DEEPER STEEL DECK AND CELLULAR DIAPHRAGMS
Supplement to 2005 Paper

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INTRODUCTION

This paper supplements the paper, “Deeper Steel Deck and Cellular Diaphragms,” Luttrell (2005)\(^4\), which includes a method to calculate diaphragm stiffness for Cellular deck at Eq. 5. That analytical method was compared with existing tests. The 2005 paper fills a gap that exists in the “Diaphragm Design Manual, Third Edition,” Luttrell (2004)\(^3\), since cellular and deep decks had not been included in this and previous editions. Bagwell (2008)\(^1\) performed additional tests sponsored by the Steel Deck Institute (SDI) and the American Iron and Steel Institute (AISI) to reinforce the results presented in the 2005 paper and to verify the method.

Deeper and Cellular Deck testing has existed for years but the majority of earlier testing was: a) sponsored by industry, b) empirical, or c) proprietary. An analytical design method based on proprietary work was presented in “Seismic Design for Buildings” (commonly called the Tri Service Manual)\(^7\), which was first published in 1966. Many manufactures used this earlier manual to develop load tables for cellular deck prior to 2005.

This paper focuses on load sharing between the cellular deck elements and the general warping term in the diaphragm stiffness equation, which here is found to be several orders of magnitude smaller than is the warping in open corrugated diaphragms. This Supplement does four things:

a. Includes the impact of perforations in cellular deck,
b. Modifies the stiffness equation for cellular deck and provides a unified transition between solid and perforated cellular deck,
c. Includes Appendices, which compare tests with the revised theory and provides examples, and
d. Provides the limits of applicability.

The strength methods for deeper and cellular deck, and the stiffness method for deeper decks are unchanged. The paper, “Perforated Metal Deck Diaphragm Design”, Luttrell (2011)\(^5\), provides a method to calculate the impact of perforations over the acceptable range of fluted profiles for non-cellular diaphragms. The paper, “Perforated Metal Deck Design with Commentary”, Luttrell (2011)\(^6\), provides a method to calculate the impact of perforations over the acceptable range of fluted and cellular profiles for other structural applications.

Footnote superscripts within the text indicate reference documents where additional information can be found.
Cellular Deck Stiffness

Among other influences, cellular deck diaphragm shear stiffness will depend on what fraction of the total diaphragm shear force travels through the flat plate. The hat-shaped element has a greater shear width than the portion of flat plate immediately below it meaning the flat plate is the stiffer of the two when they are of equal thickness. Furthermore, the hat-shape will have some tendency to warp and roll over in shear if there are no transverse end closures. With flexibility in the hat-shape and with shear warping, the bottom closure plate tends to resist even more of the applied shear. The DDM3 shear stiffness Equation 3.3-3 was developed for open corrugated diaphragms in the form:

\[
G' = \frac{Et}{A_A + \phi D_n + C}
\]

(1)

where: \(A_A = 2.6(s/p)\)

- \(s\) = developed corrugated shear width per pitch
- \(p\) = corrugation or cell width
- \(\phi\) = purlin factor, 1 for single & dual spans; 0.9 for three spans; See DDM3 Sec 3.2.
- \(D_n\) = warping factor = \(D/\ell\) for non-cellular decks.
- \(D\) = warping characteristic of deck profile and fastener pattern, adjusted for units
- \(\ell\) = panel length
- \(C\) = slip coefficient
- \(t\) = top element (hat) base metal thickness
- \(E\) = modulus of elasticity

A decrease in magnitude of any denominator term will increase the stiffness, \(G'\). The stiffness is expressed in terms of the hat thickness but the pan effect is present. \(D_n\) measures the torsion warping relaxation of the open corrugated hat. Corrugated panels and flat sheets can be used to form a cellular deck profile. The units are welded to each other along the lower flange of the hat section forming cells with high torsional stiffness. The warping effect is dramatically reduced leading to a greater increase in shear stiffness for the panel. The C-term in Equation 1 is a measure of fastener relaxation, which depends on the panel thickness. Side lap connection properties depend on the element thickness at the fastener, which most often is that of the bottom panel.

