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Importance evaluation of the structural members of moment frame intermediate buildings with X-bracing designed with various editions of the 2800 code (based on the 360 publication, 1392 edition)

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***Abstract*—** By increasing information on buildings behavior in the earthquake and codes updating, concerns exist about the seismic state of a large volume of existing buildings built without the application of new criteria. To verify this, we need to carefully evaluate the members of the buildings constructed with various editions of the 2800 code and identify vulnerable members of buildings designed with different editions of the code, and have a comparison between the various editions of the 2800 code. Given that the 2800 code is applicable to the design of new buildings and cannot be used to evaluate buildings constructed in accordance with previous codes, then we need to use a seismic rehabilitation instruction to evaluate buildings based on specific performance and certain hazard levels. The purpose of this paper is to identify vulnerable members of buildings designed with various editions of the 2800 code. In order to achieve this goal, we first design 2 buildings of 5 and 6 floors by the first, second, third, and fourth editions of the 2800 Code. In the following, after analyzing and designing with the different editions of the 2800 code, a comparison with the fourth edition of this code and the assessment of the members of the buildings based on the criteria for "Instruction of seismic rehabilitation of the existing buildings" (360 Publication) is made.

Keywords *— Members Evaluation, Identifying vulnerable members, 2800 codes of practice editions, Seismic rehabilitation instruction.*

I. INTRODUCTION

The seismic response of steel frames under periodic earthquake induced by earth movement has been investigated in different studies [1]. The results indicate that strength is an inadequate criterion for seismic design, since most of the structures yielded in strong earthquakes and entered the plastic zone. The performance-based design is a more comprehensive design philosophy in which the design criterion is expressed in terms of functional goals. The functional goal can be known as the desired level of seismic performance of the structure, such as lateral deformations, lateral displacement of the story, the element's ductility and the damage index of the element in relation to a certain level of earthquake risk. In other words, a functional goal is formed by combining a level of building performance and an earthquake level [2]. The publication of a building code of practice on the base of operational design was developed by the Seaoc Decision Group in 1992 through the 2000vision Committee, which was scheduled to be completed before 2000 but did not take any action, except for limited activities. The reason behind of the formation of this Committee was a huge $ 8 billion damage caused by the 1989 Loma Prieta earthquake

II. RELATED WORK

In January 1994, the Northridge earthquake hit a magnitude 6.7 Richter, causing a loss of about $ 20 billion. As a result, within a year, the vision2000 committee proposed performance-based design proposals. The report was released in 1995, which contains detailed works on earthquake engineering in the field of performance-based design [3]. Subsequently, in 1997, the Seaoc instruction for the new buildings and NEHRP for seismic rehabilitation of existing buildings (FEMA 273,274) were revised [4]. In this way, a primary source of performance-based design was provided, including suggestions and guidelines for designing new buildings and rehabilitation of existing buildings [3]. In Iran, the seismic rehabilitation instruction has been developed to replace the design philosophy based on performance instead of design based on resistance. In other words, the main distinguishing feature of this code of practice, which its preliminary draft framework is based on FEMA reports, with previous regulations such as 2800 [6], [7], [8], [9], is the use of a nonlinear method which has radically transformed the approach to seismic design and the method of structural analysis and design.

III. Models Reviewed

Two residential building models are considered that the first model is an irregular 5 story residential building and the second model is a regular 4 story residential building. Both models have a conventional moment frame system on one side and a simple frame with x-bracing on the other side and the gravity loading of the examined buildings is in accordance with 6th chapter of the National Building Code, ed. 1392 [10], which is given in Table (1) and their lateral loading is based on the Seismic resistant design of buildings code of practice, Iran 2800 standard revisions first [6], second [7], third [8], and fourth [9]. In calculating the earthquake coefficient (C) of buildings according to the standard 2800, the Π earth type has been selected. Design of frames was also carried out in accordance with the tenth chapter of the National Building Code of Iran, edition 1392 [11] and LRFD method. Also, seismic standards are in accordance with standard 2800 and the relative displacement of each story is considered in accordance with this standard in the design process of building. The two models plan views are shown with the names of their members in Figures (1) and (2).

