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# Current tendencies in welding of steel bridges; choice of material and use of thick plates

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**Abstract.** The emergence of new efficient materials, the high demands on the quality of the welded joints, while ensuring their safety in operation, outstanding aesthetic forms, the complexity of the new European welding standards, the pressure of the short execution times, had as result the adoption of modern solutions for steel and composite bridges. Durability is also one of the demands of the European Standards. The use of thick heavy plates can lead to reduction of the constructive depth, possibility for improved fatigue details, short execution time and easy maintenance. In this direction the fabrication efficiency is important, the need of a correct technology is vital. The role of the welding specialist is determinant. The paper presents some examples in the realization of modern steel and composite bridges with thick plates for the Romanian highways network.

## 1. Introduction

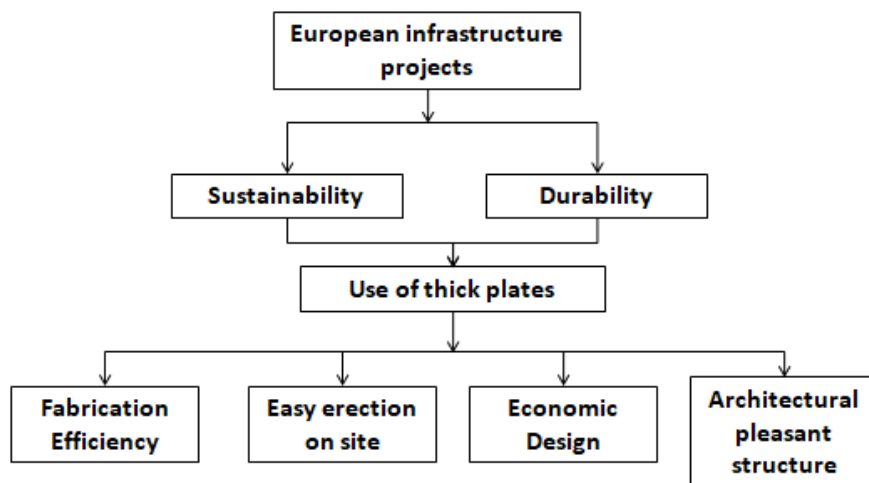
The steel making industry is continuously trying to improve the steel quality by developing more and more sophisticated steel grades [1]. The application of modern high-strength steels offers to constructors, the opportunity to realize economical and environment-friendly structures. A new and efficient tendency is the use of thick plates in structures with large spans, for example in European Infrastructure projects (figure 1). Using heavy plates, the total weight of the structure can be reduced as well as the structural safety, can be increased.

Today, heavy plates can be delivered in a nearly unlimited range of dimensions facilitating the designing problems. Plates in thicknesses up to 120 mm have been widely used in the construction of bridges and multi-story buildings in all over Europe. Steel is due to its unlimited recyclability the ideal choice for a sustainable material in construction [2].

The main advantages of thick plates are:

- reduction of the constructive depth;
- possibility for improved fatigue details;
- elimination of the cover plates (difficult welding procedure);
- multiple prefabrication possibilities;
- reduced transport energy, as well as transport costs;

