Sheathing Braced Design of Wall Studs
February 2011 Update

www.ce.jhu.edu/bschafer/sheathedwalls

for
AISI Committee on Framing Standards
Design Methods Subcommittee
Charlotte, NC
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
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
  Planning of phase 1 wall testing
  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
  Proposed Design method initiated
- 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
  Test report on sheathed walls in bending and compression
Key to Proposed Design → Sheathing Restraint

springs may differ on the two sides
<table>
<thead>
<tr>
<th>Member Capacity</th>
<th>Elastic Buckling – DSM – AISI-S100 App. 1 (Note, Fixed-Fixed)</th>
<th>Elastic Buckling – Main Spec. – AISI-S100</th>
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<tbody>
<tr>
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<td><strong>P_{cr_{\ell}}, P_{crd}, P_{cre}</strong></td>
<td><strong>F_{cr}, F_d, F_e</strong></td>
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<td></td>
<td><em>Formula, CUFSM, FEM</em></td>
<td><em>Formula, rational analysis</em></td>
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<td>Strength – DSM – AISI-S100 App. 1</td>
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<td><strong>P_{nl}, P_{nd}, P_{ne}</strong></td>
<td><strong>P_n = A e F_n; P_n = P_{nd}</strong></td>
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Determine springs to account for sheathing restraint

$$k_x, k_y, k_{\phi}$$

Test or formula
### Member Capacity

Determine springs to account for sheathing restraint
- \( k_x \) is determined from \( k_{x,d} \) and \( k_{x,f} \)
  - \( k_{x,d} \) – Diaphragm stiffness
    - Formula
    - Material Test for \( G \)
  - \( k_{x,f} \) – Local stiffness
    - Test
    - Lowerbound formula
- \( k_y \)
  - Test (ASTM – E72?) + Conversion (ASTM-E72? + new – S210/211)
  - Lowerbound formula (new – S210/211)
- \( k \) (AISI-S210-10)
  - Test (modify - AISI S901-08)
  - Formula (S210/S211)

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

- \( P_{cr,l}, P_{cr,d}, P_{cre} \)
  - Formula, CUFSM, FEM
- \( F_{cr}, F_d, F_e \)
  - Formula, rational analysis

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

- \( P_{n,l}, P_{nd}, P_{ne} \)
- \( P_n = A_e F_n, P_n = P_{nd} \)
### Sheathed Walls Overview of Proposed Specification Changes/Additions (21 Feb 2011)

**Member Capacity**

Determine springs to account for sheathing restraint

\[ k_x, k_y, k_\phi \]

Test or formula

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<td>- CUFSM 3 × ( D_{boost} )</td>
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Sheathed Walls Overview of Proposed Specification Changes/Additions (21 Feb 2011)

### Determine springs to account for sheathing restraint

- \( k_x \) is determined from \( k_{xd} \) and \( k_x \)
- \( k_{xd} \): Diaphragm stiffness
- Formula (new – S210/211 or S100?)
- Material Test for G (e.g., ASTM D2719-89)
- \( k_x \): 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)
- \( k_\phi \): 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 (\( P_{cd} \))
  - Formula (S100 C4.2)
  - CUFSM 3 \( \times D_{boost} \) (new – App.1 Commentary)
  - CUFSM 4 (new – App.1 Commentary)
  - FEM/ABAQUS
- Local (\( P_{cs} \)) (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)

### Strength – DSM – AISI-S100 App. 1

- Global (\( P_{sc} \))
  - Formula (S100 Eq.1.2.1.1)
- Distortional (\( P_{sd} \))
  - Formula (S100 Eq.1.2.1.3)
- Local-Global (\( P_{s} \))
  - Formula (S100 Eq.1.2.1.2)
- \( P_{n} = \min(P_{sc}, P_{sd}, P_{s}) \)

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

- \( F_{cr}, F_{d}, F_{e} \)
- Formula, rational analysis

### Strength – Main Spec. – AISI-S100

- \( P_{n} = A e F_{n}, P_{n} = P_{nd} \)
Determine springs to account for sheathing restraint

\[ k_x, \; k_y, \; k_\phi \]
Test or formula

Member Capacity

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

- Determine springs to account for sheathing restraint

\[ k_x, \quad k_y, \quad k_{\phi} \]

