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AN INVESTIGATION OF STRUCTURAL RESPONSE MODIFICATION FACTORS

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SUMMARY

Structural response modification factors, specified as R_w in the 1988 *Uniform Building Code* (ICBO, 1988) and as R in the 1985 NEHRP Provisions (BSSC, 1985), are derived from the K factor, which was first introduced in the 1959 edition of *Tentative Lateral Force Requirements* (SEAOC, 1959). As currently defined, R and R_w are based on committee consensus opinion and have major shortcomings. Included herein are findings to date on the ATC-19 project, which is being conducted to evaluate the R-factor approach, identify parameters that affect R (R_w) values and define a rational methodology for determining and applying structure-specific R (R_w) values.

INTRODUCTION

The structural response modification factor is a building seismic design parameter used to scale the expected ground motion at a site down to the design ground motion. This parameter is specified as R in the 1985 edition of the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* (BSSC, 1985), which is an updated version of the ATC-3-06 report (ATC, 1978), and is used to obtain strength design base shear and member forces. In the seismic provisions of the 1988 *Uniform Building Code* (ICBO, 1988), which are based on the 1985 *Tentative Lateral Force Requirements* of the Seismology Committee of the Structural Engineers Association of California (SEAOC, 1985), this parameter is specified as R_w and is used to obtain working stress design base shear and member forces. The significant implications of the inclusion of the R (R_w) factor approach in the 1985 NEHRP Provisions and the 1988 *Uniform Building Code* (UBC) are: (1) the R (R_w) factor is the single most important seismic design parameter in these new procedures; and (2) within a very short time (a few years or less) most engineered buildings in highly seismic regions of the United States will be designed using these factors.

As currently defined, R (R_w) factors are based on committee consensus opinion and have major shortcomings, including:

- They are not ground motion dependent.
- They are not frequency dependent.
- Acceptable damage, or performance criteria, is not defined.

- It is unlikely that they provide uniform risk for all types of structures.

- The extent to which other parameters, in addition to general building type, affect R (R_w) factor values is not known.

- The theoretical procedures, the physical mechanisms, and the logical procedure by which the current R (R_w) factor values were determined have not been defined or documented.

In light of these shortcomings, Applied Technology Council is conducting the National Science Foundation-sponsored ATC-19 project to:

1. Study and document the basis of the R (R_w) approach.

2. Evaluate relevant research to identify the parameters that affect R (R_w) factor values.

3. Define a rational methodology for determining and applying structure-specific R (R_w) factors.

Findings on these issues will be documented in the ATC-19 report and distributed to the structural engineering profession as a resource document for improving design practice.

The ATC-19 project is organized in the same fashion as other ATC projects. Project consultants (in this case two) representing the research community and representing professional practice are conducting the detailed technical research, including development of the recommended methodology for determining structure specific R (R_w) factors. Their work is being guided and reviewed by an advisory Project Engineering Panel comprised of four leading specialists in building seismic design and performance--in this case two from the academic community and two from professional practice.

Following are the ATC-19 project findings to date.

HISTORICAL DEVELOPMENT OF R (R_W)

The historical development of currently used R (R_w) factors has been determined by interviewing the individuals who participated in their development and by studying available background materials and back-up references.

In the case of R, which was developed in the ATC-3 project (ATC, 1978), this investigation has revealed that:

- The dominant factor affecting the development of the R factor concept was the need to reduce expected seismic loadings to realistic design loads.

- The idea was to develop a factor that could be used to reduce expected ground motions presented in the form of response spectra to lower design levels and consequently bring modern structural dynamics into the design process through one factor.

- R factors were intended to reflect reductions in design force justified on the basis of risk assessment, economics, and nonlinear behavior.

