Design of Hirosegawa river bridges determined by a competition

Transportation Bureau City of Sendai
Docon Co., Ltd.
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Synopsis

The Hirosegawa Bridge and Nishikoen Viaduct are structures span the Hirosegawa River and Nishikoen Park. Used by the Sendai Subway Tozai Line, these structures pass through the scenic Sendai area known as "Forest City." As this is an important scenic area, Sendai City required the two bridges to have an excellent aesthetic design. In 2006, the city held a competition to select a design. It was the first design competition for railway bridges in Japan. The winners of the competition were awarded a contract to design the bridges.[1], [2] Construction of the bridges began in 2008 and was completed in 2013, after which rail tracks were installed. This paper describes these very exceptional bridge designs and their construction.

Structural Data

Structure : (1) 3-span continuous partially prestressed concrete (PPC) rigid frame box-girder bridge
(2) Reinforced concrete (RC) slab concrete filled steel tube (CFT) column rigid frame viaduct

Bridge Length: (1) 172 m
(2) 118 m

Span: (1) 53.0 + 70.0 + 47.0 m
(2) 5.0 m

Width: (1) 13.976 - 7.881 m
(2) 7.885 - 10.706 m

Owner: Sendai City Transportation Bureau

Designer: Docon Co., Ltd.
(Winner of competition)

Contractor: JV of P.S. Mitsubishi Construction Co., Ltd.,Fuji P.S. Co., Ltd., and Higashinihon Concrete Co., Ltd.

Construction Period: Dec. 2008 – Sep. 2013

Location: Aobayama, Aobaku of Sendai City, Miyagi prefecture.

1. Outline of the design competition

The two bridges are located in an important scenic area of Sendai City called Aobayama, and its beautiful hills and forests are a symbol of the city.
To create bridges with an excellent design that fully takes into consideration the beautiful scenery of the area, Sendai City established an Examination Committee for Bridges in the Hirosegawa Area of the Sendai Subway Tozai Line. The committee determined the direction of the design for a bridge surrounded by the abundant greenery of Aobayama Park and Nishikoen Park.[1] "The design of the bridge should complement the surrounding beautiful scenery, and the

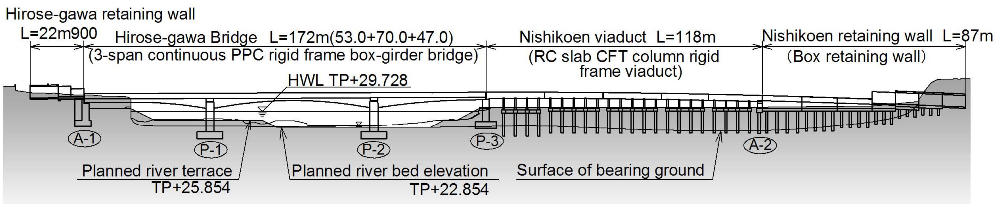

Figure 1. Side view of bridges

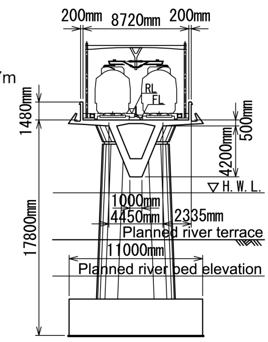

Figure 3. Typical cross-section of the Hirose-gawa Bridge

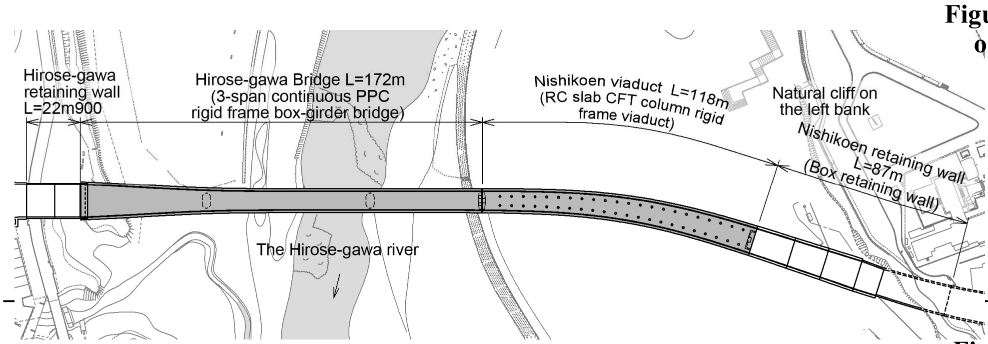

Figure 2. Plan view of bridges

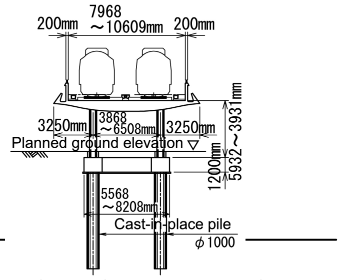

Figure 4. Typical cross-section of the Nishikoen Viaduct

bridges should provide a space for park activities." At the same time the Committee proposed a design competition.To achieve these requirements, the committee established a Design Competition for the Bridges in the Hirose-gawa Area of the Sendai Subway Tozai Line, as well as a Selection Committee. [2]

2. Outline of the winning design

The bridges in the Hirosegawa area are located in a beautiful natural environment. The Ohashi Bridge is a concrete arch bridge completed in 1938. The Nakanose Bridge is a double-deck bridge for National Road 48 and municipal roads in the area. Aobayama Park on the right bank and Nishikoen Park on the left bank of the Hirosegawa river were to be reconstructed during the construction of the subway line. The new bridges, however, clearly annoyed the users of the parks. The proposal for the new bridges stated the goal of creating new all-weather park devices that would be useful for park users. This goal was achieved by converting the annoying bridges that cut through the parks into stages for new activities.

