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Axial Force Influence on Bolted Extended End-Plate Beam-to-Column Connection Behavior

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Abstract

This paper presents some numerical studies carried out in order to investigate the performance of a bolted extended end-plate beam-to-column connection subjected to combined bending moment and axial force. This investigation utilizes nonlinear finite element modeling techniques using ABAQUS, considering both geometric and material nonlinearities. The aim of the study is to analyze the influence of various levels of axial force, tension or compression, on connection characteristics: moment-rotation curve, connection strength, connection stiffness, distribution of stresses in the connection components, connection failure mode. This study is based on a sensitivity analysis of this type of connection, subjected to bending and axial force, to the variation of some geometric or structural parameters of joint. The performed investigations have shown that axial forces influences the moment resistance of the connection, but its initial stiffness does not change significantly under an additional axial force in the beam.

Rezumat

Această lucrare prezintă rezultatele numerice obținute prin investigarea comportării unei îmbinări grindă-stâlp, cu placă de capăt extinsă și șuruburi, sub acțiunea combinată a momentului încovoietor și a efortului axial. Analiza s-a efectuat în programul ABAQUS, bazat pe metoda elementelor finite, prin considerarea neliniarităților geometrice și de material. Scopul lucrării este de a evidenția influența forței axiale, de întindere sau de compresiune, de diferite intensități, asupra caracteristicilor îmbinării: curba moment încovoietor-rotire relativă, rezistența și rigiditatea îmbinării, distribuția tensiunilor în componentele nodului, modul de cedare al acestuia. Studiul este consolidat printr-o analiză a senzitivității acestei tipologii de îmbinări, solicitate la încovoiere cu efort axial, la variația unor parametri geometrici sau structurali ai nodului. Rezultatele obținute au arătat că aplicarea unei forțe axiale suplimentare în grindă influențează rezistența îmbinării, dar nu modifică semnificativ rigiditatea sa inițială.

Keywords: bolted extended end-plate connection, bending moment and axial force, numerical model, moment-rotation curve

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1. Introduction

Axial forces induced in the structural elements of the steel frames due to certain actions (strong wind, earthquake), or due to their particular configurations (pitched-roof portal frames, frames with incomplete floors) can generate unexpected changes in the connections behavior. For this reason it was necessary to investigate the unfavorable action of these forces in order to prevent the unexpected failure of structures, by development of local phenomena, such as stress concentrations and local buckling, or premature phenomena, due to decrease of connection strength. Exceptional events (earthquakes, explosions, fires) that have occurred in recent years alerted researchers to initiate extensive studies considering the bending moment versus axial force interaction. Therefore, experimental studies have been carried out on flushed and extended end-plate beam-to-column connections, subjected to bending moment and various levels of axial force [1, 2, 3, 4] and numerical simulations were performed and then compared with experimental results [1, 2, 5, 6, 7, 8, 9, 10]. Also, in order to extend the Eurocode 3 component method for connections subjected to the simultaneous action of bending moments and axial forces, mechanical models were proposed and analytical expressions were developed to evaluate their rotational stiffness and moment capacity [11, 12, 13]. The main objective of this paper is to investigate the performance of a bolted extended end-plate beam-to-column connection subjected to combined bending moment and axial force. The studies were carried out using ABAQUS finite element package [14].

2. Description of the study

In order to analyze the behavior of a bolted end-plate stiffened (S) beam-to-column connection subjected to monotonic loading, a numerical model was proposed. The behavior of this structure was compared with experimental results in order to validate the model [15]. In Fig. 1a is presented the mechanical model for the studied structure when the axial force N was considered equal to zero. The moment-rotation curves of the connection traced from these analyses exhibited a semi-rigid behavior of the connection, Fig. 1b. The evaluation was also performed in accordance with Eurocode 3 part 1-8 prescriptions, using the component method for the determination of M-Φ curve characteristics [16].

