B)** soils with $h_1 > 15$ m Group **(C)** soils with $h_1 \leq 15$ m
Z3	Group **(C)** soils with 15 m $< h_1 \leq 50$ m Group **(D)** soils with $h_1 \leq 10$ m
Z4	Group **(C)** soils with $h_1 > 50$ m Group **(D)** soils with $h_1 > 10$ m

Table 2.3. Soil Groups [9].

Soil Group	*Description of Soil Group*	*Standard Penetration* (N/30)	*Relative Density* (%)	*Unconfined. Compressive Strength* (kPa)	*Drift Wave Velocity* (m / s)
(A)	**1.** Massive volcanic rocks, unweathered sound metamorphic rocks, stiff cemented sedimentary rocks **2.** Very dense sand, gravel... **3.** Hard clay and silty clay…	— > 50 > 32	— 85 – 100 —	> 1000 — > 400	> 1000 > 700 > 700
(B)	**1.** Soft volcanic rocks such as tuff and agglomerate, weathered cemented sedimentary rocks with planes of discontinuity…… **2.** Dense sand, gravel.......... **3.** Very stiff clay, silty clay…	— 30 – 50 16 – 32	— 65 – 85 —	500 – 1000 — 200 – 400	700 – 1000 400 – 700 300 – 700
(C)	**1.** Highly weathered soft metamorphic rocks and cemented sedimentary rocks with planes of discontinuity **2.** Medium dense sand and gravel......…………………… **3.** Stiff clay and silty clay.....	— 10 – 30 8 – 16	— 35 – 65 —	< 500 — 100 – 200	400 – 700 200 – 400 200 – 300
(D)	**1.** Soft, deep alluvial layers with high ground water level **2.** Loose sand...................….. **3.** Soft clay and silty clay…..	— < 10 < 8	— < 35 —	— — < 100	< 200 < 200 < 200

2.2.3 Seismic Design

The spectral acceleration coefficient that $A(T)$ is given in equation (2.1) must be used for determination of seismic loads. The elastic spectral acceleration S_{ae} (T), which is defined as the ordinate of elastic acceleration spectrum for 5% damped rate where the elastic acceleration the spectrum is equal to spectrum acceleration coefficient times the acceleration of gravity"g" as given in equation (2.2).

$$A(T) = A_0.I.S(T) \tag{2.1}$$

$$S_{ae}(T) = A(T)\text{g} \tag{2.2}$$

where :

A_0 : Effective ground acceleration coefficient,

I : Building importance factor,

S(T) : Spectrum coefficient,

$S_{ae}(T)$: Elastic spectral acceleration,

g : Gravitational acceleration (9.81 m/s^2) .

Table 2.4 details the effective ground acceleration coefficient (A_0).

Table 2.4. Effective Ground Acceleration Coefficient [9].

Seismic Zone	A_0
1	0.4
2	0.3
3	0.2
4	0.1

$$S(T) = 1 + 1.5\frac{T}{T_A} \qquad (0 \leq T \leq T_A) \qquad (2.3)$$

$$S(T) = 2.5 \qquad (T_A \leq T \leq T_B) \qquad (2.4)$$

$$S(T) = 2.5\ [\frac{T_B}{T}]^{0.8} \qquad (T_B < T) \qquad (2.5)$$

The spectrum characteristic periods, T_A and T_B, are specified in Table 2.5.

Table 2.5. Spectrum Characteristic Periods [9].

Local Site Class	T_A (second)	T_B (second)
Z1	0.10	0.30
Z2	0.15	0.40
Z3	0.15	0.60
Z4	0.20	0.90

Spectrum characteristic periods that are defined in Table 2.5 for local site class Z4 must be used in case where previous requirements are not met. In some cases, the elastic acceleration spectrum can be defined by special investigations via considering local seismic and site conditions.

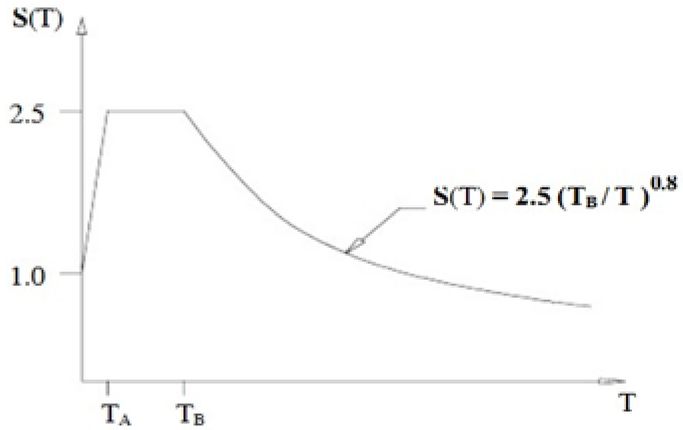


Figure 2.1. Design Acceleration Spectrums [9].

In order to consider the specific nonlinear behavior of the structural system during earthquake, the elastic seismic loads are determined in terms of spectral acceleration coefficient by dividing to the seismic load reduction factor. Where seismic load reduction factor, must be calculated according to equations (2.6) or (2.7) based on the structural system behavior factor, "R" is detaled in Table 2.6 and defined for various structural systems, and the natural vibration period T.

$$Ra(T) = 1.5 + (R - 1.5)\frac{T}{T_A} \qquad (0 \leq T \leq T_A) \qquad (2.6)$$

$$Ra(T) = R \qquad (T_A < T) \qquad (2.7)$$

Ra(T) : Seismic Load Reduction Factor.

Table 2.6. Structural Systems Behavior Factors [9].

BUILDING STRUCTURAL SYSTEM	Systems of Nominal Ductility Level	Systems of High Ductility Level
1. CAST-IN-SITE REINFORCED CONCRETE BUILDINGS		
1.1. Buildings in which seismic loads are fully resisted by frames………	4	8
1.2. Buildings in which seismic loads are fully resisted by coupled structural walls ………………………………………………………..........	4	7
1.3. Buildings in which seismic loads are fully resisted by solid structural walls ……………………………………….........................	4	6
1.4. Buildings in which seismic loads are jointly resisted by frames and solid and / or coupled structural walls …………………………………...	4	7
2. PREFABRICATED REINFORCED CONCRETE BUILDINGS		
2.1. Buildings in which seismic loads are fully resisted by frames with connections capable of cyclic moment transfer…………………………..	3	7
2.2. Single-storey buildings in which seismic loads are fully resisted by columns with hinged upper connections ………………………………..	-	3
2.3. Prefabricated buildings with hinged frame connections in which seismic loads are fully resisted by prefabricated or cast – in – situ solid structural walls and / or coupled structural walls………………………..	-	5
2.4. Buildings in which seismic loads are jointly resisted by frames with connections capable of cyclic moment transfer and cast-in-situ solid and / or coupled structural walls ……………………………………………..	3	6
3. STRUCTURAL STEEL BUILDINGS		
3.1. Buildings in which seismic loads are fully resisted by frames ……..	5	8
3.2. Single – storey buildings in which seismic loads are fully resisted by columns with connections hinged at the top …………………………	-	4
3.3. Buildings in which seismic loads are fully resisted by braced frames or cast-in-situ reinforced concrete structural walls		
a- Centrically braced frames ……………...	4	5
b- Eccentrically braced frames ………………………………………….	-	7
c- Reinforced concrete structural walls...	4	6
3.4. Buildings in which seismic loads are jointly resisted by structural steel braced frames or cast-in-situ reinforced concrete structural walls		
a- Centrically braced frames...	5	6
b- Eccentrically braced frames...	-	8
c- Reinforced concrete structural walls..	4	7

2.2.4 Definition of Load Combination According to TEC-2007

The following combinations are used to determine the design value E_d for the action of seismic design situation:

$$E_d = G + Q \pm E_x \pm 0.3E_y \quad (2.8)$$

$$E_d = G + Q \pm E_y \pm 0.3E_x \quad (2.9)$$

Where;

G : Dead load,

Q : Live load,

E_x, E_y: Earthquake in direction to x and y respectively.

In the case of unfavorable result, the below equations should be used

$$E_d = 0.9G + Q \pm E_n \pm 0.3E_y \quad (2.10)$$

$$E_d = 0.9G + Q \pm E_y \pm 0.3E_n \quad (2.11)$$

The seismic weight of the structure shall be determined by given equation:

$$W = \sum g_{i,N} + \sum n\, q_{i,N} \quad (2.12)$$

where;

g_i : Total live load at i'th storey of the building,

q_i : Total dead load at i'th storey of the building,

n : Live load participation factor,

N : Number of stories in the structure.

Table 2.7 shows Live load participation factor (n). This n must be taken as 1 in industrial buildings. 30% of snow load shall be considered for the calculation of roof weight for seismic load.

Table 2.7. Live Load Participation Factors [9].

Purpose of Occupancy of Building	n
Depot, warehouse, etc.	0.8
School, dormitory, sport facility, cinema, car park, restaurant, shop, etc.	0.6
Residence, office, hotel, hospital, etc.	0.30

2.2.5 Methods of Analysis

There are three methods used for the seismic analysis of buildings which are :

1 Equivalent Seismic Load Method

2 Mode - Superposition Method.

3 Time Domain Method.

2.2.5.1 Equivalent Seismic Load Method

Equation 2.13 is selected to determine the total equivalent seismic load (base shear), "Vt", acting on the whole building in the direction of earthquake (TEC, 2007).

$$V_t = \frac{WA(T1)}{Ra(T1)} \geq 0.10\ A_0 IW \qquad (2.13)$$

where:

Vt : total equivalent seismic load acting on the building,

T1 : The first natural vibration period of the building,

W : Total weight of the building,

A : Spectral Acceleration Coefficient,

Ra : Seismic Load Reduction Factor,

Ao : Effective Ground Acceleration Coefficient,

I : Building Importance Factor.

Total building weight "W", that used in Equation 2.13 as the seismic weight must be calculated according to Equation 2.12. Total equivalent seismic load determined by Equation 2.13 is expressed by Equation 2.14:

$$V_t = \Delta FN + \sum_{i=1}^{N} Fi \qquad (2.14)$$

Additional equivalent seismic load, ΔFN, acting at the N'th storey (top) must be calculated by using Equation 2.15 (TEC, 2007).

$$\Delta FN = 0.0075\, NVt \qquad (2.15)$$

Excluding ΔFN, remaining part of the total equivalent seismic load must be distributed to stories by Equation 2 .16 (TEC, 2007).

$$Fi = (Vt - \Delta FN)\frac{wiHi}{\sum_{j=1}^{N} wjHj} \qquad (2.16)$$

where:

Fi : Design seismic load acting at i'th storey,

Wi : Weight of i'th storey,

Hi : Height of i'th storey .

2.2.5.2 Mode Superposition Method

In Mode Superposition method displacements and maximum internal forces are calculated by the statistical combination of maximum contributions obtained from each of the sufficient number of natural vibration modes considered (TEC, 2007).

2.2.5.3 Analysis Methods in Time Domain

In this method artificially generated and recorded earthquake ground motions can be used in both the linear or nonlinear seismic analysis of buildings in the time domain.

2.3. Performance Analysis According to TEC-2007

Performance based design helps describing the inelastic behavior of the structural component of a building. By this approach the actual behavior of a building can be estimated more accurately during a specified ground motion. Since all the structural members are examined individually in performance design procedures, it is easy to see which member or member group does not satisfy the desired performance level.

This design technique has two main parameters one is the demand which represents the ground shaking motion that affects to the structure; the other is the behavior of the structure under this ground shaking motion which can be named as capacity of the structure.

2.3.1. Limits of Damage in Construction Elements and Areas of Damage

2.3.1.1. Damage Limits in Cross Sections

On the cross section for ductile element there are three limit conditions which are Minimum Damage Limit (MN), Safety Limit (GV) and Collapsing Limit (GÇ). Minimum damage limit defines the starting of the behavior beyond elasticity, safety limit can be defined as the limit when the section behavior be beyond elasticity and able to the strength safely, collapsing limit is the behavior limit before collapsing. This classification invalid for elements damaged in a brittle case.

2.3.1.2. Sectional Damaged Areas

Elements that the damages with critical sections do not reach MN are within the *Minimum Damage Region,* those in-between MN and GV are within *Marked Damage Region*, those in-between GV and GÇ are in *Advanced Damage Region*, and those going beyond GÇ are within *Collapsing Region* as detailed in Figure 2.2 [9].

2.3.1.3. Definition of Damages in Cross Sections and Elements

Damage regions that cross-sections belong to, shall be decided according to the comparison of the internal forces and / or deformation calculated using linear or nonlinear methods with the numerical values corresponding to cross section damage limits described in section 2.1.1. Damage of the element shall be decided according to the cross section of the element that with greatest damage.

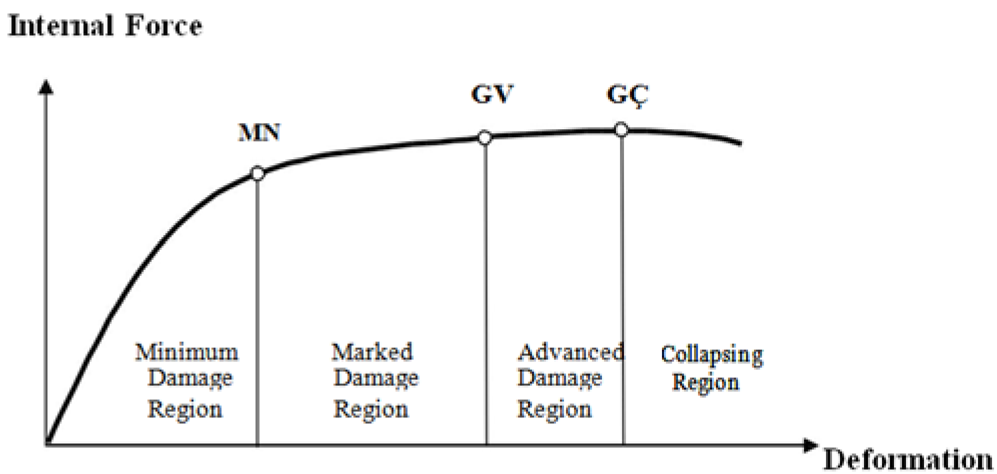


Figure 2.2. Member damage levels and member performance regions on capacity curve [9].

2.3.2. Building Performance Levels

Seismic safety of the buildings is related to the damage level possibly to occur in the structure under effect of the seismic load applied. Four building performance levels are defined.

2.3.2.1. Immediate Occupancy Level (HK)

The building can still be considered ready for use (Immediate Occupancy Level)if at most 10 % of the beams in this building exceed the Marked Damage Region Significant Damage Zone and all other elements remain in the Minimum Damage Zone.

2.3.2.2. Life Safety Performance Level (CG)

The buildings that live up to the conditions provided below that can be agreed to be in the *Life Safety Performance Level*, if there are any, are strengthened:

(a) As a result of the calculations made for each direction that the earthquake takes, applies on each floor, at most 30 % of the beams except for the secondary ones (which does not take place in the horizontal load-bearing system) at most, the proportion of the columns defined in paragraph (**b)** can be in the *Advanced Damage Zone*.

(b) The total contribution of the columns in the *Advanced Damage Zone* to the shear force that is borne by the columns in each floor should not exceed 20 %. The ratio of total shear force of the vertical components in (*Advanced)* significant damage region at roof story to total shear force of the columns at the related story ratio can not be more than 40 %.

(c) All the other loads – which bear components in the *Minimum Damage Zone or Marked Damage Zone.* However, the ratio of the shear force carried by the columns, exceeding the minimum damage limit in both upper and lower end sections at any story, to the shear force carried by all columns at the related story ratio must be less than 30 %.

2.3.2.3. Collapse Prevention Level (GÖ)

The buildings that live up to the conditions provided below, are agreed to be in the Collapse Prevention Level supported by the fact that all components that are brittle damaged are in the *Collapse Zone.*

(a) The results of the calculations concerning all earthquakes that can be applied to any of the floors. At most 20 % of the beams except for the secondary ones (that does not take place in the horizontal load-bearing system) can enter the *Collapse Zone.*

(b) All other load-bearing components are placed in the *Minimum Damage Zone, Marked Damage Zone or in the Advanced Damage Zone*. However, the ratio of the shear force carried by the columns whose minimum damage limits are exceeded in both upper and lower end sections at any story to the shear force carried by all columns at the related story ratio must be less than 30 %.

(c) The building usage under the mentioned circumstances threatens the safety of nearby human life and populace.

2.3.2.4 Collapse Level (GÇ)

If the building does not provide the conditions of collapse prevention level, it can be considered as in Collapse Level. The usage of the building in existing condition is not permitted.

2.3.3. Targeted Performance Levels for The Buildings

Three types of ground shaking are defined to be taken into consideration in performance based design and evaluation. These ground shakings are explained by having probabilities to be exceeded in 50 years.

- *Service (Usage) Ground Shaking*: It is defined as ground shaking having a 50 % probability to be exceeded in 50 years. Return period of this ground shaking is approximately 72 years. The effect of this ground shaking (spectral acceleration) is half of the effect of ground shaking defined below.
- *Design Ground Shaking:* It is defined as ground shaking having a 10 % probability to be exceeded in 50 years. Return period of this ground shaking is approximately 475 years. This ground shaking is used in the Turkish Earthquake Codes 1998 and 2007.
- *The Biggest Ground Shaking*: It is defined as ground shaking having a 2 % probability to be exceeded in 50 years. Return period of this ground shaking is approximately 2475 years. The effect of this ground shaking is 1.5 times of the effect of design ground shaking.

Table 2.8. Minimum Building Performance Targets Anticipated for Different Earthquake Levels [9].

The usage purpose and the Type of the Building	*Probability for the Earthquake to be exceeded*		
	50 % in 50 years	*10 % in 50 years*	*2 % in 50 years*
The buildings that should be used after earthquakes: Hospitals, heath facilities, fire stations, communications and energy facilities, transportation stations, provincial or district administrative bodies, disaster management centers etc.	–	IQ	LS
The buildings that people stay in for a long time period: Schools, accommodations, dormitories, pensions, military posts, prisons, museums, etc.	–	IQ	LS
The buildings that people visit densely and stay in for a short time period: cinema, theatre and concert halls, culture centers, sports facilities	IQ	LS	–
Buildings containing hazardous materials: The buildings containing toxic, flammable and explosive materials and the buildings in which the mentioned materials are stored.	–	IQ	CP
Other buildings: The buildings that does not fit the definitions given above (houses, offices, hotel, tourist facilities, industrial buildings, etc.)	–	LS	–

2.3.4. Determining the Building Performance in Earthquake with Linear Elastic Performance Analysis Method

Linear elastic calculation methods to be used for the determination of seismic performances of buildings are the calculations methods defined in 2.2.5. Additional rules as stated below shall be applied concerning these methods.

Equivalent seismic load method using if the total building height is less than 25m and 8 storey as well as have $n_{bi} < 1.4$ buckling disorder calculated without considering joint eccentricity. Equation (2.13) is used for calculation of total equivalent seismic load (ground shearing force) where R_a=1 is taken and right side of the equation is multiplied with λ factor. λ = 1.0 in one or two storey structures except cellars and in others be 0.85. When using the Mod Combination Method, in the Equation (2.18) R_a=1. In calculations of internal forces and elements capacities which are adaptable to applied seismic direction, internal force directions obtained in the mode that is dominant in this direction shall be based.

$$S_{aR}(T_n) = \frac{S_{ae}(T_n)}{R_a(T_n)} \tag{2.17}$$

$S_{aR}(T_n)$: Acceleration spectrum ordinate for the natural vibration mode [m /s2],

$S_{ae}(T_n)$: Elasticity spectrum ordinate [m /s2],

$R_a(T_n)$: Seismic Load Reduction Factor.

2.3.4.1. Determination of Damage Level in the Structural Elements of Reinforced Concrete Buildings

In the description of damage boundaries of ductile elements with linear elastic calculation methods, numerical values figured as (r) shall be used in the effect / capacity ratios of beams, column and wall elements and sections of strengthened masonary filled walls. Reinforced concrete elements are classified as “ductile” if their fracture type is under bending and “brittle” if it is under shearing effect.

a) In order the beams, columns and walls to be considered as ductile element, Shearing force "V_e" calculated in accordance with the bending capacity in the critical sections of those element should not exceed the shearing capacity "V_r" calculated according to TS - 500. On the calculation of V_e for columns, beams and walls, bearing force moments shall be used. In case the total shearing force calculated with gravity loads by taking Ra= 1 is less than V_e, then this shearing force shall be used instead of V_e.

b) In order the beams, columns and walls to be considered as ductile element also it is necessary to provide $H_w/\ell_w > 2.0$ condition.

H_w : Total height of partition,

ℓ_w : Length of partition.

c) Reinforced concrete elements that are not provide the conditions for ductile element given in **(a)** and **(b)** are defined as brittle damaged elements. Effect / capacity ratio of ductile beam, column and wall sections is determined by dividing the section moment calculated under seismic load by taking R_a= 1 to over moment capacity. On the calculation of effect / capacity direction of the applied earthquake must be taken into account.

a) Over moment capacity of section is the difference between bending moment capacity of the section and moment effect calculated on the section under gravity loads. Moment effect calculated under gravity loads in the supports of the beam can be reduced maximum 15 % according to retransfer principle.

b) Effect / capacity ratios of column and wall sections can be calculated in such a way as defined in TEC-2007 in Information Annex 7A.

Effect / capacity ratio of strengthened filled walls are the shearing force strength of shearing force calculated under the effect of earthquake. Shearing forces formed in the strengthened filled walls which are modeled with diagonal bars shall be taken into consideration as the horizontal concurrent of the axial force of the bar. Calculation of shearing force strength of the strengthened masonnary filled walls is given in TEC-2007 in Information Annex 7F. It is decided that the elements are located in which damage zone by comparing effect / capacity ratio of beam, column and wall sections and strengthened filled walls (r) with boundary values given in Table 2.9 - 2.12**.** Besides, on the determination of damage zones of strengthened filled walls in the reinforced concrete buildings boundary ratios of relative storey drift given in Table 2.12 shall also be taken into consideration. Ratio of relative storey drift shall be obtained by dividing the maximum relative storey drift to storey height. For intermediate - values given in Table 2.9 - 2.12 linear interpolations shall be applied.

Table 2.9. The effect / capacity ratios (r) defining the boundary of the damage for reinforced concrete beams [9].

Ductile Beams			**Damage Boundary**		
$\frac{\rho-\rho'}{\rho_b}$	**Coating**	$\frac{V}{b_w d\ f_{ctm}}$	**MN**	**GV**	**GÇ**
≤ 0.0	Available	≤ 0.65	3	7	10
≤ 0.0	Available	≥ 1.30	2.5	5	8
≥ 0.5	Available	≤ 0.65	3	5	7
≥ 0.5	Available	≥ 1.30	2.5	4	5
≤ 0.0	Not available	≤ 0.65	2.5	4	6
≤ 0.0	Not available	≥ 1.30	2	3	5
≥ 0.5	Not available	≤ 0.65	2.5	4	6
≥ 0.5	Not available	≥ 1.30	1.5	2.5	4

Table 2.10. The effect / capacity ratios (r) defining the boundary of the damage for reinforced concrete columns [9].

