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THE EFFECT OF COLUMN WEB STIFFENERS ON MOMENT RESISTANCE AND DUCTILITY OF EXTENDED END-PLATE BOLTED CONNECTION

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Abstract

Extended end-plate bolted connections as moment-resistant connections between beam and column usually fall in the semi-rigid partial strength category. Simplicity, duplication, and economy made this joint widely used in steel frame structures. This type of joint is prevalent nowadays which requires knowledge of the entire nonlinear moment-rotation behaviour of the joints.
Using ABAQUS FE software in this paper, a three-dimensional finite element model (FEM) is developed to identify the effect of different geometrical parameters on the behaviour of extended end-plate bolted connection with four bolts per horizontal row as a semi-rigid beam-to-column joint. The component method which, is adopted in Eurocode 3, parts 1-8, provides detailed application rules for the design of bolted end-plate connections when most of them are limited to configurations with two bolts only in each horizontal row, without column web stiffeners.
By using the finite element model, a parametric study is conducted to study the influence of column web stiffeners (compression and tension stiffeners, K stiffeners, and double web stiffeners) on three main properties of extended end-plate bolted connection, moment capacity (Mj,Rd), initial rotational stiffness (Sj.in) and rotation capacity (Φcd) under monotonic loading, using finit element (FE) analyses.

The analytical research work, done here gives specific attention to the characterization of joint ductility, which is one of the critical behaviours of semi-rigid connections compared with rigid or pinned ones based on finite element analyses.

Keywords: Beam-to-column connection, analytical modelling, moment-resisting joints, column stiffeners, ductility, four bolt per horizontal row, finite element method.

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1. Introduction

In the designing and analyzing of the steel frames, there are three essential components which have an impact on the structural behaviour of a construction building. There are beams, columns and the elements connecting them, so beam-to-column connection. Columns and beams must be designed in that way to fulfil the requirements regarding strength, stiffness and serviceability. The moment-resisting joints must show stiffness characteristics to allow the connected component and the entire structure to remain within allowable deflection limits and still have sufficient ductility to keep permanent damage at a minimum of the structure during serve loading. For all the cases analyzed in this paper, the resistance of the joint can be calculated through the component method, EN 1993-1-8, [1,2,3,4]. For simplicity, any joint can be subdivided into three zones: compression, tension and shear. Each of these zones is composed of components that contribute to the overall response of the joint. For the computation of the design properties of the joint, the active joint components for this configuration, according to Eurocode 3, are (1) column web in shear, (2) column web in compression, (3) beam flange in compression, (4) column web in tension, (5) column flange in bending, (6) bolt row in tension, (7) end plate in bending. These individual components are assembled into a mechanical model to evaluate the M-Φ response of the whole joint represented in Fig.1. Components of the joint may be strengthened by providing additional stiffeners, which are elaborated on below. In particular, this paper emphasizes analytical analyses of an extended end-plate bolted connection with four bolts per horizontal row and a different strengthening type of column web to increase the mechanical properties of the joint. The purpose is to increase the resistance and rotational stiffeners of the column panel in shear, compression and tension ensuring, also the appropriate rotation capacity.

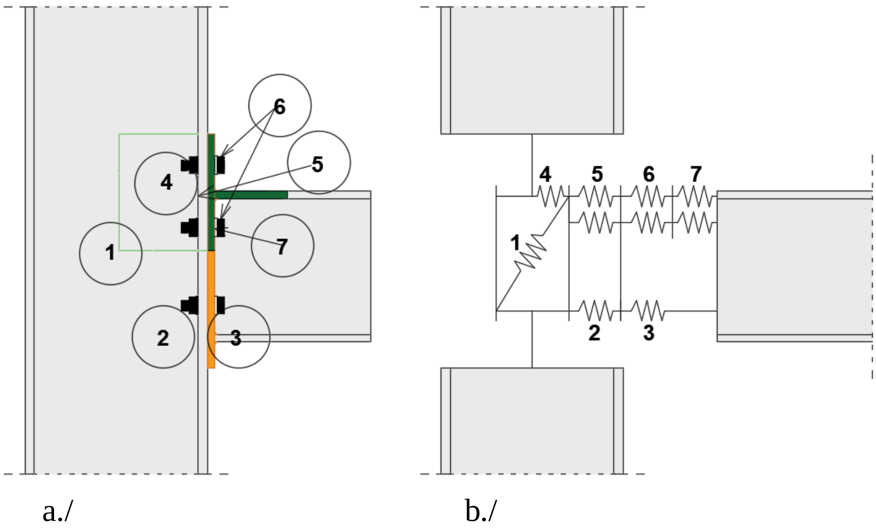

Figure 1. extended end-plate Steel joint a./Bolted beam-to-column connection and b./ component method

2. Applied strengthening of column web

The design philosophy of the semi-rigid/partial strength joints usually leads to simple solutions and more economical ones. During the designing of the joint, the proper selection of the strengthening of the joint will lead to a more cost-efficient structure. There exist several ways of strengthening each zone of the column web: compression stiffeners are generally required in portal frame joint, and their effect is by increasing the resistance to compression of the column web. A tension stiffener is used to increase the bending resistance of the column flange and the tension resistance of the column web. When the resistance of the column web does not fulfil the requirement, supplementary web plates, diagonal stiffener, and K stiffener should be used to increase the capacity of the web. Each of these stiffeners can contribute to enhancing the capacity of the connection. Stiffeners as a method of strengthening are unavoidable in a connection which are defined in Fig 2.

