Coordination of main frame strength calculations and design of joints in case of industrial buildings

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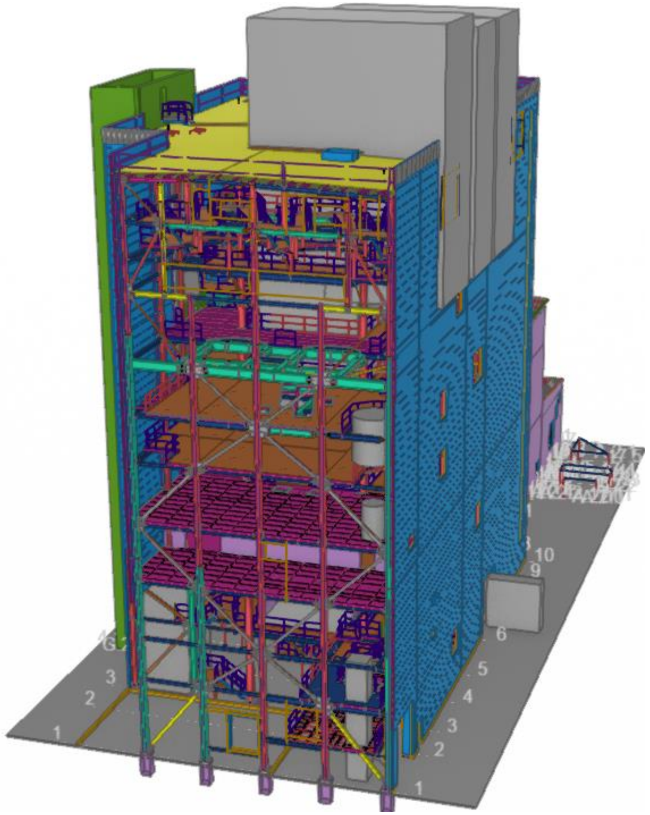
Industrial Buildings

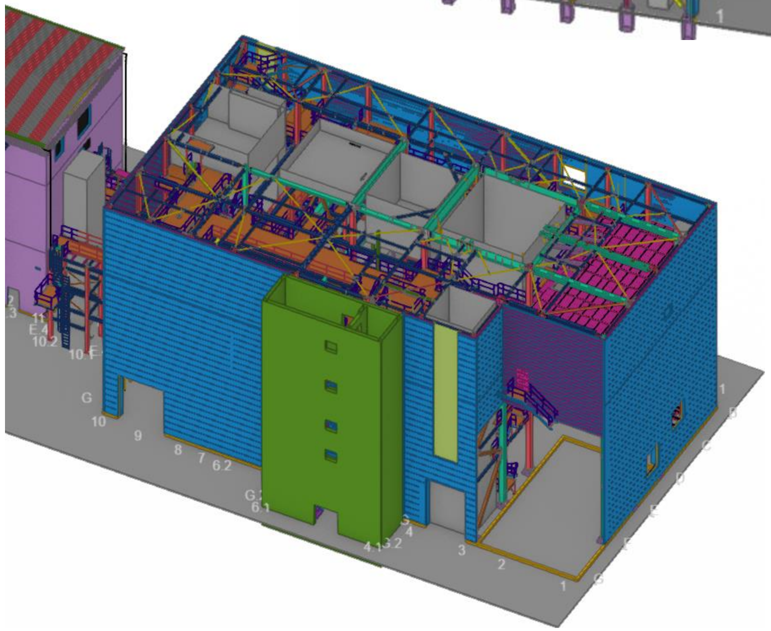
Engineering and Design Process

- In the practical dimensioning of steel structures, the assumption is only of **either hinged or fully moment-rigid** connection.

- Although, for example, the Eurocode gives formulas to calculate steel structures **with partially rigid joints**, this is not only very difficult but also **impossible** in the work order, where the building is calculated first and detailed only afterwards.

- It is usually very important to avoid **unnecessary iterations** in the building design process, because a lot of iterations usually occur for unavoidable reasons, such as changes in the building layout or other initial data of the structural design.





