Pretensioned prestressed concrete beam bridges and industrial supply

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Summary

Bridge decks built *from* by pretensioned precast *concrete* beams are widely used in road and *motorway* civil engineering. With a view to applying the technique to the construction of railway bridges, CERIB in partnership with SNCF and FIB have set up a test programme to make sure that the performance of this construction system is such that it can withstand the fatigue resulting from the load encountered on railway networks *for design working life (100 years).* The results show that this type of *structure* is capable of meeting the operational requirements. New railway bridges with this technology are built on new TGV rail line Paris-Strasbourg (East European High Speed Line)

Keywords: beam, precast, concrete, prestressing, fatigue test, railway bridges

1. Introduction

Pre-tensioned prestressed beams, which have been widely used in the building industry for many years; towards the end of the 1960s they were proposed and accepted as alternatives to conventional entirely cast-in-place solutions for bridges with moderate spans *(between 10 and 25 m). The French roads and motorways design agency (SETRA) stipulates, in the PR.AD 73 pilot specification for pretensioned prestressed beams, the range and conditions of use for the beams and recommends them for independent spans.*

The 1970s saw the emergence of precast pretensioned prestressed beams for economic reasons. This development was made possible by a number of factors: the performance of factory-produced concrete, the possibility of very significantly reducing construction times for bridges on and over trafficked roads, the elimination of falsework, the reduction in the disturbance caused by *building projects* the guaranteed high quality of factory precast products, and their competitive price. Manufacturers have adapted to increasingly draconian market requirements in terms of regulations, quality, and pricing. Deck bridges using beams erected without falsework and joined together by a cast-in-place concrete slab on non-structural permanent formwork have now become a conventional solution for spans of up to 35 or even 40 metres.

2. Recent developments

2.1. Mechanical continuity

Prestressed beams were initially intended only for independent spans, but their use has been extended to multi-span bridges, where the pier-head joint between them is spanned by a special section of reinforced-concrete deck slab (***apparent continuity*** through the deck slab); since the beams of two adjacent spans rest on two separate rows of bearings, the crosshead has to be at least one metre wide.

- Increasing knowledge of concrete and design methods has made it possible to build multi-span bridges with mechanical continuity between adjacent spans by integrating beams into a reinforced concrete crosshead on top of the piers.

Fig.1 One of the road bridge on the motorway A64 Muret St-Gaudens, France: general view

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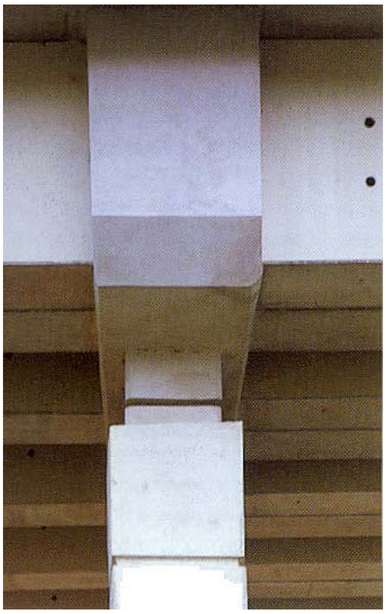

Fig.3 Intrados deck: beams and crosshead

➤ Fig.2 Pier: crosshead and beams

A large number of motorway bridges have been built using this technique (A10, A11, A71, A64 motorways, etc.).

In September 1996, a new SETRA design guide for road bridges with pretensioned prestressed beams presented the evolution of this technique.

*Then, in January, SETRA issued its "**PRAD - EL**" automatic software for designing decks of single-span and multi-span pretensioned prestressed deck bridges. This powerful software* caters to a broad range of applications, for both road and rail bridges, and will enable the future European standards to be taken into account

2.2. New type of railway bridges for the East European TGV Line

A "value analysis" type study carried out by SNCF (French Railway Administration) has shown that one solution for reducing the construction *times ?* and so the overall cost of a railway track is to build bridges with continuous decks based on precast pretensioned concrete beams.