Table.1. Design gravity load

	Load Type	Load Intensity (kg/m^2)
Roof	LROOF	150
	SNOW	150
	DEAD	615
Stories	LIVE	200
	DEAD	555
	PARTION LIVE	180

IV. Materials Properties and Sections Type of the Members

Specifications of materials are considered as follows:

$F_y = 2400\, Kgf/cm^2$ Steel yield strength

$F_u = 3600\, Kgf/cm^2$ Steel ultimate strength

$E = 2.04 \times 10^6\, Kgf/cm^2$ Steel elastic modulus

$\nu = 0.3$ Poison ratio

For columns, double IPE sections with reinforcing plates were used, and for the beams, IPE sections with reinforcing plates were used. Channel cross section is also used for braces.

Software Analysis and Design

In this research, ETABS 9.7.4 software was used to analyze and design the samples according to standard 2800, as well as to control and evaluate them according to different methods of seismic rehabilitation instruction.

Models Naming

The Building models naming is as follows:

1- 5 story building designed with the first edition of the 2800 Code: Model (F5-1)

2- 5 story building designed with the second edition of the 2800 Code: Model (F5-2)

3- 5 story building designed with the third edition of the 2800 Code: Model (F5-3)

4- 5 story building designed with fourth edition of the 2800 Code: Model (F5-4)

5- 4 story building designed with the first edition of the 2800 Code: Model (F4-1)

6- 4 story building designed with the second edition of the 2800 Code: Model (F4-2)

7- 4 story building designed with the third edition of the 2800 Code: Model (F4-3)

8- 4 story building designed with fourth edition of the 2800 Code: Model (F4-4)

The designs results and their comparison with the fourth edition of the standard 2800

After designing the models based on various editions of the standard 2800 and comparing it with the latest standard edition (Fourth Edition), the members which are not responding are listed in Tables (2) to (7).

Table.2. Weak sections in the model (F5-1)

Story / Section	First Floor	Second Floor	Third Floor	Fourth Floor	Fifth Floor
Beam	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B1-B2-B3-B8-B9-B10-B15-B16-B22 –B24
Column	C1-C2-C3-C4-C5-C6-C7-C8-C9-C10-C11-C12-C13-C14-C15	C2-C3-C4-C5-C6-C7-C8-C9-C10-C11-C12-C14-C15	C2-C3-C5-C6-C7-C8-C9-C10-C12	C5-C6-C9	C11
Brace	D1-D2-D4	D1-D2-D3-D4			

Table.3. Weak sections in the model (F5-2)

Story / Section	First Floor	Second Floor	Third Floor	Fourth Floor	Fifth Floor
Beam	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B2-B3-B8-B9-B10-B15-B16-B17-B22
Column	C2-C3-C4-C5-C6-C7-C8-C9-C10-C11-C12-C14-C15	C2-C3-C5-C6-C7-C8-C9-C10-C11-C12-C14-C15	C2-C5-C6-C7-C8-C9-C10-C12		
Brace	D1-D2	D1			

Table.4. Weak sections in model (F5-3)

Story / Section	First Floor	Second Floor	Third Floor	Fourth Floor	Fifth Floor
Beam	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B1-B2-B3-B8-B9-B10-B15-B16-B17-B22-B23-B24	B16-B17
Column	C5-C9-C8-C12	C5-C9-C8-C12	C5-C9-C8-C12		
Brace					

Table.5. Weak sections in the model (F4-1)

