PROJECT

Design and Construction of Segmental Bridges for High-Speed Rail

by Jacques Combault, Finley Engineering Group Inc.

The famous Japanese Shinkansen railway network started operating in 1964 and has been progressively improved with the objective of operating at a speed of 300 km/h (186 mph) or more. Since the Shinkansen's beginning, many countries have implemented high-speed rail (HSR) as an easy link between cities. The first section of the French TGV opened to traffic between Paris and Lyon in 1981. The operation of the 345-km-long (214-mile) Taiwanese HSR, which runs most of the time on viaducts at 300 km/h (186 mph), started in 2007. Today, HSR has become a reality in Asia, Europe, and North America, resulting in the construction of large infrastructures that are designed for dense and heavy rail traffic at speeds never before reached.

Since its creation in 1981, the French TGV developed throughout France. The South Europe–Atlantic (SEA) line is currently under construction between Tour and Bordeaux, with the anticipation of daily operation at 350 km/h (217 mph). As part of this system, many bridges had to be built according to various construction techniques and the latest refinements of the available technology in the field of prestressed concrete bridges.

Design of Railroad Bridges

The design of railroad bridges has many unique considerations when compared to the design of road bridges:

- The loads are sudden and heavy.
- The regular distribution of heavy concentrated loads running at various speeds may generate substantial dynamic effects, which cannot be ignored.
- Horizontal forces generated by the moving loads, due to track curvatures or swaying on the rails (nosing effect, also known as the coning action), as well as acceleration and breaking forces, cannot be neglected.
- The bridge design is unavoidably impacted by the rail-structure interaction when continuous welded rails (CWR) are used, which have be evaluated according to the International Union of Railways (UIC) code.

This last consideration is of fundamental concern during the design of HSR bridges. The track type, as well as the configuration and mechanical properties of the structure, govern the combined response of the structure and tracks to

- deflections and displacements of the superstructure under vertical and horizontal loads,
- differential deformations between rails and structure due to temperature and acceleration or breaking forces,
- variable horizontal forces generated along the rails, and
- stresses in the rails, which cannot impair the track strength and profile.

Available Concepts

Due to the main design considerations previously mentioned, Taiwanese HSR bridges generally consist of a box cross section about 13 m (43 ft) wide that provides space for two tracks and catenary supports. General design rules for railroad bridges significantly differ from those of road bridges. For example:

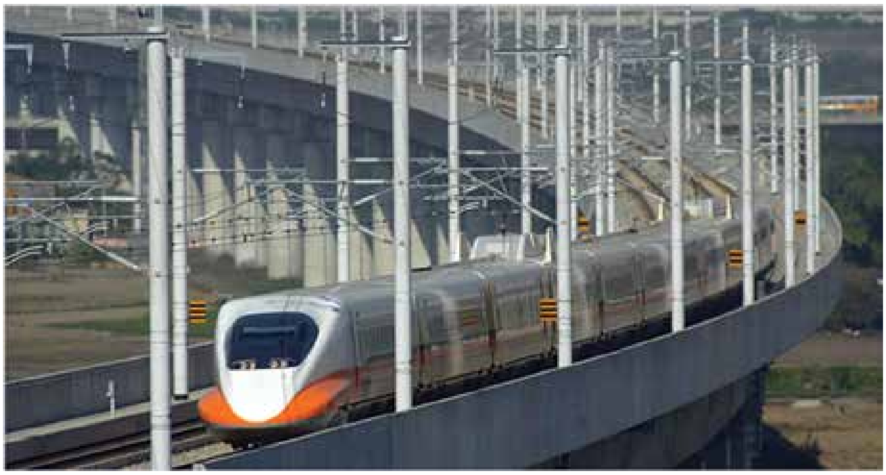
- Heavy loads and corresponding dynamic effects cause the bridge to be designed for a span length-to-depth ratio of 12 to 14.
- The rail-structure interaction favors the design of short spans. Long, continuous spans require rail expansion devices that impact the behavior of the train on the track.

