Réunion Island’s New Coastal Road: A Viaduct with a Wide Precast Deck and Piers

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Introduction: Recent Structures and Research in France

Nantes, France, will host the 40th IABSE Symposium with the main theme of ‘Tomorrow’s Megastructures’. Popularised in the 1960s as an architectural concept, a megastructure refers to a very large man-made object, although the limits of precisely how large vary considerably. In anticipation of this upcoming symposium, the current SEI Special Issue includes a collection of papers describing recent structures and research in France or by French researchers and engineers. Bridges, buildings and railway projects of varying sizes—not just megastructures—are presented, covering both new construction projects and the retrofitting of existing structures. Included in this series are two new bridges over the Rhine in Strasbourg, the Vidourle Viaduct on a high-speed rail line with mixed traffic, the railway station project under the CNIT in La Defense, Paris, the new coastal road viaduct with its precast wide deck at La Reunion Island, the Art School Emile Cohl in Lyon, as well as several other interesting papers.

It is hoped that the papers presented here will serve to excite readers about the possibility of travelling to Nantes in 2018 to participate in the upcoming IABSE Symposium organised by the French Group of IABSE and the French Association of Civil Engineering (AFGC). Not only will the symposium give attendees the chance to participate in hundreds of interesting presentations given by engineers and researchers from around the world, also featured at the symposium will be a remarkable list of keynote speakers, and panellists, as well as several workshops, technical tours and social events.

Ann Schumacher
SEI Editorial Board, Chair 2013–2017, Chief Reviewer Special Series

Bruno Godart
Chair of the Organising Committee of IABSE Symposium, Nantes 2018, Guest Chief Reviewer Special Series

Réunion Island’s New Coastal Road: A Viaduct with a Wide Precast Deck and Piers

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Abstract

After massive rock falls from a cliff cut off Réunion Island’s current four-lane coastal road, a decision was made to replace it with the New Coastal Road, allowing the inhabitants of Réunion Island—situated in the Indian Ocean to the east of Madagascar—to travel between Saint-Denis and its commercial harbour quickly and safely. Saint-Denis is the capital in the east, and the harbour is approximately 20 km west, near to La Possession. Almost completely situated at sea, the project stretches over 12.5 km and will primarily consist of the Grande Chaloupe Viaduct—a series of dykes spanning a total length of 6.7 km—and a viaduct spanning 5.4 km that is made up of seven viaducts of equal length. This paper examines a large viaduct prefabricated in its entirety near the harbour and then assembled at sea using the cantilever method. Due to its wide deck (28.9 m) and thin webs, the analysis focuses on the safe design of a structure situated in an environment prone to cyclones, strong swells and seismic events. The contract for the design and construction of the new viaduct was signed in 2014; the project is due for completion in 2018/2019.

Keywords: precast; segments; prestressing; shear keys; finite elements

Introduction

The New Coastal Road will allow the inhabitants of Réunion Island—situated in the Indian Ocean to the east of Madagascar—to travel quickly and safely between Saint-Denis, the capital in the east, and the commercial harbour situated approximately 20 km to the west (Fig. 1).

The current four-lane coastal road at the foot of the cliffs can be cut off due to strong swells and falling rocks, in spite of safety nets to protect against the latter. Traffic lanes are often closed, generating traffic jams.

The New Coastal Road stretches over 12.5 km between Saint-Denis and La Possession. The project includes a viaduct spanning 5.4 km (which will be the longest viaduct in France and all of its territories on the ground or at sea) followed by the Grande Chaloupe Viaduct and a series of dykes spanning another 6.7 km. The 5.4-km viaduct will be situated completely at sea (Fig. 2) and run parallel to the coast between 20 and 30 m above sea level.

The New Coastal Road will be clearly wider, operating a total of six lanes at first, in addition to soft traffic (pedestrians and cyclists). A trolley line will be added to the deck at a later date.

The tender—set up by EGIS, the engineering group of the owner, La Réunion Region—features two basic technical solutions, both of which employ the traditional cantilever construction method. The first features spans of 120 m in length and a
monocellular box girder with transverse ribs allowing an overhang of 0.22 m thickness. The second features spans of 100 m in length and multicellular box girders with four webs. The foundations of the solutions consist of spread foundations for one half of the piers and four deep piles of 4 m diameter for the other.

The tender was awarded to a joint venture combining VINCI Construction Major Projects (the project leader) and Dodin Campenon Bernard (two entities of VINCI’s Division of Major Projects) with Bouygues Travaux Publics and Demathieu Bard Construction due to the alternative proposed by the joint venture. The cost of this alternative amounted to €715 million with the following technical characteristics:

- Prefabrication of all the elements of the project;
- A deck of variable depth and 120 m span designed with a monocellular box girder with two webs; overhangs with transversal post-tensioning but without transverse ribs, in order to simplify the prefabrication of the segments;
- The elimination of piles (except for the two abutments at each extremity of the viaducts) through circular shallow foundations, subject to confirmation following additional geotechnical surveys, with the possibility of local soil improvement on a case-by-case basis.

