

## APPLICATION OF MODERN TYPES OF STEEL IN CONSTRUCTION FROM THE ASPECT OF MATERIAL PROPERTIES ACCORDING TO EUROCODE 3

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**Abstract.** *This subject is often discussed by researchers since it is an interesting topic in terms of the behavior of materials found in a building. Metal in construction is a point of interest for designers, suppliers, and builders due to logistical and time management advantages. Based on the researchers' information mentioned in the references, the project aims to provide details on the modern techniques for applying steel in construction according to current standards.*

**Key words:** *modern types of steel, properties material, Eurocode 3.*

### 1. INTRODUCTION

Eurocode 3 or EN 1993-1-1 is the document where all the specifications for steel structures are described. Eurocode 3 is concerned only with resistance, serviceability, durability, and fire resistance of steel structures. Other requirements, e.g., concerning thermal or sound insulation, are not covered. (En.1993.1.1.2005.Pdf, n.d.)

The choice of steel grade is detailed in EC3, where various requirements are specified. It is essential to choose the steel grade according to the mechanical material properties, respect the ductility requirements, and know the toughness and through-thickness properties. Also, the classification of steels is based on the minimum yield strength for a specific temperature. (Hechler et al., 2015)

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The steels that go through a thermomechanical (TM) rolling process have more benefits than standard steels. Another modern way to produce steels is using the Quenching and Self-Tempering (QST) process, which is more advanced than the thermomechanical (TM) rolling techniques. Both procedures are explained below in the third chapter.

## 2. MATERIALS

### 2.1. Structural steel, connecting devices, and other prefabricated products

The structures made of steel should be conformed to the steel grades recognized and listed in Standard (En.1993.1.1.2005.Pdf, n.d.). Explaining this statement, the available steel grades need to have specific values for yield strength  $f_y$  and ultimate tensile strength  $f_u$  based on the dimension of the element's thickness  $t$ . There are two cases when the element's nominal thickness should be under 40 mm, or between 40 mm and 80 mm. Table 3.1 from Eurocode 3 includes the values described above.

The steel structures require a minimum level of ductility detailed in terms of limits for the ratio  $f_u/f_y$ , the elongation, and the ultimate strain  $\epsilon_u$ . The National Annex defines these limits with recommended values, and the steel grades from Table 3.1 should satisfy these requirements.

Another information to take into consideration is the through-thickness properties. The EN 1993-1-10 standard defines a guideline to choose the adequate through-thickness properties, and the required quality class can be found in EN 10164, in table 3.2. Table 2.1 from EN 1993-1-10 defines the maximum permissible element thickness related to a steel grade, its toughness quality, the stress level, and the temperature. All the values are determined, considering the fatigue by applying a fatigue load to a member with an assumed initial flaw. In this case, the damage should be considerably less than the full fatigue damage and it permits the evaluation of the "safe period" specified for damage tolerance, according to EN 1993-1-9. The "safe period" may also cover the full design of a structure.

The structural steels must contain four crucial material coefficients for a structural analysis to be performed. These are the modulus of elasticity  $E$ , shear modulus  $G$ , Poisson's ratio in elastic stage  $\nu$ , and the coefficient of linear thermal expansion  $\alpha$ .

Structural steels have different options for connecting the elements (En.1993.1.8.2005-1.Pdf, n.d.), and all joints should have a design resistance to satisfy all the design requirements to create the structure. The fatigue load should be included and meet the principles from the Standard. It is essential to define the partial safety factors  $\gamma_M$  for joints. Table 2.1 from EN 1993-1-1 describes all these factors.

Choosing the joints depends on the distribution of internal forces and moments assumed in the analysis. It is recommended for a significant vibration to use the following jointing methods: welding, bolts (with locking devices, preloaded bolts, or other types), injection bolts, and rivets.

