# Joint stiffness and its influence on design of steel structural elements

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ABSTRACT: The article explains the individual types of joint stiffness in a steel construction. Applying the joint stiffness to the structural model brings a number of problems and inaccuracies. The article shows possibilities for solving entire member, including the end joints. A brief study describes the influence of the structural design of a joint on the redistribution of internal forces in the rod element.

## 1. INTRODUCTION

Most steel structures are analyzed in a beam model. For designing common rod elements, this idealization is quite sufficient. In the joints, it is assumed that the rod connection is perfectly rigid or ideally pinned. But the reality is somewhere between these boundary assumptions. The design of a joint is essential for the behavior of the entire member. The team of authors is concerned with the development of methods and models for more accurate analysis of the whole "joint-to-beam-to-joint" subsystem and its importance for the beam check.

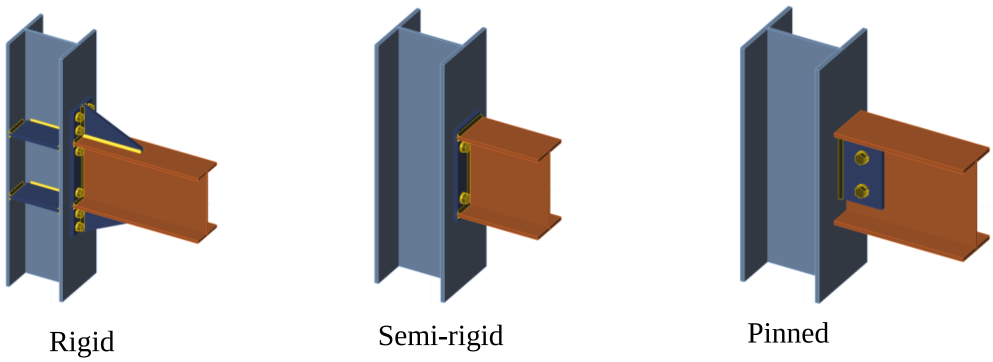


Figure 1: Examples of joints with different classification according to stiffness

## 2. JOINT STIFFNESS

Joints are classified according to EN 1993-1-8 - 5.2.2 [1] by stiffness as rigid, semi-rigid and pinned, see Figure 1. Structures with rigid joints can be considered as continuous, pinned joints transfer only moments that can be neglected thanks to their rotational capacity, but semi-rigid joints do not fall into any of these two categories, they transmit bending moments partially. Connections are classified according to the initial stiffness, which is considered up to 2/3 of the linear joint load-bearing capacity $M_{Rd}$. For semi-rigid joints, secant stiffness is important for designing the ultimate bearing capacity. After exceeding 2/3 of $M_{Rd}$, the stiffness of the semi-rigid joint is assumed to be $S_{j,ini}/\eta$, according to Article 5.1.2, where the stiffness coefficient or in accordance with Table 5.2 is assumed to be between 2 and 3.5. By using Article 5.1.2, an iterative process can be avoided. When using the secant stiffness for a specific load, the history of the loading of the joint is considered. If the load has been previously higher, the joint may exhibit plastic deformations and the beam bends more and transmits a higher torque load in the span.

Initial rigidity can be calculated by the component method in Chapter 6.3. The component method allows to calculate the stiffness of each component, and the position of the axis of rotation is estimated. The component method considers the combination of loads, such as bending moment, shear and normal force, the calculation of each load-bearing capacity with interactions, or interactions when compiling the components. The method was validated by experiments [2], but the differences in stiffness evaluation are in tens of percent. Differences are due to simplifications in determining component deformations and their assembly. Another factor is measurement errors. Particularly with rigid joints, it is difficult to measure deformations with sufficient precision and to derive the deformation of individual members, floor, load-bearing frames, etc. In addition to the stiffness of the joint, sufficient rotational capacity must be guaranteed. The code provides simplified models for rotation capability estimation in Chapter 6.4. Generally, fragile components, such as welding or concrete cone breakout in anchoring, should not be considered for load-bearing capacity. Higher deformations can occur safely in the tensioned parts in an end plate, column panel in shear or in a connected member.

## 3. STIFFNESS INFLUENCE ANALYSIS

The effect of joint bending stiffness can be illustrated by the example in Figure 2. This is a beam of length $L_b$ with a moment of inertia of the cross-section $I_b$ of material with elastic modulus $E$. The beam is loaded with a constant continuous load $q$. The beam is attached to the columns by connections with a stiffness $S_{j,\,ini}$. For simplicity, it is assumed that the columns are infinitely rigid.

Depending on the stiffness of the connection, the moment diagram corresponds to values according to the rigid type of support up to the pinned type of support.

