MULTI-YEAR ADVANCED RESIDENTIAL BUILDING SYSTEMS RESEARCH

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Gate 1B - System Evaluations & Specifications: *Advanced Header Framing Design for High-R Wall Systems*

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Advanced Header Framing Design for High-R Wall Systems

BACKGROUND & OVERVIEW

Advanced wall framing designs for residential construction have centered on reducing the framing factor of the wall system to allow more area for insulation materials. While maintaining structural performance characteristics, use of advanced framing techniques can reduce the lumber member count and the overall area of the wall that is made up of primarily solid wood components. These wood components have a lower insulating capability than insulation materials by a factor of three or more. Advanced framing techniques include a combination of details, any number of which may be used together to form the advanced framing system. One such advanced framing detail is the header design. Headers are structural members that support wall, floor and roof loads that fall over top of an opening below (e.g. window) and are designed to carry the load that would have been carried by a solid wall framing member or members. Headers are typically located directly over an opening and supported by framing members such as jack and king studs.

Advanced framing header details have primarily focused on “right-sized” header design. This design approach simply uses either engineered or prescriptive methods to size the header for the design loads – and no larger. This detail was originally necessitated from the industry practice of using one size header for all openings, resulting in much larger wood areas in the wall system than needed (Figure 1). The “right-sized” header approach utilizes only the header size necessary, leaving as much room for insulation in the wall as possible (Figure 2).

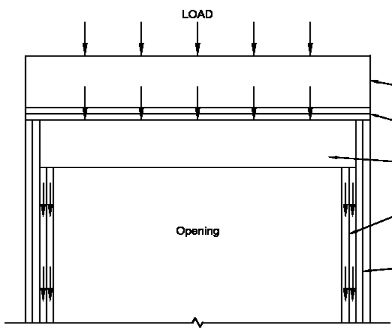

Figure 1 - Common full size header

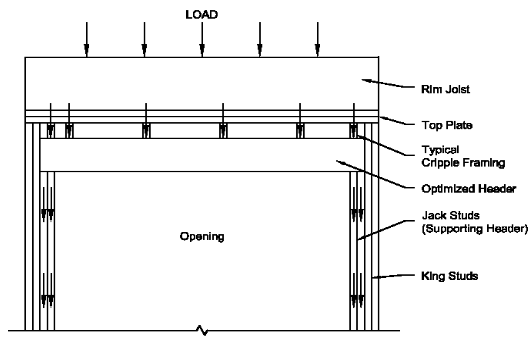

Figure 2 - Optimized header design

Yet another approach to header sizing and location is the use of the rim area for the header. This approach uses an engineered design to locate headers within the rim joist area (Figure 3). The benefit of this approach can be a significant reduction of solid wood framing within the insulated wall plane that has limited area for insulation. The rim area in most cases is not limiting for the insulation depth. While this design methodology has been demonstrated in Building America projects[1], and there exists some information from manufacturers, there is very little detail on the engineering design available to effectively use this approach, and there is virtually nothing available for use as a prescriptive method by designers and framers. This research effort analyzes the detail of moving the header from the wall area directly above the opening to the rim joist area – an integrated rim header.

[1] See http://www.carb-swa.com/articles/builder%20projects/ParagonCaseStudy.pdf and http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_bc_cdc_utah_cold.pdf for a brief description of the use of rim headers.

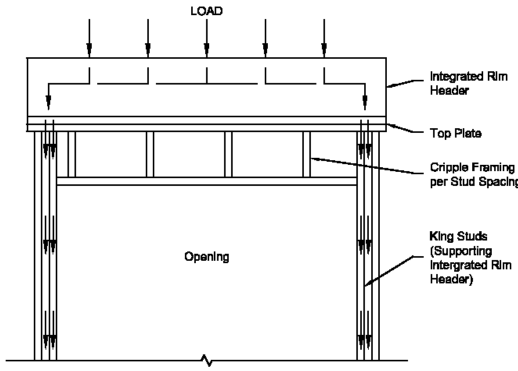

Figure 3 - Integrated rim header design

This work is performed as part of the NAHB Research Center's Building America Stage Gate 1 work and investigates systems and technologies for high performance homes. This research effort is focused on the design and application of specific features that would be applicable, using standard design methods, of a high-R wall system. The development of this detail is a necessary part of the transition from a standard light frame wall system to an optimized, highly insulated wall system with a minimal cost increase. This activity is designed to evaluate the performance benefits and develop performance specifications for an advanced header system design and incorporates laboratory testing as part of the performance evaluation effort.

