Structural S235 and S355 Steels – Numerical Analysis of Selected Rods Connection

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Abstract. The paper discusses two structural steels: S235 and S355, commonly used for making steel rod structures. The numerical analysis of a selected rod connection with static load and butt connected using high strength bolts was made. Two material criteria were adopted, assuming for the first analysis S235 steel for the column and S355 for the beams, and for the second analysis, the S355 steel for both beams and the column. The numerical model prepared in this way covers the real work of the connection and is the basis for assessing the correctness of its work, i.e. maintaining safety during exploitation.

1. Introduction

Due to the continuous development of steel rod structures, actions to improve their connections are taken [1]. It includes, among others, creating new and optimizing existing construction and material solutions. Growing requirements in the range of increasing the load capacity of elements incline the designers to use materials that have been used in construction very rarely or not at all. The paper [2] presents the results of experimental investigations of the overlap bolted connection of steel sheets made of high-strength Q460D steel. Two variants of connector arrangement were considered: a bolt axis parallel and perpendicular to the load direction. The load capacity and deformability of the analyzed connection were determined. In order to verify the obtained results, numerical analysis and analytical calculations were carried out, creating the theoretical basis for dimensioning bolted connections of elements of high-strength Q460D steel. The paper [3] discusses the results of bolt connection tests (for various types of fasteners) of elements made of ferritic stainless steel 1.4509 (AISI 441). The values of destructive loads and the accompanying deformations were determined. On the basis of the obtained results, the authors undertook to develop project guidelines according to [4]. An interesting combination of two materials commonly found in construction - steel and wood, are steel-timber composite beams (STC), which are created by joining a cross-laminated timber plate (CLT) with a steel section. In paper [5], the authors presented the results of experimental investigations of bolt connections of STC beams. Factors affecting the load capacity of the connection were indicated and the results obtained were compared to project requirements included in standards [6] and [7]. The topic related to the formation of increased deformations of connections of steel elements due to extraordinary events (earthquake, fire, breakdown of foundations) was undertaken at article [8]. The authors conducted experimental investigations for the standard flat tensile specimens made of S355 steel, determining the stress-strain relationship. Using numerical analysis, the damage was simulated and a model calibration method was proposed to achieve convergence with experimental results. The issue concerning the calculation of bolt connections of cold-bent elements (beams with columns) is discussed in [9]. Based on the experimental research, a mechanical model of
the connection named by the authors "three springs" was proposed based on which a method for calculating the stiffness of such a connection was developed.

However, S235 and S355 steels are the most commonly used constructional steels in construction; they are used, among others, for the production of I-section rolled profiles, of which industrial and utility steel rod structures are designed and constructed. This paper presents mechanical properties and chemical composition of S235J0, S235J2, S235JR and S355J0, S355J2, S355JR steel and the assessment of the selected steel connection of the rod structure was made for two material variants: S235 and S355.

2. Structural S235 and S355 Steel – the Mechanical Properties and the Chemical Composition

S235 and S355 steels are intended for welded constructions, carrying and dynamically loaded structures, such as: columns, towers, platforms, elements of machines, devices, etc. The "S" symbol of steel means that it is a structural steel. The mechanical properties and the chemical composition according to [10], are presented in the Tables 1 and 2 for S235 steel and Tables 3 and 4 for S355 steel respectively.

| Table 1. The mechanical properties of grade S235 [10] |
|-----------------------------------------------------|
| Steel grade | Minimum yield strength [MPa] | Tensile strength Rm [MPa] | Minimum elongation - A Lo = 5.65 * \sqrt{S_o} (%) | Notch impact test |
| Nominal thickness [mm] | Nominal thickness [mm] | Nominal thickness [mm] | Temperature [°C] | Min. absorbed energy [J] |
| ≤16 | >16 | >40 | >63 | >80 | >100 | ≤125 | >3 | >3 | >40 | >63 | >100 | ≤125 |
| S235J0 | 235 | 225 | 215 | 195 | 360-510 | 350-500 | 26 | 25 | 24 | 22 | 0 | 27 |
| S235J2 | 235 | 225 | 215 | 195 | 360-510 | 350-500 | 26 | 25 | 24 | 22 | -20 | 27 |
| S235JR | 235 | 225 | 215 | 195 | 360-510 | 350-500 | 26 | 25 | 24 | 22 | +20 | 27 |

