



THE RATIO OF DISPLACEMENT AMPLIFICATION FACTOR TO FORCE REDUCTION FACTOR

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SUMMARY

For Seismic design, it is important to estimate, maximum lateral displacement of structures due to sever earthquakes for several reasons. Seismic design provisions estimate the maximum roof and story drifts occurring in major earthquakes by amplifying the drifts obtained by elastic analysis with a deflection amplification factor (DAF). This factor depends on various parameters, of which the force reduction factor (FRF) is the most important one. The main objective of this paper is to evaluate the ratio of DAF to FRF (DAF/FRF). It is shown that the ratio DAF/FRF equals to the ratio of the system ductility factor (μ) to the ductility reduction factor (R_μ). So the ratio μ / R_μ was evaluated instead of DAF/FRF using the various R_μ (proposed in current years).

The results indicate that the ratio of DAF/FRF differs to those proposed by seismic provisions such as NEHRP, IBC and Iranian seismic code (standard no. 2800), and they need to be modified.

Keywords: Deflection amplification factor, Force reduction factor, maximum lateral displacement, Ductility factor

INTRODUCTION

For seismic design it is important to estimate, maximum lateral displacement of structures for several reasons; these include: estimating minimum separation joint width to avoid pounding, estimating maximum story drift to avoid destruction of non-structural elements and performance of p-delta analysis.

Due to economic reasons, present seismic codes allow structures to undergo inelastic deformations in the event of strong ground motions. As a result of this the design lateral strength is lower than the lateral strength required to maintain the structure in the elastic range. The design lateral strength is obtained by dividing the required fully elastic strength to force reduction factors (FRF). So the displacement (or drifts) calculated by analysis of structures under the design lateral force is not the real displacement of the structures and it is less than the maximum displacement of the structures during strong motions.

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Seismic design provisions estimate the maximum roof and story drifts occurring in major earthquakes by amplifying the drifts obtained by elastic analysis with a displacement (or deflection) amplification factor (DAF).

$$\Delta_{\max} = \Delta_e \times C_d \quad (1)$$

Where $\Delta_{\max}$ is the maximum inelastic deflection (roof or story drifts), Δ_e is the elastic deflection calculated by elastic analysis and C_d is the deflection amplification factor (DAF). DAF depends on force reduction factor (FRF).

RATIO OF DAF TO FRF

Fig. 1 shows the actual response envelope and idealized elasto-plastic response curves and the following three quantities are defined [1].

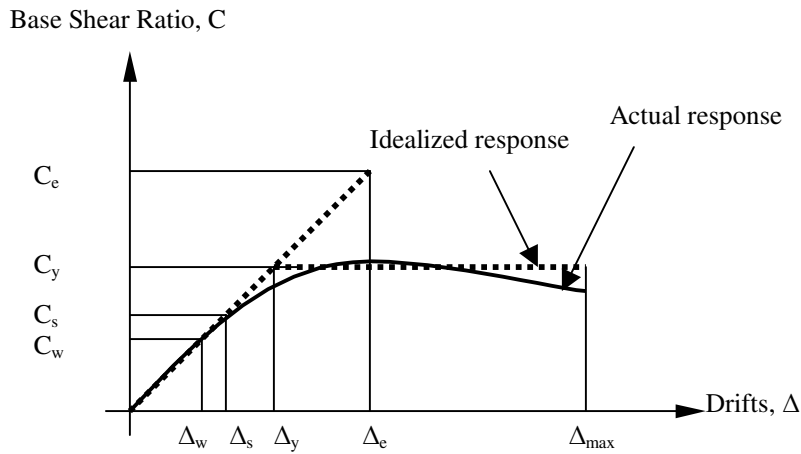


Fig. 1: General Structural Response

$$\mu = \Delta_{\max} / \Delta_y \quad (2)$$

$$R_\mu = C_e / C_y \quad (3)$$

$$R_s = C_y / C_s \quad (4)$$

Where μ = system ductility factor, R_μ = ductility reduction factor, R_s = structural overstrength factor, Δ_y = system yield displacement, C_e = fully elastic base shear ratio, C_y = yield strength level and C_s = first significant yield level.

