Evaluation of seismic performance of steel moment frames with Iran, Europe and Japan seismic codes

A. Kiani & A. Jalali & J. Fallah & S.S. Mirrezaei

Structural Engineering Department, School of Civil Engineering, University of Tabriz, Tabriz, Iran

ABSTRACT: There have been changes in concepts of different countries seismic design codes. Therefore it seems to be useful to compare some of these seismic codes. In this study, four SMRF buildings with 3, 6, 9 and 12 storey are designed with Iran (2800 standard), Europe (EC8) and Japan (BCJ) seismic codes under same circumstances and performance of these structures are evaluated with FEMA-356 and ATC-40 provisions. At the end, advantages and disadvantages of these codes are discussed.
Results of nonlinear static analysis indicate that yield displacement for the designed structures using three codes are close enough in different period ranges (short, moderate, long). Assessment of performance levels shows that BCJ code generally satisfies life safety performance level based on ATC-40. 2800 code doesn’t satisfy life safety in general. EC8 code satisfies life safety based on both FEMA-356 and ATC-40. In addition, most of plastic hinges are within IO-LS performance range.

1 INTODUCTION

United States, Newzealand and Japan are among countries that have had important roles in development of seismic codes. For instance, seismic design with static methods began in 1920 in United States or in Japan. The application of these methods goes back to 20th century. Also in Iran the development of seismic codes goes back to 2 decade ago.

As a result of theoretical and practical experiences, lots of specifications were developed, but there are some deep distinctions between these codes even in simple issues. The sources of these problems often returns to the concepts of each code and also comes back to decisions of committees who approved these provisions because of some local differences.

In this research, four two-dimensional steel moment resisting frame buildings with 3, 6, 9 and 12 storey are designed with Iran (2800 standard) , Europe (EC8) and Japan (BCJ) seismic codes under same circumstances. For performance evaluation of these structures nonlinear static analysis was performed according to FEMA-356, ATC 40provisions.

2 PRACTICAL EVALUATION OF IRAN (2800 STANDARD), EUROPE (EC8) AND JAPAN (BCJ) SEISMIC CODES

Japan is located in the middle of several earthquake prone areas. Two zone with high and intermediate seismic hazard near to Pacific Ocean and a zone with intermediate seismic hazard near to the see of Japan.

After catastrophic earthquake in Kanto, several other sever earthquakes was occurred which resulted in significant damages to buildings and utilities in Japan. After Kanto earthquake, earthquake force was considered as a lateral design force in design of new buildings.

It is notable that Japan has a seismic design code adopted in 1981, called BCJ hereinafter, that explicitly considers two levels of seismic forces, one for serviceability and the other for safety. BCJ also accounts for force redistribution after yielding due to redundancy, and trade-off between strength and ductility in accordance with the expected ductility of structures. The validity of such approaches has been tested for twenty years of practical experiences. It is notable that many of the buildings designed by this code experienced a few significant earthquakes such as the 1995 Hyogoken-Nanbu (Kobe) earthquake. There are many similarities between the approaches adopted in EC8 and BCJ, but because of the physical distance, language barrier and other factors, this

Japanese seismic design code has not been fully recognized in other countries including those in Europe.

Euro Code 8 (EC8) will change its status from the pre-standard (ENV) to the European Standard (EN). This “new code”, which is to replace respective national seismic standards, introduces various innovative European seismic design practices for steel buildings, such as the capacity design criteria and seismic force reduction factors explicitly correlated with expected ductility of the structure, among others. Many of such new concepts are already present in the national seismic codes adopted recently in many European countries (for example, DIN, 2002, O.P.C.M., 2003). It is notable, however, that such codes are not widely used in real practice; rather, familiar provisions stipulated in the old seismic codes (for example, DIN, 1981, D.M.LL.PP., 1996) are most commonly used.

Iran is located in one of three words earthquake prone areas which has caused lots of catastrophic earthquake in Iran. Importance of these events cause concentration of engineers and governors to this issue. The seismic design code of Iran was prepared with the purpose of consideration of earthquake forces as a design forces for new buildings.