Story / Section	Second Floor	Third Floor	Fourth Floor	Fifth Floor
Beam	B1-B2-B3-B4-B5-B7-B9-B10-B11-B12-B13-B14	B1-B2-B3-B4-B5-B7-B11-B12-B13-B14	B1-B2-B3-B4-B5-B9-B10-B11-B12-B13-B14	B1-B2-B3-B4-B10-B12-B13-B14
Column	C1-C2-C3-C6-C7-C8-C9-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19	C1-C2-C3-C6-C7-C8-C9-C10-C12-C13-C14-C15-C17-C18-C19	C1-C2-C3-C6-C7-C8-C9-C10-C11-C12-C13-C14-C15-C16-C17-C18-C19	C11-C12-C13-C16-C17-C18
Brace	D1-D2-D3-D4	D1-D2-D3-D4	D1-D2-D3-D4	D1-D2-D3-D4

Table.6. Weak sections in the model (F4-2)

Story / Section	Second Floor	Third Floor	Fourth Floor	Fifth Floor
Beam	B1-B2-B3-B12	B2-B11-B12-B14	B2-B3-B10-B11-B12	B1-B2-B10-B13
Column	C3-C12-C17-C18	C10	C10-C13-C14-C18	C11-C13-C16
Brace	D1-D2-D3-D4	D1-D2-D3-D4	D3-D4	

Table.7. weak sections in model (F4-3)

Story / Section	Second Floor	Third Floor	Fourth Floor	Fifth Floor
Beam	B1-B2-B4-B11-B12-B13	B1-B2-B11-B12-B13	B11-B12-B13	
Column	C12-C17-C18			
Brace	D1-D2-D3-D4	D1-D2-D3-D4	D1-D2-D3-D4	

Analysis of models

Designed samples with the first, second, third, and fourth editions of the 2800 standard were analyzed based on seismic rehabilitation instruction under baseline rehabilitation with nonlinear static method. Then we evaluate the models. It should be noted that in the non-linear static analysis the first type of lateral load distribution was applied on the structures. Since the baseline rehabilitation is selected as the purpose of rehabilitation, it is expected that under earthquake "hazard level-1" provide the life safety of the residents. This level of risk is determined on the basis of 10% probability of an earthquake event in 50 years (equivalent to the return period of 475 years), which is called the design earthquake (DBE) in Iran's 2800 standard.

Non-linear static method

For beams, nonlinear hinge of M3, V3 was defined at the beginning and the end of the beam, and for the columns nonlinear hinge of M2, M3 was assigned to the first and the end of the column, and for the braces **Axial P** is defined in the distance of 0.1 from the beginning of the brace. Two types of lateral load distribution can be applied to a model that if the building is designed in accordance with one of the standard 2800 editions, the appliance of the second type lateral load distribution (uniform distribution) is unnecessary (360 Publication). For this reason, only the first type distribution has been used.

First type distribution

Since in all buildings at least 75% of the mass of the structure was involved in the first vibration mode in the desired direction, this type of distribution was selected proportional to the lateral load distribution in the linear static method, i.e. in accordance with equation (1):

$$F_i = \frac{W_i h_i^k}{\sum_{j=1}^{n} W_j h_j^k} V \qquad (1)$$

In the above relation F_i is the lateral force on the floor i, W_i is the weight of the floor i, h_i is the height of the floor i and V is the base shear force, and the value of K is equal to:

$$K = 0.5T + 0.75$$

T is the main periodic time. For $T \le 0.5$, K is equal to 1 and for $T \ge 2.5$ is equal to 2.

For satisfying the 3.2.3 clause of the 360 publication, for each direction, lateral forces are pushed up to 30% of the target displacement along the orthogonal direction, and then the lateral load pattern is pushed up to 150% of the target displacement in the desired direction.

