New Rules for Evaluating Seismic Performance of Prefabricated Shear Panels

By Ned Waltz, P.E. and Ronald Hamburger, S.E.

Structural engineers are increasingly specifying prefabricated shear panels when designing light-frame wood and steel buildings. As architectural designs call for more window and door openings, prefabricated products provide a solution by resisting lateral loads while fitting within the remaining narrow wall segments. *Figure 1* illustrates such an application. Prefabricated shear panels are factory-built and inspected prior to acceptance at the job site. This process increases reliability, and allows their use in high-aspect ratio applications where a site-built wall is typically not permitted by the *2006 International Building Code* (2006 IBC).

Prefabricated shear panels are still relatively "new" products. Rules by which they are tested, analyzed, and incorporated into a structure continue to evolve. Several manufacturers currently offer proprietary wood and steel shear panel products with International Code Council Evaluation Service (ICC-ES) report recognition. Nearly all of these reports permit proprietary products to be designed with the same code-prescribed seismic coefficients as light-frame wood bearing wall systems sheathed with wood structural panels. While this simplifies the task of incorporating a prefabricated element into the seismic design of a structure, it assumes that prefabricated products will perform in a manner that is both consistent and compatible with benchmark wood structural panel/stud systems. Newly adopted ICC-ES "Acceptance Criteria" help clarify this issue.

Figure 1: Prefabricated Shear Panels in Application.

Proprietary Products and Assignment of Seismic Design Coefficients

Defining how prefabricated shear panel products qualify for specific seismic design coefficients is a difficult task. A decade ago, ICC-ES developed an Acceptance Criteria to provide a consistent basis for evaluating wood shear panels used in light-frame wood construction. Among other things, AC130: *Acceptance Criteria for Prefabricated Wood Shear Panels* mandates:

- that prefabricated products be cyclically tested using in-plane lateral loads with boundary conditions similar to the application (rigid foundation, raised floor, 2nd story, etc),
- a design load derivation process based upon the cyclic test data that combines a minimum factor of safety with the initial stiffness of the panel, its drift capacity, and design drift limits imposed by the building code.

Until recently, AC130 did not provide additional requirements to specifically confirm whether a prefabricated wood product should be assigned the same seismic coefficients as wood structural panel/stud construction. While AC130 has provided basic evaluation requirements for prefabricated wood shear panels for over a decade, steel panels have been introduced into the market without similar requirements. Instead, performance of these products has been rationalized by each manufacturer in different ways and evaluated by ICC-ES on a case-by-case basis.

Early in 2005, ICC-ES began to develop an Acceptance Criteria for evaluation of prefabricated steel shear panels. With the initial goal of providing a consistent test-based evaluation similar to AC130 for wood panels, AC322: *Acceptance Criteria for Prefabricated, Cold-formed, Steel Lateral-Force-Resisting Assemblies* has been debated during several ICC-ES hearings. Some of the critical points that have delayed completion of AC322 include disagreement as to:

- whether a one-third stress increase should be applied to the lateral capacity of a steel product as a load combination adjustment when used in wood frame construction (a similar increase is not permitted for a wood product in the same application),
- whether a shear-resisting panel can also be considered to be part of a bearing wall system if the components that carry vertical load fail by localized buckling in a test that imposes only lateral load, and
- how to judge whether prefabricated panels perform in a manner that could be considered seismically compatible with a wood structural panel/stud wall line and use the same seismic coefficients.

The last item has been particularly difficult to address. The 2006 IBC and related references provide only conceptual guidance on derivation of seismic design coefficients. This void led the prefabricated panel industry to search for a practical way to rationalize seismic design coefficients for proprietary, prefabricated products.

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discussion of performance issues relative to extreme events