When perforations are introduced in a flat element having a thickness, \(t\), shear introduces a displacement across a width, \(W\), that is \(\delta=(\tau/G)W\). \(G\) is the shear modulus and \(\tau\) is the shear stress. A band of perforations in the element will lower the shear stiffness in proportion to the reduction to the solid area as caused by the perforations5. The area reduction effect is easier to reflect through a modified or effective width approach. Detailed treatments of perforation effects are given in "Perforated Metal Deck Diaphragm Design", Luttrell5.
\[ \delta = \left[ W + W_p \left( \frac{1}{k} - 1 \right) \right] \frac{\tau}{G} \]  

(2)

where: 
- \( k \) = perforation reduction factor
- \( W_p \) = perforation strip width within \( W \)

Figure 1 is used to illustrate the effects of a shear load, \( P \), where the resistance to that load is from more than one element. The a-side at the left is different in width from the b-side at the right. The b-side contains a perforated band of width, \( b_p \), extending fully across the depth, \( L \).

![Figure 1 Shear distribution within non-symmetric systems.](image)

From equilibrium considerations, the end reactions are determined as follows.

\[ P_1 = \frac{b}{a+b} P \]  

(3)

\[ P_2 = \frac{a}{a+b} P \]  

(4)

The \( b_p \) wide dotted strip represents a band of perforations. These perforations reduce the shear stiffness on the right and the shear strain line will not have a uniform slope along the \( \gamma_b \) line.

From the right end, an equivalent width, \( S_{eb} \), is introduced to account for the perforations. The shear strain is \( \tau/G \) outside the perforated zone and is \( \tau/(kG) \) inside the perforated zone. \( k \) is a perforation factor. The the deflection, \( \Delta \), can be established from either side as follows:
From the left:  \[ \Delta = \frac{\tau}{G} a = \frac{P_1}{G L_t} a \]  (5)

From the right:  \[ \Delta = \frac{P_2}{G L_t_b} \left[ b + b_p \left( \frac{1}{k} - 1 \right) \right] \]  (6)

where:  
- \( t \) is the thickness over the a-width  
- \( t_b \) is the thickness over the b-width

note: \( \Delta \) is independent of the location of \( b_p \) within \( b \).

Define \( S_{eb} \) as the effective width of the b-wide unit with a \( b_p \) wide perforated strip:

\[ S_{eb} = b + b_p \left( \frac{1}{k} - 1 \right) \]  (7)

\( S_e \) is a similar term for the left side. Though no left-side perforated strip is indicated in Figure 1, such is not excluded. The left-side effective width is as follows and equal to \( a \) when \( a_p = 0 \):

\[ S_e = a + a_p \left( \frac{1}{k} - 1 \right) \]  (8)

After substituting \( S_e \) or \( S_{eb} \), Equation 5 and Equation 6 are used to find the \( P_1 \) value as a fraction of the total shear load, \( P \):

\[ P_2 = P_1 \frac{t_b}{t} \frac{S_e}{S_{eb}} \]  (9)

The total applied load is:

\[ P = P_1 + P_2 = P_1 \left( 1 + \frac{t_b}{t} \frac{S_e}{S_{eb}} \right) \]  (10)

And the fraction of the load acting across the a-side is:

\[ P_1 = \frac{P}{1 + \frac{t_b}{t} \frac{S_e}{S_{eb}}} \]  (11)

Rearranging terms leads to:
\[
\frac{P_1}{P} = \frac{tS_{eb}}{tS_{eb} + t_bS_e} = \frac{1}{1 + \frac{t_bS_e}{tS_{eb}}} 
\]  

(12)

Some numerical boundary checks are:

1. With \( S_e = S_{eb} = 1 \) and with equal thicknesses, \( t_b = t \), a symmetric system is described with \( P_1 = P/2 \) and this is OK.
2. With \( S_e = S_{eb} = 1 \) and \( t_b = 2t \), \( P_1 = P/(1+2) = P/3 \). The b-side is stiffer. OK
3. With \( S_{eb} = 2S_e \) and \( t_b = t \), \( P_1 = P/(1+0.5) = 0.67P \). OK

The \( D_n \) warping term of Equation 1 represents an open corrugated tube or hat-shaped tube with low torsional resistance relative to a similar closed tube unit. Consider a closed thin-wall tube having a radius at mid-wall thickness of \( R \) with properties listed in Figure 2.

