Evaluation of Reinforced Concrete Buildings in Terms of Seismic Design Faults in North Cyprus

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ABSTRACT

The most important phenomena in nature which cause many disasters, catastrophes, losses of life, and economic recession are earthquakes. Many engineers and scientists have been investigated this subject throughout the history, and it stands as one of the common matter nowadays. Numerous studies on this hazard lead to a better understanding of its effect on structures, and, therefore, a better engineering design. The aim of this study is to investigate the vulnerability of reinforced concrete buildings behaviour in city of Gazimağusa in North Cyprus which is situated in intensive seismic zone as a case study. In this region, structures have been commonly built by reinforced concrete. Generally, all the RC buildings in this area are between two and five stories.

In this study, four RC buildings have been chosen as case studies. They have been modelled with SAP2000, and then nonlinear static analyses, also known as pushover analysis have been performed to evaluate the respective seismic capacities of these buildings, from which the respective damage states have been deducted considering the site seismic demand. These case studies have been loading with different lateral load patterns according to FEMA356 code. On the other hand, a rapid and practical assessment method which is named P25 method has been applied to evaluate collapse of these case studies. This method is a rapid scoring method which can evaluate vulnerability of reinforced concrete buildings without any conventional structural analysis. Finally the results of these two methods have been compared together, and the predicted performance levels have been discussed. At the end of this study, P25 method required the buildings on hand to be studied in details. Then, it has been found out from pushover analyses that case study 3 exhibits a performance level of grade 1: negligible to slight damage (no structural damage, slight nonstructural damage) according to EMS98, and the three remaining display a grade level 4: very heavy damage (heavy structural damage, very heavy nonstructural damage) according to the same classification.

Keywords: P25 method; pushover analysis; collapse vulnerability

ÖZ

Birçok afetlere, felaketlere, yaşam kayıplarına ve ekonomik durgunluk veya geriliklere yol açan, doğadaki en önemli fevkalade olay depremdir. Tarih boyunca, birçok mühendis ve bilim insanı bu konuyu araştırırken, bu haliyle günümüzün en yaygın sorunlarından biri olarak ortada durmaktadır. Bu tehlike üzerinde sürdürülen bir çok çalışma, onun yapılar üzerindeki etkisinin daha iyi anlaşılmasına ve dolayısıyla daha iyi mühendislik tasarımlarına yol açmıştır. Bu araştırmanın amacı, bir vaka çalışması olarak, yoğun sismik bölgede yer alan Kuzey Kıbrıs'ın Gazimağusa kentinde inşa edilmiş betonarme binaların deprem performanslarını araştırmaktır. Bu bölgedeki yapılar çoğunlukla betonarme olarak inşa edilmişlerdir. Tüm betonarme binalar, genellikle, iki ve beş kat arasındaki yapılardır.

Bu araştırmada, vaka çalışması olarak dört adet betonarme bina seçilmiştir. Binaların deprem performanslarını değerlendirmek için SAP2000 ile modellenerek statik itme analizi uygulanmıştır. FEMA356 yönetmeliğine göre farklı yüklemeler göz önünde bulundurulmuştur. Öte yandan, P25 Metodu diye isimlendirilen hızlı değerlendirme yöntemi de seçilen örnek binalara uygulanarak deprem göçme riskleri belirlenmiştir. Bu metod hızlı bir puanlama metodu olup, herhangi bir geleneksel yapısal analiz yapılmaksızın, betonarme binaların performansını değerlendirebilmektedir. Çalışmanın sonunda, bu iki yöntemin sonuçları karşılaştırılmıştır. P25 Metodu sonuçlarına göre binaların detaylı analizleri yapılmalıdır. Yapılan statik itme analiz sonuçları kullanılarak seçilen örnek binalar EMS98'e göre değerlendirilmiş ve üçüncü örnek güvenli (Grade 1) diğer örneklerde ise ağır hasar (Grade 4) olacağı tesbit edilmiştir.

Anahtar kelimeler: P25 metodu; itme analizi; göçme riski

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A_C: Total Section Area of Columns in Critical Stories.

A_S: Total Section Area of Shear Wall in Critical Stories.

A_m: Total Section Area of Masonry Wall in Critical Stories.

A_P: Area of the Plan

A_{ef}: Total Effective Section Area

I_C: Moment of Inertia of Columns in Critical Stories

I_S: Moment of Inertia of Shear Walls in Critical Stories

I_m: Moment of Inertia of Masonry Walls in Critical Stories.

I_{ef}: Effective Total Moment of Inertia.

E_m: Module of Elastic of Masonry Wall.

E_C: Module of Elastic of Concrete.

I_{px}: Moment of Inertia of Plan in x Direction

I_{py}: Moment of Inertia in y Direction

$C_{A,ef}$: Effective Statistical Values

$\mathrm{C}_{I,ef}$: Effective Statistical Values

C_A : Statistical Values

C_I: Statistical Values

$\mathrm{C}_{I,min}$: Minimum Statistical Values

$\mathrm{C}_{I,max}$: Maximum Statistical Values

δ: Target Displacement

C_0: Modification Factor

C_1: Modification Factor

C_2: Modification Factor

C_3: Modification factor

T_e: Effective Fundamental Period

T_S: Characteristic Period of the Response Spectrum

R: Ratio of Elastic Strength Demand

Sa: Response Spectrum Acceleration

α: Ratio of Post-Yield Stiffness to Effective Elastic Stiffness

T_i: Elastic Fundamental Period

T_0: Period Building

K_i: Elastic Lateral Stiffness

K_e: Effective Lateral Stiffness

W: Effective Seismic Weight

v_y: Yield Strength

H: Height of the Building

P: Final P to Determine the Condition of Building.

β:Coefficient to Calculate Final P

P_{min}: Minimum P to Determine Final P

I: Building Importance Factor

A: Effective Ground Acceleration

n:Level of Participation of Live Loads

t: Correction Factor for Topographic Effect

LIST OF ABBREVIATIONS

NRCC: National Research Council of Canada

JBDPA: Japan Building Disaster Prevention Association

NEHRP**:** National Earthquake Prediction Evaluation Council

FEMA:Federal Emergency Management Agency

ATC-40: Applied Technology Council

ASCE: American Society of Civil Engineers

IO: Immediate Occupancy Performance Level

LS: Life Safety Performance Level

CP: Collapse Prevention Performance Level

PGA: Peak Ground Acceleration

LSP: Linear Static Procedure

LDP: Linear Dynamic Procedure

NSP: Nonlinear Static Procedure

NDP: Nonlinear Dynamic Procedure

MDF: Multi Degree of Freedom

SDOF: Multi Degree of Freedom

Chapter 1

INTRODUCTION

1.1GeneralOverview

By the end of British period (1878-1960) in Cyprus, reinforced concrete structural system started to be used instead of traditional building system and materials such as mud brick, stone, masonry, hamish, and baghdadi. Rapidly increasing population of Cyprus brought uncontrolled urbanization and building construction. This study has been focused in city of Gazimağusa (North Cyprus). In this region generally, all the structure has been built with RC systems.

On the base of the above discussion, the main aim of this study is to evaluate vulnerability of RC buildings in GazimağusaNorth Cyprus. Seismic performance of RC buildings is evaluated by using nonlinear static analysis, (pushover analysis), and P25 method developed by Gulay et al(2011).

1.2Literature Review

One of the popular methods which are used in analysis of structures is nonlinear static analysis that it is also known as pushover analysis. In analysis software packages such as SAP2000 or ETABS, pushover analysis has been integrated as a method to assess vulnerability of buildings. Pushover analysis is fast and its application has been described in reports like FEMA356 or ATC40.

The process of performing a pushover analysis of a three dimensional structure has been introduced by Habibullah and Stephen (1998). During the last twenty years, pushover method has been modified by Sozen and Saidi (1981) and Fajrfar (2000). Also pushover analysis has been explained for evaluation of the buildings by National Earthquake Hazards Reduction Program (NEHRP).NEHRP proposes a guideline to assess vulnerability of buildings. Furthermore, the method which is mentioned above is applied by Structural Engineers Association of California (SEAOC).Some scientists, during recent years, have worked on nonlinear static pushover analysis. Nonlinear static analysis (pushover) is simple in comparison with nonlinear dynamic analysis and this comparison has been an issue for scientists study. This issue has been examined by Mwafy and Elnashai (2000) carried out experiment son this subject by recording seismic vibration of 12 RC buildings as a sample with different characteristic until the collapse of the structure.

Chopra (1995) described displacement-based procedure in order to assess the seismic design of inelastic single degree of freedom structures.Mohle (2008) used pushover method for high rise buildings in USA. Shuraimet (2007) applied nonlinear static analysis for reinforced concrete buildings by using ATC-40.Girgin (2007) developed pushover method for concrete buildings that included infill walls.

The other method, which in this study has been taking into consideration, is a rapid scoring technique to assess vulnerability of RC buildings developed by Gulay et al(2011) and calledP25 method. This method is practical and is conducted without any structural analysis.

Other rapid methods which involve statistical equations to assess vulnerability of reinforced concrete buildings are published by some researchers. These methods vary in terms of their building type interest and their geographical area.

One of them has been developed by Lee, Han and Sung (2006) as arapid method to assess seismic capacity of low-rise reinforced concrete buildings. This method has been verified, and its ability to evaluate the vulnerability has been proved by comparing its results with those of other methods which are more precise like nonlinear dynamic analysis and nonlinear static analysis. A second rapid method, which considered the structural parameters, has been published by Yakut et al (2006).

In 1981, Aoyama introduceda three level procedure for evaluation of seismic capacity of reinforced concrete in Japan. Later in 2004, Boduroglu et al published. Rahman (2012) published an articleabout a visual rapid assessment method applied toassess seismic capacity of reinforcedconcrete buildings in USA. Jain et al(2010)proposed rapid visual procedure to assess RC frame buildings in India.There are numerouspublications and articles related to rapid evaluation methods in the literature.

1.3Purpose

This study has concentrated in city of Gazimağusaat North Cyprus. In this region, most of the structures have been constructed with reinforced concrete. The purpose of this study is the assessment of vulnerability of reinforced concrete buildings in Gazimağusa with two methods of analysis. The first one is P25 and the second one is pushover analysis. P25 method is rapid, practical, and easy-to-perform assessment technique. It aims to evaluate probability of reinforced concrete buildings and vulnerability of Rebuilding by scoring some factors and structural parameters, and by applying them in the formulas and statistical equation. The designer, without any structural analysis software, can identify or just have an idea on whether the building will collapse or not. The identification of building vulnerability leads the investigator to decide whether particular building needs to be strengthened or not. On the other hand, the second technique of our concern is nonlinear static analysis also called pushover method; it is one of the precise methods to evaluate performance of the existing buildings which offers salient features in the understanding of build behavior under seismic excitation. Finally in this study, the results of two aforementioned methods have been compared with each other to find out the vulnerability and performance level of buildings.

1.4Limitations

One of the limitations for this study is the choice of a unique city: because of availability and convenient situation, four RC buildings have been selected as case studies in city of Gazimağusa at North Cyprus.

Another limitation was the selection of method of analysis: nonlinear static analysis (pushover) has been chosen instead of nonlinear dynamic analysis because of its simplicity. On the other hand, as mentioned before, P25 method has been applied because it is quick and practical.

1.5Organization

Four chapters constitute the rest of this thesis.

Chapter 2 presents P25 scoring method. It encompasses all the elementary scores in details and discusses its application procedure.

The other assessment method is talked in Chapter 3. Here is thoroughly exposed pushover analysis, and compared to time history analysis. Performance level ranges are discussed as well as various load patterns.

Four buildings are selected and assessed along both of the above-mentioned technique in Chapter 4. Their vulnerabilities from each method are predicted and compared each other for each case study.

Finally, Chapter 5 recapitulates all the report, and issues some recommendations

Chapter 2

P25 SCORING METHOD TO DETERMINE COLLAPSE VULNERABILITY OF RC BUILDINGS

2.1Introduction

RC buildings are very common and popular in the world and many countries are applying this method of construction to develop cities because implementation of this method is convenient. Unfortunately, besides common loads applied on buildings, earthquake is one of the most hazardous actions they have to withstand. Consequently, many researchers have carried out studies to well understand the behavior of this material, and to propose better solution against this geological event. Standard computer software packages feature techniques to analyze cases, but analyzing thousands of RC buildings are time consuming and expensive. As the urbanization is rapidly growing, they had to develop techniques to assess a huge population of building.

Sequentially, all over recent years some practical and rapid methods have been described to evaluate RC buildings vulnerability. These methods can totally assess the damage of RC buildings quicker one than another. Also precision of these methods have been proved by many studies and researches. Some RC buildings which have been collapsed due to ground motion have been considered as case studies and analysis has been done on this issue during recent years by Gulay et al(2011). These rapid screen procedures applied widely in many countries all over the world. These rapid procedures permit to evaluate the RC buildings based on walk around the buildings by a trained evaluator. The rapid screen method is performed without any structural analysis. So to save money and time these rapid methods to evaluate RC building are reasonable. One of these rapid methods which in this study have been applied is P25 method to evaluate the level of damage and assess RC buildings which are susceptible to collapse. This method which in this study has been taken into consideration is introduced by Gulay et al(2011). Subsequently the procedure of P25 method described in following paragraph:

2.2Procedure of P25 Technique

This method is based on consideration of the most important structural variables which affect on vulnerability of RC buildings such as asymmetric plan or irregularity, torsion, floor discontinuity, projection, short column, soil type, ground water level, cross section area and considering brick walls and shear walls in critical story, weak story or soft story. This method involves seven scores (P1 to P7). To determine state of the buildings (collapse, moderate or safe), overall P must be calculated:

$0<P<25$	Collapse Range
$26<P<34$	for better investigation pushover analysis must be done
$35<P<100$	very Safe Side

2.2.1Selecting Critical Story

Usually there are tendency for architectural design due to design function some floor specially ground floor defined as a shopping center, parking, basement, bank or show room or etc, which cause higher story and lack of masonry or infill walls. Under such a circumstance it cause critical story and due to this phenomena huge shear force in this floor would occur. In fact this critical floor is the main subject which would be considered to evaluate vulnerability of building with P25 method.In Figure 1 is described how the critical story would be selected and estimated.

2.2.2 Area and Rigidity Indices

By finding plan of building in critical story L_X and $L_y$can be determined sequentially area of t

The plan can be estimated by equation: (2.1).

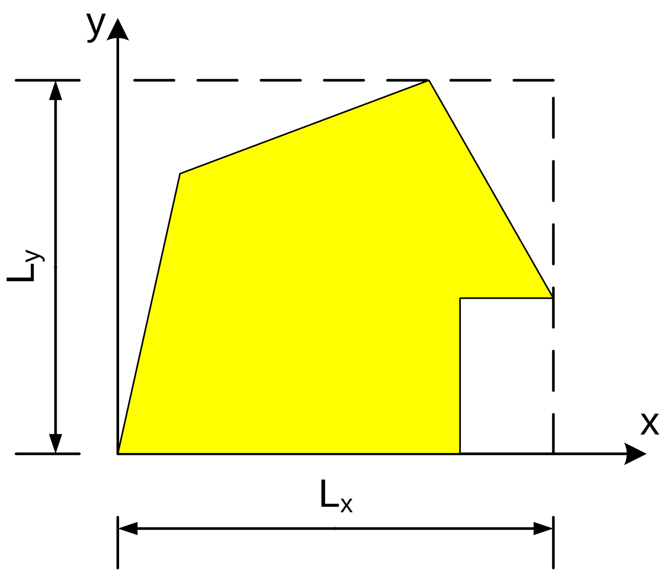


Figure 1. Plan of building style

$$A_P = (L_x L_y) \quad (2.1)$$

Also moment of inertia of plan could be calculated as following:

$$I_{px} = L_y L_x{}^3/12 \text{and} \quad I_{py} = L_x L_y{}^3/12 \quad (2.2)$$

The summation of section area of columns (A_c), area of shear walls $(A_s)$and area of masonry walls(A_m) in critical story or usually maybe ground floors, is named$\left(A_{ef}\right)$. This function (A_{ef}) must be calculated in two x and y direction. It means that(A_{cx}),(A_{sx}), (A_{mx}) in L_X in critical story, and(A_{cy}),(A_{sy}), (A_{my})in$L_y$direction.

And finally summation of these parameters would determine (A_{ef})in two direction (A_{efx}), (A_{efy}).

These functions are used in both direction (x and y) and amount of A_{ef} could be calculated by following equation :(2.3).

$$A_{ef}=\sum(A_c + A_s + 0.15A_m) \tag{2.3}$$

A_{ef}= Total effective section area

A_C= Total section area of columns in critical stories.

A_S= Total section area of shear walls in critical stories.

A_m= Total section area of masonry walls in critical stories.

0.15 is a coefficient for practical purpose which is defined as ($\frac{E_m}{E_c}$).E_m is modulus of elasticity of masonry wall and E_c is modulus of elasticity of concrete .

E_m=Modulus of elastic of masonry wall.

E_C= Modulus of elastic of concrete.

AlsoI_{ef} is summation of moment ofinertia I_C columns,I_m masonry walls, and I_s shear wallsin critical story in two directions x and y respectively, which is given in following equation:

$$I_{ef}= \sum(I_c+I_s + 0.15I_m) \tag{2.4}$$

I_{ef}=Effective total moment of inertia.

I_C=Moment of inertia of columns in critical stories

I_S= Moment of inertia of shear walls in critical stories

I_m= Moment of inertia of masonry walls in critical stories.

C_A And C_I are statistical values which is the ratio of A_{ef} over A_P which is defined in equation (2.5) and (2.6).

$$C_A = 10^5 (A_{ef}/A_P) \tag{2.5}$$

$$C_I = 10^5 \left(\frac{I_{ef}}{A_P}\right)^{0.2} \tag{2.6}$$

$C_{A,ef}$ And $C_{I,ef}$ are effective statistical values which is described in following equations: (2.7), (2.8)

$$C_{A,ef} = (\cos\theta\, C_{A,min}^2 + \sin\theta\, C_{A,max}^2)^{0.5} \tag{2.7}$$

$$C_{I,ef} = (\cos\theta\, C_{I,min}^2 + \sin\theta\, C_{I,max}^2)^{0.5} \tag{2.8}$$

θis angle dominant direction of earthquake and when there is doubt about dominant direction in the earthquake region, it is recommended to be assumed: θ =30

$C_{I_{min}}$ and $C_{I_{max}}$ are defined in equation (2.9) (2.10). These parameters are maximum and minimum statistical values which could be determined between C_{I_x}, C_{I_y} in two direction x and y. for calculation of C_{I_x}, C_{I_y} equation (2.6) must take into consideration.

$$C_{I,min} = MIN\,(C_{I,x}, C_{I,y}) \tag{2.9}$$

$$C_{I,max} = MAX\,(C_{I,x}, C_{I,y}) \tag{2.10}$$

A_P = Area of the plan

2.2.3 Height Parameter h_0

h_0 =-0.6H^2+39.6H-13.4 (2.11)

h_0 = This parameter is used as a correction factor of building height due to effective rigidity.

H=Height of the building.

This variable (h_0) is 100 for a 3m high single story and 446 for a 5- story buildings with H=15m.

2.2.4 Various Scores in P25, P1 to P7

As mention before in this chapter there are seven P which must be estimated to determine the final score P**.** The final P would be a determination score to estimate the condition of the buildings, (collapse, moderate or safe).

2.2.4.1 Structural System Score, P1

To calculate score P1 the following equation (2.12)must be applied:

$$P1= (C_{A,ef} + C_{I,ef})(\prod_{n=1}^{14} fi)/h_0 \quad (2.12)$$

$C_{A,ef}$AndC$_{I,ef}$ As mention before are effective statistical values which are described in equations: (2.7), (2.8)

fi is 14 parameters for calculating of P1which is described by Gulay et al. (2011) in Table 1:

f_1: Torsion irregularity

This parameter has been described to determine the level of irregularity of plan. Torsion would be occurred when between center of mass and center of rigidity exist a space.

f_2: Slab Discontinuity

When ducts and opening in plan is greater than $\frac{1}{3}$ of gross area in existing slabs, slab discontinuity must be taken into account

Table 2: f_i parameters

Factor	Irregularity	Degree of irregularity: High	Medium	None
f_1	***Torsional irregularity***	0.80	0.90	1.00
f_2	***Slab discontinuity***	0.84	0.92	1.00
f_3	***Vertical discontinuity***	0.70	0.85	1.00
f_4	***Distribution of mass***	0.75	0.85	1.00
f_5	***Corrosion***	0.75	0.85	1.00
f_6	***Heavy facade elements***	0.75	0.85	1.00
f_7	***Mezzanine floor*** (γ=Mezzanine floor / Full area)	0.80 $\gamma \geq 0.25$	0.90 $0 < \gamma < 0.25$	1.00 $\gamma = 0$
f_8	***Unequal levels of floor***	0.80	0.90	1.00
f_9	***Concrete quality*** [1]	$f_9 = (f_c / 20)^{0.5}$		
f_{10}	***Strong column criterion*** [2]	$f_{10} = [(I_x + I_y) / 2 I_b]^{0.13} \leq 1.0$		
f_{11}	***Lateral tie spacing*** [3]	$f_{11} = 0.60 \leq (10 / s)^{0.25} \leq 1.0$		
f_{12}	***Soil type***	0.80 (Z_4)	0.90 (Z_3)	1.00 (Z_2, Z_1)
f_{13}	***Foundation type***	0.80 - 0.90 (singular)	0.95 (continuous)	1.00
f_{14}	***Depth of foundation, D***	0.90 ($D < 1$ m)	0.95 ($1 \leq D \leq 4$ m)	1.00 ($D > 4$ m)

(1) f_c = 28th day strength of concrete in MPa.
(2) I_x, I_y = average column moments of inertia values, whilst I_b is the moment of inertia of a typical beam.
(3) s = tie spacing within the confinement zone in cm.

