C

FUTURE RESEARCH

Summary Scope of Work, Technology Refinement and Manufacturing Rationalization

Under the proposed plan for the next phase of investigation, home manufacturers would be offered an opportunity to work with MHRA in evaluating the use of steel framing for any component (trusses, walls or floor) or combination of components. The actual scope of services would be based on the overall project goals, be crafted around the aims of the partner manufacturers, and include research, demonstrations, assessments and/or feasibility studies that might include but not be limited to the following:

- Component design development and testing
- DAPIA review and approvals
- Engineering analysis
- Prototyping (full-scale mockups)
- Cost analysis
- Thermal analysis
- Manufacturing process analysis
- Transportation testing of a home with cold-formed steel components.

For example, resources could be used in developing a cold-formed steel frame exterior wall design that might include structural analysis, details integrating the steel with wood framed floor and truss systems, construction and testing of a prototype and/or subcomponents, etc. MHRA will also endeavor to identify steel suppliers to partner in these demonstrations. Participating manufacturers will be required to contribute both monetarily and in-kind to the research.

1. Form application-specific partnerships with manufacturer(s)

The DAPIA approved design resulting from the current effort provides an all-steel design solution demonstrating the feasibility of using cold-formed steel for a homes skeletal frame. This total structure solution represents a radical change in manufacturing. The current phase provides an opportunity for individual manufacturers to experiment with a more evolutionary approach where steel is substituted for wood in selected components of the home. The scope of effort would then be molded around the issues associated with the type of application selected by the manufacturer.

In the first step of this phase, an invitation would be sent to manufacturers inviting proposals for using cold-formed steel in lieu of wood for building subcomponents, components or larger scale applications. The Task Steering Committee will rank proposals based on several criteria including cost, technical hurdles, manufacturer commitment of resources and related factors.

Subsequently, agreements would be entered into with manufacturers to cooperatively develop the application. The agreements would define the scope of cooperative activities and responsibilities of all parties, but would be managed under the MHRA Committee framework. As noted earlier, the actual tasks will depend on the kind of application (technical hurdles) and resource limitations.

2. Scoping the cooperative agreement

The work will be application-specific – with the actual work plan developed in concert with the manufacturer partner – and might require subtasks in one or more of the areas described in the sections that follow:

- **Conduct laboratory testing of subcomponents** – Laboratory testing of the structural subcomponents to confirm the integrity of the proposed design and to discover other ways to further refine and value engineer the design (a detailed list of component and subsystem testing alternatives is provided in Appendix C). The laboratory tests will use subcomponents constructed and tested under third-party supervision.
- **Conduct laboratory thermal testing** – The high thermal conductivity of steel causes concentrated heat loss through the steel components often referred to as "thermal bridging". Simplified parallel heat path heat transmission calculations used in wood frame construction are inadequate to estimate component U-values in steel framed constructions. Instead, heat transmission for walls can be calculated using the modified zone method described in ASHRAE. Similar values for floor and ceiling assemblies have not stood up to peer review and further testing is needed.

  This effort would resolve thermal issues that might be associated with the manufacturers selected application of steel framing, particularly if this involves roof trusses or the floor system. This research might be linked to an ongoing effort at ORNL funded by NASFA. Specifically, testing or other kinds of evaluations will be carried out to accurately predict heat flows through the steel framed components and produce documentations acceptable to DAPIA and HUD monitoring contractor.
- **Construct and evaluate prototypes –** Prototypes will be constructed to resolve connection details, identify manufacturing issues, suggest improvements in fastening and fabrication methods and further evaluate the proposed design. The prototype may also be used for testing purposes although the purpose of developing a design mock-up depends on the kind of application.
- **Assess manufacturing implications** – This task will produce a bottom line analysis comparing the net cost to the manufacturer of using steel in place of wood frame. The cost will consider all the major factors that influence price, including materials, labor, overhead and other soft costs. The cost estimate will attempt to create a reasonably accurate basis for understanding the value to be derived in substituting steel for wood. To round out the impact analysis, an assessment will be made both of the non-monetary implications of switching to steel, such as the potential impact on customer perceptions of value and performance, the start up costs that would be encountered by the manufacturer and retailer, and other benefits and disbenefits that would result from the change.

3. Document results

The results of each of the manufacturer partnerships will be documented and made part of the task deliverables. The report will summarize the approach, interim results and findings but exclude any information that might be deemed proprietary to the manufacturer.