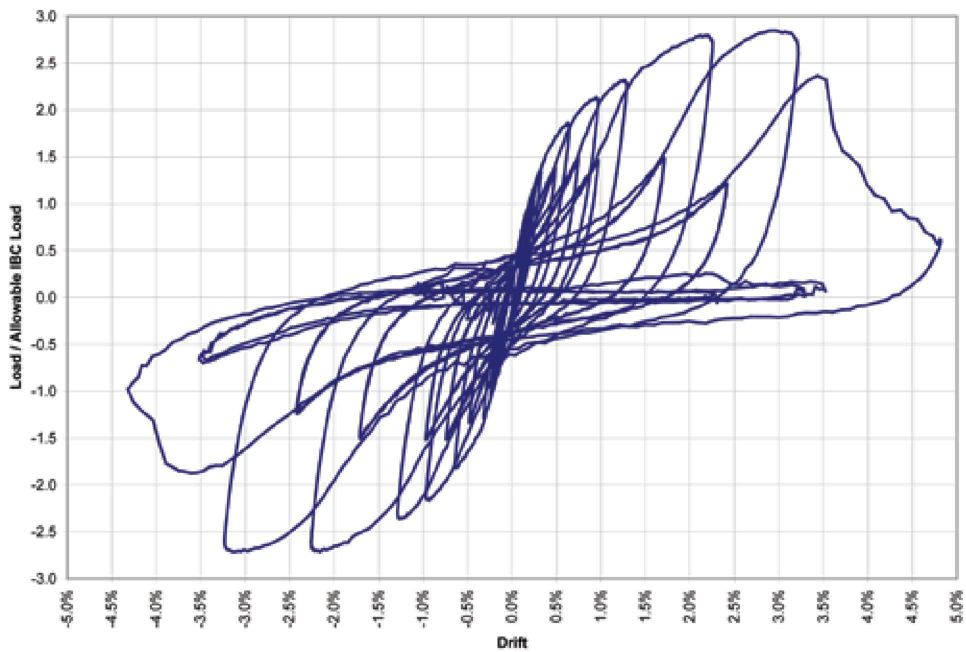

Figure 2 : Cyclic Response of a Wood Structural Panel/Stud Wall System.

In the absence of specific criteria, products with very different seismic performance attributes (stiffness, ductility, yield mechanism, damage states) have been specified into nearly identical applications. *Figures 2* and *3* illustrate the problem. *Figure 2* summarizes "benchmark" results from a typical cyclic wall test of a field-framed wood structural panel/stud shear wall. The hysteretic curve shows gradual non-linear yield, favorable ductility, moderate hysteretic pinching, and relatively large drift capacity typical for wood shear wall systems tested with realistic anchorage and a cyclic load protocol that produces representative failure modes. In this particular test, as with most similar tests, failure occurred when the connection between the panel sheathing and the framing deteriorated. Wood studs, which are assumed to carry the vertical load as part of a bearing wall system, were left intact. By comparison, *Figure 3* illustrates the cyclic response of a specific proprietary product tested using the same load protocol and boundary conditions. Results suggest a response that is further "pinched," has less ductility, and less drift capacity when compared with *Figure 2*. Failure occurred when a portion of the cross section at the base of the panel that carries both vertical and lateral load in application underwent localized buckling and crumpled. No vertical load was applied in this test. In the absence of specific guidance defining seismic compatibility, the *Figure 3* product has been designed until now using the same seismic coefficients as the benchmark wall system depicted in *Figure 2*. Given the observed differences in failure modes and performance, is the assumption of interchangeability justified?

Establishing Equivalency

A group of interested parties met in May of 2007 to discuss these issues. Representatives from prefabricated shear panel manufacturers, related wood and steel trade associations, consulting engineering firms, academia, the Federal Emergency Management Agency (FEMA), and ICC-ES were present. The group expressed agreement that the seismic design coefficients for defined lateral systems in the 2006 IBC and earlier codes were not derived by calculation either based upon cyclic shear wall test data or by other means. The code-defined seismic coefficients were developed over a period of many years by committee judgment based largely upon historical performance, limited test data, and comparison with other code-defined systems. The group also reviewed a procedure, currently under development by the Applied Technology Council (ATC) under FEMA sponsorship, for using results of cyclic test data and nonlinear analysis of assumed structures to define seismic coefficients. While this ATC-63 procedure seemed desirable for assigning seismic design coefficients to new structural systems, it seemed overly complex and inappropriate for use in qualifying products that would serve as components of a seismic force resisting system containing other elements, such as site-built walls.

If numerical assignment of seismic design coefficients is not practical, what alternatives might be considered? The group felt that it might be possible to use the concept of equivalent performance that is expressly permitted in the 2006 IBC and routinely used to rationalize proprietary products. A task group that included seismic design/consulting experts, university professors, trade associations, and several prefabricated panel manufacturers (wood and steel) was formed to establish a methodology to assess seismic equivalence. Over the next several months the task group debated how to judge equivalence to the light-frame wood structural panel/stud system defined by the 2006 IBC.

The task group concentrated on providing a practical means, based upon cyclic test data, to judge whether or not a proprietary wall performs in a manner consistent and compatible with the wood light-framing benchmark. They decided that the most reasonable approach would be to define parameters from cyclic tests of the benchmark system that could be used as targets for cyclic tests of the proprietary system.