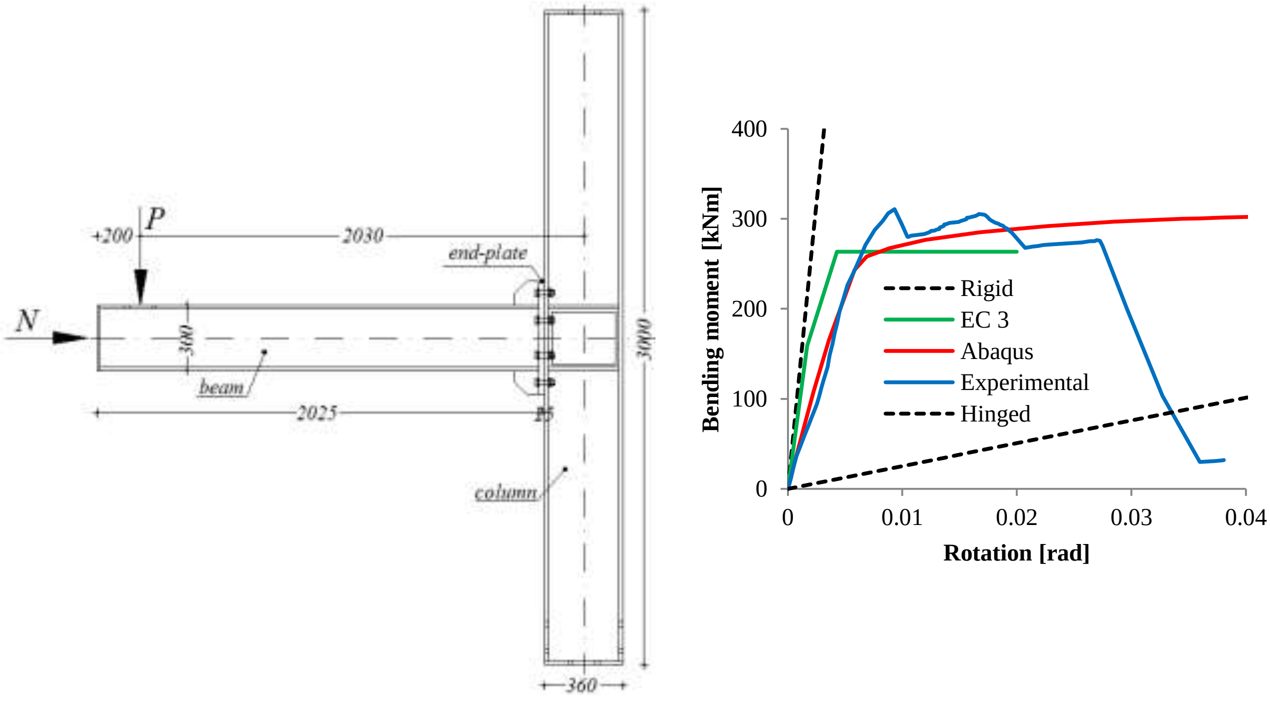

Figure 1. a. Connection mechanical model; b. M-Φ curves of the connection

Starting from the structure subjected to pure bending, a nonlinear finite element analysis of several structures was performed, identically modeled, additionally subjected to various levels of axial force, tension or compression, forces that were determined as percentage of beam axial plastic resistance, $N_{pl.Rd}$, Table 1. To provide the effect of different types of stiffeners on the connection load carrying capacity, additional numerical models were performed for partially stiffened (PS) connections and unstiffened (US) connections, identically loaded, Table 1. Also, in order to study the sensitivity of the connection subjected to a combination of bending and axial forces to the variation of some geometric parameters (end-plate thickness and beam height), two additional sets of connections were generated, also identically loaded.

Table 1: Specimens considered in the study

Stiffened (S)		Partially stiffened (PS)		Unstiffened (US)	
Specimen	$N/N_{pl.Rd}$	Specimen	$N/N_{pl.Rd}$	Specimen	$N/N_{pl.Rd}$
S-M-N-0	0	PS-M-N-0	0	US-M-N-0	0
S-M-N-1	– 0.05	PS-M-N-1	– 0.05	US-M-N-1	– 0.05
S-M-N-2	– 0.10	PS-M-N-2	– 0.10	US-M-N-2	– 0.10
S-M-N-3	– 0.20	PS-M-N-3	– 0.20	US-M-N-3	– 0.20
S-M-N-4	– 0.25	PS-M-N-4	– 0.25	US-M-N-4	– 0.25
S-M-N-5	+ 0.10	PS-M-N-5	+ 0.10	US-M-N-5	+ 0.10
S-M-N-6	+ 0.20	PS-M-N-6	+ 0.20	US-M-N-6	+ 0.20

Based on the nonlinear analysis with FEM performed on the mentioned models, the following aspects were studied:

- evolution of moment-rotation curves for the reference model, additionally subjected to different levels of axial forces;
- state of stress and local phenomena that develop in the connection elements at certain values of axial forces;
- effect of axial force on the connection moment capacity; analysis of the M-N interaction curves;
- comparative analysis of the moment-rotation curves, failure modes and particular phenomena occurring in the connecting elements, on the tension, compression and shear areas, for S, PS and US specimens;
- influence of stiffeners, end-plate thickness and beam height on the M-N interaction curve.