This is why Taiwanese HSR viaducts, which are located on flat areas, mainly consist of sections made of simply supported box girders. This means that the Taiwanese HSR viaducts have

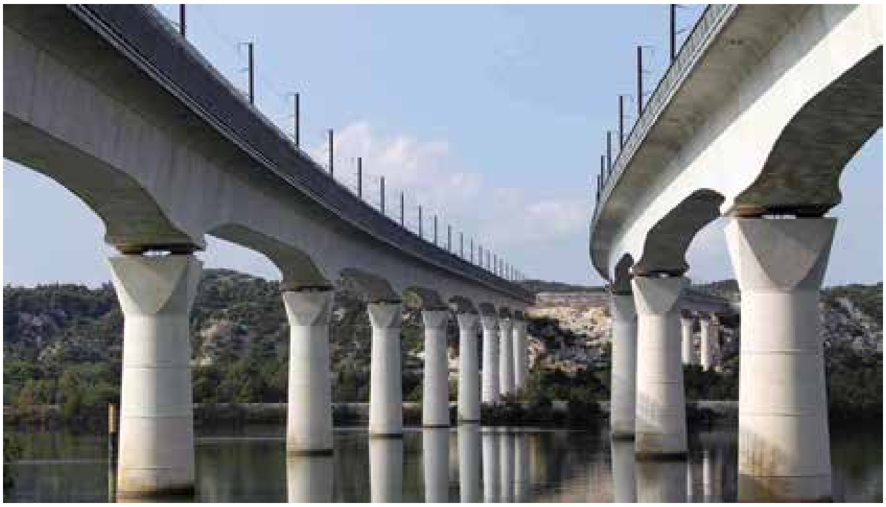
- short span lengths, and
- many piers and many bearing devices, but no rail expansion devices.

High-speed trains may also have to cross large and deep valleys. In such cases, pier spacing and span lengths have to be increased. This also requires that the superstructure be continuous and rail expansion devices are unavoidable.

For example, the HSR system near Avignon, France, required two unusual HSR bridges made of 100-m-long (328-



The Taiwanese high-speed railway running on a long series of viaducts. Photo: VINCI Construction Grands Project-France.



Twin 1000-m-long (3280-ft), high-speed railway, viaducts crossing the Rhone River near Avignon (France). Photo: VINCI Construction Grands Project-France.

On the left, the Channel Tunnel rail link viaduct crossing the the Medway River in the UK. Photo: VINCI Construction Grands Project-France.

Full-span construction technique showing placing a precast concrete box unit. Photo: SYSTRA.

ft) spans to cross the Rhone River. Similarly, the Medway River crossing in the U.K. necessitated a bridge having a 152-m-long (499-ft) span for the Channel Tunnel rail link (CTRL) between Paris and London.

Construction of Concrete Railroad Bridges

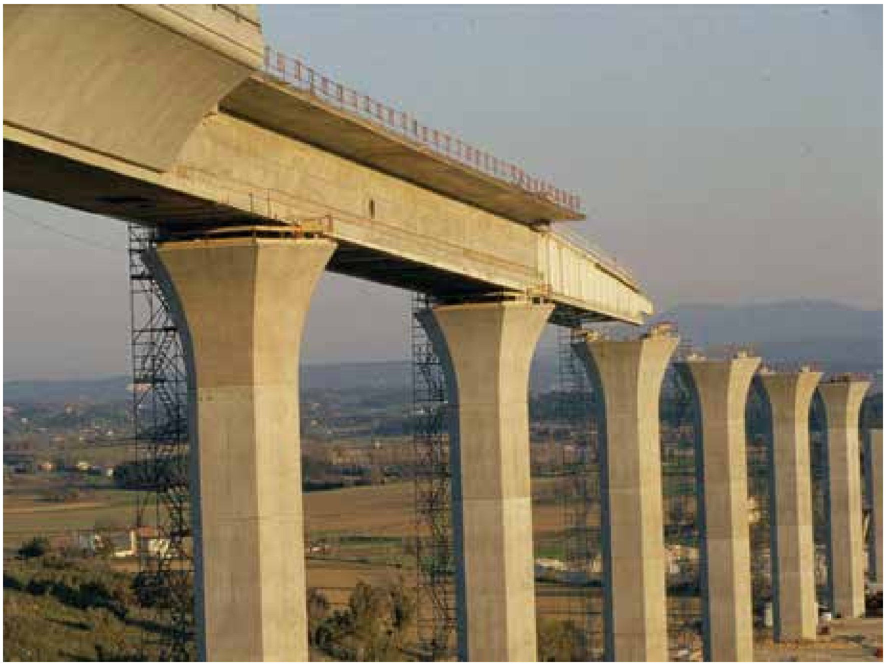
With easy access and good soil conditions, short-span railroad bridges can be readily built. Prefabrication of full-span-length units and placing those units using appropriate launching equipment is a construction method that is implemented frequently worldwide.