The stiffness of the joint can be classified according to EN 1993-1-8 by engineering estimation or by reference to the stiffness of the connected beam. The dimensionless stiffness $k^b$ is defined as:

$$k_{\mathrm{b}} = \frac{S_{\mathrm{j,ini}}.\,L_{\mathrm{b}}}{I_{\mathrm{b}}.\,E}$$

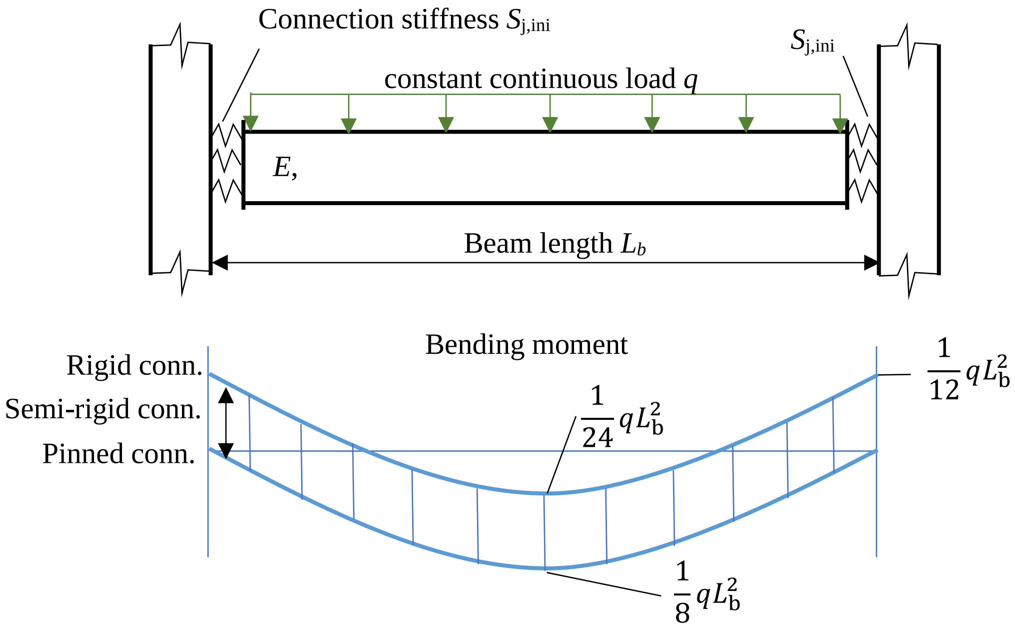


Figure 2: Influence of connection stiffness on the bending moment diagram along a beam

The influence of the dimensionless stiffness defined in this way is shown in Figure 3. It is clear from the graph that the influence of stiffness of the joint is essential. Depending on the stiffness of the joint, the moment differs by tens of percent. Three areas of the joint stiffness classification are clearly visible from the graph. EN 1993-1-8 classifies joints with stiffness $k_b$ <0.5 as pinned and joints with stiffness $k_b$ > 25 as rigid. This corresponds well to the analytical solution in Figure 3. For semi-rigid joints, determining the stiffness for the moment derivation along the beam is important for its design. Conversely, for rigid and pinned beams, the exact determination of stiffness is not significant. With increasing or decreasing stiffness, the moment does not change substantially, as shown in Figure 3. The exact determination of stiffness is problematic for rigid joints. It is a conservative estimate of the stiffness values of the individual components, which consists of an estimated arm of the internal forces. Even the orderly error in the determination of the stiffness of the joint does not have an effect on the moment and deformation of pinned and rigid joints. The beam is designed for the bending moment. When designing for ULS a 5% error is admitted and a 20% error is proposed when designing for SLS. These percentages can be depicted on the graph because the load capacity depends directly on the bending moment. In Figure 4, the IPE 330 beam stress analysis is shown that these limits are significant only for sufficiently rigid connection. The pinned connection is always a conservative estimate for the beam design. The rigid joint is on the figure represented by a pinned fin plate connection on the web and a welded connection.

