Design and Construction of Prestressed Concrete Extradosed Bridge — The Komono Second Viaduct —

3 径間連続 PC エクストラドーズド橋の設計と施工 — 菰野第二高架橋 —


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Synopsis
This document describes key aspects of the design and construction of the Komono Second Viaduct, which is a 3-span prestressed concrete (PC) extradosed bridge with a 3-cell box girder across the Mitaki River, on the Shin-Meishin Expressway at Komono in Mie Prefecture, Japan. The extradosed bridge has an overall length of 341 m and a main span of 161 m with a 23.35-m-wide deck carriageway having two lanes in each direction. Dual central cable planes are adopted, allowing for future deck widening. The stay cables comprise either 37 or 48 seven-wire prestressing strands of 15.2-mm diameter and have a four-layer corrosion protection system for a 100-year service life. The top half of the pylon is a steel–concrete composite structure, and the stay cables are anchored inside the pylon box sections to facilitate inspection and maintenance of the stay cable anchorages.

Structural Data
Structure: 3-span PC extradosed bridge with a 3-cell box girder
Bridge Length: 341.0 m
Span: 88.6 m + 161.0 m + 88.6 m
Width: 23.35 m
Owner: Central Nippon Expressway Co., Ltd.
Designer: P.S. Mitsubishi – Fuji.P.S JV
Contractor: P.S. Mitsubishi – Fuji.P.S JV
Construction Period: Feb. 2016 – Feb. 2019
Location: Mie Prefecture, Japan

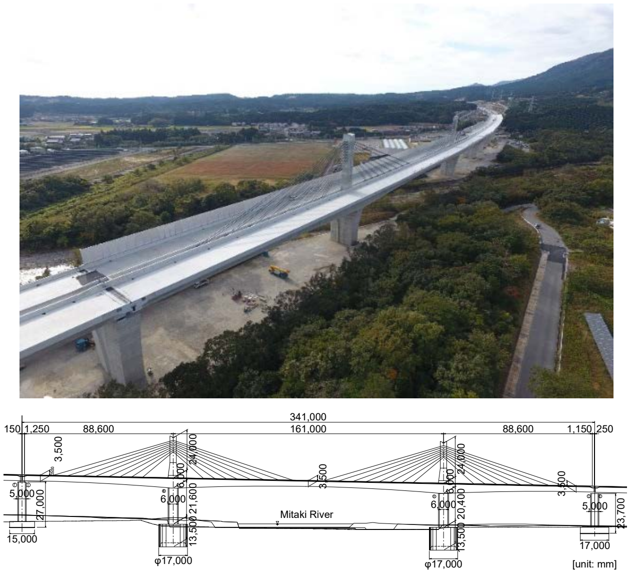

Fig. 1 Panoramic view

1. Introduction
The Shin-Meishin Expressway ("shin" means "new" in Japanese) is a major highway running about 150 km from Yokkaichi in Mie to Kobe in Hyogo in the central part of Japan. Its construction and opening have been carried out in a step-by-step manner since 1993, and as of September 2019, about 115 km of the Shin-Meishin Expressway has entered service. It is expected to compensate for the insufficiencies of the Meishin Expressway (the oldest expressway in Japan) as the main artery between the Chukyo and Keihanshin metropolitan areas.

Construction of the part of the Shin-Meishin Expressway between Yokkaichi and Kameyama in Mie began in 1999 and was completed in March 2019. This 23 km long section of expressway contains 17 bridges, of which the Komono Second Viaduct is a landmark structure, becoming the identifying image of this part of the expressway and a symbol of the community around the viaduct (**Fig. 1**).

The Komono Second Viaduct is a 3-span PC extradosed bridge with a 3-cell box girder across the Mitaki River, with approach viaducts to the north and south and carrying the Shin-Meishin Expressway at Komono in Mie Prefecture, Japan. The extradosed bridge has an overall length of 341 m and a main span of 161 m with a 23.35-m-wide deck carrying a dual carriageway having two lanes in each direction (**Fig. 2**). This paper presents key aspects of the design and construction of this extradosed bridge.

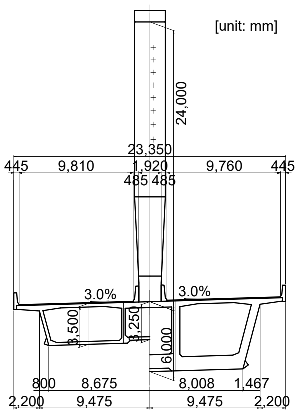

Fig. 2 Cross section

2. Design Features

The plan was to construct the part of the Shin-Meishin Expressway between Yokkaichi and Kameyama in phases, with the expressway constructed with two lanes in each direction in the first phase and then completed to have three lanes in each direction in the second/final phase. Therefore, all the bridges and viaducts were designed to allow for future deck widening.