## 2.2. Introduction about durability for steel structures

EN 1990 is the document that covers in a detailed way the durability of steel structures. During the design of a system, all the factors that may affect the execution should be considered. Some of the essential elements are the mechanical wear from fatigue and the parts that are susceptible to corrosion. If the internal humidity does not increase by more than 80%, then the corrosion protection can be ignored.

The structure should be designed so that its working life would not affect the structural performance in terms of its environment and anticipated level of maintenance (En.1990.2002.Pdf, n.d.). A few criteria should be considered for a durable structure, such as the intended or foreseeable use of the system, the expected environmental conditions, and the soil's properties. All the criteria are listed in EN 1990 in the durability chapter.

## 2.3. Structural analysis

The initial assumptions and the calculation model should reflect a structure's behavior for a particular limit state for the entire design and each component, such as the cross-sections, members, and joints. This structural modeling is better described with more details in EN 1993-1-5 and EN-1-11.

The global analysis depends on the structure's deformed geometry's effects if it modifies the structure's behavior significantly. Therefore, it is essential to determine the internal forces and moments using the first-order analysis through the initial geometry or the second-order analysis defined by the deformations' influence.

Considering the second-order analysis's imperfections, it is mandatory to verify the frames' stability or parts. The second-order effect can be accounted for totally by the global study, including the imperfections. It can also be accounted for partially by the worldwide analysis and partly through the members' stability checks.

There is another method of analysis considering the material non-linearities. In this case, the internal forces and moments may be determined using elastic global or plastic global studies. The finite element model analysis is described in EN 1993-1-5. The elastic global calculations are based on the material's linear stress-strain behavior when the global plastic analysis describes the effect of non-linearity calculations for a structural system.

Another critical aspect of the structural analysis is to know the role of the cross-sections. Their classification is relevant and helps identify the resistance and rotation capacity where its local buckling resistance limits the cross-section. Regarding the variety, four classes are defined. The difference between them is based on plastic or elastic behavior, the rotation capacity, and the cross-section's local buckling.

# 3. THE APPLICATION OF MODERN TYPES OF STEEL IN CONSTRUCTION

## 3.1. The choice of the steel grade according to EC3

As explained above, the type of steel material conforming to steel grades are listed in **Table 1 (a, b)** attached below. It is divided into two parts for hot-rolled structural steel and hollow structural sections.

Based on the mechanical properties, the nominal values for  $f_y$  and  $f_u$  are defined by adopting the values from the product standard,  $f_y = R_{eh}$ , and  $f_u = R_m$ .

**Table 1a** Nominal values of yield strength and ultimate tensile strength for hot-rolled structural steel

Standard and steel grade	Nominal thickness of the element t [mm]			
	t ≤ 40 mm		40 mm < t ≤ 80 mm	
	f <sub>y</sub> [N/mm <sup>2</sup> ]	f <sub>u</sub> [N/mm <sup>2</sup> ]	f <sub>y</sub> [N/mm <sup>2</sup> ]	f <sub>u</sub> [N/mm <sup>2</sup> ]
<b>EN 10025-2</b>				
S 235	235	360	215	360
S 275	275	430	255	410
S 355	355	$\begin{matrix} \text{AC2} \\ 490 \end{matrix}$ $\begin{matrix} \text{AC2} \\ 490 \end{matrix}$	335	470
S 450	440	550	410	550
<b>EN 10025-3</b>				
S 275 N/NL	275	390	255	370
S 355 N/NL	355	490	335	470
S 420 N/NL	420	520	390	520
S 460 N/NL	460	540	430	540
<b>EN 10025-4</b>				
S 275 M/ML	275	370	255	360
S 355 M/ML	355	470	335	450
S 420 M/ML	420	520	390	500
S 460 M/ML	460	540	430	530
<b>EN 10025-5</b>				
S 235 W	235	360	215	340
S 355 W	355	$\begin{matrix} \text{AC2} \\ 490 \end{matrix}$ $\begin{matrix} \text{AC2} \\ 490 \end{matrix}$	335	490
<b>EN 10025-6</b>				
S 460 Q/QL/QL1	460	570	440	550