Taiwan's north-to-south HSR project link includes 251 km (156 miles) of elevated bridge structures. Full-span precast concrete components and launching erection techniques have been used on 73% of these elevated structures to achieve speedy placement, shortened construction periods, and better quality control.

Continuous HSR bridges undoubtedly offer interesting opportunities in terms of construction methods. At the end of the 1990s, seven HSR viaducts were built between Lyon and Marseille in Southern France. Classical construction methods were used for these viaducts; the most frequent method used was incremental launching.

Incremental launching is well adapted to the construction of constant-depth box girders for HSR as long as the span-to-depth ratios of these bridges are much lower than those of road bridges. The use of incremental launching for building HSR bridges started at the end of the 1970s when the first French HSR link was being constructed.

Incremental launching has been successfully implemented for many of the large HSR bridges that were built as part of the French TGV extension linking Paris to the north and to the southeast of France. Incremental launching was sometimes combined with cast-in-place balanced cantilever construction when span lengths were not compatible with incremental launching capabilities. Balanced cantilever and incremental launching were also combined when other exceptional construction techniques, such as rotation, had to be used to cross existing motorways with as little traffic disturbance as possible.



Approaches of the Mediterranean high-speed railway Ventabren Viaduct in southeast France during launching. Photo: VINCI Construction Grands Project-France.

Balanced cantilevers of the main bridge of the Ventabren Viaduct to be rotated across one of the most congested motorways in France. Photo: VINCI Construction Grands Project-France.

Precast Concrete Segmental Construction of Railroad Bridges

The most significant achievement in the construction process of large HSR bridges happened at the end of the 1990s with the construction of the 1500-m-long (4921-ft) viaducts crossing the Rhone River near Avignon. Consisting of 100-m-long (328-ft) spans, these viaducts are made of precast concrete segments that were assembled according to the balanced cantilever construction process. Segments were erected using a 225-m-long (738-ft) launching gantry with a capacity of 170 metric tons (187 U.S. tons) and external continuity post-tensioning tendons. Match-cast segments were designed and assembled according to the state-of-the-art in the field of precast concrete segmental construction, which meant that there was no sand blasting of the match-cast faces and no thick epoxy joints.

The good performance of the Avignon Viaducts lead to the use of precast concrete segmental technology for seven bridges of the extension of the French TGV towards the southwest part of France, which is presently under construction. All seven bridges are similar. Each is about 500 m (1640 ft) long and mainly consists of 47-m-long (154 ft) spans. The box girder for each bridge is 3.9 m (12.8 ft) deep.

The 1340 precast concrete segments that are necessary for the project are being produced in a plant located near Poitiers. The assembly of these segments is being done according to the segment-by-segment, progressive-placing method, a construction process developed and implemented for the first time by Campenon Bernard at the end of the 1970s.

Indeed, progressive segment-by-segment construction using temporary stay cables is a competitive alternative to incremental launching because

- it does not require heavy equipment,
- segment placing is easy and fast, and
- there are no creep effects because segments are assembled in their final configuration.

In addition, this method is well adapted to external prestressing and bridges built that way are typically of high quality.

Conclusion

For more than 40 years, the construction of large bridges has been marked by prefabrication of box-girders in match-cast sections and assembly of these segments using powerful equipment, either cranes or movable launching gantries, or temporary stay cables. Associated with modern, well-designed prestressing systems (combining both internal and external post-tensioning tendons), this technique has been continuously improved and is, nowadays, extremely successful thanks to the quality and reliability of the structures built that way.

Several millions of square meters of road bridges have been built all over the

Placing the first spans using the progressive construction technique with temporary cables on the South Europe-Atlantic Viaducts. Photo: VINCI Construction Grands Project-France.

world using precast concrete segments, with the increased demand for better performances in terms of erection speed and quality.

For more than 15 years, most of the elevated rail structures have been built using the span-by-span assembly method for the placing of precast concrete sections. Clearly, the seven bridges of the SEA HSR will require prefabrication and assembly of a huge number of segments. The progressive placement method is yet another way that HSR bridges can be built. Over the years, precast concrete segmental construction has proved to be applicable to any kind of railroad bridge.

Jacques Combault is technical director at Finley Engineering Group Inc. in Tallahassee, Fla.

For additional photographs or information on these or other projects, visit www.aspirebridge.org and open Current Issue.