Efficient reconstruction of bridges with small and medium spans

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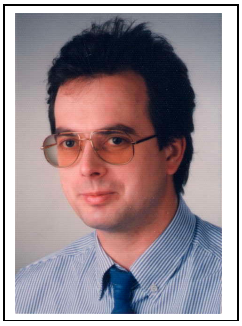

Summary

The traffic density is growing during the last decades. As a consequence numerous new roads and railway lines were built or are planned to be realized in the near future. On the other hand existing bridges must carry the increased traffic. Most of these bridges were not originally designed for the high service loads and the amount of traffic of today. Many of the structures are aged and, depending on the maintenance and repair carried out, do not longer suit the purpose. Further the demand for increased capacity requires often a deck widening for the carried traffic, or a longer span for traffic underneath. Most situations mentioned finally need the reconstruction of the bridge or replacement of the deck. According to statistics short span bridges are the most frequent category.

This paper discusses the potential for composite bridges with short and medium spans for the reconstruction of old bridges, considering the specific requirements resulting from the existing environment and by severe constraints for site work. Via case studies structural systems with hot-rolled beams and appropriate construction methods matching special site restrictions are analysed. In this regard the variety of structural systems and dimensional flexibility is shown, particularly if available construction depth is restricted. The paper is also focused on decreasing the traffic disturbances by using prefabrication and an appropriate erection method.

Keywords: Bridges, Steel, Composite, Reconstruction, Sustainability

1. Introduction

1.1 Road bridges

Road bridges are the most important carrier for the transport of people and goods. In the consequence of the stepwise enlargement of the EU also the infrastructure has to be adapted. These adjustments do not only affect the new members of the European Union, also countries, e.g. Germany becoming a transit country, are facing new demands in the frame of the new European configuration. Until 2015 the long-distance goods traffic on German motorways will increase about 60%, the passenger transportation at least 20% [1].

As a consequence numerous new roads have been built or are planned to be realised in the near future. On the other hand existing bridges must carry the amplified traffic. The realization of the development and upgrading of the existing infrastructure is, in respect to the required financial resources, a difficult task. Political priorities have been set with the consequence, that the demand of maintenance has been increased to avoid any further decay leading to restrictions of the traffic.

In the mean time the significance of maintenance has been recognized with the consequence, that it is rated higher than building new respectively develop existing infrastructure. This results in a decrease of building new constructions; e.g. in Germany 900 bridges have been built in the year 2000 whereas only 600 have been built in 2006 [1].

Most of the existing bridges were not originally designed for the high service loads and the amount of traffic, which are applicable today. Many of the structures are aged and, depending on maintenance and repair carried out, do no longer suit the purpose. Especially the structures of the

60ies, 70ies and 80ies are demanding the investment of maintenance due to missing experience on one hand, on the other due to changing demands resulting from the introduction of new types of vehicles respectively higher axial loads [1]. The increased capacity requires often a deck widening for the carried traffic, or a longer span for the traffic to be bridged. These situations finally require the reconstruction of the bridge or replacement of the deck. According to statistics short span bridges are the most frequent category.

1.2 Railway bridges

Over 220.000 railway bridges from 17 European railway administrations have been analysed in [2]. 21% of the stocks are metallic bridges, 41% masonry arch bridges, 18% reinforces concrete bridges, 5% pre-stressed or post-tensioned concrete bridges and 14% composite bridges, subdivided in filler beam bridges and composite bridges with open sections. In Germany the share of the latter is insignificant with 1.2% of the stock [3]. It is assumed that their share in other European countries is comparable. Further 31% of the bridges in stock are between 50 and 100 years old, 35% are even older than 100 years. 62% of the overall bridges have a span less 10m, 34% between 10m and 40m.

The current development shows, that new railway bridges are generally reinforced concrete bridges. Despite their long tradition steel bridges have hardly been built in Germany in the recent years; the share of filler beam bridges for new construction is even less than in the existing stock ignoring their experienced sustainability.