3 REVIEW OF DIFFERENCES AND SIMILARITIES OF THESE CODES

Reviewing these three codes showed many similarities in approved methods in seismic design of structures. In fact general comparison of these three codes without consideration of output of these provisions can be misleding. For example, if a code result a large amount of design force in comparison to other codes, it seems that we will have a stronger structure but if we consider the lateral distribution shape and reduction and behavior factor of each code, in that case the result could be different.

All codes (EC8, BCJ, 2800 standard) define two seismic force levels. The reference seismic force (having a probability of exceedance equal to 10% in 50 years, i.e. a return period equal to 475 years, according to both EC8 and BCJ,2800standard) is representative of the strong ground motions. The other seismic force level (the probability of exceedance and return period are respectively 10% in 10 years and 95 years for EC8 and 50% in 30 years and 43 years for BCJ and 99.5% in 50 years for 2800standard) is representative of moderate ground motions. In BCJ seismic force levels corresponding to moderate and strong ground motions are named Levels 1 and 2, respectively.

Ground motion is represented by means of an elastic pseudo-acceleration response spectrum. Such a spectrum is correlated with the foundation soil stratigraphy: different soil types, ranging from hard to soft soils, and the corresponding pseudo-acceleration elastic spectra are defined in each code. Overall comparison of soil types in these three codes are shown in Table 1. Because different parameters are used by the three codes to classify the foundation soil ($V_{S,30}$ in EC8 & 2800 & T_g in BCJ), the comparison has been carried out with reference to a unique soil layer, with thickness equal to 30 m, placed over the rock soil.

Table 1. Comparison of soil types in EC8, BCJ, 2800 standard

<table>
<tr><th>Code</th><th colspan="5">Soil type</th></tr>
<tr><td>2800</td><td>I</td><td colspan="2">II</td><td>III</td><td>IV</td></tr>
<tr><td>EC8</td><td>A</td><td colspan="2">D</td><td>C</td><td>D</td></tr>
<tr><td>BCJ</td><td colspan="2">I</td><td colspan="2">II</td><td>III</td></tr>
</table>

0.2 0.4 0.6 0.8 Tg(sec)

The hard soil types (soil types A in EC8 and I in BCJ and 2800) include substantially the same foundation soils in all codes. The BCJ medium soil (type II) includes mainly soil types B and C. Finally, the BCJ soft soil (type III) includes soil type D in EC8. In summary, classifications of hard and soft soils given by these codes are relatively close to each other.

4 RESPONSE SPECTRA OF IRAN (2800 STANDARD), EUROPE (EC8) AND JAPAN (BCJ) SEISMIC CODES

Figure 1 shows elastic spectrum of EC8, BCJ, 2800 standard for strong ground motion levels. In present research all structures are designed with reference to a PGA equal to 0.40g. For comparison purpose all accelerations in EC8 and 2800standard should multiplied by 0.4g. With reference to strong ground motions, EC8 and BCJ spectrum are slightly smaller than those provided in 2800 standard.

5 CHARACTERISTICS OF MODEL STRUCTURES AND RESULTS OF ANALYSIS AND DESIGNS

For exact evaluation of items in preceding sections, a group of 3, 6, 9 and 12 storey steel moment resisting frames with intermediate ductility have been selected. Design of frames was performed according to Iranian, Europe and Japanese steel design codes. The numbers of bays were identical in all frames and were equal to 3. The length of bays and storey heights are considered 3 and 3.2 meters respectively. Also contributing width of each frame is equal to 5 meters.