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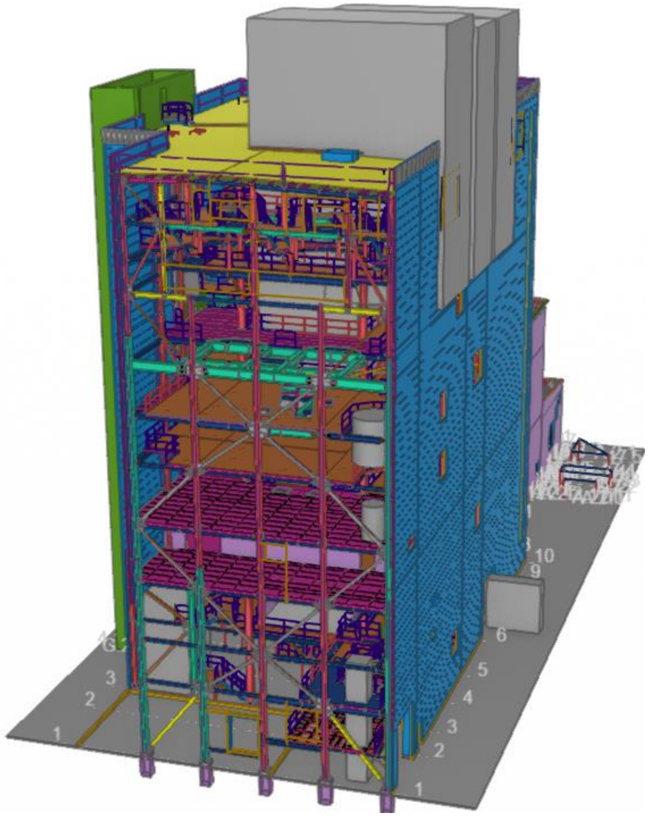
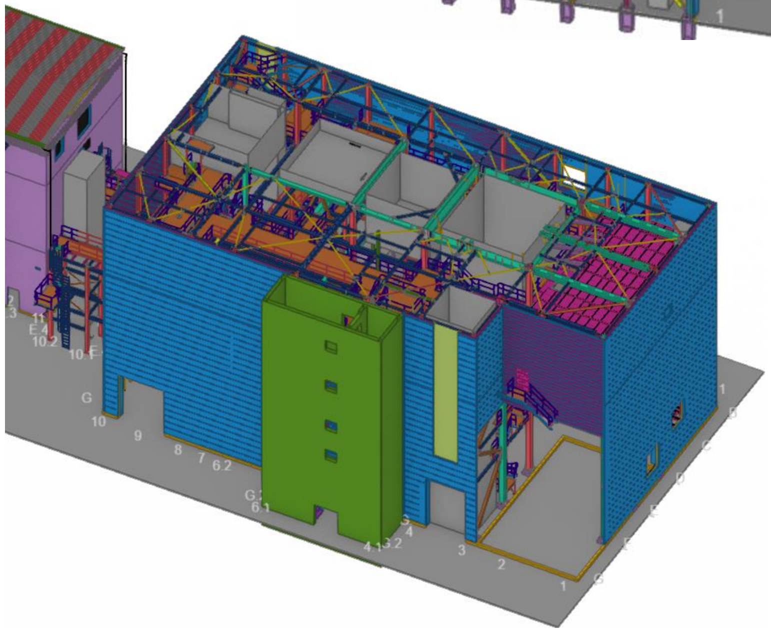
Braced Frames

Braced Frames

- Structures in industrial buildings are usually stiffened with **diagonal braces**.
- The advantage from the possible moment stiffness of the joints would be marginal, when the **stiffness of the diagonal braces** is at least several dozen times **dominant**
- It is usually not profitable to bring extra and often **useless complexity** to the project by aiming for **moment-stiff joints**, but keep the vast majority of the joints **nominally pinned**
- A hinge is placed in the structural model of the building at a **node over which no bending moment is transmitted**
- In the case of well-designed joints, the nominally pinned assumption is usually always possible based on the **lower bound theorem of the plasticity**, even though there is **no actual hinge part** at the locations in question





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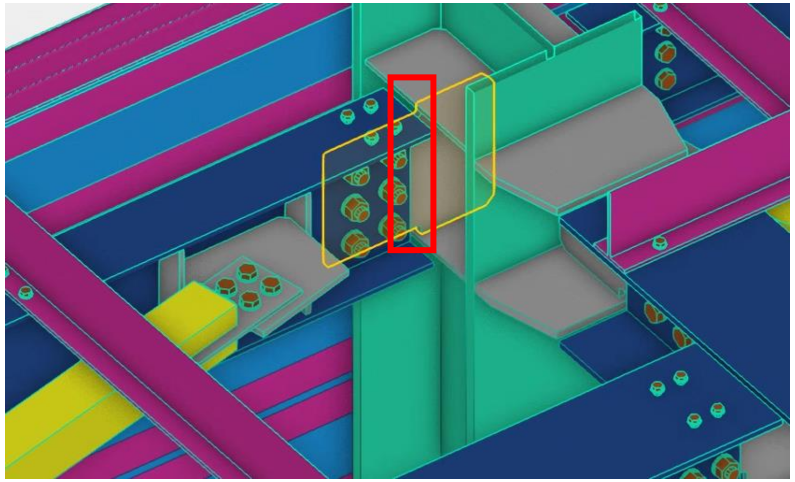
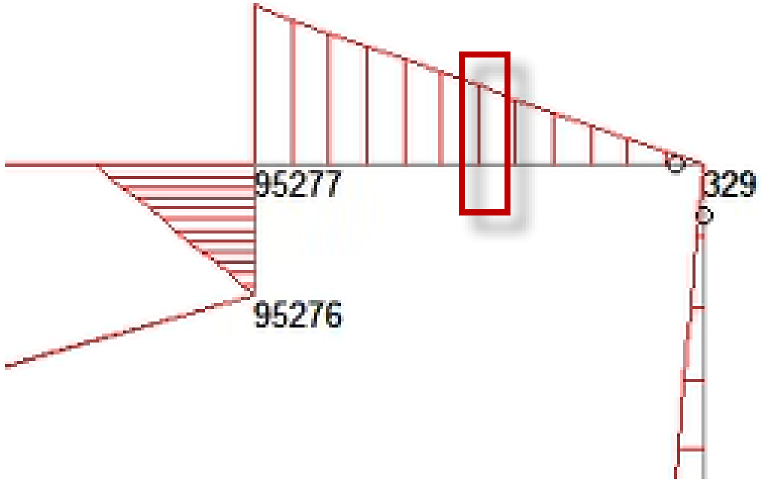
Braced Frames

