New trends in composite steel-concrete bridges

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Summary

Steel has gradually made a comeback in the deck structure of medium and long span bridges in France in the last twenty-five years. This trend started in the road bridges first and has now reached the maximum share in the new high-speed railway lines. Along with economical structures like the twin girder decks, steel has kept on being used in innovative and technically challenging design, especially in composite action with concrete. This paper shows the new trends in steel-composite bridge design taking place now in France and some other countries.

Keywords: Steel, composite, aesthetics, high-speed railways, twin girder, tied arch, double box section, construction, launching.

1. Introduction

The comeback of steel in bridges witnessed in France since the 1980's was initially due mainly to one type of deck structure: the twin girder steel concrete composite deck.

This trend started in the road bridges. Before that in the 1970's the development of prestressed concrete bridges in France had totally excluded steel from the bridge market.

About ten years later, the same phenomenon was observed in the rail bridges for the high-speed lines. The first two lines in the 1990's had only pre-stressed concrete viaducts, but the share of steel has gradually been increasing since that time.

The comeback started with the twin girder composite decks and gradually gave birth to other types of structures. The new trends with steel can now be observed in all span ranges

The reconquest period with these economical bridges has been followed with new structural forms that show to what extent steel bridges have possibilities of redevelopment when the steel structure acts in composite action with concrete. Such bridges designed nowadays also integrate sustainable construction demands.

The optimum use of the two materials: steel and concrete keeps on being explored nowadays for some new economical designs, which are presented this paper.

2. Twin girder bridge evolution

The traditional twin girder deck with two plate girders topped by a concrete deck and separated by crossbeams remains the most competitive structure in France in the medium span range between 30 and 80 meters. This structure looks very simple but in fact, it integrates advanced research in design concepts, structural analysis, steel and concrete material behavior.

Many variations have appeared to adapt this form to functional and architectural demands:

- variable depth more aesthetic without a higher cost noticeable on the total price,
- truss girders with particular fabrication,
- use of hollow sections,
- wide decks for two ways motorway,
- span length above 100 meters.

The assembling of structural prefabricated elements transported from the factory and the mounting with traditional or innovative launching techniques have brought a reduction in delay and cost. These structures with their uncomplicated design can be inspected and maintained easily.
New designs include a lower slab, which either participates only in torsional resistance as in the HSR bridges of the TGV Méditerranée line (Fig. 1) or also in longitudinal composite action as many Spanish bridges (Fig. 2)

Fig. 1 : Lower torsional non composite concrete slab – Bonpas viaduct TGV Méditerranée

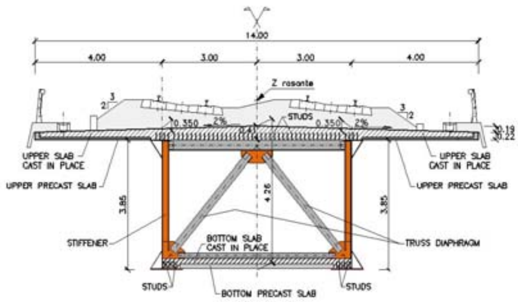

Fig 2 : Double composite deck – Las Piedr bridge - Spain.(Courtesy IDEAM)

3. Short span girder bridges

A newly developed method to achieve continuity of multi-span composite bridge girders within the 20-40 m span range consists in moment-connecting the beams to a concrete cross girder located at intermediate supports. For each of the spans, beams are erected as simply supported girders. Moment transmission is provided by concreting of the cross girder. By this procedure loads due to dead weight of steel beams, formwork and wet concrete are carried by simply supported girders, whereas loads applied after concrete has hardened, i.e. superimposed permanent loads and service loads, act on continuous girders. Compared to traditional continuous structures, overall hogging moment is reduced, whereas sagging moment within span is increased, resulting in a more equilibrated situation. This innovative splicing method greatly simplifies erection and simultaneously eliminates site bolting or welding operations. (Fig. 3-4)

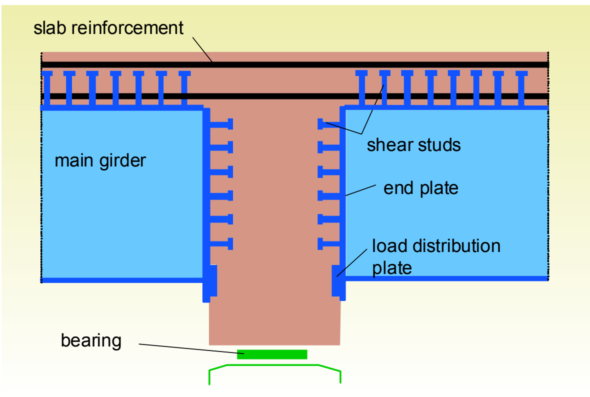

Fig. 3: Concrete cross beam on supports

Fig. 4: Wilson Bridge in Villeneuve Saint-Georges (France)

4. Concrete deck

Concerning the concrete slab connected to the upper flanges of the steel girders, the cracking during construction and service is mastered now with appropriate concreting sequence and sufficient reinforcement. However the use of pre-fabricated slab is becoming more frequent as it leads to shorter construction delay.

Whole thickness prefabricated slabs with dry joints have been tested in Sweden and provides important decrease in construction time.

New high strength concrete can also bring further economy to the total cost.

For the concrete deck, some economical construction methods can also be used:

- special prefabricated concrete formwork,
- new types of steel plate concrete composite slabs, (Fig. 5)
- different kinds of connectors.