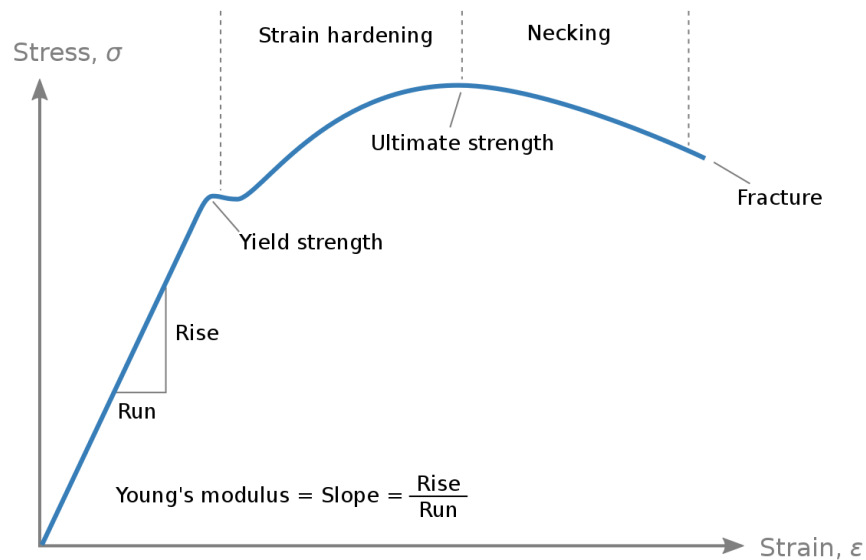
**Table 1b** Nominal values of yield strength and ultimate tensile strength for hollow structural sections

Standard and steel grade	Nominal thickness of the element t [mm]			
	t ≤ 40 mm		40 mm < t ≤ 80 mm	
	f <sub>y</sub> [N/mm <sup>2</sup> ]	f <sub>u</sub> [N/mm <sup>2</sup> ]	f <sub>y</sub> [N/mm <sup>2</sup> ]	f <sub>u</sub> [N/mm <sup>2</sup> ]
<b>EN 10210-1</b>				
S 235 H	235	360	215	340
S 275 H	275	430	255	410
S 355 H	355	510	335	490
S 275 NH/NLH	275	390	255	370
S 355 NH/NLH	355	490	335	470
S 420 NH/NLH $\begin{matrix} \text{AC2} \\ 490 \end{matrix}$	420	540	390	520
S 460 NH/NLH	460	560	430	550
<b>EN 10219-1</b>				
S 235 H	235	360		
S 275 H	275	430		
S 355 H	355	510		
S 275 NH/NLH	275	370		
S 355 NH/NLH	355	470		
S 460 NH/NLH	460	550		
S 275 MH/MLH	275	360		
S 355 MH/MLH	355	470		
S 420 MH/MLH	420	500		
S 460 MH/MLH	460	530		

### 3.2. Weldability of modern steel grade

Welding is substantial in the case of structural steel because it depends on the steel's hardness. Thus, the standards are included the rules for lowering the yield strength for thicker plates because it was visible that the required yield strength decreased when the material thickness increased. (Hechler et al., 2015)

In order to verify a product, it is necessary to conform it to a tensile test. The result defines the stress-strain curve, explained in Figure 1, where  $f_y$  and  $f_u$  values can be determined.



