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A Comparative Study on the Design Spectra Defined by Several Codes of Practice on RC Building Located in Baghdad City

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Abstract

This paper studies the effect of different design spectral response acceleration parameters as suggested by the uniform building code (UBC), unified facilities criteria (UFC), and Iraqi seismic code(1997) (ISC 97) on the seismic response of reinforced concrete multi-story framed building located in Baghdad city, Iraq. These parameters are: (a) spectral response accelerations S_s, at short periods, and S_1 at a 1-second period in accordance with international building code (IBC), (b) seismic zone factor (Z) according to UBC, (c) Seismic hazard zoning coefficient (Z) according to ISC 97. In this paper, first, the elastic seismic responses for significant modes of vibration for chosen building under design response spectrum that obtained from the above mentioned codes are calculated, and then a comparison was made among different design spectral response acceleration parameters. The intent of this study is to review the seismic provisions of the current edition of Iraqi seismic code (1997) to determine whether it provides an equivalent level of safety to that contained in other international codes. Design base shears, lateral seismic forces, inter story drifts, response spectrum modal, effective seismic modification, floors acceleration and story shears are comparatively presented.

Keywords— *Seismic Design, Iraqi Seismic Code, UBC, IBC, RC Frames, Design Response Spectrum, Story Drifts, Peak Floor acceleration.*

1. Introduction

The evaluation of seismic forces on structures is an integral part of structural design of any structure. The Iraqi seismic code (1997) (ISC 97) used for earthquake forces estimation did not identify the design requirements of response spectrum method for buildings. Moreover, it did not update the values of the ground acceleration since twenty years ago. This deficiency in ISC may result to undesirable values for earthquake forces used in the design of the structures. For that, the Ministry of Construction and Housing encouraged to update the Iraqi codes regularly, taking into account the updated seismic loads. A comparative study on RC frame building designed using different codes was carried out by many researches (Pong (2006), Dogangun and Livaoglu (2006), Singh et.al (2012), Ismaeil and Nazar (2014) and Dhanvijay et.al (2015)). Comparative study on seismic provisions base shear and story drift for different international building codes were performed.

In this paper, based on a case study of reinforced concrete framed building located in Baghdad city, Iraq, it is aim to verify design acceleration values suggested by different international seismic codes such as International Building Code (IBC) and Uniform Building Code (UBC) with the values proposed by Iraqi seismic code 1997. The response spectrum analysis procedure and the equivalent static design were used to verify the seismic design base shear, story drift, roof displacement, response spectrum modal, and peak floor acceleration under different spectral response acceleration parameters suggested by above codes.

2. Modelling and idealization

2.2 Description of Building Structure

This research studies a reinforced concrete building as a typical four storey slab –beam -column system located in Baghdad, Iraq. The building is designed for hospital use. The building frame considered for numerical analysis in the present study is designed for the seismic zone for Baghdad city (zone (I) with peak ground acceleration (PGA) of 0.05g) as per Iraqi seismic code (1997) (ISC 97) considering dense to medium soil conditions. The cylinder compressive strength (f_c') of concrete is taken as 30MPa, and the yield tensile strength (f_y) of steel is taken as 413MPa. The building has typical floor plane layout equal to 32.85m by 14.75m. The story height is typical and equal to 4.25 m (Figure (1)). The floors are made of concrete slab-beam system supported by columns. The thickness of the floor slab is 200 mm for all floors. The cross-section of the columns used to support the structure is determined as (500mm x 800mm) for smallest column dimensions in the structure and as (400mmx1200mm) for the largest ones. The beams are the same sizes at all the floors (300mmx500mm) as shown in (Figure (1)).