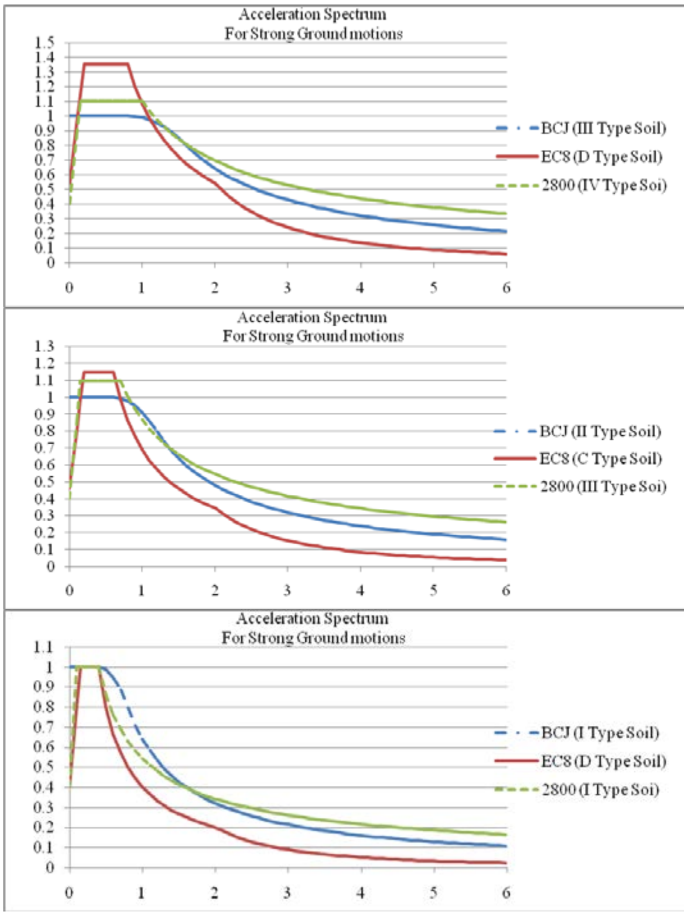

Figure 1. Elastic response spectra of 2800 standard, EC8 and BCJ for strong ground motion of different soil types.

Gravitational loading of frames was evaluated according to conventional roof systems and lateral loading of frames was assigned according to each seismic codes.

Because of the height of frames and appropriate regularity of structures both in plan and height, the application of equivalent static method is permitted according to 2800 standard, EC8 and BCJ. Following assumptions were made in evaluation of earthquake forces:

- All structures are designed with reference to a PGA equal to 0.40g and hard soils.
- All structures have intermediate importance factor and are set up in zones with very high seismic hazard regions.
- Structural system is intermediate steel moment resisting frame with 7 force reduction factor for 2800standard and 4 in EC8 and 3.33 in BCJ.
- Live load contribution factor equal to 0.2 was considered in all codes.

All case studies was analyzed and designed according to their own codes. Following controls has been imposed in design procedure.

- Control of stress limits
- Displacement control of structures based on code provisions.
- Control for serviceability load levels.
- Displacement control of each level according to serviceability earthquake loads.
- Special ductility controls.
- Control of Beam-column capacity ratio (in EC8 code)

IPE and IPB cross sections were used for modeling of beam and columns elements respectively. Figure 2 shows the result of seismic design for 6 storey frames.

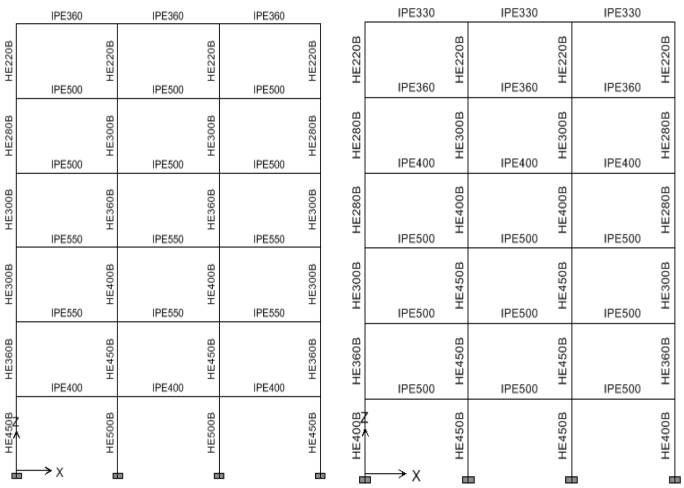

Figure 2. Designed case studies for 6 storey buildings according to 2800 standard, BCJ and EC8 (left to right).