Ductile Columns			Damage Boundary		
$\frac{N}{A_c f_c}$	Coating	$\frac{V}{b_w d\, f_{ctm}}$	MN	GV	GÇ
≤ 0.1	Available	≤ 0.65	3	6	8
≤ 0.1	Available	≥ 1.30	2.5	5	6
≥ 0.4	Available	≤ 0.65	2	4	6
≥ 0.4	Available	≥ 1.30	2	3	5
≤ 0.1	Not available	≤ 0.65	2	3.5	5
≤ 0.1	Not available	≥ 1.30	1.5	2.5	3.5
≥ 0.4	Not available	≤ 0.65	1.5	2	3
≥ 0.4	Not available	≥ 1.30	1	1.5	2

Table 2.11. The effect / capacity ratios (r) defining the boundary of the damage for reinforced concrete walls [9].

Ductile Walls	Damage Boundary		
Coating	MN	GV	GÇ
Available	3	6	8
Not Available	2	4	6

Table 2.12. The effect / capacity ratios (r) defining the boundary of the damage for strengthened filled walls and ratios of relative storey drift [9].

Ratio range of ℓ_{wall} / h_{wall} 0.5 - 2.0	Damage Boundary		
	MN	GV	GÇ
Effect / Capacity Ratios (*r*)	1	2	-
Ratios Of Relative Storey Drift	0.0015	0.0035	-

2. 3.4.2. Control of Relative Storey Drifts

In the calculation made with linear elastic methods in each earthquake direction, relative storey drifts of columns, beams or walls in each storey of the building should not exceed the value given in Table 2.13. where δ_{ji} indicates the relative storey drift calculated as a replacement difference between bottom and top ends of the j'th column or wall in i'th storey whereas h_{ji} indicates the height of the relevant element.

Table 2.13. Boundaries of Relative Strorey Drift [9].

Ratio of Relative Storey Drift	Damage Boundary		
	MN	GV	GC
δ_{ji} / h_{ji}	0.01	0.03	0.04

2.3.5. Determining the Seismic Performance of the Building using Nonlinear Analysis Methods

2.3.5.1. Definition of Nonlinear Analysis Method

The aim of the non–linear analysis methods to be used in determination of structural performances and retrofitting analysis of existing buildings under the effect of the seismic loads, is calculating the plastic rotation demands of ductile behavior and the demand for internal forces of brittle behavior for a given earthquake. Then, these demand values are compared with deformation capacities defined in this section. Evaluation of the structural performance is done for the performance level of the member and the building. The non-linear analysis methods are:

- Incremental Equivalence Seismic Load Method,
- Incremental Mode Combination Method,
- Measurement within the Scope of Time Definition Method.

First two are the methods that shall be used for the *Incremental Repulsion Analysis (**Pushover Analysis**)* that is taken as a basis for determining the non - linear seismic performances and for the strengthening measurements.

2.3.5.2. Methodology of Pushover Analysis Method

The steps that should be followed in the inelastic non-linear performance evaluation conducted applying the *Pushover Analysis* are summarized below.

(a) In order to idealize the non-linear behavior of the load-bearing system and build the analysis model the rules defined in 2.3.5.3 must be followed.

(b) A non linear static analysis in which the vertical loads that are in accordance with the masses are taken into account must be conducted before applying the pushover analysis . The results of this analysis must be using as the primary conditions of the pushover analysis.

(c) In case the incremental pushover analysis is conducted by applying the Incremental Equivalence Seismic Load Method**,** the “modal capacity diagram” belonging to the primary (dominant) mode the coordinates of which are defined as “modal displacement – modal acceleration” shall be derived. Modal capacity diagram obtained at the end of pushover analysis and elastic response spectrum are taken into consideration together and modal displacement demand of first mode will be calculated. At the last step, displacements which refer the modal displacement demands, plastic deformations (plastic rotations) and internal force demands will be evaluated.

(d) From the plastic rotational demands which are calculated for the ductile sections, the plastic curvature demands will be evaluated which will handle to find the total plastic curvature demand of the member. After that, in accordance with these the strain demands for the concrete and reinforcement steel will be achieved for reinforced concrete members. These strain demands will be compared with the strain limits which are specified for different damage levels so a performance level evaluation will be done in sectional for structural members in ductile manner. Also the obtained shear force demands will be compared with the shear capacity of sections to make a consideration in brittle manner.

2.3.5.3. Idealizing the Inelastic Non-linear Behavior

In this specification, it is suggested to use "*elastic perfectly plastic hypothesis*" for nonlinear analysis. It is assumed that plastic deformations occur uniformly distributed within the plastic hinge length. In case of simple bending, length of the plastic deformation region called *plastic hinge length* (L_p) shall be taken as equal to half of member dimension in bending direction (h) .

$$L_p = 0.5 \times h \tag{2.18}$$

It is required that plastic hinges are located in the exact middle of the plastic deformation region theoretically. But in practical operations, following approximate idealizations can be allowed:

(a) In Plastic hinges shall be located at sufficient distance from the column-beam connection region. But, it must be considered that plastic hinges can occur at spans of the beams due to vertical loads.

(b) In reinforced concrete shear walls, plastic hinges are allowed to be assigned in bottom ends of shear walls in each story. U, T, L or box typed shear walls, must be idealized as single shear wall sections. In the case of basement floors of the buildings are encircled by rigid shear walls, plastic hinges of these shear walls going towards the upper floors must be located by starting on basement.

(c) Yield surfaces of the reinforced concrete members can be modeled as yield lines and yield planes for two dimensional and three dimensional behavior conditions respectively.

2.3.5.4. Pushover Analysis Using Incremental Equivalent Seismic Load Method

In incremental equivalent seismic load method, nonlinear pushover analysis is performed under monotonically increasing equivalent earthquake load until performance point is reached. Performance point is also named as target modal displacement demand. Displacement, plastic deformation, increase in internal forces and related cumulative values are determined at each pushover step. Once the system reaches its performance point, total base reaction and roof displacement values are determined. Performance point is also named as target modal displacement demand.

To be able to use the Incremental Equivalent Seismic Load Method, it is required that; the effective mass calculated by considering first natural vibration mode of considered earthquake direction to total building mass shall not be less than 0.70 and torsional irregularity coefficient calculated without considering additional eccentricities is $\eta_{bi} < 1.4$. In addition, number of stories shall not be more than eight excluding basement.

During incremental Pushover Analysis, the distribution of the equivalent seismic load can be assumed to remain constant, independent of the plastic section formations in the load-bearing system. In such a case, load distribution shall be determined in a way that it shall be proportional to the value derived by multiplying the natural vibration mode shape magnitude of the primary (dominant in the seismic direction) that is computed for the linear elastic behavior at the first step of the analysis with the magnitude of the related mass. In the buildings where floor slabs are idealized as rigid diaphragms, two perpendicular horizontal drifts in the center of mass of each floor and the rotation around the vertical axis passing through the center of mass shall be considered as the magnitudes of the primary (dominant) natural vibration mode shapes.

By means of the repulsion analysis (Pushover Analysis) conducted in accordance with the constant load distribution the *repulsion curve* the coordinates of which are *"top translocation – ground shear force"* shall be obtained**.** Top translocation is the translocation that is calculated in each repulsion step and that takes place in the center of mass of the top floor of the building for the earthquakes in the direction x that are taken into consideration. And the ground shear force is the sum of the equivalent seismic loads of each step for the earthquake in the direction of x.

2.3.5.5. Pushover Analysis with Incremental Mode Combination Method

The aim of the *Incremental Mode Combination Method* is incrementally implementing the *Mode Combination Method* taking modal translocations that are gradually and monotonically increased in a way that shall be proportional to the sufficient number of natural vibration mode shapes representing the load-bearing system behavior and that are scaled in a way that they shall be in harmony with each other or taking the modal seismic loads that shall be in harmony with the mentioned modal. Such Pushover analysis method that is based on the "*step by step linear elastic"* behavior in the load - bearing system for each repulsion step between the formations of two sequential plastic sections is explained.

2.3.5.6. Calculation with the Non-linear within the Scope of Time Definition Method

Analysis Method in Time Domain is step by step integration of the movement equation of the system by considering non–linear behavior of the structural system. The displacement, deformation and internal forces occur in the system in the duration of the analysis in each time increase and the maximum equivalent values of them with respect to the seismic demand are calculated.

Chapter 3

ARTIFICIAL NEURAL NETWORKS

3.1 Introduction

Artificial Neural Networks (ANN) are commonly used to solve the the problems that might be complicated or there are difficult in modeling by using other techniques like mathematical modeling [10,12,13]. ANN are used in many problems in structural engineering.

This chapter exhibits the fundamentals of Artificial Neural Networks showing the history, definition, terminology used, as well as advantages and disadvantages. The mechanism of ANN, architecture classes, algorithms used for training are also reviewed. Finally, several applications of ANN used in civil engineering are included.

3.2 Definition of Artificial Neural Networks

Artificial Neural Network (ANN) is an assembly (network) of a large number of highly connected processing units, the so-called nodes or neurons. The neurons are connected by connections. The strength of the connections between the neurons is represented by numerical values (weights) [13,14,15].

3.3 Terminology used in Artificial Neural Network

The definitions of the terms that showed in Figure 3.1 are given in the following paragraphs:

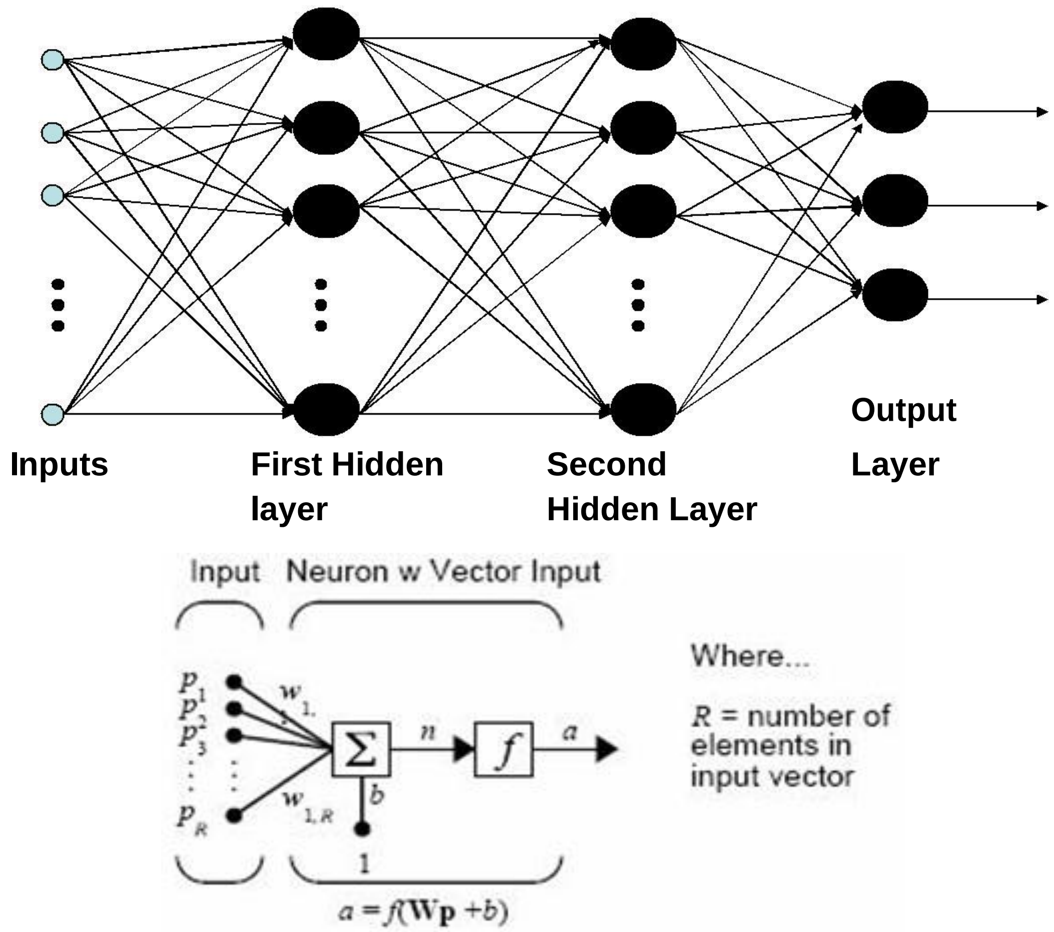


Figure 3.1. Typical Structure of ANN [11]

Neuron (artificial): It has inputs from other neurons, with each of which is associated a weight - that is, a number which indicates the degree of importance which this neuron attaches to that input, and it is also called nodes [16,17].

Weight: A parameter associated with a connection from one neuron, A, to another neuron B. Weight determines value of notice the neuron B pays to the activation it received from neuron A [17].

Input unit: It is a neuron without input connections. And its activation thus comes from outside the net [17].

Output unit: It is a neuron without output connections. And its activation thus represent the output value of the net [17].

Bias: In some neural networks like feed-forward, every hidden unit and every output unit is connected by a trainable weight to a unit (the bias unit) that always has an activation level of -1[17].

Epoch: Number of times of training. Usually it used as a measure the learning speed as in "the training has been completed after n epochs" [17].

Hidden layer: Layers that between the input and output layers (layers that consist of hidden neurons) are called hidden layers [17].

Hidden unit / node: It is a neuron that is not an input unit or an output unit [17].

A learning algorithm is a procedure for adjust the weights [12].

Note: The back-propagation consider the most widely used and successful learning algorithm used in training multilayer neural networks [12].

3.4 Advantages and Disadvantages of ANN

Artificial neural networks have many advantages that make a lot of researchers to apply it in their studies. Some of those advantages are:

1- Artificial neural networks can model some complex problems where the relationships that connect the model variables are unknown [12], [10].

2- ANN can producing correct or nearly correct result (outputs) when the presented inputs be partially incorrect or incomplete [14], [10].

3- It is not necessary to have prior knowledge about the relationship that connect between the input/output, and this is one of the benefits that neural networks distinguishes from other statistical and empirical methods . [12], [10].

4- Artificial Neural Networks can be updated for getting a better result via adding new training examples to the network [11], [10].

5- ANN can give the outputs without performing manual works like using equations, charts, or tables [15], [12].

6- Using neural networks is faster than a conventional approaches [16], [12].

7- ANN are applicable for dealing with noisy and incomplete data [18], [12].

8- ANN have the ability to learn and generalize form previous examples to produce solutions for different problems [18], [12].

9- Experimental data, theoretical data, empirical data can be presented to ANN for training based on reliable experiences [18], [12].

Although the advantages of neural networks, from another side they have also disadvantages. Some of them are :

1- They give results without explaining how they get solutions. The accuracy of ANN depends on the quality of the trained data and the capability of the user to choose reliable representative inputs [10].

2- There is no exact formula to determine the architecture of ANN and which training algorithm shall be used in a given problem. Trial and error is the best proposal solution . User can get an idea via examining the problem then deciding to start with simplest network; going on to complex ones until getting a good solution that is withen the acceptable limits of error [10].

3- The model tends to be like a black box because the relations that link between inputs and outputs did not develope by the judgment of the engineer or the user [10].

It seems that the advantages of ANN outweigh the disadvantages [10].

3.5 Mechanism of Artificial Neural Networks

Neural networks are composed of simple elements that operating in parallel. The function of network can be determined in general by the connections between elements. Neural network can be trained to perform a specific function via adjusting the values of the connections (weights) that are connect between the elements.

As shown below in Fig 3.2. , the network is adjusted, based on a comparison of the output and the target frequently until the output of the network matches the target.

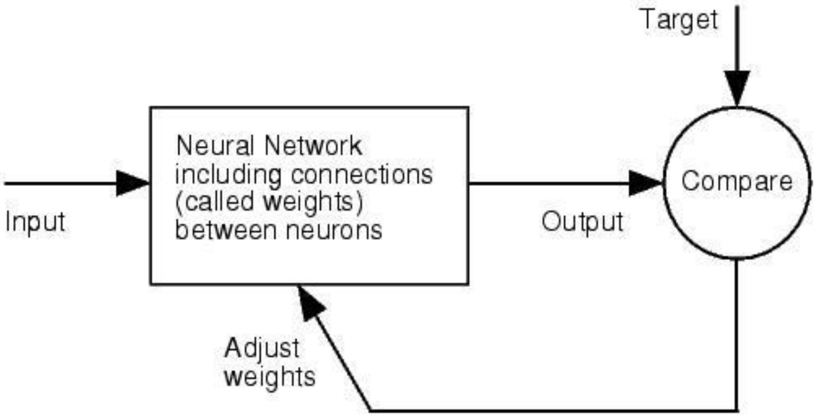


Figure 3.2. The Concept of Neural Networks [11].

3.6 Types of Artificial Neural Networks

Artificial neural networks can be classifyied according to the connection geometries. Feed-forward network is one of the most simple architectures [20].

3.6.1 Single-Layer Feed Forward Networks

The neurons in a layered neural networks are organized in layers. The simplest shape of a layered network consist of an source nodes (input layer) which projects into an computation nodes (output layer), but not vice versa. In other words, this kind of networks are feed forward or in one way. As Fig. 3.3 shows. This network is called a single-layer network, "single-layer" refers to the output layer .Since no computation is performed in the input layer it is not counted [21].

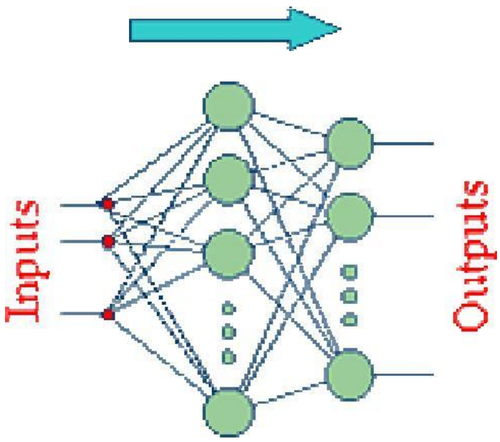


Figure 3.3. Feed forward network with a single layer of neurons [11].

3.6.2 Multi-Layer Feed Forward Networks

This type of neural networks has at least one hidden layer, where the computations dose also called hidden neurons. The main function of hidden layer is to intervene between external inputs and the outputs of network in a useful manner as detailed in Fig 3.4.

Fig. 3.4 shows the layout of a multilayer feed forward neural network with one hidden layer. This network for brevity can be referred to as a 6-4-2 network since it has 6 source neurons, 4 hidden neurons, and 2 output neurons [21].

In Fig. 3.4, the neural network is fully connected, which implies that every node in every layer is connected to each other node in the adjacent forward layer. If some of the (synapticlconnections) were missed then the network can be considered partially connected [21].

3.6.3 Recurrent Neural Networks

The difference between recurrent neural network and feed forward neural network is that, the first one has one feedback loop at least. In the network topology Recurrent Neural Network (RNN) has a closed loop. Basically, RNN developed in order to deal with the time varying or time-lagged patterns. Also they are commonly used when the dynamics of the process the problems is complex or having noisy data.

The Recurrent Neural Network can be fully or partially connected. All the hidden units in fully connected type are connected recurrently, on the other hand, the recurrent connections in the partially connected RNN are omitted partially. For instance, RNN may have a single layer of neurons where every neuron feeding its output signal back to the inputs of all the other neurons, as Fig. 3. 5 shows [21].

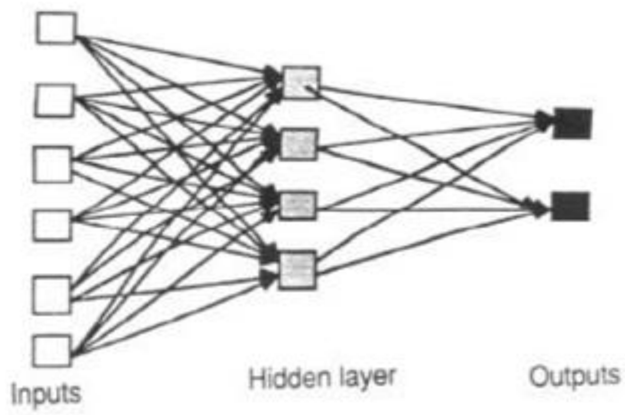


Figure 3.4. Fully connected feed forward network [11].

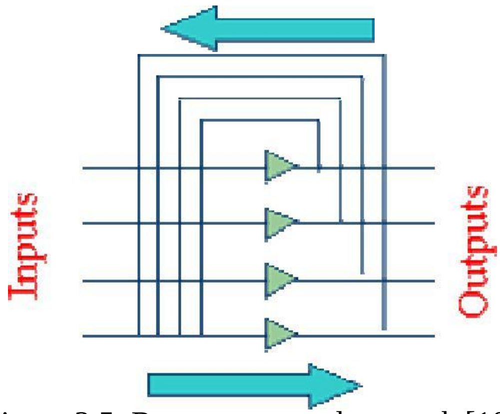


Figure 3.5. Recurrent neural network [10,11].

3.7 Functions used in developing ANN

There are many types of functions used by ANN among which training and transfer functions are listed below:

3.7.1 Training Functions

MATLAB toolbox has 4 training algorithms that apply weight and bias learning rules, namely:

- Batch training function "***trainb***".
- Cyclical order incremental training function ***"trainc***".
- Random order incremental training function ***"trainr***".
- Sequential order incremental training function ***"trains"*** [11].

3.7.2 Transfer (Activation) Functions

An activation function is the function that describes the output behavior of a neuron. Activation functions can be linear or nonlinear [11]. Fig 3.6. shows the most three commonly used functions which are :

- Hard-Limit Transfer Function.
- Linear Transfer Function.
- Log-Sigmoid Transfer Function.

-Neurons of Linear Transfer Function shown Fig. 3.6 are used as linear approximations in "Linear Filters".

- The sigmoid transfer function shown in Fig. 3.6 takes the input and squashes the output into the range 0 to 1. [11].

3.8 Algorithms used for Training Artificial Neural Network

There are several types of neural networks according to algorithms used in the training process. The following paragraphs presents some of these training algorithms :

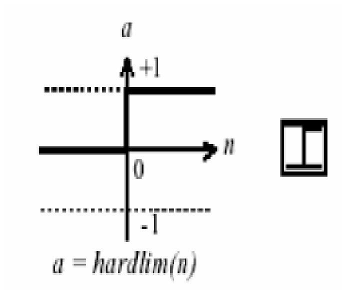
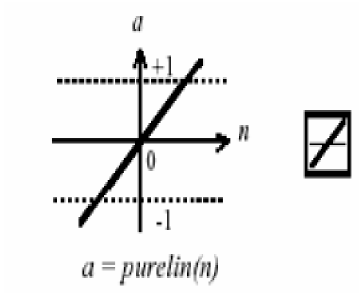
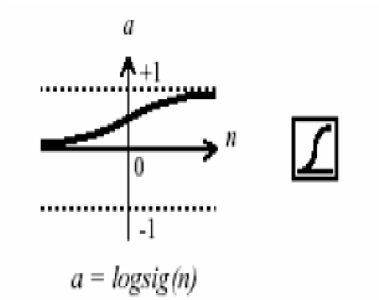
Hard-Limit Transfer Function	
Linear Transfer Function	
Log-Sigmoid Transfer Function	

Figure 3.6. Three of the most commonly used transfer functions[11]

3.8.1 Back-propagation Neural Networks

The most popular type of neural networks is the back propagation neural network (BP). Back-Propagation is a mathematical procedure that starts with the error at the output of a neural network and propagates this error backwards through the network to yield output error values for all neurons in the network. BP is a feed forward network that uses supervised learning to adjust the connection weights. In a feed forward network, the results of each layer are fed to each successive layer. A conventional BP uses three layers of nodes, but it can use more middle layers. The first layer, the input nodes, receives the input data (also called the middle layer or the hidden layer). The results of the first layer are passed to the next layer. This process is repeated for each layer until an output is generated. The difference between the generated output and a training set output is calculated. This difference is fed back to the network where it is used for connection weight readjustment by iteratively attempting to minimize the difference to within a predefined tolerance. The BP can learn many different output patterns simultaneously with dramatic accuracy [10,11].

