Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 185

A CRITICAL EVALUATION OF PERFORMANCE ASSESSMENT PROCEDURES IN THE LIGHT OF FIELD DATA

A. Dilsiz[1]

ABSTRACT

During the last two decades, many nonlinear analysis procedures have been proposed for earthquake response determination of the structures. The nonlinear response history analysis (NRHA) is accepted as the most accurate source of information for nonlinear seismic response, but nonlinear static procedures (NSP) may also provide reasonable estimates of seismic demand and inelastic behavior. However, all proposed NSPs have limitations due to the inherent approximations and simplifications including load pattern and single mode considerations. On August 17, 1999, Turkey experienced an un-planned large scale testing of buildings during the Marmara Earthquake. It would appear that, using building response observations from this earthquake and performing "back calculations" for selected structures, it might be possible to assess the "global" performance of performance assessment procedures that have been developed. The rhetorical question, "had we known one day in advance that this earthquake would occur, could we have estimated their performance globally using the widely used NSPs?" deserves an informed answer. Moderately and heavily damaged buildings have been sampled from Adapazari / Sakarya and their models built for this purpose. For this study, two moderately and two heavily damaged buildings have been selected from the building pool and a number of analysis procedures have been applied to them. For the performance assessment of buildings, the following analysis procedures have been used: NSPs of ATC-40, FEMA-356, FEMA-440, Modified Modal Pushover Analysis (MMPA), and NRHA. The study has concentrated on NSPs. These are compared with the global building performance of selected buildings. Because global damage states for buildings are known, comparing them with predictions from analyses using NSPs is done. This way, the NSP Methods are evaluated and checked whether they have estimated the global damages suitably. The study has been concluded as; there is no safety for the compatibility of pushover procedures with field observations, yet.

1. Introduction

The recent researches in Earthquake Engineering have been significantly concentrated on the idea of "performance based earthquake engineering". In order to determine the seismic

[1] Graduate Research Assistant, Dept. of Civil Eng., Middle East Technical University, Ankara, 06531, Turkey.

response of the structures, a lot of Nonlinear Static Procedures (NSP) has been proposed. In general, the reliability of NSP's has been evaluated comparing their expectations with the results of Nonlinear Response History Analyses (NRHA), which have been accepted as the "exact results".

On August 17, 1999, Turkey experienced an un-planned large scale testing of buildings during the Marmara Earthquake. The Marmara Region where the earthquake occurred has become an outdoor laboratory for the researchers from all over the world.

1.1. Objective of the Paper

This study has initiated from the question of "had we known one day in advance that this earthquake would occur, could we have estimated their global performance using the widely used NSPs?" The principal modality is to compare observed performance of buildings on the basis of field observations with estimates using nonlinear static procedures. This way a calibration of these procedures may be possible.

Moderately and heavily damaged buildings have been sampled, randomly, from Adapazari / Sakarya (one of the most effected cities during the earthquake). The blueprints of the buildings have been copied from the archives of the Adapazari Municipality.

In the regions affected from the earthquake in Turkey, the survey teams inspected the damage immediately after the earthquake. The survey teams used post-earthquake rapid screening methods, only, in order to define the global damage states. The damages are decided according to the "Damage Determination Report Form" prepared by the General Directorate of Disaster Affairs of Turkey. These damage states are defined as slight/no, moderate or heavy in the form in order to determine the global damage, however, the forms do not have enough details for the RC buildings and their damages. The plan geometry and the number of story were the only parameters which are directly related with the RC buildings. Since the detailed damage information could not be obtained for the buildings assessed, the study has concentrated on the global damage states only, not prediction of the damage distribution.

After the inspections of the survey teams, the ruins of the heavily damaged buildings lifted and the moderately damaged buildings strengthened. The computer models of the damaged buildings built assuming the information obtained from the blueprints were as built. Actually, this assumption is consistent with the author's observations on the strengthened buildings. It is observed that the information of the plan and vertical dimensions of the building, as well as the dimensions of the structural members, were consistent with the blueprints.