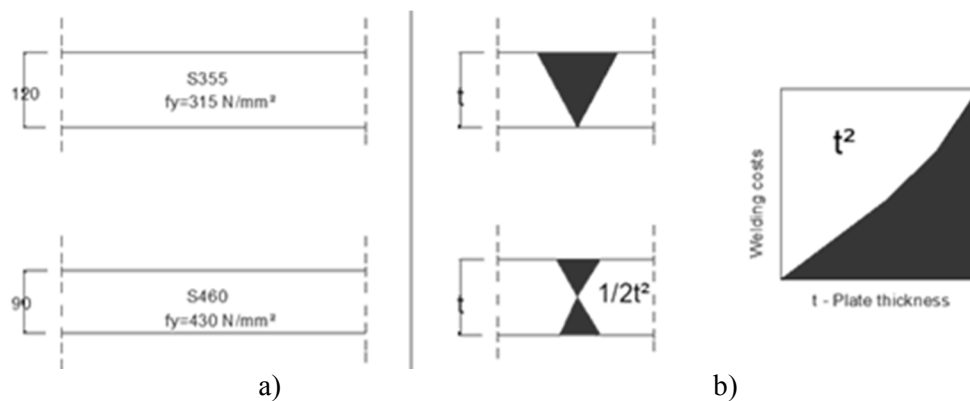




**Figure 1.** Thick plates used in the infrastructure projects – characteristics.

- short execution time (easy erection on site); short interruption of the traffic;
- easy maintenance (large flat surfaces);
- low acoustic emissions due to plate thickness;
- fabrication costs can be saved due to the outstanding strength, toughness and fabrication properties;
- furthermore, thermomechanical rolled steels (S355M/L, S420M/L and S460M/L) have an excellent weldability despite their high strength and an excellent brittle crack-arrest-toughness;
- structural safety and reliability;
- reduced costs by using higher strength steels and savings in welding as shown in figure 2 [3].

The rational exploitation of these possibilities opens new advantageous constructive solutions for steel and composite structures.



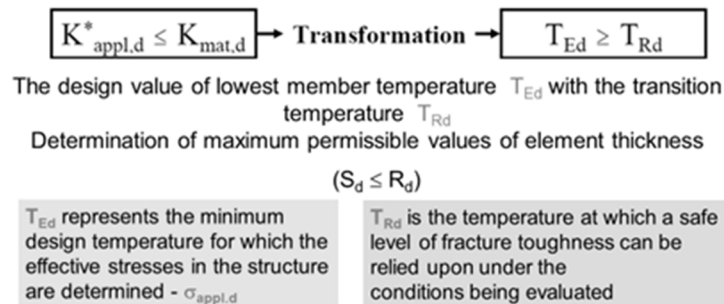
**Figure 2.** a) Reduction of plate thickness; b) Welding cost savings in function of plate thickness.

However, a major disadvantage of heavy plates is crack-induced through-thickness failures and lamellar tearing; these failures have been discovered during the processes of welding and construction of steel structures with thick plates. A special attention must be paid in this direction.

These modern steels represent the right answer to the increasing requirements on modern constructional materials [4].

## 2. Choice of the material

According to Eurocode [5], the choice of the steel grade had to follow a special methodology (figure 3).



**Figure 3.** Choice of material in welded steel constructions.

Some initial recommendations can be done [6, 7]:

- Gradually replacement of the classical S235 with S355, or a higher steel grade.
- Recommendation for using weathering steels (like S355J0 W – EN 10025-5).
- Choice from the designing stage of the correct execution category, according to EN 1090.
- At these large thicknesses the use of thermomechanical laminated steels is recommended. They have a very good weldability, together with a high ductility. For the verification of weldability, the equivalent carbon content is determined [3]:

$$CEV (IIW) = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15 \quad (1)$$

- Above the CEV % values for three S460 steels are presented in table 1.

**Table 1.** Different types of steel.

Steel	S460NL	S460QL	S460ML
CEV%	0.50	0.42	0.41

- Due to the fine granularity and a slender chemical composition, thermomechanical laminated steels should not be preheated.

For the choice of material [5], the following steps should be taken:

- calculus of the maximum applied stress  $\sigma_{Ed}$ , according to the design combination corresponding to an accidental combination (unfavourable occurrence of lowest temperature, flaw size, location of flaw and material property).

$$E_d = E \{ A [T_{Ed}] + \sum G_K + \psi_1 Q_{K1} + \sum \psi_{2,i} Q_{Ki} \} \quad (2)$$

