Seonyu Ductal® footbridge

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Summary

SEOUL Seonyu footbridge links the main town of Seoul to Sunyudo Island in the Han river. The footbridge consists of two steel accesses that will be born by a Ductal® arch.

The span length of the arch is 120 m. The accesses have a bearing situated on the arch extrados, on both sides of its axis. The pedestrians will walk directly on the central part of the arch.

The arch has got a π shaped cross section, consisting in a transversally ribbed upper slab and two girders. The width of this arch is 4.3 m and its depth 1.3 m.

Ductal® is an ultra high performance concrete reinforced with fibres. The mean compressive strength of Ductal® is 200 MPa.

The vibration of the footbridge was considered. A solution using Tuned Mass Damper (TMD) was selected and installed.

Keywords: Ultra high performance concrete, Ductal®, Footbridge, Arch, Precasting, Vibration, Tuned Mass Damper.

1. Introduction

The city of Seoul is currently in the midst of a long-term project known as “New Seoul, Our Han River,” which consists in setting up easily accessible parks near the river, re-establishing the river’s ecosystem, and organising a variety of cultural events.

Sunyudo is an island in the Han River in the centre of Seoul. The city of Seoul decided to create a park on this island and link it to the city by a footbridge to encourage visits by the public.

Within the framework of co-operation and friendship between France and Korea and to celebrate the new millennium, a French architect, Rudy Ricciotti, was selected to design this footbridge.

The footbridge connecting Sunyudo Island to the riverbank and city is 430 m long. It is composed of a 120-m arch spanning the Han River and a steel footbridge at each end.

The main contractor for the entire project is Dongyang. The construction of the arch is subcontracted to VSL Korea and Bouygues Travaux Publics.

Rudy Ricciotti, working with the design department of Bouygues Travaux Publics, designed the arch using Ductal®. This choice allowed the bridge to have a very slender and thin structure, and it fulfilled the architect's desire to have an aesthetic and elegant arch [1].

Ductal® is a new generation of ultra high strength concretes that constitutes a breakthrough in concrete mix design [2]. This family of concretes is characterised by a very dense microstructure and very high compressive strength reaching 200 MPa or more. Short organic or steel fibres are added to the material to enhance the bending strength and the ductility. With organic fibres it is used for architectural applications like façade panels. With steel fibres it is used for structural applications (beams, slabs, etc.).

For the construction of the Seonyu footbridge, a Ductal® mix with steel fibres is used. The main properties of this mix, after a heat treatment, are given in table 1.

Table 1. Properties (typical values) of Ductal® with steel fibres and after heat treatment.

Density	2500 kg/m^3
Compressive strength	180 MPa
Tensile strength	8 MPa
Post-peak strength in tension	5 MPa
Young modulus	50 000 MPa
Poisson ratio	0.2
Shrinkage	0
Creep factor	0.2
Thermal expansion coefficient	12.10^{-6} m/m

The material used to prefabricate the arch was prepared in France by Lafarge, put in big bags and shipped to South Korea.

2. Description of the arch

The structure is composed of a Ductal® arch, to which steel approach spans are connected. Only the arch is described in this paper. The connections with the steel approach spans are at 30 m from mid-span. People will walk on the 60 m central part of the arch.

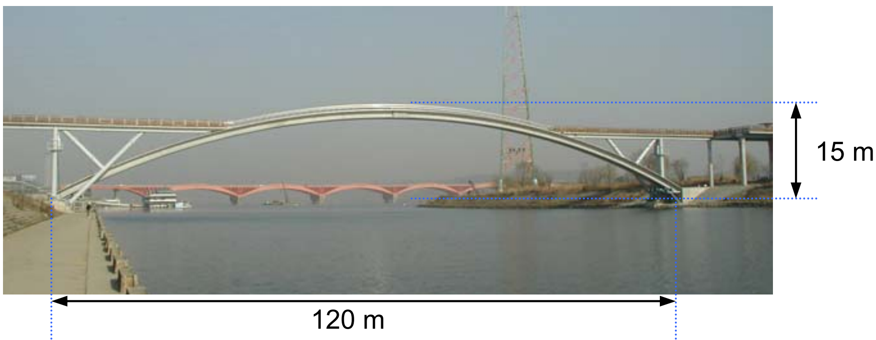

Photo 1 Ductal® arch

The 120 m arch (Photo 1) is attached at each end to two massive reinforced concrete foundations which are 9 m deep. These foundations are designed to support the horizontal thrust of the arch.

