Eylül 2006’ da İsviçre’nin Cenevre kentinde düzenlenen 1.Avrupa Deprem Konferansı’nda sunulmuştur...
THE SEISMIC RESPONSE MODIFICATION FACTOR FOR ECCENTRICALLY BRACED FRAMES

by
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Today, static elastic analysis procedures still remain the basis of earthquake resistant design practice.

In an elastic analysis procedure, elastic base shear, which is the function of code based design spectral acceleration, is reduced by the seismic response modification factor (R) considering the inelastic structural behaviour.
One constant R-value is assigned for all the buildings having the same lateral load resisting system in the seismic codes, even their geometries, locations and weights are different.
Since no supporting investigations are reported in modern seismic codes, it is likely that R-values are based on judgment, experience and observed performance of buildings during past earthquakes [Mwafy and Elnashai, 2002].

In other words, there is no technical basis for the values assigned to the R and it is empirical [Whittaker, Hart and Rojahn, 1999].


Basic Goal

R factor has been studied by various procedures in the literature.

In this study our basic goal is:

To introduce a new procedure for the evaluation of R-values by giving special attention to the EBF systems.
Effects of some earthquake properties on the R factor:

- Magnitude
- a/v ratio
- Closest distance from the fault rupture
Example Frames

- Loads and Load Combinations IBC 2003
- Capacity Design Principles AISC Seismic Provisions 2003
- Section Selection AISC-LRFD 1999
- Design Spectrum Southern California
- Site Class D – IBC (~C – USGS)
Selection of the link length during design process ensures that under seismic loads the shear yielding dominates the inelastic behaviour of each link.

The diagonal braces, the columns, and the beam segments outside of the links are designed to remain essentially elastic under the maximum forces that can be generated by the fully yielded and strain-hardened links.
Analyses

• Inelastic time history analyses of each frame are performed with DRAIN-2DX.

• Ramadan and Ghobarah’s (1995) inelastic shear-link-element model is used.
# Earthquake Records

<table>
<thead>
<tr>
<th>Earthquake Name</th>
<th>Number of Records</th>
<th>Magnitude (M)</th>
<th>Upper and lower values of distance closest to fault rupture (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imperial Valley</td>
<td>33</td>
<td>6.5</td>
<td>$R_{\text{min}} = 0.5 : R_{\text{max}} = 49.3$</td>
</tr>
<tr>
<td>Kern County</td>
<td>4</td>
<td>7.4</td>
<td>$R = 120.5$</td>
</tr>
<tr>
<td>Landers</td>
<td>16</td>
<td>7.3</td>
<td>$R_{\text{min}} = 37.5 : R_{\text{max}} = 162.1$</td>
</tr>
<tr>
<td>Loma Prieta</td>
<td>32</td>
<td>6.9</td>
<td>$R_{\text{min}} = 12.7 : R_{\text{max}} = 93.1$</td>
</tr>
<tr>
<td>Northridge</td>
<td>30</td>
<td>6.7</td>
<td>$R_{\text{min}} = 13.0 : R_{\text{max}} = 79.6$</td>
</tr>
<tr>
<td>N. Palm Springs</td>
<td>10</td>
<td>6.0</td>
<td>$R_{\text{min}} = 16.6 : R_{\text{max}} = 73.2$</td>
</tr>
<tr>
<td>Point Mugu</td>
<td>2</td>
<td>5.8</td>
<td>Closest to surface projection 16</td>
</tr>
<tr>
<td>San Fernando</td>
<td>20</td>
<td>6.6</td>
<td>$R_{\text{min}} = 21.2 : R_{\text{max}} = 223.0$</td>
</tr>
</tbody>
</table>

**TOTAL NUMBER OF RECORDS:** 147
The proposed evaluation method of R factor does not involve splitting R into component factors, thus avoids various assumptions of focusing on a particular component.

\[ R = R_\Omega \times R_\mu \times R_R \]

- REDUNDANCY (probabilistic discipline)
- DUCTILITY (inelastic spectra)
- OVERSTRENGTH (generally pushover)

DIRECTLY EVALUATED (introduced procedure)
1- FINDING THE SCALE FACTOR

Each earthquake record is scaled in the inelastic time history analyses until one of the links reaches the limit rotation angle of 0.08 radian.

In order to carry out this iterative procedure, a computer program is coded which calls drain.exe as a subroutine.
2- FINDING THE ELASTIC SHEAR OF THE CONCERNED LINK

After determining the scale factor causing the limit state, an elastic time history analysis is performed using this scale factor as if the frame remained elastic and the elastic shear of the concerned link is obtained.

It is noted that, inelastic time history analyses are performed to obtain only the scale factors corresponding to the deformation limit defined in the code.
3- FINDING THE R FACTOR

Consequently, the R factor is determined based on the link which reaches the limit plastic deformation first, by dividing the elastic shear of this link into its design shear value.

\[ R = \frac{V_{\text{LINK,ELASTIC}}}{V_{\text{LINK,DESIGN}}} \]
Some distinctive properties of the procedure

- The inelastic time history analyses of MDOF buildings are used directly in the evaluation of R factor.

- Special emphasis is given to the dependency of R-factor on the design method and seismic code.
The R-value given in the code for the example frames is 7. However, most of the R-values calculated were smaller than 7, which implies an unsafe region where the deformations are above the code limit.

Unsafe region was greater for the 6-storey EBF; however, the variation was smaller than that of the 3-storey EBF.
RESULTS

Histogram of R Values for 3-Storey EBF

Unsafe Region 61% _safe_ Safe Region 39%

Mean Value of R = 7.04
Coefficient of Variation = 0.43

R_{CODE} = 7.0
RESULTS

Histogram of RValues for 6 Storey EBF

- UNSAFE REGION 77%
- SAFE REGION 23%

MEAN VALUE OF R = 5.75
COEFFICIENT OF VARIATION = 0.18

R_CODE = 7.0
RESULTS

According to the results, the number of the stories significantly affects the R factors.

One constant R-value cannot reflect the expected inelastic behaviour of all buildings which have the same lateral load resisting system.
It is noted that the R factors are calculated for the designed EBFs, they are not the R values those should be used for the design. Namely, initial selection of the R value (in this study code-based R value) during the design process of EBFs affects the final R values calculated. Hence, an iteration on the design process with varying R values may be required.
The numerical solutions have shown “no evidence to suggest that it is necessary to take great care in the selection of records” with respect to the factors examined in this study like the results of a previous study [Iervolino and Cornell, 2005].

RESULTS  Effects of earthquake properties on R Factor -Magnitude-

Dispersion for 3-storey EBF

Dispersion for 6-Storey EBF
RESULTS  Effects of earthquake properties on R Factor -a/v Ratio-

Dispersion for 3-Storey EBF

Dispersion for 6-Storey EBF
RESULTS  Effects of earthquake properties on R Factor - Distance closest to fault rupture -
Thank you...