Research Products

- Prototype designs that are developed in cooperation with individual manufacturers. Where relevant, the designs will have DAPIA approvals.
- Full-scale mockups of the steel frame components for testing and evaluation
- Technical Support Document detailing the approach to the task, demonstrations with manufacturers and findings
- Comprehensive media, information dissemination and outreach program

D

PROJECT RESOURCES

The following companies were identified through this work as providing products, services or technologies that might be valuable resources to companies in the manufactured housing industry interested in cold formed steel framing. This list is not exhaustive. Rather these companies were asked to provide advice and information in developing the design information contained in this report. No endorsement of these companies is intended nor implied by their inclusion in this work.

- Aerosmith Fastening Systems – Fastening Systems. In addition to collaboration with Toback & Associates (see below), Aerosmith is providing mechanical fasteners and installing equipment that speed assembly time. Contact: Les Butler Aerosmith Fastening Systems 5050 South 40th Street, Phoenix, AZ 85040, (800) 528-8183, Fax: (602) 470-1840
- Alpha Systems – Adhesive, one-part urethane. Alpha Systems has developed adhesive materials for the attachment of gypsum wallboard directly to as-received steel studs. Contact: Alpha Systems, Inc. 5120 Beck Drive Elkhart, IN 46516, (800)462-4698, Fax: (219) 522-2231
- Attexor Corp. – Friction Fit Connection Equipment. Attexor is a Swiss company that produces and distributes equipment that makes a clinching and / or stitching connection of adjoining metal pieces. The Spot Clincher® makes the connection by deforming the two pieces of metal into a button configuration simultaneously. The fastening method is fast and user friendly. Investigation into connection durability under dynamic, transportation loads still needs to be conducted. Contact: Graham Smith, (888) 288-3967
- Dietrich Industries, Inc. – Design and Production of Steel Framing Parts. As noted earlier, Dietrich provided the initial structural design of a home for this project. Dietrich has also provided additional technical support and material estimates for the project. Contact: Dietrich Design Group, 1414 Field Street Building C Suite 1, Hammond, IN 46320, (219)-853-9474, Fax (219) 932-4141
- ET&F Fastening Systems, Inc. – Mechanical Fastening Systems. ET&F have provided technical data for mechanical fastening systems for metal-to-metal connections. Contact: David Nolan, ET&F Fastening Systems, Inc., 29019 Solon Rd. Solon, OH 44139, (440) 248-8655, Fax: (440) 248-0423
- ITW Foamseal – Adhesive, two-part urethane. Foamseal conducted some unwittnessed tests to provide shear strength data for interior shearwalls fabricated with its F2100 adhesive on mill run steel studs and gypsum paneling. The studs were tested as received, not cleaned. One series of tests used studs which had been deformed with approximately ⅛" tabs to space the gypsum away from the stud flange for more complete adhesive coverage of the flange. Contact: Joe Neer, ITW Foamseal 2425 N Lapeer Rd., Oxford, MI 48371, (248) 969-4217, Fax: (248) 628-7136

- ITW Paslode – Mechanical Fasteners. Paslode has provided technical data on fasteners and installing equipment for metal to metal and gypsum to metal connections. Contact: John H. Courtney, Senior Marketing Manager, Paslode, 888 Forest Edge Drive, Vernon Hills, IL 60061-3105, 1-847-634-1900, Fax: 1-847-634-6602
- Senco Fastening Systems – Mechanical Fasteners. Senco is providing fasteners and installing equipment for the shearwall testing project conducted by USG. Senco has also provided extensive fastening advice for connection designs from its internal ongoing systems research. Contact: Gary Rolih, Senco Fastening Systems 8485 Broadwell Rd., Cincinnati, OH 45244, (513) 388-2017, Fax: (513) 388-2078
- Simpson Strong-Tie Corp. – Structural Framing Connectors. Strong-Tie has provided technical data and suggested design solutions for structural connections of steel framing members. Contact: Norman Hall, Simpson Strong-Tie Corp., 411 Baltimore Blvd., Sea Girt, NJ 08750, 1-732-449-1413, Fax: 732-449-1438
- Toback & Associates – Fastening Systems. Toback & Associates, working in conjunction with Aerosmith Fastening Systems developed a fastening system using acrylic based adhesive and mechanical fasteners for the metal to metal connections and for gypsum and wood based panel connection to steel studs. Testing and refinement of these systems is continuing. Contact: Al Toback, Toback & Associates, 106 South Street, West Hartford, CT 06770, (860) 953-8483, Fax: (860) 953-4588
- US Gypsum Co. – Gypsum Wallboard. USG is planning to conduct shearwall racking tests of steel stud framed and gypsum wallboard paneled wall sections in accordance with the Manufactured Home Construction and Safety Standards for this project. Contact: Tom Sheppard, US Gypsum Corporation, 125 South Franklin Street, Department 123-1, Chicago, IL 60606-4678, (312) 606-4428, Fax: (312) 214-5959

E

Testing Plan

Some of the recommendations described in this study are subject to empirical verification and other design improvements are likely to result from a program of testing and evaluation.

