A COMPARATIVE STUDY OF THE SEISMIC PROVISIONS BETWEEN IRAQI SEISMIC CODES 2014 AND 1997 FOR KURDISTAN REGION/IRAQ

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ABSTRACT

This paper addresses the effect of the seismic design response spectral acceleration parameters recommended by the Iraq Seismic code 2014 (ISC 2014) compared to that recommended by the previous Iraq Seismic code 1997 (ISC 1997) for the cities of Kurdistan Region of Iraq (Erbil, Duhok, Sulaymaniyah and Halabja). The seismic design response spectral recommended by the ISC 2014 for these cities have been prepared for hard rock, rock, very stiff soil, stiff soil, and soft soil. Then, based on the equivalent lateral force procedure, the base shear calculated using both codes have been compared for two case studies of reinforced concrete building consists of 5 and 15 floors. the results showed that ISC 2014 provisions results in a dramatic increase in the base shear forces especially for the cities of Halabja and Sulaymaniyah, followed by Erbil city, while the effect on Duhok city was relatively low. As a supplementary work, modal response spectrum analysis has been performed using ISC 2014 on a 5 and 15 story regular reinforced concrete framed building constructed on soil type D-stiff soil and located in Erbil to evaluate the results of the equivalent lateral force procedure.based on ISC 2014 provisions, all the buildings in KRI should be assigned to the seismic risk class D, meaning that the building construction system should be either special reinforced concrete frame, special reinforced shear wall, special reinforced masonry wall, special steel frame, or ordinary/intermediate steel frame for specific frame configurations.

Keywords: Iraqi Seismic Code, Response Spectrum, Equivalent Lateral Force, Modal Analysis

1. INTRODUCTION

In spite of the fact that the Kurdistan Region of Iraq (KRI) exhibits low seismicity; it is adjacent to regions that have seen moderate to high seismic activity in the past. The source of the earthquakes affecting KRI exists beyond the north and eastern borders of Iraq (Turkey and Iran), where the Arabian, and Eurasian plates collide generating Intense earthquake activity [1]. In general, small to moderate sized earthquakes frequently occur in Kurdistan, however, in the recent years, the number and the intensity of earthquake hit KRI increased, and the largest one happened recently in Halabja on 12 November 2017; the epicenter of the earthquake was reported to be located at 34.905°N latitude 45.956°E longitude, 93 km SE of As Sulaymaniyah , 30 kilometers south of Halabja with a focal depth of 19 km according to the US Geological Survey [2]. The epicenter was located outside the Iraqi border, but it had a destructive effect on the Iraqi city of Darbandikhan, where many buildings collapsed and many buildings experienced severe damage. The location of the earthquake is consistent with the plate boundary related structures in this region, where the Arabian plate is moving towards the north with respect to Eurasian plate at a rate of about 26 mm/year [3].

The first Iraq seismic code was published on 1997 (ISC 1997) [4], which based mainly on the UBC 1985 [5]. In the ISC 1997, Iraq was divided into four zones, Duhok city was specified as the most active seismic zone (zone III with Z=0.09), while Halabja, Sulaymaniyah and Erbil cities were located in the 2nd zone (zone II with Z=0.07), see Figure 1. In 2013, the draft version of the new Iraqi seismic code ISC 2013 [6] has been published, and the official version of the code appeared as first edition of ISC 2014 [7]. The code is based mainly on the IBC 2012 [8] and ASCE/SEI07-10 [9] with local mapped acceleration parameters S_1 (1.0 Sec period) and S_S (0.2 Sec period) given for soil type B rock. These parameters are taken from the GSHP-USGS-Geologic Hazards Science Center, as stated in the code.

As could be seen in Figure 2, in the ISC 2014, the most vulnerable zone for earthquake is located within the strip from Darbandikhan city to Rania city passing through Sulaymaniyah city. On the other side, Duhok city turned from the city that was more vulnerable to earthquake in ISC 1997 within the Kurdistan region to be the city that is the less vulnerable to earthquake in ISC 2013-Draft and ISC 2014. In the next sections, ISC 2013-Draft will not be mentioned, as it similar to ISC 2014 for the parameters reported in the current study.