This technical alternative provides substantial savings to the owner’s proposals thanks to the elimination of the deep foundations. It was, therefore, developed after the awarding of the contract. For efficiency reasons, the joint venture combined the resources of the contractors’ own structural design offices rather than subcontracting the design work. The design team was located in a dedicated open-plan office and all calculations were performed with single finite element analysis software (SOFiSTiK) for all models in order to secure production.
The New Coastal Road

Essentially situated in the sea, far away from the cliffs, the marine section of the New Coastal Road is designed to have a lifespan of one hundred years, taking into account conditions such as cyclones and swells. During construction and operation there will likely be several climate hazards to overcome, including swells, cyclones, trade winds, earthquakes and even ship collisions.

The project is constituted of seven separate viaducts whose lengths are 771.285 m for the end viaducts (Viaducts 1 and 7) and 773.286 m for the middle viaducts (Viaducts 2 to 6). The lengths are defined between pier centre lines at the extremities of each viaduct, totalling 5409 m. Each of these seven viaducts have six sections spanning 120 m in length, and all of the side spans are 84.643 m in length. The alignment consists of a series of curves, the shortest radius being 1500 m (Fig. 3).

During the service life, the Owner has defined three successive types of operation modes; the last one will see the trolley line in operation. These three modes are shown in Fig. 4. The first mode (Fig. 4a) is a road-only operation with a dedicated car lane on the cliff side of the transverse cross section. The second mode (Fig. 4b) substitutes the dedicated car lane with a trolley line. The final mode (Fig. 4c) with its reserved two trolley lines will correspond to the final stage of the deck arrangement with the installation of a lateral walkway for pedestrians and cyclists on the oceanic side.

The Decks

Each deck is a prestressed concrete box girder 28.90 m in width and featuring two webs. It is totally precast and its segments are match cast. Its depth is variable, ranging from 7.3 m on the pier to 3.8 m at mid-span following a polynomial law of the power of 2.5. The thickness of the web is 0.65 m. The webs are inclined at 30° to the vertical, which is uncommon for this type of deck. This results in significant variation of the bottom slab width, which ranges from 14.024 m at the mid-span to 10 m on the pier segments.

Each half cantilever is 59.86 m long and is broken down into 14 segments relating to the lifting and erection capacities both on the precast yard and on the site. The standard length of a segment is 4.015 m. The segment weights vary between 230 and 275 t (Fig. 5). The segment on the pier (VSP) with a length of 7.3 m was split into three parts, weighing in total approximately 1300 t. The partition is guided by the lifting capacity at the casting yard to allow the first segment to be match cast against the lateral elements of the VSP. The three parts are assembled after the prefabrication of the cantilever segments on the casting yard begins. The VSP is completed on each side with the first two deck segments (V1 and V2) to constitute the mega VSP (MGVSP) with a total weight of 2400 t. At each end of the side span, the segment on the shared pier-abutment or abutment is 4.30 m long and built as a single element.

The design of the deck prestressing is typically the result of mixed technology. A prestressing internal to the concrete is used for stability during construction and completed by an external prestressing to the concrete, ensuring the total compression of joints for the operational stages. This external prestressing needs two intermediate deviator cross beams per span, as well as each side span.

To study and define all the necessary tendons, two models were created using SOFiSTiK (Fig. 6). The first uses a finite shell element model to analyse the shear lag effect and the spreading of prestressing. It takes into account the scale effect due to the large width of the box girder. This analysis provides an added lump sum stress in the sizing of prestressing in order to use the second model with beam elements and accurate, time-dependent, historical analysis of stages and creep effect.

To complete this longitudinal prestressing, a transverse prestressing with monostrands is installed and staged in the yard on the precast unit before pouring the next matchcast segment. This is to limit the differential deflections between segments and therefore retain compatibility for the site installation. In

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1 The first uses a finite shell element model to analyse the shear lag effect and the spreading of prestressing. It takes into account the scale effect due to the large width of the box girder. This analysis provides an added lump sum stress in the sizing of prestressing in order to use the second model with beam elements and accurate, time-dependent, historical analysis of stages and creep effect.
order to avoid any halt in the on-site construction cycle, no error can be accepted—so it is necessary to make an inventory of all the specificities of this precast construction and analyse feedback from similar previous constructions.

The deck is assembled following the cantilever method using a launching beam that is supported by two lattice towers, a pendulous front leg and a pendulous rear leg. During a typical sequence of cantilever construction, one of the lattice towers rests on the

Fig. 4: Operation modes: (a) functional cross-section at opening; (b) functional cross-section with one trolley line with alternated traffic; (c) functional cross-section with two trolley lines as part of final stage
cantilever during construction, the second is on the previous cantilever that has already been built, and the front leg is on the next pier (Fig. 7).

For assembly on-site, temporary prestressed bars are tensioned through concrete internal blisters or external steel blisters. Shear keys (Fig. 8) complete these dispositions to ensure the matching after applying glue and the stability before drying. These vertical joints are not considered interfaces between concrete castings at different times.