INTEGRATED RIM HEADER DESIGN AND APPLICATION

In typical residential home light frame construction, the rim joist is not designed as a flexural load-bearing member. Gravity load is transferred around the opening by a header located in the wall below the floor members. The header member is supported at each end by jack studs. The number of jack studs varies based on the width of the opening, number of stories above, floor joist span, snow loads, roof span, and other factors. King studs are installed adjacent to the jack studs on either side of the opening to resist out-of-plane wind loads (refer to Figures 1 through 3). In traditional header design, it is assumed that all gravity forces are supported by jack studs only and all wind pressure forces are resisted by the king studs only. With the integrated rim header, the king studs now carry all of the loads since jack studs are no longer necessary. However, a specific design effort will be necessary to fully incorporate the integrated rim header detail into a practical design option for a typical single family home.

Based on a few existing field trials of a rim header layout, the NAHB Research Center through their Building America work, embarked on a design effort in conjunction with a national builder, K. Hovnanian, to design and evaluate this advanced header design option for one of their existing models. The builder had considered this option in the past but elected not to move forward due in part to uncertainties in the performance and the lack of large scale experience with the system. With this opportunity to consider all of the design issues and with the potential of including this detail in many of its home designs, a focused research effort emerged. In addition, a major wood products supplier, iLevel (Weyerhaeuser), also agreed to participate in the research effort due to the compatibility with their product offerings. Therefore, rather than performing a theoretical analysis of a hypothetical wall system, the research effort focused on a thorough design of a rim header wall system to be constructed in a Building America (BA) prototype home. K. Hovnanian's BA prototype, the Schubert high performance home (HPH), is located in their Hunter's Brook subdivision in Hackettstown NJ and is currently under construction.

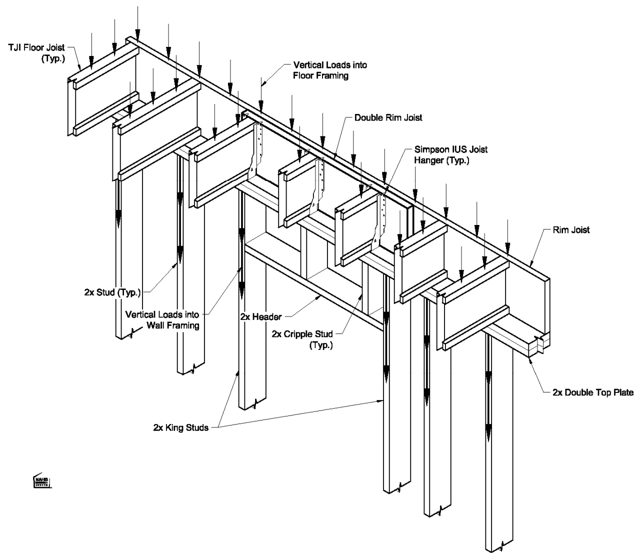

Figure 4 - Schubert HPH integrated rim header design – Framing Layout

The rim joists in the model High Performance Home (HPH) were designed to carry the gravity loads and span over openings in the wall below. This design allowed for the headers and the supporting jack studs to be eliminated from the wall section. Face-mounted joist hangers over all openings were installed to transfer the vertical loads from the floor framing into the rim joist. The rim joist carried the load to the supporting king studs without loading the wall framing above the window opening. It is important to note that the king studs were designed to resist a combined loading due to gravity forces and out-of-plane wind forces. The use of 2x6 construction reduces the required number of king studs compared to 2x4 wall construction because of the increased bending capacity of the deeper 2x6 members. The fewer number of studs results in a reduced framing factor and improved energy performance of the wall.

Integrated Rim Header Design Details

The design of the model HPH structural rim joist and supporting wall framing was undertaken by the NAHB Research Center in parallel with iLevel by Weyerhaeuser, whose engineered lumber rim board product was specified in the project, and with K. Hovnanian engineers and architects. The following design assumptions and load combinations were considered in the engineering evaluation of the integrated rim header for K-Hovnanian's model HPH.