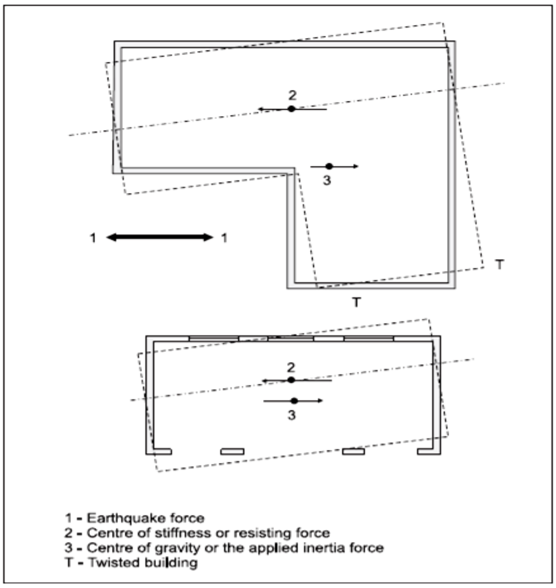


Figure 2: Torsion unsymmetrical plan

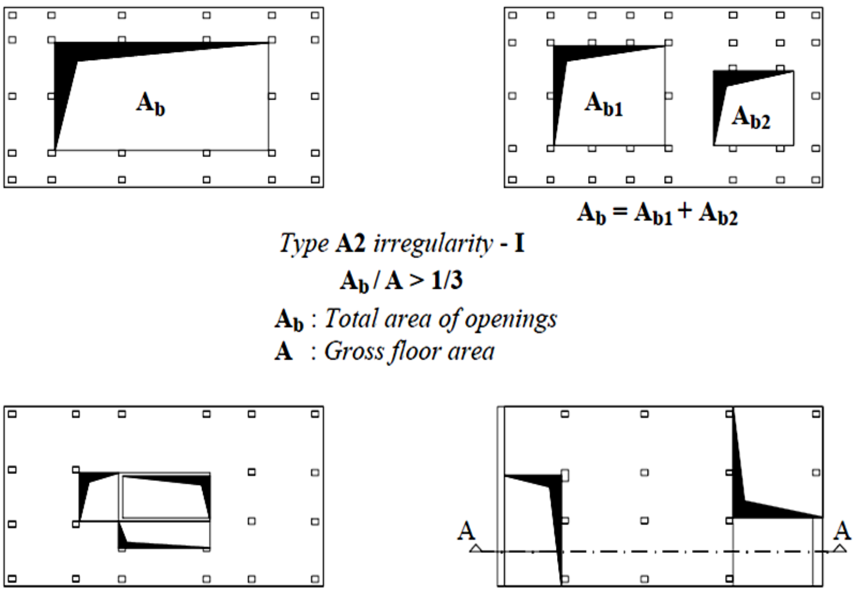


Figure 3: Slab Discontinuity

f_3: Vertical Discontinuity

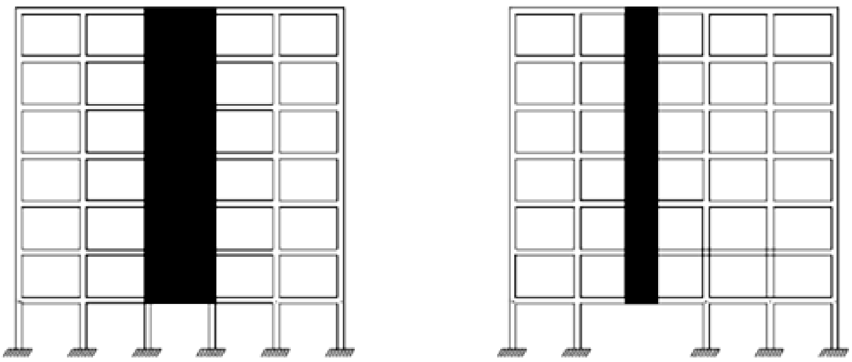


Figure 4: Discontinuity of stories

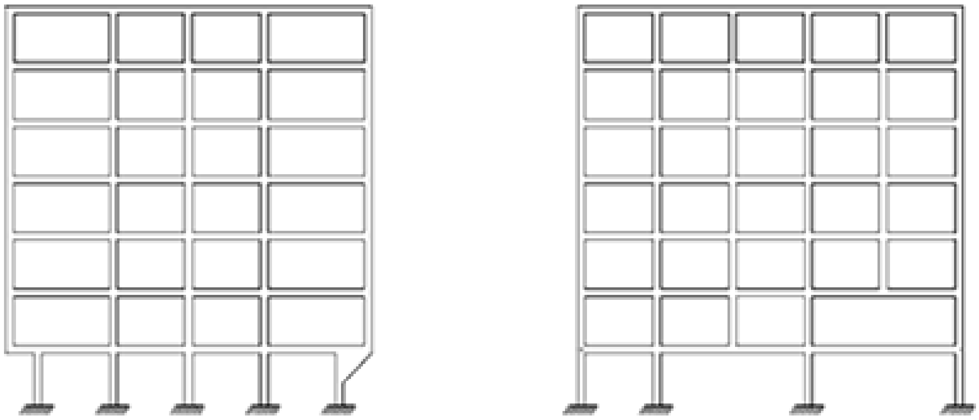


Figure 5: Weak story and soft story

f_4:Mass Distribution

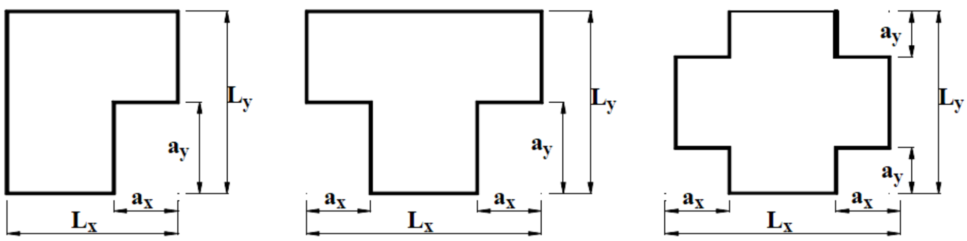
If in floor,heavy mass is distributed unsymetric like storage, ware house or escalator,ie the distribution of mass is not uniform, coefficient $f_4$must be considered.

f_5:Corrosion

When the concrete is in moisture enviroument, Corrosion must be taken into consideration.

f_6 :Heavy Facade Elements

When there are heavy facade elements in entrance of the building it must take into account.



Type **A3** *irregularity :*

Figure 6: Irregularity projection in plan

f_7: Mezzanine Floor

Considering the ratio of Mezzanine Floor / Full area,μ:

$\mu \geq 0.25$	high
$0\geq \mu \geq 0.25$	medium
μ=0	none

f_8: Unequal Level of Floor

When the levels of two floors are not equal, f_8 must take into consideration.

f_9: Concrete Quality

Quality of concrete is important. For keeping safety condition and for calculasion of f_9 flollowing formula must be applied:

$$f_9=\left(\frac{\mathrm{fc}}{20}\right)^{0.5} \leq 1 \tag{2.13}$$

f_{10}: Strong Column Criterion

To find out f_{10} and what is the state of strong column criterion the following formula would be used:

$$f_{10}=\left(\frac{I_{x+}I_y}{2I_b}\right)^{0.15} \leq 1 \tag{2.14}$$

I_X,I_Y=Average column moment of inertia values in critical story.

Ib = Moment of inertia of a typical beam in critical story.

f_{11}: Lateral Tie Spacing

$$f_{11}=0.60 \leq \left(\frac{10}{\mathrm{S}}\right)^{0.25} \leq 1 \tag{2.15}$$

S=tie spacing within the confinement zone in cm

f_{12}:Soil Type

To estimate score of f_{12}, accordingly four types of soil has been defined:

I (Z1) Stiff soil: Those soils with high capacity (more than 10 t/m2.)

II (Z2) Soft soil: Those soilswith low capacity (less than or equal to 10 t/m2.)

III (Z3) Weak soil.

IV (Z4) Very Weak soil.

The parameter of f_{12}based on Table 1 must be applied 0.8 for Z4 and 0.9 for Z3 and 1 for Z1, Z2.

f_{13}: Foundation Type

In the case when type of foundation is single f_{13}: would be 0.8-0.9 (high) and if the type of foundation is continuous it would be 0.95 (medium) and otherwise it would be 1 (none).

f_{14}: Depth of Foundation

In the case when depth of foundation is less than 1m so f_{13}: is 0.9 (high) and if depth of foundation is between 1m - 4m, it is 0.95 (medium) otherwise 1 (none) is used.

2.2.4.2 Short Column Scores, P2

Table 3: Short Column Score, P2

n= Ratio of Number of Short Columns	$\frac{\text{Short Column Height}}{\text{Critical Storey Height}}$	
	$>\frac{2}{3}$	$\leq\frac{2}{3}$
A few n<15%	70	50
Some 0.15≤ n≤ 0.30	50	30
Many n>0.30	45	20

2.2.4.3 Soft Story and Weak Story Score, P3

This parameter (P3) considers the situation of critical floor or basement or underneath floor which always is critical floor and it is under huge shear force and this floor has no any infill walls.

$$P3=100\,[r_a r_y (h_{i+1}/h_i)^3]^{0.60} \tag{2.16}$$

$$r_a = (A_{ef,i}/A_{ef,i+1}) \leq 1 \tag{2.17}$$

$$r_y = (I_{ef,i}/I_{ef,i+1}) \leq 1 \tag{2.18}$$

r_a and r_y are relative ratios of total effective cross section areas and effective moment of inertia of columns, shear walls and masonry or infill walls in two adjacent stories i and i+1 respectively. r_a and r_y are calculated in both x and y direction and average of these values (r_{ax},r_{ay}) and (r_{yx},r_{yy}) would be utilized for calculation.

2.2.4.4 Discontinuity of Peripheral Frame, P4

Table 4: Discontinuity of Peripheral Frame, P4

Location of overhanging			
Beams	At single Facade	At two Facades	At All Facades
Existing	90	80	70
None	70	60	50

2.2.4.5 Pounding Score, P5

When two adjacent buildings are very close together and they might be collide together. This effect is in term of pounding.

Table 5: Pounding Score, P5

Type of impact	Concentric impact		Eccentric impact	
	Slabs at equal level	**Slabs at different level**	**Slabs at equal level**	**Slabs at different level**
Two Last block with in a row	60	30	40	25
Two unequal buildings	55	30	35	25
Low rise next two high rise	75	40	50	35
Two identical buildings	75	50	65	45

2.2.4.6 Liquefaction Score, P6

GWT (m): Ground Water Level

Table 6: Liquefaction Score, P6

GWT (m)	Calculated Liquefaction Potential		
	Minor	**Medium**	**High**
>10 (m)	60	45	30
2 (m) - 10 (m)	45	33	20
<2 (m)	30	20	10

2.2.4.7 Soil Movement Score, P7

Table 7: Soil Movement Score, P7

Soil Type	Ground Water Level (m)	P7
Z1,Z2	–	100
	GWT≤5	25
Z3	GWT >5	35
	GWT ≤5	10
Z4	GWT >5	20

Final Score, P

Final P could be calculated by choosing P_{min}whichthe smallest P among P1 and P7 is.

The following formula (2.19) is considered as Final P:

$$P=\alpha\beta P_{min} \tag{2.19}$$

According to formula (2.20), (2.21), (2.22), (2.23), (2.24)α, β could be calculated:

$$\alpha= [\frac{1}{I}(1.4 - A)(\frac{I}{0.4n-0.88})]t \tag{2.20}$$

P: Final P (2.19) to determine the condition of building.

β: Coefficient to calculate final P

P_{min} : Minimum P which could be found out between all seven P,(P1-P7)

I: Building importance factor

A: Effective ground acceleration, A is between 0.10 g and 0.40g. Four different acceleration values depending on seismic zone.

n :Level of participation of live loads, normally the live load participation factor, n =0.30 is used for residential buildings.

t = Correction factor for topographic effect, correction factor for topographic effect is assume t= 0.7 if the building is on top of the hill, while t = 0.85 if the building is on steep slope and t = 1 for buildings lower elevation.

$$\beta=0.70 \ldots\ldots\ldots\ldots\ldots\ldots \text{for} \quad P_w<20 \tag{2.21}$$

$$\beta=0.55+0.0075P_w \ldots\ldots\ldots \text{for} \quad 20\leq P_w\leq 60 \tag{2.22}$$

$$\beta=1.00 \ldots\ldots\ldots\ldots\ldots\ldots \text{for } P_w>60 \tag{2.23}$$

$$P_w = \sum(w_i P_i)/(\sum w_i) \quad i=1\text{-}7 \tag{2.24}$$

w_i : Weighting factor which could be determined in Table 7

P_i: i is from P1 until P7

P_w: Parameter to determine β

Table 8: Weighting factors for p1 to p7

Weighting factor	P1	P2	P3	P4	P5	P6	P7	P_{min}
w_i	4	1	3	2	1	3	2	4

w_i= weighting factor which is a parameter to calculate the score P

Finally

If P0<P<25Collapse Range

If P26<P<34   for better investigation pushover analysis must be done

If P   35<P<100   Safe Side

2.3Advantage of P25 Method Compared with Other Methods

Advantage of P25 method compared with other methods has been shown in Table 8. According to Table 8 it is showing that almost most of various scoreshave been applied to investigate collapse of RC buildings.

As it could be recognized P25 method could predict 100% collapse vulnerability, because obviously as it could be identified all the structural scoring of RC building has been applied on 323 case studies and results have been shown that consequently this method is very reliable and due to this ability in this study it has been applied.

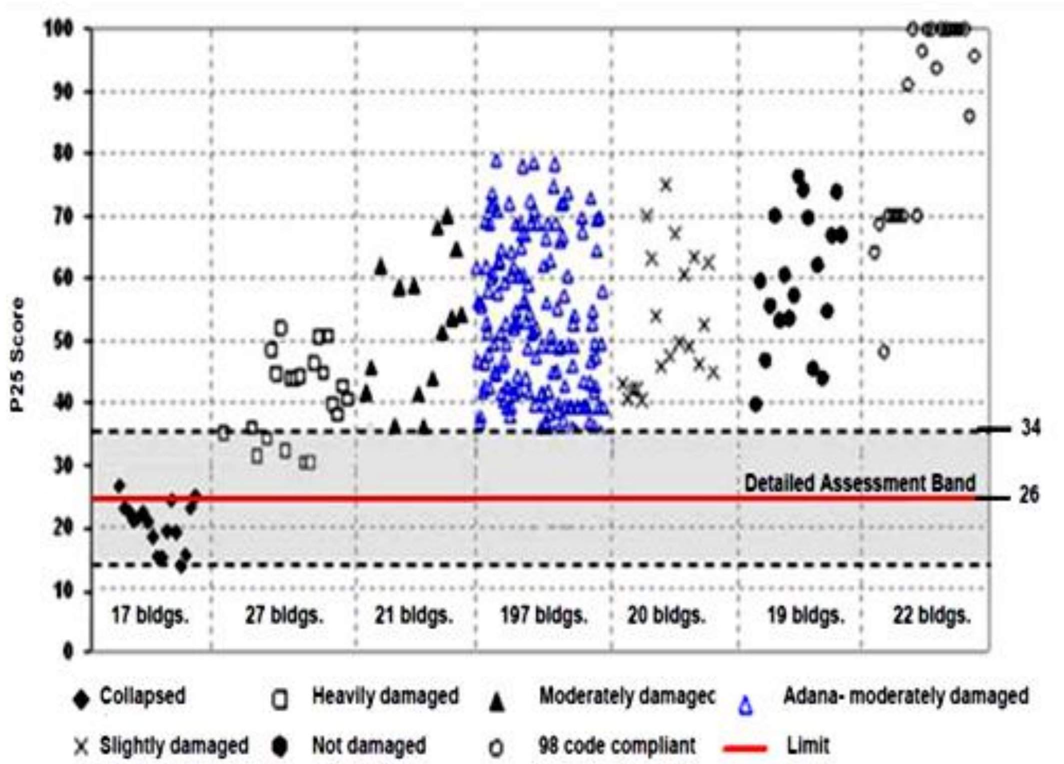


Figure 7.Statistic chart in P25 method to evaluate for 323 sample buildings which have been shown the level of damage.

Table 9: Parametric comparisons of various assessment techniques.

Parameters Considered	FEMA 155 1988	Hassan 1997	Yakut et al. 2004	Yakut et al. 2006	NRCC 1993	JBDPA 1990	P25
A_{col}, A_{wall}	-	A	A	A	A	n	A
I_{col}, A_{wall}	-	-	A	n	A	n	A
A_m = *Infill wall areas*	-	-	A	-	A	-	A
I_m = *Infill wall rigidities*	-	-	A	-	-	-	A
N = *No of storeys*	S	A	A	A	A	A	A
Torsional irregularity	S	A	-	A	A	A	A
Floor Openings	S	A	-	A	-	A	A
Discontinued wall / column	S	-	-	A	A	A	A
Mass irregularity	-	-	-	-	-	A	A
Corrosion	-	-	-	-	-	-	S
Heavy facade panels	S	-	-	-	S	-	S
Unequal floor levels	-	-	-	-	-	-	A
Concrete quality	-	A	-	A	-	A	A
'Strong' column criterion	-	S	-	-	-	-	A
Column tie spacing	-	-	-	-	-	-	A
Short column effect	S	S	-	A	A	-	A
Soft / Weak storeys	S	A	A	A	A	A	A
Pounding of bldgs	S	A	-	-	S	-	A
I = Importance factor	-	A	-	-	A	-	A
n =Live load factor	-	-	-	-	S	A	A
Soil Type	A	A	-	-	A	A	A
Liquefaction risk	-	-	-	-	-	-	S
Land slide risk	-	-	-	-	-	-	S
Earthquake zone effect	-	-	-	-	-	-	A
Topographic location	-	S	-	-	A	-	A
Case studies tested	n	n	484	89	n	**2**	**323**
Prediction in heavily damaged bldgs (%)	n	n	80	91	n	100	**100**
Prediction in collapsed bldgs (%)	n	n	n	n	n	n	**100**

S = Subjective scoring, A = Analytical scoring, n = not applicable

Chapter 3

NONLINEAR PERFORMANCE ASSESSMENT OF RC BUILDINGS

3.1Introduction

The procedures of structural and seismic engineering have been great developed since last decades. Changing the codes of practice and suggesting the new reports from Federal Management Agency (FEMA) manifest some of these changes. In fact the current design codes are based on the recent research, the fast improvement in nonlinear analysis procedures was based on the current analysis processes for the purpose of assessing the nonlinear analysis behavior of structural systems.

3.2 Short Background about Pushover Analysis

Nonlinear static analysis (pushover) has been described to structure engineer all over the world recent years and it has been utilized at the same time and it has an advantage for designing based on performance capacity of the structure. A definition of pushover analysis is a static nonlinear process which the loading gradually increase until reach to the failure mode of the elements. Static pushover analysis can be defined by the structural engineering to assess the actual strength of the structure and it is a useful method for designing on the basis of performance. For pushover analysis there are modeling processes, procedure of analysis and also acceptance criteria that are detailed in the ATC-40 and FEMA-356 documents.

There are three kinds of loading in pushover analysis in lateral loading which is defined as a uniform load pattern and the other one is inverted triangular pattern load which increase gradually and modal load pattern which is based on the first dominant mode of structure. These various lateral loads alternatively push the structure respectively. Based on pushover analysis firstly the gravity loads will be applied and then lateral loads incrementally increased until the plastic hinges occur in elements and consequently the building reach to failure mode. There are two pushover definitions that can be determined as a force control and the other one is based on displacement control. According to (FEMA356) and (ATC-40)force–deformation can be introduced based on target displacement and hinges properties is defined in computer program and properties of plastic hinges is assigned automatically to computer program (SAP2000, ETABS) as a default or as a user defined by identifying the moment curvature and rotation based on the cross section area of beams and columns and Moments 3-3, Moment 2-2, Shear force V3-3 and V2-2, axial force and interaction of P-M2-M3 is exerted to software as forces indicator. And after the analysis based on FEMA 356 andATC-40 it can be identified the performance points and the level of damage and seismic capacity of the structure could be recognized by identifying the performance point. There are five points which has been described in Figure 8. A, B, C, D, E and also three categories which has been described as Immediate Occupancy (IO), Life safety (LS), and collapse prevention (CP) by FEMA. By Pushover analysis can be understood that the structure is located in which regions and finally find out feeble elements. Sap2000 and ETABS by applying two and three dimensional analyses have ability to determine force-deformation curve and performance points. Consequently in this point (performance points) demand and capacity of structure would be identified. As a matter of fact this method is a fast and efficient method to realize the buildings vulnerability and on the other hand implementation of this method (pushover) is convenient.

3.3 Performance Based Seismic Design

Performance based seismic design implies the design, evaluate the structures due to seismic loads and it supports the needs of owners and society. Performance based seismic design determine how a building is perform, and it is given the potential earthquake hazard level.

Compared with other methods, performance based design describe a simple methodology to assess capability of a building due to ground motion.

3.4 Structural Performance Levels and Ranges

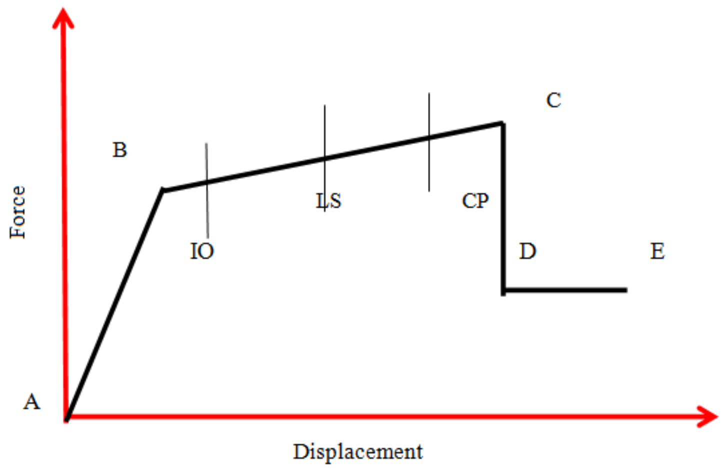


Figure 8. Force Deformation curve of pushover

3.4.1 Immediate Occupancy Performance Level (IO)

Some structural elements and components are lightly damaged, but this has not been sequenced in huge hazard level, either within or outside the building. Injuries may not be occurring during earthquake, however, it is expected that the risk of life injury is very low. It should be possible to repair the structure.

3.4.2 Life Safety Performance Level (LS)

Structural performance level, life safety, means damage state, in which significant damage to the structure has occurred, but somehow damage is light and the structure partially would be remained in safety condition. Some structural elements and components like masonry walls, brick walls and component of roof ceiling like mechanical and electrical and ventilation equipment would be severely damaged, but this has not consequently in large hazards, either within or outside the building. Injuries may occur during the earthquake, however, it is expected that the overall risk of life injury is low.

3.4.3 Collapse Prevention Performance Level (CP)

Structural performance level, collapse prevention, means the building is in versus of partial or total collapse. Substantial damage to the structure has occurred, including significant damage which leads to reduction of rigidity and resistance of the complex and system, and large lateral deformation of the structure. In this condition the vulnerability of the building is high and the structure would be severely damage, either within or outside the building. Injuries may occur during the earthquake; however, it is expected that the overall risk of life injury is high.

3.5 Comparison between Time History Analysis and Pushover Analysis

Time history analysis is a type of dynamic analysis which can be defined as an effective method for studying structural response of seismic forces. There is two type of time history analysis (linear dynamic analysis and nonlinear dynamic analysis). This method of analysis can predict the seismic performance of structures exactly. The ability and efficiency of nonlinear time history analysis for computing is significant and it is suitable for pragmatic design.But on the other hand, there are still some uncertainty and doubt about this method (time history analysis) that are basically relevant to its difficulty and furthermore, analysis of time history is totally sensitive due to input data relevant to ground motion like peak ground acceleration (PGA) of seismic zone. As a result, choosing a suitable acceleration time–history is necessary. This substantial cause computational effort dramatically increases. So nonlinear static analysis (pushover) is a simple alternative to find out the strength capacity in post elastic range also application of this method is convenient. This approach might be applied in order to identify probable feeble elements in the structures and to identify different level of damage and to determine capacity and demand of the structures.

