The main bridges of the high speed line HSL Méditerranée

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Summary

The high speed has consequences on the conceptual design of the railway bridges. But beyond the purely technical consequences that are the evolution of the calculation standards and the constructive disposals which flow from, the most important consequence is perhaps the fact that the high speed imposes to the engineer – more than in the past – to manage perfectly the conceptual design of the bridges.

One of the direction to be followed is often to come back to simple and natural forms, indeed the actual tendencies – with the help of the data processing – are often to innovate, too often synonym of complicate.

The viaducts of the Mediterranean TGV line, either in concrete, metal or composite, are the fruit of:

· The unique experience acquired by the French railways engineers for nearly 20 years at the time of the construction and the maintenance of the bridges currently in service, bridges whose behaviour appeared very satisfactory under circulations at high speed.

· The particular context of the new line, its site and in particular of the obstacles to be crossed, of its environment..., while having for objective to emphasize them

The concern of reconciling the possibilities offered by the progress of the techniques and the need for ensuring at the same time the durability of the works and the safety of railway circulations.

Keywords: Viaducts, bridge, high speed line, structures, steel, concrete

1. Introduction

The bridges made the history of the railway. Along their life, they have capitalized an unique experience in the matter of construction. Unique technical, but also human experience, whether by its vocation: offering the progress to the humanity, opening the space, or by the human behaviour revealed by it. From a certain wise, the bridges – as all constructions – when we know to look at them and to understand them, tell us the history of their period: they seem to us to be resistant or ephemeral, dynamical or still, ... and naturally ugly or beautiful !

The bridges that we construct today, will tell our period to the future generations.

The bridges on the high speed line «Méditerranée» (fig.1) do not escape from the rule : adapted to the high speed, they are the quintessence of the actual know how concerning the art of constructing of the SNCF engineers, they carry in themselves all our knowledge, even when they do not parade it : looking at a bridge, a few people are considering that it integrates so complicated different theories than the mechanic of the breaking, the material resistance, the dynamic, the soil mechanic, ... They want to be as functional as beautiful, even in their simplicity, or in contrary in the work of the material.

The construction of the high speed line «Méditerranée» was the unique occasion to apply, in real size, the major part of the knowledge obtained until today in the construction art.

All the actors (owners, prime constructor, architects, engineers, companies) have joined to keep together the knowledge – the most complicated (the mechanic of the breaking, the dynamic) – the most subjective (architectural aesthetic) – the most recent (seismic risks) – so that the constructed bridges are really works of art, testimonies of the humanity and of its knowledge at the end of the second millenary.

Fig 1. The bridges on the high speed line Méditerranée

2. Conceptual principles

The influence of the high speed on the conceptual design of the railway bridges has not uniquely been expressed by the elaboration of more severe functional criteria than the previous, criteria concerning the crossing security, the passenger comfort, the perennity of the structure. It has also been expressed by a new wise to apprehend the working of the bridges in order to allow them to respect these criteria and being also economical and beautiful; in any kind, we had to redesign conceptually the bridges by answering to the fundamental question of the functioning of the bridges and not by being satisfied to apply the construction standards. The bridge must be the continuation of the nature; it has even to recreate this prolongation when it is broken. It cannot only find its justification in its aesthetic, which is always subject to discussion. It find its justification, in the purpose for which it is designed, in its serviceability character ; it is the adequation between this destination, this serviceability character and the natural laws which will make it beautiful, without this beauty having to be ostentations : it is sufficient that it is evident. We have to really search the serviceability character of a bridge; we have to come back to the basics and to the natural laws and the bridges will be functional and beautiful.

Many people are transported by the masonry bridges and it is only justice: they are “natural”! effectively the masonry is a more particular construction material than it seems to be : how much masonry bridges collapsed by removing ! Only the bridges respecting the natural laws of stability and resistance remain. That is what gives their eternity character.

3. The high speed

The bridges constructed under high speed lines have never had the ambition to be innovative a priori. All has been made so that they remain the most simple as possible, taking into account the traffic requirements:

- a railway bridge must be undeformable, to ensure the contact rail-wheel,
- a railway bridge must be durable, for reasons of security and for economical reasons,
- a railway bridge must be easy to maintain, in order to resist to the weather.

Otherwise a railway bridge must be harmless, visually as well as acoustically.

The fundamental influence of the high speed was, taking into account the number of the concerned bridges, to oblige to a new investigation of these requirements. All the rest followed from it, all has been simplified with it and therefore some bridges became innovative.