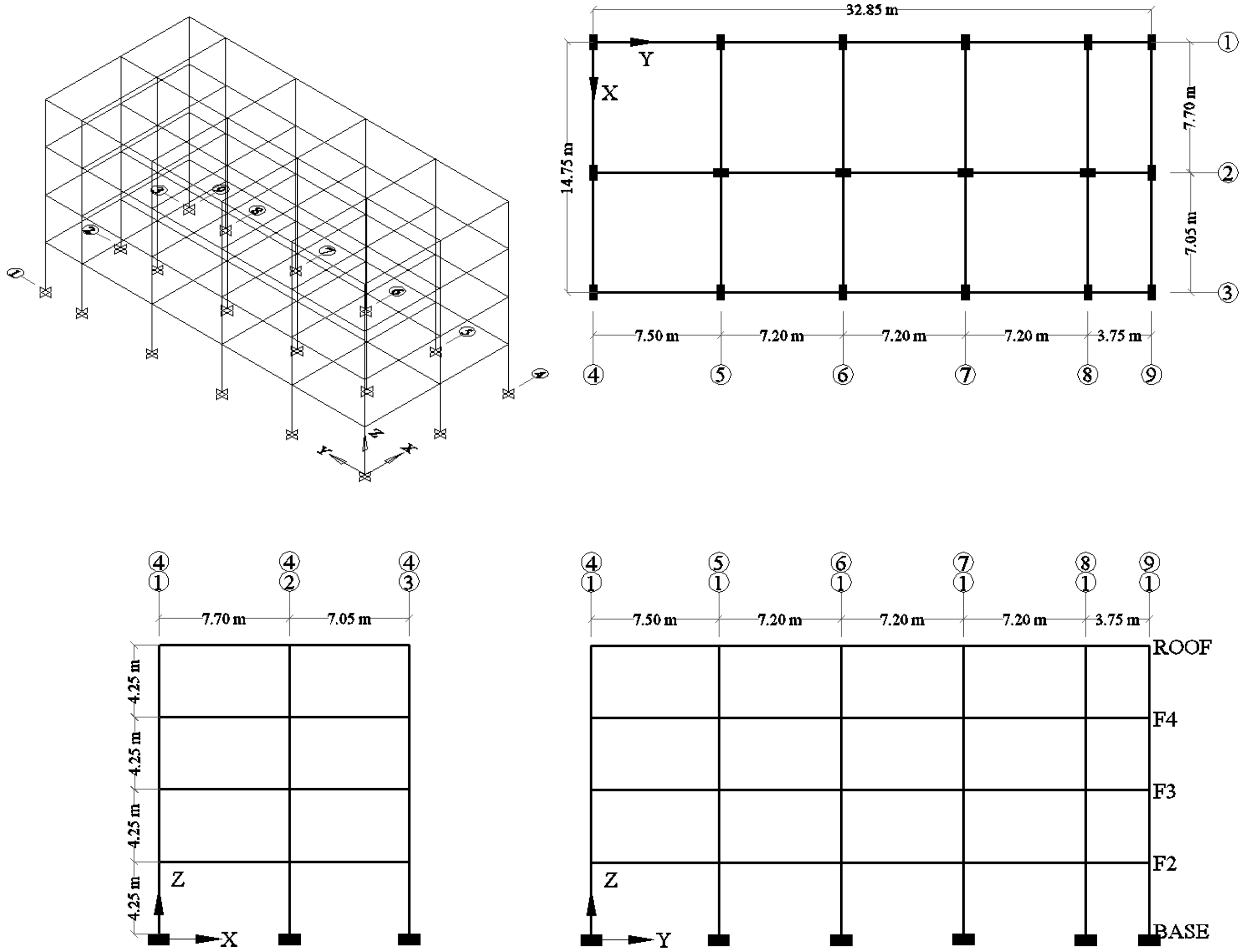

Figure 1: Three-Dimensional Computer Model and Geometry of the Building.

2.3 Finite Element Modeling of Building

ETABS software (2015) enhanced the space frame models of the buildings. The elastic analyses are implemented using ETABS software by the equivalent lateral force and response spectrum method to conclude the seismic response of the buildings. The seismic analyses of the buildings are implemented individually in the longitudinal and the transverse directions and a three-dimensional analysis is carried out in both X and Y directions (orthogonal directions) by an equivalent lateral force and response spectrum method. Figure (1) shows the sample finite element models of the building with fixed supports. Columns and beams are modelled with two nodes frame elements with six degrees of freedom per each node. For the purpose of modelling the real behaviour of the slabs under earthquake loading, membrane elements were used in modelling to ensure not providing stiffness in horizontal directions and only transfer mass of slab to columns and beams. Floors are considered as a rigid diaphragm in each floor level to transfer the lateral forces due to earthquake to the columns. Effective stiffness of the cracked RC members is considered according to ASCE 41 Update. The masses of infill walls have been included in mass calculation of the model. The density of concrete is taken as 25 kN/m^3 and Young's modulus as 28000MPa in the analysis. The 5%damping ratio is assumed for all vibration modes of the building.

3. Base Shears for the Analyzed Building

Different load calculation and base shear calculation procedure has been adopted for different codes as specified in the respective codes, i.e. UBC, IBC (ASCE) and Iraqi seismic code (ISC 97). Design spectral response acceleration parameters for Baghdad city as suggested by the Uniform Building Code (UBC) for Ca and Cv, unified facilities criteria (UFC) for S_1 and S_s, and Iraqi seismic code (ISC) for Z have been used herein. The base shear is evaluated and distributed along the height of the building at each floor. Table (1) gives the base shear definitions by different codes. The base shear of the building is obtained from analysis under earthquake loading using the design spectra corresponding to 5% critical damping ratio.

4. Horizontal Elastic Design Spectrum

From the design response spectra of UBC, IBC and ISC codes the spectral acceleration (Sa) corresponding to the fundamental period of building is determined. The values of spectral acceleration coefficients thus obtained is utilized to obtain the horizontal seismic design shear of building using the equations specified in building codes.

Figure (2) illustrates a typical shape of horizontal elastic design spectrum, (T) represents the periods of structure, (T_s) is the upper limit and (T_o) is the lower of the period of the constant spectral acceleration branch. (T_L) represents the period corresponding to the beginning of the constant displacement response range of the spectrum. Some differences are existed in spectral shapes recommended by the earthquake codes. Table (2) shows the ordinates of elastic design spectra of UBC, IBC and ISC Codes.

