



Seismic Design Parameters Assessment of Special Steel Moment Resisting Frames Using the Collapse Margin Ratio (CMR) Method

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ABSTRACT: This research intends to quantitatively evaluate the seismic parameters of special steel resisting moment frames designed via the prescribed values in the Iran standard No. 2800. Sixteen designed frames having 4, 6, 8, and 12 stories and grouped into four types are dynamically non-linearly analyzed by means of OPENSEES software incorporating the element stiffness degradation. The general far-fault 22 record pairs presented by FEMA_P695 is used in the process of preparing the frame's fragility curves where are localized with multiplying their medians by corresponding predicted spectral shape factors (SSF). The frame's seismic parameters (R factor and over-strength factor) are calculated using two methods; FEMA_P695 criteria, developed on the basis of epsilon as the spectral shape parameter, and the proposed approach, developed on the actual definition of spectral shape parameter. The results of this study showed that use of FEMA_P695's rules end up with acceptable groups' seismic parameters, opposed to those groups where have been associated with rock and soft soil conditions and judged by the other approach. It is expected that the whole seismic parameters presented in the standard No. 2800 will be evaluated based on the currently used analytical methods in the near future.

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1- Introduction

Nowadays, it is quite postulated that a code-conforming structure should remain safe against the hazard levelled extreme event ground shaking most likely to happen during within the next fifty years. The lateral force prescribed in the existing seismic design provisions are much lower than the lateral strength required. Its reason is that the existing design softwares are developed on the basis of elastic behavior of structures while the designed structures would behave non-linear against the code's design spectra. Therefore, the induced real earthquake shear force should be reduced to the lower level of strong motion's lateral force which structures typically behave elastic. This done by a factor namely "modification factor" or R factor which permits the analyst to linearly distribute the applied seismic code lateral force. During the last decades, several researchers have expressed their concern about the lack of rationality in current R factors [1, 2]. Therefore, R factor improvement has been identified as a way to improve the reliability of present earthquake-resistant design provisions [3].

2- Collapse Safety Under Rare Event

Recent advancements in non-linear dynamic analysis and performance-based earthquake engineering are making it possible to rigorously assess structural collapse. The problem has been solved by the Applied Technology Council (ATC)

document which has recently completed the FEMA_P695 [4] and contains a formalized assessment methodology for quantifying structural collapse safety under seismic loading. ATC-63 requires that the likelihood of structural collapse be controlled to an acceptably low level, that is, "ten percentile probability of collapse" due to the hazard levelled extreme event (MCE) i.e., with 2% chance in fifty years.

2- 1- Collapse Capacity Prediction

In order to achieve the requirement of ATC-63, as mentioned above, one need to develop a log-normal collapse distribution of the structure under study termed "fragility curve". The fragility curve is prepared through performing 44 numbers of dynamic analysis using the IDA approach. The general far-field set of 44 recordings are presented by FEMA_P695 [4]. The output of this step is 44 structure's collapses which are used to fit a lognormal distribution and identifying its median value, $(S_{a_{col}})_{T_1}$.

3- Collapse Margin Ratio (CMR)

To ensure that the collapse of the given structure would happen not more than ten percentile probability of collapse, as is constrained by ATC-63, attention should be paid to the selection of the three seismic parameters modification factor (R), system over-strength (Ω_0) and deflection amplification factor (C_d). Selection of appropriated these three parameters leads to sufficiently large mean collapse capacity of the structure due to MCE earthquake. The ratio of the structure's

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mean collapse capacity to the MCE's spectral ordinate at T_1 is called CMR as shown by Equation 1.

$$CMR = \hat{S}_{CT} / S_{MT} \quad (1)$$

4- Spectral Shape Effect (SSF)

FEMA_P695 [4] presented a framework to adjust the median collapse obtained from the fragility curve, $Sacol(T_1)$, to that of the hazard levelled target event (MCE) by spectral shape factor (SSF). Equations 2 and 3 present the formula for calculation of SSF. Where $\mathcal{E}_0(T)$ and $\mathcal{E}_0(T)_{records}$ in Equation 3 are the site's most likely mean epsilon at the site under study and the mean epsilon corresponding to the 44 far-field general set respectively and μ_T represents the ductility factor (as shown in Figure 2 of Persian Version). An adjustment is made between the above mentioned CMR by SSF which leads to Equation 4.

$$\beta_1 = 0.14(\mu_T - 1)^{0.42}; \mu_T = \delta_u / \delta_{y,ff} \leq 8 \quad (2)$$

$$SSF = \exp[\beta_1(\bar{\mathcal{E}}_0(T) - \bar{\mathcal{E}}_0(T)_{records})] \quad (3)$$

$$ACMR = SSF \times CMR \quad (4)$$

In fact, Equation 4 ensures that the MCE's spectral ordinate at T_1 remain under the ten percentile probability of collapse.

5- Modification Factor (R), System Over Strength (Ω_0) and Deflection Amplification Factor (C_d)

These factors are fundamentally critical in the specification of seismic design loading. The structural seismic parameter (R factor) explicitly is used to reduce the real sheaf base force in the form of Equation 5 expressed as:

$$V = \frac{Sa_{MCE}(T_1) / 1.5}{R / I} \times W \quad (5)$$

Where, R and I are the reduction and importance factors respectively. The nominator of Equation 5 shows the hazard levelled extreme target event spectral amplitude at the structure's first mode period (MCE) (2% chance in 50 year) divided by 1.5 to convert it the code's design spectral amplitude. It is important to note that the nominator in Equation 5 should be replaced by spectral amplitude corresponding to ten percent probability of exceedance if the Iran standard code (2800) is used which convert Equation 5 to Equation 6 expressed as:

$$V = \frac{Sa_{PE=10\%}(T_1)}{R / I} \times W \quad \text{or} \quad V = \frac{A \times B(T_1)_{2800}}{R / I} \times W \quad (6)$$

The over-strength, Ω_0 , and the deflection amplification factors, (C_d), prescribed in the code's provisions, are two non-linear related seismic parameters which is implicitly correlated to R factor [5].

