# Example Evaluation of the ATC-63 Methodology for Wood Light-Frame System

**Authors:**

Andre Filiatrault, University at Buffalo, State University of New York, Buffalo, NY, Phone: 716-645-2114, Ext. 2434, Fax: 716-645-3733, af36@buffalo.edu
Ioannis P. Christovasilis, University at Buffalo, State University of New York, Buffalo, NY, ipc@buffalo.edu

## OBJECTIVES

This paper presents a full example of the application of the ATC-63 methodology [ATC, 2007; Deierlein et al., 2007] to assess the seismic performance of the class of wood light-frame buildings. The system design requirements of ASCE 7-05 are used as the framework, and then the seismic performance factors, SPFs, are determined by iteration until the acceptance criteria of the ATC-63 methodology are met.

## DESIGN REQUIREMENTS

This example assessment of wood light-frame systems utilizes the design requirements for engineered wood light-frame buildings included in ASCE 7-05 in place of the requirements that would need to be developed for a newly proposed system. However, an initial R = 6 factor is used initially as the admissible R value per the ATC-63 methodology closest to the current R = 6.5 value contained in ASCE 7-05 for wood light-frame shear wall systems with wood structural panel sheathing. The ASCE 7-05 design requirements are categorized as “A-Superior” since they represent many years of development and include lessons learned from a number of major earthquakes, as well as recent results obtained from large research programs, such as the FEMA-funded CUREE-Caltech Woodframe Project and the NSF/NEES-funded NEESWood Project.

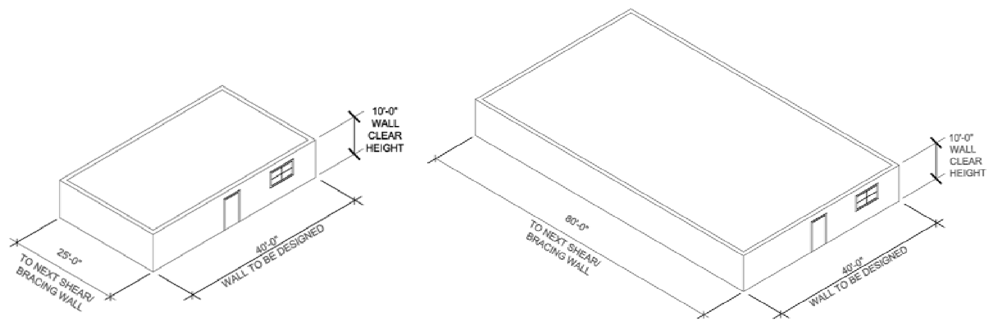
## TEST DATA

This example assessment relies on existing published sheathing-to-framing wood connection and whole wood shear wall test data in place of test data that would be developed for a newly proposed system. Specifically, this example relies on the sheathing-to-framing connection test database developed during the CUREE-Caltech Woodframe Project and the NEESWood Project, as well as the data of the CoLA wood shear wall test program [ATC, 2007].

The quality of the test data is an important consideration of the ATC-63 methodology when quantifying the uncertainty in the overall collapse assessment process. The monotonic and cyclic test data used in this example cover a wide range of wood sheathing types and thicknesses (e.g. Oriented Strand Board and Plywood), framing grades and species and connector types (e.g. common vs box nails). All loading protocols were continued to deformations large enough for the peak strength to be observed, which allows a better calibration of models for structural collapse assessment. Nevertheless, some uncertainties still exist with these test data sets including a) premature failures in some of the CUREE data set caused by specimens with smaller connector edge distances than specified, b) the use of the Sequential Phased Displacement, SPD, loading protocol in the CoLA tests that tends to cause premature specimen failure by connectors fatigue, which is seldom observed after real earthquakes and c) the inherent large variability associated with the material properties of wood. Therefore, for the purpose of assessing uncertainty, this test data set is conservatively categorized as “B-Good.”

## IDENTIFICATION OF WOOD LIGHT-FRAME ARCHETYPE CONFIGURATIONS

Figure 1 shows the two different building configurations used to define the two-dimensional archetype configurations for wood light-frame shear wall systems with wood structural panel sheathing. The first configuration is representative of residential building dimensions, while the second configuration is associated with office, retail, educational, and warehouse/light manufacturing wood buildings.




Residential Building Dimensions        Commercial/Educational Building Dimensions

FIGURE 1 - BUILDING CONFIGURATIONS CONSIDERED FOR THE DEFINITIONS OF WOOD LIGHT-FRAME ARCHETYPE BUILDINGS

Table 1 lists the range of design parameters considered for the development of the two-dimensional archetype wall models. Two-dimensional archetype wall models, not accounting for torsional effects, are considered acceptable because the intended use of the ATC-63 methodology is to verify the performance of a full class of buildings, rather than one specific building with a unique torsional issue. Wall finishes, such as stucco and gypsum wallboard, were not considered for the design of the archetype wall models. Depending on their type, wall finishes may greatly influence the seismic response of wood buildings. The influence of interior gypsum wallboard was introduced once it was realized that the wood-only archetypes designed with R = 6 did not meet the acceptance criteria of the ATC-63 methodology. Introducing gypsum wallboard was deemed reasonable since it is likely that it will be incorporated to the interior surfaces of structural wood walls of most wood buildings. The influence of nonstructural gypsum wallboard partitions, however, was not considered since the amount of partitions will vary greatly depending on the architectural layouts of wood buildings and can not be reliably counted on. The influence of exterior wall finishes, such as stucco, can not be counted on when verifying the performance of a full class of wood buildings for which various types of wall finishes may be utilized. Low ( 1:1 to 1.43:1) and high (2.70:1 to 3.33:1 ) aspect ratio walls were incorporated in the archetype designs to consider the influence of the aspect ratio strength adjustment factor for wood shear walls contained in ASCE 7-05.