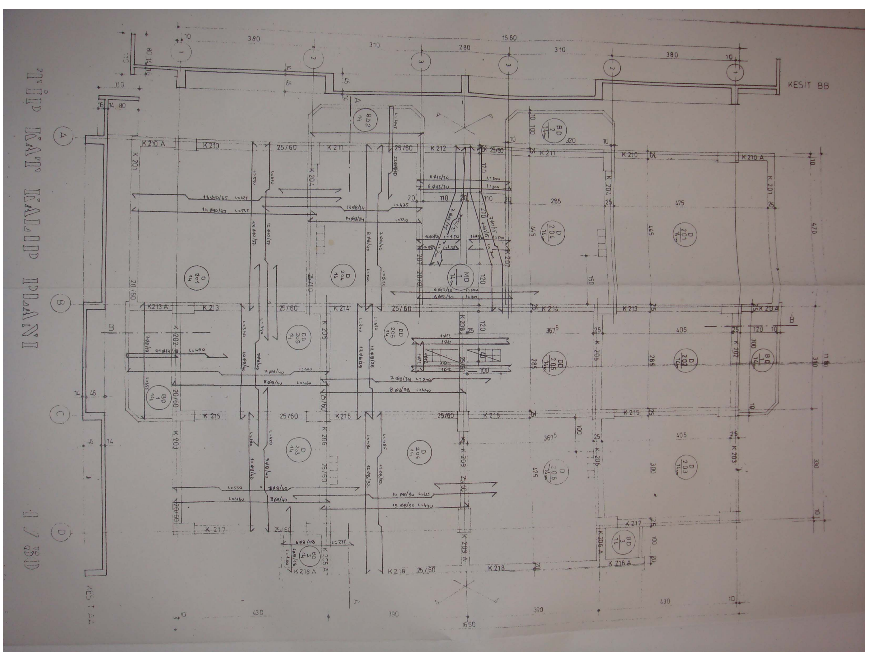
In order to compare the estimations of the NSPs with the results of NRHA and the observed global damage, a number of analysis procedures have been applied to two moderately damaged and two severely damaged buildings, with different geotechnical and structural attributes. For the performance assessment of buildings, the following analysis procedures have been used: NSPs of Capacity Spectrum Method (ATC-40 and FEMA-440) (ATC 1996, ATC 2005), Displacement Coefficients Method (FEMA-356 and FEMA-440) (ASCE 2000, ATC 2005), and Modified Modal Pushover Analysis (MMPA) (Chopra et al 2004). In addition to the NSPs, NRHA has been carried out as well.

2. General Features of the Buildings Assessed

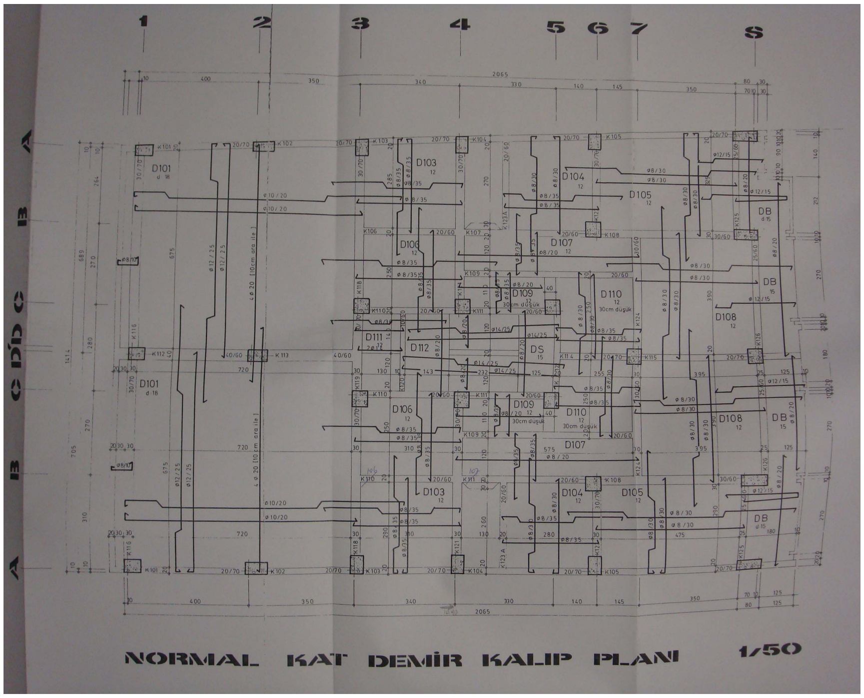
In this study, four buildings (two moderately and two severely damaged) which are located in the Adapazari city center and experienced damage during the August 17, 1999, Marmara Earthquake, have been selected for the assessment. Sample buildings' blueprints have been obtained from the archives of the Adapazari Municipality and modeled in computer. For the models and analyses SAP 2000 Nonlinear (Computers & Engineering Software & Consulting) software has been used.