5- 1- Structure's Selected R Factor Evaluation

The ability to accurately and reliably quantify R factor is important for evaluating the current building seismic design code standard (2800 in this study). In particular, the evaluation method presented in NIST [3] is significantly useful for evaluating not only code-conforming designs but also the new seismic force-resisting systems being proposed for adoption.

6- Uniform Risk Factor, $R_{U10\%}$

As already stated, the current evaluation of structures should be performed within a group of identical structural resisting systems such as moment frames or braced frames. Based on ATC-63, the acceptable mean collapse capacity probability of a grouped structure (e.g., 4 types of moment frame systems on specific site soil condition) (what is carried out in this study), based on the total system collapse uncertainty, is taken as 10% while each individual structure is 20%.

The value of a uniform risk factor, $R_{U10\%}$, is the R factor of the structural model of interest that corresponds approximately to a 10% probability of collapse [3]. Its mathematic form for United State design procedure is shown by Equation 3a expresses as Equation 7a:

$$R_{U10\%} = \left[\frac{S_{MT} / 1.5}{V / W} \right] \left[\frac{ACMR_i}{ACMR_{10\%}} \right] \quad (7a)$$

The numerator of Equation 7a represents the risk-targeted site's spectral acceleration corresponding to MCE earthquake (2% chance in 50 year) [5] divided by 1.5 and the denominator is the seismic design coefficient (Cs). However, for the reason that Iran's seismic code doesn't deal with risk-targeted spectral acceleration, the first term in Equation 7b reduces to simple hazard-based R factor (non-risk targeted) corresponding to structure's life safety performance (10% chance in 50 year). Therefore, for the Iran standard No. 2800, Equation 7a changes to Equation 7b expressed as:

$$R_{U10\%} = \left(\frac{ABI / R}{V / W} \right) \left(\frac{ACMR_i}{ACMR_{10\%}} \right) = R_{2800} \left(\frac{ACMR_i}{ACMR_{10\%}} \right) \quad (7b)$$

7- Results and Conclusion

The R factors prescribed by 2800 code for sixteen SMF steel structures varying in height from 4 to 12 stories and built at far field sites with four different site soil conditions are evaluated using the criteria presented in FEMA_P695 [4] and NIST [3]. The mean collapse capacity prediction Equation 8 proposed by Nicknam et al. [6], in the form of geo-metric mean, is used to calculate the numerator of Equation 7b., Equation 8 is a spectral shape based approach which has been established using 78 far-field recordings. Full description of Equation 4 is found at [6]. The mathematic form of Equation 8 is expressed as:

$$Sa_{col-cap}(T_1) = Sa_{GM-MCE}(T_1) \times \left[3.86 \left(\frac{2Sa_{MCE-GM}(T_1) + Sa_{MCE-GM}(2T_1)}{Sa_{MCE-GM}(T_1) \times Sa_{MCE-GM}(2T_1)} \right) e^{0.528/T_1} RDR_{ult-sr}^2 + 1.629 \right] \quad (8)$$

Where, $Sa_{GM-MCE}(T_1)$ and $Sa_{GM-MCE}(2T_1)$ are the spectral acceleration at the first mode period of the structure under

study and that at the effective period ($2T_1$) corresponding to the concurrent spectral acceleration. Table 4 lists the information concerning the site soil conditions, the structures' story numbers, the maximum base shears, ductility factors and over-strength factors used. The comparison of collapse capacity mean values at the assumed site between the FEMA's approach [4] and those of Nicknam et al. [6] are shown in Table 5. The final results of this study in the forms of fail/pass resulted from the use of FEMA_P695 and those of Nicknam et al, [6], in the both forms, grouped structures and individual structure, are illustrated in Table 6. As seen, while a number of structures failed to respond an appropriate R factor from the Nicknam' point of view, the whole structures passed the FEMA's criteria. The major factor of such differences of evaluation may be attributed to the amounts of the structure's mean collapse capacities predicted by the two approaches.

References

- [1] C.M.Uang, 1991. "Establishing R (or R_w) and Cd Factor for Building Seismic Provision", *Structural Engineering*, Vol.117, No.1, pp-19-28.
- [2] PEER/ATC-1-72, 2010. "Modeling and Acceptance Criteria for Seismic Design and Analysis of Tall Buildings".
- [3] NIST, 2012. "Tentative Framework for Development of Advanced Seismic Design Criteria for New Buildings", National Institute of Standards and Technology NIST GCR.
- [4] Federal Emergency Management Agency (FEMA), 2009. "Quantification of Building Seismic Performance Factors".
- [5] American Society of Civil Engineers. ASCE7-10, 2010. "Minimum Design Loads for Buildings and Other Structures", Reston, VA.
- [6] A. Nicknam, et al, 2015. "A Three Elements Vector Valued Structure's Ultimate Strength-Strong Motion-Intensity Measure" *World Academy of Science, Engineering and Technology, International Journal of Civil and Environmental Engineering*, Vol: 2, No: 11, Venice, Italy.

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