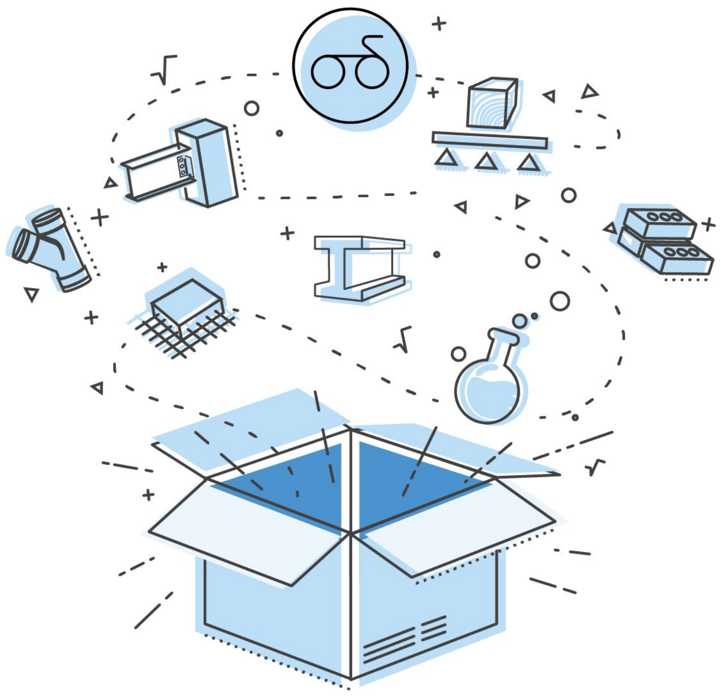
The Direct Strength Method

In Cold-Formed Steel Design



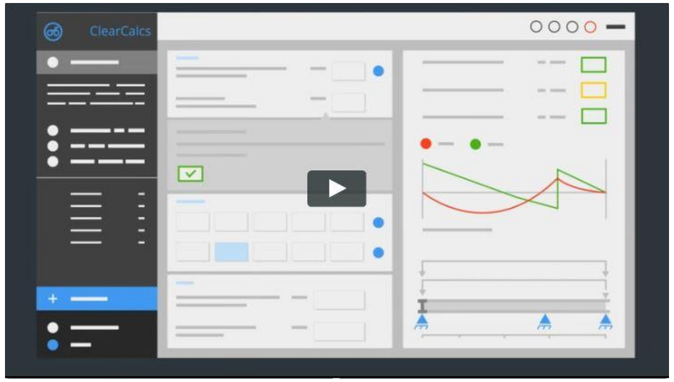
Brooks H. Smith, CPEng, P.E.
brooks.smith@clearcalcs.com

ClearCalcs

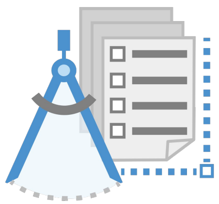
About ClearCalcs.com

ClearCalcs helps engineers design without compromise by bringing together powerful FEA analysis with easy to use design tools for concrete, steel, cold-formed steel and timber.

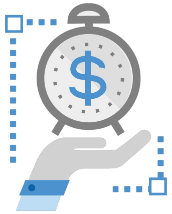
Explore our range at clearcalcs.com



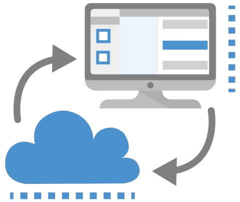
Intro Video Hyperlink



More Accurate
Design more accurately with unrestricted and accessible FEA analysis



Eliminates Wasted Time
Eliminate time wasted using clunky methods or waiting for software licenses to free up



Available Everywhere
Empower engineers to work effectively from office, home, or site

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Meet the Presenter

- **Brooks H. Smith | Head of Engineering R&D**
  - Chartered Professional Engineer (AU) & P.E. (USA)
    - MCivE from University of Massachusetts
    - BEng from Dartmouth College
  - 8 years of previous experience in:
    - Structural engineering R&D consulting, specialising in cold-formed steel
    - Research fellowship in system behaviour of thin-walled steel
    - Forensic structural engineering, specialising in reinforced and PT concrete
  - Almost 5 years now with ClearCalcs
    - Focusing on R&D and QA

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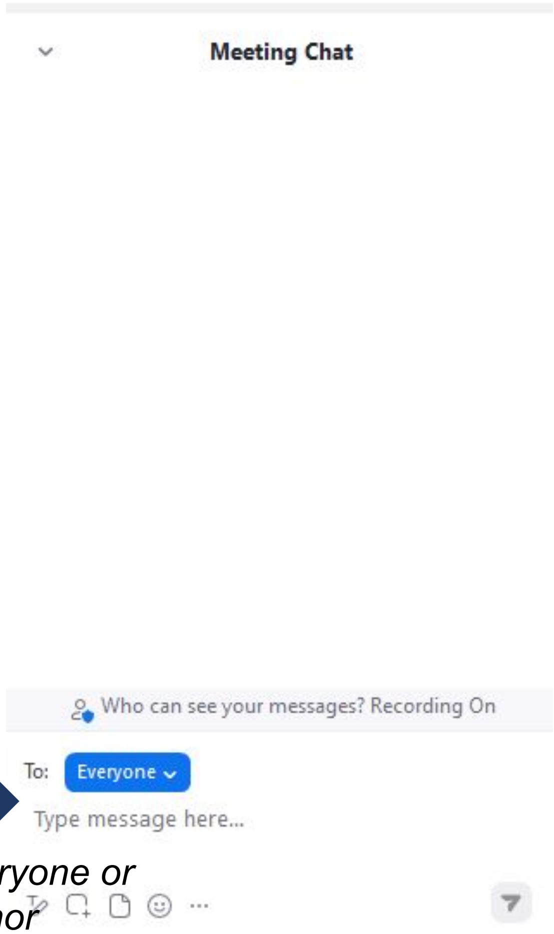
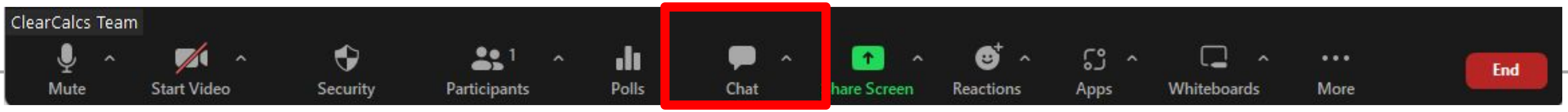
How to Ask Questions

- **Type your questions in the Chat tab on your Zoom control panel and click Send**
  - Please send your questions to everyone
  - We will address all questions in the second half of the webinar during the 15-minute Q&A session
  - We might invite you to unmute yourself to ask your question live!