The structural system for each of the building is reinforced concrete frame system. Basement has never been built in the sample buildings. The amount of infill walls has been decreased if the ground floor is used commercially. Considering these features, the sample models reflect the general situation of building stock in Adapazari city, and entire Turkey. The general features of the buildings are given in Table 1. The pictures of typical floor plans for two of the buildings studied have been shown in Figure 1. The pictures are taken from the blueprints of the buildings. When the floor plans are examined, the buildings have some irregularities, i.e. imperfect frames in each principle axes of the building, projections in plan.

The geotechnical information given in Table 1, has been obtained from the results of the microzonation studies held by DRM and GDDA (DRM 2003, GDDA 2004).



(a)



(b)

Figure 1. Typical floor plans; (a) building #2, (b) building #4

3. Seismic Performance Assessment of the Buildings

The 3D models of the buildings have been evaluated using the NSPs of i. Nonlinear Dynamic Analysis of Equivalent SDOF System (Eq. SDOF), ii. Capacity Spectrum Method (CSM) (ATC 1996, ATC 2005), iii. Displacement Coefficients Method (DCM) (ASCE 2000, ATC 2005), iv. Modified Modal Pushover Analysis (MMPA) (Chopra et al 2004), and v. NRHA.

As explained in Section 1, since the detailed damage distribution information could not be obtained for the buildings assessed, the study has concentrated on the global damage states only, not prediction of the damage distribution. In order to estimate the global seismic response of the buildings, the roof displacement demand parameter has been used. The deformation demand of each structural element differs by changing level of the roof displacement. Thus, the roof displacement is used as a global parameter for estimation of the probable damage of the building. If the demand is within tight limits, the performance estimations can be consistent.

3.1. Strong Ground Motion

The site specific ground motion string which has been obtained from the original strong ground motion – recorded at Sakarya Station (SKR-EW) – is used for the analyses (Bakır et al 2002). At the Sakarya Station only one component (SKR-EW) of the motion could be recorded during the earthquake.

Table 1. General features of the buildings

	Building ID	Built	No. of Story	Concrete f_{cd} (kg/cm^2)	Reinf. Steel f_{yd} (kg/cm^2)	Coordinates Lat (deg.)	Coordinates Long (deg.)	Distance to Fault (km)	Footprint Dimensions (m)	T_1 (s)
Moderate Damage	Building #1	30.05.1988	4	95	1910	40.77414	30.40219	11.3	13,5 * 20	0.92
	Building #2	12.08.1994	5	95	1910	40.79496	30.39966	13.7	11,5 * 16,5	0.63
	Building ID	Built	No. of Story	Concrete f_{cd} (kg/cm^2)	Reinf. Steel f_{yd} (kg/cm^2)	Lat (deg.)	Long (deg.)	Distance to Fault (km)	Footprint Dimensions (m)	T_1 (s)
Severe Damage	Building #3	31.12.1993	6	95	1910	40.78106	30.39536	12	11 * 11,5	0.93
	Building #4	31.05.1990	5			40.77845	30.39779	11.6	21,2 * 15	0.81

	ID	Bedrock Depth (m)	NEHRP Site Class	Turkish Site Class	Vs (m/s)	T (s) Pred. Per.	Groundwater Depth (m)	Liquefaction Severity I.	Note
Moderate Damage	1	175	E	Z4	< 263	> 1.23	0 - 5	1	Strengthening with same material
	2	150	E	Z4	< 263	< 0.82	> 15	0	Technical Report available
	ID	Bedrock Depth (m)	NEHRP Site Class	Turkish Site Class	Vs (m/s)	T (s) Pred. Per.	Groundwater Depth (m)	Liquefaction Severity I.	Note
Severe Damage	3	175	E	Z3	263< Vs< 371	> 1.23	0 - 5	2	Design Software: Ahmet Babalıoğlu
	4	200	E	Z4	> 371	> 1.23	0 - 5	3	

The bedrock depth for the buildings studied has been assumed to be 150 m (DRM 2003, GDDA 2004, Bakır et al 2002, Bakır et al 2005) and “site specific strong ground motion record” has been taken for this depth. Nevertheless, any attenuation relationship has not been considered within the city. The site specific ground motion record which is used for the analyses is shown in Fig. 2, and the corresponding response spectrum is shown in Fig. 3.