<u>Design load assumptions include:</u>

- Roof dead load of 20 psf,
- Snow load of 30 psf,
- Attic (bottom chord) load of 20 psf,
- Floor dead load of 10 psf,
- Floor live load of 30 psf,
- Wall dead load of 12 psf, and
- Wind zone of 90 mph

<u>Applicable load combinations include:</u>
(*ASCE/SEI 7-05 Minimum Design Loads for Buildings and Other Structures - Section 2.4.1*)
Header:

1. D
2. D + L
3. D + S
4. D + 0.75L + 0.75S

King Stud:
1. D
2. D + L
3. D + S
4. D + 0.75L + 0.75S
5. D + 0.75L + 0.75S + 0.75W

Design checks include:

Header:
- Bending moment
- Bending shear
- System deflection
- Bearing

King Stud:
- Combined axial and bending
- Bearing on plates

Joist Hangers:
- Reaction load

Engineers calculated loads and load paths for the integrated rim header and supporting wall framing in the prototype home. Deflection analysis for the rim joist header in the prototype home accounted for slip in the joist hanger at design loads. This slip was obtained from Simpson Strong-Tie joist hanger testing reports.

IMPLEMENTATION AND CONSTRUCTION

Based on the design efforts of the structural team (K. Hovnanian, iLevel, and NAHB Research Center), the house framing design was changed from 2x4 16” o.c. to 2x6, 24” o.c. framing with integrated rim headers. The builder elected to panelize the wall sections and rough framing of the prototype home was started on November 3, 2009. The wall panels were prefabricated offsite and shipped to the job site via flat bed truck. The structural rim joists were delivered as part of the overall floor package by iLevel. All of the members of the floor system, including the rim joists, were pre-cut to length and labeled for installation. The following is a brief summary of the structural rim joist installation process:

1. First floor exterior and interior load-bearing walls were installed;
2. Second floor joists were laid out;
3. The structural rim joists were toe-nailed on the outside face to the top plate of the wall (Figure 5); the rim joists were precut such that the end of the rim joist member was extending at least 12 inches beyond the opening;
4. Over the openings, the second rim member was installed and tacked to the first rim member with face nails;
5. Face mounted hangers were fully attached to the double rim members at each floor joist location over openings (Figure 6);
6. A small amount of construction adhesive was placed in the saddle of the joist hangers (Figure 7)
7. The floor joists were installed in the hangers (Figure 8);
8. The double rim members were further attached together with (2) 8d nails at 12 inches on center;
9. Lastly, the bottom flange of the joist was face nailed to the top plate of the wall (Figure 9 and Figure 10).

Figure 5 – Installation of rim member

Figure 6 – Installation of joist hangers

Figure 7 – Installed joist hangers with construction adhesive

Figure 8 – Installation of floor joists

Figure 9 – Nailing of floor joists to top plate

Figure 10 – Complete window framing

LABORATORY TESTING (PHASE I)

Initial exploratory testing was undertaken by the NAHB Research Center prior to the final design phase of K. Hovnanian's model HPH prototype to evaluate the ability of the joist hangers to transfer gravity loads from the floor joists into the structural rim member without causing excessive deflection in the wall framing over the opening.

Test Specimen Construction

Table 1 provides a summary of the materials used in specimen construction and Table 2 provides the nailing and connections schedule used in specimen construction. The rim member (single 1-3/4-inch-thick) was designed to resist the applicable gravity loads at a six-foot opening in the first floor exterior bearing wall of a two-story model home located in New Jersey. (It should be noted that the detail used in the construction of the Schubert HPH prototype home used a double 1-1/8-inch rim joist member.)