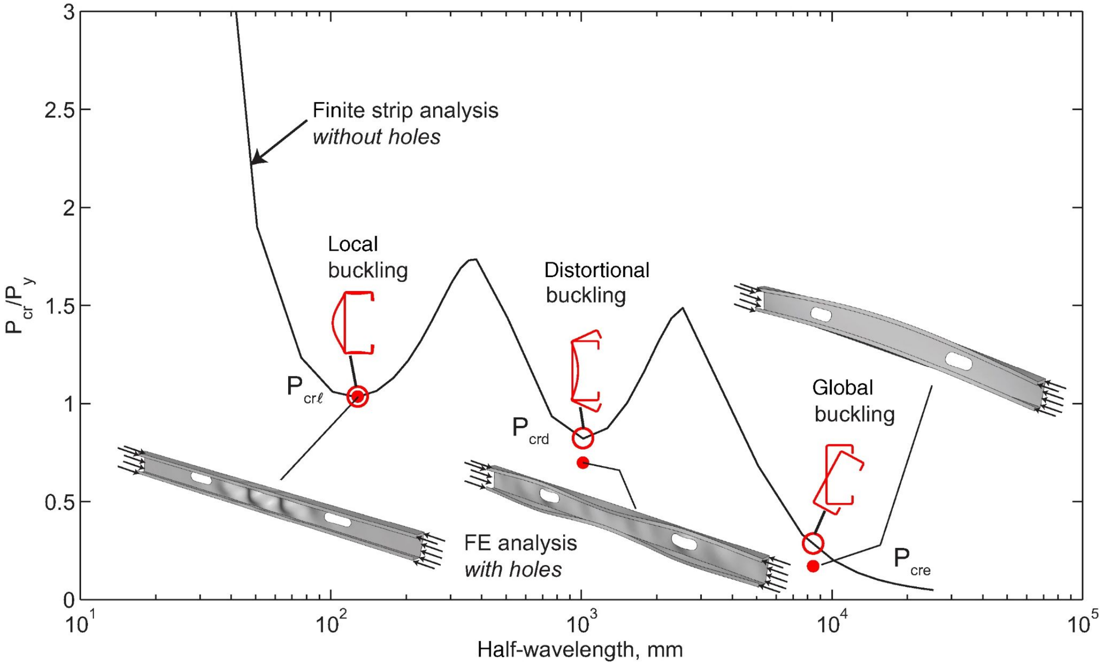
Ask your questions here

You can send to everyone or directly to Connor



Agenda – Today's Goals

- **Theory on the Direct Strength Method**
  - DSM vs Effective Width Method
  - Finite Strip Method
- **Practically Using DSM**
  - Keeping Finite Strip Method Simple
  - Using DSM in AS/NZS 4600:2018
- **Demonstration in ClearCalcs**
  - Just the Design
  - Doing a Finite Strip Method Analysis



Theory on the Direct Strength Method

Comparing with the Effective Width Method, and doing a finite strip analysis

Buckling in Cold-Formed Steel

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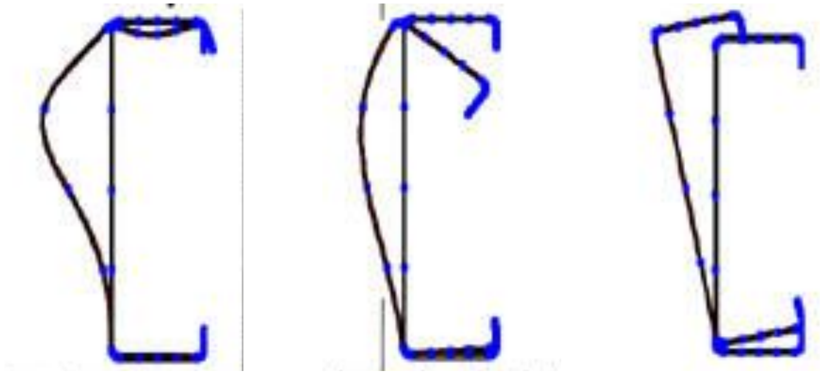
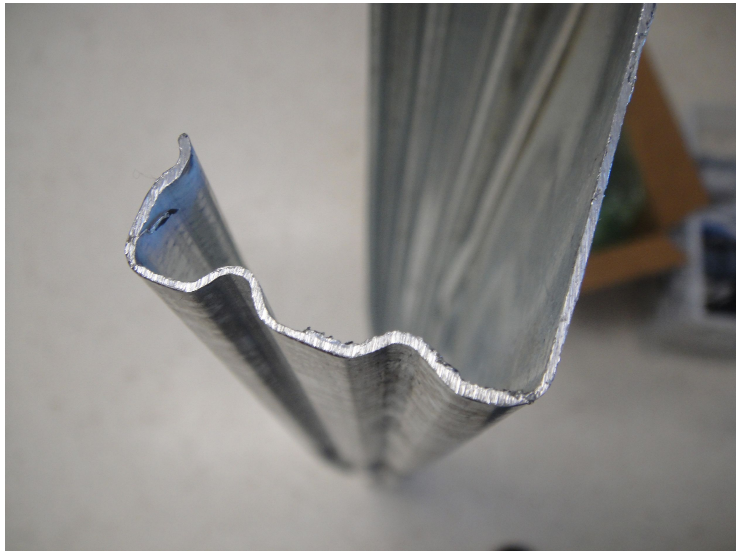
- Hot-rolled steel classifies sections as compact, non-compact, or slender – and requires extra equations for "slender"
  - In cold-formed steel, "slender" checks basically always need to be done
- Local, distortional, or global buckling for bending or compression
  - Global encompasses both lateral and torsional buckling
- Stiffeners function to mitigate buckling





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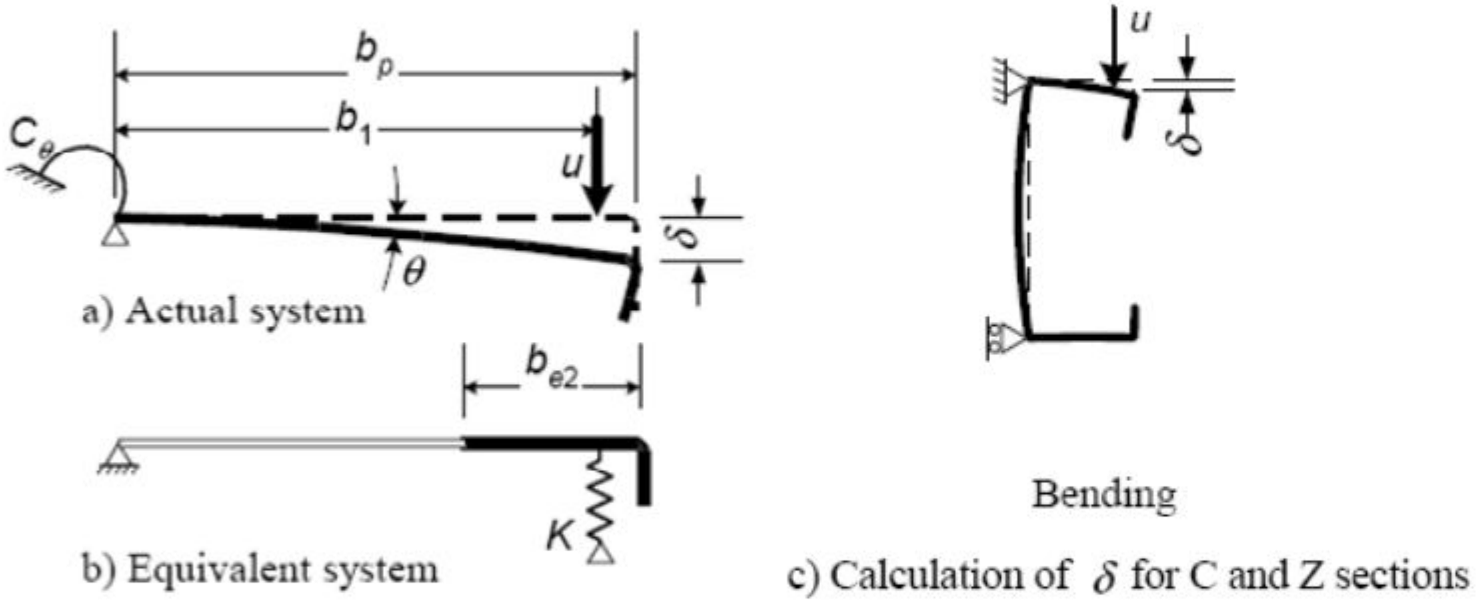
Old Method - Effective Width