The above mentioned requirements have always been the attribute of the railway bridges. The high speed has only amplified them for three reasons:

- the speed it self,
- the standardisation of the load models created for the high speed, homogeneous and compact train sets with constant repetition of axles,
- the traffic conditions : the high speed involves traffic sequences, and more than in the past, regularity ...

The speed and the excitation generated by the regularity of the axles create conditions of resonance for the structures, which were never encountered at this scale in the past. That is “aggravated” by the fact that the modern structures are composed of materials with weak “structural” damping (few loss of energy at the connections, in particular).

The regular excitation of the structures induces fatigue phenomena, i e. accelerated ageings which can have consequences on the conditions of circulation on the bridges, when these phenomena are not perfectly verified and managed.

Analysing the consequences of the high speed on the bridges, it must not be neglected that to the « traditional » effect of loading at speed is to add the repetitivity of this loading generating a supplementary magnification having consequences on the durability of the structure.

4. The specifications

The railway bridge has to allow a crossing by the train without any disturbance of the circulation. The safety, the comfort have to be the same on the bridge and on the open line, the timelessness and the speed have to be those of the line.

4.1. The safety

The safety imposes the respect of the trajectory, the continuity of the rail and the permanence of the rail-wheel contact. Therefore, rules were elaborated in the national standards and are integrated in the Eurocodes (European construction standards).

They concern:

- the vertical acceleration of the deck: its limitation ($g < 0{,}35\ g$) (fig 2)- taking into account the safety factors – ensure the contact rail-wheel as well as the track stability. In the case of a ballasted track, it allows to ensure that the "compaction" and the "cohesion" of the ballast remain sufficient to guarantee the behaviour, the stability;

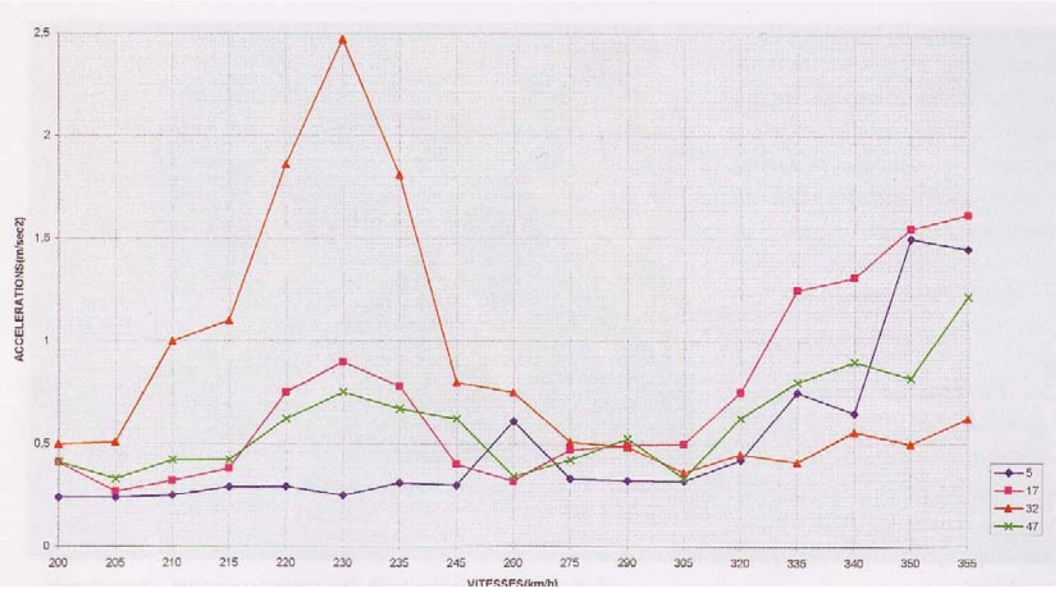

Fig 2 . Acceleration

- the twist and the horizontal deformations : their limitation make compatible the horizontal and torsional deformations of the decks, with the “stiffness ” of the frame and bogies ;
- the rotations of the deck at the end of the bridge, i. e. in the areas where the rail is going from an undeformable support (embankment) to a deformable support (bridge). The limitation of these rotations ensure the continuity of the (no breaking of the rail in tension) and the stability of the track (no buckling) as well as the good behaviour of the ballast.

