IDEA StatiCa®

Calculate yesterday's estimates

STIFFNESS ANALYSIS OF STEEL CONNECTIONS

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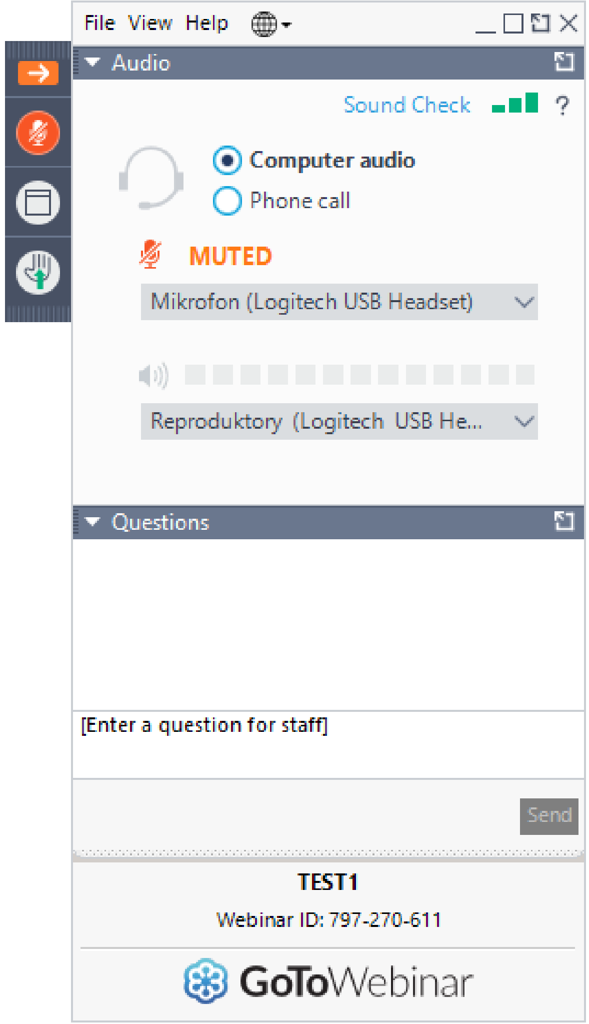
QUESTIONS



● Computer audio
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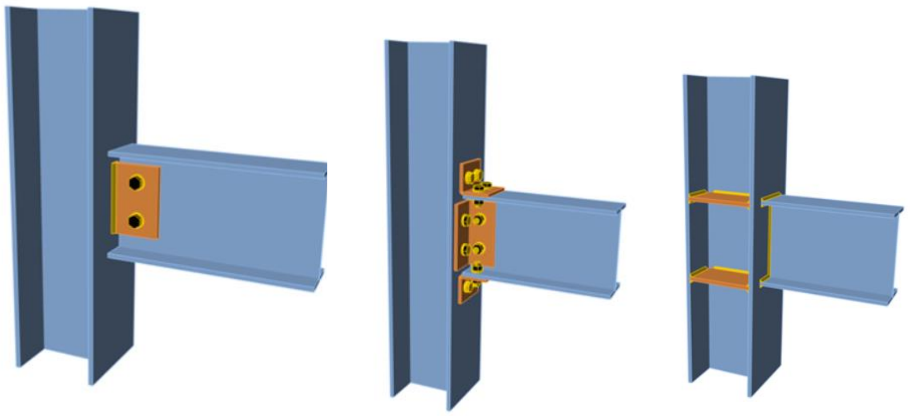
TEST1

Webinar ID: 797-270-611

AGENDA

a) Why calculating Stiffness analysis?
b) Classification of steel connections per AISC
c) Stiffness analysis in IDEA StatiCa
d) Stiffness value input in other apps
e) Moment diagram comparisons
f) IDEA Member



WHY CALCULATING STIFFNESS OF A STEEL CONNECTION?

① *We've got a bolted end plate connection that we want* ***to prove behaves effectively as fully restrained*** *as defined in AISC Commentary B3.4.*

② *I have a project where I'm reviewing the stiffness of a handful of connections.*

One of the connections has bolt group as shown below. We want ***to model the behavior of the bolt group and determine the moment that the semirigid connection would generate*** *on the verticals.*

Is this something that StatiCa can model?

The bolts are intended to be bearing bolts in standard holes (not slip-critical)

③ How do I **make sure** the beam flanges are welded to stiffeners or other column flanges to make sure I am getting **a moment connection** ?

WHY CALCULATING STIFFNESS OF A STEEL CONNECTION?

④ We use this to **assess stiffness of connection** like HSS moment connection with flange plate to get a **sense of rigidity** of the connection, but it'll consume of a lot of time **to input these values back in structural analysis software**. Unless when we deal with a very complex structures with moment connections then we will need to consider this rigorously.

⑤ How can **I analyze the rotation** that is happening at a connection on IDEA?

⑥ To get **moment-rotation** graphs for a verification studies

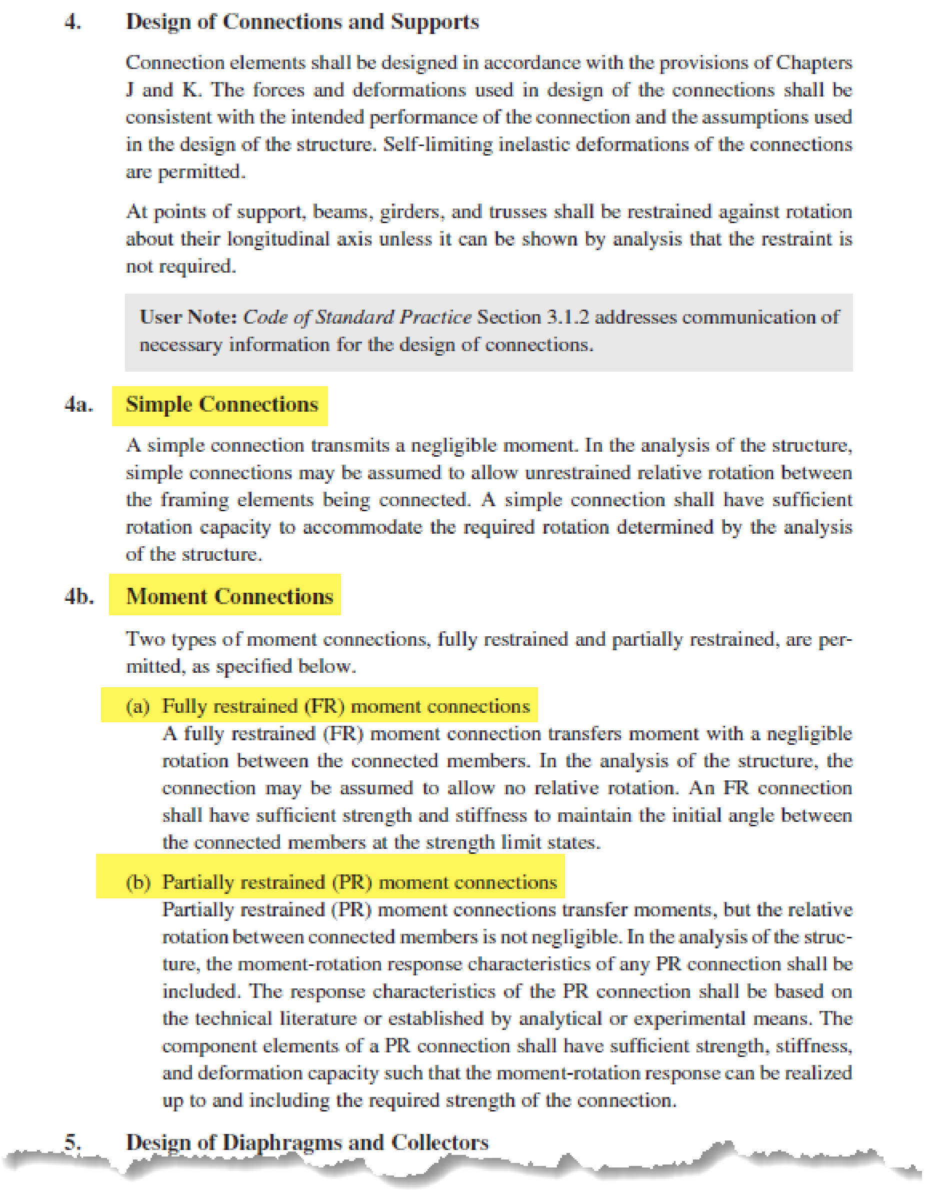
SUMMARY

- Ensure stiffness **assumptions** – prove that the connection is fully rigid or pinned
- Get **rotation** for the given moment and in some cases get **moment-rotation curves** for verification studies
- **Assessment** of members already constructed including the current connections
- Complex **member design with partially restrained connection**. Input spring rigidity in the global analysis software
- **Bridge** connection design – (deep girder compression flange bracing)

POLL QUESTION

CLASSIFICATION OF STEEL CONNECTIONS

AISC 360-22 CHAPTER B.4



4. Design of Connections and Supports

Connection elements shall be designed in accordance with the provisions of Chapters J and K. The forces and deformations used in design of the connections shall be consistent with the intended performance of the connection and the assumptions used in the design of the structure. Self-limiting inelastic deformations of the connections are permitted.

At points of support, beams, girders, and trusses shall be restrained against rotation about their longitudinal axis unless it can be shown by analysis that the restraint is not required.

> **User Note:** *Code of Standard Practice* Section 3.1.2 addresses communication of necessary information for the design of connections.

4a. Simple Connections

A simple connection transmits a negligible moment. In the analysis of the structure, simple connections may be assumed to allow unrestrained relative rotation between the framing elements being connected. A simple connection shall have sufficient rotation capacity to accommodate the required rotation determined by the analysis of the structure.

4b. Moment Connections

Two types of moment connections, fully restrained and partially restrained, are permitted, as specified below.

(a) Fully restrained (FR) moment connections

A fully restrained (FR) moment connection transfers moment with a negligible rotation between the connected members. In the analysis of the structure, the connection may be assumed to allow no relative rotation. An FR connection shall have sufficient strength and stiffness to maintain the initial angle between the connected members at the strength limit states.

(b) Partially restrained (PR) moment connections

Partially restrained (PR) moment connections transfer moments, but the relative rotation between connected members is not negligible. In the analysis of the structure, the moment-rotation response characteristics of any PR connection shall be included. The response characteristics of the PR connection shall be based on the technical literature or established by analytical or experimental means. The component elements of a PR connection shall have sufficient strength, stiffness, and deformation capacity such that the moment-rotation response can be realized up to and including the required strength of the connection.

5. Design of Diaphragms and Collectors

CLASSIFICATION OF STEEL CONNECTION PER AISC 360 CHAPTER B

Simple connections

- A **simple** connection transmits a negligible moment.
- Simple connections may be assumed to allow unrestrained relative rotation between the framing elements being connected.

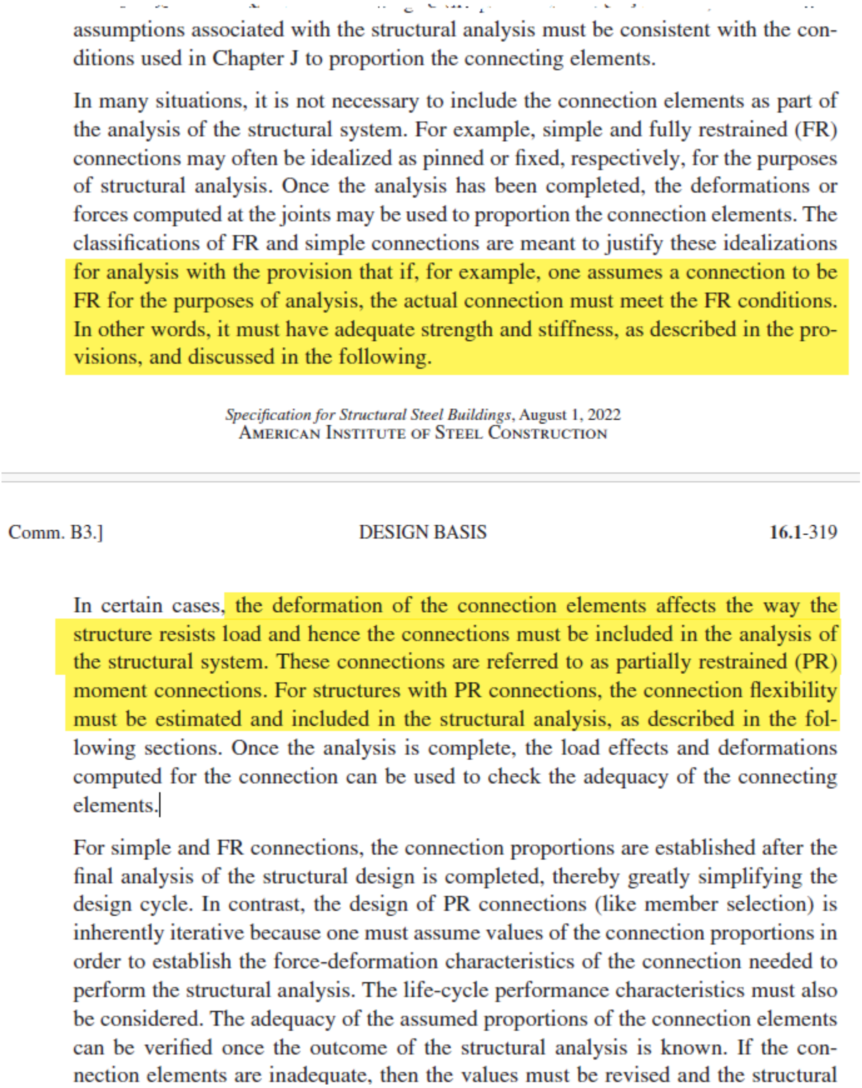
Moment connections

- **Fully restrained (FR)**
  - Transfers moment with a negligible rotation between the connected members.
  - The connection may be assumed to allow no relative rotation
- **Partially restrained (PR)**
  - Transfer moments, but the relative rotation between connected members is not negligible.
  - The response characteristics of the PR connection shall be based on the technical literature or established by analytical or experimental means.

AISC 360-22 COMMENTARY SECTION, CHAPTER B

We use assumptions to model the connections in our global analysis

- Simple= pinned joint
- Fully restrained = fixed joint
- Partially restrained = Fixed joint?



assumptions associated with the structural analysis must be consistent with the conditions used in Chapter J to proportion the connecting elements.

In many situations, it is not necessary to include the connection elements as part of the analysis of the structural system. For example, simple and fully restrained (FR) connections may often be idealized as pinned or fixed, respectively, for the purposes of structural analysis. Once the analysis has been completed, the deformations or forces computed at the joints may be used to proportion the connection elements. The classifications of FR and simple connections are meant to justify these idealizations for analysis with the provision that if, for example, one assumes a connection to be FR for the purposes of analysis, the actual connection must meet the FR conditions. In other words, it must have adequate strength and stiffness, as described in the provisions, and discussed in the following.

Specification for Structural Steel Buildings, August 1, 2022
American Institute of Steel Construction

Comm. B3.] DESIGN BASIS **16.1-319**

In certain cases, the deformation of the connection elements affects the way the structure resists load and hence the connections must be included in the analysis of the structural system. These connections are referred to as partially restrained (PR) moment connections. For structures with PR connections, the connection flexibility must be estimated and included in the structural analysis, as described in the following sections. Once the analysis is complete, the load effects and deformations computed for the connection can be used to check the adequacy of the connecting elements.

For simple and FR connections, the connection proportions are established after the final analysis of the structural design is completed, thereby greatly simplifying the design cycle. In contrast, the design of PR connections (like member selection) is inherently iterative because one must assume values of the connection proportions in order to establish the force-deformation characteristics of the connection needed to perform the structural analysis. The life-cycle performance characteristics must also be considered. The adequacy of the assumed proportions of the connection elements can be verified once the outcome of the structural analysis is known. If the connection elements are inadequate, then the values must be revised and the structural

Connection Classification. The basic assumption made in classifying connections is that the most important behavioral characteristics of the connection can be modeled by a moment-rotation, M-θ, curve. Figure C-B3.2 shows a typical M-θ curve. Implicit in the moment-rotation curve is the definition of the connection as being a region of the column and beam along with the connecting elements. The connection response is defined this way because the rotation of the member in a physical test is generally measured over a length that incorporates the contributions of not only the connecting elements, but also the ends of the members being connected and the column panel zone.

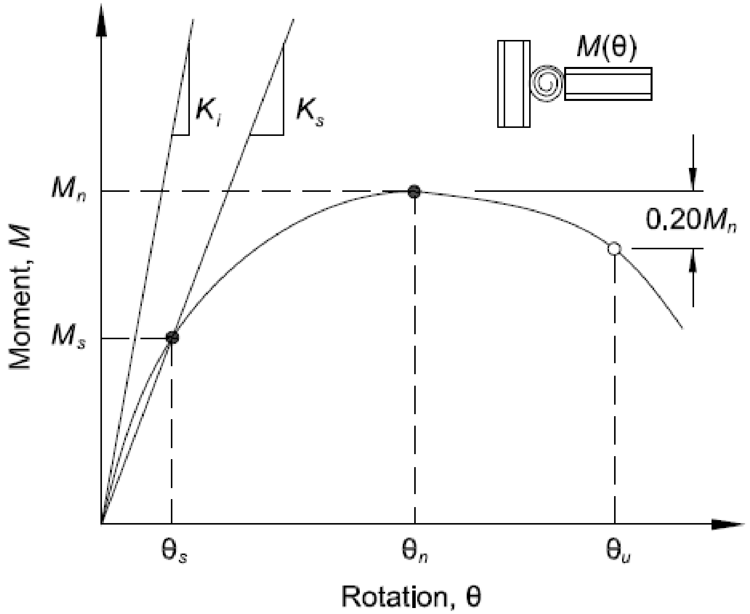


Fig. C-B3.2. Definition of stiffness, strength, and ductility characteristics of the moment-rotation response of a partially restrained connection.