6 RESULT OF NONLINEAR STATIC ANALYSIS OF STRUCTURES, CAPACITY CURVES AND TARGET DISPLACEMENTS OF STRUCTURES

Nonlinear static analysis was performed with SAP2000 program according to FEMA-356 and ATC-40 provisions. We briefly report some resully in following sections. Figure 4 shows capacity spectrum of structures with different lateral load patterns. Capacity spectrum of each structure has been drawn under following conditions:

- Capacity spectrum of structures considering lateral load pattern given by dynamic response spectrum analysis with 0.9 for dead load factor. (Push Xd-Spec)
- Capacity spectrum of structures considering rectangular lateral load pattern with 0.9 for dead load factor. (Push Xd-Rectangular)

In Table 2 the numbers of plastic hinges for different lateral load pattern at performance level of each structure are shown.

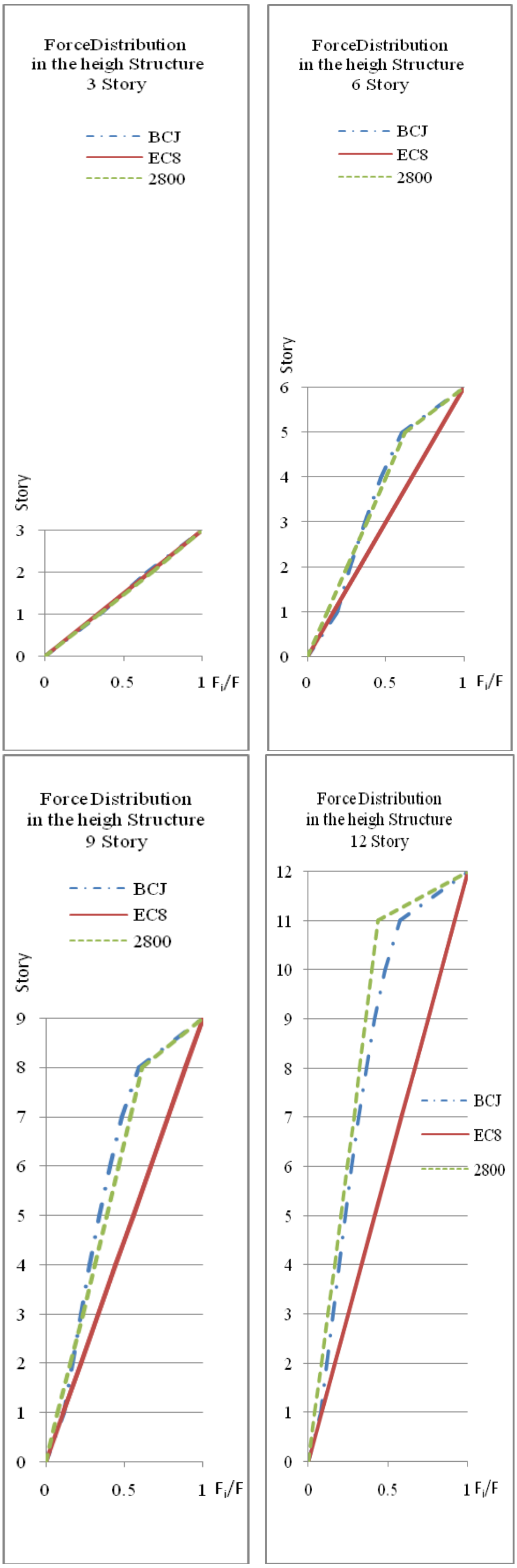

Figure 3. Lateral force distribution in 2800 standard, BCJ and EC8 for 3, 6, 9, 12 storey buildings.