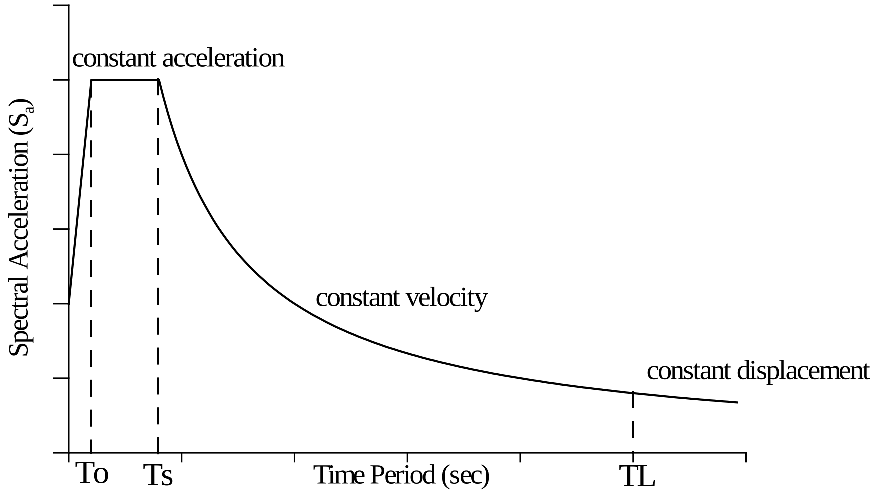

Figure 2: Typical Horizontal Elastic Design Spectrum**.**

Table 1: Horizontal Seismic Design Shear Defined in the UBC, IBC and ISC.

Codes	Base Shear	Seismic Parameters
UBC	$V = (0.11C_a\, I\, W, V(for\ zone\ 4) = \frac{0.8\, Z\, N_v\, I}{R}\, W) \leq V = \frac{C_v}{R}\,\frac{I}{T}\, W \leq V = \frac{2.5C_a\, I}{R}\, W$	“seismic zone factor Z for zone 3”=0.3 “seismic coefficient C_a”=0.36 “seismic coefficient C_v”=0.54 “Importance factor, I”=1.25 “Over strength factor, R”=3.5

IBC	$V = max(0.044SD_S\, I\, W, 0.01W) \le V = \frac{SD_S}{\frac{R}{I}}\, W \le \begin{cases} V = \frac{SD_1}{T\,(\frac{R}{I})}\, W \quad for\ T \le TL \\ V = \frac{SD_1\, TL}{T^2\,(\frac{R}{I})} W \quad for\ T > TL \end{cases}$	“0.2 sec spectral acceleration S_s”=1.3 “1 sec spectral acceleration S_1”=0.7 “Long-period transition period T_L”=8 sec “Response modification ,R”=3 “Occupancy importance ,I”=1.5 “Site coefficient F_a”=1 “Site coefficient F_v”=1.5 “the design spectral response acceleration parameter at short periods”, $SD_S = \left(\frac{2}{3}\right) F_a S_S = 0.8667$ “the design spectral response acceleration parameter at 1-s period” $SD_1 = \left(\frac{2}{3}\right) F_v S_1 = 0.7$
ISC	$V = Z\, I\, S\, K\, W$	“Seismic hazard zoning coefficient (Z)”=0.05 “Seismic importance factor, I”=1.5 “Dynamic coefficient related to soil condition”=1. “Structural system coefficient (TYPE NO.2), K”=1. “Effective Seismic Weight, W”= Total Dead Load + Superimposed Dead Load + 25% Live Load.

Table 2: Horizontal Elastic Design Spectrum Coordinates Of UBC, IBC and ISC Codes.

Codes					
UBC	Time period	$0 \le T \le T_O$	$T_O \le T \le T_S$	$T \ge T_S$	
	spectral acceleration	$S_a = 1.5\, \frac{C_a}{T_O}\, T + C_a$	$S_a = 2.5\, C_a$	$S_a = \frac{C_V}{T}$	
IBC	Time period	$0 \le T \le T_O$	$T_O \le T \le T_S$	$T_S \le T \le T_L$	$T \ge T_L$
	spectral acceleration	$S_a = 0.6\, \frac{S_{DS}}{T_O}\, T + 0.4S_{DS}$	$S_a = S_{DS}$	$S_a = \frac{S_{D1}}{T}$	$S_a = S_{D1}\, \frac{T_L}{T^2}$
ISC	Time period	$0 \le T \le T_O$		$T \ge T_S$	
	spectral acceleration	$S_a = 1.0$		$S_a = \frac{1.0}{T}$	

5. Seismic Response Coefficient

The dynamic character of seismic loads is simplified to a horizontal force in the equivalent lateral load procedure. Because the amount of force is dependent on the mass of the object (W), the code simplifies the calculation base shear (V) to be a certain percent of W, (V=Cs W). The seismic response coefficient (Cs) is used to represent the horizontal elastic acceleration response of a building to the input ground excitation. Finally the design response spectrum values, where obtained from Table (2) above, need to be converted to seismic load by using scale factor to multiply the ordinates of elastic design spectra as follows, Table (3), for respective codes. i.e. UBC, IBC (ASCE) and ISC:

Table 3: Scale Factor UBC, IBC and ISC Codes.

Codes	Design Response Spectrum Values	Scale factor
UBC	Ordinates of elastic design spectra from Table (2)	I/R
IBC	Ordinates of elastic design spectra from Table (2)	I/R
ISC	Ordinates of elastic design spectra from Table (2)	I*K
where I,R and K values defined in Table (1)		

The comparison of the results for the ordinates of seismic response coefficient (Cs) at different time periods are shown graphically in Figure (3) for UBC, IBC (ASCE) and Iraqi seismic code.