It has been shown [1] that the force reduction factors and deflection amplification factors can be expressed by the following formulas:

$$FRF = R_\mu \times R_s \text{ (or } R_\mu \times R_s \times Y) \quad (5)$$

$$DAF = \mu \times R_s \text{ (or } \mu \times R_s \times Y) \quad (6)$$

$$Y = C_s / C_w \quad (7)$$

Where Y = allowable stress factor applied for working stress design and C_w = corresponding design force level.

From (5) and (6), the ratio between DAF and FRF is:

$$\frac{DAF}{FRF} = \frac{\mu \times R_s}{R_\mu \times R_s} \text{ (or } \frac{\mu \times R_s \times Y}{R_\mu \times R_s \times Y}) = \frac{\mu}{R_\mu} \quad (8)$$

(8) shows that the ratio DAF/FRF for ultimate stress design and working stress design is the same and it would be better to evaluate the ratio $\frac{\mu}{R_\mu}$ instead of DAF/FRF. So it is concluded that the ratio DAF/FRF

depends on the parameters which affect on R_μ , such as system ductility factor, fundamental period of structures, load-deflection models of materials, damping ratio, site effects and the characteristics of earthquake (PGA, duration and frequency contents)[2].

RATIO OF DUCTILITY FACTOR TO DUCTILITY FORCE REDUCTION FACTOR

Several formulas have been suggested as ductility force reduction factor (R_μ) by Newmark and Hall [2], Riddell [3], Krawinkler [4] and Miranda [5].

The R_μ factor proposed by Newmark-Hall depends on ductility factor (μ) and fundamental period (T):

$$\begin{aligned} R_\mu &= \sqrt{2\mu - 1} & T \leq 0.5 \\ R_\mu &= \mu & T > 0.5 \end{aligned} \quad (9)$$

Ductility factor and fundamental period affects on formula suggested by Riddell too:

$$\begin{aligned} R_\mu &= 1 + \frac{R^* - 1}{T^*} & T \leq T^* \\ R_\mu &= \mu & T > T^* \end{aligned} \quad (10)$$

Where R^* and T^* are determined from the table proposed by Riddell in terms of system ductility factors.

The R_μ factor proposed by Krawinkler depends on fundamental period of system (T), ductility factor (μ) and strain hardening ratio (α). It is assumed that the value of strain hardening ratio is equal to zero in this paper:

$$R = [C(\mu - 1) + 1]^{1/C} \quad (11)$$

$$C = \frac{T^a}{T^a + 1} + \frac{b}{T}$$

According to the table suggested by Krawinkler the values of a and b are equal to one and 0.42 respectively when $\alpha=0$.

The force reduction factor suggested by Miranda depends on ductility factor (μ), fundamental period (T), predominant period of the ground motion (T_g) and site characteristics. The formula for rock sites is used in this paper:

$$R_\mu = \frac{\mu - 1}{\Phi} + 1 \geq 1 \quad (12)$$

$$\Phi = 1 + \frac{1}{10T - \mu T} - \frac{1}{2T} \exp\left[-\frac{3}{2}\left(\ln T - \frac{3}{5}\right)^2\right]$$

Using R_μ factors which are above explained the ratios of μ to R_μ have been calculated in terms of μ and T. Fig. 2 to 11 show the ratio of μ to R_μ (DAF/FRF) in terms of μ and T.

Fig. 2 indicates relationship between the ratio of DAF to FRF and system fundamental period determined by above said formulas. Several observations can be made from fig. 2. The minimum value for DAF/FRF is 0.85 approximately extracted from Miranda formula. The maximum value for DAF/FRF is 1.35 related to Miranda and Krawinkler formulas. The ratio DAF/FRF is high when the period is low. The ratio will be equal to one when the period is high.

The ratio DAF/FRF computed using formulas explained before are shown in Fig. 3 to 6 for $\mu=3, 4, 6$ and 8 respectively. The minimum value for all cases is 0.8 approximately. The maximum value increases with increasing of ductility factor. The ratio DAF/FRF is higher than one when the fundamental period is less than 0.7 sec.