4.2. The comfort

The comfort of the passengers imposes that the vehicles crossing the bridge, have also a stabilized trajectory and that therefore the accelerations transmitted to the car bodies remain in permissible limits. The criteria relative to the security are physical criteria that are easy to limit. The criteria relative to the comfort are partly physiological criteria, and much more difficult to quantify. For the elaboration of limiting values it was necessary to make a lot of experimentations with “volunteers” on vibrating tables in the situation of passengers and describing their sensations. This research was made by UIC (International Union of Railway of Railways) and has allowed to conclude with values of bridge deformations – in function of the speed, the spans and of the duration of the crossing – not to be exceeded, in order to ensure different stages of comfort. Very schematically, for a very good comfort, the bridge deformation do not generate in the car bodies vertical accelerations higher than 0,1 g.

4.3. The perennity

The timelessness is ensured when the following rules are respected:

- the conceptual design is the most simple, striped, natural as possible, i. e. the force lines take a natural way;
- the bridge is accessible at each moment, that requires, in addition to the access means to be available, when it is possible, to separate the railway area and the structure to be maintained. The construction of a thick concrete slab to support the track allows it;
- the structure is protected from the atmospheric actions, therefore the laying of a simple and continuous water tightness on the extrados;
- the bridge is conceptually designed by respecting the design rules for fatigue, this meets the first of the above mentioned aims and requires constructive dispositions avoiding the stress concentrations by fluidifying the efforts. It is also necessary to limit the appearance of “new”

effort linked to the deformations of pieces, when these deformations originate directly from the application of the loads as well as from local, even general instabilities. The "breathings" of pieces are to be studied very precisely.

5. The basic concepts

5.1. General concepts

For a quick synthesis concerning the consequences of the respect of the above criteria, it is possible to affirm that the high speed requires for a bridge:

- to be the most stiff as possible;
- to be heavy in the traffic stage in order to limit the dynamic phenomena;
- to limit the connections, which obligatorily, due to their forms and their techniques, concentrate the efforts, that is harmful for the behaviour at fatigue ;
- to avoid the elements which are too flexible ; they could deform and vibrate.

A train at high speed requires a stable trajectory and as undeformable as possible.

Undeformability is the master word of the railway dynamic "bridges". One of the most strong constraints that must respect a railway bridge is its quasi-undeformability so that the bogie guided by the rails, remain always in contact with them and that the ballast, which stabilize the sleepers supporting the rails, do not vibrate, otherwise it could not stabilize the sleepers.

Furthermore, the life cycle of the bridges has to allow them to ensure the serviceability in security and quietude during more than hundred years. A fatigue analysis of all details has to be considered.

Of course, a complementary analysis has to be made as usually to ensure that the vibrations of the structural elements have no consequence on the noise emissions of the bridges. The deliberate choice made by SNCF of a ballasted track on concrete slab, which acoustical impedance is very important- does it participate to the bridge resistance or not – gives a good orientation.

5.2. Particular constraints

Concerning the high speed line Méditerranée, other specific constraints in the conceptual design of the bridges are existing : the taking into account of the seismic risks, of strong hydraulic constraints going from the ship impact of 2500 tons to the necessity to considere that the foundations can be washed out on about 10 m depth for certain foundations.

When the taking into account of the seismic risks, which is now obligatory in France for the bridges, has had consequences concerning the design of some parts of the decks, the consequences have been more important on the design of the piers and foundations ; the current designing efforts have been multiplied by factors sometimes higher than 5 in the longitudinal direction, and forces of several 100 tons were to take into account in the transversal direction (relevant to the deck axle). Furthermore the foundations situated in aquatic areas had to be designed taking into account the heights of scor, which decrease considerably the thrust available to support these forces : the dimensions of the foundations are the consequence.

Generally, when it is possible, the most simple solution was adopted so that the supplementary resistant element envisaged for the seismic forces does not disturb the functioning of the foundations adopted for the permanent loads and for the traffic loads. That has also allowed to further the plastification – at the ultimate limit states – factor that is favourable for an economical designing.

This are to further the plastification for taking into account the extremes forces is also clear in the design of the seismic stopper and of the bearings : very schematically the last one have been designed to take into account the serviceability limit state, the steel stopper and conter-stopper as deformable as possible, taking into account the ultimate efforts, the bearings and or their fixations are then used as fusible equipments.

6. The architectural approach

The participation of architects to the conceptual design of bridges, relatively marginal during the construction of the first high speed line (Paris-Lyon), has progressively taken more importance with the next lines (HSL Atlantique, HSL Nord…), and becomes essential for some viaducts of the high speed line Méditerranée.

