Bridge at Joigny: High-Strength-Concrete Experimental Bridge

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An experimental bridge constructed of high-strength concrete has been built at Joigny, France. The project is part of a national research program bringing together the French Ministry of Public Works and Ministry of Research, the cement industry, university and state laboratories, and professional associations and institutions. The bridge has been instrumented in order to verify its long-term behavior and its durability in comparison with that of ordinary concrete bridges.

In 1985 the French Ministry of Public Works, in association with the Ministry of Research, launched the so-called Projets Nationaux de Recherche et de Développement (National R&D Projects) in the field of civil engineering. One of these projects was devoted to Voies Nouvelles du Matériau Béton (New Developments for Concrete). The objectives of this project are clearly defined by its title: to identify and develop new ways to use the materials that make up concrete.

The objectives of this project can be achieved through construction of experimental structures based on preliminary applied research and through instrumentation of these structures. The implementation of this project is based on four leading principles:

1. To ensure a continuous relationship among basic research, end-user-oriented research, experimental structures, codes, and development. The construction of experimental structures is necessary to demonstrate the actual usefulness of new materials, to evaluate their durability, to assess their economic input, to calibrate and update future codes, and to raise new subjects for further research.
2. To associate new materials with new design concepts.
3. To highlight the notion of "high-performance materials." A global approach to the various properties of concrete allows the adviser, the designer, or the owner to emphasize one or several specific properties of the material. If, as far as new concretes are concerned, their most familiar property is their high compressive strength, it should be borne in mind that other prominent properties should be considered, such as increased durability, frost-thawing resistance, abrasion resistance, or imperviousness to water and gas. This explains why the American high-strength concrete (HSC) has been termed "high-performance concrete" in France.
4. To stress the fact that, as a rule, these high-strength or high-performance concretes, because of their increased durability, will be specified more and more by clients.

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To fulfill its objectives, the project brings together state and private owners such as the Ministry of Public Works, the French Electricity Board (EDF), and the Paris Airport Authority (ADP); the cement industry; large contractors; university, private, and state laboratories; as well as professional associations and institutions.

The project is funded by these members. The budget amounts to about $10 million (U.S.) for a 5-year period, excluding the cost of experimental construction. The Ministry of Public Works subsidizes the project by an incentive support of about $1.20 million (U.S.).

As a matter of fact, a highly valuable contribution is made by the Direction des Routes (Road Direction) of the Ministry of Public Works through its active support in helping to find possible construction sites for experimental HSC bridges.

THE BRIDGE AT JOIGNY

Extensive research and development carried out on HSC in several French civil engineering laboratories made it possible to consider the construction of an actual experimental bridge with HSC.

Aim of the Experiment

The French Ministry of Public Works agreed with the national project team on the following criteria for choosing the nature and location of the experimental bridge:

- The bridge should be representative of current bridge construction and not be exceptional in any way.
- The bridge should not be located near large towns or industrial areas, in which facilities would easily be found.
- The 28-day characteristic strength of the concrete should be 60 MPa (8,600 psi) (generally, French bridges use 35- to 40-MPa concretes).
- The bridge should be built using local cement and aggregates. Local ready-mixed concrete plants were to furnish the material so that their proper capabilities could be checked. The use of silica fume was excluded, because it had been proved that this material was not really necessary to obtain the specified HSC.
- The bridge should be designed according to French building code BPEL 83, which deals with prestressed concrete structures. All the possibilities offered by the enhanced strength of the concrete should be exploited.

- The bridge should be instrumented in order to collect data on its behavior and to verify the validity of the conceptual approach. This criterion led to the specification of cast-in-situ construction methods in order to avoid interference by construction temporary stress distribution.

To summarize these criteria, it can be said that the aim of the experiment was to demonstrate the feasibility of building a typical bridge using C 60 concrete and the unsophisticated means and materials that can be found everywhere in France.

Basic Features of the Bridge

Geometrical Description

The bridge crosses the Yonne River near the town of Joigny. Its concept is quite classical. Aesthetics as well as economics influenced the choice of a balanced, continuous, three-span bridge [i.e., 34, 46, and 34 m (112, 151, and 112 ft)] with a height of 2.2 m (87 in.) and an overall width of 15.8 m (52 ft).