The first step was to assemble the available cyclic test data for the benchmark system. A total of 48 wall tests were collected for the wood structural panel/stud system. The database included a variety of aspect ratios, design capacities, sheathing panel thicknesses, nail sizes, and nail spacings. The available data was obtained from four independent laboratories from test programs that used both realistic panel anchorage and a consistent cyclic load protocol developed during the FEMA-sponsored CUREE Wood Frame project.

After the benchmark database was assembled, appropriate performance parameters were identified. The task group considered parameter candidates that included various definitions of component overstrength, ductility, drift capacity, relative stiffness, failure modes, and energy dissipation. Keeping in mind that some of these are addressed in the design load derivation process, the task group selected the following additional parameters as a practical means for a prefabricated product to prove seismic equivalence to the benchmark wood panel/stud system:

- Maximum and minimum bounds on component overstrength. The minimum bound provides that strain hardening will continue after yielding initiates, and a maximum bound ensures that the component overstrength will not attract a large amount of load that would greatly exceed the design engineer's assumptions with regard to required anchorage strength or collector connections.
- A minimum boundary on ductility.
- A minimum boundary on absolute drift capacity. Ductility and drift capacity were judged to be of critical importance to achieve compatibility with the benchmark wood panel/stud wall system that would be required to work with the prefabricated product within a wall line.

- A requirement that the panel failure mode during the lateral load test cannot compromise its ability to carry its assigned vertical load as part of a bearing wall system.

The task group next focused on how to consistently define these boundaries using the benchmark cyclic test database for wood panel/stud shear walls. It was acknowledged that the cyclic shear wall test data sets available to serve as a benchmark for any code-defined lateral force resisting systems are typically limited, and will not provide a comprehensive and statistically valid representation of all possible permutations of the code-defined system. With this in mind, the task group discussed whether limits for selected parameters should be based upon extremes of the benchmark data set, average performance, or something else. The task group consensus was that upper and lower bounds for a parameter would be established based upon average performance of the benchmark plus or minus one standard deviation, respectively. It was judged that consistently establishing data-driven limits in this fashion would ensure a product performs within the expected range of the code-defined system and yet provide leeway for innovation. With only one exception, the task group used this data-driven basis to define targets to prove equivalency to the wood sheathing/stud lateral force resisting system. That exception was the establishment of an upper bound on permitted component overstrength. That target was raised to a level 25% greater than the benchmark database indicated. The increase was based upon the task group's judgment as to how the 2006 IBC design provisions impact the overstrength of field-framed high aspect ratio shear walls, and recognition that the benchmark data was skewed toward walls with aspect ratios of 1:1. The group recognized that more slender site-built walls would tend to have higher overstrength and provided for this deviation using their collective judgment.

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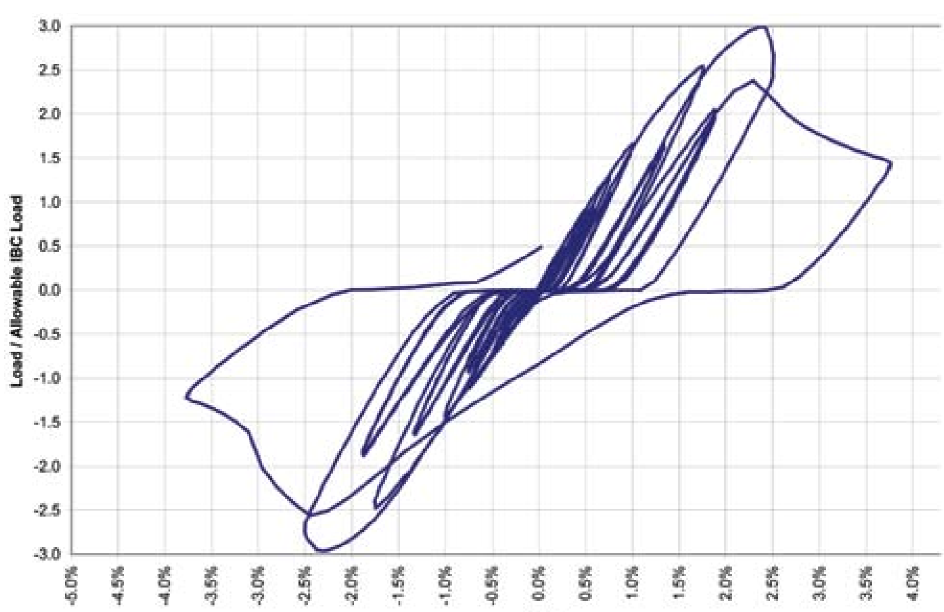

Figure 3: Cyclic Response of a Prefabricated Product Previously Judged to be "Equivalent."