However, an economical composite solution, in term of global cost could be the use of closely spaced rolled profiles without intermediate cross beams and a high strength concrete slab above 60 Mpa (Fig 6).

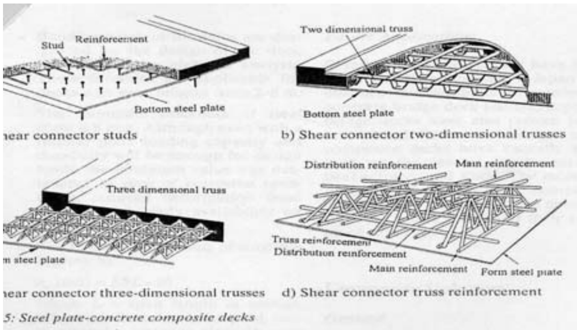

Fig. 5: Steel plate concrete composite decks

Fig.6 : Leyse Bridge –Chambéry France- Composite deck without intermediate cross beams

5. Composite box section decks

Nowadays more and more motorway bridges are built with a single wide deck reaching sometimes thirty meters. With a box section about 7 meters wide with tubular diagonals to support the cantilever sides, narrow piers can be built while at the same time reducing the construction delay. This is especially interesting for very tall piers like at Verrières viaduct, or river piers at the viaduct over the Rhône at Valence. The maximum spans are respectively 144 m. and 125 m. The tubular brackets can enhance the bridge aesthetics when inclined both longitudinally and transversely; but with a slightly higher fabrication cost. (Fig 7)

A narrower box section requires plate girder cantilevers, with perhaps more difficult maintenance. (Fig. 8)

Fig. 7 : Verrières viaduct : Composite box section with inclined tubular brackets – 144 m amx span on 140 m high pier

Fig. 8 : Bridge in Italy - Narrow box section with plate girder brackets

6. Arch bridges

It was with the TGV Méditerranée that arch bridges have made a spectacular come back. Having succeeded to reconcile the service constraints of high-speed railways with an architecture that blends in the ecologically sensitive landscape, the SNCF has brought back the modern form of the large truss arch bridges, which are still in service since over 125 years.

Tied-arch bridges or bowstrings are more frequently built now in the road infrastructure with a diversity of structural forms given by the combination of different structural elements:

- two or more arches parallel or inclined inside,
- a single arch centered or on one side inclined on the outside,
- a single arch spanning the deck diagonally,
- absence or presence of upper bracing between the arches designed as a truss beam, diagonals,
- the hangers with cables or bars that are parallel, radial, or diagonal network.
- the main structure of the deck: composite concrete slab connected to transverse cross girders
- the transverse section of the deck: composite cross beams.

The arch form has a more environmentally friendly image, in spite of the higher construction cost. A comeback of these structures in the medium span range with a composite deck can also be seen nowadays. The composite deck also acts as the tie beam and it contributes to the overall stiffness; at the same time it shares the bending moment with the arch ribs.

But more impressive structures have also been designed by using further composite action: concrete inside the box section arch helps to withstand compression and bending like in the diagonal arch of Hulme bridge, concrete supports in continuity of the steel arches for heavy live loads like the two level 420 m span of Caiyunba bridge in China (Fig.9, 10)

Fig.9: Hulme bridge, Manchester, UK.-50 m diagonal arch- 25 m high – bow section filled with concrete to withstand compression and bending(Phot Chris Wilkinson Architects)

Fig. 10: Long span tied arch bridges : Caiyuanba bridge-China.420 m span,30 m wide; 6 road lanes and 2 walkways on upper deck, 2 monorail tracks on lower deck (PhotoTy Lin International)

7. Cable-stayed and suspension bridges

The lightweight nature of the steel material combined to a high resistance is particularly advantageous in large spans where the permanent loads are crucial. These spectacular bridges for large crossings have a proportion of structural steel, which rises with the span length. For spans of up to 600 meters, twin girder composite decks are still competitive.

There are however smaller crossings where steel-concrete composite structures are the logical solution. A composite or a all steel deck combined with a steel pylon brings a more economical solution if the price includes in the material and fabrication costs the guarantee of delay and precision as well as future maintenance.

8. Other composite structures

Other types of composite decks which are being built nowadays include:

- Lateral plate girders for the high-speed railway TGV EST line for skew crossings and low clearance over the A4 motorway, with spans reaching about 50 meters. The deck is very often a rolled profile concrete encased slab working preferentially in the transverse direction.
- Twin box girder composite deck for the high-speed railway line also. The box girders have thick webs with few stiffeners, and they are dimensioned with dynamic and fatigues criteria.
- Composite box with concrete flanges and steel webs – either special plate or tubular truss.

This list must also include some other composite structural elements, for example concrete filled tubular piers or composite pylon heads.

9. Modern steel for bridges

The advantages of steel in bridges can be outlined by:

- high strength to weight ratio,
- quality and reliability,
- versatility and aesthetics,
- durability,
- easy and quick modification, deconstruction or repair.

Steel for construction benefits from the continuous R&D aimed at meeting the growing demands on the material for industrial or mechanical issues. The steel producers nowadays provide a large choice of grades and qualities for bridges.
Thermo-mechanical grades facilitates the site welding of thick plates, longitudinally profiled plates bring a decrease in weight and fabrication cost.

Universal beams and hollow sections are available within a wide choice. Stainless and weathering steels offer an interesting alternative to paintings [3].

10. Conclusion

The examples of built bridges from many countries prove to what extent optimal design is based on the efficient use of the appropriate material in different structural parts. Steel and concrete, with their specific characteristics always bring important advantages in construction delay and durability.

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