According to the German administration the share of the reconstruction of railway bridges will be larger than of building new bridges until the year 2015 [3]. This is partly due to the changing demands on the clearance, the allowable loading and, mainly, the age distribution of the existing structures. For many aged bridges a refurbishment is not economic respectively realisable any more.

1.3 Refurbishment

For the refurbishment of bridges intelligent solutions are requested. On one hand the interest of the public economy has to be satisfied; on the other hand the technical, economic and political boundaries have to be respected [4]. In this regard steel respectively composite constructions are providing an economical potential with the possibility to use cost-effective construction techniques and advanced construction procedures. With the choice of the appropriate steel grade the conditions for timely economic refurbishment is provided [5] [6]. Further the principles of a sustainable development are respected as steel is a building material which is to 100% recyclable [5].

Due to the hard competition of the 80ies the steel industry has developed new production techniques. In consequence the resulting steel qualities are satisfying the requirements of today. Steels according to EN 10025 have yield strengths of 355 N/mm^2. Further weldable, fine grain, high strength steels are commonly used in construction nowadays. With the continuous development according to EN 10025-4 the thermo mechanical steels (grade M) are produced with a sophisticated heat input control during the rolling process. They gain high yield strengths with hardly the composition of fine grain creators and therefore have specific advantages during fabrication [5].

1.4 Efficiency in costs and maintenance

The final decision for a construction technique often purely depends on the construction costs. Although factors like user costs, costs for maintenance and repair as well as the possibility for strengthening should not be neglected. In the following these costs are defined and discussed in reference to composite bridges.

Construction costs are minimised as composite constructions combine the positive characteristics of the building materials concrete and steel - these materials are in optimal use. Due to the composite action a significant increase in load carrying capacity and stiffness is achieved. Considerable savings in dead load and construction depth, especially when using high strength materials, are possible. The typically high degree of prefabrication guaranties a high quality of the construction, corrosion resistance and results in short construction times with little traffic interference.

The user costs are the public damage due to loss in time, route diversions and changed accidental volume for roads and the costs for operation interference for railways. They are hardly considered although they can multiply the construction costs to a greater extend if the economical loss due to traffic interference by e.g. traffic jams are taken into account.

The current costs for inspection and maintenance, occurring during the service life of a construction, are independent from the construction type and instrumentation of the bridge. Composite bridges with open sections are easy to inspect. In addition the possibility of strengthening for higher service loads is given by e.g. welding a plate under the lower flanges considering the fatigue resistance.

In Table 1 three construction types are compared in respect to the factors specified above. The economic competitiveness of composite bridges is becoming obvious if user costs are consulted. The high degree of prefabrication is resulting in saving of construction time respectively the traffic interference is minimized; reduced costs and public savings are achieved.

Table 1 *Comparison of construction types in resp. to requirements*

	Pre-stressed concrete	**Reinforced concrete**	**Composite Construction**
Construction costs	+	+ +	+
Construction time	O	-	+ +
Slenderness	+	-	+
Maintenance (p.a.) [9]	1.1 %	0.8 %	1.1 %
Robustness	-	+ +	+
Inspection	- -	-	+
Strengthening	- -	- -	+ +

+ + very good + good O acceptable - fair - - poor

For reconstruction this applies for the traffic to be bridged as well as for the traffic to be carried over. Higher construction costs are easily compensated.

Furthermore, with the use of composite construction providing large spans, the possibility should be checked to abdicate the intermediate support for small and medium span bridges over motorways. The construction is much easier as the setup of the construction site in the middle of the road leading to complex traffic guidance is avoided. In addition the effect on the traffic is generally kept small as the members are prefabricated to a high degree and can be placed e.g. at night during quiet traffic times respectively during short traffic cuts with a minimum of interference [3] [7]. The investment in a intermediate support is saved during construction (up to 25% of the overall building costs [3]). Costs for inspection and maintenance during service life are not present. In addition the potential higher costs for the superstructure are easily compensated by savings for the substructures.

Overall the short construction time and an easy erection are leading to a sustainable construction. Inspecting composite bridges is simple with a large reliability [3]. Tenders including the life cycle costs proof the competitiveness of composite construction for bridges with small and medium spans.