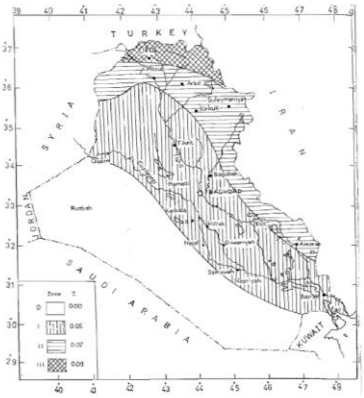
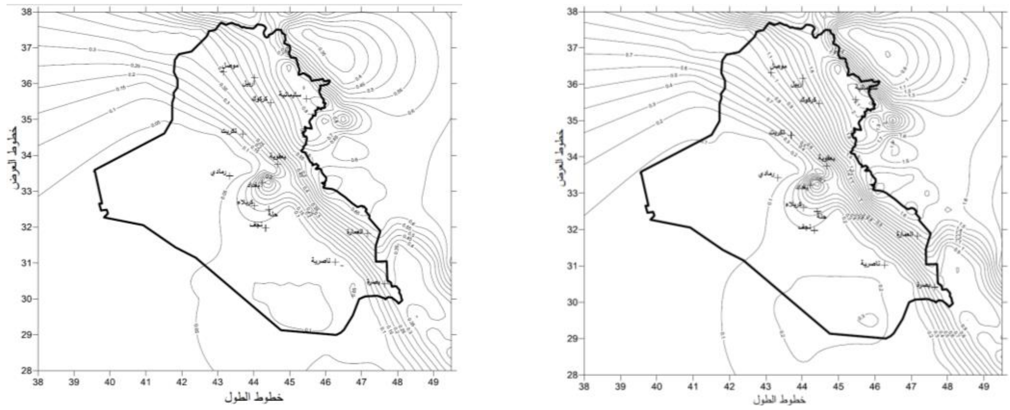


FIGURE 1**.** Seismic zonic map for Iraq **(**ISC 1997)



a) 0.2 Sec

b) 1.0 Sec

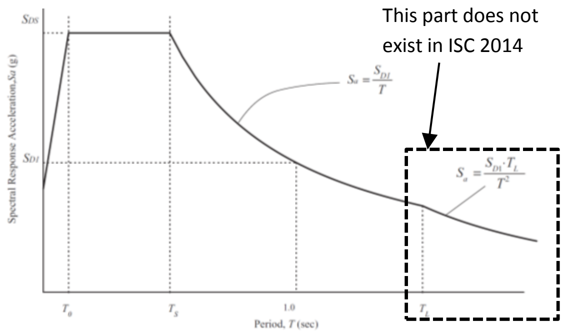
FIGURE 2. Spectral response acceleration (5% of critical damping), site class B rock (ISC 2013-draft and ISC 2014)

In this paper, the ISC 2014 provisions is evaluated through the effects on the base shear force in comparison with that found using ISC 1997 provisions, calculated using equivalent lateral force analysis. For this purpose, two case studies of reinforced concrete framed buildings (5 story and 15 Story) located in the main cities of the KRI (Erbil, Duhok, Sulaymaniyah and Halabja) were taken. The base shear force is the key indicator on the level that the building needs to be proportionated, designed and detailed to resist earthquake forces.

2. ISC 2014 RESPONSE SPECTRUM

The response spectrum components defined in the ISC 2014 is similar to that defined in the IBC 2012 [8] and ASCE/SEI7-10 [9], except for having no long-period transition at large period range, where for all buildings with periods greater than T_s, the spectral response acceleration (S_a) is found by S_{D1}/T, see Figure 3.

Based on ISC 2014 [7], the response spectrum has been prepared for all four main cities in KRI for all soil types as classified by ISC 2014 (A: hard rock, B: rock, C: very stiff soil, D: stiff soil, E: soft soil), see Figure 4. As could be seen, the most vulnerable cities to the effect of the earthquake are Halabja and Sulaymaniyah, while Duhok city is the least vulnerable city within the KRI.



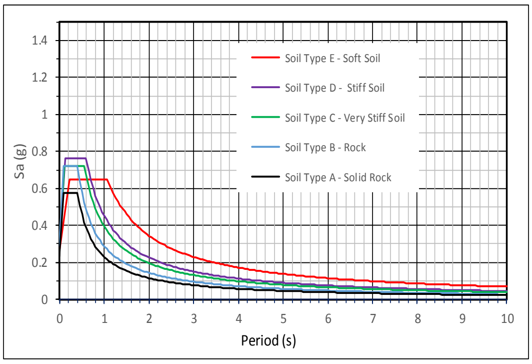
S_s=0.2-second spectral response acceleration, from maps.
S_1=1-second spectral response acceleration, from maps.