The arch has got a π-shaped cross-section, consisting of a transversally ribbed upper slab and two girders. The width of this arch is 4.3 m and its depth 1.3 m. The structure is composed of a thin, 30 mm thick slab, which is supported by transverse ribs, each measuring 1.225 m, and two longitudinal ribs at the extremities of the transversal section. This ribbed slab is supported by two 160 mm thick webs (Figure 1). The π-shaped form was selected for easy demoulding of the segments.

The transverse ribs are prestressed by one or two 0.5” sheathed and greased monostrands. Specially adapted, small anchors similar to those used in the construction of Sherbrooke footbridge [3] were used to transfer the prestressing forces from the strands to the material.

In the longitudinal direction, the structure is prestressed by three tendons per web. VSL cables are used. Thin steel ducts are positioned; the strands are individually positioned and then stressed. There are nine strands in each of the lower ducts and 12 strands in the upper ducts. After completion of the stressing phase, all the ducts are grouted.

The total volume of Ductal® is 120 m^3. 12 tons of prestressing are installed and no conventional reinforcement used.

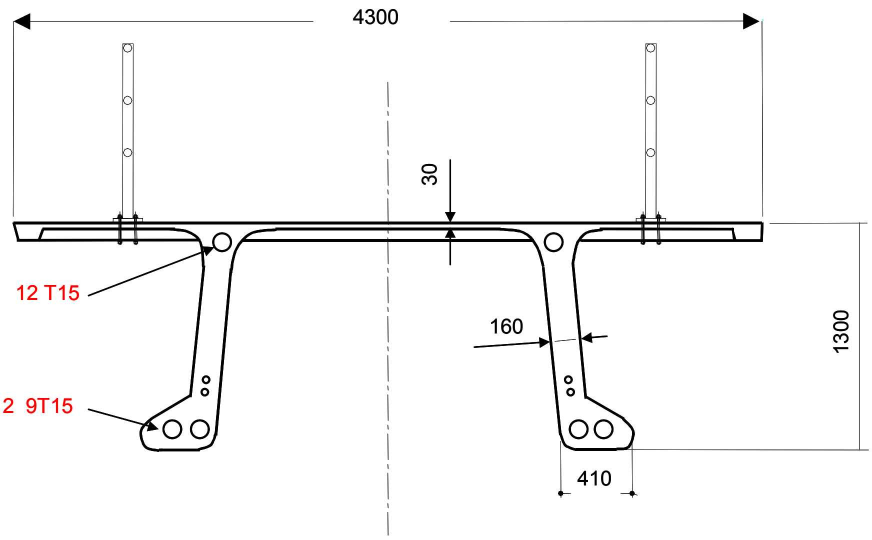

Fig. 1 Transverse section (dimensions in mm)

The arch is composed of six segments. These segments are prefabricated in an area next to the final location of the arch. Diaphragms are added at the extremity of each segment. The diaphragms next to the foundations are used to spread the compressive loads in the ordinary concrete of the foundations, while the diaphragms at the central section are used for jacking the two halves of the arch.

The segments are erected using five temporary supports in the river. The assembling is done using longitudinal prestressing and cast-in-place Ductal® joints.

3. Casting the precast elements

The segments have a 3D shape, so a lot of work was required to design a mould. A steel mould of 50 tons was fabricated. The extremities of the mould are adaptable so that diaphragms of different shapes could be cast.