Examples of connection classification schemes include those in Bjorhovde et al. (1990) and Eurocode 3 (CEN, 2005a). These classifications account directly for the stiffness, strength, and ductility of the connections.

Connection Stiffness. Because the nonlinear behavior of the connection manifests itself even at low moment-rotation levels, the initial stiffness of the connection, K_i, (shown in Figure C-B3.2) does not adequately characterize connection response at service levels. Furthermore, many connection types do not exhibit a reliable initial stiffness, or it exists only for a very small moment-rotation range. The secant stiffness, K_s, at service loads is taken as an index property of connection stiffness. Specifically,

$$K_s = M_s/\theta_s \qquad \text{(C-B3-7)}$$

where

M_s = moment at service loads, kip-in. (N-mm)

θ_s = rotation at service loads, rad

If $K_sL/EI \geq 20$, it is acceptable to consider the connection to be fully restrained (in other words, able to maintain the angles between members). If $K_sL/EI \leq 2$, it is acceptable to consider the connection to be simple (in other words, it rotates without developing moment). Connections with stiffnesses between these two limits are partially restrained and the stiffness, strength, and ductility of the connection must be considered in the design (Leon, 1994). Examples of FR, PR, and simple connection response curves are shown in Figure C-B3.3. The points marked θ_s indicate the service load states for the example connections and thereby define the secant stiffnesses for those connections.

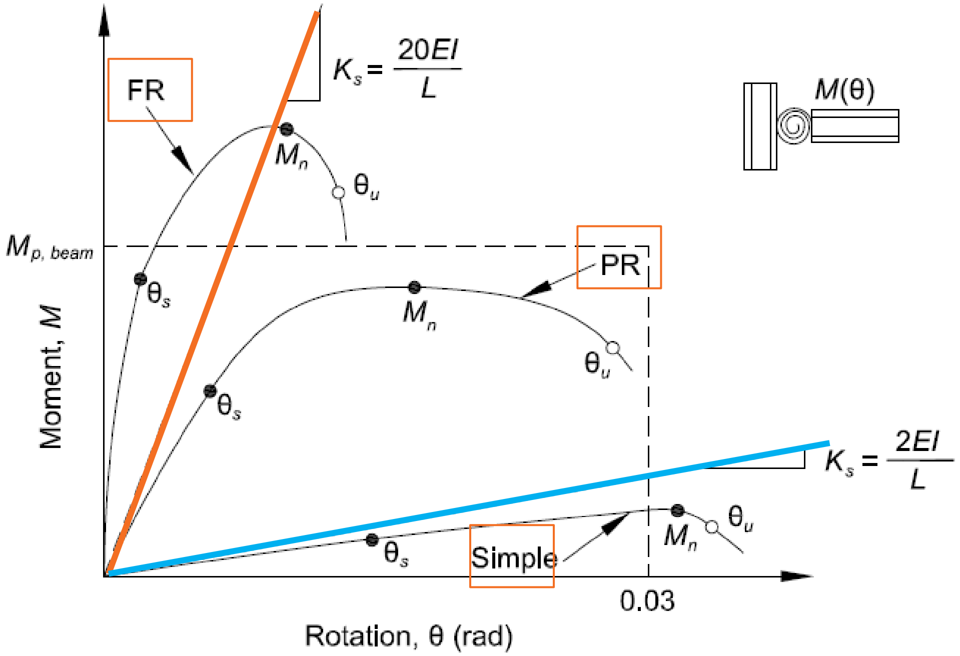
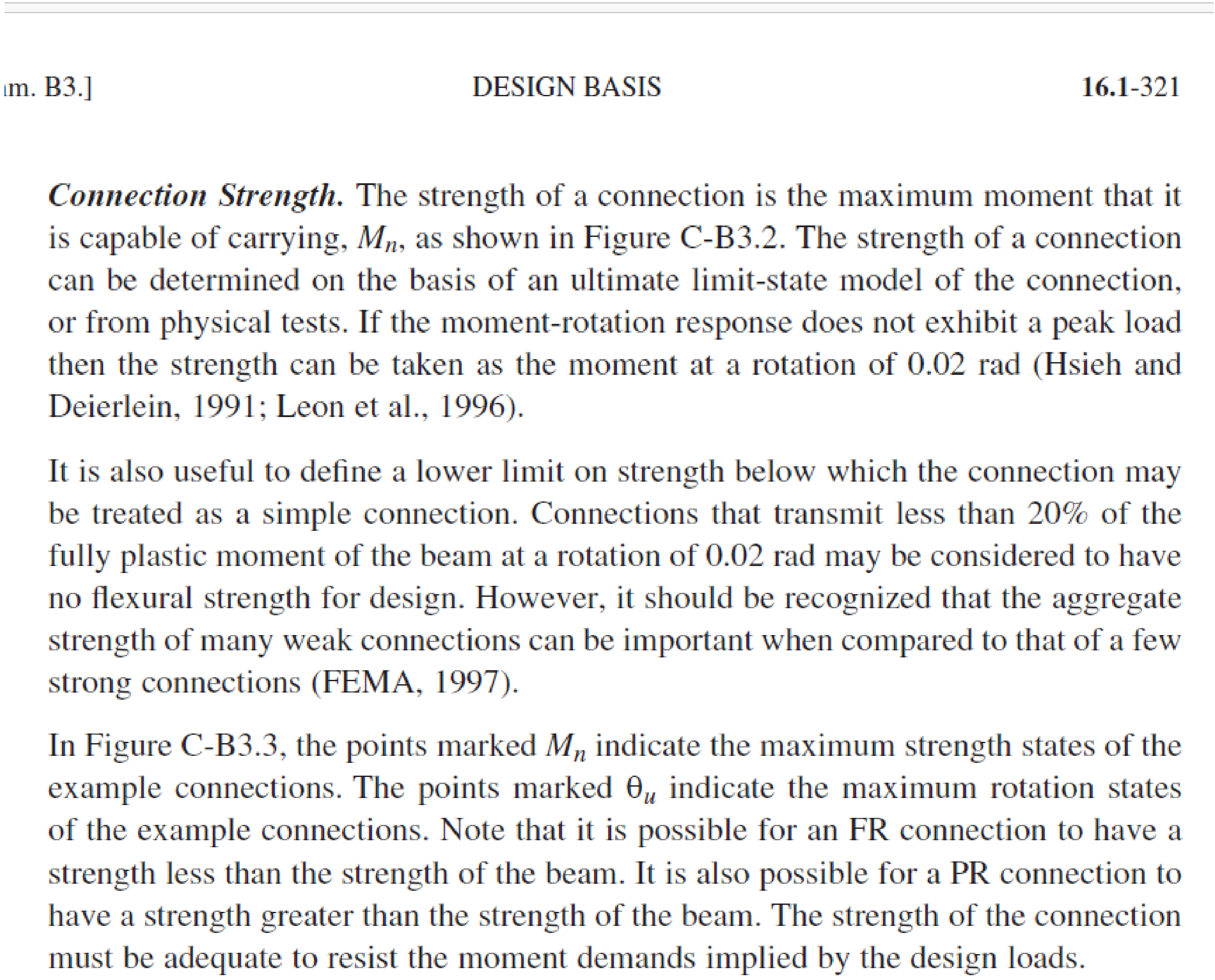


Fig. C-B3.3. Classification of moment-rotation response of fully restrained (FR), partially restrained (PR), and simple connections.

CONNECTION STRENGTH



Connection Strength. The strength of a connection is the maximum moment that it is capable of carrying, M_n, as shown in Figure C-B3.2. The strength of a connection can be determined on the basis of an ultimate limit-state model of the connection, or from physical tests. If the moment-rotation response does not exhibit a peak load then the strength can be taken as the moment at a rotation of 0.02 rad (Hsieh and Deierlein, 1991; Leon et al., 1996).

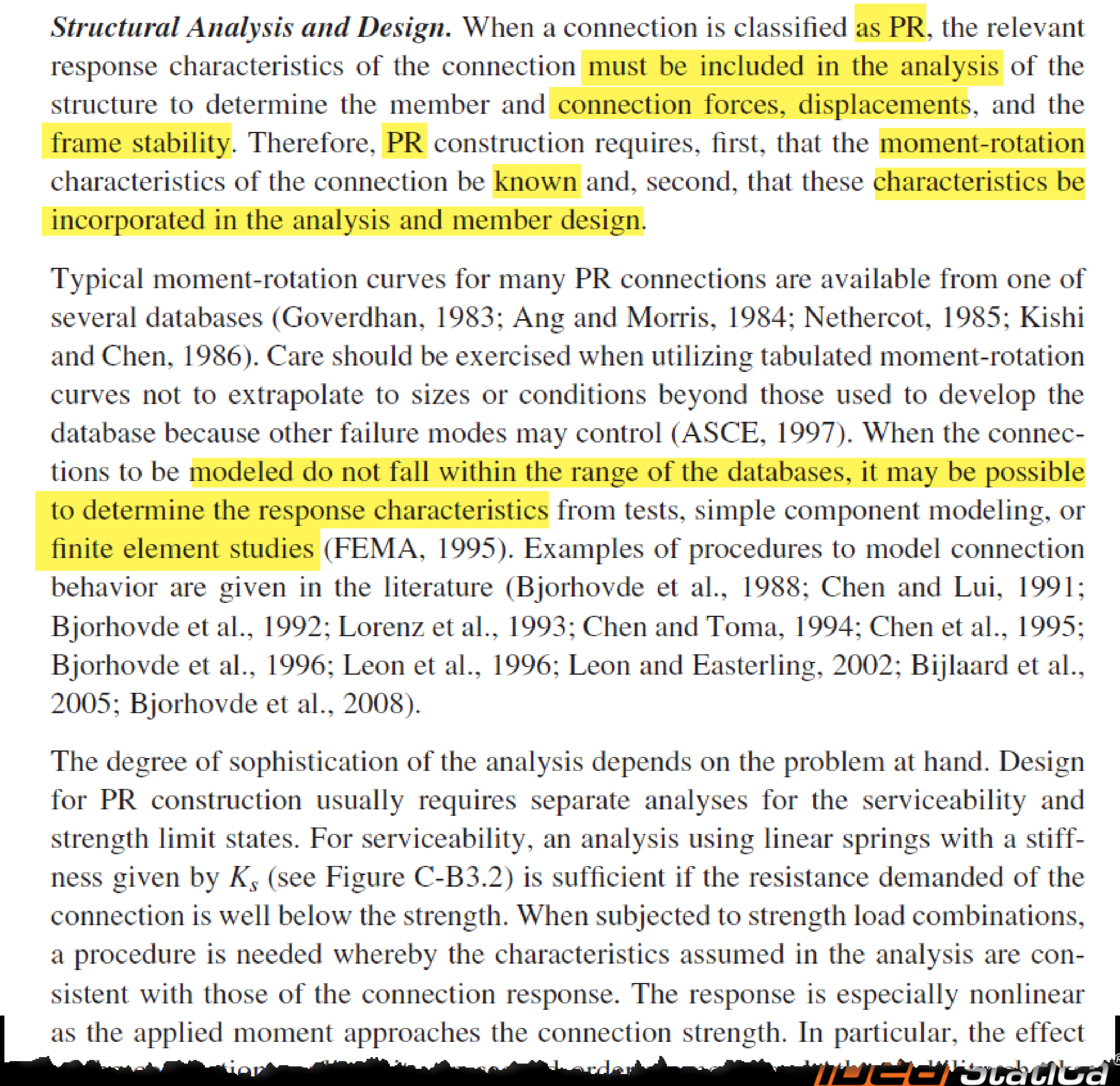
It is also useful to define a lower limit on strength below which the connection may be treated as a simple connection. Connections that transmit less than 20% of the fully plastic moment of the beam at a rotation of 0.02 rad may be considered to have no flexural strength for design. However, it should be recognized that the aggregate strength of many weak connections can be important when compared to that of a few strong connections (FEMA, 1997).

In Figure C-B3.3, the points marked M_n indicate the maximum strength states of the example connections. The points marked θ_u indicate the maximum rotation states of the example connections. Note that it is possible for an FR connection to have a strength less than the strength of the beam. It is also possible for a PR connection to have a strength greater than the strength of the beam. The strength of the connection must be adequate to resist the moment demands implied by the design loads.

STRUCTURAL ANALYSIS AND DESIGN

AISC 360-22 COMMENTARY SECTION B3

- Moment-rotation characteristics of PR connections must be included in the analysis
- When the connections do not fall within the databases ranges, it may be possible to use Finite element studies



Structural Analysis and Design. When a connection is classified as PR, the relevant response characteristics of the connection must be included in the analysis of the structure to determine the member and connection forces, displacements, and the frame stability. Therefore, PR construction requires, first, that the moment-rotation characteristics of the connection be known and, second, that these characteristics be incorporated in the analysis and member design.

Typical moment-rotation curves for many PR connections are available from one of several databases (Goverdhan, 1983; Ang and Morris, 1984; Nethercot, 1985; Kishi and Chen, 1986). Care should be exercised when utilizing tabulated moment-rotation curves not to extrapolate to sizes or conditions beyond those used to develop the database because other failure modes may control (ASCE, 1997). When the connections to be modeled do not fall within the range of the databases, it may be possible to determine the response characteristics from tests, simple component modeling, or finite element studies (FEMA, 1995). Examples of procedures to model connection behavior are given in the literature (Bjorhovde et al., 1988; Chen and Lui, 1991; Bjorhovde et al., 1992; Lorenz et al., 1993; Chen and Toma, 1994; Chen et al., 1995; Bjorhovde et al., 1996; Leon et al., 1996; Leon and Easterling, 2002; Bijlaard et al., 2005; Bjorhovde et al., 2008).

The degree of sophistication of the analysis depends on the problem at hand. Design for PR construction usually requires separate analyses for the serviceability and strength limit states. For serviceability, an analysis using linear springs with a stiffness given by K_s (see Figure C-B3.2) is sufficient if the resistance demanded of the connection is well below the strength. When subjected to strength load combinations, a procedure is needed whereby the characteristics assumed in the analysis are consistent with those of the connection response. The response is especially nonlinear as the applied moment approaches the connection strength. In particular, the effect

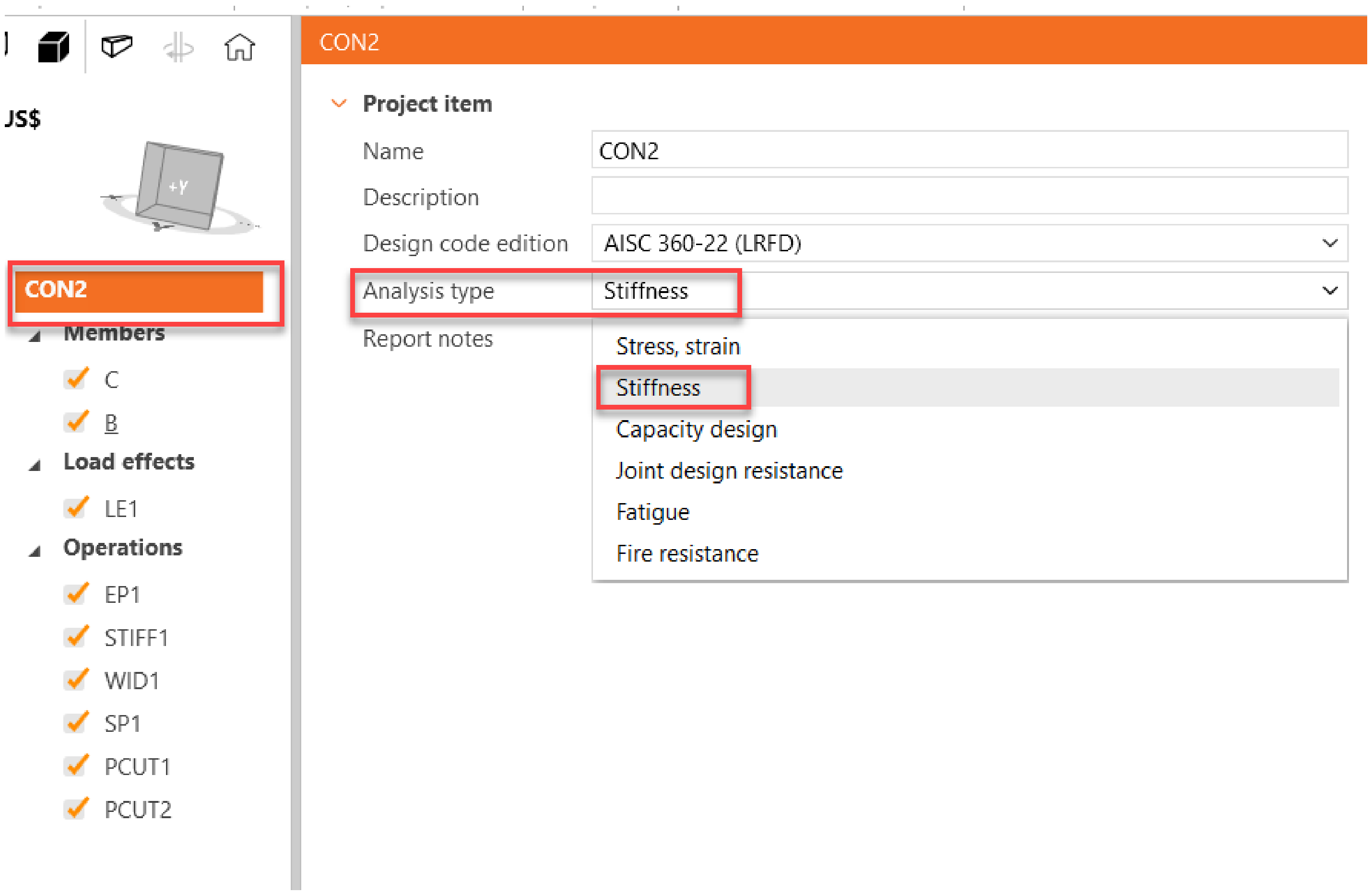
STIFFNESS ANALYSIS IN IDEA STATICA

STEP BY STEP

Tutorial

1. Perform Stress/strain analysis first, to ensure correct modeling
2. Copy the connection and change the analysis type to Stiffness analysis
3. Select the analyzed member, only one member in the joint can be analyzed
4. Stiffness lengths
5. Input moment force/axial force, depending what value of stiffness is needed. It is recommended to input only one force in the analyzed member
6. Calculate and review results