S_{MS} = Fa S_S
S_{M1} = Fv S_1
Fa, Fv = Site coefficient, taken from tables based on the soil type and the spectral response acceleration

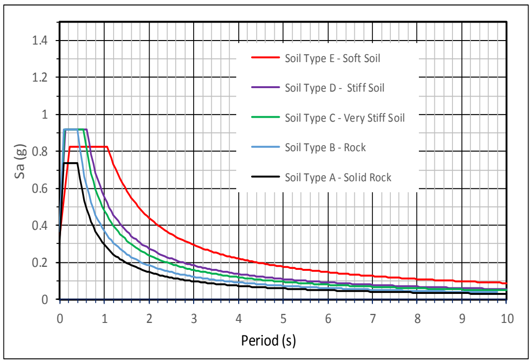
S_{DS}= 2/3 S_{MS}
S_{D1}= 2/3 S_{M1}
T = the fundamental period of the structure, sec
T_0 = 0.2 (S_{D1} / S_{DS})
Ts = (S_{D1} / S_{DS})

From ISC 2014
S_S= 1.08, S_1= 0.43 (Duhok)
S_S= 1.38, S_1= 0.55 (Erbil)
S_S= 2.10, S_1= 0.84 (Sul.)
S_S= 2.16, S_1= 0.86 (Halabja)

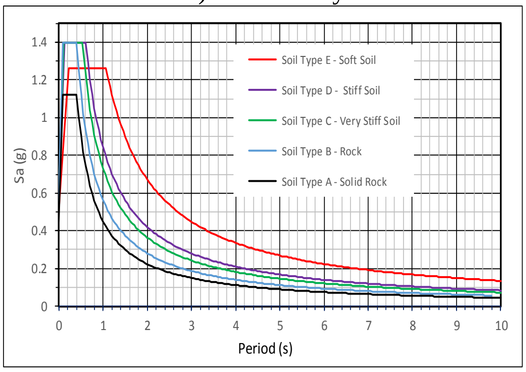
FIGURE 3. Seismic design response spectrum, as defined in ASCE/SEI7-10 [9] and IBC 2012 [8]



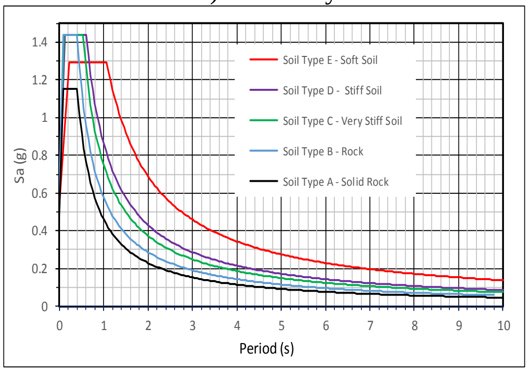
a) Duhok City



b) Erbil City



c) Sulaymaniyah City



d) Halabja City

FIGURE 4. Seismic design response spectrum for the Kurdistan region of Iraq, based on the ISC 2014 [7]

Abdulhameed A. Y et. al. [10] suggested three response spectrums for building design in KRI, see Figure 5, dividing the region into two zones: zone A (the strip at the border with Iran and Turkey) and B (the remaining parts of KRI). These spectra were based on using PGA (Peak Ground Acceleration) equal to 0.5g for zone A, and 0.4g for zone B. In Figure 6, the response spectra for Halabja, Erbil and Duhok cities for the soil types B (rock) and D (stiff soil) as suggested by the ISC 2014 are presented to be compared with Figure 5.

The comparison shows good agreement for Halabja (rock), Erbil (rock) and Erbil (Soil). However, for Duhok city, it is not clear from Figure 5 whether it is included within zone A or B, and no information was found in the paper in the respect. The spectra for Sulaymaniyah is not reported in Figure 6, as they are very close to those reported for Halabja city, see Figure 4.

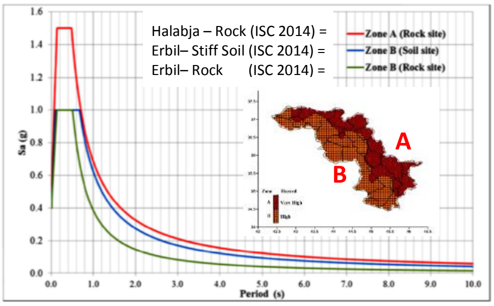


FIGURE 5. Response spectrums for KRI as recommended by Yaseen A. A. et. Al. [10]

