ДГКС ASES | E-29
Kongres 2026
Congress 2026

doi: 10.67563/ASESCONF2026010J

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RECLAIMED BEAM LENGTH ADJUSTMENT VIA INNOVATIVE AND TRADITIONAL STRUCTURAL JOINT SOLUTIONS

Summary: The reuse of structural steel elements is an effective strategy for reducing the environmental impact of construction. However, the practical application of reclaimed steel members may be limited by geometric incompatibilities between existing member dimensions and the requirements of new structural systems. The possibility of adjusting the effective length of reclaimed beams in new frame structures is investigated using an innovative beam-to-column joint solution. Based on experimental tests, advanced FE models of the proposed joint were developed, validated and integrated into an FE frame model. An additional frame model incorporating conventional solutions, including a beam-to-column end-plate joint and a splice connection, was also developed. The structural performance of the innovative joint integrated within the frame structure is evaluated through comparative analysis, with emphasis on moment–rotation behaviour at SLS and ULS.

Keywords: bolted connection, demountable structure, reuse, moment-resisting joint, moment frame, moment–rotation

PRILAGOĐAVANJE DUŽINE PRETHODNO KORIŠĆENE GREDE PRIMENOM INOVATIVNIH I TRADICIONALNIH REŠENJA VEZA

Rezime: Ponovna upotreba elemenata čeličnih konstrukcija predstavlja efikasnu strategiju za smanjenje negativnih uticaja građevinske industrije na životnu sredinu. Međutim, praktična primena prethodno korišćenih čeličnih elemenata može biti ograničena geometrijskim nekompatibilnostima između dostupnih elemenata za ponovnu upotrebu i zahteva novoprojektovane konstrukcije u koju je potrebno ove elemente ugraditi. U ovom radu ispitivana je mogućnost prilagođavanja dužine prethodno korišćene grede novoj ramovskoj konstrukciji primenom inovativnog rešenja veze greda-stub. Na osnovu eksperimentalnih rezultata razvijeni su i validirani složeni numerički modeli predložene veze, koji su potom integrisani u numerički model čeličnog rama. Takođe, formiran je dodatni model rama u kom su primenjena tradicionalna rešenja, poput momente veze greda-stub sa čeonom pločom i montažnog nastavka grede sa podvezicama. Konstrukcijske karakteristike inovativne veze u okviru ramovske konstrukcije analizirane su kroz komparativnu analizu, sa posebnim osvrtom na relaciju moment–rotacija pri graničnim stanjima upotrebljivosti i nosivosti.

Ključne reči: veza sa zavrtnjevima, demontažna konstrukcija, ponovna upotreba, momentna veza, ramovski nosač, moment–rotacija

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1. INTRODUCTION

The reuse of reclaimed steel elements recovered from disassembled structures and their integration into newly designed structures represents a more environmentally favourable option than steel recycling. The global warming potential (GWP) of steel produced in electric arc furnaces using 85–100% recycled scrap typically ranges from 0.4 to 0.7 kg CO_2e/kg of steel [1]. In contrast, when steel elements are directly reused, most of the emissions associated with steel production are avoided. Although steel reuse may result in additional environmental impacts related to deconstruction, transportation, element inspection and required modification and fabrication in the shop, the overall reduction in greenhouse gas emissions compared with steel recycling is estimated to range from 60% to 90% [2].

Despite these environmental benefits, several barriers limit the widespread adoption of steel reuse in practice. These include the limited availability of reclaimed steel elements, dependence on demolition schedules, uncertainty regarding future supply, and potentially higher costs associated with testing and logistics [3]. Furthermore, the dimensions of reclaimed elements may not match the requirements of new structures, i.e. the available beam lengths may be insufficient for the desired structural spans. To address this challenge, specially designed adaptable construction joints for beam-to-column connections have been proposed in recent years. These joints are intended to facilitate the reuse of structural members across multiple life cycles by accommodating varying span requirements and enabling flexible structural configurations, while also offering simple assembly and disassembly. Both pinned connection solutions [4], [5] and moment-resisting connection solutions [6] have been developed for this purpose.

An innovative beam-to-column joint solution that enables beam length adjustment in steel moment-resisting frames through member extensions of approximately 100–200 mm at each end has been proposed, developed, and investigated at the University of Belgrade within the Horizon Europe project Circ-Boost. Initially, prototype testing was conducted under laboratory conditions to evaluate two different joint geometries and examine the influence of using reclaimed rather than newly manufactured steel for the joint components [7], [8]. Following the experimental campaign, advanced finite element (FE) models were developed and validated against the test results. These models were subsequently employed in a comprehensive parametric study to enhance the joint design and improve its structural efficiency [8]. In the next phase, the FE model of the final joint configuration was incorporated into a structural frame model, and its performance was assessed with respect to various parameters, including frame span and column support conditions [9]. The proposed joint design was subsequently implemented in the steel frame of a pilot house to be constructed in the courtyard of the Faculty of Civil Engineering. The frame structure will serve as a testbed for monitoring and experimentally assessing its performance under serviceability loading conditions [10]. Additionally, the pilot house will not only demonstrate the proposed beam-to-column joint solution but also highlight a broader range of circular and sustainable construction technologies, including a demountable steel column base, a reusable steel–concrete composite slab with profiled steel sheeting, prefabricated concrete columns incorporating recycled aggregates, and other innovative solutions designed to facilitate material reuse and resource-efficient construction.