2. Reconstruction

2.1 General requirements

The requirements for the reconstruction of a bridge are quite different from those of building an entirely new construction. The bridge must geometrically fit the existing traffic ways. If the foundations are reused, loading limitations have to be dealt with. Especially construction has to take place with space and time restrictions. An appropriate erection method must be chosen in order to minimize disturbance to existing traffic. Therefore careful analysis of the situation and expert design are needed for successful realization of the projects.

Steel construction offers many advantages through its flexibility, lightness and cost effectiveness. Consequently replacement decks are most frequently made of steel and, for short and medium spans, are based on steel-concrete composite structural systems. Primary bearing elements are hot rolled beams which are industrially produced; available in a full range of sizes and steel grades, including the upper mentioned high strength grades. Consequently the use of steel and composite construction complies with the requirements for refurbishment as follows [7], [8]:

- Industrial produced members with just-in-time-transport to the site;
- Corresponding smaller construction sites and construction site equipment;
- Short and hardly weather depending construction time;
- Quality control already in the shop;
- Fast erection due to standard connections;
- Minimal noise and dust disturbance in the area of the construction site;
- Optimal realization of the principles of sustainable development.

2.2 Case studies: Road Bridges

If sufficient construction space is available, the new bridge may be built at a site located near the old bridge. This option greatly simplifies construction, and traffic on the old bridge may be maintained until the completion of the new bridge. This does not mean that all constraints are eliminated. Construction over traffic flow asks for purpose-designed solutions. Available construction depth imposed by infrastructure is often problematic.

If the span is short, prefabrication may include the entire deck or half of it, however the element weight must not exceed the capacity of currently available transport and lifting devices.

A good example for a very efficient construction of a composite bridge is the Horlofftal Bridge. This bridge has 8 spans with an overall length of 236.2m; the singles spans vary between 23.7m up to 35.9m. 5 spans have been built with rolled beams HE 1000 B with the steel grade S460M. The cross section is consisting of 4 beams with prefabricated slab elements.

This large spanning bridge is crossing two German railway tracks, a former mining area and the river Horloff. Due to a strict environmental classification and to avoid any influence on protected areas scaffolding was not allowed. The most economic solution was the composite construction using prefabricated elements. The scaffolding for concreting the caps and the devices for the safety at work have also been prefabricated and fixed to edge beams before placing. Consequently the clearance has not been interfered at all. The placing of the prefabricated composite beams is shown in Fig. 1, the almost finished bridge in Fig. 2.

Fig. 1 *Horlofftal Bridge: Placing of the prefabricated composite beams*

Fig. 2 *Horlofftal Bridge: Almost finished bridge*

The most critical construction step was the erection of the beams over the railway tracks, as railway traffic could only be interrupted during a few hours at night.

In general two options are available: erection by crane and splicing by welding to be carried out at sections located within span (where bending moment is low), or assembling of steel structure prior to launching into final position. Nowadays, e.g. for the Horlofftal bridge described above, a more efficient and less cost-intensive method is applied: for each of the two spans, the pre-assembled girders are erected with a crane as simply supported beams. Structural continuity over intermediate support is achieved by moment connection to a concrete cross girder. Hence splicing consists just in concreting of the cross girder and the deck slab (see Fig. 3) [8].

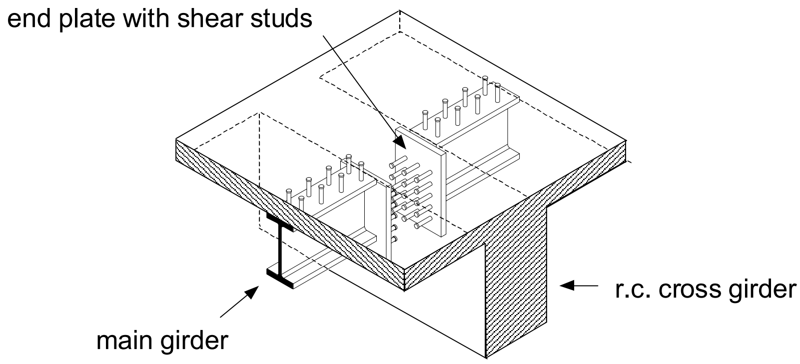

Fig. 3 *Sketch of moment connection at intermediate support*

If the new bridge is built at the same site as the old bridge, reduced construction time is essential in order to minimize traffic disturbance. As mentioned above steel and composite construction meets the requirements through lightness, prefabrication and fast erection methods.

