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COMPARATIVE SEISMIC STUDY BETWEEN ALGERIAN CODE (RPA99), EUROPEAN CODE (EC8) AND AMERICAN CODE (UBC97)

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ABSTRACT

Earthquake codes have been performed on the design spectra. In this paper, the design spectra recommended by Algerian Code, Uniform Building Code 97, and Eurocode 8, are considered for comparison. The main purpose of this study is to investigate the differences caused by the use of different codes in the dynamic analysis and seismic verification of a 10 story building located at code defined different sites. The differences in expressions and some important points for elastic and inelastic spectra defined by the codes are briefly illustrated in tables and figures. Base shears, lateral displacements of floors for the analyzed building located at code defined ground type are comparatively presented.

INTRODUCTION

The first version of the Algerian seismic code which calls “Algerian earthquake resistant regulations”, was RPA 81, it was modified to RPA88, and then to RPA99. Unfortunately, the May 21st 2003 destructive Boumerdes earthquake ($M_w = 6.8$) occurred in Algeria, and resulted in more than 2.000 caused deaths and 11.000 injuries. More than 100.000 buildings were heavily damaged and some 13.300 others totally collapsed. All these results led to a partial revision of the RPA99 which became RPA99 version 2003.

It has become recognized that the local site conditions have a very important role on the response of structures. The soil and rock at a site have specific characteristics that can significantly amplify the incoming earthquake motions traveling from the earthquake source. The importance of local site conditions was recognized in the 1960s by the influence of ground motions on midheight buildings in the Caracas, Venezuela earthquake. For buildings of about the same height with similar construction, it was observed that such buildings founded on deep soils were more damaged than the similar buildings founded on rock. The seismic codes take into account site effects by introducing different categories of sites. The Uniform Building Code (UBC) acknowledged the importance of local site effects and the concept of a “Soil Factor” was added to the lateral force design procedure in the 1976 edition of the UBC, and after many changes were made in defining soil factor and soil types, the last version defines six soil types.

The Eurocode8 defines five main types of soil and two special types with a soil factor “S” for each type, whereas RPA99/2003 considers four types S1, S2, S3 and S4 without soil factor. The site classification system is based on definitions of mean shear waves velocity, standard penetration test,

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unconfined compression test, and relative density. Borcherdt (1994), recommended shear wave velocity V_{S-30} as a mean of classifying sites for building codes. Boore et al. (1994) indicate that the ideal parameter would be the average shear-wave velocity to a depth of one-quarter wavelength for the period of interest, as was used by Joyner and Fumal (1984). By the quarter-wavelength rule, 30m is the appropriate depth for period of 0.16 s for stiff soil and period values tend to increase as the soil gets softer (Boore et al., 1994). It should be noted that code defined spectra depending on ground types are provided only for cases where the 30m of soil immediately below the site dominates the frequency content of the design motions.

Table 1 shows the different soil types with shear wave velocity defined in the three codes and the values of site factor "S" for spectra type 1 and type 2 of EC8.

Table 1. Ground types defined in EC8, UBC97 and RPA99/2003

Eurocode 8			UBC 97	RPA 99/2003
	Type 1	Type 2		
Soil type A: $V_{s,30}>800$ m/s	S=1	S=1	Soil type A : $V_{s,30}\geq1500$ m/s	Soil type 1 : $V_s\geq800$ m/s
Soil type B : $360<V_{s,30}<800$ m/s	S=1.2	S=1.35	Soil type B: $760\leq V_{s,30}<1500$m/s	Soil type 2 : $400\leq V_s<800$m/s
Soil type C : $180<V_{s,30}<360$ m/s	S=1.15	S=1.5	Soil type C: $360\leq V_{s,30}<760$m/s	Soil type 3 : $200\leq V_s<400$ m/s
Soil type D : $V_{s,30}<180$ m/s	S=1.35	S=1.8	Soil type D: $180\leq V_{s,30}<360$m/s	Soil type 4 : $100\leq V_s<200$ m/s
Soil type E: A soil profile consisting of a surface alluvium layer with $V_{s,30}$ values of class C or D and thick-ness varying between about 5 and 20 m, underlain by stiffer material with $V_{s,30}>800$ m/s	S=1.4	S=1.6	Soil type E: $V_{s,30}<180$m/s	
			Soil type F: Soils Requiring Site-Specific Evaluation	

As seen from Table 1, shear wave velocities for EC8 and UBC97 are taken for a depth of 30 m, whereas for RPA, the depth is 10 to 20 first meters.