The bridge double-tee cross section is made of two main beams with a trapezoidal cross section and an upper slab. The distance between beam axes is 8 m (26 ft). Their minimal width at the bottom chord is 0.5 m (20 in.).

Prestressing

The structure is prestressed longitudinally by 13 external tendons, each made of twenty-seven 1.5-cm (0.6-in.) strands. External tendons offer three advantages:

1. The width of the webs can be reduced to a minimal value determined chiefly by normal stress considerations. A lighter structure is thus obtained.
2. The tendons may be easily replaced if necessary. This is an advantage, because the C 60 concrete being more durable than ordinary concrete, the life span of the high-tensile steel may be shorter than that of the concrete.
3. In the case of an experimental structure, this layout allows simpler and more accurate prestressing force measurements in the tendons.

Design Stresses

The bridge was designed according to the French codes Béton Précontraint aux Etats Limites (BPEL) (Limit-States Design of Prestressed Concrete) and Béton Armé aux Etats Limites (BAEL) (Limit-States Design of Reinforced Concrete). These codes formerly dealt only with concretes up to C 40 but have been upgraded in order to incorporate C 60 concretes. Only minor adjustments to the codes had to be made, mainly concerning the creep coefficient, which was reduced from 2.00 to 1.50 for C 60 concretes.

The use of these codes, which include different safety factors, led to an actual maximal compressive stress of 30 MPa in the lower fiber of the midsection of the central span during the last stages of prestressing.

High-Strength Concrete Versus Ordinary Concrete

It should be emphasized that comparisons carried out during the preliminary studies of the bridge showed that the concrete quantities could be reduced from about 1395 m^3 (1,800 yd^3), when ordinary C 35 concrete was used to 985 m^3 (1,300 yd^3) with C 60 HSC. This 30 percent reduction in concrete volume led to a 24 percent load reduction onto the pier, abutments, and foundations.

The decreased dead weight also induces savings in the quantities of prestressing strands. Because the height-to-span ratios were slightly different in the two solutions, the steel savings were not as large as they could have been if these ratios had been identical.

Concrete Design

Exhaustive laboratory tests were run in order to define a mix design allowing the production of a ready-mixed concrete with the following properties:

- Mean 28-day strength of about 70 MPa with a minimal standard deviation,
- Ability to be transported and delivered fresh to a construction site 30 km (about 20 mi) from the concrete plant,
- Ability to be pumped in pipes 120 m (470 ft) long,
- High workability after a sufficient time.

The concrete batch constituents were as follows:

- Fine aggregate: sand from Yonne River, 0/4 mm; corrective sand, 0.080/0.13 mm;
- Coarse aggregate, 6/20 mm;
- Cement HS PC, 450 kg/m^3 (760 lb/yd^3);
- Water, 161 liters/m^3 (271 lb/yd^3);
- WRA and retarder.

Concrete Properties

Fresh Concrete

The water/cement (W/C) ratio, measured at the plant for every batch, remained between 0.362 and 0.377. The slumps, measured at the site, were over 200 mm for more than 2 hr. The entrained air contents were within 0.5 and 1 percent.

Hardened Concrete

Compressive Strength The concrete strength was measured on test samples. According to the French standards, these are cylinders with a diameter of about 160 mm (cross section of 20,000 mm^2) and a height of 320 mm, which were cast in metallic molds.

The mean compressive strength f_{cm} was as follows:

Age (days)	*Strength (MPa)*
3	26.10
7	53.60
8	78.00
57 (150-mm-diameter in situ cores)	86.05

At 28 days, the minimum and maximum strength values were 65.5 and 91.7 MPa, respectively, and the standard deviation σ reached 6.75 MPa. The French Construction Code (Fascicule 65) requires for this kind of ready-mixed concrete that

1. The mean strength be at least equal to the characteristic strength value f_{ck} plus a margin

$$f_{cm} \geq f_{ck} + 1.30\sigma$$

2. The minimum strength be larger than the characteristic strength f_{ck} minus a margin

$$f_{cmin} > f_{ck} - 3 \text{ MPa}$$

These 28-day strength requirements were easily met.