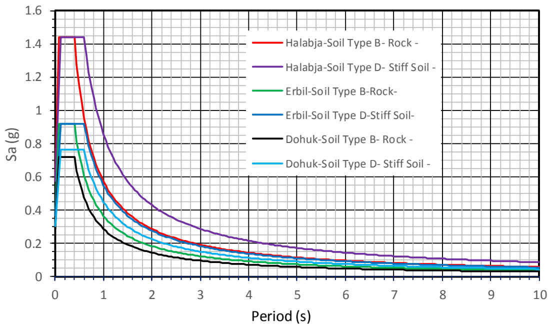


FIGURE 6. Response spectrums for KRS as recommended by ISC 2014 [7]

1. SEISMIC RESPONSE COEFFICIENT (ISC 2014 - ISC 1997)

The reported response spectrums given in Figure 4 could be used in any of the two seismic analysis methods specified by the ISC 2014 [7]: i) Equivalent Lateral Force Analysis (ELFA); ii) Modal Response Spectrum Analysis (MRSA). On the other side, ISC 1997 [4] does not include MRSA as an analysis tool; instead, it specifies the Dynamic Time History Analysis (DTHA) as the 2nd analysis tool. Therefore, for a rational comparison between these two codes, only the ELFA results will be compared in the current paper. for both ISC 1997 and ISC 2014, the seismic response coefficient (Cs), required for the ELFA method, has been constructed for a study case (special reinforced concrete frame building) with high occupancy rate (more than 300 persons) with no special or high importance to the public for all four cities. This case has been chosen because it has the same live load ratio included within the effective seismic weight (W = total dead load + 25 % of the floor live load) in both codes; further, it represents the large percentage of the frame buildings constructed in the KRI region. the Seismic Response Coefficient (C_S) represents the amount of the base shear at the bottom floor taken as a ratio of the total gravity vertical seismic load (W). The procedure for the calculation of the Cs in both codes are summarized in Table 1. The calculated C_S coefficient is shown in Figure 7 for soil of types A, B, C, D and E as classified in the ISC 2014 [7]; by comparing this coefficient between the ISC 2014 and ISC 1997, the change in the base shear will be clear; for comparison purposes, soils of Types I, II and III as specified in the ISC 1997 [4] are equivalent to soil types A-B, C-D, E-F in the ISC 2014 [7], respectively.

TABLE 1.

Details of the equivalent lateral force analysis procedure

ISC 1997 [4]		ISC 2014 [7]	
I	I = 1.0 Class III	I	I = 1.25 Class III
T	0.1 N ; N: Number of floors	T	T = 0.1 N (for 5 story); N: Number of floors T = 0.044 $h^{0.9}$ (for 15 story); h: floor height
K	K = 0.85 (High ductility moment resisting frame)	R	R = 6.5 (Special RC frame)
Z	Z= 0.09 Duhok Z= 0.07 (Halabja, Sulaymaniyah , Erbil)	(S_S) (S_1)	S_S= 1.08, S_1= 0.43 (Duhok) S_S= 1.38, S_1= 0.55 (Erbil) S_S= 2.10, S_1= 0.84 (Sulaymaniyah) S_S= 2.16, S_1= 0.86 (Halabja)
S	S=0.5/T (rock) S=0.75/T (stiff, medium Stiff Soil) S= 1.0/T (soft Soil); S≤ 1.0 (all soils)	S_{MS} S_{M1}	S_{MS} = Fa S_S S_{M1} = Fv S_1 Fa, Fv = Site coefficient
		S_{DS} S_{D1}	S_{DS}= 2/3 S_{MS} S_{D1}= 2/3 S_{M1}
Cs	Cs=Z K I S	Cs	Cs = S_{DS} / (R / I) Cs ≤ S_{D1}/ (R . T / I) Cs ≥ 0.044 S_{D1} I ; Cs ≥ 0.01
Vs	Vs = Cs W	Vs	Vs = Cs W

I, Importance Factor

T, Building Fundamental period

K, Structural System Coefficient

Z, Seismic Hazard Coefficient

S, Dynamic Coefficient

Cs, Seismic Response Coefficient

Vs, Base Shear

I, Importance Factor

T, Building Fundamental period

R, Response modification coefficient

S_S, Mapped spectral accelerations for short period

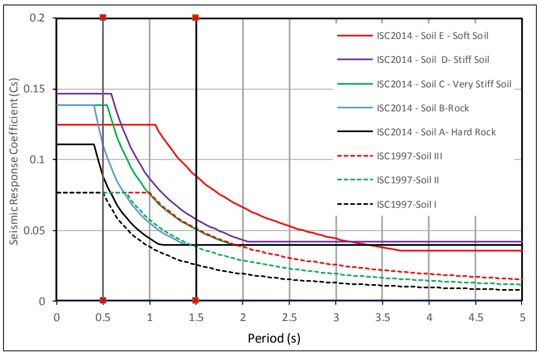
S_1, Mapped spectral accelerations for 1-Sec period