Soil types of UBC used in this study are B-C-D-E because these sites are characterized by shear wave velocities close to those of RPA(S1-S2-S3-S4) and EC8(A-B-C-D).

Elastic and inelastic response and design spectra

The response spectrum is an important parameter in the seismic code. The earthquake induced ground shaking is generally represented in the form of acceleration response spectra or displacement response spectra. Earthquake parameters such as soil condition, epicentral distance, magnitude, duration, and source characteristics influence the shape and amplitudes of response spectra. While the effects of some parameters may be studied independently, the influences of several factors are interrelated and cannot be discussed individually. Ambraseys et al. (1996) and Bommer and Acevedo (2004) presented and discussed the effects of earthquake magnitude, source-to-site distance, site classification, and style-of faulting on the strong-motion accelerograms and consequently response spectra. As known, the damping ratio and structural vibration period are other parameters affecting the response spectra.
In all current seismic codes, the earthquake actions are represented in the form of a spectrum of absolute acceleration.

The UBC 97 tried to introduce a new understanding of the amplification of ground motion and considers the effects of near source, factors of near source were introduced (Na and Nv) for long and short periods, respectively, in the seismic zone 4, this change is intended to recognize the amplification of ground motion that occurs at distances close to the source. This is justified by the fact that the recording strong movements in recent powerful earthquakes such as Northridge in 1994 and Kobe in 1995, showed that the ground motion is significantly important near the source of the earthquake.

EC8 defines two types of spectra: Type 1 for the far field and Type 2 for the near field. If the earthquakes that contribute most to the seismic hazard defined for the site for the purpose of probabilistic hazard assessment have a surface-wave magnitude, *Ms* not greater than 5.5, it is recommended that the Type 2 spectrum is adopted, if not, Type 1 is recommended.

RPA99/2003 defines only one type of spectra depending on seismic zone and some other factors according to the building.

The ordinates of elastic design spectra *Se* and *Sd* for EC8, UBC97 and RPA99/2003 are given by their expressions in Table 2.

In Table 2, β shows lower bound factor for the horizontal design spectrum, recommended value for *β* is 0.2.

The periods of elastic design spectra of the three codes depend on soil type.

Seismic hazard is expressed in EC8 by a parameter namely reference peak ground acceleration a_gR at the rock surface for a reference return period. The reference return period recommended for the non-collapse performance level is the 475 year, corresponding to 10% probability of exceedance in 50 years. In EC8 the design ground acceleration is equal to a_gR times the importance factor γI.

The Algerian seismic code subdivided the territory into five zones of increasing seismicity as: Zone 0: neglected seismicity, Zone I: low seismicity, Zones *IIa* and *IIb:* moderate seismicity, Zone III: high seismicity. It defines a coefficient of zone acceleration “A” according to the seismic zone and the using group of the building.