Table 1 – Construction materials

Material	Detail
Rim joist:	(1) 1-3/4-inch x 11-7/8-inch TimberStrand LSL (1.55 E material)
Floor joists:	TJI 210 x 11-7/8 I-joists, spaced 24 inches on center
Joist hangers:	Simpson IUS 2.37/11.88 or IUS 2.06/11.88 face mount hangers attached w/ (10) 1-1/2-inch long x 10d Simpson hanger nails
Floor sheathing:	3/4-inch T&G OSB
Wall studs:	In-line, 2x6 SPF #2 grade framing at 24 inches on center; (2) king studs at each end of opening;

Table 2 – Nailing schedule

Description	Detail
Floor sheathing to framing:	To rim: 8d (2.5" x 0.131") nails at 6 inches on center To floor joist: 8d (2.5" x 0.131") nails at 12 inches on center
Floor joist to framing:	To wall top plate: (2) 8d (2.5" x 0.113") face nails through bottom flange To rim: (1) 10d (3.25" x 0.128") end nail into top flange
Rim joist to top plate:	8d (2.5" x 0.113") toe nails at 6 inches on center
Window top sill plate to king studs	(2) 16d (3.5" x 0.135") end nails
Top and bottom plate to stud:	(2) 16d (3.5" x 0.135") end nails
Double king studs:	10d (3.25" x 0.128") face nail at 6 inches on center, staggered

A total of four specimens were tested. Figure 11 shows the typical specimen construction. Table 3 provides a test matrix summarizing the differences between test specimens.

Table 3 – Test matrix

Test #	Opening size	Joist hanger	Top plate
Test #1	3-foot opening	Simpson IUS 2.37/11.88 face mount hanger	Single top plate
Test #2	6-foot opening	Simpson IUS 2.37/11.88 face mount hanger	Single top plate
Test #3	6-foot opening	Simpson IUS 2.06/11.88 face mount hanger	Single top plate
Test #4	6-foot opening	Simpson IUS 2.06/11.88 face mount hanger	Double top plate w/ a joint in the uppermost member at the center of the wall opening; top plate was spliced with (4) 16d (3.5" x 0.135") face nails on each side of the joint

The typical test specimen consisted of two identical 8-foot long by 3-foot high wall sections, 24 inches apart, each with an opening and an integrated rim joist header design. This specimen configuration was chosen to provide symmetrical loading of the rim joists and stability during testing. Floor I-joists spanned between the two walls. The I-joists were in line with framing and the I-joist layout was symmetrical about the center of the opening. The I-joists located over the openings were attached to the rim joist using face mount hangers. This connection detail provided a continuous load path for the gravity floor loads between the joists and the structural rim member.