The design called for bridges with unimposing and subtle forms. The bridges should blend in with the surrounding natural scenery when seen from a distance, but their elegantly designed parts should gradually appear as viewers approached the bridges. The plans for the two bridges are as follows:

River bridge: a 3-span continuous PPC rigid frame box-girder bridge with an inverted triangle cross-section that creates a wide deck overhang and a distinct nuance in the space under the girders. (**Figures 1, 2, 3, 5**)

Viaduct: an RC slab CFT column rigid frame bridge with a span of only 5 m, creating an attractive colonnaded arcade with a wide, overhanging ceiling and columns under the girders. The bridge should have a subtle form that contributes to the Sendai way of enjoying the beauty of nature through citizen activities held in the space created by the new bridges. (**Figures 1, 2, 4, 6**)

Figure 5. The shape of the Hirosegawa Bridge

3. Outline of the structures

Fig. 1-4 shows an outline of the bridge structures. The notable feature of the bridges is that even though the structures of the river bridge and the viaduct differ clearly, the open channels along the outer sides of the both structures create continuity and unity of appearance. The open channels, which are drainage devices, soften the heavy impression of the wall railings. (**Figure 7**)

4. The Hirosegawa Bridge

(1) Bridge plan

In designing the Hirosegawa Bridge, the arches of the Ohashi Bridge, which is located about 200 m downstream from the Hirosegawa Bridge, were taken into consideration.

Figure 6. The shape of the Nishikoen Viaduct

Figure 7. Wide overhang for the open channel

Built in the early years of the Showa era, the Ohashi Bridge imparts a sense of space. The new bridge, a 3-span continuous concrete bridge with sections of varying size, was designed to form a double silhouette with the Ohashi Bridge (the two bridges simultaneously come into view). Because the new bridge has a similar rhythm as the Ohashi Bridge, the shape of the newly constructed structure further enhanced the visual effects of the old and new bridges. The cross-sectional shape of the main girder is a large inverted triangle, and the main girder's wide overhang creates a nuanced space beneath the bridge.

(2) Structural design

This bridge has a PPC structure. The height of the pier is 10 m, which is low for the 70-meter maximum span length. The rigid frame structure provides high earthquake resistance and maintenance and economical efficiencies and was selected after considering the possibility of reduced stiffness should the piers crack.
The cross-section of the main girder was designed in a way similar to that of box-girders with diagonal webs. The following points were investigated and verified for the inverted triangle cross-sectional main girder.
1) At the location of a pier, where compressive stress concentrates, the lower deck slab has a width of 1.00 m and a thickness of 1.50 m.
2) Sufficient resistance to biaxial flexural stress was ensured through dynamic response analysis of seismic motions perpendicular to the railway tracks.
3) By conducting 3-D frame analysis with an eccentric train load, it was verified that the effects of twisting moments were very small.

5. The Nishikoen Viaduct

(1) RC slab CFT column rigid frame structure

This bridge has the following structure. (**Figure 4**)
1) The pier is a CFT column.
2) The superstructure of the RC slab and the CFT columns are directly connected.
3) The CFT columns are directly connected to underground beams (Two-layered rigid frame structure including the superstructure).
4) The span is 5.0 m in length and the CFT columns are placed directly under the tracks.

The structure of the bridge is a special rigid frame in which the RC slab is directly supported by multiple CFT columns connected to the RC underground beams. The structure was designed using a frame model that showed the rigid frame structure made up of the slab, column, and beam. In the model, standard beam members were used for the CFT columns and underground beams. The effective width of the slab is based on the distribution characteristics of normal stress obtained from a 3-D elastic FEM analysis. A beam member of this effective width replaced the slab.