Table 2. Ordinates of elastic and inelastic spectra for EC8, RPA99/2003 and UBC97

Eurocode 8	RPA99/2003	UBC97
$0 \leq T \leq T_B$ $Se = a_g . S[1 + \frac{T}{T_B}(2{,}5 . \eta - 1)]$ $Sd = a_g . S[\frac{2}{3} + \frac{T}{T_B}\left(\frac{2{,}5}{q} - \frac{2}{3}\right)]$	$0 \leq T \leq T_1$ $\frac{Sa}{g} = 1{,}25\ A[1 + \frac{T}{T_1}(2{,}5\eta\frac{Q}{R} - 1)]$	$T \leq T_B$ $Se = (C_a + \frac{1{,}5 C_a T}{T_B}) . g$ $Sd = (C_a + \frac{1{,}5 C_a T}{T_B}) . g . \frac{\gamma_1}{R}$
$T_B \leq T \leq T_C$ $Se = a_g S\ 2{,}5\ \eta$ $Sd = a_g . S . \frac{2{,}5}{q}$	$T_1 \leq T \leq T_2$ $\frac{Sa}{g} = 1{,}25 . A . 2{,}5 . \eta . (\frac{Q}{R})$	$T_B \leq T \leq T_C$ $Se = 2.5 . C_a . g$ $Sd = 2.5 . C_a . g . \frac{\gamma_1}{R}$
$T_C \leq T \leq T_D$ $Se = a_g . 2{,}5 . \eta . S[\frac{T_C}{T}]$ $Sd = a_g . S . \frac{2{,}5}{q}\ [\frac{T_C}{T}] \geq \beta . a_g$	$T_2 \leq T \leq T_3$ $\frac{Sa}{g} = 1{,}25 . A . 2{,}5 . \eta . (\frac{Q}{R}) . (\frac{T_2}{T})^{2/3}$	$T \geq T_C$ $Se = \frac{C_v}{T} . g$ $Sd = \frac{C_v}{T} . g . \frac{\gamma_1}{R}$
$T_D \leq T \leq 4\ s$ $Se = a_g . 2{,}5 . \eta . S[\frac{T_C T_D}{T^2}]$ $T_D \leq T$ $Sd = a_g . S . \frac{2{,}5}{q}\left[\frac{T_C T_D}{T^2}\right] \geq \beta . a_g$	$T \geq 3\ s$ $\frac{Sa}{g}\ 1{,}25 . A . 2{,}5 . \eta . \left(\frac{Q}{R}\right) . \left(\frac{T_2}{3}\right)^{2/3} (\frac{T}{3})^{5/3}$	

The seismic parameters of UBC97: Ca and Cv are determined from the seismic zone factor Z which defines the seismic zone, the UBC97 named five seismic zones *I*, *IIa*, *IIb*, *3* and *4*.

In Table 2, *S* is the soil factor defined in EC8 depending on ground types and *η* is the damping correction factor with a reference value of *η* = 1 for 5% viscous damping.