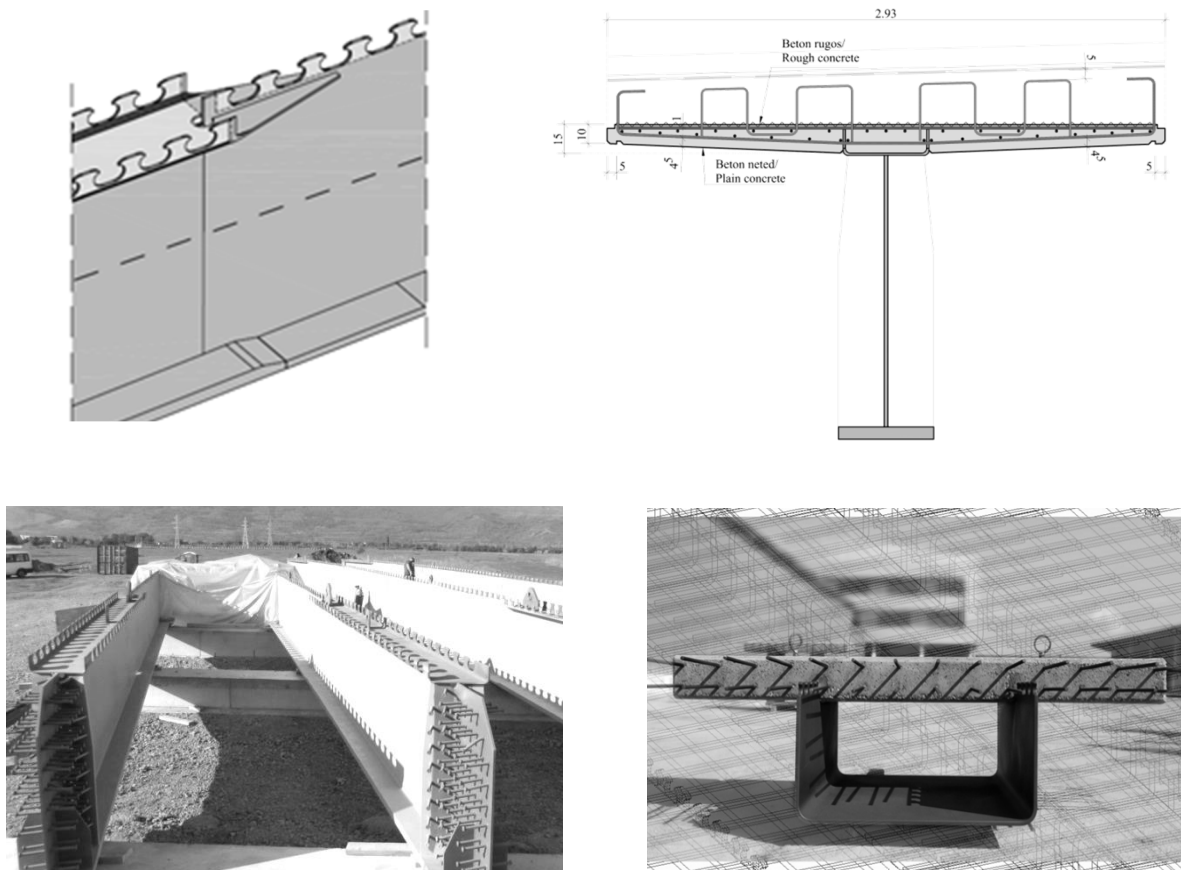
where the leading action A is the reference temperature  $T_{Ed}$  that influences the toughness of material of the element considered and might also lead to stress from restraint of movement.  $\sum G_K$  are the permanent actions,  $\psi_1 Q_{K1}$  is the frequent value of the variable load and  $\psi_{2,i} Q_{Ki}$  are the quasi-permanent values of the accompanying variable loads, that govern the level of stresses on the material.

- Calculation of the maximum applied stress  $\sigma_{Ed}$ , which should be the nominal stress at the location of the potential crack initiation, determined as for the serviceability limit state considering all combinations of permanent and variable actions and will not exceed 75% of the yield strength. The reference stresses  $\sigma_{Ed}$  should be determined using an elastic analysis.
- Calculus of the reference temperature  $T_{Ed}$  at the potential fracture location

$$T_{Ed} = T_{md} + \Delta T_r + \Delta T_\sigma + \Delta T_R + \Delta T_\varepsilon + T_{escf} \quad (3)$$

where:

- $T_{md}$  is the lowest air temperature defined at the stress level corresponding to  $\sigma_{appl,d}$  (for example for middle Europe is defined as  $-25^{\circ}\text{C}$ ); where  $\sigma_{appl,d}$  is the stress produced by the permanent and variable actions at the minimum operating temperature ( $T_{Ad}$ ),
- $\Delta T_r$  is an adjustment for radiation loss (can be considered  $-5^{\circ}\text{C}$ ),
- $\Delta T_{\sigma}$  is the temperature range determined by the crack size  $a_d$  and the effective value of stress  $\sigma_{appl,d}$ , an adjustment for stress and yield strength of material, crack imperfection and member shape and dimensions (resulted from the Failure Assessment Diagram FAD (R6 Method - Assessment of the Integrity of Structures Containing Defects - CEGB), Wallin-Sanz-correlation between the stress intensity factor  $K$  and the temperature  $T$  (Master Wallin Curve which include the relation between the stress intensity factor  $K_{Jc}$  and temperature and Sanz correlation  $T100 = T27J - 18^{\circ}\text{C}$ ),
- $\Delta T_R$  is a safety allowance, if required, to reflect different reliability levels for different applications (in relation with the reliability index  $\beta$  and the failure probability  $P$ ),
- $\Delta T_{\epsilon}$  is the adjustment for a strain rate other than the reference strain rate  $\epsilon_0$ ,
- $\Delta T_{\epsilon cf}$  is the adjustment for the degree of cold forming. Normally it is considered a material without cold deformation so that  $\epsilon_{cf} = 0\% \rightarrow \Delta T_{\epsilon cf} = 0$ . Currently there are practical executed examples of steel plate cold forming facilitating the development of composite bridge sections (figure 4).



**Figure 4.** Composite bridge sections with cold bend steel plates.

The importance of applying the principles of fracture mechanics results also from the fact that the European Standards EUROCODE provides as a criterion of material choice, respective as a fundamental element to preventing brittle fracture, the relation (4).

$$K_{mat} \geq K_I = Y \cdot \sigma \cdot (\pi \cdot a)^{1/2} \quad (4)$$

Usually  $T_{Ed}$  is equal to  $T_{mdr}$ ; according to the DAST Richtlinie 009 [6], it can be taken – for Central Europe - table 2.

**Table 2.** Different types of steel.

No.	Member	Reference Temperature $T_{mdr}$ (°C)
1.	<i>Steel and composite bridges</i>	-30
2.	<i>Buildings</i>	
	- Members exposed to external climate	-30
	- Members protected from external climate	0
3.	<i>Crane runways</i>	
	- Members exposed to external climate	-30
	- Members protected from external climate	0
4.	<i>Hydraulic structures</i>	
	- Members almost fully emerged from water	-30
	- Members with one sided contact with water	-15
	- Members partially submerged in water	-15
	- Members fully submerged in water	-5

The maximum allowable values of element thickness is given in Eurocode 1993 Annex 3 table 2, in function of:

- the maximum permissible values of element thickness appropriate to a steel grade,
- its toughness quality in terms of KV-value,
- the reference stress value  $\sigma_{Ed}$  and the reference temperature  $T_{ed}$  (°C), in terms of three stress levels expressed as proportions of the nominal yield strength:

$$\sigma_{Ed} = 0.75 f_y(t) \text{ (N/mm}^2\text{)}$$

$$\sigma_{Ed} = 0.50 f_y(t) \text{ (N/mm}^2\text{)}$$

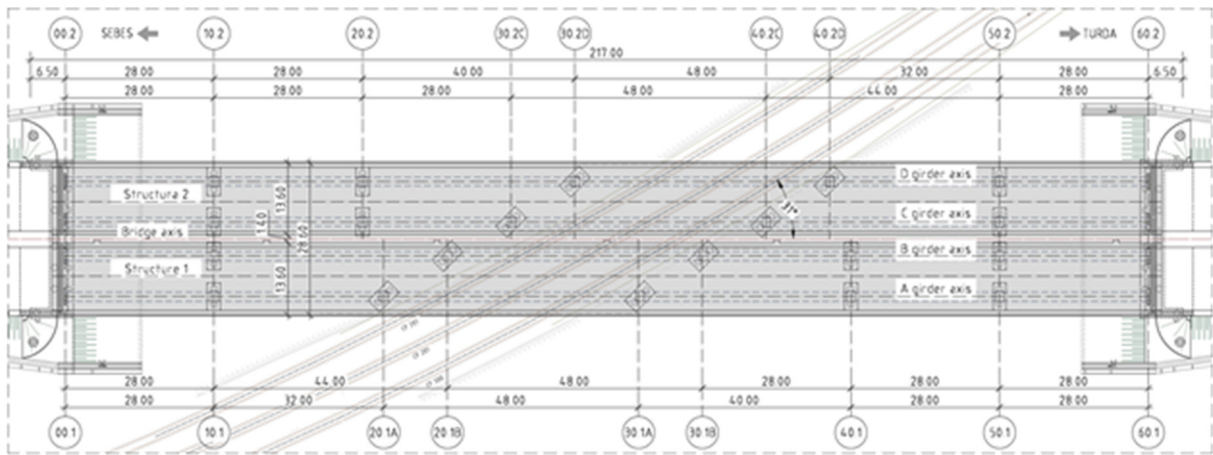
$$\sigma_{Ed} = 0.25 f_y(t) \text{ (N/mm}^2\text{)}$$