3.8.2 Radial Basis Neural Networks

Radial Basis Functions are powerful techniques for interpolation in multidimensional space. A Radial Basis Function (RBF) is another type of feed-forward ANN as showen in Fig 3.7. Typically in RBF network, there are three layers: one input, one hidden and one output layer. Unlike the back-propagation networks, the number of hidden layer can not be more than one. The hidden layer uses Gaussian transfer function instead of the sigmoid function. In RBF networks, one major advantage is that, if the number of input variables is not too high, then learning is much faster than other type of networks.

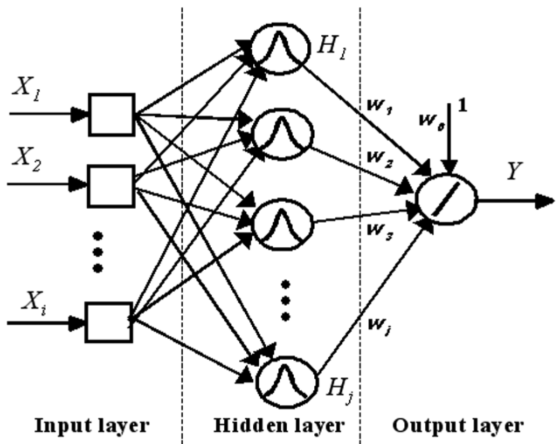


Figure 3.7. Architecture of radial basis function neural network [11].

3.8.3 Hopfield Neural Networks

Hopfield network is the recurrent neural network that has no hidden units. The concept of this type of networks is to gain a convergence of weights to find the minimum value for function of energy. Each neuron in the Hopfield network is connected with all other neurons except itself, therefore the flow does not going in one way**.** Even a node can be connected to itself in a way of receiving the information back through other neurons [22, 24].

Chapter 4

METHODOLOGY

4.1 Introduction

This chapter deals with modeling of earthquake performances of reinforced concrete buildings using artificial neural networks. The reliability of the data collected used in this research and definition of parameters considered in the study (parameters affecting on earthquake performance of RC buildings) which represent the input of the data collected have been explained. The preprocessing which applied on the collected experimental results is explained.

This chapter also presents the adopted training process to develop a trained neural network model; the training process includes defining the topology of the required neural network and identifying all neural network parameters.

The following methodology will be adopted to in this study:

1- Dozens of models of buildings will be carried out for getting database to be used in training the neural network then testing the results.

2- Effective parameters on earthquake performance will be investigated using Artificial Neural Network (ANN) and then will be sorted according to their significances.

4. 2 Case Study

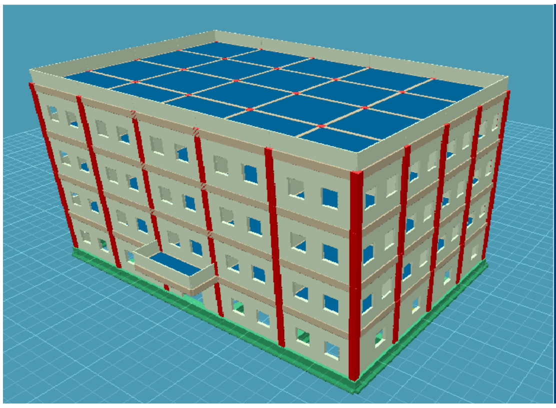
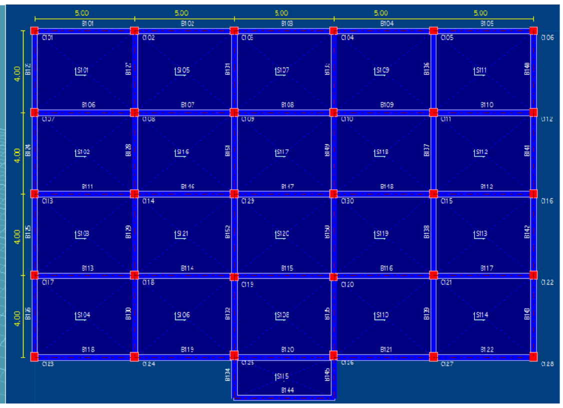
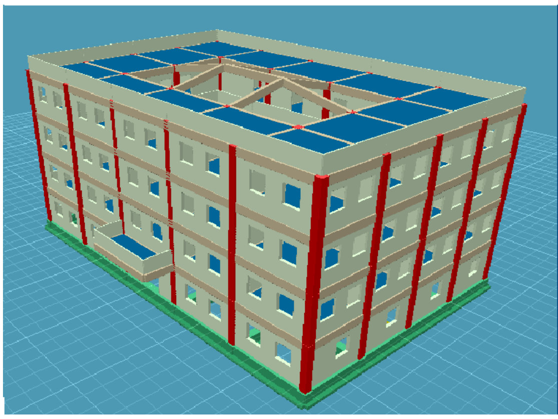
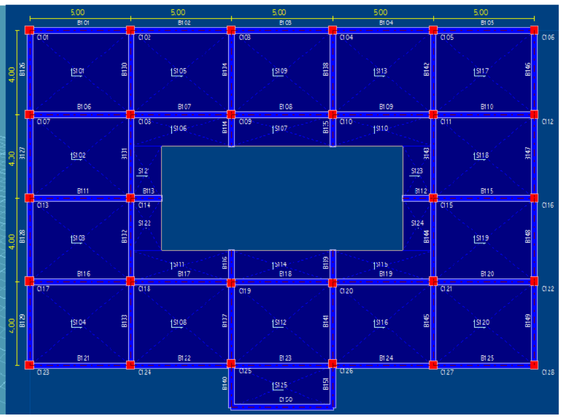
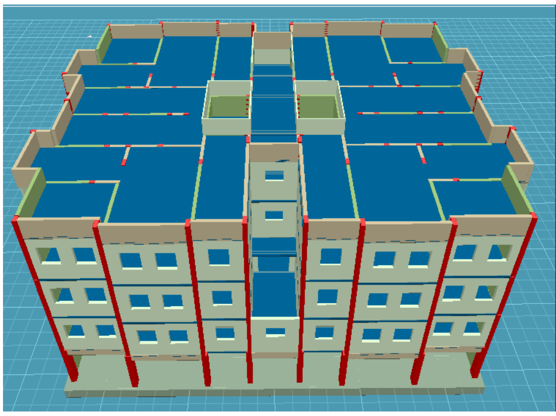
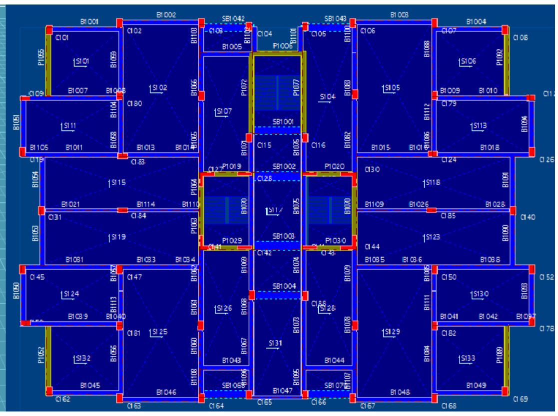
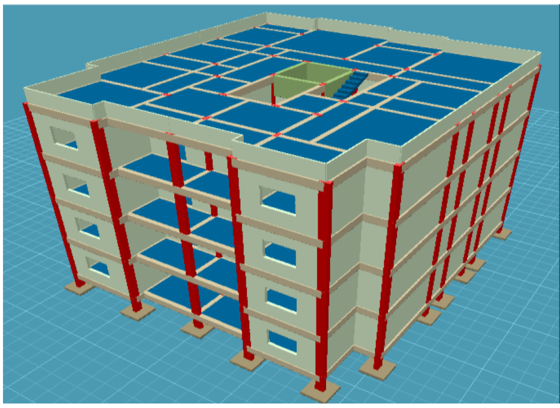
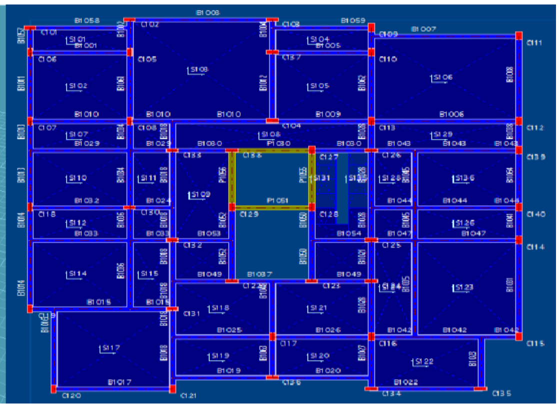
In this study, collected total of 260 reinforced concrete buildings with 4 storey, that were chosen to represent the existing RC buildings. The commercial program STA4cad is used for modeling and analysing these buildings. The performance analysis of these 260 RC buildings have listed in the Appendix that were used for training neural networks. The parameters that affect on earthquake performance represent the input and the performance represent the output. The performance analysis of RC buildings was performed according to both the linear performance analysis and nonlinear (static pushover analysis) procedures as specified in TEC-2007 [9]. Performance level details are given in Table 4.1. Fig. 4.1 shows 10 different of buildings models out of 260 residence buildings chosen in this analysis. Earthquake performance of a RC building is based on several parameters. Table 4.2 indicates these parameters and their variation intervals of the selected 260 buildings for this study.

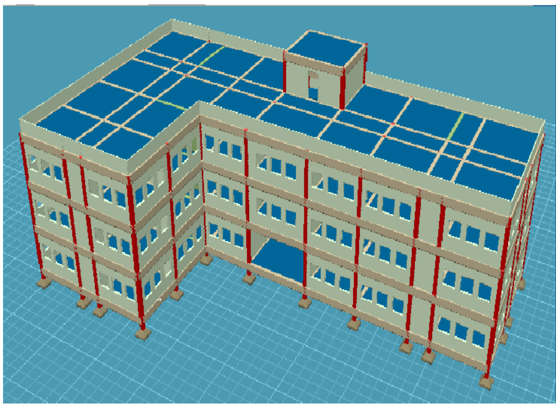
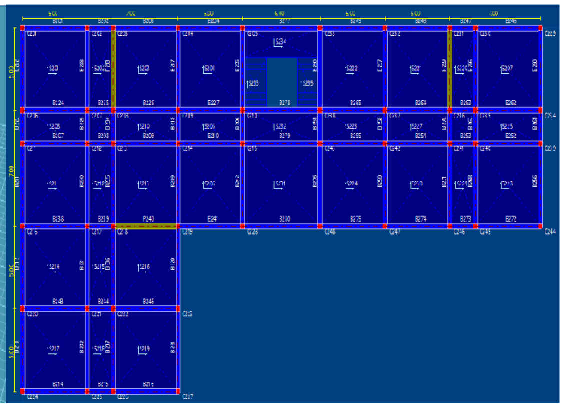
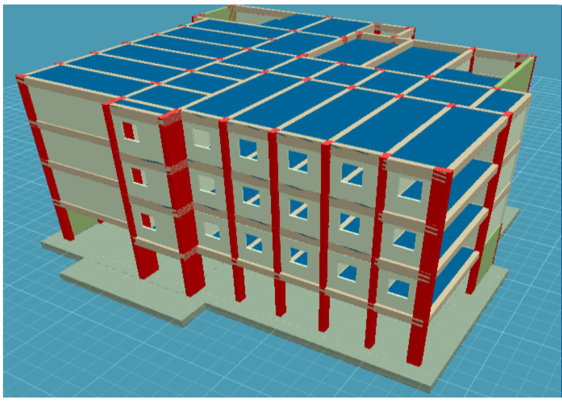
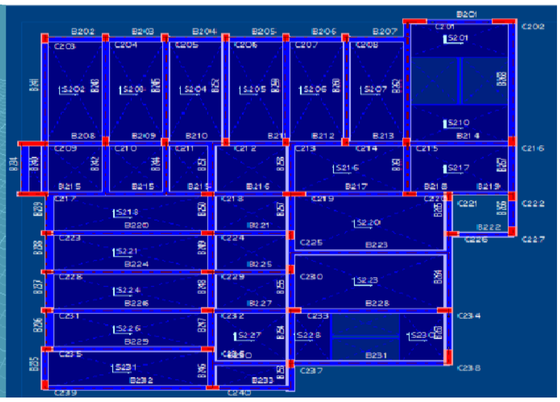
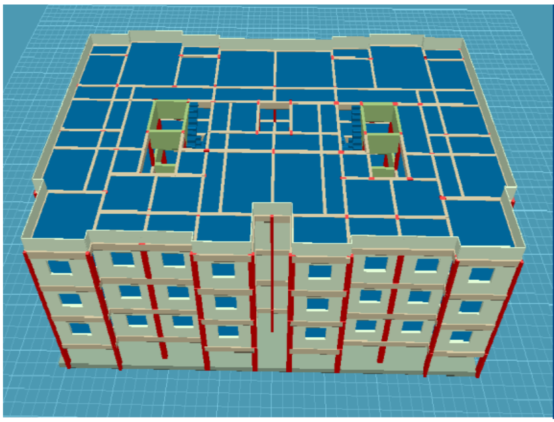
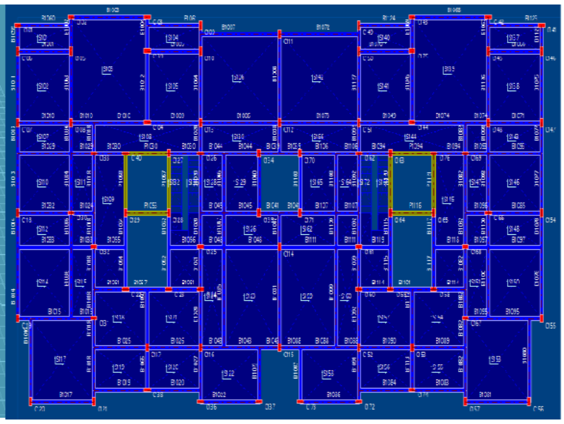
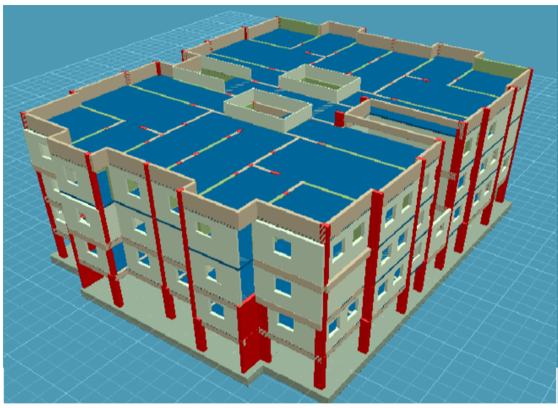
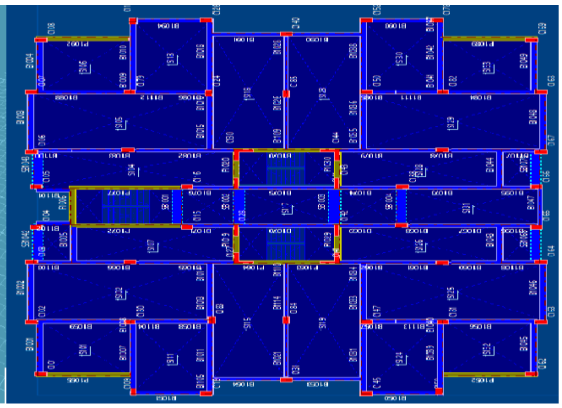
Table 4.1. Structural Performance Based on Damage [9].

Performance Group	Performance Level	Performance Criteria
S1	Immediate occupancy (IO)	• The ratio of beams in Slight Damage (SD) and Moderate Damage (MD) shall not exceed 10% in any story. • There must not be any columns beyond Slight Damage (SD). • There must not be any beams beyond Heavy Damage (HD).
S2	Life Safety (LS)	• The ratio of beams in Moderate Damage (MD) and Heavy Damage (HD) shall not exceed 30% in any story. • In any story, the shear force carried by columns in Heavy Damage (HD) shall not exceed 30% of story shear.
S3	Collapse Prevention (CP)	• The ratio of beams in Heavy Damage (HD) must not exceed 20% in any story. • In any story, the shear force carried by column that passed Slight Damage (SD) must not exceed 30% of story shear force.
S4	Collapse (C)	• If the failure cannot be prevented, it is under failure condition.

Table 4.2. Parameters considered in the study

Parameter	1	2	3	4
A1-Torsional Irregularity	Exist	None		
A2- Slab Discontinuities	Case 1 $Ab / A > 1/3$	Case 2 $Ab / A > 1/3$	Case 3 $Ab / A > 1/3$	None
A3 – Projections in Plan	Exist ax > 0.2 Lx , ay > 0.2 Ly	None		
B1- Interstorey Strength Irregularity (Weak Storey).	[ηci = (*Ae*)i / (*Ae*)i+1 < 0.80]	None [ηci > 0.80]		
B2- Interstorey Stiffness Irregularity (Soft Storey)	Exist open ground storeys >=%50	Exist height difference between the floors >1.3 times	None	
B3 - Discontinuity of Vertical Structural Elements	Exist	None		
C2 Weak Column – Strong Beam	Exist	None		
Stirrup Spacing	Ok	Not ok		
Average Shear Wall Ratio (ρ_{SWA})	N/A %0			% 0.01
Average Column Ratio (ρ_{CA}CA)	% 0.007			% 0.02
Concrete Compression Strength (C)	20	25		
Type of steel	220	360		
Soil Type (Z)	Z1	Z2	Z3	Z4
Code	2007	1997	1975	
Earthquake zone (EZ)	0.4	0.3	0.2	0.1
Importance Factor (I)	1	1.2	1.4	1.5
Structural Performance (S1-S4)	S1	S2	S3	S4

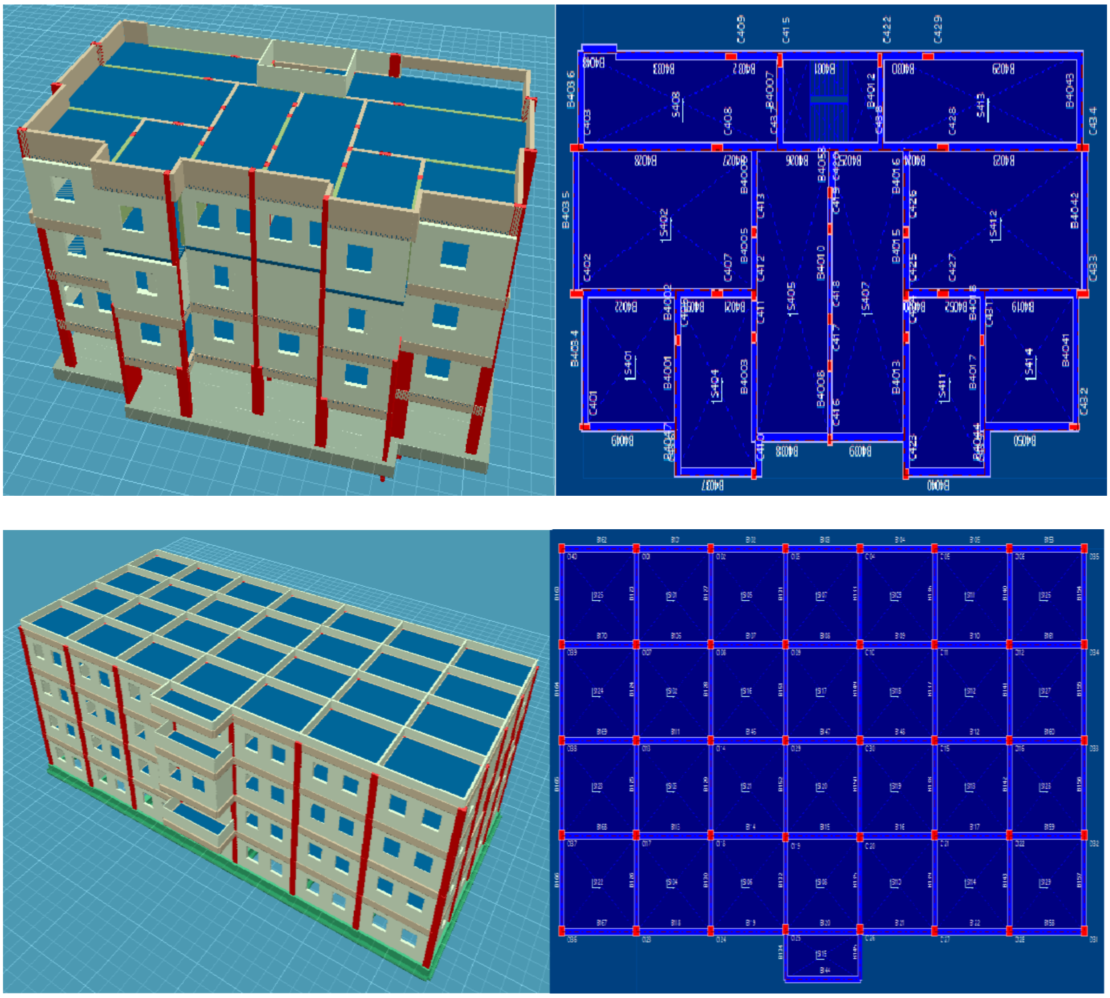


Figure 4.1. Ten different plans of building models used in this study

4.3 Definition of Parameters Affecting on Earthquake Performance of RC Buildings.

1) Number of Storey (NS)

This study deals with RC buildings with 4 storey only.

2) A1-Torsional Irregularity

Torsional irregularity is the first type of irregularity in TEC-2007 and called A1-type irregularity. Torsion in buildings is resulting from the asymmetrical distribution of rigidity. The case where Torsional Irregularity Factor, η_{bi}, which is defined as the ratio of the maximum drift at any storey to the average storey drift at the same storey in the same direction, is greater than 1.2, as shown in Figure 4.2.

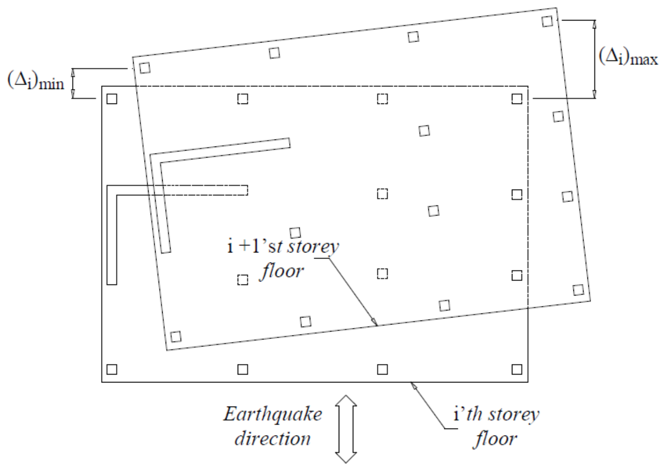


Figure 4.2. Type A1- Torsional Irregularity [9].

In this case the behaveior of floors are assumed to be rigid diaphragms:

$$\eta_{bi} = (\Delta i)_{max}/(\Delta i)_{ort} > 1.2 \tag{4.1}$$

$$(\Delta i)_{ort} = 1/2\,[(\Delta i)_{max} + (\Delta i)_{min}] \tag{4.2}$$

where;

η_{bi} : Factor of torsional irregularity for i'th storey,

$(\Delta_i)_{ort}$: Average storey drift of i'th storey of the building,

$(\Delta_i)_{max}$: Maximum storey drift of i'th storey of the building,

$(\Delta_i)_{min}$: Minimum storey drift of i'th storey of the building.