Force distribution in calculation model

- It is trivial that the location of the **nominal pin** is clearly important for the **internal force distribution**
- Often, compared to the dimensions of the building, the **small moment arm** in the immediate vicinity of the joint **is decisively large**, especially in terms of the resistance of the joint
- It may be critical for example for the **buckling of columns**
- It has been observed that even **errors** significant in terms of structural safety in this matter **are common**
- It has been observed that often the structural engineer of the main frame uses a **different assumption** for the location of the joint than the structural designer of the joint. This kind of carelessness can result in **weaker joints** than assumed in the main frame calculation





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Nominal pins in calculation model

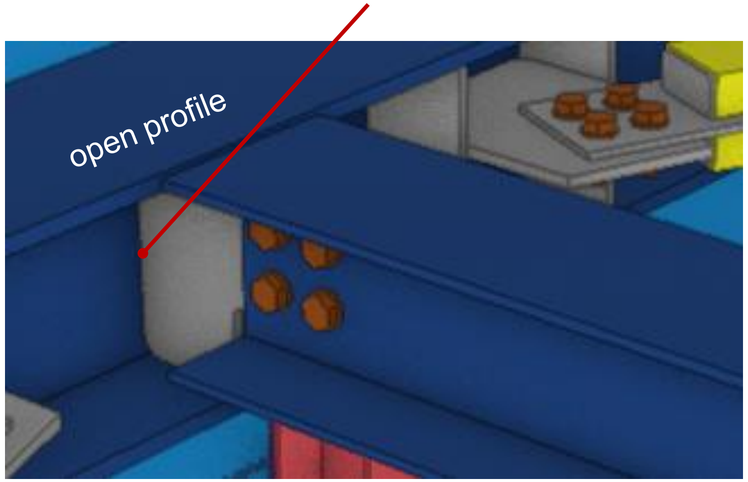
Functional locations

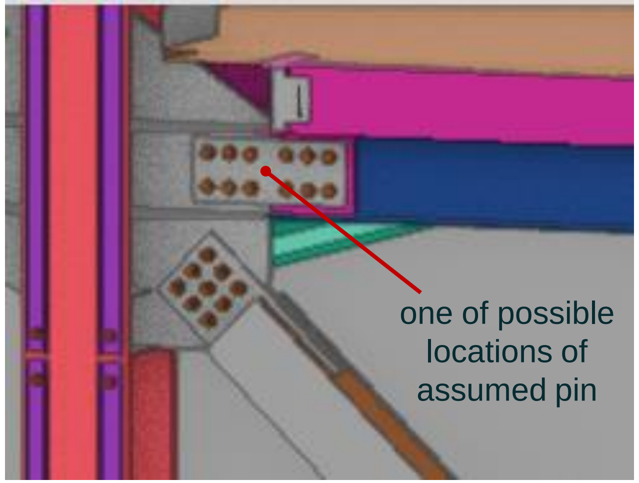
- In a proper collaboration, the structural engineer of main frame carefully **places the pin** in such a place where the main members of the building can take the force at the pin with **rigid and strong features** of the structural members
  - usually other than the torsion of open profiles
  - in the case of an ending profile, often also the bending about the weak axis

- It is important for structural engineer also to **document the location of the pin** as mandatory input for the structural designer of the joint.

- Only in this way can the **both sides** of the nominal pin in the joint area get designed to be **strong enough** to transfer the forces corresponding to the assumptions in main frame analysis