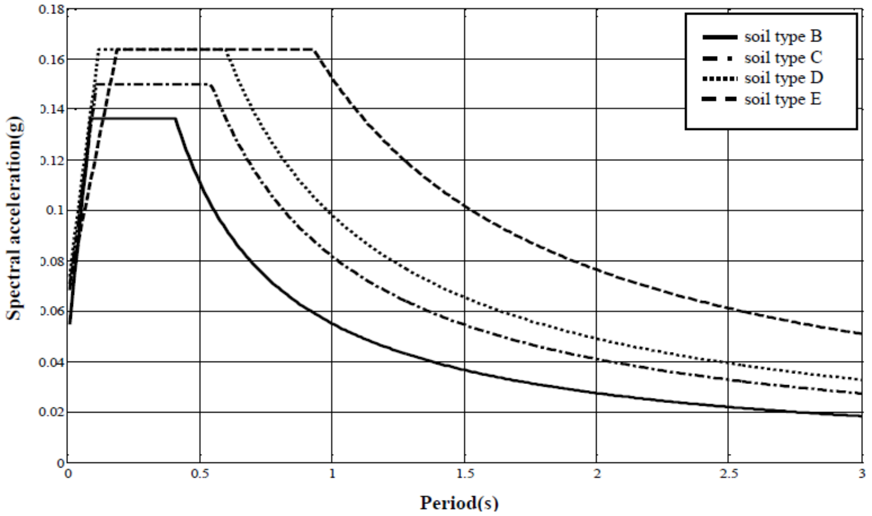

Figure 1. Inelastic design spectra for UBC97

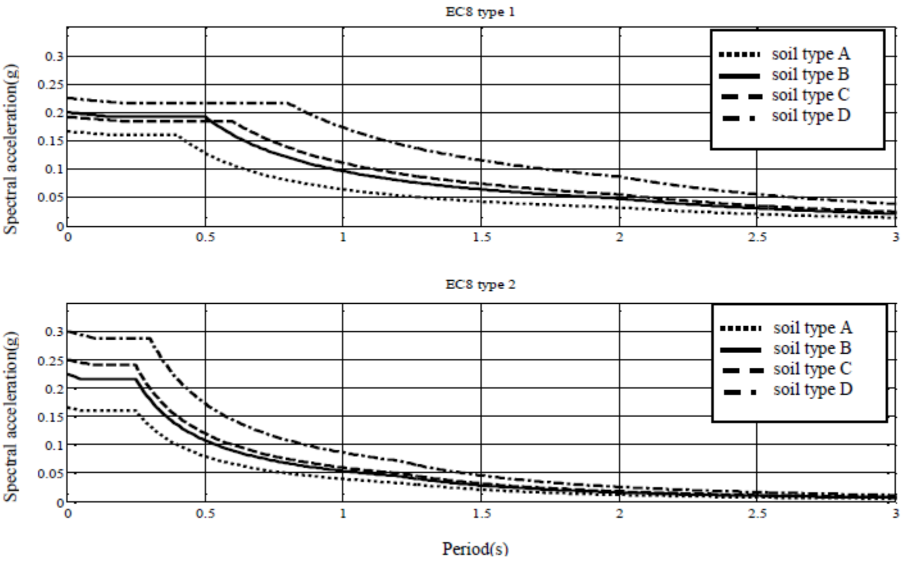

Figure 2. Inelastic design spectra for EC8

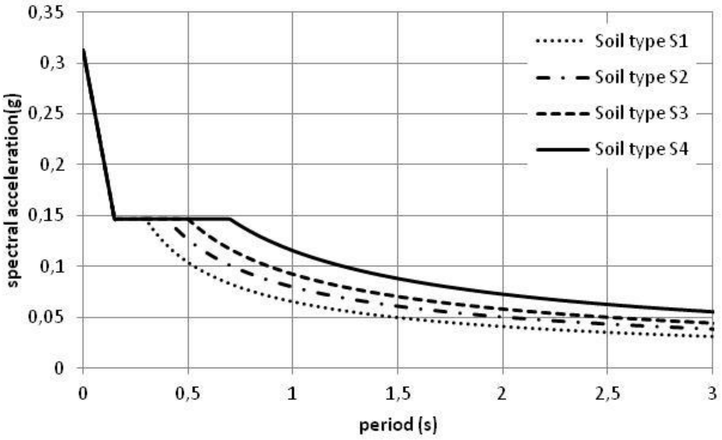

Figure 3. Inelastic design spectra for RPA99/2003

Fig.1 to 3 show inelastic design spectra for UBC97, EC8 (spectra Type 1 and Type 2) and RPA99/2003, they were obtained considering the behavior factor equal to 5,5 for UBC, 3,9 for EC8, and 5 for RPA99/2003, the reference peak ground acceleration is equal to 0.25g.

From these figures, we can see some differences between inelastic spectras of the three codes such as spectral shape, the frequency content, the inclusion of near field and far field (EC8), the behavior factor and soil factors which are defined only in EC8 and UBC97.

As seen from fig.2, the two types of EC8 give the maximum peak values for ground types other than ground type A, and the values of acceleration decrease from 0 to T_B for type 1 and type 2. EC8 type 2 gives maximum accelerations for very soft soil D and for periods between T_B and T_C. For RPA, the trend of the graph shows that for all ground types, the values of acceleration decrease for periods 0 to T_1, then tend to be constant for periods between T_1 and T_2, it has the same stage for all ground types, and this is because of the non consideration of soil factor, and finally decrease from T_2, for UBC 97, acceleration increases for periods 0 to T_B, then it becomes constant between T_B and T_C, for periods greater than T_C, acceleration decreases.