To further familiarise the construction community with the proposed demountable beam-to-column joint for steel moment-resisting frames and to assess its performance relative to conventional solutions for beam length adjustment, a comprehensive numerical study was conducted according to previously validated FE models. The results are presented, analysed, and discussed in this paper, providing a comparative assessment of the moment–rotation behaviour of the investigated joint solutions under both serviceability limit state (SLS) and ultimate limit state (ULS) conditions. The influence of key parameters, including frame span and friction coefficient in connections with preloaded bolts, was examined to evaluate their effects on joint response for both the innovative and traditional structural joint configurations.

2. INNOVATIVE VS. TRADITIONAL JOINT SOLUTIONS

The proposed innovative joint is intended for use in steel moment-resisting frames composed of I-section beams and columns. The solution is based exclusively on mechanical fasteners, i.e. bolts, eliminating the need for welded connections. This approach ensures full demountability of the joint, simplifies fabrication, and facilitates efficient assembly and disassembly on site. The joint is fabricated from standard hot-rolled steel sections and comprises: (1) a link element made from the same I-section as the beam, (2) T-stubs produced by cutting one flange from an I-section, and (3) cleats produced by cutting one flange from a U-section, as illustrated in Figure 1a. Two T-stubs connect the flanges of the beam and link element to the column flange, while two cleats connect the webs of the beam and link element to the column flange on both sides.

A key feature of the proposed solution is the adaptable link element positioned between the beam and the column, which enables adjustment of the beam length to suit the span requirements of a new structure. In typical applications, the link provides an extension of approximately 100–200 mm. The maximum achievable link length is governed by the dimensions of the associated joint components, i.e. the availability of suitable hot-rolled sections for T-stubs and cleats.