Although a span length of 161 m is quite common for PC extradosed bridges, central cable plane extradosed bridges with a deck wider than 20 m are rather uncommon because two outer cable planes are generally used for such wide extradosed bridges. For the future deck widening, a central cable support structure was adopted for the Komono Second Viaduct. In this section, design features of the viaduct are explained in detail, focusing especially on the stay cables.

(1) Stay Cables

Dual cable planes were chosen because if a single cable plane had been adopted, the stay cables and anchorages would have been too large and therefore too expensive. The number and size of stay cables were determined considering the construction time: more stay cables would allow them to be smaller, but then the risk of construction delays would increase because the number of construction cycles would also increase. By maximizing the stay cable size with a constrained size of the anchorages to be fitted in the girders and pylons, it was determined that eight stay cables should be arranged for each cable plane on each side of a pylon. The bottom six and top two stay cables were designed to comprise 37 and 48 seven-wire prestressing steel strands of 15.2-mm diameter, respectively.

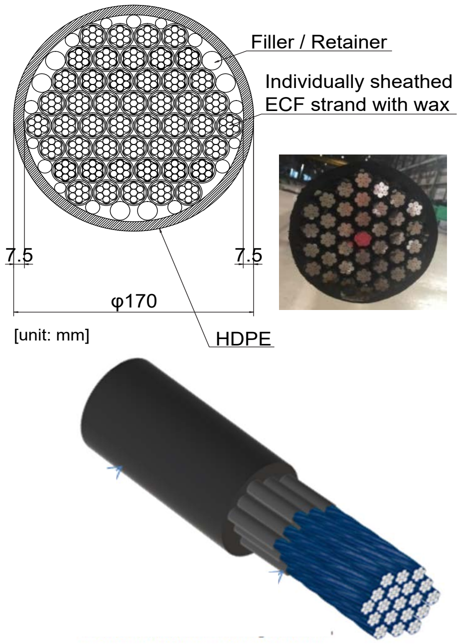

Fig. 3 Stay cable with four-layer corrosion protection

1) Vibration Mitigation

Because of the dual central cable planes, an aerodynamic stability problem particular to groups of stay cables—namely, wake galloping—had to be addressed. Wake galloping is unstable oscillation of the downstream cable when two cables are aligned in parallel and close to each other. As recommended in the Wind-Resistant Design Manual for Highway Bridges[1], to make wake galloping less likely, the distance between cable centers was made larger than 5*D* but smaller than 7*D*, where *D* is the cable diameter.

In addition, measures to mitigate rain/wind-induced vibration were also designed for the stay cables. To suppress rain/wind-induced vibrations, the Wind-Resistant Design Manual for Highway Bridges [1] recommends that damping of stay cables be 0.02–0.03 in logarithmic decrement (a Scruton number of 140–200) for the first three vibration modes. Assuming that the inherent damping of the stay cables is 0.005 in logarithmic decrement based on previous research [2], by installing two high-damping rubber dampers on each stay cable, their damping was made higher than 0.05 in logarithmic decrement at 20°C. These dampers are also expected to mitigate cable vibration due to wake galloping because adjusting the cable spacing is insufficient to prevent the occurrence of wake galloping.

2) Corrosion Protection

The stay cables were furnished with a four-layer corrosion protection system that is expected to give them a service life of more than 100 years. The system is as follows: epoxy coating on the inside and outside surfaces of the steel strands (called “epoxy coated and filled steel strand”, ECF strand hereafter), where the average thickness of the epoxy coating is 400–1,200 µm; wax filling between a strand and its high density polyethylene (HDPE) sheath; and an HDPE stay pipe encapsulating the entire bundle of individually sheathed strands (**Fig. 3**). Because these are the largest multi-strand stay cables using ECF strands in Japan, the fatigue safety of the stay cable system was verified by performing a uniaxial tensile fatigue test using a full-scale specimen.

3) Fire Protection

Each stay cable was covered with insulating and heat-tolerant materials for fire protection, with 19-mm-thick alumina fiber insulation (**Fig. 4**) wrapped around the stay cable and surrounded by 0.3-mm-thick stainless steel plate. The thickness of the alumina fiber insulation was determined such that it will keep the temperature of the HDPE stay pipes below 250°C for 20 min if the stay cables are subjected to fire; 250°C is the temperature below which the mechanical properties of HDPE remain unchanged, and 20 min is the approximate time before firefighting operations begin. Meanwhile, the stainless steel plate was coated with fluorocarbon polymers. Fire protection was provided on the stay cables up to a height of 7.5 m from the road surface (**Fig. 5**), which was determined based on research findings that when oil and other flammable liquids are spilled on roads because of accidents or other reasons and then ignite, the flare reaches a maximum height of 7.5 m [3].