S_{MS} S_{M1}, Maximum Considered Earthquake (MCE) spectral response acceleration

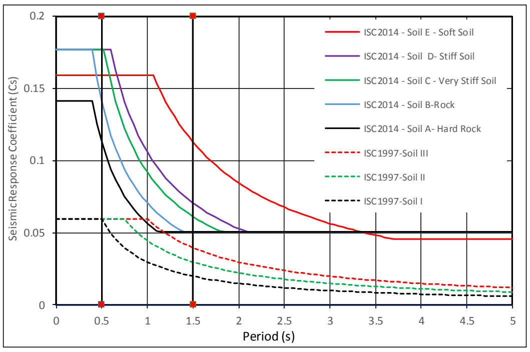
S_{DS} S_{D1}, 5% damped Design spectral response acceleration

Cs, Seismic Response Coefficient

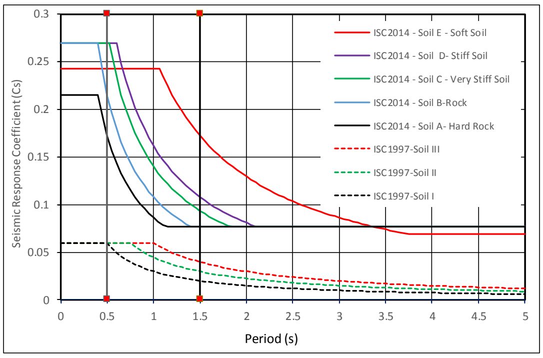
Vs, Base Shear



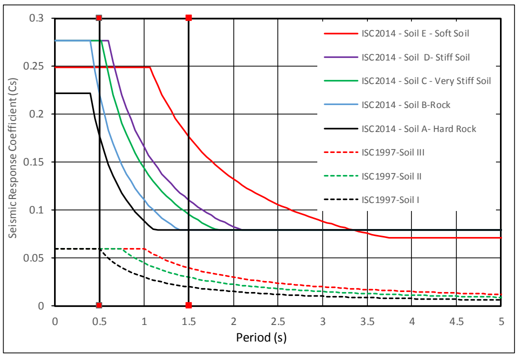
a) Duhok City



b) Erbil City



c) Sulaymaniyah City



d) Halabja City

FIGURE 7**.** Seismic response coefficient (C_s) using ISC 1997 [4] and ISC 2014 [7]

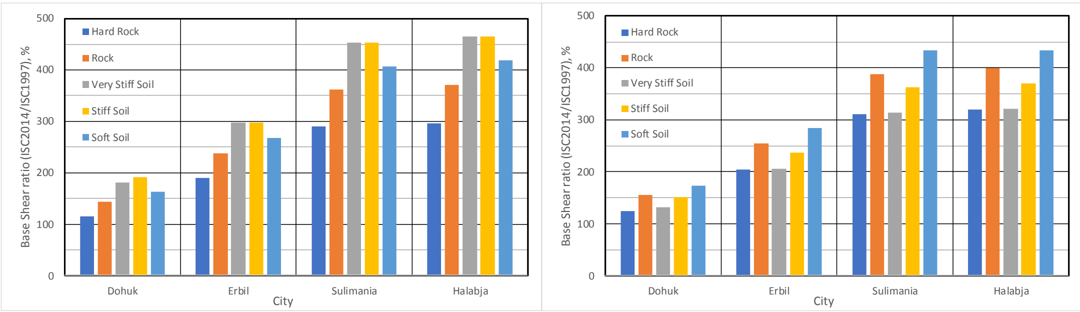
As two case studies, two values of building periods are taken, T=0.5 Sec (low-rise concrete frame building of 5 stories), T=1.5 Sec (intermediate-rise concrete frame building of 15 stories). For these two-time periods, C_S have been extracted from Figure 7 for both ISC 2014 and ISC 1997 codes; further, the ratios between C_S coefficients, which are equal to the base shear ratio, are reported in Table 2 and shown graphically in Figure 8 for different soil types and for all four main cities.

As could be seen, there is a significant increase in the base shear forces for the two building cases in Halabja and Sulaymaniyah, followed by Erbil then Duhok. This shows the massive impact that the introduction of the ISC 2014 has on the value of design seismic forces, and consequently the design implications.