The hyperstatic solution is preferred by SNCF, especially for high-speed trains (TGV), for several reasons:

- mechanical continuity appreciably improves the dynamic behaviour of the entire structure when high-speed trains go across it, which is an essential parameter for safety and passenger comfort,

- the monolithic nature of the deck helps reduce end rotations and mid-span deflection relative to the "series of independent spans" solution, thus limiting stresses in the rails which are already subject to substantial loading effects,
- the absence of inter-span joints limits disorders in the ballast which supports and reduces the maintenance cost,
- the stiffness of the deck means it can be made thinner, which means more refined architecture can be used to integrate bridges more smoothly into the landscape
- there is a single line of bearings atop the piers, which, relative to isostatic bridges, reduces the cost of maintenance and the corresponding constraints on traffic.

This study took place in several steps :

- sizing and design of a representative test specimen in accordance with SNCF design regulations ;
- precasting of pretensioned beams for all the tests in a precast plant and construction of appropriate test specimens on testing sites ;
- performance of a static loading test to failure on a first test specimen ;
- performance of a 50-million-cycle fatigue test on a second specimen, this corresponds to a lifetime of about 100 years, followed by a static test to failure.
- The large number of fatigue cycles made this test campaign a "first" in terms of behavioural studies of pretensioned structures.

2.2.1. Description of the tests

The test specimens consist of two 5.35 m long spans joined together end to end. Each of these spans consists of a pretensioned beam with a cast-in-place reinforced-concrete slab making a T-shaped cross-section. The reinforced-concrete continuity section consists of a crossbeam poured at the same time as the top slab. The classes of concrete used are C52 for the pretensioned beams and C36 for the cast-in-place concrete.

- The test specimens were designed in accordance with the SNCF's design standard (Handbook 2.01).

The loading rig chosen was designed to simulate the dead load caused by ballast and equipment as well as the live loads due to the passage of trains. It applied loads at two points on the span, 1 m and 2.20 m from the abutment bearings (Fig. 3).

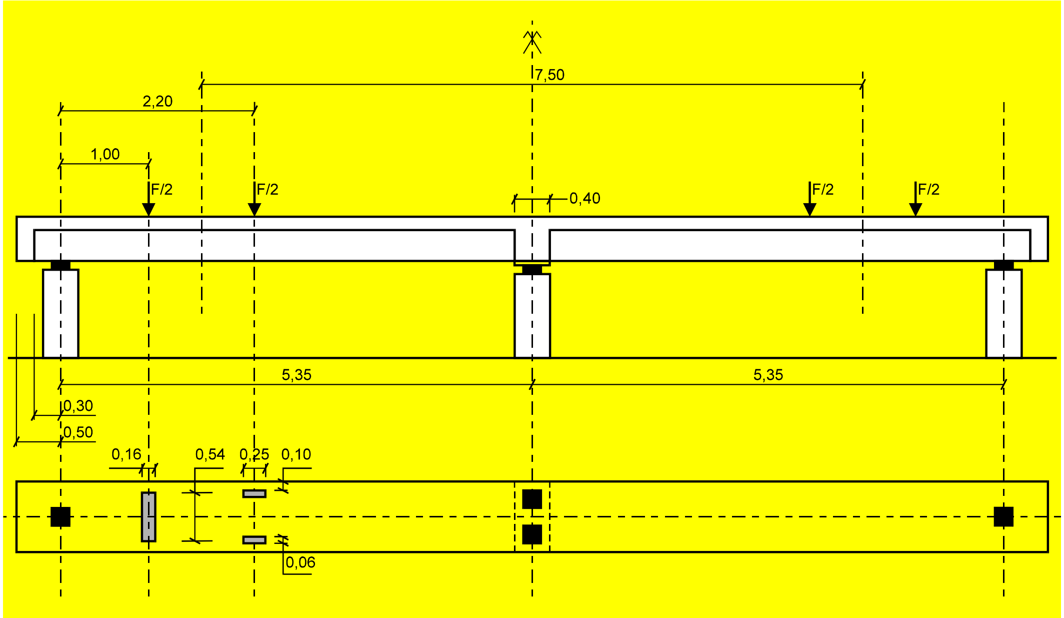

Fig. 3 Layout of load test

The spans were loaded symmetrically. The fatigue test was carried out at a frequency of 8 hertz, i.e. about ¼ of the frequency corresponding to the first natural-vibration mode.