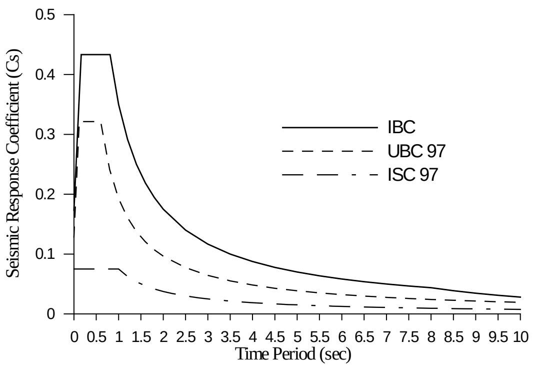

Figure 3: Comparison of Seismic Response Coefficient.

6. Results of Analysis

6.1 Mode Shapes and Period of Vibrations

The time periods and mode shapes of the building have been computed using the software ETABS. Table (4) gives the time periods in the first six modes. The first six mode shapes are shown in Figure (4) for the building. The first two modes are three dimensional modes with a dominance vibration along the X and Y directions respectively. The third mode is predominantly torsional mode for the building.

6.2 Design Base Shear

The seismic response coefficient shown in Table (5) is evaluated from different codes formulas and for a period of variation in the X-axis obtained from the first mode.

Figures (5) and (6) illustrate the horizontal seismic design shear gained for the chosen building in the X and Y axes respectively. As shown in Figure (6), the maximum base shears is given by IBC for equivalent ground types defined in UBC and ISC. The horizontal seismic design shear obtained from the modeling in the X-axis and Y-axis for different codes is given in Table (6). The effective seismic weight of the building includes both the total dead load and a minimum of 25 percent of the reduced floor live load as per UBC, IBC (ASCE) and Iraqi seismic codes.

The analysis results show that the horizontal seismic design shear of IBC is increased by (81%) compared with horizontal seismic design shear calculated from UBC for X and Y direction. The design base shear of IBC is increased by (191% and 234%) compared with horizontal seismic design shear calculated from ISC for X and Y direction respectively.

Table 4: Periods of Vibration.

Mode number	1	2	3	4	5	6
Period of Vibration (second)	1.601	1.397	1.323	0.414	0.378	0.355

Table 5: Seismic Response Coefficient and Design Base Shears Values.

Codes	Period Used (sec)	Cs	W (kN)	V (kN)=Cs*W
UBC	1.601	0.121	28997	3493
IBC	1.601	0.219	28997	6339
ISC	1.601	0.075	28997	2175

Table 6: Horizontal Seismic Design Shear (V) Defined in the UBC, IBC and ISC.

Codes	V in X direction (kN)	V in Y direction (kN)
UBC	3493	4003
IBC	6339	7265
ISC	2175	2175