This method by applying a predefined lateral load pattern that affects the building throughout its height, then the lateral forces continuously would increase till building reach to a specific level of deflection which is defined as a specific displacement control. This displacement is called target displacement. (FEMA) this displacement is a drift corresponding for assessment purpose. This approach would allow identifying of yielding and failure of the members, and also the capacity curve of a typical structure.

Static pushover procedure has been investigated mainly during recent year by (Sozen, Saiidi 1981) and (Fajrfar 2000) and Gaspersic (1996) and Bracci et al (1997).This method is also introduced by National Earthquake Hazard Prediction (NEHRP) and (FEMA). Furthermore, the so called method is taken into consideration by Structural Engineers Association of California (SEAOC) among the analysis procedures.

3.6 Evaluation of Nonlinear Static Pushover Procedure

In the study conducted by law, Sashi and Kunnath (2000) effectiveness of pushover procedures was examined. Pushover procedures are recommended by FEMA 356 document for assessment of the seismic performance of buildings due to earthquake hazard. Two steel and two reinforced concrete buildings were used to evaluate the 34 procedures. Strong-motion records during the Northridge earthquake were available for these buildings.

The American Society of Civil Engineers (ASCE1997) is in the process of producing an U.S. standard for seismic rehabilitation existing buildings. It is based on Guidelines for Seismic Rehabilitation of Buildings (FEMA 1997)which was published in 1997 by the U.S. Federal Emergency Management Agency(FEMA 356) Consists of three basic parts: (a) definition of performance capacity (b) demand prediction, and (c) acceptance criteria using force - deformation limits. FEMA-356 suggests four different analytical methods to estimate seismic demands:

I. Linear Static Procedure (LSP)

II. Linear Dynamic Procedure (LDP)

III. Nonlinear Static Procedure (NSP)

IV. Nonlinear Dynamic Procedure (NDP)

3.6.1 Pushover Load Pattern

Some loading patterns would determine a pushover procedures which they are mention following. These initial methods are essential to set up pushover analysis. Their procedures are various mostly in form of lateral force distribution. FEMA-356 recommends the following three procedures**:**

a) Inverted Triangular Pattern

b) Uniform Load Pattern

c) Modal Load Pattern

3.7 Analysis Methods

3.7.1 Linear Analysis Method:

Base shear is calculated according to seismic response coefficient and total dead load and portion of other loads would spread to building. This base shear is distributed to different floor levels and response of building estimated on the basis of static analysis. (FEMA 356).

To estimate the effect force of the earthquake on the buildings, the initial estimation was assumption the percentage of building weight which participates in earthquake force. To estimate the amount of this force Japanese determined an initial coefficient which by multiplying to weight the base shear force of the earthquake could be determined. This coefficient was 0.10. By passing the time this formula developed and some other factors like acceleration of the ground motion and important of building and behavior of the structure and times period took into consideration. The last equation which has been applied until now is: V=CW

The C factor is defined by the following equation**:**

$$C = \frac{ABI}{R} \qquad (3.1)$$

W= building weight

V= base shear

R= structure behavior

I=important of the building

A=acceleration of ground motion

B=coefficient of period. To estimate T (period) there is an experimental equation which is described as following:

$$T=\alpha H^{0.75} \quad (3.2)$$

α=0.8 Flexural steel frame

α=0.7 Flexural concrete

α=0.7 braced steel frame with eccentric axial

α=0.5 other structural system

3.7.2 Nonlinear Analysis Method:

For nonlinear analysis procedures that are considered, these methods can be mentioned: nonlinear static analysis (pushover), capacity spectrum analysis by Skokan and Hart (1999) and nonlinear time history analysis. (FEMA356). In nonlinear static procedure (pushover) by considering P-Δeffects a target displacement is assign on top of the building and by pushing with an incremental lateral load till target displacement reaches to a specific point. And finally level of damage would be recognized.

Capacity spectrum approach is substantially applicable for reinforce concrete structures (ATC40). And nonlinear time history method is the same as linear time history analysis. But for this method merely nonlinearity material as well as geometric effects should be taken into consideration in order to evaluate structure response. In nonlinear method software can draw hysteretic loop for each members and amount of energy absorption can be evaluated.

3.7.2.1 Dynamic Analysis

Structural dynamics depends on a period of time; dynamic load is various to one direction or position over a period. It must be determined by implementing dynamic analysis by Ashfaqul (2010).There is significant discrepancy between structural dynamic analysis and static analysis in two ways. First of all, dynamic analysis is considered as differential of time. The second one is used for tall structures. Magnitude of the inertia force is depended on the acceleration and mass characteristics. On the contrary to static analysis, dynamic analysis is too much depends on damping and mass. For purpose of writing equations of motion there are three components or parameters, namely mass, damping and stiffness characteristics. For changing dynamic force into static forces equivalent lateral load method is being applying. Although it cannot reflect real dynamic response, but because resonance cannot be described in a static approach, therefore it can identify somehow the real dynamic analysis.

3.7.2.2 Modal Analysis

Modal analysis is being applied in spatial structures based on the summation of high effective modes and changed the buildings to MDOF system. It is a convenient method of computing for dynamic response related to a linear structural system by Chopra (2007).

3.7.2.3 Pushover Analysis

Pushover analysis presented by Federal Emergency Management Agency (FEMA 356) recent years and advantage for designing based on performance capacity of the structure, is simplicity. An easy definition of pushover is a static nonlinear processed which the loading gradually increase until reach to the failure mode of elements.

3.7.2.3.1 Assessment of Nonlinear Behavior

Structural response curve is a basic criterion to assessment the nonlinear parameters of a structures. These parameters such as performance point, base shear; target displacement and so on can all be extracted from pushover curve.

3.7.2.3.2 Choice of the Method of Analysis

Several methods were used in order to analysis of structure based on different codes. As mentioned before in this study because pushover analysis is more convenient and practical than dynamic analysis, therefore the first option (pushover) has been take into consideration.

3.7.2.3.3 Computer Software Selection for Analysis

There are many types of programs which have capability to pushover analysis. IDARC, DRAIN, PERFORM 3D, ETABS and SAP2000 are the most well-known programs and widely use for such an analysis and they are powerful enough to provide reliable results.

3.7.2.3.4 Displacement-Based Pushover Analysis

There are two methods for pushover analysis; Force-based and Displacement-based. According to these methods, the displacement method is more precise because it is considering high ductility. If there is low ductility or considering not ductile behavior then, the first method (Force-based) can be used for pushover analysis even if it has little accuracy.

3.7.2.3.5 Nonlinear Material Characteristic

Nonlinear material property is being defined as a default to do an approximate analysis because computer soft ware (SAP2000, ETABS) would assume the property as ductile material but to achieve the exact analysis the nonlinear material property (M_P ,M_Y , φ, θ) parameters and section elements must be identified to assign to soft ware.

According to FEMA 356 and ATC 40. Also P-Delta effects should be taken into consideration in order to get more accurate results.

3.7.2.3.6 Failure Criteria

Pushover can realize that structure is located in which regions and finally how can assess level of damage and buildings vulnerability and feeble elements.

3.7.2.3.7 Plastic Hinge Characteristic

Accordingly there are axial plastic hinges which is due to axial loads P in columns and moment plastic hinges which is due to moment 3-3 and moment 2-2 in beams and shear plastic hinges which is due to shear force, V 3-3 and V 2-2 in beams and interaction of axial load and moment in columns, P-M3-M2 which can be assigned to elements by user define or program default.

3.7.2.3.8 Column Hinge Properties

According to FEMA (356), the plastic hinge behavior is significant. Therefore, interaction for P-M2-M3 is utilized to demonstrate behavior of plastic hinges for columns in a structure.

3.7.2.3.9 Beam Hinge Properties

Moments in M3 and M2 section of beams and shear plastic hinges V2-V3 at beginning and end of beam is defined to determine the plastic properties of beams.

3.7.2.3.10 Idealization for Pushover

In order to find out the factor of the performance treatment of the building target displacement, base shear, performance point, capacity and demand of the structures.

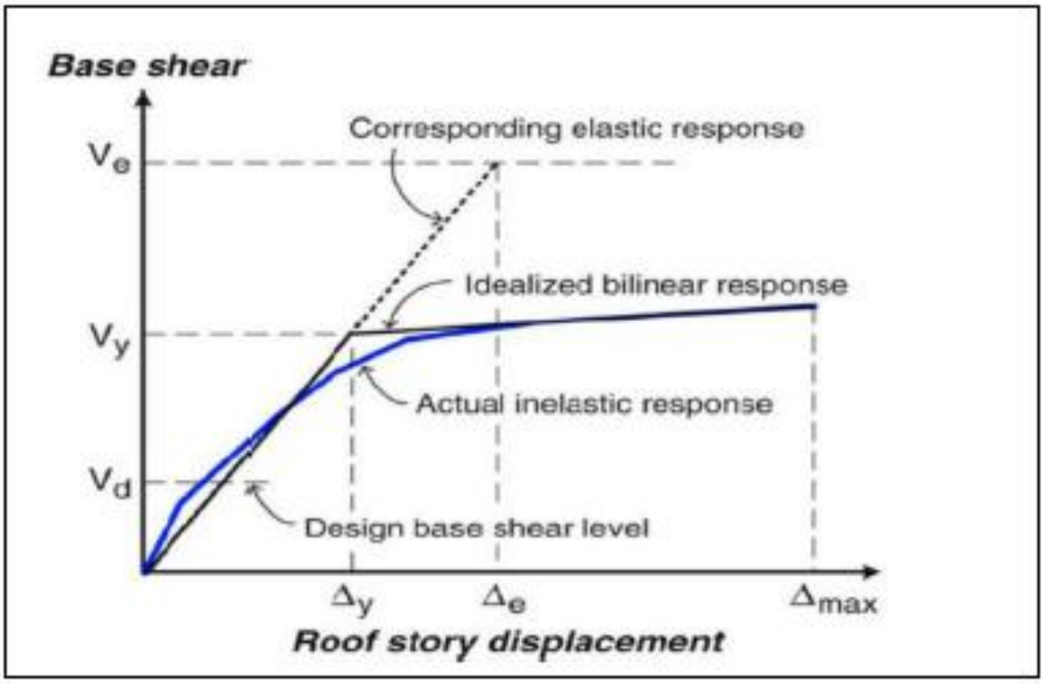


Figure 9.Idealize curve for pushover analysis

3.7.2.3.11 Target Displacement

The estimation of target displacement is a significant procedure to define to pushover to set up a nonlinear analysis. As an initial step there is an assumption to estimate target displacement which is 0.04H, and H is height of the building.

$$\delta = (C_0 C_1 C_2 C_3 S_a)\,\frac{T_e^2}{4\pi^2}g \qquad (3.3)$$

C_0: Modification factor

C_0 Can be assuming 1 to make calculation easy in following condition:

The contribution coefficient of the first mode in control point level.

The contribution coefficient modes in the control point level which can be obtain from the displacement of the building in target displacement. This method can be used when loading of the structure is simultaneous with deformation of the structure.(FEMA356 2000).

Table 9. Modification Factor C_0 FEMA 356

	Shear Buildings		Other Buildings
Number of Stories	Load (Triangular)	Load (Uniform)	Load (Any)
1	1	1	1
2	1.2	1.15	1.2
3	1.2	1.2	1.3
5	1.3	1.2	1.4
10 +	1.3	1.2	1.5

C_1: Modification factor

$T_e \geq T_s C_1 = 1.0$ (3.4)

$T_e < T_s C_1 = \frac{[(1+(R-1)TS/Te]}{R}$ (3.5)

But not greater than:

$T_e <. T_s C_1 = 1.5$ (3.6)

$T_e \geq T_s C_1 = 1.0$ (3.7)

Te: Effective fundamental period

T_s: Soil period

$R = \frac{Sa}{vy/w} c_m$ (3.8)

Table 10.Coefficient Factor C_2 based on FEMA

	T≤ 0.1		T≥ T_s	
Structural Performance Level	Framing Type 1	Framing Type 2	Framing Type1	Framing Type 2
Immediate Occupancy	1.0	1.0	1.0	1.0
Life safety	1.3	1.0	1.1	1.0
Collapse prevention	1.5	1.0	1.2	1.0

C_3: Coefficient Factor

$$C_3 = 1 + \frac{[\alpha](R-1)^{3/2}}{T_e} \qquad (3.9)$$

Sa: Response Spectrum Acceleration,

α: Ratio of Post-Yield Stiffness

T_e= Effective Basic Period

$$T_e = T_i \sqrt{\frac{K_i}{K_e}} \qquad (3.10)$$

T_i= Elastic Fundamental Period

K_i= Elastic Lateral Stiffness

K_e= Effective Lateral Stiffness

R=Ratio of Elastic Strength Demand to Calculated Yield Strength Coefficient

w= Effective Seismic Weight

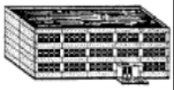
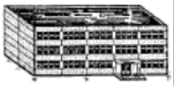
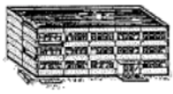
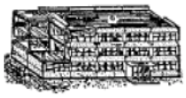
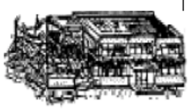
v_y=Yield Strength

Sa=Response Spectrum Acceleration

As pushover analysis results, a table depicting plastic hinge history is yielded by the package. European Macro seismic Scale (EMS 98) presents a method of classification of damage to reinforced concrete buildings. It differentiates five grade levels ranging from grade 1 to grade 5 depending to observable damage that occur on structures. These different grade levels correspond to various plastic hinge apparition and performance level. Table 11 reproduced the classification from EMS 98.

Based on this classification, the plastic hinge history is distributed into grade levels. Once the target point is determined from FEMA 356, the corresponding grade level is read from the pushover analysis result table.

Table 11.Classification of damage to reinforced concrete buildings

Damage Grade	**Simulation**	**EMS 98**	**Identification (Start of Damage Grade)**
Grade 1		***Negligible to slight damage (no structural damage, slight non-structural damage)*** Fine cracks in plaster over frame elements or in walls at base. Fine cracks in partitions and infills.	After cracking. Onset of tensile strength of members.
Grade 2		***Moderate damage (slight structural damage, moderate non-structural damage)*** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.	First plastic section. Reduction starts in structural stiffness.
Grade 3		***Substantial to heavy damage (moderate structural damage, heavy non-structural damage)*** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of wall-panels.	Final plastic section before individual section failure. Building stiffness tends to zero.
Grade 4		***Very heavy damage (heavy structural damage, very heavy non-structural damage)*** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam-reinforced bars; tilting of columns. Collapse of a few columns or a single upper floor.	First individual section failure. Start of reduction in base shear.
Grade 5		***Destruction (very heavy structural damage)*** Collapse of ground floor or parts of the building.	Final individual section failure. Loss of lateral stability. Buckling of some columns.

Chapter 4

SELECTED CASE STUDIES AND ANALYSIS OF RC BUILDINGS

4.1 Introduction

In this chapter, four RC buildings have been selected to be evaluated in term of their seismic performance or vulnerability. The first case study is a three story building, the second case study is a seven story one, the third one is made of four stories, and the last case study has three stories. Firstly, P25 Method has been used to investigate the collapse, and then, secondly, pushover analysis has been used to evaluate performance of the structures. Finally these two methods have been compared with each other.

4.2 Description of Buildings

All these RC buildings are located in Larnaka Street (Gazimağusa-North Cyprus), and were constructed in 1970-80. The most structural problems of these buildings are (1) connection between beams and columns, (2) irregularity in plan and projection,(3) weak and soft stories which cause critical floor. Also major structural problems in these case studies are design section of beams and columns. The other problem in these case studies concerns ground floors which experiences huge shear forces due to lack of infill walls.

4.3 Material Properties

The material which is used for these buildings is reinforced concrete that is made of concrete and steel bar. The properties of these materials are described as following:

Modulus of Elasticity of steel, Es = 2×10^6 kg/cm^2

Modulus of Elasticity of concrete, Ec= 2×10^5 kg/cm^2

Characteristic strength of concrete, fc = 210 kg/cm^2

Yield stress for steel, fy = 4000 kg/cm^2

4.3.1 Three Story Building (First case study)

This building is located in Larnaka Street. It is 14.1m long and 7.6m wide in X- and Y-direction, respectively. This building has three spans in X-direction and three others in Y-direction. The height of each story is 2.85 m, and the thickness of infill walls is 20cm. The compressive strength of concrete and the tensile strength of steel bars are 210kg/cm^2 and 4200kg/cm^2, respectively. The plan of this building is shown in Figure 10.

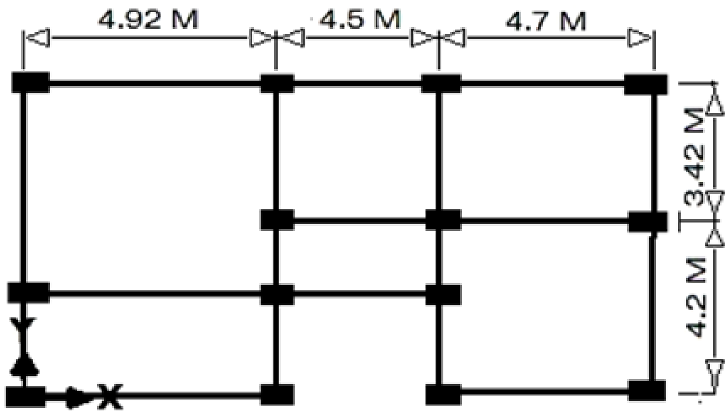


Figure 10.The plan of four story building

Also cross sectional area for beams and columns which were used in this building is shown in Table 11.

Table 11. The cross section area of beams and columns

Story number	Beam	column
Story 1	20 X 55 cm	20 X 40 cm
Story 2	20 X 55 cm	20 X 40 cm
Story 3	20 X 55 cm	20 X 40 cm
Story 4	20 X 55 cm	20 X 40 cm

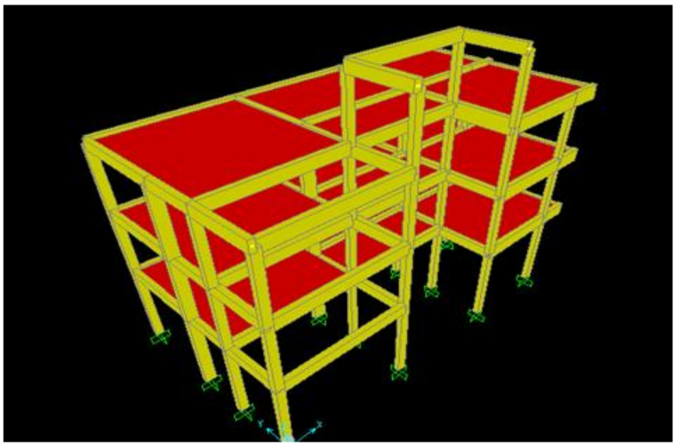


Figure 11. The three dimension of four story building

4.3.1.1 P25 Method

In this method, soil has been considered as to be type II and water under ground level, 2.5m.The effect of liquefaction has been taken into account. Moment of inertia in beams and columns in critical story (first story) has been calculated in two directions ($L_X$and L_y) separately. Also moment of inertia of brick walls in two directions has been considered. The below table shows the calculation details of P25:

0 <P< 25	Collapsed
26 < P < 34	No Collapse but Pushover Analysis must be done
35<P<100	Safe Side

Based on P25 Method analysis, the obtained value is 31.5 and because it is between 26 and 34 therefore for precise assessment this building needs pushover analysis.

4.3.1.2 Pushover Analysis

For pushover analysis, the amounts of dead load and live load have been considered as 250 kg/m^2 and 500 kg/m^2, respectively. All the slabs have been defined as a diaphragm, separately for each floor level.

Table 12. Calculation of buildings by P25 Method

		H=	2.85				f1=	0.8	w1=	4
	AP=LX*LY	AP=	118.503	8.1	14.63		f2=	0.84	w2=	1
	IPX=(LX*LY^3)/12	IPX=	2113.667897				f3=	0.7	w3=	3
	IPY=(LY*LX^3)/12	IPY=	647.9151525				f4=	0.75	w4=	2
	Aefx=SUM(Acx+Asx+AMx*0.15)	Aefx=	10.92	10.92	0	0	f5=	0.75	w5=	1
	Aefy=SUM(Acy+Asy+AMy*0.15)	Aefy=	9.66	9.66	0	0	f6=	0.85	w6=	3
	Iefx=SUM(Icx+Isx+Imx*0.15)	Iefx	0.29	0.29	0	0	f7=	1	w7=	2
	Iefy=SUM(Icy+Isy+Imy*0.15)	Iefy	0.27	0.27	0	0	f8=	1		
	CAx=(Aefx/AP)*10^5	CAX=	9214.956583				f9=	1		
	CAy=(Aefy/AP)*10^5	CAY=	8151.692362				f10=	0.8		
	CAmax	CAmax=	9214.956583				f11=	0.9		
	CAmin	CAmin=	8151.692362				f12=	1		
	CAef=(COS(x)*CAmin^2+SIN(x)*CAmax^2)	CAef=	100005177				f13=	0.8		
							f14=	0.9		
	CIx=10^5*(Iefx/IPX)^.2	CIx=	16883.87971							
	CIy=10^5*(Iefy/IPY)^.2	CIy=	21084.7825							
	CImax	CImax=	21084.7825							
	CImin	CImin=	16883.87971							
	CIef=(COS(x)*CImin^2+SIN(x)*CImax^2)	CIef=	469157899.6							
H=2.85	h=(-.6H^2)+39.6H-13.4	h=	94.5865							
	p1=SUM(CAef+CIef)*(f1*f2*f3*f4*f5*f6*f7*f8*f9*f10*f11*f12*f13*f14)/h									
		P1=	70.15866576							
		P2=	50							
		P3=	100							
		P4=	90							
		P5=	75							
		P6=	**45**							
		P7=	100							
		Pmin=	45							
	pw=SUM(W1*P1+W2*P2+W3*P3+W4*P4+W5*P5+W6*P6+W7*P7*W7+pmin*4)/20									
	B=.7 IF(Pw<20)	PW=	175868975							
	B=.55+.0075Pw IF(20<Pw<60)									
	B=1 IF(Pw>60)	B=	1							
	a=(1/1)*(1.4-.35)(1/(.4*.3+.88))*.7	a=	0.7							
	p=a*B*Pmin	p=	31.5	pushover must be done						

In order to evaluate building based on pushover analysis, three nonlinear load cases were used. The first nonlinear load pattern is defined based on dominant mode which in this case is first mode, according to mass participation in earthquake (modal load). The second nonlinear load pattern is defined as a factor of gravity load which is 1.1(DL+LL) based on FEMA356. The third nonlinear load case is defined push (x) and push(y).On the other hand, linear load pattern like dead load, live load, and earthquake in X- and Y-direction are defined to SAP2000. Coefficient of acceleration and period of building have been estimated and spectrum curve produced and assigned to SAP2000.The value of this spectrum is shown in Table 13. After analysis by SAP2000, considering the Y-direction, FEMA 356 yields to the target point (V=54717.118 kgf; D=0.300 m). This point lies between step 14 and step 15. The damage grade level assignment shows that, the building suffers from a damage of grade 4: very heavy damage (heavy structural damage, very heavy nonstructural damage).For the X-direction, the target point is found to be (V=103585.27 kgf; D=0.147 m) that also corresponds to the range between steps 29 and 30 or the grade level 4.