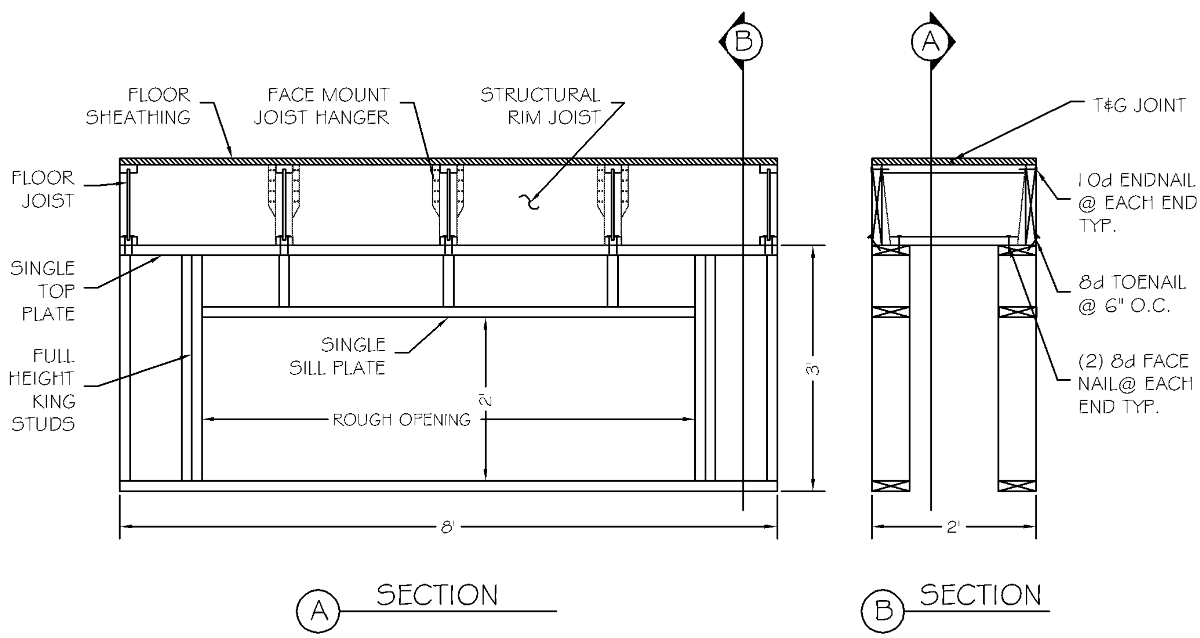

Figure 11 – Specimen construction

Test Setup and Protocol

Figure 12 and Figure 13 provide a schematic and photograph of the test setup, respectively. Load was applied to the joists using a steel distribution beam to simulate the floor gravity load. Displacements were measured at the following locations:

- Between the ends of the floor joists and the rim joist

- Between the rim joist and the wall top plate
- Window top sill plate relative to the king stud (this deflection was used in the analysis of the test result - Δ_{floor})