the only functional location
of assumed pin

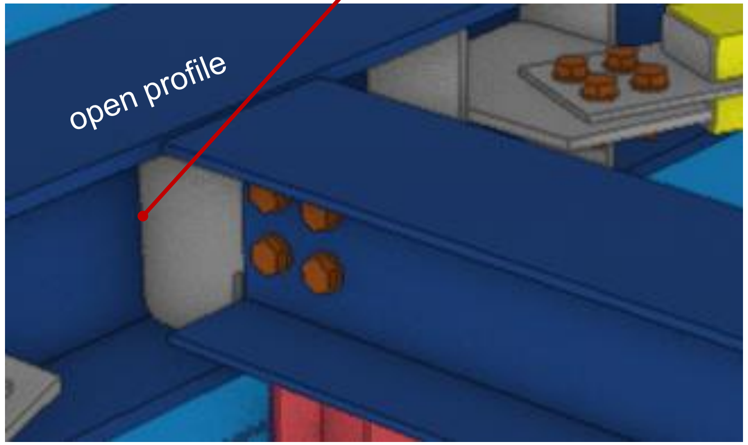


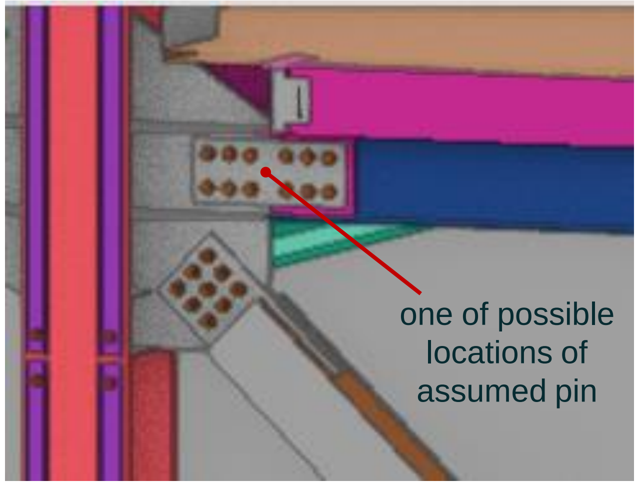


Functional joints

Structural details

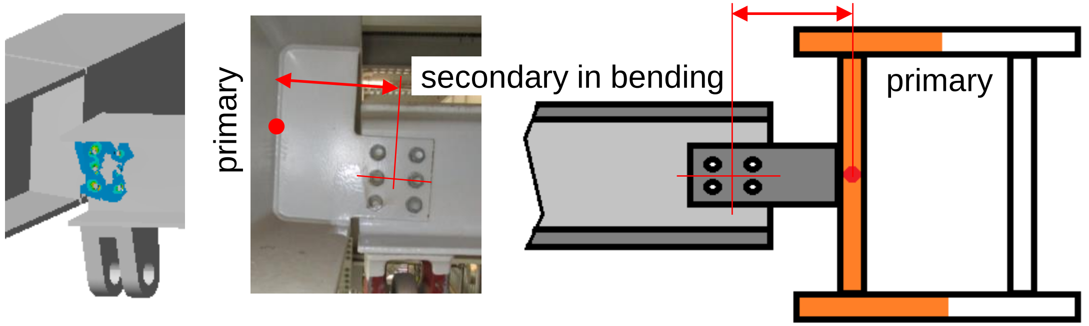
- There are often places on both sides of the nominal pin that require the use of **additional structural details**
- This is to make joint strong enough to withstand the bending moment according to the **moment arm between the detail and the nominal pin**
- It is quite **seldom reasonable** to place the nominal pin at the center point of the bolt group
- More often it is necessary to use **bolts** that are significantly **larger in size or number** compared to the case of a bolted joint that transmits shear force only
- It often makes the most sense to place the nominal pin at e.g. the **outer surface of the column**, because the location of this point is **already known** before the design of the joints, and this point is usually **not too far moment arm** away from the structural details on both sides of the joint



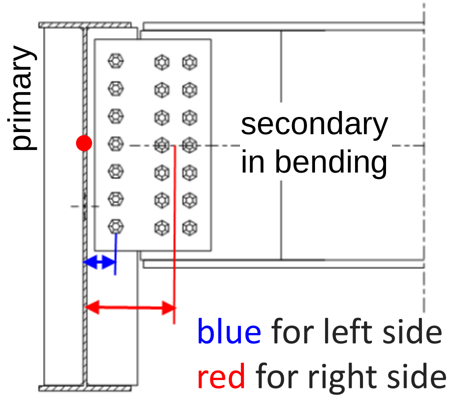


Shear transfer location of STL joints

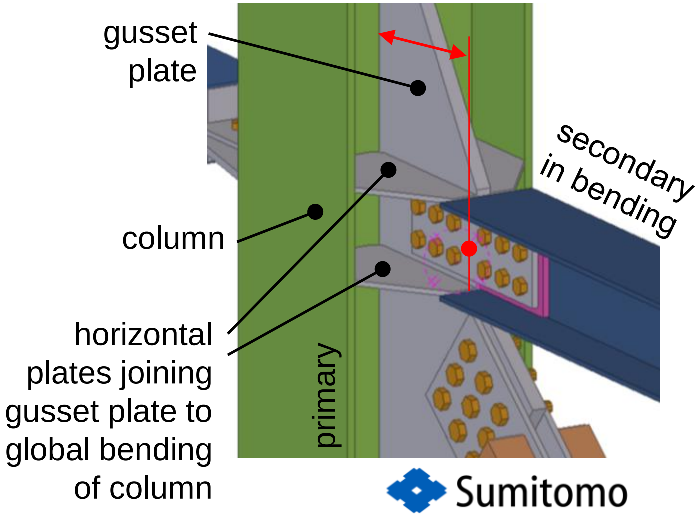
- The usual practice is to assume pin between STL members
- The location of assumed pin must be carefully set, and considered in both sides of the joint
- The location shall not be more far from the primary member than the far most location that is connected to primary member bending with stiff and strong details of the joint. Open profile cannot be stiffened to take significant torsion
- Global torsion of primary member should not be utilized unless primary member is box section. If torsion stiffness of box section is utilized, the end joints of this member must be designed for the torsion
- If the location is not in the place that is naturally stiff, the joint design must be accomplished with stiffening features, see *horizontal plates* in the figure as example
- The joint must be calculated with moment lever arm associated with the location of shear transfer
- The primary member must be evaluated for the moments for which the moment arm is the distance from the middle of the member to the shear transfer location of the joint
- The secondary member must be calculated for the span measured from the shear transfer location of the joint