To represent these ranges of design parameters, 40 archetypes could have been used to evaluate the system (two building configurations, five story heights, two shear wall aspect ratios and two seismic design categories). However, 16 archetypes were found to be sufficient. These 16 wood archetypes were divided in four performance groups: a performance group of three low aspect ratio wall buildings designed for the maximum ground motions of the Seismic Design Category D, SDC $D_{max}$, a performance group of five SDC $D_{max}$ - high aspect ratio wall buildings, a performance group of one low aspect ratio shear wall building designed for the minimum ground motions of SDC Dmin and a performance group of seven SDC Dmin - high aspect ratio shear wall buildings. It is believed that this ensemble of 16 archetypes covers the current design space for wood light-frame buildings. Detailed descriptions of the 16 archetype models developed for wood light-frame buildings can be found elsewhere [ATC, 2007].

| Variable | Range |
|---|---|
| Number of stories | 1 to 5 |
| Seismic Design Categories (SDC) | $D_{max}$ and $D_{min}$ |
| Story height | 10 ft |
| Interior Nonstructural wall finishes | Not considered in design<br>Considered in Modeling |
| Exterior Nonstructural wall finishes | Not considered |
| Wood shear wall pier aspect ratios | High/Low |

TABLE 1 - RANGE OF VARIABLES CONSIDERED FOR THE DEFINITION OF WOOD LIGHT-FRAME ARCHETYPE BUILDINGS

Table 2 shows the properties for each of these 16 archetype designs. The high- and low-seismic demands are represented by the maximum and minimum ground motions of Seismic Design Category (SDC) D, respectively. The archetypes are designed for a soil type D and acceleration parameters $S_{DS}$ = 1.0 g and $S_{D1}$ = 0.6 g for SDC $D_{max}$ (High Seismic in Table 2) and $S_{DS}$ = 0.50 g and $S_{D1}$ = 0.20 g for $S_{DC}$ $D_{min}$ (Low Seismic in Table 2).

The Maximum Considered Earthquake, MCE, ground motion spectral response accelerations, $S_{MT}$, shown in Table 2 and utilized in the analysis of the archetype buildings are based on the ASCE 7-05 mapped values. The periods reported in Table 2 are the fundamental period of the buildings based on the upper limit of Section 12.8.2 of ASCE 7-05 ($T = C_u T_a$) with a lower bound of 0.25 sec.

## DEVELOPMENT OF NONLINEAR STRUCTURAL ARCHETYPE MODELS

Structural modeling of the wood light-frame archetypes for the purpose of conducting nonlinear time-history collapse analyses is based on a "pancake" approach [Isoda et al., 2001]. This system-level modeling approach simulates the three-dimensional seismic response of a wood light-frame building through a degenerated two-dimensional planar analysis. The computer program SAWS: Seismic Analysis of Woodframe Structures, developed within the CUREE-Caltech Woodframe Project [Folz and Filiatrault, 2004a, b], was used to analyze the wood light-frame archetype models.

In the SAWS model, the building structure is composed of rigid horizontal diaphragms and nonlinear lateral load resisting shear wall elements. The pinched, strength and stiffness degrading hysteretic behavior of each wood shear wall in the building can be characterized using an associated numerical model [Folz and Filiatrault, 2001] that predicts the load-displacement response of whole wall assemblies under general quasi-static cyclic loading based on sheathing-to-framing connection cyclic test data. Alternatively, cyclic test results on full-scale walls can be used directly to characterize their hysteretic response. In the SAWS model, the hysteretic behavior of each wall panel is represented by an equivalent nonlinear shear spring element. The hysteretic behavior of this shear spring element includes pinching, stiffness and strength degradation and is governed by 10 different physically identifiable parameters [Folz and Filiatrault 2004a, b], as shown in Figure 2. The predictive capabilities of the SAWS program have been demonstrated by comparing its predictions with the results of shake table tests performed on full-scale wood light-frame buildings [Folz and Filiatrault, 2004b].