- At its most basic, accounts for buckling by pretending that each 'plate' within an element is shorter than it really is
  - More susceptibility to buckling = shorter 'effective width'
- Separate equations for local vs distortional vs global buckling



New Method - Direct Strength

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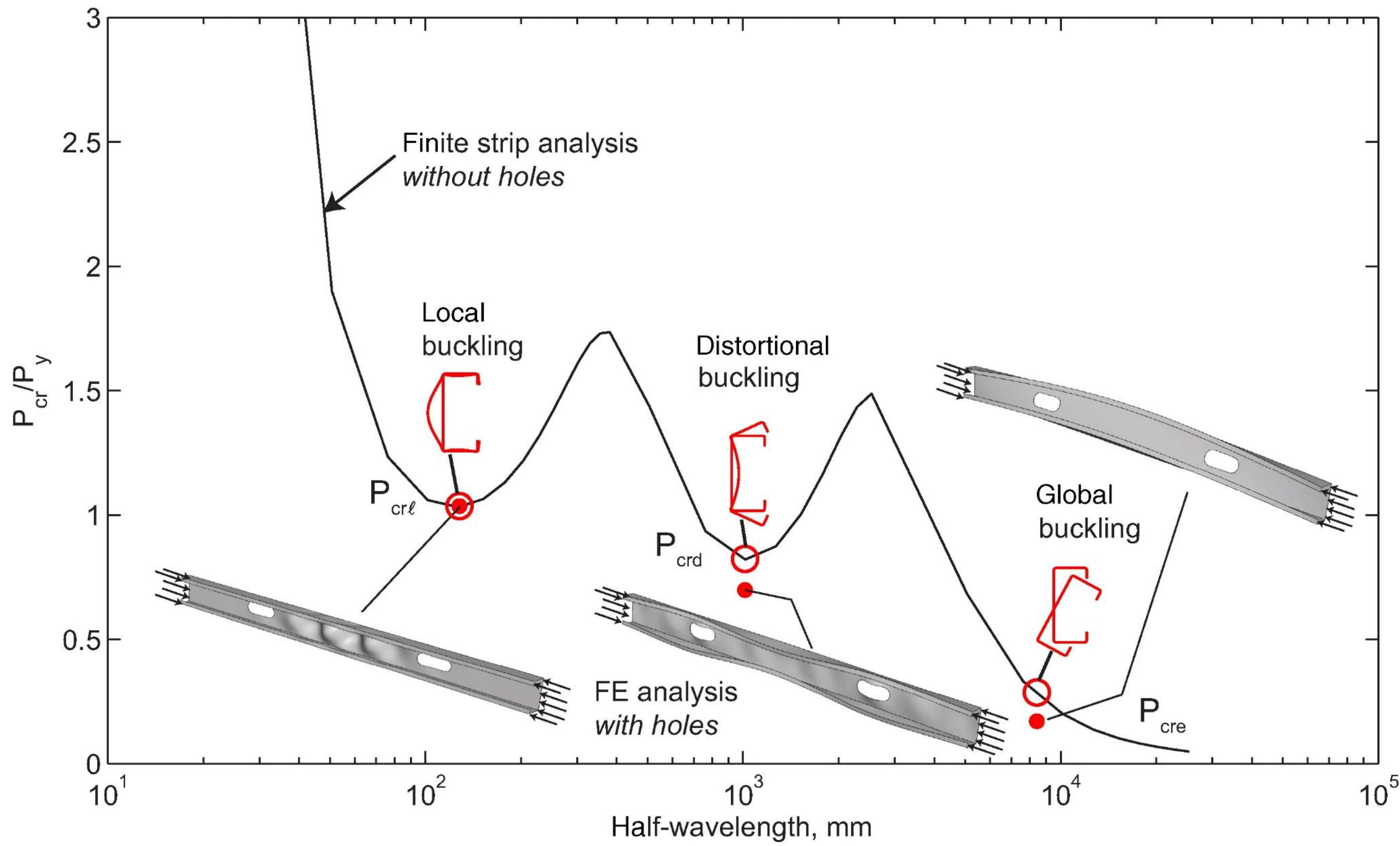
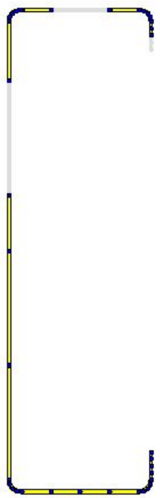
- Directly consider the strength and stiffness of the cross-section *as a whole*
- Consider every half-wavelength for buckling susceptibility
- Every type of buckling in one unified method

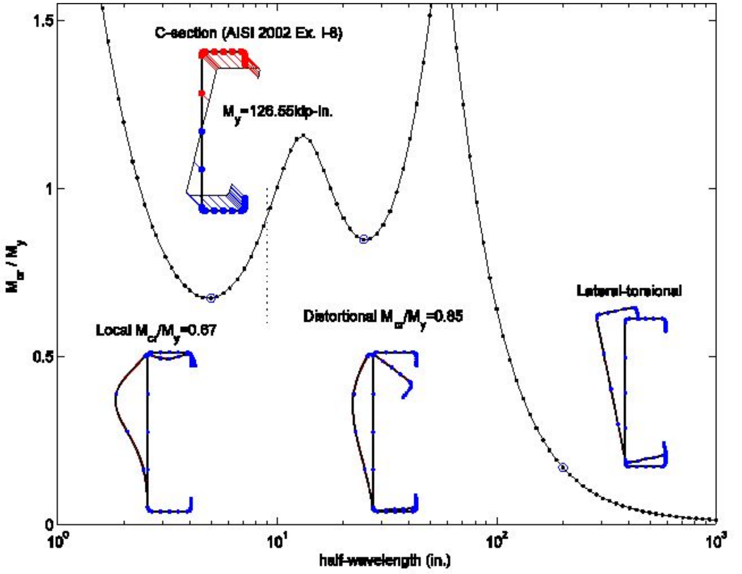


EWM vs DSM: Why Switch?

