Response modification factor - Review paper

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Abstract. Response modification factor \( R \) has a main function in the seismic design of new construction materials and is a seismic design parameter in equivalent static analysis. It determines the nonlinear performance of building structures during strong earthquakes. \( R \) is based on experimental test and engineering judgment, and no uniform technique exists to determine such a value for different conditions. The development in the reliability of modern earthquake-resistant buildings requires systematic assessment of building response characteristics that mainly affect the rates allocated to \( R \), which is formulated based on three aspects, namely, strength, ductility, and redundancy factors. Response modification is affected by the height of structures. This review paper aims to summarize relevant information from different experimental and analytical studies on overstrength, ductility, and \( R \).

1. Introduction

Response modification factor \( (R) \) is a key parameter in seismic construction design. Equivalent statistical analysis, which is frequently used to estimate the seismic response of structures, can be implemented by determining \( R \). In particular, \( R \) indicates the ability of a structure to dissipate energy through inelastic behavior, as demonstrated in recent building codes. The effect of \( R \) was studied by several researchers (Wu et al., 1989; Hanson et al., 1993), who mostly focused on displacement response (Hanson et al., 1993; National Earthquake Hazards Reduction Program (NEHRP), 1994; Federal Emergency Management Agency (FEMA)-273, 1997). The findings of Wu et al. (1989) were implemented in NEHRP (1994) and the Uniform Building Code (UBC, 1994) to design passive energy dissipation systems. The propositions of Newmark and Hall (1982) were used in the Applied Technology Council (ATC)-40 (1996), UBC (1997), FEMA-273 (1997), NEHRP-97 (1997), International Building Code (IBC, 2000), and Structural Engineers Association of California (SEAOC) Blue Book (1999) to design buildings with passive energy dissipation and seismic isolation systems. Existing seismic design codes, such as those of UBC and NEHRP, are force-based procedures. However, damping reduction factors that are acceptable in codes are derived from the effects of viscous damping...
on the displacement response of elastic single-degree-of-freedom (SDOF) systems. Documents such as ATC-19 (1995) ratiocinate the effects of added damping to decrease the force response of buildings. Additional damping to a building is expected to reduce displacements. Static elastic analysis procedures remain as the foundation of seismic design in the United States (US). Static lateral force method has been used in different forms for over 70 years (ATC, 1995b). ATC-3-06 (1978) introduced $R$ during the late 1970s to reduce base shear force ($V_e$) that is calculated according to elastic analysis of 5% damped acceleration response spectrum ($S_{a,5}$) and to gauge design base shear force ($V_b$). The $R$ value can fall within the range of two to eight ductile seismic framing systems and can be determined from empirical horizontal force factors accepted in the SEAOC Blue Book (1999) and in accordance with ATC (1995a).

According to IBC (2000), $R$ should be applied to evaluate the design of reduced seismic forces of structures and the deflection amplification factor ($C_d$) to convert elastic lateral displacements into total lateral displacements. In such an application, the effect of inelastic deformations should be considered. Values of $R$ and $C_d$ provided in IBC (2000) are established based on the clarification of performances of different structural systems in previous strong earthquakes, technical justifications, and traditions (NEHRP, 2000). The $R$ coefficient is proposed to explain ductility $R_\mu$, overstrength $\Omega$, and energy dissipation through the soil foundation system (NEHRP, 2000).

Numerous studies focused on selecting $R$ for structural seismic design. Miranda (1994) summarized different investigations on the $R$ coefficient, which was described as a strength reduction factor ($R_\mu$), and suggested that $R_\mu$ is mostly a function of displacement ductility ($\mu$), natural period of the structure ($T$), and the conditions.