● shear transfer location



blue for left side bolt group
red for right side bolt group



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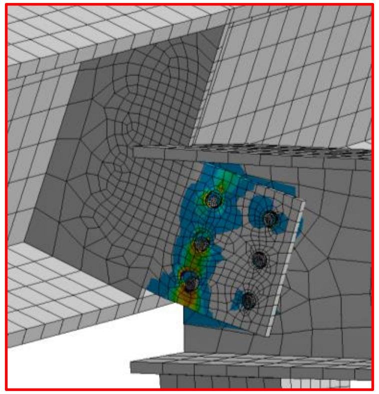
GMNA = Geometrically and Materially Non-linear Analysis
MNA = Materially Non-linear Analysis

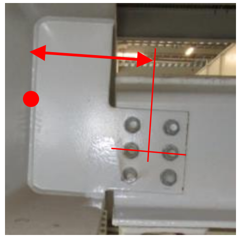
Bolt joint reinforcements at construction site

- The need for reinforcement may usually be evaluated with GMNA analysis
  - Large deflections (**G**)
  - Strain hardening material (**M** with BISO or BKIN)
  - True Stress and Strain
  - Tangent modulus calculated according to material properties
  - Failure criteria: True Strain ultimate elongation

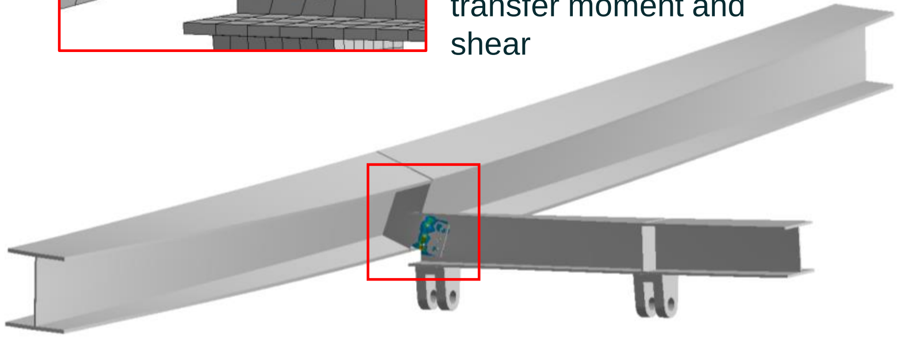
BISO = Bi-linear ISOtropic
BKIN = Bi-linear KINematic

- If bolted joint is reinforced by welding, the strength calculation must be made without assistance from bolts. This is because of significant stiffness differences between bolted and welded joint. This basic rule may be violated only if bolts are slip-resistant at the ultimate limit state. The new design should usually be made with MNA to reach good match with Eurocode equations
  - Ideal plasticity (tangent modulus 1 MPa)
  - Weld yield point as per $f_u / (\beta_w \cdot \gamma_{M2})$, where β_w = 0.9 for S355 and γ_{M2} = 1.25
  - No bolts in the model
- Related clauses in Eurocode EN 1993-1-8
  - 2.4 Resistance of Joints: “(3) Where fasteners with different stiffnesses are used to carry a shear load the fasteners with the highest stiffness should be designed to carry the design load. An exception to this design method is given in 3.9.3”
  - 3.9.3 Hybrid connections: “(1) As an exception to 2.4(3) , preloaded class 8.8 and 10.9 bolts in connections designed as slip-resistant at the ultimate limit state (Category C in 3.4) may be assumed to share load with welds, provided that the final tightening of the bolts is carried out after the welding is complete”

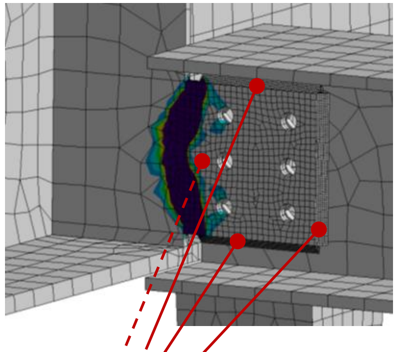




Joint with bolts observed too weak to transfer moment and shear

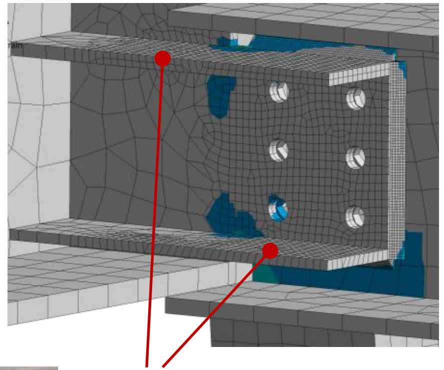


Partially reinforced:
gusset plate still too weak



no bolts in calculation model

Fully reinforced:



four fillet welds added

two flanges added for gusset plate

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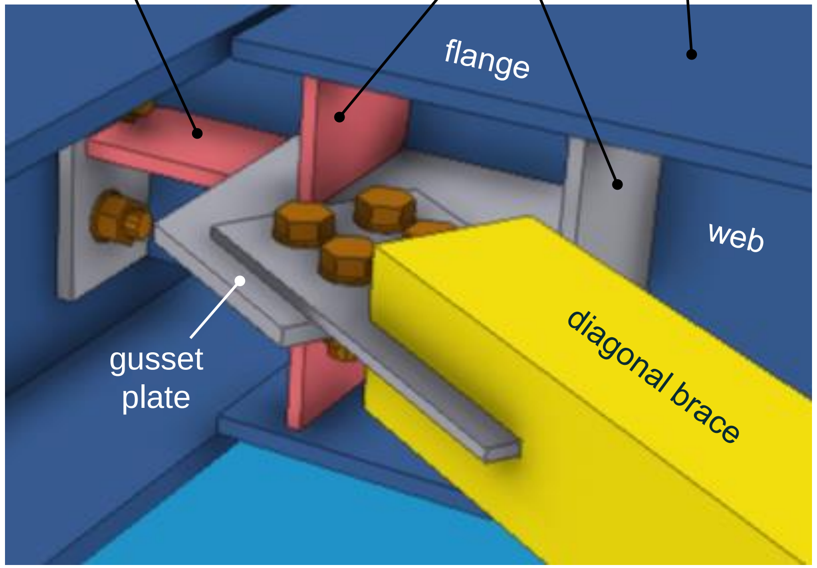
Ending profiles

Local weak axis bending

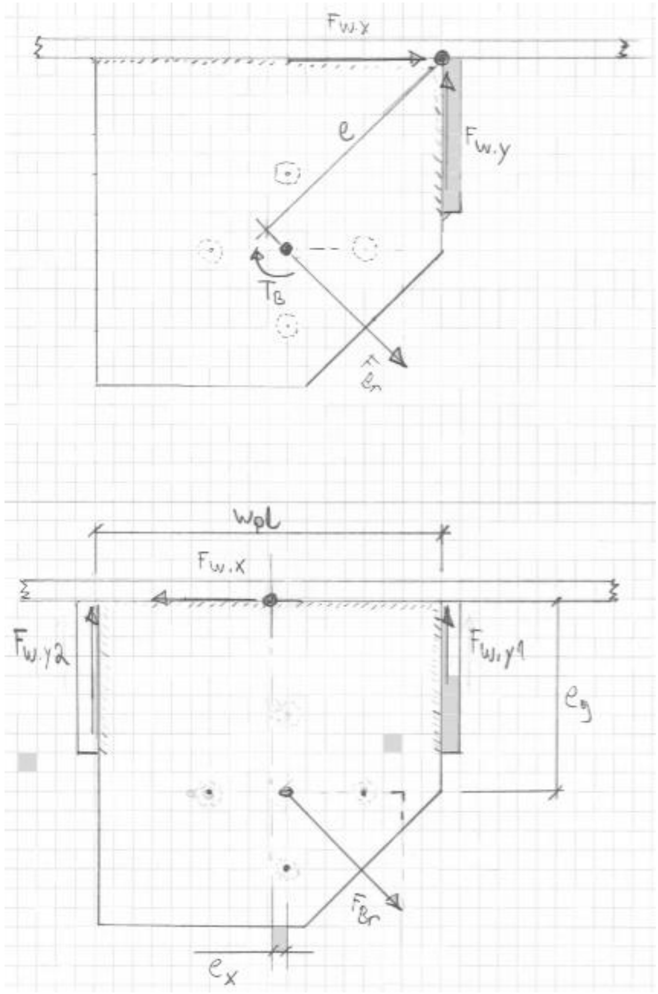
- In the case of an ending profile, it is common that **flanges are no longer present** in the profile **near the nominal pin**, because the web is able to transmit the slight **strong** axis bending moment prevailing in the joint area
- But such a joint area is very **weak** for the weak axis bending moment
- E.g. axial **force from the diagonal brace** can easily cause several dozens times **bigger bending moment** compared to weak axis bending resistance of such a web
- This kind of **bending cannot be avoided** by aiming the force line of the diagonal brace at any specific point, when the length of the non-flange section is greater than zero
- In such a case, it is usually **necessary to stiffen** the joint area for the weak axis bending

