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# Investigation of Effects of Displacement Coefficient Method on Performance Evaluation of Multi-Story Buildings According to the IRAQI Seismic Code Requirements

## ABSTRACT

The aim of this study is to assess the performance objectives defined in the Iraqi Seismic Code (ISC) in order to make a realistic evaluation related to Performance-Based Seismic Design (PBSD) of multi-story reinforced concrete buildings. Comparison and evaluation of structural response demands obtained from nonlinear static analysis procedures according to two versions of the displacement coefficient method (DCM), which are recommended in FEMA 356 and FEMA 440, are performed. Two groups of three-dimensional RC buildings with different heights, designed according to Iraqi Building Code Requirements for Reinforced Concrete (IBC), are investigated. Pushover analyses are carried out to determine the nonlinear behavior of the buildings under three different seismic hazard levels, for two Iraqi seismic zones, of earthquake loads. In order to determine performance levels of the buildings, maximum inter-story drift demands are determined and compared with the related limits using the DCM recommended in FEMA 356 and FEMA 440. From the results of this research, it can be concluded that RC buildings designed according to the Iraqi codes sufficiently provide the performance objectives stipulated in the ISC.Comparing structural response quantities obtained from the two versions of DCM, effects on performance evaluations of the buildings are investigated comparatively, as well.

**Keywords:** pushover analysis, displacement coefficient method, seismic capacity, Iraqi seismic code, PBSD, RC buildings

## Introduction

Building damages and collapses in severe earthquakes have caused huge life and economic losses, in different parts of the world. Even smaller earthquakes have also caused the inelastic behavior in buildings. Therefore, it is necessary to examine and discuss the current country codes and develop alternative approaches to the traditional force based design [1]. Performance-based design (PBSD) is a major shift from traditional structural design concepts and represents the future of earthquake engineering. The procedure provides a method for determining acceptable levels of earthquake damage. Also, it is based on the recognition that yielding does not constitute failure and that preplanned yielding of certain members of a structure during an earthquake can actually help to save the rest of the structure. The structural engineer is interested in its concepts due to its potential benefits in assessment, design, and better understanding of structural behavior during ground motions. It also, permits the owners and designers to select personalized performance goals for the design of different structures. It seems that PBSD concepts, which allow multi-level design objectives, could provide a framework to improve the current codes; by obtaining structures that perform appropriately for all of seismic hazard levels [2].

In determination of response demands for seismic assessments of buildings within PBSD concept, nonlinear static analysis procedures (NSPs) are becoming more popular in structural engineering practice. Although nonlinear time history analysis is the most reliable analysis in determination of the seismic response demands, it requires rather sophisticated input data and provides output, which is difficult to interpret. For this reason, NSPs are frequently used in ordinary engineering applications to avoid sophisticated assumptions required by the latter. As a result, simplified NSPs recommended in ATC 40 [3], FEMA 237 [4], FEMA 356 [5], and other documents have become popular [6 and 7]

The nonlinear static procedure requires development of a pushover curve, a plot of base shear versus roof displacement, by nonlinear static analysis of the structure subjected first to gravity loads, followed by monotonically increasing lateral forces with a specified invariant height wise distribution. At least two force distributions must be considered [5 and 7]

Then, maximum structural response demands, (such as drifts, inter-story drifts, shear strength, etc.) are obtained by using this curve. Single degree- of-freedom (SDOF) system approach is used in determination of demands in NSPs recommended in ATC 40 and FEMA 356, which is called as capacity spectrum method (CSM) and displacement coefficient method (DCM), respectively. However, these procedures have some discrepancy in determination of displacement demand for the same building model and under a specific ground motion [8 and 9]. Consequently, same building performances may not be obtained due to these discrepancies in the analysis procedures.

Applied Technology Council with funding provided by FEMA conducted the ATC 55 [10] project to overcome the deficiencies and discrepancies in the

NSPs using performance based engineering methods for seismic design, evaluation, and rehabilitation of buildings [11]. The ATC 55 Project had two objectives: the development of practical recommendations for improved prediction of inelastic structural response of buildings to earthquakes (i.e., guidance for improved application of inelastic analysis procedures), and the identification of important issues for future research.

The Displacement coefficient method (DCM) has gained considerable popularity amongst pushover users. It is of important to investigate effects of the DCM versions in performance evaluations of RC buildings, having different structural characteristics, within PBSD and assessment concept**.**

In order to obtain useful elements of comparison between the two versions of CSM, the building performance is evaluated in this work with the features proposed in FEMA 356 and FEMA 440 and by comparing the seismic response estimation of the analyzed buildings in terms of drift profiles, roof drift ratios, inter-story drift ratios, and base shear demands.

Performances of RC buildings designed according to the Iraqi Building Code IBC 1987 [12] and Iraqi Seismic Code ISC 1997 [13] are examined, in an attempt to investigate the behavior of RC buildings in Iraq through evaluation of the performance objectives stipulated in the ISC. As in several contemporary country codes, general principles of earthquake resistant structure design are stated in the ISC 1997, which consists of rather indistinct definitions concerning the expected seismic hazard and damage levels. Stipulated performance objectives of the ISC are as follows:

1. The structure should withstand, without any structural and non-structural damage, the effects of slight seismic motion.
2. The structure should withstand, with limited non- structural damage and limited non-linear behavior of structural members, the effects of moderate seismic motion (design earthquake).
3. The structure should not collapse under sever or maximum expected earthquake.

The code provisions attempt to provide these performance objectives with various requirements (i.e., ductility and capacity requirements, displacement restrictions, etc.). These restrictions are very similar in all of the contemporary codes. However, it is not possible to check the states of the stipulated performance objectives by means of the traditional force based design. In order to determine the expected performances of the buildings, the performance based approaches including displacements rather than forces should be used in design and assessment.

A group of three-dimensional RC multi-story buildings are investigated in this study. The group has three buildings (3, 6, and 9 stories). The buildings in the have a soft story in the first level. In order to determine building performance, base shear– roof displacement relationships (capacity curves) of each building designed according to Iraqi codes are obtained by pushover analysis.

Each building is subjected to two kinds of lateral load distribution, P1**,** and P2, across its height. The first one is according to an equation of equivalent static forces as in ISC, while the second is proportional to the story masses at each story level. Two different seismic zones were chosen from the seismic zoning map of Iraq and three seismic hazard levels, derived from the ISC design spectrum, are considered in this study for each zone. Then, buildings' performances are determined using the two versions of DCM. Comparing the performances of the modeled RC buildings to the stipulated objectives in the ISC, the behavior of RC buildings in Iraq is evaluated.

## Properties of the Buildings

In order to compare seismic demands obtained from the DCM on RC buildings, three dimensional (3D) structural systems having three (3S), six (6S), and nine (9S) stories are designed according to the Iraqi codes (IBC and ISC Codes). In order to investigate the effects of having a soft first story on performance, the first story height was taken 50% more than the other stories. The basic structure is symmetrical in two directions and has no structural irregularity. All buildings are residential having the same square plan dimensions 20mx20m with 5m bays in both directions. All stories have the same (3m) height, except in the first stories of the buildings, Figures1a and 1b.

The systems were designed to carry: Live Load of 2kN/m$^2$, Flooring Load of 1.5kN/m$^2$, Partitions Load of 2kN/m$^2$, Mechanical and Electrical load of 0.5kN/m$^2$ in addition to the slab weight of 150mm thickness. The equivalent horizontal static seismic load was also considered according to the Iraqi seismic code. The sectional details were done for those residential buildings according to the Iraqi building code and the results are shown in Table 1.