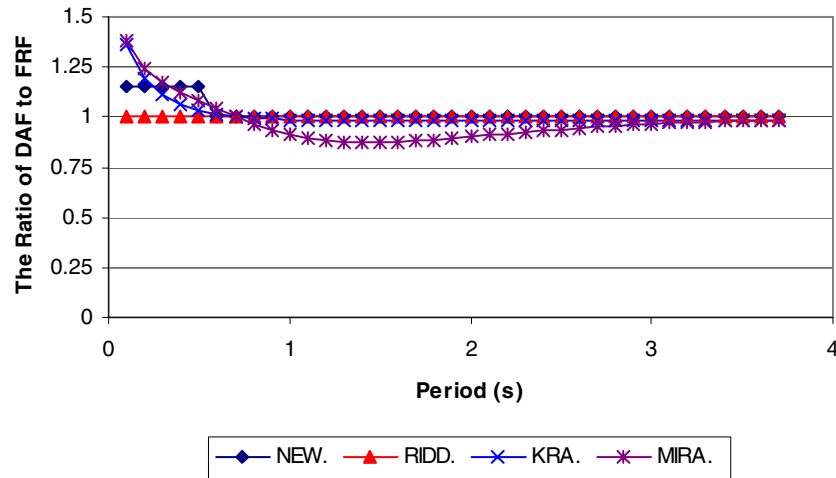


Fig. 2: The ratio DAF/FRF versus fundamental period for system ductility factor=2

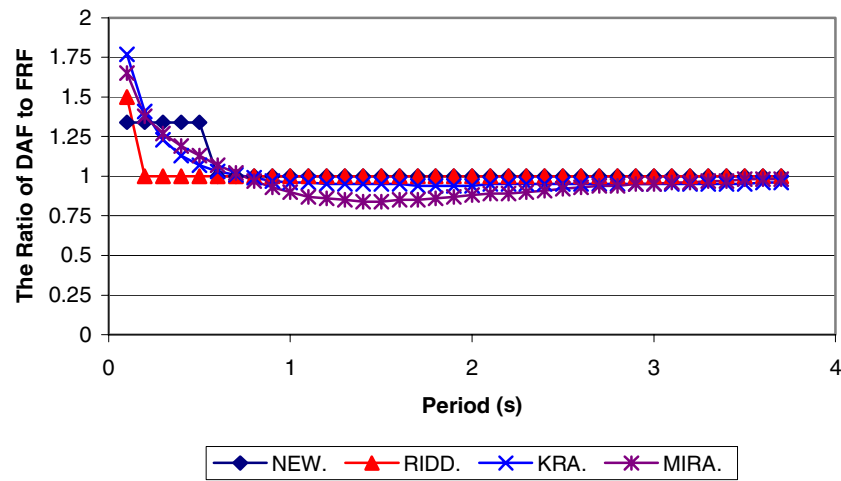


Fig. 3: The ratio DAF/FRF versus fundamental period for system ductility factor=3

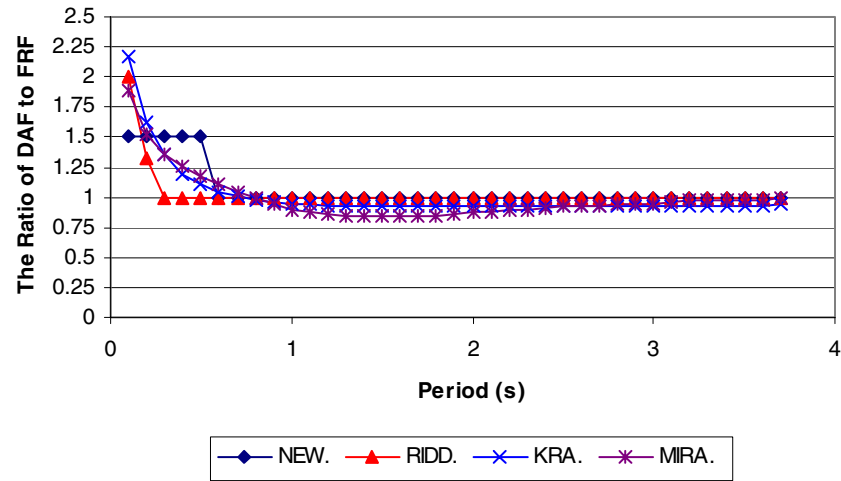


Fig. 4: The ratio DAF/FRF versus fundamental period for system ductility factor=4

