Sheathing Braced Design of Wall Studs
July 2011 Update
www.ce.jhu.edu/bschafer/sheathedwalls

for
AISI Committee on Framing Standards
Design Methods Subcommittee
Cleveland, OH
overview

• Previous findings on sheathed walls in compression

• New work on fastener demands

• New experiments on sheathed stud in compression + bending
Wall Bracing

a) All steel

b) Sheathed wall (no bridging)
Compression testing (full-scale walls)
Observed failure modes

Bare-Bare: FT

OSB-Bare: FT

OSB-Gyp: L + D
Gyp removed in picture

OSB-Gyp: L

OSB-OSB: L
Full-scale wall tests ($P-\Delta$)

Comparison between different boards combination

- 2-BARE-BARE.txt
- 1-OSB-BARE.txt
- 11-GYP-GYP.txt
- 3-OSB-GYP.txt
- 9-OSB-OSB.txt

Load (kip) vs. position (in)
Comparison to design methods

![Graph showing comparison to design methods]
Project timeline

- **Apr 2008**  Report on Existing Design Methods
  Idea for separation of local and diaphragm stiffness
- **Oct 2008**  “Completion” of walls testing rig, Phase 1 planning
  Reliability investigation for “2a” fastener spacing rule
- **Apr 2009**  Fastener stiffness (Winter) tests completed
  Single column testing completed
- **Aug 2009**  Majority of full-scale wall tests completed
- **Feb 2010**  Full-scale wall tests completed
  “Strip” test demonstrating local vs. diaphragm
- **July 2010**  Design method realized and compared
  Formulas for $k_{xd}$, $k_x$, $k_y$ derived
  Beam-column testing matrix, materials ordered
- **Feb 2011**  Formalization of design method
  Work on fastener demands
- **Aug 2011**  Final report on sheathed walls in compression
- **Fall 2011**  Test report on sheathed walls in bending and compression
- **Feb 2011**  Project closeout and beginning of ballots on walls

$=0$
Exploring “fastener” demand/capacity

springs may differ on the two sides
Fastener Demands (state of knowledge)

• Local buckling
  - Ignored
    probably consistent given springs not assumed to help local

• Distortional buckling
  - Ignored
    problematic, usual amplification does not apply because of post-buckling, could pick an arbitrary rotation limit to get force, note this is primarily the demand on a pull-through failure mode

• Global buckling
  - Hand calc method derived
  - CUFSM based method with amplification determined
  - Conservative simplifications possible, lead to overly large forces?

• Direct torsion, shear etc.
  - Ignored for columns
    to be added for beam-columns – method to do this clear

• Accumulation
  - FE modeling underway, more questions than answers with recent findings
## Fastener Capacity (state of knowledge)

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<thead>
<tr>
<th>Connections</th>
<th>Fastener</th>
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<tbody>
<tr>
<td></td>
<td>Shear – AISI-S100-07 says per manufacturer table or test</td>
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<tr>
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<td>Tension – AISI-S100-07 says per manufacturer table or test</td>
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<td>Shear + Tension – No AISI provisions, expression for bolts could provide a rational answer</td>
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<thead>
<tr>
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<tr>
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<td>o Wood – APA 2004 Panel Design Specification provides allowable stresses for plywood and OSB in shear</td>
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<tr>
<td></td>
<td>o Gypsum – Could GA 229-08 be used?</td>
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<tr>
<td></td>
<td>Bending</td>
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<tr>
<td></td>
<td>o Wood – APA 2004 Panel Design Specification provides allowable stresses for plywood and OSB in shear these could be converted and used</td>
</tr>
<tr>
<td></td>
<td>o Gypsum – GA 235-05 provides strength values for gypsum</td>
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<tr>
<th>Connections</th>
<th>Assembly</th>
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<tr>
<td></td>
<td>Stud/Track-Fastener-Sheathing</td>
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<tr>
<td></td>
<td>o Tilting, Bearing, Edge tear out, Pull-out, Pull-through – AISI-S100-07 + NDS-2005 (Bearing eq. for wood alone) + APA E830D (limited set of values for plywood-to-steel) and Gypsum (?)</td>
</tr>
<tr>
<td></td>
<td>o Test</td>
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<td></td>
<td>Stud-Track-Sheathing by Fastener</td>
</tr>
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<td>o Addition of steel may strengthens the assembly but fastener may have greater demands</td>
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- Tested capacities of sub-assemblies (Winter test, rotation test, composite test) provide the easiest assembly capacity predictions
- Mashup with wood and gypsum places many of the capacity calculations outside of AISI and requires the use of NDS, or more often manufacturer and other data
- Best path forward is not 100% clear to me in our timeframe
New modeling exploring fastener demands