The segments, which are 20-22 m long, are curved. The slope at the extremities is more than 8%. As Ductal® is a self-compacting material, we were obliged to use a steel cover at the extremities. To get uniform quality on the top of the deck, it was decided to cover the entire mould. Also, burlap was placed under the cover to help air escape.

The 30 mm thick slab is supported by ribs in both directions. To make the casting of this slab easy, polystyrene blocks are used as the mould form for the upper part of the slab.

The volume of a segment is 22.5 m^3. The total mixing time is five and a half hours. An intermediate agitating hopper with an integrated pump is used. During all the casting, 7.5 m^3 is temporarily stored in the agitating hopper/pump. The mould is filled using eight injection points positioned midway at the internal surface of the legs.

During the casting operations, the fluidity of the mix is controlled. A shock table test is performed for every batch (ASTM C230). The fluidity of the mix is maintained constant throughout the project. A fluidity value of 235 mm is obtained after 20 shocks with a low value for standard deviation (7 mm).

After casting, the segment is cured at 35°C for 48 hours. A spread beam is used to move the segment from the mould area to a heat treatment chamber. The heat treatment chamber is closed and steam is injected inside with a targeted temperature of 90°C. A thermocouple system is used to monitor the temperature. The segment is kept at 90°C for 48 hours, and the temperature is lowered slowly in order to prevent thermal shocks.

After heat treatment, all the segments are stored on concrete columns 5 m above ground to keep them safe from any risk of flooding in the precasting area.

Photo 2 Transversal section before and after demoulding

4. Erection

During the casting period, six segments, two connecting elements and a 0.5 m long key segment are fabricated and heat-treated. Five temporary piles were constructed in the Han River along the axis of the arch to support the segments.

First, three segments, corresponding to half an arch, are positioned using a crane supported by a barge. The transfer beam used in the precasting area to move the segments from the mould to the heat treatment chamber and then to the storage zone is adapted and used to erect the segments and position them on the temporary piers.

The upper part of the foundation is cast in place after the positioning of the segments. The stitches between the 3-cm-thick segments are cast in place. The required volume (30 litres per stitch) is prepared using a small laboratory mixer.

When the targeted strength of the stitch (85 MPa) is reached, the longitudinal cables are prestressed and the steel ducts are grouted.

The same work is done on the second half of the arch.

The key segment is positioned. Using two jacks, a horizontal force of 2300 kN is applied between the two parts of the arch. The two stitches are then cast in place.

When the strength of the stitches reaches 85 MPa, the two jacks are downloaded and the force is transferred via the key segment. Thus, the arch is definitely under compression.

During the jacking operations, the foundations are monitored for any displacement. The measurements show that there is no displacement of the two massive foundations.

Photo 3 Erection of the arch

Eight continuity prestressing bars, each with a diameter of 38 mm, are installed and stressed at 850 kN each. These bars balance the local bending moments at the key section and re-establish the continuity of the arch. Photo 3 shows the positioning operation using a crane and a spread beam, which is kept parallel to the segment, and a view of half an arch after erection.

The two connecting elements are positioned. Cast-in-place material is used to establish the continuity of the structure. The steel footbridge is then erected and connected to the arch.

5. Vibration study

During the detailed design of the footbridge, a dynamic analysis of the arch was made. The calculated natural frequencies of the arch are within the range of values that could make people crossing it uncomfortable.

Using the following comfort criteria:

- Limitation of the horizontal acceleration to 0.2 m/s^2
- Limitation of the vertical acceleration to 0.5 m/s^2

Tuned Mass Dampers were designed to damp the vibrations of the modes next to the natural frequency caused by a pedestrian.

Preliminary dynamic tests were first made to determine the exact frequencies of the arch and their associated critical damping ratio. Table 2 presents the measured values and the calculated values obtained during the detailed design.