- More flexible: EWM is a PIA for complex sections/many plates
  - But every section is exactly as much work for you in DSM!
- More accurate: DSM is will give you up to ~10% more capacity
- Easier calculations: Maths mostly done by finite strip analysis



effective section of
-section in bending



(b) semi-analytical finite strip solution of a C-section in bending
showing local, distortional and lateral-torsional buckling

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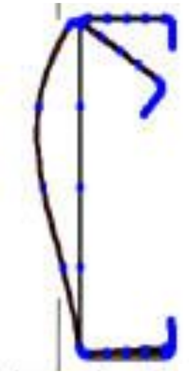
Interjection: Buckling Modes

- **Local Buckling:** corners of the cross-section stay still, while the flat plates bend
  - Usually occurs at a half-wavelength of about 100-250 mm

- **Distortional Buckling:** corners of the cross-section move, but not all corners move together
  - Usually occurs at a half-wavelength of about 400-800 mm



- **Global Buckling:** whole cross-section rotates or translates as a single unit
  - Usually occurs at a half-wavelength greater than ~1.5 m

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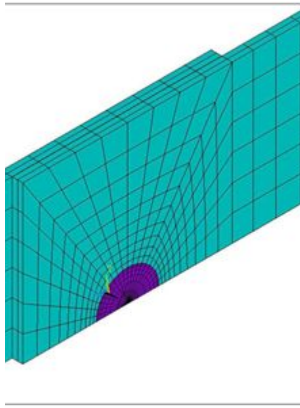
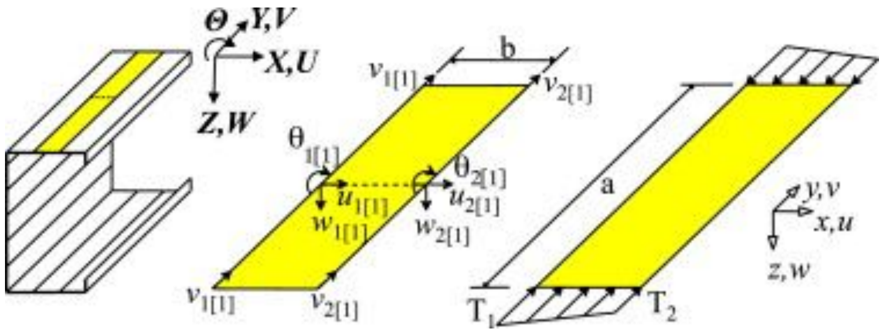
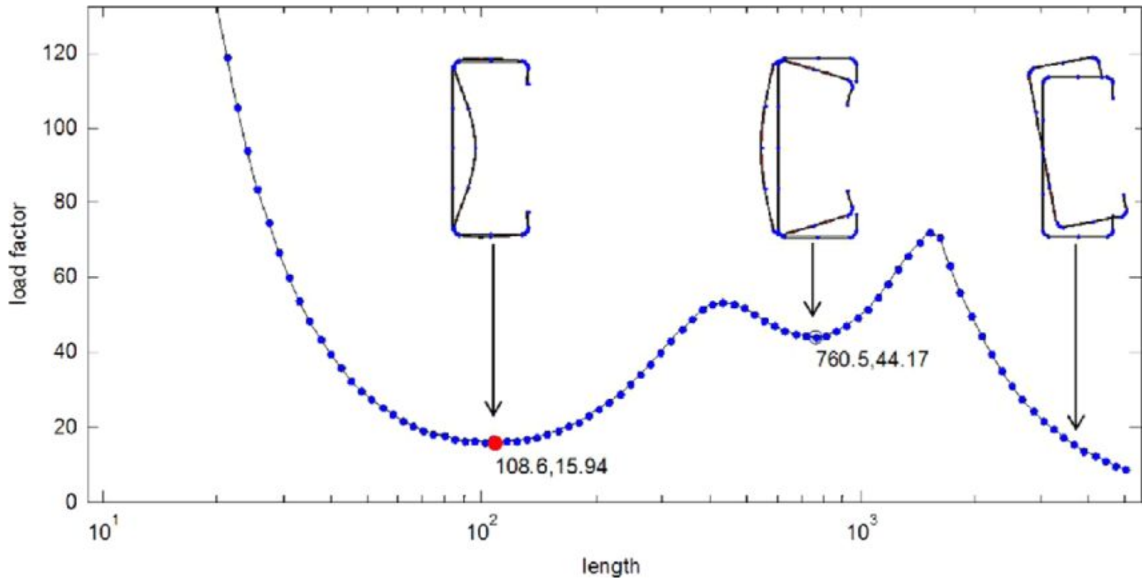
What is the Finite Strip Method?



- The Direct Strength Method requires a rational analysis that usually takes the form of the Finite Strip Method
  - Instead of finite elements of little triangles or rectangles, we have entire *strips* of arbitrary length
  - All buckling modes



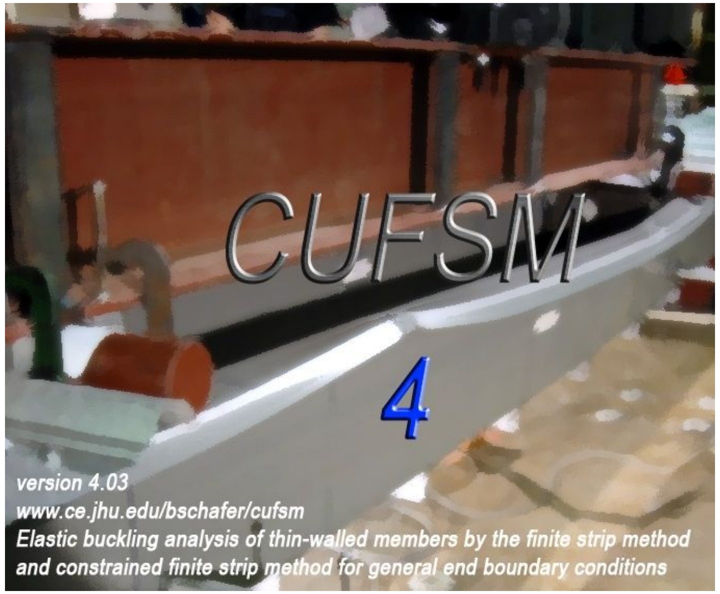
https://doi.org/10.1016/j.tws.2013.09.004



https://dx.doi.org/10.1016/j.tws.2014.01.005

Finite Strip Software

- A couple main pieces of software available:
  - CUFSM (free), from Johns Hopkins University
    - pyCUFSM (free), ported to Python by Brooks Smith
  - THIN-WALL (paid), from the University of Sydney



THE UNIVERSITY OF SYDNEY

Centre for Advanced Structural Engineering
THIN-WALL

Finite Strip - Signature Curves

- Commentary to the US's [AISI S100 standard]() is very helpful (and free!)
  - AS/NZS 4600's DSM section is almost verbatim copied from AISI S100
  - It's just in Imperial instead of Metric units!