In general, structures are initially designed according to equivalent static forces specified by building codes. The division of these static forces is implicitly based on elastic vibration modes. Current structural design codes focus on absolute safety and sturdiness, which are impossible to achieve during an earthquake with a reasonable possibility of occurrence. However, several structural and nonstructural damages can be studied to economically achieve a high level of safety in structural design by applying an inelastic energy dissipation system. Most seismic codes authorize a reduction in design loads by stating that structures possess a significant amount of reserve strength (overstrength $\Omega$) and capacity to dissipate energy (ductility $R_\mu$). These features are merged in structural design by $R$ (Kim et al., 2005). In lateral strength design, lateral strength is typically lower than that required for structures to stay within the elastic range according to seismic codes.

Osteraas and Krawinkler (1990) observed $\Omega$ and $R_\mu$ of steel frames that were designed to comply with working stress design provisions of UBC. Daza (2010) illustrated the relationship between $R$ and the essential strength of a building ($C_{\Omega}$), which is established on these mechanisms, and the pushover analysis of the building. According to Daza, estimating $R$ is not rationally addressed by codes because such codes assign a particular value based on the structural system and experience. Shedid et al. (2010) found the values of seismic force reduction factor ($R$) to be close to 5.0 for rectangular walls and 36.0 for corresponding flanged and end-confined walls. The values are reliable according to the American Society of Civil Engineers-7 standard.

Mondal et al. (2013) estimated the actual $R$ value for realistic reinforced concrete (RC) moment-frame building and compared the said value with that suggested for the design according to the Indian standard code. They conducted research based on Indian standards to approximate actual $R$ values for realistic RC moment frames. Mahmoudi and Zaree (2010) evaluated $R$ for congenital concentric braced frames (CBFs) and buckling-restrained braced frames (BRBFs). In addition, Mahmoudi and Abdi
(2012) proposed the $R$ for TADAS frames, and they discovered that the $R$ for T-steel moment-resisting frames (SMRFs) exhibit a higher value than that of SMRFs. Furthermore, Mahmoudi et al. (2013) investigated the equivalent damping and $R$ values of frames with pall friction dampers. According to Mahmudi and Zaree (2013), $R$ for BRBFs have high values, and the number of bracing bays and building height considerably affect $R$. Through experiments, Zeynalian and Ronagh (2012) estimated the lateral seismic characteristics of lightweight knee-braced cold-formed steel structures.

Bosc et al. (2013) predicted height-wise damage during the collapse of EBFs when applied to concentrically braced frames. According to Galasso et al. (2014), code provisions are not conservative; such provisions provide a basis for improving the calibration of future editions of building seismic design codes. Izadinia et al. (2012) developed a derivation of factors, such as $\Omega$, $R_{\mu}$, and $R$, from capacity curves achieved using different APA and CPA methods. Kappos et al. (2013) evaluated $R$ for concrete bridges in Europe.

$R$ is an important parameter in seismic construction design. Equivalent statistical analysis is frequently applied in estimating structural seismic response. The important factor is developed independently to produce a seismic effect code and non-seismic load condition. This paper presents mostly information extracted from ATC-19 (1995), which is entitled Structural Response Modification Factor. Review of $R$ literature shows that no investigation has been conducted on the response modification for structures equipped with viscous damper devices. As an essential formulation of the main $R$ factors (ATC 3-06), ATC-19 warranted research; values recommended as of the time of writing are based on judgment and reconsidered at regular intervals.

2. Evolution of Seismic Codes and Response Modification Factor:
The Great San Francisco Earthquake of 1906 marks the beginning of earthquake engineering in the US (Atkinson and Kiland, 2004). Several seismic events occurred in the state of California over the next two decades. Consequently, the Structural Engineers Association of Southern California (SEAOSC) was founded in 1929 (Atkinson and Kiland, 2004).