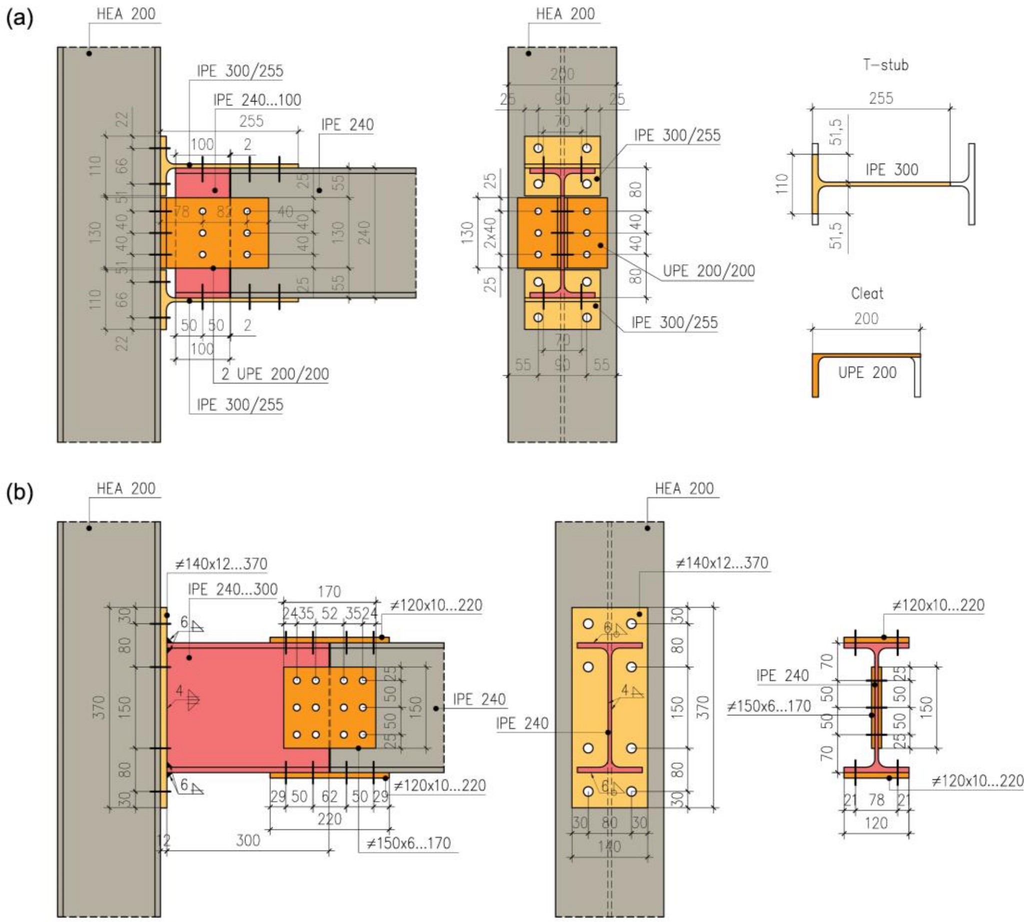

Figure 1: (a) Innovative joint solution, (b) Traditional joint solution

The investigated joint connects a hot-rolled HEA 200 column to an IPE 240 beam and incorporates a 100 mm long link element. The T-stubs are fabricated from IPE 300 sections, while the cleats are manufactured from UPE 200 sections. All structural components are made of S355 steel grade. The connection employs fully threaded bolts, grade 10.9, pretensioned to a preload force according to EN 1993-1-8 [11]. Since that friction coefficient has a major influence on the slip resistance of preloaded bolts, selecting an appropriate surface treatment and the corresponding friction coefficient is an important aspect of joint design. The influence of this parameter was subsequently investigated through an FE study. M16 bolts are used to connect the T-stubs to the column flange and to the flanges of the beam and link element, whereas M12 bolts are used to connect the cleats to the column flange and to the webs of the beam and link element. The presented joint configuration was selected based on the outcomes of a previously conducted numerical optimisation study [9]. Compared with the initial design investigated experimentally [7], [8], the finally adopted design provides increased moment resistance, enhanced rotational stiffness, and improved failure behaviour by preventing premature bolt failure.

For comparison purposes, a conventional solution for beam length extension was designed, consisting of an end-plate connection between the column and the link element, together with a splice connection between the link element and the beam. While the innovative solution transfers the bending moment using T-stubs and cleats via bolted tension and shear connections, the conventional approach separates these mechanisms: the end-plate connection transfers the load through fillet welds and bolts in tension, while the splice connection transfers the load through bolts in shear. The traditional joint configuration was designed to provide a comparable level of structural performance to the proposed innovative solution, thereby enabling a meaningful comparison in the subsequent analyses. As well as the innovative joint, the conventional joint connects a hot-rolled HEA 200 column to an IPE 240 beam. The end plate, with a thickness of 12 mm, is welded to the link element and connected to the column flange by M16 bolts. The splice connection consists of flange plates with a thickness of 10 mm and web plates with a thickness of 6 mm. Bolts M16 are used in the flange splice plates, while bolts M12 are used in the web splice plates. As in the innovative joint solution, all structural components are fabricated from S355 steel, while all bolts are fully threaded, preloaded high-strength bolts of grade 10.9. Unlike the innovative joint, the conventional solution requires a longer link element to accommodate the splice connection. Consequently, the link length was increased from 100 mm to 300 mm, as the proposed traditional configuration could not be practically realised with a 100 mm link. The adopted length of 300 mm was selected to represent a relatively small beam length extension while maintaining a reasonable separation between the end-plate connection and the splice connection.

To compare the innovative and conventional joint solutions in terms of material consumption and fabrication requirements, a summary of joint component weights, number of bolts, and welding requirements is presented in Table 1. As shown, both solutions require a similar amount of steel for joint components. However, the proposed innovative solution achieves a reduction in the number of bolts required for assembly and, more importantly, eliminates the need for welding operations entirely, simplifying the fabrication process.

Table 1: Material consumption for the two analysed joint solutions

Joint solution	Weight of steel sections and plates* [kg]	Number of bolts		Welding
		M12	M16	
Innovative	10.80	12	20	not required
Traditional	11.43	12	24	required

* *excluding beam, column and link sections, and excluding waste during component fabrication*

3. FE MODEL DEVELOPMENT

The comparative analysis of the innovative and conventional joint solutions was carried out by implementing each joint type within a one-bay steel frame and evaluating their performance under uniformly distributed vertical load applied along the beam span. The frame consisted of a 3 m high HEA 200 column and an IPE 240 beam with a variable span. The FE model of the frame was developed in the software Abaqus using the Dynamic Explicit solver. The modelling approach was based on previously validated numerical models of experimental tests performed on the innovative beam-to-column joint, as described in detail in Ref. [8]. The same modelling procedure was adopted for both joint solutions, with the only difference being the geometry of the beam-to-column connection.

The FE models are illustrated in Figure 2. Beam and column members were modelled using three-dimensional beam elements (B31), whereas the beam-to-column joint region was represented using eight-node linear brick elements with reduced integration (C3D8R). The mesh density was selected to ensure at least three FE through each plate thickness, while a minimum element size of 2 mm was adopted for bolts, washers, and adjacent regions.