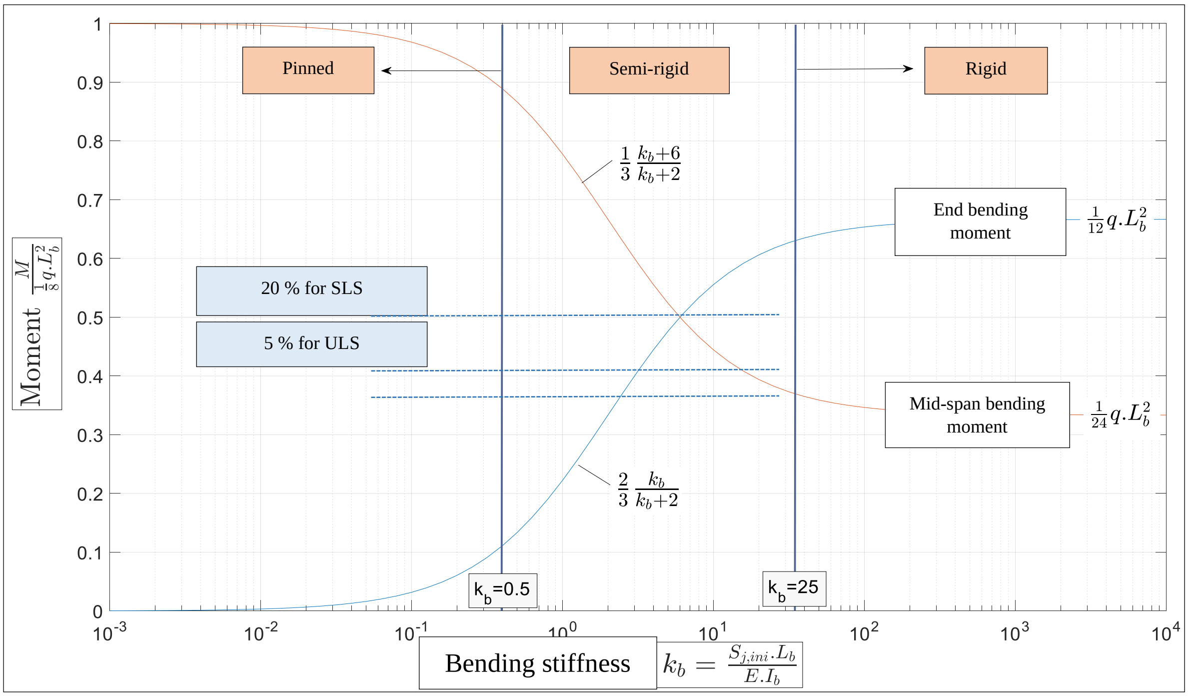


Figure 3: Influence of the relative bending stiffness of the joint in logarithmic scale to the relative mid-span bending moment

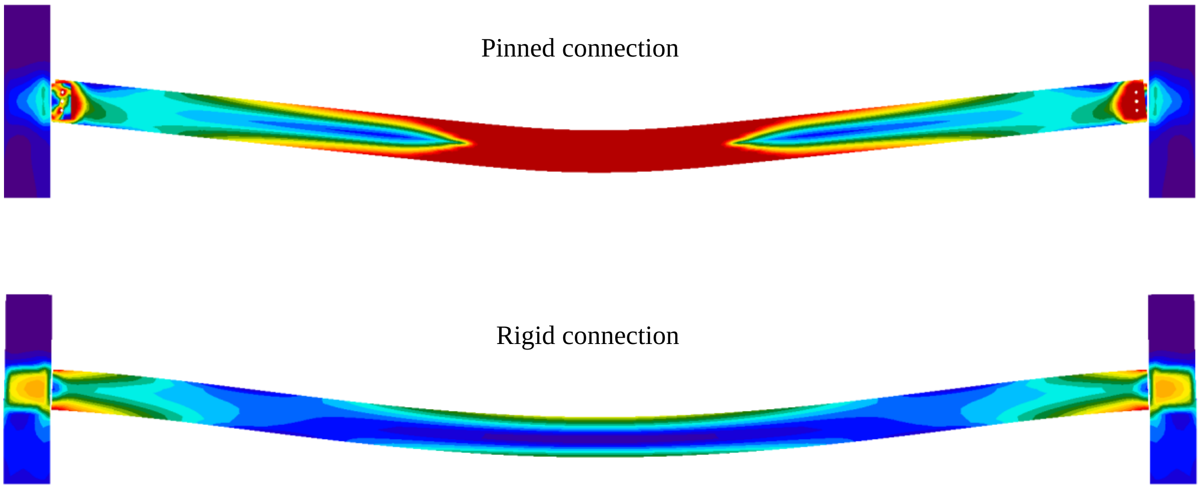


Figure 4: Output of von Mises stress on a beam supported by pinned and rigid connections in the IDEA StatiCa Member application

## 4. SUMMARY

Changing the joint stiffness causes the bending moments to be redistributed in the attached member. Even a large change in stiffness at a rigid or pinned joint only causes a slight redistribution. Changing stiffness is quite important when designing semi-rigid joints.

The vast majority of the members in the steel structure can be easily and reliably designed using standard procedures. The successful IDEA StatiCa Connection software, which is becoming the world standard for the design of joints (used by 1,500 offices), has put into practice a good way of designing joints using the component method and finite element method [3]. Knowledge of the behavior of joints can be used to refine the design of more complex and non-standard beams and columns.

IDEA StatiCa prepares for its users an application for the detailed design of atypical members by their geometrically and materially non-linear analysis including joints. The philosophy of the new program is the same as for Connection. Offering a wide range of designers FEM models in a very user-friendly interface.

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