Table of main contributors to exceptional viaducts

Viaduct	• Design • Architects	Detailed Design	Companies: Concrete	Companies: Steel
Prestressed Concrete	**SNCF Direction de l'ingénierie +**			
La Grenette	Cf. Sncf	Serf	Quillery	
Avignon	Setec M.Virlogeux	Bouygues Gtm	Bouygues Gtm	
Vernegues	Amedeo/Padlewski	Secoa – Sfee	Dodin Sogea	
Ventabren	Ch Lavigne	Campenon-Bernard Spie-Batignolles Eeg-Serf	Campenon Bernard Spie-Batignolles Eeg-Serf	
Roquemaure	A Amadeo	Px Consultants	Demathieu & Bard Fougerolle Razel - Emcc	
Metal and Composites	**SNCF Direction de l'ingénierie +**			
Arc	B. Gaudin	Beg	Baudin	Baudin
Donzere	M. Mimram	Beg - Serf	Gfc	Buyck - Eiffel
Mornas	JP. Duval	Beg – Ioa	Spie Campenon Emcc	Baudin
Mendragon		Beg – Serf	Spie Campenon Emcc	J R Ducros Secometal
Avignon Toll	Igoa & JP. Duval	Serf	Demathieu Et Bard	Secometal

For all works, the client was RFF (Réseau Ferré de France), represented by the "Direction de la ligne nouvelle TGV Mediterranée" (SNCF – LN5)

All the bridges of this high speed line were submitted to consultations for associating architects f reputation and study offices of the prime constructor, at the stage of pre-project. Furthermore some viaducts, selected on the basis of their own characteristics and/or of their environment were submitted to a particular proceeding, which gives to the architect, on the basis of the Specifications and of an initial study, a great independence concerning the modifications to bring to this study in order to obtain a better adequation between the structure and the landscape.

Totally, seven viaducts have been qualified as « exceptional ». From the north to the south, there are the viaducts of the Grenette, of Donzère (la Garde Adhémar), of Mornas and of Mondragon, of Avignon, of Vernègues, of Ventabren and of Arc.

Through their insertion in the landscapes, even the transcendency of the sites, the bridges of the high speed line Méditerranée are revealers of a will to be meant not only for the customer of the railway but for all the men and women liable to admire them.

These bridges have been really designed as elements for the urban and rural planning, the scope of a durable development.

7. The prestressed concrete viaducts

The French network of high speed lines opened for the traffic has many prestressed concrete viaducts. Their decks are from the type continuous prestressed by post-tension box girders. This structure is now classical ; it is adapted to the current construction techniques (cantilever, launching), it preets a certain architectural interest and especially has good behaviour concerning the multiple constraints required for the railway bridges, in particular in the matter of mastering the deformations and vibrations. The designers of the bridge of the high speed line Méditerranée had obviously to respect these constrains and also to take into account the subjections particular to the sitescrossed by the high speed line.

The proceeding made for the architectural conceptual design of the bridge has made possible a closed collaboration, from the beginning of the studies, between architects, landscape-specialists and engineers having as aim, in each case, the study of the structure being the best integrated in the environment and respecting the imposed technical constraints.

From the five prestressed concrete viaducts of the high speed line Méditerranée, four were classified as « exceptional ». There are, from the north to the south, the viaducts of the Grenette, of Avignon, of Vernègues and of Ventabren, as mentioned before. The fifhth bridge is the viaduct of Roquemaure.

The principal innovations concerning these bridges in comparison with those of the previous high speed lines are:

- The use of external prestressing for the continuity prestressing, the cables of first stage (cantilever, launching) remaining internal in the concrete of the slabs ; the external prestressing allows a better control of the cables and their replacement in case of eventual problem.
- The use of concrete with higher strength (B44 to B52, instead of B35 to B40),
- The use of prefabricated segments, in the case of the viaducts of Avignon,
- The taking into account of the seismic risks.

The other particularities of these bridges are mentioned below.

7.1. The viaduct of the Grenette

The high speed line Méditerranée crosses, with the viaduct of the Grenette (fig3), a relatively deep valley, near from the village of la Roche sur Grane. The viaduct, with a length of about 950 m, is immediately at the north of the Tartaiguille tunnel.

Fig 3. Viaduct of the Grenette

The deck is a classical box with 2 inclined webs, with a constant thickness of 4,50. The current spans have a length of 53 m. The longitudinal cutting of the deck, linked to the constraints of the railway, is obtained by the introduction of an isostatic span at the middle of the bridge, where the expansion device of the track will be installed..

The construction has been realized by launching from the south abutment (tunnel side).

The principal characteristic of this bridge concerns its piers, very high (about 60 m) and with a great slenderness; it results from an aesthetic will taking into account the relatively weak length of the spans (53 m).