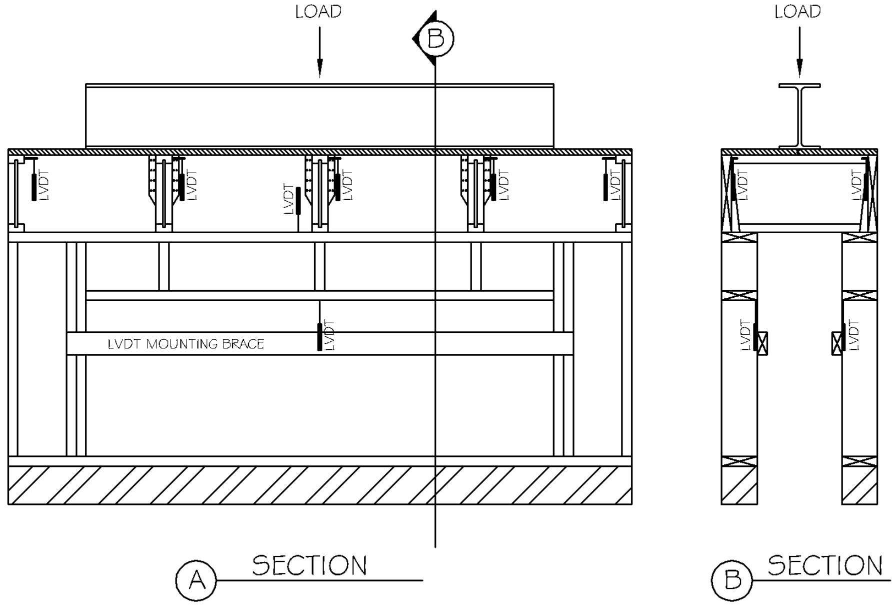

Figure 12 – Schematic of test setup and instrumentation

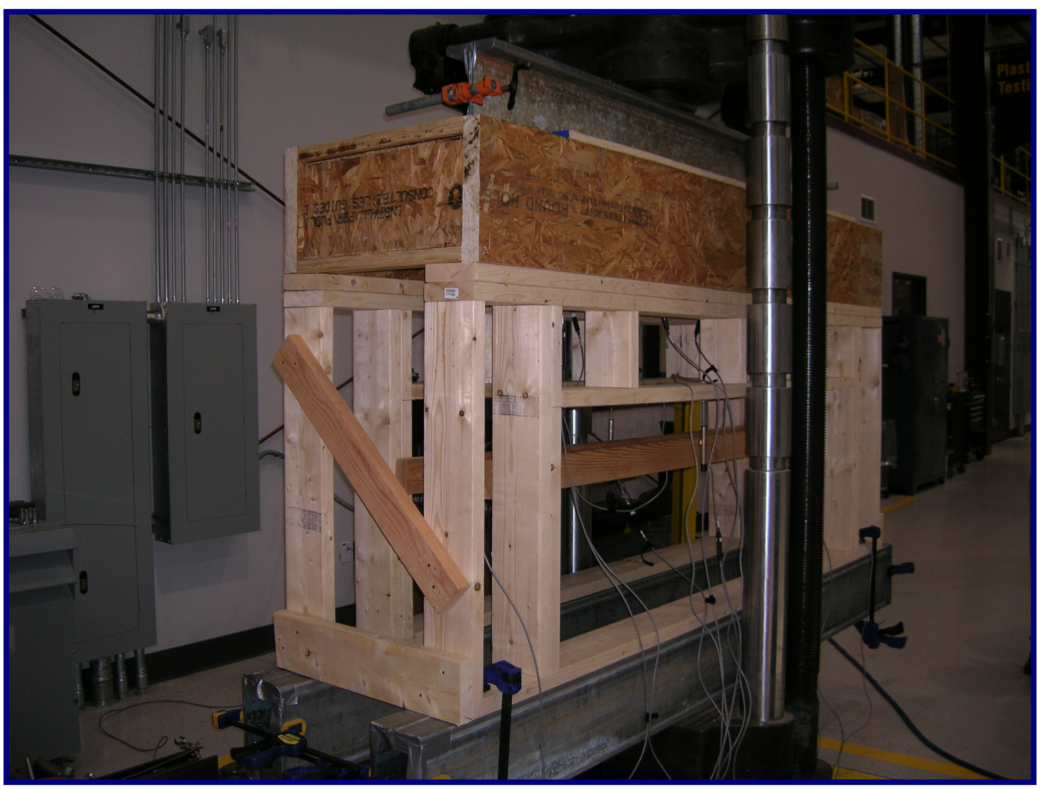

Figure 13 – Test setup

Testing Results and Analysis

In accordance with the *AF&PA Wood Frame Construction Manual – 2001 Edition* [1][2], residential wood headers are designed to a live load deflection of L/360. Therefore, deflections at service live load levels were analyzed and compared to the L/360 requirement. This deflection analysis was used only to evaluate the general serviceability performance of the structural rim joist system and is separate from the deflection analysis used in the design of the Schubert HPH prototype.

The deflection measured across the opening represented the deflection caused by floor load only. Therefore, additional deflection of the rim joist due to roof and wall loads acting directly on the structural rim member were calculated and added to the deflections measured at floor service loads during testing. In accordance with *ASCE 7-05 Section 2.4.1 Load Combination 4*, the floor live load and roof snow load was multiplied by 0.75.

Design forces were determined using the design loads and spans of the prototype home model as follows:

<u>Design Loads:</u>

Floor DL = 2nd floor dead load
= 10 psf

Floor LL = 2nd floor live load [non-bedroom/sleeping area]
= 40 psf

Roof LL = Un-balanced snow load, P_g = 30 psf
= 512 plf

<u>2nd floor framing:</u>

Joists at 24" o.c.
Maximum span length = 15'-3"

Tributary area to single end of floor joist = (15.25' / 2) x 2' spacing
= 15.25 sq ft

Floor joist reaction at support due to dead load = Trib. area x (DL)
= 15.25 sq ft (10 psf)
= 152 lb / end of joist

Corresponding load during testing:
= 152 lb / end of joist x 2 ends per joist x 3 loaded joists
= 912 lb load

Floor joist reaction at support due to dead and live load = Trib. area x (DL+LL)
= 15.25 sq ft (50 psf)
= 763 lb / end of joist

Corresponding load during testing:
= 763 lb / end of joist x 2 ends per joist x 3 loaded joists
= 4,575 lb load [un-factored floor live load]
= 3,657 lb load [factored floor load, DL + 0.75LL]

Example Deflection Calculation:

Test deflection of window's top sill plate at design floor dead loads:

Test #3:

$\Delta_{floor\ DL}$ = 0.0229 inches at 910 lb

Test deflection of window's top sill plate at design floor dead and live loads:

Test #3:

$\Delta_{floor\ DL+LL}$ = 0.0844 inches at 3,657 lb

Deflection of window's top sill plate during testing due to live load only

Deflection under dead and live loads – deflection under dead load only

$\Delta_{floor\ LL}$ = 0.0844"- 0.0229"

$\Delta_{floor\ LL}$ = 0.0615 inches

Calculated deflection of the rim joist under roof live loads:

Simply supported, single span w/ uniform live load

Span length = 6'-0"

Deflection of the rim joist member:

$$\Delta = \frac{270wL^4}{Ebd^3} + \frac{28.8wL^2}{Ebd}$$ (per *Weyerhaeuser ICC-ES ESR-1387*) [4]

