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Connection Design

Tips, Tricks, and Lessons Learned

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Session Description
19.6 The Chevron Effect
March 18, 2019

V- and inverted V-type braced frames are common brace configurations. Generally referred to as chevron systems, the configuration requires braces to frame to braced frame beams away from the beam-column joint. Typically, the effects of the brace forces on the beam and the impact on the beam end connections are overlooked. Standard practice in connection design is to assume that the joint is isolated from the frame, and to assume that the impact of the brace forces on the beam is isolated to the connection region. If the algebraic sum of the vertical components of the braces forces is zero, this assumption is generally valid. However, connection designers rarely deal with a zero summation of vertical force components. When the summation of the vertical components of the brace forces is non-zero, the location of the work point along the length of the beam and the span of the beam can significantly impact how beam shear and moment is distributed along the span of the beam, especially in the region of the connection. This is referred to as the chevron effect.

This webinar presents discussion on how brace forces are distributed through a chevron connection, and explores the impact of the brace forces on the design of the beam . Formulas are presented which allow the designer to determine if the Chevron Effect will impact the beam design.

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Learning Objectives

- Describe the chevron effect and its influence on the internal forces and moments in the beam of a braced frame.
- List the historic analysis methods that engineers use at chevron bracing connections, and explain how they might lead to underestimating the load effects on the beam in a braced frame.
- Identify the forces and their locations in the free body diagram associated with the symbiotic method.
- Explain how engineers might be able to estimate the chevron effect prior to designing the full chevron connection.

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Night School 19 Connection Design: Tips, Tricks, and Lessons Learned

Session 6: The Chevron Effect
March 18, 2019

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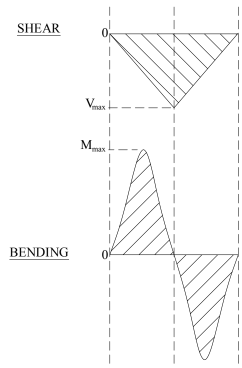
The Chevron Effect



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The Chevron Effect
A Paradigm Shift

This presentation is based on two papers which define the 'chevron effect' and 'paradigm shift' of the title. These are:

The **Chevron Effect** and the Analysis of Chevron Beams – A Paradigm Shift (2017)
Patrick J. Fortney and William A. Thornton
AISC Engineering Journal, Vol. 54, 4th Qtr., pp. 263- 296

The **Chevron Effect** – Not an Isolated Problem (2015)
Patrick J. Fortney and William A. Thornton
AISC Engineering Journal, Vol. 52, 2nd Qtr., pp. 125-163

Presented by William Thornton

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The Chevron Effect

- What is it?
- Why is it important?
- What are the historic methods to design chevron beams and chevron brace connections?
- Are there ways to determine the chevron effect apriori?

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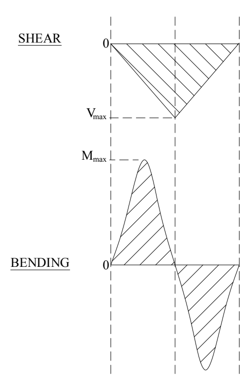
The Chevron Effect

- What is it?
- It is the shear and bending moment generated in the frame beam adjacent to the chevron gusset plate.



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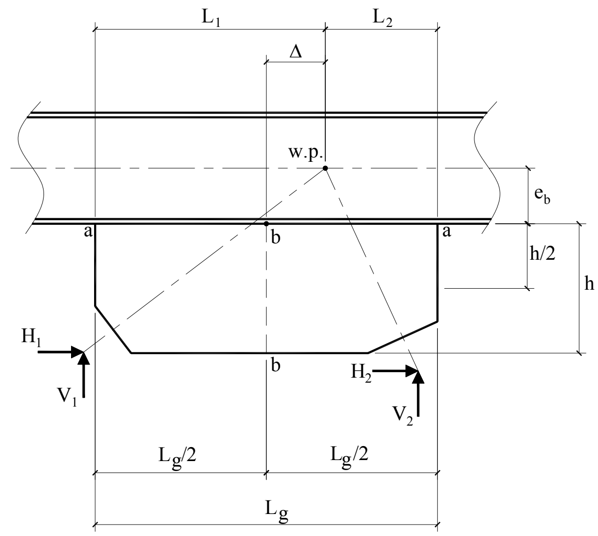
The Chevron Effect



Section a-a

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The Chevron Effect

- Why is it important?
- Because it can increase the shear and bending moment in the beam adjacent to the gusset. This can produce stresses that exceed the code specified shear and bending stresses in the beam. This may cause a need for expensive web doublers and flange cover plates.

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The Chevron Effect

- What are the historic methods to design chevron beams and chevron brace connections?
- For the connection designer, the isolated method (IM). This isolates the connection from the rest of the beam and considers only what happens in the connection region of the beam.
- It also considers the loads on the beam/gusset interface (interface a-a) to be concentrated at the gusset quarter points rather than being distributed.

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The Chevron Effect

- What are the historic methods to design chevron beams and chevron brace connections?
- For the beam or main frame designer – The Net Vertical Force (NVF) method. This is also called the Pab/L method.
- This method considers what happens in the beam outside of the connection, but ignores what happens in the gusset region of the beam. The beam designer does not know the gusset size and therefore can not determine what happens here.

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The Chevron Effect

- Are there ways to determine the chevron effect apriori?

- Yes.
- Methods will be presented that will allow designers to determine if a beam needs to be larger to accommodate the chevron effect shear or the chevron effect moment.

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The Chevron Effect

First, some preliminaries.

- Statics
- Free Body Diagrams
- Sign Convention

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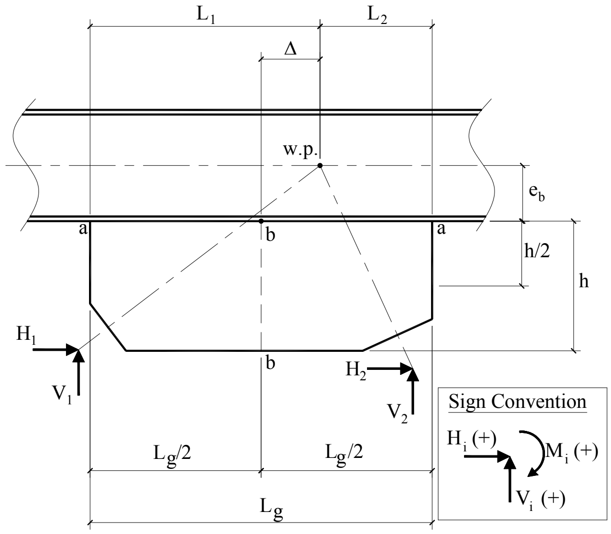
The Chevron Effect



Schematic to Address Force Distribution

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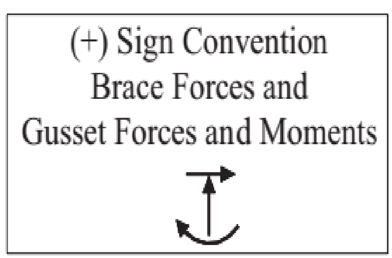
Sign Convention



- The sign convention is important for all equations in this presentation, especially for the Design Aid equations.

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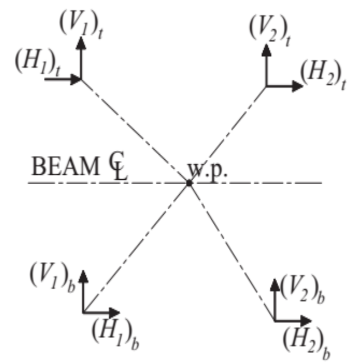
Sign Convention For Beam Forces



$$\left(\Sigma V\right)_T = (V_1)_t + (V_2)_t + (V_1)_b + (V_2)_b$$

The $(V_i)_t$ and $(V_i)_b$ are positive up; $(\Sigma V)_T$ is positive up.

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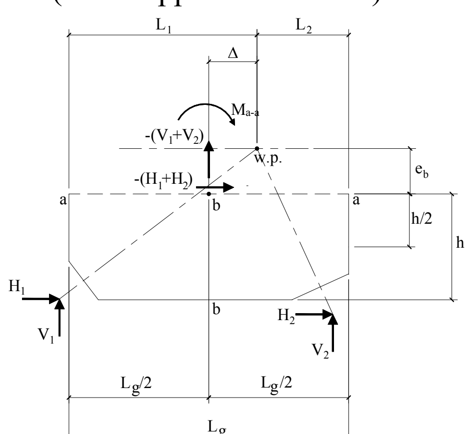
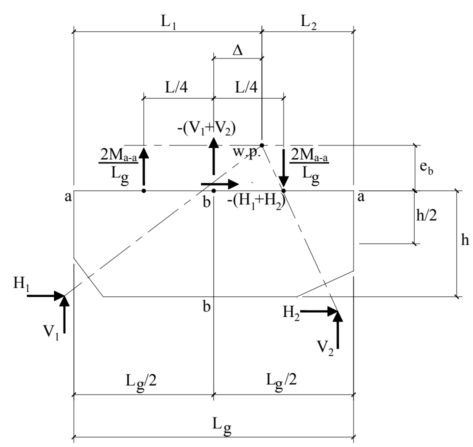
Free Body Diagrams

- Forces Acting on Section a-a also act on the adjacent beam flange (in the opposite direction)



With Moment, $M_{a\text{-}a}$



With Equivalent Couple, $2M_{a\text{-}a}/L_g$

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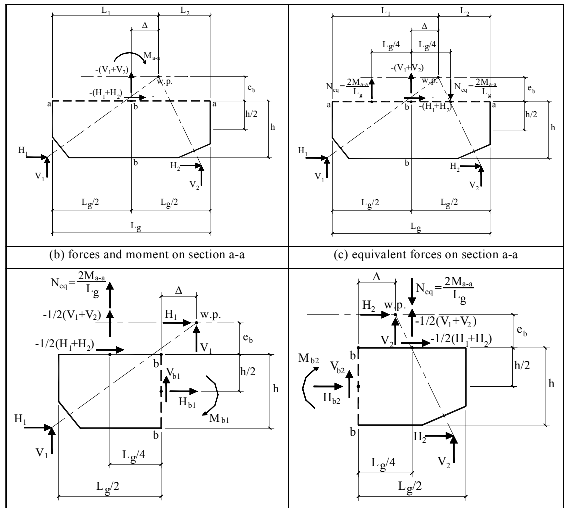
Free Body Diagrams

- Note that all these free body diagrams use concentrated forces and moments on the cut sections a-a and b-b. These will be usually converted to statically equivalent distributed forces for eventual design.
- The IM method uses these forces as-is.