| Model No. | No. of Stories | Building Configuration | Wall Aspect Ratio | Period $T$ (sec) | V/W | $S_{MT}$ (g) |
|---|---|---|---|---|---|---|
| **High Seismic (SDC $D_{max}$) - Low Aspect Ratios - R = 6** | | | | | | |
| 1 | 1 | Commercial | Low | 0.25 | 0.167 | 1.50 |
| 5 | 2 | Commercial | Low | 0.26 | 0.167 | 1.50 |
| 9 | 3 | Commercial | Low | 0.36 | 0.167 | 1.50 |
| **High Seismic (SDC $D_{max}$) - High Aspect Ratios - R = 6** | | | | | | |
| 2 | 1 | 1&2 Family | High | 0.25 | 0.167 | 1.50 |
| 6 | 2 | 1&2 Family | High | 0.26 | 0.167 | 1.50 |
| 10 | 3 | Multi-Family | High | 0.36 | 0.167 | 1.50 |
| 13 | 4 | Multi-Family | High | 0.45 | 0.167 | 1.50 |
| 15 | 5 | Multi-Family | High | 0.53 | 0.167 | 1.50 |
| **Low Seismic (SDC $D_{min}$) - Low Aspect Ratios - R = 6** | | | | | | |
| 11 | 3 | Commercial | Low | 0.41 | 0.063 | 0.75 |
| **Low Seismic (SDC $D_{min}$) - High Aspect Ratios - R = 6** | | | | | | |
| 3 | 1 | Commercial | High | 0.25 | 0.063 | 0.75 |
| 4 | 1 | 1&2 Family | High | 0.25 | 0.063 | 0.75 |
| 7 | 2 | Commercial | High | 0.30 | 0.063 | 0.75 |
| 8 | 2 | 1&2 Family | High | 0.30 | 0.063 | 0.75 |
| 12 | 3 | Multi-Family | High | 0.41 | 0.063 | 0.75 |
| 14 | 4 | Multi-Family | High | 0.51 | 0.063 | 0.75 |
| 16 | 5 | Multi-Family | High | 0.60 | 0.063 | 0.75 |

TABLE 2 - WOOD LIGHT-FRAME ARCHETYPE STRUCTURAL DESIGN PROPERTIES

## UNCERTAINTY DUE TO MODEL QUALITY

For the purpose of assessing uncertainty per the ATC-63 methodology, the structural modeling approach for the wood light-frame archetypes captures the primary shear deterioration modes of the shear walls that precipitate side-sway collapse. However, not all behavioral aspects are captured by this system-level modeling, such as axial-flexural interaction effects of the wall elements, the uplift of narrow wall ends, and the slippage of sill and top plates. These effects are secondary for walls with low aspect ratios, which deform mainly in a shear mode, but are important for archetypes incorporating walls with high aspect ratios. Therefore, the structural model for the archetypes incorporating low-aspect ratio walls is rated as “B-Good”, while the same structural model for the archetypes incorporating high-aspect ratio walls is rated as “C-Fair”.

## NONLINEAR STRUCTURAL ANALYSES

To compute the system overstrength, Ω, and help verify the structural model, monotonic static pushover analysis is used with an inverted triangular lateral load pattern. To compute the collapse capacity of each wood light-frame archetype design, the Incremental Dynamic Analysis, IDA, approach is used with the Far-Field ground motion set and ground motion scaling method included in the ATC-63 methodology. The intensity of the ground motion causing collapse of the wood light-frame archetype models is defined as the point on the intensity-drift IDA plot having a nearly horizontal slope but without exceeding a peak inter-story drift of 7% in any wall of a model

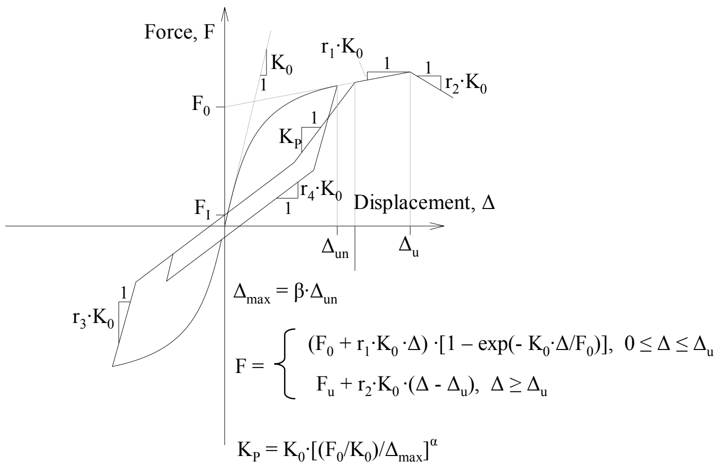



FIGURE 2 - HYSTERETIC MODEL OF SHEAR SPRING ELEMENT INCLUDED IN SAWS PROGRAM (FOLZ AND FILIATRAULT 2004A, B).

Static pushover analyses were conducted and the IDA method was applied to each of the 16 wood light-frame archetype designs without gypsum wallboard. Table 3 summarizes the results of these analyses. These IDA results indicate that the average collapse margin ratio (computed as the ratio of the spectral acceleration causing collapse in 50% of the analyses, $S_{CT}$, to the MCE spectral acceleration value at the period of each archetype, $S_{MT}$) is 1.42 for the SDC $D_{max}$ – low aspect ratio buildings, 1.85 for the SDC $D_{max}$ – high aspect ratio buildings, 2.35 for the SDC $D_{min}$ – low aspect ratio buildings and 2.46 for the SDC $D_{min}$ – high aspect ratio buildings. These margin values, however, have not yet been adjusted for the beneficial effects of spectral shape as included in the ATC-63 methodology [Deierlein et al., 2007].