The piers are hollow ; they have a lower part with a rectangular cross section with dimensions varying from 7,40 m x 3,40 m x 5,83 m at the basis for the highest. The upper part has a constant cross section of 7 m x 3 m and has a rounded shape at its ends.

The concrete has a grey clear colour for the pper part (smooth facings) and a beige colour with sanded facings for the lower part.

The foundations are piles foundations or superficial foundations.

7.2. The Viaduct of Avignon

The viaducts of Avignon (fig4) allow the crossing of the Rhône, between its confluent with the Durance ad the city of Avignon, by the high speed branch Marseille-Valence on the one hand, and the high speed branch Marseille-Montpellier on the other hand.

Fig 4. Viaduct of Avignon

The two bridges are parallel on the most part of their length, near from 1500 m. They allow, arriving from Valence or from Montpellier, to come down from the plateau des Angles to the plaine de Courtine, where the future station of Avignon will be installed and are composed from :

- the viaducts properly so called with a length of about 1120 m,
- side Marseille, the elevated railway structures, with a length of about 400 m.

With a current span of about 100 m, the deck of the viaducts have a height of 5 m at mid-span and 8,50 m on the pier, this variation is realized with the help of parabolic gusset plates having a length of about 28 m each.

In the particular case of these bridges, the longitudinal splitting up of the deck is made with the help of a cantilever joint in the span P5-P6, this avoid the installation of an isostatic span (with a length limited to about 50 m), which was not compatible with the will of the architect for a regular spans succession.

The type of construction for these decks is the cantilever method with prefabricated segments, that constitutes also the first one in the matter of railway bridge.

The concrete has a characteristic strength at 28 days of fc28 = 52 MPa and has a very clear colour (use of white cement).

The decks of the elevated railway structures are composed of independent spans of about 50 m length (due to the impossibility to install expansion devices for the track in the concerned areas) and of prefabricated segments similar to those of the principal bridges, but with a constant height of 4 m.

The piers are constituted from hollow shafts in the shape of a truncated cone with a circular basis, with a diameter of 5 m under the head cap supporting the deck and reaching 8,50 m at the basis for the highest (about 50 m). they are realized in situ, in reinforced concrete with a clear colour (as the deck). Their form and their dimensions were determined taking into account the hydraulic constraints, the very important efforts to be resisted (seismic forces and ship collision), but also the limitations of the head deformation, under breaking in particular.

The foundations are, either foundations on circular plate foundations and concrete plug in immersed concrete in the crossing of the Rhône, or deep foundations on piles reaching the marly or chalk horizonts. They are designed to resist to the different forces mentioned above concerning the piers. The supports situated in the Rhône were realized with the help of sheetpiles cofferdam, with a circular form in order to respect the hydraulic constraints, and protected by duc d'Albe.

The definitive protection against the scor is realized with rockfill.

7.3. The viaduct of Vernègues

The viaduct of Vernègues, with a length of about 1210 m, ensure the crossing of the valley de Cazan, near Vernègues (Bouches du Rhône).

This site is very exceptional and has led the design team (architects-engineers), after a long research work concerning practically the whole envisagable structures, to choose a prestressed concrete deck with rounded shape, the longest possible in order to avoid the end embankments, supported by piers having variable forms and being more and more closed together when their height decreases.

The spans vary then from 80 m in the middle area to 15 m at the end, the ratio of the span to the average height of the consecutive piers remaining constant.

As in the case of the viaducts of Avignon, when the bridge length required a splitting up of the deck, it was to be wished to avoid the realization of an intermediate isostatic span. This problem had been solved in this case, due to the fact that the span length was weaker, and by setting in the deck a simple joint on support and not a cantilever.

The deck is from a particular type. It is a multibox, which underface has the shape of a cylindrical shell in the middle part and is cutted by an oblique plane at each end, so that the height of the deck decreases when the length of the spans decreases. This height vary thus from 5,25 m at the middle of the bridge to 1,50 m on the abutments; it results from a compromise between the will of slenderness of the architect and constraints of resistance and of deformability of the bridge, taken into account the spans and the transversal form of the deck, less favourable than the traditional box. The parapets are also in concrete and their form is integrated to that of the deck.

the concrete has a characteristically strength at 28 days of fc28 = 52 MPa. The facings have a clear colour and are lightly sanded.

The erection of the deck has been realized by launching for the two end parts and with the cantilever method for the middle part.

The piers, also in concrete of clear colour and sanded, are constituted from a hollow shaft with an oblong shape in the middle part of the bridge, and are splitted progressively in two shafts at the ends, while their height decreases from about 33 m to 5 m.