Finite element modelling of building

The structure studied here is a 10 story mixed moment resistant frame-shear walls. The building height is 38.08 m, the two first stories height is 4.08 m and the other ones 3.74 m. The plan dimensions of the first and second floor are: 33 m by 38.4 m, and 22.2 m by 28.10 m for the other ones.

To evaluate the seismic response of the building, elastic analyses were performed by the response spectrum method using the computer program SAP2000. The seismic analyses of the building are carried out separately in the longitudinal and the transverse directions. However, seismic responses only for x direction are comparatively presented with graphs and tables in this paper for the sake of brevity. Sample finite element model is shown in fig.4.

Degrees of freedom at the base nodes are fixed, for other nodes are left free. Therefore, there is no finite element model for subsoil to consider soil-structure interaction. Columns and beams are modeled with frame elements, structural walls are modeled with shell elements. Slabs have been considered as a rigid diaphragm in each story level. In the analysis, Young’s modulus and unit weight of concrete are taken to be 32000MPa and 25 KN/m^3, respectively. The damping ratio is assumed as 5% in all modes. It is assumed that the building is sited in high seismicity zone, so the reference peak ground acceleration is taken to be 0.25 g that is recommended in high seismicity zone (zone 3) in both RPA and UBC97, and the same value is taken for a_g for EC8 to make the comparison.

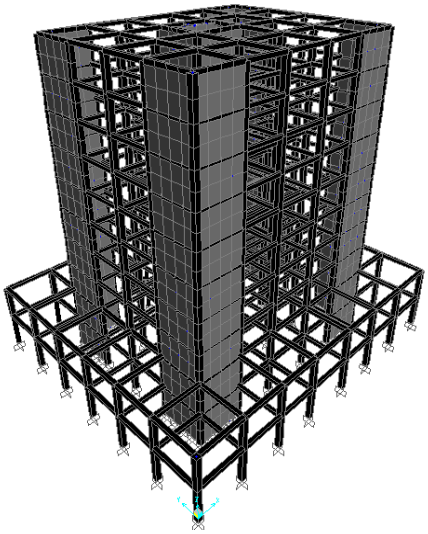

Figure 4. View of three dimensional finite element model of the building

Modal and seismic analysis of the building

The mode number taken into account for this building is 12. The first eight modes with periods and participating mass ratios for the building are presented in Table 3. In the first and second mode the building vibrates respectively in the x and y direction. The third mode takes place as torsional mode.

As Table3 shows, only eight modes give a cumulative sum of the participating ratios greater than 90% for *x* and *y* directions.

Table 3. First eight modes and modal participating ratios of the building

		Individual mode (%)			Cumulative sum (%)		
Mode	Period(s)	Ux	Uy	Uz	Ux	Uy	Uz
1	0,628774	60,757	0,002327	0	60,757	0,002327	0
2	0,612355	0,002335	61,07	0,021	60,759	61,072	0,021
3	0,470333	0,13	0,000007572	0	60,889	61,072	0,021
4	0,147303	24,469	0,0007029	0,000001151	85,359	61,073	0,021
5	0,146465	0,0006903	24,006	0,048	85,36	85,078	0,069
6	0,122867	0,024	0	0	85,384	85,078	0,069
7	0,072354	9,029	0,000001537	0	94,412	85,078	0,069
8	0,071793	0,000001322	9,076	0,014	94,412	94,155	0,084

The base shears of the building and lateral displacements of floors were acquired from seismic analysis using the design spectra corresponding to 5% critical damping and considering fixed base condition. Seismic analyses of building were carried out for four ground types defined in RPA and their equivalent in EC8 and UBC97. Fig.5 presents the base shears of the building.