SEAOSC later merged with a similar group from Northern California, thereby forming the SEAOC in late 1931 (Atkinson and Kiland, 2004). Publications from the SEAOC Seismology Committee and ATC were used as the basis of current earthquake design in the US. Seismic design methodology continually evolved since the first introduction of a seismic lateral force equation in 1927 in the UBC, a regional model building code. After each major earthquake, engineers and researchers studied building behavior and failures and changed building codes based on their observations. The beginning of modern seismic design methodology is found in the first edition of SEAOC-Recommended Lateral Force Requirements and Commentary (Blue Book) in 1959 (SEAOC, 2007) and was significantly changed in 1978 with the publication of ATC 3-06. The new publication (ATC 3-06) recommended that seismic provisions use $R$ and change seismic load from stress level to strength level. Seismic design methodology and $R$ continued to change since then.

Until the late 20th century, seismic design was not well understood or practiced in the US. UBC first introduced seismic design in 1927 because of the frequency of large earthquakes in southern California in the early 1900s. Several building codes adopted the methods in the Blue Book but allowed exemptions for specific geographic areas based on historic seismic activity and damage records. The exceptions allowed most geographic regions in the US to prove that considering seismic forces is unnecessary for buildings in those regions.
The effect of $R$ on building seismic design is clearly seen in the comparison of equation for the design base shear for inelastic response (Eq.1) and that for base shear for elastic response ($V_e$) (Eq. 2).

$$V = \frac{2.5A_a}{R}W$$  \hspace{1cm} (1)  

$$V_e = S_{e,5}W$$  \hspace{1cm} (2)

Where $A_a$ is the effective peak acceleration of the design ground motion, and $S_{e,5}$ is the elastic 5-percent damped pseudo acceleration response spectral ordinate. The elastic spectral ordinate in Eq. (2) is equivalent to the term $2.5A_a$ in Eq. (1). Eq. (1) and (2) are thus identical if $R=1.0$ in Eq. (1). In practice, the design base shear (for inelastic response) is calculated by dividing the base shear force elastic response by $R$, a value that generally varies between 4.0 and 8.0 (ATC, 1995).

$R$ is the ratio of forces that would grow in the structure under a specified ground motion if the behavior were entirely elastic compared to the prescribed design forces at the level of significant yield (ATC, 1978). $R$ reduces the design value of the base shear for the design earthquake, which ensures that the structure could enter the inelastic range if the design earthquake or a larger event occurs (see Figure 1). Each point on the normalized elastic response spectrum is divided by $R$ to produce the design spectrum for a given structure type (ATC, 1995).

**Figure. 1** Use of $R$ factors to reduce elastic spectral demands to the design force level (ATC-19)

$R$ is the main factor to be considered in the seismic design process but is still subject to debate. No other parameters in the design base shear equation influences the design action in seismic framing system as does the value assigned to $R$. $\Omega$ and $R$, factors for major seismic framing systems differ according to seismic zones because of the differences in the proportions of gravity loads to seismic loads.
3. Component of response modification factor:

$R$ that were proposed for the first time in ATC-3-06 (1978) were selected according to the observed performance of buildings during previous earthquakes and the estimation of $\Omega$ and damping (ATC-19, 1995). Components of $R$ factors, such as $\Omega, R_\mu,$ and redundancy $R_R$, are based on ATC-19 (1995) and ATC-34 (1995). $R$ factor is the ratio of strength required to maintain structural elasticity in force-based seismic design procedures. This factor is important in estimating the seismic force of a structural building.

Much research (ATC, 1982B; Freeman, 1990; ATC, 1995) have been completed since the first formulation for $R$ was proposed. Recent studies, including those in the companion project ATC-34, support a new formulation for $R$, that is, a formulation in which $R$ is expressed as the products of three factors:

$$R = R_S R_\mu R_R$$ (3)

Where $R_S$ is the period-dependent strength factor, $R_\mu$ is the period-dependent ductility factor, and $R_R$ is the redundancy factor.

A commentary to the 1988 NEHRP Provisions (BSSC, 1988) defines $R$ factor as “an empirical response modification (reduction) factor intended to account for both damping and ductility inherent in a structural system at displacement great enough to approach the maximum displacement of the system.” The components of $R$ can be defined in several ways, each dependent on the performance level under consideration.