| Table 2. The chemical composition of grade S235, [10] |
|---------------------------------------------|
| Steel grade | C max. [%] | Mn max. [%] | Si max. [%] | P max. [%] | S max. [%] | N max. [%] | Cu max. [%] | Other max. [%] | CEV max. [%] |
| Nominal thickness [mm] | Nominal thickness [mm] |
| ≤16 | >16 | >40 |
| S235J0 | 0.17 | 0.17 | 0.17 | 1.40 | - | 0.035 | 0.035 | 0.012 | 0.55 | - | 0.35 | 0.35 | 0.38 |
| S235J2 | 0.17 | 0.17 | 0.17 | 1.40 | - | 0.030 | 0.030 | - | 0.55 | - | 0.35 | 0.35 | 0.38 |
| S235JR | 0.17 | 0.17 | 0.20 | 1.40 | - | 0.040 | 0.040 | 0.012 | 0.55 | - | 0.35 | 0.35 | 0.38 |
Table 3. The mechanical properties of grade S355, [10]

| Steel grade | Nominal thickness [mm] | Minimum yield strength Reh [MPa] | Tensile strength Rm [MPa] | Minimum elongation - A Lo = 5.65 * lSo (%) | Notch impact test |
|-------------|------------------------|----------------------------------|--------------------------|---------------------------------------------|------------------|
|             | ≤16                   | >16 ≤40                           | >40 ≤63                   | >63 ≤80                                     |                  |
|             |                       | >80 ≤100                          | >100 ≤125                 | >100 ≤125                                   |                  |
| S355J0      | ≤16                   | 355                               | 345                       | 335                                         |                  |
|             |                       | 325                               | 315                       | 295                                         |                  |
| S355J2      | >16 ≤40               | 355                               | 345                       | 335                                         |                  |
|             |                       | 325                               | 315                       | 295                                         |                  |
| S355JR      | >40 ≥60               | 355                               | 345                       | 335                                         |                  |
|             |                       | 325                               | 315                       | 295                                         |                  |

Table 4. The chemical composition of grade S355, [10]

| Steel grade | C max. [%] | Mn max. [%] | Si max. [%] | P max. [%] | S max. [%] | N max. [%] | Cu max. [%] | Other max. [%] | CEV max. [%] |
|-------------|------------|-------------|-------------|------------|------------|------------|-------------|----------------|--------------|
|             | ≤16        | >16 ≤40     | >40         | ≤30        | >30        | >40        | ≤30         | >40 ≤63        | ≤30          |
| S355J0      | 0.20       | 0.20        | 0.22        | 1.60       | 0.55       | 0.035      | 0.035       | 0.012          | 0.45         |
| S355J2      | 0.20       | 0.20        | 0.22        | 1.60       | 0.55       | 0.030      | 0.030       | -              | 0.45         |
| S355JR      | 0.24       | 0.24        | 0.24        | 1.60       | 0.55       | 0.040      | 0.040       | 0.012          | 0.45         |

Equivalents for steel S235 and S355 are presented in the tables 5 and 6 for selected national standards of other countries.

Table 5. S235J0 steel grade equivalent

| China GB | Japan JIS | England BS | European old EN | Russia GOST | India IS | International ISO |
|----------|-----------|------------|-----------------|-------------|----------|-------------------|
| S235J0   | Q235C     | SM400B     | 40C             | Fe360C      | St3ps    | E235C             |
| S235J2   | Q235D     | -          | 40EE            | Fe360D2     | St2ps    | -                 |
| S235JR   | Q235A     | Q235B      | -               | St3sp       | IS226    | -                 |

