Qualifications for Equivalence

An Illustration and Discussion of New Seismic Evaluation Provisions

By Reynaud Serrette, Ph.D

Prefabricated, proprietary lateral-force-resisting elements (panels and frames) are necessary and common structural components in modern light-frame construction. These elements range in width from 12 inches up to 80 inches, and are commonly used in conjunction with conventional (code-approved) lateral-force-resisting elements.

In the aftermath of the costly damage to wood frame construction from the 1994 Northridge Earthquake, the Federal Emergency Management Agency (FEMA) funded a four-year wood frame research project (CUREE-Caltech Woodframe Project) involving hundreds of individuals from both the public and private sectors. The goal of the CUREE-Caltech project was "to develop reliable and economical methods of improving wood frame building performance in earthquakes" (CUREE Publication No. 30a). The project resulted in several reports, including CUREE Publication Nos. W-30a and W-30b *Recommendations for Earthquake Resistance in the Design of Woodframe Buildings – Parts 1 and 2.* For prefabricated proprietary elements, identified in the CUREE-Caltech report as "pre-engineered devices and systems," CUREE Publication No. 30a suggested that equivalent performance to wood structural panel, wood light-frame shear walls may be achieved if prefabricated elements met the following criteria:

- A usable inelastic displacement capacity equal to 2.5% of the prefabricated element's height. The report did not clearly identify the strength level associated with this displacement, but a post-peak strength equal to 80% of the peak strength may be inferred from the discussion in CUREE Publication No. 30b.
- A ratio of the peak strength to ASD strength (V_{PEAK}/V_{ASD}) greater than or equal to 2.0.
- An ASD strength displacement (Δ_{ASD}) less than or equal to 0.50% of the element height.

It appears that the 2.5% usable inelastic displacement limit was based on the Woodframe Project research for structures with reserve capacity and repairable damage (2%), and structures near partial collapse with damage beyond a reasonable expectation of repair (≥ 3%).

In 2006, manufacturers of proprietary lateral-force-resisting elements raised concerns regarding the performance of competing prefabricated cold-formed steel elements. Citing the provisions in ASCE 7-05, Section 12.2.1, they argued that existing ICC-ES criteria did not adequately address the issue of equivalent performance to code-approved light-frame shear walls. Specifically, in accordance with ASCE 7-05, appropriate analytical and test data must be provided to "establish the dynamic characteristics and demonstrate the lateral force resistance and energy dissipation capacity to be equivalent to the structural systems listed in Table 12.2-1 for equivalent response modification coefficient, R, system overstrength coefficient, Ω_o, and deflection amplification factor, C_d, values." The language in ASCE 7-05, Section 12.2.1, was not new. In fact, this language existed in the FEMA *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* prior to the 1994 Northridge Earthquake. Nevertheless, the concerns raised by the manufacturers warranted a review of existing ICC-ES criteria for prefabricated lateral-force-resisting elements.

This article presents and illustrates the criteria recently adopted by the International Code Council Evaluation Services (ICC-ES) Inc. to qualify wood-based proprietary lateral-force-resisting elements as equivalent to code-approved wood structural panel, wood light-frame shear walls. In addition, this article highlights the importance of addressing stiffness when ICC-ES approved proprietary elements are used in conjunction with code-approved shear walls in light-frame structures.

Equivalency Criteria for Wood Structural Panel, Wood Light-Frame Shear Walls

The current equivalency requirements for prefabricated wood-based lateral-force resisting elements (ICC-ES AC130) are based on the recommendations of an 11-member task group (AC322 Task Group) comprising manufacturers, wood-trade association representatives, engineers and academicians. The task group evaluated response data from 48 reversed cyclically tested (CUREE basic test protocol) wood frame shear walls. *Table 1* summarizes the wood shear wall configurations included in the task group's evaluation. After considering several different parameters to characterize the overall response/performance of the walls in the database, the task group settled on three parameters. The task group then determined characteristic values for these three parameters using a mean-less-one-standard-deviation analysis of the data.