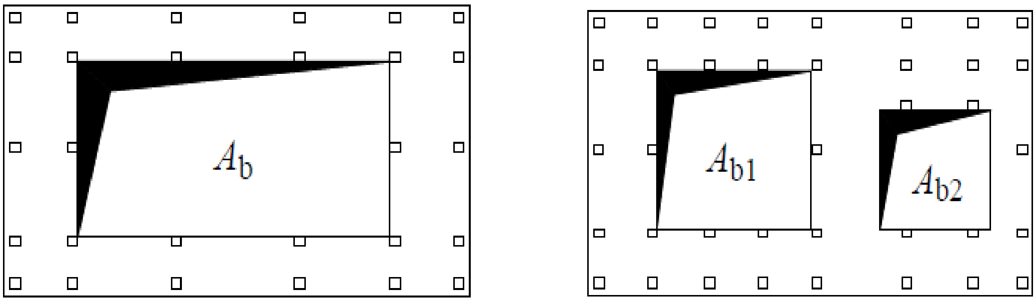
Storey drifts shall be calculated by considering the effects of ± %5 additional eccentrics [9].

In particular, it is quite difficult to determine Torsional Irregularity and in rapid assessment methods, it is selected based on engineering judgment, in this study Torsional Irregularity have been checked by Sta4cad software in order to be sure about the effect of Torsional Irregularity on earthquake performance.

3) A2-Floor Discontinuities

"Floor Discontinuities" is the second type of irregularity are called" A2-type irregularity". There are 3 cases of floor discontinuity irregularities that may occur in any floor:

- First case where the area of the openings in any floor exceeds 1/3 of the total gross area, as shown in Figures 4.3 (a) and (b).



Type A2-Irregularity-I (b) Type A2-Irregularity-I

Figure 4.3. Type A2- Floor Discontinuity Cases I [9].

$$A_b = \mathrm{A_{b1}} + \mathrm{A_{b2}} \tag{4.3}$$

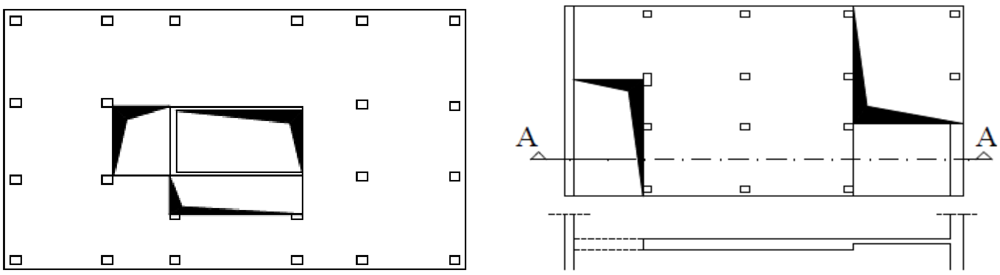
$$A_b/A > 1/3 \tag{4.4}$$

where;

A_b : Total area of openings

A : Total gross area of the floor

- Second cases where openings in the floor lead a difficult transfer of seismic loads safely to vertical elements in the structur, as shown in Figure 4.4 (a) and (b).



(a) Irregularity-II (b) Irregularity-III

Figure 4.4. Type A2- Floor Discontinuity Cases II [9].

- The third case having reductions in the in-plane strength and stiffness of floors.

4) A3- Projections in Plan

This type of irregularity called "A3-type of irregularity". The cases where projections beyond the re-entrant corners exceed the total plan dimensions by more than 20%. There are three drawings explaining this irregularity are shown below:

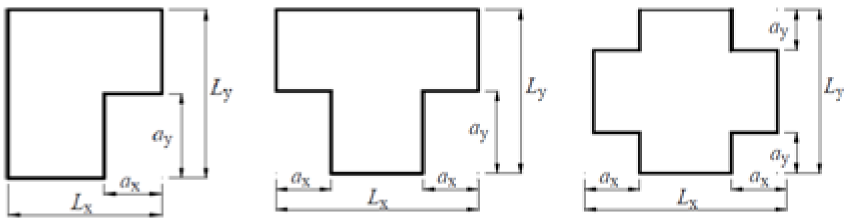


Figure 4.5. Type A3- Irregularity [9].

$$a_x > 0.2L_x \tag{4.5}$$

$$a_y > 0.2L_y \tag{4.6}$$

where;

L_x, L_y : Length of the building at x, y direction,

a_x, a_y : Length of re-entrant corners in x, y direction,

5) B1- Interstorey Strength Irregularity (Weak Storey).

This type of irregularity called "B1-type " in TEC-2007. In each of the orthogonal earthquake directions, the case where Strength Irregularity Factor η_{ci}, is less than 0.80 , where η_{ci} is the ratio of the effective shear area of any story to the effective shear area of the story immediately above. B1-type is commonly exist in the ground floors of the commercial buildings.

$$\eta_{ci} = (A_e)_i / (A_e)_i+1 < 0.8 \tag{4.7}$$

where;

A_e : Effective shear area.

Definition of effective shear area in any storey:

$$A_e = \quad A_w + \quad A_g + 0.15 \quad A_k \tag{4.8}$$

where;

A_w : Effective of web area of the column cross sections,

A_g : Section areas of structural elements at any storey,

A_k : Infill wall areas.

6) B2- Interstorey Stiffness Irregularity (Soft Storey)

This type is called B2-Type of irregularity. In each of the two orthogonal earthquake directions, the case where stiffness irregularity factor η_{ki} is greater than 2.0, where η_{ki} is the ratio of the average storey drift at any storey to the average storey drift at the storey above or below, as shown in the expression (4.9.a) and (4.9.b) :

$$\eta_{ki} = (\Delta_i/h_i)_{ave} / (\Delta_{i+1}/h_{i+1})_{ave} > 2.0 \tag{4.9.a}$$

$$\eta_{ki} = (\Delta_i/h_i)_{ave} / (\Delta_{i-1}/h_{i-1})_{ave} > 2.0 \tag{4.9.b}$$

where:

η_{ki}: Stiffness irregularity factor defined at i'th storey of the building,

Δ_i: Storey drift of i'th storey of the building [m],

h_i: Height of i'th storey of building [m].

Storey drifts shall be calculated, by considering the effects of ±%5 additional eccentricities.

Soft Story: It is exists when the stiffness of one story is less than the others. In a rapid visual screening, it is not possible to quantitatively determine and compare the stiffness of each story [6]. Generally in building the ground floor is designed to be higher than the other floors. Therefore, this causes a difference in stiffness or rigidity between floors. Also open ground storeys (i.e. shops) cause soft story, while great storey drift will be in the ground floor, the upper floors move such as a diaphragm. High stress concentration occurs and maybe leads to collapse the structure [27],[25]. Certain observable conditions, however, provide clues that a soft story may exist. If one of these conditions described below exist:

- One of the stories has fewer walls or columns (or more windows and openings) than the floor above it. Length of lateral system at any story is between 50% of that at story above. Figure 4.6 shows an industrial building with large openings at the ground floor. These large openings cause the first floor piers to be narrower than the piers at upper stories resulting in a weak story. This is considered as sevare vertical irregularity[6].

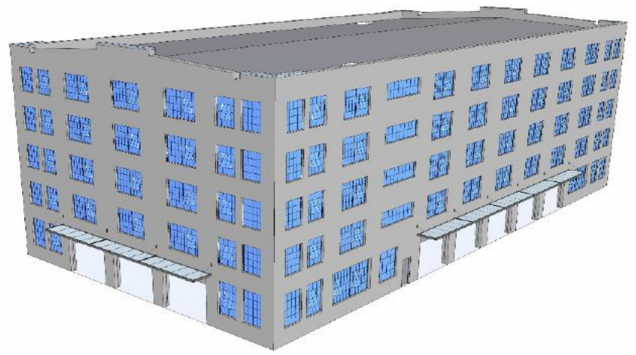


Figure 4.6. Illustration of a building with a soft ground story due to large openings and narrow piers.

- One of the stories is particularly tall compared to the other stories (height of any story is between 1.3 and 2.0 times the height of the story above). Figure 4.7 shows a building with a ground story significantly taller than the stories above. This difference in story height causes the piers to be taller at the first floor than at the upper stories resulting in a soft story. This is considered a severe vertical irregularity [6].

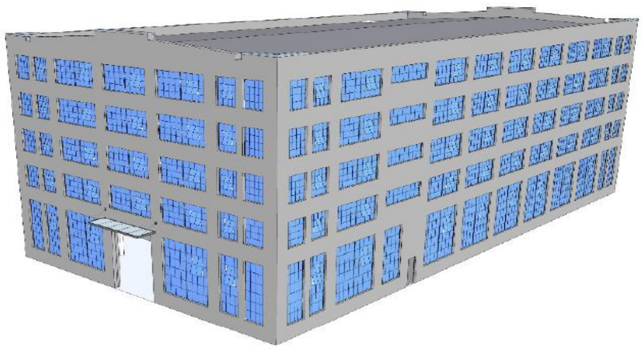


Figure 4.7. Illustration of a building with a soft ground story due to tall piers.

7) B3-Discontinuity of Vertical Structural Elements

In the TEC-2007 this type is called "B3- type of irregularity". This case occur when the vertical structural elements are removed or when the structural walls are supported by beams or columns, as shown in Figure 4.8.

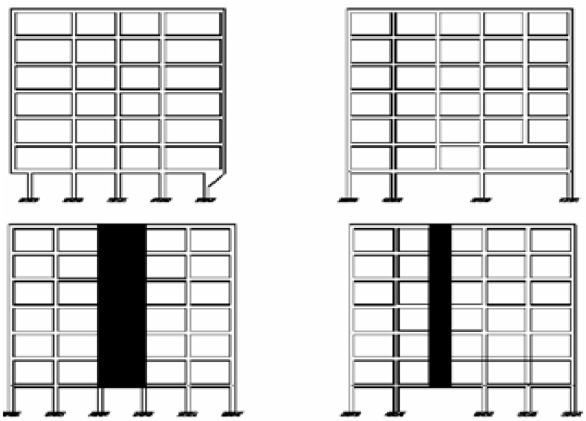


Figure 4.8. Type B3- Discontinuities of Vertical Structural Elements [9].

8) Weak Column – Strong Beam

When columns are weaker than beams, they cannot prevent the plastic hinge formations at columns ends. This kind of plastic hinging mechanisms result in high inelastic deformations at story level and thus instability of the frame system which may bring the failure. In the database E and NE representing existing or non existing Weak Column – Strong Beam respectively.

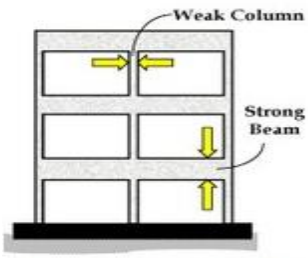


Figure 4.9. Weak Column – Strong Beam

9) Stirrup Spacing

In the database “OK” represents that Stirrup Spacing is according the code requirements and “NOT OK” represents that Stirrup Spacing is not according the code requirements.

10) Average Shear Wall Ratio

Shear walls increase strength and stiffness of buildings, which significantly reduces the lateral sway [28]. There are 3 different parameters used as an indication of the base shear capacity of the most critical story. These parameters indicating normalized areas of the members, which are :

- Normalized total column area (ntca).
- Normalized total wall area in x − direction (ntwa-x).
- Normalized total wall area in y − direction (ntwa-y).

The total column and wall areas are normalized with the normal floor area. In the calculation of the parameter, contribution of the partition walls are considered to be 10% of the contribution of the shear walls. The minimum of the normalized lateral strength indexes for walls calculated in the two orthogonal directions (ntwa-x, ntwa-y) from the following equations and the smaller value was considered in data.

$$ntwa - x = \frac{((A_{tsw})_x + 0.1(A_{tmw})_x)}{A_{nf}} \tag{4.10}$$

$$ntwa - y = \frac{((A_{tsw})_y + 0.1(A_{tmw})_y)}{A_{nf}} \tag{4.11}$$

where;

$(A_{tsw})_x$, $(A_{tsw})_y$: Total cross-sectional area of shear walls in x and y directions, respectively.

$(A_{tmw})_x$, $(A_{tmw})_y$: Total cross-sectional area of masonary walls in x and y directions, respectively.

A_{nf} : Normal floor area.

11) Average Column Ratio (CA)

Namely normalized total column area (ntca)

$$ntca = \frac{A_{tc}}{A_{nf}} \tag{4.12}$$

A_{tc} : Total cross-sectional area of columns,

A_{nf} :Normal floor area.

12) Concrete Compression Strength (C)

The compressive strength of concrete was considered as 20 MPa, 25 MPa to represent Concrete Compression Strength of existing buildings.

13) Type of Steel

The yield strength of the steel was selected as 220 MPa, 360 MPa and for longitudinal and transverse reinforcement in existing buildings.

14) Soil Type (Z)

Table 4.3. details the soil types in TEC-2007 that represent the most common local soil conditions. Table 4.4. details the local site classes that shall be considered as the bases of determination of local soil conditions.

Table 4.3. Local Site Classes [9].

Local Site Class	*Soil Group according to Table 6.1 and Topmost Soil Layer Thickness* (h_1)
Z1	Group (**A**) soils Group (**B**) soils with $h_1 \leq 15$ m
Z2	Group (**B**) soils with $h_1 > 15$ m Group (**C**) soils with $h_1 \leq 15$ m
Z3	Group (**C**) soils with 15 m $< h_1 \leq 50$ m Group (**D**) soils with $h_1 \leq 10$ m
Z4	Group (**C**) soils with $h_1 > 50$ m Group (**D**) soils with $h_1 > 10$ m

Table 4.4. Soil Groups [9]

Soil Group	Description of Soil Group	Standard Penetration (N/30)	Relative Density (%)	Unconfined. Compressive Strength (kPa)	Drift Wave Velocity (m / s)
(A)	**1.** Massive volcanic rocks, unweathered sound metamorphic rocks, stiff cemented sedimentary rocks **2.** Very dense sand, gravel... **3.** Hard clay and silty clay...	— > 50 > 32	— 85 – 100 —	> 1000 — > 400	> 1000 > 700 > 700
(B)	**1.** Soft volcanic rocks such as tuff and agglomerate, weathered cemented sedimentary rocks with planes of discontinuity…… **2.** Dense sand, gravel......... **3.** Very stiff clay, silty clay…	— 30 – 50 16 – 32	— 65 – 85 —	500 – 1000 — 200 – 400	700 – 1000 400 – 700 300 – 700
(C)	**1.** Highly weathered soft metamorphic rocks and cemented sedimentary rocks with planes of discontinuity **2.** Medium dense sand and gravel......................... **3.** Stiff clay and silty clay.....	— 10 – 30 8 – 16	— 35 – 65 —	< 500 — 100 – 200	400 – 700 200 – 400 200 – 300
(D)	**1.** Soft, deep alluvial layers with high ground water level **2.** Loose sand................... **3.** Soft clay and silty clay.....	— < 10 < 8	— < 35 —	— — < 100	< 200 < 200 < 200

15) Code

Code 1975

Code 1975 was valid for more than 20 years. Therefore, a lot of the existing buildings were constructed and designed, when this code was in effect. The term “ductility” was used for the first explicitly in this code. [35]. The seismic zone coefficient are (0.10, 0.08, 0.06 and 0.04, for Zones I, II, III and IV respectively).

Code 1998

For the seismic zones I, II, III and IV, the effective seismic acceleration coefficient (Ao) must be taken as 0.40, 0.30, 0.20 and 0.10, respectively,

This code includes ;

• Definition of the acceptable structural performance under the design earthquake,

• Quantitative definition of irregularities,

• Definition of the elastic design spectrum [35].

Code 2007

After 1999 Marmara Earthquake, it is seen obviously that the existing earthquake code is not adequate to figure out the seismic performance of the existing buildings. To understand the performance levels of the buildings and to take precautions for the earthquake in terms of retrofit strategies the earthquake code was revised. The new code which includes the performance based design was published at 06.03.2007 and also partially revised at 03.05.2007. This section of the study states the information of the performance based design according to TEC 2007. Most recent versions of codes for the seismic design published after 2007 includes a part about seismic safety assessment of existing buildings and retrofitting [9] [35].

16) Seismic Zone (EZ)

Fig.4.10 shows the current seismic risk map of Turkey. Zone 1 represent highest risk, while Zone 4 having minimum seismic risk.

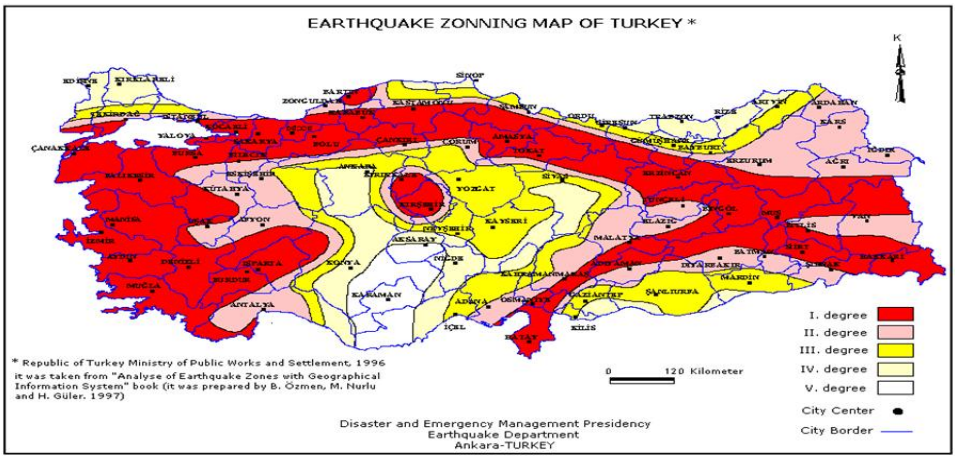


Figure 4.10. Seismic Hazard Zonation Map of Turkey [35].

Table 4.5 shows the effective seismic acceleration coefficient (*Ao)* for the seismic zones.

Table 4.5. Effective Ground Acceleration Coefficient (Ao)

Seismic Zone	A_o
1	0.40
2	0.30
3	0.20
4	0.10

17) Building Importance Factor (I)

Table 4.6. Building Importance Factor (I) [9].

Purpose of Occupancy or Type of Building	*Importance Factor (I)*
1. Buildings required to be utilized after the earthquake and buildings containing hazardous materials **a)** Buildings required to be utilized immediately after the earthquake (Hospitals, dispensaries, health wards, fire fighting buildings and facilities, PTT and other telecommunication facilities, transportation stations and terminals, power generation and distribution facilities; governorate, county and municipality administration buildings, first aid and emergency planning stations) **b)** Buildings containing or storing toxic, explosive and flammable materials, etc.	1.5
2. Intensively and long-term occupied buildings and buildings preserving valuable goods **a)** Schools, other educational buildings and facilities, dormitories and hostels, military barracks, prisons, etc. **b)** Museums	1.4
3. Intensively but short-term occupied buildings Sport facilities, cinema, theatre and concert halls, etc.	1.2
4. Other buildings Buildings other than above defined buildings. (Residential and office buildings, hotels, building-like industrial structures, etc.)	1.0

4.4 Matlab Neural Network Toolbox

The neural network toolbox is available in MATLAB 2015 Version 8.3 was used in this study to build the ANN model. Neural network algorithms in MATLAB2015

Version 8.3 can be quickly performed, and wide range of problems can be tested easily.

4.5 Construction of ANN Model

By applying the preprocessing criteria, it was thought that a reliable training set of data was obtained. The following sections explain the details of the training process that was followed in this research. Also the validation of the developed ANN model is discussed.

4.5.1 Training Strategy of the ANN Model

Feed forward back propagation algorithm was chosen after pre-processing the data has been completed. Back propagation is the most successful and widely used in civil engineering applications [30,13].

The first step in training is the data scaling.

Sigmoid transfer function usually used in the networks. Upper and lower limits of output are generally 1 and 0, respectively. Scaling of the inputs between [-1, +1] helping in improving the learning speed significantly [18]. A simple linear normalization function between zero and one is:

$$S = {(P - P_{min})}\big/{(P_{max} - P_{min})} \tag{4.13}$$

where S is the normalized value of the variable P, $P_{\min}$ and $P_{\max}$ are variable minimum and maximum values, respectively.

The second step in training a feed forward network is to create the network object. A feed forward network can be created via using the function nntool by using a graphical user interface (GUI). This interface enable you to:

• Create neural networks,

• Enter the data into the GUI,

• Initialize, train, and simulate networks,

• Export the training results from the GUI to the command line workspace,

• Import the data from the command line workspace to the GUI.

The third step is setting the training parameters:

a) The number of ‘epochs’(number of times of training) affects on the performance. This number depends on many factors, the most important are :

- Number of training data,
- Number of hidden layers,
- Number of neurons in hidden layers,
- Number of dependent output parameters [18].

b) Maximum permissible error.

c) The number of iterations for which the error becomes constant.

d) The training status is displayed for every show iteration of the algorithm.

In Back propagation algorithm inside MATLAB the data can be divided into 3 sets: training, validation and testing sets.

The training set is used to reduce the ANN error. The error on the validation set is monitored during the training process. The validation set error will normally decrease during the initial phase of training, as does the training set error [13,31].

However, when the network start to over-fit the data, the error on the validation set will start to increase. When the validation set error increases for a specified number of epochs, the training is stopped. The test set is used as a further check for the generalization of the ANN, but it has no any effect on the training.

In this study, data set was devided into three sets : a %70 for training, 15% for validation and 15% for testing [13].

The final step is plotting the training progress and the correlation coefficient “r”.

The training process of ANN is presented in a flow chart in Fig 4.11.

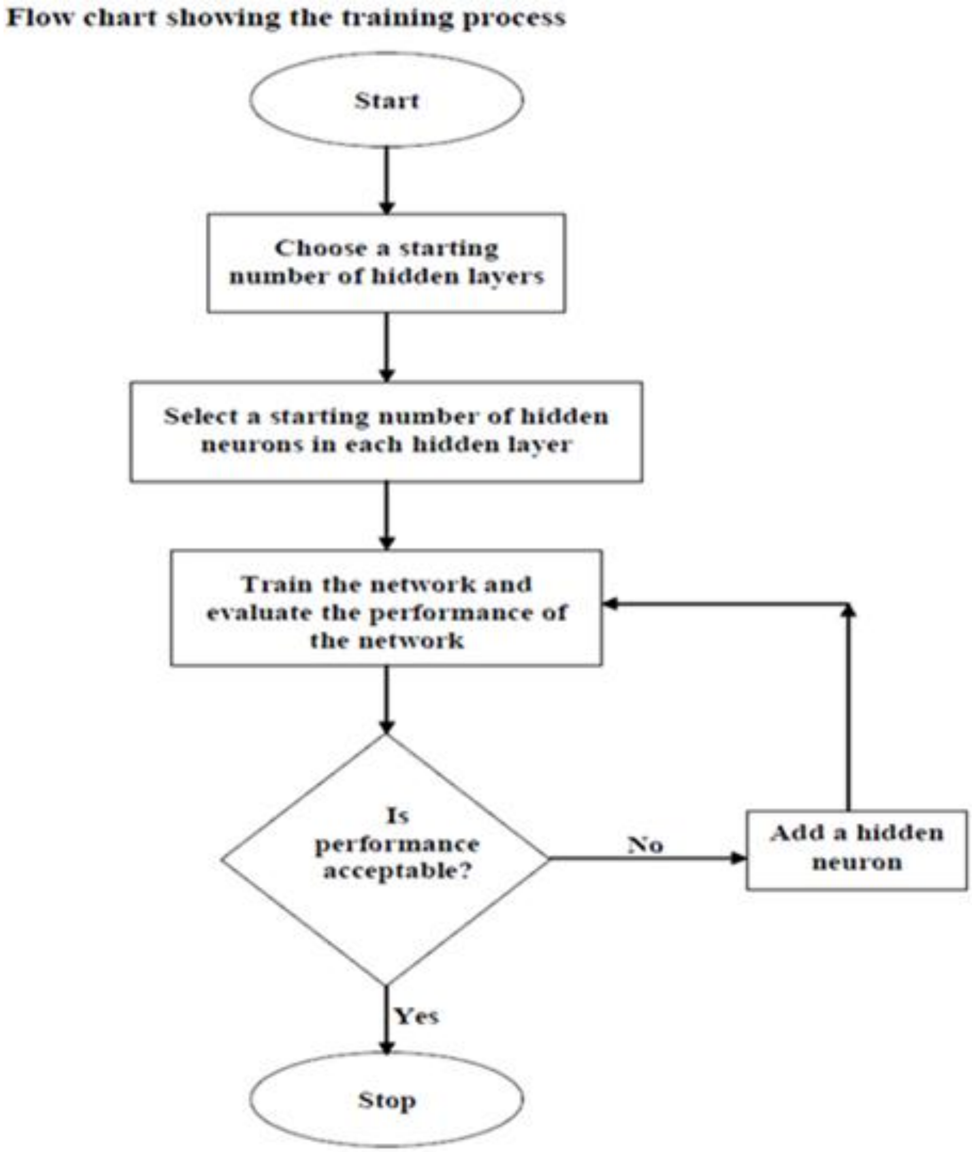


Figure 4.11. Flow chart for training process of neural networks [32]

4.6 Topology of the developed ANN

Two separate ANN models were trained: one for the linear performance analysis method, and the second one is the nonlinear static pushover analysis method.