The \( \phi \) term is the twist per unit length developing from the torque, \( T \). Figure 2 E is for a closed tube with an inverse polar moment of inertia coefficient, \( 1/(2\pi r^3) \). For the Figure 2 D open tube, there is a multiplier, \( 3r^2/t^2 \). Suppose \( t = 0.03" \) and \( r = 3" \) the multiplier becomes 30,000 meaning that the open tube is 30,000 times more flexible in this specific case. The same general argument holds for open or closed rectangular tubes and open or closed corrugated deck panels. Closed deck cells will exhibit no discernable twist and the \( D_n \) term in Equation 1 will vanish for cellular deck as shown in Equation 13.

Note that the Figure 1 solution is for systems in shear and that other alignment forces exist to maintain the P-force in a vertical path. Indeed, the above is a model of the system in Figure 3.
Figure 3. Cellular Deck Model.

Figure 3 represents a hat-shaped top unit affixed to a lower flat plate by spot welds along each lower flat of the cell such that both units exhibit exactly the same shear deflection along the right side. The total P-shear is then shared between the two elements according to their shear stiffness.

Note that, if this unit were mathematically opened up about a left side hinge and the hat unit flattened out, the conditions would be modeled by Figure 1 where \( a = W_b + 2W_w + W_t \). \( W_b, W_w, \) and \( W_t \) represent the bottom, web, and top dimensions of the hat.

The fraction, \( P_1 \) of the total load, \( P \), is described in Equation 12 and it can have a major impact on the stiffness as described in the modification of Equation 1 shown below.

\[
G' = \frac{E_t}{A_A + C}
\]  

(13)

The \( A_A \) term is related to shear strain in the top unit as if all the shear moves through the hat. Obviously it does not. Of the total shear applied, represented by \( P \), only that part described by Equation 12, goes through the hat. In the original paper, "Deeper Steel Deck and Cellular Diaphragms", Luttrell\(^4\), the case for a 2 in. deep roof deck with an 8 in. pitch was presented where the \( A_A \) term was \( 2.6(s/p) = 3.90 \). The paper's modifications reduced that to 1.56 representing the plate's effect when the plate and hat had the same thickness. The current consideration of using a proportioned load, Equation 12, has \( S_e = 12 \) in. and \( S_{eb} = 8 \) in., which leads to \( P_1 = 0.40P \) and \( A_A = 3.90(0.40) = 1.56 \), the same value as the original paper for a non-perforated application. But the current approach has the advantage of having the perforation influence built into the formulas.
A fluted element is shown in Figure 4 where the top part is flat and defines a rectangle a-b wide and a-a' long. This rectangle is part of a thin-wall assembly that has vertical web elements, running the full length of the system and connecting to narrow flat elements at the bottom. With p-dimension being the corrugation width and distance between welds in deck bottoms, Figure 4 can represent part of a steel roof deck panel where an end view may lead to the description, hat shaped. Finally, the ends are closed with transverse diaphragms as indicated by the hash-marked trapezoid below the a-b line.

The Figure 4 assembly is attached to structural support members that deliver a shear force, P, to the edge of the hat shaped unit. The force produces a shear stress $\tau = P/Lt$ where L is the length and t is the assembly wall thickness. An opposing parallel force, P, acts at the far side of the unit leading to a couple. End shear forces at the base of the transverse diaphragms stabilize the assembly. The P-load produces only shear stresses in the hat.