Table 13.Spectrum values

Period	Acceleration	Period	Acceleration	Period	Acceleration
0	1	1.55	1.170026371	3.1	0.672003684
0.05	1.5	1.6	1.140683141	3.15	0.663456672
0.1	2	1.65	1.112945387	3.2	0.655150424
0.15	2.5	1.7	1.086680495	3.25	0.647074552
0.2	2.5	1.75	1.061770293	3.3	0.639219267
0.25	2.5	1.8	1.038109116	3.35	0.631575338
0.3	2.5	1.85	1.015602184	3.4	0.624134048
0.35	2.5	1.9	0.994164219	3.45	0.616887163
0.4	2.5	1.95	0.973718272	3.5	0.609826894
0.45	2.5	2	0.954194727	3.55	0.602945873
0.5	2.5	2.05	0.935530434	3.6	0.596237117
0.55	2.5	2.1	0.917667969	3.65	0.589694011
0.6	2.5	2.15	0.900554998	3.7	0.583310279
0.65	2.34493238	2.2	0.884143716	3.75	0.577079962
0.7	2.209950657	2.25	0.868390362	3.8	0.570997401
0.75	2.091279105	2.3	0.8532548	3.85	0.565057216
0.8	1.986044702	2.35	0.838700147	3.9	0.559254289
0.85	1.892020634	2.4	0.824692444	3.95	0.553583749
0.9	1.807452952	2.45	0.811200373	4	0.548040957
0.95	1.730940441	2.5	0.798194998	4.05	0.542621491
1	1.661349515	2.55	0.785649547	4.1	0.537321135
1.05	1.597752735	2.6	0.773539206	4.15	0.532135866
1.1	1.539383619	2.65	0.761840945	4.2	0.527061843
1.15	1.485602894	2.7	0.750533355	4.25	0.522095398
1.2	1.435872944	2.75	0.739596511	4.3	0.517233023
1.25	1.389738211	2.8	0.729011843	4.35	0.512471365
1.3	1.346809984	2.85	0.718762021	4.4	0.507807216
1.35	1.306754469	2.9	0.70883085	4.45	0.503237505
1.4	1.269283342	2.95	0.699203182	4.5	0.49875929
1.45	1.234146191	3	0.689864831	4.55	0.494369753
1.5	1.201124434	3.05	0.680802493	4.6	0.490066193

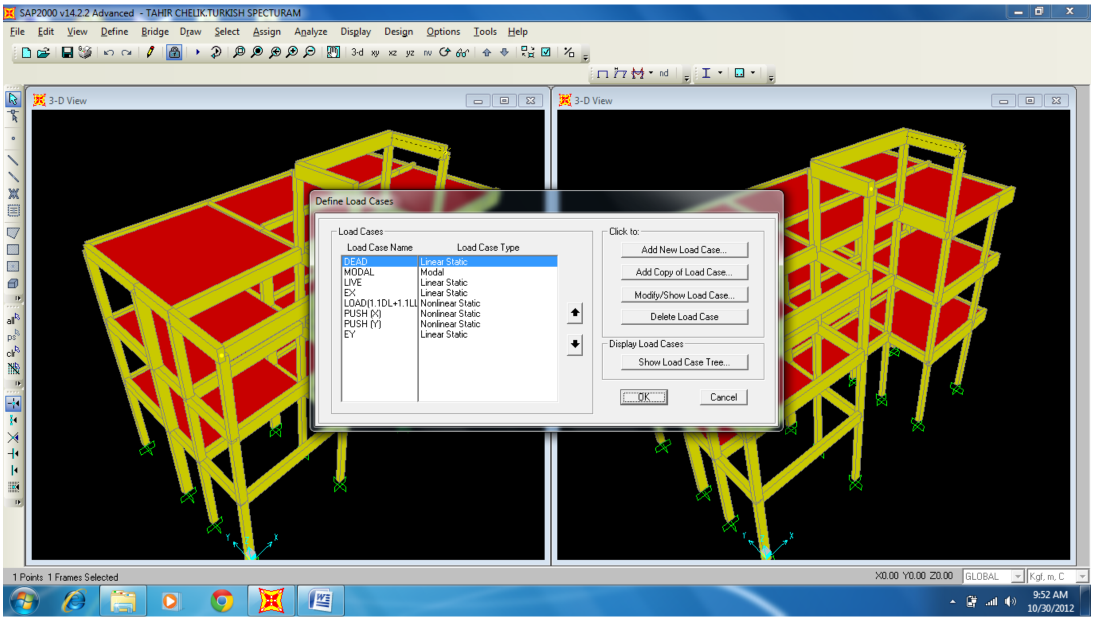


Figure 12. The definition of linear and nonlinear load cases

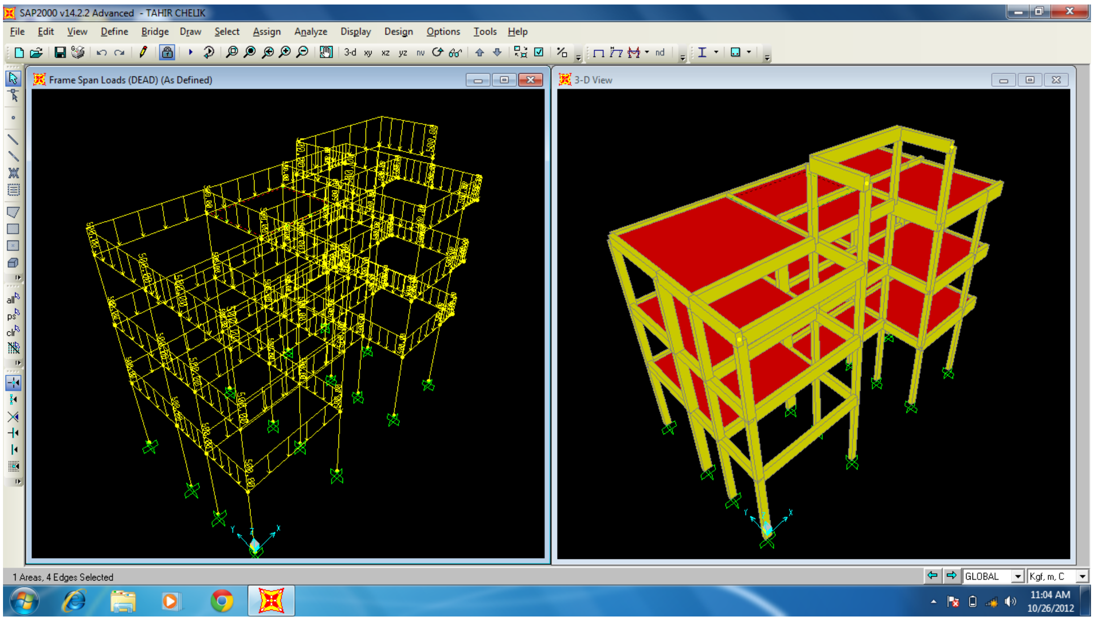


Figure 13. The distribution of dead load

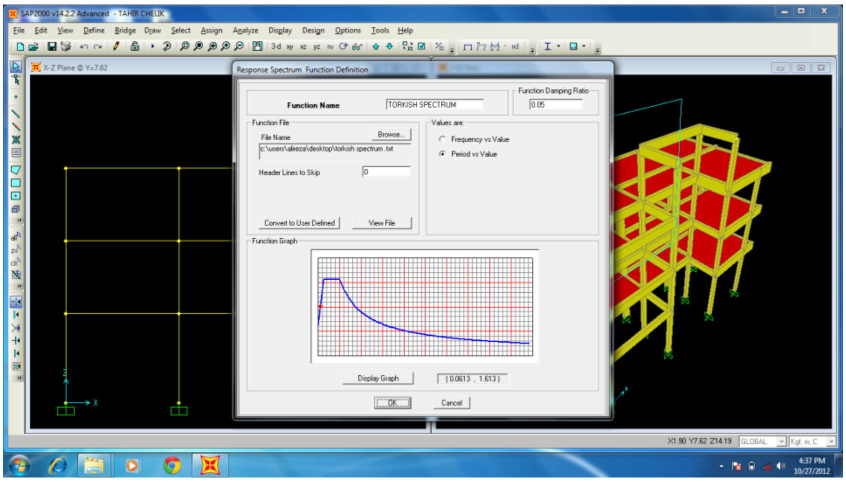


Figure 14. Spectrum of the earthquake based on seismic zone

The definition of ATC 40 and FEMA 356 are shown in Figures 16 and 15 respectivly .

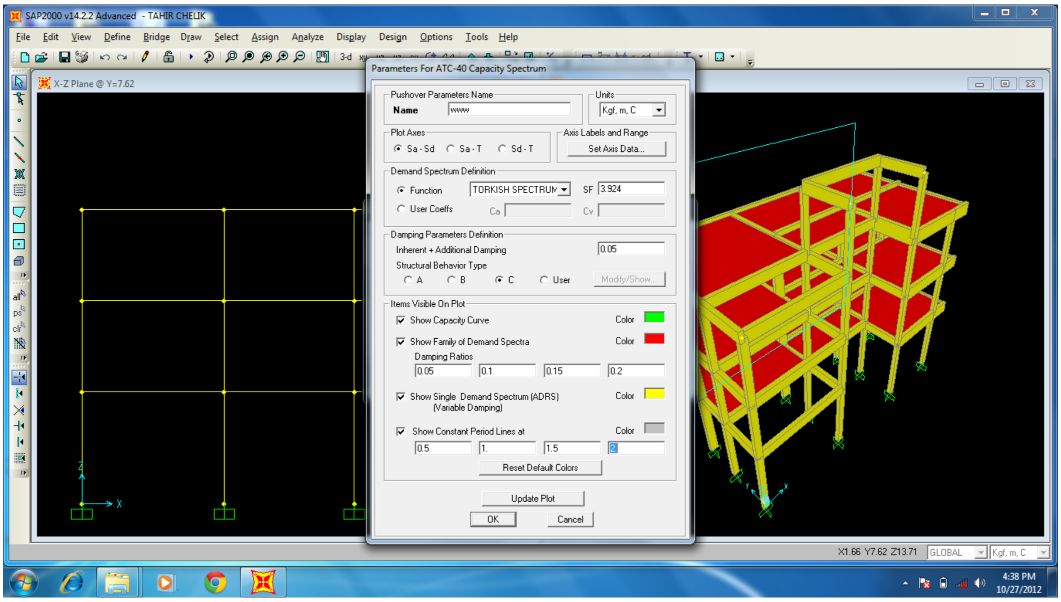


Figure 15. ATC 40 Capacity Spectrums

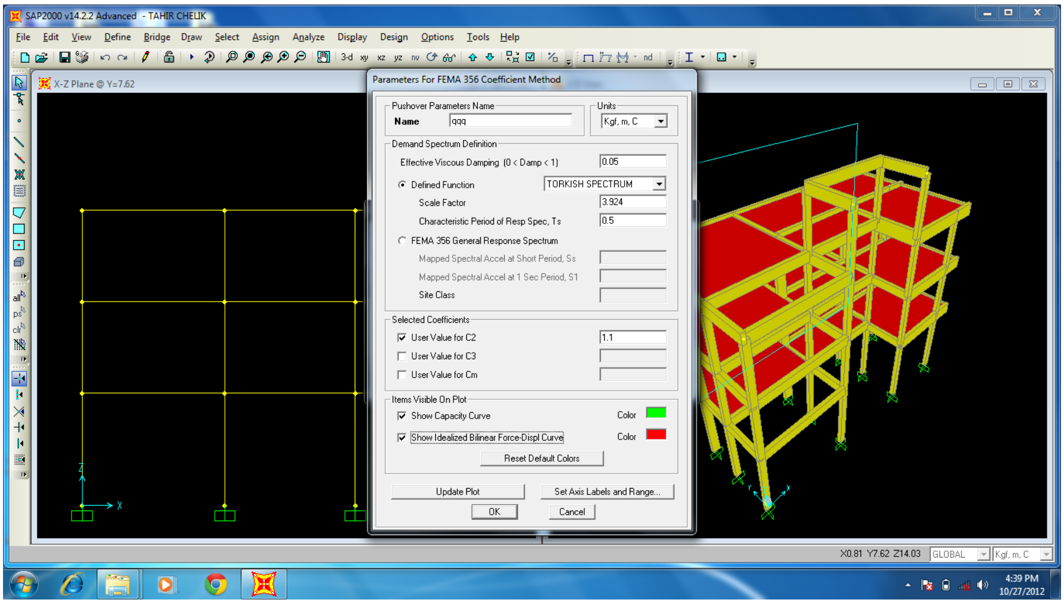


Figure 16. FEMA356 coefficient methods

Pushover curves and performance point based on FEMA 356 in X- and Y-direction are shown in Figures 17 and 18, respectively.

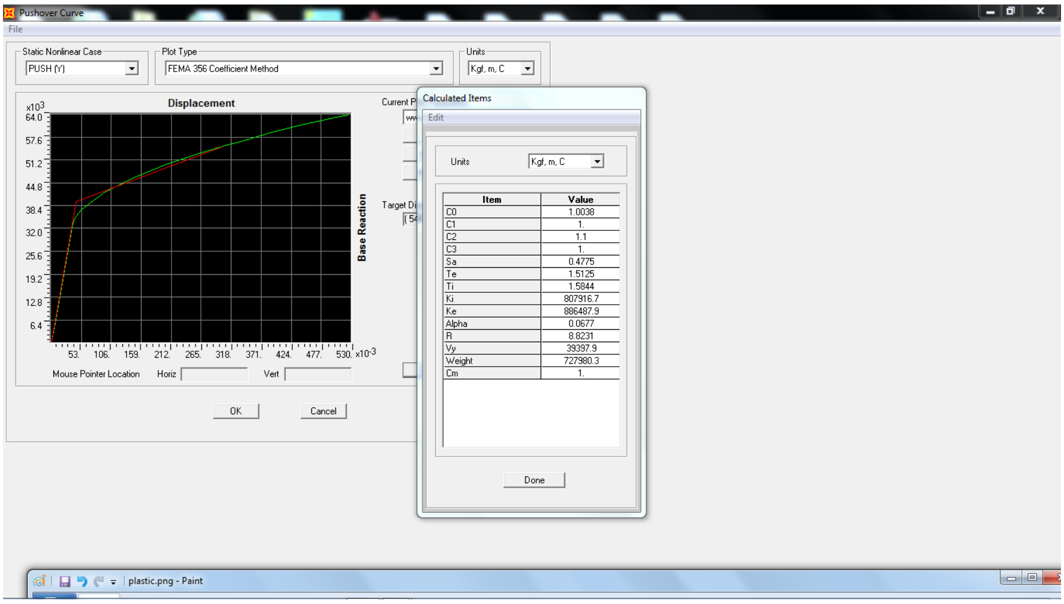


Figure 17. FEMA 356 calculation parameter push (y)

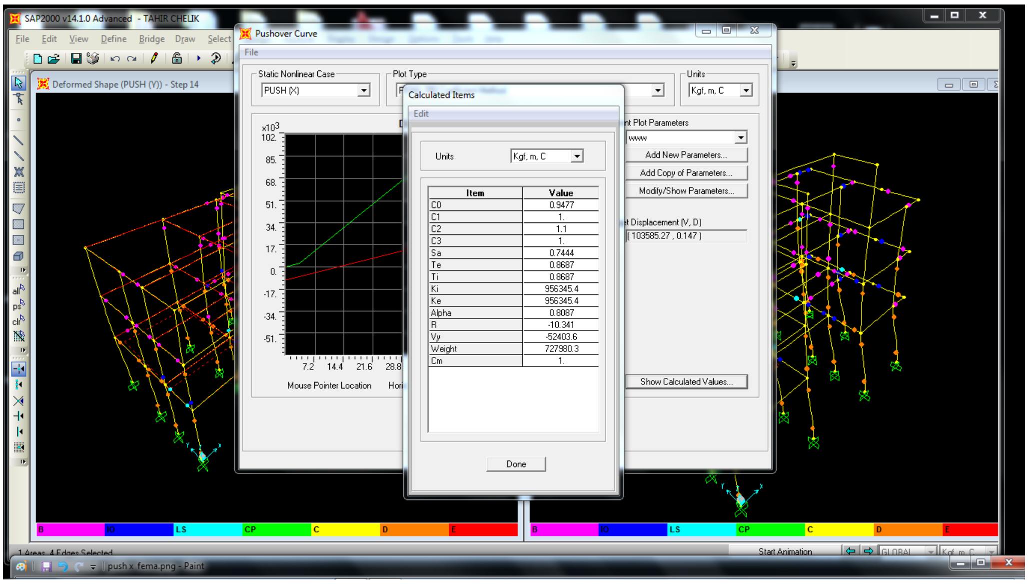


Figure 18. FEMA 356 calculation parameter push (X)

Also the performance point based on FEMA 440 is shown in figure 19.

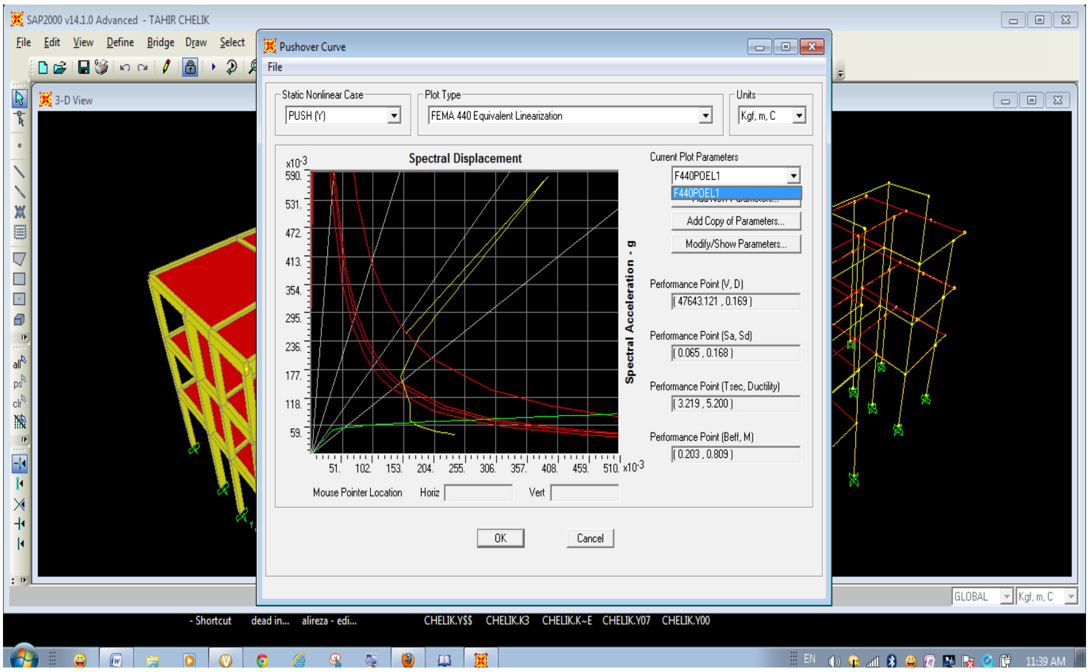
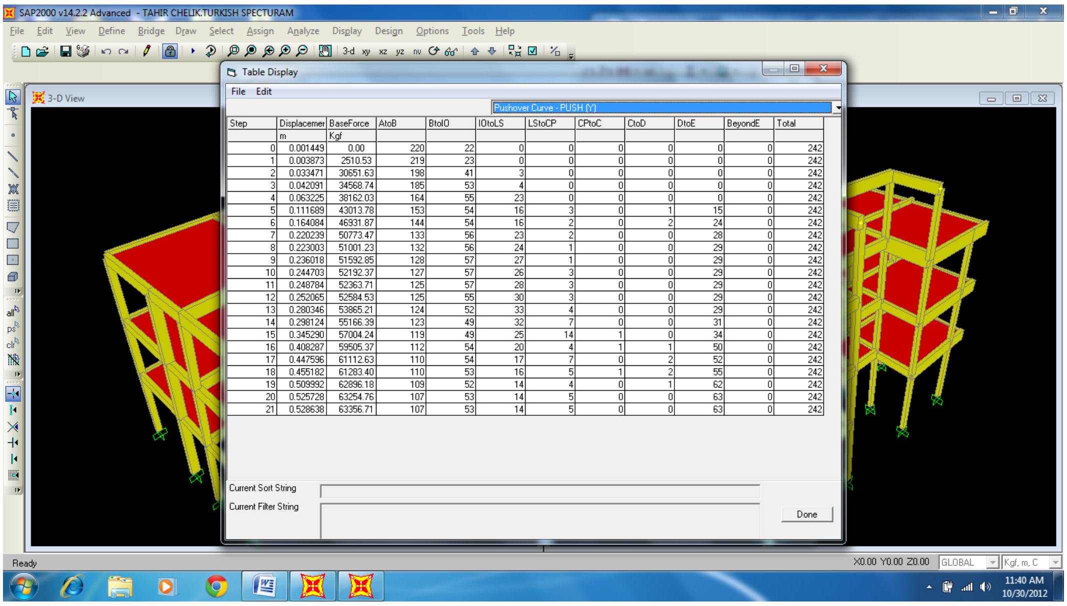


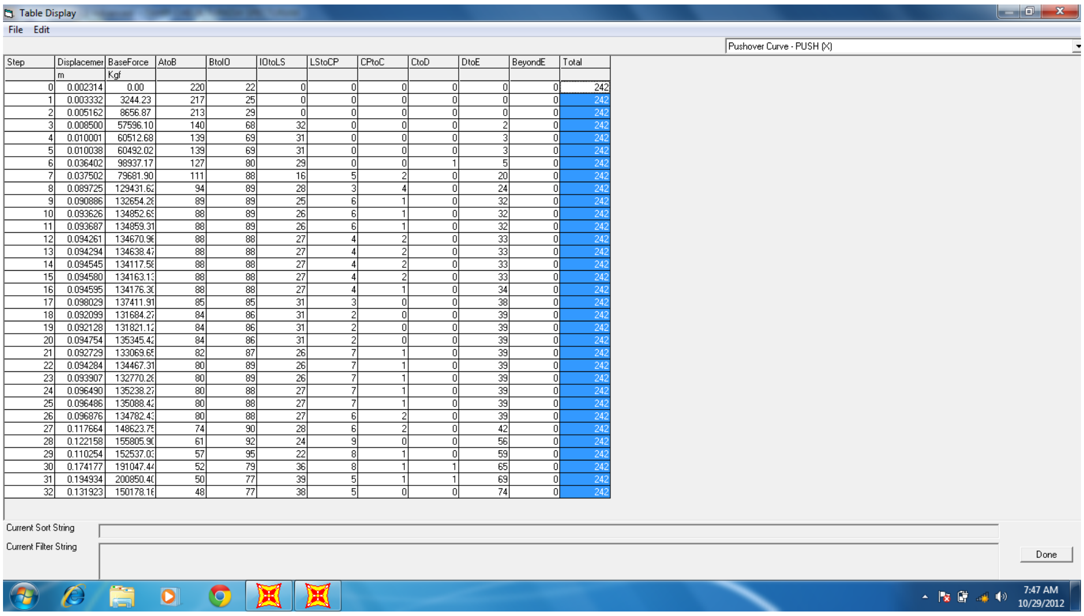
Figure 19.Performance point and performance parameters in Y direction