Where:

w = uniform load (lb / in)
L = span (ft)
E = modulus of elasticity (lb / in^2)
b = width, in
d = depth, in

$$\Delta_{roof} = \frac{270(384lb/ft)(6')^4}{(1.55x10^6\,psi)(2930in^4)} + \frac{28.8(384lb/ft)(6')^2}{(1.55x10^6\,psi)(20.78in^2)}$$

Δ_{roof} = 0.042 inches

Total deflection at design live loads:

$\Delta_{total} = \Delta_{floor\ LL} + \Delta_{roof}$

Where:

$\Delta_{floor\ LL}$ = Measured from test results
Δ_{roof} = Calculated

Δ_{total} = 0.0615" + 0.042"
= 0.1035"
= L/695

Table 4 provides a summary of the results including total deflection, Δ_{total}, at design live loads and the ultimate load resisted by the specimen. Web crippling of the floor joists was the primary failure mode observed.

Table 4 – Analysis of results

Test number - brief description	Total deflection (Δ_{total}) at LL (in) / (L/__)	Ultimate load (lb)
Test 1 – 3 foot opening, single top plate	0.043” / L/837	13,900
Test 2 – 6 foot opening, single top plate	0.138” / L/524	19,180
Test 3 – 6 foot opening, single top plate	0.104” / L/695	19,800
Test 4 – 6 foot opening, double top plate	0.134” / L/538	18,530

Conclusions from Phase I Testing

The following conclusions were drawn from the testing of the connection detail between a structural rim joist and the floor framing:

1. The estimated deflection of the integrated rim header was consistently below the live load deflection limit of L/360. The largest estimated total deflection was 0.138”, which corresponds to an L/520 deflection limit for the six-foot opening.
2. The tested face mounted floor joist hangers can adequately transfer end reaction loads from the floor joists to a structural rim member without causing excessive deflection in the wall framing over the opening.

Additional testing is planned to complete a comprehensive evaluation of the structural performance of the integrated rim joist header detail.

BUILDING AMERICA STAGE GATE 1 SUMMARY

The Building America Program utilizes a stage gate process to evaluate the progress technologies and systems under research make towards achieving the joule targets set forth in the program. In and of itself, this technology system is only part of a larger system; however, this research has multiple advantages leading towards much higher energy savings in homes. The NAHB Research Center’s header research detailed above is one support technology to encourage the shift to high-R wall systems – that is, wall systems that have much higher thermal performance than typical new home construction.

The stage gate process encompasses “Must” and “Should” Meet criteria and each is detailed below.

BA Stage Gate 1B “Must Meet” Criteria

1. Source Energy Savings and Whole Building Benefits - New whole house system solutions must provide demonstrated source energy and whole building performance benefits relative to current system solutions based on BA test and analysis results.

For rim header designs, the primary advantage is the significant reduction in framing factor of the wall system. Use of rim headers alone does not contribute to the framing factor reductions, however, the rim header research enables:

- The use of 2x6 framing at a very low or zero wall cost increase for the builder, including insulation,

- Reliable application by the framer to ensure consistent performance avoiding field installation of unnecessary framing members, and
- Much lower framing factors leading to higher insulated walls.

2. <u>Performance-Based Code Approval</u> - Must meet performance-based safety, health, and building code requirements for use in new homes.

For rim header research, this effort provided a significant base for developing performance methods for employing the rim headers in standard wall sections. Although previous Building America research has evaluated rim header application, no design information or laboratory testing was detailed in the final reports. Furthermore, manufacturers have developed specifications for use of rim boards as headers; however, much of the information is proprietary. This research has demonstrated the capability of using engineered designs to incorporate rim headers and establishes a methodology for developing more prescriptive design tables. Further testing and design efforts to develop prescriptive methodology are necessary.

BA Stage Gate 1B "Should Meet" Criteria

1. <u>Prescriptive-Based Code Approval</u> - Should meet prescriptive safety, health, and building code requirements for use in new homes.

For rim header research, this effort provided a significant base for also developing prescriptive methods for employing the rim headers in standard wall sections. Completion of this research will lead to development of prescriptive code changes to facilitate the not only the use of rim headers, but more importantly the use of advanced framing systems that significantly reduce framing factors.

2. <u>Cost Advantage</u> - Should provide strong potential for cost benefits relative to current systems within a whole building context.