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

- Global (\( F \))
  - Formula
  - Rational Analysis

- Distortional (\( F_d \))
  - Formula
  - Rational Analysis

- Local (\( F_{lo} \))
  - Formula element only

Strength – DSM – AISI-S100 App. 1

| \( P_{nl} \), \( P_{nd} \), \( P_{ne} \) |  
---|---

Strength – Main Spec. – AISI-S100

- \( \begin{align*}
P_n &= A_e F_n, \\
P_n &= P_{nd}
\end{align*} \)
**Sheathed Walls Overview of Proposed Specification Changes/Additions (21 Feb 2011)**

**Member Capacity**
- Determine springs to account for sheathing restraint

**Sheathed Walls Diagram**

- **k_x, k_y, k_ϕ**
- Test or formula

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

- **P_cr, P_crd, P_cre**
- Formula, CUFSM, FEM

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

- Global (F_g)
  - Formula
  - Rational Analysis
    - (new S100 – C4 formulas)
    - (see DSM F_c=P_c/Ag)

- Distortional (F_d)
  - Formula
  - Rational Analysis
    - (S100 C4.2)
    - (see DSM F_d=P_c/Ag)

- Local (F_l)
  - Formula element only
    - (AISI-S100 k’s in Ch. B)

**Strength – DSM – AISI-S100 App. 1**

- **P_nl, P_nd, P_ne**

**Strength – Main Spec. – AISI-S100**

- Distortional (P_a)
  - Formula
    - (S100 C4.2)

- Local-Global (P_a)
  - P_a=A_F, A_c=f(F_c), F_a=f(F_c)
    - (S100 C4.1)

- P_a=min(P_a,C4.2, P_a,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. Need AISI/PMTG input on details to be tabled, not too many details...
Fastener/Connections – State of knowledge

- A lot of activity here, but still a bit of a weak link in the work as greatest attention has been focused on member design.
- 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.
- ABAQUS shell element models, loaded to collapse, show fastener forces less than 2% even at local buckling location and less than 1% in the main of the member at peak strength.
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)

<table>
<thead>
<tr>
<th>Connections</th>
<th>Fastener</th>
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<tbody>
<tr>
<td></td>
<td>Shear</td>
<td></td>
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<tr>
<td></td>
<td>- AISI-S100-07 says per manufacturer table or test</td>
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<td></td>
<td>Tension</td>
<td></td>
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<tr>
<td></td>
<td>Shear + Tension</td>
<td></td>
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<tr>
<td></td>
<td>- No AISI provisions, expression for bolts could provide a rational answer</td>
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<td>- Wood – APA 2004 Panel Design Specification provides allowable stresses for plywood and OSB in shear</td>
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<td></td>
<td>- Gypsum – Could GA 229-08 be used?</td>
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<td>Bending</td>
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<td>- Gypsum – GA 235-05 provides strength values for gypsum</td>
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<th>Connections</th>
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<td></td>
<td>Stud/Track-Fastener-Sheathing</td>
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</tr>
<tr>
<td></td>
<td>- 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>
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<tr>
<td></td>
<td>Test</td>
<td></td>
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<tr>
<td></td>
<td>Stud-Track-Sheathing by Fastener</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 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
Beam-column testing

M₁

M₂

P

H

or

P
Compression + bending tests (rig)
Addition of lateral load application

Only lateral Load application shown
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??)
• Feedback on how to handle fastener capacity issues that begin to scope outside of current AISI
• Guidance regarding preference for end boundary conditions on beam-column testing

Conclusions

• We are well on are way to providing an entirely new approach where design may specifically account for the benefits of sheathing in restraint of structural members.
• Design expressions, limitations, tabled solutions, for columns next meeting, along with beam-column test results
Supplement
Graphical summary of new methods related to design of sheathed walls
Sheathed Walls Overview of Proposed Specification Changes/Additions (21 Feb 2011)

**Member Capacity**

- Determine springs to account for sheathing restraint
  - \( k_x \) is determined from \( k_{xd} \) and \( k_{x/} \)
    - \( k_{xd} \) – Diaphragm stiffness
      - Formula
      - Material Test for \( G \)
        - (new – S210/211 or S100?)
        - (e.g., ASTM D2719-89)
    - \( k_{x/} \) – Local stiffness
      - Test
      - 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/S2111)