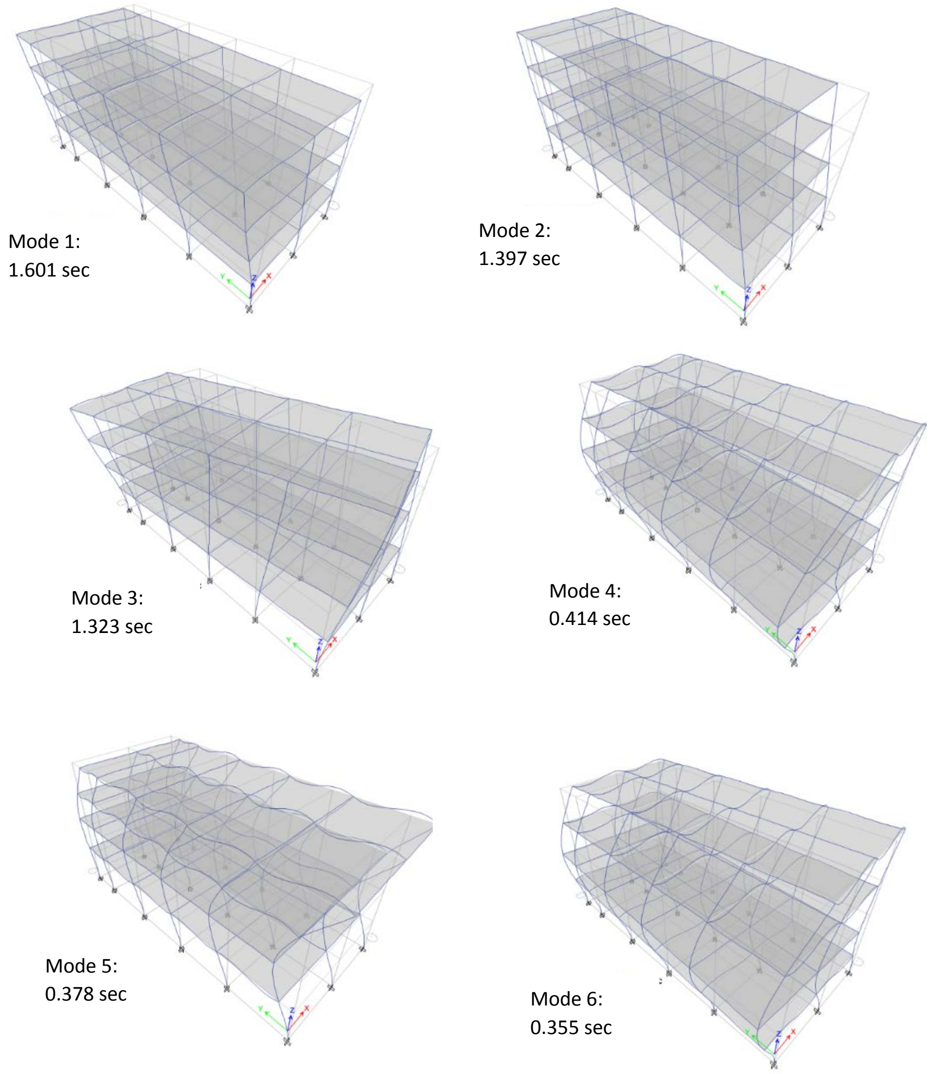

Figure 4: Mode Shapes for the Building.

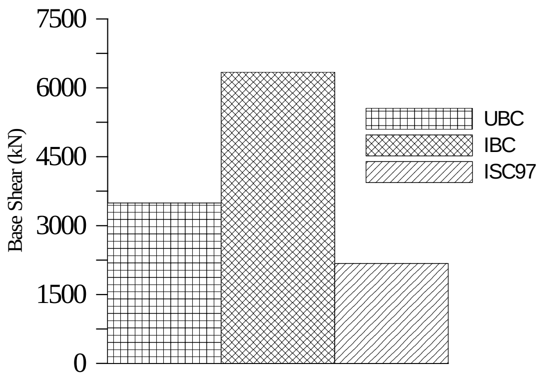

Figure 5: Comparison of Base Shears Defined in the Codes for EQ in X-direction.

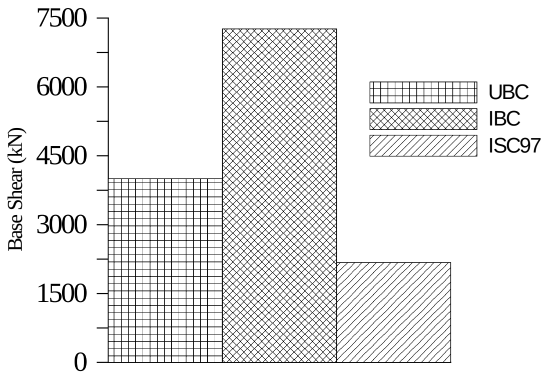

Figure 6: Comparison of Base Shears Defined in the Codes for EQ in Y-direction.

6.3 Lateral Seismic Forces

Thus, the horizontal seismic design shear (V) is obtained then distributed along the height of the building using a profile distribution expression given in Table (7) shown below. The lateral loads given in Table (8) are calculated according to the Table (7). The analysis has been carried out for the building under the lateral seismic forces (static) calculated in Table (8), as well as under gravity loads in order to obtain member forces and displacements. The analysis results show that the lateral load of IBC is increased by maximum ratio equal to (109% and 106%) compared with lateral load calculated from UBC for X and Y direction respectively at level F4. The lateral load of IBC is increased by maximum ratio equal to (250% and 289%) compared with lateral load calculated from ISC for X and Y direction respectively at roof.

Table 7: Comparison of Lateral Loads (kN) Expression by UBC, IBC and ISC.

Codes	UBC	IBC	ISC
Lateral force (F_x)	$F_x = (V - F_t)\ \frac{w_x\ h_x}{\sum_{i=1}^{n} w_i\ h_i}$	$F_x = (V)\ \frac{w_x\ h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$	$F_x = (V)\ \frac{w_x\ h_x}{\sum_{i=1}^{n} w_i\ h_i}$
"The concentrated force Ft at the top, which is in addition to Fx, shall be determined from the formula: $F_t = 0.07\,T\,V \ \leq 0.25\,V; F_t = 0\ when\ T \leq 0.7\ sec.$ V = total design lateral force or shear at the base of the structure (kN). wi and wx = the portion of the total effective seismic weight of the structure (W) located or assigned to Level i or x. hi and hx = the height from the base to Level i or x. k = an exponent related to the structure period as follows: for structures having a period of 0.5 sec or less, k = 1. For structures having a period of 2.5 sec or more, k = 2. For structures having a period between 0.5 sec and 2.5 sec, k shall be 2 or shall be determined by linear interpolation between 1 and 2".			

Table 8: Comparison of Lateral Loads (kN) by UBC, IBC and ISC.

Direction		Lateral seismic forces in X direction (kN)			Lateral seismic forces in Y direction (kN)		
Codes		UBC	IBC	ISC	UBC	IBC	ISC
Level	ROOF	1565	2878	823	1758	3200	823
	F4	964	2018	676	1123	2310	676
	F3	643	1076	451	748	1284	451
	F2	321	367	225	374	470	225
	BASE	0	0	0	0	0	0

6.4 Inter Story Drifts

The comparison of maximum drifts for the chosen building in X and Y axes are shown in Figures (7) and (8) respectively. The drifts are determined from the seismic analysis for different codes (UBC, IBC (ASCE), and Iraqi Seismic Code). There are considerable differences between the three codes (UBC, IBC, and ISC). The maximum displacement is observed from IBC while the minimum displacement was observed from ISC. From the IBC and according to the design spectra, the highest change in the design ground motion parameters is now in SD_S and SD_1 as per IBC and not in seismic zone factor as per UBC and ISC.