While not detailed in this report, early review of costs for the entire advanced framing system, including the rim headers has indicated that this research effort will result in a wall system that can save at least 8% heating and cooling energy while resulting in nearly a level cost with the builder standard practice. Once construction of the model HPH is complete, the NAHB Research Center will complete a whole house source energy savings and cost neutral analysis as part of future BA Stage Gate 2 work.

3. <u>Reliability Advantage</u> - Should meet reliability, durability, ease of operation, and net added value requirements for use in new homes.

The application of the rim header design in the prototype home did uncover areas where the framer, panelizer, and the builder will require a better understanding of the wall system performance goals. For example, the framer will need to better understand the nailing pattern for the joist hangers and its attachment to the top plate for rim headers, an uncommon detail. This and other details can cause a disruption in the framing or inspection process until resolved with confidence.

4. <u>Manufacturer/Supplier/Builder Commitment</u> - Should have sufficient logistical support (warranty, supply, installation, maintenance support) to be used in prototype homes.

This research effort was initiated with the support of K. Hovnanian the builder (and the builder's designers), iLevel the material supplier, and H.M. Stauffer and Sons, Inc. the panelizer along with the research team. Because of the strong support from these stakeholders, there was a high level of confidence in the success of the design and the system. Yet, the design process included many hours of teleconference and further discussions onsite during the construction process. When considering the potential for success for the rim header design, there has been a very positive consideration from all of the stakeholders.

5. Gaps Analysis - Should include system's gaps analysis, lessons learned, and evaluation of major technical and market barriers to achieving the targeted performance level.

The steps looking forward, which include analyzing any gaps that would inhibit more widespread adoption of the rim header design, point towards a more fully developed design analysis for the rim header. Manufacturer material specifications must be analyzed in conjunction with wall designs as well as specifications for locating and installing brackets and nailing specifications. These details are now proprietary and the potential for a more prescriptive approach must be investigated.

In addition, subsequent laboratory tests will be necessary to identify specific layouts for opening sizes as well as the installation of windows to measure deflections of the window flange and frame. Development of prescriptive tables as well as materials to communicate the rim header design will greatly support the use of the rim header, especially in a complete advanced wall system design. The NAHB Research Center is currently planning additional structural work to support these gaps for 2010.

SUMMARY

A structural redesign effort was undertaken by the NAHB Research Center to modify a builder's typical production 2-story home design using a standard 2x4 light frame engineered wall system to incorporate an advanced framing system with the unique feature of integrated rim headers. The standard engineering approach included right-size headers but otherwise incorporated standard 16" o.c. framing methods. The redesign investigated using 2x6 framing at 24" o.c. and employed no jack studs or extra cripple members. The goal of the effort was to reduce the framing factor, increase the overall insulation of the wall system, while maintaining a level cost for the complete wall system.

Within the redesign of the framing system, use of integrated rim headers was specifically investigated. While a specific structural design for K. Hovnanian's Schubert high performance home (HPH) was performed, the research project focused specifically on testing the performance of the integrated rim header to carry the floor loads within acceptable deflection specifications. The installation of the integrated rim header was such that the joist bracket rested directly on the top plate and therefore could cause an interaction that eventually would be reflected down to the opening framing. Laboratory tests were performed to investigate this performance aspect with positive results.

Based on these results and an engineered detail for an integrated rim header, the Schubert HPH prototype was constructed using the advanced wall system. The integrated rim header meets all of the BA Stage Gate 1B "must meet" and "should meet" criteria. However, to allow the full design to be incorporated across many different house designs and for builders who use prescriptive code requirements, further testing of fully loaded integrated rim headers is necessary. The NAHB Research Center is currently planning this work and plans to further their structural Building America Stage Gate 1 work in 2010.

ACKNOWLEDGEMENTS

The NAHB Research Center would like to acknowledge the significant and dedicated efforts of the research team including K. Hovnanian staff, corporate, engineering and design, and at the division level in the construction of the prototype home. In addition, the support of iLevel management and engineers led to the successful implementation of the rim header design along with many other advanced framing details not included in this report. In addition, we would like to acknowledge the panelizer, H.M. Stauffer and Sons, Inc., for their participation and finally, the framing crew who completed their work under very trying circumstances of a research investigation.

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