where  $f_y(t) = f_y - 0.25 \cdot t/t_0$  ( $t$  – plate thickness in mm and  $t_0 = 1$  mm).

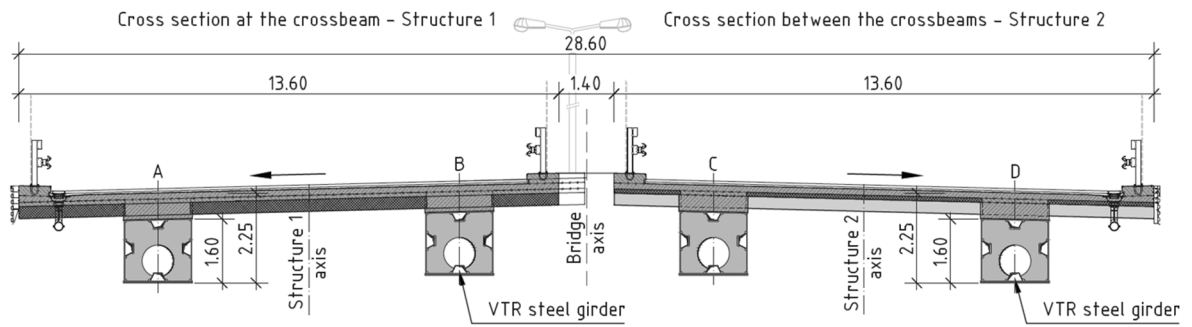
The values are presented in terms of a choice of seven reference temperatures: +10, 0, -10, -20, -30, -40 and -50 °C.

### 3. Case study - composite highway bridge

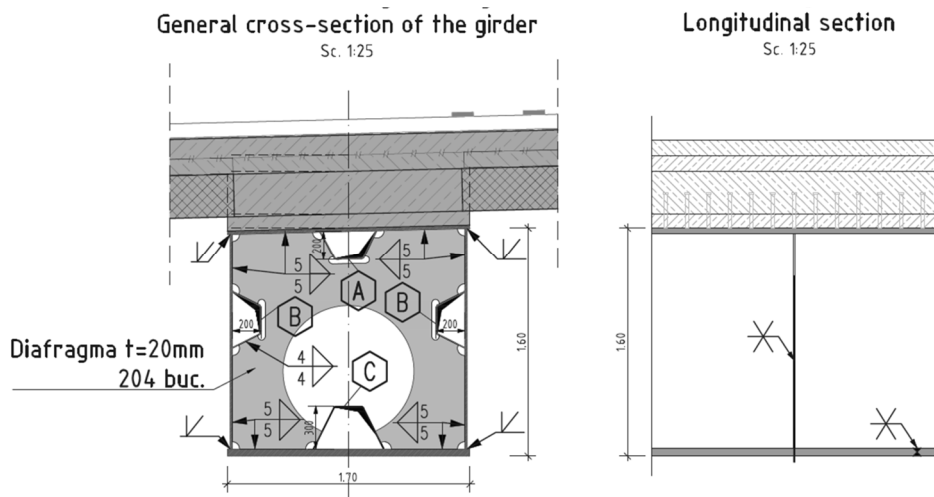
The highway bridge is situated at km 26 + 350 over three electrified, main railway lines, the CF300 and the double CF201. Because the VTR® solution is well suited for skew bridges, the middle span could be reduced from the initial 80 m length, to 48 m length. The main advantage in this case is that the main girders can be lifted and mounted at once, without the use of temporary supporting towers. This is especially important when working near electrified railway lines. The bridge has a length of 217.00 m (figure 5), with 6 spans (28.00 m + 32.00 m + 48.00 m + 40.00 m + 28.00 m + 28 m). The substructure follows the skew of 31° between the highway axis and the railways. The bridge is made of two parallel structures, each 13.60 m wide (figure 6). The structure is an integral bridge, with rigid connection between the sub- and superstructure. Most of the longitudinal deformation is taken over by pendulum-like columns in the abutment area. No bearings are used, and expansion joints are needed only at the abutments.



