A new concept for a large vertical lift bridge over the River Seine in Rouen

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Summary

A large new lift bridge is being completed over the River Seine, half way between the City of Rouen and its harbour located downstream.

To fit with this environment engineers and architects have designed an innovative structure, which combines efficiency, reliability and elegance.

Its masterpiece is the lifting system, located in between the two independent lifting spans. It features two reinforced concrete hollow shafts supporting an innovative and ingenious butterfly–shaped, cross-leverage system, which optimizes both structural and mechanical designs.

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Fig 1: The new bridge and its towers, half way between city and harbour (photo-montage)

1. Introduction

Rouen is a historical harbour city located half way between Paris and Le Havre harbour. As early as 1972, urban planning showed that a new North-South highway connection was required, with a new crossing of the River Seine, at a location where maritime traffic had to be maintained in order to allow large cruise-ships, as well as historical sail-ships, to reach the city heart. This new construction raised many environmental and urban issues, until a decision was taken to build a vertical lift bridge.
Because of the size and impact of the project, located half way between the historical city of Rouen, dominated by its famous cathedral, and the harbour (fig 1), a design competition between engineers and architects teams was organised. The award winning team, led by Arcadis, with Michel Virlogeux as consultant, Aymeric Zublena as architect and Eurodim as E&M Engineer, developed a new concept, with lifting towers located in between the two independent spans.

This paper first presents shortly the project context, and a brief review of lift bridges history. It then describes the design development, starting with the lifting towers, which were the key architectural and structural item, and goes on with deck design, mechanical engineering, wind engineering and ship impact risk assessment.

It shows how a global approach, combining structural and functional optimisation with sensible architecture led to an elegant, efficient and economical structure. It describes also the specificity of this project which combines civil and mechanical engineering at an exceptional level of interference.

2. Context

The need for this new highway connection appeared in Rouen area urban planning as early as 1972. It was clear from the beginning that it should be located along the western city limits, half way between the historical centre and the harbour. It therefore had to cross the River Seine.

Maritime traffic from Le Havre towards Paris stops in Rouen, from where inland traffic only is allowed to navigate upstream. As a matter of fact, the existing five bridges crossing the River Seine in Rouen allow inland traffic only, while all three bridges downstream (Normandy, Tancarville and Brotonne bridges) allow maritime traffic.

However it was decided that this new crossing, located downstream and referred to as “the 6th crossing”, had to allow seagoing ships, with sizes up to 40000 DWT, to sail through it. Although this traffic is stopped 1.5 km upstream by Guillaume le Conquérant Bridge, it was indeed considered mandatory that cruise ships, as well as “Armada” large sail ships, could navigate up as close as possible to the historical city centre.

Three options were considered: a tunnel, a high rise fixed bridge, or a lift bridge. The high rise bridge was not acceptable because of its visual impact, nearby the historical city and its famous cathedral. As the tunnel appeared too expensive, the lift bridge option was adopted.

While the River Seine at this location is 180 m wide, the basic clearance requirements were a minimum opening of 86 meters, and a minimum height of 55 m when lifted, 7 m when lowered. Typically, lift bridges require two high towers which carry the lifting equipments and guide the lifting spans. With a vertical clearance of 55 meters, these towers have to be about 80 meters high, and have a strong impact upon the surrounding landscape, which in the vicinity of the bridge is widely opened, with the cathedral towers in the background.

3. Lift bridges state of the art

Among mobile bridges, lift ones appear as the right answer when relatively long spans are needed. Bascule bridges or rotating ones are more limited, because of their overhanging decks.

In France the existing lift bridge with the longest span is “Recouvrance” Bridge in Brest (fig 2), with an 87.5 meters lifting span.

But most large bridges of this kind are located in New Jersey, where many waterways allow maritime traffic. The longest lifting span in the world belongs to Arthur Kill Bridge with 170 meters, no longer in operation. An other significant structures is shown below: Gil Hodges Memorial Bridge (fig 3), with a main span in the range of 160 meters.
As it appears these bridges decks are steel trusses, with a relatively heavy and industrial aspect. Our approach departed strongly from these, in order to meet the owner’s expectations of elegance and fitness with the surrounding urban and industrial environment.
4. Design

The design brief specified that the bridge comprise two independent spans carrying 3 roadway lanes and a 2.5 meter wide walkway, which leads to 18 metre wide decks. Furthermore, in order to facilitate maintenance, each span has to be lifted independently.

4.1 Towers design and lifting principles:

The towers design, definitely the main issue, was the result of a thorough process, as illustrated in fig5. We first considered placing towers on each side of both spans, independent or forming an arch (sketches 1, 2, and 3), but these solutions appeared rather clumsy. Furthermore, the bridge alignment is at a skew angle with the River, and the towers have to be perpendicular to the bridge alignment. Consequently such wide towers would have led to a significantly longer central span and would have interfered with the flow.