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<td>- CUFSM 3 at KL</td>
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<td>• Distortional (( P_{cred} ))</td>
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<td>- Formula</td>
</tr>
<tr>
<td>• Distortional (( P_{nd} ))</td>
<td>- (S100 C4.2)</td>
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<tr>
<td>- Formula</td>
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<tr>
<td>• Local-Global (( P_{n/} ))</td>
<td>• Local-Global (( P_n ))</td>
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|   - Formula                                                   |   - \( P_n = A_n F_{st}, A_e = f(F_c), F_n = f(F_e) \) (S100 C4.1)
|                                                                 |   - \( P_n = \min(P_{n/C4.2}, P_{n/C4.1}) \) |
| • \( P_n = \min(P_{ne}, P_{nd}, P_{n/}) \)                   |                                           |
**Member Capacity**

Determine springs to account for sheathing restraint

- $k_x$ is determined from $k_{xd}$ and $k_{x}$
  - Formula
  - Material Test for G
    - (new – S210/211 or S100?)
    - (e.g., ASTM D2719-89)
  - $k_{x}$ – Diaphragm stiffness
    - Test
    - Lowerbound formula
      - (new – S210/211 or S100?)
  - $k_y$
    - Lowerbound formula
      - (new – S210/211)
  - $k$, (AISI-S210-10)
    - Test
    - Formula
      - (modify - AISI S901-08)

**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 $\times D_{boost}$
    - (new – App.1 Commentary)
  - CUFSM 4
    - (new – App.1 Commentary)
  - FEM/ABAQUS
- Local ($P_{cr}$) (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)

**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)
- $P_n = \min(P_{ne}, P_{nd}, P_{cr})$

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

- Global ($F_c$)
  - Formula
    - (new S100 – C4 formulas)
  - Rational Analysis
    - (see DSM $F_c = P_{cr}/A_g$)
- Distortional ($F_d$)
  - Formula
    - (S100 C4.2)
  - Rational Analysis
    - (see DSM $F_d = P_{crd}/A_g$)
- Local ($F_c$)
  - Formula element only
    - (AISI-S100 k’s in Ch. B)

**Strength – Main Spec. – AISI-S100**

- Distortional ($P_n$)
  - Formula
    - (S100 C4.2)
- Local-Global ($P_n$)
  - $P_n = A_f F_p, A_f = f(F_c), F_p = f(F_c)$
    - (S100 C4.1)
  - $P_n = \min(P_{n,C4.2}, P_{n,C4.1})$
\( k_{xd} \)

Material Test for G
(e.g., ASTM D2719-89)

Formula
(new – S210/211 or S100?)

\[
k_{xd} = \frac{2\pi Gtw_t f}{L} \sin\left(\frac{\pi d_f}{2L}\right) \approx \frac{\pi^2 Gtd_f w_t f}{L^2}
\]
### Member Capacity

**Determine springs to account for sheathing restraint**

- $k_x$ is determined from $k_{xd}$ and $k_{x,f}$
  - $k_{xd}$: Diaphragm stiffness
    - Formula: (new – S210/211 or S100?)
    - Material Test for $G$ (e.g., ASTM D2719-89)
  - $k_{x,f}$: 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 ($P_{crl}$) (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 ($F_{cl}$)**
  - 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 ($P_{nl/g}$)**
  - Formula: (S100 Eq.1.2.1.2)
- $P_{n}=\min(P_{ne}, P_{nd}, P_{nl/g})$

### Strength – Main Spec. – AISI-S100

- **Distortional ($P_n$)**
  - Formula: (S100 C4.2)
- **Local-Global ($P_n$)**
  - $P_n=A_n F_{st}, A_n=f(F_{cr}), F_n=f(F_e)$: (S100 C4.1)
  - $P_n=\min(P_{n,C4.2}, P_{n,C4.1})$
\[ k_{x_l} = \frac{P}{d} = \frac{(3Ed^4t^3p)}{(4t_{\text{board}}^2(9d^4p + 16t_{\text{board}}t^3))} \]

Lowerbound formula
(new – S210/211 or S100?)
\[
\frac{1}{k_{\text{total}}} = \frac{1}{k_{\text{local}}} + \frac{1}{k_{\text{diaphragm}}}
\]

\[
k_x = (1/k_{xl} + 1/k_{xd})^{-1}
\]
Determine springs to account for sheathing restraint

- \( k_x \) is determined from \( k_{xd} \) and \( k_{x,t} \)
  - \( k_{xd} \) = Diaphragm stiffness
    - Formula
    - Material Test for \( G \)
    - (e.g., ASTM D2719-89)
  - \( k_{x,t} \) = Local stiffness
    - Test
    - Lowerbound formula
    - (new – S210/211 or S100?)