Concerning the foundations, the soil quality (limestone, compact marly) has allowed superficial plate foundations supported by blocks in rough concrete.

7.4. The viaduct of Ventabren

With a length of 1730 m, this viaduct is situated near Ventabren (fig 5) and Eguilles (Bouches du Rhône) and allows the crossing of the highway A8.

Fig 5. Viaduct of Ventabren

The deck is a box with 2 vertical webs and lateral shells supporting the cantilevers.

The current spans have a length of 45 m ; the crossing of the highway without any support on the middle platform required a span of 100 m.

The concrete has a characteristically strength at 28 days of fc28 = 44 MPa, with a grey clear colour.

The piers have a variable height from about 14 to 28 m. They are hollow and their shafts are hexagonal, inscribed in a circle of diameter 5 to 6 m ; the head caps are also hexagonal, inscribed in a circle of diameter 9 to 10 m.

The foundations are, either deep foundations, either superficial foundations.

The principal characteristic of this bridge is the realization method used :

- the current spans have been launched;
- the span of 100 m and the adjacent spans have been constructed with the cantilever method and concreted in situ, the handles were firstly parallel to the highway, then brought to their definitive position by rotation (then overbalancing to obtain the longitudinal gradient).

This method brought the best security guarantee for the highway; each rotation operation, realized by night with traffic stop on certain ways of the A8, had a duration of 3 hours.

It can be mentioned also the fact that the viaduct of Ventabren, as the viaduct of Vernègues, is equipped with dampers on the abutments in order to minimize the consequences of an eventual seism.

7.5. The viaduct of Roquemaure

It crosses the Rhône between Valence and Avignon, near Orange and Roquemaure.

Its deck, with a length of 680 m, is a classical box, which was concreted in situ and realized with the cantilever method.

The principal spans have a length of 105 m, and that is a record in the matter of prestressed concrete railway viaduct.

The piers in the Rhône have a lengthened shape, and are oriented in the flowing direction of the Rhone; they are dimensioned as the piers of the viaducts of Avignon, to resist to ship impact of 2500 tons.

They are on deep foundations, using piles ∅ 2,00 m for certain supports, as the central pier P4 which resist to the braking and longitudinal seism forces.

8. Steel and composite viaducts

It is by the forms used that steel must confer on the work a sufficient stiffness to almost prevent it from deformation, because its resistance is such as relatively few material is enough to withstand the efforts to which it is subjected.

The form thus does not only have an aesthetic function.

For the current spans, the alliance carried out between the steel and the concrete makes it possible to recreate this stiffness.

8.1. Twin girders

8.1.1 Current twin girders

The archetypal steel structure is the composite twin girders, with full webs, of slenderness ratio 1/15, 1/14 (which includes the slab); it is a stiff structure due to the use of a fairly high full web, of thick flanges, and due to the introduction of diaphragms and of an inferior bracing which allows it to work in flexure and in hindered torsion, which strengthens its behaviour and creates a redundancy between beams, thus improving the level of safety of the works.

This type of structure has already been used on the TGV Nord (Northern TGV): in particular the Haute Colme Viaduct which, with a length of 1 827 m, is the longest French railway viaduct.

For the girders of the TGV "Méditerranée", thick plates, up to 150mm, have been necessary. In length profiled plates (TPL) – with variable thickness - have also been used.

In the upper part, the two girders are connected to a concrete slab cast directly on the steel frame, via steel pins.

Features of certain twin girders: the use of inferior concrete slab instead of a bracing and steel floor plate for economical, architectural reasons such as reducing noise emission.

The greater part of the structures had been launched after prefabrication.

For the framework of Cavaillon, the spans of 53m were entirely prefabricated and assembled on the bank (beam, diaphragm, part of bridge, grating) i.e. weights of almost 200 T transported using a crane with caterpillar of strong power on artificial submarine dams built in the bed of the river. The spans were connected together on support.

The solution of stiff abutments has been chosen in order to resist to seismic forces, as in fact for all the other steel bridges.

Quoting amongst the great composite structures: the bridges of the Durance crossing; Cavaillon and its length of 1 500m, Cheval Blanc and Orgon and their lengths of 1000m each.

The supports of these bridges are driven in to more than 10m into the bed of the Durance to avoid scour; even more, they are protected by rockfill and are anchored in the substratum with the help of steel piles;

For the bridge of Cavaillon, spans of 53 m were entirely prefabricated and assembled on the bank (girders, diaphragms, floor beams, floorplate) being weigths near to 200T transported with the help of a powerful crawler crane on artificial submersible dykes built on the river bed. The spans have been connected together on supports.