Figure 2 shows that overstrength and ductility factors are evaluated based on the pushover curve and are considered as key component factors in $R$ formulation. The parameters in this figure are described as follows: design base shear force ($V_d$), displacement caused by the design base shear force ($\Delta_w$), base shear force versus roof displacement relationship at yield point ($V_Y$), roof displacement relationship at yield point ($\Delta_Y$), max base shear force ($V_\mu$), and max displacement ($\Delta_{\text{max}}$).
Figure 2 Idealization of inelastic response of structure

4. Ductility factor:
The seismic response parameters of displacement capacity, ductility, and ductility ratio are closely interrelated but often confused. For example, a frame with a large displacement capacity might exhibit small ductility and small ductility ratio, and a frame with a small displacement capacity might exhibit small ductility but a large ductility ratio. Ductility ratio ($\mu$) can be calculated at the element levels, story, and system. At the story levels and system, the ductility ratio is normally stated in terms of the displacement ductility ratio. At the element level, ductility ratio can be expressed in terms of curvature ductility ratio, strain ductility ratio, and rotation ductility ratio. Displacement ductility ratio was used to determine ductility factor.

The reduction factor attributed to $R_\mu$ was used to calculate the nonlinear response of a structure that is caused by the hysteretic energy. $R_\mu$ depends on structural properties, such as damping, ductility, and the fundamental period of vibration, in addition to the characteristics of earthquake ground motion. $R_\mu$ is expressed in terms of maximum structural drift ($\Delta_{max}$); the drift corresponds to the idealized yielding point ($\Delta_y$), which was developed by Newmark and Hall (1982) as follows:

$$R_\mu = \begin{cases} \mu & T > 0.5 \text{sec} \\ \sqrt{2\mu - 1} & 0.1 < T < 0.5 \text{sec} \\ 1 & T < 0.03 \text{sec} \end{cases}$$

(4)

Where $T$ is the fundamental period and $\mu$ is the displacement ductility factor defined as follows:
\[ \mu = \frac{\Delta_{\text{max}}}{\Delta_y} \]  

(5)

Where \( \Delta_{\text{max}} \) is the maximum displacement (displacement corresponding to the limit state), and \( \Delta_y \) is the yield displacement of the structure.

According to Miranda and Bertero (1994), the extent of inelastic deformation experienced by a structural system subjected to a given ground motion or a lateral load is presented by the displacement ductility ratio \( \mu \) (ductility demand), which is defined as the ratio of the maximum absolute relative displacement to its yield displacement, as follows:

\[ \mu = \frac{\Delta_{\text{max}}}{\Delta_y} \]  

(6)

Ductility reduction factor, sometimes called the strength reduction factor (the reduction in strength demand attributed to post-elastic behavior), is presented in Eq. (7)(Miranda and Bertero,1994).

\[ R_\mu = \frac{F_y(\mu=1)}{F_y(\mu=\mu)} \]  

(7)

Newmark and Hall (1982) conducted essential studies on \( R \) factors attributed to ductility. \( R_\mu \) is sensitive to the natural period of the structure. Five periods with different ranges exist, and \( R_\mu \) can be determined according to the different values. Figure 3 illustrates \( R_\mu-\mu-T \) for numerous ductility ratios and periods, and Eqs. (8)–(12) were used to estimate \( R_\mu \) factor for different natural periods of the structure.

Periods \( \leq 0.03 \) sec:

\[ R_\mu = 1.0 \]  

(8)

Periods \( 0.03 < t < 0.12 \) sec:

\[ R_\mu = 1 + \frac{(T-0.03)\sqrt{(2\mu-1)}}{0.09} \]  

(9)

Periods \( 0.12 \leq T \leq 0.5 \) sec:

\[ R_\mu = \sqrt{2\mu - 1} \]  

(10)

Periods \( 0.5 < T < 1.0 \) sec:

\[ R_\mu = \sqrt{2\mu - 1} + 2(T - 0.5)\sqrt{(\mu - 2\mu - 1)} \]  

(11)

Periods \( T \geq 1.0 \) sec:

\[ R_\mu = \mu \]  

(12)
In addition, Newmark and Hall (1982) introduced a method that is acceptable to other researchers; this method, which offers verified equations, was used in different real seismic records. Nasser and Krawinkler (1991) and Miranda and Bertero (1994) indicated that $R_{\mu}$ is dependent on ground motion frequency and ground soil types.