A list of structural assemblies to be tested to the MHCSS for design values that are more closely related to the design values that are currently used for wood design is presented below. As testing proceeds, the list of assemblies to be tested will change based on early results. The list below is a starting point for a comprehensive and structured testing regimen whose principle aim is to identify other opportunities to reduce construction cost and speed home fabrication time.

There are several aspects of a testing program that must be resolved before a formal, time based testing program can be presented including a budget. These aspects of the testing are:

- Test protocols and agreement on the tests to be performed
- Material sources
- Fabrication resources, location(s) and basic frame connection methods
- Testing agency (agencies)

Test Protocols

A test protocol is included with each of the recommended tests listed below where a protocol exists. One of the problems with existing protocols is that they are founded on testing wood and wood based assemblies. Manufactured housing industry testing agencies for the most part have little experience with testing steel framed assemblies.

Further, some of the protocols that might be applied in this phase are not currently in general use. There is no clear experience to draw upon when deciding whether or not the DAPIA approval is sufficient or if the design must be submitted to the HUD Secretary.

Material Sources

Materials required for the value engineering test program are as follows:

- Cold formed steel studs and track of several different sizes and thicknesses for wall assemblies and roof trusses
- Gypsum wallboard for shearwall and ceiling testing and oriented strand board (OSB)
- Flat stock of several thicknesses that can be formed in the several “L” headers and the wall to floor and roof to wall tie configurations in the design manual
- Rated sheathing for roof diaphragm testing
- Exterior wall sheathing for diaphragm and “blow off” testing

- Mechanical fasteners, equipment and supplies for pneumatic pins, staples, screws, clinching technologies

Ideally these materials will be provided by steel fabricators that partner in testing effort.

Connectors

The recommended testing list below includes fastening methods of the wall sheathing where applicable but it does not specify the fastening methods for the steel frame members of the test assembly. The design values determined by this testing will be predicated on the fabrication method used on the test assembly. Consideration of the three principal frame fastening methods must be completed before fabrication of the witnessed test assemblies can be conducted.

At this time there does not seem to be sufficient data and history to include an adhesive/pin connection system of any of the frame systems to be tested. Selection of the fastening systems seems to be limited to the self-tapping screw and / or the pneumatic pin methods. Fasteners play a major role in home fabrication time and warrant further investigation.

Testing location

Location of fabrication and resources to perform the fabrication should be determined in conjunction with the material suppliers and selected test agency or agencies. Normally agency personnel would conduct component fabrication and testing at the agencies testing laboratory. Representatives of the suppliers should observe the initial fabrication work to assure that the materials are being used correctly, appropriate assembly practices are followed and that special equipment, if provided, functions properly.

Testing Agencies

The following is a partial list of recognized agencies that are familiar with and experienced in the testing requirements of the MHCSS and are candidates to conduct this phase of the work:

- NTA, Inc.
  305 N. Oakland Ave.
  Nappanee, IN 46550
  Tel: (219) 773-7975
  Fax: (219) 773-2732
- PFS Corporation
  2402 Daniels St.
  Madison, WI 53718
  Tel: (608) 221-3361
  Fax: (608) 221-4806
  RADCO, Inc.
- 3220 E. 59th St.
  Long Beach, CA 90805
  Tel: (562) 272-7231
  Fax: (562) 529-7513

- T.R. Arnold & Associates
  700 E. Beardsley Ave.
  Elkhart, IN 46514
  Tel: (219) 264-0745
  Fax: (219) 264-0740

- Underwriters Laboratories, Inc.
  USA Corporate Headquarters
  333 Pfingsten Rd.
  Northbrook, IL 60062
  Tel:(847) 272-8800
  Fax: (847) 272-8129

Consideration of the agency's facilities, capabilities and workload will weigh on the selection decision.

Proposed Testing

The following is a summary of potential testing and value engineering that may be pursued to create more cost effective solutions for the prototype design.