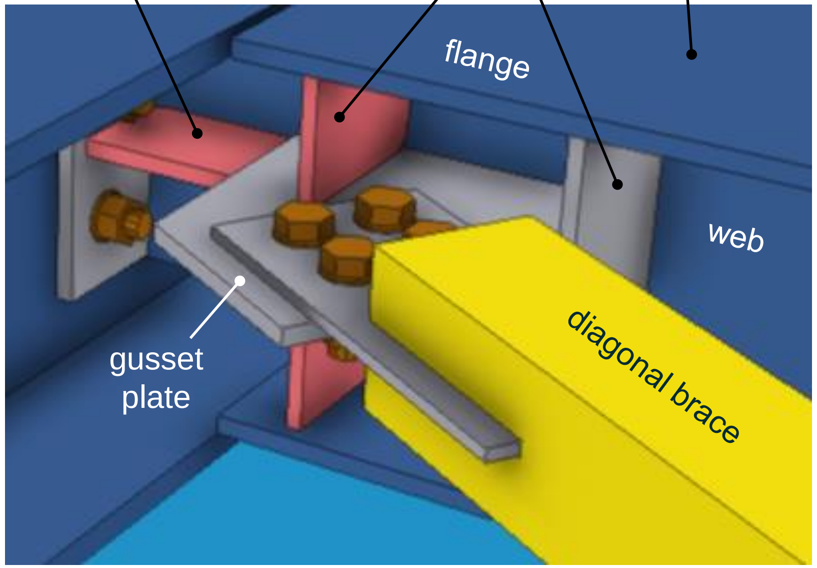


Joints to web

Local stiffening

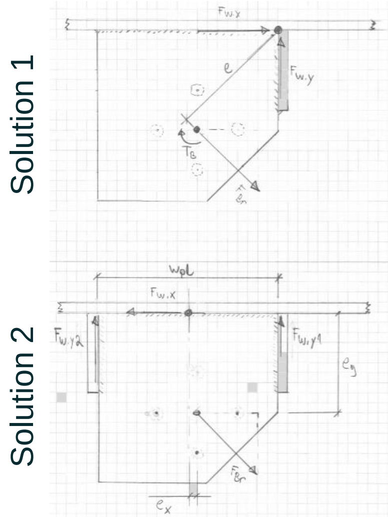
- The connection at the end of the diagonal brace with the beam web is also prone to design mistakes
- Designer should consider the web as a soft structural plate-like part for lateral forces if not stiffened
- It is usually mistake if it left without sufficient web stiffening