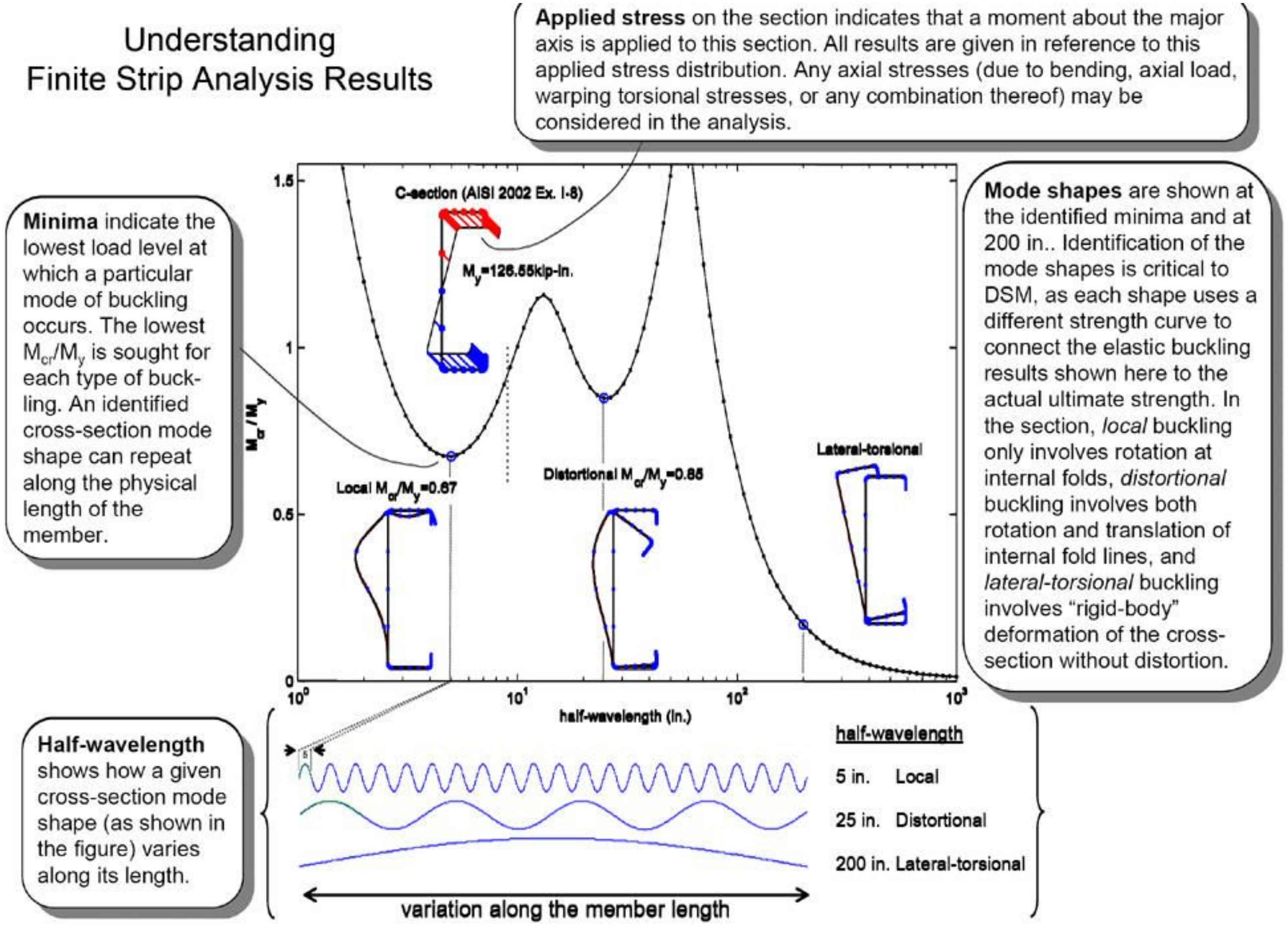


Figure 2 Understanding Finite Strip Analysis Results

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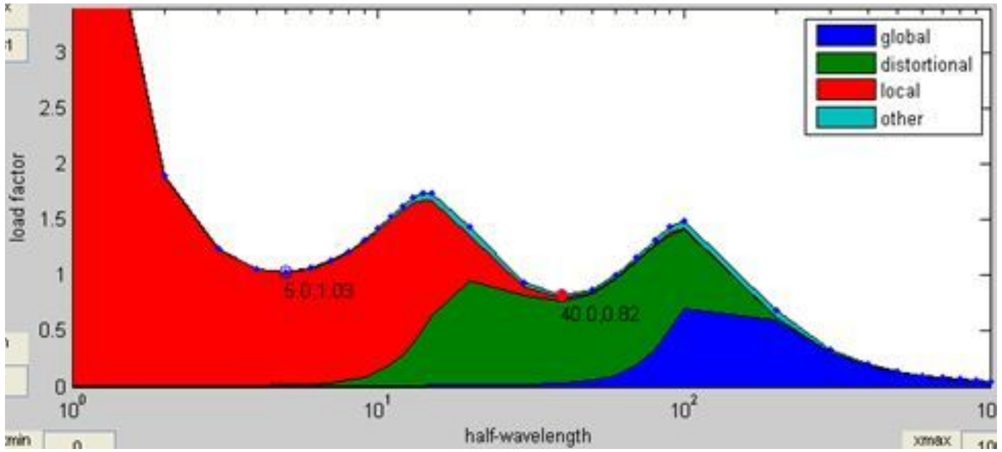
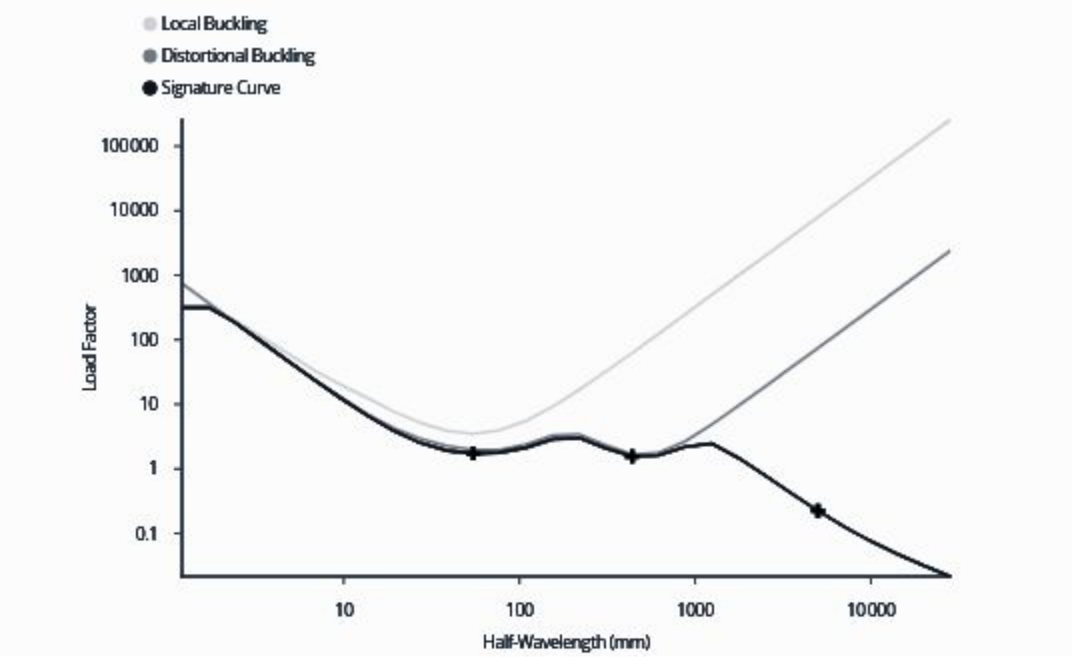
Finite Strip - Mode Classification

- Signature curves are not always as clear as previous example
- “Constrained Finite Strip Method” (cFSM); two methods:
  1. Classifying a signature curve, or
  2. Multiple FSM analyses, with ‘constrained’ modes





Practically Using DSM

Finite Strip Analysis in real life, and how it fits with AS/NZS 4600:2018

Direct Strength Method Req’ts (Cl 7.1.2)

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- DSM is applicable to *most* sections you may encounter
  - But should still check this:

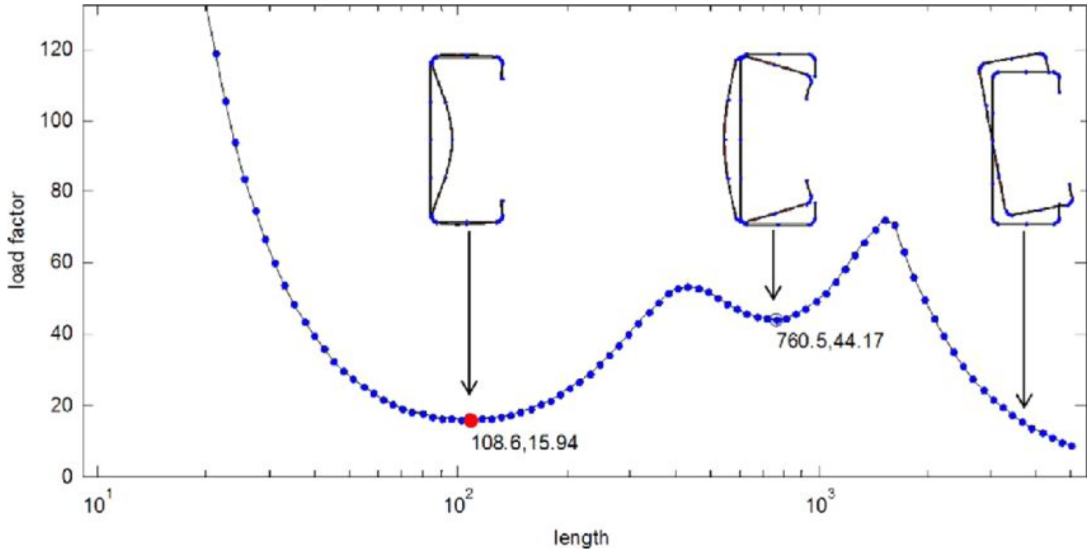


TABLE 7.1

LIMITS OF APPLICABILITY FOR DESIGN USING THE DIRECT STRENGTH METHOD

Criteria	Limiting variables	DSM prequalification limits
Stiffened element in compression [Figure 1.3(C)]	b_2/t	≤500
Edge stiffened element in compression [Figure 2.4.2(a)]	b/t	≤160
Unstiffened element in compression [Figure 2.3.1(a)]	d/t	≤60
Stiffened element in bending [Figure 2.2.3(a)]	b/t	≤200 for unstiffened web ≤260 for bearing stiffener ≤300 for bearing and intermediate stiffener
Inside bend radius	r_{min}/t	≤20
Simple edge stiffener overall length/overall width ratio	$\frac{(d + r_{min} + t)}{(b + 2r_{min} + 2t)}$	≤0.7
Maximum number of intermediate stiffeners in b_2	n_f	4
Maximum number of intermediate stiffeners in b	n_{fe}	2
Maximum number of intermediate stiffeners in web	n_w	4
Yield stress used in design	f_y	≤655 MPa

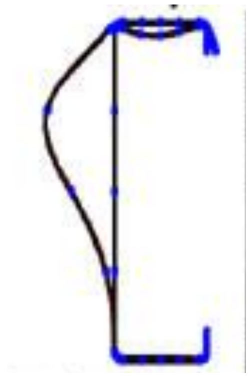
Local & Distortional Buckling

- Just a couple simple equations for determining if that buckling mode will occur, and then calculating the actual buckled capacity
    - Similar equations for bending moment or axial compression

$$\lambda_l = \sqrt{\frac{M_{be}}{M_{ol}}} \quad \ldots 7.2.2.3(3)$$

For $\lambda_l \leq 0.776$: $M_{bl} = M_{be}$ ...7.2.2.3(1)

For $\lambda_l > 0.776$: $M_{bl} = \left[1 - 0.15\left(\frac{M_{ol}}{M_{be}}\right)^{0.4}\right]\left(\frac{M_{ol}}{M_{be}}\right)^{0.4} M_{be}$ ...7.2.2.3(2)



$$\lambda_d = \sqrt{\frac{M_y}{M_{od}}} \quad \ldots 7.2.2.4(3)$$

For $\lambda_d \leq 0.673$: $M_{bd} = M_y$ ...7.2.2.4(1)

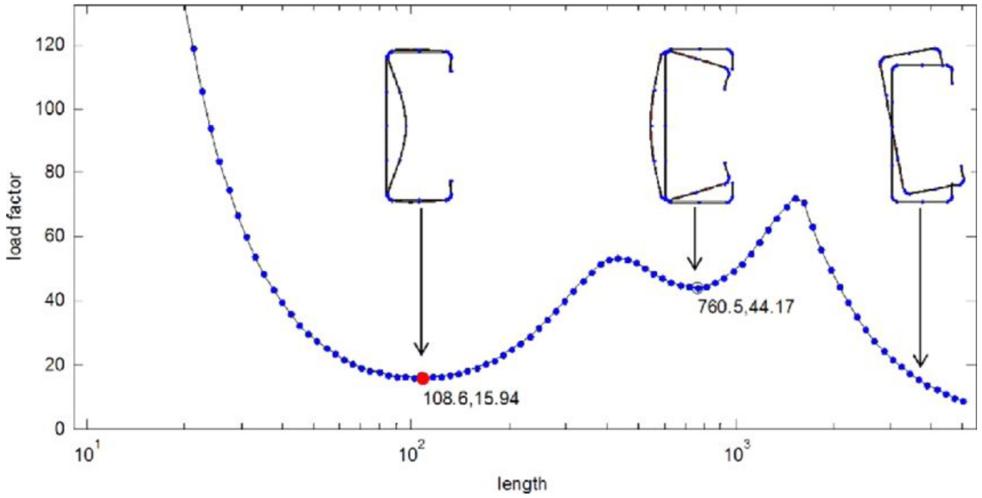
For $\lambda_d > 0.673$: $M_{bd} = \left[1 - 0.22\left(\frac{M_{od}}{M_y}\right)^{0.5}\right]\left(\frac{M_{od}}{M_y}\right)^{0.5} M_y$ ...7.2.2.4(2)

Global Buckling

- Critical buckling factor can be from Finite Strip Method results
- But, for standard sections, analytical formulae can be easier
  - Just need formulae for f_{oy}, f_{oz} , and (for axial) f_{oyz}

$$M_o = C_b A_g r_{o1} \sqrt{f_{oy} f_{oz}} \qquad \ldots \text{D2.1.1(1)}$$

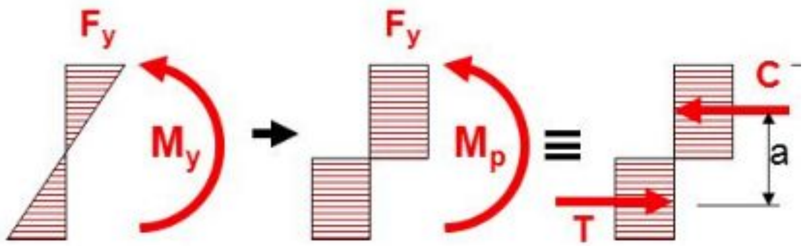
- Then similar equations as local and distortional buckling



Inelastic Reserve Capacity

- Allows small amounts of localised yielding that don't affect stability
  - Optional; certain connections (like welds) may forbid it
  - Only allowed if critical global buckling >> yield strength
- Weighted average of M_y and M_p

$$M_{be} = M_p - (M_p - M_y)\left(\frac{\left(\sqrt{\left(\frac{M_y}{M_o}\right)} - 0.23\right)}{0.37}\right) \le M_p \qquad \ldots 7.2.2.2(5)$$