Shearwall Tests

The following items are listed as potential tests for improving the shearwall design.

- ½" gypsum wallboard with 22 gauge studs, unblocked, sheathed (1) side only, increase fastener spacing (boundary and field), single studs at the ends of the shearwalls, tested with and without the hold down straps.
- 7/16" OSB exterior hardboard
- Exterior Hardieboard™
- Foam attached ½" gypsum wallboard to interior face of metal studs (22 gauge and/or 20 gauge studs)
- Gypsum shearwalls with pneumatic pins may be an available option in the near future. Aerosmith is expected to release a new pin that can pneumatically attach gypsum wallboard to metal studs. Examples of the fastened assemblies are available and shearwall testing of this assembly is will hopefully allow a very cost effective comparable value to current timber shearwall practice

Horizontal Diaphragm Tests

The prototype design uses a pneumatic pin fastener with specific manufacturer ICBO reports for values. Tests may be in order for:

- Pneumatic pins through 7/16" OSB over cold-formed truss top chord. These assemblies are currently available through four or five different pin manufacturer ICBO reports. It should be noted that these reports specifically do not provide acceptance for OSB in lieu of plywood.
- Pneumatic pins or screws through ½" gypsum ceiling board to underside of cold-formed truss bottom chord.
- Pneumatic pins through 23/32" particle board (for 24" on center joist spacing) to cold-formed floor joist.
- Foam attached ½" gypsum ceiling board to underside of cold-formed truss bottom chord.

Truss Panel Point Connection and/or Full Truss Tests

- Alternate truss connection fasteners: The current plans show screw connecting cold-formed truss elements (truss chords and webs). It is anticipated that a combination of adhesive and pneumatic pins may be a very cost effective truss panel connection.
- Alternate truss element section shape: A hemmed angle for the top, bottom, and web members was investigated and found that although it did not calculate out on paper (because of lack of code addressing these elements) it might be a potential test item. It is recommended, therefore, that a 20 gauge 2" x 2" angle with ½" hems might be an effective section for testing.

Attachment of gypsum wallboard to interior non-load bearing studs

- It appears that Senco (see Appendix E for supplier contact information) has a staple that would be cost effective for attaching the gypsum wallboard to the 25 gauge interior non-load bearing studs. This is not specifically a structural load transfer issue and as such has not been addressed in the current plans.

Other Structural Assemblies Recommended for Testing

Shearwall - ASTM E-72 Racking Test

a. Interior shear wall

- Test with 22 gauge studs at 24" on center, 5/16" gypsum wallboard one side fastened with Senco staples at 6" and 12" on center edge and field spacing.
- Test with 22 gauge studs at 24" on center, 5/16" gypsum wallboard two sides, fastened with Senco staples at 6" and 12" on center edge and field spacing.
- Test with 22 gauge studs at 24" on center, ½" gypsum wallboard one side fastened with Senco staples at 6" and 12" on center edge and field spacing.
- Test with 22 gauge studs at 24" on center, ½" gypsum wallboard two sides, fastened with Senco staples at 6" and 12" on center edge and field spacing.

b. Endwall shearwall

- Test with 22 gauge studs at 24" on center, 5/16" gypsum wallboard on inside fastened with Senco staples at 6" and 12" on center edge and field spacing and 7/16" OSB sheathing on exterior side fastened with pneumatic pins at 6" and 12" on center edge and field spacing.

Interior Non-Load Bearing Wall - 5 lb. Lateral load (Drunk test)

- Test 22 gauge studs, 114" long at 24" on center, 5/16" gypsum wallboard on one side fastened with Senco staples at 6" and 12" on center edge and field spacing. Test load to be applied on gypsum wallboard side.

Exterior Sidewall – ASTM draft test procedure

Test procedure is for combined lateral wind load bending and wind uplift load from roof connection.

- Test with 22 gauge studs at 24" on center, 5/16" gypsum wallboard on inside fastened with Senco staples at 6" and 12" on center edge and field spacing and 7/16" OSB

sheathing on exterior side fastened with pneumatic pins at 6" and 12" on center edge and field spacing.

Exterior Sidewall – ASTM draft test procedure

Test procedure is for combined lateral wind load bending and gravity load from roof connection.

- Test with 22 gauge studs at 24" on center, 5/16" gypsum wallboard on inside fastened with Senco staples at 6" and 12" on center edge and field spacing and 7/16" OSB sheathing on exterior side fastened with pneumatic pins at 6" and 12" on center edge and field spacing.