(b) forces and moment on section a-a | (c) equivalent forces on section a-a | (d) forces on left half of gusset | (e) forces on right half of gusset

Statically Determinate Chevron Gusset Forces

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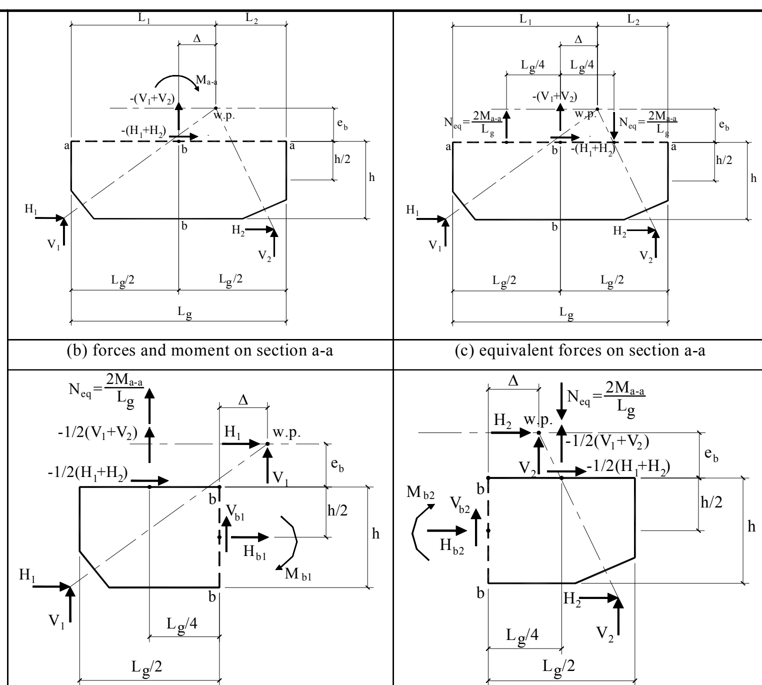

(b) forces and moment on section a-a

(c) equivalent forces on section a-a

(d) forces on left half of gusset

(e) forces on right half of gusset

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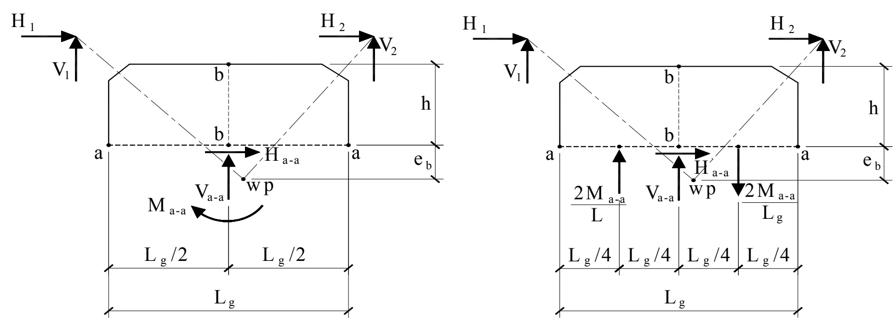
Connection Force Distributions
Top Braces

- A similar set of equations can be written for braces framing to the top of the beam



Resultant Forces

Equivalent Normal Forces

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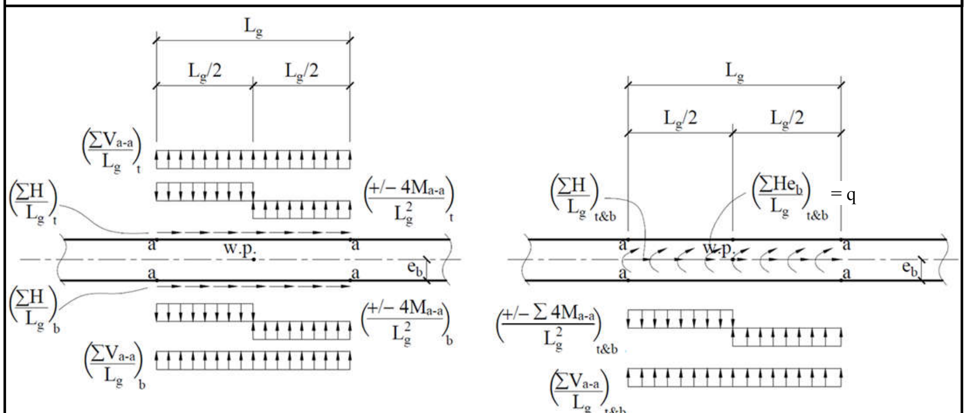
Transition of Forces from Beam Flanges to Beam Neutral Axis



Top and Bottom Forces

Net Forces at Beam Neutral Axis

Interface Forces

- Note that these diagrams assume L_g is the same top and bottom, and that the vertical edges of the gussets are aligned. This is not necessary but simplifies the calculations.

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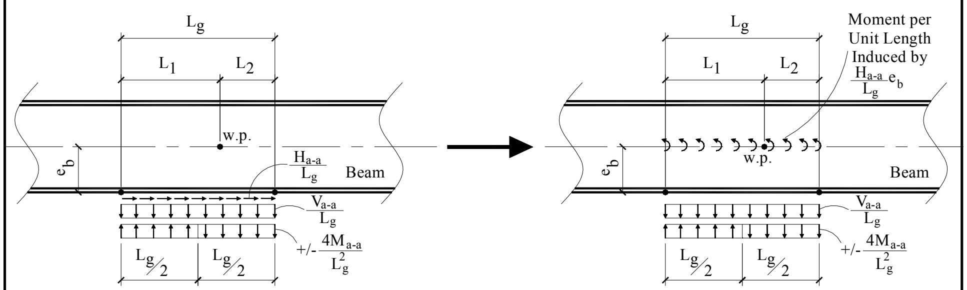
Transition of Forces from Beam Flange to Beam Neutral Axis



<u>These are Reasonable Interface Force Distributions</u>

This interface force distribution, derived from the original concentrated forces, is supported by nonlinear Finite Element Analysis. See Williams, G.C. (1986), *Steel Connection Designs Based on Inelastic Finite Element Analysis*, Ph.D. Dissertation, University of Arizona (Ralph Richard: Advisor).

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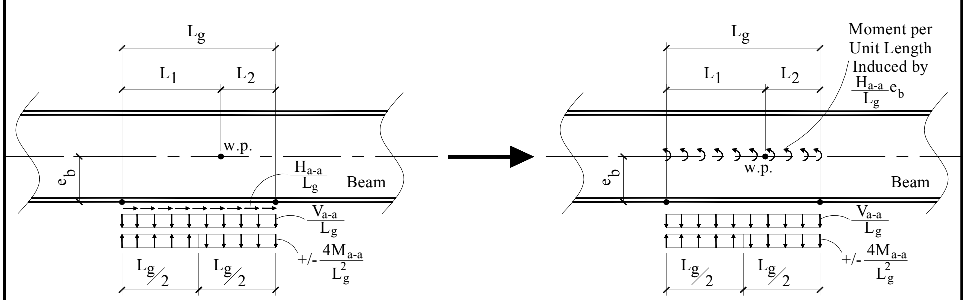
The Chevron Effect



<u>These are Reasonable Interface Force Distributions</u>

But these distributed force distributions are an assumption. This assumption is the only one made thus far. All of the forces themselves follow from a statically determinate free body analysis. There are no assumptions made in the free body analysis.

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How is the Joint Modeled

There are Two Possible Load Cases

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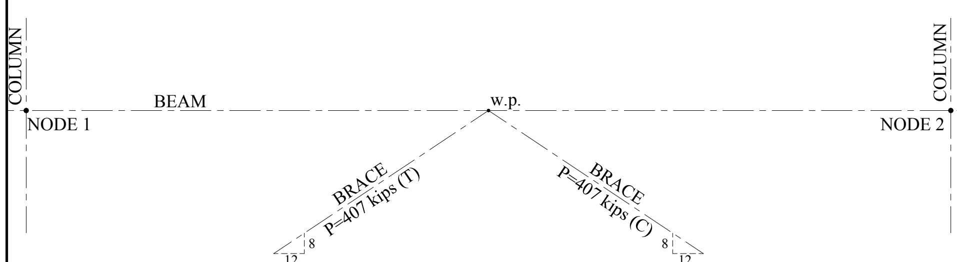
Two Possible Load Cases

$(\Sigma V)_T = 0$ Case



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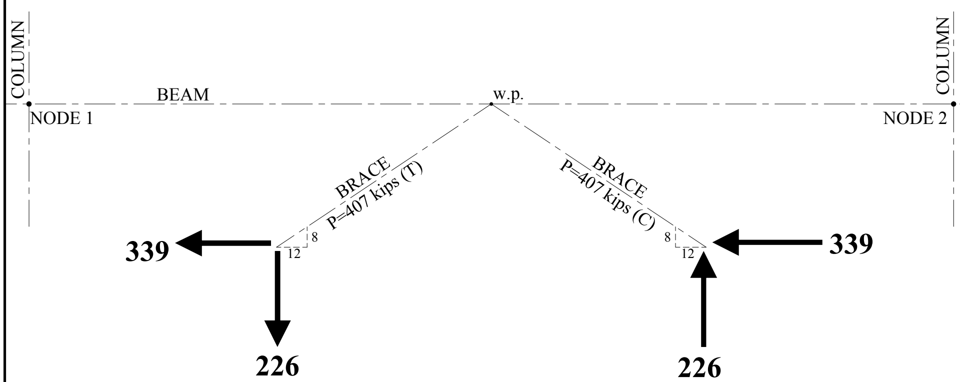
How is the Joint Modeled