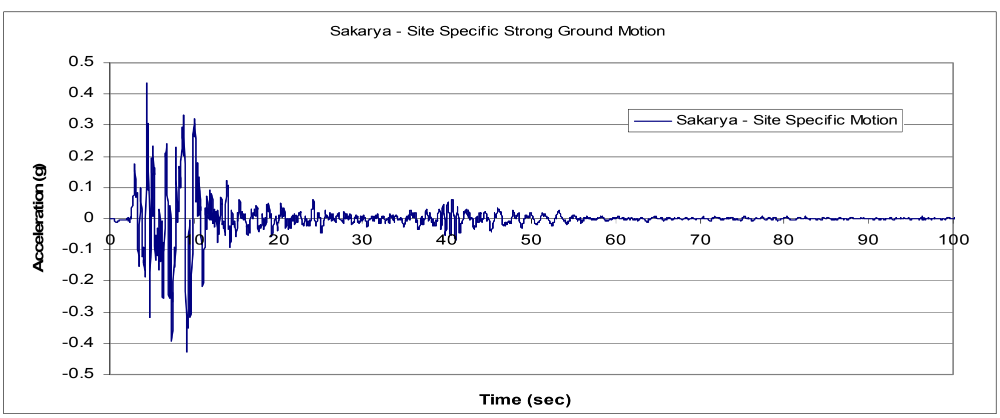


Figure 2. Site specific strong ground motion record (soft soil – bedrock depth: 150 m)

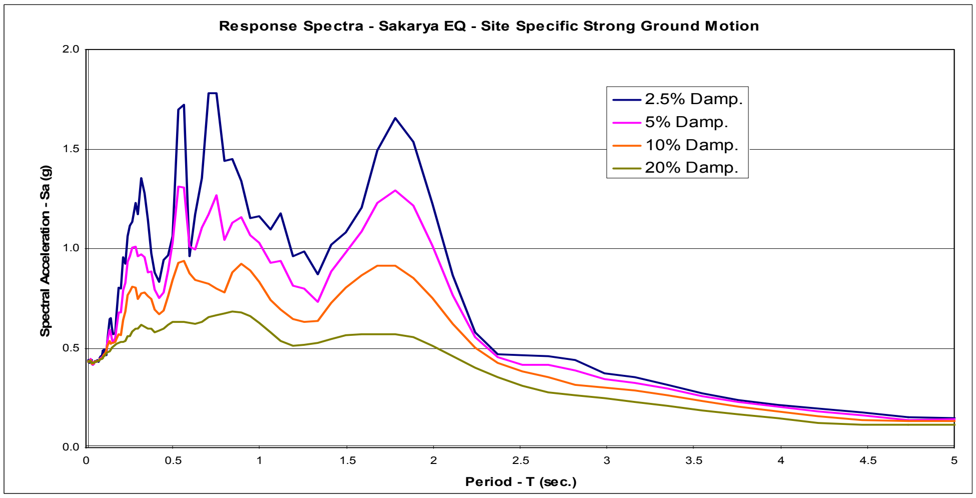


Figure 3. Response spectra (corresponding to the site specific strong ground motion record)

3.2. Performance Assessment Using Nonlinear Static Procedures

The buildings whose general structural and geotechnical features are given in Table 1 have been assessed using the approximate nonlinear procedures. The pushover results and the performance estimations of NSPs and NRHA for each of the building are given in the following sections.

3.2.1. Building #1

The 4-story building has a mezzanine in the ground floor, and the ground floor has been commercially used. The total height is 13.1 m. The building experienced moderate damage during the 1999 Marmara earthquake and strengthened. This damage state defined during the post-earthquake inspections by the survey teams, however, the detailed damage information is not available. The pushover curve with performance estimations are shown in Fig 4.

As it can be seen in the Fig. 4, performance estimations obtained from approximate procedures are far beyond the capacity (pushover) curves for each direction of the building. Although these estimations mean that the building would be severely damaged / collapsed, the building experienced moderate damage during the earthquake. However, the global seismic response has been obtained using NRHA.