8.1.2. The Viaduct of the Arc

With regards to the structure of the Arc (fig6), a composite structure which departs from traditional forms, the progression of the design – with a greater part due to the architect – is carried out from the initial form proposed by the engineer- composite twin girder, constant height of girders – to make the most transparent possible – in eliminating all useless material and, where it is necessary, to focus it where the whole form of the structure which resemble a funicular of normal and shear forces. This form thus acquired a bare fullness, which gives it serenity due to perhaps its gravid character which it suggests.

Fig 6. Viaduct of the Arc

8.2. Four-girders and twin boxes

Other standard composite bridges: the four-girders are used in the case of weak thickness available for the deck and/or in the case of a skew crossing.

The design is the same as for the twin girders, but without inferior bracing, (the flexibility – relative-in torsion being favourable); the number of four beams are reduced: only on supports, possibly one or two in span. There too, the objective is to create a redundancy between beams.

Still in the family of composite bridges, it is to be specified the construction of "reduced boxes", with thick plates and limited stiffening, easily transportable, which are relatively economical compared to the alternative solution of four-girders and adapt better to skew crossings, the number of support devices (and possibly of supports) being divided by two.

This type of structure has at times been launched; it has also been put into place by a crane, the different sections being jointed up in situ.

Such a finished structure is almost as thin as concrete slab.

One regret nevertheless; a big twin box with external truss web which has not been built and which remains only as a project design: a substitute has just been built on the TGV Est (the Eastern TGV) but with a external full web.

8.3. Through bridges

New type of structures built on the high speed line: the through bridges with full webs connected by transversal floor with embedded girders chosen also for skew reasons and above all for the reduced thickness of the deck.

One particularity, the RAPL of RD 59 work, isostatic of 60m of span, very skew, which had been launched, which is not very common! An important cutwater had been necessary, as a ballasting for the rear part: it concerns simply a concreting of a part of the deck with embedded girders.

8.4. Bow Strings

The bowstring bridges for great spans are usually (or basically) only decks with lateral beams such as those described above, suspended with arches which use them as ties, so that arch thrust are not transmitted to the bearings.

This provision, which can appear heavy, sees this disadvantage very largely compensated by the simplicity of construction which results from it, by the stiffness brought as well with respect to local and general instabilities as with respect to the dynamic behaviour.

Let us recall that the designing character of a railway bridge is its deformability and that, in a bowstring, the major part of the deformability is generated by the bending of the arch with the entry or the exit of the trains circulating on the bridge.

Such solutions (with inclined hangers if necessary) were proposed at the preliminary project stage to architects, who could work on their forms.

8.4.1 The Viaduct of Donzère

The crossing of the channel of the Rhone at Donzère (fig 7): is realized using 2 mixed spans of 55m framing a continuous bowstring of 110 m. The solution which was adopted ultimately consists of 2 access spans of the same thickness than the deck of the bowstring, whose side arches plunging to the channel are connected by an upper arch, in an aesthetic goal.

Fig 7. Viaduct of Donzère

The bridge was worked over again on the level of the transverse section; the hangers of the bowstring became triangular boxes.

Finally, one gave to the upper arch a functional role by bonding it to the two other arches by inclined buttresses. The end piers, made up of 4 columns, are embedded in the access spans; the bowstring beams rest overhanging on these quadripodes.

On the site, the quadripodes were filled with concrete to reinforce them with respect to the ship impacts, even if calculation did not make it necessary, account - held of their robustness.

The penetration of the lugs of hangers in the boxes - arches or ties – of the bowstrings was the subject of particular care in order to limit the fatigue effects. For this purpose, a penetration without direct contact other than a deformable plate of water tightness with weak thickness was carried out.

The part out of concrete of the supports, located under the level of water is very important: the equivalent of a diameter of 16 m out of 18 m in height; the unit is founded on piles for earthquake reasons.

For construction, each direction of navigation was neutralized one after the other. The prefabrication of elements of strong dimensions in factory (on average 180 to 200 T) brought by sea by circumventing the Straits of Gibraltar, made it possible to limit the number of provisional supports in the bed of the channel to enable the final assembly.

These elements were set up using a crane on bank of strong power (800 T).

The hangers and their system of fixing to the deck and the arches were designed to be replaced without disturbing the operation of the bridge nor the railway circulation.

8.4.2 Viaducts of Mornas and Mondragon

Other bowstring beams which will form part of the national heritage: twins of Mornas and Mondragon, located on both sides elbow of the Rhone. Compared to the basic solution, the architect duplicated the arches to reduce the visual impact of it, what brought, thereafter, the engineer to bond them between them to restore the stiffness of it, at the crown as at the springers.