$(\Sigma V)_T = 0$ Case



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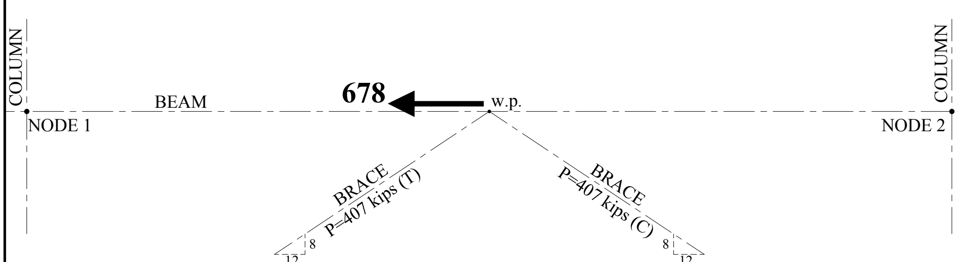
How is the Joint Modeled

$(\Sigma V)_T = 0$ Case



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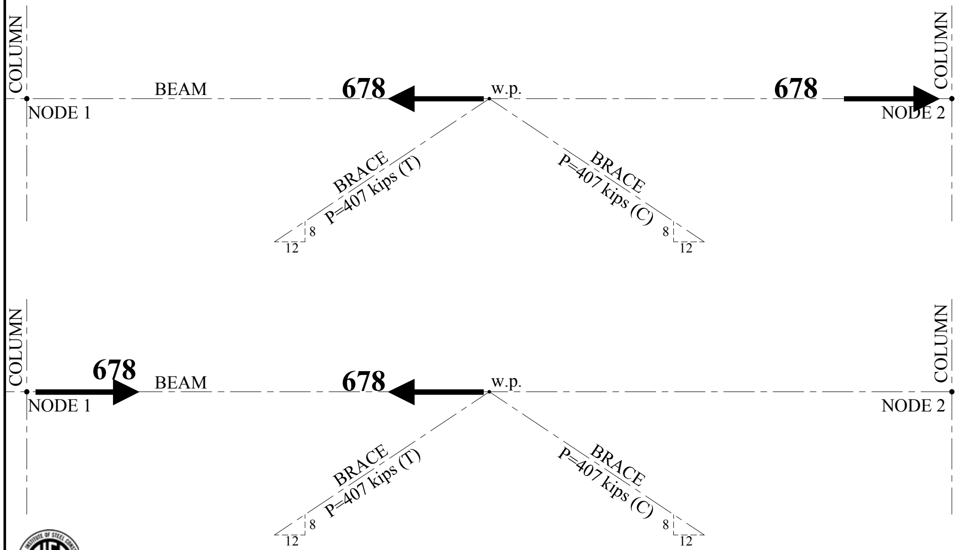
How is the Joint Modeled



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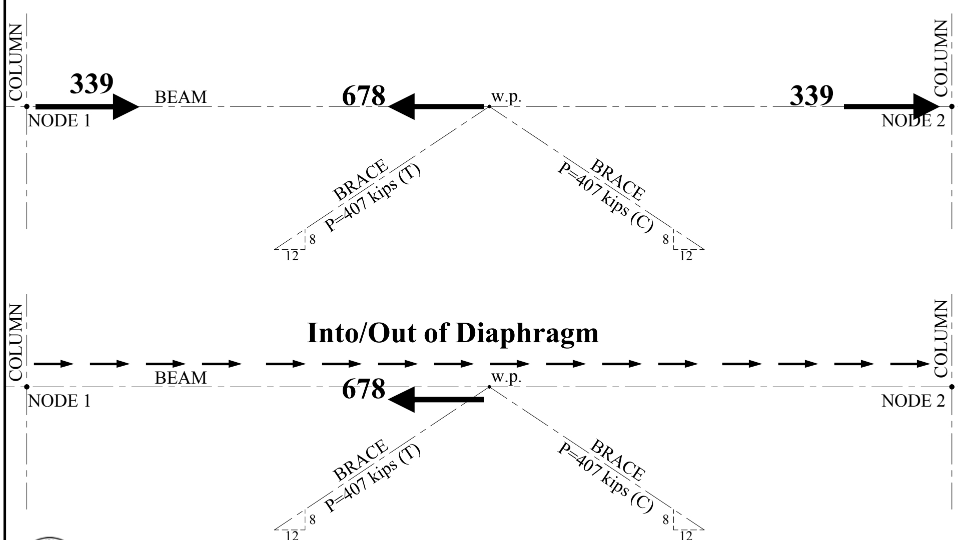
How is the Joint Modeled



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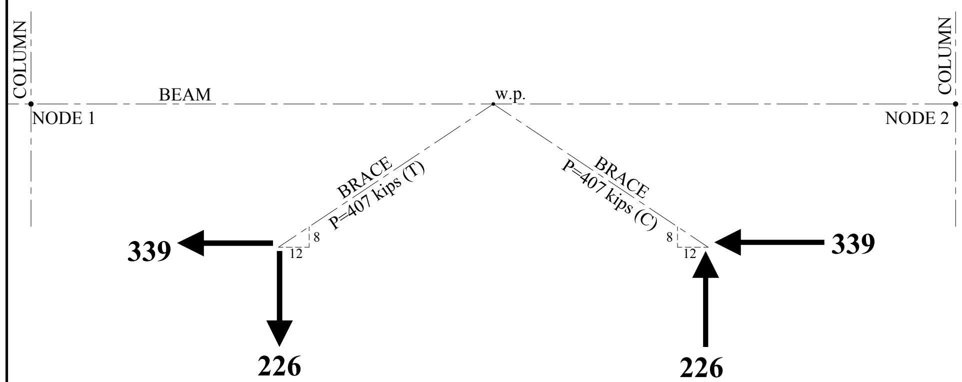
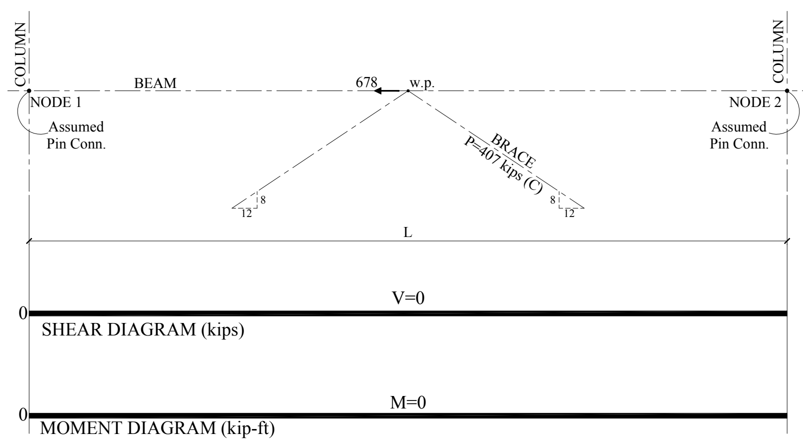
How is the Joint Modeled

$(\Sigma V)_T = 0$ Case



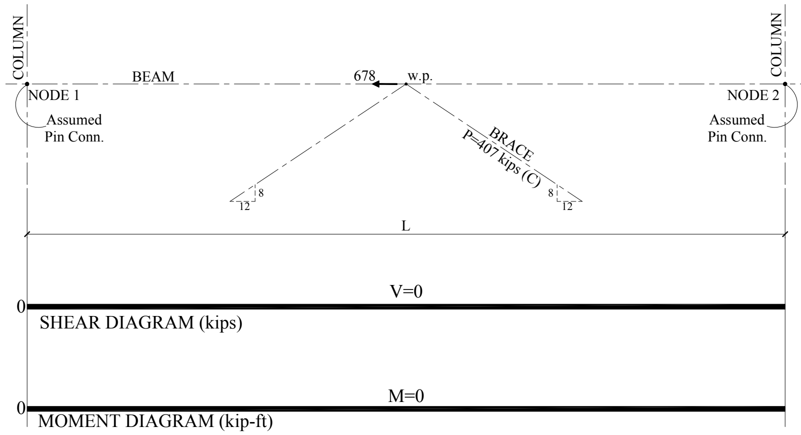
$(\Sigma V)_T = 0$

If the $\Sigma(V)_T$=0, what is the demand on the beam using the NVF method?



$(\Sigma V)_T = 0$

If the $\Sigma(V)_T$=0, what is the demand on the beam?



The beam is designed for an axial load only? Yes, per the NVF method.