2. CHANGE THE ANALYSIS TYPE



Name: CON2

Description:

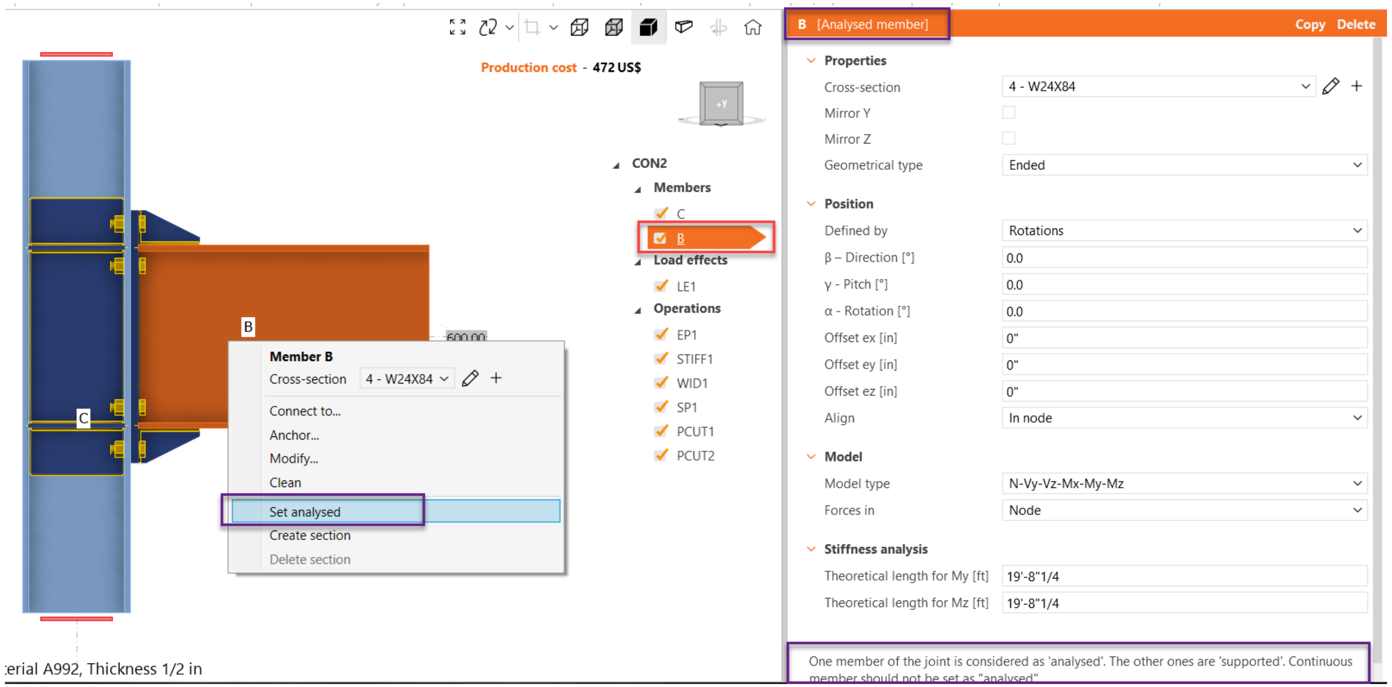
Design code edition: AISC 360-22 (LRFD)

Analysis type: Stiffness

Report notes

3. SELECT THE ANALYZED MEMBER

Rotational/axial stiffness is analyzed only for one member



Cross-section: 4 - W24X84

Mirror Y: ☐

Mirror Z: ☐

Geometrical type: Ended

Defined by: Rotations

β – Direction [°]: 0.0

γ - Pitch [°]: 0.0

α - Rotation [°]: 0.0

Offset ex [in]: 0"

Offset ey [in]: 0"

Offset ez [in]: 0"

Align: In node

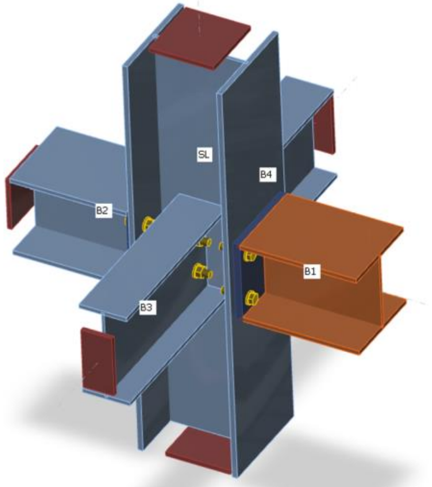
Model type: N-Vy-Vz-Mx-My-Mz

Forces in: Node

Theoretical length for My [ft]: 19'-8"1/4

Theoretical length for Mz [ft]: 19'-8"1/4

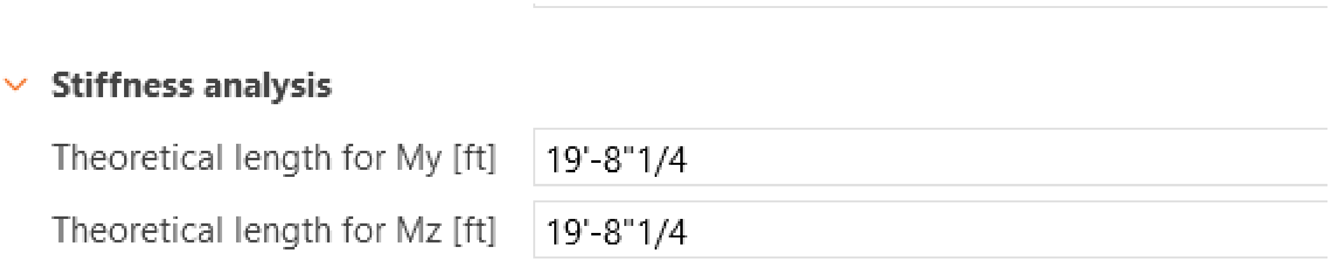
One member of the joint is considered as 'analysed'. The other ones are 'supported'. Continuous member should not be set as "analysed"



4. STIFFNESS LENGTHS

It can be compared to the buckling lengths

These are the geometric distances between supports for the purpose of the bending of the element



Stiffness analysis

Theoretical length for My [ft] 19'-8"1/4

Theoretical length for Mz [ft] 19'-8"1/4

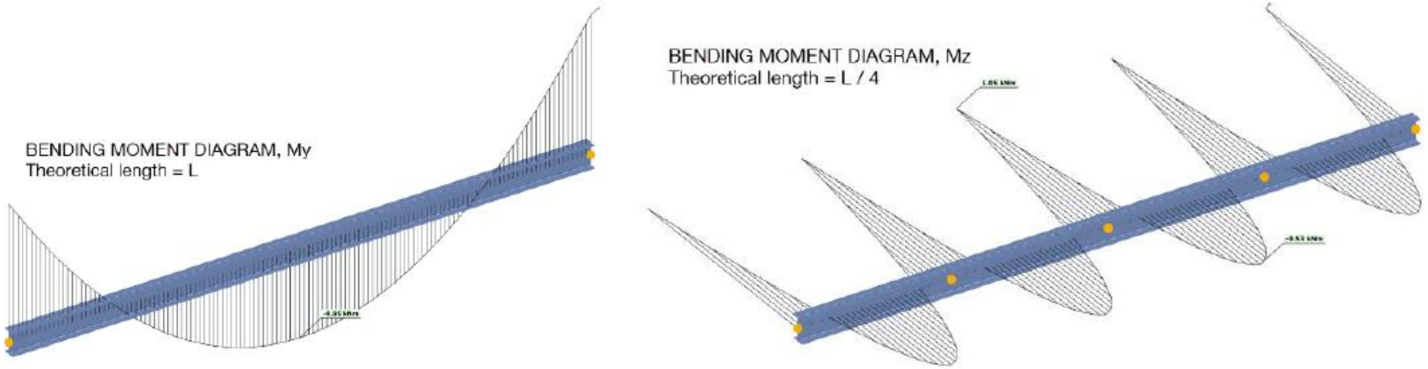


Figure 06.9. Comparison of theoretical lengths for My and Mz of the stiffness analysis.

5. INPUT MOMENT/AXIAL FORCES

Stiffness analysis is an **incremental** and **iterative** process, only **one** member is analyzed

IDEA StatiCa calculates **rotational** and **axial** stiffness

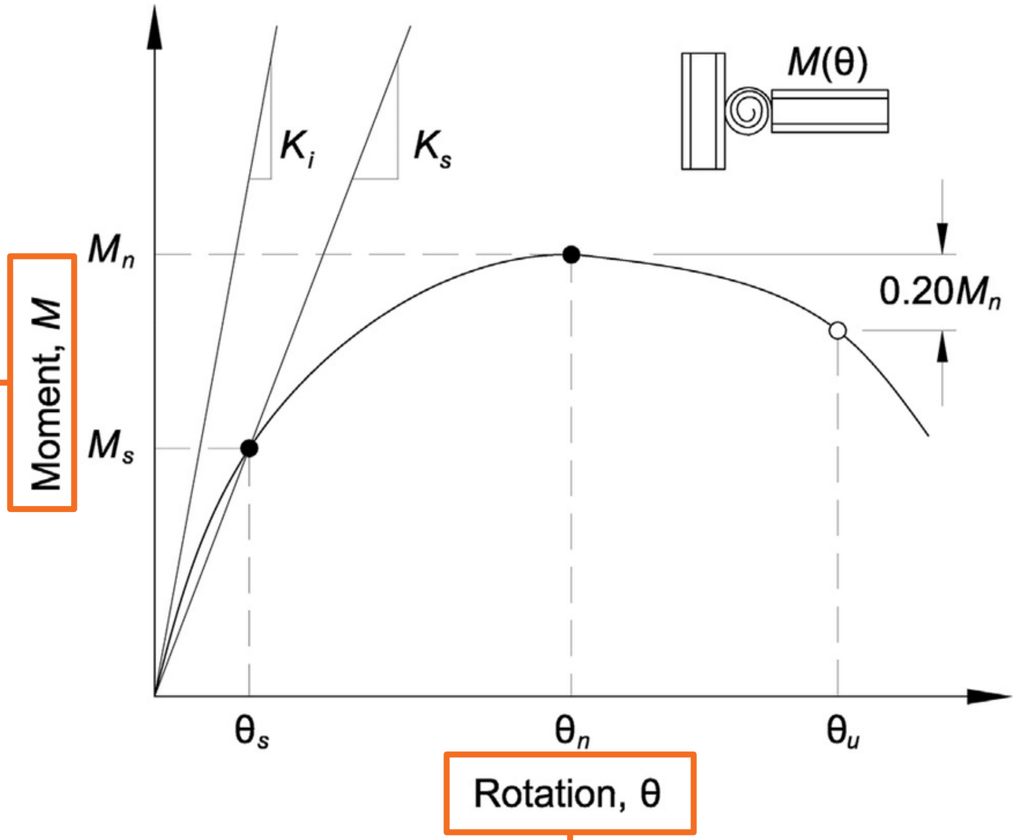
The user activates the required calculation by the **input** forces

My=Rotational stiffness around local axis Y

Mz=Rotational stiffness around local axis z

N= Axial stiffness in the longitudinal axis

ANALYSIS BEHIND THE SCENES



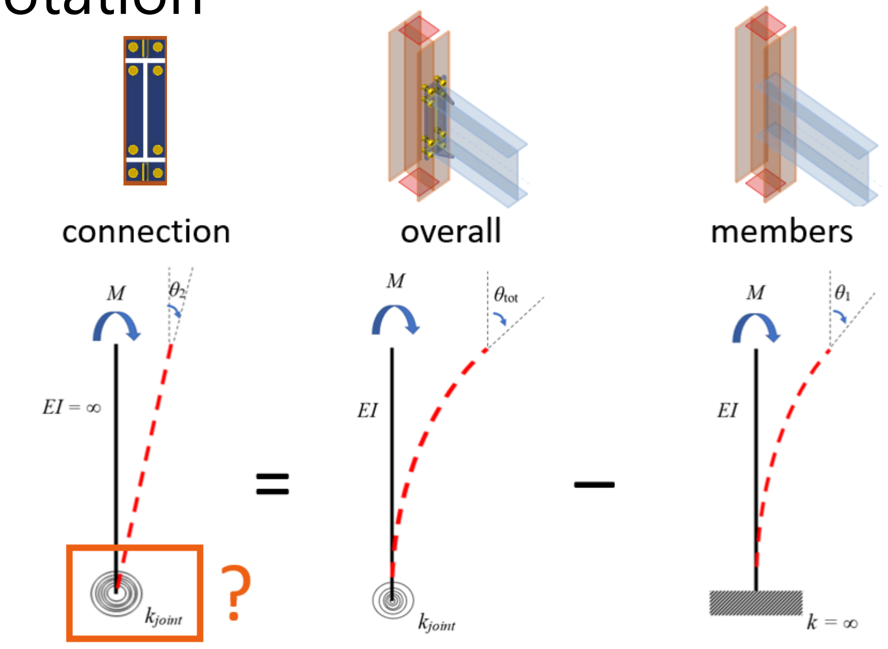
2. Connection ultimate resistance
(Joint design resistance analysis)

1. Moment - Rotation calculation

ANALYSIS

1. Moment-rotation curve

The software applies load steps (bending moment) and evaluates the rotation



$$k_{joint} = M / \theta_2 = M / (\theta_{tot} - \theta_1)$$

The software estimates the deformation capacity as a point where one of the following conditions is achieved, to get the **ultimate rotation capacity**

Bolt or anchor resistance in tension, shear, or tension/shear interaction is reached

Weld resistance is reached

Plastic strain in plates is **15%**

ANALYSIS

2. Connection ultimate resistance

To get representative stiffness values, it is important to get **the maximum capacity of the connection**

A third analysis is done, like Joint design resistance

DR analyses conduct checks for the following components:

Plastic strain in plates **5%**

Bolts – shear, tension, and a combination of tension and shear

Anchors – tension and shear steel resistance

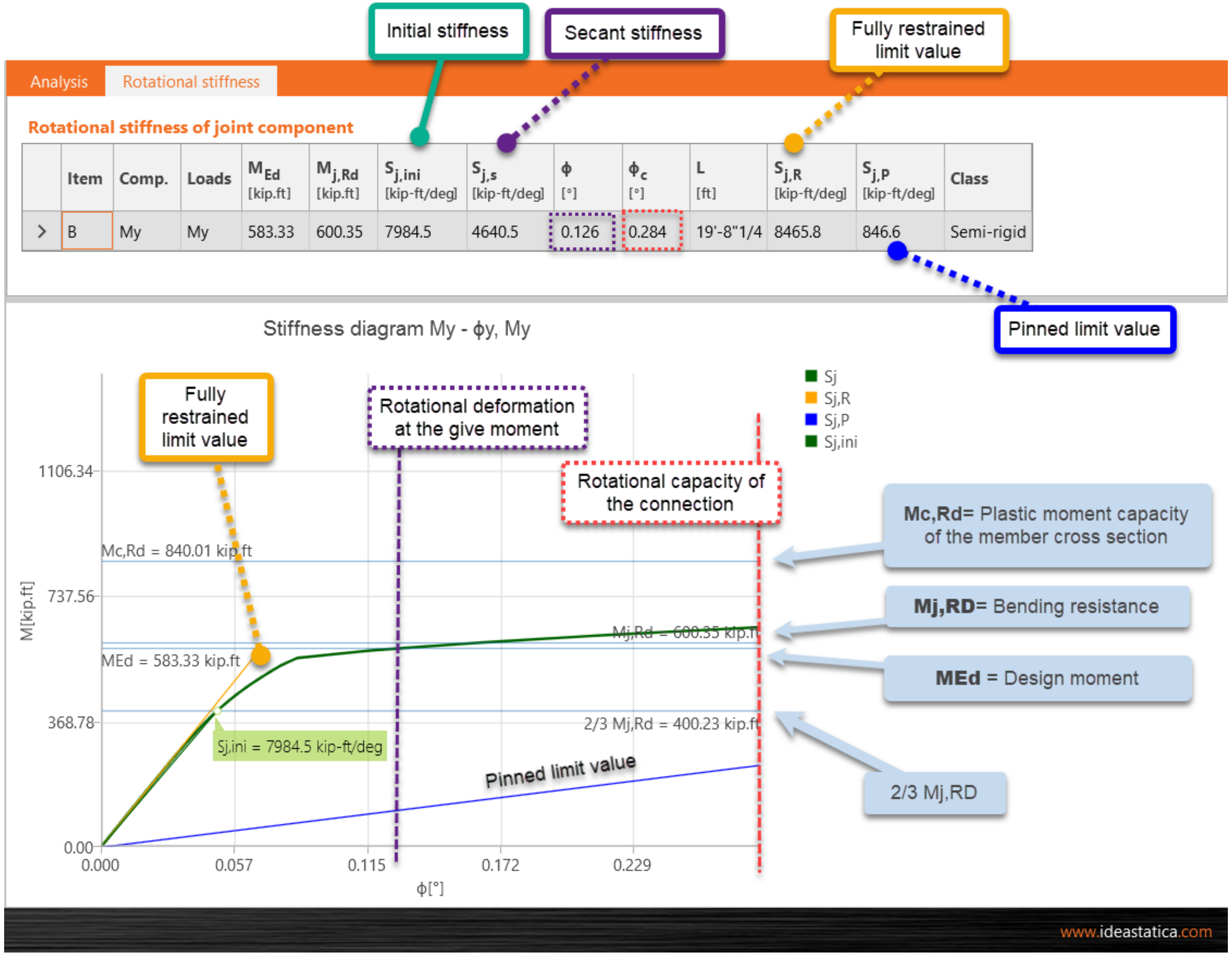
Welds

6. RESULTS

Sj, ini - Initial stiffness= Stiffness value where the behavior of the connection still linear. The stiffness is estimated using 2/3 of Mj,RD.

Sj,s - Secant stiffness= Value of the stiffness calculated as the intersection of the input design moment

$$S_{j,s} = M_{Ed}/\Phi$$



Analysis | Rotational stiffness

Rotational stiffness of joint component

	Item	Comp.	Loads	M_{Ed} [kip.ft]	$M_{j,Rd}$ [kip.ft]	$S_{j,ini}$ [kip-ft/deg]	$S_{j,s}$ [kip-ft/deg]	ϕ [°]	ϕ_c [°]	L [ft]	$S_{j,R}$ [kip-ft/deg]	$S_{j,P}$ [kip-ft/deg]	Class
>	B	My	My	583.33	600.35	7984.5	4640.5	0.126	0.284	19'-8"1/4	8465.8	846.6	Semi-rigid

Initial stiffness

Secant stiffness

Fully restrained limit value

Pinned limit value

Stiffness diagram My - ϕy, My

Fully restrained limit value

Rotational deformation at the give moment

Rotational capacity of the connection

Mc,Rd= Plastic moment capacity of the member cross section

Mj,RD= Bending resistance

MEd = Design moment

2/3 Mj,RD

IDEA StatiCa®

DEFINITIONS OF THE RESULTS

In the following list, each of the different parameters obtained from this analysis is detailed:

Item: Name given to the element being analysed, in this case, Beam B.

Comp.: Component of internal force for which the rotational stiffness is being evaluated. As men-tioned, it may be for My or for Mz. In the event that both have been evaluated, a row will appear in the table for each of them. Depending on the line that's selected, the stiffness diagram will be for one or the other component.

Loads: Specifies the name of the load combination that's been introduced to perform the analysis. In the event of there being various combinations, a line will appear in the table for each of them.

For this reason, as stated, it doesn't make sense to enter various combinations; it's enough to introduce one initial combination with an arbitrary value for the bending moment, given that, otherwise, the same analysis would be done multiple times, without obtaining any advantage.

MEd: Design bending moment introduced in the load combination. This value will only have any relevance if the secant stiffness is being evaluated, as will be seen further on.

Mj,Rd: Resistant moment, or bending resistance, of the connection, for the purpose of the connection's yielding. As can be seen in the graphic, the connection still has a reserve of ductility and rotational capacity after this ultimate moment although, evidently, it would no longer satisfy the check of 5% plastic strain.

Mc, Rd: This is only provided on the Stiffness Diagram. It represents the value of the ultimate plastic moment of the cross-section of the analyzed element. It provides a general idea of how resistant the connection is in relation to the ultimate moment of the element.

In the case of connections designed to capacity, it's evident that Mj,Rd has to be superior to Mc, Rd, in order to meet the condition that the connection should be more resistant than the ultimate plastic moment of the beam.

DEFINITION OF THE RESULTS

Sj,ini: Value of initial rotational stiffness. As can been seen in Figure 06.15, the rotation curve of the connection could be split into two areas: a first area in which the stiffness is linear; and a second in which the stiffness has a behavior that is highly non-linear.

Usually, this linear section can be defined as the stiffness of the connection up to a value of 2/3 of the ultimate moment of the connection, that is, this linear stiffness behaviour tends to be maintained up to a value of 2/3 Mj,Rd.

As it's linear, the stiffness value does not depend on the bending moment of the load, given that the gradient of the curve will remain, more or less, constant.

Sj,s: Value of secant rotational stiffness. From this value of 2/3 of Mj,Rd, the gradient of the curve changes rapidly and it can no longer be considered that it maintains a constant value of stiffness. Therefore, the Code establishes a second stiffness value, secant, defined as the intersection of the design bending moment, MEd, and the stiffness curve of the connection, Sj.

In this case, the secant stiffness value is highly dependent on the value of the bending moment and it would be necessary to use an iterative analysis in order to estimate the final stiffness of the connection.

Φ: Rotational deformation obtained for the design bending moment, MEd, introduced. This deformation is obtained as the intersection of the stiffness curve, Sj, and the bending moment.

Φc: Rotational capacity of the connection. That is, the ultimate rotational deformation that the connection would have.

L: Length value of the analysed element. As has been mentioned, this length is only relevant from the point of view of obtaining the pinned and rigid limits, as well as for the corresponding classification of the connection.

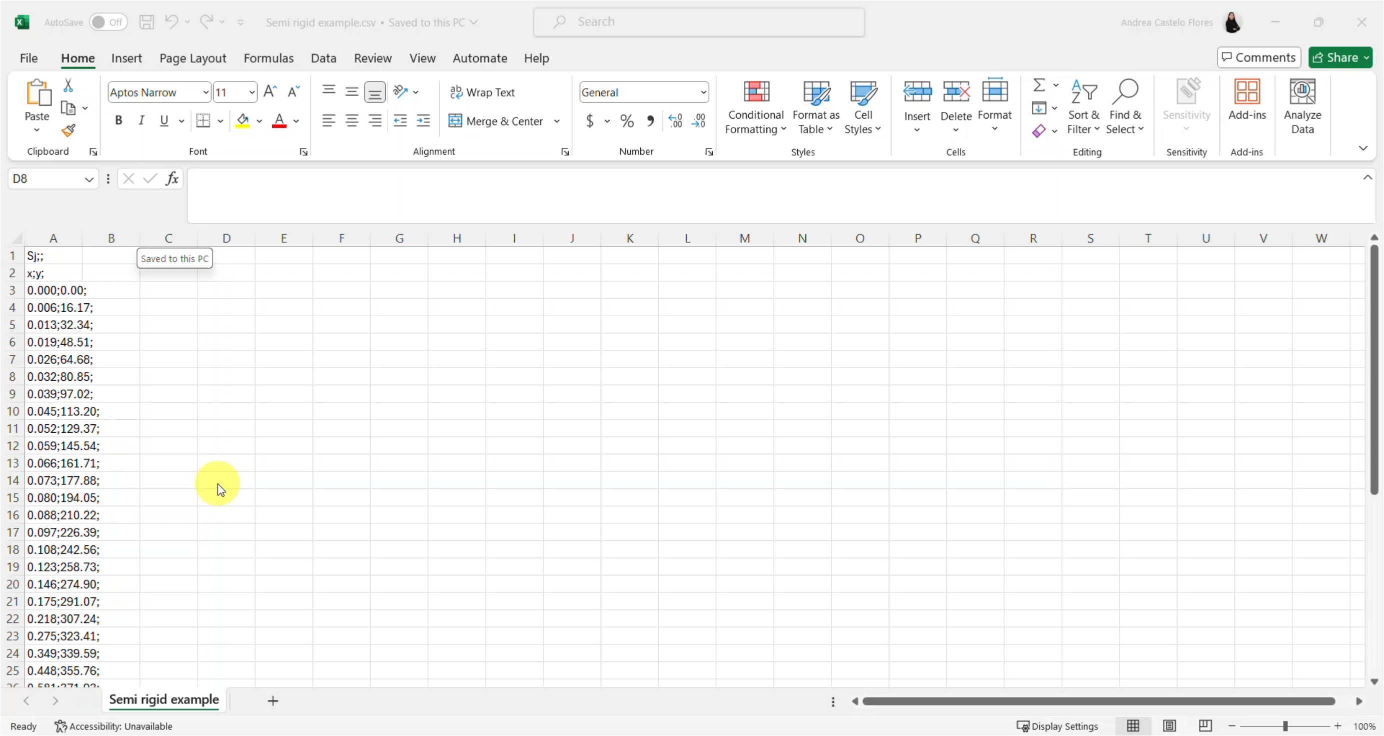
Sj,R: Stiffness value for the boundary between Rigid and Semi-rigid

Sj,P: Stiffness value for the boundary between Semi-Rigid and Pinned.

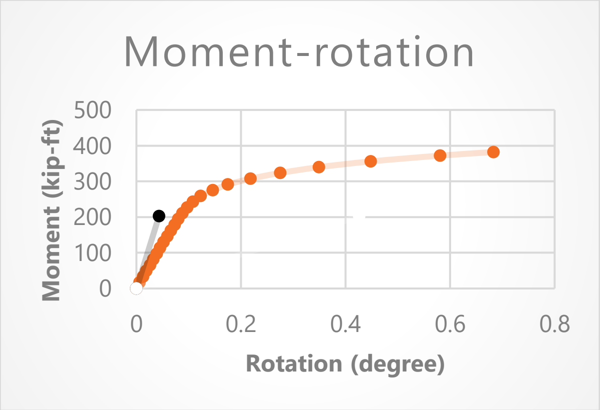
Class: Depending on the stiffness obtained in relation to the limits calculated, the connection will be classified as Rigid, Semi-rigid or Pinned. Clearly, if the connection is semi-rigid, the stiffness value obtained will be a value falling within the interval defined by Sj,R and Sj,P.

MOMENT-ROTATION CURVE EXPORT TO CSV/DXF/JPG

1. Right click on the graph, select CSV
2. Open it in Excel
3. Convert text to columns
4. Plot the graph



	A
1	Sj;;
2	x;y;
3	0.000;0.00;
4	0.006;16.17;
5	0.013;32.34;
6	0.019;48.51;
7	0.026;64.68;
8	0.032;80.85;
9	0.039;97.02;
10	0.045;113.20;
11	0.052;129.37;
12	0.059;145.54;
13	0.066;161.71;
14	0.073;177.88;
15	0.080;194.05;
16	0.088;210.22;
17	0.097;226.39;
18	0.108;242.56;
19	0.123;258.73;
20	0.146;274.90;
21	0.175;291.07;
22	0.218;307.24;
23	0.275;323.41;
24	0.349;339.59;
25	0.448;355.76;



AISC DEFINITION

Examples of connection classification schemes include those in Bjorhovde et al. (1990) and Eurocode 3 (CEN, 2005a). These classifications account directly for the stiffness, strength, and ductility of the connections.

Connection Stiffness. Because the nonlinear behavior of the connection manifests itself even at low moment-rotation levels, the initial stiffness of the connection, K_i, (shown in Figure C-B3.2) does not adequately characterize connection response at service levels. Furthermore, many connection types do not exhibit a reliable initial stiffness, or it exists only for a very small moment-rotation range. The secant stiffness, K_s, at service loads is taken as an index property of connection stiffness. Specifically,

$$K_s = M_s/\theta_s \qquad \text{(C-B3-7)}$$

where

M_s = moment at service loads, kip-in. (N-mm)

θ_s = rotation at service loads, rad

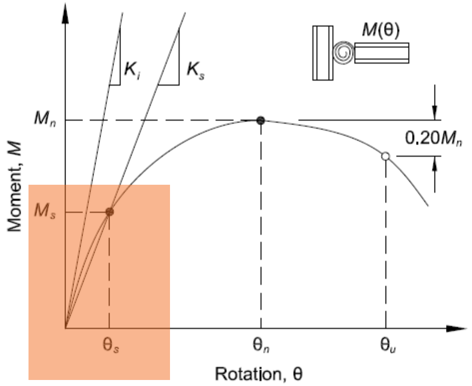


Fig. C-B3.2. Definition of stiffness, strength, and ductility characteristics of the moment-rotation response of a partially restrained connection.

If $K_sL/EI \geq 20$, it is acceptable to consider the connection to be fully restrained (in other words, able to maintain the angles between members). If $K_sL/EI \leq 2$, it is acceptable to consider the connection to be simple (in other words, it rotates without developing moment). Connections with stiffnesses between these two limits are partially restrained and the stiffness, strength, and ductility of the connection must be considered in the design (Leon, 1994). Examples of FR, PR, and simple connection response curves are shown in Figure C-B3.3. The points marked θ_s indicate the service load states for the example connections and thereby define the secant stiffnesses for those connections.

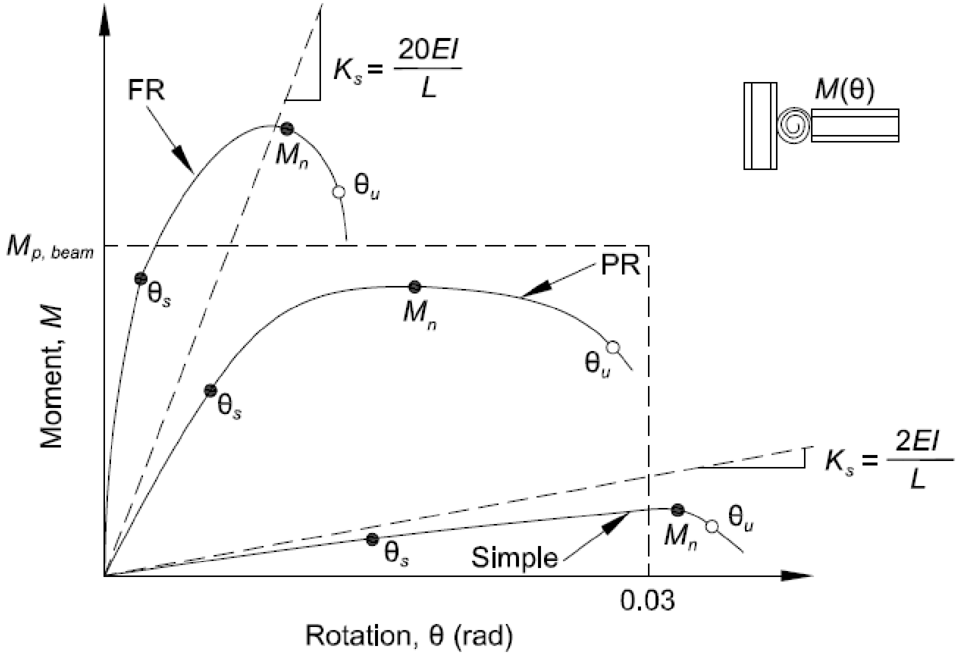
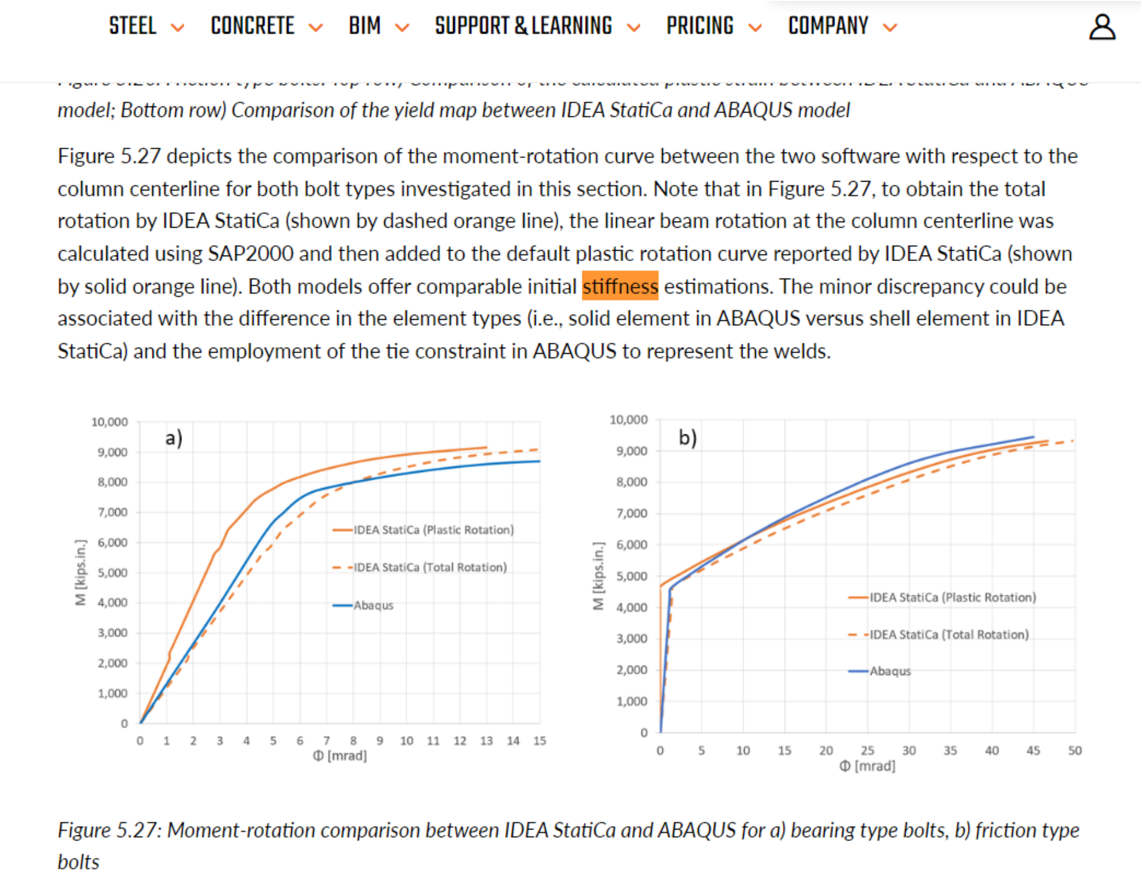


Fig. C-B3.3. Classification of moment-rotation response of fully restrained (FR), partially restrained (PR), and simple connections.