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3. FE numerical model

In order to investigate the contribution of the column web stiffeners, finite element (FE) analyses have been used. In general, are analysed four types of extended end-plate bolted connections, with four bolts per horizontal row; when the variable here is the way of strengthening the column web, the FE models were run using the general static analysis modelled in Abaqus [5]. The column and beam lengths were set to 2000mm and 1500 mm respectively. The Young's modulus and the Poisson's ratio were taken equal to 21000MPa and 0.3, receptively. While the other mechanical properties of the steel and bolts are taken from [7].

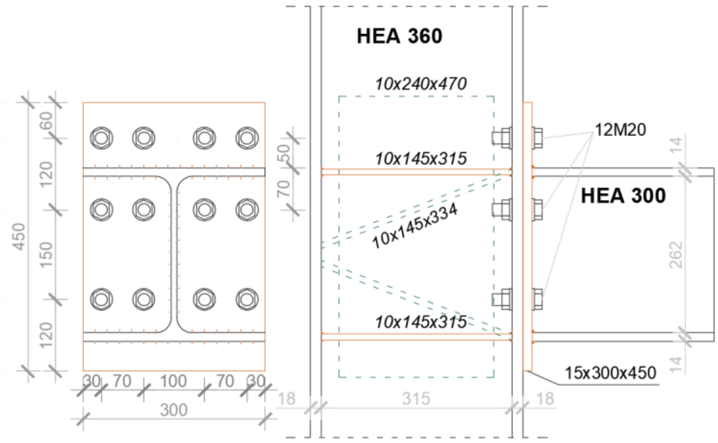

Figure 2. Typology of connections

Table 1- Connections geometry data.

	Type 1	Type 2	Type 3	Type 4
Stiffeners	Non (mm)	Tension Compresion 10x145x315 (mm)	K-Stiffeners 10x145x334 (mm)	Web double plate 10x240x470 (mm)
Column	360	360	360	360
Beam	300	300	300	300
End-plate	15	15	15	15
Bolts	d-20, 8.8	d-20, 8.8	d-20, 8.8	d-20, 8.8
Steel	235	235	235	235
Stiffnes class	Semi	Semi	Semi	Semi
Strength Class	Partial	Partial	Partial	Partial

The overall mesh sizes for the column and the beam were set as 20mm and 25, respectively, and the much finer mesh was prescribed in the region of connection, end-plate, column flange and bolts. The three-dimensional FE model of a typical beam-to-exterior column joint is shown in Fig 3. While regarding the boundary conditions in FE models, all DOF at each end of the column were restrained, except for the rotation about the strong axis of the column. Similarly, the degrees of freedom of the beam ends were restrained except for the vertical displacement. Meanwhile, the bolt pretension forces were defined by using the bolt load command, which was taken according to Eq. (1). In general, four contact pairs between the end-plate and column flange, the bolt head and column flange, the bolt nut and end-plate, and the bolt shank and corresponding bolt hole were defined. The property of the contact pairs was defined as finite-sliding and surface-to-surface with a friction formulation using the penalty method for tangential response with friction coefficient 0.15 of all contact surfaces, while the default hard contact model was used for the normal behaviour.

$$F_{pre} = \frac{0.7 \cdot f_{ub} \cdot A_S}{\gamma_{M7}} \quad (1)$$

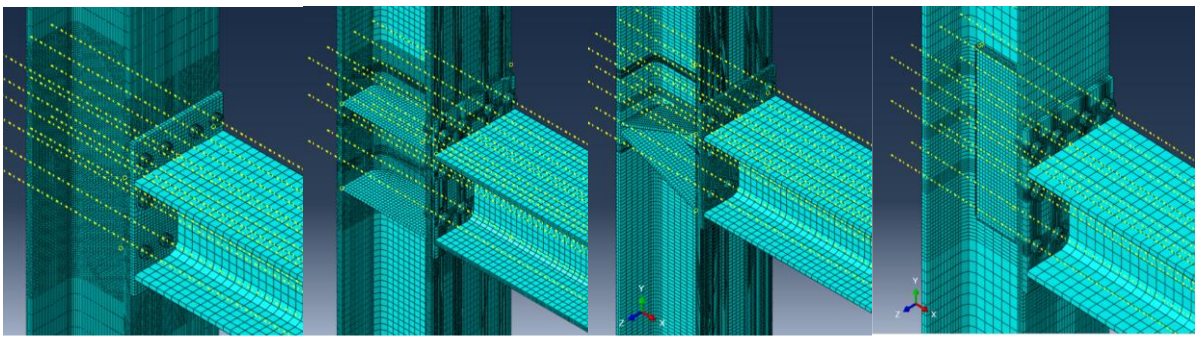

Figure 3. FE model for beam-to-column extended end-plate joint

The failure modes include bending deformation of the end-plate and column flange, buckling of the compression beam flange, bolt rapture, and failure of the fillet welds between the end-plate and beam flange. The end plate in bending and the column web panel in shear are the main dissipative components

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involved in the connections, displaying apparent ductile features. The results are shown in Figures 4 and 5. When it is displayed and can be concluded that in Type 1 failure is governed by the failure of filled welds and column web panel in shear, Type 2 and Type 3 respond in the elastic range displaying a failure mode one by forming a plastic hinge in the beam flange and bolt rapture. Type 4 exhibits a failure mode due to bolt fracture and buckling of the end plate.