2.2.2. Instrumentation

Fig.4 Loading rig

Apart from measurement of mid-span deflection, the instrumentation focused chiefly on the behaviour of the crossbeam, by measuring rotation on either side of the reinforced-concrete area, and on the deformation of the areas with the biggest loading effects, by means of strain gauges.

2.2.3. Main Results and findings

- Behaviour in service

The specimens behaved similarly, showing a slight cracking pattern under service loads in the reinforced concrete parts atop the continuity bearing.

Stiffness evolution, evaluated by rotation measurements, was in accordance with tension stiffening models of cracked sections in bending (Fig. 5).

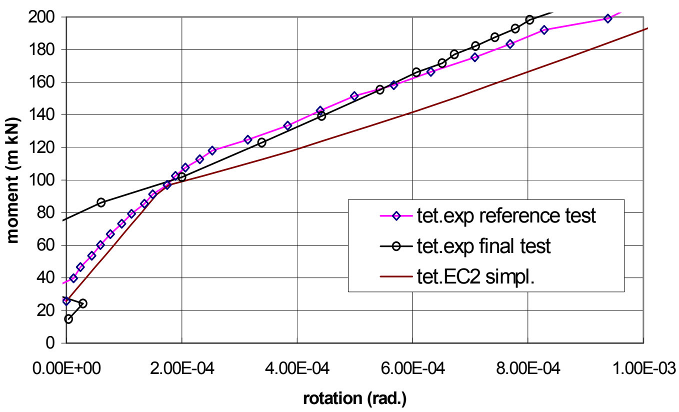

Fig.5 : Moment rotation behaviour

The consequence of this behaviour was a mechanical continuity coefficient slightly below 1 (coefficient given by the ratio of continuity moment compared with a continuous beam with constant inertia): under service loads this coefficient was around 0.78 for all tests.

- Fatigue test

The overall mechanical behaviour of the second test specimen did not change during the test: the coefficient of redistribution, k, defined above remained very close to 0.78. However, several things showed that the structure had undergone some change:

- cracks in the continuity zone became slightly wider, while remaining quite tight (from 0.13 mm at the start of the test to 0.17 mm at the end, with service loads) ;
- the modulus of elasticity of sections fitted with strain gauges decreased slightly, reflecting the fatigue of the materials at the local level;
- the overall stiffness of the spans, defined by the ratio of the force applied by the deflection measured mid-span, also decreased.

The above results appear to indicate that the test specimen has undergone some adaptation; in other words, the losses of stiffness mid-span and above the continuity bearing have been compensated so as to maintain a constant rate of redistribution throughout the duration of the test.

- Post elastic behaviour and failure phase

The failure mechanism for both tests are absolutely identical. A plastic hinge developed mid-span (plastification of the prestressing wires), then the beam/slab assembly separated between the point of maximum moment and a shear-bending crack near the crossbeam (Fig. 6). . It should be mentioned that up to collapse no slippage of tendons was recorded at the simply supported end of the beams.

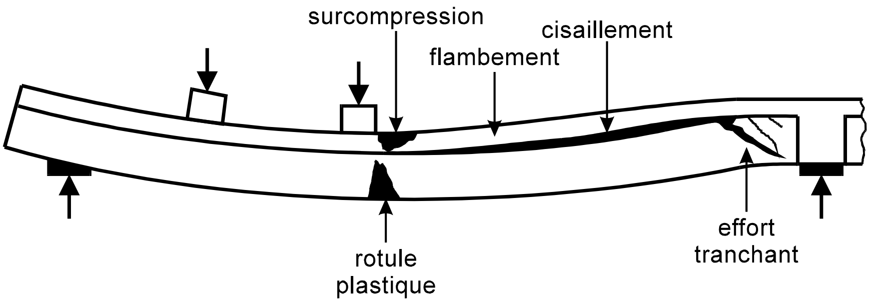

Fig.6: Failure mechanism

- CONCLUSION FATIGUE TEST

The test campaign demonstrated the capacity of pretensioned components to withstand fatigue effects, particularly with respect to the strength of prestress anchor zones.