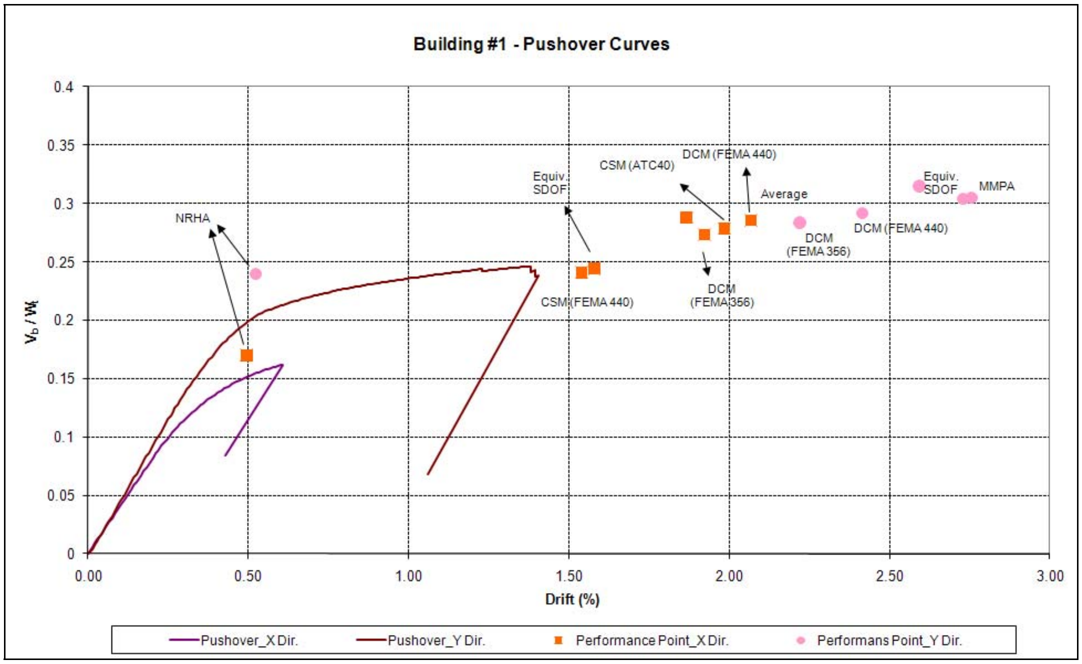


Figure 4. Pushover curves and the performance estimations for building #1

3.2.2. Building #2

The total height of the 5-story building is 13.6 m. Moderately damaged building during the 1999 earthquake has been strengthened. This damage state defined during the post-earthquake inspections by the survey teams, however, the detailed damage information is not available. The pushover curve with performance estimations are shown in Fig. 5.

According to the assessment only the estimations of Displacement Coefficients Method in Y direction fit with the moderate damage of the building. The other estimations imply that the building would be severely damaged during the earthquake. On the other hand, the results of the NRHA are consistent with the global damage state of the building only in Y direction.

3.2.3. Building #3

The ground floor of the 6-story building is commercially used. The total height is 17.5 m. This building experienced severe damage during 1999 earthquake. This damage state defined during the post-earthquake inspections by the survey teams, however, the detailed damage information is not available. The pushover curves with performance estimations are shown in Fig. 6.

Almost all the performance point estimations of assessment procedures are beyond the building capacity. According to the DCM results in Y direction, the building would experience moderate damage, which is not “exact result”. The results of the NRHA are consistent with the global damage state of the building in both X and Y directions.