The beam and solid regions of the model were connected using the multi-point constraint (MPC) Beam option. Previous investigations indicated that the influence of column base support type (pinned or fixed) on the joint response is relatively small for the analysed frame configurations subjected to vertical loading applied along the beam span [9]. Therefore, only the fully fixed support condition was considered in the present study ($u_x = u_y = u_z = r_x = r_y = r_z = 0$). As the joint behaviour was investigated under vertical loading applied along the beam span, symmetry boundary conditions were imposed at the beam mid-span ($u_z = r_x = r_y = 0$), allowing only half of the frame to be modelled and thereby reducing the computational effort. In addition, lateral deformations of both the beam and column were restrained to prevent out-of-plane instability.

Interactions between the solid components of the joint were modelled using the general contact option, with “hard” contact defined in the normal direction and a penalty friction formulation adopted in the tangential direction. In the conventional joint solution, the welded connection between the end plate and the link element was represented using a tie constraint

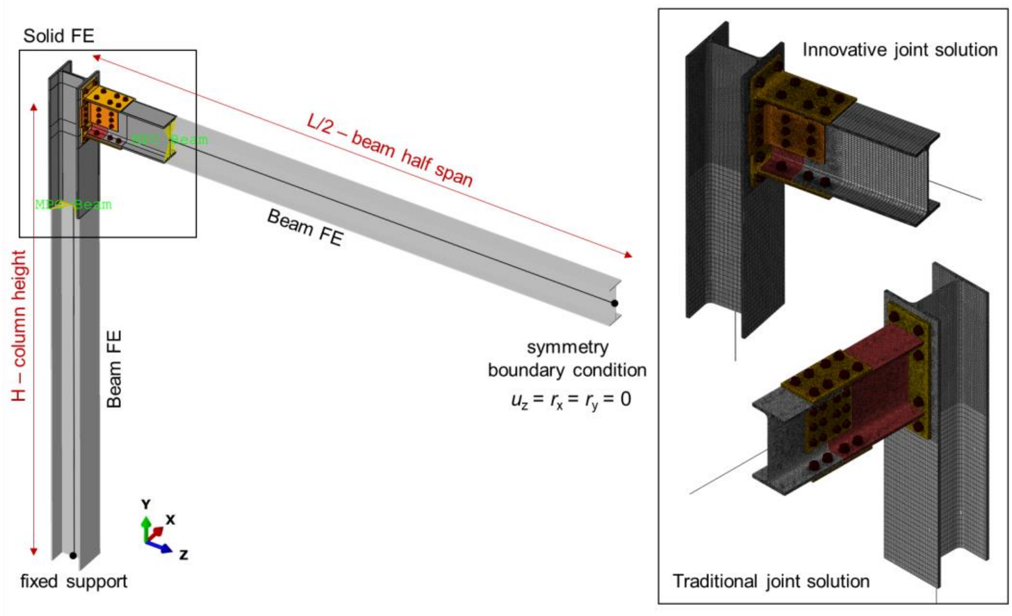

Figure 2: FE frame models

The numerical analysis was performed in two steps: (1) bolt preloading, with a duration of 100 s, and (2) load application, with a duration of 1000 s. A fixed time increment of 0.001 s was adopted through mass scaling to improve computational efficiency. Bolt preload was introduced by means of a temperature gradient, calibrated to generate the required full preload force at the end of the first step. In the second step, a uniformly distributed vertical line load was applied along the beam length. The load was introduced using a smooth-step amplitude function to ensure a gradual increase and minimise dynamic effects.

Material models were adopted from the previously validated FE simulations presented in Ref. [8], which were based on the results of tensile coupon tests. Structural steel was modelled using an elastic–plastic constitutive law, with the elastic response defined by the modulus of elasticity and Poisson's ratio, and the plastic response represented through experimentally derived true stress–strain curves. The bolts were modelled using the same material formulation, supplemented with a damage initiation and evolution model to enable the simulation of potential bolt failure.

Two parameters were varied through the numerical study: frame span and friction coefficient. Frame models with beam spans of 6 m, 7 m, and 8 m were analysed. The friction coefficient, μ, was assigned values of 0.20, 0.30, and 0.40, corresponding to friction surface classes D, C, and B, respectively, according to EN 1993-1-8 [11] and EN 1090-2 [12]. The selected parameter range enabled the assessment of both geometric and contact-related influences on the moment–rotation response of the innovative and conventional joint solutions.

