Nordic Steel Bridges—Trends and Development

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Abstract: The development of steel bridges has been very strong for many years implementing composite structures, higher steel grades and hybrid girders, thus improving cost efficiency in bridge superstructures. As construction moves more towards inner city, there is need for even more improvement. As global resources are scarce, and society in general expect more value for same money. With Constructional Excellence—a well defined process from steel mill to installed bridge which includes design management, new foundation solutions, the best practice of current steel bridges and intelligent installation put together in robust system solutions. This paper will show resource efficiency in three dimensions, money, time and less traffic disturbance.

Key words: Design management, steel bridges, steel pipe foundation, resource efficiency.

1. Introduction

The business and technology environment is challenging and the pace of change is increasing, as it should be, and end-users are demanding that the construction industry can increase their efficiency to create more value for the same money. For example the Swedish transport administration has a 90 points programme running to save 300 million Euro by a yearly efficiency improvement of 2%. That goal is to be achieved by year 2017 and expectations are also that the other key players in the infrastructure construction market will take the challenge and opportunity to step up to the next level.

From a technology point of view, the infrastructure construction segment is considered low-tech and conservative, so there is room for improvement and a gap to close—steel bridges and foundation solutions can play an important role here if you combine current best practise into new Nordic solutions.

Closing a gap by bringing the construction industry from focus on OPEX (operational excellence) to increased focus on COEX (constructional excellence) is neither a small step nor a giant leap. A lot of efforts and focus have been placed in internal efficiency amongst the different players in infrastructure construction and for sure, many have succeed well—but what happens at site, where it finally is decided if a project is a success or not. Does the current business logic support that all the investments made in early phase for perfect production really ends up in a best practise performance and the intended solution with same high qualities of performance for a long time?

Today, in infrastructure construction, many seek to differentiate themselves from others with either higher internal efficiency (low cost and low margins) or in more demanding projects with higher installation skills, but the next step must be to own our own future by implementing constructional excellence, putting all the pieces together both in small and big projects.

Sustainable business and technology development should focus more on resource efficiency in at least three dimensions, costs, time saving and less traffic disturbance with robust system solutions, keeping their value over time and with low sensitivity for disturbance in construction stages.

Components, as foundation pile systems for example, are not likely to have room for significant improvement and with innovation process slow in infrastructure with long lead times for implementation, there is another way ahead, which was shown in several
cases carried out in Nordic countries in recent years.

The main idea behind this is a well defined process emphasizing on the whole process from steel mill to installed bridge, also taking into perspective future maintenance and a life cycle cost perspective in the future. In this context, one can not highlight the importance of design management, i.e., in very early phase open up dialogue on how to make good decisions in design with an overall cost and time efficiency perspective, based on steel workshop input and experiences made in earlier projects (Fig. 1).

Five different project cases will make the base for clarifying this, and then by pattern recognition it will be shown several new possibilities for Nordic best practice and the best combination of current steel bridge solutions, foundation steel pile systems and intelligent installation methods all put together.

However, implementation of Eurocode into the Nordic countries has just started and it seems that there could be some challenges, considering the fatigue design criteria, for higher steel grades, and thus hybrid girders. For railway bridges, fatigue design criteria have already been used with earlier country specific Swedish design codes, which led to the elimination of steel grades S420 and S460.

2. Steel Bridge Superstructures and Recent Development

Design management which is an early dialogue to optimize overall cost, by developing a method and systematic approach for early dialogue with designer and contractor opportunities have opened up for optimization of overall costs including of course common practice today using higher steel grades and hybrid girders (Fig. 2). This means steel workshop fabrication adjusted design, right choices of materials, geometric best choices for web and flange plates to fully utilize the steel and also taking transport and handling into consideration. It is all put together in the guideline—better steel bridges [1] which also describe cost and risk reducing steel pipe pile foundation examples recently implemented in Sweden for smaller bridges [2].

Steel workshop efficiency with design management as a tool in very early phase aims for total cost optimization, robust system solutions using relatively simple components and means a different mindset—instead of just installing what was designed and will be built.