3. Analysis of the results

3.1. Effect of axial force on connection behavior

The action of axial force on the beam is manifested at the joint level by varying the compressive stresses of the contact plates and implicitly their degree of detachment, thus influencing the connection strength and/or flexibility. Moment vs. rotation curves obtained from numerical simulations highlight increases of the moment resistance due to the increase of compressive axial force in the beam, Fig. 2. Therefore, specimen S-M-N-1 loaded with a compressive force equal with 5% of the beam plastic resistance registers an increase of connection strength of 4.12% compared with reference model, S-M-N-0. Increasing the compression in the beam at a value of 10% of $N_{pl.Rd}$, specimen S-M-N-2, produces a 12.42% increase of connection moment capacity compared to specimen S-M-N-0, without reducing its ultimate moment value. The highest moment resistance was obtained for an axial force equal to 20% of the beam plastic resistance, when the connection strength was increased with 16.88% compared to the reference model, which was subjected to pure bending; local buckling of bottom beam flange and the decrease of the ultimate moment were also observed. Beyond this level, for an equivalent compression equal to 25% of $N_{pl.Rd}$, the intensification of local phenomena in the compressed area occurs, leading to the reduction of the connection moment capacity, which still remains greater than in the case of S-M-N-0 specimen; there can be also observed a decrease of ultimate moment by approximately 20% compared with specimen subjected to pure bending, the M-Φ curve having a descending evolution in the post-elastic domain. The additional application of a tensile force in the beam to the reference model loading, specimens S-M-N-5 and S-M-N-6, results in bending moment reduction with about 15 and 30 percent of moment capacity of the S-M-N-0 specimen, with an ascending evolution of M-Φ curves in the post-elastic domain to the values of the ultimate moment close to that of the reference model.

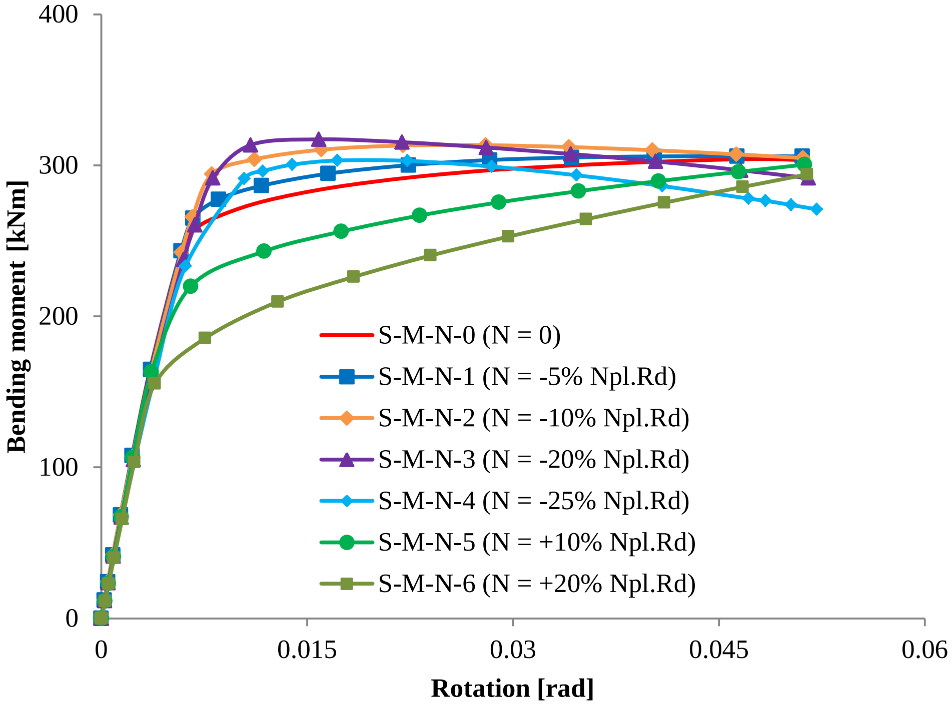

Figure 2. M-Φ curves of the S specimens subjected to a combination of bending and axial forces

