DIAGNOSIS AND RESTORATION OF FOUR EXCEPTIONAL EIFFEL-TYPE RAIL VIADUCTS

Cédric LAMARSAUDE, Renaud LECONTE, Christophe RAULET

DIADES

Claire DEFARGUES

SETEC FERROVIAIRE

1. INTRODUCTION AND PROJECT BACKGROUND

As part of the Auvergne Rail Plan agreed between the French Government, the Region of Auvergne and the French rail network (RFF), significant works of restoration to the rail networks, including works to the tracks, bridges and other civil engineering structures, tunnels and earthworks were carried out under SETEC's project management. The works consisted of modernising, upgrading and ensuring the safety of three rail lines in Auvergne including the Bordeaux Lyon line between Montluçon and Gannat (lines 705000 and 707000), by eliminating and preventing numerous delays.

The Montluçon Gannat line, which was opened in 1868, includes four exceptional metal viaducts, two of which were built by the young Eiffel Company and the other two by the Fives Lille Company.

2. PRESENTATION OF THE WORK

The Rouzat viaduct (Fig. 1) and the Neuvial viaduct (Fig. 2), which were built by G. Eiffel between 1867 and 1869, are in the department of Allier, on the single-track line from Commentry to Gannat. They are situated at 386.840 and 388.813 km respectively between GANNAT and BELLENAVES stations.

These two structures have been registered on the 'inventaire supplémentaire des monuments historiques' (the list of historical monuments of regional importance) since 1965. The Rouzat viaduct is situated in the commune of SAINT-BONNET-DE-ROCHEFORT. It comprises three metal spans of 55.125 metres – 57.75 metres – 49.125 metres which are extended by a stone access viaduct of approximately 13 metres, on the Commentry side. The 162-metre-long puddled iron deck rests on two piles each consisting of 4 hollow cast iron columns of 50 odd centimetres in diameter, which have crosswise struts or rafters and which stand on stone pillars. The metal parts of the piles are 46 and 41 metres high respectively. The pile on the Commentry side stands in the middle of the river Sioule.

The Neuvial viaduct is in the commune of BEGUES. It comprises two metal spans of 49.2 metres each extended by a stone access viaduct of approximately 31 metres, on the Commentry side and of a secondary metal span of 23.5 metres on the Gannat side. The 98.40 metre-long puddled iron deck rests on a pile consisting of four hollow cast iron columns of 50 odd centimetres in diameter and 41.5 metres high, and which stand on a stone pillar.

The decks of these two bridges are 4.5 metres wide between the side railings. They consist of lateral lattice girders, 4 metres in height (excluding the corner irons) and a centre-to-centre distance of 3.5 metres. Floor beams are spaced 3 metres apart and support central steel girders which were replaced in 1965. The interior of the deck has a fixed footbridge which enables it to be inspected.

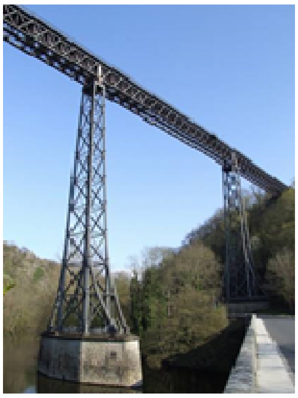

Figure 1: Rouzat viaduct

Figure 2: Neuvial viaduct

The Bellon viaduct (Fig. 3) and the Bouble viaduct (Fig. 4), built by J.F. Cail and the Fives-Lille company between 1867 and 1869, are also situated on the Commentry to Gannat line. They are at 368.212 and 363.637 km, between LOUROUX de BOUBLE and BELLENAVES stations. The structures straddle the communes of LOUROUX de BOUBLE and COUTANSOUZE, as to the Bellon viaduct, and LOUROUX de BOUBLE and ECHASSIERES, as to the Bouble viaduct.

These two structures have been registered on the list of natural historic monuments and of sites of artistic, historical, scientific, legendary or picturesque character of Allier since 1991.