**Figure 5.** View of the bridge – plan.



**Figure 6.** View of the bridge – cross section.



**Figure 7.** Cross section of the bridge and types of welding joints.

The maximum stress value in the steel structure – lower flange, is presented in figure 8.

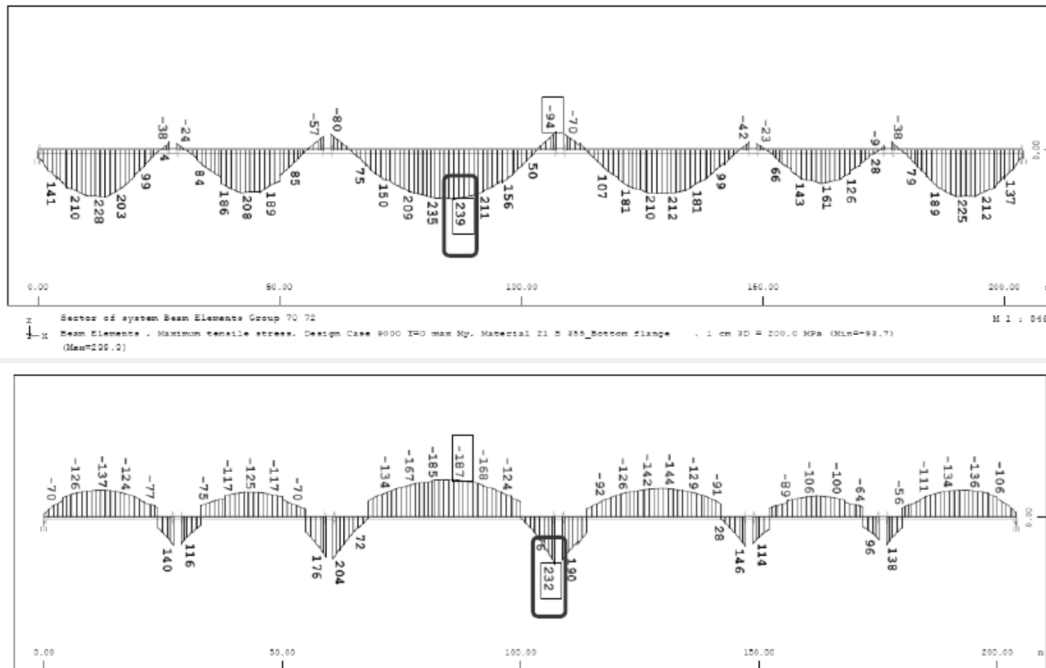


Figure 8. Maximum stress values in the lower flange of the main girder.