(2) Structure of the connection

1) Slab-column connection (steel beam, reinforcing bar inserting connection)
The CFT column and slab are connected using a widely used method of steel beams and reinforcing bars. (**Figure 8, top half**)
2) Column, underground beam, and pile connection (Socket connection)
The CFT column, underground beam, and pile are connected using a widely used socket connection method. (**Figure 8, bottom half**)

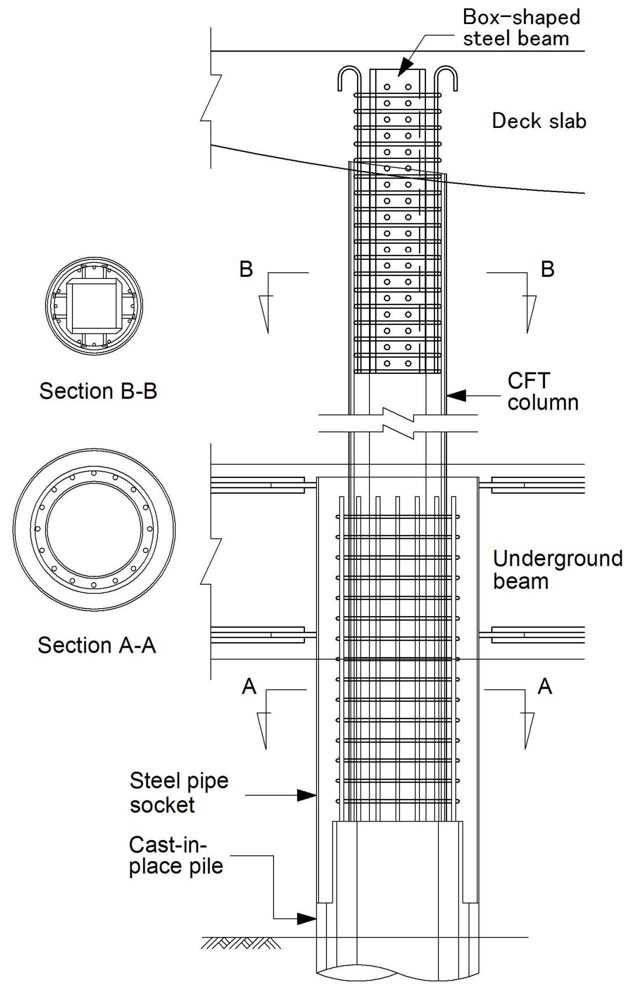

Figure 8. Cast-in-place pile-deck slab connection

(3) Ensuring quality connections

Shrinkage compensating mortar was poured between the steel pipe socket and the CFT column. Concrete was poured between the inner part of the CFT column and the box-shaped steel beam. To ensure a high quality mortar connection, a full-scale pouring experiment using a CFT column was conducted before actual construction. To verify the quality of the connection, a concrete pouring sensing system (Jutendar) with a vibration device was used. For the pour between the CFT column and the box-shaped steel beam, where a high quality pour was thought to be challenging, a sample column was cut and visually inspected after the concrete had solidified (**Figure 9**).

(4) Finishing the deck slab

The bottom mold frames of the viaduct were left in place for a relatively long period, which often leaves stains on the surface. The bottom of the bridge deck was designed to serve as the ceiling of the promenade. The concrete surface was given a rough texture by sand blasting the surface using pressurized air. (**Figure 10**)

Conclusion

At the time of the Great Eastern Japan Earthquake of March 11, 2011, the Hirosegawa Bridge was undergoing cantilevering processes. A detailed inspection after the earthquake revealed only minor cracks (max. width of 0.3 mm) in the proximities of the heads of piers P1 and P2. They were considered to be caused by the earthquake and were repaired in due course.

Construction began after a detailed inspection in July 2011. Construction was completed in September 2013. Before the civil engineering work starts, rail tracks will be installed. After test operations, the Tozai Line is expected to open in the 2015 fiscal year.

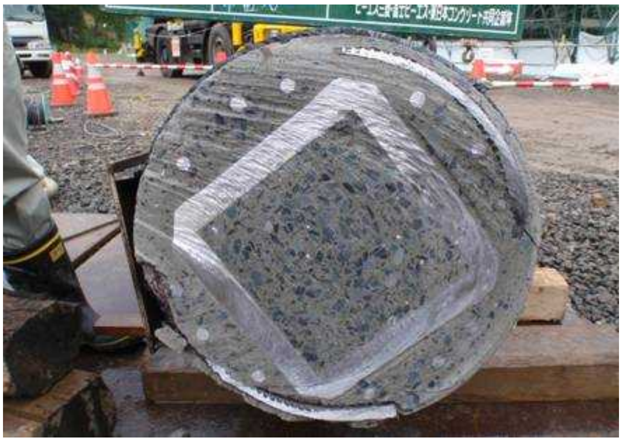

Figure 9. Cross-sectional view of the box-shaped steel beam in the CFT column

Figure 10. Polishing by sandblasting

References

[1] *Report on the Design Competition for the Hirose-gawa Bridge, and other;* Headquarters for Construction of the Tozai Line, Sendai City Transportation Bureau; Mar., 2007. (in Japanese)

[2] Kimura,T, Kikuya,M: *Design Competition for the Hirose-gawa Bridge, and other on the Tozai Line of Sendai Subway;* Bridge and Foundation Engineering, Vol. 41 - 8, pp. 49 - 52, Aug., 2007. (in Japanese)

[3] Mori,K, Chiba,M, Hatayama,Y, Juraku,K, Ebina,T, and Saito,K: *Design and Construction of the Hirose-gawa Area Bridges of the Tozai Line of Sendai Subway;* Bridge and Foundation Engineering, Vol. 47-4, pp. 5 - 11, Apr., 2013. (in Japanese)