VERIFICATION STUDIES: PREQUALIFIED CONNECTIONS

[Prequalified Steel Connections (AISC) - Summary, Conclusion, and Recommendations]



model; Bottom row) Comparison of the yield map between IDEA StatiCa and ABAQUS model

Figure 5.27 depicts the comparison of the moment-rotation curve between the two software with respect to the column centerline for both bolt types investigated in this section. Note that in Figure 5.27, to obtain the total rotation by IDEA StatiCa (shown by dashed orange line), the linear beam rotation at the column centerline was calculated using SAP2000 and then added to the default plastic rotation curve reported by IDEA StatiCa (shown by solid orange line). Both models offer comparable initial stiffness estimations. The minor discrepancy could be associated with the difference in the element types (i.e., solid element in ABAQUS versus shell element in IDEA StatiCa) and the employment of the tie constraint in ABAQUS to represent the welds.

Figure 5.27: Moment-rotation comparison between IDEA StatiCa and ABAQUS for a) bearing type bolts, b) friction type bolts

WHAT TO DO WITH THE RESULTS?

Confirm assumptions: Pinned or rigid

If Partially restrained, input Stiffness value in the global analysis software to model the actual behavior of the connection and re-calculate member design

After the Stiffness analysis is done, you can set the rotational stiffness in joints of the global analysis model. You can import it

as a single value

- if M_{ed} is lower than 2/3 $M_{j,Rd}$ you can directly use Initial Stiffness of connection
- if M_{ed} is higher than 2/3 $M_{j,Rd}$ - iteration process

or as a non-linear function

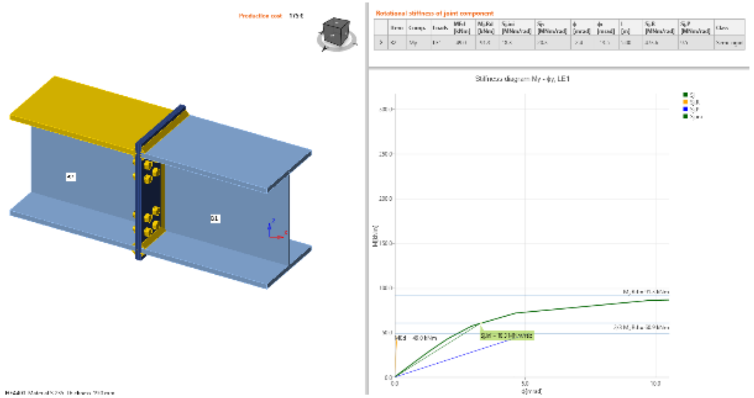
MOMENT-ROTATION CHARACTERISTICS IN GLOBAL ANALYSIS SOFTWARE

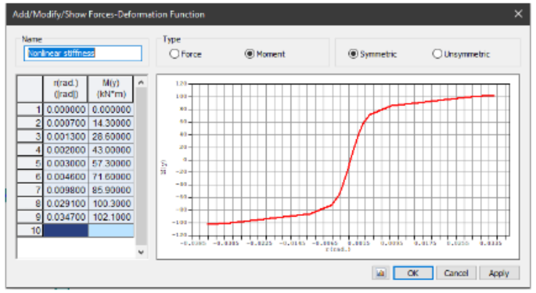
① Moment/rotation plot - Nonlinear spring

SAP 2000

ETABS

Midas





Add/Modify/Show Forces-Deformation Function

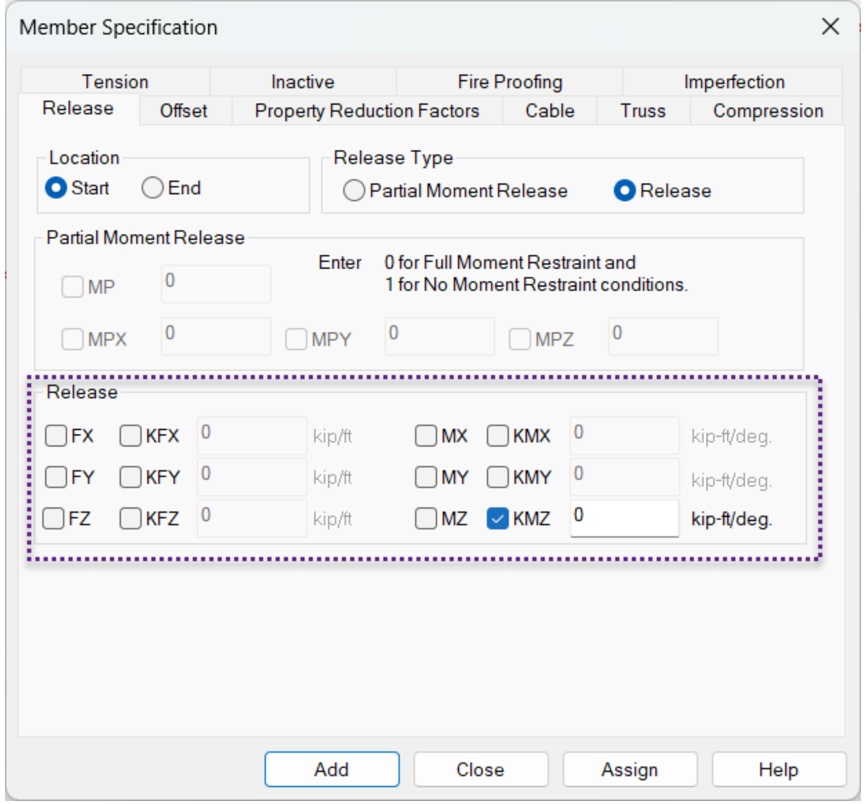
Name: Nonlinear stiffness

Type: ○ Force ● Moment

● Symmetric ○ Unsymmetric

	r(rad.) (rad)	M(y) (kN*m)
1	0.000000	0.000000
2	0.000700	14.30000
3	0.001300	28.60000
4	0.002000	43.00000
5	0.003000	57.30000
6	0.004600	71.60000
7	0.009800	85.90000
8	0.029100	100.3000
9	0.034700	102.1000
10		

② Single value - Linear spring



Member Specification

Location: ● Start ○ End

Release Type: ○ Partial Moment Release ● Release

Partial Moment Release

Enter 0 for Full Moment Restraint and 1 for No Moment Restraint conditions.

☐ MP 0

☐ MPX 0 ☐ MPY 0 ☐ MPZ 0

Release

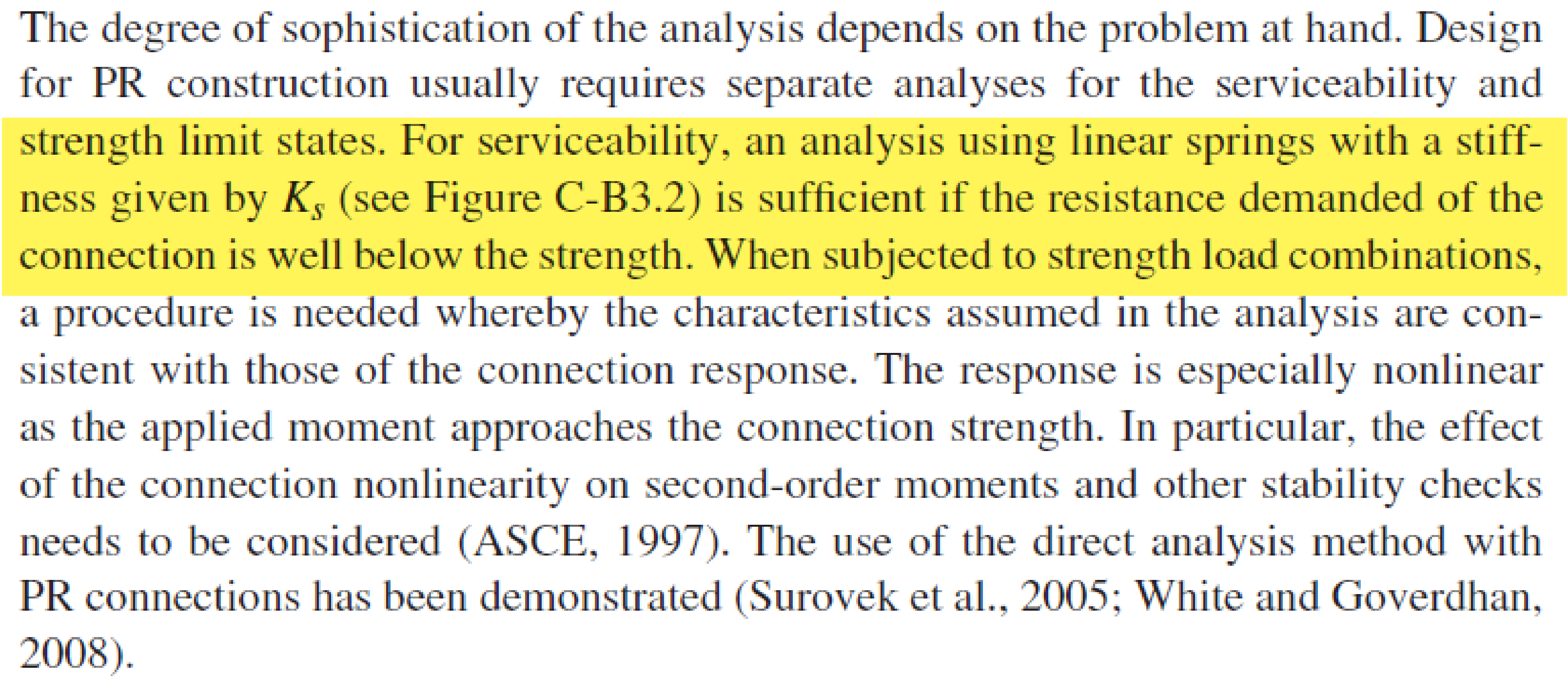
☐ FX ☐ KFX 0 kip/ft ☐ MX ☐ KMX 0 kip-ft/deg.

☐ FY ☐ KFY 0 kip/ft ☐ MY ☐ KMY 0 kip-ft/deg.

☐ FZ ☐ KFZ 0 kip/ft ☐ MZ ☑ KMZ 0 kip-ft/deg.

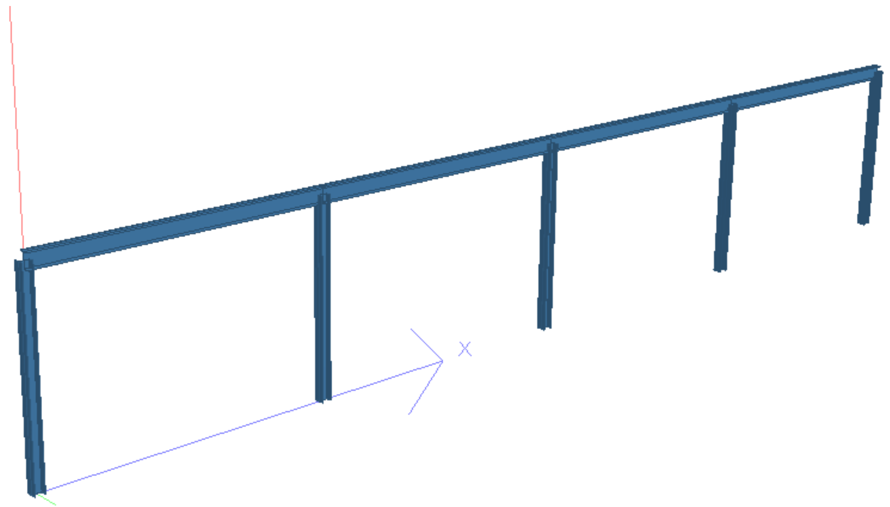
STRUCTURAL ANALYSIS AND DESIGN

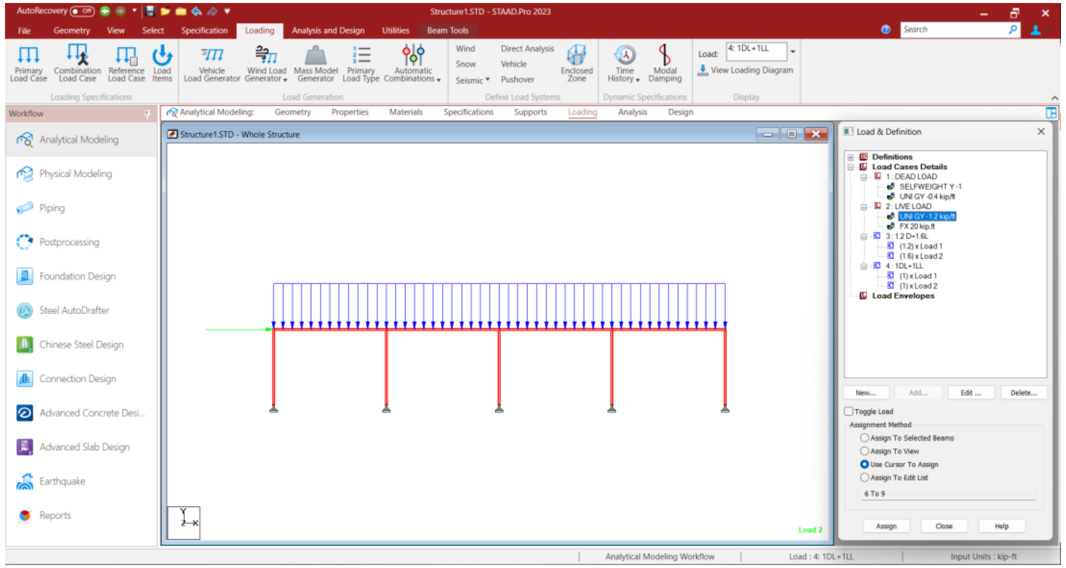
AISC 360-22 COMMENTARY SECTION B3



The degree of sophistication of the analysis depends on the problem at hand. Design for PR construction usually requires separate analyses for the serviceability and strength limit states. For serviceability, an analysis using linear springs with a stiffness given by K_s (see Figure C-B3.2) is sufficient if the resistance demanded of the connection is well below the strength. When subjected to strength load combinations, a procedure is needed whereby the characteristics assumed in the analysis are consistent with those of the connection response. The response is especially nonlinear as the applied moment approaches the connection strength. In particular, the effect of the connection nonlinearity on second-order moments and other stability checks needs to be considered (ASCE, 1997). The use of the direct analysis method with PR connections has been demonstrated (Surovek et al., 2005; White and Goverdhan, 2008).