**Table 1.** *Section Details of Reinforced Concrete Frames*

| **Building** | **Level** | **Exterior Columns** | | **Interior columns** | | **Beams** | | |
|---|---|---|---|---|---|---|---|---|
| | | Size (mmxmm) | Steel (mm$^2$) | Size (mmxmm) | Steel (mm$^2$) | Size (mmxmm) | Top Steel (mm2) | Bottom Steel (mm2) |
| Three Stories | 1 | 450x450 | 5130 | 450x450 | 5130 | 300x700 | 1000 | 1000 |
| | 2 | 450x450 | 5130 | 450x450 | 5130 | 300x700 | 1000 | 1000 |
| | 3 | 450x450 | 5130 | 450x450 | 5130 | 300x700 | 1000 | 1000 |
| Six stories | 1 | 500x500 | 6330 | 500x500 | 6330 | 300x700 | 1250 | 1250 |
| | 2 | 500x500 | 6330 | 500x500 | 6330 | 300x700 | 1250 | 1250 |
| | 3 | 500x500 | 6330 | 500x500 | 6330 | 300x700 | 1250 | 1250 |
| | 4 | 450x450 | 5130 | 450x450 | 5130 | 300x700 | 1000 | 1000 |
| | 5 | 450x450 | 5130 | 450x450 | 5130 | 300x700 | 1000 | 1000 |
| | 6 | 450x450 | 5130 | 450x450 | 5130 | 300x700 | 1000 | 1000 |
| Nine stories | 1 | 550x550 | 7660 | 550x550 | 7660 | 300x700 | 1500 | 1500 |
| | 2 | 550x550 | 7660 | 550x550 | 7660 | 300x700 | 1500 | 1500 |
| | 3 | 550x550 | 7660 | 550x550 | 7660 | 300x700 | 1500 | 1500 |
| | 4 | 500x500 | 6330 | 500x500 | 6330 | 300x700 | 1250 | 1250 |
| | 5 | 500x500 | 6330 | 500x500 | 6330 | 300x700 | 1250 | 1250 |
| | 6 | 500x500 | 6330 | 500x500 | 6330 | 300x700 | 1250 | 1250 |
| | 7 | 450x450 | 5130 | 450x450 | 5130 | 300x700 | 1000 | 1000 |
| | 8 | 450x450 | 5130 | 450x450 | 5130 | 300x700 | 1000 | 1000 |
| | 9 | 450x450 | 5130 | 450x450 | 5130 | 300x700 | 1000 | 1000 |

**Figure 1a.** *Perspective, 3D View of the Investigated Buildings*

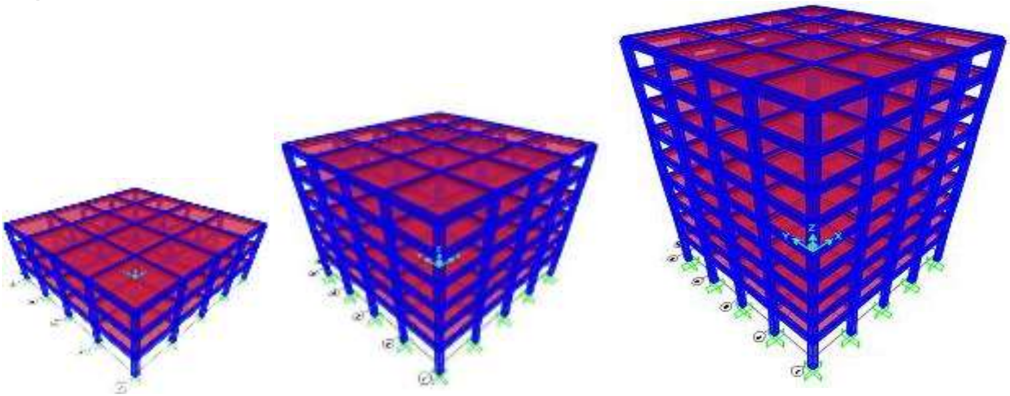
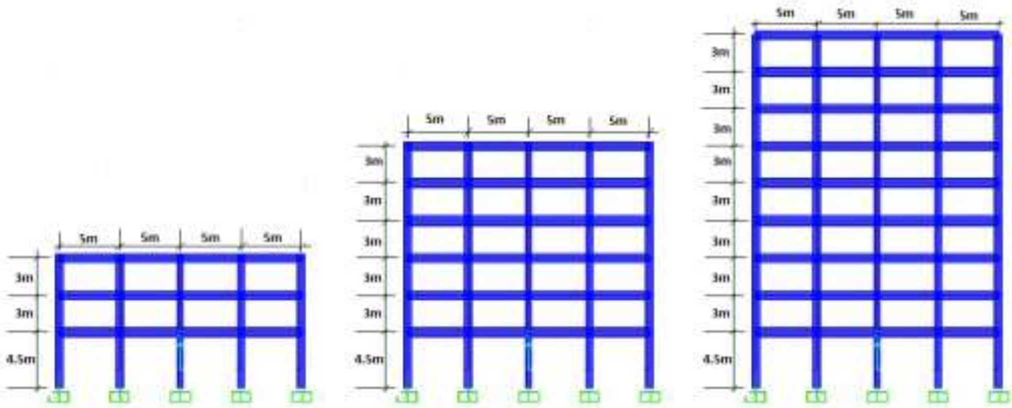


**Figure 1b.** *Buildings, with Soft First Story*




## Assumption of the Structural Model

The next step in PBSD is the estimation of seismic demands in the structure due to imposed earthquake loads. The prediction of deformation demands is arguably the most critical step in PBD. Determining demands necessitates the development of a structural model of reasonable complexity. Errors in estimating the demand as a result of an inadequate structural model can propagate through and lead to misleading conclusions on the performance of the structure.

Nonlinear bending and axial deformations are assumed to occur at certain sections, which are defined as plastic sections, whereas the other portions of the building remain elastic. It is assumed that plastic hinges occur with pure bending moment in beams and with combined bending moment and axial force in columns.

Shear force and torsional moment capacities of beams and columns are also checked separately in the analyses. Moment–plastic rotation relationships of column and beam sections are assumed as rigid plastic with kinematic hardening, and characteristic values of them (plastic moment and maximum plastic rotation values) are taken from ATC 40 .Cracked section stiffness

values for columns and beams are taken as proposed in FEMA 356. For the cases where members lose all or a significant portion of their lateral load carrying ability, but could continue to deflect with no other unacceptable effects, ATC 40 and FEMA 356 purpose a procedure in order to determine the capacity curves and the performance points for these types of buildings.
The SAP 2000 structural analysis program was used in the pushover analyses of the RC buildings [14]. Table 2, shows the weight, the fundamental period, and the legend for each building.

**Table 2.** *Building, Weight, Modal Mass, Fundamental Period, and Legend*

| Frame Geometry | Number of Stories | Weight (kN) L+D | $\alpha_1$ modal mass coefficient | $T_1$ Fundamental Period (s) | Building Legend |
|---|---|---|---|---|---|
| Three-Dimensional Frame | Three Stories | 15820 | 0.967 | 0.785 | 3D-3S |
| | Six Stories | 31760 | 0.904 | 1.208 | 3D-6S |
| | Nine Stories | 47980 | 0.847 | 1.606 | 3D-9S |

## Performance Objectives

A performance objective may be regarded as the main element in PBSD and is composed of two parts: a performance level and a seismic hazard level which describes the expected seismic load at the site. Terms such as Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) are examples of performance levels, as defined in FEMA 356 [5] and ATC 40 [3].