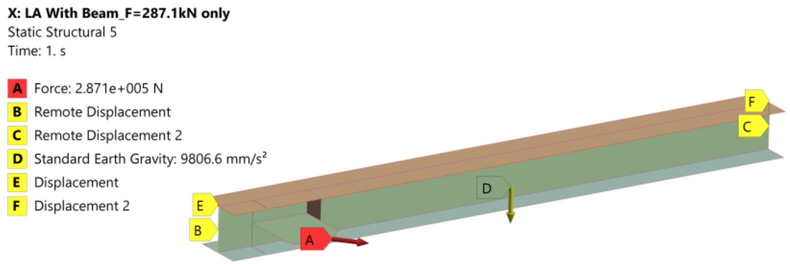


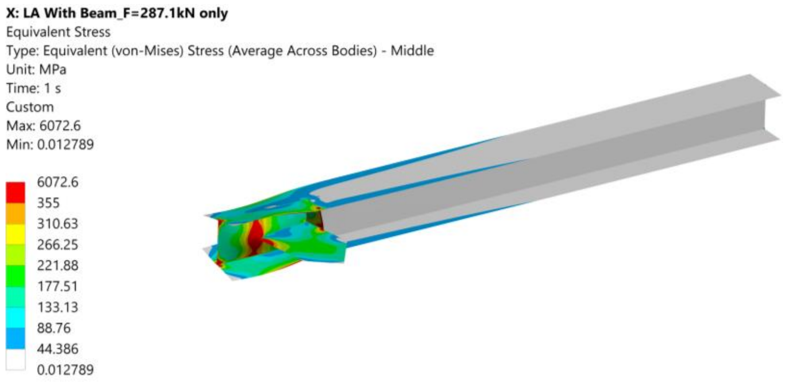


Joints to web

Comparison of solutions. Loads exaggerated for study purpose

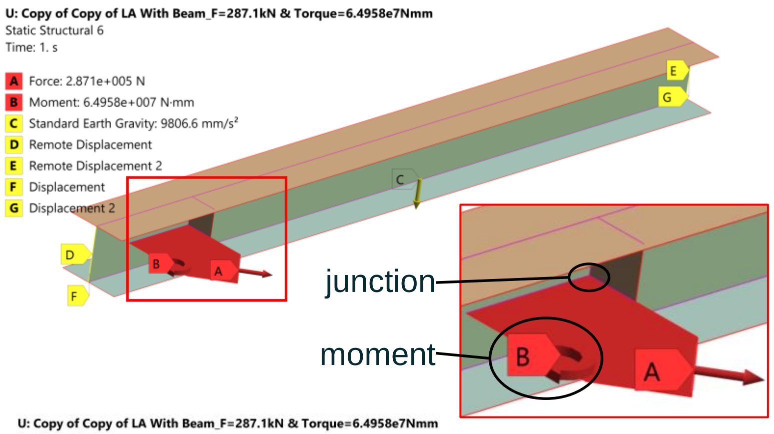


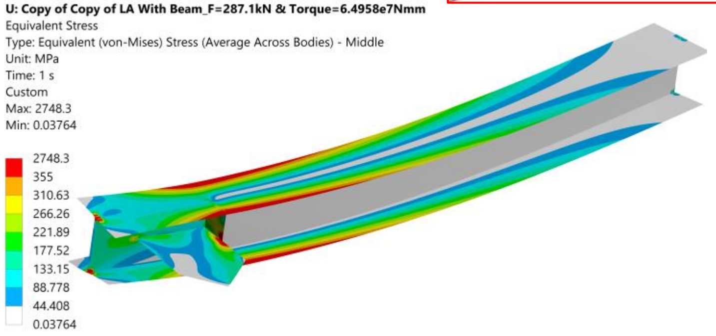




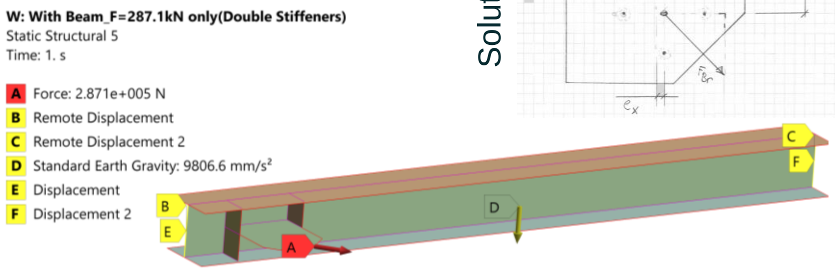
Problem: joint originally not detailed suitable to take pure axial load from the diagonal brace.

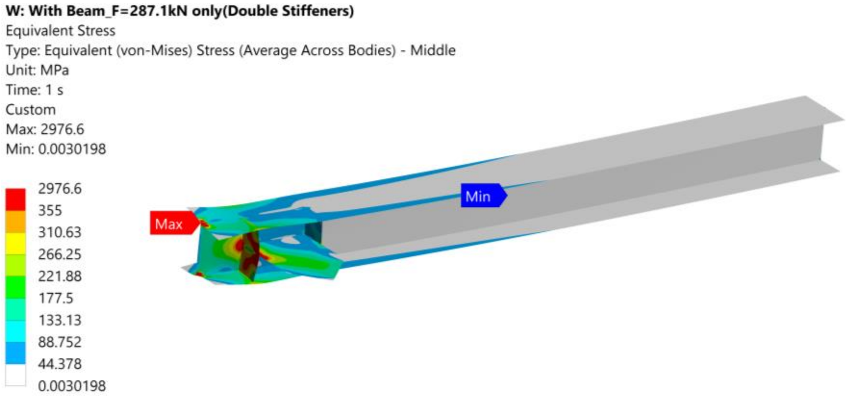
The force from diagonal brace cannot be transferred to flanges of beam by web bending





Possible solution 1: hinge location is moved into junction of web and web stiffener. Causes moment to diagonal brace, its end joint and also to beam (weak axis bending)





Possible solution 2: added web stiffener to fix gusset plate to flanges in moment rigid way

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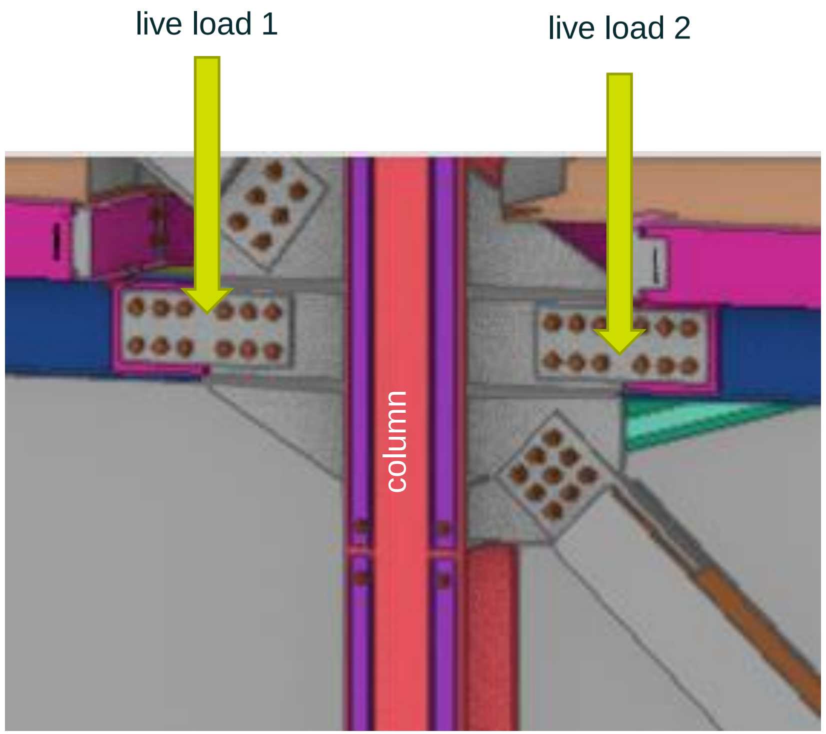
Joints to columns

Bending moment to columns

- Even in the main frame analysis, it is necessary to pay special attention to the fact that a significant **bending moment** can be applied to the column **through the nominal pins**
- In the simplest structural calculation, this moment can go **unnoticed if** such a pin is on both sides of the column to **balance the moments** from each other
- But this is a **mistake**, at least in cases where the moments are present due to **live loads**, such as the live load on working platforms
- In a correctly performed structural calculation, the strength of such a column is examined for the most **unfavorable combination** of the live loads



Live loads currently balancing moments from each other

The key take away

Put the location of your nominal pin into main frame calcutation model. This means additional node that is low cost to go for successful co-operation where all parties can read the assumption in the model