The results shown in Table 3 show that the wood light-frame buildings without gypsum wallboard designed in low-seismic regions (SDC $D_{min}$) have higher collapse margin ratios (lower collapse risk) compared with the performance group of buildings designed in high-seismic regions (SDC-$D_{max}$). It is believed that this result originates from the longer period of vibrations of the low-seismic buildings compared to those of the high-seismic buildings, which reduce the seismic demands. Also, buildings incorporating walls with high aspect ratios have higher collapse margin ratios than those for buildings incorporating low aspect ratios. This is the result of the ASCE 7-05 strength reduction factor applied to walls with high aspect ratios, which cause an increase in required number of nails to reach a given strength. This increased nailing density causes an increase in the shear capacity of the walls with high aspect ratios; only shear deformations are considered in the structural analysis modeling of the wood light-frame archetypes, as discussed above.

## EVALUATION OF COLLAPSE MARGIN RATIO AND ACCEPTANCE CRITERIA FOR LIGHT-FRAME WOOD ARCHETYPES WITHOUT GYPSUM WALLBOARD

The collapse margin ratios computed above do not account for the unique spectral shape of rare ground motions. Spectral shape adjustment factors, SSF, defined in the ATC-63 methodology (ATC 2008) must be applied to the collapse spectral acceleration, SCT, to account for spectral shape effect. Based on the simplified method contained in the ATC-63 methodology, the SSF can be established for each archetype model based on its global ductility capacity, $\mu_c$, obtained from the pushover curve.

| Model No. | No. of Stories | Building Configuration | Wall Aspect Ratio | Period $T$ (sec) | V/W | $S_{MT}$ (g) | Static $\Omega$ | $S_{MT}$ (g) | $S_{CT}$ (g) | CMR |
|---|---|---|---|---|---|---|---|---|---|---|
| **High Seismic (SDC $D_{max}$) - Low Aspect Ratios - R = 6** | | | | | | | | | | |
| 1 | 1 | Commercial | Low | 0.25 | 0.167 | 1.50 | 1.55 | 1.50 | 1.94 | 1.29 |
| 5 | 2 | Commercial | Low | 0.26 | 0.167 | 1.50 | 2.04 | 1.50 | 2.15 | 1.43 |
| 9 | 3 | Commercial | Low | 0.36 | 0.167 | 1.50 | 1.56 | 1.50 | 2.28 | 1.52 |
| Mean | | | | | | | 1.72 | | | 1.42 |
| **High Seismic (SDC $D_{max}$) - High Aspect Ratios - R = 6** | | | | | | | | | | |
| 2 | 1 | 1&2 Family | High | 0.25 | 0.167 | 1.50 | 3.06 | 1.50 | 2.51 | 1.67 |
| 6 | 2 | 1&2 Family | High | 0.26 | 0.167 | 1.50 | 2.80 | 1.50 | 2.93 | 1.95 |
| 10 | 3 | Multi-Family | High | 0.36 | 0.167 | 1.50 | 2.81 | 1.50 | 2.98 | 1.99 |
| 13 | 4 | Multi-Family | High | 0.45 | 0.167 | 1.50 | 2.71 | 1.50 | 2.77 | 1.85 |
| 15 | 5 | Multi-Family | High | 0.53 | 0.167 | 1.50 | 2.37 | 1.50 | 2.71 | 1.81 |
| Mean | | | | | | | 2.75 | | | 1.85 |
| **Low Seismic (SDC $D_{min}$) - Low Aspect Ratios - R = 6** | | | | | | | | | | |
| 11 | 3 | Commercial | Low | 0.41 | 0.063 | 0.75 | 1.56 | 0.75 | 1.76 | 2.35 |
| Mean | | | | | | | 1.56 | | | 2.35 |
| **Low Seismic (SDC $D_{min}$) - High Aspect Ratios - R = 6** | | | | | | | | | | |
| 3 | 1 | Commercial | High | 0.25 | 0.063 | 0.75 | 2.72 | 0.75 | 1.67 | 2.23 |
| 4 | 1 | 1&2 Family | High | 0.25 | 0.063 | 0.75 | 4.09 | 0.75 | 1.81 | 2.41 |
| 7 | 2 | Commercial | High | 0.30 | 0.063 | 0.75 | 3.10 | 0.75 | 1.90 | 2.53 |
| 8 | 2 | 1&2 Family | High | 0.30 | 0.063 | 0.75 | 2.51 | 0.75 | 1.76 | 2.35 |
| 12 | 3 | Multi-Family | High | 0.41 | 0.063 | 0.75 | 3.07 | 0.75 | 2.13 | 2.84 |
| 14 | 4 | Multi-Family | High | 0.51 | 0.063 | 0.75 | 2.59 | 0.75 | 1.98 | 2.64 |
| 16 | 5 | Multi-Family | High | 0.60 | 0.063 | 0.75 | 2.44 | 0.75 | 1.68 | 2.24 |
| Mean | | | | | | | 2.93 | | | 2.46 |

TABLE 3 - SUMMARY OF COLLAPSE RESULTS FOR WOOD LIGHT-FRAME ARCHETYPE DESIGNS WITHOUT GYPSUM WALLBOARD

The adjusted collapse margin ratio, ACMR, is then computed for each wood light-frame archetype design without gypsum wallboard as the multiple of the SSF and CMR (from Table 4). Table 4 shows the resulting adjusted collapse margin ratios for the wood light-frame archetypes.