Fabrication, including the corrosion protection of steel elements, is carried out at the workshop. Rolled beams are produced with a maximum length of 32m; exceptionally up to 40m. Consequently very long pieces can be delivered to site (if access allows for) and the number of splices, if any, is kept to a minimum. Pre-assembling prior to erection speeds up lifting into final position. Added bracing gives lateral stability to the elements during handling and construction. Low weight of steel elements allows mostly erection by crane, which is a fast and cost-efficient method [10].

For composite decks, precast concrete planks are most frequently used as formwork. As an alternative to site-concreting, precast deck units may be used. By this method consists in the reduction of the number of site operations is reduced and substantial saving in construction time is achieved.

The mentioned advantages in construction and costs of composite bridges using prefabricated slabs have pushed their acceptance on the last years. Especially the short construction time is of great significance for inner-city projects.

Frequently there is mainly a need for deck replacement, whereas work on foundations, abutments and piers is limited to repair, strengthening or minor adjustments. Self-weight of the deck structure is then an essential parameter, as actual overall load capacity cannot be exceeded. It is particularly crucial if the new bridge should carry heavier traffic loads than those of the original design. Composite decks with steel girders supporting a reinforced concrete slab meet this requirement. The developed high strength steel grades for rolled beams (yield strength 460 N/mm^2) offer an additional possibility to reduce steel weight.

In the small city of Buchfart, about 5km in the south of the Schloß Belvedere in Weimar, a wooden bridge of the 18th century is located (see Fig. 4). The origin of this crossing, called Ilmbrücke, goes back into the 16th century. This roofed bridge is representing a landmark in the national heritage.

In the frame of the refurbishment of the wooden roof the deck has been adopted to the traffic demands of today. Sustaining the old abutments could be economically realised on the basis of hot-rolled sections.

Fig. 4 *Landmarked wooden bridge in Buchfart, Germany, after deck replacement*

2.3 Case studies: Railway Bridges

In urban areas the replacement of existing railway bridges has got the following motivation linked to the listed requirements:

Motivation	Requirements:
- Replacement due to danger of impact for cast-iron supports,	- Retaining of the elevation of the rails,
- Increased clearance,	- Noise reduced construction,
- Increased carrying capacity,	- Short interruption of the traffic on and under the bridge,
- Corrosion of the superstructure,	- Minimized overlap of superstructure over the abutments (horizontal movement of superstructure reduced).
- Elimination of railway level crossings.	

Compared to road bridges, reconstruction of railway bridges generally is subject to even more severe constraints. Complete traffic disruption is acceptable only for a short time. With multiple track lines, traffic may be diverted, but with the result of substantial speed and volume reductions. Hence the reconstruction method of short span railway bridges consists typically in first constructing the new deck next to the site, dismantling the old deck and moving the new one in its final location. The work is organized in several steps, each corresponding to a single-track deck portion.

To bring the new deck into position, a mobile gantry crane moving on the rails may be used, if the dimensions and weight are within the capacity of the special equipment. The deck replacement of the double track bridge crossing a canal in Roux, France, is an example of this method. The new deck has a span length of 15.7m and is of composite type, with 8 main girders (HE 900 M rolled sections) supporting a reinforced concrete deck. It was completely prefabricated (steel structure and concrete slab) in two pieces, one for each track, and brought to site with a mobile lifting device (SNCF-type with a capacity of 100t [mobile] and 170t [static]). After positioning over the old structure, the old deck was dismantled and the new one lowered into final position (Fig. 5). The work was carried out at night and took only a few hours for each half-deck.