The Bellon viaduct comprises three spans of 40 metres – 48 metres – 40 metres framed by two stone access viaducts of 57.8 metres on the Commentry side and 42 metres on the Gannat side. The 128-metre-long puddled iron deck rests on two piles each consisting of 4 hollow cast iron columns of about 50 centimetres in diameter, and which stand on a stone pillar; the metal parts are 36 metres high.

Figure 3: Bellon viaduct

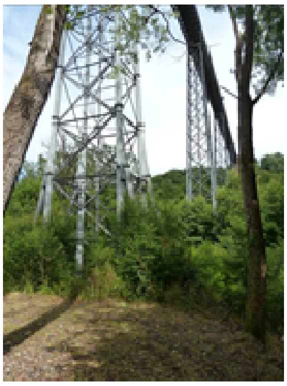

Figure 4: Bouble viaduct

The Bouble viaduct comprises six spans of 50 metres framed by two stone access viaducts of 71.3 metres on the Commentry side and 23.7 metres on the Gannat side. The 395-metre-long puddled iron deck rests on five piles each consisting of four hollow cast iron columns of about 50 centimetres in diameter, with crosswise struts, and standing on a stone pillar; the metal parts are between approximately 40 to 55 metres high, bringing the structure to approximately 70m above the Bouble valley (Fig. 5).

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Figure 5 : Construction Bouble viaduct

The decks of these two structures are 4.5 metres wide between the side railings. They consist of multiples fourth-order lateral lattice girders and are 4.54 metres in height (excluding the corner irons) and a centre-to-centre distance of 3.5 metres. Floor beams are spaced 2 metres apart and support central steel girders which were replaced in 1965. The interior of the deck has a fixed footbridge which enables it to be inspected and which was also replaced in 1965.

3. THE DIAGNOSIS

As part of this study, the purpose of the preliminary diagnostic phase was to determine the general state of these structures by checking that they were able to provide the service required, in terms of load and frequency. Where applicable, the definitive reinforcement measures required to ensure this service and the provisional reinforcement measures required in order to implement the program of restoration works were defined.

In order to ensure a thorough understanding of the structures based primarily on the information in the project files, specific investigations have been carried out, including:

- ⇨ *Brief visits carried out by means of rope access works (Fig. 6) and completed at night using hydraulic cradles (Fig. 7) designed to provide up to date information on all the defects which may affect the structures (elements coming apart, splitting, possible cracking, and so on),Taking additional dimensional measurements required for structural models and studies (Fig. 8),*
- ⇨ *Carrying out magnetoscopic inspections of a few compositions in order to search for incidents of damage, in sensitive areas, that are imperceptible to the naked eye,*
- ⇨ *Carrying out an anti-corrosion diagnosis to reveal the presence of lead oxide in the existing anti-corrosion system (Fig. 9),*
- ⇨ *Researching, by means of spectrocolorimetry, the tints of the painting that was originally carried out at the request of the Architectes des Bâtiments de France (ABF),*
- ⇨ *Taking samples and carrying out chemical and mechanical analyses of such samples in order to ensure the accuracy and reliability of the information regarding the materials in situ (Fig. 10),*
- ⇨ *Carrying out complete models of calculation of the structures using the Pythagore® software, developed by Setec TPI,*
- ⇨ *Finally, carrying out night-time loading tests coupled with instrumentation to support the digital models.*