To calculate acceptable values of the adjusted collapse margin ratio, the total system uncertainty is needed. The ATC-63 methodology provides guidance for this calculation. These composite uncertainties, which account for the variability between ground motion records of a given intensity (defined as a constant $\beta$ = 0.40), the uncertainty in the nonlinear structural modeling, the quality of the test data used to calibrate the element models, and the quality of the structural system design requirements. For this example assessment, the composite uncertainty was based on a "B-Good" model quality for archetypes with low aspect ratio walls and a "C-Fair" for archetypes with high aspect ratio walls, "A-Superior" quality of design requirements" and "B-Good" quality of test data. Thus, from the ATC-63 methodology, $\beta$ = 0.65 for archetype buildings incorporating low aspect ratio walls and $\beta$ = 0.75 for archetype buildings incorporating high aspect ratio walls [ATC, 2007]. An acceptable collapse margin ratio must now be selected based on a composite uncertainty, $\beta$, and a target collapse prevention probability. The ATC-63 methodology presents acceptable values of adjusted collapse margin ratio computed assuming a lognormal distribution of collapse capacity. The collapse prevention objectives are associated with a conditional collapse probability of 20% for all wood light-frame archetype models, and 10% for the average of each of the four performance groups of wood light-frame archetypes (two SDC and two wall aspect ratios). For archetype buildings incorporating low aspect ratio walls, this corresponds to an acceptable collapse margin ratio CMR20% of 1.73 for every wood light-frame archetype and a CMR10% of 2.30 for each performance group. For archetype buildings incorporating high aspect ratio walls, this corresponds to an acceptable collapse margin ratio

CMR20% of 1.88 for every wood light-frame archetype and a CMR10% of 2.61 for each performance group.

Table 4 presents the final results and acceptance criteria for each of the 16 wood light-frame archetype designs without gypsum wallboard. The table presents the collapse margin ratios computed directly from the collapse fragility curves, CMR, the ductility capacities, μc, the SSF, and the adjusted collapse margin ratio, ACMR. The acceptable adjusted collapse margin ratios are shown and each archetype is shown to either pass or fail the acceptance criteria. Average collapse margin ratios are also shown for the four different performance groups of archetypes.

The results shown in Table 4 indicate that the high-seismic designs control and have lower adjusted collapse margins ratios than the low-seismic designs. It is believed that this is the result of the longer period of vibration associated with the low-seismic designs, which limits the seismic demands on these archetype buildings. Similarly, the archetype buildings incorporating low-aspect ratio walls control with lower collapse margin ratios than the high-aspect ratio designs. This is a direct consequence of the strength reduction factor included in ASCE 7-05 for walls with high aspect ratios, which induces denser nailing pattern in these narrow walls and increases their shear capacities in the model.

The results shown in Table 5 indicate also that all but one (Archetype No. 1) of the 16 wood light-frame archetype designs have acceptable individual adjusted collapse margin ratios. Also, the two high seismic performance groups (SDC $D_{max}$) do not have acceptable average collapse margin ratios and fail the acceptance criteria of the ATC-63 methodology. Therefore, if wood light-frame buildings without consideration of gypsum wallboard were a "newly proposed" seismic-force-resisting system with R = 6, it would not meet the collapse performance required by the ATC-63 methodology and could not be added as a "new system" in the building code provisions. The effect of gypsum wallboard applied on the interior faces of the structural wood walls is considered in the next section.

## CONSIDERATION OF GYPSUM WALLBOARD

Since the R = 6 light-frame wood archetype buildings without consideration of gypsum wallboard did not pass the acceptance criteria of the ATC-63 methodology, the archetype buildings are re-analyzed with ½ in. thick gypsum wallboard applied to the interior surfaces of all wood structural panel shear walls in the archetype buildings. Although gypsum wallboard is not specifically considered by ASCE 7-05 in the design process for light-frame wood buildings braced by structural panel shear walls, it is applied to the interior surfaces of structural wood walls in the vast majority of buildings, making it reasonable to consider gypsum wood panels in the analytical model. The collapse capacity of each wood light-frame archetype building with gypsum wallboard in addition to wood structural panel sheathing is re-evaluated using the Incremental Dynamic Analysis, IDA, approach described above using the Far-Field ground motion set.