Seismic hazard levels are typically prescribed in terms of response spectra and are controlled by site characteristics. As the performance objectives in the ISC are not clearly defined as to seismic hazard levels and performance levels, it is not possible to fully validate or interpret building performance. For this purpose, based on the performance and substitute damage levels defined in ATC40, performance objectives of the ISC are defined in the study. The seismic zoning map of Iraq is shown in Figure 2 [13]. In the seismic design of the buildings two different seismic zoning areas, Baghdad and Dehok, Figure 3, were chosen from the seismic zoning map of Iraq. The corresponding short time and 1 second time, seismic coefficients $\mathbf{S_S}$ and $\mathbf{S_1}$ are 0.275, and 0.21 for Baghdad zone and 0.50, and 0.25 for Dehok zone. According to this, three different seismic hazard levels for each zone, with a seismic importance factor of 1, are considered in determination of the structural and nonstructural response demands of the RC buildings. These seismic hazard levels are expressed as:

1. Seismic Hazard Level I – (E1) In low-intensity earthquakes with 50% probability of being exceeded in 50 years, it is assumed that the buildings remain at immediate occupancy (IO) performance level or better.

2. Seismic Hazard Level II - (E2) In moderate earthquakes with 10% probability of being exceeded in 50 years , it is assumed that the buildings remain between immediate occupancy (IO); performance level and life safety performance level (LS); and
3. Seismic Hazard Level III – (E3) In the Maximum earthquake with 2% probability of being exceeded in 50 years, it is assumed that the buildings remain at (LS) performance level of the building or very close to it and should never reach collapse prevention (CP) performance level.

There are two criteria for determining performance levels in order to make performance evaluations of the buildings. These criteria are the maximum plastic rotation values in the members of the structural system (beams and columns) and maximum inter-story drift values of the building, which is pushed statically until the maximum displacement demand is reached.

**Figure 2.** *Seismic Zoning Map of Iraq*

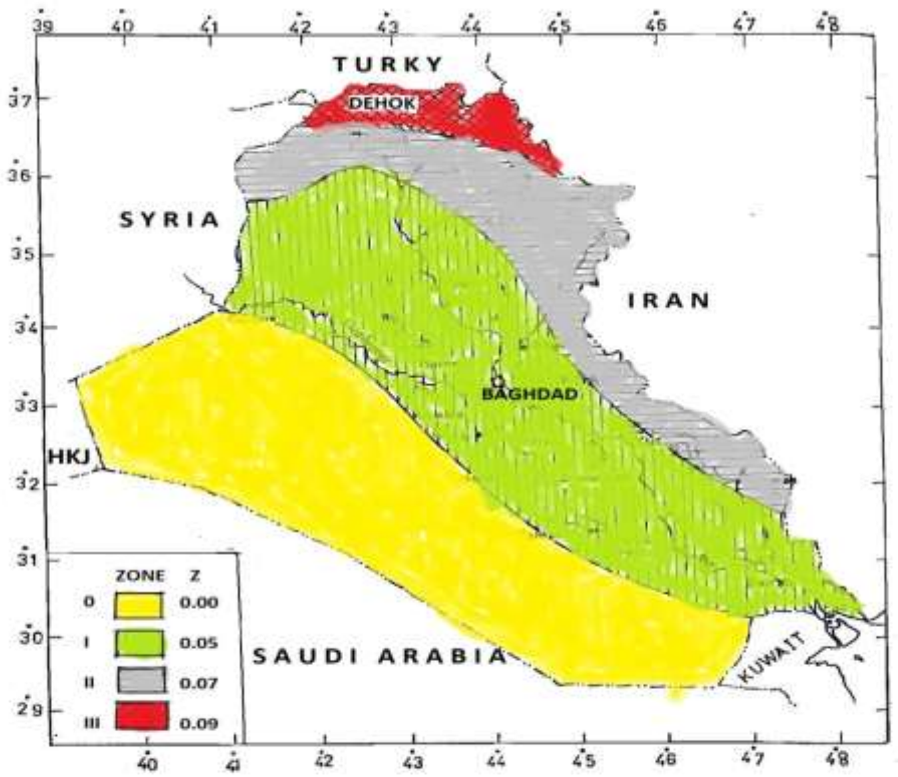


**Figure 3a.** *Response Spectrum, Baghdad Zone*

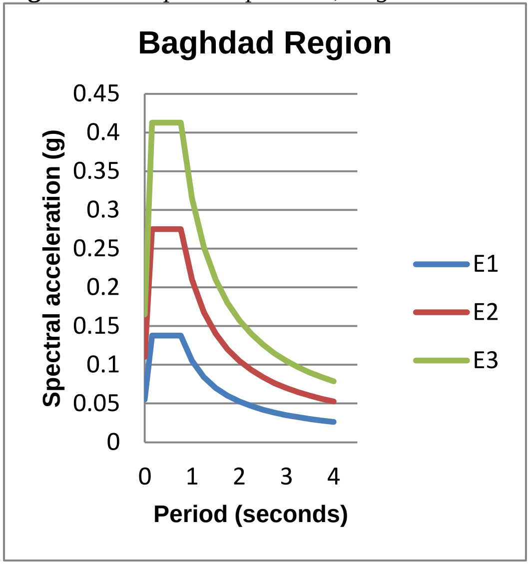
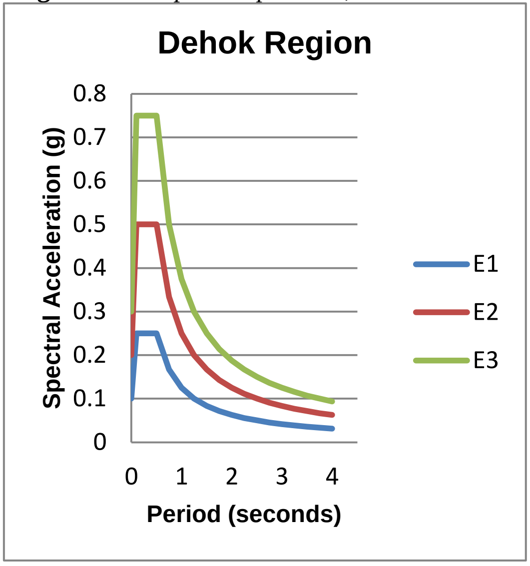



