Seismic Effects on Structures Located in the Region of Palestine: A Critical Review on International Building...

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Fahed Salahat
Palestine Polytechnic University
2 PUBLICATIONS 0 CITATIONS

Pedro Martinez-Vazquez
University of Birmingham
31 PUBLICATIONS 56 CITATIONS

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Seismic Effects on Structures Located in the Region of Palestine

A Critical Review on International Building Regulations

F.H. Salahat, P. Martinez-Vazquez

***Abstract* - A qualitative assessment of seismic effects on a regular building located in Palestine is presented. The assessment is based on two distinct approaches, one by following recommendations from the International and Uniform Building Codes (IBC and UBC) and the other using response spectra inferred from international historical records whose level of seismicity compares to those in Palestine. The study shows that both the IBC and UBC tend to underestimate the maximum response of structures whose fundamental period of vibration falls between 0.1s and 3s. The difference reduces gradually for periods above 3s. The rate of underestimating the seismic effects varies with the fundamental period of vibration of the structure and its distance from the Dead Sea Fault Line, but it can be up to ~ 50%. It thus appears necessary to address such differences by taking into account local seismic conditions in the region of Palestine through a new local design code.**

***Keywords*—seismic response of buildings, response spectra, time history analysis, international standards.**

I. Introduction

In developing countries the impact of strong earthquake events on infrastructures is as important as the phenomenon itself. As a developing country, Palestine has limited resources to deal with emergencies caused by such a naturally occurring phenomenon. Therefore, mitigating earthquake risks should be done by correctly evaluating the seismic loads and improving current design practices. In addition to other measures that involve the retrofit of old structures, urban development and contingency plans. Structural resilience to earthquake events depends on the accuracy in estimating the seismic demand and so the structural response. The use of response spectra is the most common method to estimate the seismic demand and accordingly design earthquake-resisting infrastructures in Palestine and elsewhere.

This paper considers the use of some of the adopted design codes, namely: the Uniform Building Code (UBC) and the International Building Code (IBC), and their suitability to represent the seismic demand in Palestine using the response spectrum analysis method.

F.H. Salahat
University of Birmingham
United Kingdom
fahedsalahat@yahoo.com

P. Martinez-Vazquez
University of Birmingham
United Kingdom
P.Vazquez@bham.ac.uk

II. Development of local response spectra

A. Selecting representative earthquakes

Linear and nonlinear dynamic analysis for seismic design and evaluation of structures require seismic loads to be represented either by a response spectrum or time history records. In this paper, a response spectrum is developed based on the maximum response of a SDOF oscillator subjected to time history acceleration records. The acceleration records were selected based on three criteria that define their compatibility with the local seismicity in Palestine.

The factors for selecting representative records are the magnitude (M) and the distance from the geological fault (R) acting as the source of seismic waves [1], in this study, the soil type (S) is used to account for the local seismicity in the region. Therefore, an M-R-S relationship is used to select acceleration records for earthquake events that have occurred in different places in the world and which are likely to reproduce in Palestine.

The magnitude (M) was set to the range of 6.0-7.5 in Richter scale in order to consider the maximum seismic demand that was experienced in the region according to the available earthquake catalogue, which was used to develop the currently used seismic hazard map [2]. Palestine is located in the area that is adjacent to the Dead Sea Fault Line (See Figure 1), the distance from the fault is considered normal to tangent of the fault line and it covers 74 km on average all over the country. Therefore, R falls within the range 0-74 km. while previous studies [3] show that the shear velocity through the soil media has a range of 500-1500 m/s which corresponds to soil type S_C-S_B according to the UBC soil classification system.

Based on the selection criteria described above, ten earthquake acceleration records were downloaded from the Pacific Earthquake Engineering Research Centre (PEER) ground motion data base [4] and selected to represent the local seismic demand in Palestine, the characteristics of the earthquakes are presented in Table 1 – where g represents the gravitational constant.