**Fig.1** Stress-strain curve

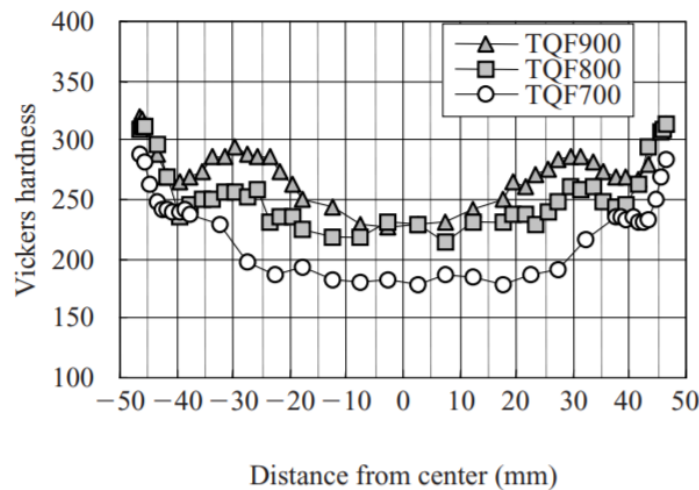
Besides, there is an essential connection between material strength and weldability, which refers to the common alloy type. This material is characterized by poor weldability because of its reduced resistance and higher alloying content. Again, for keeping the thick products' good weldability, a thermomechanical rolling process can be used at the point where high strength steel can be produced without a significant carbon increase. The steels that go through a thermomechanical (TM) rolling process have more benefits, like reduced scale formation, excellent cold formability, best flatness, and cuttability.

This process has many benefits for steel material. The paper "The Right Choice of Steel" (Hechler et al., 2015) provides an excellent example by using TM steel where the economic factor is well evaluated. The model is referring to a column with known dimensions that requires 8 hours of welding. Using the TM steel in HISTAR quality, one-third of the welding time can be saved.

### 3.3. Fabrication of modern types of steels according to EC3

A stylish way to produce steels is using the Quenching and Self-Tempering (QST) process. For example, heavy hot-rolled H-beams made through the QST process in high strength structural steel grades perform better in terms of weldability characteristics. Lucien Weber explained in his paper "Histar High-Performance Hot-Rolled Beams" (Weber, 2003) why the QST process is more advanced than thermomechanical (TM) rolling techniques. The reason is that TM is limited by the mechanical power of the rolling mills due to the high deformation rates that this process implies. Another limitation is the impossibility of substantial reduction of the carbon in steel and improving its weldability. The QST process includes the TM rolling to cover these limits.

The QST technique is based on water and rolling heat usage. Treatment of heavy steel beams comprises applying a homogeneous temperature on the element's entire cross-section before introducing it in the cooler bank. Therefore, substantial temperature differences on the cross-section can be eliminated. An example with different results is defined in one of the reports of JFE Bars&Shapes, (On-Line Quenched and Self-Tempered High Strength Steels.Pdf, n.d.), where the hardness distribution of the horizontal cross-section displays a U-curve distribution corresponding to the cooling characteristics (see Fig. 2). The above layer has high hardness, so it has good resistance, while the middle one has low hardness and high ductility and toughness. Combining them results in high fatigue strength and bending strength in the entire round bar, so in an outstanding balance of strength and toughness. A computer controls the parameters of this industrial process.



**Fig. 2** Hardness curves of a cross-section

During the QST process, due to the lower carbon values compared to the conventional structural steel grade, the weldability and steel grades' ductility are significantly improved.

To avoid the cracks and fragile parts of an element or in the base material, during welding or during a seismic action, it is mandatory to have an established level of toughness of the steel material. In the QST technique, the steel can be supplied with a better toughness at low temperatures. This is why HISTAR grades are more used and more appreciated in the construction of offshore platforms.

Another advantage of the QST process is the well-being of a structure regarding ductility, good characteristics for seismic actions, or other actions that comprise the beams' bending. During bend tests and after it, at high temperatures such as 180°, the HISTAR elements do not show any cracks. The bending test was also made on different welding procedures or heat inputs. It was shown that after the welding without preheating, the welding does not affect the ductility of QST steels.