EXAMPLE: SIMPLE FRAME

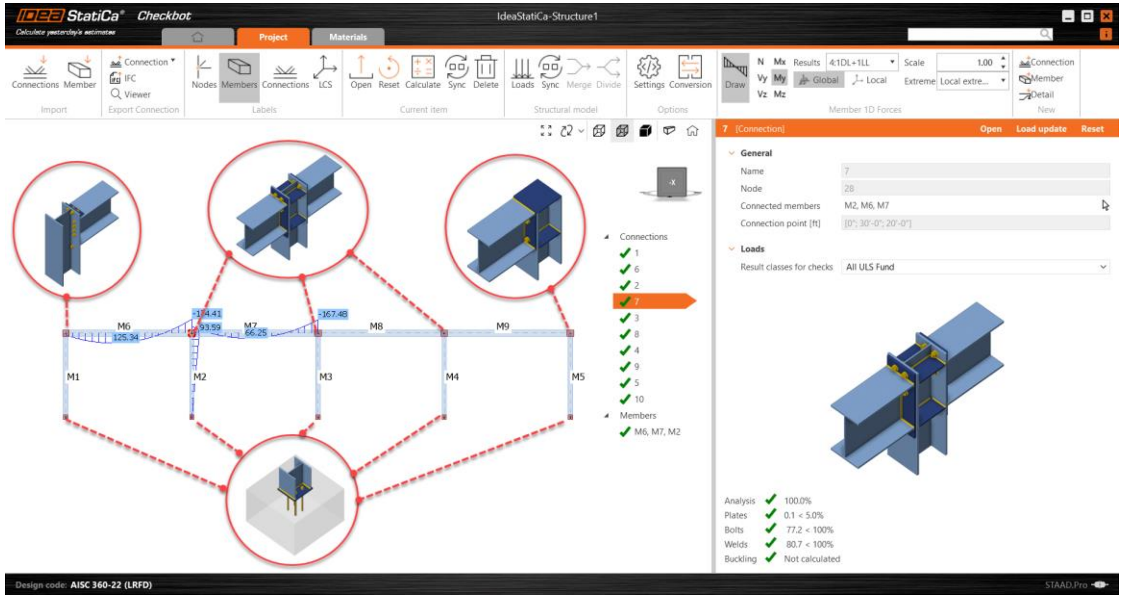




Definitions
Load Cases Details
1 : DEAD LOAD
SELFWEIGHT Y -1
UNI GY -0.4 kip/ft
2 : LIVE LOAD
UNI GY -1.2 kip/ft
FX 20 kip.ft
3 : 1.2 D+1.6L
(1.2) x Load 1
(1.6) x Load 2
4 : 1DL+1LL
(1) x Load 1
(1) x Load 2
Load Envelopes

- Modeling in STAAD.Pro using rigid assumptions
- Strength and service load combinations – Analysis and design
- Export it to Checkbot
- Connection design and stiffness analysis
- Single stiffness value into STAAD.Pro
- Re-calculation of analysis and design
- Results Comparisons

EXAMPLE: SIMPLE FRAME



7 [Connection] Open Load update Reset

General

Name: 7

Node: 28

Connected members: M2, M6, M7

Connection point [ft]: [0'; 30'-0"; 20'-0"]

Loads

Result classes for checks: All ULS Fund

Analysis ✓ 100.0%

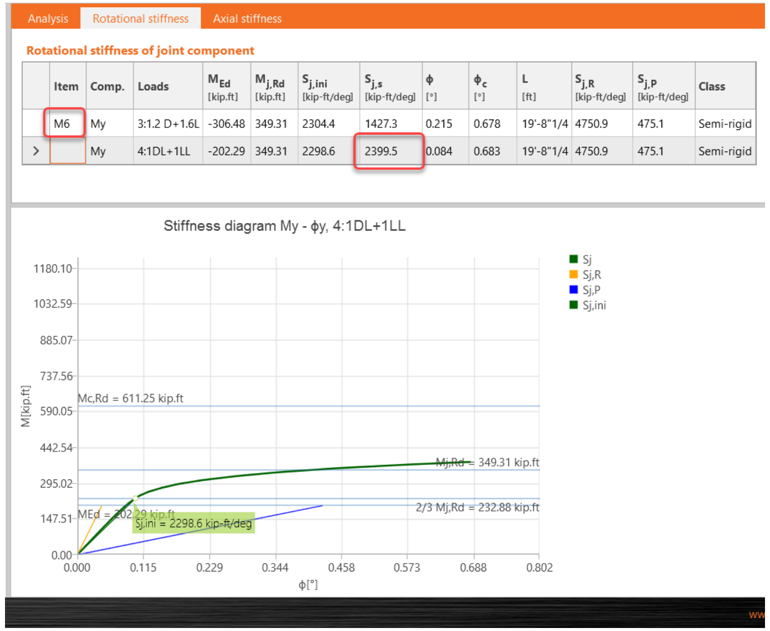
Plates ✓ 0.1 < 5.0%

Bolts ✓ 77.2 < 100%

Welds ✓ 80.7 < 100%

Buckling ✓ Not calculated

Design code: AISC 360-22 (LRFD)



Rotational stiffness of joint component

	Item	Comp.	Loads	M_{Ed} [kip.ft]	$M_{j,Rd}$ [kip.ft]	$S_{j,ini}$ [kip-ft/deg]	$S_{j,s}$ [kip-ft/deg]	ϕ [°]	$ϕ_c$ [°]	L [ft]	$S_{j,R}$ [kip-ft/deg]	$S_{j,P}$ [kip-ft/deg]	Class
	M6	My	3:1.2 D+1.6L	-306.48	349.31	2304.4	1427.3	0.215	0.678	19'-8"1/4	4750.9	475.1	Semi-rigid
>		My	4:1DL+1LL	-202.29	349.31	2298.6	2399.5	0.084	0.683	19'-8"1/4	4750.9	475.1	Semi-rigid

Modeling in STAAD.Pro using rigid assumptions

Strength and service load combinations – Analysis and design

Export it to Checkbot

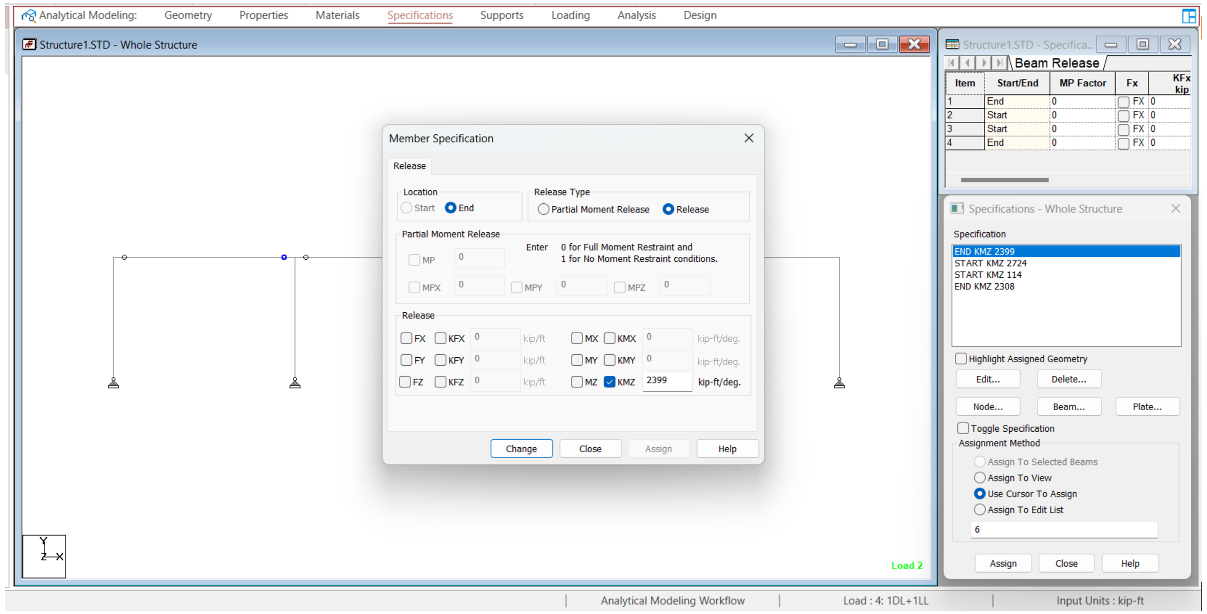
Connection design and stiffness analysis

Single stiffness value into STAAD.Pro

Re-calculation of analysis and design

Results Comparisons

EXAMPLE: SIMPLE FRAME



Member Specification

Release

Location: ○ Start ● End

Release Type: ○ Partial Moment Release ● Release

Partial Moment Release

☐ MP 0 Enter 0 for Full Moment Restraint and
1 for No Moment Restraint conditions.

☐ MPX 0 ☐ MPY 0 ☐ MPZ 0

Release

☐ FX ☐ KFX 0 kip/ft ☐ MX ☐ KMX 0 kip-ft/deg.
☐ FY ☐ KFY 0 kip/ft ☐ MY ☐ KMY 0 kip-ft/deg.
☐ FZ ☐ KFZ 0 kip/ft ☐ MZ ☑ KMZ 2399 kip-ft/deg.

Beam Release

Item	Start/End	MP Factor	Fx	KFx kip
1	End	0	☐ FX	0
2	Start	0	☐ FX	0
3	Start	0	☐ FX	0
4	End	0	☐ FX	0

Specifications - Whole Structure

Specification
END KMZ 2399
START KMZ 2724
START KMZ 114
END KMZ 2308

☐ Highlight Assigned Geometry

☐ Toggle Specification

Assignment Method
○ Assign To Selected Beams
○ Assign To View
● Use Cursor To Assign
○ Assign To Edit List
6

Analytical Modeling Workflow | Load : 4: 1DL+1LL | Input Units : kip-ft

Modeling in STAAD.Pro using rigid assumptions

Strength and service load combinations – Analysis and design

Export it to Checkbot

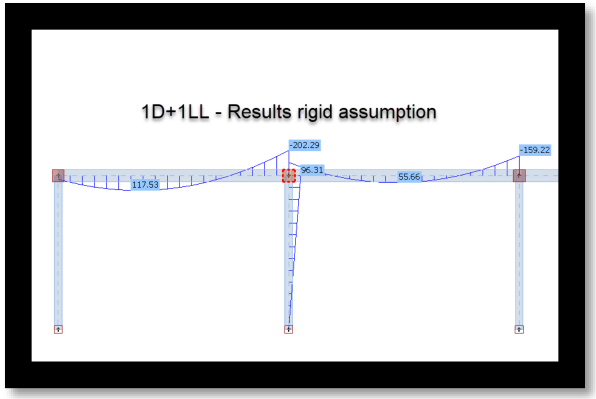
Connection design and stiffness analysis

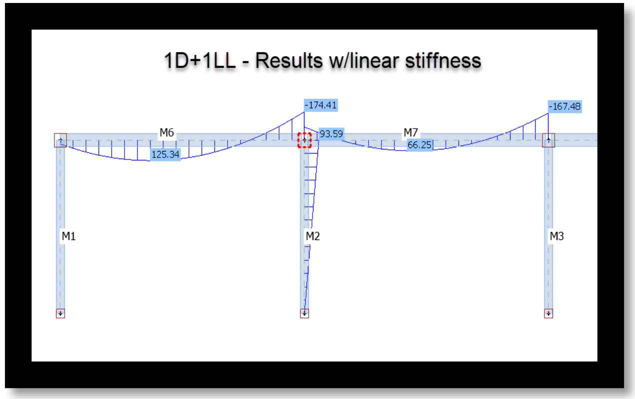
Single stiffness value into STAAD.Pro

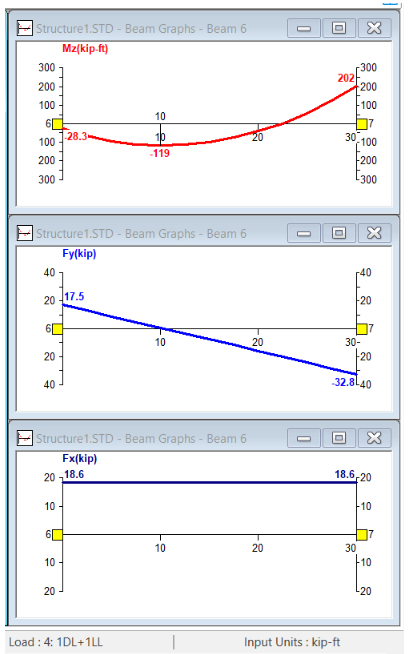
Re-calculation of analysis and design

Results Comparisons

EXAMPLE: SIMPLE FRAME


1D+1LL - Results rigid assumption


1D+1LL - Results w/linear stiffness



Load : 4: 1DL+1LL

Input Units : kip-ft

Modeling in STAAD.Pro using rigid assumptions

Strength and service load combinations – Analysis and design

Export it to Checkbot

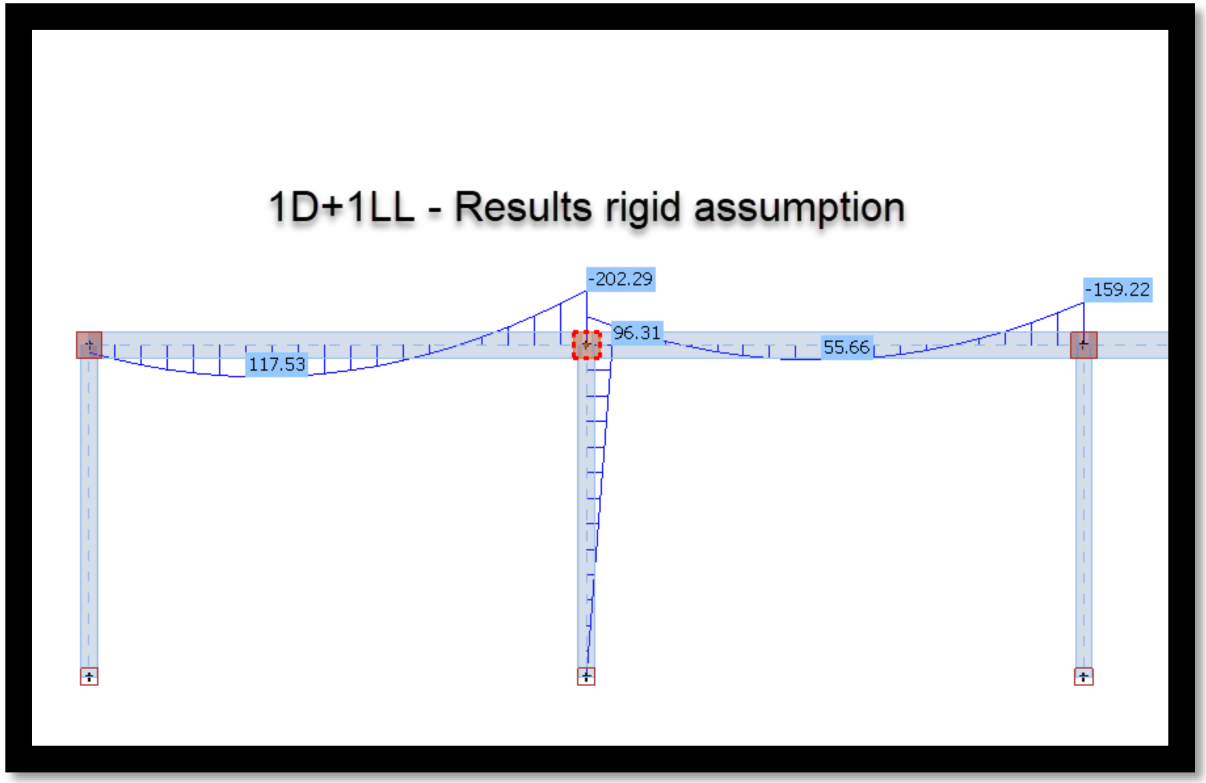
Connection design and stiffness analysis