TABLE 2.

Base shear ratio (ISC 2014/ISC 1997)

	Base shear ratio (ISC 2014/ISC 1997), %											
	5 story building, T=0.5 Sec						15 story building, T=1.5 Sec					
	Soil type					average	Soil type					average
	hard rock	rock	very stiff	stiff	soft		hard rock	rock	very stiff	stiff	soft	
	A	B	C	D	E		A	B	C	D	E	
Duhok	115	144	181	192	163	159	124	155	132	151	173	147
Erbil	190	237	297	297	268	258	204	255	205	237	284	237
Sulaymaniyah	290	362	452	452	407	393	311	388	314	362	434	362
Halabja	296	371	465	465	419	403	319	399	321	371	434	369



a) 5-Storey Building

b) 15-Storey Building

FIGURE 8. Base shear ratio (ISC 2014/ISC 1997)

2. MODAL RESPONSE SPECTRUM ANALYSIS

Apart from the ELFA, there is no common seismic analysis procedure between ISC 2014 and ISC 1997; this was the reason for choosing ELFA for comparison. To confirm that the ELFA is the driving seismic analysis tool for regular low-rise to intermediate-rise building, modal response spectrum analysis has been conducted according to ISC 2014 for 5-storey and 15-storey special reinforced concrete frame building (Importance Class III) located in Erbil city, constructed on a site class D stiff soil using ETABS 16.2.0, see Figure 9.

The seismic base shear determined by both methods (equivalent lateral force (V_s) and maximum response spectrum analysis (Vd)) are reported in Table 3. According the ISC 2014, as Vd is less than 0.85Vs, then the Vd must be raised to be equal to 85% of Vs. Based on that, the ELFA is superior to MRSA for regular RC buildings in the range of number of floors tested; this justify the use of the ELFA as the base for comparison between the ISC 2014 and ISC 1997 in the current paper

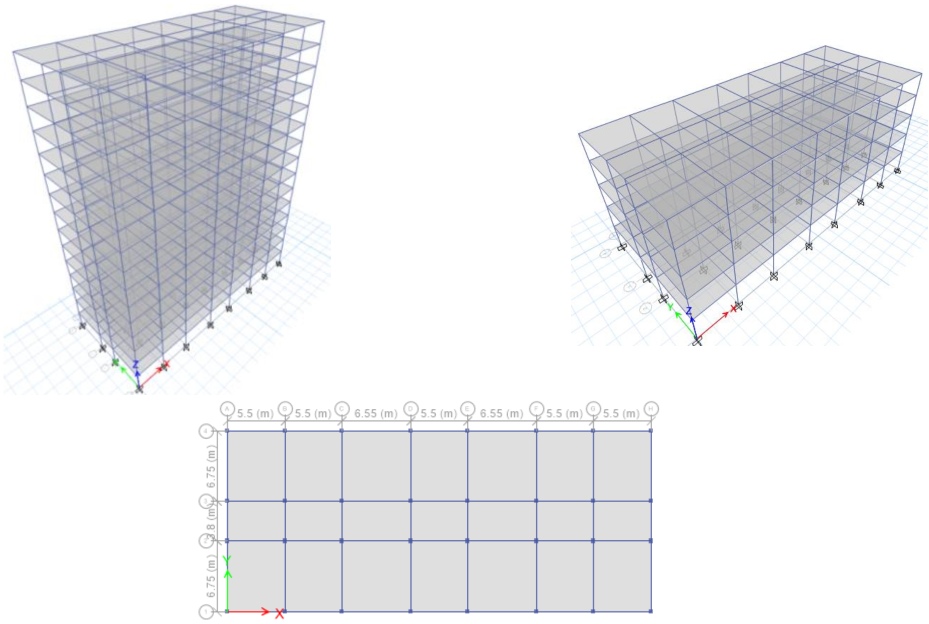


FIGURE 9. ETABS model geometry of the buildings.

TABLE 3.