Final Capacity

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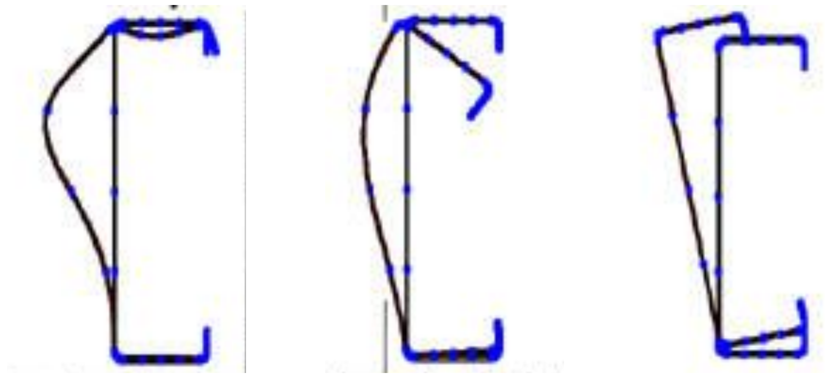
- Just simply the minimum of local, distortional, and global buckling capacities
  - ϕ_b = 0.9 in bending, or 0.85 in compression

$$\phi_b M_b = 0.9 * min(M_{bl}, M_{bd}, M_{be})$$

$$\phi_c N_c = 0.85 * min(N_{cl}, N_{cd}, N_{ce})$$



Load Interactions

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- **Bending + Shear:** some equations for shear differ slightly
  - We need compatible capacities so that we can combine them

$$\left(\frac{M^*}{\phi_b M_s}\right)^2 + \left(\frac{V^*}{\phi_v V_v}\right)^2 \leq 1.0 \qquad 7.2.3(9)$$

  - Note that M_s is a slightly different value - it's M_{bl} but without consideration of global buckling
    - i.e. $\lambda_l = \sqrt{M_y/M_{ol}}$ instead of $\lambda_l = \sqrt{M_{be}/M_{ol}}$

- **Bending + Axial:** first, separately calculate pure bending and pure axial capacities using the Direct Strength Method

$$\frac{N^*}{\phi_c N_c} + \frac{M_x^*}{\phi_b M_{bx}} + \frac{M_y^*}{\phi_b M_{by}} \leq 1.0 \qquad 7.2.4$$

Deflections

- Also more accurate using our DSM results
  - Conservatively, can use I_{eff} values given by manufacturers
  - But more accurate is to use our DSM moment capacities
    - M is the maximum service moment demand
    - $M_n = M_b$, except that we replace all instances of M_y with M

$$I_{eff} = I_g \left(\frac{M_n}{M} \right) \leq I_g \quad \text{. . . 7.1.4}$$

Demonstration in ClearCalcs

How does the workflow look like in ClearCalcs

Questions?

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THANK YOU!

- We will send you a recording of the webinar by email.
- There will be a survey at the end of this webinar, we would appreciate your feedback on how we can improve.
- If you have further questions, send an email to help@clearcalcs.com or use the Help button in ClearCalcs
- Stay tuned for webinar [Webinar Title] next month!

Appendix

About ClearCalcs

Happy Engineers Using ClearCalcs

ClearCalcs has been used in 2,000,000+ designs by a growing number of engineers across the globe, with the US becoming our largest customer base in 2021.

"You are light years ahead of the competition on features and ongoing growth."

Don C.
Foundation Engineering Specialists, LLC

"Why didn't you just use ClearCalcs for that?"

Helen W. via Landon R.
Criterium Engineers

"The program basically does the work for you...Wow, I can finally throw away the last of my spreadsheets!"

Jason M.
J. Michael Engineering, PLLC

The ClearCalcs Team

A growing team of passionate engineers, programmers, customer success specialists, product managers, marketers, and more!

What Sets Our Calculations Apart

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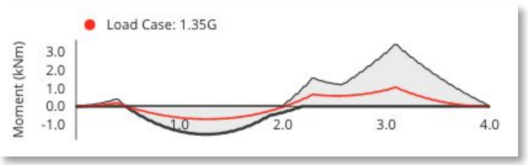
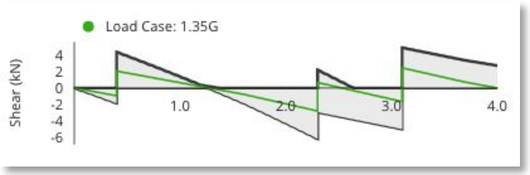
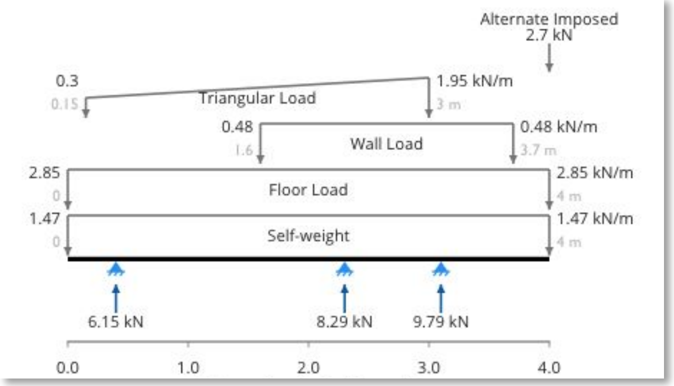
- **Live solutions**
  - *Instantly see how every change you make affects the design, in all load cases*

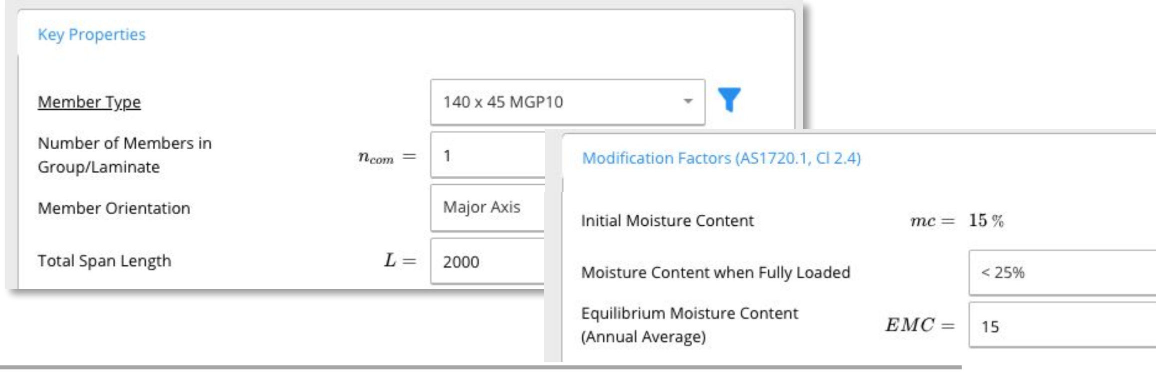




- **Finite Element Analysis**
  - *Get the most accurate results no matter what your configuration*

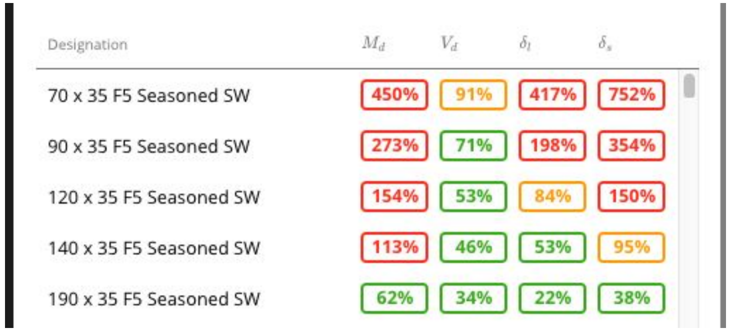


- **As simple or complex as you want**
  - *Safely enter in only a few properties, or tune every parameter – it's up to you*