Comparative tests were carried out between different types of samples: ϕ 160- x 320-mm usual reference cylinders, ϕ 160- x 320-mm cylinders with ground bearing faces, ϕ 110- x 220-mm cylinders, ϕ 100- x 100- x 100-mm cubes, ϕ 150- x 300-mm in situ cores, ϕ 100- x 200-mm in situ cores, and ϕ 70- x 140-mm in situ cores.

The results were as follows:

Sample	*Strength (MPa)*
Reference	71.9
Ground	71.2
Cylinder	67.7
Cube	83.9
150-mm core	76.7
100-mm core	84.2
70-mm core	75.5

Tensile Strength The tensile strength was measured on cylinders with the Brasilian splitting test. The average tensile strength was 5.07 MPa on 28-day samples.

Placement of Concrete

The contract required that the concrete be poured in one continuous phase. In order to avoid any delay, two independent ready-mixed concrete plants were to deliver the same concrete. In this way, even if one of them was out of order, the nonstop pouring operations could be completed at a lower rate.

The 1000 m^3 (1,300 yd^3) of concrete was placed without any incident by two pumps in 24 hr, as planned.

Instrumentation

The bridge was instrumented in order to follow its behavior during a period of several years. The experimentation is being run by the Laboratoire Central des Ponts et Chaussées (Central Laboratory for Roads and Bridges), which is under the direction of the Ministry of Public Works.

The goals of the experimentation are threefold: to observe the thermal evolution of concrete during the setting phase, to determine prestressing forces and deformations, and to study creep and shrinkage of the concrete.

Thermal Evolution of Concrete

During the setting phase at the mid-central span and in the massive end blocks, the maximum temperatures measured were

- 73°C in the middle of the end blocks,
- 57°C in the webs, and
- 32°C in the upper slab.

A special finite-element program was run to check these values. In order to calibrate the finite-element calculations, a quasi-adiabatic test was carried out to obtain the temperature variations of a concrete specimen. The results of the calculations are in good accordance with the measurements.

Prestressing Forces and Deformations

The deformations of a cross section located near the middle of the central span were continuously recorded. The rotations of the same span were also measured and recorded. The measured deformations are currently 15 percent smaller than those predicted by calculation. This discrepancy can be attributed to an underevaluation of the Young's modulus.

The time evolution of the tensile forces in the longitudinal tendons was measured. The first measured values were 5.10 MN per tendon near the anchorages and 5.20 MN at the mid-central span. The calculations predicted 5.10 and 4.90 MN, respectively. These differences can be attributed to an over-evaluation of friction at the deviator transverse beams.

Creep and Shrinkage of Concrete

A major part of the experiment was devoted to the study of the shrinkage and creep of the concrete. Sixteen tests are to be carried out during the next few years on various specimens:

1. On specimens made with the in situ concrete, two shrinkage tests, with and without drying, and two creep tests, with and without drying, loaded at 28 days.
2. On laboratory specimens made with a concrete using the site materials with the same composition as the in situ concrete, four shrinkage tests and eight creep tests loaded and unloaded at different ages.

The results of these tests will be available within a few years.

CONCLUSIONS

The first French prestressed concrete bridge designed and built with a 60-MPa characteristic strength concrete according to the French building codes was successfully completed by early 1989.

The bridge has been instrumented in order to verify the assumptions taken into account in the calculations, to check its long-term behavior, and more generally to assess its supposedly increased durability as compared with that of ordinary concrete bridges.

Economic comparisons made it clear that although its unit price per cubic meter is higher than that of ordinary concrete, HSC leads to reduced immediate total investments thanks to material savings and higher construction productivity. These conclusions were reached without taking into account immaterial and long-term added savings provided by the inherent enhanced durability of HSC.

It is worth stressing that the bridge, which was built for the Ministry of Public Works, is to be incorporated into one of the main French roads. This first achievement of the national project on new concretes is to be followed by further steps:

1. In accordance with the wishes of the French Road Direction, the utilization of C 60 concretes will be extended to the construction of most bridges in the coming years.
2. Other experimental bridges implementing HSC with higher characteristic strength will be built in the near future.

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