4.6.1 Earthquake Performances ANN Model.

There were 16 input parameters; Torsional Irregularity (A1), Slab Discontinuities (A2), Projections in Plan (A3), Weak Storey (B1), Soft story (B2), Discontinuity of Vertical Structural Elements (B3), Weak Column – Strong Beam (C2), Stirrup Spacing (*cm*), Average Shear Wall Ratio, Average Column Ratio (CA) , Concrete Compression Strength (C), Type of steel (Fy), Soil Type (Z), Code (1975– 1997-2007), Earthquake zone (EZ) and Importance Factor (I) The output parameter is the Structural Performance (S1-S4).

After several trials and iterations using MATLAB tools the following topology can be obtained for the Earthquake Performances of Reinforced Concrete Buildings.

The topology of the network is:

Type of architecture : Multi-layer feed forward

Number of layers (hidden + output): 2

Note : The input layer does not count of source nodes because no computation is performed there.

Table 4.7. Number of Used Neurons and Transfer Functions.

Layer Name	**Number of Neurons**	**Transfer Function**
First hidden layer	10	logsig
Output layer	4	purlin

Training algorithm used: Back probation algorithm

Number of epochs required for training: 1000

Performance function: Mean Square Error (MSE) .

The architecture of ANN model for the Earthquake Performances of Reinforced Concrete Buildings is shown in Fig 4.12.

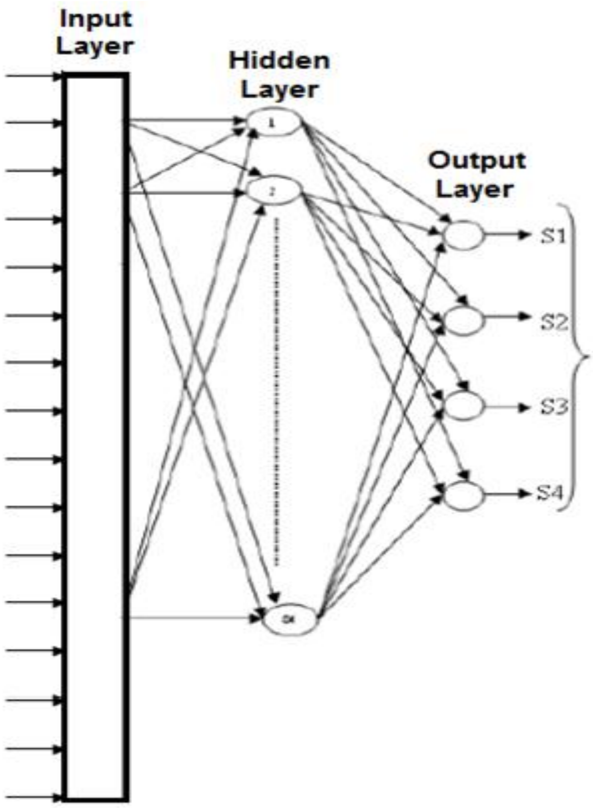


Figure 4.12. The architecture of ANN model for Earthquake Performances of Reinforced Concrete Buildings.

4.7 Performance of ANN

The Mean Square Error (MSE) using to monitor the training process. Process of training will stop when any of the following criteria is satisfied:

- When the number of (epochs) reach to the maximum;
- When the average training error reach to the target;
- The performance has been minimized to the target;
- When the validation set error starts to increase [31,18,13].

The progress of the training was examined by plotting the training, validation and test Mean Square Error (MSE), versus the performed number of iterations, as presented in Fig. 4.13.

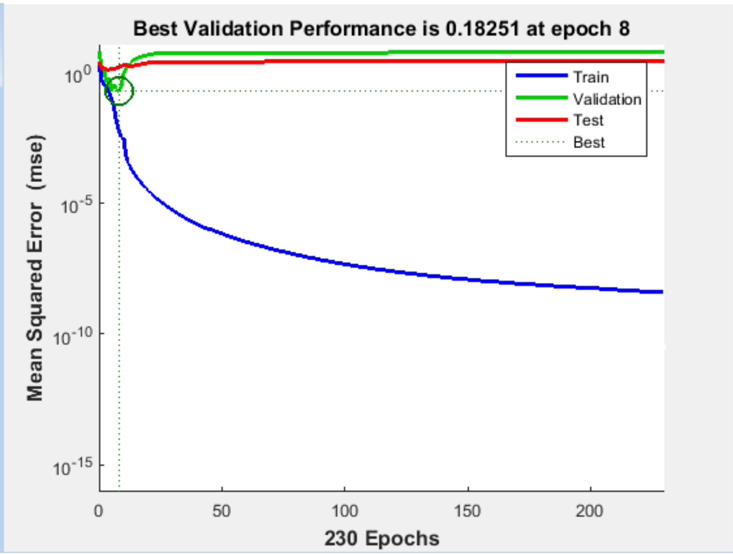


Figure 4.13. Training progress of ANN

The results shown in Fig. 4.13 shows that there is no significant over-fitting occurred because both of the validation set error and the test set error have similar characteristics. To insure the adequacy of the trained neural network model, the testing data which has been taken randomly from the whole data is taken and trained separately.

Fig. 4.14 gives comparisons of the Earthquake Performances from experiments and those obtained from the trained neural network (a) for 182 training data set and (b) for 39 validation data set (c) for 39 testing data set.

One can see from this comparisons that, earthquake performance using the trained ANN model is in good agreement with the experimental results 90% accuracy for non-linear static pushover analysis method and about 89% accuracy for linear performance analysis method.

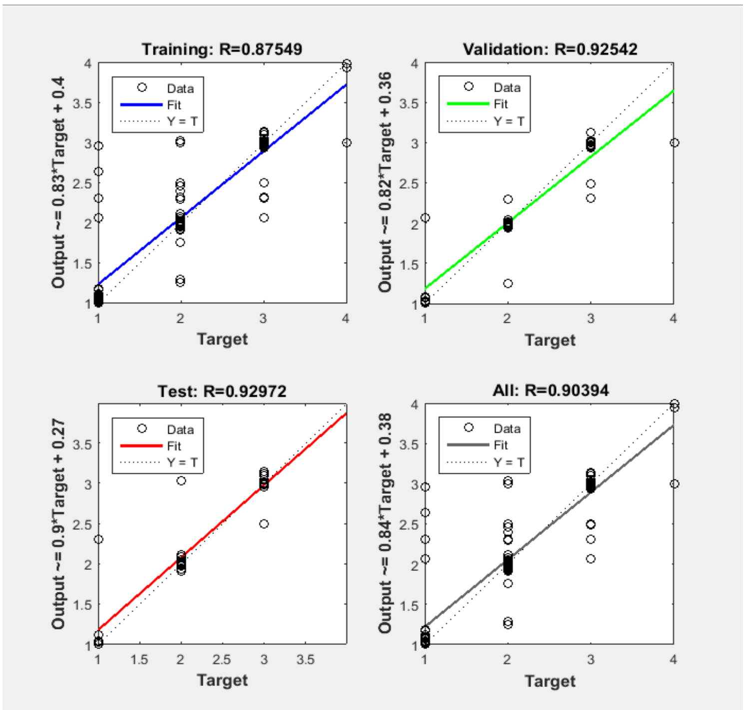


Figure 4.14. Performance of ANN for nonlinear static pushover analysis method

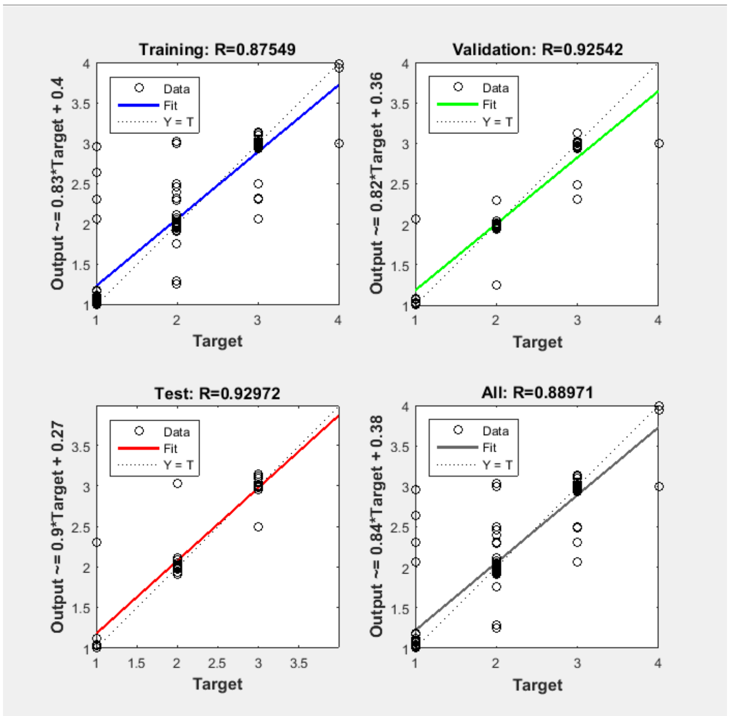


Figure 4.15. Performance of ANN for linear performance analysis method

4.8 Testing of Neural Network Performance

In order to check the ability of ANN model to predicting the earthquake performance of RC buildings, 10 models of buildings that were not used in the training network have been used in comparison between the predicted performance by ANN model and the performance by analysis using (STA4cad) as Table 4.9 shows.

The developed neural network model succeed to predict the earthquake performance for 9 Buildings correctly.

where :

1: Exist

0: None

Table 4.8. Data used in testing the neural network model

Parameter	1	2	3	4	5	6	7	8	9	10
A1-Torsional Irregularity	0	1	0	0	1	1	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	1	0	1	0	0	1
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	1	0	1	0	0	1
B3 - Discontinuity of Vertical Structural Elements	0	0	0	1	1	0	1	0	0	1
C2 Weak Column – Strong Beam	0	0	1	0	1	0	1	0	0	1
Stirrup Spacing	1	1	0	0	0	0	0	1	1	0
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	2	2	0	2
Average Column Ratio (ρ_{CA}CA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.0087	0.01
Concrete Compression Strength (C)	20	25	20	20	20	20	20	20	25	20
Type of steel	220	220	220	220	360	360	220	360	360	220
Soil Type (Z)	Z2	Z1	Z1	Z1	Z1	Z2	Z3	Z1	Z2	Z1
Code	1975	1997	1975	1975	1997	1975	1975	1997	2007	1975
Earthquake zone (EZ)	0.1	0.3	0.2	0.2	0.2	0.4	0.2	0.4	0.2	0.4
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Linear Performance by STA4cad	1	2	2	3	4	2	3	2	1	4
Non Linear Performance by STA4cad	1	2	2	2	3	4	1	2	1	4
Linear Performance by ANN	**1**	2	2	3	4	2	3	**4**	1	4
Non Linear Performance by ANN	**1**	2	2	2	3	4	1	**4**	1	4

Chapter 5

PARAMETRIC STUDY

5.1 Introduction

The advantage of trained neural network models is that parametric studies can be easily done by simply varying one input parameter and all remaining input parameters are set to constant values [34]. In this chapter the effective parameters on earthquake performance have been investigated by using the trained model of Artificial Neural Network to determine the most effective parameters on earthquake performance of RC buildings.

Each one of the parameters have an impact on the seismic performance of buildings, according to the results of the 260 model analysis, but this effect may be obvious and significant in some cases and in others it have not shown clear because there is another factor more important. In order to determine the most parameters affect on seismic performance of buildings the effect of each parameter on the seismic performance of the building has been checked separately in three different cases where the value of each parameter has changed in each case with the stability of the rest of the parameters in each case. These three cases are:

The first case: In this case, all the parameters are in the lower case with less value or non-existent, the effect of each parameter on the seismic performance of the building has been checked separately to determine its effect on the seismic performance in the absence of the effect of other variables.

The second case: In this case, all the parameters are in the average case with medium value, the effect of each parameter on the seismic performance of the building has been checked separately to determine its effect on the seismic performance with a limited effect from the rest of the parameters.

The third case: In this case, all the parameters are in the upper case with maximum value, the effect of each parameter on the seismic performance of the building has been checked separately to determine its effect on the seismic performance with full effect from the rest of the parameters.

5.2 Linear Performance Analysis Model

Table 5.1. The cases used in testing of effect of each parameter

Case A : The lower case	Case B : The average case	Case C : The upper case
(A1) = None	(A1) = None	(A1) = Exist
(A2) = None	(A2) = None	(A2) = Exist
(A3) = None	(A3) = None	(A3) = Exist
(B1) = None	(B1) = None	(B1) = Exist
(B2) = None	(B2) = None	(B2) = Exist
(B3) = None	(B3) = None	(B3) = Exist
(C2) = None	(C2) = None	(C2) = Exist
Stirrup Spacing = Not Ok	Stirrup Spacing = Not Ok	Stirrup Spacing = Ok
(ρ_{SWA}) = None	(ρ_{SWA}) = None	(ρ_{SWA}) = 1%
(CA) = 0.007	(CA) = 0.007	(CA) = 0.02
(C) = 20	(C) = 25	(C) = 25
(Fy) = 220	(Fy) = 360	(Fy) = 360
Soil Type = Z1	Soil Type = Z1	Soil Type = Z1
Code = 1975	Code = 1997	Code = 2007
(EZ) = 0.2	(EZ) = 0.3	(EZ) = 0.4

5.2.1 The Shear Wall ratio

It can be noted from Fig. 5.1 that the performance increases with increasing the shear wall ratio while other parameters are constant. This is consistent. Also the increasing rate in the predicted performance is larger in all cases, which means that the shear wall ratio is the most significant structural components that affect the performance.

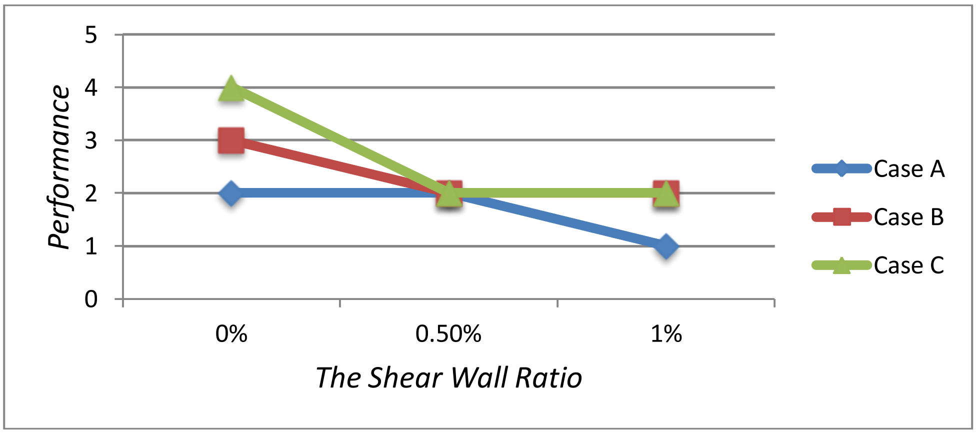


Figure 5.1. Effect of Shear Wall Ratio on earthquake performance

5.2.2 A1-Torsional Irregularity

It can be noted from Fig. 5.2 that, the performance decreases when A1-Torsional Irregularity be exist while other parameters constant. In other words, it is clear that the performance is inversely proportional to the A1-Torsional Irregularity ratio .

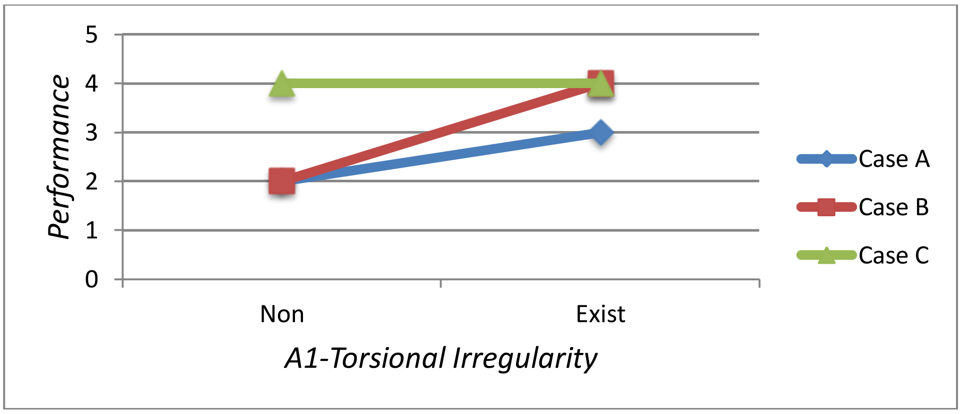


Figure 5.2. Effect of A1-Torsional Irregularity on earthquake performance

5.2. 3 A2- Slab Discontinuities

Fig. 5.3 shows that, the performance has no clear change when Slab Discontinuities (A2) be exist while other parameters constant.

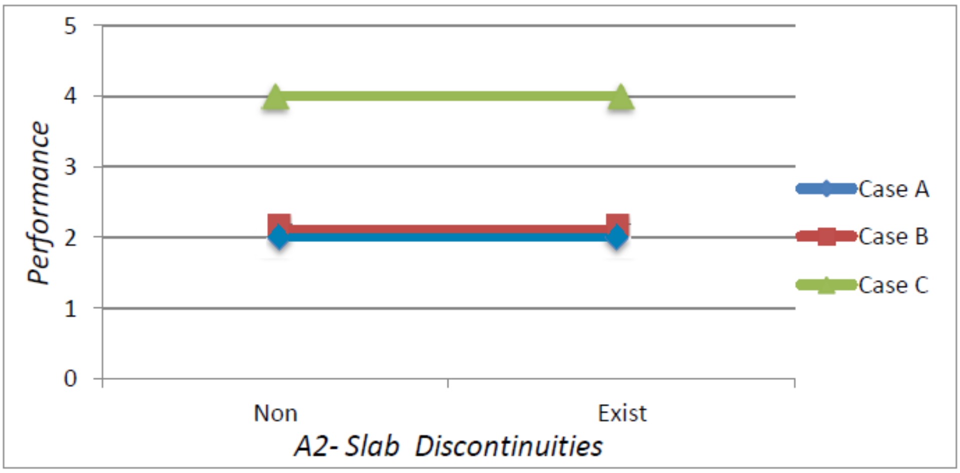


Figure 5.3. Effect of A2- Slab Discontinuities on earthquake performance

5.2. 4 A3 – Projections in Plan

Fig. 5.4 shows that the performance has no clear change when Projections in Plan (A3) be exist while other parameters constant.

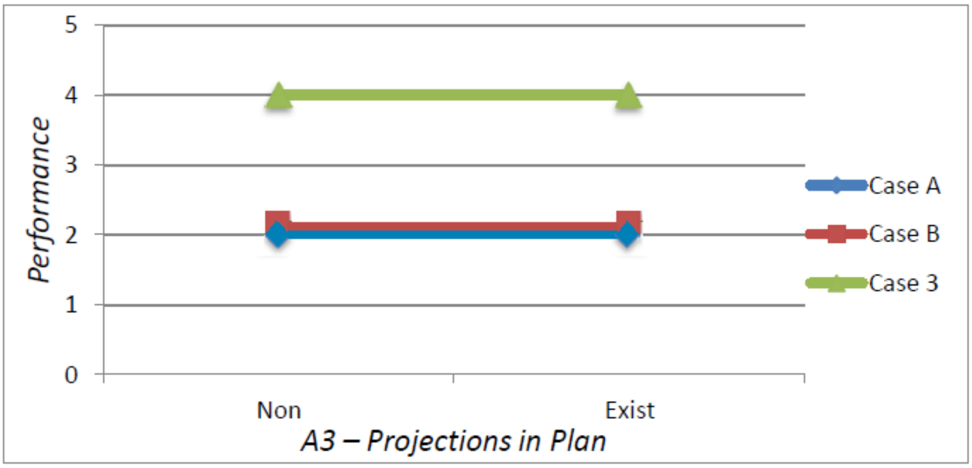


Figure 5.4. Effect of A3 – Projections in Plan on earthquake performance

5.2. 5 B1- Interstorey Strength Irregularity (Weak Storey)

We can see in Fig. 5.5 that. when Weak Storey exist the performance decreases and causes building to collapse .

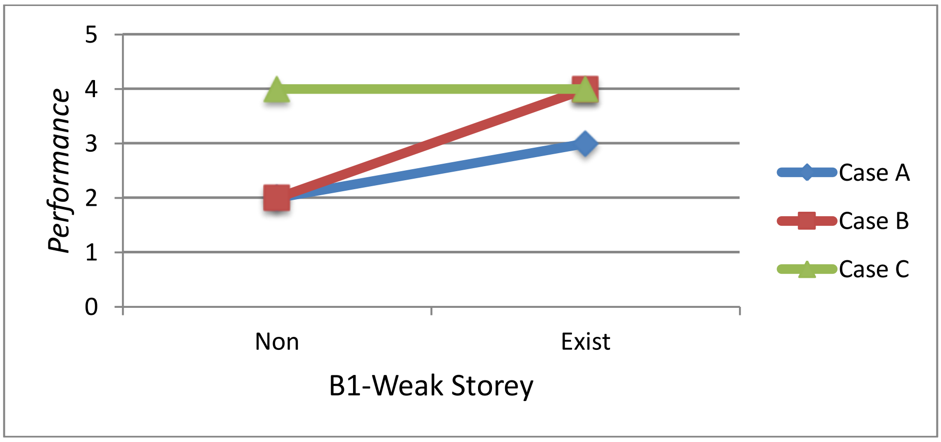


Figure 5.5. Effect of Weak Storey on earthquake performance

5.2.6 B2- Interstorey Stiffness Irregularity (Soft Storey)

Fig. 5.6 illustrate that Soft Storey has negative effect on the performance of building and lead to Poor performance .