These decisions resulted in the development of an R factor that was essentially a factored inversion of the K factor used in previous codes. Having decided that

R should appear in the denominator, the base shear equation in the ATC-3 project took the following form:

$$V = 2.5(A_a/R)W \quad \text{for structures for which } T \text{ is not calculated} \tag{1}$$

where: V = Lateral seismic base shear
A_a = Effective peak acceleration
R = Response modification factor
W = Total gravity load
T = Fundamental building period

or

$$V = 1.2(A_v S/RT^{2/3})W \quad \text{for structures for which } T \text{ is calculated} \tag{2}$$

where: A_v = Effective peak velocity-related acceleration
S = Soil profile coefficient

A maximum value of R was first determined for the structure type(s) considered to be the best performers (i.e., structure type(s) with highest reserve strength or ductility). Structures considered to be in this category were: (1) special steel moment frames; and (2) reinforced concrete shear-wall structures with special moment frames capable of resisting at least 25% of the prescribed seismic forces.

R(maximum) was determined by equilibrating V_w, as computed in working stress design (per the then current UBC), to V, as computed in strength design per ATC-3. Implicit in this equilibration was the decision by the ATC-3 project participants that it was not necessary to increase design base shear to improve siesmic performance, but rather such improvement should be achieved by other means (e.g., through improved detailing). R(maximum) was computed using the structure type--special steel moment frames--and assuming a period equal to 1.0 second. On this basis and accounting for the difference in the working stress versus strength design approaches, it followed that:

$$V_w(1.67/1.33) = V/0.9 \tag{3}$$

where: V_w = Working stress design lateral seismic base shear per the then current UBC.
V = Strength design lateral seismic base shear per ATC-3.
1.67 accounts for the margin of safety in working stress design.
1.33 accounts for an increase in allowable stress in working stress design.
0.9 is the capacity reduction factor in strength design.

or

$$ZIKCS_1W(1.67/1.33) = (1.2A_vS/RT^{2/3})W/0.9$$

where: Z = Zone factor
I = Building occupancy importance
K = Horizontal force factor
S_1 = Site coefficent (per the then current UBC)
W = Total gravity load
A_v,S,R,T are as defined above

If $Z = I = T = 1.0$, $S_1 = 1.5$, $C = 1/15(T)^{1/2}$, $A_v = 0.4$, and $S = 1.2$, then:

$$(1.0)(1.0)K(.067)(1.5)(1.67/1.33) = (1.2)(.4)(1.2)/R(1.0)(0.9)$$

$$(0.1256)K = 0.64/R$$

or

$$R = 5.1/K \qquad (4)$$

For K = 0.67, which was the then current UBC horizontal force factor for moment resisting frame systems, R(maximum) was then computed as follows:

$$R = 5.1/0.67 = 8$$

The R for reinforced concrete shear-wall structures with special moment frames capable of resisting at least 25 percent of the prescribed seismic forces was assigned the same maximum value as assigned to special steel moment frames per the above calculation (i.e., R = 8). R values for other structure types were generally assigned on the basis of Equation 4 and then adjusted in accordance with committee consensus opinion. Structure types not considered in the then current UBC were assigned R values also on the basis of committee consensus opinion.

Values for R_w (structural response modification factors for working stress design) were similarly determined by the Seismology Committee of the Structural Engineers Association of California and published in the Tentative Lateral Force Requirements (SEAOC, 1985), otherwise known as the "Blue Book." In this case, SEAOC elected to introduce R_w, rather than R, in order to ease the burden (on practicing structural engineers) of eventual probable conversion to strength design.

R_w is essentially a factored inversion of K, just as is R. An analytical approach suggested in Rojahn and Hart (1988) indicates that R_w and K are related as follows:

$$R_w = 7.86/K \qquad (5)$$

Values for K, R, and R_w for the various structural system types, as determined on the basis of committee consensus opinion, are summarized in Table 1. Values shown were obtained from the 1985 Uniform Building Code (K values), ATC-3-06 report (R values), NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings (BSSC, 1985; R values), and the 1988 Uniform Building Code (R_w values). With few exceptions, R factors obtained from the ATC-3-06 report (ATC, 1978) are the same as those obtained from the 1985 NEHRP Provisions (BSSC, 1985). The exceptions are an increased R value in the NEHRP Provisions for special concrete moment resisting space frames and the addition of R factors for concrete intermediate moment resisting space frames. R_w factors obtained from the 1988 Uniform Building Code are the same as those provided in the 1985 "Blue Book" (SEAOC, 1985).