Pushover Curve - PUSH (Y)

Step	Displacemer	BaseForce	AtoB	BtoIO	IOtoLS	LStoCP	CPtoC	CtoD	DtoE	BeyondE	Total
	m	Kgf									
0	0.001449	0.00	220	22	0	0	0	0	0	0	242
1	0.003873	2510.53	219	23	0	0	0	0	0	0	242
2	0.033471	30651.63	198	41	3	0	0	0	0	0	242
3	0.042091	34568.74	185	53	4	0	0	0	0	0	242
4	0.063225	38162.03	164	55	23	0	0	0	0	0	242
5	0.111689	43013.78	153	54	16	3	0	1	15	0	242
6	0.164084	46931.87	144	54	16	2	0	2	24	0	242
7	0.220239	50773.47	133	56	23	2	0	0	28	0	242
8	0.223003	51001.23	132	56	24	1	0	0	29	0	242
9	0.236018	51592.85	128	57	27	1	0	0	29	0	242
10	0.244703	52192.37	127	57	26	3	0	0	29	0	242
11	0.248784	52363.71	125	57	28	3	0	0	29	0	242
12	0.252065	52584.53	125	55	30	3	0	0	29	0	242
13	0.280346	53865.21	124	52	33	4	0	0	29	0	242
14	0.298124	55166.39	123	49	32	7	0	0	31	0	242
15	0.345290	57004.24	119	49	25	14	1	0	34	0	242
16	0.408287	59505.37	112	54	20	4	1	1	50	0	242
17	0.447596	61112.63	110	54	17	7	0	2	52	0	242
18	0.455182	61283.40	110	53	16	5	1	2	55	0	242
19	0.509992	62896.18	109	52	14	4	0	1	62	0	242
20	0.525728	63254.76	107	53	14	5	0	0	63	0	242
21	0.528638	63356.71	107	53	14	5	0	0	63	0	242

Figure 20. Plastic hinges performance steps for Y direction



Pushover Curve - PUSH (X)

Step	Displacemer	BaseForce	AtoB	BtoIO	IOtoLS	LStoCP	CPtoC	CtoD	DtoE	BeyondE	Total
	m	Kgf									
0	0.002314	0.00	220	22	0	0	0	0	0	0	242
1	0.003332	3244.23	217	25	0	0	0	0	0	0	242
2	0.005162	8656.87	213	29	0	0	0	0	0	0	242
3	0.008500	57596.10	140	68	32	0	0	0	2	0	242
4	0.010001	60512.68	139	69	31	0	0	0	3	0	242
5	0.010038	60492.02	139	69	31	0	0	0	3	0	242
6	0.036402	98937.17	127	80	29	0	0	1	5	0	242
7	0.037502	79681.90	111	88	16	5	2	0	20	0	242
8	0.089725	129431.6	94	89	28	3	4	0	24	0	242
9	0.090886	132654.2	89	89	25	6	1	0	32	0	242
10	0.093626	134852.6	88	89	26	6	1	0	32	0	242
11	0.093687	134859.31	88	89	26	6	1	0	32	0	242
12	0.094261	134670.9	88	88	27	4	2	0	33	0	242
13	0.094294	134638.4	88	88	27	4	2	0	33	0	242
14	0.094545	134117.5	88	88	27	4	2	0	33	0	242
15	0.094580	134163.1	88	88	27	4	2	0	33	0	242
16	0.094595	134176.3	88	88	27	4	1	0	34	0	242
17	0.098029	137411.91	85	85	31	3	0	0	38	0	242
18	0.092099	131684.2	84	86	31	2	0	0	39	0	242
19	0.092128	131821.1	84	86	31	2	0	0	39	0	242
20	0.094754	135345.4	84	86	31	2	0	0	39	0	242
21	0.092729	133069.6	82	87	26	7	1	0	39	0	242
22	0.094284	134467.31	80	89	26	7	1	0	39	0	242
23	0.093907	132770.2	80	89	26	7	1	0	39	0	242
24	0.096490	135238.2	80	88	27	7	1	0	39	0	242
25	0.096486	135088.4	80	88	27	7	1	0	39	0	242
26	0.096876	134782.4	80	88	27	6	2	0	39	0	242
27	0.117664	148623.7	74	90	28	6	2	0	42	0	242
28	0.122158	155805.9	61	92	24	9	0	0	56	0	242
29	0.110254	152537.0	57	95	22	8	1	0	59	0	242
30	0.174177	191047.4	52	79	36	8	1	1	65	0	242
31	0.194934	200850.4	50	77	39	5	1	1	69	0	242
32	0.131923	150178.1	48	77	38	5	0	0	74	0	242

Figure 21. Plastic hinges performance steps for X direction plastic hinges

Figure 21shows that after 32 steps all of the hinges located in collapse limit. In this step the value of displacement and the base shear force are 13cm and 150 tonf, respectively.

4.3.1.3 Comparison of Methods

So, based on result of P25 method, pushover method must be done in order to evaluate of building performance. After pushover analysis, it can be predicted that the building on hand will very heavy damages both structural and nonstructural (grade 4).

4.3.2 Seven Story Building (Second Case Study)

This building is also located in Larnaka Street. Its dimension are 14.4m and 16.75m in X and Y direction, respectively. This building has four spans in X-direction and five spans in Y-direction. The height of each story is 2.85 m and the thickness of infill walls is 20cm.Short columns constitute the main structural problem in this case study, and this effect has been investigated. The other problem in this case study is related to beams whose heights are equal to slab thickness, so they do not have suitable rigidity, or moments of inertia are not enough versus of columns. The shear walls at the exterior perimeter of the first story produce high rigidity and stiffness into this story, and do not match to other stories. The plan of this building is shown in Figure 22.

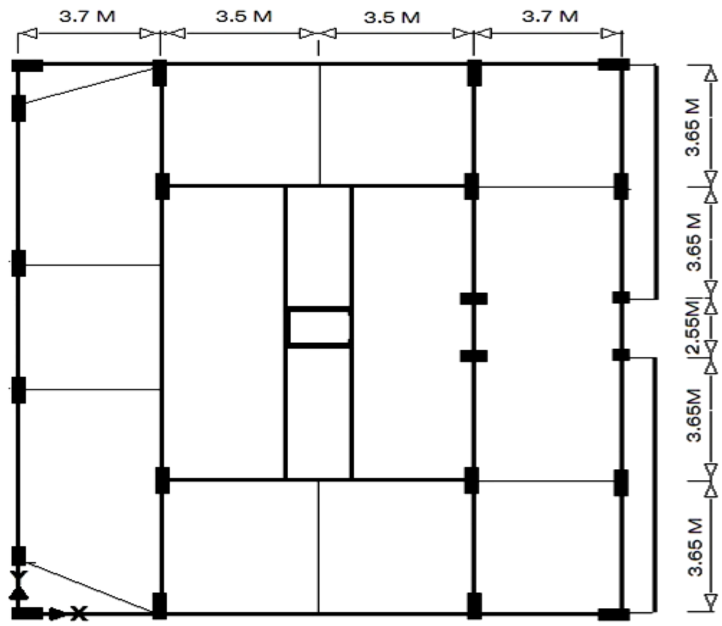


Figure 22. The plan of seven story building

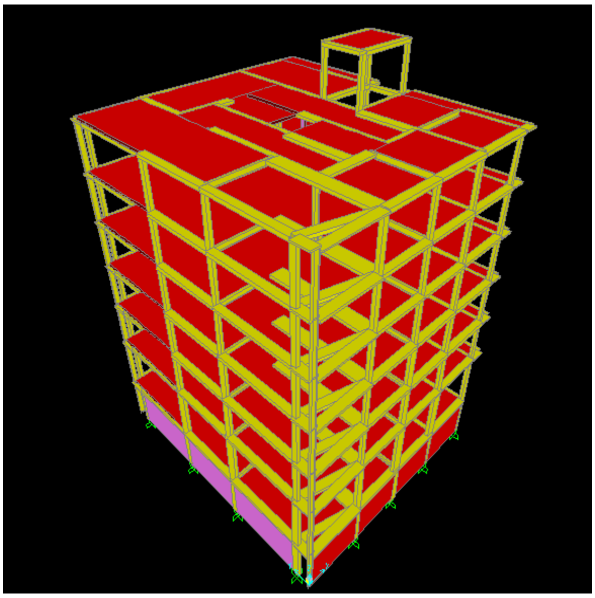


Figure 23. The three dimension of seven story building

Beams' and columns' cross section area are shown in Table 14.

Table 14.Section area for columns and beams

Story Number	Beam (cm)	Column (cm)
Story 1	55 X 10	20 X 45
Story 2	55X 10	20 X 45
Story 3	45 X 15	20 X 45
Story 4	50 X 15	20 X 45
Story 5	60 X 15	20 X 45
Story 6	70 X 15	20 X 45
Story 7	85 X 15	20 X 30

4.3.2.1 P25 Method

Moments of inertia in beams and columns in critical story (First story) have been calculated in to direction (Lx and Ly) separately. Also moments of inertia of brick walls in two directions have been taken in to account. Table 15.shows calculation details of P25.

Table 15. Calculation of buildings by P25 Method

		H=	2.85				f1=	1	w1=	4
	AP=LX*LY	AP=	249.66	17.1	14.6		f2=	1	w2=	1
	IPX=(LX*LY^3)/12	IPX=	4434.7938				f3=	1	w3=	3
	IPY=(LY*LX^3)/12	IPY=	6083.59005				f4=	1	w4=	2
	Aefx=SUM(Acx+Asx+AMx*0.15)	Aefx=	10.92	10.92	0	0	f5=	0.75	w5=	1
	Aefy=SUM(Acy+Asy+AMy*0.15)	Aefy=	9.66	9.66	0	0	f6=	1	w6=	3
	Iefx=SUM(Icx+Isx+Imx*0.15)	Iefx	0.29	0.29	0	0	f7=	1	w7=	2
	Iefy=SUM(Icy+Isy+Imy*0.15)	Iefy	0.27	0.27	0	0	f8=	1		
	CAx=(Aefx/AP)*10^5	CAX=	4373.94857				f9=	1		
	CAy=(Aefy/AP)*10^5	CAY=	3869.262197				f10=	0.8		
	CAmax	CAmax=	4373.94857				f11=	0.9		
	CAmin	CAmin=	3869.262197				f12=	1		
	CAef=(COS(x)*CAmin^2+SIN(x)*CAmax^2)	CAef=	22531143.86				f13=	0.8		
							f14=	0.9		
	CIx=10^5*(Iefx/IPX)^.2	CIx=	14558.10721							
	CIy=10^5*(Iefy/IPY)^.2	CIy=	13472.26959							
	CImax	CImax=	14558.10721							
	CImin	CImin=	13472.26959							
	CIef=(COS(x)*CImin^2+SIN(x)*CImax^2)	CIef=	263154626.9							
H=2.85	h=(-.6H^2)+39.6H-13.4	h=	94.5865							
	p1=SUM(CAef+CIef)*(f1*f2*f3*f4*f5*f6*f7*f8*f9*f10*f11*f12*f13*f14)/h									
		P1=	117.4317981							
		P2=	50							
		P3=	100							
		P4=	70							
		P5=	75							
		P6=	45							
		P7=	100							
		Pmin=	45							
	pw=SUM(W1*P1+W2*P2+W3*P3+W4*P4+W5*P5+W6*P6+W7*P7*W7+pmin*4)/20									
	B=.7 IF(Pw<20)	PW=	175868975							
	B=.55+.0075Pw IF(20<Pw<60)									
	B=1 IF(Pw>60)	B=	1							
	a=(1/1)*(1.4-.35)(1/(.4*.3+.88))*.7	a=	0.7							
	p=a*B*Pmin	p=	31.5	NO COLAPSE BUT PUSHOVR MUST BE DONE						

Result: 26<P<34 (No Collapse but Pushover must be done)

Based on P25 analysis, the obtained value of P is 31.5, and because it is between 26 and 34 therefore this building needs to be investigated in detail by pushover analysis in order to evaluate of accurate result.

4.3.2.2 Pushover Analysis

For pushover analysis, the amount of dead load and live load are considered to be 250 kg/m^2 and 500 kg/m^2, respectively. All slabs are defined as a diaphragm, separately for each floor level. Nonlinear load case is showing in Figure 24.

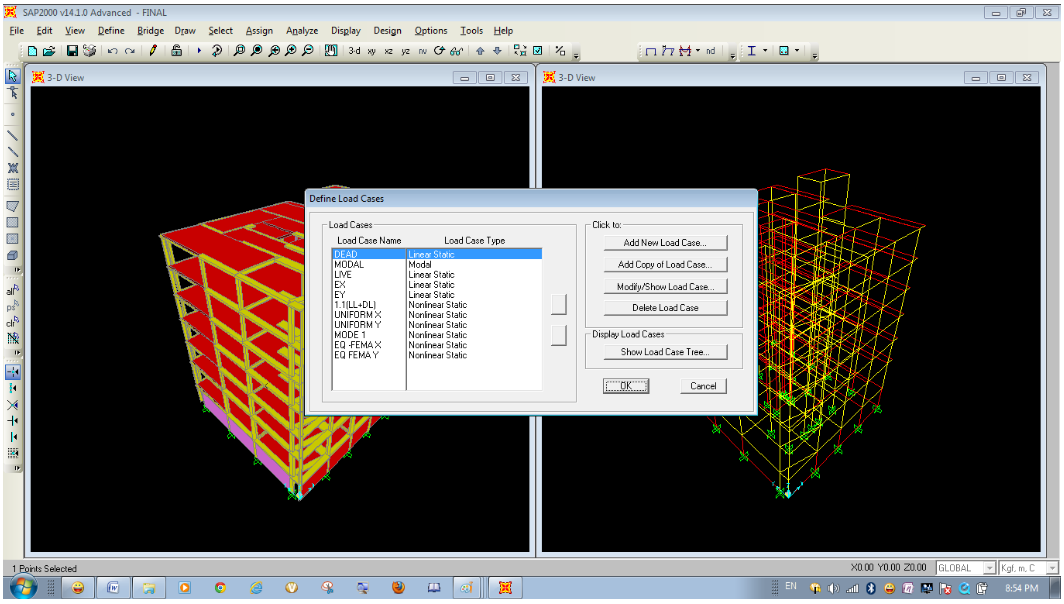


Figure 24. The definition of linear and nonlinear load cases

The definition of ATC 40 and FEMA 356 are shown in following figures.

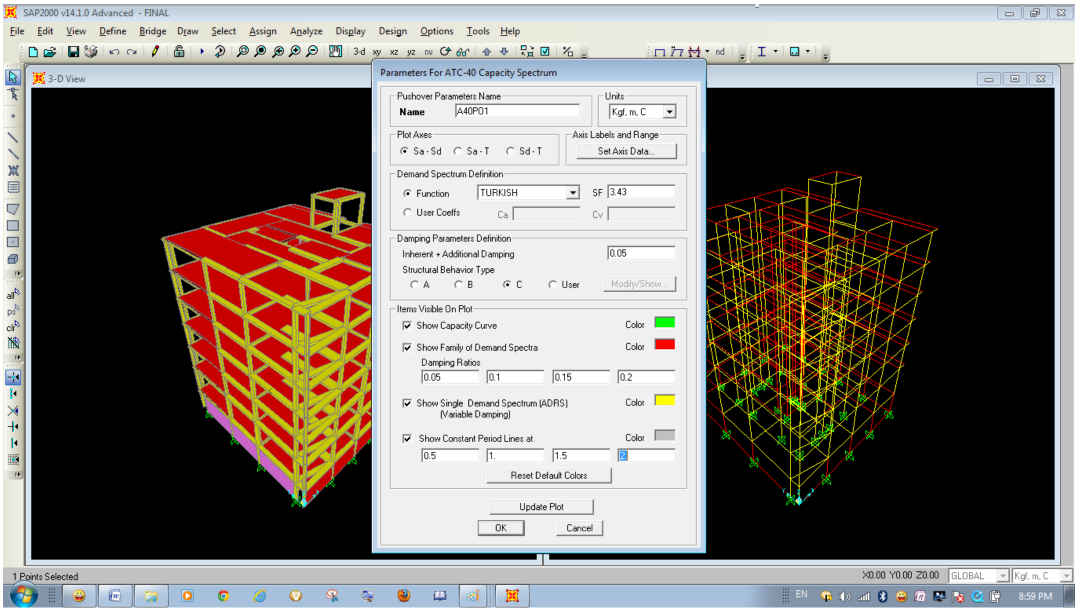


Figure 25. The ATC 40 Capacity Spectrums

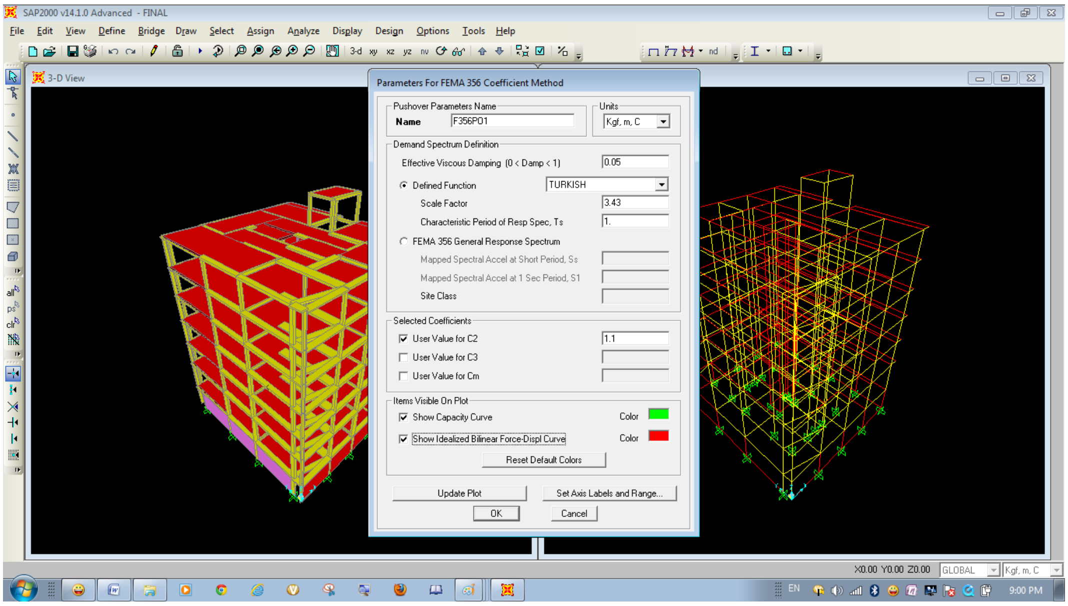


Figure 26. The FEMA356 coefficient method

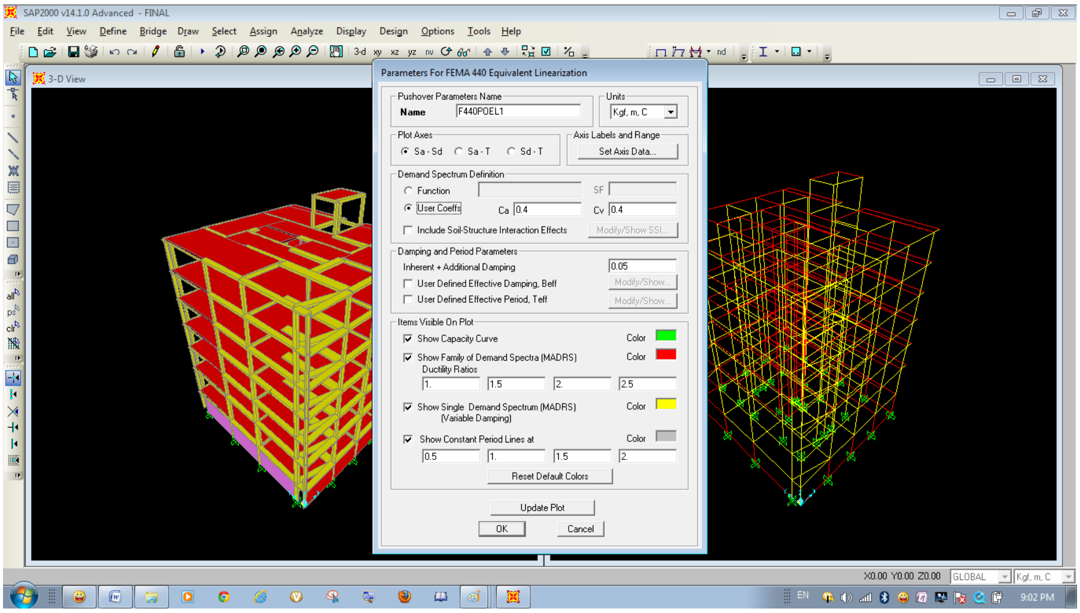


Figure 27. The FEMA 440 coefficient method

The pushover curves and target displacement parameters based on FEMA 356 in X is shown in figures 28.

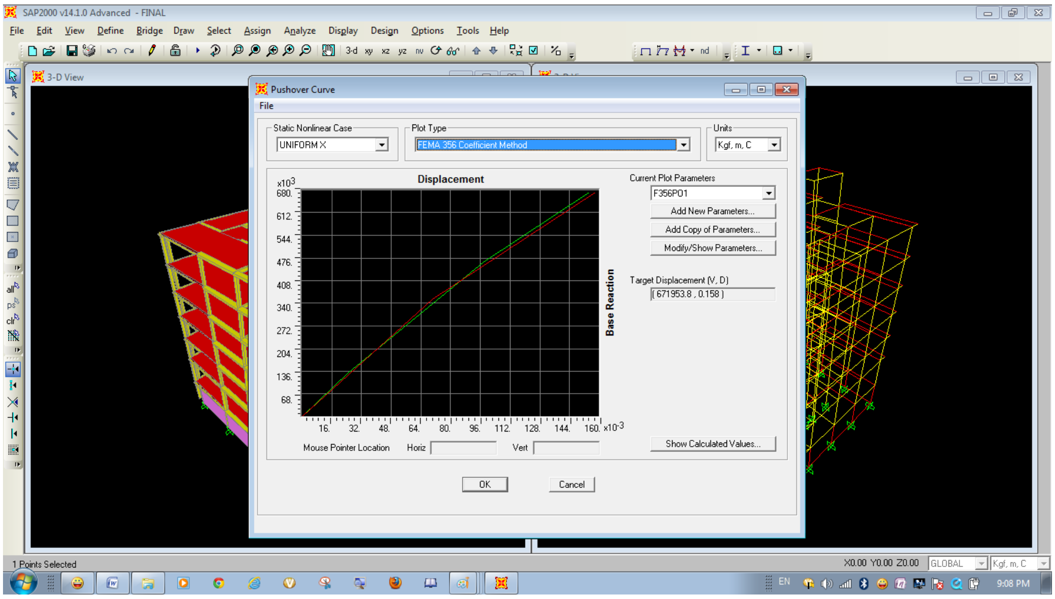


Figure 28. The pushover curves in X direction

Based on Figure 28 in performance point curve according to ATC40, base shear (v) was 612 tonf and displacement is 13 cm. Also base shear was 671tonf and displacement is15.8 cm according to FEMA 356. As in this analysis has been realized the result based on two codes (ATC40 –FEMA 356) is close together.

