Special heavy plates and steel solutions for bridge building

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Abstract. In many European countries infrastructure, -road as well as railway infrastructure-, needs intensive investments to follow the growing demands of mobility and goods traffic. Steel or steel composite bridges offer in this context viable and very sustainable solutions. Due to its unlimited recyclability steel can in general be seen as the ideal material for such sustainable constructions, but especially when designers or fabricators exploit the nowadays available possibilities of steel industry very cost-efficient and remarkable constructions are realizable. This paper will highlight some of these newest developments in heavy plates for bridge building. For example, for small span railway bridges the so-called thick plate trough bridges have proven to be a favourable concept. Very heavy plates with single plate weights up to 42 t allow building these bridges very efficiently out of one or very few single plates. Another interesting development is the so-called longitudinally profiled plates which allow a varying plate thickness along the actual loading profile. As last point the rising entry of higher strength steels in bridge building will be discussed and it will be shown why thermomechanically rolled plates are the ideal solution for these demands.

1. General instructions
In many European countries infrastructure, -road as well as railway infrastructure-, needs intensive investments to follow the growing demands of mobility [1] and goods traffic. Steel or steel composite bridges offer in this context viable and very sustainable solutions [2]. Due to its unlimited recyclability steel can in general be seen as the ideal material for such sustainable constructions. Especially when the designers or fabricators take advantage of what the steel industry offers them nowadays very cost-efficient and remarkable constructions are realizable. This paper will highlight some of these developments in heavy plate production, adjusted to the needs of modern bridge building. For example, the so-called thick plate trough bridges have proven to be a very favorable concept for small span railway bridges [3]. Very heavy plates with single plate weights up to 42 t allow building these bridges very efficiently out of one or very few single steel plates. Another interesting development is the so-called longitudinally profiled plates which allow a varying plate thickness along the actual loading profile. As last point the benefits of high thickness thermomechanically rolled plates (TM-Steel) will be discussed which offer the ideal solution as higher strength steels in bridge building gain more and more ground.

2. Heavy single plate weights for thick plate through bridges
Europe’s rail infrastructure is showing its age. Bridge refurbishment projects - and new bridges - are needed urgently at many locations. The continent’s politicians have recognized this and have set up programs of investment in many European countries. In Germany, for example, over 800 rail bridges
are to be (re)constructed by 2019 [4]. These will, in the main, be short-span bridges, such as rail overbridges, for example. Nowadays not only the “classical” criteria, such as construction costs and project completion time, but also, more and more frequently, other important factors, such as the sustainability and durability of these bridge structures, are taken into account in investment decisions. In most cases, construction must be implemented on the existing system, i.e., “in traffic”, for which reason the rapidity with which bridges can be completed is now playing an ever more important role. Trough bridges featuring thick deck plates have proven to be the ideal bridge design for such short-span overbridges (Figure 1).

Figure 1. Trough bridge with thick deck plates ready for installation.

The special benefit of this type of trough bridge is the fact that the deck plate consists of ideally one single thick steel plate (possibly also more plates with weld joints), with the advantage that it is possible to dispense with crossbeams underneath the track plate. Web plates are in many cases welded on to stiffen the trough walls.

The advantages of thick-plate trough bridges:

- High vehicle headrooms and clearances are possible, thanks to the lower structural height compared to conventional trough bridges (with crossbeam thickness 360-500 mm).
- Short traffic-interruption times (“possessions”), easy fabrication and fast installation thanks to high level of prefabrication.
- Reduced noise emissions and thus less noise nuisance, thanks to the heavy foundation plate.
- Good maintenance conditions thanks to the flat and homogeneous bridge undersides.
- Life-cycle assessment benefit, plus sustainability [3].

Grades S275NL/ML or S355NL/ML in accordance with DIN EN 10025, Parts 3 and 4 are generally used for the deck plate (plate thickness ~ 100 mm). Plates of particularly great widths are popular here, in order to avoid joints in the deck plate. Where a deck plate joint is unavoidable, the weld should be positioned in length direction at the one-third point, referred to bridge length, and must be tested for its fatigue strength.

Thanks to the large range of dimensions and formats available, steel heavy plates make it possible to avoid, or at least reduce to minimum, transverse and longitudinal joints in thick-plate trough bridges, also achieving, simultaneously, an improvement in fatigue performance. Grades S275NL/S355NL can, for example, be supplied in maximum plate weights of up to 42 t and in plate widths of up to 4,750 mm for such applications, while Grades S275ML/S355ML are available up to 35 t and 4,600 mm.

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The following maximum plate lengths are available for a 100 mm thick plate in Grade S355NL, assuming a maximum plate weight of ~ 42.5 t (Figure 2).

![Figure 2. Possible plate length for a 100 mm thick S355NL with different plate widths.](image)

3. Longitudinally profiled plates

Another interesting product of the steel making industry is the longitudinally profiled (LP) plate. By perfect control of the rolling parameters during rolling the thickness over the length of a plate can be varied to a certain extent and a thickness profile can be obtained [5]. Figure 3 gives an overview of the possible profile types. A segment defined as plate part which has either the same thickness or the same slope has to be at minimum 1000 mm long, but a longitudinally profiled plate can generally have up to 5 such segments. Newest developments for the production of such LP plates could increase the possible slope of up to 10 mm/m. These new possibilities offer a greater freedom to the engineering in choosing the plate profile desired and adjusted to the load situation for various applications, e.g. bridge girders.