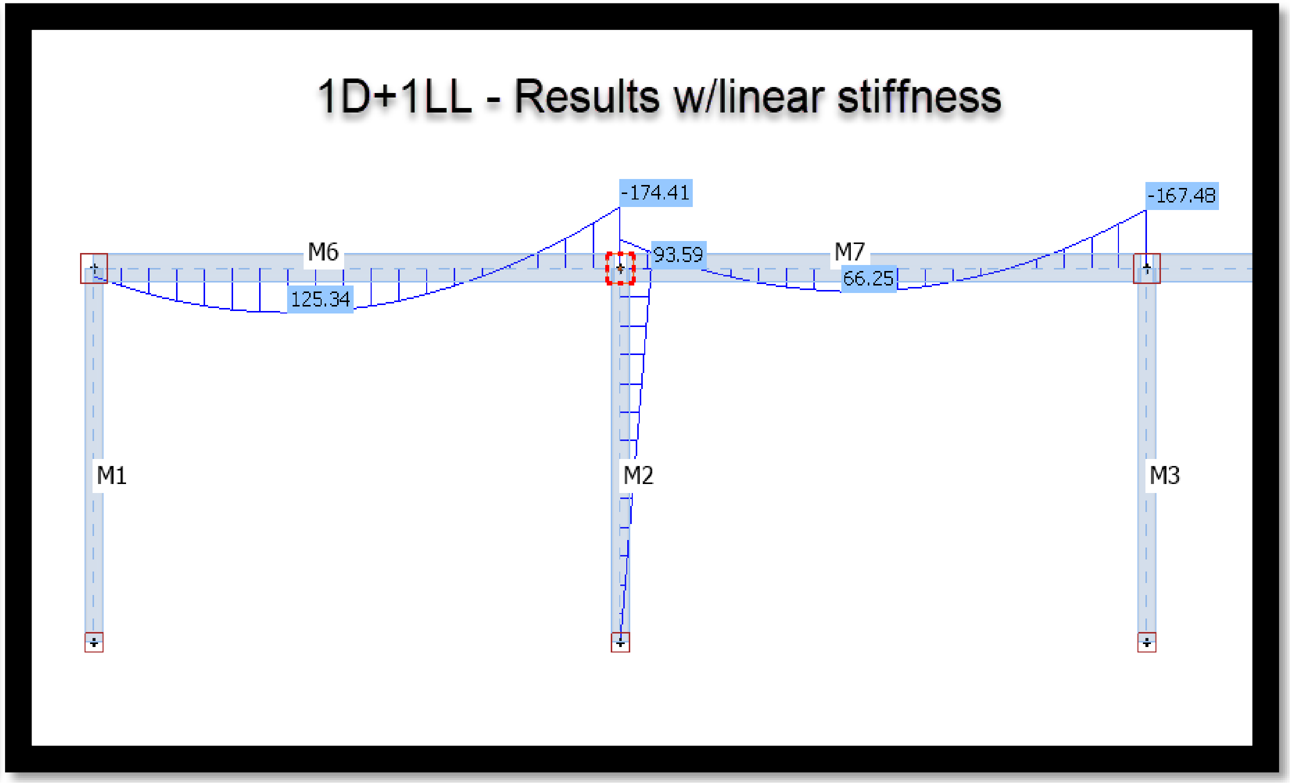
Single stiffness value into STAAD.Pro

Re-calculation of analysis and design

Results Comparisons

MOMENT DIAGRAM COMPARISON

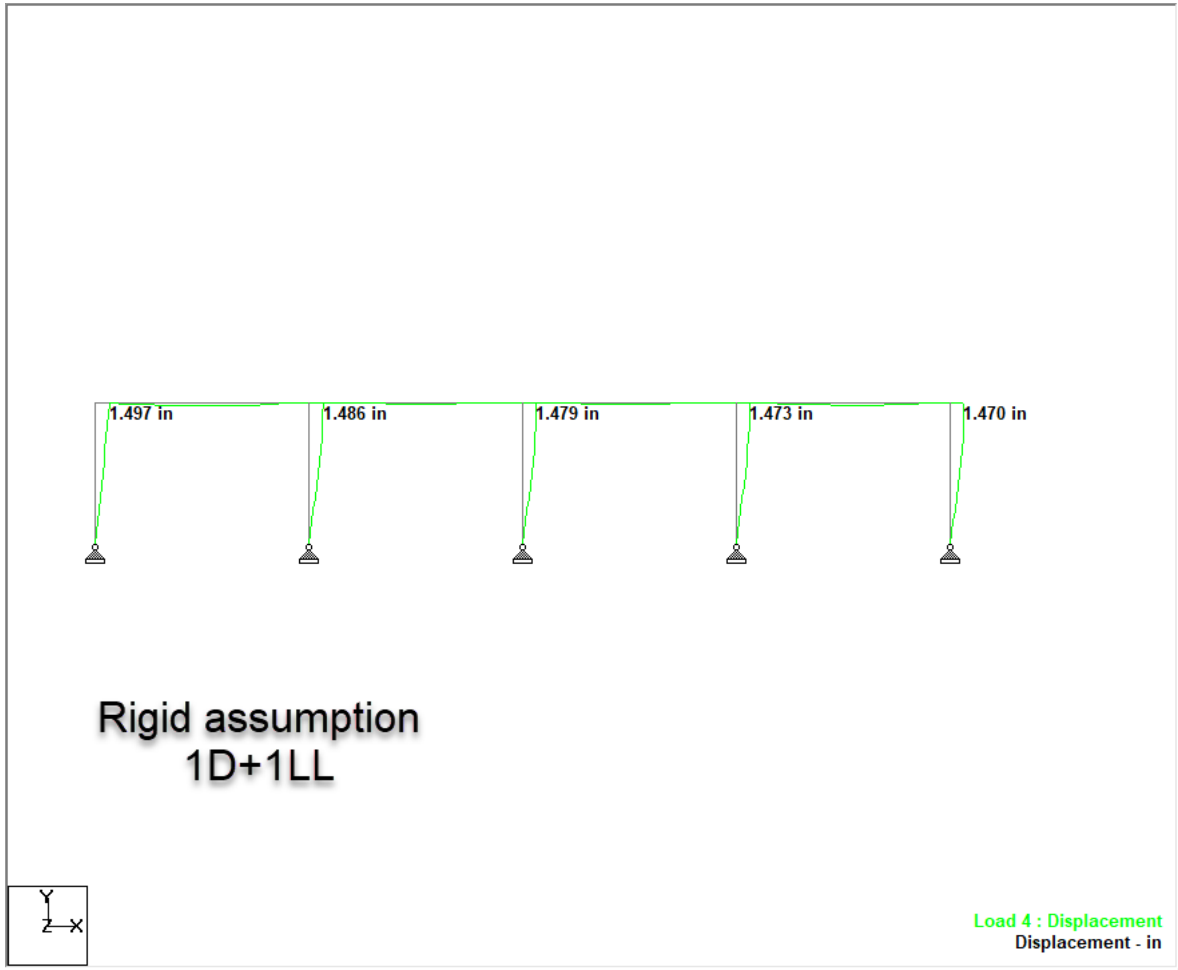




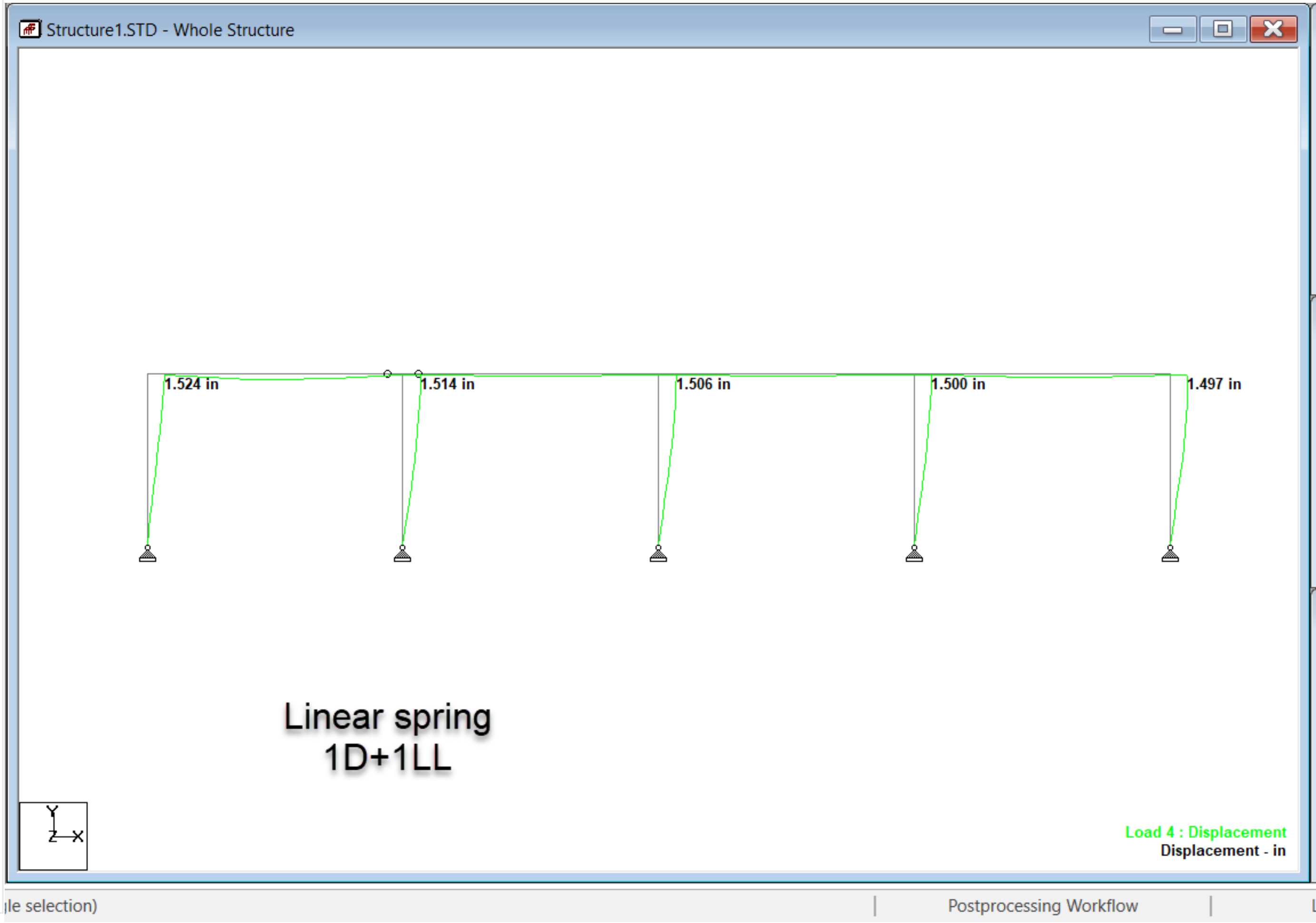
Checkbot moment diagram view
Results from STAAD.Pro

IDEA StatiCa®

TOTAL DEFLECTION COMPARISON

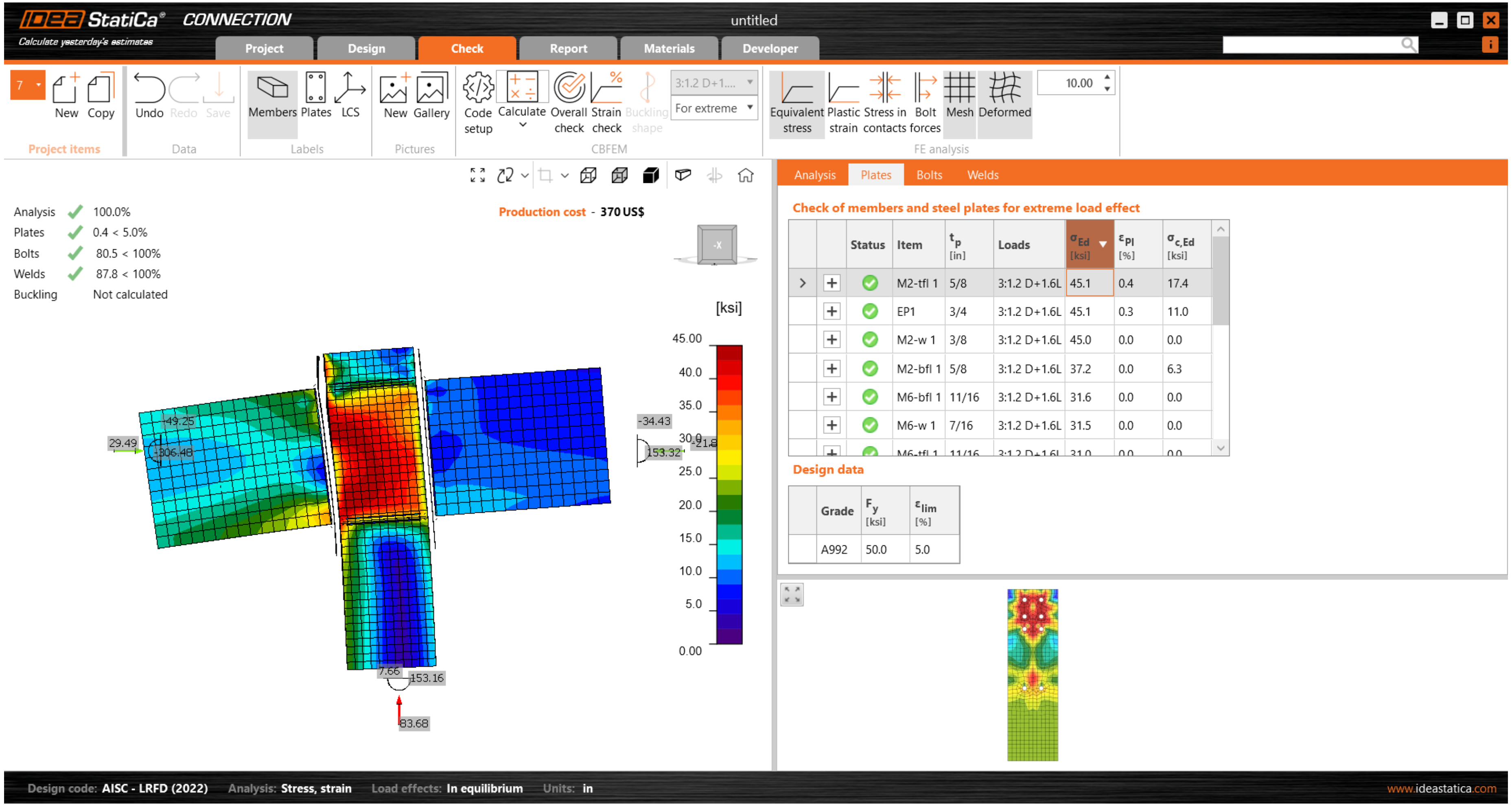


Rigid assumption
1D+1LL



Linear spring
1D+1LL

CONNECTION RESULTS – RIGID ASSUMPTION



Analysis	✓	100.0%
Plates	✓	0.4 < 5.0%
Bolts	✓	80.5 < 100%
Welds	✓	87.8 < 100%
Buckling		Not calculated

Production cost - **370 US$**

Check of members and steel plates for extreme load effect

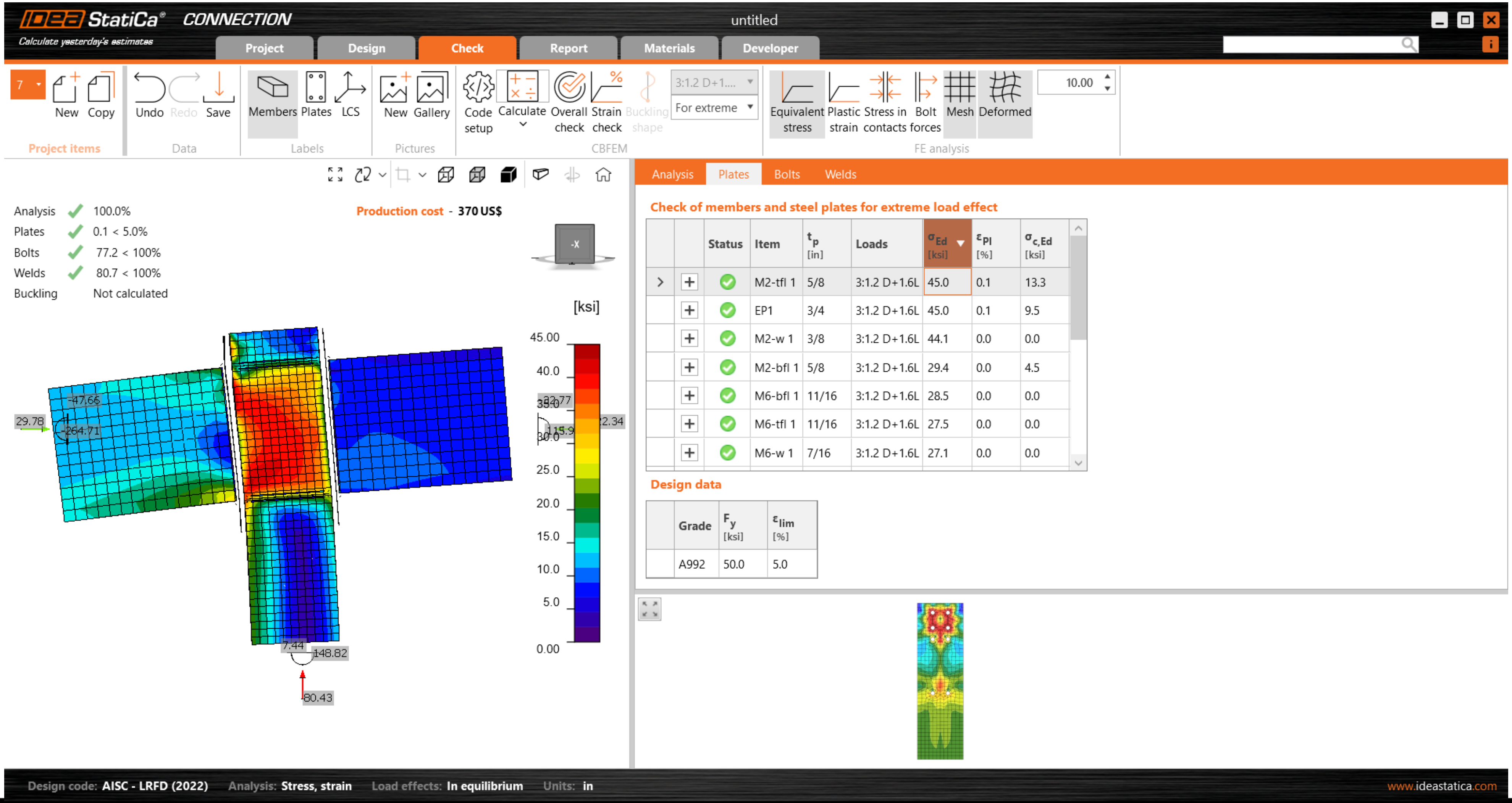
		Status	Item	t_p [in]	Loads	σ_{Ed} [ksi]	ε_{Pl} [%]	$\sigma_{c,Ed}$ [ksi]
>	+	✓	M2-tfl 1	5/8	3:1.2 D+1.6L	45.1	0.4	17.4
	+	✓	EP1	3/4	3:1.2 D+1.6L	45.1	0.3	11.0
	+	✓	M2-w 1	3/8	3:1.2 D+1.6L	45.0	0.0	0.0
	+	✓	M2-bfl 1	5/8	3:1.2 D+1.6L	37.2	0.0	6.3
	+	✓	M6-bfl 1	11/16	3:1.2 D+1.6L	31.6	0.0	0.0
	+	✓	M6-w 1	7/16	3:1.2 D+1.6L	31.5	0.0	0.0
	+	✓	M6-tfl 1	11/16	3:1.2 D+1.6L	31.0	0.0	0.0