The analysis results show that the inter story drift ratio of IBC is increased by maximum ratio equal to (90%) compared with inter story drift ratio calculated from UBC for both X and Y directions. The inter story drift ratio of IBC is increased by maximum ratio equal to (230% and 271%) compared with inter story drift ratio calculated from ISC for X and Y direction respectively.

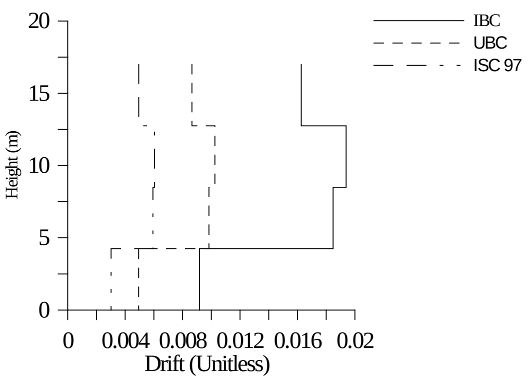

Figure 7: Comparison of Maximum Story Drift for EQ in X –direction.

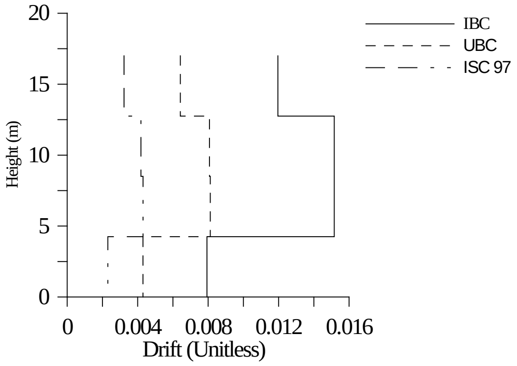

Figure 8: Comparison of Maximum Story Drift for EQ in Y- direction.

6.5 Modal Response Spectrum Analysis

The modal response spectrum analysis provides insight to the dynamic behavior of the building. The natural mode shapes and corresponding time periods are needed to be calculated in order to modal interaction effects need for use in modal response spectrum analysis. The mode shapes and frequencies are automatically computed by ETABS software using the structural masses (dead load + 0.25 live load, as per UBC, IBC (ASCE) and Iraqi seismic codes) and the same mathematical model used for the equivalent lateral force. The first 12 modes of response are computed and composed using the complete quadratic combination (CQC) approach. In CQC calculations, a damping ratio of 5 % was used. The comparison of modal response spectrum with different codes (IBC, UBC and ISC) are given in Figures (9) and (10).

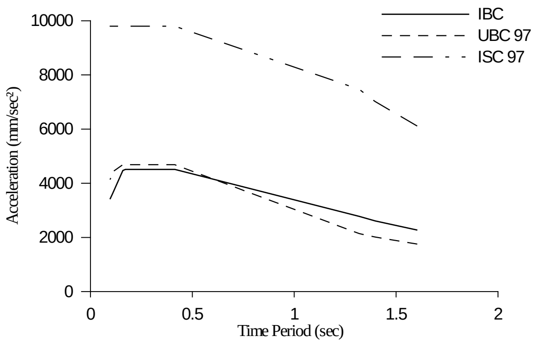

Figure 9: Comparison of Response Spectrum Modal in X-Direction for 5% Damping.

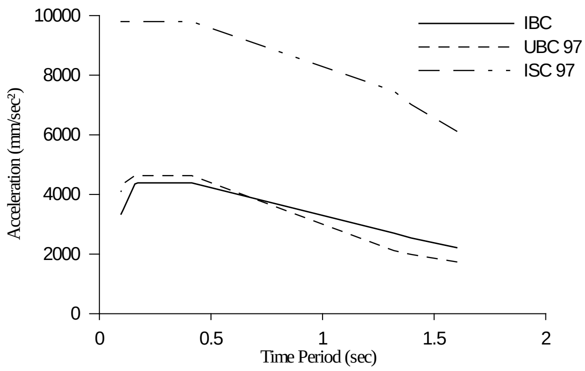

Figure 10: Comparison of Response Spectrum Modal in Y-Direction for 5% Damping.

6.6 Effective Seismic Modification

As shown in Table (9), the seismic base shear (Vdynamic) calculated firstly by response spectrum analysis (RSA) procedure shows that less than 85% of seismic base shear (Vstatic) from equivalent lateral force (ELF) procedure. The force demands need to be raised so that the Vdynamic from RSA procedure is equal to 0.85Vstatic. To meet this requirement, the RSA was carried out again with ETABS software by replacing the “R/I” scale factor with effective seismic modification “Reff”, where “Reff” shall be the lesser of R/I multiplied by (Vdynamic/0.85Vstatic) and R/I, as shown in Table (9).