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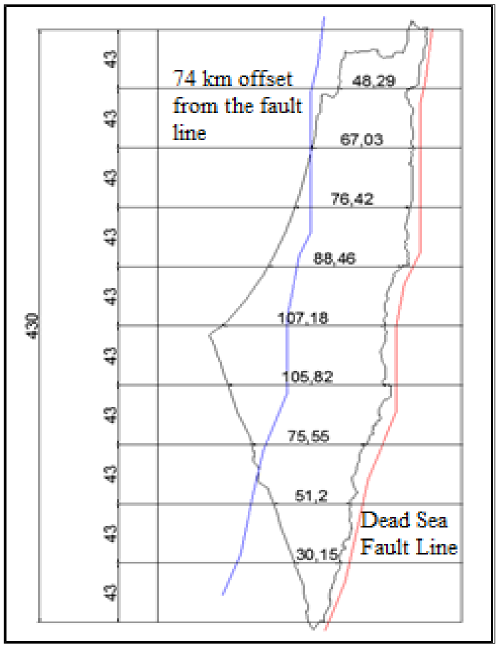

Figure 1: Determination of (R) range

Table 1: The representative earthquake events

ID	Event name	Date	M	PGA (g)	R (km)
1	Parkfield–California	28-06-1966	6.1	0.375	14.7
2	Morgan Hill- San Francisco	24-04-1984	6.2	0.292	11.8
3	Victoria - Mexico	09-06-1980	6.4	0.621	34.8
4	Imperial Valley – California	15-10-1979	6.5	0.204	14.2
5	Superstition Hills – California	24-11-1987	6.7	0.455	0.7
6	Kobe - Japan	16-01-1995	6.9	0.821	0.6
7	Duzce - Turkey	12-11-1999	7.1	0.134	15.6
8	Gulf of Aqaba – Palestine	22-11-1995	7.2	0.100	44.1
9	Landers – California	28-06-1992	7.3	0.785	1.1
10	Kocaeli – Turkey	17-08-1999	7.4	0.220	4.8

Typically, two horizontal components and one vertical component are recorded for an event. However, for each of the records that are shown in Table 1, the largest horizontal component in terms of the peak ground acceleration (PGA) was considered whilst vertical component of the seismic motion was neglected. All the records are considered to cause vibration in the same direction.

B. *Spectral representation of the selected records*

SDOF oscillators characterised by vibration periods in the range of 1-10s and 5% damping were subjected to the seismic records described above. The period of the oscillator was modified by varying the structural mass (see Figure 2). The increment of the period dT was 0.1s until T=1s, thereafter an increment dT of 1s applied until T=10s.

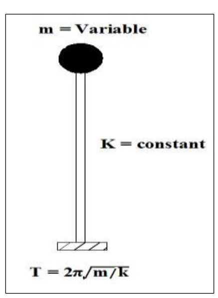

Figure 2: SDOF oscillator

The maximum elastic displacement (MED) response of the oscillators for each of the ten earthquakes was obtained by using SAP2000 [5]. Then the displacement response was converted to acceleration using Equation 1.

$$S_a = (2\pi/T)^2 \cdot S_d \qquad (1)$$

Where:

S_a: The spectral acceleration

S_d: The spectral displacement

T: The period of vibration.

Figure 3 shows the spectral accelerations estimated for the ten selected earthquakes.

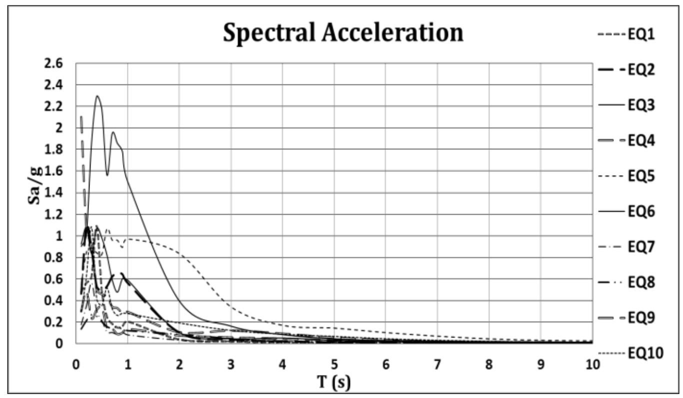

Figure 3: The spectral accelerations for the ten earthquakes

It is observed in Figure 3 that response spectra cover a wide range of spectral ordinates. Therefore two groups of spectra are distinguished, the first includes earthquakes within and beyond 5 km from the fault (all the records) to represent near fault seismicity. The seconds includes earthquakes beyond the 5 km border (earthquakes 1, 2, 3, 4, 7 and 8 – see Table 1) to represent the lower seismicity region. Figure 4 shows the average spectra estimated for each one of these groups together with their idealised version. M1 represents the mean spectrum of the first group, which is idealised as IM1 whilst M2 represents the mean spectrum of the second group which is idealised as IM2.