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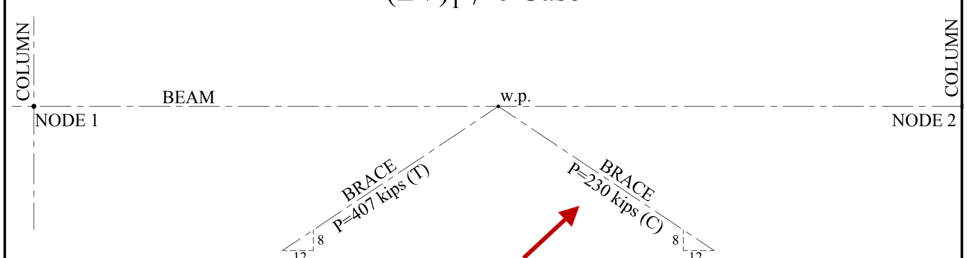
How is the Joint Modeled

$(\Sigma V)_T \neq 0$ Case



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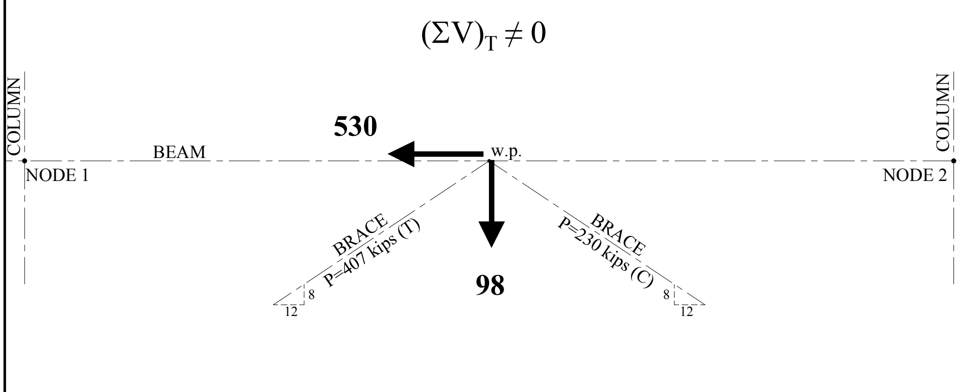
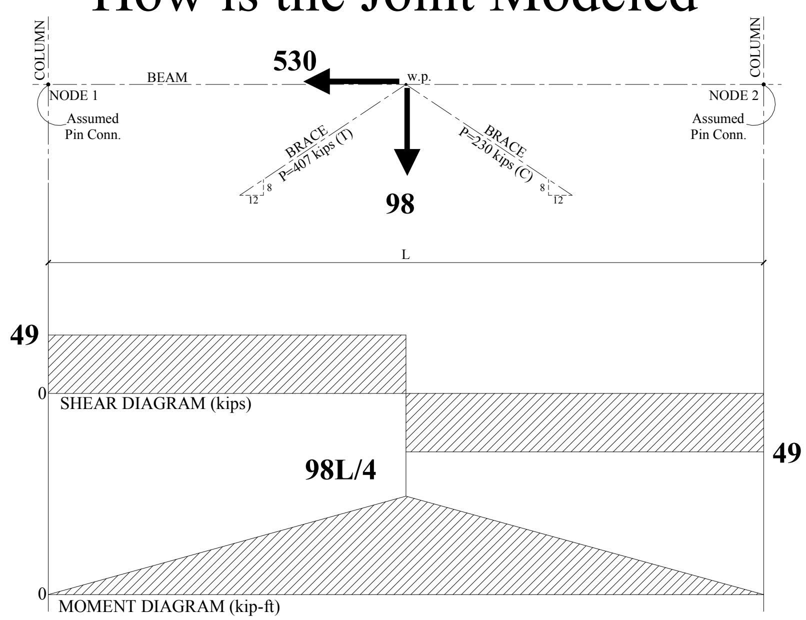
How is the Joint Modeled



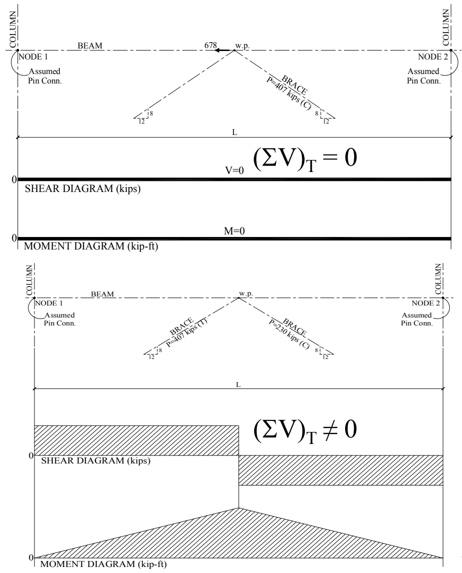
How is the Joint Modeled



How is the Joint Modeled

- This is the NVF or Pab/L method.

- This is the typical method used by EORs to size beams in chevron frames.
- It has been called the net vertical force (NVF) method or the Pab/L method.



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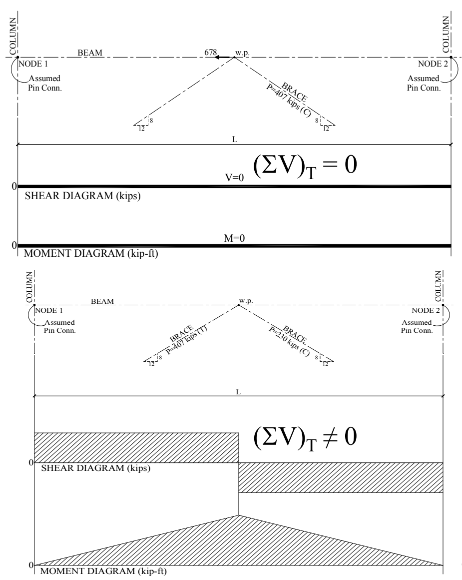
How is the Joint Modeled

- This is the NVF or Pab/L method

- This is the typical method used by EORs to size beams in chevron frames

For this course we will use the **NVF** terminology.



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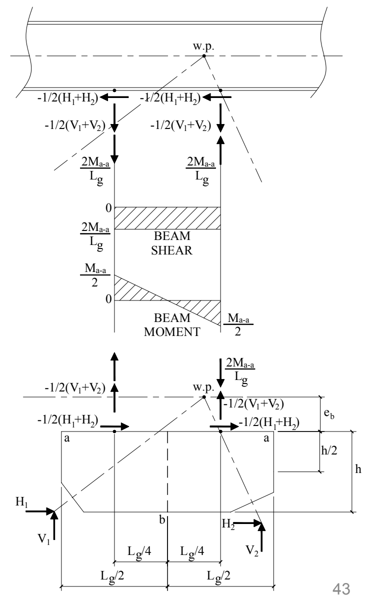
How is the Joint Modeled

The IM Approach

- This is the typical method used by Connection Designers to evaluate beam shear and moment. It uses the original concentrated forces at the gusset ¼ points and ignores the moment due to (H_1+H_2) acting at e_b from the beam neutral axis.



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The "Symbiotic" Method (SM)

- This is no more and no less than what you learned in engineering school, once you know the loads on the beam. Previous slides have shown how to get these loads. You need to know the gusset length, L_g, to get the beam loads, and that is the hang-up. Neither the NVF nor the IM are correct and reliable methods for design.

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The "Symbiotic" Method (SM)

The Symbiotic Method Differential Equations

$$\frac{dV}{dx} = w$$

$$\frac{dM}{dx} = V + q$$

The "q" is probably not something you have seen before. It makes for unusual moment diagrams.

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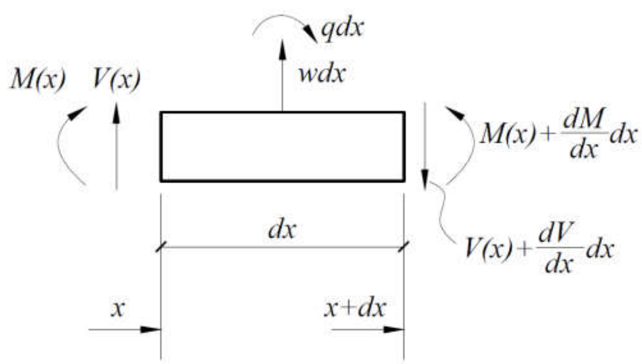
Shear and Bending Moment Differential Equations and Sign Convention

$$\frac{dV}{dx} = w$$

$$\frac{dM}{dx} = V + q$$



w, *q*, *V* and *M* are positive as shown

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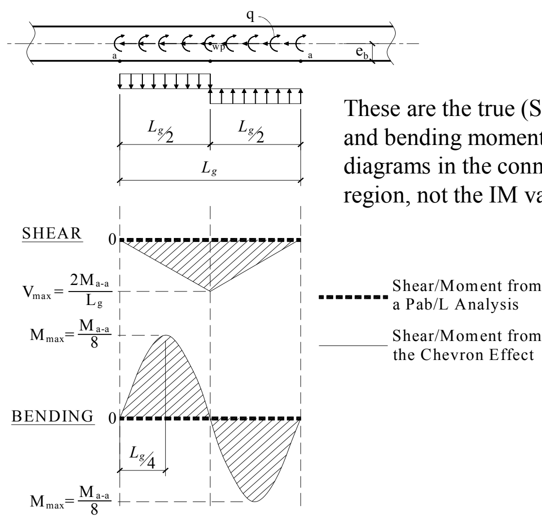
The Chevron Effect

It is important to recognize that, even <u>when $(\Sigma V)_T=0$</u>, beam shear and moment exist in the connection region!



These are the true (SM) shear and bending moment diagrams in the connection region, not the IM values.

Refer to Fortney, P. J., and W.A. Thornton (2015), "The CHEVRON EFFECT- Not an Isolated Problem," Engineering Journal, AISC, Vol.52, 2nd Qtr., pp.125- 163

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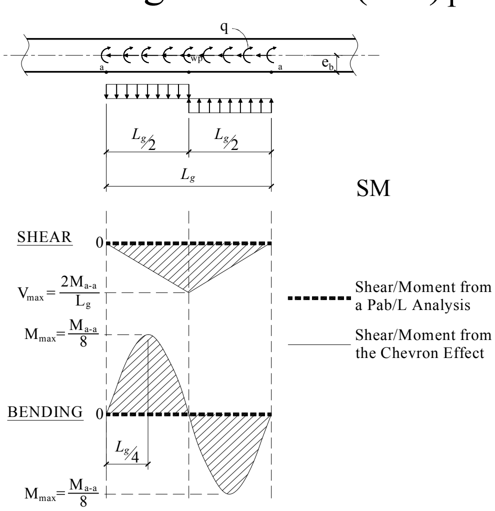
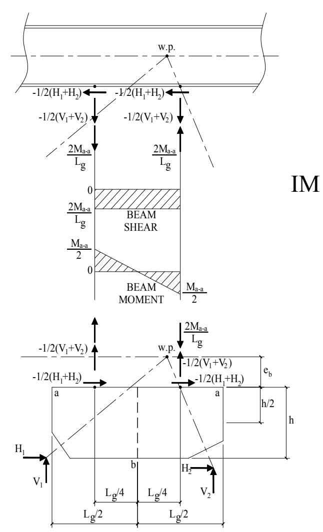
SM and IM distributions in the connection region for the $(\Sigma V)_T = 0$ load case