Static and dynamic calculated base shear

Building	Direction	Vs (Static) kN	Vd (Dynamic) kN	0.85Vs/Vd
5 Story	X	7304.76	2591.62	2.396
	Y	7304.76	2524.03	2.460
15 Story	X	8979.99	3393.49	2.249
	Y	8979.99	3255.56	2.345

3. STRUCTURAL DESIGN CONSIDERATION FOR KRI

Based on the ISC 2014, there are four classes (A, B, C, D) for seismic design classification. This does not match ASCE/SEI7-10 [9], where six seismic design classes are defined (A, B, C, D, E, F). In the ISC 2014, the class for each site depends on the values of S_{DS} and S_{D1}; if $S_{DS} \geq 0.5$ g or $S_{D1} \geq 0.2$ g, the category of the site is assigned to be class D. Referring to Figures 3 and 4, both conditions are valid, therefore, all buildings constructed in the KRI region is considered to be of class D for all soil types no matter what it is the function or the construction system of the building. Based on ISC 2014 [7] and ASCE/SEI7-10 [9], for class D, all concrete frame building should be special type, as no ordinary or intermediate concrete frame is allowed to be built. ISC 2014 refers to ACI318 code [11] as the designing and construction tool of reinforced concrete buildings for ordinary and seismic loading; therefore, these special concrete frame buildings built in KRI should confirms to ACI requirements, which requires special member size and strength limitations and reinforcement details for the columns, beams and foundation that are not applied currently in the construction in KRI region. The effects of the building systems in KRI to be in seismic design class D will be increasing the requirements for detailing and proportioning, with expectations of increased deformation capacity, meaning that further design criteria need to be applied as listed in Tables 4 and 5.Regarding the Seismic Analysis Procedure Selection, Table 6 lists the selection criteria used in ISC 1997 [4] and ISC 2014 [7]. As seen, ISC 1997 considers only the importance class of the building, while ISC 2014 bases the selection on the building height (T value) and the irregularity in the building, which is more rational, as the dynamic behavior of the building is related to these two factors.

TABLE 4.

Seismic design criterial needs for masonry and steel construction constructed in KRI (seismic class D), based on ISC 2014 [7]

Building system	Structural system allowed	Limits (ISC 2014, Table 3-2-1)
Masonry wall system *	Special* masonry reinforced shear wall is allowed.	Height ≤ 50 m
Moment resisting steel frame#	Special	No limit
	Intermediate & ordinary	Specific limitations listed

*: Building Code Requirements for Masonry Structures (ACI 530-02/ASCE 5-02/TMS 402-02) [12] is the code permitted by the ISC 2014 for designing Masonry Wall system.

#: Seismic Provisions for Structural Steel Buildings (ANSI/AISC 341-16) [13] is the code permitted by the ISC 2014 for designing Masonry Steel frame.

TABLE 5.
Design criterial needs for reinforced concrete frame Buildings constructed in KRI (seismic class D), based on ISC 2014 [7] and ACI 318-14 [11]

Building system	Structural system allowed	Limits (ISC 2014, Table 3-2-1)	Ordinary ACI chapters to satisfy	Additional ACI sections to satisfy
Cast-in-place RC concrete shear wall	Special*	Height ≤ 50 m	CH 1 to 17 CH 19 to 26	Sections 18.2.2 - 18.2.8 Sections 18.10
Reinforced concrete shear walls in dual systems with **special** reinforced concrete frame	Special*	No Limit	Same	Sections 18.2.2 - 18.2.8 Sections 18.10
Reinforced concrete shear walls in dual systems with **intermediate** reinforced concrete frame	Special*	Height ≤ 50 m	Same	Sections 18.2.2 - 18.2.8 Sections 18.10
Cast-in-place moment resisting RC concrete frame	Special*	No limit	Same	Sections 18.2.2 - 18.2.8 Sections 18.6 - 18.8
Foundation			Same	Sections 18.13

* the term “special” (Compared with “ordinary”, “intermediate”, and) refer to increasing requirements for detailing and proportioning, with expectations of increased deformation capacity, as defined in ACI 318.

TABLE 6.

Seismic analysis selection procedure

Analysis Procedure	ISC 1997 [4]	ISC 2014 [7]
Equivalent lateral force analysis	All cases apart from buildings of I=1.5	Regular buildings with T < 3.5 Ts
		Irregular buildings with T < 3.5 Ts, but with specific type of irregularity
Modal response spectrum analysis	Not included in the code	All other cases
Dynamic time history analysis	Buildings of Importance class I=1.5	Not included in the code