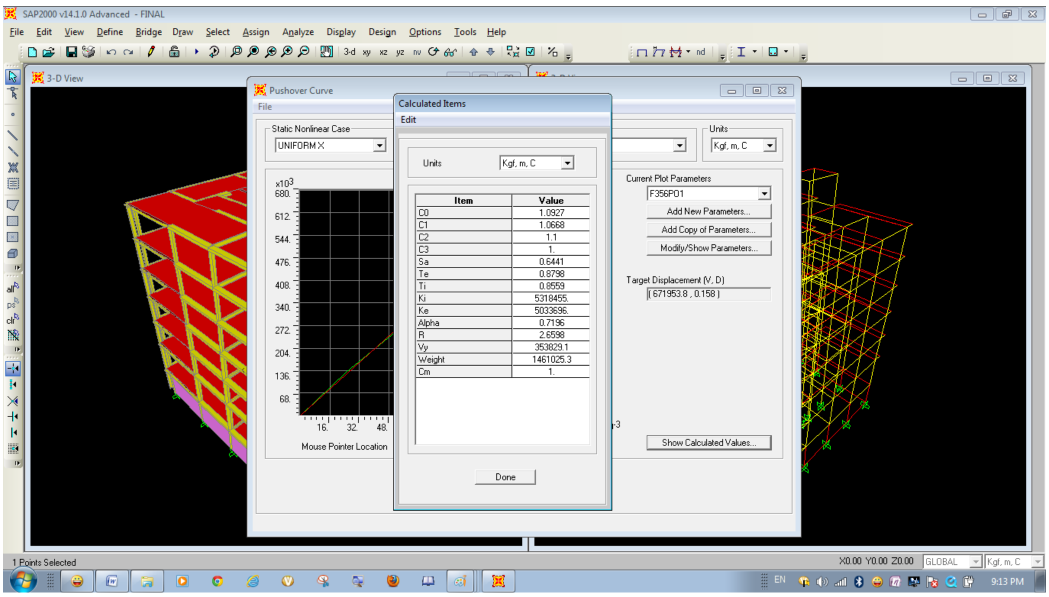


Figure 29. Story building push(x) parameters

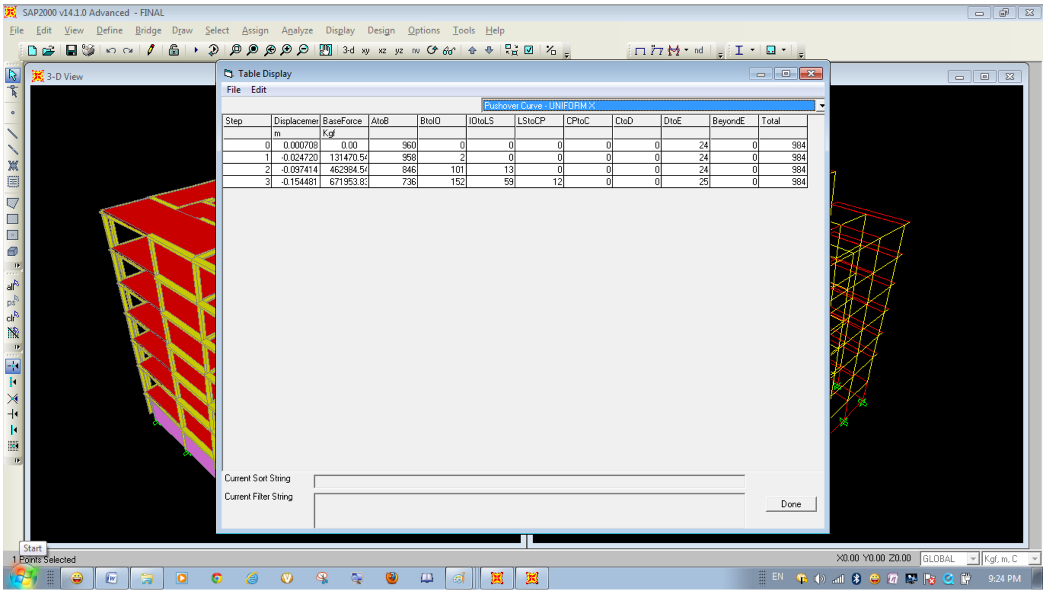


Figure 30. Table of plastic hinges in push(x)

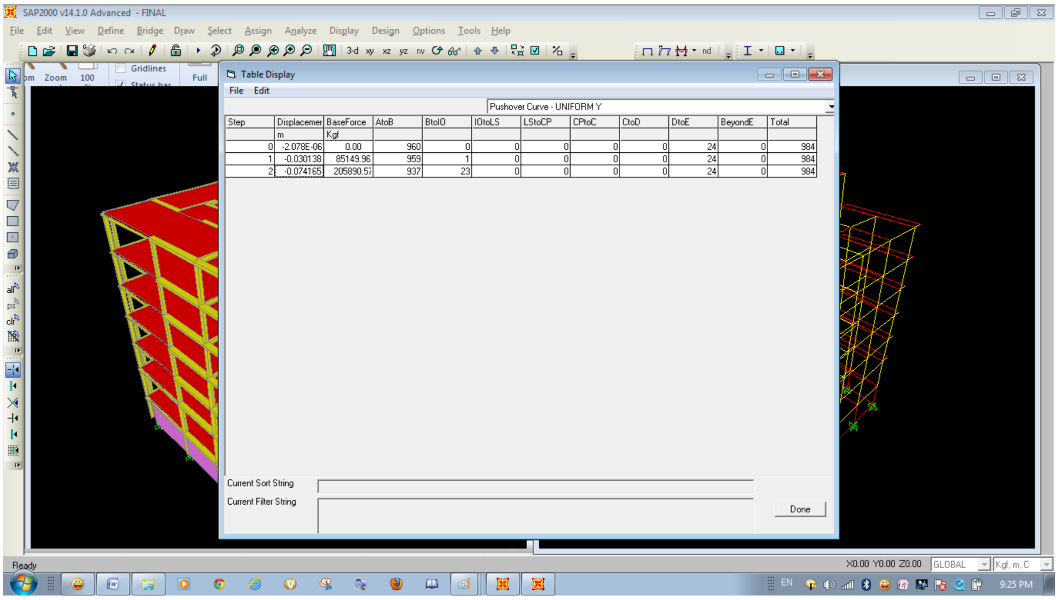


Figure 31. Plastic hinges Table in push(y)

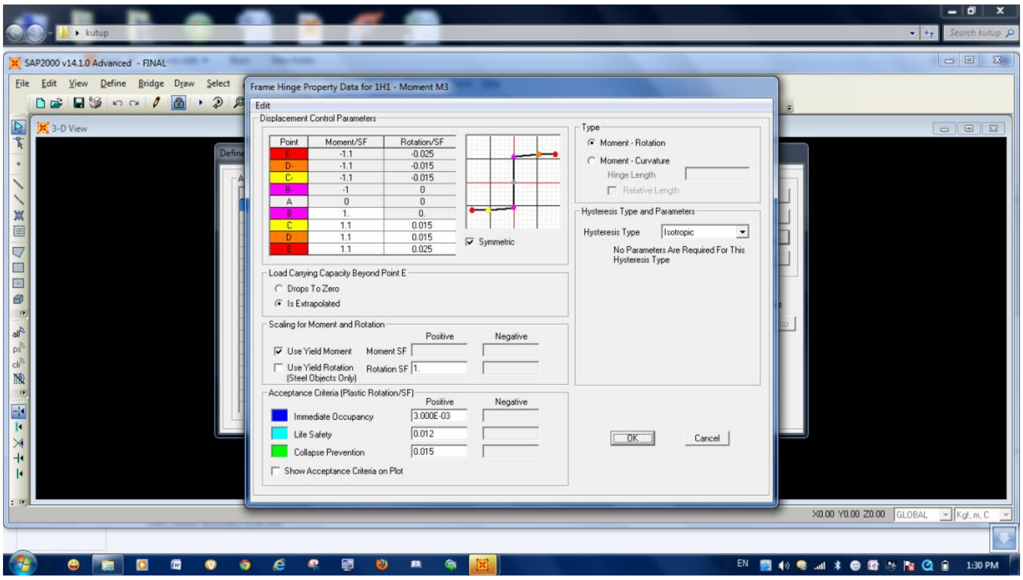


Figure 32. Hinge properties

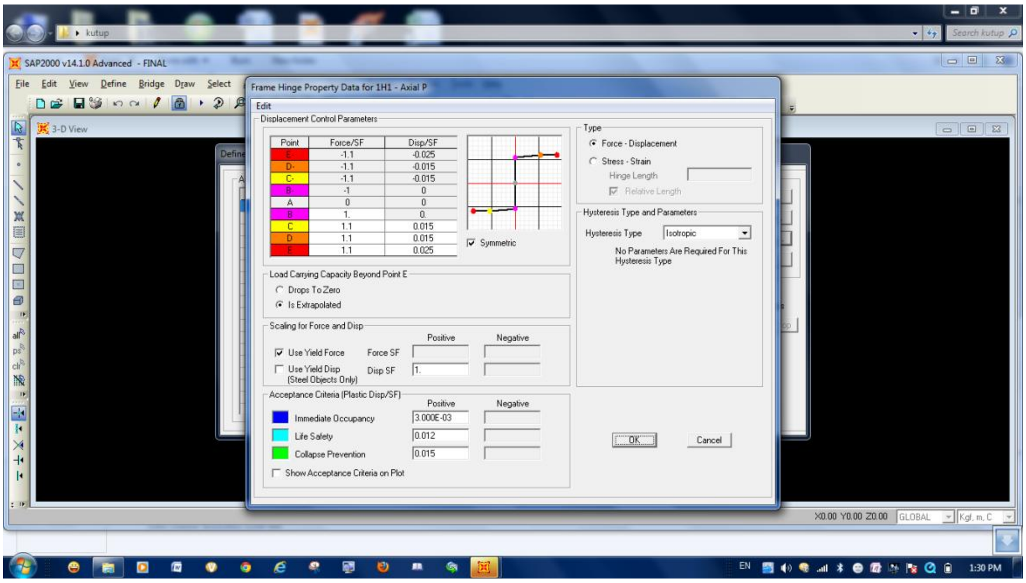


Figure 33. The hinges properties

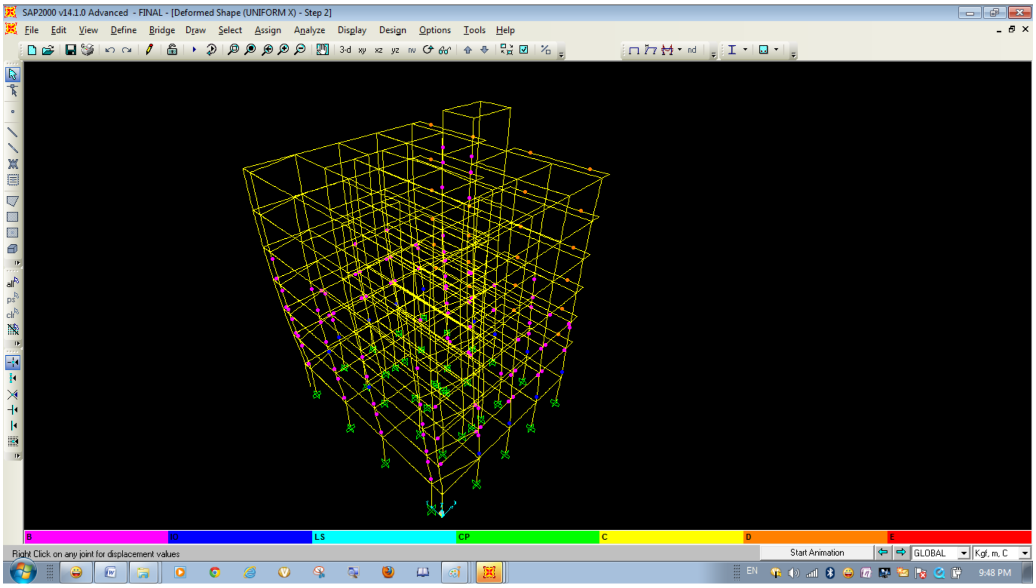


Figure 34.The plastic hinges limit for pushover in X direction

In this case study, looking up in Figures 30 and 31, whether it is X- or Y-direction, all pushover steps correspond to grade 4: very heavy damage (heavy structural damage, very heavy nonstructural damage).

4.3.2.3 Comparison of Methods

P25 method yields to detailed assessment by pushover analysis; the latter predicted a vulnerability of grade 4.

4.3.3 Four Story Building (Third Case Study)

The major problem in this case study concerns the ground floor which should experience huge amount of shear forces due to lack of infill walls. Based on design plans, height of the ground floor is 2.85 m and a parking ramp links the yard and the ground floor. This structural problem has been taken into consideration while performing analyses by each of the two methods (P25 and pushover). The plan of this building is shown in Figure 35.

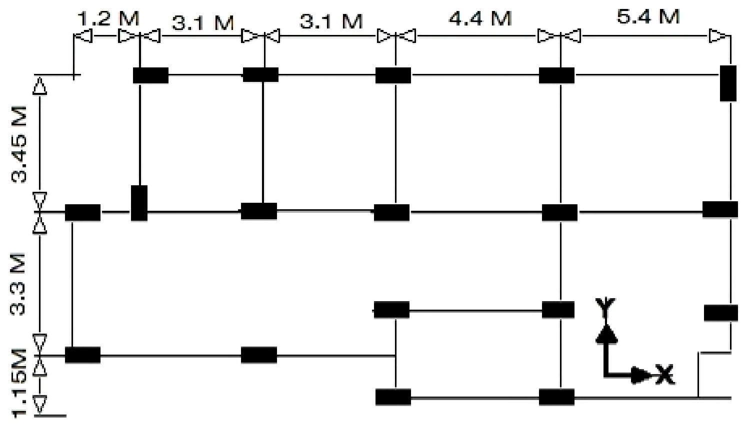


Figure 35. The plan of four story building

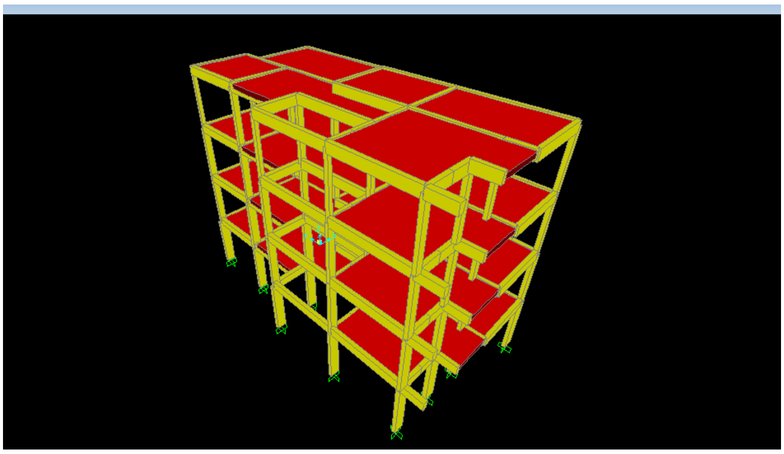


Figure 36. The three dimension of four story building

Table 16 shows the cross section area for beams and columns.

Table 16. The section area for columns and beams

Story number	Beam	column
Story 1	20 X 50 cm	20 X 65 cm
Story 2	20 X 45 cm	20 X 40 cm
Story 3	25 X 45 cm	20 X 35 cm
Story 4	25 X 45 cm	20 X 20 cm

4.3.3.1 P25 Method

Moments of inertia in beams and columns in critical story (first story) have been calculated in two directions (L_x and L_y), separately. Also moments of inertia of brick walls in two directions have been taken into account. Table 17 shows the calculation details of P25.

Table 17. Calculation of Buildings by P25 Method

	H=	3.2				f1=	0.8	w1=	4
AP=LX*LY	AP=	139.44	16.8	8.3		f2=	0.84	w2=	1
IPX=(LX*LY^3)/12	IPX=	800.5018				f3=	0.7	w3=	3
IPY=(LY*LX^3)/12	IPY=	3279.6288				f4=	0.75	w4=	2
Aefx=SUM(Acx+Asx+AMx*0.15)	Aefx=	10.92	10.92	0	0	f5=	0.75	w5=	1
Aefy=SUM(Acy+Asy+AMy*0.15)	Aefy=	9.66	9.66	0	0	f6=	0.85	w6=	3
Iefx=SUM(Icx+Isx+Imx*0.15)	Iefx	0.29	0.29	0	0	f7=	1	w7=	2
Iefy=SUM(Icy+Isy+Imy*0.15)	Iefy	0.27	0.27	0	0	f8=	1		
CAx=(Aefx/AP)*10^5	CAX=	7831.325301				f9=	1		
CAy=(Aefy/AP)*10^5	CAY=	6927.710843				f10=	0.8		
CAmax	CAmax=	7831.325301				f11=	0.9		
CAmin	CAmin=	6927.710843				f12=	1		
CAef=(COS(x)*CAmin^2+SIN(x)*CAmax^2)	CAef=	72228138.94				f13=	0.8		
						f14=	0.9		
CIx=10^5*(Iefx/IPX)^.2	CIx=	20502.51494							
CIy=10^5*(Iefy/IPY)^.2	CIy=	15244.3115							
CImax	CImax=	20502.51494							
CImin	CImin=	15244.3115							
CIef=(COS(x)*CImin^2+SIN(x)*CImax^2)	CIef=	411431365.7							
h=(-.6H^2)+39.6H-13.4	h=	107.176							
p1=SUM(CAef+CIef)*(f1*f2*f3*f4*f5*f6*f7*f8*f9*f10*f11*f12*f13*f14)/h									
	P1=	52.61577126							
	P2=	50							
	P3=	100							
	P4=	70							
	P5=	75							
	P6=	45							
	P7=	100							
	Pmin=	45							
pw=SUM(W1*P1+W2*P2+W3*P3+W4*P4+W5*P5+W6*P6+W7*P7*W7+pmin*4)/20									
B=.7 IF(Pw<20)	PW=	175868975							
B=.55+.0075Pw IF(20<Pw<60)									
B=1 IF(Pw>60)	B=	1							
a=(1/1)*(1.4-.35)(1/(.4*.3+.88))*.7	a=	0.7							
p=a*B*Pmin	p=	31.5	NO COLLAPSE BUE PUSHOVER MUST BE DONE						

Based on P25 analysis, the obtained value of P is 31.5; and because it is between 26 and 34, this building needs pushover analysis in order to evaluate of accurate result.

4.3.3.2 Pushover Analysis

Definition of ATC 40 and FEMA 356 are shown in Figures 37 and 38respectivly.