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Wall Configuration				Number of tests
Sheathing	Fastener and Fastener Schedule	Wall Height (ft.)	Aspect Ratio (wall height to wall width)	
7/16-in. OSB	8d common/box/galv. box @ 4 in. / 6 in.	8.0	1:1	12
7/16-in. OSB	8d common @ 3 in. / 12 in.	8.0	1:1	18
19/32-in. OSB	10d common @ 2 in. / 12 in.	8.0	1:1	4
3/8-in. OSB	8d box @ 6 in. / 12 in.	8.0	1:2	2
3/8-in. OSB	8d box @ 3 in. / 12 in.	8.0	2.56:1	4
3/8-in. OSB	8d box @ 6 in. / 12 in.	8.0	0.8:1	4
3/8-in. OSB	16 ga. staples @ 6 in. / 12 in.	8.0	1:2	2
15/32-in. S1 OSB	10d common @ 2 in. / 12 in.	8.5	1.89:1	2

Table 1: Summary of test data evaluated by AC322 Task Group.

In accordance with the current AC130, wood-based prefabricated elements qualify for seismic performance factors R = 6.5, C_d = 4.0 and Ω_o = 3.0 if the measured envelope response meets the following three requirements:

1) $V_{PEAK}/V_{ASD} \geq 2.5$
   The ratio of the peak strength (V_{PEAK}) to the ASD strength (V_{ASD}), referred to in this article as the element ASD-based overstrength, shall equal or exceed 2.5.
2) $\Delta_{0.8VPEAK} \geq 2.8\%$ of the element height
   The element's displacement at a strength no less than 80% of its peak strength (maximum usable inelastic displacement), $\Delta_{0.8VPEAK}$, shall equal or exceed 2.8% of the panel height.
3) $\Delta_{0.8VPEAK} \geq 11 \times \Delta_{ASD}$
   The ratio of the maximum usable inelastic displacement ($\Delta_{0.8VPEAK}$) to the ASD strength displacement (Δ_{ASD}) shall equal or exceed 11.

Under the first of the three requirements, there is no upper limit on V_{PEAK}/V_{ASD}. However, the AC322 task group felt that ASD-based overstrength values greater than 5.0 might not result in a desirable response during larger earthquakes. As such, the task group recommended that when V_{PEAK}/V_{ASD} exceeds 5.0, anchorage and collectors should be designed to develop the smaller of the capacity of the lateral element or the amplified forces defined in ASCE 7-05, Section 12.4.2.3. The three performance requirements listed above were considered adequate for establishing equivalent dynamic characteristics, lateral resistance and energy dissipation capacity to code-approved wood light-frame shear walls with R = 6.5.

Figures 1, *2* and *3* show the distribution (histogram and cumulative percent) of the data reviewed by the task group for each equivalency parameter. The characteristic value for each parameter is superimposed on the distribution, along with the percent of data below that value. For example, in *Figure 1*, 10.4% of the data analyzed by the task group had V_{PEAK}/V_{ASD} values less than or equal to 2.5, or alternatively, 89.6% of the test data exceeded the limit value. As shown in *Figures 1*, *2* and *3*, in all cases, more than 85% of the test data values exceeded the prescribed equivalency parameter values.

The AC130 equivalency requirements do not explicitly account for the form of an element's response between the ASD displacement, Δ_{ASD}, and the maximum usable inelastic displacement, $\Delta_{0.8VPEAK}$. As illustrated in *Figure 4*, the four tri-linear plots all meet the

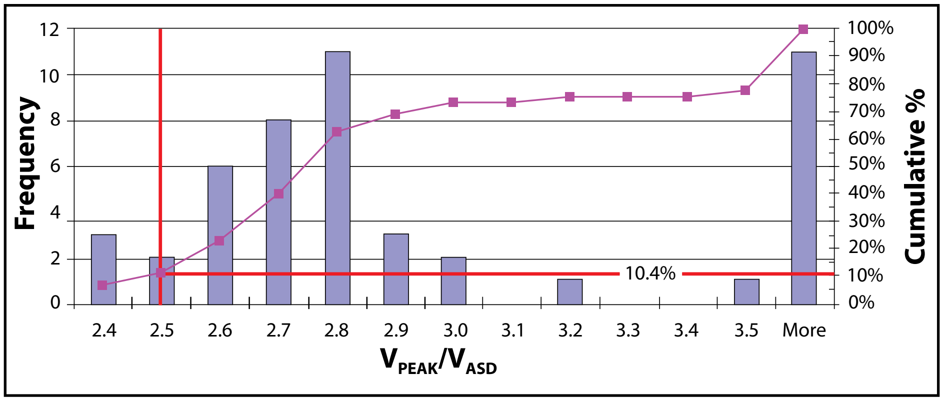

Figure 1: Distribution of test data for V_{PEAK}/V_{ASD}.

