MIXED R-VALUES IN WOOD FRAMED RETROFITS

B. Olson¹, K. Palmer², and B. Maison³

ABSTRACT

A practical seismic retrofit for a wood-frame building typically involves a combination of different seismic force resisting systems (SFRSs). Wood structural panel (WSP) shear walls provide economic strength and stiffness. Steel moment resisting frames allow openings for parking and storefronts to remain, with ordinary moment frames (OMF) being common. The most common design approach is based on IEBC Chapter A4, which incorporates the seismic design provisions of ASCE 7. For combinations of SFRS, ASCE 7 requires the lowest R-value for any system in that direction to be used for all systems in that direction. For combined WSP and OMF systems (R-values of 6.5 and 3.5) the ASCE 7 requirement results in nearly double the force in the WSP elements. This result in longer shear walls, larger holdowns, and more foundation strengthening than if the same structure used only WSP shear walls.

Analysis of case study buildings shows that retrofits using the R-value associated with WSP and OMF on independent lines of resistance have performance better than that of a retrofit consisting solely of WSP. Retrofits using the code-required lowest R-value for both WSP and OMF systems, result in better performance than WSP and OMF systems using mixed R-values. However, the enhanced performance was less than that might be expected, and may be overly-conservative in meeting the objectives of a retrofit program. These findings support allowing the use of mixed R-values for SWOF retrofits using combinations of SFRSs.

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Introduction

Seismic retrofit ordinances have been enacted in California in recent years. Most common are ordinances to address older wood frame structures with a Soft, Weak, or Open Front (SWOF) story. A number of cities in the San Francisco Bay area and Los Angeles area have adopted such ordinances and many other cities are expected to follow. Table 1 summarizes mandatory retrofit programs that have been adopted throughout the state, and the approximately 21,000 buildings affected, primarily in San Francisco (4,900) and Los Angeles (13,500) \cite{1}.

Table 1. Case Study 1 – Mandatory Retrofit Programs in California

<table>
<thead>
<tr>
<th>City</th>
<th>Buildings</th>
<th>Program Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berkeley</td>
<td>270</td>
<td>Due to be complete by end of 2018</td>
</tr>
<tr>
<td>Fremont</td>
<td>22</td>
<td>Complete in 2012</td>
</tr>
<tr>
<td>San Francisco</td>
<td>4,900</td>
<td>Estimated 4,000 to be complete by mid-2019, balance by late 2020</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>13,500</td>
<td>Notices started May 2016, staggered deadlines by end of 2024</td>
</tr>
<tr>
<td>Santa Monica</td>
<td>1,600</td>
<td>Expected to begin end of 2017, to be completed by end of 2024</td>
</tr>
<tr>
<td>West Hollywood</td>
<td>800</td>
<td>Expected to begin April 2018, to be completed by end of 2023</td>
</tr>
</tbody>
</table>

Buildings targeted under these ordinances are larger residential structures built prior to the late 1970\textsuperscript{’}s. They are characterized by a number of fairly regular upper stories and a ground story that has a large number of openings (windows, garage doors, setbacks, etc.) on at least one exterior wall line. Failures of these structures were observed in the 1989 Loma Prieta and 1994 Northridge earthquakes, with failures most commonly occurring in the ground story. Due to the mix of solid and open wall lines, a retrofit will involve the use of multiple lateral force resisting systems (LFRS). Typically, wood structural panel (WSP) shear walls are used wherever possible due to their economy, but alternate systems such as steel moment resisting frames must be used where necessary to provide open access or additional strength.

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The California Existing Building Code Appendix Chapter A4 (Chapter A4) provides provisions for reducing the earthquake risk in SWOF buildings [2]. This is one of the compliance methods allowed under the San Francisco ordinance [3], and forms the basis of the Los Angeles ordinance [4]. Many of the other mandatory ordinances are similar to either the San Francisco (Berkeley) or Los Angeles (Santa Monica, West Hollywood) ordinances. All retrofit elements are to be designed in accordance with ASCE 7. Of particular note is the response modification factor (R value). Per the requirements of Section 12.2.3.3, when there is a combination of lateral force resisting systems (LFRS) in a horizontal direction, the lowest applicable R value in that direction is to be used for all LFRS elements in that direction [5]. WSP shear walls are a relatively ductile system with an R value of 6.5. Steel ordinary moment frames (OMF), commonly used along open wall lines, have an R value of only 3.5, or nearly half that of the WSP shear walls. This requires the design forces on the WSP shear walls to be nearly doubled. Many engineers question the necessity of this restriction, which often creates problems with the design and placement of stronger WSP, holdowns, and foundations within the building envelope. This presentation describes the Structural Engineers Association of Northern California (SEAONC) Existing Buildings Committee (EBC) efforts in determining whether using the lowest R value in parallel systems is necessary to protect life safety. This study was performed at the request of the City of San Francisco. The presenting author is the Chair of the EBC.