Based on previous studies, Andalib et al. (2014) analytically and numerically analyzed the use of steel rings (made from steel pipes) as an energy dissipation system to increase the ductility of energy dissipater members at the intersection of braces. Bojórquez et al. (2014) studied the influence of cumulative plastic deformation demands on target ductility values and their corresponding strength reduction factors. Dang and François (2014) proposed a new ductility factor to specify the change in ductility caused by corrosion in RC beams. This factor is the ratio between the ultimate deflection of corroded and non-corroded beams. Riddell et al. (1989) based their study on inelastic spectra computed for four earthquake records by using SDOF systems with an elasto-plastic behavior and 5% damping. Habibi et al. (2013) proposed use of passive energy and pushover analysis to determine yield force and ductility factor as alternatives to strength- and displacement-based methods in seismic retrofitting.

5. Strength factor:
The utmost lateral strength of a building generally exceeds its design strength. The strength factor depends on many parameters, which are not immediately evident to many design professionals. In addition, buildings located in poor seismic zones are likely to exhibit different reserve strength values from those in upper seismic zones because of varying ratio of gravity loads to seismic loads, thereby resulting in zone-dependent values for the strength factor. The difference between actual construction practices and that between actual and nominal material strength also affects the value of the strength factor but in unpredictable ways (ATC-19).

Nonlinear static analysis (pushover analysis) was used to estimate the strength of a building system (ATC, 1982b). The steps in the estimation are as follows:

i. Using nonlinear static analysis to construct the base shear–roof displacement relationship for the building.

ii. Calculating the base shear force ($V_0$) in the building at the roof displacement corresponding to the limiting state of response. The reserve strength is equal to the difference between design base shear ($V_d$) and $V_0$.

iii. Calculating strength factor by using the following expression:
The actual strength of a structure is likely higher than its design strength because of overall design simplifications. Modern computer-aided tools allow engineers to model and design a structure as close as to what is actually built. Major simplifications and assumptions are incorporated into the process. These assumptions and design practices typically favor a conservative design to remain safe. The existence of overstrength in structures may be examined through local and global approaches.

The findings indicate that structures may considerably overcome high forces compared to those that are actually designed to do so. This phenomenon is attributed the presence of significant reserve strength that was not originally considered in the structural design (Rahgozar et al., 1998). Overstrength helps structures to remain safe during powerful tremors and reduces elastic strength demand. This feature was determined through the force reduction factor (Mahmoudi, 2003).

Review of other research on overstrength factor (e.g., Güneyisi et al., 2013) revealed that the ductile design of steel structures is directly influenced by flexural behavior of steel beams and developed analytical formulas to predict flexural overstrength factor of steel beams with a wide range of cross-section typologies. Freeman (1990) reported the overstrength factors for three-story steel moment frames, two of which were constructed in seismic zone 4 and one in seismic zone 3, as 1.9, 3.6, and 3.3, respectively. Kappos (1999) examined five RC buildings with one to five stories, which consist of beams, columns, and structural walls, and obtained an overstrength factor ranging from 1.5 to 2.7.

Mohebkhah and Chegeni (2014) investigated the overstrength factor and inelastic rotation capacity of eccentrically braced frames (EBFs) and determined that the two factors are key parameters for design economy or safety. They concluded that the strain hardening overstrength factor of short link beams made of European IPE sections with closely spaced stiffeners is greater than the provisions factor. Zulham et al. (2013) investigated the overstrength factor of RC frames that were designed based on Eurocode EC2 and EC8 as regular and irregular in elevations with a setback studied based on nonlinear static analysis. They concluded that frame geometry and ductility affect the overstrength factor.