![Figure 3. Overview of possible profiles for longitudinally profiled plates (LP plates).](image)

Similar to the usage of high strength steels the economic and ecologic benefit of this very special type of steel plates lies mainly in an achievable material weight reduction. The tunable plate thickness gives the opportunity to save excess material in regions where the thickness is not needed from static
calculations. Furthermore the welds in e.g. a bridge girder can be moved to positions where the fatigue is less governing the design (Figure 4). Given that the usage of LP plates can offer a cheaper solution by representing less excess material and less welding costs with possibly improved fatigue properties. This consideration implies only the fabrication cost and is not involving the inherent reduction of transportation cost and energy which is associated with such a lower component weight.

![Figure 4](image)

**Figure 4.** Possible applications of LP plates in a bridge girder.

4. Thick high strength plates, thermomechanically rolled

Higher strength steels, as S460 with a minimum specified yield strength of 460 MPa, are gaining more and more ground in international bridge building due to its great benefits regarding weight savings and achievable cost reductions. Depending on the load situation significant reduction in the cross-section is possible by stepping into a higher strength class. If for example comparing the rated values for S355 and S460 ($f_y = 315$ MPa at 100 mm plate thickness to $f_y = 430$ MPa at 73 mm plate thickness), the change towards a higher strength steel allows a plate thickness reduction of around 30 % (not taking into account fatigue effects which are depending on the exact construction detail) (Figure 5).

![Figure 5](image)

**Figure 5.** Possible reduction of plate thickness when using higher strength steel leads to savings in material consumption [6].

Beside the reduced material amount these reduced cross sections impact the cost and eco-balance of a construction in multiple ways [7]. First, the lower component weight enables bigger assembly units and thereby faster assembly plus optimized transportation. The hence lowered transport energy expenses (for example less truck transport) add a relevant sustainable aspect to the high economic efficiency of high strength steels in bridge building.

But the biggest impact on cost reduction is coming from the fact that the thinner steel plates lead to a considerable reduction of welding costs. Due to the geometrical situation the weld seam volume is a quadratic function of the plate thickness and therefore the enabled savings in weld material and welding time are disproportionately high with decreasing plate thickness (Figure 6).
Figure 6. Realizable cost savings in welding dependent on plate thickness.

To achieve such “higher” strength steel grades (with yield strength > 355 MPa) different production routes are possible [8]:

1. Alloying: higher carbon equivalents and therefore decreased weldability
2. Thermomechanical rolling: excellent weldability, mainly up to 500 MPa
3. Quenching and Tempering: in special cases used up to 690 MPa in bridge building

The big advantage of using thermomechanically rolling as a production route for achieving higher strength steel grades is the remaining excellent weldability, while the other processes tend to an increased carbon equivalent and by that to a reduced weldability.

Figure 7. Yield strength as a function of alloying, expressed by the carbon equivalent CE (IIW).

Thermomechanically rolled plates need less carbon and alloying material compared to its normalized equivalent to achieve the same strength (Figure 7). Their low alloying contents are therefore the basis for the major advantage of TM-steels, their excellent weldability. This is even more evident when talking about higher strength steels, as the gap between the Carbon equivalent (CE(IIW)) of a normalized steel and a TM-steel increases with yield strength.

Up to recently the big advantages thermomechanically rolling offer especially for higher strength plates, as e.g. S460M/ML, were only available for plate thickness up to 120 mm. Surpassing this limit
lead to the situation that the fabricator had to choose between a normalized steel, as S460NL, which has a high CET and needs special care during welding and a quenched and tempered steel which has an indeed acceptable CET value but higher cost due to more energy intense production route.

The highest thickness for thermomechanically rolled plates is mainly limited by the availability of strong rolling forces as well as of semi-finished steel products with appropriate product thickness in order to allow a minimum degree of thickness deformation between the slab and the final heavy plate. This is of crucial importance to achieve the beneficial properties of TM-Steels. Thus EN 10025-4, as standard for TM plates in steel constructions, has defined such steels also only up to a thickness of 120 mm. Nevertheless, newest developments in steel manufacturing, e.g. very thick slabs up to 500 mm possible due to the invest in a new innovative continuous caster, are now able to push this production-driven limit to 150 mm. In order to allow maximum usability in bridge constructions these thick TM-plates fulfill the same mechanical requirements as a 120 mm thick plate according to EN 10025-4.

With this new development now also for plates exceeding 120 mm an excellent weldable and cost-efficient steel grade alternative is available for the fabricator. The significantly improved weldability of TM-steels can be verified when comparing the carbon equivalent CET, as common measure of weldability, for the different alternatives of S460 (Table 1). CET was computed with Eq. 1 [9].

\[ \text{CET} = C + \frac{\text{Mn} + \text{Mo}}{10} + \frac{\text{Cr} + \text{Cu}}{20} + \frac{\text{Ni}}{40} \]  

**Table 1.** Typical CET values for S460 steels in 140 mm.

| Steel grade | typical CET /% | typical CEV /% | max. CEV /% acc. to EN 10025 |
|-------------|----------------|----------------|-----------------------------|
| S460NL      | 0,34           | 0,50           | 0,55                        |
| S460QL      | 0,31           | 0,42           | 0,50                        |
| S460ML      | 0,26           | 0,41           | -                           |

**Figure 8.** Higher strength thermomechanically rolled steel (S460ML) in bridge construction, Botlek Bridge in Rotterdam, Netherlands (Copyright SEH Engineering).

5. Conclusions
By developing and refining modern steel concepts, the steel producers can significantly support the efficiency and design of a modern sustainable steel bridge. Mainly the potential savings these modern steel grades enable, are associated with a reduction of fabrication time (less welding, less time for preheating or transportation) or also with reduced energy and material consumption (weight...
reduction). Therefore positive effects on the environment are immanent. This combination of effects can help the steel fabricators reaching the ambitious goals of high profitability, safety and sustainability in modern bridge construction.

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