The initial stiffness of the connection does not change significantly under axial force, slight changes in its value occur, depending on type of axial force (tension or compression) and its value. An increase of initial stiffness was noted for low levels of compressive axial forces applied in the beam, of 5 and 10% of $N_{pl.Rd}$, but beyond this level of compression initial stiffness decreases, due to occurrence of local buckling of bottom beam flange. Decrease of connection initial stiffness was also noted in the case of tensile force applied in the beam. Therefore, when a tensile force of 10% and 20% of $N_{pl.Rd}$ was applied in the beam, the connection initial stiffness decreases by 7.56% and 12.93% respectively, compared to S-M-N-0. In the case of high levels of compression in the beam, connection initial stiffness decreases by 3.45% for specimen S-M-N-3, respectively with 9.29% for specimen S-M-N-4, compared with specimen subjected only to bending, while for the specimens subjected to combined bending and compression of 5% and 10% of $N_{pl.Rd}$, there was increases in the initial stiffness of 5.09% and 6.33%, respectively.

3.2 Influence of stiffeners on the behavior of the connection subjected to bending and axial forces

Reducing the stiffening of the connection elements by eliminating the rib stiffener, PS-M-N specimens, does not fundamentally change the M-N interaction, compared with the S-M-N specimens, while in case of specimens without stiffeners, US-M-N specimens, the axial force determines decreases of connection moment capacity, Fig. 3. This behavior is explained by development of local phenomena, stress concentrations and local buckling, in the compressed area of the connection, which becomes more vulnerable in the absence of stiffeners. Also, for these specimens there is a reduction of the connection initial stiffness due to the increase of deformability of web panel, end-plate and column flange, caused by the absence of transversal column stiffeners, Fig. 4.

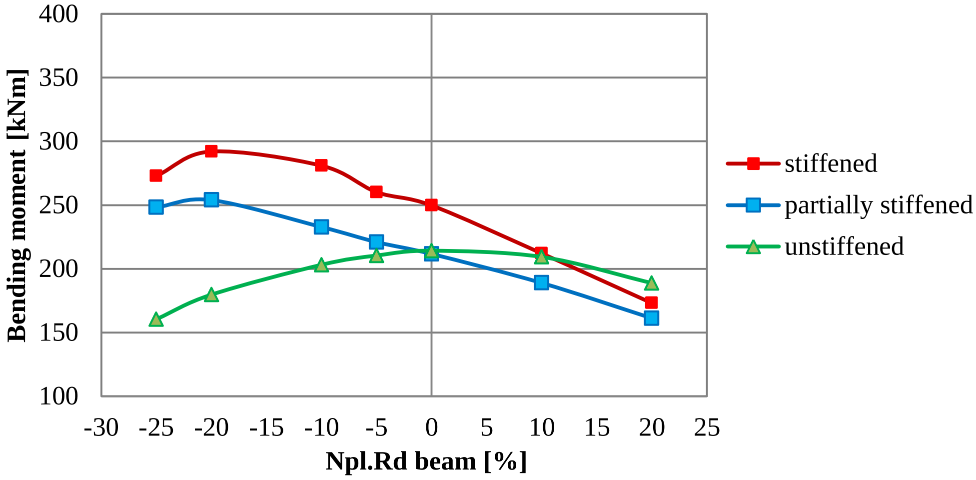

Figure 3. M-N interaction diagram for the studied connection

The M-N interaction diagram, plotted in Fig. 3, for stiffened, partially stiffened and unstiffened connections, proves the favorable effect of the tensile force instead of the compressive force on the connection moment carrying capacity for the unstiffened specimens.