**Figure 3b.** *Response Spectrum, Dehok Zone*



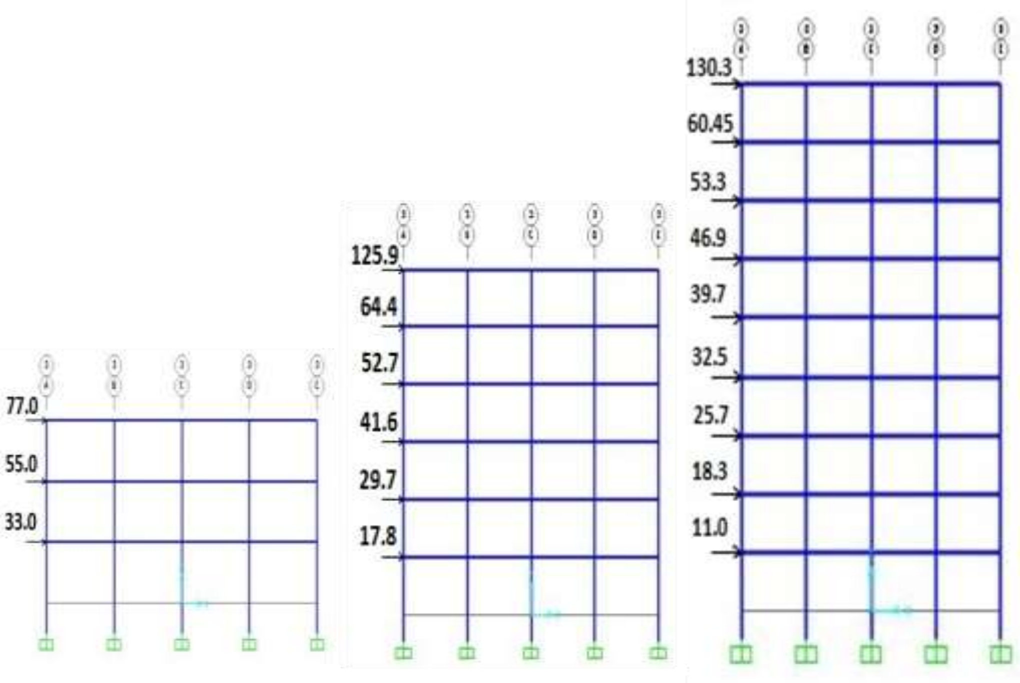

## Distribution of Seismic Forces

To represent the earthquake effects, the buildings are subjected to a lateral load distribution across its height according to two patterns; the equivalent static ISC [13] triangular load pattern **P1**, and the uniform load pattern **P2**. In the first pattern, the total horizontal seismic design force $\boldsymbol{V}$ should be distributed over the height of the building in accordance with the following formula [13]:

$$\boldsymbol{V_i} = \frac{\boldsymbol{W_i h_i}}{\sum_{j=1}^{N} \boldsymbol{W_j h_j}} \boldsymbol{V} \tag{1}$$

In the above expression, $\boldsymbol{V_i}$ is the seismic design force in the i-th level, $\boldsymbol{W_i}$ and $\boldsymbol{W_j}$ are the i-th and j-th floor weights, $\boldsymbol{h_i}$ and $\boldsymbol{h_j}$ are the heights of the i-th and j-th floors from the top of the foundation, and $\boldsymbol{N}$ is the total number of levels. The lateral loads were increased monotonically in the pushover analyses. Figure 4, shows the equivalent Horizontal Static Design Seismic Loading in kN, applied on a typical Interior Frame according to the ISC in Baghdad Zone for the investigated Buildings. For buildings with more than five levels, **0.15**$\boldsymbol{V}$ shall be considered to be concentrated at the top level while the remaining **0.85**$\boldsymbol{V}$ shall be distributed in accordance with the above formula.

**Figure 4.** *Equivalent Horizontal Static Design Seismic Loading (kN), Applied on a Typical Interior Frame According to the ISC in Baghdad Zone for the Investigated Buildings*




## Determination of Capacity Curves

In the pushover analyses, combinations of vertical and lateral loads were based on the rules of the Iraqi Seismic code (ISC) and the design was based on the Iraqi Building Code (IBC1987). According to this, capacity curves including the load combinations (D+L+E with e=0, and D +L+E with *e*=0.05) were determined for the investigated buildings. In these formulas, D, L, E, and *e* denote dead load, live load, earthquake load, and eccentricity (5% additional eccentricity in buildings without plan irregularities), respectively. The lateral loads were increased monotonically in the pushover analyses to produce the capacity curves.

Dividing the values of the base shear by the weight and the top drift by the height of the building, the normalized capacity curves were obtained. Those curves are shown for the three story buildings using the two load patterns P1 and P2 in Figure 5a. The first yield points FYP are also indicated on the curves. It is found that the curves ordinates are greater for P2 than P1. The same conclusion could be obtained for the six story, and nine story buildings as shown in Figures 5b and 5c. Figure 5d demonstrates that the normalized capacity curves values for the three story buildings are the highest while those of the nine story buildings are the lowest.