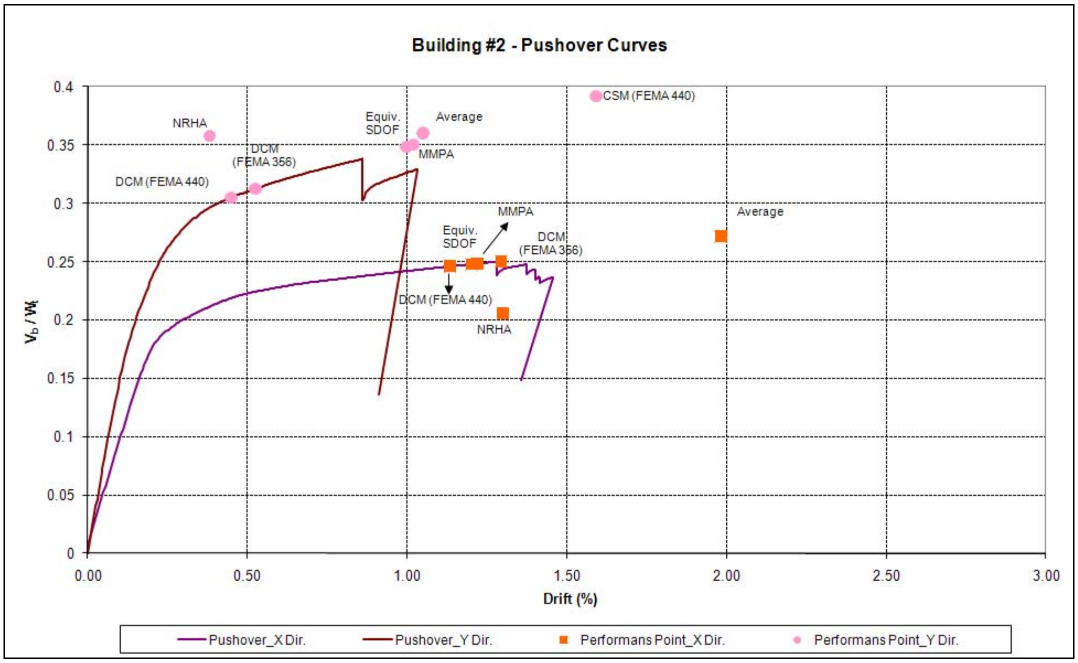


Figure 5. Pushover curves and the performance estimations for building #2

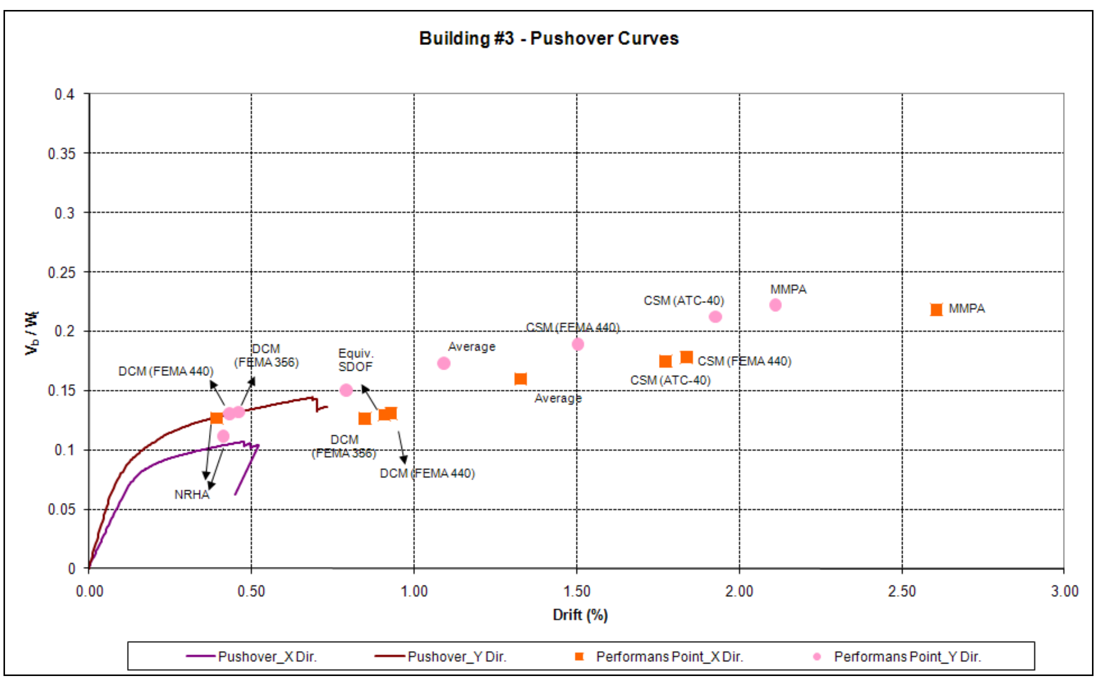


Figure 6. Pushover curves and the performance estimations for building #3

3.2.4. Building #4

The total height of the 5-story building is 15.6 m. The building experienced severe damage during the 1999 earthquake. This damage state defined during the post-earthquake inspections by the survey teams, however, the detailed damage information is not available. The pushover curve with performance estimations are shown in Fig. 7.