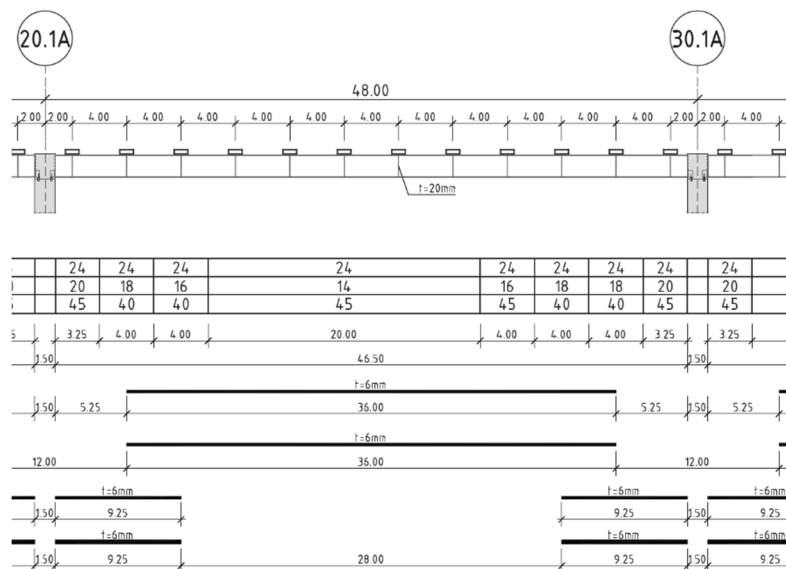


Figure 9. The thickness of the material in the section with maximum stress.

Entrance parameters [5]:

$$f_y(t) = f_y - 0,25 \times \frac{t}{t_0}; cu t_0 = 1,0$$

$$f_y(t) = 355 - 0,25 \times \frac{45}{1} = 343,75 \text{ N / mm}^2$$

$$\frac{\sigma_{Ed}}{f_y(t)} = \frac{23,9}{34,375} = 0,695$$

$$\Rightarrow \sigma_{Ed} \cong 0,695 \times f_y(t)$$

Marchi	Calitate	Temperatura de referință $T_{ref}$ [°C]																						
		Energia Charpy K					$\sigma_{Ed} = 0,75 f_d(t)$					$\sigma_{Ed} = 0,50 f_d(t)$												
		$t_{ref}$ [°C]	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	
S235	JR	20	27	60	50	40	35	30	25	20	90	75	65	55	45	40	35	135	115	100	85	75	65	60
	J0	0	27	90	75	60	50	40	35	30	125	105	90	75	65	55	45	175	155	135	115	100	85	75
	J2	-20	27	125	105	90	75	60	50	40	170	145	125	105	90	75	65	200	200	175	155	135	115	100
S275	JR	20	27	55	45	35	30	25	20	15	80	70	55	50	40	35	30	125	110	95	80	70	60	55
	J0	0	27	75	65	55	45	35	30	25	115	95	80	70	65	50	40	165	145	125	110	95	80	70
	J2	-20	27	110	95	75	65	55	45	35	155	130	115	95	80	70	65	200	190	165	145	125	110	95
	M,N	-20	40	135	110	95	75	65	55	45	180	155	130	115	95	80	70	200	200	190	165	145	125	110
	ML,NL	-50	27	185	160	135	110	95	75	65	200	200	180	155	130	115	95	230	200	200	200	190	165	145
S355	JR	20	27	40	35	25	20	15	10	65	55	45	40	35	30	25	25	110	95	80	70	60	55	45
	J0	0	27	60	50	40	35	30	25	15	95	80	65	55	45	40	30	130	130	110	95	80	70	60
	J2	-20	27	90	75	60	50	40	35	30	130	115	95	80	65	55	45	200	175	150	130	110	95	80
K2,M,N	J2	-20	27	90	75	60	50	40	35	30	130	115	95	80	65	55	45	200	175	150	130	110	95	80
	K2,M,N	-20	40	110	90	75	60	50	40	35	155	135	110	95	80	65	55	200	200	175	150	130	110	95
	ML,NL	-50	27	155	130	110	90	75	60	50	200	180	155	135	110	95	80	210	200	200	200	175	150	130
S420	M,N	-20	40	95	80	65	55	45	35	30	140	120	100	85	70	60	50	200	185	160	140	120	100	85
	ML,NL	-50	27	135	115	95	80	65	55	45	190	165	140	120	100	85	70	200	200	200	185	160	140	120
S460	Q	-20	30	70	60	50	40	30	25	20	110	95	75	65	55	45	35	175	155	130	115	95	80	70
	M,N	-20	40	90	70	60	50	40	30	25	130	110	95	75	65	55	45	200	175	155	130	115	95	80
	QL	-40	30	105	90	70	60	50	40	30	155	130	110	95	75	65	55	200	200	175	155	130	115	95
	ML,NL	-50	27	125	105	90	70	60	50	40	180	155	130	110	95	75	65	200	200	200	175	155	130	115
	QL1	-60	30	150	125	105	90	70	60	50	200	180	155	130	110	95	75	215	200	200	200	175	155	130
S690	Q	0	40	40	30	25	20	15	10	10	65	55	45	35	30	20	20	120	100	85	75	60	50	45
	Q	-20	30	50	40	30	25	20	15	10	80	65	55	45	35	30	20	140	120	100	85	75	60	50
	QL	-20	40	60	50	40	30	25	20	15	95	80	65	55	45	35	30	165	140	120	100	85	75	60
	QL	-40	30	75	60	50	40	30	25	20	115	95	80	65	55	45	35	190	165	140	120	100	85	75
	QL1	-40	40	90	75	60	50	40	30	25	135	115	95	80	65	55	45	200	190	165	140	120	100	85
QL1	-60	30	110	90	75	60	50	40	30	160	135	115	95	80	65	55	200	200	190	165	140	120	100	