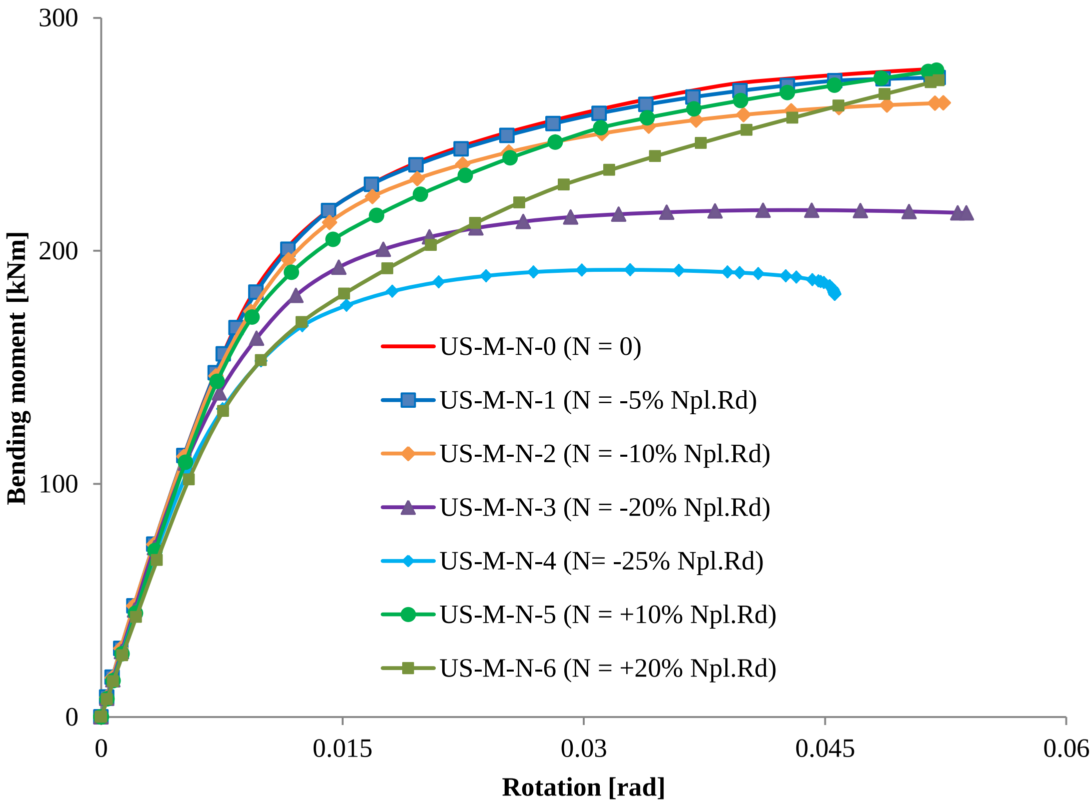

Figure 4. M-Φ curves of the US specimens subjected to a combination of bending and axial forces

The analysis of von Misses stress distribution in the connection area, for specimens with different types of stiffeners, presented in Fig. 5, emphasizes changes in the degree of detachment of the plates in contact, stress concentrations in certain elements of connection and in some cases local buckling of the plates under compression and changes in the failure mode of connections. Thus, for stiffened connections, the increase of compressive force over 20% of beam plastic resistance can cause excessive deformations in the beam flange and the corresponding rib, Fig. 5, which results in decreased strength of connection. For the unstiffened specimens (US-M-N-i, i=1,4) increasing the compressive force results in almost complete reduction of separation of plates and excessive stress of column web panel, Fig. 5. Tensile force applied on these specimens produces an increase in connection deformability and a more balanced stress distribution in this area.