As seen from Fig.5, base shears become more important for soft soils because of the low fundamental frequency of the building. The results show also that EC8 type 1 gives the maximum base shears for all soil types, because the ordinate of inelastic spectra of fundamental period of the building which is 0.628 s is more important for EC8 type 1, whereas EC8 type 2 gives values of base shear greater than RPA and UBC97 only for very soft soil, which can be explained by the importance of soil factor defined by EC8 for this soil type which is equal to 1.8.

Fig.6 shows lateral displacements of stories given by seismic analysis. As seen from Fig.6, the displacement increases when the soil gets softer, and the maximum value is given by the last story. EC8 type 1 gives values of displacements greater than those of UBC97 and RPA and for all ground types, for very soft soil, the displacements given by EC8 type 2 and RPA are close.

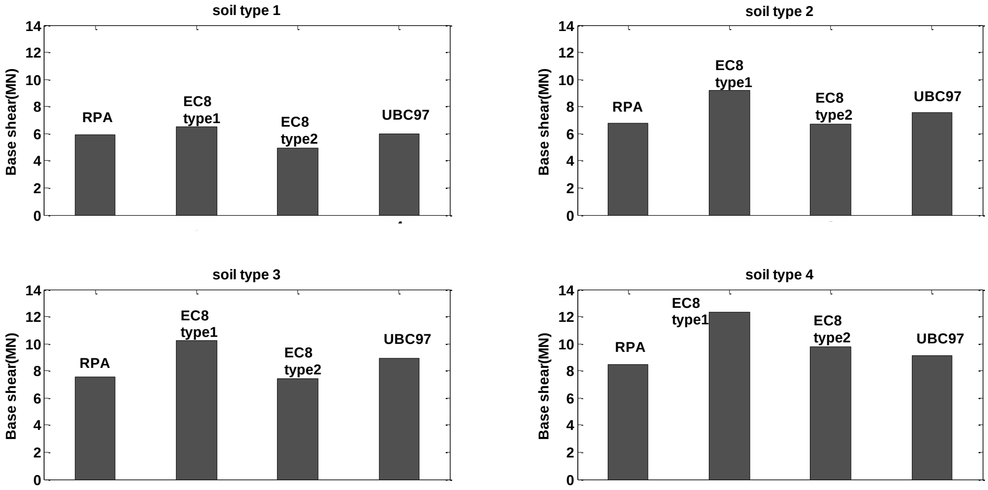

Figure 5. Base shear of the building considering four types of soil.

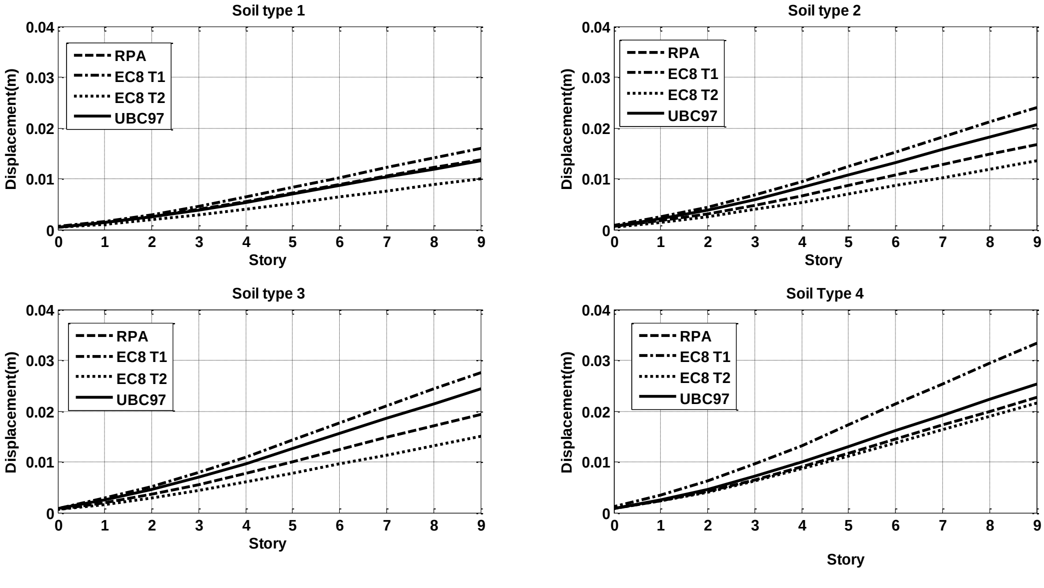

Figure 6. Displacements of stories considering four ground types.