As it can be seen in the Fig. 7, performance estimations obtained from approximate procedures are far beyond the capacity (pushover) curves for each direction of the building. These estimations imply that the building would experience severe damage / collapse. The building experienced severe damage during the earthquake. On the other hand, the NRHA results are consistent with the building damage state.

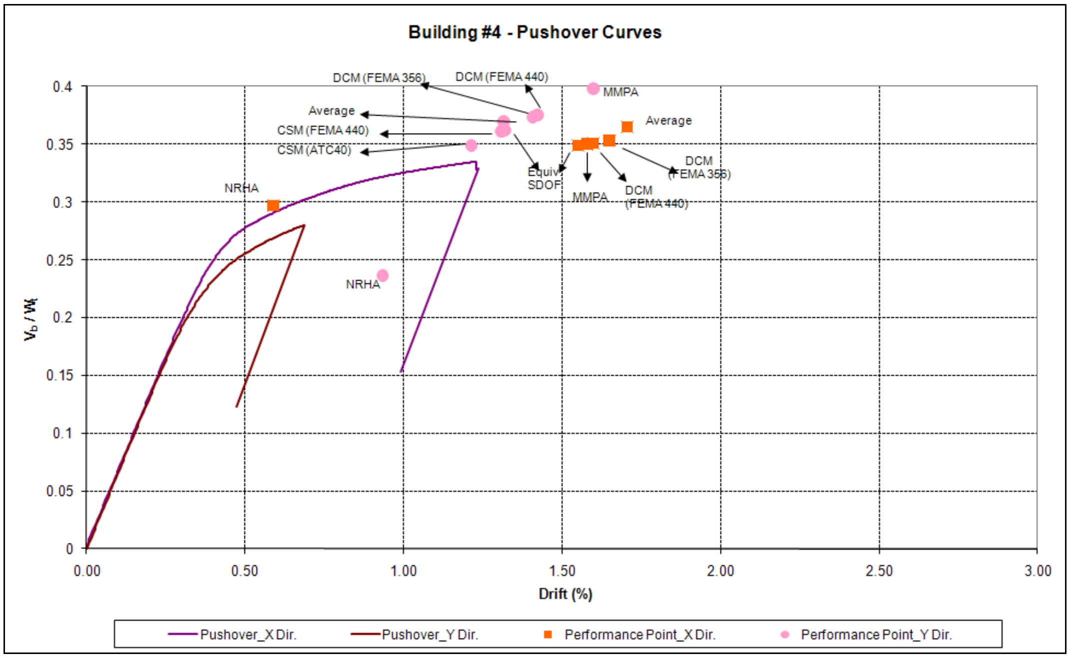


Figure 7. Pushover curves and the performance estimations for building #4

4. Conclusions

The study has concentrated on the application of NSPs to the large building stocks in Turkey. The approximate assessment procedures are compared with the global building performance of selected buildings. Since global damage states for buildings are known, comparing them with predictions from analyses using NSPs is done. This way, the NSP Methods are evaluated and checked whether they have estimated the global damages suitably.

In general, the results of assessment procedures for the idealized building models may be satisfying. However, the results for the real buildings of same procedures are very misleading. The building assessment examples given in this study clearly shows that those misleading results. The results of the analyses are seriously affected by inadequate information about the soil effects and the approximations for the structural modeling. On the other hand, the workmanship effects and shear failure or bonding effects can not be modeled definitely. Especially, if the building collapsed and the ruin has been lifted, the deficiency of information is more important.

The first two building in this study (3.2.1 and 3.2.2) experienced moderate damage and the other two buildings (3.2.3 and 3.2.4) are severely damaged during the earthquake. However, most of the analyses results could not predict the level of damage accurately. Using these results it is not possible to determine the seismic response and the damage of the buildings before the occurance of earthquake.

The study has been concluded as; there is no safety for the compatibility of pushover procedures for the assessment of global damage states with field observations, yet. It is necessary to investigate the proposed assessment procedures in a detailed manner and to check the results for "real buildings". The approximate nonlinear static assessment procedures should be improved for reliable damage estimation.

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