OTHER PRELIMINARY FINDINGS

Investigations to date on the ATC-19 project suggest that the factors affecting R values include damping, ductility, and overstrength (V. V. Bertero, oral commun.). Of these, ductility and overstrength appear to have the largest impact.

Work to date also suggests that ductility levels can be inferred from existing K, R, and R_w values. See Rojahn and Hart (1988) for further information on this subject.

CONCLUDING REMARKS

Investigations to date on the NSF-sponsored ATC-19 project show the evolution of R and R_w from the K factor (horizontal force factor), which was first introduced by SEAOC in the 1959 edition of Tentative Lateral Force Requirements. R and R_w are both factored inversions of K and are based on committee consensus opinion. The ATC-19 investigations also indicate (1) the major shortcomings of R and R_w; and (2) the extent to which ductility, overstrength, and damping affect R and R_w. These data and information will be used under the ATC-19 project to develop a rational methodology for determining and applying structure-specific R (R_w) factors.

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Table 1.- Committee Consensus K, R, and R_w Values

BASIC STRUCTURAL SYSTEM (K Factor)/ Lateral Load Resisting System	R (ATC, 1978)	R (BSSC, 1985)	R_w (UBC, 1988)
BEARING WALL SYSTEM (K = 1.33)			
1. Light Framed Walls with Shear Panels	6.5	6.5	
a. Plywood walls, 3 stories or less			8
b. All other light framed walls			6
2. Shear Walls			
a. Concrete	4.5	4.5	6
b. Masonry	3.5	3.5	6
3. Light Steel Framed Bearing Walls with Tension-only Bracing	-	-	4
4. Braced Frames Carrying Gravity Loads	4	4	
a. Steel			6
b. Concrete			4
c. Heavy Timber			4
5. Unreinforced Masonry Shear Walls	1.25	1.25	-
BUILDING FRAME SYSTEM (K = 1.00)			
1. Steel Eccentric Braced Frame (EBF)	-	-	10
2. Light Framed Walls With Shear Panels	7	7	
a. Plywood walls, 3 stories or less			9
b. All other light framed walls			7
3. Shear Walls			
a. Concrete	5.5	5.5	8
b. Masonry	4.5	4.5	8
4. Concret Braced Frames	5	5	
a. Steel			8
b. Concrete			8
c. Heavy Timber			8
5. Unreinforced Masonry Shear Walls	1.5	1.5	-
MOMENT RESISTING FRAME SYSTEM (K = 0.67)			
1. Special Moment Resisting Space Frames (SMRSF)			
a. Steel	8	8	12
b. Concrete	7	8	12
2. Concrete Intermediate Moment Resisting Space Frames (IMRSF)	-	4	7
3. Ordinary Moment Resisting Space Frames			
a. Steel	4.5	4.5	6
b. Concrete	2	2	5
DUAL SYSTEM (K = 0.80)			
1. Shear Walls			
a. Concrete with SMRSF	8	8	12
b. Concrete with Concrete IMRSF	-	6	9
c. Masonry with Concrete SMRSF	6.5	6.5	8
d. Masonry with Concrete IMRSF	-	6	7
2. Steel EBF with Steel SMRSF	-	-	12
3. Concentric Braced Frames			
a. Steel with Steel SMRSF	6	6	10
b. Concrete with Concrete SMRSF	6	6	9
c. Concrete with Concrete IMRSF	-	5	6
4. Wood Sheathed Shear Panels			
a. SMRSF	-	8	-
b. IMRSF	-	7	-