Design data

	Grade	F_y [ksi]	ε_{lim} [%]
	A992	50.0	5.0

Design code: **AISC - LRFD (2022)** Analysis: **Stress, strain** Load effects: **In equilibrium** Units: **in**

CONNECTION RESULTS – LINEAR SPRING



Analysis	✓	100.0%
Plates	✓	0.1 < 5.0%
Bolts	✓	77.2 < 100%
Welds	✓	80.7 < 100%
Buckling		Not calculated

Production cost - **370 US$**

Check of members and steel plates for extreme load effect

		Status	Item	t_p [in]	Loads	σ_{Ed} [ksi]	ε_{Pl} [%]	$\sigma_{c,Ed}$ [ksi]
>	+	✓	M2-tfl 1	5/8	3:1.2 D+1.6L	45.0	0.1	13.3
	+	✓	EP1	3/4	3:1.2 D+1.6L	45.0	0.1	9.5
	+	✓	M2-w 1	3/8	3:1.2 D+1.6L	44.1	0.0	0.0
	+	✓	M2-bfl 1	5/8	3:1.2 D+1.6L	29.4	0.0	4.5
	+	✓	M6-bfl 1	11/16	3:1.2 D+1.6L	28.5	0.0	0.0
	+	✓	M6-tfl 1	11/16	3:1.2 D+1.6L	27.5	0.0	0.0
	+	✓	M6-w 1	7/16	3:1.2 D+1.6L	27.1	0.0	0.0

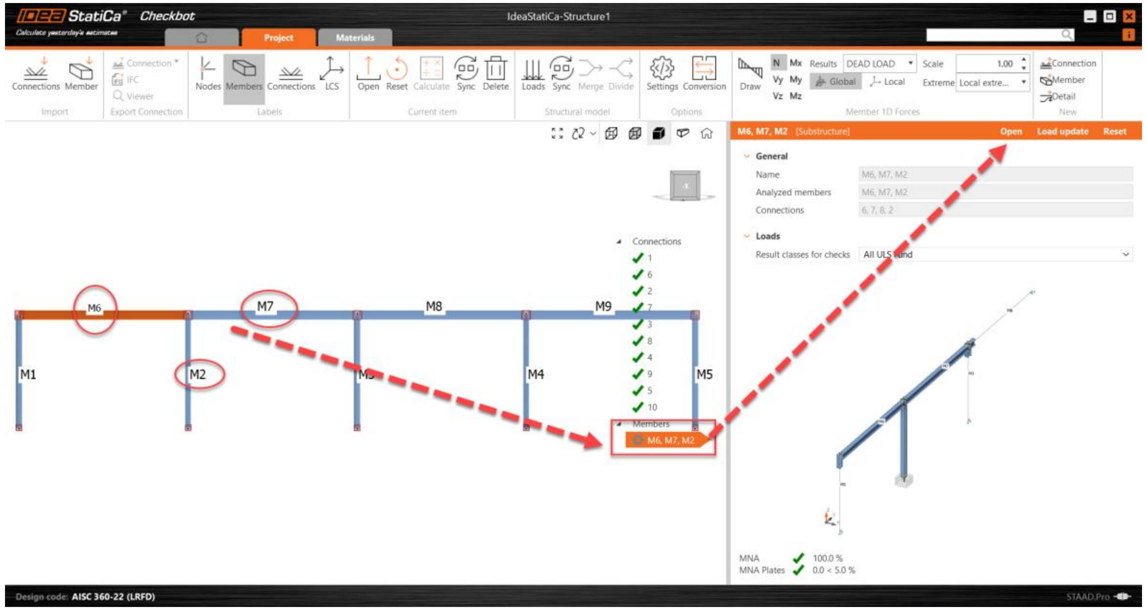
Design data

	Grade	F_y [ksi]	ε_{lim} [%]
	A992	50.0	5.0

Design code: **AISC - LRFD (2022)** Analysis: **Stress, strain** Load effects: **In equilibrium** Units: **in**

www.ideastatica.com

IDEA MEMBER – ANALYSIS AND DESIGN OF FRAMES



M6, M7, M2 [Substructure]

General

Name: M6, M7, M2

Analyzed members: M6, M7, M2

Connections: 6, 7, 8, 2

Loads

Result classes for checks: All ULS fund

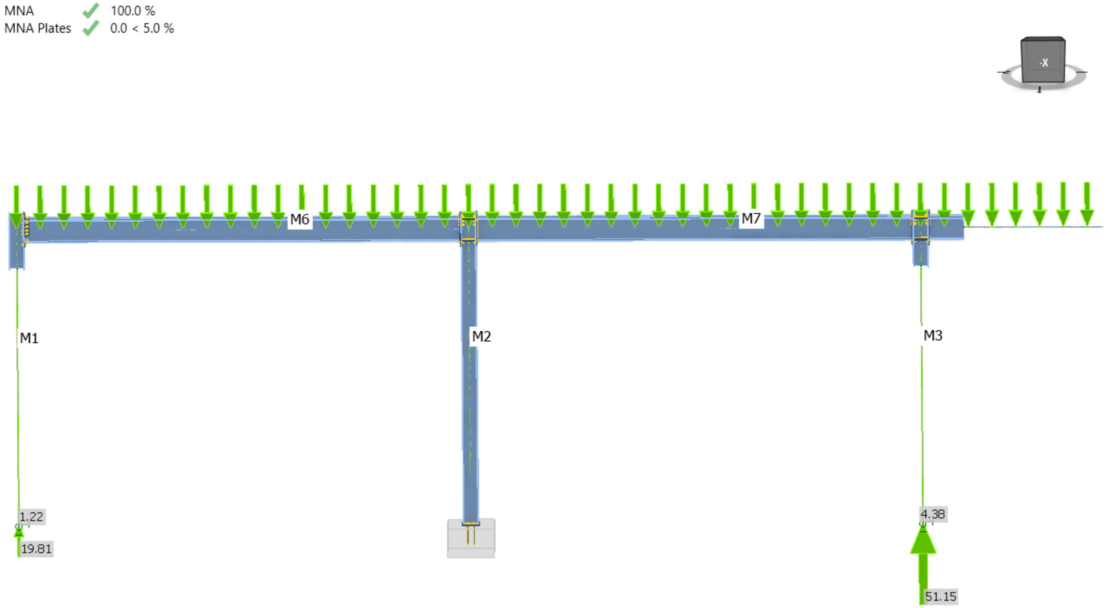
MNA ✓ 100.0 %

MNA Plates ✓ 0.0 < 5.0 %

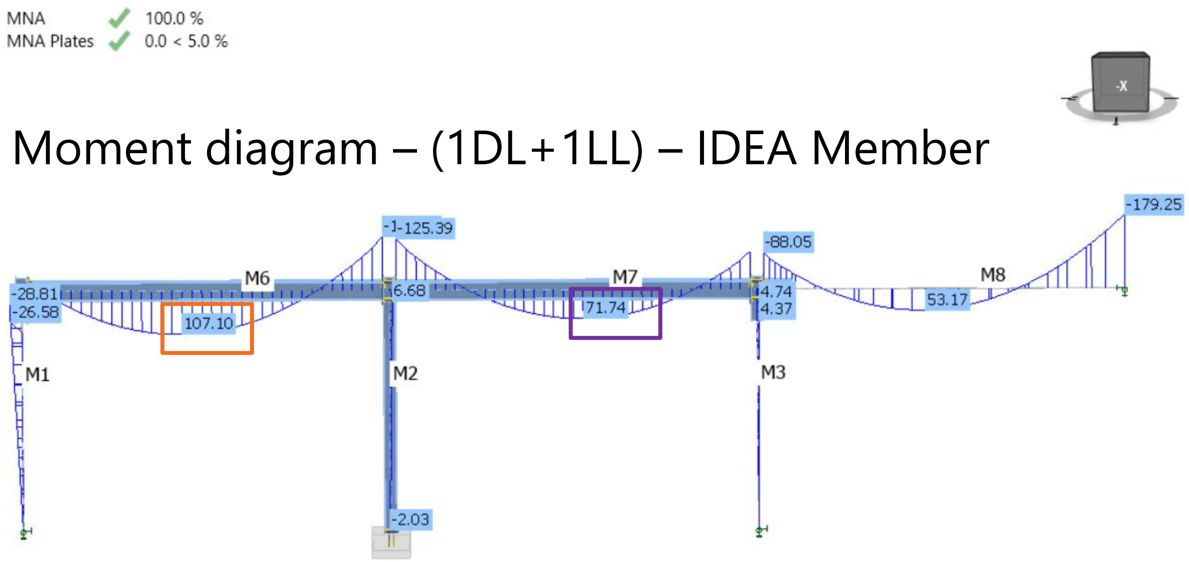
Design code: AISC 360-22 (LRFD)

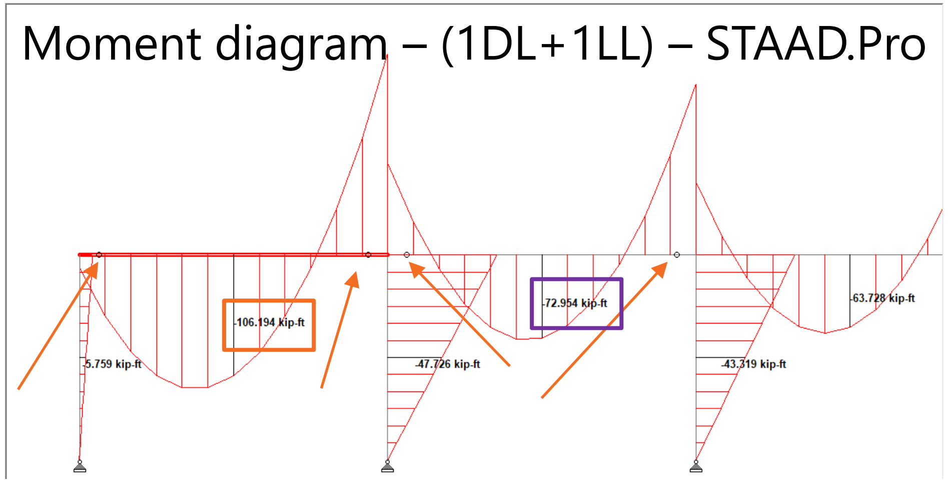
- Frame exported from Checkbot in Member app
- Forces exported from STAAD
- Connections from IDEA StatiCa Connection

IDEA MEMBER – ANALYSIS AND DESIGN OF FRAMES



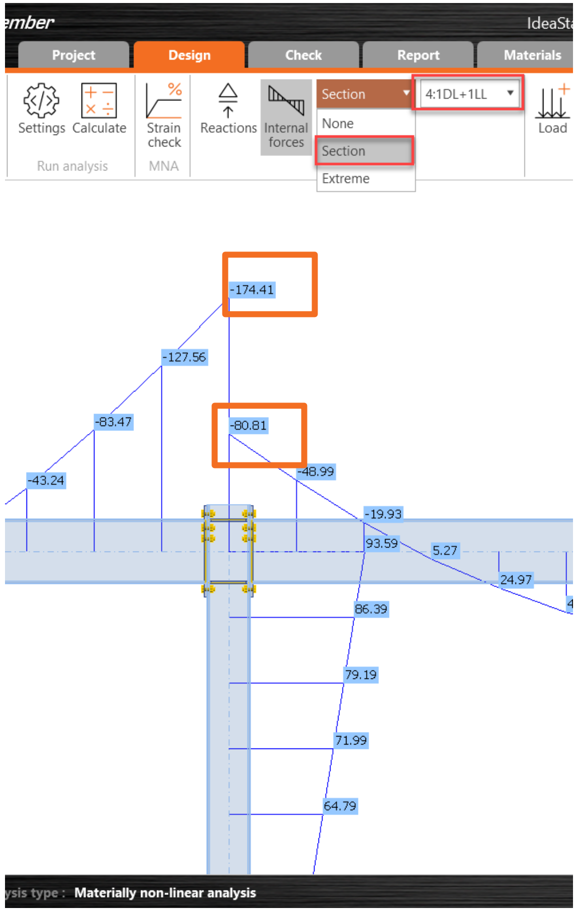
- Frame exported from Checkbot in Member app
- Forces exported from STAAD
- Connections from IDEA StatiCa Connection


Moment diagram – (1DL+1LL) – IDEA Member


Moment diagram – (1DL+1LL) – STAAD.Pro

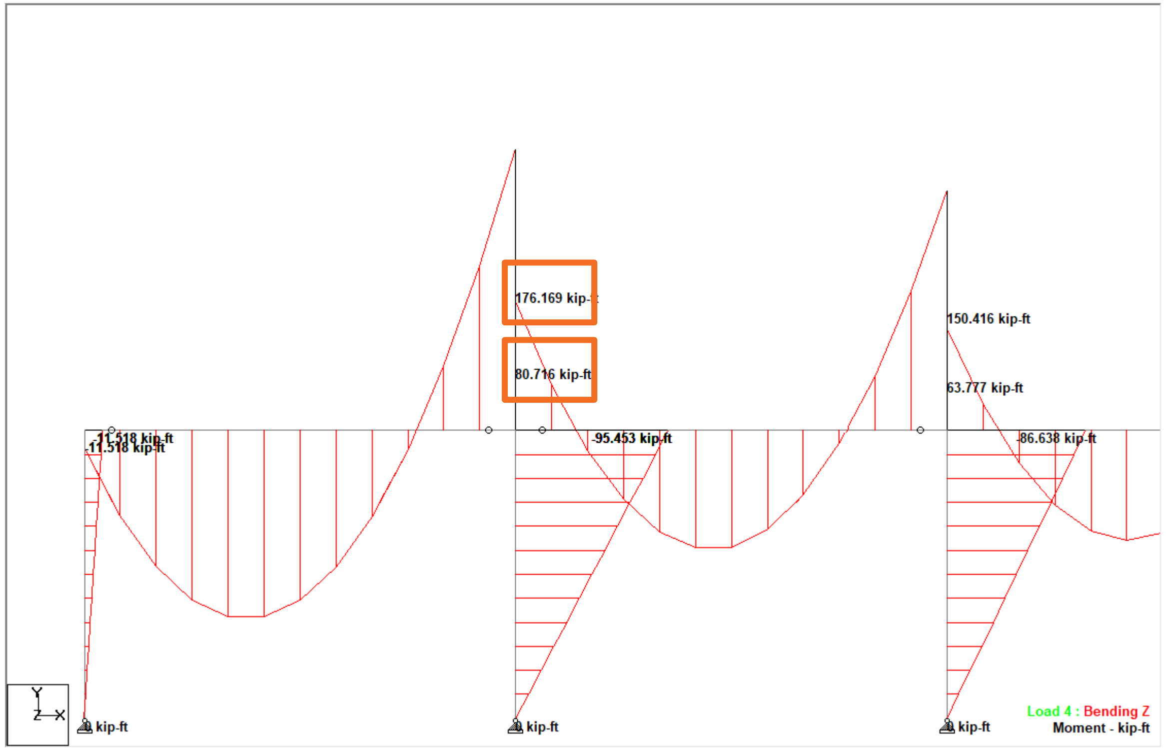
IDEA StatiCa®

MOMENTS AT THE NODE – IDEA MEMBER



ysis type : **Materially non-linear analysis**

IDEA StatiCa Member
Results at the node position
Moment diagram service loads



STAAD.Pro
Results at the node position
Moment diagram service loads

SUMMARY

- Confirm the assumptions by running stiffness analysis
- Make sure you use the service combination to calculate the stiffness, when using AISC
- If PR is needed, use IDEA StatiCa to input the stiffness constant in the analysis
- Depending on the problem, select if you use a nonlinear spring or linear spring in your analysis software
- Many resources about the topic are available, IDEA StatiCa eases the calculation. User your engineering judgement.
- IDEA Member is a tool that can help you to analyze and design complex members as the connection stiffness is included. No iterations are needed.

Calculate yesterday's estimates

Q&A

UPCOMING EVENTS

In person

SEA of Alabama – 8/29

SEA of California – 9/3-6

SEA of Ohio – 9/12-13

SDS2 User Summit – 9/25-26

SEA of Colorado – 10/3

NCSEA Summit – 11/6-8

Webinars

Online Cxn Library / Viewer – 9/25

Catalog of Limit States AISC – 10/23

Updates from V24.1 -12/4