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Buckling Resistance of Reinforcing Bars Made of Steel without Distinctive Yield Stress

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Abstract. The article presents the results of experimental research concerning inelastic buckling of reinforcing bars made of steel without distinctive yield stress. Research has shown that the buckling capacity of these reinforcing bars depends in a significant way on their slenderness. The buckling resistance of the bars, depending on their slenderness, may be greater or lower than the yield stress.

1. Introduction

In reinforced concrete elements which are working in the state of postcritical deformations, it is necessary to consider inelastic buckling of longitudinal bars of longitudinal reinforcement. Buckling of bars takes place not until the detachment of the concrete cover. After buckling, longitudinal reinforcement bars can carry compressive forces, and the maximum compressive stress in the bar can be greater than the yield strength. The maximum compressive force transmitted by the bar is called the buckling resistance of this bar.

Reinforcing bars used in reinforced concrete structures are made of steel, which are characterized by diversified mechanical properties, such as: yield strength, resistance, ductility and the type of yield strength. In the last period of time reinforcing bars are made of steel, without distinctive yield stress, which is the result of the cold rolling process.

Numerous results of experimental and numerical analyses of inelastic buckling of reinforcing bars are presented in the literature. The vast majority are the results of tests made of steel with a distinctive yield strength. The paper presents the results of experimental tests of compressed reinforcing bars made of steel without a distinctive yield stress.

2. Inelastic buckling of reinforcing bars.

While analysing the behaviour of reinforced concrete elements in the state of postcritical deformations, and when the ultimate deformations of a concrete cover are exceeded, it is necessary to consider inelastic buckling of compressed longitudinal bars.

The carried out experimental tests and numerical analysis of compressed bars [1 – 6] imply that the geometry of the bars (slenderness), as well as the mechanical features of steel that the bars are made of (i.e. yield strength, the length of the plastic plateau, the relation between strength and yield strength and the course of the reinforcement curve) influence the inelastic buckling. Moreover, the impact on the behaviour of compressed bars in the reinforced concrete element has a way of loading the element, geometric imperfections of the bars and the element, as well as strain and deformations of reinforced concrete elements [7]. On the basis of experimental and numerical analyses, mathematical models of compressed bars have been developed [2, 8, 9], including the possibility of their inelastic buckling.

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Buckling of bars in a reinforced concrete element takes place not until the detachment of the cover. Therefore, the cover contributes to delaying the buckling process in reinforcement bars. The issue of the influence of the concrete cover on the buckling of rods was dealt with, among others [8, 10, 11, 12]. The presented research tried to determine using analytical and numerical methods: the value of limit stress in the reinforcement cover at the moment of buckling [10], the limit value of the transmission force of the longitudinal rod to the reinforcement cover at buckling [11], lateral boundary stress from bending in concrete cover at the moment of buckling of the bars [8], as well as the influence of the cover on the buckling capacity of the bars. Much more research is about the impact of ties on the global inelastic buckling of bars of longitudinal reinforcement [8, 13, 14].

In the above-quoted works, the subject of research and analysis were bars made of steel with a distinctive yield stress. Currently used reinforcing bars are obtained by cold rolling. Such technology of making reinforcing bars allows for greater accuracy of their making and this technology allows for greater resistance. Cold-rolled rods are characterized by the lack of a clearly defined yield strength.

3. Description of the carried out tests

The aim of the research was to determine the effect of slenderness of bars, expressed as the quotient of the distance between the clamps of the testing machine and the diameter of the bar, for the buckling capacity of these bars. Experimental tests were carried out on smooth bars (18 mm diameter) made of B400 steel. The relation between the stress and the training for steel is illustrated on figure 3. (material curve). The conventional yield stress was f_{sy} = 400 MPa, tensile strength f_{st} = 586 MPa, maximum strain for tensile strength was ε_{st} = 0.18 and Young modulus was E = 200 GPa. Therefore, this steel is characterized by high ductility and according to EC2 its ductility is in the "C" class.

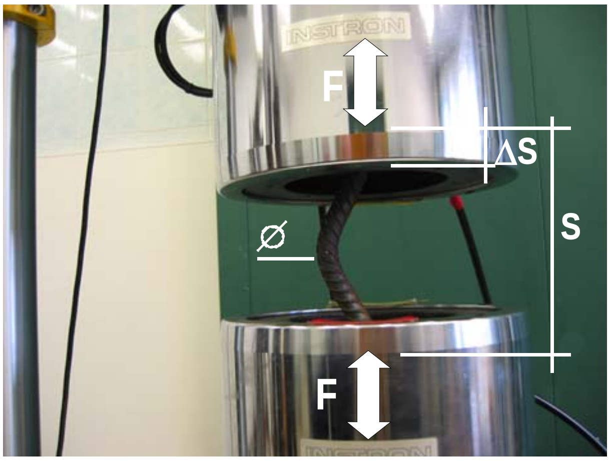

Figure 1. Bar during testing.