The sum of the panel element widths per corrugation width, p, is the sum of five parts: $S_e = W_t + 2W_w + 2E$ representing the top, webs, and bottom elements respectively. P then produces a shear deflection requiring shear stiffness developed as follows.

$$G' = Gt = \frac{\tau t}{\gamma}$$

(14)

With diaphragm of width a, the shear strain is defined as $\gamma = \Delta_s/a$ leading to $G' = (Pa/L)/\Delta_s$. Since $G = E/(2(1+\nu))$, the pure shear deflection per width, a, adjusted for the shear path through the hat is:
\[ \Delta_s = \frac{Pa}{L} \frac{2(1+\nu)}{Et} \frac{S_e}{p} \]  

(15)

The \( S_e/p \) multiplier indicates the developed shear width per corrugation pitch, \( p \). Equation 8 will define \( S_e \) when perforations are present but perforations in cellular deck top hat units are not typical.

If the transverse end diaphragms were removed while maintaining the shear load, the Figure 4 a-b line would shift to the left and line a'-b' to the right resulting in a small increase in the shear displacement.

\[ \Delta = \Delta_s + \Delta_w \]  

(16)

The Figure 4 assembly can be made into a cellular unit by attaching a flat closure plate below the bottom flanges. The upper and lower components will then share the shear load, \( P \), as was illustrated in Figure 3. The free body of Figure 5 shows the webs and top flat element of a cellular assembly where external loads have produced a shear force, \( \tau_t \). A similar opposing shear exists at the far side. The \( P' \) and \( H \) forces are internal and shown for illustrative purposes. For a top flat element of width, \( W_t \), and length, \( L \), equilibrium requires \( H = P'(L/W_t) \).

Figure 5. Upper free body.

Removal of the end closures places both \( P' \) and \( H \) at zero permitting small increases in the deflection, \( \Delta_w \). This increase is limited by shear deflections in the bottom plate already contained in the \( A_A \) term of Equation 1.

Two views of warping influences are contained in Figures 6 and 7 from Virginia Tech Studies, Bagwell (2008). The first shows an open corrugated deck diaphragm under advanced shear loading. It is clear that adjacent flange elements have significant relative movement associated with panel end warping and imposed shear forces. The second view is for a cellular
diaphragm at maximum load where the lower flat plate has limited diaphragm shear deflection and rendered the warping effect invisible.

Figure 6. View of end warping in open corrugated section.

Figure 7. Negligible end warping in deep cellular section at ultimate shear.
Recommendations

Based on the above discussions and on observations from cellular diaphragm tests, it is found that the warping term in the Equation 1 denominator is substantially zero. Therefore it is recommended that Equation 1 be reformed as follows:

\[ G' = \frac{E_t}{A_{A} + C} \]  

(17)

With consideration of the shear sharing between the top element and bottom plate, the \( t \) term in the numerator of Equation 17 is the top element thickness and the \( A_{A} \) term in the denominator is:

\[ A_{A} = \frac{2.6 \left( \frac{s}{p} \right)}{1 + \left( \frac{s}{w_{d}} \right) \frac{t_{b}}{t}} \]  

(18)

where: The terms are defined below Equation 1 with the following refinements

- \( s \) = developed width of the cell top hat adjusted for perforations in accordance with the method of Equation 8
- \( p \) = corrugation or cell top hat pitch
- \( w_{d} \) = width of the cell measured between the fastener lines in the cellular deck adjusted for perforations in the bottom plate in accordance with the method of Equation 8
- \( t \) = thickness of cell top hat
- \( t_{b} \) = thickness of bottom plate

Appendix 2 evaluates the ratio, \( G'_{\text{test}}/G'_{\text{theory}} \), using Equation (17) and provides an average value of 0.96 for 32 tests. The tests covered a broad range of profile depths, spans, thickness combinations, connection types, and number of connections. The average and scatter for these tests are consistent with Equation 1 as reported in Steel Deck Institute Diaphragm Design Manual, First Edition Luttrell (1981)\(^2\) however the cellular deck outliers were greater than those reported in 1981.