Table 2. Comparison of measured/calculated frequencies

Mode	Measured frequency	Measured damping (in % of critical damping)	Calculated frequency	Main displacement
1	0.75 Hz	0.6 %	0.67 Hz	horizontal
2	1.34 Hz	1.3 %	1.26 Hz	vertical
3	2.03 Hz	0.4 %	1.99 Hz	vertical

Also, during the preliminary tests a group of 30 people was used to vibrate the arch at different frequencies. During these tests, the vertical and horizontal accelerations were measured. The values for modes 1 and 3 exceed the comfort limits and confirm the need for TMDs for these two modes.

Four TMDs were designed, two for mode 1 and two for mode 3. Figure 2 indicates their locations.

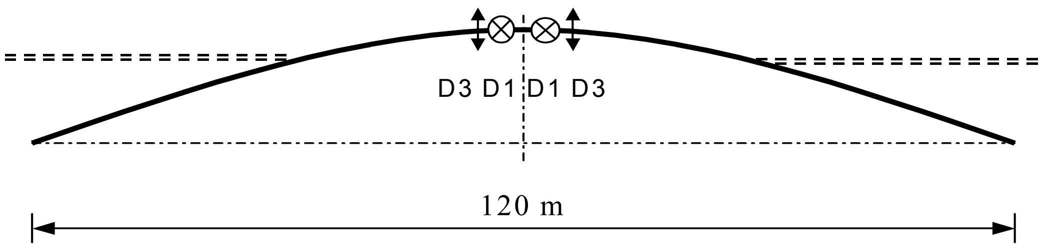

Fig. 2 Location of the TMD in the longitudinal direction

After installation, control tests are made. The results show that the installed system allows to reach the targeted accelerations in both horizontal and vertical direction and fulfill the comfort criteria.

6. Conclusion

The Seonyu footbridge built with Ductal® links the city of Seoul to Sunyudo Island in the Han River. The footbridge consists of two steel access spans that are supported by an arch.

It is the first time in the world that an ultra high performance concrete reinforced with steel fibres has been used for a span of 120 m.

The properties of Ductal® make it possible to design a very slender arch with thin sections, giving the footbridge an elegant look.

The arch is composed of six segments, which are prefabricated in an area next to the final location of the arch. A sophisticated mould is used. The segments are erected using five temporary supports across the river. They are assembled with longitudinal post-tensioning and cast-in-place joints.

A special study of vibrations was done and tuned mass dampers were added to the arch at an early stage of the project so that the footbridge would be comfortable to use.

Photo 4 Ductal® arch after complete erection

Four footbridges were constructed using Ductal® -Sakata Mirai [4] in Japan, Sermaises in France [5], Sherbrooke in Canada [3] and Seonyu in Korea- and one is under completion in Japan. This increasing number of uses for footbridges shows that Ductal® suits very well such kind of applications. Ductal® allows to design slender and thin structures, aesthetically pleasant surfaces and very durable elements and fulfils the wishes and demands of architects and end-users

7. References

[1] Ricciotti, R. "*The Footbridge of Peace*". Sujet-Objet, Editions Jean-Michel Place, January 2001.

[2] Orange, G. Acker, P. and Vernet, C. "*A new generation of UHP concrete: Ductal®, Damage Resistance and Micromechanical Analysis*," Proceedings of the 3rd International RILEM workshop (HPFRCC 3), May 1999, Mainz, pp 101-111.

[3] Lachemi, M. et al. "*The Sherbrooke Footbridge: The First Reactive Powder Concrete Structure*" Structural Engineering International 2/98, pp 140-144.

[4] Tanaka, Y et al. "*Design and construction of Sakata Mirai footbridge using reactive powder concrete*". FIB 2002 Congress in Osaka. Proceedings, session 1, pp 417-424.

[5] Durukal, A and Casanova, P. "Ther Sermaises footbridge : a fire resistant ultra high performance fibre reinforced concrete footbridge without reinforcement". Footbridge 2002 Congress in Paris, proceedings pp 167-168.