Target displacement

The target displacement for a structure with rigid diaphragms should be estimated with respect to the nonlinear behavior of the structure. In this paper, according to the 360 publication, as an approximate method, the following equation is used to calculate the target displacement:

$$\delta_t = C_0 C_1 C_2 C_3 \int_a \frac{T_e^2}{4\pi^2} g \qquad (2)$$

Where T_e is the effective main periodic time of the building according to $T_e = T_i \sqrt{\frac{ki}{ke}}$ relation for the desired extension. Since it is necessary to have the effective main periodic time of the structure, T_e, for the purpose target displacement calculation, but as long as the structural capacity curve is not available, it is not possible to calculate the exact effective main periodic time of the structure. So in the preliminary assumption, assuming that the analytic periodic times of the structures are defined, the displacement values for each model are computed.

C_0 Coefficient: According to the controls taken, it was found that our buildings in this study are not shear buildings (the shear building is a building in which relative lateral displacement of each floor is smaller than its lower floor).

The C_1, C_2 coefficients are also determined according to the existing parameters in Chapter 3, since in all models $T_e \rangle 1$ so in all of them C1 = 1, also considering that in all models $T_e \rangle 0/7$, so in all models C1 = 1. S_a is also calculated from the product of the reflection index in the design acceleration (AB).

Table.8. target change according to seismic recovery instruction

Building Type	2800 Standard	Target Displacement (meter)
Irregular 4 stories	Version 1	0/16
	Version 2	0/13
	Version 3	0/12
	Version 4	0/11
Regular 5 stories	Version 1	0/20
	Version 2	0/16
	Version 3	0/16
	Version 4	0/16

Evaluation of model members in static nonlinear analysis

The main objective of this paper is to evaluate the importance of the members of the two irregular 4-story and regular 5-story models in planes. Therefore, after evaluating the design results of the models, we performed a nonlinear static analysis according to the seismic rehabilitation instruction (360 publication), and then by studying the color of the joints formed in the models and their vulnerability, the level of importance of the members were obtained.

Table.9. Members evaluation of model F4-1

Model F4-1				
Members	The importance percentage of the fourth floor members	The importance percentage of the third floor members	The importance percentage of the second floor members	The importance percentage of the First floor members
B1	7.1	9.6	9.6	4.7
B2	4.7	23.9	23.9	4.7
B3	2.3	7.1	7.1	7.2
B4	7.1	7.2	7.2	4.7
B5	0	7.2	7.2	0
B6	0	0	0	0
B7	0	9.7	9.7	0
B8	0	0	0	0
B9	0	0	0	0
B10	0	2.3	2.3	2.3
B11	0	7.1	7.1	2.3
B12	0	2.3	2.3	4.7
B13	0	2.3	2.3	2.3
B14	2.3	0	0	2.3
D1	0	0	28.9	28.9
D2	85.8	85.8	90.5	90.5
D3	0	0	0	0
D4	0	0	0	0

Table.10. Members evaluation of model F4-2 model

Model F4-2				
Members	The importance percentage of the fourth floor members	The importance percentage of the third floor members	The importance percentage of the second floor members	The importance percentage of the First floor members
B1	4/7	9/6	9/6	7/1
B2	4/7	9/6	14/5	16/8
B3	0	4/7	2/3	7/1
B4	4/7	4/7	4/7	0
B5	0	2/3	2/3	0
B6	0	0	4/7	2/3
B7	0	0	4/7	2/3
B8	0	0	2/3	0
B9	0	0	0	0
B10	0	0	0	0
B11	0	2/3	2/3	0
B12	0	2/3	2/3	0
B13	2/3	0	2/3	2/3
B14	0	0	0	0
D1	0	0	0	0
D2	14/3	28/9	85/8	85/8
D3	0	0	0	0
D4	14/3	85/8	85/8	85/8