**Existing Alternatives**

R values are used in ASCE 7 to allow linear modeling of the expected non-linear response of the structure under seismic loading. One of the assumptions is that least ductile system will control deformation of the structure, and the limit on R values is to account for this [6]. There is an existing exception in Section 12.2.3.3 to allow the use of different R values on independent lines of resistance provided specific criteria are met. By their nature, the wood framed residential structures covered by the ordinances are Risk Category II (requirement 1) and light framed construction (requirement 3). Both the San Francisco and Los Angeles ordinances only apply to structures of three or more stories and thus do not meet requirement 2. A review ASCE 7 and the Commentary does not provide any insight on why two stories was chosen as a limiting criteria. A design per ASCE 7 using the non-linear procedures in Chapter 16 would not utilize R values.

FEMA P-807 and ASCE 41 are alternates to Chapter A4, and do not use R values to account for inelastic response of the system. FEMA P-807 estimates the performance of the model structure based upon non-linear analysis of a suite of similar structures [7]. These other structures can include a mix of LFRS on independent lines of resistance including materials not allowed to be considered when A4 is used (plaster, gypsum, etc). ASCE 41 includes both linear and non-linear methods for analyzing a structure [8]. Linear methods include an m factor to account for inelastic behavior of different elements, with no restrictions on combinations of elements in the LFRS. Non-linear methods directly model the inelastic behavior and deformation of different elements.

Limitation on the use of R values are specific to retrofits designed under Chapter A4, and there currently exist alternate methods that do not penalize the more ductile elements of the LFRS as described above. San Francisco Department of Building Inspection (DBI) indicates that the majority of retrofits under the San Francisco ordinance are being completed using Chapter A4 [9], even with P-807 and ASCE 41 recognized as alternate acceptance methods. This stems in part
from the unfamiliarity of DBI plan checkers with these other methods, resulting in increased times for review. Under the Los Angeles ordinance, which imposes additional requirements on the use of P-807 or ASCE 41, retrofits are expected to be completed almost exclusively with Chapter A4.

**Case Studies**

At the request of DBI, the EBC reviewed a proposal to allow the use of different $R$ values on independent lines of resistance in SWOF structures covered by the retrofit ordinance. DBI frequently consults EBC for technical guidance on questions related to existing buildings. EBC’s review involved case studies of an archetypical building covered by the ordinance [10].

The building used for the case studies is a 3-story midblock building with an open front at the ground floor. This style of building is believed to be representative of the majority of structures covered by the San Francisco ordinance. Figure 1 shows an aerial view of a block of similar buildings and a typical front elevation of the midblock building used in the case studies.

![Figure 1. Typical soft-story midblock buildings. (a) Aerial View. (b) Front elevation showing residential units in the upper stories (B) and open first story for auto parking (A).](image)

The EBC undertook two independent case studies of the archetypical buildings. Incremental dynamic analysis (IDA) using a suite ground motions were conducted to estimate the spectral acceleration corresponding to collapse at the first story. Median spectral acceleration at collapse was taken as the *spectral capacity* of the retrofit. Each case study modeled a number of different retrofits using WSP shear walls and steel moment frames (MF) to provide lateral strength and stiffness in the transverse direction. The benchmark (BM) for each case study was a retrofit using WSP shear walls at all lines of resistance. While not representative of an actual retrofit, this represents a ductile ($R = 6.5$) system as defined by the code. A retrofit was deemed acceptable if its spectral capacity equaled or exceeded that of the benchmark. Retrofits were designed in accordance with the CEBC Chapter A4. For both case studies, use of a steel moment frame along the front line of the building, whether with a uniform $R$ value or a mixed $R$ value resulted in a greater spectral capacity than for the benchmark building (Figure 2). Designs using a uniform $R$ value result in greater spectral capacity than a mixed $R$ value, which is to be expected given the larger base shear capacity.
Conclusions

The findings of the case study buildings support the use of mixed $R$ values in seismic retrofits of wood framed buildings. This is consistent with the results of analysis methods (FEMA P-807, ASCE 41) that have been developed for existing buildings. LFRS systems using a combination of WSP shear walls and steel MF elements, designed using $R$ values independent to each line of resistance, exhibited performance greater than a system using solely WSP shear walls. Systems containing concrete moment frames or shear walls or steel braced frames were beyond the scope of this study, and it is recommended that they continue to be designed with a uniform $R$ value. The city of San Francisco has now made changes to their retrofit program to allow design using mixed $R$ values per EBC recommendations.

References

6. American Society of Civil Engineers. ASCE 7-10: Commentary for Chapters 11-22 2013. American Society of Civil Engineers: Reston, VA.