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

- \( k_z \) (AISI-S210-10)
  - Test
  - Formula
    - (modify - AISI S901-08)
    - (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 \( \times D_{boost} \)
    - (new – App.1 Commentary)
  - CUFSM 4
    - (new – App.1 Commentary)
  - FEM/ABAQUS

- **Local (\( P_{cre} \))** (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 (\( F_c \))**
  - Formula
    - (new S100 – C4 formulas)
  - Rational Analysis
    - (see DSM \( F_c = P_{cre}/A_g \))

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

- **Local (\( F_c \))**
  - Formula element only
    - (AISI-S100 k’s in Ch. B)

---

**Strength – DSM – AISI-S100 App. 1**

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

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

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

- \( P_n = \min(P_{sc}, P_{sd}, P_{sg}) \)

**Strength – Main Spec. – AISI-S100**

- **Distortional (\( P_n \))**
  - Formula
    - (S100 C4.2)

- **Local-Global (\( P_n \))**
  - \( P_n = A_n F_n, A_n = f(F_c), F_n = f(F_c) \)
    - (S100 C4.1)

- \( P_n = \min(P_{n,C4.2}, P_{n,C4.1}) \)
Test (ASTM – E72?) + Conversion (ASTM-E72? + new – S210/211)

Lowerbound formula (new – S210/211)

\[ k_y = \frac{2E_w L \pi^3}{L^3} \cdot \sin \left( \frac{\pi d_f}{2L} \right) \]
### Member Capacity

Determine springs to account for sheathing restraint
- \( k_x \) is determined from \( k_{xd} \) and \( k_{xc} \)
  - \( k_{xd} \) – Diaphragm stiffness (new – S210/211 or S100?)
    - Formula
    - Material Test for G (e.g., ASTM D2719-89)
  - \( k_{xc} \) – Local stiffness (new – TS?)
    - Test
    - Lowerbound formula (new – S210/211 or S100?)
- \( k_y \)
  - Test (ASTM – E72?) + Conversion (ASTM-E72? + new – S210/211)
  - Lowerbound formula (new – S210/211)

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

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global (( P_{cre} ))</td>
<td>(new – S100 C4 formulas)</td>
</tr>
<tr>
<td>Distortional (( P_{crd} ))</td>
<td>(S100 C4.2)</td>
</tr>
<tr>
<td>Local (( P_{cre} )) (ignore springs)</td>
<td>(DSM Guide/App.1 Comm.)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global (( F_e ))</td>
<td>(new S100 – C4 formulas)</td>
</tr>
<tr>
<td>Distortional (( F_d ))</td>
<td>(S100 C4.2)</td>
</tr>
<tr>
<td>Local (( F_{cr} ))</td>
<td>(AISI-S100 k’s in Ch. B)</td>
</tr>
</tbody>
</table>

#### Strength – DSM – AISI-S100 App. 1

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global (( P_{ne} ))</td>
<td>(S100 Eq.1.2.1.1)</td>
</tr>
<tr>
<td>Distortional (( P_{nd} ))</td>
<td>(S100 Eq.1.2.1.3)</td>
</tr>
<tr>
<td>Local-Global (( P_{n} ))</td>
<td>(S100 Eq.1.2.1.2)</td>
</tr>
<tr>
<td>( P_{n}=\min(P_{ne}, P_{nd}, P_{nf}) )</td>
<td></td>
</tr>
</tbody>
</table>

#### Strength – Main Spec. – AISI-S100

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distortional (( P_{n} ))</td>
<td>(S100 C4.2)</td>
</tr>
<tr>
<td>Local-Global (( P_{n} ))</td>
<td>(S100 C4.1)</td>
</tr>
<tr>
<td>( P_{n}=\min(P_{n,C4.2}, P_{n,C4.1}) )</td>
<td></td>
</tr>
</tbody>
</table>
\[ k_\phi = \frac{1}{k_{\phi W}} + \frac{1}{k_{\phi C}} \]

\[ k_{\phi W} = \frac{EI_w}{L_1} + \frac{EI_w}{L_2} \]