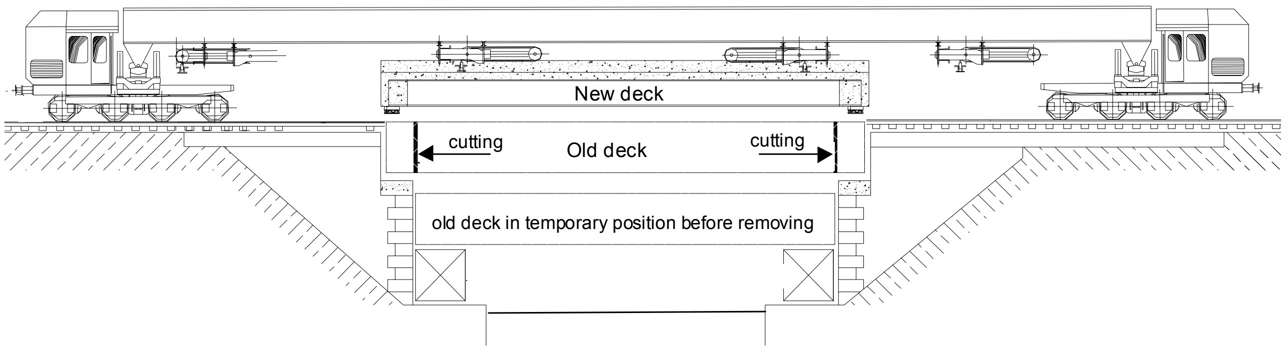

Fig. 5 *Deck replacement by a mobile gantry crane*

Most frequently with old decks, rails are directly fastened to the steel structure. Nowadays continuity of ballasted track over bridge sections is generally preferred. Consequently the construction depth of the new deck is reduced, requiring a more slender design. Filler beam construction solves the problem with a slenderness ratio of 30 to 40 [11]. The new deck is constructed on temporary supports, parallel to the bridge. The old deck is dismantled. If needed, the foundations and abutments are strengthened or reconstructed (during these stages temporary track support may be required to minimize traffic disruption). The new deck is moved into position by lateral rolling- or sliding-in. A schematic view of this erection method is shown in Fig. 6.