Figure 6.8 – Model that considers $k_x$, $k_z$, $k_{sv}$, and sheathing is also simulated. a) Overall view of FE model, steel members are represented in gray and OSB in brown. b) Part of the sheathing is removed to show the stud. d) Zoomed view of stud end where local buckling takes place. c) von Mises stress on stud end.
Figure 6.10 – FE Model considers $k_x$, $k_z$, $k_p$, $k_{x\beta}$, and sheathing is also simulated (OSB-OSB) a) Overall view of FE model, steel members are represented in gray and OSB in brown, b) Zoomed view of stud end where local buckling takes place, the sheathing is partially removed to provide view of the stud, c) von Mises stress on stud end, special attention is brought to the stud-to-track connection where plastic failure takes place.
Figure 6.11 – Force and Moment in the springs at peak load for non-linear sheathed wall-stud model ($k_x$, $k_z$, $k_n$, $k_{\phi}$) (OSB-OSB). The biggest marker is equivalent to the maximum moment or force of each picture.
Figure 6.12 – Distribution of the forces in the $k_x$ springs varying side that is being attached and axial load (OSB-OSB wall). The biggest marker is equivalent to the maximum moment or force of each picture.
Sum of $x$ fastener force on field stud

Figure 6.15 – Sum of fasteners force in the $k_x$ spring on second stud (left to right) of sheathed wall-stud (Figure 6.11 (a)) versus axial load
Analytical model can predict...

Figure 6.17 – Comparison between FE model and analytical solution considering all the buckling modes. a) Single-column FE model as depicted in Figure 6.6, b) Wall stud as depicted in Figure 6.10.
Empirically we observed that in all tested specimens the member limit states, not the fastener or sheathing limit states controlled (this does not imply sheathing undamaged, but capacities are consistent with member limit states not fastener limit states)

Testing conducted for $k_x$ and $k_\phi$ (and potentially $k_y$) include fastener-sheathing limit states (screw shear, edge tear out, pull through, etc.) and could be used for fastener-sheathing capacities

We have derived expressions for the amplification of demands in global torsion (these are new). Twist amplification takes same form as flexural amplification, but due to distance from shear center can result in higher fastener demands. Implementation involved. These expressions are now verified

ABAQUS shell element models, loaded to collapse, provide fastener demands with all the messy nuances. Fastener demands can become large near peak (particularly due to local buckling) but this is ok because we are not asking fasteners to restrict this mode.

All the pieces are in place for a design method including fastener demand and capacity – simplification is still needed – particularly for demand.
 springs may differ on the two sides
Determine springs to account for sheathing restraint

\[ k_x, k_y, k_\phi \]

Test or formula

Elastic Buckling – DSM – AISI-S100 App. 1 (Note, Fixed-Fixed)

- \( P_{cr\ell}, P_{crd}, P_{cre} \)
  - Formula, CUFSM, FEM

Elastic Buckling – Main Spec. – AISI-S100

- \( F_{cr}, F_d, F_e \)
  - Formula, rational analysis

Strength – DSM – AISI-S100 App. 1

- \( P_{n\ell}, P_{nd}, P_{ne} \)

Strength – Main Spec. – AISI-S100

- \( P_n = A_e F_n, P_n = P_{nd} \)
### Member Capacity

- **k_x** is determined from **k_xd** and **k_xl**
  - **k_xd** – Diaphragm stiffness
    - Formula (new – S210/211 or S100?)
    - Material Test for G (e.g., ASTM D2719-89)
  - **k_xl** – Local stiffness
    - Test (new – TS?)
    - Lowerbound formula (new – S210/211 or S100?)

- **k_y**
  - Test (ASTM – E72?) + Conversion (ASTM-E72? + new – S210/211)
  - Lowerbound formula (new – S210/211)

- **k_i** (AISI-S210-10)
  - Test (modify - AISI S901-08)
  - Formula (S210/S211)

### Elastic Buckling – DSM – AISI-S100 App. 1 (Note, Fixed-Fixed)

- **Global (P_{cre})**
  - Formula (new – S100 C4 formulas)
  - CUFSM 3 at KL (DSM Guide/App.1 Comm.)
  - CUFSM 4 (new – App.1 Commentary)
  - FEM/ABAQUS

- **Distortional (P_{crd})**
  - Formula (S100 C4.2)
  - CUFSM 3 × D_{boost} (new – App.1 Commentary)
  - CUFSM 4 (new – App.1 Commentary)
  - FEM/ABAQUS

- **Local (P_{ct})** (ignore springs)
  - Formula element only (DSM Guide/App.1 Comm.)
  - Formula with interaction (DSM Guide/App.1 Comm.)
  - CUFSM 3 or 4 (new – App.1 Commentary)

### Elastic Buckling – Main Spec. – AISI-S100

- **Global (F_{e})**
  - Formula (new S100 – C4 formulas)
  - Rational Analysis (see DSM F_{e}=P_{cre}/A_g)

- **Distortional (F_{d})**
  - Formula (S100 C4.2)
  - Rational Analysis (see DSM F_{d}=P_{crd}/A_g)

- **Local (F_{l})**
  - Formula element only (AISI-S100 k’s in Ch. B)

### Strength – DSM – AISI-S100 App. 1

- **Global (P_{ne})**
  - Formula (S100 Eq.1.2.1.1)

- **Distortional (P_{nd})**
  - Formula (S100 Eq.1.2.1.3)