**Table B6-2**

<table>
<thead>
<tr>
<th>( t ) (mils)</th>
<th>( t ) (in.)</th>
<th>( k_c ) (lbf-in./lin./rad)</th>
<th>( k_c ) (N-mm/mm/rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>0.018</td>
<td>78</td>
<td>348</td>
</tr>
<tr>
<td>27</td>
<td>0.027</td>
<td>83</td>
<td>367</td>
</tr>
<tr>
<td>30</td>
<td>0.03</td>
<td>84</td>
<td>375</td>
</tr>
<tr>
<td>33</td>
<td>0.033</td>
<td>86</td>
<td>384</td>
</tr>
<tr>
<td>43</td>
<td>0.043</td>
<td>94</td>
<td>419</td>
</tr>
<tr>
<td>54</td>
<td>0.054</td>
<td>105</td>
<td>468</td>
</tr>
<tr>
<td>68</td>
<td>0.068</td>
<td>123</td>
<td>546</td>
</tr>
<tr>
<td>97</td>
<td>0.097</td>
<td>172</td>
<td>766</td>
</tr>
</tbody>
</table>

**Test**

(modify - AISI S901-08)
### Member Capacity

**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 ($P_{cr}$) (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)

**Strength – DSM – AISI-S100 App. 1**

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

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

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

- $P_n = \min(P_{sc}, P_{sd}, P_{cr})$

**Strength – Main Spec. – AISI-S100**

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

- **Local-Global ($P_{n}$)**
  - $P_n = A_n F_n$, $A_n = f(F_{cr})$, $F_n = f(F_c)$ (S100 C4.1)

- $P_n = \min(P_{n,C4.2}, P_{n,C4.1})$

---

**Determine springs to account for sheathing restraint**

- $k_x$ is determined from $k_{xd}$ and $k_{x,r}$
  - $k_{xd}$ – Diaphragm stiffness
    - Formula
    - Material Test for G (e.g., ASTM D2719-89)
  - $k_{x,r}$ – Local stiffness
    - Test
    - 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 – 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 ($F_{cr}$)**
  - Formula element only (AISI-S100 k’s in Ch. B)
Here is the classical method to find the global buckling load, used in our Spec.

\[ u = A_1 \sin \left( \frac{\pi z}{L} \right) \quad v = A_2 \sin \left( \frac{\pi z}{L} \right) \quad \phi = A_3 \sin \left( \frac{\pi z}{L} \right) \]

\[
\begin{bmatrix}
P_y & 0 & 0 \\
0 & P_x & 0 \\
0 & 0 & \left( I_o / A \right) P_\phi
\end{bmatrix}
- P
\begin{bmatrix}
1 & 0 & y_o \\
0 & 1 & -x_o \\
y_o & -x_o & \left( I_o / A \right)
\end{bmatrix}
\begin{bmatrix}
A_1 \\
A_2 \\
A_3
\end{bmatrix} = 0
\]

\[ P_y = \frac{\pi^2 EI_y}{L^2} \quad P_x = \frac{\pi^2 EI_x}{L^2} \quad P_\phi = \frac{A}{I_o} \left( GJ + \frac{\pi^2}{L^2} EC_w \right) \quad I_o = I_x + I_y + A \left( x_o^2 + y_o^2 \right) \]
\( P_{\text{cre}} \)

with springs added

Formulas updated with the inclusion of springs, Mathcad (maybe Excel) becomes only way

\[
\begin{align*}
\mathbf{A} & = \begin{pmatrix}
P_y & 0 & k_x L^2 \left( y_o - h_y \right) \\
0 & P_x & -k_y L^2 \left( x_o - h_x \right) \\
k_x \frac{L^2}{\pi^2} \left( y_o - h_y \right) & -k_y \frac{L^2}{\pi^2} \left( x_o - h_x \right) & I_o P_\phi + k_x \frac{L^2}{\pi^2} \left( y_o - h_y \right)^2 + k_y \frac{L^2}{\pi^2} \left( x_o - h_x \right)^2 + k_\phi \frac{L^2}{\pi^2}
\end{pmatrix}
\end{align*}
\]

\[
\left[ \begin{array}{cccc}
1 & 0 & y_o \\
0 & 1 & -x_o \\
y_o & -x_o & \left( I_o / A \right)
\end{array} \right]
= 0
\]

\[
\begin{align*}
P_y &= \frac{\pi^2 EI_y^2}{L^2} \\
P_x &= \frac{\pi^2 EI_x^2}{L^2} \\
P_\phi &= \frac{A}{I_o} \left( GJ + \frac{\pi^2}{L^2} EC_w \right) \\
I_o &= I_x + I_y + A \left( x_o^2 + y_o^2 \right)
\end{align*}
\]