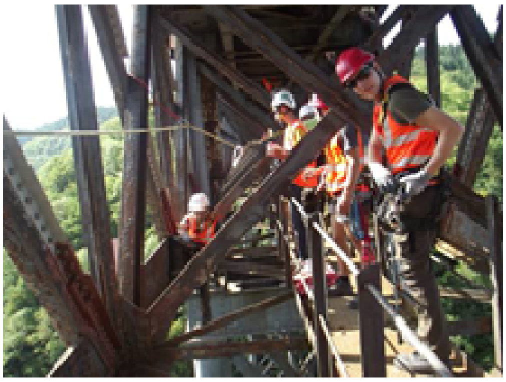

Figure 6: Visit by means of rope access works

Figure 7: Visit using hydraulic cradles

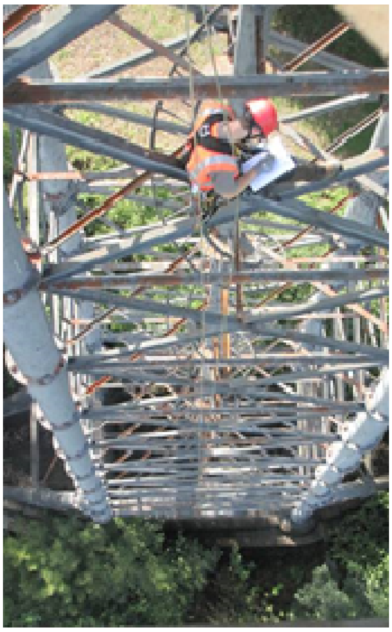

Figure 8: Additional dimensional measurements

Figure 9 : Anti-corrosion diagnosis

Figure 10: Samples of puddled iron for analysis

4. THE STRUCTURAL STUDIES

Because of the presence of lead in old paints, it was necessary to put in place impermeable containments to avoid polluting the environment in any way. These containments resulted in open meshed structures being significantly exposed to the wind, which required structural checks of the working methods to be carried out as from the concept *study phase. At the project stage, the hypotheses consisted in using wheeled scaffolding of 20 to 21 ml, depending on the structures, in parallel with the complete confinement of a pile and on the basis of the abrasive recycling technique.*

Comprehensive models of each bridge were created by SETEC TPI and DIADES using Pythagore® software, in order to check the structure of the bridges in these cases of unusual load.

These models were constructed from for reconstituting detailed geometry, and the results of samples taken in respect of the characteristics of puddled iron. In order to ensure the accuracy and reliability of the results of calculations that predicted the performance of these bridges, the models were based on the instrumentation and the load tests carried out during the diagnosis phase (Fig. 11).

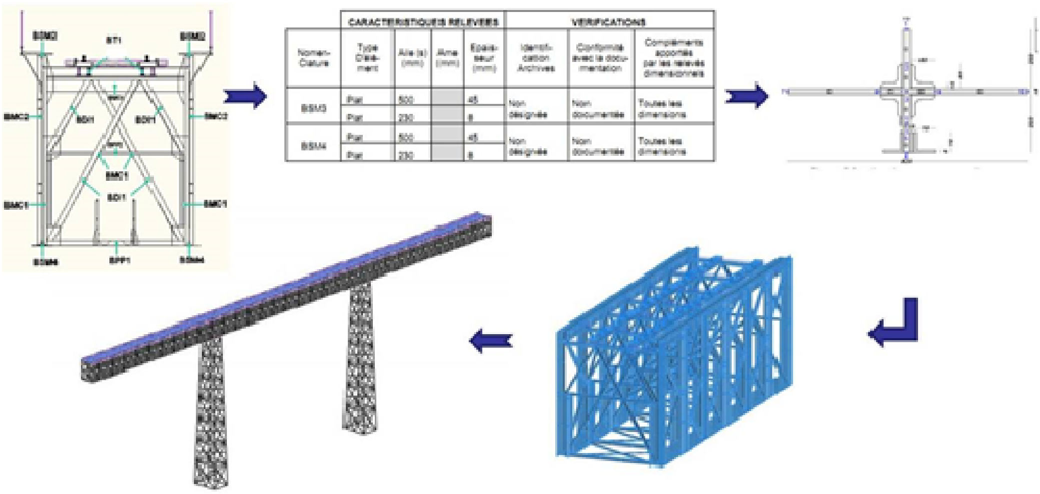

Figure 11: Structural analysis and modelling

5. FATIGUE CALCULATIONS

Given the age of these four metal viaducts, test calculations in relation to the occurrence of fatigue were carried out in order to detect sensitive zones and, where applicable, cumulative theoretical damage to the structures.
On the basis of estimates produced on the traffic since 1869 and the counts available in respect of the period from 2000 to 2007, a histogram of the loads was drawn up, which distinguished between freight and passenger trains. For each sensitive section of structure, the cumulative damage was calculated after having established pressure histograms using the water droplet method with the Pythagore® software. The results highlighted theoretical cumulative damage that was sometimes superior to 1 and revealed potential damage in certain sections.