The ratio of the distance between the supportive points *s*, i.e. the distance between edges of testing machine clamps and bar diameter Ø was: s / Ø = 5, 6, 7 ,8, 9, 10, 12, 14. Bars were fixed in both ends in INSTRON 8804 testing machine clamps. During compression tests were controlled by the speed of the forced stress in time, which was 1 MPa/s. Figure 1 illustrated one of the testing bar in the testing machine before and after doing test. Figure 2 illustrated all of the bars after testing.

Figure 2. Reinforcing bars after testing.

4. Research results and their analysis

Figure 3 presents relations between average compressed stress in bars σ = N / A and average relative shortening ε = Δs / s of the bar for various slenderness s / Ø. The figure 3 also include the material curve. for tensile bar (dashed line).

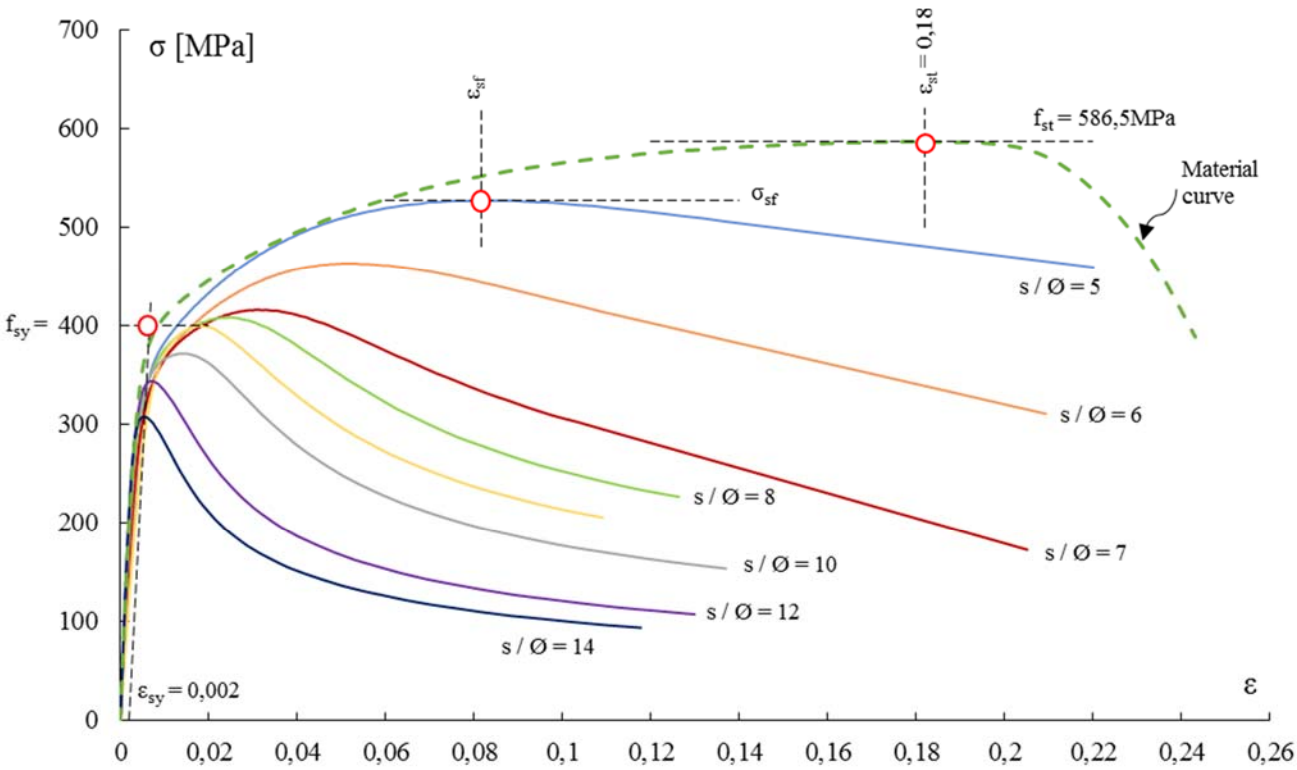

Figure 3. Relations stress – strain for various options of bar slenderness.

As can be seen, buckling strength of bars expressed by maximum average stress in the bar $\sigma_{sf} = N_{sf} / A$ significantly depends on their slenderness. The slender bar is smaller, its buckling capacity is higher. For the slenderness of bars s / Ø <10, their buckling capacity is greater than the yield stress $f_{sy} = N_{sy} / A$. However, for slenderness s / Ø >10, the buckling capacity of the bars is less than the yield stress. Thus, the behaviour of compressed rods made of steel without a distinctive yield stress is different than the behaviour of compressed bars made of steel with a distinctive yield stress. The buckling resistance of the bars with a distinctive yield stress is not lower than the yield stress. The buckling capacity of these bars for slenderness 14 ≥ s / Ø ≥ 10 is kept constant and is equal to the yield stress [1, 5, 7].

Figure 4 illustrated changes relative maximum stress (figure 4a) and relative maximum strain (figure 4b) in bars in the function of bar slenderness s/Ø.