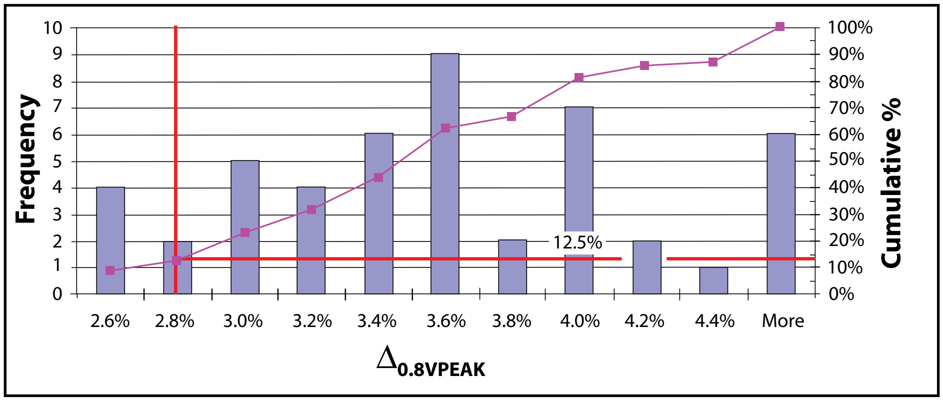

Figure 2: Distribution of test data for $\Delta_{0.8VPEAK}$.

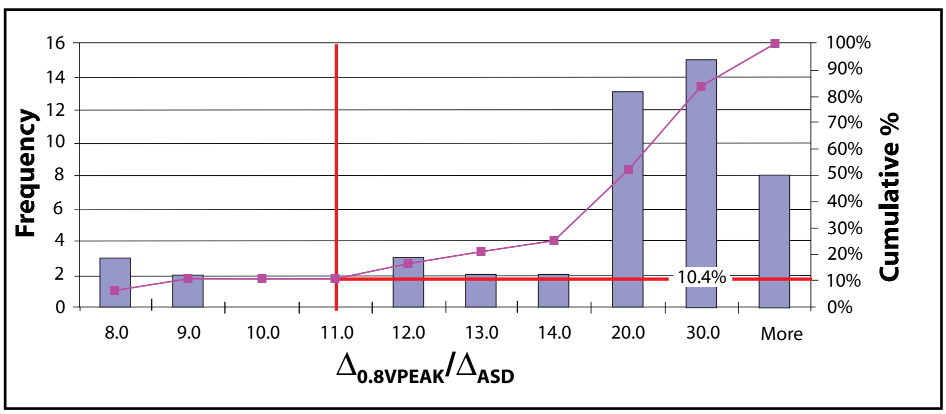

Figure 3: Distribution of test data for $\Delta_{0.8VPEAK}/\Delta_{ASD}$.

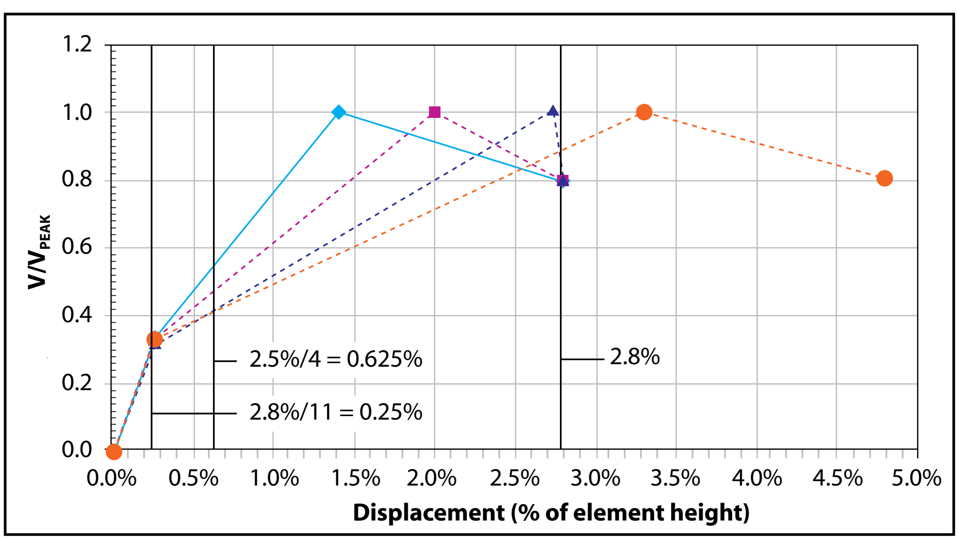

Figure 4: Possible tri-linear relationships that meet the equivalency requirements.