In order to remove doubt as to the presence of cracks due to fatigue, additional investigations were carried out using magnetoscopy (for simple structures) and radiography (for structures showing more than two plats) on sensitive zones initially identified by the calculation. Radiography tests were carried out using a source of iridium 192 and D4 and D5 double films.

6. PREPARATION OF RESTORATION WORKS TO THE ROUZAT VIADUCT

The Rouzat viaduct was in fact the only one to have undergone restoration works and repainting in the second semester of 2013. Lassarat was responsible for these works with an alternative proposal consisting of using two wheeled scaffoldings of 18 ml on the deck alongside the complete confinement of the two piles (Fig. 12). The lost abrasive technique was used.

This study highlighted the need to carry out provisional reinforcements to the bottom brace of the deck (excessive compression and risk of buckling) with pliers and areas of splitting to the shafts of the piles to the right of the rafters (excessive traction in the cast iron). The cast iron piles were partially prestressed by 80 tons by being anchored into the stone by 20 tons per shaft.

Finally, a specific procedure of wind management was drawn up to provide for the partial removal of the containment of the wheeled scaffolding in an emergency should the wind speed exceed a particular limit.

Figure 12: Scaffolding on the Rouzat viaduct

Figure 13: Construction of the wheeled

In order to ensure the technical feasibility of this alternative procedure in a mandatory period of closure of the track, a specific study was carried out during the preparatory period in order to define, in close collaboration between the project manager, Lassarat and its design offices IOA and SEMI. The purpose of the study was to check that the reinforcements could be implemented without piercing the existing structure.

Given the limited size of the site and the significant heights, these operations required correspondingly substantial handling procedures to be implemented. To this end, a 120-tons crane was used to convey reinforcement collars for the piles, necessitating the closure of the RD 37 route, which the viaduct crosses.

The scaffolding around the piles was erected from the 15 April 2013, outside the period of closure of the viaduct to trains, as access to the deck was, during this phase of the works, strictly forbidden.

Once the whole bridge was placed in the hands of Lassarat on 24 June 2013, a 200-tonne crane was used to place wheeled scaffolding on the deck (Fig. 13).

7. IMPLEMENTATION OF WORKS

As the river Sioule is regulated by an upstream dam, the site accommodation could be set up along the river without fear of flooding. Two offices, a canteen, showers and changing rooms suitable for twenty or so workmen were installed below road level. A power generator, a generator of dry compressed air, and a suction device for vacuuming sanded particles were also set up nearby (Fig. 14).

Figure 14: Installation works

Figure 15: Sanding machines and abrasive reservoir

The whole area around the pile along the road was used, housing the lift, which was indispensable for transporting the teams and equipment 52 metres above the road and for optimising work time, a three-compartment airlock to manage the risk of lead, and the sanding and filtering workshops. The sanding machines were gathered in a container above which stood an abrasive reservoir container (Fig. 15). This installation, which was developed by Lassarrat, enabled the sanding machines to be gravity fed, with minimal handling and reduced outage times. The proximity to the road simplified the supply of abrasive, which was delivered by silo trucks. The area was also deployed to collect sanded particles using an impermeable container which enabled the automated bagging in an impermeable big-bag of 1.2 m³. This system was also used where the risk of asbestos was present. Finally, the air renewal plant with total filtering capacity of 60,000 m³ per hour ensured that air in containment was recycled: between 6 and 8 volumes per hour, depending on the sections.

Due to the presence of led, the sanding operations had to be carried out in a confined environment, which was created using heat-sealed tarpaulin with a thickness of 230 µm at the sides and of 600 µm on the floor of the wheeled scaffolding on the deck. Air openings were carefully positioned to ensure the renewal of air within the confined area which had a lower pressure because of the dedicated suction plant. Cramped spaces, where there was a risk that workmen may perforate the containment, were protected by means of plywood boards or by reinforcing the tarpaulin. All the workmen were given medical assessments and had blood tests prior to the start of the works and then on a monthly basis in order to monitor the risk of lead contamination in the blood.

During the design phase, a preliminary consultation process had been set up with the Pensions and Occupational Health Fund (CARSAT and CRAM) and the Professional Organisation for prevention in construction and public works (OPPBTP), which promotes health and safety and the prevention of injury in the workplace.