**Figure 5a.** *Capacity Curves for 3S*

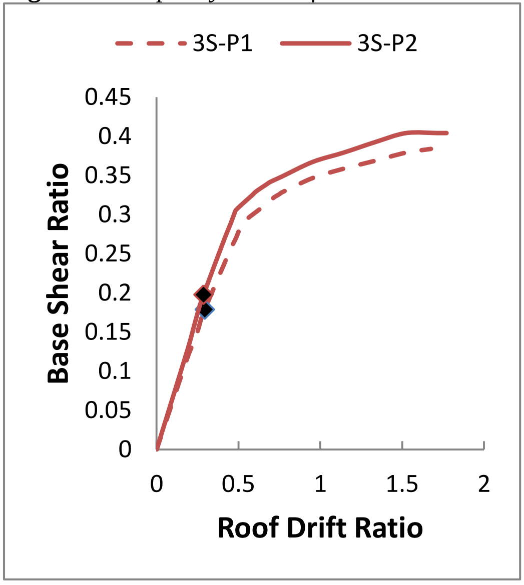



**Figure 5b.** *Capacity Curves for 6S*

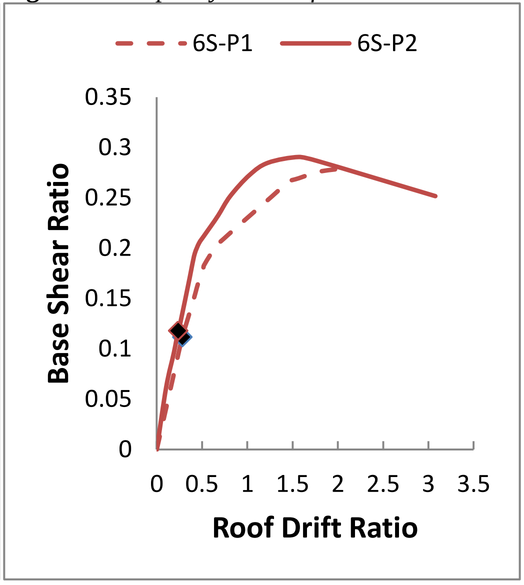



**Figure 5c.** *Capacity Curves for 9S*

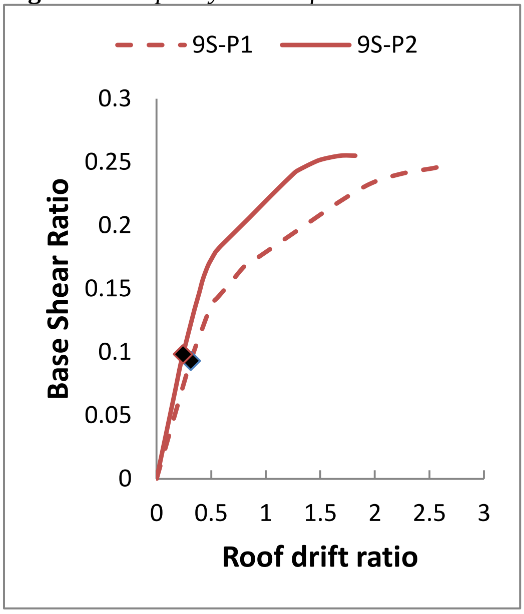
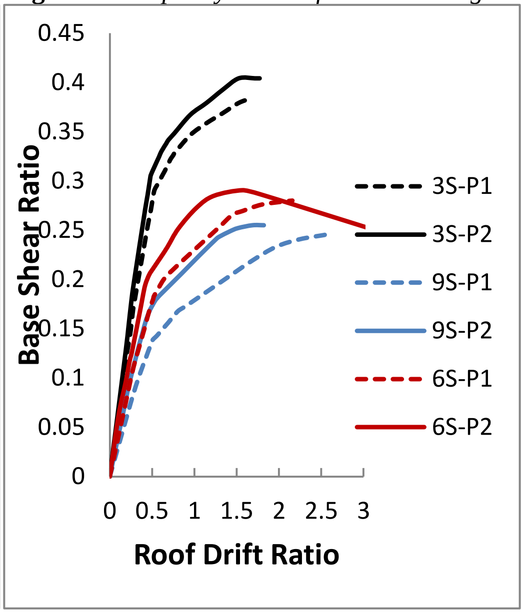
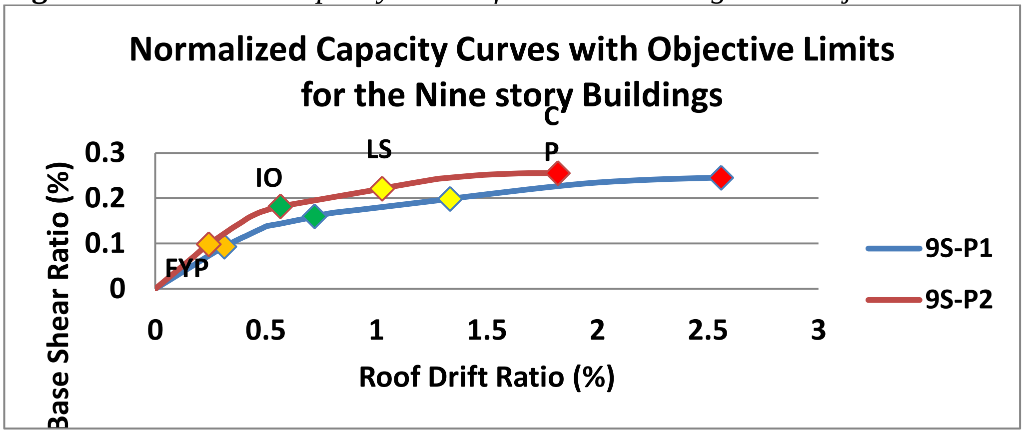



**Figure 5d.** *Capacity Curves for All Buildings*




The normalized capacity curves with objective limits and the first yield point are shown for the nine story buildings in Figure 6. It is found that: 1-The performance points for E1 are lower than FYP, which means that the structures will remain elastic. 2- The curves ordinates due to P2 are always higher than P1.

**Figure 6.** *Normalized Capacity Curves for the 9S Buildings with Objective Limits*




## Prediction of Seismic Response Demands

Displacement and strength demands for the various building configurations were determined according to the investigated versions of DCM for both lateral load patterns using the three seismic hazard levels of each seismic zone. The maximum displacement and strength demand values obtained from the CSM (**$\delta_{max}$,** and **$V_b$**) are shown in Tables 3a and 3b. The displacement profiles of the buildings pushed to maximum displacement demands are shown in Figures 7 for seismic hazard level E3.

**Table 3a.** *Analysis Results for P1, in Baghdad and Dehok*

| **Buildg.** | **Seismic Hazard Level** | FEMA 356 | | | | FEMA 440 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $\delta_{max}$(cm) | | $V_b$(kN) | | $\delta_{max}$(cm) | | $V_b$(kN) | |
| | | **Bag.** | **Dehok** | **Bag.** | **Dehok** | **Bag.** | **Dehok** | **Bag.** | **Dehok** |
| **3S** | $E_1$ | 4.6 | 6.7 | 3974 | 4882 | 4.2 | 6.8 | 3623 | 4911 |
| | $E_2$ | 8.5 | 10.7 | 5269 | 5567 | 8.1 | 11.1 | 5203 | 5603 |
| | $E_3$ | 11.5 | 13.8 | 5636 | 5832 | 11.3 | 14.4 | 5618 | 5887 |
| **6S** | $E_1$ | 9.9 | 11.3 | 5712 | 6078 | 9.9 | 11.3 | 5712 | 6078 |
| | $E_2$ | 16.1 | 18.4 | 6868 | 7152 | 16.1 | 18.4 | 6868 | 7152 |
| | $E_3$ | 21.3 | 23.6 | 7531 | 7820 | 21.3 | 23.6 | 7532 | 7820 |
| **9S** | $E_1$ | 13.6 | 15.6 | 6361 | 6813 | 13.6 | 15.6 | 6361 | 6813 |
| | $E_2$ | 22.1 | 25.1 | 7905 | 8276 | 22.1 | 25.1 | 7905 | 8276 |
| | $E_3$ | 29.4 | 32.5 | 8703 | 9018 | 29.4 | 32.5 | 8703 | 9018 |

**Table 3b.** *Analysis Results for P2, in Baghdad and Dehok*

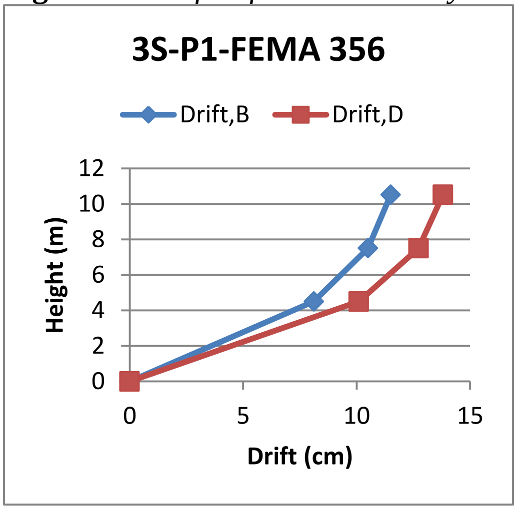
| **Buildg.** | **Seismic Hazard Level** | FEMA 356 | | | | FEMA 440 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $\delta_{max}$(cm) | | $V_b$(kN) | | $\delta_{max}$(cm) | | $V_b$(kN) | |
| | | **Bag.** | **Dehok** | **Bag.** | **Dehok** | **Bag.** | **Dehok** | **Bag.** | **Dehok** |
| **3S** | $E_1$ | 4.0 | 6.2 | 3974 | 5183 | 3.7 | 6.4 | 3717 | 5221 |
| | $E_2$ | 7.8 | 10.1 | 5480 | 5794 | 7.3 | 10.5 | 5403 | 5835 |
| | $E_3$ | 10.5 | 12.9 | 5844 | 6096 | 10.2 | 13.6 | 5803 | 6175 |
| **6S** | $E_1$ | 8.6 | 9.9 | 6400 | 6670 | 8.6 | 9.9 | 6400 | 6670 |
| | $E_2$ | 14.2 | 16.1 | 7588 | 7995 | 14.2 | 16.1 | 7588 | 7995 |
| | $E_3$ | 18.7 | 20.7 | 8509 | 8747 | 18.7 | 20.7 | 8509 | 8747 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **9S** | **$E_1$** | 11.6 | 13.2 | 7297 | 8005 | 11.6 | 13.2 | 7297 | 8005 |
| | **$E_2$** | 18.9 | 21.5 | 9130 | 9513 | 18.9 | 21.5 | 9130 | 9513 |
| | **$E_3$** | 25.0 | 27.6 | 10027 | 10419 | 25.0 | 27.6 | 10027 | 10419 |

## Performance Assesment

In this final phase of the procedure the seismic demands, at both global and local levels, computed in the previous steps are compared with acceptable levels of damage for various performance states. Ultimately, the objective of a seismic evaluation is to identify deformation demands in structural components during an earthquake and whether these demands will exceed the capacity of the element. The drifts are the key elements to build on for performance assessment. The inter-story drift ratio is determined from the drifts and the maximum Inter-story drift ratio is concluded then from them. The latter is compared with the deformation limits mentioned in ATC and FEMA documents for assessment. Figures 7a-d and Figures 8a-d show the drifts and the inter-story drift ratio for the buildings.