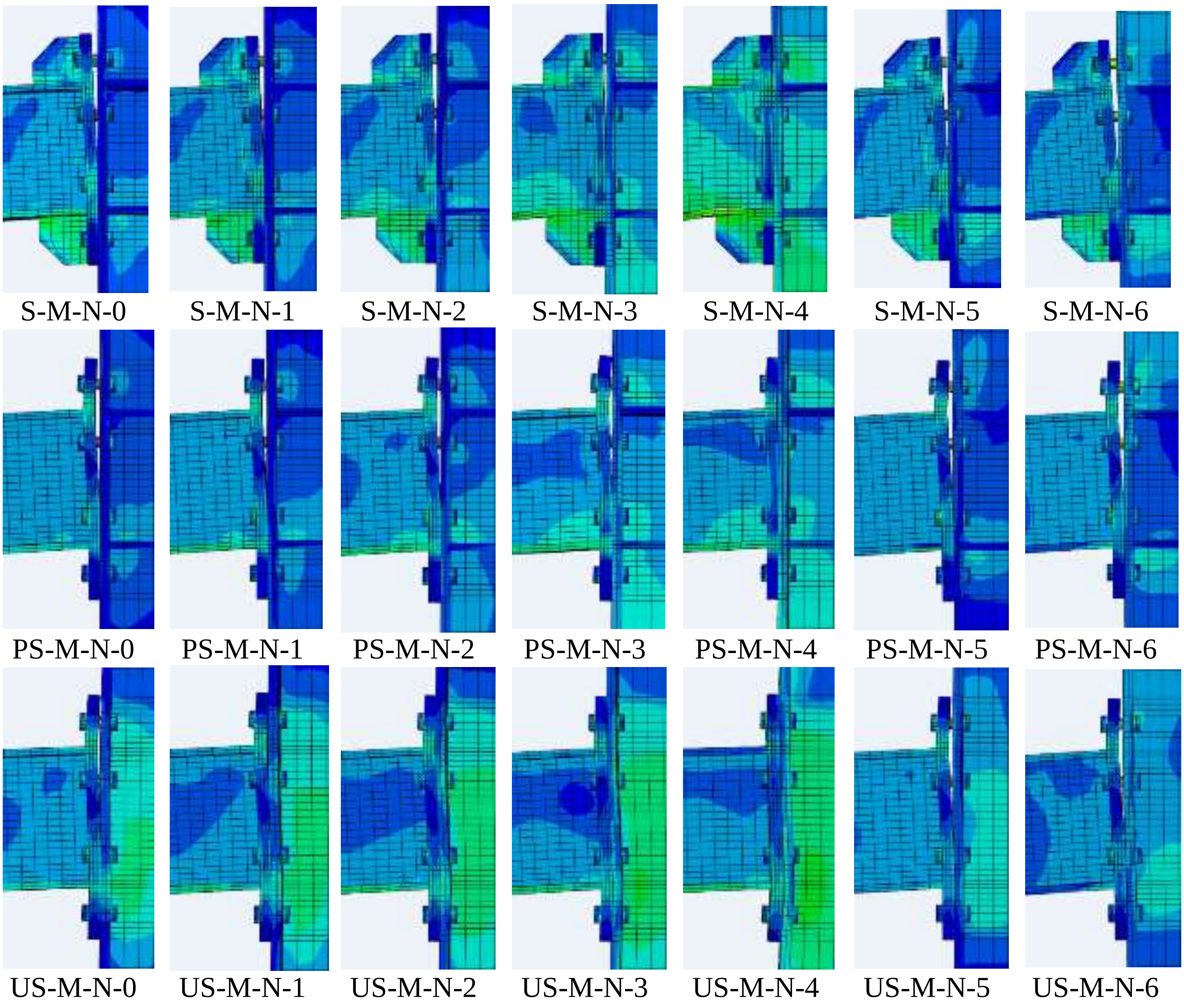

Figure 5. Von Misses stress distribution in the connection area

3.3 Influence of end-plate thickness on the behavior of the connection subjected to bending and axial forces

The influence of end-plate thickness on the behavior of the connection subjected to bending and axial forces was studied by considering another 3 specimens, additional to the reference model, by changing only the end-plate thickness: from 25mm to 15, 20 and 30mm. Fig. 6 illustrates the M-N interaction diagrams for these specimens. It is noticed that increasing the end-plate thickness from 25mm to 30mm does not influence the connection behavior. For specimens subjected to bending and compressive forces, decreasing the end-plate thickness causes reduction of the bending moment capacity, while those loaded in bending and tensile forces exhibited approximately the same moment resistance, regardless of the end-plate thickness.