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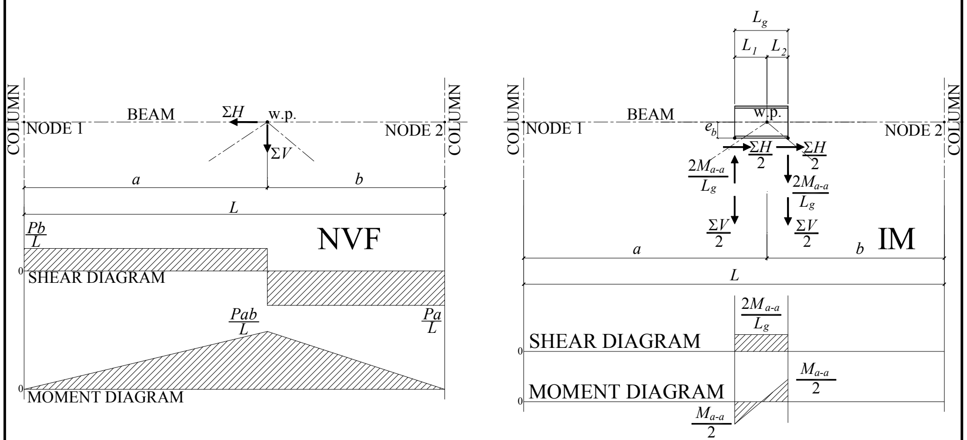
EORs' Approach Compared to Connection Designer's Approach And The Symbiotic Method



So the question **begging** to be asked is,

SHEAR: How do NVF and IM compare to **SM ?**

MOMENT: How do NVF and IM compare to **SM?**

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Some Examples

Example 1

Fortney/ Thornton 2017 Chevron Effect Paper

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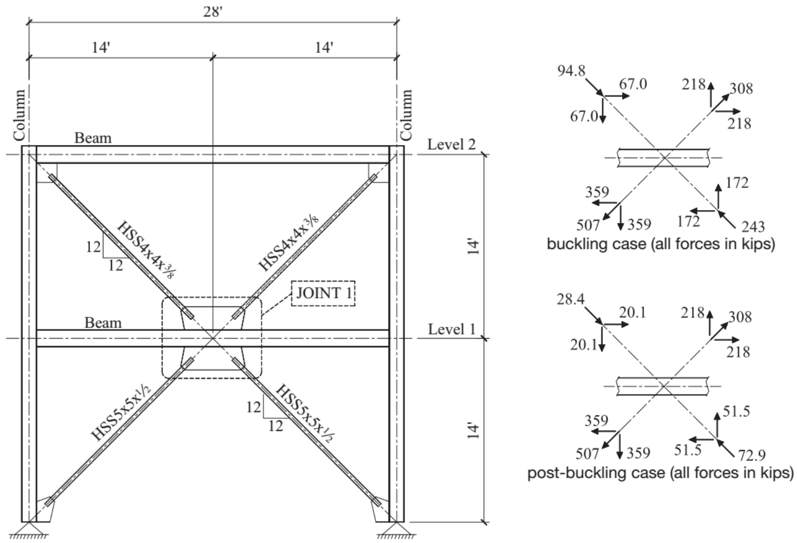
An example from Fortney/ Thornton (2017 AISC Journal Paper)



(a) Frame elevation (b) Brace loads

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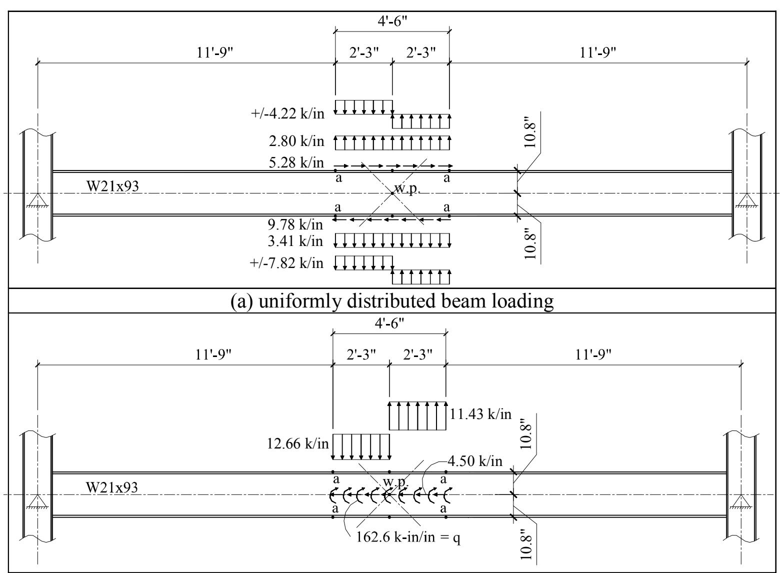
An example from Fortney/ Thornton (2017)



(a) uniformly distributed beam loading

(b) statically equivalent net beam loading

An example of Interface Force Distributions, Buckling Case

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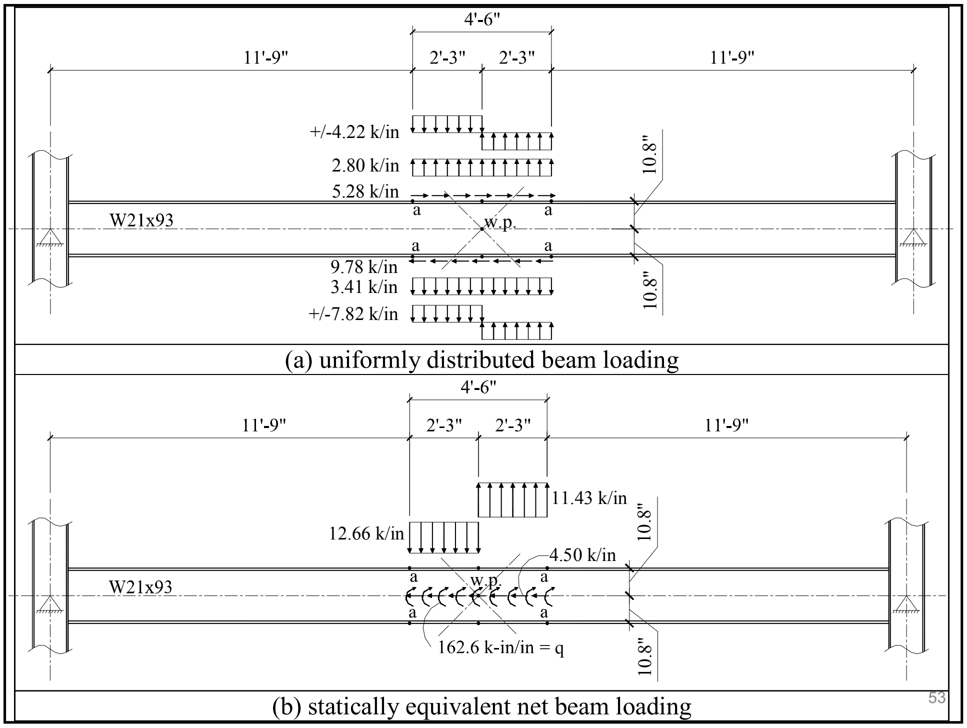
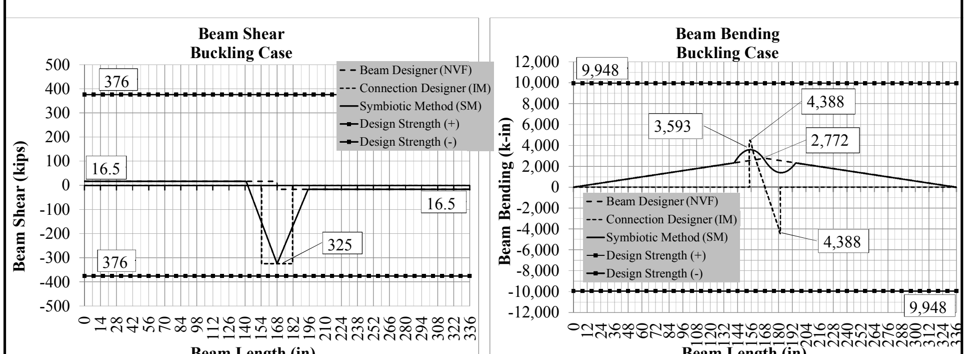


NVF and Symbiotic Methods Compared



<u>Beam Shear and Bending for Beam Shown in Previous Slide</u>

$$\frac{V_{NVF}}{V_{SM}} = \frac{16.5}{325} = \frac{0.051}{1} \qquad \frac{M_{NVF}}{M_{SM}} = \frac{2772}{3593} = \frac{0.772}{1}$$

Beam shear and bending significantly underestimated using NVF method!

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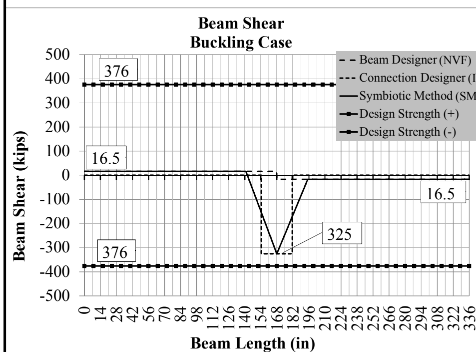
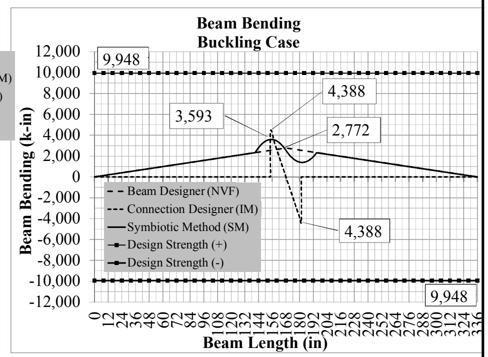
IM and Symbiotic Methods Compared





<u>Beam Shear and Bending for Beam Shown in Previous Slide</u>

$$\frac{V_{IM}}{V_{SM}} = \frac{325}{325} = \frac{1}{1} \qquad \frac{M_{IM}}{M_{SM}} = \frac{4388}{3593} = \frac{1.22}{1}$$

The isolated method and the symbiotic method give the same shear, and the isolated method over-estimates the moment.