**Figure 7a.** *Drifts of the Three Story Buildings According to FEMA 356*



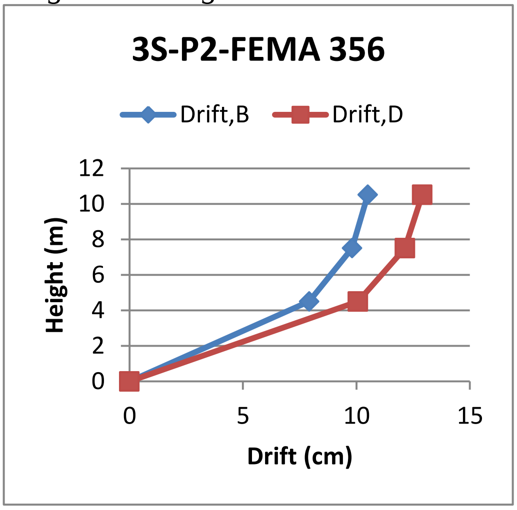



**Figure 7b.** *Drifts of the Three Story Buildings According to FEMA 440*

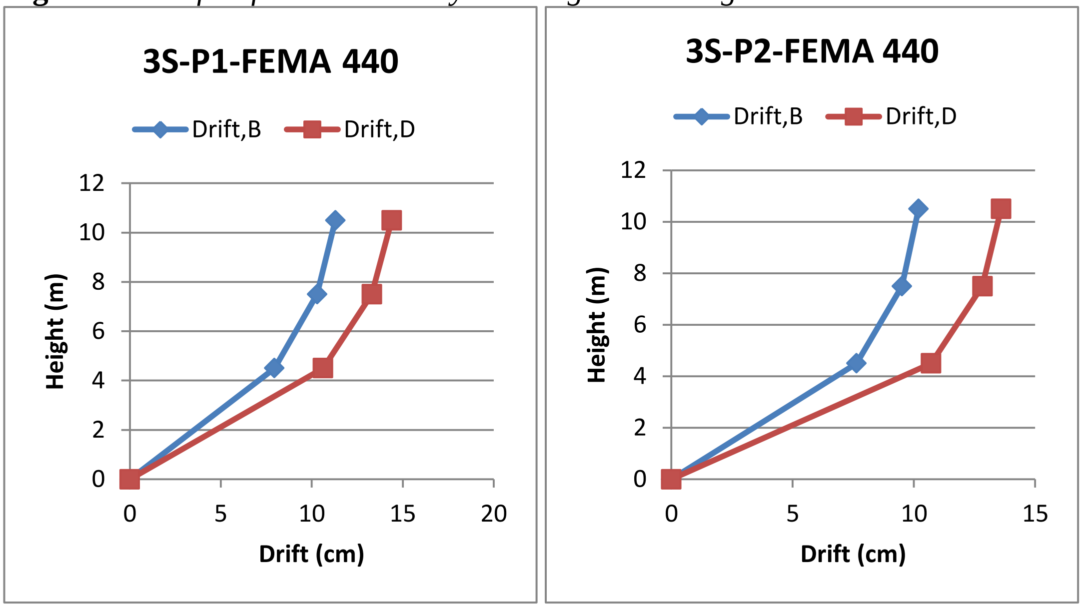



**Figure 7c.** *Drifts of the Six Story Buildings According to FEMA 356*

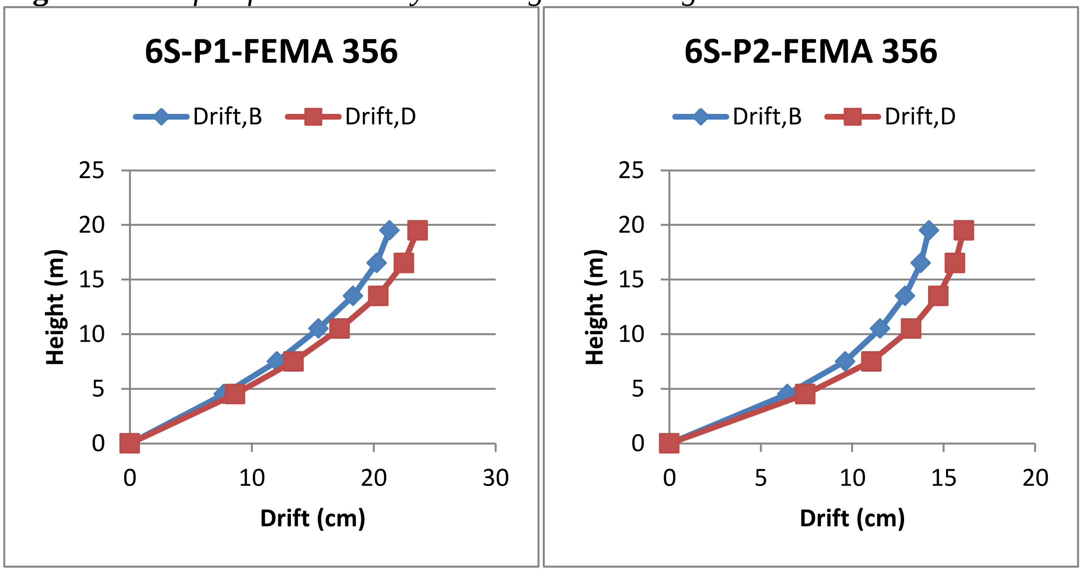


**Figure 7d.** *Drifts of the Nine Story Buildings According to FEMA 356*

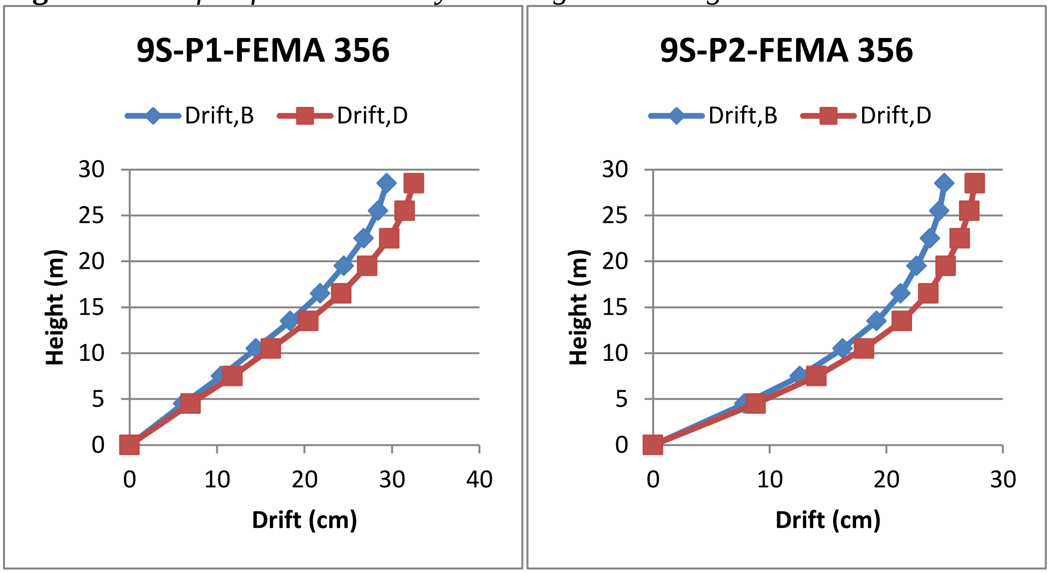



**Figure 8a.** *The Inter-story Drift Ratio for the Three Story Building According to FEMA 356*

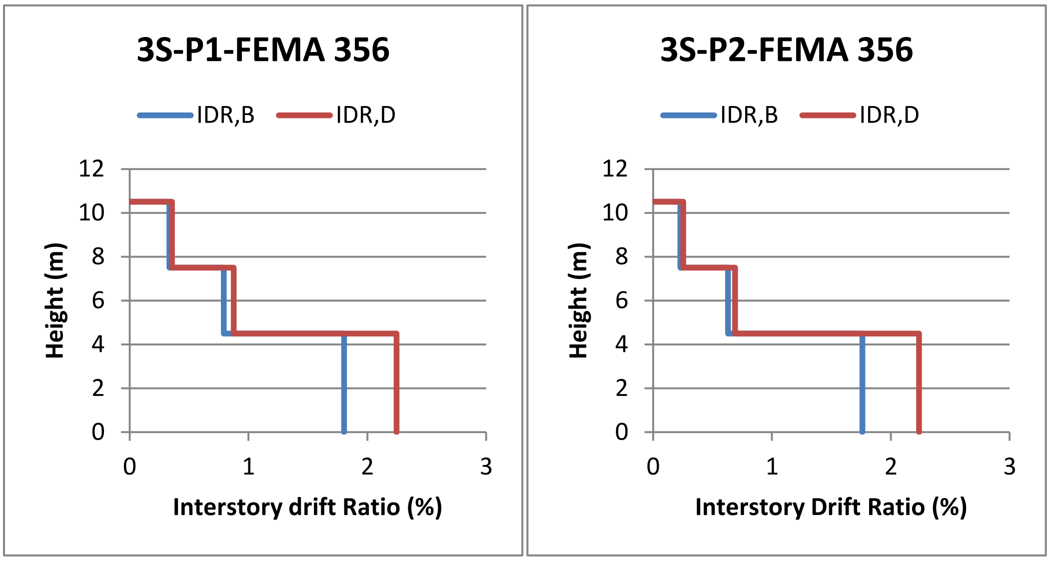


**Figure 8b.** *The Inter-story Drift Ratio for the Three Story Building According to FEMA 440*

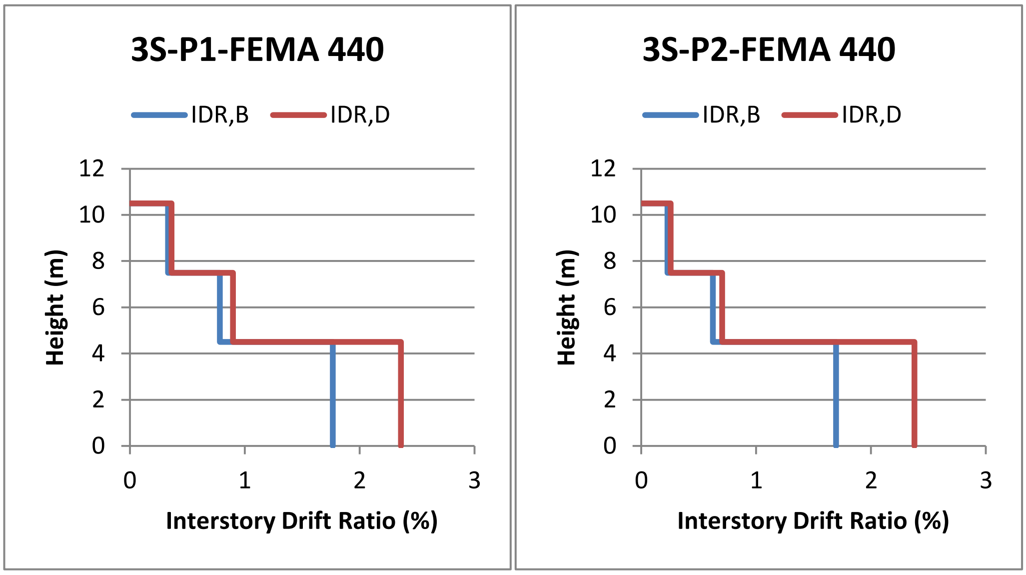