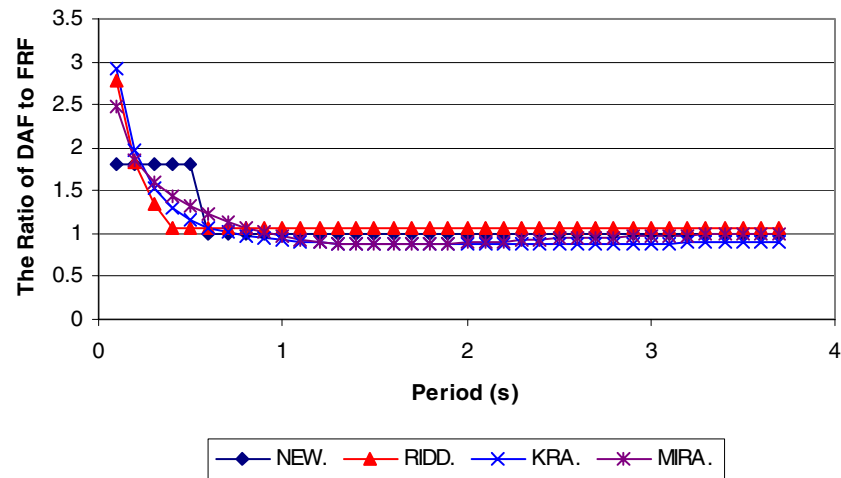


Fig. 5: The ratio DAF/FRF versus fundamental period for system ductility factor=6

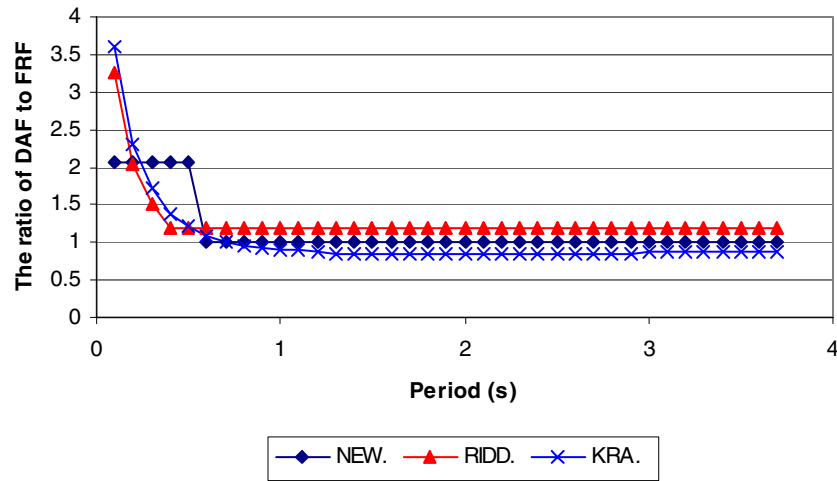


Fig. 6: The ratio DAF/FRF versus fundamental period for system ductility factor=8

Fig. 7 represents the variation of the DAF/FRF due to ductility factor for $T=0.1$. The figure shows the ratio depends on ductility factor strongly. The minimum value is one for all formulas.

Fig. 8 to 11 show the relationship between the ratio DAF/FRF in terms of ductility factor computed for $T=0.3, 0.5, 1$, and 4 sec. The minimum value for the ratio DAF/FRF in figures 8 and 9 is one and also equal to 0.9 and 0.85 in figures 10 and 11 respectively. The maximum value of the ratio DAF/FRF increases with increasing of ductility factor and decreases due to increasing in T .

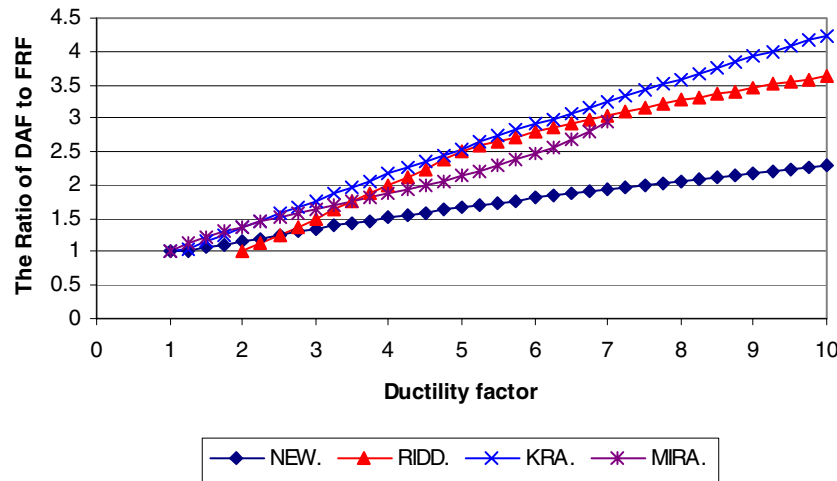


Fig. 7: The ratio DAF/FRF versus system ductility factor for fundamental period=0.1 sec.