Fig. 4 Alumina fiber insulation

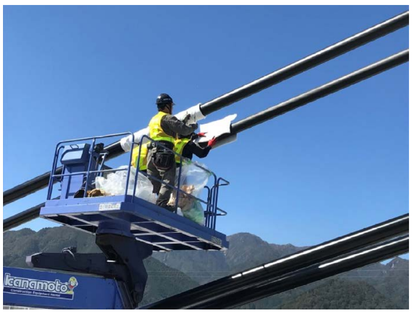

Fig. 5 Installation of the fire protection layer

(2) Pylon

The height of the pylons is 24 m (**Fig. 2**). The lower part of the pylon is a reinforced concrete (RC) structure, while the upper part—where the stay cables are anchored—is a steel–concrete composite structure. the pylon has a hollow section in which the stay cables are anchored, thereby allowing easy inspection and maintenance of the stay cable anchorages.

If the entire pylon had been designed as a concrete structure, then it could not have had a hollow section. This is because the dimensions of the pylon section could not have been increased to accommodate large cable anchorages in a hollow section because there is limited space for a central reservation where the pylons are built. Moreover, the way to anchor the stay cables at the pylon would have had to be changed to make the dimensions of the pylon section smaller to be fit in the central reservation. In this case, anchoring the stay cables by overlapping or using deviation saddles are alternative ways to anchor them at the pylons, but these two styles of cable anchorages are probably not optimal solutions because then inspection and maintenance of the stay cable anchorages would be difficult. Although a more expensive solution, a steel–concrete structure was adopted for the pylons to have a hollow section and accommodate large cable anchorages inside the pylon box, thereby allowing easy maintenance of and access to the cable anchorages.

(3) Girder

The girder is a 3-cell box girder designed to carry a dual carriageway having two lanes in each direction with a 23.35-m-wide deck in the first construction phase. In the second/final construction phase, the deck will be widened to 37.45 m with an additional 7.05 m on each side by extending the deck overhang supported by struts. At each cable anchor point, the box girder was strengthened to properly transfer the force from the cable to the girder. Details of the strengthening were determined by performing three-dimensional finite-element analysis. The thicknesses of the deck and the diaphragm of the central cell were increased at the cable anchor points from 300 mm to 500 mm and 600 mm, respectively. Moreover, additional prestressing was introduced into the deck at the cable anchor points by arranging as many steel strands as possible longitudinally and transversely. Because concrete cracking stresses still arose at several cable anchor points even after the strengthening, additional steel rebars were arranged to carry the tensile stresses.

3. Construction

The viaduct was built using the balanced cantilever method with cast-in-situ segments. The girder was divided into 19 segments for each form traveller, and the production rate was 12 and 10 days for the segments with and without cable anchorages, respectively.

The viaduct is frequently subjected to wind blowing down from the nearby mountains, and for this reason

it was considered to be difficult to fabricate the stay cables on site. Therefore, semi-prefabricated stay cables were chosen instead of on-site fabricated stay cables. Although semi-prefabricated stay cables are more expensive, their quality was improved and the erection duration was reduced because all the stay cable assembling was performed in well-controlled factories, with only stressing and anchoring carried out on site.
The stay cables were installed by using a rough terrain crane with a maximum lifting capacity of 25 ton, together with multiple electric winches. Stay cable prestressing was carried out inside the box girder, where a 1,100-ton center hole jack was used (**Fig. 6**). Because the center hole jack weighed about 3 ton, to reduce safety risks and facilitate the stay cable stressing, a specialized wheeled platform and jack installation equipment were developed.

Fig. 6 Stay cable prestressing

Concrete casing of the RC part of a pylon was performed by dividing it into three segments. Steel pipes were arranged at the center of the pylon section to make space for access to the cable anchorages in the upper part of the pylon. A connection element made of a steel frame was set up at the top of the RC part for connecting the steel structure of the steel–concrete composite part of the pylon (**Fig. 7**). The steel structure of the steel–concrete composite part of the pylon was formed by connecting five segments—each of which weighed approx. 25 ton—using friction-type bolted connections.

Fig. 7 Steel–concrete connection element made of steel frame in a pylon

4. Conclusion

This paper described key aspects of the design and construction of the Komono Second Viaduct, focusing on the stay cables in particular.

- For a 100-year service life, the stay cables were provided with four-layer corrosion protection.
- High-damping rubber dampers were installed on all the stay cables to mitigate rain/wind-induced vibration and prevent wake galloping.
- Alumina fiber insulation was wrapped around the stay cables and surrounded by stainless steel plate for fire protection.
- The top half of the pylon was built with a steel–concrete composite structure, and the stay cables were anchored inside the pylon box sections to facilitate inspection and maintenance of the stay cable anchorages.

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概　要

新名神高速道路 菰野第二高架橋は，三重県三重郡菰野町に位置する PRC3径間連続 3 室箱桁エクストラドーズド（以下 ED）橋である。本橋は，中央径間長161.0m を有しており，「1 面吊り構造」+「コンクリートウェブ」を採用した ED 橋（複合構造を除く）としては，日本国内最大級の支間長を有する。これにより斜材容量も ED 橋では日本国内最大となる48s15.2B（800t ケーブル）が採用されるに至っている。本稿では，この斜材ケーブルの「耐久性」「耐風安定性」「耐火性」「維持管理性」の側面から報告するものである。