**Figure 8c.** *The Inter-story Drift Ratio for the Six Story Building According to FEMA 356*

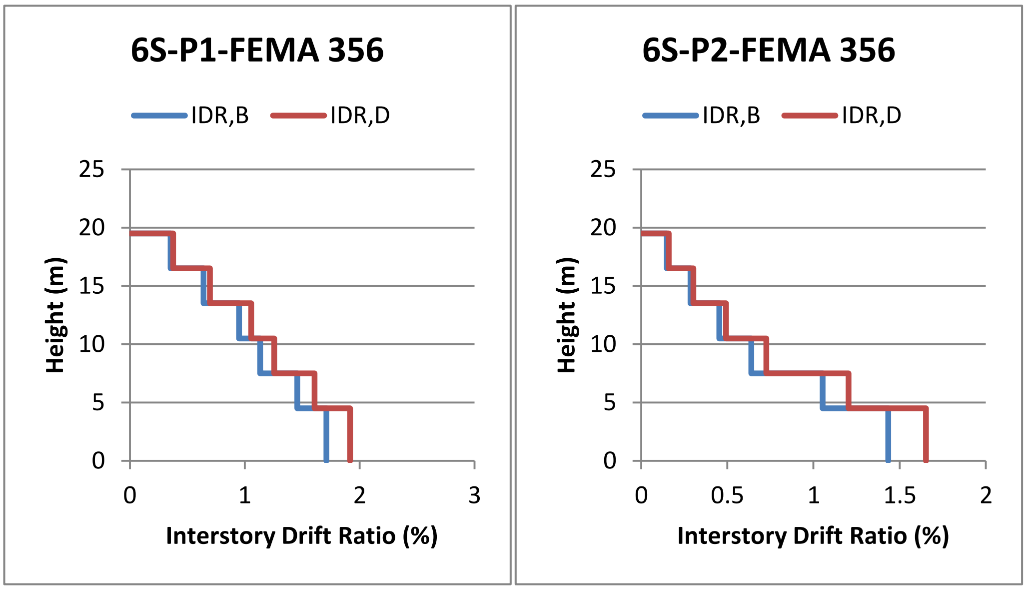
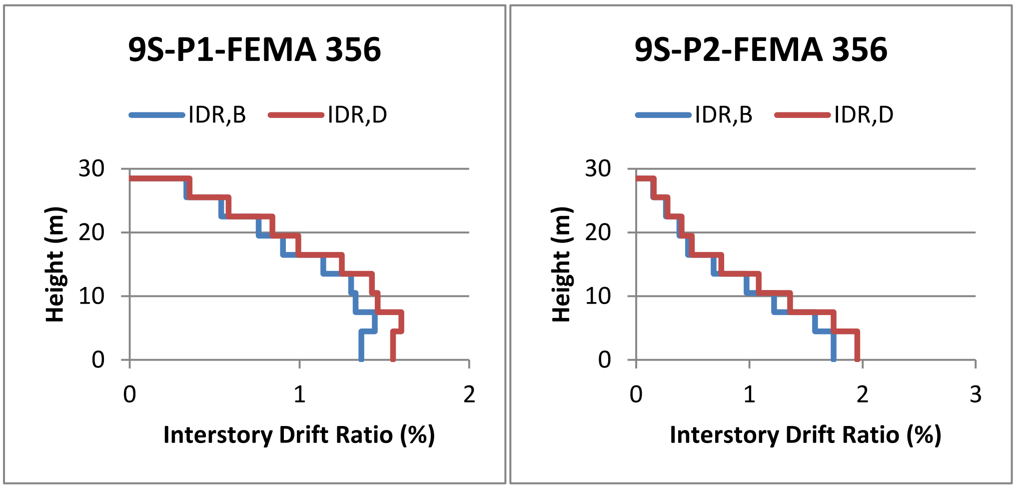


**Figure 8d.** *The Inter-story Drift Ratio for the Nine Story Building According to FEMA 356*




It is clear from Tables 3a-b, Figures 7a-d and Figures 8a-d that the drifts the inter-story drift ratios (IDR) are higher for Dehok zone compared with Baghdad zone. Although P1 pattern yields higher values for the IDR, P2 pattern accentuates IDR of the soft story in the first level. For this reason P2 is more suitable for exploring buildings having soft stories.