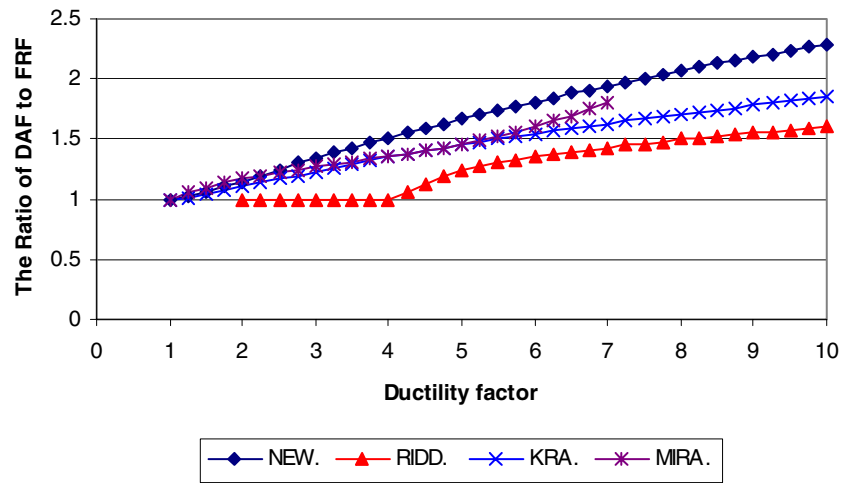


Fig. 8: The ratio DAF/FRF versus system ductility factor for fundamental period=0.3 sec.

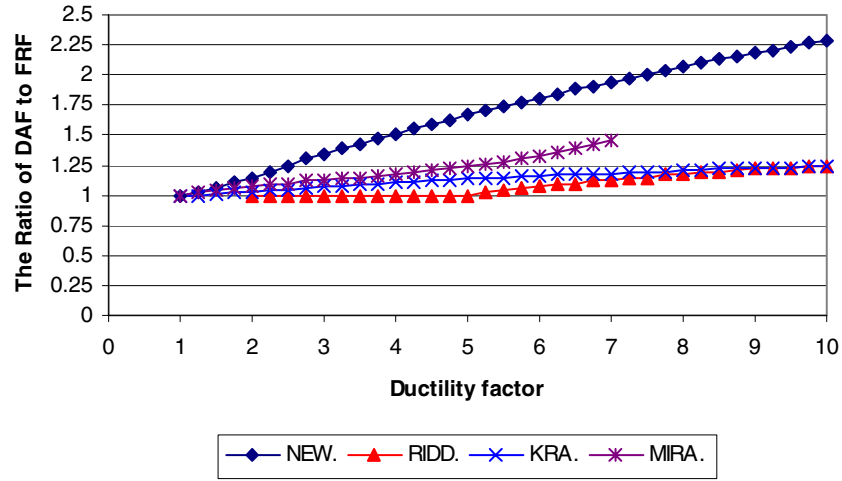


Fig. 9: The ratio DAF/FRF versus system ductility factor for fundamental period=0.5 sec.