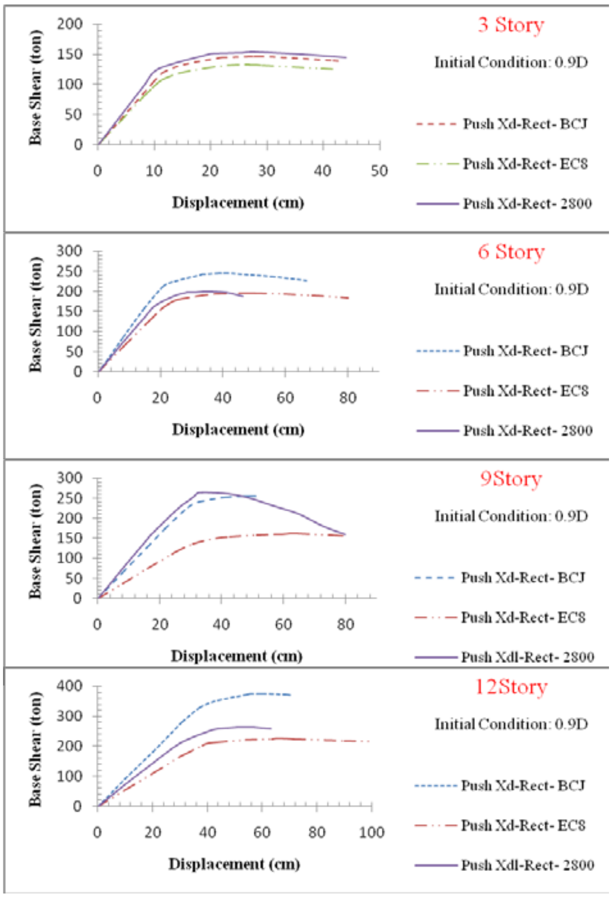

Figure. 4. Comparison of capacity curves are given by three codes.

Figure 5. Situations of plastic hinges in different performance level for 6 storey moment resistant frame

Table2. The numbers of hinges in each performance level.

6 Story 2800	A = 0.40g (10% - 50y)									
	ATC 40		A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Total
	Base shear (ton)	d_{target} (cm)								
Push X_D (Spec)	167.8	29.6	62	4	15	2	0	1	0	84
Push X_{D+L} (Spec)	165.9	29.5	61	5	14	1	0	3	0	84
Push X_D (Moda1)	167.2	29.2	65	3	13	2	0	1	0	84
Push X_{D+L} (Moda1)	164.8	29.2	64	4	10	3	0	3	0	84
Push X_D (Static Ex)	169.2	28.8	67	1	13	2	0	1	0	84
Push X_{D+L} (Static Ex)	167.1	28.7	66	2	10	3	0	3	0	84
Push X_D (Rect)	186.9	24.2	68	2	10	3	0	1	0	84
Push X_{D+L} (Rect)	183.8	24.0	70	1	6	4	0	3	0	84
6 Story BCJ	A = 0.40g (10% - 50y)									
	ATC 40		A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Total
	Base shear (ton)	d_{target} (cm)								
Push X_D (Spec)	194.7	25.7	60	6	18	0	0	0	0	84
Push X_{D+L} (Spec)	193.1	25.8	61	3	18	2	0	0	0	84
Push X_D (Moda1)	173.5	28.6	59	2	22	1	0	0	0	84
Push X_{D+L} (Moda1)	172.6	28.8	59	4	19	2	0	0	0	84
Push X_D (Static Ex)	183.1	27.7	58	8	18	0	0	0	0	84
Push X_{D+L} (Static Ex)	182.4	27.7	60	3	20	1	0	0	0	84
Push X_D (Rect)	219.1	22.5	65	2	17	0	0	0	0	84
Push X_{D+L} (Rect)	218.6	22.5	65	3	16	0	0	0	0	84
6 Story EC8	A = 0.40g (10% - 50y)									
	ATC 40		A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Total
	Base shear (ton)	d_{target} (cm)								
Push X_D (Spec)	132.4	27.0	67	5	12	0	0	0	0	84
Push X_{D+L} (Spec)	129.7	26.9	67	7	10	0	0	0	0	84
Push X_D (Moda1)	129.4	26.9	67	6	11	0	0	0	0	84
Push X_{D+L} (Moda1)	127.1	26.8	67	6	11	0	0	0	0	84
Push X_D (Static Ex)	136.8	26.4	69	5	10	0	0	0	0	84
Push X_{D+L} (Static Ex)	134.5	26.2	71	2	11	0	0	0	0	84
Push X_D (Rect)	168.8	22.7	69	9	6	0	0	0	0	84
Push X_{D+L} (Rect)	165.9	22.6	67	7	8	2	0	0	0	84