Application Limits

The limits of applicability in “Diaphragm Design Manual, Third Edition,” Luttrell (2004)\(^3\), apply to cellular deck with the following additional limitations:

1. Cellular deck depth less than or equal to 7.5 in.
2. Combined top and bottom deck thickness less than or equal to 0.155 in.
3. Thickness of each element greater than or equal to 0.035 in.
4. Top element pitch less than or equal to 12 in.
5. Bottom element that is nominally a flat plate with or without stiffeners
This does not preclude application of the theory to products outside of these limits in designs, which are verified by tests.

References

Example 1

Calculate the Stiffness of Cellular Deck
(Figure shows perforations in all flats. This is possible but is not requisite and is not the norm. Perforations are far more common in the bottom plate only.)

\[
G' = \frac{Et}{A_A + C} \\
A_A = \frac{2.6 \frac{s_{et}}{p}}{1 + \left(\frac{s_{et}}{s_{eb}}\right) \frac{t_b}{t}} \\
C = \left(\frac{Et}{w}\right) \left(\frac{2L}{2\alpha_1 + n_p \alpha_2 + 2n_s \frac{S_f}{S_s}}\right)
\]

DATA

<table>
<thead>
<tr>
<th>Material</th>
<th>(F_y) (ksi)</th>
<th>(p_o)</th>
<th>(p_o) = Perf. area percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hat Thickness</td>
<td>(t = 0.0474)</td>
<td>(W_t = 8.50)</td>
<td>within band as decimal</td>
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<tr>
<td>Bottom Thickness</td>
<td>(t_b = 0.0598)</td>
<td>(W_{tp} = 8.00)</td>
<td>Band widths are arbitrary to illustrate the method</td>
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<td>Hat Depth</td>
<td>(D = 6)</td>
<td>(W_b = 3.03)</td>
<td>All elements - same hole pattern</td>
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<td>Inside Radius</td>
<td>(R_i = 0.1875)</td>
<td>(W_{bp} = 7.50)</td>
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</tr>
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<td>Cover Width</td>
<td>(w = 24)</td>
<td>(W_w = 5.58)</td>
<td>Perf. centered in flat element</td>
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<tr>
<td>Pitch</td>
<td>(p = 12)</td>
<td>(W_{wp} = 5.00)</td>
<td>No perforations at corners</td>
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</tbody>
</table>

\[
k_e = 1 - 2.175p_o \quad \text{for} \quad p_o < 0.2 \\
k_e = 0.9 + p_o^2 + 1.875p_o \quad \text{for} \quad 0.2 \leq p_o \leq 0.58 \\
k_e = 0.565
\]
Determine the contribution of shear strain in the material to diaphragm deflection considering shear sharing between the top and bottom elements -- $A_A$

\[
s_{et} = \text{Developed width of top element adjusted for perforations.}
\]
\[
s_{eb} = \text{Width of bott. plate between cellular deck connections adjusted for perfs.}
\]
\[
w_d = 10.470 \text{ in.}
\]
\[
w_{eb} = 16.244 \text{ in.}
\]
\[
w_{et} = 37.170 \text{ in.}
\]
\[
\text{Note: } 1.5" \text{ is an allowance for total distance from webs to cellular deck connections}
\]
The shear strain in the bott. plate between connectors is partly covered by the ratio: $s_{et}/p$

\[
A_A = 2.072
\]

If there are no perforations in the top hat or bottom plate, $A_A = 1.312$ Ratio: 0.63

Determine the contribution of side lap slippage to diaphragm deflection -- $C$

Consider the following diaphragm construction to define a particular $C$:

**Shear Span, $L_{v}$ (ft) = 16**

**Number spans = 2**

**Total panel length, $L_r$ (ft) = 32**

![Diaphragm Construction Diagram]

See DDM03 for definitions and tabulation (page AIV-7): $\alpha_1, \alpha_2, S_f, S_s, n_p$ and $n_s$

\[
\alpha_1 = 1 \quad \alpha_2 = 1
\]