Table.11. Members evaluation of model F4-3

Model F4-3				
Members	The importance percentage of the fourth floor members	The importance percentage of the third floor members	The importance percentage of the second floor members	The importance percentage of the First floor members
B1	0	2/3	9/6	14/5
B2	2/3	9/5	9/6	14/5
B3	0	0	2/3	14/5
B4	2/3	7/1	7/1	38/5
B5	0	0	2/3	0
B6	0	4/7	4/7	4/7
B7	0	2/3	9/5	7/15
B8	0	0	4/7	7/15
B9	0	0	2/3	7/15
B10	0	0	0	0
B11	0	2/3	2/3	4/7
B12	0	0	2/3	2/3
B13	0	0	2/3	4/7
B14	0	0	2/3	2/3
D1	0	0	0	19/2
D2	19/2	28/9	85/8	85/8
D3	0	0	0	0
D4	26/8	85/8	85/8	85/8

Table.12. Members evaluation of model F4-4

Model F4-4				
Members	The importance percentage of the fourth floor members	The importance percentage of the third floor members	The importance percentage of the second floor members	The importance percentage of the First floor members
B1	2/3	2/3	4/7	9/6
B2	0	7/1	7/2	28/8
B3	2/3	2/3	4/7	4/7
B4	2/3	7/1	0	14/6
B5	0	0	2/3	0
B6	0	2/3	4/7	4/7
B7	0	4/7	4/7	4/7
B8	0	2/3	4/7	2/3
B9	0	0	0	2/3
B10	0	0	0	0
B11	0	2/3	2/3	2/3
B12	0	0	2/3	2/3
B13	0	2/3	2/3	2/3
B14	0	0	0	2/3
D1	0	0	0	0
D2	0	28/9	85/8	85/8
D3	0	0	0	0
D4	0	28/9	85/8	85/8

Table.13. Members evaluation of model F5-1

Model F5-1					
Members	The importance percentage of the fourth floor members	The importance percentage of the third floor members	The importance percentage of the second floor members	The importance percentage of the First floor members	The importance percentage of the fourth floor members
B1	4/7	4/7	7/1	12	11/9
B2	0	4/7	2/3	4/7	2/3
B3	0	0	2/3	9/6	4/7
B8	7/1	7/1	11/9	19/2	14/3
B9	0	0	2/3	2/3	2/3
B10	0	0	2/3	7/2	4/7
B15	0	0	0	7/1	7/1
B16	0	0	0	2/3	0
B17	0	0	2/3	4/7	4/7
B22	0	0	2/3	2/3	2/3
B23	0	0	0	2/3	0
B24	0	0	0	2/3	4/7
D1	0	0	9/6	24	28/9
D2	42/9	85/8	90/5	90/5	95/2
D3	0	0	0	28/9	28/9
D4	85/8	85/8	85/8	95/2	100

Table.14. Members evaluation of model F5-2

Model F5-2					
Members	The importance percentage of the fourth floor members	The importance percentage of the third floor members	The importance percentage of the second floor members	The importance percentage of the First floor members	The importance percentage of the fourth floor members
B1	0	4/7	11/9	21/7	19/2
B2	0	2/3	4/7	4/7	4/7
B3	0	4/7	4/7	14/5	9/6
B8	2/3	9/5	21/7	19/3	19/2
B9	0	0	2/3	2/3	2/3
B10	0	2/3	4/7	4/7	4/7
B15	0	0	0	4/7	11/9
B16	0	0	0	0	4/7
B17	0	2/3	7/1	4/7	4/7
B22	0	0	9/5	9/5	9/5
B23	0	0	0	2/3	0
B24	0	0	4/7	4/7	4/7
D1	0	0	0	19/2	23/8
D2	0	85/8	61/9	81	90/5
D3	0	0	0	23/8	28/6
D4	0	85/8	85/8	90/5	95/2

Table.15. Members evaluation of model F5-3

Model F5-3					
Members	The importance percentage of the fourth floor members	The importance percentage of the third floor members	The importance percentage of the second floor members	The importance percentage of the First floor members	The importance percentage of the fourth floor members
B1	0	14/3	21/7	24/2	21/7
B2	2/3	4/7	7/1	7/1	4/7
B3	4/7	7/1	16/8	14/4	16/8
B8	4/7	16/7	21/7	24/2	21/7