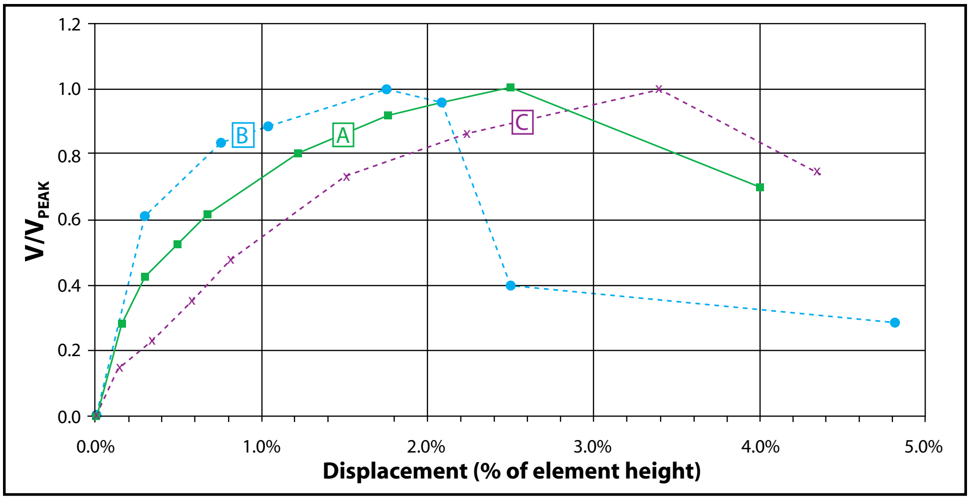

Figure 5: Prefabricated lateral-force resisting element (A, B and C) responses.

equivalency requirements noted, however, the relationships between $\Delta_{0.8VPEAK}$ and the displacement at the peak strength are quite different.

Application of AC130

To illustrate application of the AC130 equivalency requirements, the envelope response curves for three prefabricated lateral-force resisting elements (A, B and C) are considered in *Figure 5*. The load (vertical) axis in *Figure 5* is normalized with respect to peak strength, and lateral displacement is given as a percent of the element height.

For each of the response curves shown in *Figure 5*, the maximum ASD level strength and its associated displacement are determined in accordance with applicable requirements of AC130 as summarized below:

i) Assume R = 6.5, C_d = 4.0 and Ω_o = 3.0 is sought for the prefabricated lateral-force resisting element. *Under the current provisions, qualification requirements are provided for R = 6.5 only.*

ii) The ASD strength is determined considering both strength and displacement criteria. The lesser of the strengths from the two criteria define the maximum usable ASD strength.

a) *Strength criterion*: ASD strength is equal to the peak strength divided by 2.5 (safety factor). The displacement at this strength defines the ASD displacement. The 2.5 safety factor implies a ratio of peak to LRFD strength of 1.75 (= 2.5 x 0.7) compared to the system overstrength factor of 3.0.

b) *Displacement criterion*: The ASD strength is equal to 0.7 times the lesser of the strength associated with the peak strength displacement divided by C_d and the strength associated with 2.5% maximum displacement divided by C_d. The 2.5% displacement assumes the element is used in a structure "*four (4) stories or less with interior walls, partitions, ceilings and exterior wall systems that have been designed to accommodate the story displacement.*" Assuming the 2.5% displacement is appropriate, and it is smaller than the peak strength displacement, the upper limit on the