Note, coupling of modes now happens due to geometry and due to springs
$P_{cre}$

Narrative calculation possible and completed – but involved – FSM makes more sense.
"KL" separation may require cFSM.

New to engineers, requires a few more inputs.
$P_{cre}$

ABAQUS/Shell FE
**Member Capacity**

---

**Determine springs to account for sheathing restraint**

- $k_x$ is determined from $k_{xd}$ and $k_{xt}$
  - $k_{xd}$ – Diaphragm stiffness
    - Formula
    - Material Test for $G$ (e.g., ASTM D2719-89)
  - $k_{xt}$ – Local stiffness
    - Test
    - Lowerbound formula (new – S210/211 or S100?)

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

- $k_z$ (AISI-S210-10)
  - Test
  - Formula (modify - AISI S901-08)

---

**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 \times D_{boost} (new – App.1 Commentary)
  - CUFSM 4 (new – App.1 Commentary)
  - FEM/ABAQUS

- **Local ($P_{cri}$) (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)

**Strength – DSM – AISI-S100 App. 1**

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

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

- **Local-Global ($P_{s}$)**
  - Formula (S100 Eq.1.2.1.2)
  - $P_{s} = \min(P_{se}, P_{sd}, P_{at})$

---

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

**Strength – Main Spec. – AISI-S100**

- **Distortional ($P_n$)**
  - Formula (S100 C4.2)

- **Local-Global ($P_n$)**
  - $P_n = A_e \cdot F_n, A_e = f(F_{cr}), F_n = f(F_c)$ (S100 C4.1)
  - $P_n = \min(P_n^{C4.2}, P_n^{C4.1})$
$P_{crd}$

**Formula (S100 C4.2)**

$$F_d = \frac{k_{\phi e} + k_{\phi we} + k_{\phi}}{\tilde{k}_{\phi fg} + \tilde{k}_{\phi wg}}$$

**CUFSM 3 × D_{boost}**

(new – App.1 Commentary)

$$D_{boost} = 1 + \frac{1}{2} \left( \frac{L_{crd}}{L} \right)^2$$

Approximately accounts for fixed ends on the increase in distortional buckling.
New to engineers, requires a few more inputs.
$P_{crd}$

ABAQUS/Shell FE
**Sheathed Walls Overview of Proposed Specification Changes/Additions (21 Feb 2011)**

### Member Capacity

**Determine springs to account for sheathing restraint**
- $k_x$ is determined from $k_{xd}$ and $k_{x,f}$
  - $k_{xd}$ – Diaphragm stiffness
    - Formula (new – S210/211 or S100?)
    - Material Test for $G$ (e.g., ASTM D2719-89)
  - $k_{x,f}$ – 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 ($P_{cre}$)**
  - Formula (S100 C4.2)
  - CUFSM 3 × $D_{boost}$ (new – App.1 Commentary)
  - CUFSM 4 (new – App.1 Commentary)
  - FEM/ABAQUS
- **Local ($P_{cre}$) (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 ($F_c$)**
  - Formula (new S100 – C4 formulas)
  - Rational Analysis (see DSM $F_c=P_{cre}/Ag$)
- **Distortional ($F_d$)**
  - Formula (S100 C4.2)
  - Rational Analysis (see DSM $F_d=P_{cre}/Ag$)
- **Local ($F_{cr}$)**
  - 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)
- $P_n=min(P_{ne}, P_{nd}, P_{n,f})$

### Strength – Main Spec. – AISI-S100

- **Distortional ($P_n$)**
  - Formula (S100 C4.2)
- **Local-Global ($P_n$)**
  - $P_n=A_eF_n, A_e=f(F_{cr}), F_n=f(F_c)$ (S100 C4.1)
  - $P_n=min(P_{n,C4.2,}, P_{n,C4.1})$