B9	0	4/7	2/3	2/3	2/3
B10	0	4/7	9/6	9/6	9/6
B15	0	0	9/5	14/5	14/3
B16	0	2/3	2/3	4/7	4/7
B17	0	7/1	12	16/8	12
B22	0	4/7	11/9	19/2	19/2
B23	0	0	4/7	4/7	4/7
B24	0	4/7	7/1	12	9/5
D1	0	0	0	9/6	19/2
D2	0	0	14/4	61/9	85/8
D3	0	0	0	19/2	28/6
D4	0	0	85/8	90	90/5

Table.16. Members evaluation of model F5-4

Model F5-4					
Members	The importance percentage of the fourth floor members	The importance percentage of the third floor members	The importance percentage of the second floor members	The importance percentage of the First floor members	The importance percentage of the fourth floor members
B1	0	14/4	12	9/5	9/5
B2	0	4/7	2/3	2/3	0
B3	2/3	7/2	4/7	4/7	2/3
B8	0	12	21/7	7/2	4/7
B9	0	2/3	0	0	0
B10	0	4/7	4/7	7/2	4/7
B15	0	0	2/3	4/7	4/7
B16	0	2/3	0	0	0
B17	0	4/7	4/7	9/6	4/7
B22	0	4/7	4/7	4/7	2/3
B23	0	0	0	0	0
B24	0	4/7	4/7	2/3	2/3
D1	0	0	14/3	28/9	28/6
D2	0	0	23/9	85/8	90/5
D3	0	0	19/2	28/9	28/9
D4	0	14/3	66/8	90/5	95/2

V. CONCLUSIONS

1. Buildings with bracing system with moment frame are not able to provide a life safety performance level due to the major weakness of the compressive bracings.

2. By comparing the push curves and hinges condition, it can be said that in these buildings, due to the truss performance, they increase the hardness of the steel frame to a large extent, but they do not have a proper ductility and this non-ductile behaviour often results from the early destruction of bracing members during major deformations, and the underlying cause of this phenomenon can be seen in the philosophy governing design codes, in which instead of requiring that bracing members and joints have to tolerate early deformations (that is, sufficient ductility), regulations generally require additional lateral forces in their design.

3. The process of forming plastic hinges in models shows that at first the braces, then the beams and at the end the columns form hinge, which this process of plastic hinges forming shows that the push-over analysis done is correct. In general, it can be said that the braces are more important than the beams, and the beams are more important than the columns.

4. The formation of plastic hinges in the moment frame beams shows that the beams located on the borders of the plan are more important than the other beams.

5. The plastic hinge dose not form in none of the beams of the braced frame models, which indicates that these beams are used only for connecting members and do not play a role in bearing the deformations resulting from the displacement of the structure and all deformations occur in the bracings.

6. In the irregular 4-story model, it can be seen that the beams located in the middle of the span are mainly form plastic hinge in large displacements.

7. In the regular 5-level model, it can be seen that the beams located in the moment frame of the stair box also form hinge in small displacements, indicating the importance of these beams in regular buildings.

8. In the 5-story building, in all models designed with different editions of the 2800, B8 beam has the most impotency in most stories, after which the B1 beam is

ranked as the second important beam, and B3 is in the third position, and the B22, B17, and B15 beams are among the 5 important beams in most of the models.

9. In the 5-story building, in all models designed with various editions of the 2800 code, in most stories, D4, D2, D3, D1 braces are in the first to fourth positions in terms of their importance, respectively.

10. In the 4-story building, in all models designed with different editions of the 2800 code, B2 beam is the most important beam in all stories, and then B1, B4, and B3 are among important beams in most of the stories.

11. In the 4-story building, in all models designed with various editions of the 2800 code, in most stories D4, D2, D3, D1 brackes are in the first to fourth positions in terms of their importance, respectively.

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