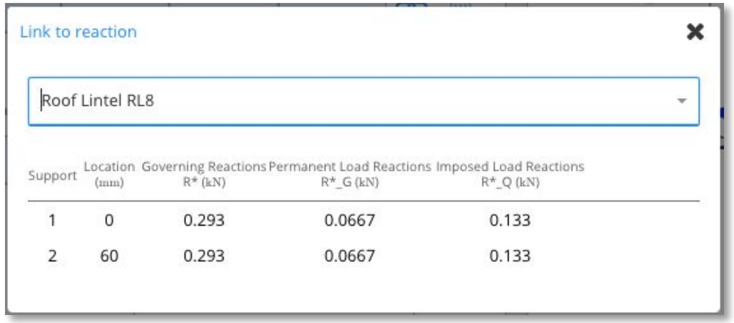
What Sets Our Design Process Apart

- **Member selector**
  - *Check every possible member in seconds*



Designation	M_d	V_d	δ_l	δ_s
70 x 35 F5 Seasoned SW	450%	91%	417%	752%
90 x 35 F5 Seasoned SW	273%	71%	198%	354%
120 x 35 F5 Seasoned SW	154%	53%	84%	150%
140 x 35 F5 Seasoned SW	113%	46%	53%	95%
190 x 35 F5 Seasoned SW	62%	34%	22%	38%

- **Link your loads**
  - *No need to manually copy reactions into the next sheet – just create a link*

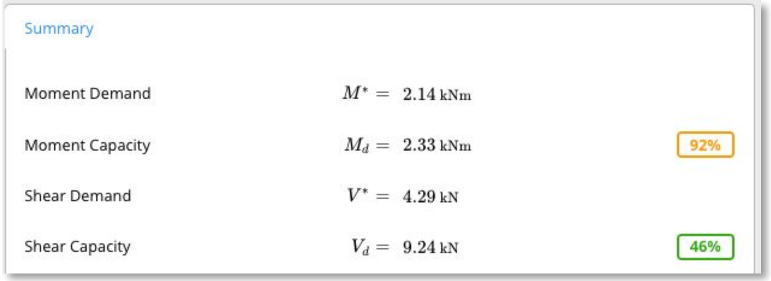


Link to reaction

Roof Lintel RL8

Support	Location (mm)	Governing Reactions R* (kN)	Permanent Load Reactions R*_G (kN)	Imposed Load Reactions R*_Q (kN)
1	0	0.293	0.0667	0.133
2	60	0.293	0.0667	0.133

- **Simple traffic light indicators**
  - *See at a glance how close your design is to perfection*



Summary

Moment Demand	$M^* = 2.14$ kNm	
Moment Capacity	$M_d = 2.33$ kNm	92%
Shear Demand	$V^* = 4.29$ kN	
Shear Capacity	$V_d = 9.24$ kN	46%

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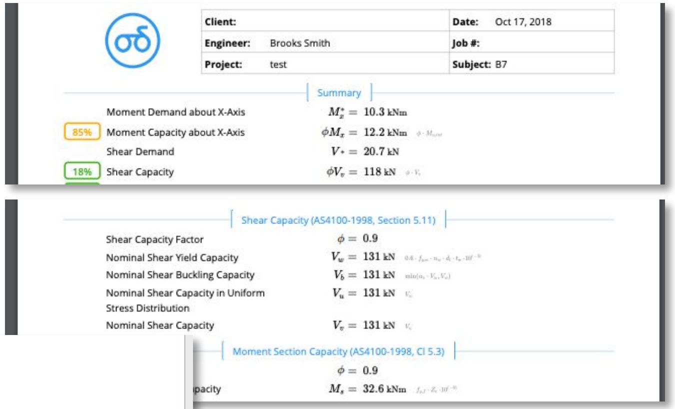
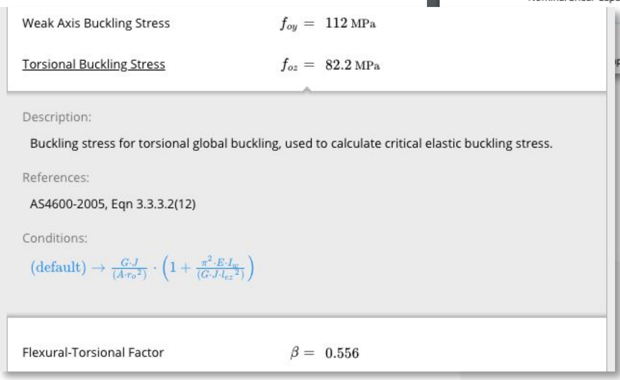
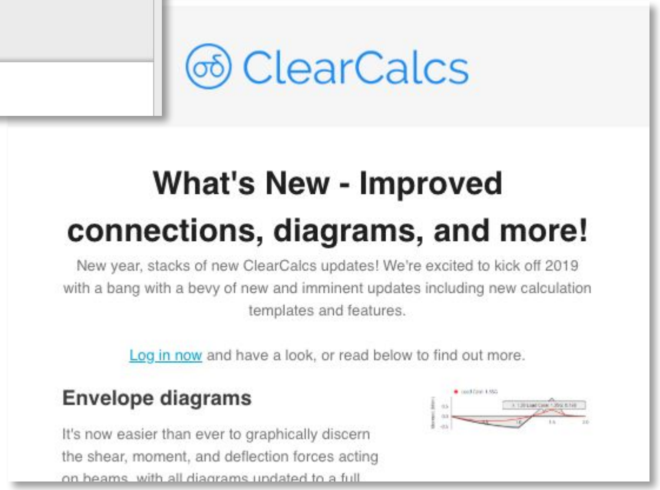
What Sets Our Platform Apart

- **Clean, clear printouts**
  - *Beautiful results your clients can understand*
- **See full detail for every field**
  - *References, equations, and more*
- **Rapid product updates**
  - *Receive new features and calculations within days, not years*







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Key Advantages

ClearCalcs is designed for the modern efficiency focused engineering practice

More accurate results.

Get far better quality and efficiency than spreadsheets with highly accurate FEM calculations and dynamic load path tracking between members.

Easy to understand.

Work faster and impress clients and checkers with professional, easy to understand calculations and quick export to PDF.

Never lose work again.

ClearCalcs was built in the cloud. That means we automatically save your work as you type and keep it securely backed up on our servers.

Help when you need it.

Need help? Our customer support is built right in to the platform. With a single click you can talk to one of our talented engineers.

Save time.

Our wide range of templates and easy linking, duplication, and export are all designed to help automate creation of repetitive calculations.

Always have access.

Shared licenses and lock-outs are a thing of the past! Our simple pricing model makes it easy to give everyone access to ClearCalcs when they need it.

Easy collaboration.

No more USBs or sending files over email! Everything is shared inside ClearCalcs so you can easily collaborate on projects.

Upgrades are always free.

We added over 250 updates to ClearCalcs last year. All of our users had them as soon as they were released, and we didn't charge them a cent extra.

Mobile. Tablet. Desktop.

ClearCalcs was designed to work on any modern device. Nothing to download or install, all you need is a web browser.