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Example 2

Fortney/ Thornton 2015 Chevron Effect Paper

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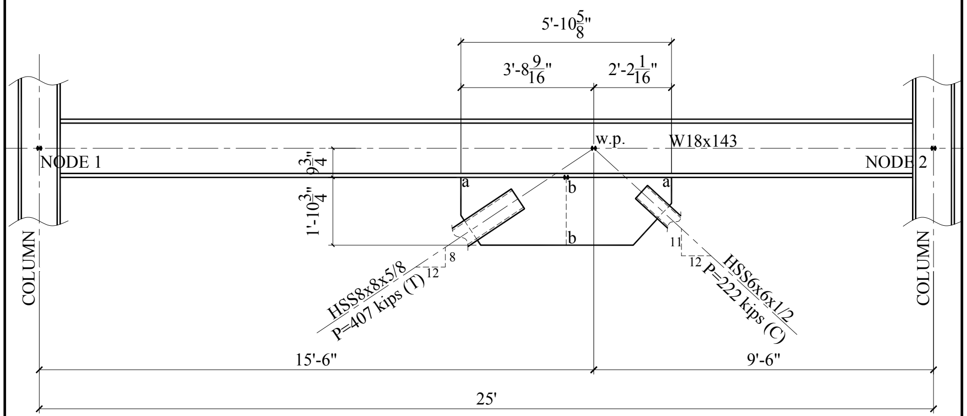
Example 2 – Fortney/Thornton (2015 Journal Paper)

- Consider the geometry and loading shown. Generate the shear and bending moment diagrams. This is the SM solution.



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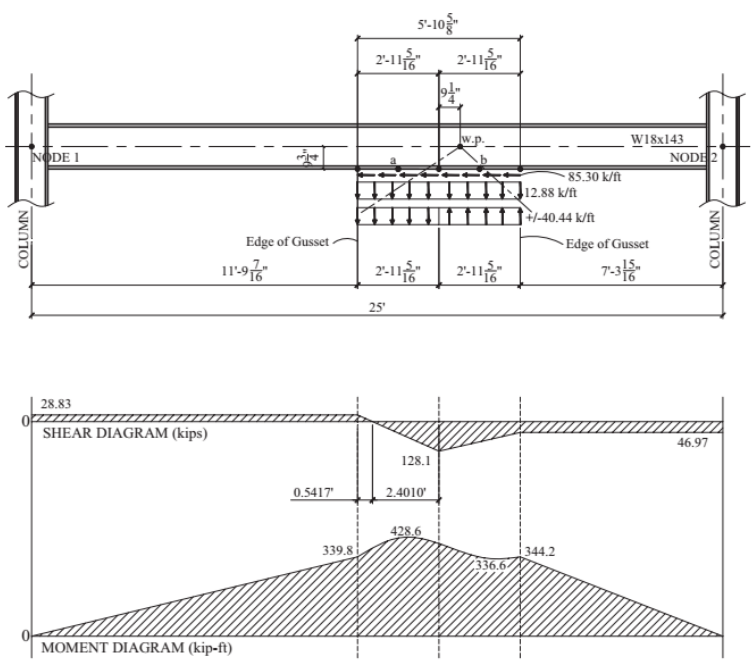
Symbiotic Method (SM) Shear and Bending Moment Diagrams



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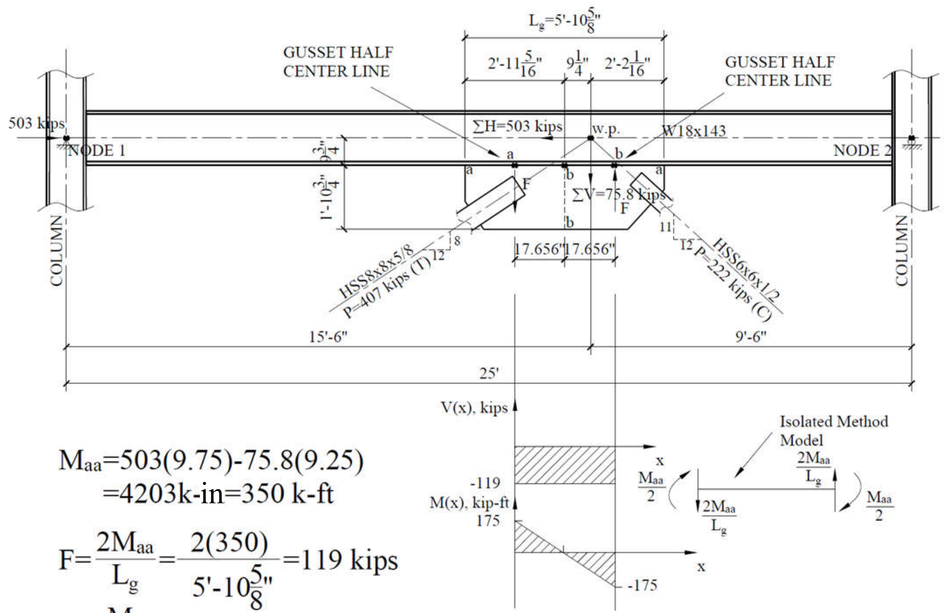
Isolated Method (IM) Shear and Bending Moment Diagrams



M_{aa}=503(9.75)-75.8(9.25)
=4203k-in=350 k-ft

$F=\frac{2M_{aa}}{L_g}=\frac{2(350)}{5'\text{-}10\frac{5}{8}"}$=119 kips

$M=\frac{M_{aa}}{2}$= 175 k-ft

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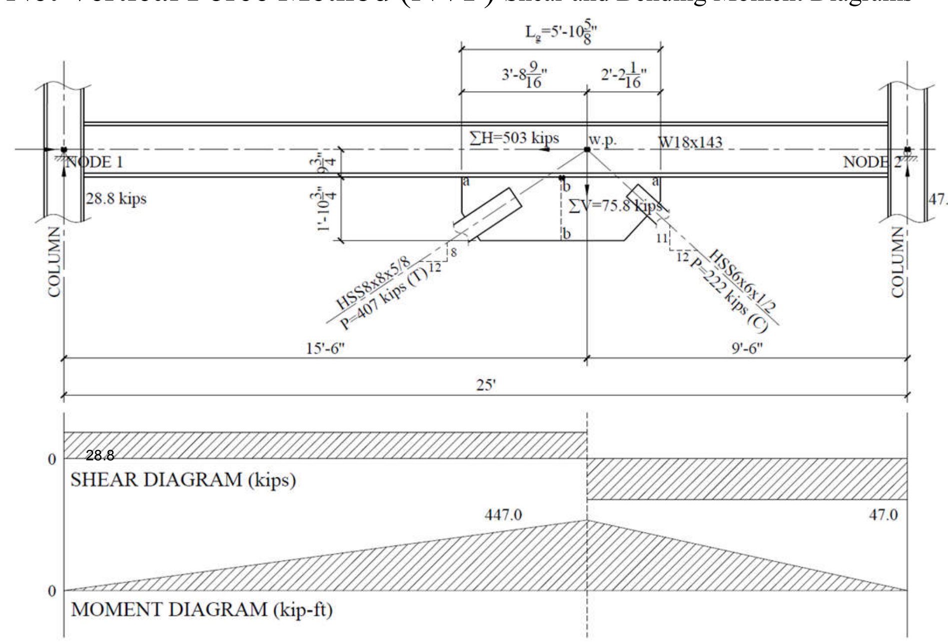
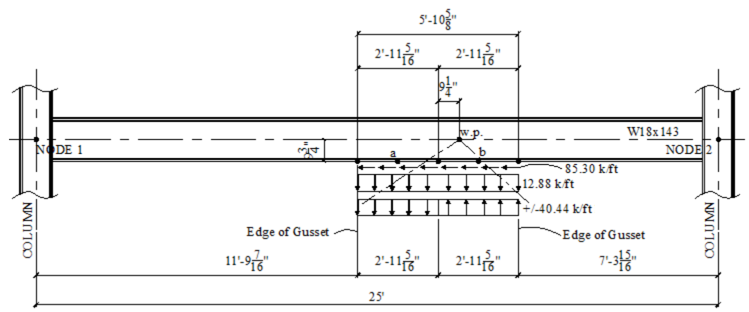
Net Vertical Force Method (NVF) Shear and Bending Moment Diagrams



60

Beam shear and Bending Moment Comparison of the SM, NVF and IM



	Maximum Shear (kips)	Maximum Moment(kip-ft.)
Symbiotic Method (SM)	128	429
NVF Method	47	447
Isolated Method (IM)	119	175

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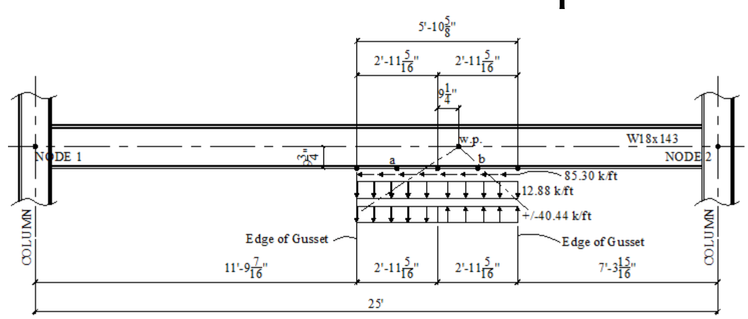
Beam shear and Bending Moment NVF and SM Compared



For the beam shown above , from previous slides:

$$\frac{V_{NVF}}{V_{SM}} = \frac{47}{128} = \frac{0.367}{1} \qquad \frac{M_{NVF}}{M_{SM}} = \frac{447}{429} = \frac{1.04}{1}$$

The NVF underestimates the shear and overestimates the moment.