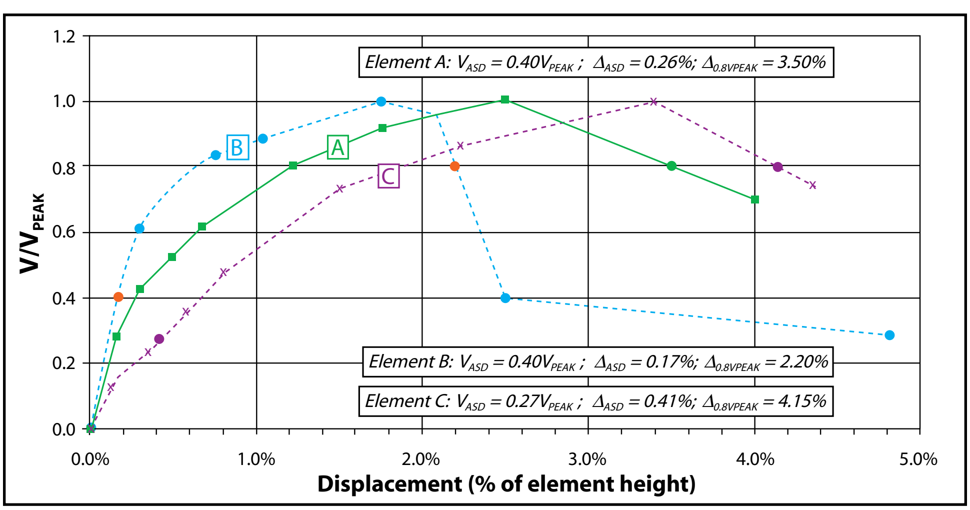

Figure 6: ASD design values for prefabricated elements A, B and C.

ASD displacement will be approximately 0.025 x (0.7/ C_d) = 0.0044 or 0.44% of the wall height. This upper limit on the ASD displacement assumes a linear response up to the LRFD strength level and is less than the 0.50% recommended in the CUREE-Caltech project. It is worth noting that the average ASD displacement for the wood frame shear walls analyzed by the AC322 task group was 0.21%, with an average-less-one-standard-deviation value of 0.11%.

For the three elements in *Figure 5 (page 21)*, the ASD design values and the maximum usable inelastic displacements are shown in *Figure 6 (page 21)*. *Table 2* compares the response characteristics of the three prefabricated lateral-force resisting elements to the requirements for equivalency. As noted by the underlined value in *Table 2*, the maximum usable inelastic displacement $\Delta_{0.8VPEAK}$ for Element B is 2.20%. Since this value is less than 2.80% of the panel height, Element B does not and cannot qualify as equivalent to wood structural panel, wood light-frame shear walls. Element C meets all the requirements for equivalence except the maximum usable inelastic displacement to the ASD strength displacement ratio, $\Delta_{0.8VPEAK}/\Delta_{ASD}$, equals 10.1. Thus, at the maximum usable ASD strength, Element C does not qualify for equivalence. Element A is the only element that satisfies all of the equivalency requirements at its maximum usable ASD strength.

Although Element C did not qualify for equivalence under AC130 at its maximum usable ASD strength, if V_{ASD} is reduced (i.e. the ASD strength is rated down), the associated Δ_{ASD} value will also be reduced. In fact, if V_{ASD} is taken as $0.25V_{PEAK}$ instead of $0.27V_{PEAK}$, the resulting Δ_{ASD} is 0.38%, and $\Delta_{0.8VPEAK}/\Delta_{ASD}$ meets the 11 ratio. At the reduced ASD strength, Element C is now equivalent to a wood structural panel, wood light-frame shear wall. A reduction in the ASD strength to meet the equivalency requirements will generally require the use of more elements for a given design, and this would effectively result in an increased stiffness along that particular lateral line.

Parameter/ Characteristic	Type A Shear Wall	Proprietary Panel
Height	8 ft.	8 ft.
V_{ASD}	1200 lb.	1200 lb.
Δ_{ASD}	0.15 in. (0.156%)	0.30 in. (0.312%)
K_{ASD} (Effective Elastic Stiffness)	8000 lb/in.	4000 lb/in.
V_{PEAK}/V_{ASD}	4.30	3.42
$\Delta_{0.8VPEAK}$	> 1.65 in. > 11 x Δ_{ASD} > 2.8% of height	> 3.3 in. (> 11 x Δ_{ASD}) > 2.8% of height

Table 3: Type A shear wall and proprietary panel design data.