4. RESULTS AND DISCUSSION

The moment–rotation curves obtained from the frame FE models and presented in Figure 3, illustrate the joint behaviour under a uniformly distributed vertical line load up to 20 kN/m acting on the beam. Considering that the analysed frame represents part of an industrial hall with a total roof load of approximately 2.5 kN/m^2 (including permanent and variable actions) and a frame spacing of 5–6 m, a uniformly distributed line load of 20 kN/m was assumed to represent the ULS. For the SLS, a line load of 14 kN/m was considered, and the corresponding point on each load–displacement curve is indicated in Figure 3. The bending moment was evaluated at the section corresponding to the beam-to-column joint, specifically at the column flange. Joint rotation was determined in accordance with EN 1993-1-8 [11] as the relative rotation between the beam and column, obtained by subtracting the column rotation from the beam rotation.

Each diagram in Figure 3 also includes the stiffness limits used for stiffness-based joint classification according to EN 1993-1-8 [11]. The rigid-joint limit was taken as $25EI_b/L_b$, while the nominally pinned-joint limit was taken as $0.5EI_b/L_b$, where E is the Young's modulus of steel, I_b is the second moment of area of a beam, and L_b is the beam span. As illustrated, both the proposed innovative joint solution and traditional joint solution behave as semi-rigid, with stiffness closer to that of rigid joints rather than nominally pinned ones.

The difference in behaviour between the traditional and innovative joint solutions becomes more pronounced for larger spans and lower friction coefficients. In particular, for the frame with an 8 m span and a friction coefficient of μ = 0.2, the innovative joint develops lower bending moments than the traditional solution at both the SLS and ULS. This behaviour can be attributed to a slip occurring in the preloaded bolts subjected to shear, connecting the T-stubs to the beam flange. A similar response is observed for frames with an 8 m span and μ = 0.3, and for frames with a 7 m span and μ = 0.2. However, in these cases, the reduction in bending moment occurs only at the ULS. In contrast, for a friction coefficient of μ = 0.4, the moment–rotation curve of the innovative joint lies above that of the conventional joint.

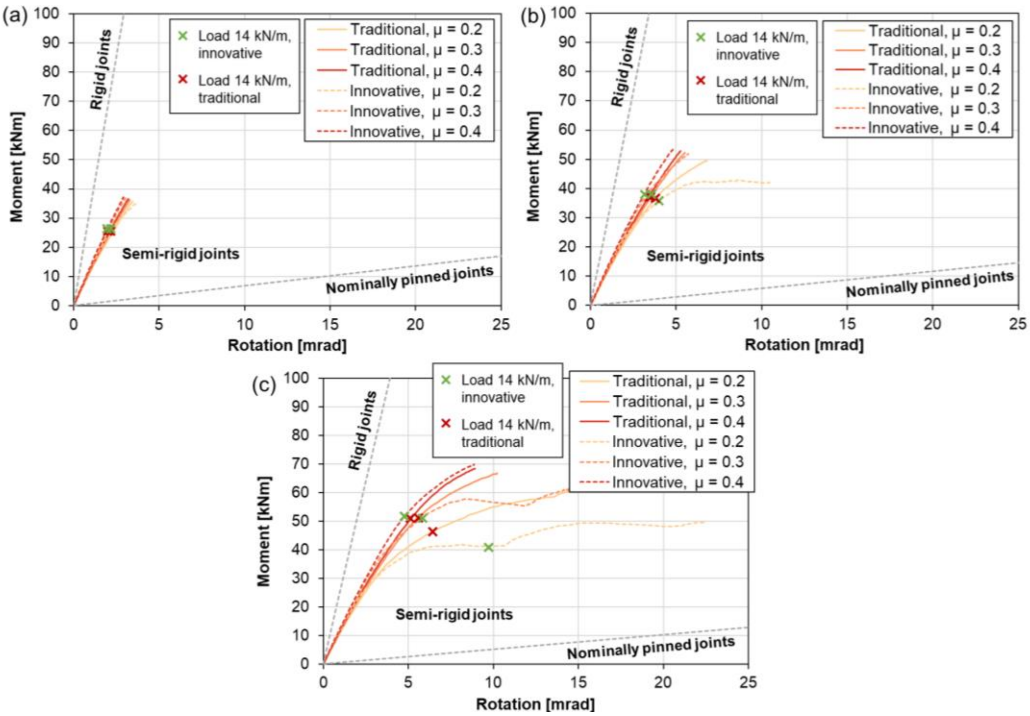

Figure 3: Moment–rotation curves of innovative and traditional joints in frames spanning: (a) 6 m, (b) 7 m, and (c) 8 m

To further explain this behaviour, the moment–rotation responses of frames with an 8 m span are presented in greater detail in Figure 4. As previously noted, joint rotation for both solutions was determined by subtracting the column rotation from the beam rotation (denoted as total rotation in Figure 4). In addition, a second measure of rotation was evaluated by subtracting the column rotation from the rotation of the link element (denoted as link rotation in Figure 4). A non-negligible difference in link rotation between the conventional and innovative joint solutions can be observed, with the innovative solution exhibiting smaller link deformations. However, bolt slip occurring at the T-stub–beam contact in the innovative joint results in increased beam rotation, which ultimately governs the overall moment–rotation behaviour. Consequently, for friction coefficients of $\mu = 0.2$ and $\mu = 0.3$, the total rotation of the innovative joint becomes larger than that of the conventional joint despite the smaller deformation of the link element. In the conventional solution, the difference between link rotation and total joint rotation is less pronounced. Nevertheless, the link rotation is greater than that observed in the innovative solution in all analysed cases. For $\mu = 0.4$, the bolt slip resistance is sufficient to limit relative movement at the T-stub–beam contact. As a result, the innovative joint exhibits slightly lower rotations and higher stiffness than the conventional solution.