Conclusion

The inelastic design spectra showed that acceleration values of RPA99/2003 have the same peak values for all ground types, whereas, EC8 type 1 and type 2 and UBC97 specified different peak values depending on ground types, this difference can be explained by the fact that EC8 takes into account site effect by introducing site factor *S*, and near and far field, and UBC97 also considers soil factor.

EC8 specifies the values of the maximum allowable behavior factor depending on type of structural system, regularity in elevation and prevailing failure mode in the system with walls, but the behavior factor defined in RPA99/2003 only depends on structural type of the structure.

In this study, base shears and displacements increase when soil gets softer, so the maximum value is given for soil type S4-D (very soft soil). The displacement also increased with stories, which means that the maximum value of displacement is given in the last story. EC8 type 1 gives the maximum displacement and base shear values for all ground types. The results show also that RPA results are close to those of UBC97, and EC8 type 2 gives base shears and displacements lower than RPA except for soil type S4-D, this is because of the importance of soil factor for this soil type.

REFERENCES

Algerian earthquake resistant regulations “RPA99/ version 2003” (2004) national center of applied research in earthquake engineering

Ambraseys, N. Simpson, K. Bommer, J. (1996) Prediction of horizontal response spectra in Europe, *Earthquake Engineering and Structural Dynamics*, **25**:371-400

Bommer, JJ. Acevedo, AB. (2004), The use of real earthquake accelerograms as input to dynamic analysis. *Journal of Earthquake Engineering*. **8**: 43-91.

Boore, DM. Joyner, WB. Fumal, TE. (1994). Estimation of response spectra and peak accelerations from western North American earthquakes. A*n interim report,* **USGS Open-File Report**: 94–127.

Borcherdt, RD. (1994). Estimates of site-dependent response spectra for design (methodology and justification), *Earthquake Spectra*. **10:** 617-653.

Dogangün, A. Livaoglu, R. (2006)**.** A comparative study of the design spectra defined by Eurocode 8, UBC, IBC and Turkish Earthquake Code on R/C sample buildings. *Journal of Seismology.* **10**: 335-351.

EC 8 (2004) Eurocode 8: design of structures for earthquake resistance Part 1: general rules, seismic actions and rules for buildings, European Norm. European Committee for Standardization, European Committee for Standardisation Central Secretariat, rue de Stassart 36, B-1050 Brussels.

Joyner, WB. Fumal, TE. (1984) Use of measured shear wave velocity for predicting geologic site effects on strong ground motions. *Proc 8thWorld Conference of Earthquake Engineering San Francisco*. **2**:777-783.

Laouami, N. Slimani, A. Bouhadad, Y. Chatelain, J. L. and Nour, A. 2006. Evidence for fault-related directionality and localized site effects from strong motion recordings of the 2003 Boumerdes (Algeria) earthquake: consequences on damage distribution and the Algerian seismic code. *Soil Dynamics and Earthquake Engineering*. **26**, pp 991-1003.,

Sabetta, F. Bommer, JJ. (2002). Modification of the spectral shapes and subsoil conditions in Eurocode 8. *Proc 12th European Conference of Earthquake Engineering, London,* **Paper No 518**.

SAP2000 (2005) Integrated Software for Structural Analysis and Design: Computers and Structures. Inc. Berkeley, California.

UBC (1997) Uniform Building Code, International Conference of Building Officials. Whittier, California, USA