### 3.4. Example of modern types of steel in high importance structures

Lucian Weber's study (Weber, 2003) explained the difference between HISTAR 460 and other types of steel in high-rise buildings. Using HISTAR 460 helps reduce the columns' weight with an average of 15-25% compared to S355, and with 45% compared to S235. It can also be used in the design, where columns with concrete core are needed, supporting all the lateral loads. Accordingly, the benefits of using HISTAR in columns with regular buckling lengths go to an economic impact by reducing the costs. Also, regarding the design, it is a reason to reduce the weight of the structure. An example is the Mapfre Tower from Barcelona, Spain, where a diagram was made to show the weight savings in gravity columns using HISTAR 460 (see Fig. 3).

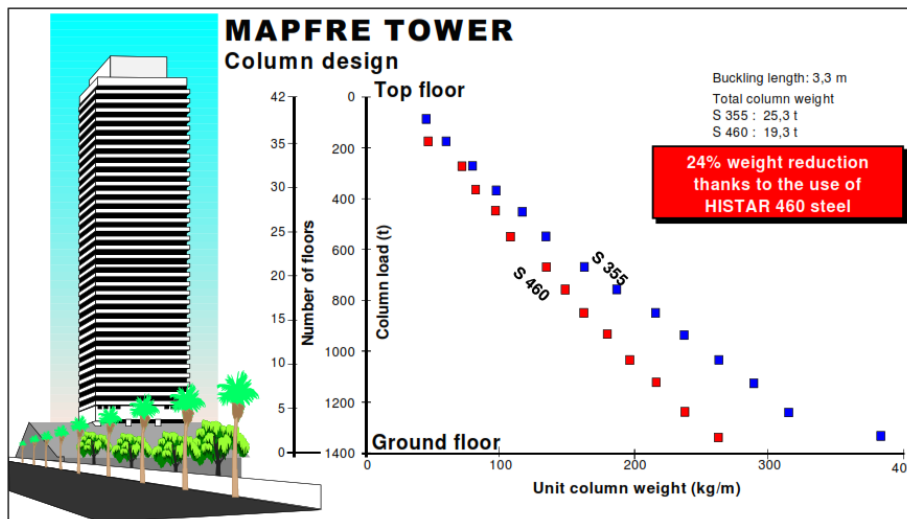
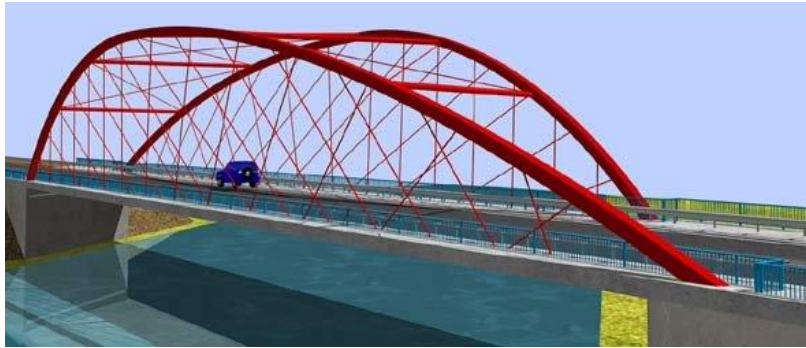