As shown in Ref. [2], the usage of epoxy glue during polymerization results in a structural continuity that is completed by the grouted tendons working as bonded reinforcement. The joint stability was performed using the recommendations in Refs. [3–4] and provisions were completed using the results of the research conducted in Refs. [5–6].

The shear keys in the bottom and top slabs with a low density ease the assembly on-site and avoid local high loads when assembling adjacent segments with small geometrical differences due to shrinkage, local creep and temperature gradient. Specific and detailed calculations were generated using finite element models in SOFiSTiK1 to check the deflections of wide corbels due to the match-casting stages inducing creep and shrinkage with the transverse prestressing. The following impacts of deflections were taken into account:

1. Thermal deflections inducing the bowing effect phenomenon.
2. Stages of transverse prestressing.
3. Long-term deflection due to storage in the casting yard.
4. Impact of the lifting sequences during erection.

The bowing effect is limited to the segments where the width-to-length ratio w/l is over 6 to 7 (if the segments are not slender).5,7 In the NRL project (w = 28.9 m) this is only the case with the first joint between the pier segment and the first segment V1, as the second and third parts of the pier segments have a length of 1.7 m. This effect creates an expectable horizontal deflection that prevents the match cast of the next joint and the joints that follow. Thus, a non-match-cast joint poured in the yard was provided between V1 and the VSP at the top fibre to wipe away any deflection (Fig. 9).

Deflections due to prestressing stages and storage were studied with a time-dependent analysis in SOFiSTiK1 to foresee the differential variations of deflections between segments. Therefore, the shear introduced into the keys during erection was checked with the pressure between the joints’ glued surfaces to fit very accurately.
The effect of lifting during erection was also introduced into the analysis. Other analyses were also performed, such as checking the deflection of the upper slab, under the tyre-mounted, low-bed, semi-trailer load used to feed each segment to the launching girder, in order to check the behaviour of the joints.

The segments are brought into alignment and adjustment in the precast cellar using computing data. All constraints of the project alignment and the camber coming from the structural bridge analysis were taken into account. Prefabrication was extended to the piers and foundations.

The Piers and Foundations

The piers and foundations were analysed to assure the stability of the cantilevers during cyclones, cyclone swells and the construction processes. Once operational, the results of the analyses will ensure that the foundations and piers can withstand earthquakes, ship collisions and cyclones.

The piers and foundations were segmented into two parts to define two stages of assembly on-site. A joint of 1.5 m height cast in place is kept to pour in good condition the stitch between these segments.

The first part includes shallow foundations that are 20 to 23 m in diameter completed with the lower part of the pier shaft, ensuring that a certain amount of the joint remains above sea level. The diameter depends on whether the bearings are fixed or not, and whether or not there is a shared pier between two viaducts. The weight of this part is around 3200 to 4200 t.

The second part includes the end of the shaft, which is completed by the pier cap, where temporary bearings and definitive bearings are installed. This second part, weighing 1000 to 2000 t, receives the MGVSP.

The installation on-site is carried out using the “Zourite” barge capable of lifting up to 4800 t (Fig. 10). The erection of the piers on-site requires two trips with three sequences of lifting. The second trip concerns the second part of the process, which is completed with the MGVSP erection, yielding a total weight of 4400t. Each of these two trips does not exceed the capacity of the Zourite barge.
The sequences of lifting follow the sketch in Figure 11 wherein the beginning of the cantilever erection follows phase 3 (the erection of the MGVSP via the Zourite barge). The main issue here is obtaining accurate positioning of the pier and the MGVSP erection despite the swell and the wind.

The first viaduct (V7) was completed in July 2017, and V6 and V5 are completed at the time of writing (Fig. 12). The erection of the remaining viaducts (V4 to V1) is scheduled to follow a consistent tempo with the aim of completing the whole span in 2018/2019.

Conclusions

An entirely precast viaduct requires a lot of detailed calculations in order to provide an accurate adjustment of all the elements of the process of on-site assembly. These analyses can predict the behaviour of the structure during all construction stages, from prefabrication in the casting yard through to erection on-site. To date, no interruptions to the construction cycle have occurred due to abnormal deflections and the surveys have not revealed values outside the permitted tolerances. It is necessary to bear in mind, however, that the precast segmental method should only be attempted by experienced professionals.

References

[1] SOFiSTiK. Oberschleissheim: SOFiSTiK AG.

SEI Data Block

Owner: La Réunion Region
Owner's Engineer: EGIS
Contractor: Joint Venture VINCI Construction Major Projects (leader), Dodin Camponon Bernard (two entities of VINCI’S Division of the Major Projects), Bouygues Travaux Publics, Demathieu Bard Construction
Designer: Engineers from the JV

Concrete deck (m³): 143 500
Concrete for piers and spread foundations (m³): 99 890
Reinforcement (t): 50 000
Prestressing (t): 9 250
Estimated cost (EUR millions): 715
Estimated service date: 2019

Fig. 12: Overhead view of the viaducts V7 and V6 (© Sébastien Marchal)