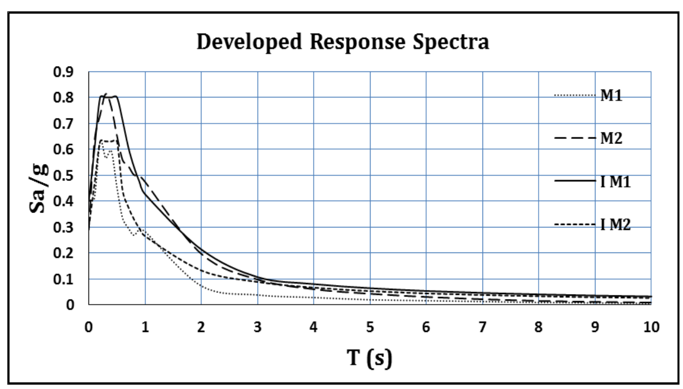

Figure 4: The mean response spectra with their idealisation

Eq. (2) and (3) define the idealisation of IM1 and IM2.

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$$IM1\begin{cases} 0 \le T \le 0.2 \rightarrow & Sa/g = 0.4 + 2T \\ 0.2 \le T \le 0.5 \rightarrow & Sa/g = 0.8 \\ 0.5 < T \le 2 \rightarrow & Sa/g = 0.8^2/1.5T \\ T > 2 \rightarrow & Sa/g = 0.8^2/2T \end{cases} \quad (2)$$

$$IM2\begin{cases} 0 \le T \le 0.2 \rightarrow Sa/g = 0.3 + 1.65T \\ 0.2 \le T \le 0.5 \rightarrow \quad Sa/g = 0.63 \\ T > 0.5 \rightarrow \quad Sa/g = 0.63^2/1.5T \end{cases} \quad (3)$$

Note that at T = 0, Sa/g is taken as the average PGA for the considered earthquakes (0.4 for M1 and 0.29 for M2).

III. The currently adopted code response spectra in Palestine

A. *UBC and IBC response spectra*

The UBC97 [6] and IBC09 [7] response spectra are the most popular codes of practice in Palestine. The UBC response spectrum is shown in Figure 5.

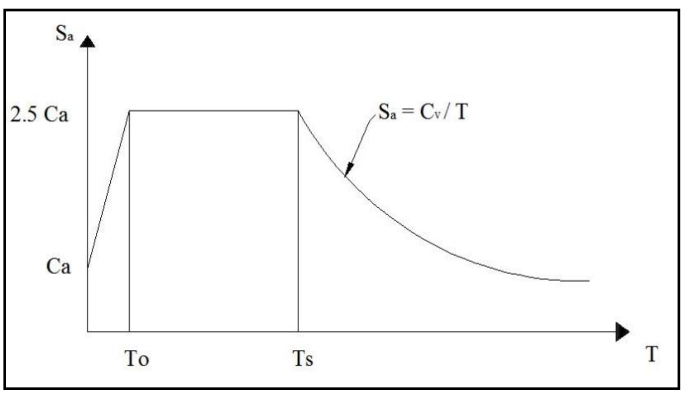

Figure 5: UBC 97 design response spectrum

Where:

$T_S = C_V/2.5\ C_a$

$T_o = 0.2\ T_S$

T = Fundamental period of Vibration

The parameters C_a and C_V depend on the seismic zone factor (Z) and the soil type (S) [8]. In Palestine the value of Z is taken as 0.2 and the soil type is considered as S_B. For Z of 0.2 and soil type S_B, the values for C_a and C_V are 0.2 and 0.2 respectively. Similarly, the IBC response spectrum also depends on the site seismicity and the soil type. In the next section, the UBC97 and the IBC09 spectra are presented and compared with the IM1 and IM2 response spectra i.e. those inferred from the real time history records.