Fig. 3 Weight savings in gravity columns using HISTAR 460 for Mapfre Tower

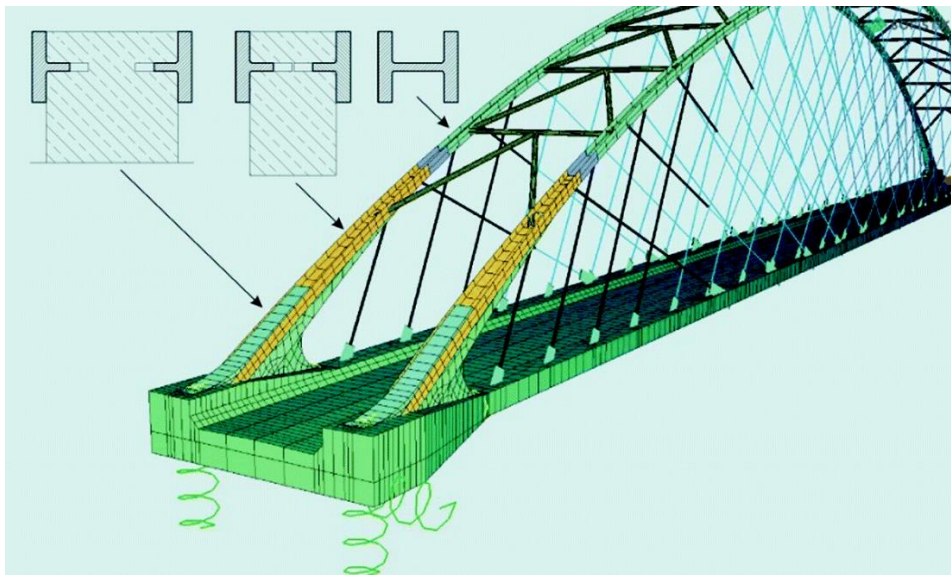
It is suitable to use HISTAR for trusses for tension and compression members with short buckling length, which allows a weight reduction of 15% compared to the S355 type. This reduction is a function of the truss span and the importance of the dead loads (Weber, 2003), easily implemented on bridges. An example is the WD-57 bridge in

Poland (see Fig. 4), where rolled I-beams in the structure's network arches were used. The engineers choose this option to optimize the construction costs and the building time, and due to the structural analysis, less steel was needed to resist the high compression forces in the arches (Lorenc et al., 2018).



**Fig. 4** Net-arch bridge with rolled I-sections in Poland (WD-57 Bridge)

Based on its efficiency, another bridge in Poland, the MS-15 Bridge with a 120m span length (see Fig. 5), was constructed using the same procedure. For this bridge, steel profiles in HISTAR 460 steel grade were used. In this case, the arches were delivered in pieces assembled by the builders using welded site joints. The beams had weld access holes (see Fig. 6) to allow for a residual stress reduced joint.



**Fig. 5** MS-15 Bridge with 120 m span length in Poland





**Fig. 6** Beam with weld access holes

#### 4. CONCLUSION

The modern types of steel can be considered optimal for energy-saving and process saving. This is the reason why, for example, HISTAR steels are the right choice instead of conventional structural steels. The grounds also include the shortest time for the preheating procedure. Besides, the costs and time can be saved for this type of steel. For HISTAR steels, the cost savings are the results of weight reduction and the fabrication process in high loaded columns, truss members, bridge structures, or strong column-weak beam concept.

Thanks to the modern types of steel, the efficiency of bridge constructions can be optimized, regarding time, efficiency, cost-saving, and sustainability. Besides, the solutions with hot-rolled sections are more economical for bridges.

The steels that go through a TM rolling process have more benefits, like reduced scale formation, excellent cold formability, best flatness, and cuttability. Another modern way to produce steels is using the QST process, which is more advanced than TM rolling techniques. The rolling mills' mechanical power limits the TM due to the high deformation rates that the process implies.

The favorable combination of high strength, high toughness at low temperatures, and easy weldability also make these new steel grades very suitable for offshore applications. (Hechler et al., 2015).

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### **PRIMENA SAVREMENIH TIPOVA ČELIKA U KONSTRUKCIJAMA SA ASPEKTA OSOBINA MATERIJALA PREMA EVROKODU 3**

*Istraživači često raspravljaju o ovoj temi a posebno u pogledu ponašanja čelika kao materijala koga najčešće srećemo u građevinarstvu. Primena čelika u građevinarstvu je posebno zanimljiv ne samo za projektante, dobavljače već i za izvođače radova zbog niza logističkih prednosti. Na osnovu analiziranih podataka u ovom radu je detaljno analizirana mogućnost primene savremenih vrsta čelika u građevinskim konstrukcijama prema Evrokodu 3 sa aspekta mehaničkih karakteristika čelika kao materijala.*

**Ključne reči:** *savremene vrste čelika, karakteristike materijala, Evrokod 3*