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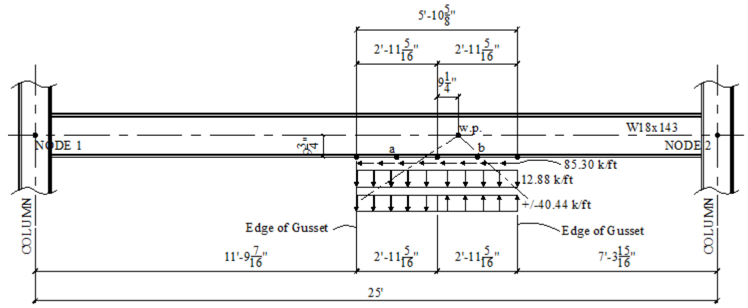
Beam shear and Bending Moment IM and SM Compared



For the beam shown above , from previous slides:

$$\frac{V_{IM}}{V_{SM}} = \frac{119}{128} = \frac{0.93}{1} \qquad \frac{M_{IM}}{M_{SM}} = \frac{175}{429} = \frac{0.408}{1}$$

The IM underestimates both the shear and the moment.

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Summary and Conclusion

The Chevron Effect – A Paradigm Shift

Three methods for the analysis and design of Chevron beams have been presented:

1. The Isolated Method (IM),this is the connection designers' approach. It considers only the effects local to the connection. It uses statically equivalent concentrated forces at gusset quarter points. It ignores the moment caused by moving the beam flange shears to the beam neutral axis.

2. The Net Vertical Force Method (NVF), this is the beam designers' approach. This considers global effects but ignores effects local to the connection.

3. The Symbiotic Method (SM)-This method is the "Paradigm Shift" of the presentation title. It includes both local and global effects.

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The "Symbiotic" Method (SM)

- This is no more and no less than what you learned in engineering school, once you know the loads on the beam. Previous slides have shown how to get these loads. **BUT, you need to know the gusset length, L_g, to get the beam loads, and that is one hang-up for the beam (mainframe) designer. Another is that an estimate of the beam depth is necessary to determine the Chevron Effect.** Neither the NVF nor the IM are correct and reliable methods for design.

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Summary and Conclusions

The Chevron Effect – A Paradigm Shift

Discussion of the results thus far:

- The NVF method especially under-estimates the beam shear.
- The IM method can over or under estimate the beam moment. It gives a reasonable estimate for the beam shear.
- Neither of the above methods can be relied upon to produce reliable results.

<u>The SM is presented here as the "gold standard."</u> It includes both local and global effects and involves only one assumption-that involving the distribution of forces on section a-a. This assumption has been validated by inelastic finite analysis performed at the University of Arizona.

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How can we use these methods
(IM, NVF, SM)
to
facilitate the design of
Chevron Beams?

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Design Aids for Beam Designers And
Connection Designers

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Rules of Thumb for Design Accounting for Connection Geometry

- These are from the 2015 Fortney/ Thornton paper:

Approximate Gusset Length, $L_{g,app}$ *($L_{g,app}$ and L in same units)*

$$L_{g,app} = \frac{L}{6} \qquad \text{where } L = a + b = \text{beam span}$$

Approximate Beam Depth, e_b

$e_{b,app}$ (in inches) = 0.75(span of the beam in feet)

These approximations are ratios averaged from twenty different chevron brace connections taken from real connections designed by the authors over several years. The twenty different chevron connections were taken from a mix of different types of projects with varying types of braces, bevels, and brace forces.

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Evaluating the Chevron Effect

An excerpt from the 2017 Fortney/Thornton paper

Does the Chevron Effect Dominate?

There are many ways the chevron effect can be evaluated. Two methods are presented here:

1. For a given condition (i.e., the beam span, work point location, and unbalanced vertical force are known), an equivalent gusset length is calculated and compared to the provided gusset length to determine if the chevron effect will dominate—a method that will be useful to the connection designer.
2. For a known beam span, L, an approximated gusset length, $L_{g,app}$, and an approximated half beam depth, $e_{b,app}$, an equivalent unbalanced vertical force can be calculated and compared to the actual unbalanced vertical force to determine if the chevron effect will dominate—a method that will be useful to beam designers.

The equations shown for the following two methods assume that the maximum beam moment occurs in the left half of the gusset. For a specific case where the maximum beam moment occurs in the right half of the gusset, the equations presented can be used by reversing the brace loads.

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Connection Designers' Aid for Maximum Moment

- The connection designer knows the beam depth and can determine a gusset length once the brace to gusset connections are known.
- An equivalent gusset length $L_{g,eq}$ can be calculated which gives a relationship between the SM moment and the NVF moment

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Connection Designers' Aid for Maximum Moment

- If $L_g > L_{g,eq}$, then $M_{SM} < M_{NVF}$
  NVF is conservative
- If $L_g < L_{g,eq}$, then $M_{SM} > M_{NVF}$
  NVF is unconservative

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Connection Designers' Aid for Maximum Moment

From Fortney/Thornton, 2017

$$L_{g,eq} = \frac{M_T\left(\frac{b}{L}\right) - \eta}{(\Sigma V)_T\left[\frac{b}{L} - \left(\frac{b}{L}\right)^2\right]}$$

$$\eta = \sqrt{(\Sigma V)_T^2 \Delta^2\left[\frac{b}{L} - \left(\frac{b}{L}\right)^2\right] + (\Sigma V)_T M_T \Delta\left[-8\left(\frac{b}{L}\right)^3 + 10\left(\frac{b}{L}\right)^2 - 2\left(\frac{b}{L}\right)\right] + M_T^2\left(\frac{b}{L}\right)}$$

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Connection Designers' Aid for Maximum Moment

Some Notation:

$M_T = (M_{a\text{-}a})_t + (M_{a\text{-}a})_b$
= summation of the moments acting on the top and bottom **gusset** sections a-a (positive clockwise)

$(\Sigma V)_T$ = summation of the brace forces acting on the **beam** (positive up)

b = distance from work-point to right end of beam

Δ = horizontal misalignment between the work point and centroid of the gusset-to-beam interface

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Connection Designers' Aid for Maximum Moment

When $\Delta = 0$, $L_{g,eq}$ reduces to:

$$L_{g,eq} = \frac{M_T}{(\Sigma V)_T}\left[\frac{\frac{b}{L} - \sqrt{\frac{b}{L}}}{\frac{b}{L} - \left(\frac{b}{L}\right)^2}\right]$$

This is a good reason to take $\Delta=0$.

Connection Designers' Aid for Maximum Moment

Example 1 – Fortney/Thornton (2017)

$$M_T = \left(4.22\frac{k}{in} + 7.82\frac{k}{in}\right)(2' - 3")(2' - 3")$$

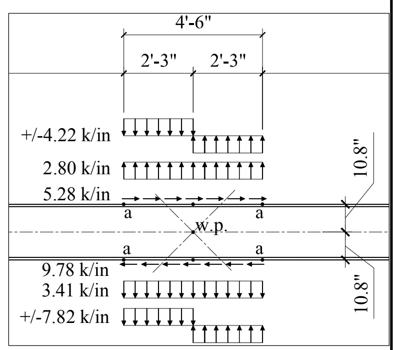
= 8777 kip-inches

$$(\Sigma V)_T = \left(2.80\frac{k}{in} - 3.41\frac{k}{in}\right)(4' - 6") = \text{-32.9 kips}$$

b/L = 0.5 (w.p. at center of beam)

Δ=0 (gussets symmetric about the w.p.)

$$L_{g,eq} = \frac{8777}{-32.9}\left(\frac{0.5 - \sqrt{0.5}}{0.5 - 0.5^2}\right) = 221 \text{ inches}$$



Beam Loading at Chevron Connection (from Slides 52 and 53)

- Since 221 inches > 54 inches, the NVF method is unconservative.

Connection Designers' Aid for Maximum Moment

- Remember that (from Slide 54):

M_{SM} = 3593 kip-inches
&
M_{NVF} = 2772 kip-inches

- So the $L_{g,eq}$ formula predicts the correct result.

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Beam Designers' Aid for Maximum Moment

- The beam designer is trying to determine a beam size. The designer knows the brace forces and therefore knows $(\Sigma V)_T$. But the designer doesn't know L_g and e_b yet. These can be estimated from the "Rules of Thumb" given. Given these, the designer wants to know if the chevron effect will increase the NVF moment. An equivalent vertical load, $(\Sigma V)_{T,eq}$ can be calculated which gives a relationship between the SM moment and the NVF moment.

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Beam Designers' Aid for Maximum Moment

- If $\left|(\Sigma V)_{T,eq}\right| < \left|(\Sigma V)_T\right|$, then $M_{SM} > M_{NVF}$
  The NVF method is unconservative
- If $\left|(\Sigma V)_{T,eq}\right| > \left|(\Sigma V)_T\right|$, then $M_{SM} < M_{NVF}$
  The NVF method is conservative

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Beam Designers' Aid for Maximum Moment

From Fortney/Thornton, 2017

$$(\Sigma V)_{T,eq} = \frac{q\left[\frac{b}{L} + \frac{4\Delta}{L_g}\left(\frac{b}{L}\right)\right] - q\sqrt{\left(\frac{b}{L}\right)^2\left(\frac{8\Delta}{L_g} + \frac{16\Delta^2}{L_g^2}\right) + \left(\frac{b}{L}\right)\left(1 - \frac{2\Delta}{L_g} - \frac{8\Delta^2}{L_g^2}\right)}}{\left(\frac{b}{L}\right)\left(1 - \frac{2\Delta}{L_g} - \frac{8\Delta^2}{L_g^2}\right) - \left(\frac{b}{L}\right)^2}$$

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Beam Designers' Aid for Maximum Moment

Some More Notation:

q = the distributed moment at the beam's neutral axis due to the shear forces at the beam flanges, i.e., the brace force horizontal components

$$q = \left[\Sigma H_t - \Sigma H_b\right]\frac{e_b}{L_g}$$

- This is positive when clockwise on the **beam**.