The greater sensitivity of the innovative joint to bolt slip resistance, compared with the conventional solution, can be attributed to the number of bolts in shear connecting the link to the beam and the different force levels acting on these bolts in the two configurations. In the traditional solution, the splice connection is located 300 mm away from the end-plate joint. In contrast, the innovative joint features a substantially shorter link, resulting in a smaller distance between the column flange and the bolts connecting the T-stub to the link and beam. Consequently, larger bending moments are transferred through the splice connection of the innovative joint, leading to higher bolt shear forces and an increased likelihood of slip. As a result, bolt slip occurs at lower load levels and has a more pronounced influence on the overall moment–rotation response of the innovative joint.

The smaller link rotation observed in the innovative joint solution compared with the traditional joint is primarily associated with the column-to-link connection. The larger number of bolts connecting the link to the column flange in the innovative solution reduces the bending deformation of the column flange. Additional stiffness of the column-to-link connection is provided by the two cleats, which enhance the restraint between the column and the link.

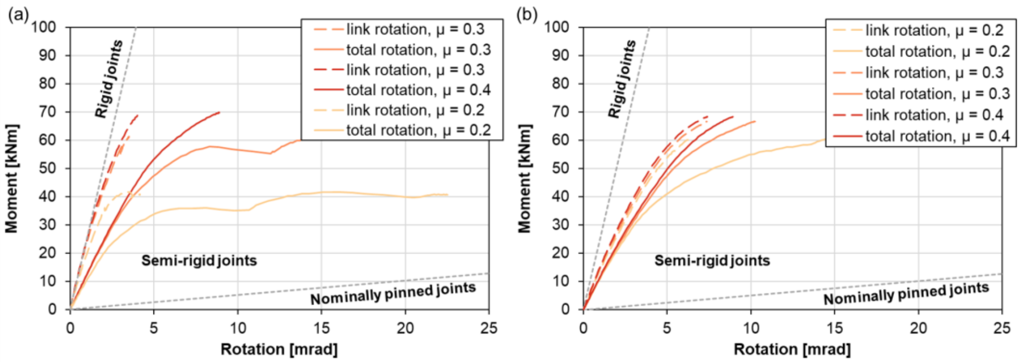

Figure 4: Moment–rotation curves in the frame spanning 8 m, obtained through beam rotation (total rotation) and link rotation: (a) Innovative joint, (b) Traditional joint

The described effects are illustrated in Figure 5, which shows the deformed configurations at ULS of the innovative and conventional joints for a frame with an 8 m span and a friction coefficient of $\mu = 0.2$. At this load level, almost all components of the innovative joint remain within the elastic range. Only minor plastic deformations were observed in the T-stub due to local bending, whereas no plastic deformations were identified in the flange splice plate of the conventional joint. This difference can be attributed to the different force levels and smaller thickness of the T-stub web (7.1 mm) compared with that of the flange splice plate (10 mm). This results in larger bending moments, lower bending stiffness and consequently larger deformations of the T-stub web. Conversely, the conventional joint exhibits plastic deformations in the column flange and web, which are not observed in the innovative solution. As discussed previously, this difference is primarily related to the larger number of bolts arranged along the column flange and the presence of cleats in the innovative joint, which provide improved restraint and load transfer compared with the conventional joint. Overall, the presented response of the innovative joint demonstrates the potential of the proposed structural system for reuse in subsequent life cycles, as the primary load-bearing members (beam and column) remain within the elastic range even at the considered ULS load level. The demountable nature of the proposed joint enables the potential reuse of its individual components, or recovery and replacement if necessary.

To further compare the initial stiffness of the two analysed joint solutions, the obtained values are compared with the corresponding rigid-joint limit of $25EI_b/L_b$, as shown in Figure 6. In addition, the numerical values of the initial stiffness for all analysed joints are provided. For all analysed configurations, the innovative joint exhibits a higher initial stiffness than the conventional solution, with an increase of approximately 7–8%. The initial stiffness decreases with increasing frame span, by approximately 5% when the span is increased from 6 m to 7 m, and by 8–9% when the span is increased from 6 m to 8 m. Nevertheless, the ratio between the initial stiffness and the rigid-joint limit of $25EI_b/L_b$ increases with increasing span length. The influence of surface properties, represented by the friction coefficient, on the initial stiffness is relatively small. Increasing the friction coefficient from 0.2 to 0.3, or from 0.3 to 0.4, results in a stiffness increase of only 2–4%.