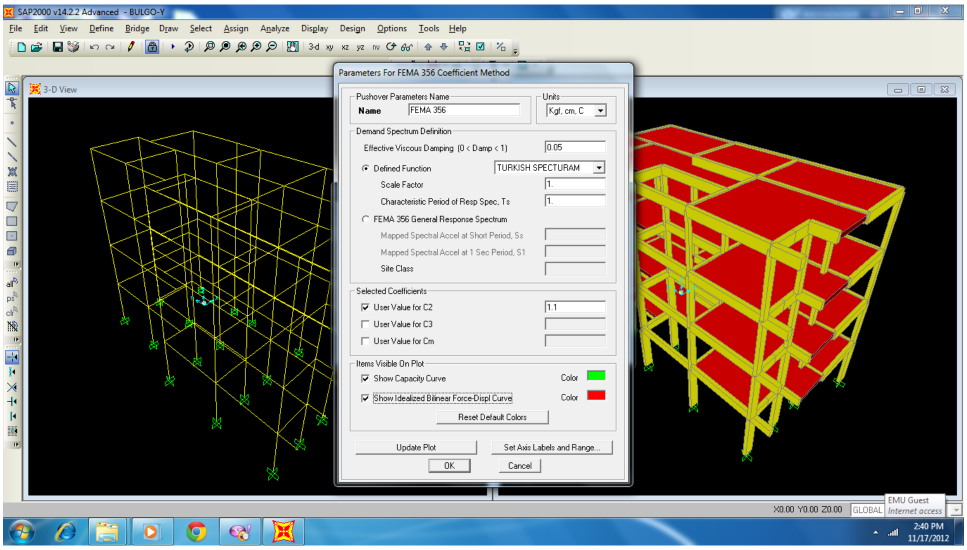


Figure 37. The parameters for FEMA356 Coefficients Method

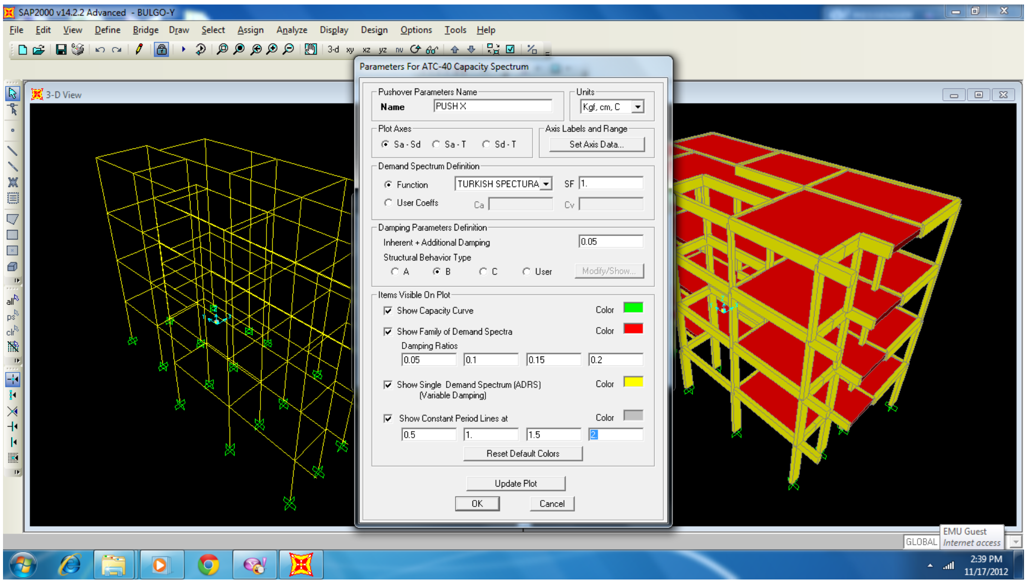


Figure 38. For ATC-40 capacity spectrum in X direction

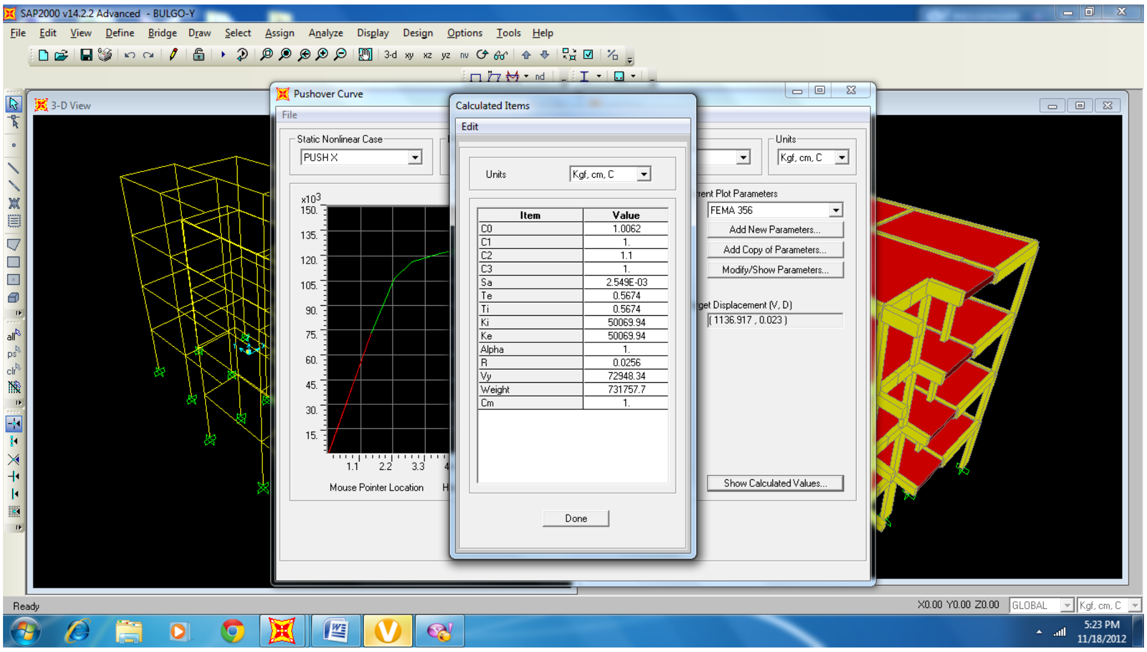


Figure 39. Pushover curve based on FEMA 356 in X direction

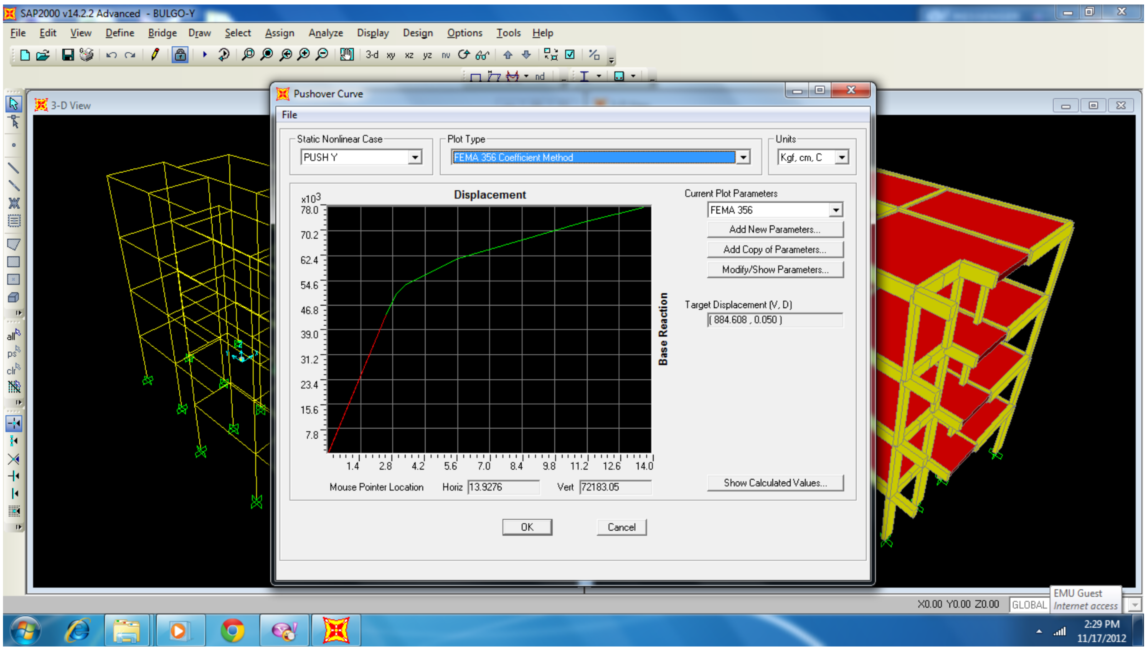


Figure 40. Pushover curve based on FEMA 356 in Y direction

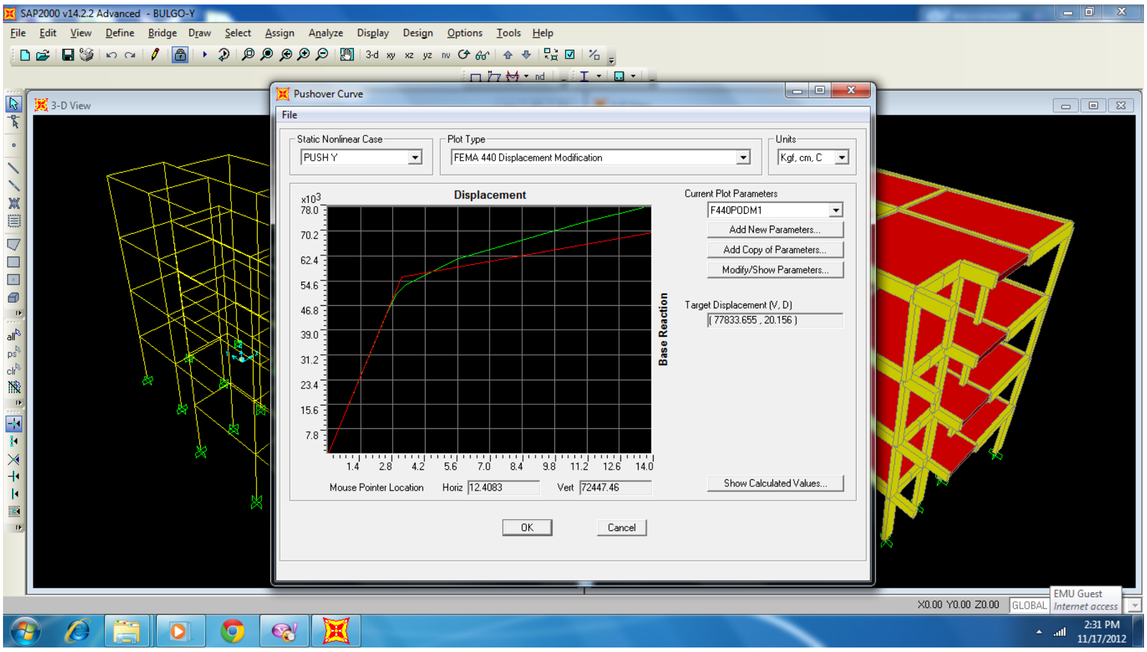


Figure 41. The idealize of Pushover curve based on FEMA 440 in Y direction

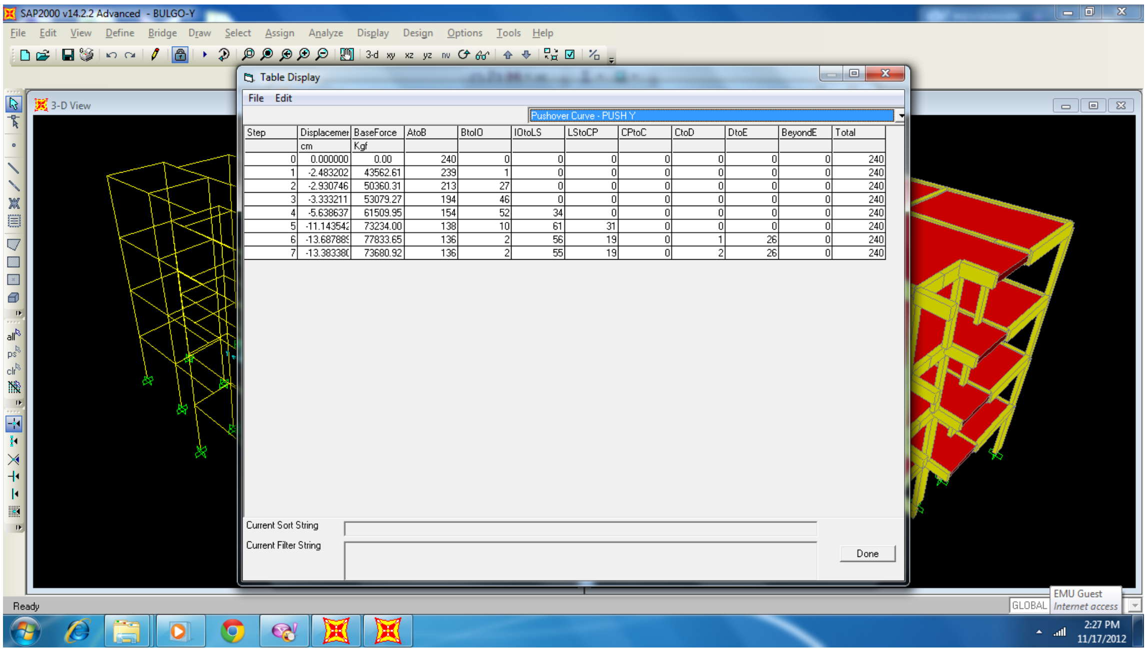


Figure 42. Plastic hinges information in Y direction

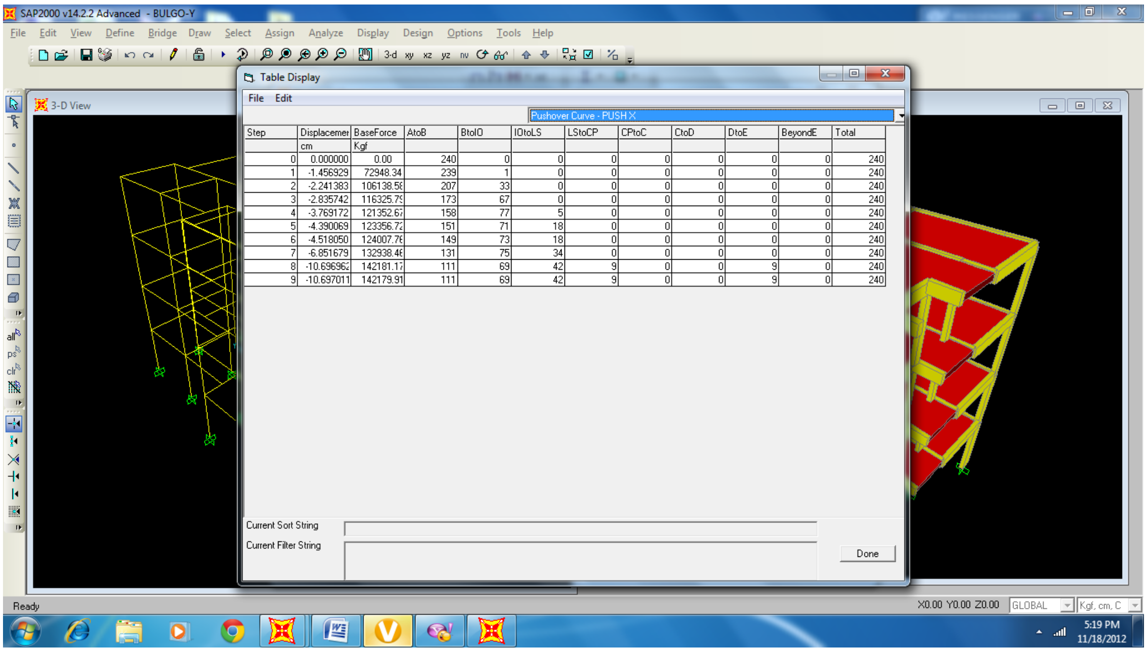


Figure 43. Plastic hinges information in X direction

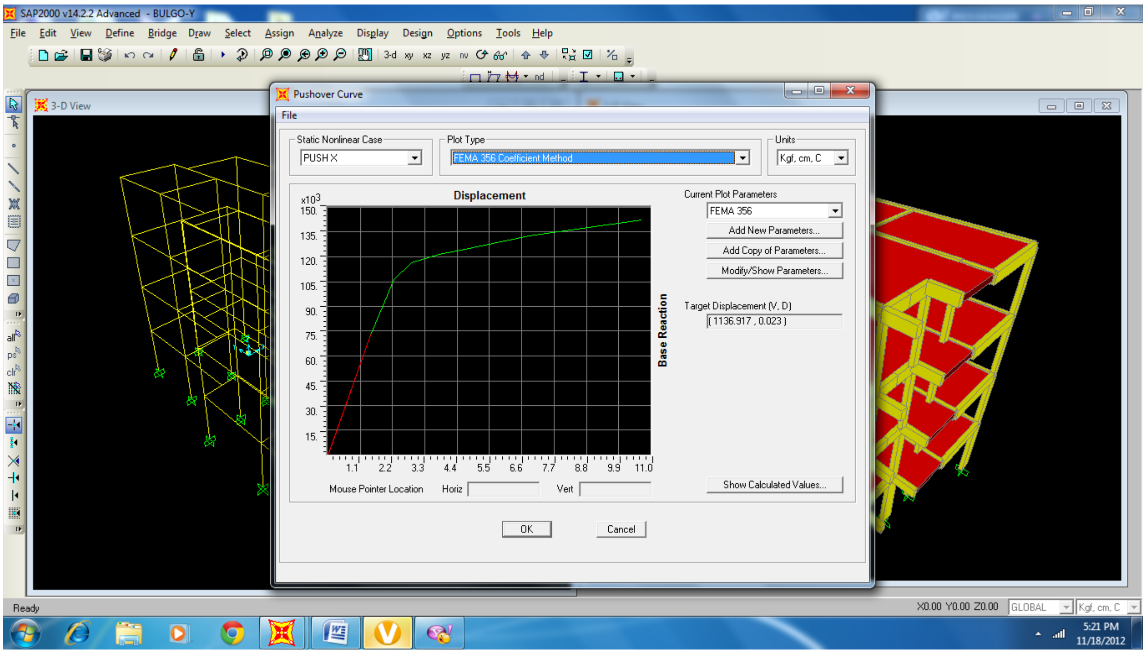


Figure 44. Pushover curve based on FEMA 356 in X direction

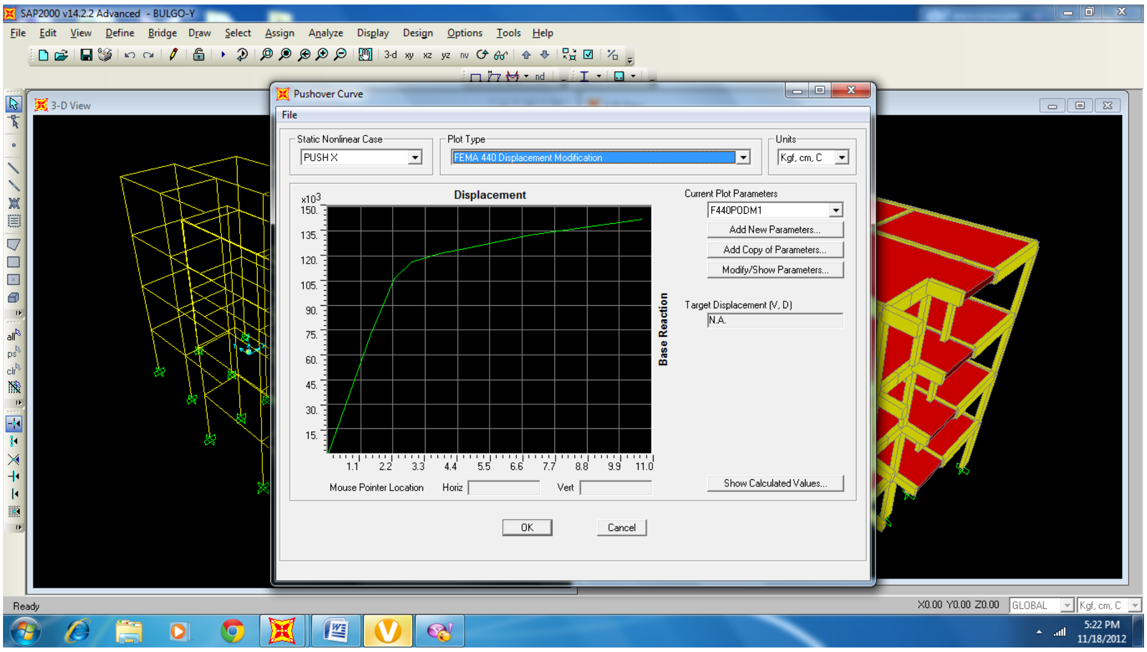


Figure 45. Pushover curve based on FEMA 440 in X direction

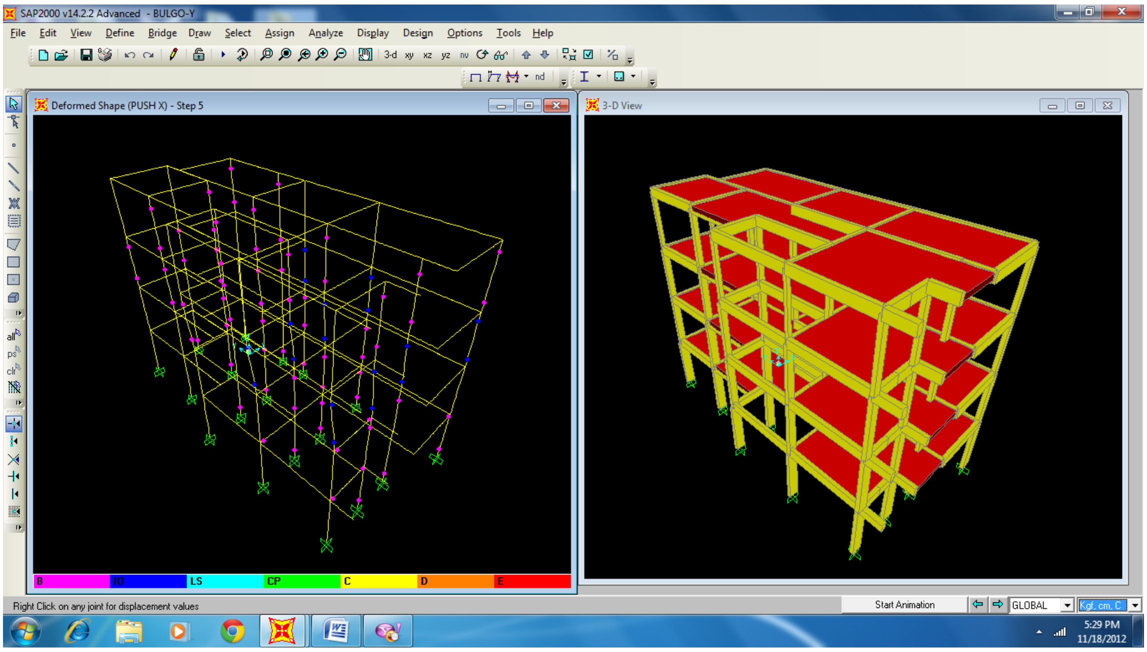


Figure 46. The plastic hinge performance limit in X direction

Here, FEMA 356 has been retained. The target point (V=1136.917 kgf; D=0.023 cm) has be found for X-direction between step 0 and 1. Reading from the table in

Figure 43, it is shown that the building undergoes a damage grade 1: negligible to slight damage (no structural damage, slight nonstructural damage).

Accounting for Y-direction, Figure 42 exhibits once more that the structure will experience damage grade 1, since the target point is (V=884.608 kgf; D=0.050 cm) and lays between 0 and 1.

4.3.3.3 Comparison of Methods

In this case, P25 method yields to detailed assessment by pushover analysis; the latter predicted a vulnerability of grade 1.

4.3.4 Three Story Building (Fourth Case Study)

One of the special problems of this case study is the fact there is no beam or frame element between columns,but columns are joined together by a 15 cm thick slab which operates as diaphragm. Plan of this building is showing in Figure 47.

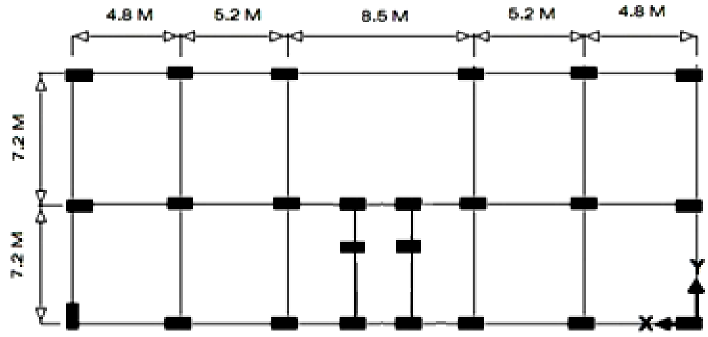


Figure 47. The plan of three story building

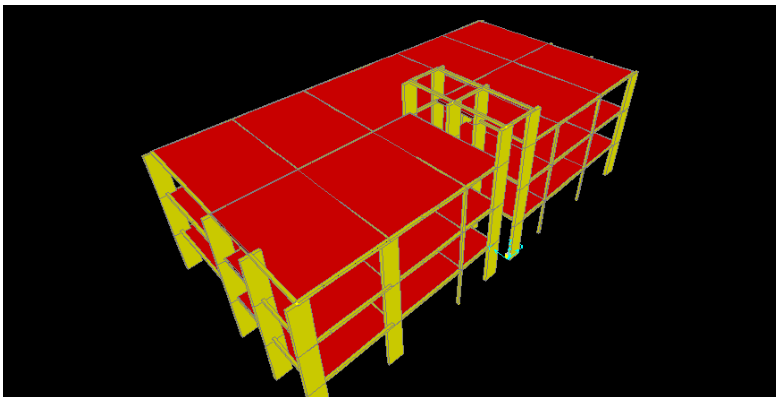


Figure 48. The three dimension of three story building

Also cross sectional area for beams and columns are consignedin Table 18.