6.7 Computed Floor Acceleration

As a part of this research paper, a comparison of the computed floor acceleration are made for the roof level. Estimation of the peak floor acceleration (PFA) is required for the design and reliability assessment of acceleration-sensitive non-structural elements and floor diaphragms in buildings. Results of this study are shown in Figures (11) and (12). Table (10) provides a comparison of maximum computed peak acceleration obtained from different codes

Table 9: Effective Seismic Modification.

Codes	Direction	Vstatic	0.85Vstatic	Vdynamic	0.85V/Vdynamic
IBC	X	6339	5388	5073	1.062
	Y	7265	6175	5974	1.034
UBC	X	3493	3144	2958	1.063
	Y	4003	3603	3430	1.050
ISC	X	1363	1022	14125	0.072
	Y	1546	1159	16759	0.069

Table 10: Maximum Scaled Accelerations at Roof.

Codes	Direction of Response	Scaled Acceleration (mm/sec^2)
IBC	X	4806
	Y	3558
UBC	X	4239
	Y	4090
ISC	X	873
	Y	743

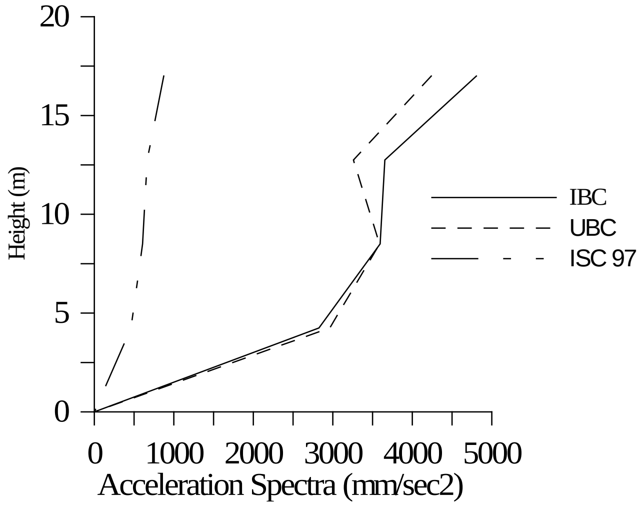

Figure 11: Comparison of Story Scaled Acceleration Spectra for EQ in X-direction.

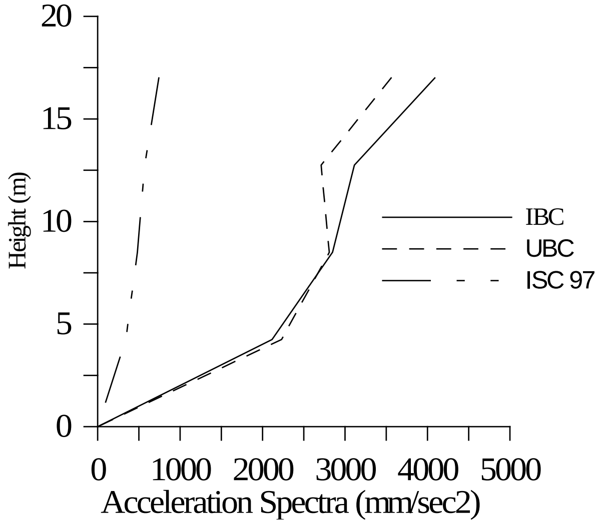

Figure 12: Comparison of Story Scaled Acceleration Spectra for EQ in Y-direction.

The analysis results show that the computed maximum floor acceleration of IBC is increased by (13%) and decreased by (13%) compared with maximum computed floor acceleration calculated from UBC for X and Y directions respectively. The maximum computed floor acceleration of IBC is increased by maximum computed floor acceleration (451% and 379%) compared with maximum computed floor acceleration calculated from ISC for X and Y direction respectively.

6.8 Story Shears

Story shears are calculated as part of the static lateral seismic force analysis. The story shear comparison are shown in Figure (13).

The analysis results show that the maximum story shear of IBC is increased by (90%) compared with maximum story shear calculated from UBC for both X and Y directions. The maximum story shear of IBC is increased by (250% and 290%) compared with maximum story shear calculated from ISC for X and Y direction respectively.

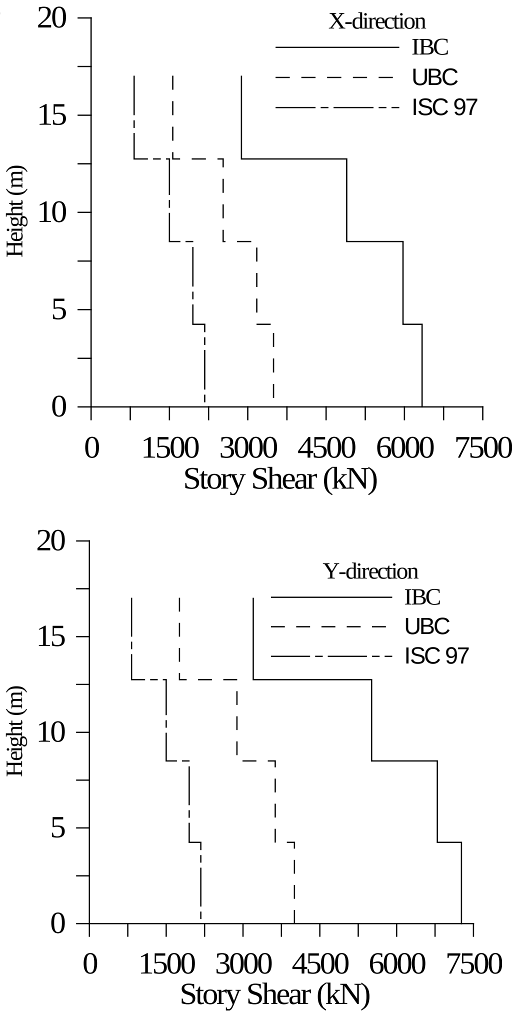

Figure 13: Comparison of Story Shears for EQ in X and Y-directions respectively

7. Conclusions

The following main conclusions can be drawn from above comparative study:

1. The horizontal seismic design shear obtained using IBC is increased by (81%) in comparison with horizontal seismic design shear calculated from UBC.
2. The horizontal seismic design shear of IBC is increased by (234%) in comparison with design base shear calculated from ISC.
3. The lateral load of IBC is increased by (109%) in comparison with lateral load calculated from UBC.
4. The lateral load calculated using IBC is increased by maximum ratio equal to (289%) in comparison with lateral load calculated from ISC.
5. The inter story drift ratio of IBC is increased by (90%) in comparison with inter story drift ratio calculated from UBC. The inter story drift ratio of IBC is increased by maximum ratio equal to (271%) in comparison with inter story drift ratio calculated from ISC.
6. The computed maximum floor acceleration of IBC is increased by (13%) and it is decrease by (13%) in comparison with maximum computed floor acceleration calculated from UBC for X and Y directions respectively.
7. The maximum computed floor acceleration of IBC is increased by maximum computed floor acceleration (451%) in comparison with maximum computed floor acceleration calculated from ISC.
8. The story shear of IBC is increased by (90%) in comparison with maximum story shear calculated from UBC.
9. The maximum story shear of IBC is increased by (290%) in comparison with maximum story shear calculated from ISC. As seen from results, very different horizontal seismic design shear, inter story drift ratio, story shear, floor acceleration values were obtained for ISC as compared with IBC and UBC codes. There are significant differences between the three codes (UBC, IBC and ISC).
10. The horizontal seismic design shear, inter story drift ratio, story shear, floor acceleration values for ISC are lesser than those obtained from IBC and UBC codes.
11. The horizontal seismic design shear, inter story drift ratio, story shear, floor acceleration values for IBC are greater than those obtained from UBC and ISC codes.
12. From the IBC and according to the design spectra, the highest change in the design ground motion parameters is now in SDS and SD1 as per IBC and not in seismic zone factor (Z) as per UBC and ISC.

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دراسة مقارنة الإستجابة الطيفية التصميمية المعرفة بعدد من المدونات المعتمدة على بناية خرسانية تقع في مدينة بغداد

حسين خلف جار الله
قسم الهندسة المدنية
الجامعة المستنصرية

زاهر نوري محمد تقي
قسم الهندسة المدنية
جامعة النهرين

الخلاصة

تم في هذا البحث دراسة تأثير مختلف قيم مُعامِلات الإستجابة الزلزالية المقترحة في مدونة البناء الموحد (UBC) والمعايير موحدة المرافق (UFC) والمدونة الزلزالية العراقية للمباني لسنة 1997(ISC 97) على السلوك الزلزالي لبناية مكونة من نظام هيكلي بنائي متعدد الطوابق من الخرسانة المسلحة تقع في مدينة بغداد، العراق. هذه المعاملات هي: (أ) تعجيل الإستجابة الطيفية عند الفترات القصيرة (S_s) وتعجيل الإستجابة الطيفية عند فترة 1 ثانية(S_1) وفقا للـ(IBC) و (ب) معامل تقسيم المخاطر الزلزالية (Z) وفقا لمدونة البناء الموحد (UBC) و(ج) معامل تقسيم المخاطر الزلزالية (Z) وفقا للمدونة الزلزالية العراقية للمباني (97)، في هذا البحث تم استخدام التحليل الزالزالي الخطي للبناية تحت تأثير الاستجابات الطيفية التصميمية للتسارع المختلفة التي تم الحصول عليها من المدونات اعلاه مع الاخذ بنظر الاعتبار الاطوار المهمة للبناية ، ومن ثم تم إجراء مقارنة بين معاملات الاستجابات الطيفية التصميمية للتسارع المختلفة التي تم الحصول عليها. الهدف من هذه الدراسة هو النظر في تقييم الطبعة الحالية من المدونة الزلزالية العراقية للمباني (1997) لتحديد ما إذا كان توفر مستوى أمان معادلا لتلك الواردة في المدونات الدولية الأخرى. تم مقارنة القص القاعدي الزلزالي والقوة الزلزالية الجانبية وانحراف الطوابق والأستجابة الطيفية التصميمية للتسارع و تعديل الزلزالي فعال وتسارع الطوابق والقص التصميمي الزلزالي في الطابق.

الكلمات المفتاحيةـــ التصميم الزلزالي، مدونة الزلازل العراقية،مدونة البناء الموحد، المدونة العالمية للمباني، هياكل الخرسانة المسلحة،اطياف الاستجابة التصميمية، انحراف الطابق ،ذروة تسارع الطابق.