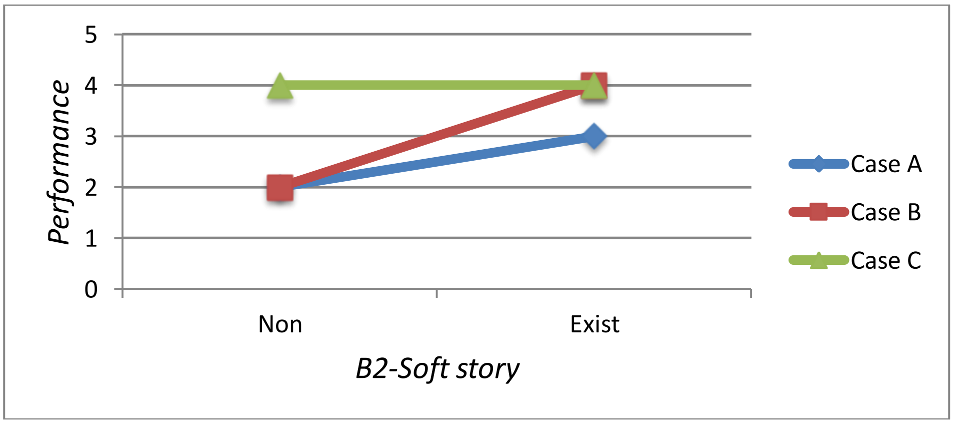


Figure 5.6. Effect of Soft Storey on earthquake performance

5.2.7 B3 - Discontinuity of Vertical Structural Elements

The existing of B3- Discontinuity of Vertical Structural Elements lead to reduction in the performance as Fig. 5.7 shows and collapsing may occur.

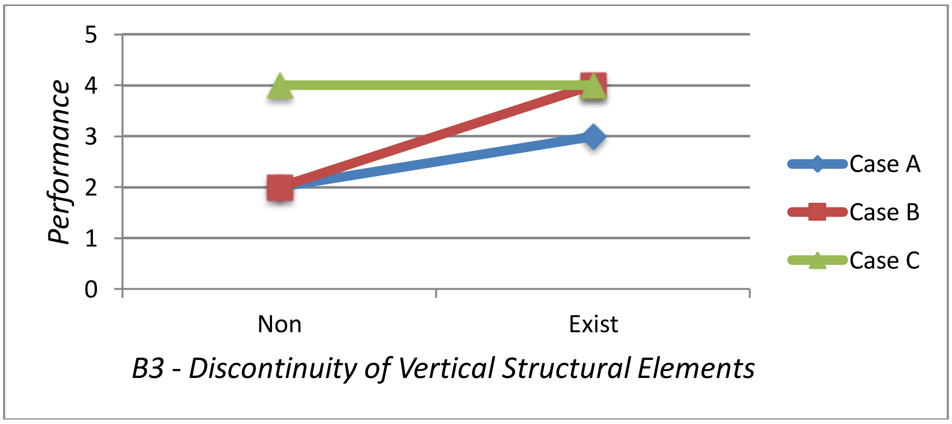


Figure 5.7. Effect of B3 - Discontinuity of Vertical Structural Elements on earthquake performance

5.2.8 C2 Weak Column – Strong Beam

Fig. 5.8 elucidate the Effect of Weak Column – Strong Beam on earthquake performance, this effect is very small when exist alone as in case A and also it's effect not significant when the effect of rest of parameters are exist as in case C but it can be dangerous if it participated with other parameters like insufficient Stirrup Spacing or low steel tension strength as in case B.

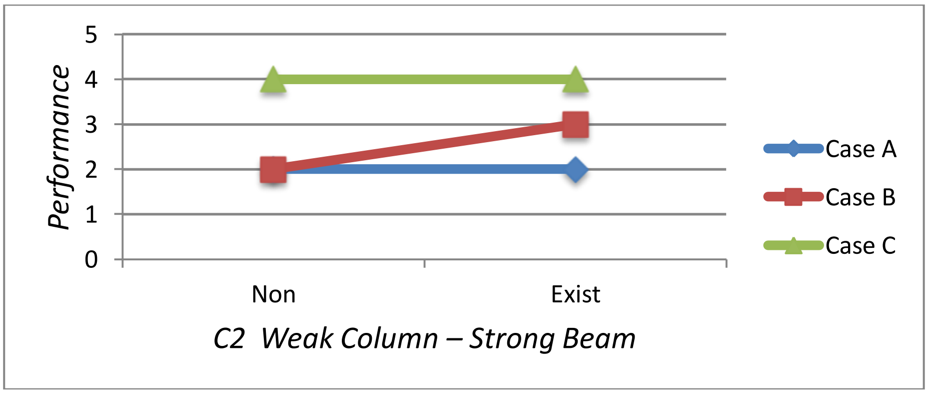


Figure 5.8. Effect of Weak Column – Strong Beam on earthquake performance

5.2.9 Stirrup Spacing

It can be noted from Fig. 5.9 that, the performance decreases when Stirrup Spacing is not OK. If other parameters were sufficient, Stirrup Spacing has no effect or has slight effect on the performance alone as in case A and C but this effect could be worse in the presence of other parameters as low ratio of columns as in case B.

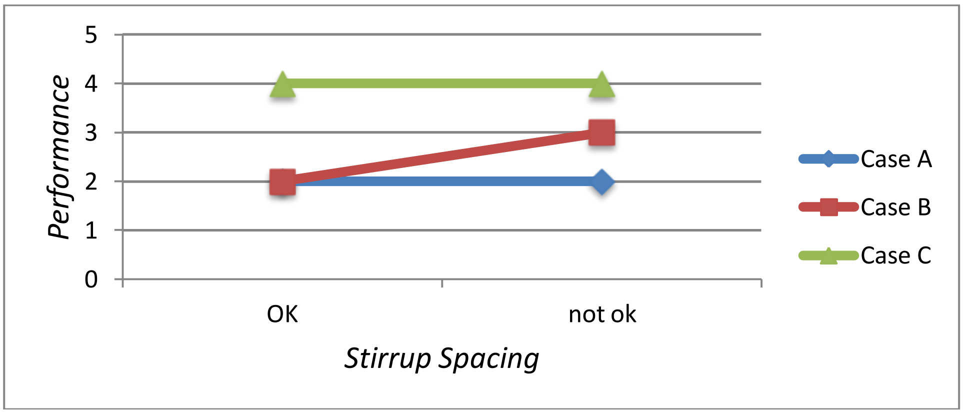


Figure 5.9. Effect of Stirrup Spacing on earthquake performance

5.2.10 Average Column Ratio

Fig. 5.10 shows that the Average Columns Ratio has a significant effect on the earthquake performance especially when there is no shear walls, buildings that have high Average Columns Ratio and do not have vertical irregularity did not collapsed in most of the cases except when **Earthquake zone (EZ) = 0.4.**

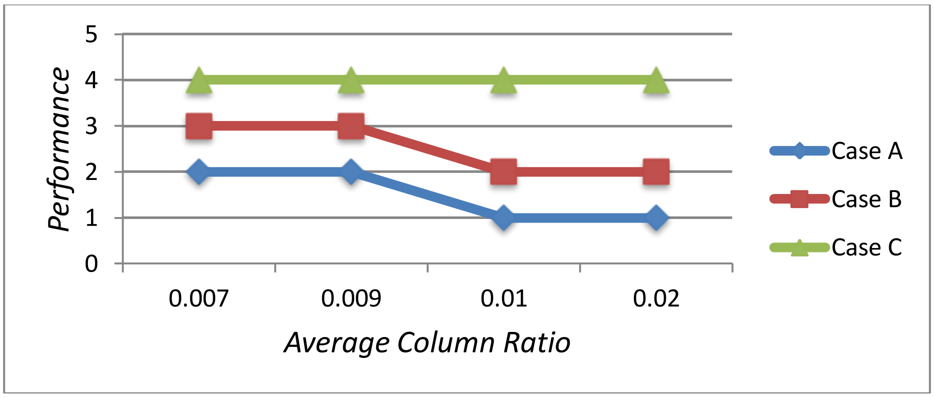


Figure 5.10. Effect of Average Column Ratio on earthquake performance

5.2. 11 Concrete Compression Strength (C)

According to Fig. 5.11, increasing of Concrete Compression Strength improves the performance .

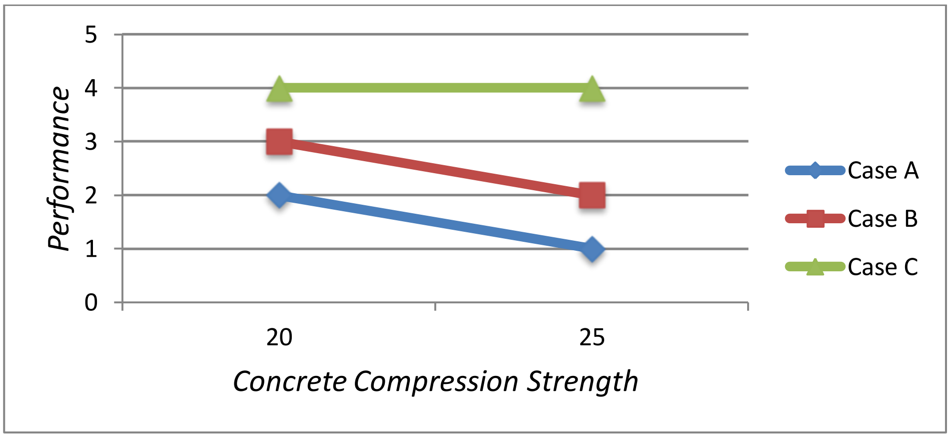


Figure 5.11. Effect of Concrete Compression Strength on earthquake performance

5.2.12 Type of Steel

According to Fig. 5.12, increasing of Steel Tension Strength improves the performance .

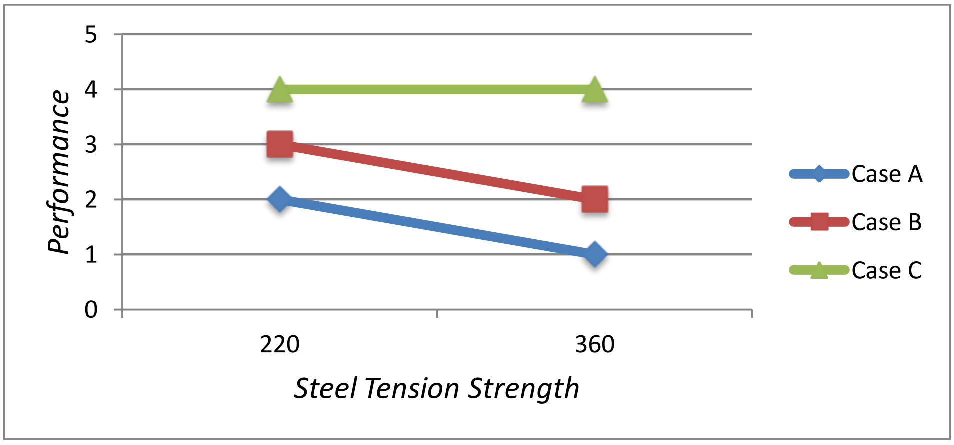


Figure 5.12. Effect of Steel Tension Strength on earthquake performance

5.2.13 Soil Type

It can be noted from Fig. 5.13 that, in case C with full effect from the rest of the parameters Soil type has no effect but in case B change soil type from Z2 to Z1 can prevent structure from collapsing

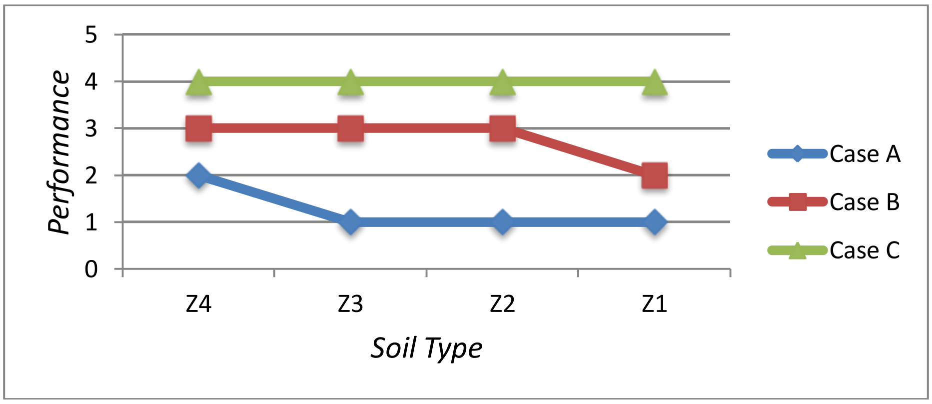


Figure 5.13. Effect of Soil Type on earthquake performance

5.2.14 Code

The code using in designing buildings and the year of construction are very important and affect the seismic performance as Fig. 5.14 shows, where buildings that were built according to code 1975 and 1997 have been collapsed in cases C however there is no collapsing in the buildings that were built according to code 2007 in all cases.

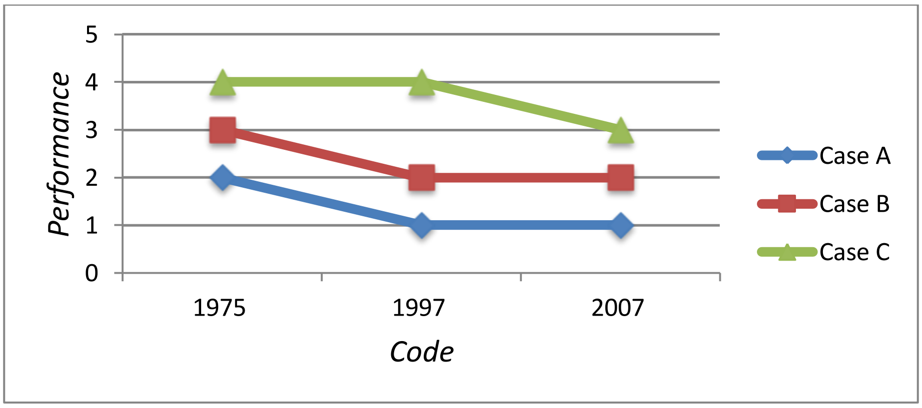


Figure 5.14. Effect of Code on earthquake performance

5.2.15 Earthquake zone (EZ)

Fig. 5.15 shows that, all buildings in case A still in life safety level in all the Earthquake zones, but those in case C collapsed in zones 0.3 and 0.4 and buildings in case B also collapsed in zones 0.4.

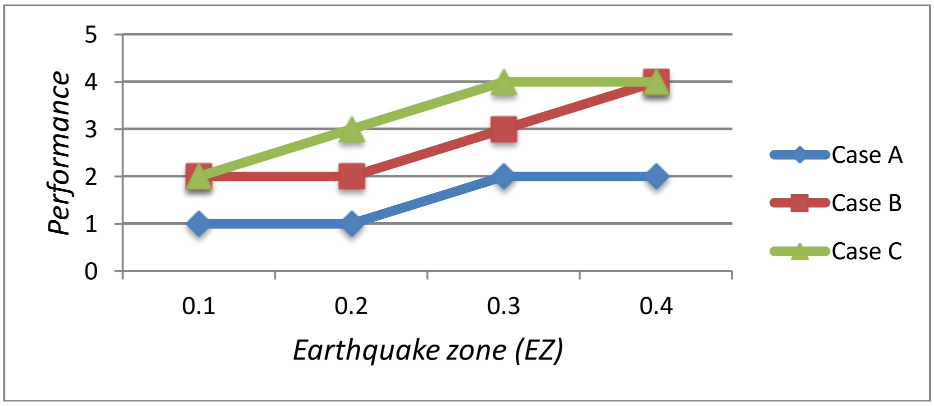


Figure 5.15. Effect of Earthquake Zone on earthquake performance

5.2.16 Importance Factor (I)

According to Fig. 5.16, all buildings in case C have been collapsed with all different values of Importance Factor. On the other hand, buildings in case A and B still under safety level except the building with Importance Factor = 1.5 in case B that enter collapse prevention level.

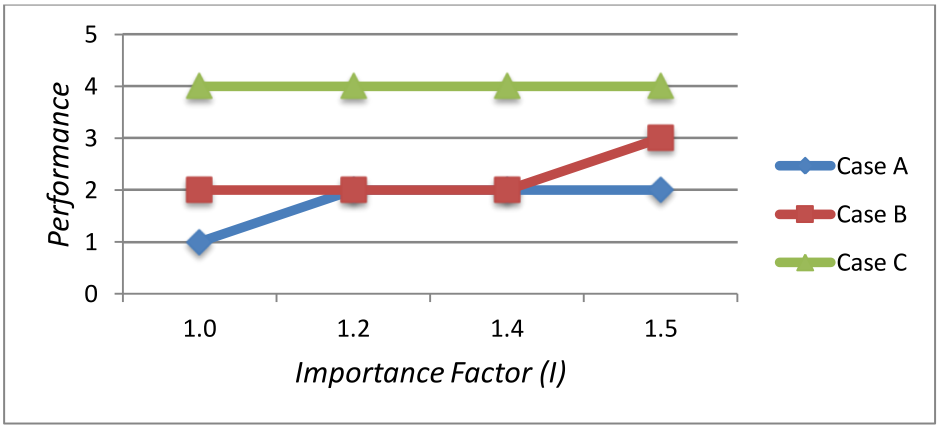


Figure 5.16. Effect of Importance Factor (I) on earthquake performance

5.3 Nonlinear Performance Analysis Model

Table 5.2. The cases used in testing of effect of each parameter

Case A : The lower case	Case B : The average case	Case C : The upper case
(A1) = None	(A1) = None	(A1) = Exist
(A2) = None	(A2) = None	(A2) = Exist
(A3) = None	(A3) = None	(A3) = Exist
(B1) = None	(B1) = None	(B1) = Exist
(B2) = None	(B2) = None	(B2) = Exist
(B3) = None	(B3) = None	(B3) = Exist
(C2) = None	(C2) = None	(C2) = Exist
Stirrup Spacing = Not Ok	Stirrup Spacing = Not Ok	Stirrup Spacing = Ok
(ρ_{SWA}) = None	(ρ_{SWA}) = None	(ρ_{SWA}) = 0.5%
(CA) = 0.007	(CA) = 0.009	(CA) = 0.02
(C) = 20	(C) = 25	(C) = 25
(Fy) = 220	(Fy) = 360	(Fy) = 360
Soil Type = Z1	Soil Type = Z1	Soil Type = Z1
Code = 1975	Code = 1997	Code = 2007
(EZ) = 0.2	(EZ) = 0.3	(EZ) = 0.4

5.3.1 The Shear Wall Ratio

It can be noted from Fig. 5.17 that, the performance increases with increasing the shear wall ratio while other parameters constant. This is consistent shows also that the increasing rate in the predicted performance is larger in all cases, which means that the shear wall ratio is the most significant structural components that affect the performance.

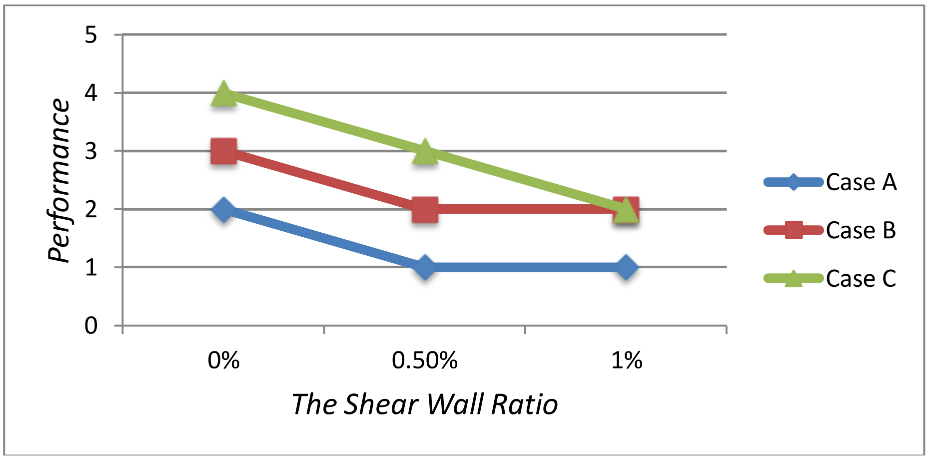


Figure 5.17. Effect of Shear Wall Ratio on earthquake performance

5.3.2 A1-Torsional Irregularity

It can be noted from Fig. 5.18 that, the performance decreases when A1-Torsional Irregularity be exist while other parameters constant. In other words, it is clear that the performance is inversely proportional to the A1-Torsional Irregularity ratio .

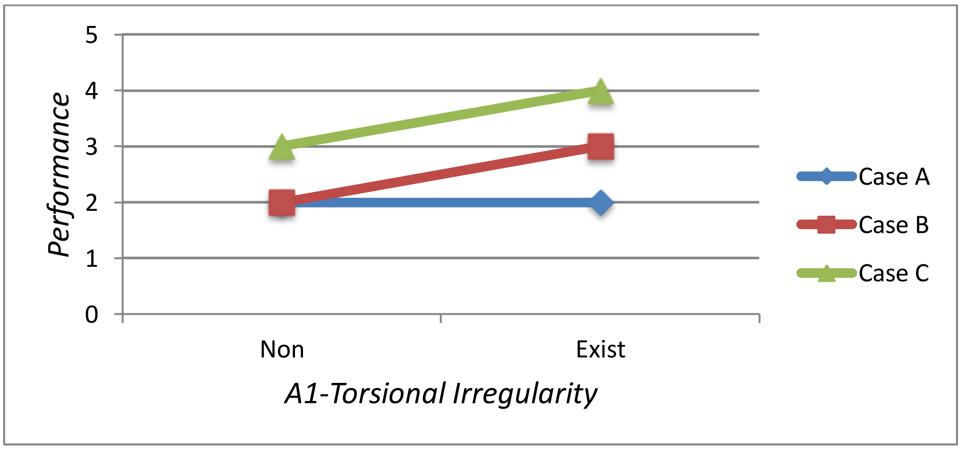


Figure 5.18. Effect of A1-Torsional Irregularity on earthquake performance

5.3.3 A2- Slab Discontinuities

Fig. 5.19 shows that, the performance has no clear change when Slab Discontinuities be exist while other parameters constant in case B and C and slight effect in case A.

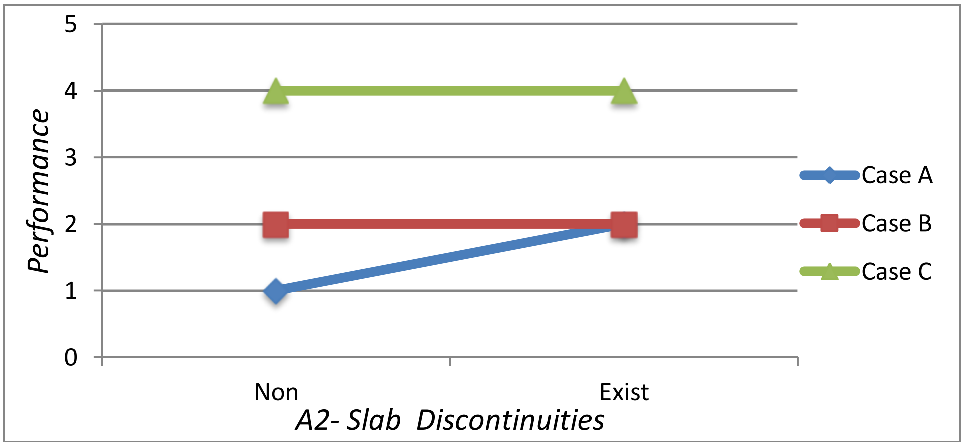


Figure 5.19. Effect of A2- Slab Discontinuities on earthquake performance

5.3.4 A3 – Projections in Plan

Fig. 5.20 shows that the performance has no clear change when Projections in Plan (A3) be exist while other parameters constant in case B and C and slight effect in case A.