Fig. 1  A good example of a design managed section ($h = 3.2$ m, $b = 2.5$ m) for the 900 m long railway Ålandsfjärden, which is very simple open longitudinal stiffeners by splitting a steel coil, means no waste and the whole upper flange serves both as form work and platform for the contractor during construction.
3. The Time Component of Steel Bridge Construction

Good principles of steel bridge design must consider the whole process of construction from steel mill to installed bridge, and furthermore also future maintenance and the life cycle cost perspective. If designer, contractor and steel supplier together, early in the design process, make the right choices, substantial benefits can be achieved, especially as steel bridge construction has long lead times in steel mill and that basis of design must consider also transient design situations, which refer to temporary conditions applicable to the structure during execution or repair.

3.1 The Lövö Bridge—500 m Bridge Installed in Just Five Days

The lifting was done by a German sea crane with lifting capacity of 600 tons and steel bridge sections were shipped by barge to the site. From workshop point of view, shorter sections were made and then put together in harbour to up to 115 m long sections, to be lifted in place (Fig. 3).

Design management was used in very early dialogue with designer and main contractor to identify and quantify opportunities to optimize overall cost for the project including shortening construction time (Fig. 4). This means also reducing the risk for later disturbances due to lack of communication or misunderstanding, creating a common picture of what to achieve and how [3]. This was also supported by Tekla software used for design and workshop drawings—Finnish common practice since many years ago.

3.2 The Partihall Link—Complex Steel Bridge Tailoring

In the heart of Gothenburg, the new Partihall link, including a 1,150 m long bridge, is connecting the highways E20 and E45 to improve traffic flow and enable further development of the city (Fig. 4). The construction work was made in very complex environment, with road traffic running, several railway tracks going through and sensitive natural environment with the Säve River also passing.

The steel boxes are hybrid girders, with S355 steel in webs and S420 and S460 in flanges, but in this case boxes were open with internal painting and traditional form work was used for casting of concrete deck (Figs. 5 and 6).
Fig. 3  In the Finnish archipelago nearby Abo, up to 115 m long bridge sections were lifted by sea crane to complete a 500 m long I-girder bridge in just five days, this was an alternative proposal from designer, main contractor and steel bridge supplier to shorten construction time with three months.

Fig. 4  The traffic flow and enable further development of the city: (a) the relatively simple component, two I-girders with form work for casting of concrete deck already in place from land; (b) all components put together in a beautiful bridge, well-adapted to the landscape and gently taking a leap over the water.

Fig. 5  The lifting of box sections, during severe snowstorm, over railway was planned 18 months ahead, this section weighs 140 tons and for the whole projects several combinations of installation methods were used, lifting, launching and barge from Säve River.
Once again optimization, starting with design management, of the combination of relatively simple components, even though in this case, every box section is unique, and the industrial DNA of steel bridge construction and the time component are the most suitable installation methods—steel bridge tailoring in its true essence [4].

4. Steel Pipe Foundation Systems—A Catalyst for Further Improvement

In Sweden and Norway, quite recently significant progress has been made in simplifying foundation solutions and thus lowering investment costs and reducing (geotechnical) project risk by developing and implementing Finnish methods for foundation of bridges on steel pipe piles, either with smaller dimensions (Ø170-220 mm) or larger diameter (Ø600-800 mm), commonly referred to as RR-piles or RD-piles, depending on the method of installation. The Swedish association, FIA (Renewal in the Civil Engineering Industry), have in the project Dyran [5], recently built, estimated that 40% lower investment cost was achieved by this approach. This model is now developing further and the pipe-line of coming projects have developed fast, also creating new Nordic solutions, with the current practices from Sweden, Norway and Finland put together in improved best practices. It is noted that this type of bridges (integral bridges) is different from the use of large diameter steel pipe piles for bridge foundations since the superstructure is directly connected to the piles thus eliminating footings, sheet piles and other typical structures in traditional construction (Fig. 7).

Another basic component is the drilled micropile system, as demand for resource efficient construction methods are key drivers for technology development either by technology push or market pull (end-user and society) or a combination where they meet, it has been recognized by foundation contractors that one simple way to do it is using higher steel grades and replacing steel core piles with drilled steel pipe piles [6]. In Swedish construction projects today the foundation contractor easily can half the consumption of steel and still maintain the same capacity, typically 2 MN for a steel pipe pile RD220 × 12.5. If ground conditions (surrounding soil) allow for higher steel grade, S550, the potential is even 10%-15% more in savings. Other benefits with steel pipe pile systems (RD-piles) are that work site conditions improve as they have treaded splices, which means also no welding at site thus improving quality (Fig. 8).