To announce access spans consisting of composite twin girders much more important than in Donzère: approximately 600 m with Mondragon and 800 m with Mornas (average span 45 m). As for the totality of the steel structures, a perfect trial erection in workshop allowed a very precise accosting, without final improvement.

For these two works also, the piers are true cathedrals.

The installation was made using motorized trucks, the bowstring beams having been assembled on the banks. Placed under the zones of support of the deck, these trolleys allowed the rolling of the latter, since the surfaces of assembly, to the river to allow the front part of the trolley to accost and to go up on barges equipped accordingly. Once the barges loaded, the unit, pushed by the rear trolley, always rolling on firm ground, crossed the river, accosted on the other bank and was discharged on the final supports of the work.

8.4.3 The Southern Toll of Avignon

Last Bowstring Bridge, that which has the greatest span of the Mediterranean TGV 124 m: The southern toll of Avignon crossing viaduct. It is the basis solution, without architectural modification: a deck with lateral beams, on which one came to embed the two arches, lateral beams being in addition suspended with those.

The installation also used motorized trolleys placed at each end of the deck. The unit was advanced on the backfill.. Following a certain number of operations, the carriages were descended on the level from the original ground and the deck was supported there via auxiliary support of great height. This unit has advanced then by circumventing the cabins of toll, the support on the rear trolley, on backfill, being provided with a hinge allowing rotation. After having circumvented the obstacles, the front support came to accost on the right abutment, the left support being then above the left abutment.

It thus did not remain whereas to leave the carriages and to unjack the structure to make it completely in conformity with the image of the project!

9. Conclusion

The main bridges of the new high speed line HSL “Méditerranée” are the fruit:

- Of the unique experience acquired by the engineers of the SNCF since nearly 20 years at the time of the construction and the maintenance of the works currently in service, works whose behaviour appeared very satisfactory under circulations at high speed.
- Particular context of the new line, its site and in particular of the obstacles to be crossed, of its environment..., while having for objective to emphasize them
- Concern of reconciling the possibilities offered by the progress of the techniques and the need for ensuring at the same time the timelessness of the works and the safety of railway circulations.

A well built bridge must give the impression to whoever looks at it that it is in perfect adequacy with the loads which will cross it. That does not claim any particular knowledge in resistance of materials: that’s to be felt, quite simply.

A railway bridge which must support heavy loads must oppose a certain resistance and certain stiffness to them. Conceived in this manner, pleasing to the eye, it will seem acceptable with all and calculations will show that indeed it is adapted. On the contrary, one "badly figures out" a train passing on a highway-bridge or a footbridge, and calculations show it too.

High speed does not modify this perception basically, but gives it depth, amplifies it! Everyone has once felt the vibrations of a stirring wheel to understand that if speed increases, the phenomenon increases: when a part vibrates, little is sometimes enough to stop the movements (to put the finger on it, for example). It is the same with bridges: the more the speed of the trains will grow and the more they will tend to enter in vibration. Simple artifices can be enough to oppose to it. All the art of the engineer is to conceive them and to implement them.

For that purpose, it is necessary for all to understand the structure and its operation. Hitherto, all calculations carried out were static calculations; the bridges were inert, lifeless. High speed makes them live and dynamic calculations have become necessary.

The engineer must now not only visualize the bridge moving, he must calculate it this way too, the bridge breathes; and with this intention, he must know the structure even better than in the past.

May be one of the main contributions of the high speed was to help the engineers to more thoroughly understand the structures! For that, it is necessary to strip them of all their artifices, to make them natural, to give again the simplest possible functioning:

High speed accepts neither what is complicated, nor what is artificial.

High speed, like any technical progress, thus results in compelling the engineer to better control his art of constructor. This mastery cannot mean complication; it can only mean comprehension and simplification. It is a fundamental need of which one has to be completely conscious, especially at a time when data processing can give the impression to control the matter in its least details; data processing can only help with this control, it is not the control itself..

To build, the builder of cathedral did not have other means but to be in harmony with the forces and materials, to live them and to understand them. We had sometimes forgotten it, we still forget it sometimes. If we forget too often the need to understand our bridges, their behaviour, when they are crossed at high speed brings back for us to reality. High speed reveals the behaviour of the bridges; their design must take it into account.

The modern materials help the design to be as obvious as possible.

It is the combination of the steel and of the concrete, their complementarities and not their opposition, that have allowed the high speed line to be an irrefutable proof.