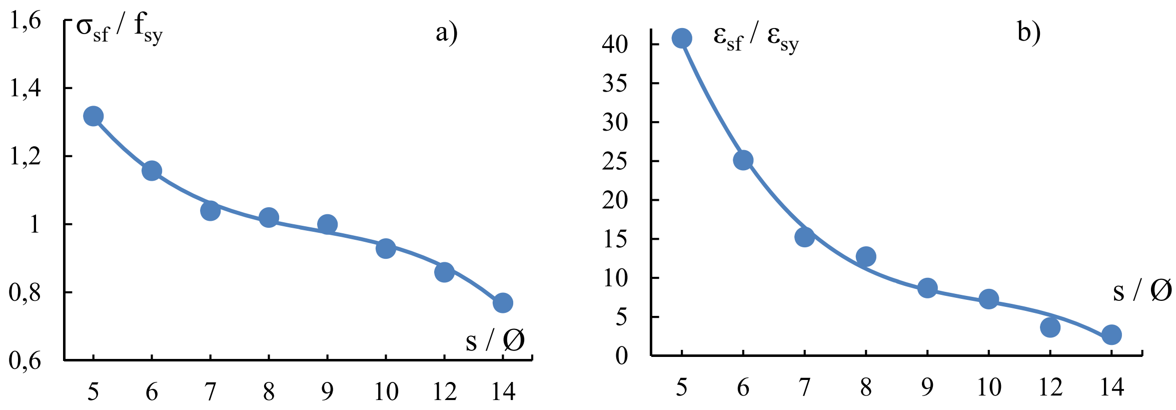

Figure 4. The influence of slenderness on: a) maximum stress σ_{sf}, b) strain ε_{sf}.

Maximum stress in the bars correspond to the maximum force transmitted by the bar, which is the buckling strength. The buckling capacity of the testing bars is smaller or greater than the yield stress and it changes in the range from $1.4f_{sy}$ to $0.8f_{sy}$. The strain ε_{sf} accompanying the maximum stresses σ_{sf} in the bar change in a very wide range. This strain, depending on the bar slenderness, varies from $40\varepsilon_{sy}$ for slenderness s / Ø = 5 to $3\varepsilon_{sy}$ for slenderness s / Ø = 14. This means that in the case of small slenderness s/Ø<8 compressed bars do not show a decrease in load capacity for a very large range of strain.

Ductility is the ability of materials, elements of structures or structures to transmit elastic deformations without considerable deterioration in load-bearing capacity. Material ductility is measured by a strain ductility coefficient which was defined as a quotient of strain ε_{sfu} at the moment of formal loss of load-bearing capacity $0.75\sigma_{sf}$ and strain ε_{sf} at the moment of reaching capacity σ_{sf}. Figure 5 presents alterations of the ductility coefficient for bars in the function of longitudinal bars' slenderness s / Ø.

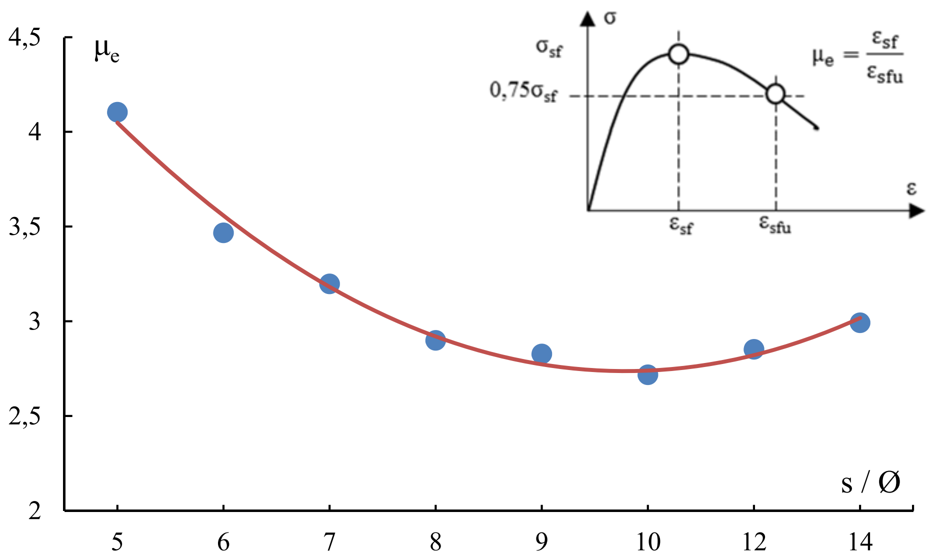

Figure 5. Alterations in ductility of bars in the function of bar slenderness.

Reinforcing bars, after reaching the load capacity, still have a significant capacity reserve. The contractual exhaustion of the load capacity, which is a 25% decrease in buckling capacity, can only take place when strain ε_{sfu} is greater than from 2.75 to 4.1 of strain ε_{sf}.

5. Conclusion

Reinforcing bars made of steel without distinctive yield strength are commonly used in reinforced concrete structures. Inelastic buckling of these bars has similar character as inelastic buckling of reinforcing bars with a distinctive yield stress. However, the buckling capacity of the bars without distinctive yield stress may be less than the yield point when the bar slenderness is s / Ø >10.

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