During the iterative process involving various spacing of drywall screws, it was found that the collapse capacity of the wood light-frame archetypes was mainly governed by the spacing of the screws in the first story of the buildings. The spacing of the screws in the upper stories had very little influence on the collapse capacity of the wood archetype buildings incorporating gypsum wallboard. This is to be expected since the collapse mechanism associated with the wood light-frame archetype buildings is mainly governed by a weak first floor side-sway collapse mechanism.

| Model No. | No. of Stories | Building Configuration | Wall Aspect Ratio | Period $T$ (sec) | Static $\Omega$ | CMR | $\mu_c$ | SSF | ACMR | Acceptable ACMR | Pass/Fail |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **High Seismic (SDC $D_{max}$) - Low Aspect Ratios - R = 6** | | | | | | | | | | | |
| 1 | 1 | Commercial | Low | 0.25 | 1.55 | 1.29 | 4.45 | 1.26 | 1.63 | 1.73 | Fail |
| 5 | 2 | Commercial | Low | 0.26 | 2.04 | 1.43 | 4.36 | 1.26 | 1.81 | 1.73 | Pass |
| 9 | 3 | Commercial | Low | 0.36 | 1.56 | 1.52 | 4.05 | 1.25 | 1.90 | 1.73 | Pass |
| Mean | | | | | 1.72 | 1.42 | | | 1.78 | 2.30 | Fail |
| **High Seismic (SDC $D_{max}$) - High Aspect Ratios - R = 6** | | | | | | | | | | | |
| 2 | 1 | 1&2 Family | High | 0.25 | 3.06 | 1.67 | 3.89 | 1.24 | 2.07 | 1.88 | Pass |
| 6 | 2 | 1&2 Family | High | 0.26 | 2.80 | 1.95 | 3.91 | 1.25 | 2.44 | 1.88 | Pass |
| 10 | 3 | Multi-Family | High | 0.36 | 2.81 | 1.99 | 4.74 | 1.27 | 2.52 | 1.88 | Pass |
| 13 | 4 | Multi-Family | High | 0.45 | 2.71 | 1.85 | 2.99 | 1.20 | 2.22 | 1.88 | Pass |
| 15 | 5 | Multi-Family | High | 0.53 | 2.37 | 1.81 | 2.98 | 1.22 | 2.20 | 1.88 | Pass |
| Mean | | | | | 2.75 | 1.85 | | | 2.29 | 2.61 | Fail |
| **Low Seismic (SDC $D_{min}$) - Low Aspect Ratios - R = 6** | | | | | | | | | | | |
| 11 | 3 | Commercial | Low | 0.41 | 1.56 | 2.35 | 2.73 | 1.19 | 2.79 | 1.73 | Pass |
| Mean | | | | | 1.56 | 2.35 | | | 2.79 | 2.30 | Pass |
| **Low Seismic (SDC $D_{min}$) - High Aspect Ratios - R = 6** | | | | | | | | | | | |
| 3 | 1 | Commercial | High | 0.25 | 2.72 | 2.23 | 4.20 | 1.25 | 2.78 | 1.88 | Pass |
| 4 | 1 | 1&2 Family | High | 0.25 | 4.09 | 2.41 | 4.18 | 1.25 | 3.02 | 1.88 | Pass |
| 7 | 2 | Commercial | High | 0.30 | 3.10 | 2.53 | 3.06 | 1.20 | 3.04 | 1.88 | Pass |
| 8 | 2 | 1&2 Family | High | 0.30 | 2.51 | 2.35 | 3.55 | 1.23 | 2.89 | 1.88 | Pass |
| 12 | 3 | Multi-Family | High | 0.41 | 3.07 | 2.84 | 3.25 | 1.21 | 3.44 | 1.88 | Pass |
| 14 | 4 | Multi-Family | High | 0.51 | 2.59 | 2.64 | 2.60 | 1.18 | 3.12 | 1.88 | Pass |
| 16 | 5 | Multi-Family | High | 0.60 | 2.44 | 2.24 | 2.58 | 1.23 | 2.76 | 1.88 | Pass |
| Mean | | | | | 2.93 | 2.46 | | | 3.00 | 2.61 | Pass |

TABLE 4 ADJUSTED COLLAPSE MARGIN RATIOS AND ACCEPTABLE COLLAPSE MARGIN RATIOS FOR WOOD LIGHT-FRAME ARCHETYPE DESIGNS WITHOUT GYPSUM WALLBOARD

Table 5 presents the results of the analyses and acceptance criteria for the 16 archetype buildings incorporating gypsum wallboard attached with #6 1-1/4 in. long screws spaced at 4 in on center along the vertical studs and top and bottom plates in the first story and at 16 in. on center along the vertical studs only in the upper stories of the archetypes buildings. The results of Table 5 show that all of the 16 high seismic wood light-frame archetype designs have acceptable individual adjusted collapse margin ratios. Only the high seismic – low aspect ratios performance group slightly underachieves the acceptable average collapse margin ratio (ACMR = 2.12 vs Acceptable ACMR = 2.30). Considering that other gypsum partition walls will contribute to the collapse capacities of the archetype buildings, it could be concluded that the current seismic provisions for engineered wood light-frame construction included in the ASCE 7-05 are adequate to provide an acceptable collapse safety with R = 6 if ½" thick gypsum wallboard is attached to the interior surfaces of the structural wood walls with #6 1-1/4 in. long screws spaced at most at 4 in. on center along the vertical studs and the top and bottom plates in the first stories and 16 in. on center along the vertical stud only in all the other upper stories of the buildings.