If want more precise determination:

\[
\alpha_1 = \left(\frac{2*11.25+0}{24}\right) = 0.9375
\]

\[
\alpha_2 = \left(\frac{2*11.25+0}{24}\right) = 0.9375
\]

**Fastener Schedule:**

**Support**

- Type = # 12 screws
- Pattern = 24/3

**Side lap**

- Type = Button Punch
- Spacing = 24 in.
- Over Supports = Yes

Although it is possible that screw will only be through $t_b$ at the center, use the total thickness $(t + t_b)$ to determine $S_t$.

\[
S_f = 1.3/\left(1000\sqrt{t + t_b}\right)
\]

\[
S_s = 30/\left(1000\sqrt{t_b}\right)
\]

**Use in Calcs**

**Fasteners are not in perforated zone**

Number of side lap fasteners along panel length, $L$. $n_s = 17$ $n_p = 1$

$C = 45.404$ Note: $C$ is unitless so $L$ has to be converted to inches.

Slip (C) dominates stiffness and deflection.

**Perf:** $G' = 29.5$ kips/in

**If no perfs in top hat or in bott. plate:**

$G' = 29.9$ kips/in Ratio: 0.985

**Results:** Not much difference in this case since slippage ($C$) dominates. $C >> A_A$
Example 2

Calculate the Stiffness of Cellular Deck

Do the same problem as Example 1 but revise the fastener schedule so side lap slippage does not totally dominate -- use welds at side lap and supports.

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<th>Fastener Schedule</th>
<th>Support</th>
<th>Side lap</th>
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<tbody>
<tr>
<td>Type = 3/4&quot; ø arc spot</td>
<td>Type $L_w$ (in.)= 1.50 arc seam weld</td>
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<tr>
<td>Pattern = 24/3 weld</td>
<td>Spacing = 24 in. o. c.</td>
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<tr>
<td>Over Supports = Yes</td>
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<td></td>
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</tbody>
</table>

$A_A = 2.072$

$\alpha_1 = 0.9375$

$n_b = 17$

$\alpha_2 = 0.9375$

$n_p = 1$

Total panel length, $L_r$ (ft) = 32

$s_f = 1.15 \left( \frac{1000 \sqrt{t + t_b}}{1.5} \right)^{0.25}$

$s_s = 1.12 \left( \frac{L_w}{1000 \sqrt{t_b}} \right)$

$C = \left( \frac{E_t}{w} \right) \left( \frac{2L}{2\alpha_1 + n_p \alpha_2 + 2n_s \frac{s_f}{s_s}} \right) S_f$

$G' = \frac{E_t}{A_A + C}$

No Perforations in Top and Bottom

$A_A = 1.312$

$C = 5.441$

$G' = 186.1$ kips/in

$\Delta G' = 207.1 - 186.1 = 21.0$

Results: In this case with $A_A/C = 0.24$, the perforations reduce the stiffness by 10%. This is an unusual case with perforations over most of the width of all elements. This impact is relatively minor.

Do the same problem as Example 2 but with no perforations in the top hat while perforations are in the bottom plate. This application is quite common.

No Perforations in Top and Perforations in Bottom

$A_A = 1.772$

$C = 5.441$

$G' = 193.9$ kips/in

$s_{et} = 22.422$ in.

$\Delta G' = 207.1 - 193.9 = 13.2$

Results: In this case with $A_A/C = 0.33$, the bottom perforations reduce the stiffness by 6.4%. The impact is relatively minor.
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Note: Shaded Results are repeat tests. TS = Top Seam Weld  
BP = Button Punch 
S_s for TS welds is based on Nunna (2012). Other flexibilities are taken from DDM03, Luttrell (2004).
Calibration of Cellular Deck Stiffness Equation Using Luttrell Report Data Listed in Table A2-1

Table A2-2 Calibration

<table>
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<th>Test Number</th>
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<th>s</th>
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<th>( A_\lambda )</th>
<th>C</th>
<th>( G'_\text{theory} )</th>
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<th>( (R_i - m)^2 )</th>
<th>( R_m )</th>
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All test = single span  \( n_p = 0 \)