B. *Comparing IM1, IM2 response spectra with the UBC and IBC spectra*

Figure 6 compares the UBC97 and IBC09 response spectra with the developed IM1 and IM2 response spectra for 5% damping.

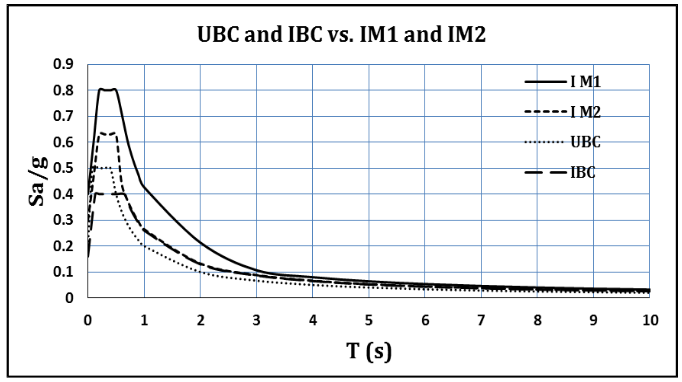

Figure 6: Comparing the adopted design response spectra with IM1 and IM2

The comparison amongst the spectra presented in Figure 6 will be done by considering different period ranges. The ordinates of the short period range are presented in Table 2.

Table 2: Comparison of the spectral ordinates for various values of T

	UBC	IBC	IM1	IM2	$\frac{UBC}{IM1}$	$\frac{UBC}{IM2}$	$\frac{IBC}{IM1}$	$\frac{IBC}{IM2}$
Period (s)	Sa/g				$x\ 10^2$			
T = 0	0.2	0.16	0.4	0.29	50	69	40	55.2
T = 0.1	0.5	0.345	0.6	0.465	83.3	107.5	57.5	74.2
T=0.2-0.4	0.5	0.4	0.8	0.63	62.5	79.4	50	63.5
T = 0.5	0.4	0.4	0.8	0.63	50	63.5	50	63.5

From Table 2 it can be observed that both UBC and IBC response spectra underestimate the local earthquake demand in the period range of 0-0.4s except at T= 0.1s when the UBC ordinate slightly exceeds that of IM2. The differences are clearer on sites within 5km from the fault line. The UBC and IBC recommend using peak spectral accelerations (PSA) of 0.5g and 0.4g respectively. This represents 62.5% (UBC) and 50% (IBC) of the PSA in IM1 and correspondingly 79.4%, 63.5% of the PSA in IM2. The UBC is closer to IM1and IM2 than the IBC in this period range. At T = 0.5s, the UBC equals the IBC ordinates at PSA of 0.4g which represents 50% and 63.5% of IM1 and IM2 respectively. After T = 0.5s, the IBC ordinates become closer than the UBC and almost match IM2. However, for the near fault sites represented by IM1 differences remain significant until about T=3s.

IV. Case studies

In the previous sections it was pointed out that applying the UBC and IBC regulations in Palestine results in underestimating the local seismic demand. This section considers the effect of such underestimation by observing the

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maximum storey drift of 5% damped reinforced concrete buildings that were analysed by using SAP2000. Four case studies are considered for that purpose. These are characterised by having periods of vibration of 0.4s, 0.5s, 1.5s, and 3s. The selected range would cover all possible scenarios of incompatibility amongst the international building codes and the spectra derived from historical data. The general characteristics of the building model with T=1.5s are shown in Table 3 whilst Figures 7 and 8 show a plan and 3D view of the model respectively.

Table 3: Characteristics of the building model with T = 1.5 s

Model properties	Description
Structural system	Dual (frames + shear walls)
Number of storeys	6
Storey height (m)	4
Number of bays in each direction	3
Bay width (m)	5.35
Columns section (cm)	45x45
Beams section (cm)	30x40
External shear walls section (cm)	200x30
Internal shear walls section (cm)	150x20
Non-structural mass (Kg)	613938

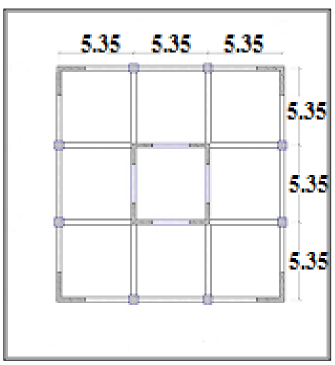

Figure 7: Plan view of the model

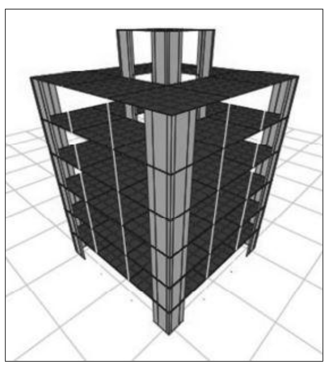

Figure 8: The 3D model

The following section discusses the results of the analyses.