This led us to develop a new concept by placing towers in between the spans, with lifting equipments overhanging out on both sides, symmetrically (Sketches 4 to 8). Two lifting principles were considered: either cantilever beams connected to a vertical element located inside the towers, or cables attached to overhanging structures located at towers top. In both case lifting was obtained by a combination of counterweights and winches.

Choosing between these two concepts was clearly a key issue, and we fully analyzed advantages and disadvantages of both. We finally opted for the second one, because of its simplicity, reliability and lower cost.

As shown by sketches 6 to 8, we refined this solution, mainly by crossing the cables, which avoided applying bending into the towers.

Fig 5: Towers design
Each span may be lifted independently of the other by the action of winches located into large caissons supporting the towers. These lifting principles are illustrated by fig 6, which shows how the structural design fits with forces diagrams.

Each tower comprises two hollow concrete shafts, resting upon an elliptical caisson. In order to minimize interference with the river flow, this caisson is parallel to the river main direction, while the tower shafts are at right angle to the bridge alignment (fig 7).

At the top, an elegant steel structure supports the pulleys with three parallel frames, designed in such a way that members carry normal forces only. Its shape led to call it the “butterfly” (fig 8).
4.2 Deck design:

For architectural reasons, we disregarded conventional approaches using lateral truss beams, and opted for a box beam. To minimize their weight, which in the case of a lift bridge is mandatory, the spans are entirely made of steel, and the roadway overlay is an 8 mm thick epoxy layer.

The deck cross section evolved from a rectangular box with large overhangs stabilized by inclined struts, to a streamlined box (fig 9) with inclined webs. This evolution was dictated by wind engineering, as explained in 4.4 below.

Fig 9: Deck section design
4.3 Mechanical Engineering:

4.3.1 Lifting system:

Each span is lifted by 16 cables, 8 at each extremity, and 4 on each side of the roadway. Of those 4 cables, 2 are connected to a “dead” counterweight, and the other 2 to a counterweight connected itself to a winch. Each extremity of a span is therefore lifted by two winches, and a total of 8 winches is installed, 4 in each tower. The 8 winches used to lift the two spans are synchronized, 4 by 4.

This design is extremely reliable, because of its simplicity, and for the following specific reasons:

- All pulleys are independent, which avoids risks linked to micro-differential movements.
- Cables are coupled: thus in case of a cable rupture, its load is transferred to the adjacent one.
- Cables fatigue is minimized: load variations either do not exist (cables connected to “dead” counterweights), or are relatively low (cables connected to “active” counterweights).

Locking in upper position is obtained through the winches electrical motors. To keep things simple there is no mechanical locking. As a consequence, cables apply a permanent uplift force to the spans, which reduces significantly the load applied by these spans to their supports. This is one of the reasons why the deck had to be streamlined, in order to minimize the overturning moment resulting from wind action.

It ought to be mentioned that, with the motors acting as brakes, decks may be locked at any height.

4.3.2 Deck Guiding system during lifting operations:

In order to control horizontal movements during lifting operations, spans are guided at each extremity by “chariots” rolling up and down into a groove located alongside the towers shafts.

4.4 Wind engineering:

Although it was not anticipated at early planning stages, preliminary design showed that wind would have significant effects and that a thorough analysis was necessary, including wind tunnel testing. Furthermore, these tests were necessary to take into account “screen” interaction between the two adjacent spans, in their various positions.

Two aspects of wind action needed indeed to be addressed:

- As indicated in 4.3.1 above, wind loads on spans, when resting upon their permanent bearings, create overturning and uplift forces which may result into uplift at bearing locations, since permanent loads are significantly reduced by cables uplift forces. Therefore overturning and uplift forces had to be carefully checked.
- Vibrations induced by wind needed also to be analyzed through wind tunnel test. This lead to the addition of tuned mass dampers into the decks, at mid span and at both extremities.
4.5 Ship impact protection:

Large cruise ships, up to 40000DWT, will be allowed under the bridge. It appeared necessary, although those ships shall sail at very low speeds (approx 2m/s), to protect piers against ship impact. To do so four large dolphins (fig 7) were placed upstream and downstream of each pier. These are large concrete cylindrical boxes, 20 m in diameter, resting directly upon the river bed, and filled with gravels.

5. Conclusion

This simple and efficient design led to an elegant structure which reflects a strong and thorough cooperation between engineers and architects, and departs radically from previous approaches to lift bridges design. It may hopefully initiate new developments in this particular field, where civil and structural engineering have to meet increasing demands for architectural quality.

Construction is now completed and fine tuning is under way prior to operations.