For better appreciation of hinges` situation in designed structure in three codes, the number of plastic hinges in different performance level of 6 storey building considering different lateral load shape was shown again in different diagrams. Figure 3 shows the ratio of all plastic hinges in a performance level of structure.

In the preceding sections, target displacement was calculated according to different methods and it was clear that there was some differences in amount of target displacement that can be misleading. In oreder to compare the results and gain more insight the target displacement given by ATC-40, was used. Because of space limitation we have not presented the results.

7 CONCLUDING REMARKS

- Steel moment frames designed with 2800 seismic code, have not satisfied life safety performance level based on FEMA-356 and ATC-40 provisions.
- Steel moment frames designed with BCJ seismic code, have satisfied life safety performance level based on ATC-40 provisions. Also all most all of plastic hinges were between IO-LS performance levels.
- Steel moment frames designed with BCJ seismic code, have not satisfied life safety performance level based on FEMA-356 provisions.
- Steel moment frames designed with EC8 seismic code, have satisfied life safety performance level based on FEMA-356 and ATC-40 provisions.
- Among these three seismic codes, 2800 standard considers greater earthquake loads for structures with long periods.
- Yield displacement of designed structures with these three codes, mostly correspond to each other.
- From strength point of view, overall strength of short and middle period structures among these three codes are almost identical but it differs for high rise structures with long periods.
- It seems that structures designed with EC8, have better behavior before and during yielding and also even after yielding of structure the total stability of structure without minus stiffness was preserved. This returns directly to appropriate distribution of stiffness among seismic resistant elements.
- Observation of minus stiffness in structures designed with 2800 standard is concerning. Although the overall strength level of this code is more than others but distribution of stiffness in height prevents structure from a uniform behavior in all steps of seismic loading.

8 REFERENCES

2800 code. 2005. Seismic resistant design of buildings - Code of practice. *Institute of Standards and Industrial Research of Iran*: 3st.revision

AIJ, 1973, Design standard for steel structures. Tokyo: *Architectural Institute of Japan*; [in Japanese].

AISC, 1989. Load and Resistance Factor Design Specification for Structural Steel Buildings" AISC, Inc., Chicago.

ATC40, 1996, Seismic evaluation and retrofit of steel buildings, ATC 40, Redwood City, CA.

BCJ, 1997, Structural provisions for building structures. 1997 edition Tokyo: Building Center of Japan.

CEN. Euro Code 8: Final draft of Euro Code 8: Design of structures for earthquake resistance Part 1: General rules, seismic actions and rules for buildings. Bruxelles: *European Committee for Standardization*.

FEMA 356, 2002, Prestandard and Commentary for the seismic rehabilitation of buildings, Federal Emergency Management Agency, Washington D.C.

Midorikawa, M. & Okawa, I & Iiba, M. & Teshigawara, M. 2003. Performance-based seismic design code for buildings in Japan. *Earthquake Engineering and Engineering Seismology* 2003;4(1):15–25.

Nakashima, M. & Roeder, CW. & Maruoka, Y. 2000. Steel moment frames for earthquakes in United States and Japan. *Journal of Structural Engineering, ASCE 2000*;128(8):861–8.

Pan, P. & Zamfirescu, D. Nakashima, M. & Nakayasu, N. 2005. Base-Isolation design practice in Japan: Introduction to the post-Kobe approach. *Journal of Earthquake Engineering* 2005;9(1):147–71.

Performance-based seismic design concepts and implementation. In: Proceedings of an international workshop. *PEER Report 2004/15. Berkeley: Pacific Earthquake Engineering Research Center*; 2004.