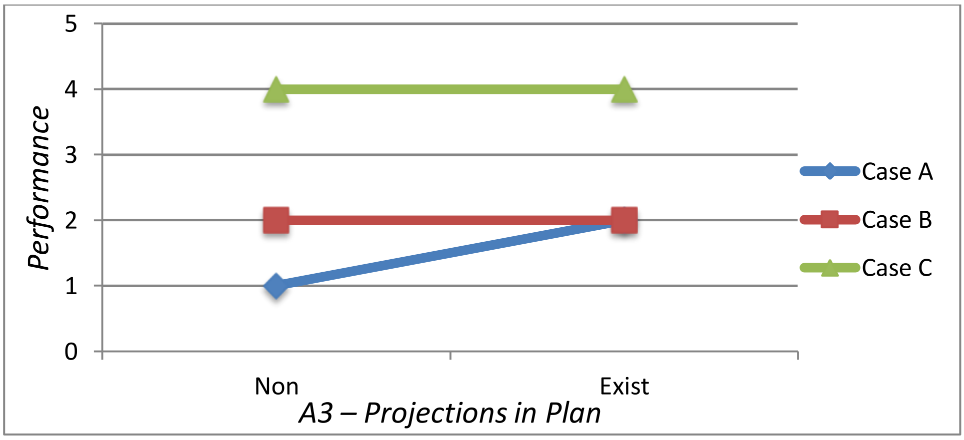


Figure 5.20. Effect of A3 – Projections in Plan on earthquake performance

5.3.5 B1- Interstorey Strength Irregularity (Weak Storey)

We can see in Fig. 5.21 that when Weak Storey be exist the performance decreases and cause building collapse.

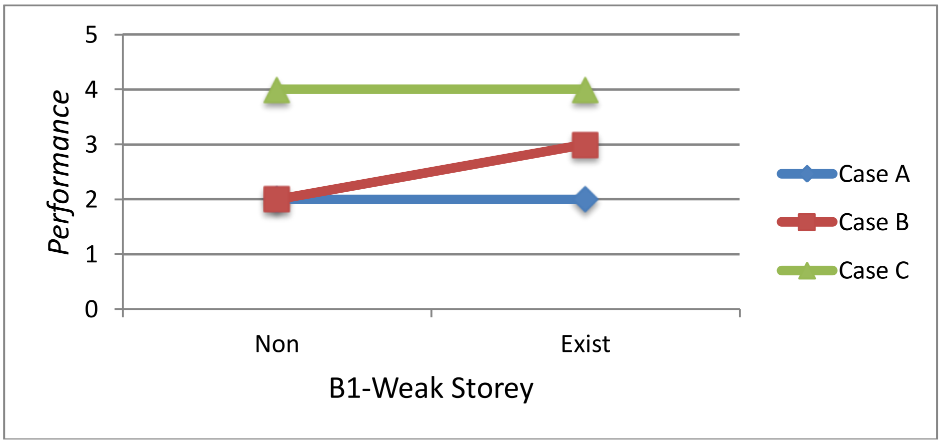


Figure 5.21. Effect of Weak Storey on earthquake performance

5.3.6 B2- Interstorey Stiffness Irregularity (Soft Storey)

Fig. 5.22 illustrate that, Soft Storey has negative effect on the performance of building and lead to Poor performance.

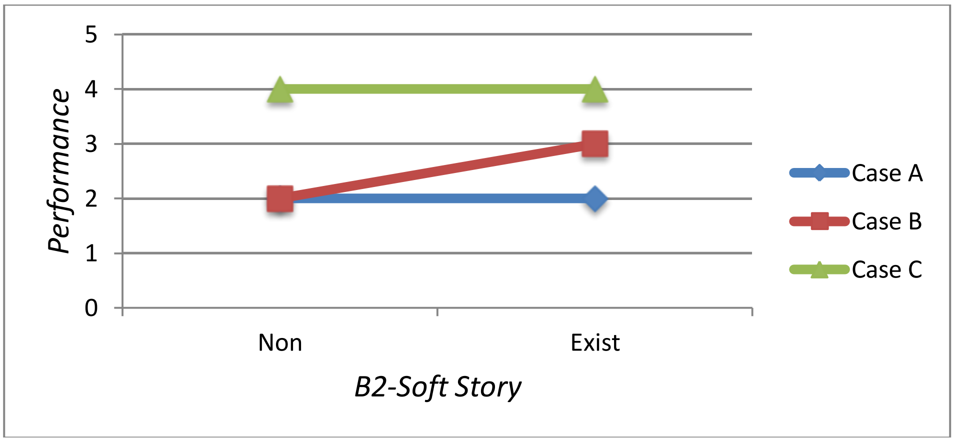


Figure 5.22. Effect of Soft Storey on earthquake performance

5.3.7 B3 - Discontinuity of Vertical Structural Elements

The existing of B3 - Discontinuity of Vertical Structural Elements lead to reduction in building performance as Fig. 5.23 shows.

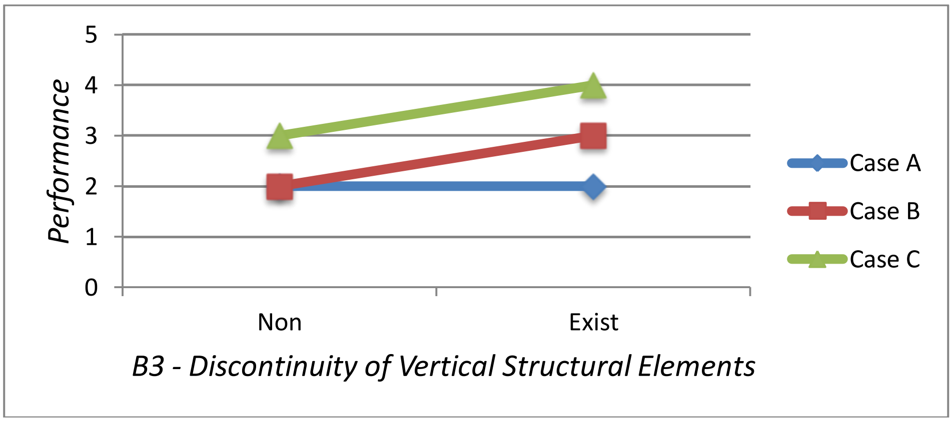


Figure 5.23. Effect of B3 - Discontinuity of Vertical Structural Elements on earthquake performance

5.3.8 C2 Weak Column – Strong Beam

Fig. 5.24 elucidate the effect of Weak Column–Strong Beam on earthquake performance, this effect is very small.

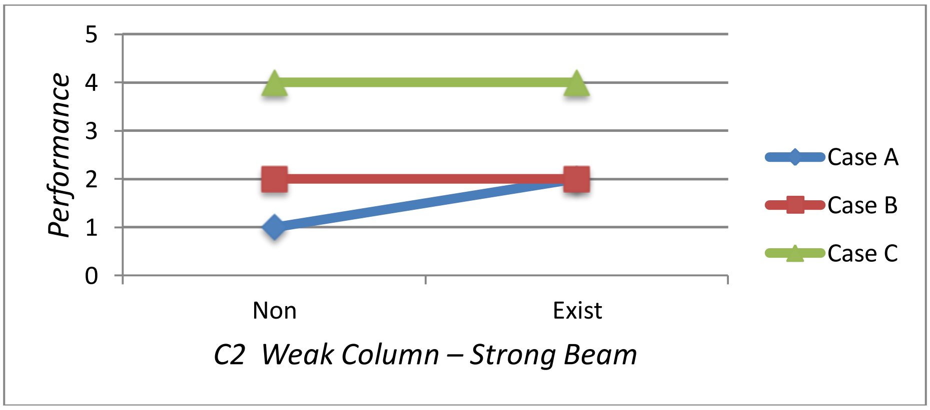


Figure 5.24. Effect of Weak Column – Strong Beam on earthquake performance

5.3.9 Stirrup Spacing

It can be noted from Fig. 5.25 that, the performance decreases when Stirrup Spacing are be not OK. If other parameters were sufficient Stirrup Spacing has no effect in case B and C and has slight effect on the performance in case A.

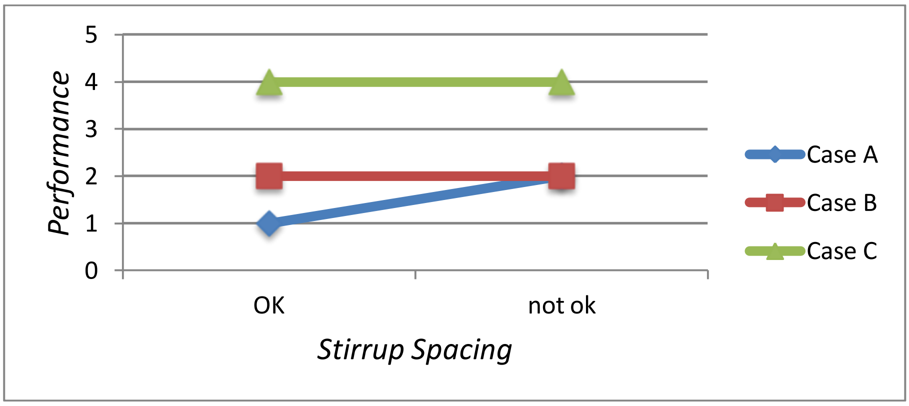


Figure 5.25. Effect of Stirrup Spacing on earthquake performance

5.3.10 Average Column Ratio

Fig. 5.26 shows that, the Average Columns Ratio has a significant effect on the earthquake performance especially when there is no shear walls, buildings that have high Average Columns Ratio and do not have vertical irregularity did not collapsed in most of cases except when **Earthquake zone (EZ) = 0.4.**

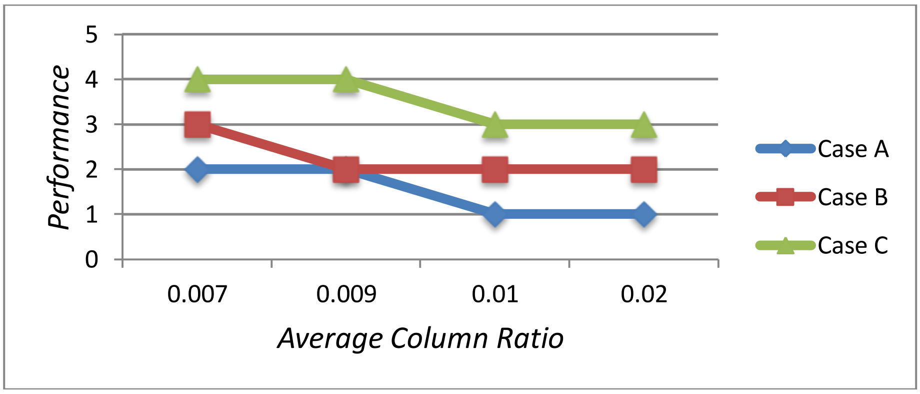


Figure 5.26. Effect of Average Column Ratio on earthquake performance

5.3.11 Concrete Compression Strength (C)

According to Fig. 5.27, increasing of Concrete Compression Strength improves the performance.

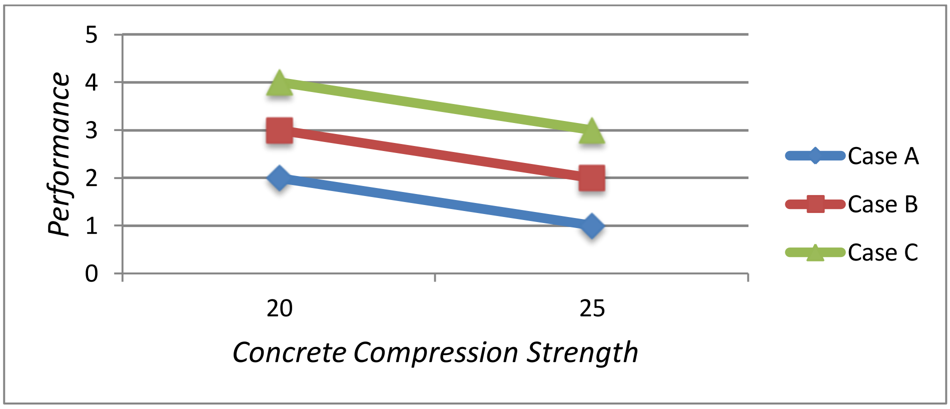


Figure 5.27. Effect of Concrete Compression Strength on earthquake performance

5.3.12 Type of Steel

According to Fig. 5.28, increasing of Steel Tension Strength improves the performance.

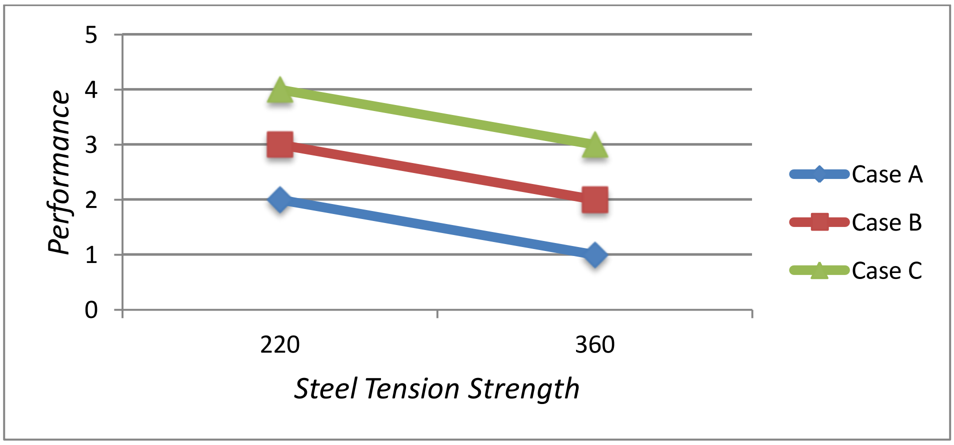


Figure 5.28. Effect of Steel Tension Strength on earthquake performance

5.3.13 Soil Type

It can be noted from Fig. 5.29 that, in analysis with nonlinear static pushover Soil Type has more effect than the linear analysis as It can be noted from Fig. 5.29 that changing the type of soil can be improve the performance and change the performance collapse level (4) to collapse prevention level (3) in case C, and from collapse prevention level (3) to Life safety (2) in case B and from Life safety (2) to Immediate Occupancy level (1) in case B.

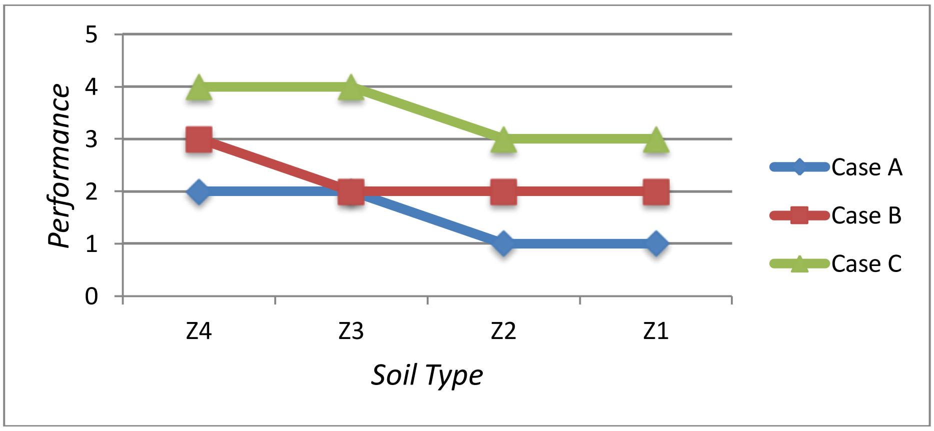


Figure 5.29. Effect of Soil Type on earthquake performance

5.3.14 Code

The code using in designing buildings and the year of construction are very important and Affect the Seismic Performance as Fig. 5.30 shows, where buildings that were built according to code 1975 and 1997 have been collapsed in cases C however there is no collapsing in the buildings that were built according to code 2007 in all cases.

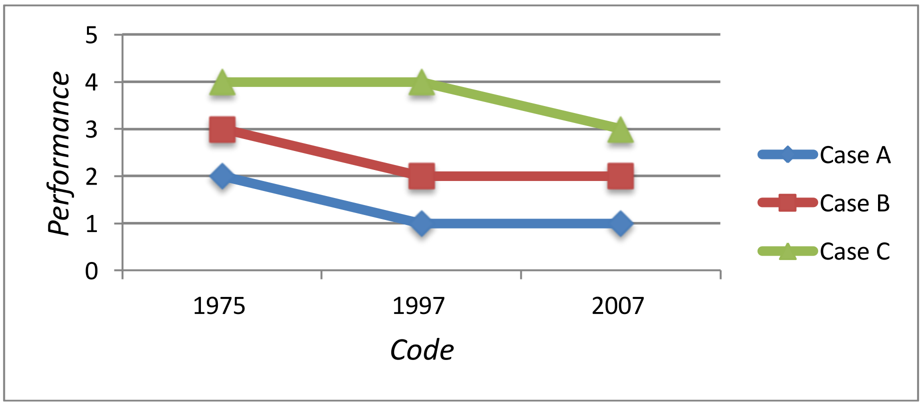


Figure 5.30. Effect of Code on earthquake performance

5.3.15 Earthquake zone (EZ)

Fig. 5.31 shows that, all buildings in case A still in life safety level in all the Earthquake zones, but those in case C collapsed in zones 0.3 and 0.4 and buildings in case B also collapsed in zones 0.4.

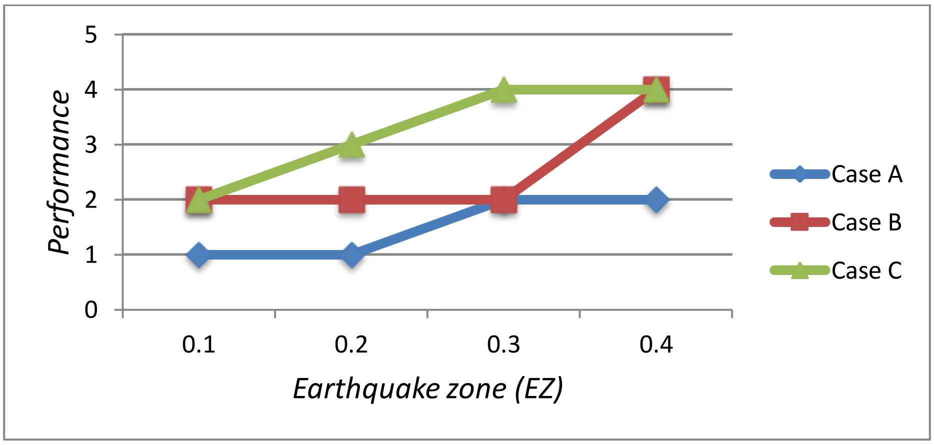


Figure 5.31. Effect of Earthquake zone on earthquake performance

5.3.16 Importance Factor (I)

According to Fig. 5.32, all buildings in case C have been collapsed with all different values of Importance Factor. On the other hand, buildings in case A and B still under safety level except the building with Importance Factor = 1.5 in case B that enter collapse prevention level.

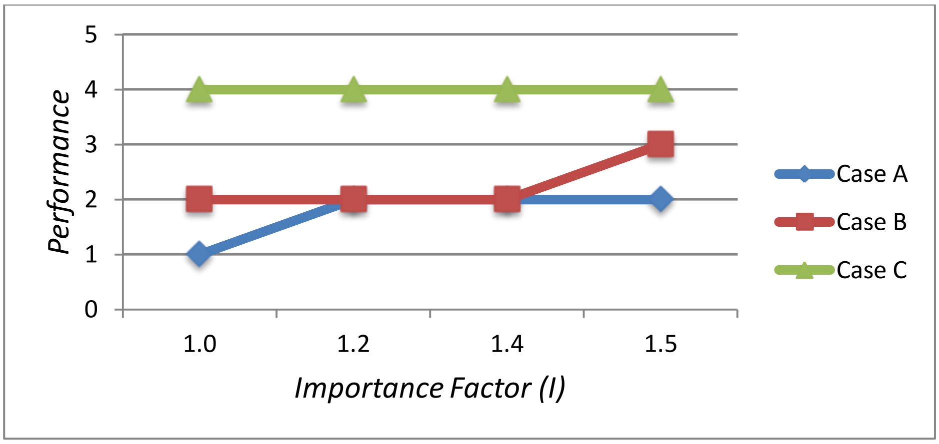


Figure 5.32. Effect of Importance Factor (I) on earthquake performance

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The application of Artificial Neural Networks (ANN) to evaluation the collapse vulnerability of reinforced concrete buildings has been investigated in this Thesis. An ANN model is built, trained and tested using the available test data of 260 RC buildings that were modeled with the commercial program STA4cad program.

The ANN model was used to perform parametric studies in order to evaluate the effects of the variables of on the earthquake performance which is the chosen output parameter.

6.2 General conclusions on the use of ANN

On the basis of results obtained in this study, important conclusions would be summarized as follows:

1) The study has added another success for Artificial Neural Networks. The ANN are powerful tools and have strong potential in learning the relationship between the inputs and outputs parameters and thus predicting outputs from new inputs.

2) The ANN is capable of modeling civil engineering problems.

6.3 Conclusions on the use of ANN in predicting earthquake performance of RC buildings

The topology of the network for both linear and non-linear performance analysis methods has the following features:

1- The type of architecture used was the multi-layer feed forward, three layers with the input layer containing 16 neurons, the first hidden layer contains 10 neurons while in the output layer there were 4 neurons. The training algorithm used was back probation algorithm.

2- The developed neural network model in this study has succeed in predicting the earthquake performance of RC buildings with 90% accuracy for non-linear static pushover analysis method and about 89% accuracy for linear performance analysis method .

6.4 Conclusions of the performed parametric study

Using the current technique the ANN, it was possible to study the effect of each of the influencing parameters on the earthquake performance of RC buildings .

The parametric study was conducted using the trained artificial neural networks, the following conclusions may be drawn:

6.4.1 Linear Performance Analysis model

When using the linear analysis, buildings that were built according to Code 1975 and 1997 and do not have adequate shear walls and having vertical irregularity were collapsed in most of the cases .

The earthquake performance of RC buildings increases with increasing the shear wall ratio, and has the most significant effect on the earthquake performance.

Performance decreases when A1-Torsional Irregularity exist, while other parameters left constant. In other words, it is clear that, the performance is inversely proportional to the A1-Torsional Irregularity ratio .

A2- Slab Discontinuities and A3 – Projections in Plan have a slight effect on the earthquake performance when there are no shear walls and have no effect when shear walls exist or when Average Column Ratio is high.

Moreover, the effect of stirrup spacing and strong column - weak beam is very small when exist separately and also it's effect not significant when the effect of rest of parameters are exist as, but it can be dangerous if it participated together with other parameters. Soil Type has no effect with full effect from the rest of the parameters. However, it must be remembered that, each of these parameters have high importance on the performance of the load-carrying system.

The Average Columns Ratio has a significant effect on the earthquake performance especially when there is no shear walls, buildings that have high Average Columns Ratio and do not have vertical irregularity did not collapsed in most of cases except at Earthquake zone (EZ) = 0.4.

The predicted earthquake performance increases with the increasing of Steel Tension Strength and Concrete Compression Strength, buildings that have Concrete

Compression Strength = 20 MPa or less and Steel Tension Strength =220 MPa exposed to collapse at Earthquake zone (EZ) = 0.4 or 0.3.