Table 6. S355J0 steel grade equivalent

| China GB | Japan JIS | France AFNOR | England BS | European old EN | Italy UNI | India IS |
|----------|-----------|--------------|------------|-----------------|-----------|----------|
| S355J0   | 16Mn      | SS490B       | E36-3      | 50C             | Fe510C    | Fe510C   |
| S355J2   | Q345D     | SS490YA      | -          | -               | Fe510D2   | -        |
| S355JR   | Q345C     | SM490A       | E36-2      | 50B             | Fe510B    | Fe510B   |

3
3. Problem Formulation

The considered butt bolted joint, concerns the connection of the column designed as rolled profiles of HEB180 with beams perpendicular to its flanges, which were designed as a rolled profile IPE 330, Figure 1. The butt joint of the beams and the column were loaded statically and was forming with high strength bolts. M20 bolts of 10.9 classes to connect beams to the column were used. At the time of design and during the construction of the object, the connection met all the requirements ensuring the safety of its work.

Due to the planned modification of the ceiling load, the connection will be loaded with additional shear force and bending moment. These loads operate on both sides of the column. After loads modification, the shear force Vz is equal 180 kN and the bending moment My has a value of 130 kNm.

Two analyses were carried out: the first concerns the use of two different structural steels, i.e. S235 steel for the column and S355 steel for the beams, the second applies only to S355 steel both to the column and the beams.

4. Numerical Analysis

The report generated from the IdeaStatiCa software indicates that in the case of the first analysis, the column web is not able to safely transfer external impacts (see Figure 2a), and the fasteners, i.e. M20 bolts of class 10.9, will work correctly in the connection. In the case of the second analysis (see Figure 2b), the connection works safely and meets all the criteria required to maintain the correctness of the connection work.

Figure 1. 3D visualization of the considered connection: column HEB 180, beams IPE 330

Figure 2. 3D visualization of the connection: a) column - S235 steel, beams - S355 steel; b) column and beams - S355 steel. In Figure a) the column web does not transfer external impacts safely.
4.1. Deformation of the Connection
The first analysis shows that the deformations exceed the limit values and disqualify the correctness of the connection work. In the present case, the local loss of staidness occurs in the web. The second analysis confirms the security of the connection work.

![Deformations: a) column - S235 steel, beams - S355 steel; b) column and beams - S355 steel](image)

**Figure 3.** Deformations: a) column - S235 steel, beams - S355 steel; b) column and beams - S355 steel

4.2. Stresses in the Connection
Figures 4a and 4b show the distribution of stresses obtained as a result of numerical analysis of the considered connection. The results of the first analysis (Figure 4a) clearly indicate that stresses in the web oscillating within the value of 235 MPa, which is a threat to the safety of the connection work. The tabular report shows that in the web we have the local stresses amounting to 246.6 MPa. The second analysis (Figure 4b) gives a completely different stress distribution. While there is no difference in the stress distribution in the beams, which oscillate within 355 MPa, in the column we see a different map of stresses, the concentration of which is clearly visible on the extension of the beam flanges, but as the tabular report shows, the value of this stresses is safely transmitted by the column material. This does not pose any threat to the safety of the connection work.

![Stresses: a) column - S235 steel, beams - S355 steel; b) column and beams - S355 steel](image)

**Figure 4.** Stresses: a) column - S235 steel, beams - S355 steel; b) column and beams - S355 steel

5. Summary
Numerical tests of the considered connection in the external loads, based on the IdeaStatiCa software, showed that in the case of the first analysis there is a need to strength the connection, because with the use of two different materials, i.e. S235 and S355 steel does not meet the safety requirements.

The second analysis showed that there is no difference in the stress distribution in the beams, and the use of S355 steel for both the column and the beams ensures the safe of the connection work.
Moreover, the clearly visible concentration of stresses in the column, on the extension of the beam flange, unambiguously indicates the areas that should be reinforced to ensure correct work of the connection made of two different types of structural steel, i.e. S235 steel for the column and S355 steel for the beams. Strengthening the connection with transverse stiffener plate should ensure proper work of the analyzed connection. It is important to check and compare the results of numerical analysis with the results of test, in which the real behavior of the bolted connection can be observed, it was made for example in [11]. The results of the comparison can be used to improve the analyzed model.

6. References
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