Strength and Stiffness in Design

Prefabricated elements are most commonly used in areas where there is not sufficient wall length to develop the expected design forces using conventional framing. Prefabricated elements also tend to be more flexible than conventional shear walls for the same design loads. In choosing proprietary elements for a particular design, the building code requires consideration of both strength and stiffness. In light-frame construction, engineers typically adopt one of the following two strategies when specifying proprietary elements:

- Equal or higher ASD strength compared to the conventional system, or
- Equal or higher ASD strength and stiffness compared to the conventional system.

These two strategies will not generally result in the same structural response, particularly when the prefabricated elements are used in conjunction with code-approved shear walls (the predominant situation). There is an important distinction between equal or higher strength alone, and equal or higher strength and stiffness. Neglecting the effects of finish materials, designs that provide equal or higher strength alone may have relatively low stiffness and permit larger displacements with a potential increase in building damage. On the other hand, components that provide equal or higher strength and stiffness are more likely to provide significant overstrength with equal or less damage than conventional light-frame shear walls (again, neglecting the effect of finish materials). The equal or higher stiffness design approach may result in increased demands on anchorage and collectors if the resulting ASD-based overstrength, V_{PEAK}/V_{ASD}, exceeds 5.0. This distinction between strength vs. strength and stiffness is illustrated in the example presented in *Figures 7* and *8*.

Figure 7 shows the shear wall layout for a simple "textbook" building for which the two relatively narrow (aspect ratio = 2.56:1) wood light-frame shear walls along the east wall line, designated Type A walls, are to be replaced with narrower prefabricated proprietary panels. The distribution of load shown in *Figure 7* assumes that the diaphragm of this light-frame structure is flexible. Data on the Type A walls and the replacement proprietary panels are given in *Figure 7* and *Table 3*, respectively.

Equivalency		Prefabricated Element		
Parameter	Value	A	B	C
V_{PEAK}/V_{ASD}	≥ 2.5	2.5	2.5	3.7
$\Delta_{0.8VPEAK}$	≥ 2.8%	3.50%	***2.20%***	4.15%
$\Delta_{0.8VPEAK}/\Delta_{ASD}$	≥ 11	13.5	12.9	***10.1***

Table 2: Equivalency requirement check.

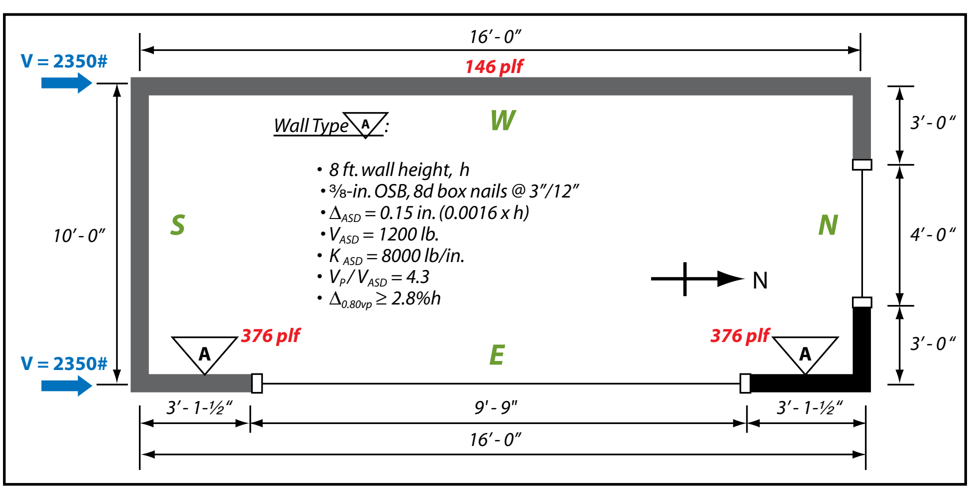

Figure 7: Shear wall layout for a simple rectangular structure.

The values given in *Table 3* indicate that the stiffness of the proprietary panel is 50% less than the stiffness of the wood shear wall, but both the proprietary element and the wood shear wall have the same strength. Considering the two design strategies outlined above (equal or higher strength versus equal or higher strength and stiffness), two Type A shear wall replacement designs are possible.