## CALCULATION OF $\Omega_0$ USING SET OF ARCHETYPE DESIGNS

Table 5 shows the calculated Ω values for each of the archetypes, with a range of values from 1.6 to 6.4, and an average value of 3.2. The average values for each Performance Group, are 2.1, 3.2, 1.6, and 3.6, with the largest value of 3.6 being for the high aspect ratio walls designed for low-seismic demands. As per the ATC-63 methodology, the $\Omega_o$ value should be conservatively based on these individual values, rounded to the nearest 0.5, and limited to a maximum value of 3.0; this is subject to judgment and the Peer Review process. For this example, the upper-bound value of $\Omega_o$ = 3.0 is warranted, due to the large average Ω values observed for several of the archetype buildings, and the average values being greater than 3.0 for two of the Performance Groups.

| Model No. | No. of Stories | Building Configuration | Wall Aspect Ratio | Period $T$ (sec) | Static $\Omega$ | CMR | $\mu_c$ | SSF | ACMR | Acceptable ACMR | Pass/Fail |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **High Seismic (SDC $D_{max}$) - Low Aspect Ratios - R = 6** | | | | | | | | | | | |
| 1 | 1 | Commercial | Low | 0.25 | 2.41 | 1.52 | 8.05 | 1.35 | 2.05 | 1.73 | Pass |
| 5 | 2 | Commercial | Low | 0.26 | 2.05 | 1.63 | 6.13 | 1.30 | 2.12 | 1.73 | Pass |
| 9 | 3 | Commercial | Low | 0.36 | 1.71 | 1.67 | 6.29 | 1.31 | 2.18 | 1.73 | Pass |
| Mean | | | | | 2.06 | 1.61 | | | 2.12 | 2.30 | Almost Pass |
| **High Seismic (SDC $D_{max}$) - High Aspect Ratios - R = 6** | | | | | | | | | | | |
| 2 | 1 | 1&2 Family | High | 0.25 | 4.79 | 1.98 | 7.64 | 1.34 | 2.65 | 1.88 | Pass |
| 6 | 2 | 1&2 Family | High | 0.26 | 2.88 | 1.99 | 7.49 | 1.34 | 2.66 | 1.88 | Pass |
| 10 | 3 | Multi-Family | High | 0.36 | 2.90 | 2.07 | 6.64 | 1.32 | 2.74 | 1.88 | Pass |
| 13 | 4 | Multi-Family | High | 0.45 | 3.02 | 2.09 | 5.83 | 1.30 | 2.72 | 1.88 | Pass |
| 15 | 5 | Multi-Family | High | 0.53 | 2.47 | 1.89 | 3.07 | 1.22 | 2.30 | 1.88 | Pass |
| Mean | | | | | 3.21 | 2.00 | | | 2.62 | 2.61 | Pass |
| **Low Seismic (SDC $D_{min}$) - Low Aspect Ratios - R = 6** | | | | | | | | | | | |
| 11 | 3 | Commercial | Low | 0.41 | 1.62 | 1.99 | 3.90 | 1.25 | 2.48 | 1.73 | Pass |
| Mean | | | | | 1.62 | 1.99 | | | 2.48 | 2.30 | Pass |
| **Low Seismic (SDC $D_{min}$) - High Aspect Ratios - R = 6** | | | | | | | | | | | |
| 3 | 1 | Commercial | High | 0.25 | 4.23 | 2.47 | 8.63 | 1.35 | 3.33 | 1.88 | Pass |
| 4 | 1 | 1&2 Family | High | 0.25 | 6.35 | 2.89 | 7.77 | 1.34 | 3.88 | 1.88 | Pass |
| 7 | 2 | Commercial | High | 0.30 | 3.20 | 2.61 | 6.05 | 1.30 | 3.40 | 1.88 | Pass |
| 8 | 2 | 1&2 Family | High | 0.30 | 3.06 | 2.59 | 7.09 | 1.33 | 3.44 | 1.88 | Pass |
| 12 | 3 | Multi-Family | High | 0.41 | 3.07 | 2.47 | 3.66 | 1.23 | 3.03 | 1.88 | Pass |
| 14 | 4 | Multi-Family | High | 0.51 | 2.59 | 2.59 | 3.75 | 1.24 | 3.21 | 1.88 | Pass |
| 16 | 5 | Multi-Family | High | 0.60 | 2.42 | 2.00 | 3.30 | 1.23 | 2.46 | 1.88 | Pass |
| Mean | | | | | 3.56 | 2.52 | | | 3.25 | 2.61 | Pass |

TABLE 5 ADJUSTED COLLAPSE MARGIN RATIOS AND ACCEPTABLE COLLAPSE MARGIN RATIOS FOR WOOD LIGHT-FRAME ARCHETYPE DESIGNS WITH ½ IN. THICK GYPSUM WALLBOARD ATTACHED WITH #6 1-1/4 DRYWALL SCREWS SPACED AT 4 IN. IN FIRST STORY AND 16 IN. IN ALL OTHER UPPER STORIES

## ALTERNATIVE WOOD-ONLY DESIGNS WITH REDUCED R FACTORS

As an alternative to relying on the application of gypsum wallboard on the interior surfaces of wood structural walls design with R = 6, wood-only structure could also be designed with a lower R value and still meet the acceptance criteria of the ATC-63 methodology. An iterative process is used to identify a reduced value of R that meets these criteria without consideration of the effects of gypsum wallboard. Only the high seismic - low aspect ratios archetype models are considered since this performance group controls the selection of R.