In order to manage the risks presented by winds, wind gauges were placed at different locations of the structure. The emergency removal of the containment and the monitoring of the weather forecasts were procedures that were strictly followed in the event of violent winds. The forecasts enabled these events to be anticipated and the works could be organised so as to prevent risks of damage to the environment in the event that the containment had to be opened.

During the suitability tests, a particular problem was discovered in respect of the stripping of the cast iron piles: there were patches of carbon deposits on the cast iron. In order to obtain even anti-corrosion protection over the entire surface of the piles, it was decided that all traces of carbon deposits should be removed and that stripping be carried out to a Sa2 ½ grade.

The structure is old and made up primarily of iron corners which have been assembled through riveting, which produces numerous rough patches and air-gaps. Stripping these surfaces is therefore very time consuming and good experience of sanding is needed in order to obtain the requisite medium G type roughness without deforming the iron by repeatedly blasting it with the abrasive.

27 tonnes of abrasive per week was used during the peak in production that was achieved by two teams of six sandblasters working in two shifts.

The sandblasters wore full-face helmets including drapes that covered the shoulders, and a glass visor to protect them against the abrasive particles bouncing off the substrate. The glass cover was regularly changed as it was polished by the abrasive.

Each operator received fresh air through a full-face mask placed under the helmet and connected to a compressor equipped with suitable filters and the change of air, a minimum of 6 volumes per hour, ensured proper visibility within the sandblasting enclosure.

The cleaning was carried out in several stages. Firstly, as much residue as possible was vacuumed up. Then all the surfaces were swept and air-blown and the area was vacuumed again. A final blast with dry air, to prevent the corrosion of the bare steel, was required prior to starting the painting works. The painting was carried out from the top to avoid depositing particles, often found in the scaffold elements, onto the freshly treated surfaces.

The application of the paint followed a specific protocol. The weather conditions were deciding factors. According to the tolerance of the applied paint, the humidity had to be less than 85% relative humidity, ambient temperature between 3 and 35°C and the temperature of the substrate had to be at least 3°C higher than the dew point. These conditions could be met either naturally or by using air heaters or heating systems in the enclosure area.

Paint pre-touches were applied to the angles and rivets by brush prior to the application by air-less sprayers of three coats of paint from the C4AMV system in order to ensure the requisite minimal thickness of paint at all points of the structure (Fig. 16).

The works was carried out over a total period of eight months, the railway line was closed for six months and the deck was in the hands of Lassarat for four and a half months. The line was restored on time and commercial traffic resumed on 16 December 2013, on a fully restored viaduct (Fig. 17).

Figure 16: First coast of painting

Figure 17: The fully restored Rouzat viaduct

8. PARTICIPANTS IN THE PROJECT

The essential parties in the realisation of this project:

- *RFF (French rail network – Réseau Ferré de France) as the client,*
- *SCET (Société Centrale pour l'Equipement du Territoire), ALGOE, EGIS, SeAu (Société d'équipement de l'Auvergne) as the client representative,*
- *SETEC FERROVIARE and DIADES as project manager with the occasional assistance of IPRS, SETEC TPI,*

and the companies which accompanied us during this project :

- *LASSARAT assisted by ENTREPOSE in supplying the scaffolding system,*
- *ADS for the metal framewotk,*
- *IOA for the different implementation studies,*
- *SEMI which provides the methods.*

9. PRINCIPAL QUANTITIES

During the reparation work on the Rouzat viaduct, nearly 9,000 hours were dedicated to the bridge by the company, with 2 shifts of 24 workmen, two supports persons and up to eight sandblasters working simultaneously; generating 1200 tons of waste on a combined weight of the scaffoldings of 130 tons. The surface of containment was about 6300 m² and the stripped surface about 10 200 m². About 1500 liters of paint were used for the application of 3 coats of the anti-corrosion complex.

10. CONCLUSIONS

The works was carried out over a total period of eight months, the railway line was closed for six months and the deck was in the hands of Lassarat for four and a half months. The line was restored on time and commercial traffic resumed on 16 December 2013, on a fully restored viaduct.