Table 18. The section of area for columns and beams

Story number	Beam	column
Story 1	15 X 15 cm	20 X 100 cm
Story 2	15 X 15 cm	20 X 100 cm
Story 3	15 X 15 cm	20 X 100 cm

4.3.4.1 P25 Method

Table 19 shows the calculation details of P25.

Table 19. Calculation of Buildings by P25 Method

		H=	3				f1=	1	w1=	4
	AP=LX*LY	AP=	118.503	8.1	14.63		f2=	1	w2=	1
	IPX=(LX*LY^3)/12	IPX=	2113.667897				f3=	1	w3=	3
	IPY=(LY*LX^3)/12	IPY=	647.9151525				f4=	1	w4=	2
	Aefx=SUM(Acx+Asx+AMx*0.15)	Aefx=	10.92	10.92	0	0	f5=	0.75	w5=	1
	Aefy=SUM(Acy+Asy+AMy*0.15)	Aefy=	9.66	9.66	0	0	f6=	1	w6=	3
	Iefx=SUM(Icx+Isx+Imx*0.15)	Iefx	0.29	0.29	0	0	f7=	1	w7=	2
	Iefy=SUM(Icy+Isy+Imy*0.15)	Iefy	0.27	0.27	0	0	f8=	1		
	CAx=(Aefx/AP)*10^5	CAX=	9214.956583				f9=	1		
	CAy=(Aefy/AP)*10^5	CAY=	8151.692362				f10=	0.8		
	CAmax	CAmax=	9214.956583				f11=	0.9		
	CAmin	CAmin=	8151.692362				f12=	1		
	CAef=(COS(x)*CAmin^2+SIN(x)*CAmax^2)	CAef=	100005177				f13=	0.8		
							f14=	0.9		
	CIx=10^5*(Iefx/IPX)^.2	CIx=	16883.87971							
	CIy=10^5*(Iefy/IPY)^.2	CIy=	21084.7825							
	CImax	CImax=	21084.7825							
	CImin	CImin=	16883.87971							
	CIef=(COS(x)*CImin^2+SIN(x)*CImax^2)	CIef=	469157899.6							
H=2.85	h=(-.6H^2)+39.6H-13.4	h=	100							
	p1=SUM(CAef+CIef)*(f1*f2*f3*f4*f5*f6*f7*f8*f9*f10*f11*f12*f13*f14)/h									
		P1=	221.2906042							
		P2=	50							
		P3=	100							
		P4=	70							
		P5=	75							
		P6=	45							
		P7=	100							
		Pmin=	45							
	pw=SUM(W1*P1+W2*P2+W3*P3+W4*P4+W5*P5+W6*P6+W7*P7*W7+pmin*4)/20									
	B=.7 IF(Pw<20)	PW=	175868975							
	B=.55+.0075Pw IF(20<Pw<60)									
	B=1 IF(Pw>60)	B=	1							
	a=(1/1)*(1.4-.35)(1/(.4*.3+.88))*.7	a=	0.7							
	p=a*B*Pmin	p=	31.5	pushover must be done						

Based on P25 analysis, the obtained value of P is 31.5, and because it is between 26 and 34 therefore this building needs pushover analysis in order to evaluate of accurate result.

4.3.3.2 Pushover Analysis

The definition of ATC 40 and FEMA 356 are shown in following Figures 49.

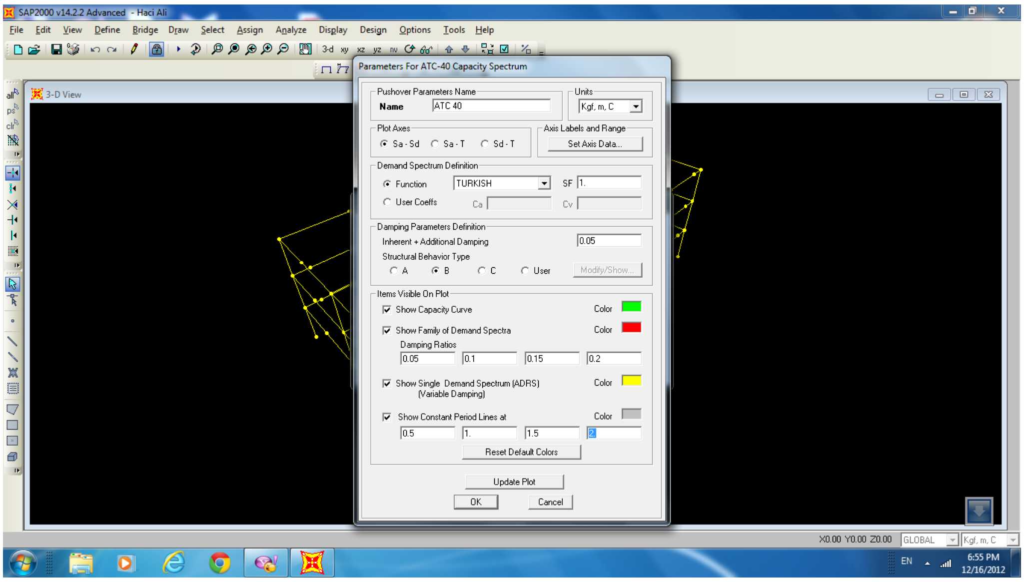


Figure 49. For ATC-40 capacity spectrums

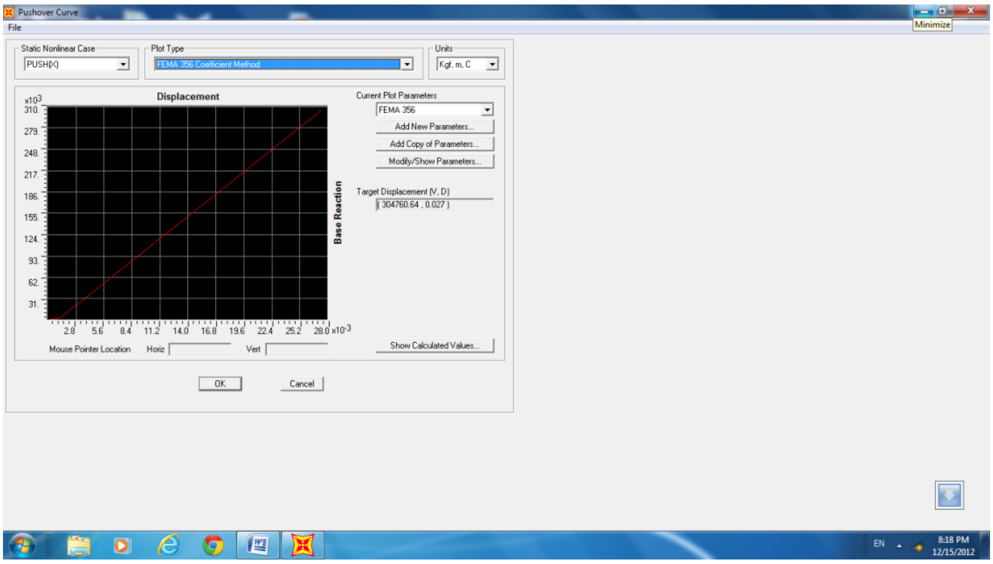


Figure 50. The pushover curves in X direction

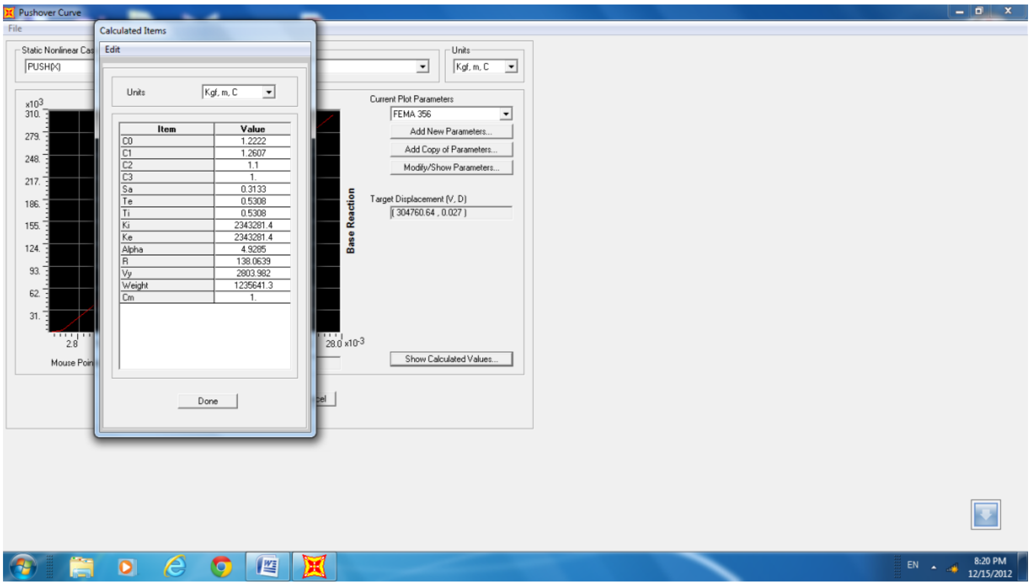


Figure 51. The FEMA 356 parameter in X direction

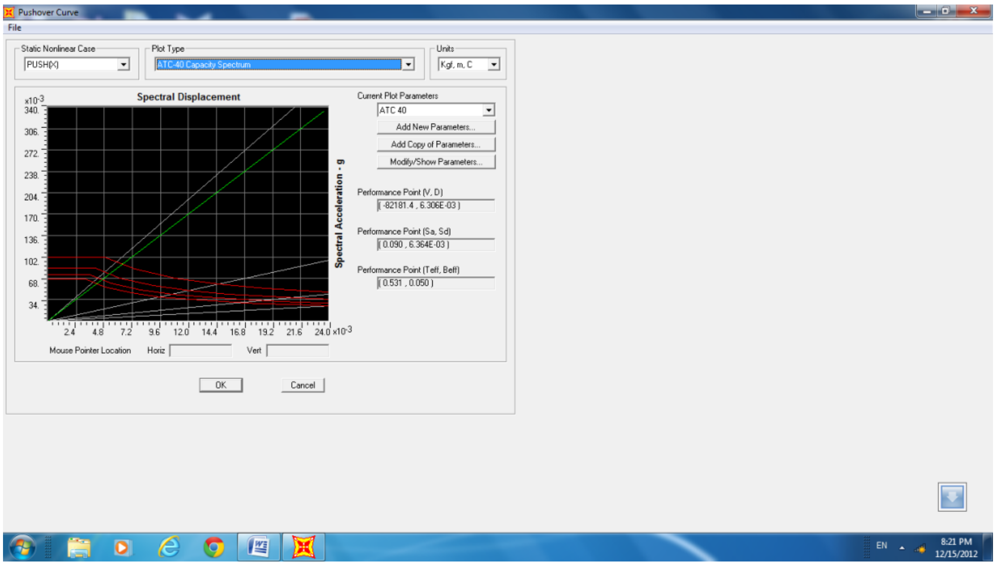


Figure 52. The performance point properties based on ATC-40 in X direction

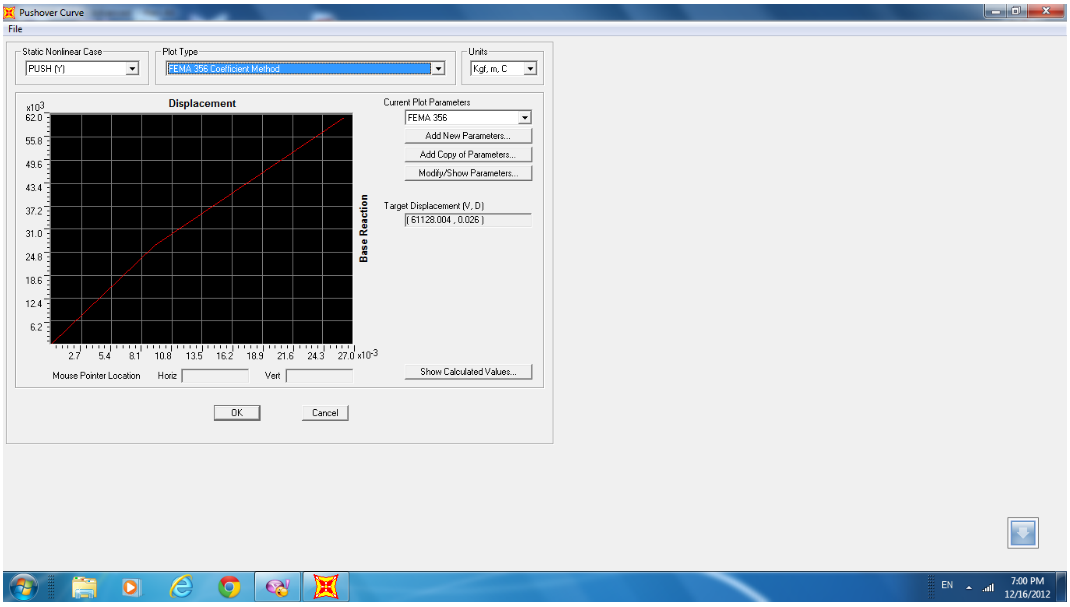


Figure 53. The pushover curve in Y direction based on FEMA 356

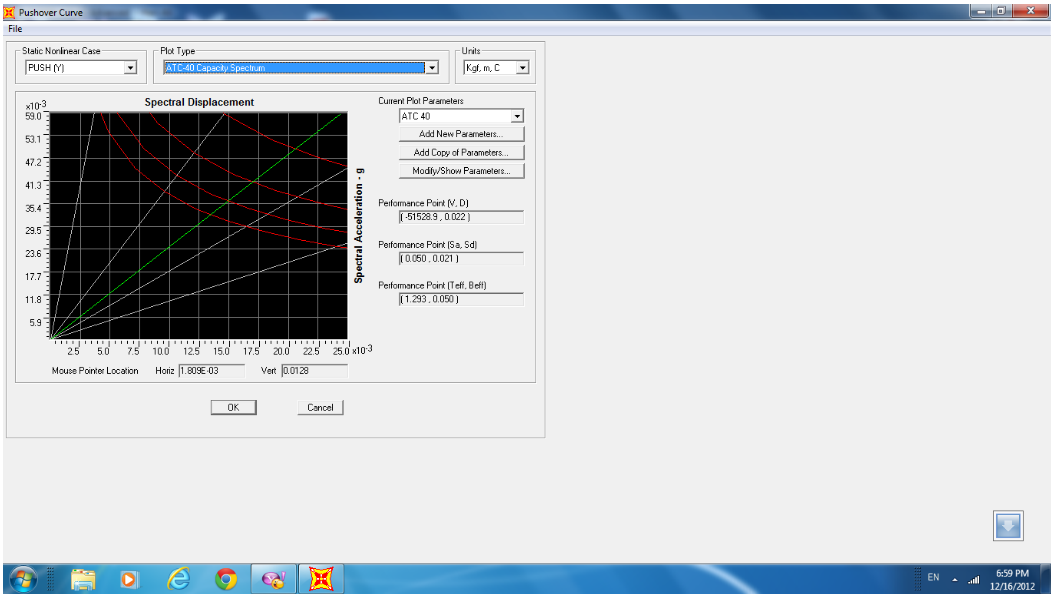


Figure 54. The performance point properties based on ATC-40 in Y direction

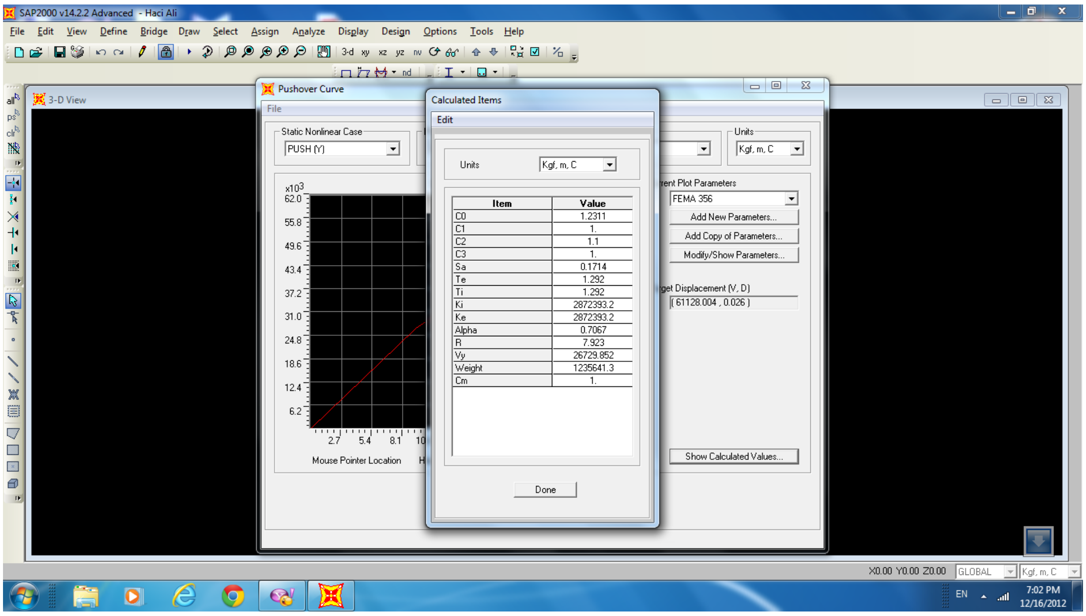


Figure 55. The target displacement property based on FEMA 356 in Y direction

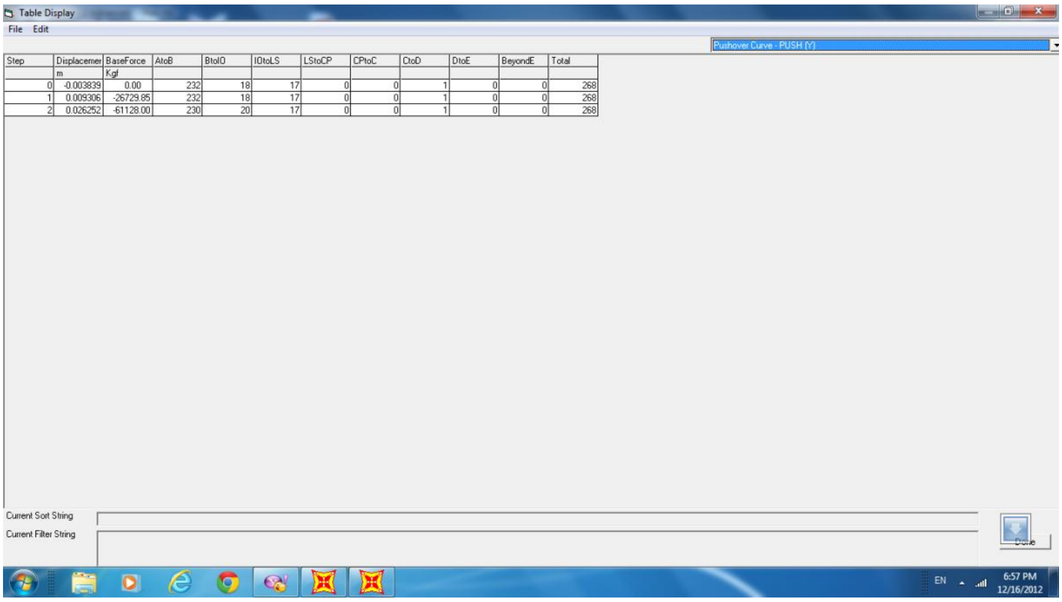


Table Display

Pushover Curve - PUSH (Y)

Step	Displacemen	BaseForce	AtoB	BtoIO	IOtoLS	LStoCP	CPtoC	CtoD	DtoE	BeyondE	Total
	m	Kgf									
0	-0.003839	0.00	232	18	17	0	0	1	0	0	268
1	0.009306	-26729.85	232	18	17	0	0	1	0	0	268
2	0.026252	-61128.00	230	20	17	0	0	1	0	0	268

Current Sort String
Current Filter String

Figure 56. The plastic hinges information in Y direction

Figure 56 which deals with Y-direction shows that all pushover steps correspond to grade 4: very heavy damage (heavy structural damage, very heavy nonstructural damage). It must be say that in this case study because in X direction the length of this case study is too much, So just push in Y direction has been discuss due to dominate mode.

4.3.4.3 Comparison of Methods

Once more, P25 method requires detailed assessment by pushover analysis; the latter predicted a vulnerability of grade 4.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Three Story Building (Fist Case Study)

Based on result of P25 method, pushover method is needed in order to evaluate building performance. So, after pushover analysis, results shows that in X-direction, based on FEMA 356 target displacement is 0.147m; and according to Figure 21, performance of building located between step 29 and 30. Similarly, in Y-direction, the first plastic hinge occurred in step 5 and at the last step, 107 plastic hinges in A-B, 53 plastic hinges in B-IO, 14 plastic hinges in IO-LS, 5 plastic hinges in LS-CP appeared. In the last step, 107 plastic hinges in A-B, 53 plastic hinges in B-IO, 14 plastic hinges in IO-LS, 5 plastic hinges in LS-CP appeared. According to Figure 20, after 21 steps, the displacement at target point reached 52cm and base shear is 63.35 tonf. Based on FEMA 356 the target displacement is 0.169m and according to Figure 20, performance of building located between step 6 and 7. And in these steps 26 and 28 hinges were placed after CP. From EMS98 classification, building vulnerability has been shown to be of grade 4: very heavy damage (heavy structural damage, very heavy nonstructural damage) for both directions.

5.1.2 Seven Story Building (Second Case Study)

Based on result of P25 method, pushover method is needed in order to evaluate of building performance. Based on Figure 30 in performance point curve according to ATC40, base shear (V) is 612 tonf, and displacement is 13 cm. Also base shear is

671tonf and displacement is 15.8 cm according to FEMA 356. It is important to note that the results based on two different codes (ATC40 –FEMA 356) are close to each other.

Based on FEMA 356 the target displacement is 0.151m and according to Figure 30, the performance of building is located in step 3. As seen above, from EMS98 classification, whether it is X- or Y-direction, all pushover steps correspond to grade 4.

5.1.3 Four Story Building (Third Case Study)

Based on result of P25 method, pushover method is needed in order to evaluate of building performance. Based on FEMA 356 in X-direction, target displacement is 0.023m, and according to Figure 43, performance of building located in step 2. In this step, hinges were placed in IO limit. Based on FEMA 356 in Y-direction, target displacement is 0.05m and according to Figure 42, performance of building is located in step 5. And in this step, hinges were placed in LS limit. Therefore it can be understood from EMS98 that this buildings might undergo, both in X- and Y-direction, a damage grade level 1. So, this building has a good performance based on the FEMA 356.

5.1.4 Three Story Building (Fourth Case Study)

Based on result of P25 method, pushover method is needed in order to evaluate of building performance. Based on FEMA 356 in Y-direction, target displacement is 0.026m and according to Figure 56, performance of building is located in step 2. And in this step, hinges were placed in CD limit. So, this building might experience a damage grade 4 along its Y-direction according to EMS98.

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