Similarly, the composite beam/slab structure made continuous with reinforced concrete proved to behave very well : no change in overall performance, little evolution of cracking on the continuity bearing or of mid-span deformation throughout the duration of the test, i.e. 50 million cycles.

The safety margin at failure relative to the service load was more than 2.8 for both tests; this ratio is considered to be satisfactory.

At the end of both tests, the behaviour of the test specimen was modelled in detail: in terms of the overall mechanical situation, consideration of the loss of stiffness in cracked sections correctly represented the redistributions observed in the tests; similarly, analysis of the beam with shear strain reproduced its dynamic behaviour.

The results obtained mean this construction process can be validated for the construction of rail bridge decks. The findings can be used to improve design methods for this type of structure.

3. Presentation of the prefabricated pretensioned concrete beams viaducts on the East European High Speed Line in France.

The East European High Speed Line consists of building 406 km of new line from Paris to Strasbourg. The first phase of the construction of the new line is about 300 km between Vaires sur Marne and Baudrecourt near Metz and Nancy. The second phase (about 106 km) is planned in 2010.

The new line is designed for a 350 km/h speed. However the commercial speed will be 320 km/h. The longitudinal profile allows a maximum gradient of 35 millimetre per metre. The distance between tracks has been set to 4.5 m in the zones where train will run with a speed superior or equal to 300 km/h. When the new line will be completely built, Strasbourg will be at one hour and fifty minutes from Paris instead of five hours today. The huge construction site costs 3,415 billion of Euro in which 1,6 billions is dedicated for the only part of civil engineering work. The line will have 327 civil engineering structures, including 14 railway viaducts.

This part of the paper describes the design of 3 elevated single track supported structure in the commune of Clay-Souilly and Annet sur Marne in the region of Paris where the East European TGV line and the Interconnection TGV line are connected. First there is the Thérouane viaduct carrying 2 tracks on the East TGV main line which length is 322 m. The deck structure of the bridges is formed of prefabricated concrete girders pre-tensioned by bonding of the pretensioning. Deck continuity across the piers is achieved by means of a cross girder and a deck slab of reinforced concrete poured in situ in second phase.

In order to avoid having to provide expansion device of the track, the deck length subject to expansion has been carefully limited to 90 m.

3.1. Design concept of pretensioned prestressed and precast concrete bean bridges.

For the structure of the East European High Seed new Line, a composition with a succession of decks were adopted for the connecting viaducts between the East European main line and the Interconnection High Speed Line in Parisian region on the one hand and the Thérouane viaduct of the East European main line on the other hand. The decks are carrying one track (6.70 m of with and composed of 7 girders beams) for the first one and two tracks for the second one (12.30m of width and composed ok 13 girders).

Each deck is constituted of two or three or four spans of 22.5m and has the fixed bearings on the central piers and the movable bearing on the extremity piers (abutment on common pier between two consecutive decks). This configuration of structures is chosen in order to satisfy the criteria with regard to the response of the combined system “rail-bridge structure” which impose a limitation of dilatation length inferior length inferior or equal to 90m. The slender of the deck is of order of $1/14^{th}$ so for the span of 22.50m. The total height of the beam and the deck slab together is 1.60m (1.35 m for the prefabricated beams made of concrete having 60 MPa of characteristic strength in compression , 0.25 m for the slab made of concrete having 40 MPa of characteristic strength in compression).

As stated above, the deck in line with the intermediate pier comprises a cross girder (transverse diaphragm) providing continuity which is realised after that the beams has been laid on temporary bearings, by concrete keying cast in place in the second phase at the same time as the deck slab and directly into the permanent bearing devices. After the remove of temporary bearings, the decks transfer the load to the pier and abutment caps via the be-permanent bearing devices.

Once the keying has been done, the structure has a statically interdeterminated behaviour pattern. Consequently, the bridges design must take into account their static behaviour in each phase of construction and the evolution of their material behaviour (shrinking, creep, relaxation,..)