First, the three archetype buildings of the high seismic - low aspect ratios performance group were re-designed with a value of R = 4. The results obtained indicate that these archetypes designed for R = 4 still do not meet the acceptable average collapse margin ratio [ATC, 2007].

The three archetypes buildings of the high seismic - low aspect ratios performance group were re-designed again for a value of R = 2. Table 6 presents the results of the IDA analyses and acceptance criteria for each of these re-designed wood light-frame archetype buildings. The results shown in Table 6 indicate that the three archetypes re-designed for R = 2 now meet the acceptable average collapse margin ratio.

## CONCLUSION

This paper illustrated the application of the ATC-63 assessment methodology to the wood light-frame wood shear wall system as if it were a “newly-proposed” system. This example illustrated that current seismic provisions for engineered wood light-frame construction included in ASCE 7-05 are inadequate to provide an acceptable collapse safety according to the ATC-63 methodology with R = 6 if the effects of nonstructural wall finishes materials are ignored. Acceptable collapse safety is obtained with R = 6 only when the contribution of ½ in. thick gypsum wallboard attached with #6 1-1/4 in. long screws to the interior surfaces of all wood structural walls is considered. The results show that the screws must be spaced at most at 4 in. on center along vertical studs and top and bottom plates in the first story and at 16 in. on center along vertical studs only in all other upper stories along vertical studs only. Therefore, these specifications for gypsum wallboard would need to be included in the seismic provisions of engineering wood light-frame for an R = 6 to be valid. Alternatively, the results indicated also that a value of R = 2 would be adequate if the contribution of gypsum wallboard is ignored. Note that a value of R = 3 may also be adequate but has not been verified in this study. Finally, the results showed that, when including gypsum wallboard, the overstrength factor $\Omega_0 = 3.0$ should be used in the design provisions for the light-frame wood system.

| Model No. | Period $T$ (sec) | Static $\Omega$ | CMR | $\mu_c$ | SSF | ACMR | Acceptable ACMR | Pass/Fail |
|---|---|---|---|---|---|---|---|---|
| **High Seismic (SDC $D_{max}$) - Low Aspect Ratios - R = 2** | | | | | | | | |
| 1B | 0.25 | 2.03 | 2.41 | 4.17 | 1.25 | 3.01 | 1.73 | Pass |
| 5B | 0.26 | 1.70 | 2.53 | 3.90 | 1.25 | 3.17 | 1.73 | Pass |
| 9B | 0.36 | 1.70 | 2.47 | 3.24 | 1.21 | 2.98 | 1.73 | Pass |
| Mean | | 1.81 | 2.47 | | | 3.05 | 2.30 | Pass |

TABLE 6 ADJUSTED COLLAPSE MARGIN RATIOS AND ACCEPTABLE COLLAPSE MARGIN RATIOS FOR WOOD LIGHT-FRAME ARCHETYPES RE-DESIGNED FOR R = 2 AND WITHOUT GYPSUM WALLBOARD

## ACKNOWLEDGEMENTS

The work forming the basis for this publication was conducted as part of the ATC-63 Project "Quantification of Building System Performance and Response Parameters," pursuant to a contract with the Federal Emergency Management Agency. The substance of such work is dedicated to the public. The author(s) are solely responsible for the accuracy of statements or interpretations contained in this publication. No warranty is offered with regard to the results, findings and recommendations contained herein, either by the Federal Emergency Management Agency, the Applied Technology Council (ATC), its directors, members or employees.

## REFERENCES

[1] Deierlein, G.G., Liel, A.B., Haselton, C.B. and Kircher, C.A., "Assessing Building System Collapse Performance and Associated Requirements for Seismic Design," SEAOC 2007 Convention Proceedings, Lake Tahoe, CA, 2007, 14 p.

[2] Applied Technology Council [ATC], "Recommended Methodology for Quantification of Building System Performance and Response Parameters," ATC-63 90% Draft, Redwood City, CA, 2007.

[3] Isoda, H., Folz, B., and Filiatrault, A. "Seismic Modeling of Index Woodframe Buildings. Report No. W-12, Consortium of Universities for Research in Earthquake Engineering, Richmond, CA, 2001, 144 p.

[4] Folz, B., and Filiatrault, A. "Seismic Analysis of Woodframe Structures I: Model Formulation", ASCE Journal of Structural Engineering, 130(8), 2004a, 1353-1360.

[5] Folz, B., and Filiatrault, A. "Seismic Analysis of Woodframe Structures II: Model Implementation and Verification", ASCE Journal of Structural Engineering, 130(8), 2004b, 1361-1370.

[6] Folz, B., and Filiatrault, A. "Cyclic Analysis of Wood Shear Walls", ASCE Journal of Structural Engineering, 127(4), 2001, 433-441.