Case 1: T = 0.4 seconds (Figure 9).

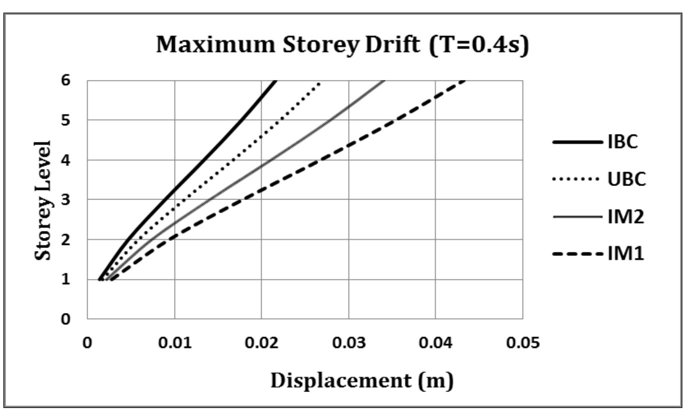

Figure 9: Maximum storey drift of the model with T=0.4 s

Figure 9 shows that both the IBC and UBC codes underestimate the local seismic demand. At the 6th storey, the IBC and UBC induce a maximum elastic displacement (MED) of about 2.2, 2.7 cm respectively whereas using the IM2 and IM1 the MED at the 6th storey is of 3.4, 4.3 cm respectively. Thus for locations beyond 5 km from the fault line, the estimated MED associated to the IBC and UBC response spectra are of about 64% and 80% of the IM2 respectively i.e. the UBC provides a closer approximation for Case Study 1. However, if this building model is located within 5 km from the fault line, the proportion between IBC and UBC with respect to IM1 becomes 51% and 63% respectively, i.e. the underestimation becomes more critical near fault sites. These results are consistent with the differences amongst spectral ordinates presented in Table 2.

Case 2: T = 0.5 seconds (Figure 10).

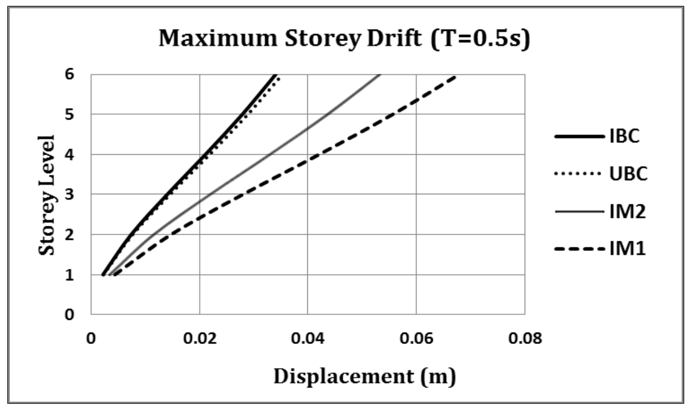

Figure 10: Maximum storey drift of the model with T=0.5 s

Figure 10 suggests that there is compatibility between the IBC and UBC ordinates when T=0.5s and shows that their approach tends to underestimate the MED when compared to IM1 and IM2. At the 6th storey, IM1 and IM2 result on MED of 6.8cm and 5.3cm respectively, whereas the IBC and UBC give 3.5 cm. this represents ~51% compared to IM1 and 66% compared to IM2 results which again are consistent with the spectral ordinates presented in Table 2.

Case 3: T = 1.5 seconds (Figure 11).