Figure 10. Eurocode table for the choice of the thickness

Determination of maximum permissible values of element thickness is done according with Eurocode norm. Considering that the base material is S355 J2 with  $t_{max} = 45$  mm, it results the admissible thickness  $t_{adm} = 47.5$  mm (interpolation).

Welding details and edge preparation are presented in figure 11.

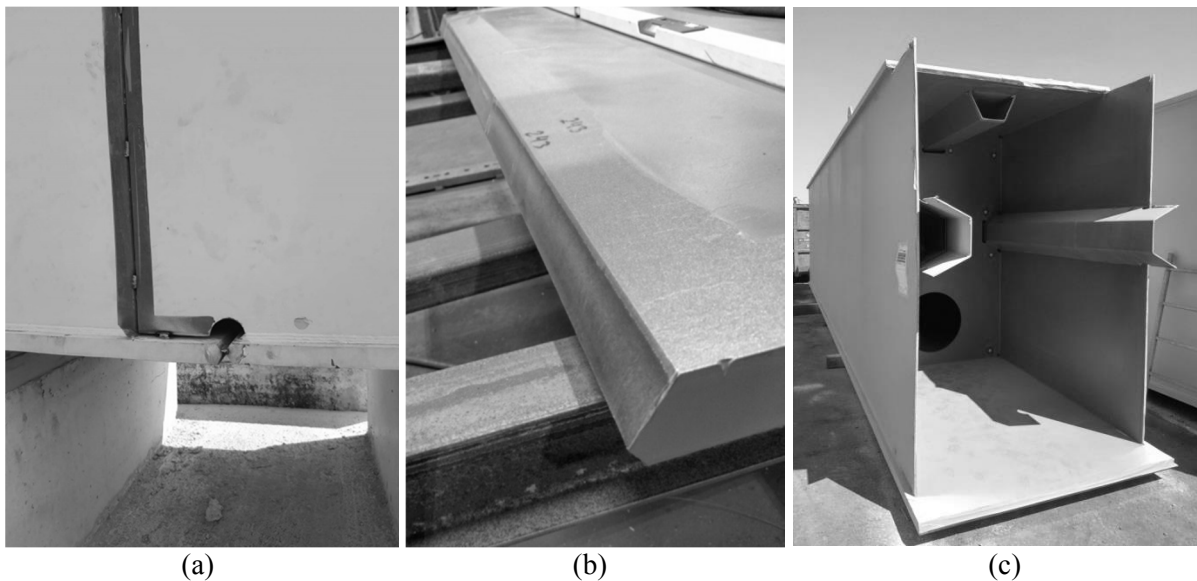


Figure 11. (a) Welding detail on the site; (b) Edge preparation of the thick plate; (c) Steel assembly in the workshop.

#### 4. Conclusions

In the present context of the important European Infrastructure Projects, the Eurocodes Standards, the necessity of safe and sustainable steel constructions, the role of the Welding Specialist is decisive. A special attention must be paid to the education in the welding field Education in welding IWE (International welding Engineer) and IWSD (International Welding Designer). During the Round Table Discussion "Developments in welded steel constructions" held in Timisoara in September 2018, a final Statement regarding the importance and necessity of the education in the welding field, was adopted [8, 9].

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