6. Redundancy factor:

The function of redundancy factor is to quantify the improved reliability of seismic framing systems that use multiple lines of vertical seismic framing in each principle direction of a building. A redundant seismic framing system should be composed of multiple vertical lines of framing, each designed and detailed to transfer seismic-induced inertial forces to the foundation. Although redundancy is encouraged for lateral force-resisting systems designed in the US, the recent trend in California is building seismic framing systems composed of only a small number of vertical lines of seismic framing, that is, framing systems with minimal redundancy (ATC 19).

Redundancy in a system may be active or on standby. All members of a system participate in load carrying for active redundant systems. By contrast, in systems with standby redundancies, several members are inactive and become active only when active components fail. Redundancy is commonly defined as “beyond what is essential or naturally excessive” (ATC-19, 1995). In general, redundancy in a structural system is active under an earthquake-resistant design. ATC-19 (1995) explains that the redundancy factor value is based on the line of vertical seismic framing. The values of the redundancy factor are presented in Table 1.

| Table 1. Redundancy factor R_R |
| Line of vertical seismic framing | Redundancy factor $R_R$ |
|---------------------------------|-------------------------|
| 2                               | 0.71                    |
| 3                               | 0.86                    |
| 4                               | 1.00                    |

Furuta et al. (1985) pointed out the complexity of defining and quantifying the sum effect of redundancy after applying probabilistic and fuzzy interpretations to review several definitions of structural redundancy. Frangopol and Curley (1987) illustrated how damage can be generated to identify members that are critical to the integrity of a structure. Tang and Yao (1987) derived a relationship among structural damage, member damage, and redundancy based on the expected ultimate strength of a structure and a reserve resistance factor. In addition, Bonowitz et al. (1995) studied the relationship between damage to welded steel moment frame connections and redundancy, and Zhu and Frangopol (2014) investigated the effect of post-failure material behavior on the redundancy factor for structural design components in nondeterministic systems by using two to four components.

### 7. Damping factor:

Damping is the general term often used to characterize energy dissipation in a building frame whether the energy is dissipated by hysteretic behaviour or by viscous damper (ATC-19). The damping accomplished by hysteretic behaviour in a building that responds in the elastic range is generally termed equivalent viscous damping; it is assigned a value that is equal to 5% of the critical value. Current seismic design procedures that use $R$ factors are force-based procedures. The addition of viscous damping to a building frame reduces displacement but may increase inertial forces if viscous forces become substantial. The relationship can be demonstrated a follow. The equation of motion for SDOF frame is:

$$m\ddot{v}(t) + c\dot{v}(t) + kv(t) = 0$$  \hspace{1cm} (14)

Or

$$m\ddot{v}(t) + c\dot{v}(t) + kv(t) = -m\ddot{g}(t)$$  \hspace{1cm} (15)

Equation 14 rewritten as;

$$\ddot{v}(t) = -\frac{k\nu(t)}{m} - \frac{c\dot{v}(t)}{m}$$  \hspace{1cm} (16)

Then simplified to read;

$$\ddot{v}(t) = -\omega^2\nu(t) - 2\omega\xi\dot{v}(t)$$  \hspace{1cm} (17)

Where;

$$\omega^2 = \frac{k}{m} \text{ and } 2\omega\xi = \frac{c}{m}$$  \hspace{1cm} (18)
In this equation, $\omega^2 v(t)$ is the hysteretic (or spring) force per unit mass, and $2\omega\xi \dot{v}(t)$ is the damping force per unit mass. The equation of motion is

$$v(t) = -\left(\frac{1}{\omega^2}\right) \int_0^t \dot{v}_p(\tau)e^{-\xi \omega (t-\tau)} \sin \omega_D (t-\tau) d\tau$$

The maximum value of $v(t)$ is termed the spectral displacement, which is equal to pseudo-displacement.