Given all above, the basic components of efficient steel bridge and foundation construction in Nordic countries are still potential for improvement that can and will be capitalized already in the next project with significant time and cost savings, also reducing traffic disturbance, and this will be exemplified by the case of Rotebro bridges. Currently under construction, it
Fig. 7 By connecting the bridge superstructure directly to the steel pipe pile foundation, both construction time and (geotechnical) project risk is reduced and investment cost is significantly lowered—a basic element construction method: (a) driven; (b) drilled into the bedrock.

Fig. 8 The most commonly used steel pipe pile in Sweden RD220 × 12.5 (to the right) for infrastructure projects has replaced the steel core pile, to large extent, and thus reducing steel content by 50% while keeping the same capacity and also improving work environment and construction speed.

a robust system solution, with quite simple components, that can serve as the first example of many to come for a new era in resource efficient construction in three dimensions—constructional excellence.

5. Constructional Excellence—Rotebro Bridges

On highway E4, north of Stockholm, two existing concrete bridges (Figs. 9 and 10) will be replaced during three years of construction by a new steel composite bridge, 325 m long, based on two sections of I-girder superstructures with foundation of RD-pile system, RD220 × 12.5.

The foundation is mainly RD-piles (in total 20,000 m), replacing earlier proposed steel core piles and thereby saving 1 million € alone.

This solution was a winning alternative proposal by main contractor and steel bridge supplier, and the three key factors that were evaluated by transport administration were price, traffic flow during construction and options to shorten construction time (Fig. 11). Compared to, by clients own design, proposed solution and budget, this proposal had 11
Fig. 9  Highway E4 with heavy traffic passing over several railway tracks and connecting roads.

Fig. 10  Built in 1962 the current bridges in concrete have run out of service life due to very heavy traffic, 70,000 vehicles/day, under the bridges run two railway tracks with train speed of 200 km/h, one of which is the main connection to the airport Arlanda, so the site is more demanding.

Fig. 11  The six span, 325 m long steel bridge with composite concrete deck, Girders are hybrid, once again, with different steel grades in webs and flanges, foundation based on RD-piles with threaded sleeves, a system solution and common practice today in Sweden.
million € lower investment cost, shortened construction time by three months and enabled six lanes of traffic during construction instead of only five (17% better traffic flow) [7].

5.1 Basic Components—Intelligent System Steel Solution

Based on RD-piles, two I-girder steel bridge sections and a concrete composite deck the solution look quite simple, and so it is, when finally installed on its support.

5.2 The Installation Stages—The Essence of the Project

What makes this a good example of constructional excellence is the installation, and its sequence of different stages where both new and existing bridges are used to keep traffic running, and also the last stage, a side-launch of one whole half of the bridge with concrete deck is 325 m long (Figs. 12-14).

Fig. 12 First stage: (a) the new western bridge is built; (b) traffic on one existing bridge; (c) new eastern bridge.

Fig. 13 Second stage: (a) the new western bridge is built; (b) traffic on one existing bridge; (c) new eastern bridge.

Fig. 14 Final stage, after last part of old bridge is demolished, the new eastern bridge is side-launched during traffic break from its temporary supports to its permanent supports, in one 325 m long piece including the concrete deck to complete the project and let the traffic run for another 120 years, the expected technical service life of new bridges will be designed and constructed in Sweden.
6. Conclusions

The main conclusions are:

(1) There is a significant potential for improvement to be capitalized already in coming projects by implementing current best Nordic practices for steel bridges and steel pipe foundations in new combined solutions. Examples from Sweden show 40% reduction in costs for smaller bridges on steel pipe foundation;

(2) A systematic approach for design management supports this even further, and eliminates quality errors due to poor communication and/or misunderstandings regarding common project goals;

(3) Knowledge acquired in practice which can not be described explicitly [8] is underestimated in the construction industry as a base for successful projects or at least to understand why things did not proceed as expected in other scenarios than the planned or intended. There is a link missing here between state of the art research compared to applied (project) knowledge in the construction industry today;

(4) Construction industry as a whole can increase the use steel bridges and steel foundation solutions to support resource efficiency in at least three dimensions—costs, time and less traffic disturbance, which fits well with society’s overall increasing demands and expectations.

References