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Beam Designers' Aid for Maximum Moment

When Δ=0, formula for $(\Sigma V)_{T,eq}$, reduces to:

$$(\Sigma V)_{T,eq} = q\left[\frac{\frac{b}{L} - \sqrt{\frac{b}{L}}}{\frac{b}{L} - \left(\frac{b}{L}\right)^2}\right]$$

Again, take $\Delta = 0$ if possible.

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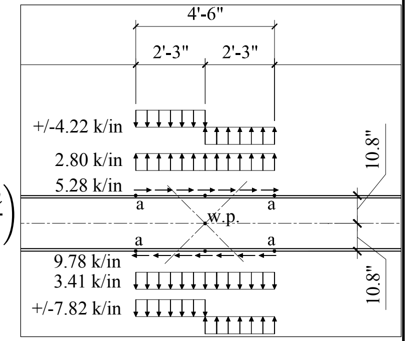
Beam Designers' Aid for Maximum Moment

Example 1 again (Fortney/Thornton, 2017)

Using: L_g =54 inches

$(\Sigma V)_T$ = -32.9 kips



Beam Loading at Chevron Connection (from Slides 52 and 53)

$$q = \left[\left(5.28\frac{k}{in}\right)(54in) - \left(-9.78\frac{k}{in}\right)(54in)\right]\left(\frac{10.8in}{54in}\right)$$

$q = [285 - (-531)](10.8/54)$ = 163 kip-inches/inch

$$(\Sigma V)_{T,eq} = 163\left(\frac{0.5-\sqrt{0.5}}{0.5-0.5^2}\right)$$ = -135 kips

Beam Designers' Aid for Maximum Moment

- Note that $(\Sigma V)_T$ and $(\Sigma V)_{T,\,eq}$ will always have the same sign. Since 135 > 32.9, $M_{SM} > M_{NVF}$.
- the NVF method is unconservative.

Beam Designers' Aid for Maximum Moment

- Remember that (from Slide 54):

$$M_{SM} = 3593 \text{ kip-inches}$$
&
$$M_{NVF} = 2772 \text{ kip-inches}$$

- So the $(\Sigma V)_{T,\,eq}$ formula predicts the correct result.

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Beam and Connection Designers Design Aid for Shear

- Exact solution for maximum shear:

$$V_{SM} = \frac{V_{IM}L - (\Sigma V)_T(0.5L - b)}{L}$$

- Remember that:

$$V_{IM} = \frac{2M_T}{L_g}$$

- This formula can be derived from Equation 33 of the Fortney/Thornton 2017 AISC Journal article.

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Beam and Connection Designers Design Aid for Shear

- Exact solution for maximum shear:

$$V_{SM} = \frac{V_{IM}L - (\Sigma V)_T(0.5L - b)}{L}$$

- Remember that:

$$V_{IM} = \frac{2M_T}{L_g}$$

- The only appearance of L_g in this formula is in V_{IM}. Neither M_T nor $(\Sigma V)_T$ depend on L_g.

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Beam and Connection Designers Design Aid for Shear

Example 1

From Slide 76:

M_T = 8777 kip-inches
L_g = 54 inches
$(\Sigma V)_T$ = -32.9 kips

$V_{IM} = 2M_T/L_g$ = 325 kips

From Slide 51:

L = 28 feet
b = 14 feet

$$V_{SM} = \frac{(325)(28) - (-32.9)(14 - 14)}{28} = 325 \text{ kips}$$

- This is the exact maximum beam shear.

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Beam and Connection Designers Design Aid for Shear

Example 2

Similarly (Refer to Slides 57-59):

V_{IM} = 119 kips
$(\Sigma V)_T$ = -75.8 kips
L = 25 feet
b = 9.5 feet

$$V_{SM} = \frac{(119)(25) - (-75.8)(12.5 - 9.5)}{25} = 128 \text{ kips}$$

- This is the exact maximum beam shear.

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Beam and Connection Designers Design Aid for Shear

- So, if an L_g is known (Connection Designer) or approximated, L_g = L/6 (Beam Designer), the beam true maximum shear, V_{SM} ,can be calculated fairly easily.

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Summary and Conclusions

The Chevron Effect – A Paradigm Shift

1. The NVF method especially under-estimates the beam shear.
2. The IM method can over- or under-estimate the beam moment.
3. Neither of the above methods can be relied upon to produce reliable results.
4. The SM method is the correct method to determine the shear and bending moment anywhere in the beam.
5. Design Aids for chevron connections are introduced to facilitate the use of the SM method by both beam designers and connection designers.

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Summary and Conclusions

The Chevron Effect – A Paradigm Shift

This presentation has been based on two papers which define the 'chevron effect' and 'paradigm shift' of the title. These are:

The **Chevron Effect** and the Analysis of Chevron Beams – A Paradigm Shift (2017)
Patrick J. Fortney and William A. Thornton
AISC Engineering Journal, Vol. 54, 4th Qtr., pp. 263- 296

The **Chevron Effect** – Not an Isolated Problem (2015)
Patrick J. Fortney and William A. Thornton
AISC Engineering Journal, Vol. 52, 2nd Qtr., pp. 125-163

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Summary and Conclusions

The Chevron Effect – A Paradigm Shift

For development of the design aids and the complete free body diagrams, refer to the two papers upon which this night school session is based.

The **Chevron Effect** and the Analysis of Chevron Beams – A Paradigm Shift (2017)
Patrick J. Fortney and William A. Thornton
AISC Engineering Journal, Vol. 54, 4th Qtr., pp. 263- 296

The **Chevron Effect** – Not an Isolated Problem (2015)
Patrick J. Fortney and William A. Thornton
AISC Engineering Journal, Vol. 52, 2nd Qtr., pp. 125-163

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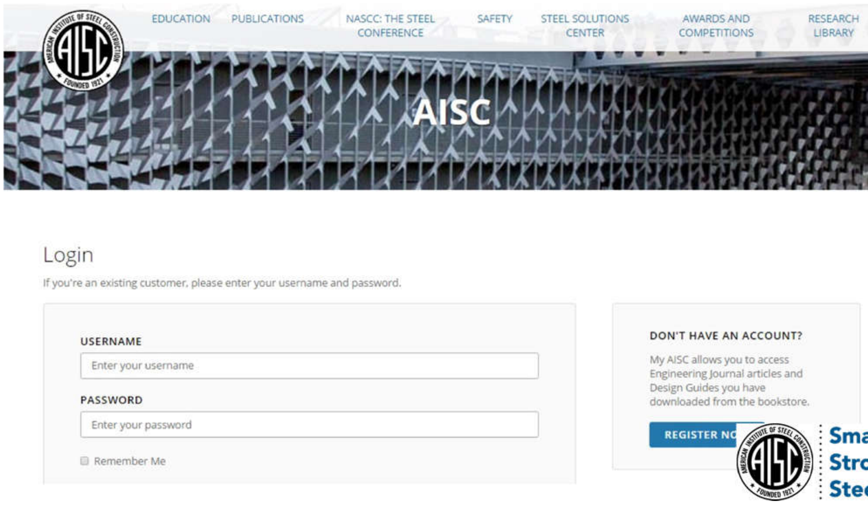

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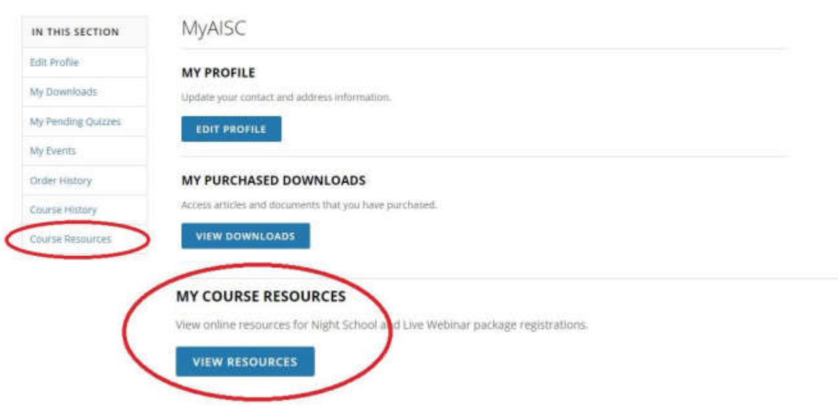

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Course Resources

Event	Start Date
NS 13 8-Session Package-Night School 13 - Design of Industrial Buildings	1/30/2017 7:00:00 PM
NS 14 8-Session Package-Night School 14 - Fundamentals of Stability	6/5/2017 7:00:00 PM

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Night School 13: Design of Industrial Buildings

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS13 - Design Criteria	1/30/2017 7:00:00 PM	Handouts	View Passcode: NS13DSN	Pass Score: 80	Pending
NS13 - Economic Considerations	2/6/2017 7:00:00 PM	Handouts	Available 02/08/2017 5pm EST	Available 02/08/2017 5pm EST	Pending
NS13 - Lateral Load Systems and Details	2/13/2017 7:00:00 PM	Handouts	Available 02/15/2017 5pm EST	Available 02/15/2017 5pm EST	Pending
NS13 - Preliminary Design Procedures	2/27/2017 7:00:00 PM	Handouts	Available 03/01/2017 5pm EST	Available 03/01/2017 5pm EST	Pending
NS13 - Crane Girder Design and Frame Analysis	3/6/2017 7:00:00 PM	Handouts	Available 03/08/2017 5pm EST	Available 03/08/2017 5pm EST	Pending
NS13 - Frame Member and Connection Design	3/13/2017 7:00:00 PM	Handouts	Available 03/15/2017 5pm EST	Available 03/15/2017 5pm EST	Pending
NS13 - Transfer Crane Girder & Longitudinal Bldg Bracing Dsn	3/27/2017 7:00:00 PM	Handouts	Available 03/29/2017 5pm EST	Available 03/29/	
NS13 - Building Envelope and Bracing Design	4/3/2017 7:00:00 PM	Handouts	Available 04/05/2017 5pm EST	Available 04/05/	
NS13 - Final Exam	4/10/2017 7:00:00 PM			Available 04/12/	

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