Several researchers investigated the damping factor. For example, Lin and Chang (2003) studied damping reduction factor for buildings under earthquake ground motions. Ramirez et al. (2000, 2002) derived damping factor data by using 10 earthquake occurrences for linear elastic SDOF systems with damping ratios ranging from 2% to 100%. NEHRP (2000) developed a two-parameter model to design structures with damping systems. Wu and Hanson (1989) obtained a formula for the damping reduction factor from a statistical study on nonlinear response spectra with high damping ratios; 10 earthquake records were used as input ground motions for elasto-plastic SDOF systems with damping ratios between 10% and 50%. Ashour (1987) developed a relationship to explain the reduction in the displacement response spectrum for elastic systems with changes in viscous damping, and NEHRP (1994) adopted an $\alpha$ value of 18 to design buildings with passive energy dissipation systems. Mollaioli et al. (2014) studied displacement damping modification factors for pulse-like and ordinary records. They used records from 110 near-fault pulse-like ground motions and 224 ordinary ground motions to calculate elastic displacements and dimethylformamide spectra that correspond to different damping ratios that range from 2% to 50%.

8. Nonlinear static analyses:

Nonlinear static analysis estimates overstrength and ductility factors, which are required in determining the $R$ factor for structures. The equivalent lateral force distribution adopted for pushover analysis suggested in IBC code is as follows:

$$F_x = C_{vx}V$$

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$$

Where $F_x$ is the lateral seismic force at any level; $w_x$ is the total effective seismic weight of the structure located or assigned to level $i$ or $x$, $h_i$ and $h_x$ are the heights to the $i$ and $x$ floors, respectively; and $n$ is the total number of stories.

The capacity curve presents the primary data for evaluating $R$ for structures. Relevant information collected from the plot should be idealized so that overstrength and ductility reduction factors may be obtained by studying the pushover curve. Overstrength factor can be easily calculated as the ratio of yield strength to design strength by using these resultant data. In addition, ductility ratio can be calculated as the ratio of ultimate displacement to yield displacement, which is the key element to calculate the ductility reduction factor.

According to NEHRP guidelines (FEMA-273, 1997), seismic demands are calculated via a nonlinear static analysis of a structure exposed to monotonically increasing lateral forces with a constant height-wise distribution until a target displacement occurs. Nonlinear structural analysis was taken one step further with the publication of FEMA-273 (1997), FEMA-356 (2000), and FEMA-440 (2005), which
are documents that included extensive recommendations for load-deformation modeling of individual elements and for adequate values of force and deformation parameters for evaluating performance.

9. Conclusion:
This paper reviewed response modification factor and formulation. Numerous studies investigated the behaviour of $R$ factor for different structural systems. $R$ factor formulations identified in this review paper consisted of ductility ($R_\mu$), overstrength ($R_s$), and redundancy ($R_r$) factor. The objective of seismic design practice is gleaned from other research on earthquake safety design. The dependability of the values allocated to $R$ factors should change and improve if the dependability of the new building is repaired.

Practicing engineers and researchers in seismic design produced classifications systems of the original structures. Arbitrarily and intuitively, they added $R$-associated factors to show a decrease in force based on the nonlinear behaviour. More studies and deeper comprehension are needed on this issue because structures have become increasingly intricate in terms of design, configuration, and systems. Structural engineers should continue striving for designs that are practical, economical, and safe.

This study reviewed the application, design, and use of $R$ factor. We found that no study has been conducted on the effect of viscous damper on $R$, which indicates the capability of a structure to dissipate energy through inelastic behavior. Additional damping to structures is expected to reduce displacements according to base shear force. Based on the lateral strength design, lateral strength is typically lower than that required for structures to stay within the elastic range as per seismic codes. Other studies showed that overstrength factor varies based on building height, building type, and seismic zone. According to ATC-19, redundancy factor varies according to number of lines of strength and stiffness.

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