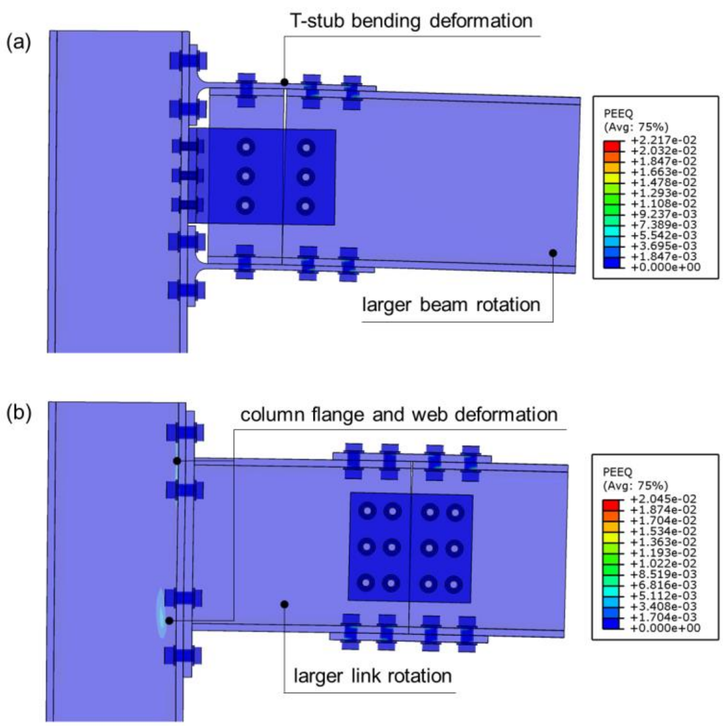

Figure 5: Deformed shapes at ULS in the frame spanning 8 m, μ = 0.2: (a) Innovative joint, (b) Traditional joint

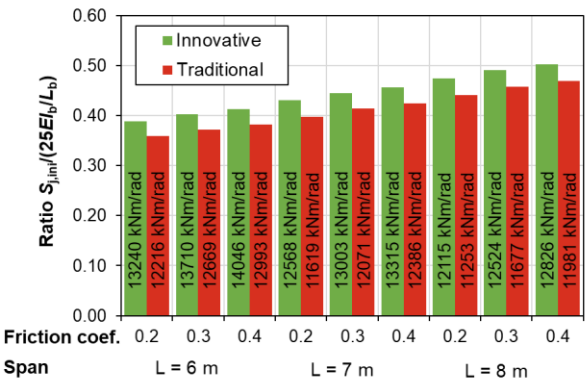

Figure 6: Ratio between the initial joint stiffness and the lower stiffness limit for rigid joints

To quantify the influence of the moment–rotation response of the analysed joints on the global frame behaviour, the beam mid-span deflections at SLS are presented in Figure 7. For frames with spans of 6 m and 7 m, the differences in beam deflection between the innovative and conventional joint solutions are minor. It is also worth noting that, in both cases, the calculated deflections satisfy the serviceability criterion of L/300. In contrast, the frame with an 8 m span exceeds this limit. For the 8 m span, the differences between the analysed models become more pronounced, with beam deflection increasing as the friction coefficient decreases. This trend is more evident for the innovative joint solution than for the conventional one. The largest deflection is obtained for the innovative joint with μ = 0.2, which exhibits a beam deflection approximately

10% greater than that of the corresponding conventional joint. In the remaining cases, the differences between the two joint solutions are relatively small.

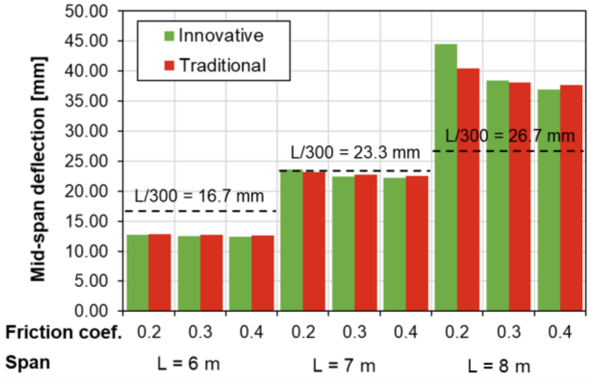

Figure 7: Beam mid-span deflections at load of 14 kN/m

5. CONCLUSIONS

The presented results provide a comparative assessment of the behaviour of the proposed innovative joint and the corresponding conventional joint solution. Both joint configurations were developed to accommodate minor beam length adjustments, which may be required when reclaimed steel beams are incorporated into new structures.