- Equal or Higher Strength Design (*Figure 8a*): Ignoring the stiffness of the wood shear walls to be replaced, each Type A wall segment can be replaced by a single proprietary panel which, in this example, has the same ASD strength (1200 pounds) as the shear wall. If this option is adopted, at the 2350-pound design load, the displacement of the East wall line will be twice that of the original wood shear wall line, and the dynamic response of the structure to earthquake-induced forces will very likely be different. This design approach is similar to a design where a decision is made to use prefabricated elements at the outset (with the same diaphragm assumptions) and lateral displacement is not explicitly considered, except for the maximum code displacement check inherent in AC130.
- Equal or Higher Strength and Stiffness Design (*Figure 8b*): Under this design scenario, a sufficient number of proprietary panels are specified to attain the same or higher strength and stiffness compared to the Type A wall segments. For the proprietary element characteristics given in *Table 3*, two proprietary panels would be required to replace each Type A wall segment to satisfy the equal or higher stiffness requirement. The strength requirement is also satisfied since the proprietary element and the shear wall in this case have the same ASD strength. Further, by providing equal stiffness, this option results in a ratio of the peak strength to the ASD load of 6.84. Thus, in accordance with the requirements of AC130, since the overstrength exceeds 5.0 in each panel, anchorage and collectors should be designed for the code amplified forces or the capacity of the panels, whichever is less.

As shown above, unless a proprietary element has strength and stiffness equal to or greater than that of the wood walls that would otherwise be used, the resulting structural response may be quite different from what is anticipated (neglecting finish materials).

The example and discussion above illustrate differences between equivalence as defined in AC130 and equivalence in terms of the expected performance of a structure (neglecting the effect of finish material) – a difference that designers should be aware of when relatively flexible "equivalent" proprietary elements are incorporated in structures.

Conclusion

In summary, the recently adopted seismic equivalency provisions adopted by ICC-ES provide designers and building code officials with a better understanding of expected performance of prefabricated proprietary lateral force-resisting elements in wood light-frame construction. However, even though an element meets all the requirements of AC130, elements that provide equal or higher strength alone may permit larger than anticipated displacements with associated increases in damage, unless appropriate stiffness criteria are also adopted in design. In addition, designs based on equal or higher strength and stiffness may produce overstrength values that exceed 5.0, thereby triggering a need to evaluate anchorage and collectors for code-amplified forces or the capacity of the specific element.▪

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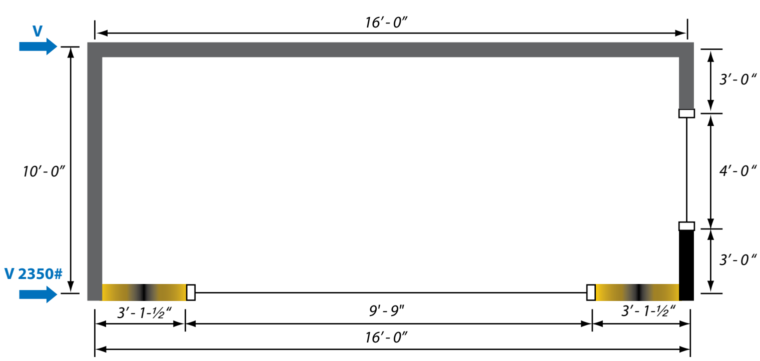

Figure 8a: Equal or higher ASD strength.

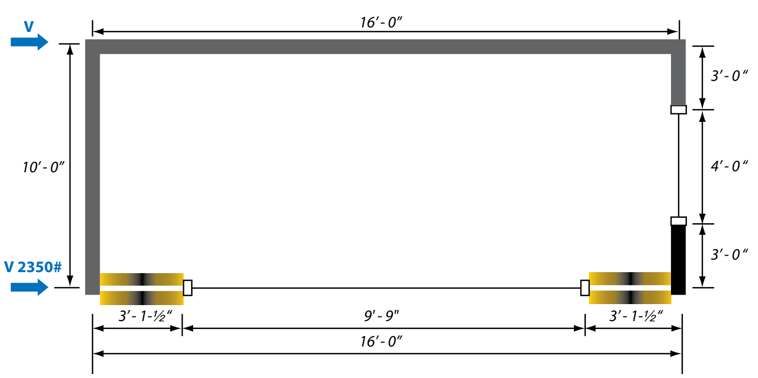

Figure 8b: Equal or higher ASD strength and stiffness.

Figure 8: Panel replacement based on equal strength or equal strength and stiffness.