- **Local-Global (P_{n})**
  - Formula (S100 Eq.1.2.1.2)

- **P_n=min(P_{ne}, P_{nd}, P_{nl})**

### Strength – Main Spec. – AISI-S100

- **Distortional (P_{n})**
  - Formula (S100 C4.2)

- **Local-Global (P_{n})**
  - P_{n}=A_{c}F_{c}^{*}, F_{c}^{*}=f(F_{c}), F_{n}=f(F_{c}) (S100 C4.1)

- **P_n=min(P_{n,C4.2}, P_{n,C4.1})**
Member Design Approach - Directions

As summarized on the previous slides, general method is:

• **Analysis-based**
  - Traditional/formulaic
    • Closed-form
    • Programmable
    • Long
  - Computational/FSM
    • Simplest to start
    • Analysis requires modest interpretation

• **Spring stiffness**
  - Test or formula?

An alternative for COFS Prescriptive or other COFS?

• **Tabled**
  - Fully detailed wall
  - Full intermediate analysis details provided
  - Final strength provided

This approach may lead to regimes where strength may be simplified. Still need AISI/PMTG input on details to be tabled, not too many details…
AXIAL + BENDING
**Test Matrix (Single Sheathed Studs)**

Test Matrix for Isolated Beam-Column Testing of Sheathed 362S162-68 (50 ksi) Stud

<table>
<thead>
<tr>
<th>LOADING</th>
<th>SHEATHING (B=BARE, G=GYPSUM, O=OSB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>H</td>
</tr>
<tr>
<td>100%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6 (4')</td>
</tr>
<tr>
<td></td>
<td>7 (6')</td>
</tr>
<tr>
<td></td>
<td>22 (8')</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LOADING</th>
<th>SHEATHING (B=BARE, G=GYPSUM, O=OSB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB</td>
<td>OB</td>
</tr>
<tr>
<td>80%</td>
<td>to failure</td>
</tr>
<tr>
<td>60%</td>
<td>to failure</td>
</tr>
<tr>
<td>60%</td>
<td>to failure</td>
</tr>
<tr>
<td>40%</td>
<td>to failure</td>
</tr>
<tr>
<td>10%</td>
<td>to failure</td>
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**Legend**

- Refers to existing test results of Vieira and Schafer, Vieira et al., first number is index, second number is length
- This configuration not tested
- This test series (Peterman and Schafer)

B=Bare, no sheathing
G=xx in. gypsum board fastened with #yy Simpson... fasteners at 12 in. o.c.
O=xx in. OSB board fastened with #yy Simpson .. fasteners at 12 in. o.c.

OB = OSB on west side, Bare on East Side (load applied) --> BO = Bare on west side, OSB on East Side (load applied)
Experimental Setup
$P, \Delta$

- Fastener/sheathing springs
  - Translation and rotation

$H, \theta$

- Rotation/twist at midheight $\phi$

$e_H$ (resultant)

$s_e$

- Axial
  - Moment (drawn on tension side)
- Shear
- Torsion

Of course, knowing $\theta$ is a real challenge...
Specimen Design

Fastener Plan

Sensor Layout
Specimen Detail: End Fixities

3/4" thick plates block tracks ends from twist

Loading Beam to Track Connection
Specimen Detail: Stud to Track

3/4” bolt connects track to plate

Side View: Stud to Track Connection

Top View: Stud to Track Connection

362S162-068
S38–OO

at $P=11.45\text{kip}$

$M_{\text{max}}=18.03\text{kip-in.}$

$\Delta_{\text{direct}}=0.062\text{ in.}$

$\delta_{\text{mid}}=1.138\text{ in.}$

$\Phi_{\text{board}}=-0.807\text{ deg}$

$\delta \times 10$ at $M_{\text{max}}$
S20–GG

at P=11.61kip

\( M_{\text{max}} = 11.93 \text{ kip-in.} \)

\( \Delta_{\text{direct}} = 0.063 \text{ in.} \)

\( \delta_{\text{mid}} = 0.994 \text{ in.} \)

\( \Phi_{\text{board}} = -0.158 \text{ deg} \)

\( \delta \times 10 \) at \( M_{\text{max}} \)
OSB-Gypsum
Gypsum-OSB
P-M Space (as of a few days ago!)

\[ \frac{P}{P_{\text{nom}}} \quad \frac{M}{M_{\text{nom}}} \]

- OO
- OG or GO
- GG
- OB or BO
- BB
- Local Only
Needs

• Details on subset of sheathed walls to be Tabled up: Stud, length, spacing, sheathing, fastener, spacing, etc.

• Guidance of committee on where best to introduce the fastener stiffness values and the overall methodology (in COFS, in COS, in wall stud? Floor and roof??) How to ballot all this??

• Feedback on how to handle fastener capacity issues that begin to have scope outside of current AISI (a smaller detail, but concerning)

Conclusions

• Design methods for sheathed walls is ready to go for generating ballots and details that the committee can consider

• Tabled solutions and completed beam-column tests next meeting (single column tests will be complete, full walls unsure/unlikely, trying to get an unpaid master’s student)

• Project closeout next meeting