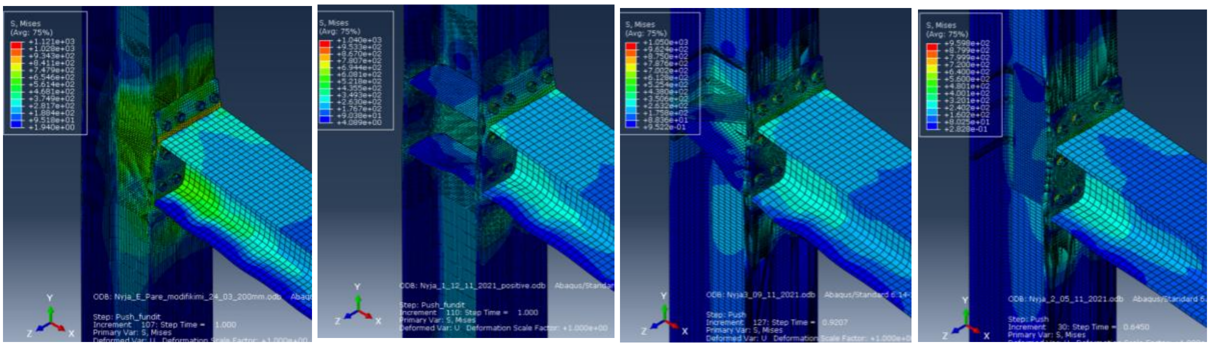

Figure 4. Von Mises stress representation and ultimate failure modes.

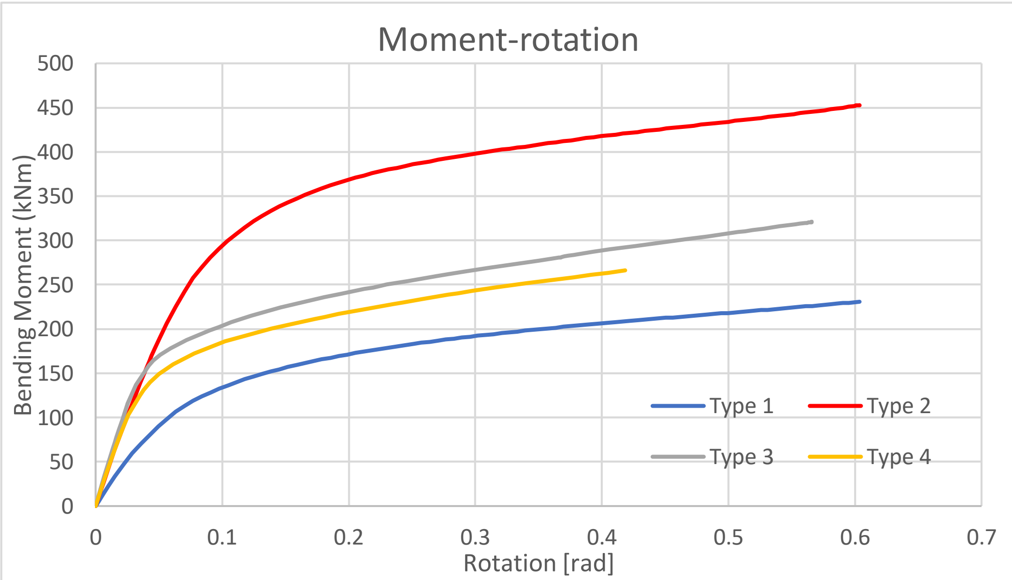

Figure 5. Monotonic results for moment and rotation capacity of the connections.

4. Conclusion

The results herein focused on developing a finite element model developed in ABAQUS, capable of representing the monotonic behaviour of the extended end plate connections with the partial strength and stiffeners classification according to [1] by using different column web stiffeners. The finite element method for the monotonic analyses allowed concluding that the numerical behaviour is in good agreement with the procedures described in [1.2,3,4] for the estimation of connection response and can provide valuable results for the mechanical behaviour of connections. The column web stiffeners described in this paper increase the moment resistance and the rotation capacity Figure 5, especially at Type 2 when the plastic strain concentration is close to welds between the beam flange and the end plate. Using each of these stiffeners can minimise the deformation of the panel zone of the connection. Designing the end-plate bolted connection without column web stiffeners can lead to column web buckling. According to [1], the connection design process is very time-consuming, so creating tables for designing end-plate bolted connections with or without column web stiffeners would be an excellent solution, also future investigations should provide information on FE model calibration according to the experimental results.

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