The DCM of both versions yielded the same seismic demands for buildings with periods more than 1 second. It has no effect on the 6S and 9S Buildings with periods of 1.208 and 1.606 seconds, respectively. The 3S building yielded different seismic demands for using DCM of both versions. The period for the 3S building is 0.785 second. Table 4a, shows the roof drift ratios while Table 4b, shows the Interstory drift ratios for the buildings under seismic hazard level E3.

**Table 4a.** *The Roof Drift Ratio for Seismic Hazard E3*

| Type of Building | No. of Stories | Baghdad Zone | | | | Dehok Zone | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | P1 | | P2 | | P1 | | P2 | |
| | | FEMA 356 | FEMA 440 | FEMA 356 | FEMA 440 | FEMA 356 | FEMA 440 | FEMA 356 | FEMA 440 |
| **T1S** | **3S** | 1.10 | 1.08 | 1.00 | 0.97 | 1.31 | 1.37 | 1.23 | 1.30 |
| | **6S** | 1.09 | 1.09 | 0.73 | 0.73 | 1.21 | 1.21 | 0.83 | 0.83 |
| | **9S** | 1.03 | 1.03 | 0.88 | 0.88 | 1.14 | 1.14 | 0.97 | 0.97 |

**Table 4b.** *The Maximum Inter-Story Drift Ratio for Seismic Hazard E3*

| Type of Building | No. of Stories | Baghdad Zone | | | | Dehok Zone | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | P1 | | P2 | | P1 | | P2 | |
| | | FEMA 356 | FEMA 440 | FEMA 356 | FEMA 440 | FEMA 356 | FEMA 440 | FEMA 356 | FEMA 440 |
| **3D** | **3S** | 1.81 | 1.77 | 1.76 | 1.70 | **2.25** | **2.36** | **2.24** | **2.38** |
| | **6S** | 1.71 | 1.71 | 1.43 | 1.43 | 1.92 | 1.92 | 1.65 | 1.65 |
| | **9S** | 1.44 | 1.44 | 1.75 | 1.75 | 1.60 | 1.60 | 1.95 | 1.95 |

## Performance Levels of the RC Buildings

For the three seismic hazard levels the inter-story drift ratios (IDR) for each story are determined for each building configuration pushed until the related maximum displacement demand is achieved. Performance levels of the buildings are determined by comparing the maximum plastic rotation and story drift values with the relevant limit values relating to performance levels (IO, LS, and CP) defined in ATC 40 [3].

Considering the results obtained performance levels of each building configuration can be expressed as follows:

1. For levels E1—It is determined that performance of every modeled building, is better than the IO performance level, actually it is nearer to the first yield point (FYP).
2. For level E2—It is determined that the performance levels of all buildings, for all the cases, are between FYP and IO.
3. For level E3—It is determined that the performance level of all buildings is between IO and LS, except for the 3S building in Dehok zone where the cases exceeded the LS although below CP. Those cases are shown bold in Table 4b, where IDR is more than 2.

## Comparison of Seismic Demands for the Two DCM Versions

In order to compare the structural and nonstructural response demands obtained from the two DCM versions, seismic response quantities related to the RC building configurations are determined and compared to each other by considering various parameters. The roof drifts and shear strength demands obtained from DCM of FEMA 356 and FEMA 440 for each building are shown in Tables 3. The results show that the investigated DCM versions give considerable different displacement demands, for the 3S building where the period is less than 1 second. It is found that there was no difference from using either version for 6S and 9S buildings where the period is more than 1.

## Performances of RC Buildings Designed According to ISC

Each building performance is evaluated by comparing performance results with the performance objectives of the ISC 1997. The comparison suggests these observations:

1. For all buildings, each one has shown much better performance than the stipulated level for low-intensity (E1) and somewhat better performance than the stipulated level for the design earthquake (E2) and the maximum (E3).

2. For the identical, peer, cases the demand values for Baghdad zone are always lower than those for Dehok zone.
3. The P1 pattern of the equivalent seismic load distribution always produces higher values for the displacement demands than the P2 pattern of uniform load, while lower values for strength demands.

## Conclusions

This study investigated performance of the multi-story RC buildings designed according to the IBC and reviewed the performance objectives defined in the ISC. There are two purposes of this study the first is to assess the performance objectives defined in the Iraqi Seismic Code (ISC) in order to make a realistic evaluation related to Performance Based Seismic Design (PBSD) of multi-story reinforced concrete buildings and the second is to compare and evaluate structural response demands obtained from nonlinear static analysis procedures according to two versions of the displacement coefficient method (DCM) which are recommended in FEMA 356 and FEMA 440.

A group of regular RC residential buildings, having different number of stories (3S, 6S, & 9S) are adopted in this research. Twenty four performance points were determined and evaluated for each building due to two different load patterns (P1 & P2), three seismic hazard levels (E1, E2, & E3) for two Iraqi seismic zones (Baghdad & Dehok), and according to the two versions of DCM.

The results obtained after investigating the 72 study cases are summarized as follows:

1. It is found that the performance objectives stated in Iraqi Seismic Code (ISC) for low intensity, design, and maximum earthquake hazard levels are accomplished to a great magnitude. In summary, it is determined that the investigated buildings will not collapse in earthquakes in Iraq. If properly designed and constructed, they will have met, even better, performance objectives stipulated in the (ISC).
2. Effects of different DCMs in performance evaluations of the buildings are investigated in terms of several parameters. The structural response demands (displacement, strength, and interstory drift demands), obtained by using the DCM of FEMA 356 and FEMA 440, are compared and evaluated thoroughly. The results can be summarized as follows:

    a. It is found that adopting of the two different DCMs yield different seismic demands and may yield different performance state, only for the 3S building where the period is less than 1 second.
    b. When the period is more than 1 second, as the case for the 6S and 9S buildings, it is found that no differences existed neither

in seismic demands nor in performance states from adopting any of the two DCM versions.

## Notation

The following symbols are used this paper:

$S_S$, $S_1$ site seismic coefficients to describe the standard elastic site response spectra

D: dead load;
e: eccentricity;
E: earthquake load;
$h_i$, $h_j$ the heights of the i-th and j-th floors from the top of the foundation;
$h_0$ constant story height in a building;
H height of the building;
L live load;
$IDR_i$ inter-story drift ratio of story i of the building;
RDR roof drift ratio of the building;
N total number of levels;
$T_1$ fundamental vibration period in the direction under consideration;
V total horizontal seismic shear force;
$V_i$ seismic design force in the i-th level;
$V_b$ base shear force of the building;
$W_i$ , $W_j$ the i-th and j-th floor weights;
$\alpha_1$ modal mass coefficient for the first natural mode;
$\delta_{max}$ displacement demand of building;

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