The results indicate that the two joint solutions exhibit comparable structural behaviour, particularly for shorter beam spans. The innovative joint is more sensitive to variations in surface class and friction coefficient, exhibiting larger rotations at ULS for frames spanning 7 m and 8 m with lower friction coefficients. Nevertheless, the innovative joint demonstrates a slightly higher initial stiffness than the conventional solution. According to EN 1993-1-8 [11], both joint configurations may be classified as semi-rigid. Differences in beam mid-span deflections at SLS are generally small, except for the frame spanning 8 m with a friction coefficient of $\mu = 0.2$, where a more pronounced increase in deflection is observed for the innovative solution.

Based on the presented results, it may be concluded that the proposed innovative joint provides satisfactory mechanical performance and may therefore be considered a practical solution when shorter beam length adjustments are required. From the perspective of material consumption and fabrication, its application is advantageous, as it requires fewer resources than the conventional joint solution. This benefit is particularly reflected in the elimination of welding operations.

However, the influence of surface condition on the moment–rotation response must be carefully considered during design. Particular attention should be paid to ensuring that the slip resistance of the bolts connecting the link and beam through T-stubs is not exceeded under the relevant design conditions, whether at SLS or ULS. Consequently, when reclaimed elements are prepared for reuse, their surfaces should be carefully treated before assembly to achieve the required friction performance. Similar considerations apply in subsequent reuse cycles, where the condition of the contact surfaces should be inspected and, where necessary, restored after each service life cycle to ensure the designed structural performance.

FUNDING SOURCES

This research is co-funded by the European Union, within the framework of the Horizon Europe project "Circ-Boost: Boosting the uptake of circular integrated solutions in construction value chains", Grant No. 101082068.

REFERENCES

[1] "Steel Sustainability," Steel Calculator. Accessed: Jun. 10, 2026. [Online]. Available: https://steelcalculator.app/reference/steel-sustainability/

[2] J. Berglund-Brown and J. Ochsendorf, "Reusing Heavy-Section Steel in Buildings: Carbon Reduction Potential and Material Availability," *J. Archit. Eng.*, vol. 31, no. 2, p. 04025020, Jun. 2025, doi: 10.1061/JAEIED.AEENG-1918.

[3] D. Densley Tingley, S. Cooper, and J. Cullen, "Understanding and overcoming the barriers to structural steel reuse, a UK perspective," *Journal of Cleaner Production*, vol. 148, pp. 642–652, Apr. 2017, doi: 10.1016/j.jclepro.2017.02.006.

[4] X. Dai, J. Yang, D. Lam, T. Sheehan, and K. Zhou, "Experiment and numerical modelling of a demountable steel connection system for reuse," *Journal of Constructional Steel Research*, vol. 198, p. 107534, Nov. 2022, doi: 10.1016/j.jcsr.2022.107534.

[5] C. Odenbreit, J. Yang, A. Romero, and A. Kozma, "A Lego-like steel-framed system for standardization and serial production," *Steel Construction*, vol. 16, no. 1, pp. 56–64, 2023, doi: 10.1002/stco.202200021.

[6] N. Janković, J. Dobrić, N. Gluhović, J. Conde, F. Ljubinković, and L. S. da Silva, "Numerical Characterization of Innovative Demountable Beam-Column Connections Using Long Bolts," *ce/papers*, vol. 7, no. 1–2, pp. 45–54, 2024, doi: 10.1002/cepa.3021.

[7] I. Jakovljević, J. Dobrić, N. Gluhović, and M. Spremić, "Moment-resisting beam-to-column joints in reusable building structures," in *The International Colloquium on Stability and Ductility of Steel Structures, Barcelona, 8-10 September 2025*, Barcelona, 2025, pp. 805–810. doi: 10.1002/cepa.70180.

[8] I. Jakovljević, J. Dobrić, N. Gluhović, and M. Spremić, "Beam–to–column joint solutions for reusable moment-resisting steel frames," *Journal of Constructional Steel Research*, vol. 238, p. 110163, Mar. 2026, doi: 10.1016/j.jcsr.2025.110163.

[9] I. Jakovljević, J. Dobrić, N. Gluhović, and M. Spremić, "Performance and structural efficiency of demountable joints in reusable steel moment frames," in *Eurosteel 2026, Krakow, 16-18 September 2026 (accepted for publication)*, Krakow, 2026.

[10] "Pilot 3 – Belgrade, Serbia," Circ-Boost. Accessed: Jun. 11, 2026. [Online]. Available: https://circboostproject.eu/pilot-3-belgrade-serbia/

[11] EN 1993-1-8, *Eurocode 3: Design of steel structures. Part 1-8: Design of joints*. Brussels: CEN, 2005.

[12] EN 1090-2, *Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures*. Brussels: CEN, 2018.