6.4.2 Non-linear Performance Analysis model

When using non-linear analysis method, to evaluate the earthquake performance of RC buildings the numbers of buildings that collapsed is less than linear analysis method especially for the structures that have irregularites and Soil Type has more effect than the linear analysis.

6.5 Recommendations for future studies

The current study showed very promising results in predicting the earthquake performance of RC buildings. However, the following points would be recommended for future studies to support the findings of this study:

1- It is recommended to carry out neural network modeling using different ANN types such as recurrent networks with various training algorithms such as radial bases can be used.

2- It is recommended to utilize other artificial intelligence techniques such as fuzzy logic or genetic programming to compare their results.

3- Obtain more training data from newly tested buildings models and add them to the training data. This will improve the training process of the problem.

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APPENDIX

Appendix A: Data Used in The Study

Parameter	1	2	3	4	5	6	7	8	9	10
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey)	0	0	0	0	0	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096
Concrete Compression Strength (C)	25	25	20	20	25	20	20	20	25	25
Type of steel	220	220	220	220	220	220	220	220	220	220
Soil Type (Z)	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1
Code	2007	2007	1997	1997	1997	1975	1975	2007	2007	2007
Earthquake zone (EZ)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4) Linear /non	2 2	2 2	4 3	2 3	2 2	4 4	3 2	2 2	2 2	2 2

Parameter	11	12	13	14	15	16	17	18	19	20
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096
Concrete Compression Strength (C)	20	25	25	20	20	25	25	20	20	25
Type of steel	360	220	360	220	360	220	360	220	360	220
Soil Type (Z)	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1
Code	1997	1997	1997	1975	1975	1975	2007	1997	1997	1997
Earthquake zone (EZ)	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	2 2	2 2	2 2	4 2	2 2	4 2	1 1	1 1	1 1	1 1

Parameter	21	22	23	24	25	26	27	28	29	30
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	1	1
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	1	1
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.01	0.01
Concrete Compression Strength (C)	20	20	25	20	20	25	20	20	25	20
Type of steel	220	360	360	220	360	360	220	360	360	360
Soil Type (Z)	Z1	Z2	Z1	Z1	Z1	Z1	Z2	Z1	Z2	Z1
Code	1975	1975	2007	1997	1997	1997	1975	1975	2007	1997
Earthquake zone (EZ)	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.4
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	3 2	2 2	1 1	1 1	1 1	1 1	2 1	1 1	2 2	3 2

Parameter	31	32	33	34	35	36	37	38	39	40
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	1	1	1	1	1	1	1	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	1	1	1	1	1	1	1	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	1	1	1
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Concrete Compression Strength (C)	20	25	25	20	20	20	20	25	20	20
Type of steel	220	360	360	360	220	360	220	360	360	220
Soil Type (Z)	Z1	Z2	Z2	Z3	Z3	Z4	Z2	Z1	Z1	Z1
Code	1975	1975	2007	1997	1975	1975	1975	2007	1997	1975
Earthquake zone (EZ)	0.4	0.4	0.3	0.2	0.2	0.2	0.1	0.4	0.4	0.4
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	4 4	**3** **3**	2 2	1 1	3 2	2 2	2 1	3 2	3 2	4 2

Parameter	41	42	43	44	45	46	47	48	49	50
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	1	1
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	1	1
B3 - Discontinuity of Vertical Structural Elements	1	1	1	1	1	1	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	0	0	0	0
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0096	0.0096	0.0096	0.0096	0.0097	0.0096	0.0096	0.0094	0.0094	0.01
Concrete Compression Strength (C)	20	25	20	20	20	20	25	20	20	20
Type of steel	360	360	360	220	360	220	360	360	220	360
Soil Type (Z)	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1
Code	1975	2007	1997	1975	1975	1975	2007	1997	1975	1975
Earthquake zone (EZ)	0.4	0.3	0.2	0.2	0.2	0.1	0.4	0.4	0.4	0.4
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	4 3	3 2	3 1	3 1	3 1	3 1	4 2	4 2	4 4	3 2

Parameter	51	52	53	54	55	56	57	58	59	60
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	1	1	1	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	1	1	1	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	1	1	1	1	1
Stirrup Spacing	0	0	0	0	0	0	0	0	0	0
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0093	0.0099	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0098	0.0098
Concrete Compression Strength (C)	25	20	20	20	20	25	20	20	20	25
Type of steel	360	360	220	360	220	360	360	220	360	360
Soil Type (Z)	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1
Code	2007	1997	1975	1975	1975	2007	1997	1975	1975	2007
Earthquake zone (EZ)	0.3	0.2	0.2	0.2	0.1	0.4	0.4	0.4	0.4	0.3
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	4 2	2 2	2 1	2 1	2 1	2 2	2 2	3 4	2 4	2 2

Parameter	61	62	63	64	65	66	67	68	69	70
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	Case1	Case1	Case1	Case1	Case1	Case1
A3 – Projections in Plan	0	0	0	0	1	1	1	1	1	1
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	1	1	1	1	1	1
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	1	1	1	1	1	1
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	1	1	1	1	1	1
C2 Weak Column – Strong Beam	1	1	1	1	1	1	1	1	1	1
Stirrup Spacing	0	0	0	0	0	0	0	0	0	0
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096
Concrete Compression Strength (C)	20	20	20	20	25	20	20	20	25	20
Type of steel	360	220	360	220	360	360	220	360	360	360
Soil Type (Z)	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1
Code	1997	1975	1975	1975	2007	1997	1975	1975	2007	1997
Earthquake zone (EZ)	0.2	0.2	0.2	0.1	0.4	0.4	0.4	0.4	0.3	0.2
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	2 2	2 2	2 2	2 1	4 3	4 3	4 3	4 3	4 3	4 3

Parameter	71	72	73	74	75	76	77	78	79	80
A1-Torsional Irregularity	0	0	0	1	1	1	1	1	1	1
A2- Slab Discontinuities	Case1	Case1	Case1	0	0	0	0	0	0	0
A3 – Projections in Plan	1	1	1	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	1	1	1	0	0	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	1	1	1	0	0	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	1	1	1	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	1	1	1	0	0	0	0	0	0	0
Stirrup Spacing	0	0	0	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Concrete Compression Strength (C)	20	20	20	25	20	20	20	25	20	20
Type of steel	220	360	220	360	360	220	360	360	360	220
Soil Type (Z)	Z3	Z3	Z2	Z2	Z2	Z4	Z4	Z2	Z2	Z2
Code	1975	1975	1975	2007	1997	1975	1975	2007	1997	1975
Earthquake zone (EZ)	0.2	0.2	0.1	0.4	0.4	0.4	0.4	0.3	0.2	0.2
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	4 3	4 3	3 1	2 2	2 2	4 3	4 3	2 2	2 2	3 2

Parameter	81	82	83	84	85	86	87	88	89	90
A1-Torsional Irregularity	1	1	1	1	1	1	1	1	1	1
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	0	0	0	0	0	0	0	0
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Concrete Compression Strength (C)	20	20	25	20	20	20	25	20	20	20
Type of steel	360	220	360	360	220	360	360	360	220	360
Soil Type (Z)	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1
Code	1975	1975	2007	1997	1975	1975	2007	1997	1975	1975
Earthquake zone (EZ)	0.2	0.1	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.2
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	3 2	2 2	2 2	2 2	3 3	3 2	2 2	2 2	2 2	2 2

Parameter	91	92	93	94	95	96	97	98	99	100
A1-Torsional Irregularity	1	1	1	1	1	1	1	1	1	1
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	1	1	1	1	1	1	1	1	1
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	1	1	1	1	1	1	1	1	1
B3 - Discontinuity of Vertical Structural Elements	0	1	1	1	1	1	1	1	1	1
C2 Weak Column – Strong Beam	0	1	1	1	1	1	1	1	1	1
Stirrup Spacing	0	0	0	0	0	0	0	0	0	0
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Concrete Compression Strength (C)	20	25	20	20	20	25	20	20	20	20
Type of steel	220	360	360	220	360	360	360	220	360	220
Soil Type (Z)	Z1	Z2	Z2	Z1	Z1	Z2	Z1	Z1	Z1	Z1
Code	1975	2007	1997	1975	1975	2007	1997	1975	1975	1975
Earthquake zone (EZ)	0.1	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.2	0.1
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	2 1	4 3	4 3	4 3	4 3	4 3	4 3	4 3	4 3	3 1

Parameter	101	102	103	104	105	106	107	108	109	110
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0.008	0.003	0.003	0.005	0.008	0.008	0.003	0.007	0.0025	0.0045
Average Column Ratio (ρ_{CA}CA)	0.0096	0.01	0.01	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096
Concrete Compression Strength (C)	25	20	20	25	20	20	25	20	25	25
Type of steel	360	220	360	360	220	360	360	360	220	360
Soil Type (Z)	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1
Code	2007	1997	1997	1997	1975	1975	2007	1997	1997	1997
Earthquake zone (EZ)	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	2 2	3 2	3 2	2 1	3 1	2 1	2 2	2 1	2 2	2 1

Parameter	111	112	113	114	115	116	117	118	119	120
A1-Torsional Irregularity	0	0	0	0	0	1	1	1	1	1
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	1	1	1	1	1
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	1	1	1	1	1
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	1	1	1	1	1
C2 Weak Column – Strong Beam	0	0	0	0	0	1	1	1	1	1
Stirrup Spacing	1	1	1	1	1	0	0	0	0	0
Average Shear Wall Ratio (ρ_{SWA})	0.0055	0.003	0.0075	0.0075	0.0025	0.005	0.0045	0.008	0.005	0.0045
Average Column Ratio (ρ_{CA}CA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Concrete Compression Strength (C)	20	20	25	20	20	25	20	20	25	20
Type of steel	220	360	220	220	220	360	220	360	360	220
Soil Type (Z)	Z3	Z3	Z4	Z4	Z2	Z1	Z1	Z1	Z1	Z1
Code	1975	1975	1975	1975	1975	2007	1997	1997	1997	1975
Earthquake zone (EZ)	0.3	0.3	0.3	0.2	0.1	0.4	0.4	0.4	0.4	0.4
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	2 1	2 2	2 1	1 1	1 1	4 2	4 3	3 3	4 3	4 3

Parameter	121		122		123		124		125		126		127		128		129		130	
A1-Torsional Irregularity	1		1		1		1		1		1		1		1		1		1	
A2- Slab Discontinuities	0		0		0		0		0		0		0		0		0		0	
A3 – Projections in Plan	0		0		0		0		0		0		0		0		0		0	
B1- Interstorey Strength Irregularity (Weak Storey).	1		1		1		1		1		1		1		1		1		1	
B2- Interstorey Stiffness Irregularity (Soft Storey)	1		1		1		1		1		1		1		1		1		1	
B3 - Discontinuity of Vertical Structural Elements	1		1		1		1		1		1		1		1		1		1	
C2 Weak Column – Strong Beam	1		1		1		1		1		1		1		1		1		1	
Stirrup Spacing	0		0		0		0		0		0		0		0		0		0	
Average Shear Wall Ratio (ρ_{SWA})	0.0085		0.05		0.007		0.0045		0.002		0.007		0.003		0.008		0.0055		.0045	
Average Column Ratio (ρ_{CA}CA)	0.01		0.01		0.01		0.01		0.01		0.01		0.01		0.01		0.01		0.01	
Concrete Compression Strength (C)	20		25		20		25		25		20		20		25		25		20	
Type of steel	360		360		360		220		360		220		360		220		360		360	
Soil Type (Z)	Z1		Z1		Z1		Z1		Z1		Z1		Z1		Z1		Z1		Z1	
Code	1975		2007		1997		1997		1997		1975		1975		1975		2007		1997	
Earthquake zone (EZ)	0.4		0.3		0.3		0.3		0.3		0.3		0.3		0.3		0.2		0.2	
Importance Factor (I)	1		1		1		1		1		1		1		1		1		1	
Structural Performance (S1-S4)	4	3	4	2	4	3	4	3	4	3	4	3	4	3	4	3	4	2	4	3

Parameter	131	132	133	134	135	136	137	138	139	140
A1-Torsional Irregularity	1	1	1	1	1	1	1	1	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	1	1	1	1	1	1	1	1	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	1	1	1	1	1	1	1	1	0	0
B3 - Discontinuity of Vertical Structural Elements	1	1	1	1	1	1	1	1	0	0
C2 Weak Column – Strong Beam	1	1	1	1	1	1	1	1	0	0
Stirrup Spacing	0	0	0	0	0	0	0	0	1	1
Average Shear Wall Ratio (ρ_{SWA})	0.0085	0.005	0.004	0.008	0.005	0.004	0.003	0.003	0	0
Average Column Ratio (ρ_{CA}CA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.0095	0.0072
Concrete Compression Strength (C)	20	20	25	20	20	25	20	20	25	20
Type of steel	220	360	360	220	360	360	220	360	360	360
Soil Type (Z)	Z3	Z3	Z4	Z4	Z1	Z1	Z1	Z1	Z2	Z1
Code	1975	1975	2007	1997	1997	1997	1975	1975	2007	1997
Earthquake zone (EZ)	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.4
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	4 3	4 3	3 2	4 3	3 2	3 2	4 3	4 2	2 2	4 2

Parameter	141	142	143	144	145	146	147	148	149	150
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0084	0.009	0.013	0.009	0.012	0.0087	0.0087	0.0082	0.0095	0.0058
Concrete Compression Strength (C)	20	20	25	25	20	25	25	25	25	25
Type of steel	220	360	220	360	220	360	220	220	220	220
Soil Type (Z)	Z1	Z1	Z1	Z1	Z2	Z2	Z2	Z2	Z1	Z1
Code	1975	1975	1997	1997	1975	1975	1975	1997	1997	1975
Earthquake zone (EZ)	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	4 3	3 2	3 2	2 2	4 3	3 2	4 3	3 2	2 2	2 2

Parameter	151	152	153	154	155	156	157	158	159	160
A1-Torsional Irregularity	1	1	1	1	1	1	1	1	1	1
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	1	1	1	1	1	1	1	1	1	1
B2- Interstorey Stiffness Irregularity (Soft Storey)	1	1	1	1	1	1	1	1	1	1
B3 - Discontinuity of Vertical Structural Elements	1	1	1	1	1	1	1	1	1	1
C2 Weak Column – Strong Beam	1	1	1	1	1	1	1	1	1	1
Stirrup Spacing	0	0	0	0	0	0	0	0	0	0
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.019	0.019	0.02	0.017	0.018	0.018	0.015	0.016	0.015	0.016
Concrete Compression Strength (C)	25	20	20	20	25	25	20	20	20	20
Type of steel	360	360	220	360	360	360	360	220	360	220
Soil Type (Z)	Z1	Z1	Z1	Z1	Z2	Z2	Z2	Z2	Z1	Z1
Code	2007	1997	1975	1975	1997	2007	1997	1975	1975	1975
Earthquake zone (EZ)	0.4	0.4	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.1
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	4 3	4 4	4 4	4 3	3 2	3 2	4 2	4 3	3 2	4 3

Parameter	161	162	163	164	165	166	167	168	169	170
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0 ,L	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	[40*40]*30/500	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096
Concrete Compression Strength (C)	25	25	20	20	25	20	20	20	25	25
Type of steel	220	360	220	360	360	220	360	360	220	360
Soil Type (Z)	Z2	Z2	Z2	Z2	Z2	Z2	Z2	Z2	Z2	Z2
Code	2007	2007	1997	1997	1997	1975	1975	2007	2007	2007
Earthquake zone (EZ)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4) Lin /non lin	2 2	2 2	4 3	**2** **3**	2 2	4 4	4 2	2 2	2 2	2 2

Parameter	171	172	173	174	175	176	177	178	179	180
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096
Concrete Compression Strength (C)	20	25	25	20	20	25	25	20	20	25
Type of steel	360	220	360	220	360	220	360	220	360	220
Soil Type (Z)	Z3	Z3	Z3	Z3	Z3	Z3	Z3	Z3	Z3	Z3
Code	1997	1997	1997	1975	1975	1975	2007	1997	1997	1997
Earthquake zone (EZ)	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	2 2	2 2	2 2	4 2	2 2	4 2	2 1	2 2	2 2	2 2

Parameter	181	182	183	184	185	186	187	188	189	190
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	Exist	Exist
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	Exist	Exist
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.01	0.01
Concrete Compression Strength (C)	20	20	25	20	20	25	20	20	25	20
Type of steel	220	360	360	220	360	360	220	360	360	360
Soil Type (Z)	Z4	Z4	Z4	Z4	Z4	Z4	Z4	Z4	Z1	Z1
Code	1975	1975	2007	1997	1997	1997	1975	1975	2007	1997
Earthquake zone (EZ)	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.4
Importance Factor (I)	1	1	1	1	1	1	1	1	1.5	1.5
Structural Performance (S1-S4)	3 2	2 2	1 1	2 2	2 2	2 2	2 2	2 2	2 2	2 2

Parameter	191	192	193	194	195	196	197	198	199	200
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	1	1
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	1	1
B3 - Discontinuity of Vertical Structural Elements	1	1	1	1	1	1	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	0	0	0	0	0	0	0	0	0	0
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Concrete Compression Strength (C)	20	25	20	20	20	25	20	20	20	20
Type of steel	220	360	360	220	360	360	360	220	360	220
Soil Type (Z)	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1
Code	1975	2007	1997	1975	1975	2007	1997	1975	1975	1975
Earthquake zone (EZ)	0.1	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.2	0.1
Importance Factor (I)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Structural Performance (S1-S4)	2 2	4 3	4 3	4 3	4 3	4 3	4 3	4 3	4 3	4 2

Parameter	201	202	203	204	205	206	207	208	209	210
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	1	1
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	1	1
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Concrete Compression Strength (C)	20	25	25	20	20	20	20	25	20	20
Type of steel	220	360	360	360	220	360	220	360	360	220
Soil Type (Z)	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z2	Z2
Code	1975	1975	2007	1997	1975	1975	1975	2007	1997	1975
Earthquake zone (EZ)	0.4	0.4	0.3	0.2	0.2	0.2	0.1	0.4	0.4	0.4
Importance Factor (I)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1	1
Structural Performance (S1-S4)	4 4	**3** **3**	2 2	2 1	3 2	2 2	2 2	3 2	3 2	4 2

Parameter	211	212	213	214	215	216	217	218	219	220
A1-Torsional Irregularity	1	1	1	1	1	1	1	1	1	1
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	1	1	1
B2- Interstorey Stiffness Irregularity (Soft Storey)	1	1	1	1	1	1	1	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	1	0	1	0	0
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0096	0.0096	0.0096	0.0096	0.0097	0.0096	0.0096	0.0094	0.0094	0.01
Concrete Compression Strength (C)	20	25	20	20	20	20	25	20	20	20
Type of steel	360	360	360	220	360	220	360	360	220	360
Soil Type (Z)	Z1	Z2	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1
Code	1975	2007	1997	1975	1975	1975	2007	1997	1975	1975
Earthquake zone (EZ)	0.4	0.3	0.2	0.2	0.2	0.1	0.4	0.4	0.4	0.4
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	4 3	3 2	3 1	3 1	3 1	3 1	4 2	4 2	4 4	3 2

Parameter	221	222	223	224	225	226	227	228	229	230
A1-Torsional Irregularity	1	1	1	1	1	0	0	0	0	0
A2- Slab Discontinuities	0	0	0	0	0	Case1	Case1	Case1	Case1	Case1
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	1	1	1	1	1	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	0	0	0	0	0	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0093	0.0099	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0098	0.0098
Concrete Compression Strength (C)	25	20	20	20	20	25	20	20	20	25
Type of steel	360	360	220	360	220	360	360	220	360	360
Soil Type (Z)	Z1	Z1	Z2	Z2	Z1	Z1	Z1	Z1	Z1	Z1
Code	2007	1997	1975	1975	1975	2007	1997	1975	1975	2007
Earthquake zone (EZ)	0.3	0.2	0.2	0.2	0.1	0.4	0.4	0.4	0.4	0.3
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	4 2	2 2	2 1	2 1	2 1	2 2	2 2	3 4	2 4	2 2

Parameter	231	232	233	234	235	236	237	238	239	240
A1-Torsional Irregularity	0	0	0	0	0	0	0	0	0	0
A2- Slab Discontinuities	Case1	Case1	Case1	Case1	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	1	1	1	1	1	1
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	1	1	1	1	1	1
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	1	1	1	1	1	1
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	1	1	1	1	1	1
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	1	1	1	0	0	0	0	0
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0.003	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096
Concrete Compression Strength (C)	20	20	20	20	25	20	20	20	25	20
Type of steel	360	220	360	220	360	360	220	360	360	360
Soil Type (Z)	Z1	Z1	Z1	Z2	Z1	Z3	Z3	Z4	Z4	Z3
Code	1997	1975	1975	1975	2007	1997	1975	1975	2007	1997
Earthquake zone (EZ)	0.2	0.2	0.2	0.1	0.4	0.4	0.4	0.4	0.3	0.2
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	2 2	2 2	2 2	2 1	4 2	4 3	4 3	4 3	4 3	4 3

Parameter	241	242	243	244	245	246	247	248	249	250
A1-Torsional Irregularity	0	0	0	1	1	1	1	1	1	1
A2- Slab Discontinuities	Case1	Case1	Case1	0	0	0	0	0	0	0
A3 – Projections in Plan	1	1	1	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	1	1	1	0	0	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	1	1	1	0	0	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	1	1	1	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	1	1	1	0	0	0	0	0	0	0
Stirrup Spacing	0	0	0	1	1	1	1	1	1	1
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Concrete Compression Strength (C)	20	20	20	25	20	20	20	25	20	20
Type of steel	220	360	220	360	360	220	360	360	360	220
Soil Type (Z)	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1
Code	1975	1975	1975	2007	1997	1975	1975	2007	1997	1975
Earthquake zone (EZ)	0.2	0.2	0.1	0.4	0.4	0.4	0.4	0.3	0.2	0.2
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	4 3	4 3	3 1	2 2	2 2	4 3	4 3	2 2	2 2	3 2

Parameter	251	252	253	254	255	256	257	258	259	260
A1-Torsional Irregularity	1	1	1	1	1	1	1	1	1	1
A2- Slab Discontinuities	0	0	0	0	0	0	0	0	0	0
A3 – Projections in Plan	0	0	0	0	0	0	0	0	0	0
B1- Interstorey Strength Irregularity (Weak Storey).	0	0	0	0	0	0	0	0	0	0
B2- Interstorey Stiffness Irregularity (Soft Storey)	0	0	0	0	0	0	0	0	0	0
B3 - Discontinuity of Vertical Structural Elements	0	0	0	0	0	0	0	0	0	0
C2 Weak Column – Strong Beam	0	0	0	0	0	0	0	0	0	0
Stirrup Spacing	1	1	0	0	0	0	0	0	0	0
Average Shear Wall Ratio (ρ_{SWA})	0	0	0	0	0	0	0	0	0	0
Average Column Ratio (ρ_{CA}CA)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Concrete Compression Strength (C)	20	20	25	20	20	20	25	20	20	20
Type of steel	360	220	360	360	220	360	360	360	220	360
Soil Type (Z)	Z1	Z2	Z2	Z2	Z4	Z3	Z1	Z2	Z2	Z2
Code	1975	1975	2007	1997	1975	1975	2007	1997	1975	1975
Earthquake zone (EZ)	0.2	0.1	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.2
Importance Factor (I)	1	1	1	1	1	1	1	1	1	1
Structural Performance (S1-S4)	3 2	2 2	2 2	2 2	3 3	3 2	2 2	2 2	2 2	2 2