\( \alpha_2 = 0 \)

\[
R_i = \frac{G'_{\text{test}}}{G'_{\text{theory}}}
\]

\[
R_m = \frac{\Sigma R_i}{n}
\]

\[
G' = \frac{E_t}{A_{\lambda} + C}
\]

\[
A_{\lambda} = \frac{2.6 \left( \frac{s}{p} \right)}{1 + \left( \frac{s}{w_d} \right)^{\frac{1}{2}}}
\]

\[
C = \left( \frac{E_t}{w} \right) \left( \frac{2L}{2a_i + n_p a_2 + 2n_s S_f S_s} \right)
\]

\[
R_m = 1.118 \quad \Sigma = 4.203
\]

Note:  \( s \) in numerator of \( G' \) is top element thickness

Shaded areas are outliers that skew results.

Average of all TS is 0.908; average of all BP is 1.422.  Each set has values either side of 1.0.  Average of all is 1.118.

\( R_m \) is consistent with the results of identical tests - 322/230 = 1.4, 276/205 = 1.35, 218/191 = 1.14, and 119/109 = 1.09.

\( \text{Coefficient of variation. See Commentary of AISI Specification Section F1.1.} \)
## Calibration of Cellular Deck Stiffness Equation Using Bagwell Report Data Listed in Table A2-3

### Table A2-3 Summary of Bagwell 2008 Report Data Based on Corner Deflections

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<tr>
<th>Test Number</th>
<th>Source</th>
<th>Number Type</th>
<th>Top Depth</th>
<th>Pitch</th>
<th>Bottom Depth</th>
<th>Cover</th>
<th>Support Pattern</th>
<th>Side-lap Type</th>
<th>Spacing</th>
<th>t + t₀</th>
<th>t₀</th>
<th>Sₖ</th>
<th>Sₛ</th>
<th>Flexibility - in/kip</th>
<th>Span ft</th>
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<td>USD 18/18</td>
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### Calibration of Cellular Deck Stiffness Equation Using Bagwell Report Data Listed in Table A2-3

#### Table A2-4 Calibration

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<th>Elements - in.</th>
<th>Fastener Schedule</th>
<th>Flexibility - in/kip</th>
<th>Span ft</th>
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**Note:** #12, #10 = Screw

**Hilti = X-ENP-19 L15 BP = Button Punch**

Bagwell report has apparent discrepancy at Tests 16, 19; the reported thickness does not agree with nomenclature and connection strength back calculation. The thickness in calibration is most probable answer.

USD side lap is unique. Sₖ should be based on the average of t₀ and t + t₀ and Sₛ on t₀. VC Sₖ is based on t+t₀ and Sₛ on t₀.

Total Tests = n = 10

All test = single span  nₙ = 0  α₂ = 0

Shaded areas are outliers that skew results.

\[ R_m = \frac{0.626}{\Sigma} = 0.859 \]

\[ V_p = 0.49 \]
### Table A2-5 Calibration of All Cellular Deck Stiffness Data

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<th>G''_theory kip/in.</th>
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\[ R_m = 0.964 \quad \Sigma = 6.733 \quad V_p = 0.483 \]

**Cellular Deck Stiffness Data**

**Comments:**

Data covers a wide range of configurations varying: span, thickness combination, connection type, and number of side lap connections. Each side lap connection sub-set has data either side of 1.0.

Greatest scatter occurs at BP but most BP tests are conservative - Test > Theory.

The Bagwell tests generally are not conservative even with screws but Bagwell also measured diagonal readings, which is allowed by AISI S907.

When diagonal readings are used, the average of tests, \( R_{av} \), changed from 0.63 to 1.92 for all and from 0.72 to 2.32 for screws. This confirms that accurate measurement of deflection is both difficult and essential. Historical testing used corner readings.

The scatter of the cellular deck stiffness equation (84% > 0.6) is consistent with DDM01 Luttrell (1981), which ranged between 0.61 and 1.41.

The proposed stiffness method is reasonable.