4. PEAK GROUND CANCELATION (PGA)

The comparison presented in this study showed that there is a significant increase in the base shear for buildings constructed in KRI according to ISC 2014 compared to ISC 1997. This increase is mainly due to S_1 and S_S parameters assigned to this region by ISC 2014, which are affecting the values of the parameters S_{D1} and S_{DS}. To assess these values, they need to be returned back to their original status, which is Peak Ground Acceleration (PGA), the maximum amplitude of recorded acceleration, termed also as zero period acceleration [14, pp. 1-11].Therefore, at T=0:

$$PGA = S_a \qquad (1)$$

From Figure 1, the first inclined part in the response spectrum is defined as:

$$S_a = S_{DS}\,(\,0.4 + 0.6\,(T/T_0)\,) \qquad (2)$$

Then, at T=0:

$$S_a = 0.4\ S_{DS} \qquad (3)$$

The S_{DS} value is related to an earthquake with a 10% probability of occurrence in 50 years (Corresponding to 475-year recurrence interval) [15, p. 385]. On the other hand, the PGA map for Iraq (given in Figure 10) is for the same probability of occurrence, therefore by substituting Equation (1) in Equation (3)

$$PGA = 0.4\ S_{DS} \qquad (4)$$

$$PGA = 0.4 \ x\ (2/3)\ x\ F_a\ x\ S_S \qquad (5)$$

As F_a = 1 for Site Class B rock in ISC 2014 [7] , then

$$PGA = S_S\ /\ 3.75 \qquad (6)$$

Based on Equation (6) and Figure 3, the PGA values for Site Class B rock taken by ISC 2014 seems to be as follows: 0.282g for Duhok, 0.368g for Erbil, 0.56g for Sulaymaniyah and 0.576g for Halabja. On the other hand, the 475-year return period PGA map in Figure 10, provided by the Global Seismic Hazard Assessment Program [2], shows the PGA values to be around 0.21g for Duhok, 0.24g for Erbil, 0.42g for Sulaymaniyah and 0.42g for Halabja. The comparison suggests that the values of S_S and S_1 recommended by ISC 2014 are overestimated,

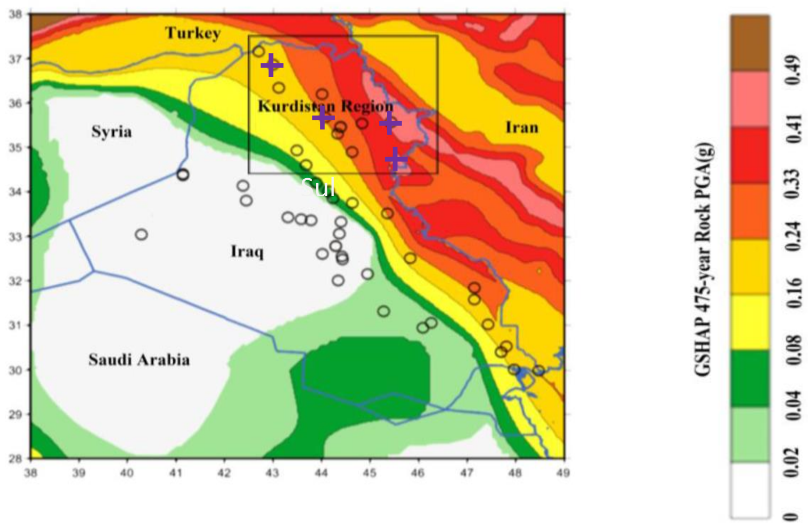


FIGURE 10**.** Peak ground acceleration (PGA) map for rock with a 10% probability of exceedance in 50 years (475-year return period) as reported by Global Seismic Hazard Assessment Program [16]

5. CONCLUSIONS

The conclusions drawn from the current study could be summarized as below:

1- The equivalent lateral force analysis for the two case studies of Reinforced Concrete Frame buildings (5 and 15 Stories) showed an increase in the Base shear using ISC 2014 compared with that obtained using ISC 1997 in the percentages shown below
-115 % to 192 % for Duhok city; 190 % to 297 % for Erbil city.
-290 % to 452 % for Sulaymaniyah city; 296 % to 465 % for Halabja city.

2- The applications of the current ISC 2014 imply considerable change in the building systems built in KRI, including the requirement of having:
-Special system (according to ACI318-14) for reinforced concrete frames, reinforced shear wall systems.
-Special system for steel frames in general (according to ANSI/AISC 341-16), with some exception to use ordinary or intermediate systems for some specific cases of low rise buildings.
-Special system for Masonry Bearing Wall system (according to ACI 530-02/ASCE 5-02/TMS 402-02).
These require a dramatic change in the structural analysis and the design procedures applied currently on the buildings constructed in KRI region.

3- The Equivalent lateral force analysis is proved to be superior to the modal response spectrum analysis as a seismic analysis tool for regular reinforced concrete buildings up to 15 floors in the ISC 2014.

4-The recommended S_S and S_1 values in the ISC 2014 seems to be overestimated compared with the local values for the peak ground acceleration given by GSHAP.

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