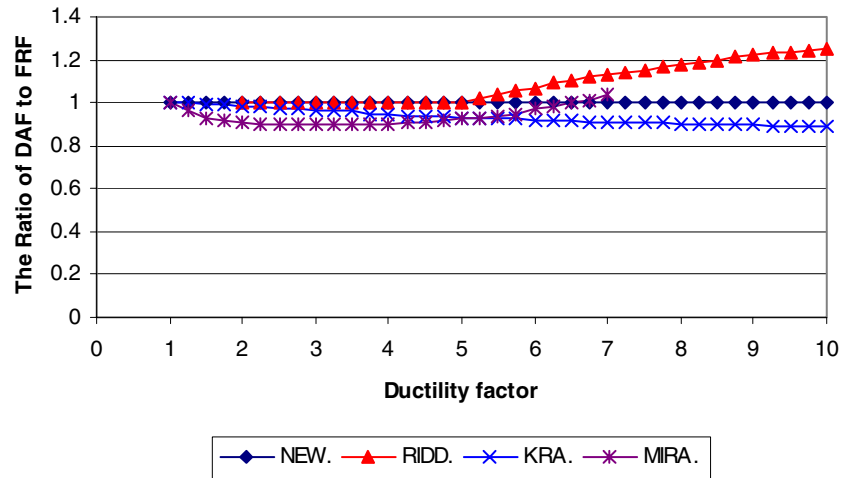


Fig. 10: The ratio DAF/FRF versus system ductility factor for fundamental period=1 sec.

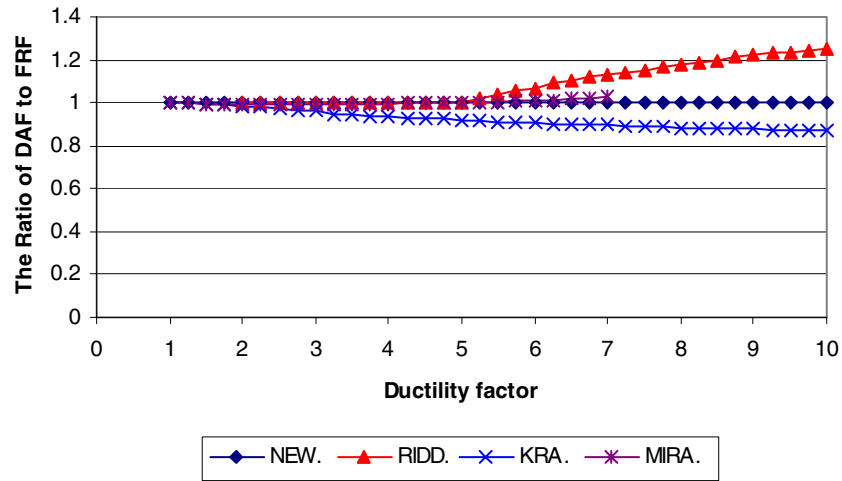


Fig. 11: The ratio DAF/FRF versus system ductility factor for fundamental period=4 sec.

SEISMIC PROVISIONS OF DAF/FRF

In this section the DAF/FRF recommended by NEHRP, IBC and Iranian seismic code (standard no. 2800) will be presented.

The maximum and minimum values as ratio between DAF and FRF proposed by NEHRP are listed in table 1 [6].

Table 1: NEHRP- recommended maximum and minimum ratio between DAF and FRF

Structural systems	Maximum value	Minimum value
Bearing wall system	1	0.62
Building frame system	1	0.5
Moment resisting frame system	0.92	0.69
Dual system with a special moment frame ...	0.85	0.5
Dual system with an intermediate moment frame ...	0.9	0.64
Inverted pendulum structures seismic force resisting system	1	1

Table 2 indicates the maximum and minimum values for DAF/FRF recommended by IBC code [7].

Table 2: IBC- recommended maximum and minimum ratio between DAF and FRF

Structural systems	Maximum value	Minimum value
Bearing wall system	1	0.67
Building frame system	1	0.5
Moment resisting frame system	0.92	0.69
Dual system with a special moment frames	0.93	0.5
Dual system with an intermediate moment frames	0.91	0.75
Inverted pendulum structures seismic force resisting system	2	0.5

Iranian seismic code uses only one value for DAF/FRF which is 0.4 [8].

According to tables 1 and 2, it is observed that the ratio DAF/FRF is never larger than one except for Inverted pendulum structures seismic force resisting systems.

CONCLUSION

The results discussed in the previous sections indicate that the minimum value for the ratio between deflection amplification factor (DAF) and force reduction factor (FRF) is 0.8. The minimum value increases with increasing of ductility factor and decreasing of fundamental periods.

The ratio DAF/FRF can be much higher than 1.0 for ductile frame systems (high ductility) and stiff buildings (low fundamental period). The ratio DAF/FRF was more than 2.5 for low period systems. The DAF (C_d) recommended by NEHRP, IBC and Iranian seismic code (standard no. 2800) are low and therefore they need to be modified, especially for buildings having high ductility and low periods.

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