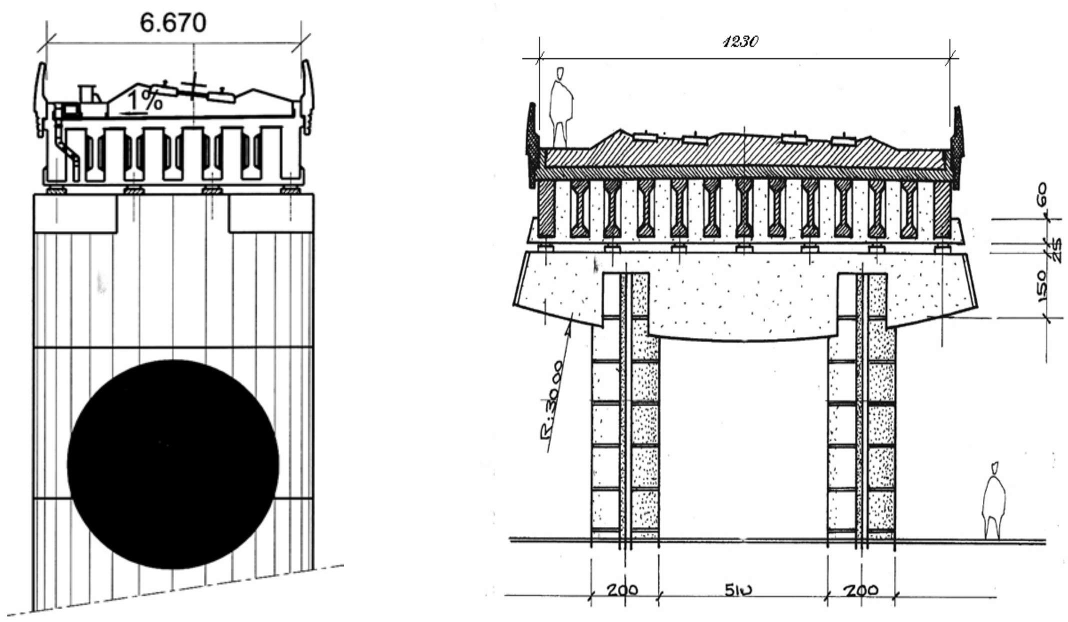

Fig. 7 Architectural view of the cross sections of deck carrying for one and two tracks

The figures 7 and 8 show respectively a typical cross section and architectural view of the deck carrying one track adapted for the connecting viaducts and the one carrying two tracks adopted for the Therouanne viaduct. These sections were slightly modify by the constructor of construction.

From these figures , it is noted that the I from beams with a rectangular thickening at their end are adopted for intermediate girder and the rectangular beams for the edge girders. The latter are provided in order to ensure resistance to accidental impacts such as road vehicle shock or derailment of trains on the deck.

3.2. Design of support

The design of the piers and abutment has many common points with other types of bridge deck. However the construction methods used required a few special arrangement such as the possibility of fixing a steel frame at the pier cap or a pier cap sufficiently ide to permit temporary placement of the beams and their temporarily support.

Figures 4 and 5 show the longitudinal elevation and plan view of single pier and double pier for the connecting viaduct and the Therouan viaduct.

The piers funded in the pile foundation about 20m of length (4* Ø1200mm for the movable bearing pier at the of deck and 4* Ø1500mm from the fixed bearing piers of the connecting viaducts; 6* Ø1200mm for movable piers and 6* Ø1500mm from the fixed bearing piers of the Thérouane viaduct). The bearings in the intermediate piers are pot type fixed bearings and the end bearings are made of elastomeric bearings. (placed in limited numbers 4 for one track decks 6 for two tracks decks)