Exterior sidewall "L" header – ASTM Standard for Beam testing under gravity loading.) Test 36" long "L" header

- Test 22 gauge header fastened to header framing with pin fastener at 12" on center to top track and one fastener to vertical frame members. No interior or exterior wall sheathing

Roof truss to wall connector to serve as sidewall header – ASTM Standard for Beam testing under gravity loading.) Test 36" long connector / header

- Test 22 gauge roof connector assembly fastened to top track with pins from above at 12" on center and fastened to simulated truss end posts with 2 - 0.100" pins at each post.

Exterior wall tie down strap stud to floor (tension test)

- Test 1¼" x 12" x 31 gauge strap with 6 - 0.100" pins each above and below track-to-floor joint. Test with ¼" misalignment between wall edge and floor edge.

Ceiling gravity load test of attachment to simulated steel truss bottom chord. (Airbag vacuum test procedure)

- Test ½" gypsum ceiling board attached to truss bottom chord with Foamseal F-2200. Not a diaphragm test, vertical test of ceiling board weight and "inaccessible attic" load, i.e., insulation and light fixture attached to cross blocking at ceiling level. Need to consider dynamic transportation loads.

Roof sheathing diaphragm test

- Test 7/16" OSB roof sheathing attached to 24" on center roof truss top chord with pneumatic pin at 4" and 12" on center edge and field spacing.

Floor diaphragm test

- Test 23/32" D-2 particleboard floor sheathing on 16 gauge floor joists at 24" on center Fasten decking to floor joists at 6" and 12" on center with pneumatic pins. Floor framing shall have end bay blocking and drag strap. Decking shall be 4' x 8' sheets laid out 8' in house longitudinal direction. Decking shall have no edge blocking.

Roof truss testing

- Test to develop more efficient roof truss design for trusses at 24" on center

F

References

1. McBride, Merle F., "International Code Committee Proposed Code Changes to the International Energy Conservation Code on Residential Steel Framed Ceilings and Floors, Report No. OC-CR-99-1, Owens Corning Science and Technology Center Granville, Ohio, 1999.
2. 2000 ICC Code Change Proposal to the International Energy Conservation Code Section 502.2.1.2 Roof/Ceiling, American Iron and Steel institute, 1999
3. ASHRAE "Modified Zone Method for Metal Stud Walls with Insulated Cavities" ASHRAE Handbook of Fundamentals, 1997 Chapter 24 pp.11-12.
4. Overall U-Values and Heating/Cooling Loads, PNL-8006 1992.
5. Manufactured Home Construction and Safety Standards, Part 3280 of the Code of Federal Regulations. April 1995.
6. US Department of Housing and Urban Development. August 1997. *Commentary on the Prescriptive Method for Residential Cold-Formed Steel Framing.* Second Edition. Prepared by NAHB Research Center for HUD and AISI.
7. Nisson, J.D. Ned, and Don Best. 1997. "Steel Framing for Houses." *Energy Design Update.* Arlington, MA: Cutter Information Corporation.
8. North American Steel Framing Alliance. March 2000. *Low-Rise Residential Construction Details.* Publication NT6-00. Washington, D.C.
9. North American Steel Framing Alliance. December 1999. *L-Shaped Header Field Guide.* Publication NT19-99F. Washington, D.C.
10. Steel Stud Manufacturers Association. 2000. ICBO ER-4943P. *Product Technical Information.*
11. U.S. Department of Housing and Urban Development, Office of Policy Development and Research. July 1994. *Alternative Framing Materials in Residential Construction: Three Case Studies.* Instrument No. DU100K000005911. Prepared by NAHB Research Center.
12. U.S. Department of Housing and Urban Development, Office of Policy Development and Research. April 1993. *Alternatives to Lumber and Plywood in Home Construction.* Prepared by NAHB Research Center.
13. U.S. Department of Housing and Urban Development, Office of Policy Development and Research. December 1999. *Builders' Guide to Residential Steel Floors.* Prepared by NAHB Research Center.

14. U.S. Department of Housing and Urban Development, Office of Policy Development and Research. April 1996. *Field Evaluations and Recommendations for Steel Framed Homes: Jordan Commons Project.* Prepared by NAHB Research Center.

15. U.S. Department of Housing and Urban Development, Office of Policy Development and Research. February 2000. *Residential Structural Design Guide: 2000 Edition.* Prepared by NAHB Research Center, Inc.