Implementation

The consensus task group recommendations to prove seismic equivalency to a wood panel/stud wall system, and the related AC130 allowable load derivation process, were incorporated into a draft of AC322 compiled in July 2007. The same equivalency provisions were simultaneously submitted to update the wood shear panel acceptance criteria AC130. The equivalency recommendations received support from FEMA as a reasonable interim approach while the FEMA project "ATC-63" is still underway and were debated at the ICC-ES hearings in October 2007. The ICC-ES Committee subsequently adopted them for both AC130 and AC322 with effective dates of November 1, 2007 and March 1, 2008, respectively.

One adjustment to the task group recommendations made at the hearing was that a manufacturer would be permitted to produce a product with an overstrength that exceeds the already elevated maximum boundary of 5.0 by any margin. However, these panels will require the structural engineer to specifically account for the component overstrength in design of the structure per *Minimum Design Loads for Buildings and Other Structures* (ASCE 7) Section 12.4.3. The manufacturer must identify these panels and their overstrength in their code report.

In addition, applicability of AC322 recognition was extended to include use in steel light-frame structures at the hearing. Although the task group had attempted to define equivalency targets applicable to systems that consisted of steel studs with wood structural panels and/or steel sheets, this effort did not reach a conclusion. Even though they share the same seismic coefficients, the available data indicated that the steel stud systems had significantly lower performance parameters for ductility and drift capacity when compared to wood structural panel/stud systems. However, at the ICC-ES hearing, a letter was presented from three steel trade associations acknowledging the noted performance difference and requesting that parameters for the wood frame benchmark to be conservatively applied to the steel stud systems.

Points of Contention

The adoption of new performance targets for established products rarely happens without objection. A minority of task group members have provided several objections to these new procedures. While presented in various ways, the issues raised would essentially permit higher overstrength, less ductility, and less drift capacity for the related parameters than the benchmark database would support. Specific arguments include:

- **Issue:** Minimum overstrength should be raised to a level approximated by a 90% confidence interval of the mean. **Consensus:** The task group discussed that this approach was both statistically invalid and inconsistent with the methodology used to establish the other minimum parameters based upon the benchmark data. Early on, the task group judged the use of a near-mean basis to be overly restrictive, noting that half of the walls in the benchmark data set would fail such a requirement.
- **Issue:** Ductility and drift capacity targets should be reduced because the proposed targets lead to required deformation capacity in excess of the 2.5% drift level commonly associated with structural design. **Consensus:** The task group previously concluded that drift capacity and ductility beyond this level is both consistent with the minimum performance of the wood benchmark database and necessary to satisfy collapse limit state requirements under a "maximum considered earthquake" referenced in Chapter 11 of ASCE 7.
- **Issue:** Proposed targets neglect initial stiffness. **Consensus:** The task group discussed that initial stiffness is considered both in establishment of design load and by the designer assigning load to wall segments in proportion to their relative stiffness. Further, example designs were performed to demonstrate that this was not a problem.

These and similar issues received consideration by the task group and often dominated the discussion. They were also addressed at the ICC-ES code hearing. In the end, the consensus task group recommendations were adopted by the ICC-ES committee without related revisions.

What Does This Mean to the Designer?

As might be expected, these new seismic performance requirements are likely to change both the available product offerings and design information. Product manufacturers will be implementing these changes in 2008. Engineers who specify prefabricated shear panels should note that:

- These new provisions only apply to products stating compliance to the 2006 (and later) versions of the IBC in their ICC-ES reports. Code report provisions for earlier versions of the IBC or UBC will not include consistent consideration of seismic equivalency and compatibility to a wood structural panel/stud benchmark using these new procedures.
- Some products may require special consideration during building design for overstrength in excess of what is normally assumed when designing a wood structural panel/stud wall system. These considerations could include design of anchors and collectors for loads that include consideration of the actual overstrength of the product. Panels requiring this consideration will be identified in their ICC-ES evaluation report.
- To be consistent with the load provisions of the 2006 IBC, a one-third stress increase for multiple transient loads will no longer be permitted for steel products.

Conclusion

Proprietary shear panel products recognized for the 2006 IBC and assigned seismic design coefficients for wood structural panel/stud wall systems will have been subjected to a consistent review of cyclic test data that has never before been in place. Going forward, the designer should have peace of mind that these products have been reviewed for seismic compatibility to the rest of the light-frame structure.▪

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