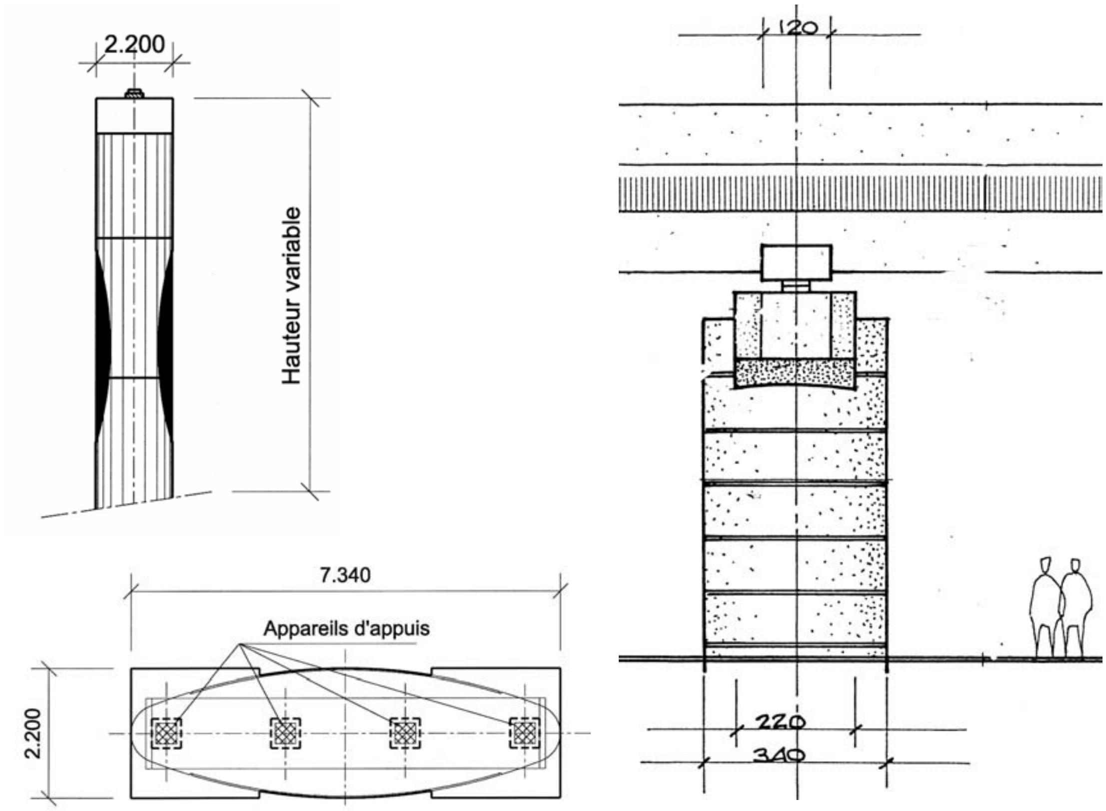

Fig. 8 Elevation and plan view of intermediate pier

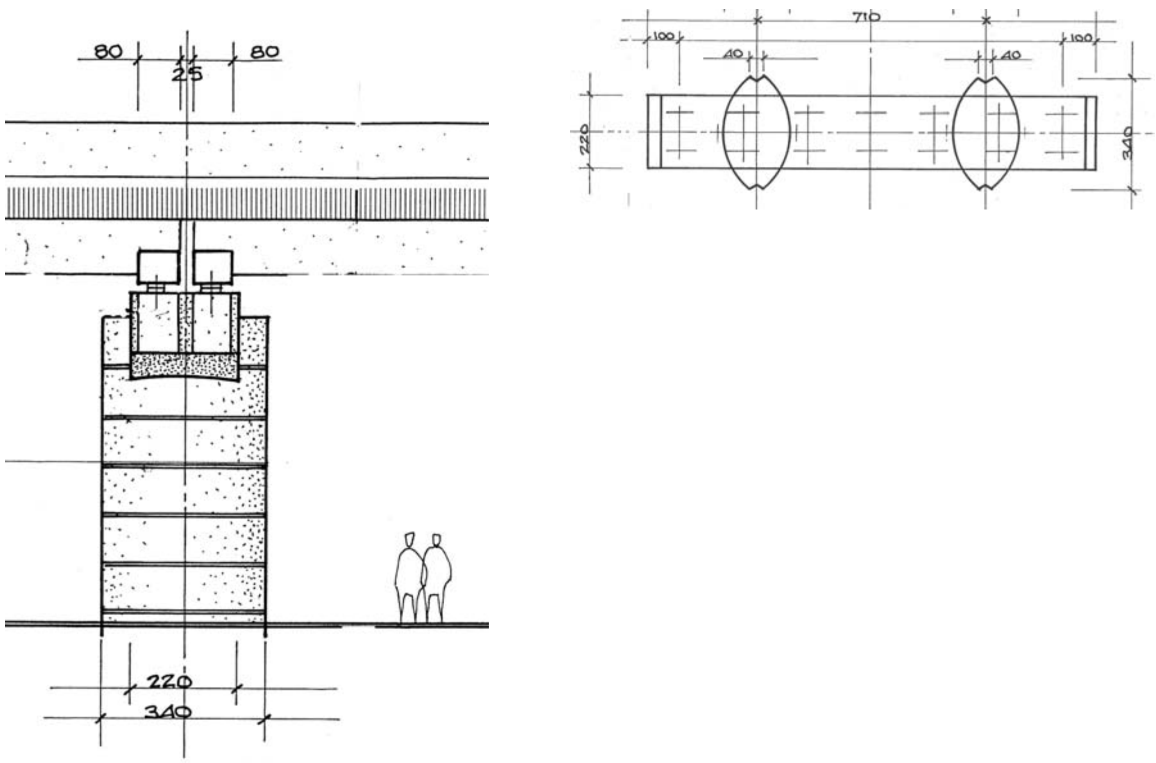

Fig. 9 Elevation and plan view of double pier

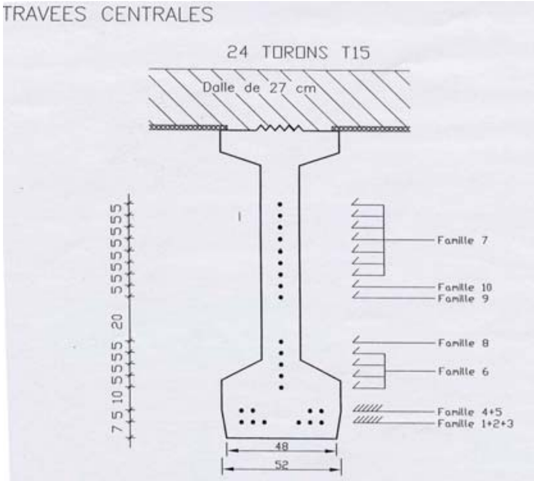

Fig 10: Composite longitudinal beams dimensions

Fig 11: Precast beams stocking before delivery

3.3. Design specification

In durable situation, tensile stress in the concrete is not admitted in the prefabricated beams under the effects of load mode 71 except for the end zones where the prestressing force is not established completely. In this zone, the section has the behaviour of reinforced concrete.

The design must take into account accurately the phase of construction, the static behaviour and the evolution of characteristics of materials (shrinkage, creep, relaxation…) in the calculations.

The limit of stresses of reinforcement is 240 MPa at the characteristic load combination in the serviceability limit state. At the same SLS with quasi-permanent combinaison, the limit stress of reinforcement is 200 MPa for the diameter is big than 25 mm.

The displacement of the deck must be limited in order to satisfy the criteria of the "combined response “track –bridge structure” due to the effect of differential temperature, braking, acceleration and traffic load. For instance, the relative displacement between the two consecutive decks shall not exceed 5mm) and for this reason the fixed pier column and pile foundations must be stiff enough in order to satisfy these criteria.

The acceleration of the deck under the dynamic trains must be limited in order to ensure the security of trains operating ($\gamma \leq 0{,}35$ g and twist $\leq 1{,}5$mm/3m). The passenger's comfort level very good is adopted and the associated vertical acceleration of the deck is limited to 1 m/s^2.

3.4. Conclusions

The studies carried by the SNCF and by enterprise show that this method of construction is reliable.

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Main participants

- Owner: RFF - Direction des Opérations de la LGV Est européenne,
- Main contractor for the section concerned: Grouping of SNCF and Simecsol
- Design engineer: SNCF New Infrastructures Structures Department (IGON).