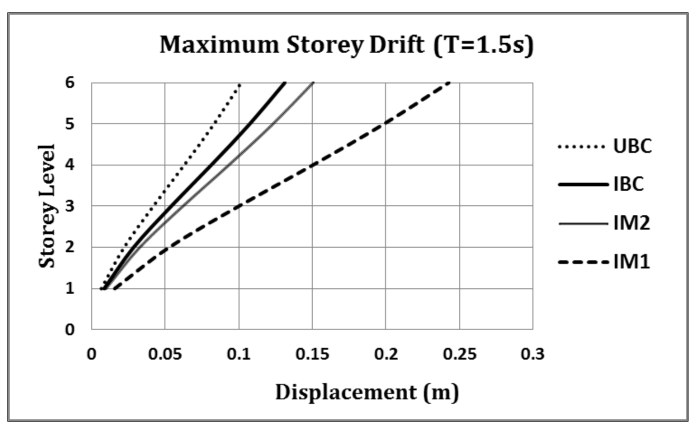

Figure 11: Maximum storey drift of the model with T=1.5 s

Figure 11 shows that the IBC and UBC still underestimate the MED; however, the underestimation is less critical when

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T=1.5s. The MED at the 6th storey by IBC and UBC is 13.1cm and 10.1cm respectively; which translates into 87.3% and 67.3% of the MED (15cm) given by the IM2. If the same comparison is done against IM1 results (MED=24.3 cm), the percentage of UBC/IM1 and IBC/IM1 are of 54% and 41.5% respectively. This shows that for T=1.5s the IBC provides the better approximations. However, the differences are still considerable.

Case 4: T = 3 seconds (Figure 12).

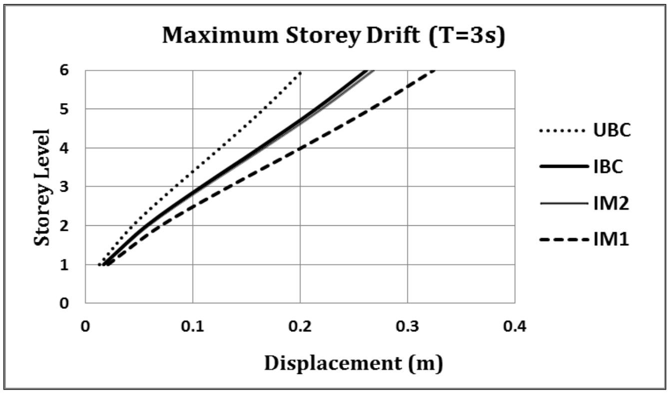

Figure 12: Maximum storey drift of the model with T=3 s

In this case the differences between IBC and IM2 are small whilst UBC results still underestimates the MED given by IM2. At the 6th storey, the ratios UBC/IM2 and UBC/IM1 are of 0.77 and 0.63 respectively whereas the ratios IBC/IM2 and IBC/IM1 are of 0.98, 0.82. Thus, although UBC approaches to IM1 and IM2 as T increases the rate of variation is slower than that of the IBC which gives the best estimation after T=0.5s.

V. Conclusion

The various analyses show that the current design practice in Palestine, which follows recommendations by the UBC and IBC, underestimate the structural response of buildings whose period of vibrations falls within the range 0.1s-3.0s. The rate of variation changes with the natural period of vibration and distance to the fault parameter. The analyses show that compared to response spectra derived from real earthquakes records, the UBC gives a better estimation than the IBC in the period range of 0.0-0.4s. Whereas the displacement demand given by the IBC and UBC match at T=0.5s. For T>0.5s the IBC consistently provides the best approximation to the real spectral case. It is important to note that the majority of the current infrastructure in Palestine includes low to medium rise buildings, i.e. structures whose fundamental period fall within the critical period region (0.1s-3.0s) as derived from this analysis. Therefore given the possibility that earthquake events of a magnitude of 6.0-7.5 in the Richter scale or above may hit the region makes it necessary to ponder the amount of risk that underdeveloped countries can accept, given the limited resources and strategic plans that are currently in place to deal with natural disasters caused by earthquakes.

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[8] Table 16-Q and Table 16-R in UBC1997

About Authors:

	Fahed H. Salahat, MSc. Civil Engineering. Research interests include: Earthquake Engineering and computer applications, performance-based seismic design and assessment.
	Dr P. Martinez-Vazquez. Research interests include random vibrations, artificial intelligence, image recognition techniques, structural analysis, and structural design