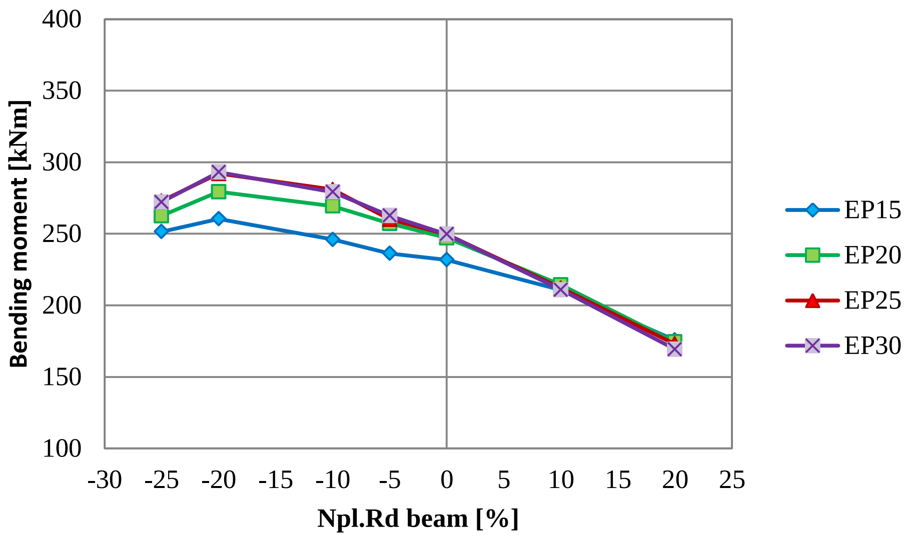

Figure 6. M-N interaction diagrams for specimens with different end-plate thicknesses

3.4 Influence of beam height on the behavior of the connection subjected to bending and axial forces

In order to study the influence of beam height on the behavior of the connection subjected to bending and axial forces, additional to the reference model, which had a 300mm beam height, there were considered another 3 specimens, with 270, 330 and 360mm beam height. It was noticed that this parameter affects the connection behavior under bending and axial forces. According to Fig. 7, the values of yielding moment increased with the increase of compressive axial force in the beam up to values of 20% of the beam plastic resistance and decreased for levels of compressive forces higher than that. The application of a tensile force in the beam results in similar values for the bending resistance for all the tests considered, Fig. 7.

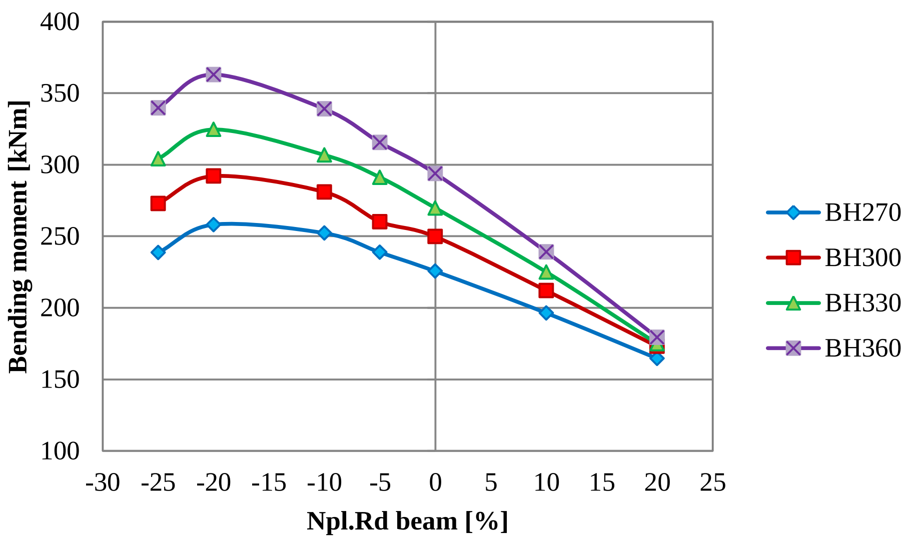

Figure 7. M-N interaction diagrams for specimens with different beam height

4. Conclusions

This paper has presented a numerical study that analyses a beam-to-column extended end-plate connection behavior, of different types and details, under bending and axial forces, using ABAQUS finite element package. This study has started from a numerical reference model, which was compared for validation to previously conducted physical tests. Additional specimens were modeled, in order to demonstrate how different types of stiffeners and variations of end-plate thickness and beam height affect this connection.

The moment-rotation curves for all specimens indicate that the presence of the axial force in the beam significantly affects the connection behavior. For all the cases considered in this study, except unstiffened specimens, the bending moment resistance was increased for an additional compressive force applied in the beam and its maximum value was obtained for an axial force level of 20% of the beam plastic resistance.

For the stiffened connection an increase of the moment capacity was noted for the additional compressive force applied in the beam, but their compressed area is severely affected by local phenomena for high levels of compression. The presence of a tensile force in the beam results in immediate reduction of the bending moment, due to the early yielding of the critical connection component in the tension area, which is endplate in bending.

In the case of partially stiffened specimens the compressive axial force contribution to increasing the connection strength is slightly diminished and the local phenomena in the compressed area are less aggressive.

The axial force in the beam has an unfavorable effect on the unstiffened connection behavior. The initial stiffness of the connection does not change significantly under axial force, slight changes in its value occur, depending on type of axial force (tension or compression) and its value.

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