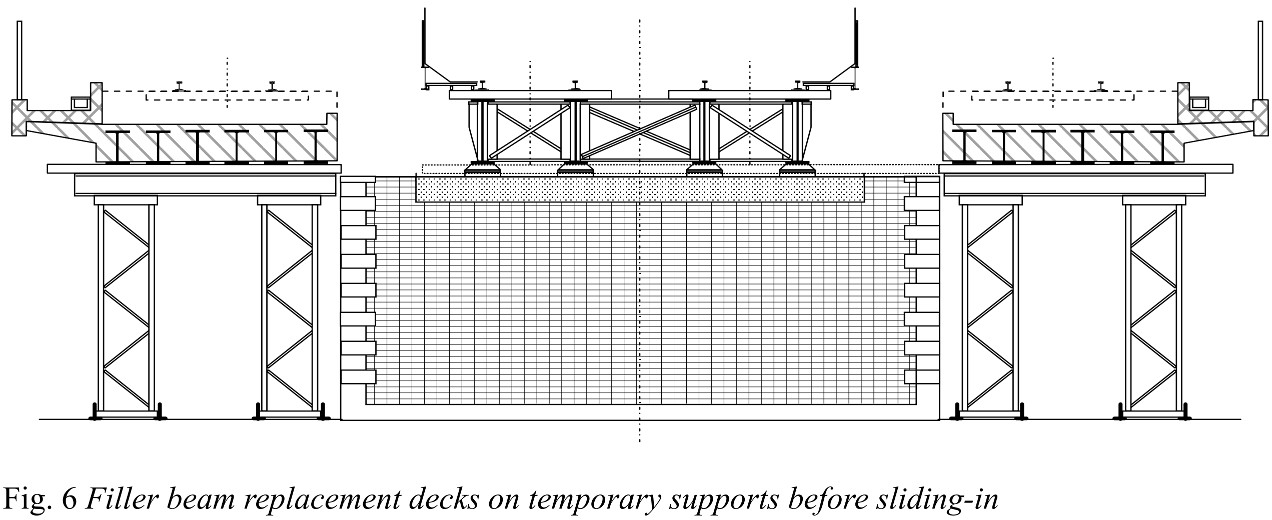

Fig. 6 *Filler beam replacement decks on temporary supports before sliding-in*

If available depth for the construction of the deck below the track is particularly low, trough bridges are appropriate. Each single track is supported by a floor slab of minimum depth spanning between the main girders at lower flange level, transversely to the bridge longitudinal axis. The floor slab is of filler beam type with steel beams acting as multiple cross girders. For lateral stability of the main girders, some of the filler beams are moment-connected to form rigid U-frames.

Fig. 7 shows the section of a trough bridge in Differdange, Luxembourg. Main girders are 1m deep rolled sections with a span length of 13m. Construction depth under the track corresponds to the 34cm thick filler beam slab. Two separate units were needed for the replacement of the old double track deck. Assembling of the steel elements and concreting of the floor were carried out on site, close to the existing bridge. A mobile crane was used to remove the old deck and to lift the new structures into final position.

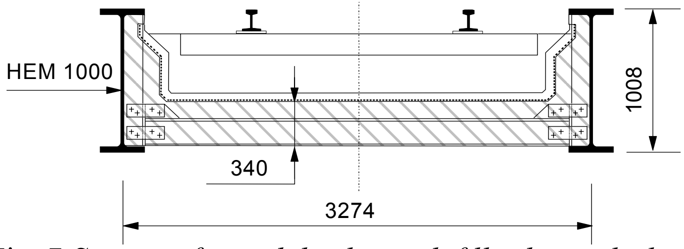

Fig. 7 *Section of trough bridge with filler beam deck*

An other example is the bridge EÜ Bahrenfelder Kirchenweg in Hamburg, Germany (see Fig. 8, 9) with a span of 15m. The old superstructure divided in a north and south part, with a single track on each, was not satisfying the demands of the present traffic anymore. In the consequence of the restricting situation for refurbishment there has been an extremely limited construction height. Finally a trough bridge with two rolled beams HL1100 M as longitudinal main beams and a filler beam deck in transverse direction based on HE 140 M has been constructed. As steel grade S355M has been chosen.


Fig. 8 *EÜ Bahrenfelder Kirchenweg, lower view*


Fig. 9 *EÜ Bahrenfelder Kirchenweg, longitudinal view*

Furthermore bridges with integral abutment (frames) should be considered as an option for the construction of railway bridges.

In the following advantages of bridges with integral abutments are listed [12]:

- No maintenance and repair for joints;
- Larger spans resp. low construction heights;
- Less construction costs;
- Short construction time;
- Small angular rotation at the end of the deck;
- Beneficial behaviour against resonance effects;
- Transition to backfill rectangular if possible;
- Robust and fatigue resistant construction.

More information on bridges with integral abutments can be found e.g. in [12] and [13].

3. Conclusions

Reconstruction of bridges is characterized by specific requirements resulting from the existing environment and by severe constraints for site work. Composite decks with steel beams made of hot rolled sections meet these requirements through the variety of structural systems and dimensional flexibility, particularly if available construction depth is restricted. By using prefabrication and an appropriate erection method, traffic disturbances are kept to a minimum.

The use of hot-rolled sections for steel and composite bridges with small and medium spans is an economical solution. Their advantages are [7]:

- Rolled beams are an industrial product with high quality and good availability;
- Economic due to minimal fabrication costs;
- Large delivery length avoiding field jointing;
- Production in the mill and consequently delivery of end product to site ready for placing.

A number of case histories have confirmed that a good overall efficiency is achieved by using rolled beams in steel and composite construction, both for road and railway bridges.

For the final choice of a construction technique safety, robustness, sustainability and competitiveness should be the main governing factors.

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