Repair Project of Existing Suspension Bridges for Long Lifespan

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Large scale suspension bridges are very important infrastructures for supporting national economic activities. However, recently regarding suspension bridges that were built more than 30 years ago, the decline in durability due to local damage from aging is a concern. Since replacing suspension bridges is very costly, it is common and reasonable to try prolonging bridge lifespans by repairing and reinforcing the damaged part of the bridge. Against this backdrop, projects involving existing suspension bridges for the purpose of increasing the lifespan have been increasing. This report describes three major projects carried out by IHI Infrastructure Systems Co., Ltd. worldwide.

1. Introduction

There are various factors contributing to the damage experienced by suspension bridges that were constructed over 30 years ago, including simply reaching the end of the useful life of the materials used in the bridges, failure to adequately perform daily maintenance, as well as traffic volume and environmental changes that were not anticipated at the time of construction. Meanwhile, even in cases in which such a bridge would reach the end of its lifespan in several years if left untouched, it is possible to extend its life by 20 or 30 years by repairing damage and reinforcing it as needed. Therefore, the need for repair and reinforcement work for aging suspension bridges is expected continue to increase in the near future.

The details of repair and reinforcement work for suspension bridges vary depending on the part of the bridge and the purpose. This article reports the details of the repair and reinforcement works that IHI Infrastructure Systems Co., Ltd. (IIS) executed for the “Wakato Bridge” in Kitakyushu City, Fukuoka Prefecture, the “Bosphorus Bridge” in the Republic of Turkey (hereinafter called “Turkey”), and the “Matadi Bridge” in the Democratic Republic of the Congo (hereinafterr called “DRC”).

2. Continuation of the orthotropic steel decks of the “Wakato Bridge”

“Wakato Bridge” is Japan’s first long-span suspension bridge and it was completed in 1962. This suspension bridge plays a major role, not only as a key part of the infrastructure in the Kitakyushu Industrial Area, but also as a residential road connecting Wakamatsu Ward and Tobata Ward. The traffic volume on the bridge is approximately 30 000 vehicles per day, with a cumulative total for the past 57 years exceeding 600 million vehicles. **Figure 1** provides a panoramic view of the “Wakato Bridge” and **Fig. 2** provides a general drawing of the bridge.

Key specifications

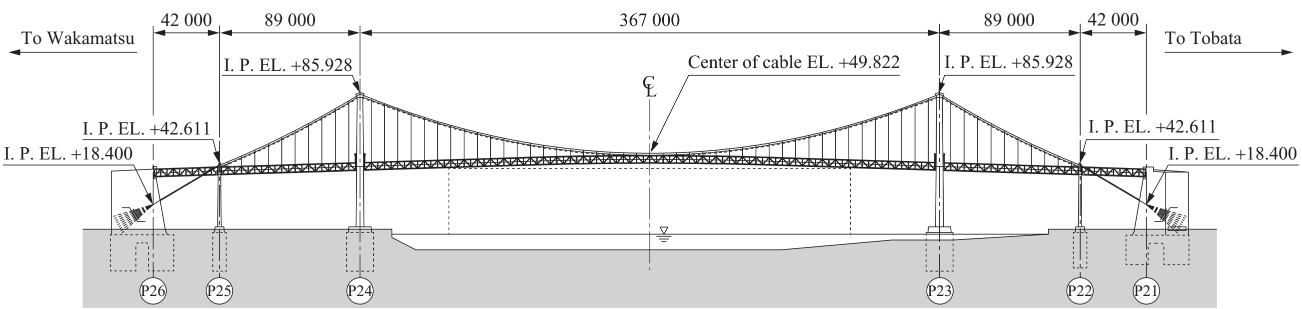
Length of bridge	629 m
Span length	42 m + 89 m + 367 m + 89 m + 42 m
Width	16.2 m (two lanes in each direction)
Year of completion	1962

In 2012, the bridge underwent large-scale repair of its suspension bridge, which was executed by IIS. In this project, renovation work was conducted on the orthotropic steel decks of the suspended girder. The “Wakato Bridge” had concrete slabs when it was completed, but in 1987, the sidewalks was abolished and the number of lanes were increased to four, as well as the concrete slabs were replaced with orthotropic steel decks in order to reduce the dead load.

As illustrated in **Fig. 3**, one block of the orthotropic steel decks was supported by a floor frame structure consisting of six continuous spans (25-m blocks), and the bearings are located on the floor truss upper chords. The entire suspension bridge was comprised of 25 orthotropic steel deck blocks, with a rubber expansion joint located between each block; however, these rubber expansion joints frequently became damaged due to heavy traffic. Damaged rubber expansion joints leaked water, advancing the corrosion of the floor truss upper chords as well as contributing to early deterioration of the asphalt pavement. Thus, it was necessary to implement asphalt pavement replacement every 20 years. **Figure 4** shows the corrosion of a floor truss upper chord.

Moreover, damage to the rubber expansion joints also contributed to noise and vibration that affected the surrounding areas, making it an issue in maintenance and

Fig. 1 Panoramic view of “Wakato Bridge”



(Note) P** : Pier
EL. : Elevation (unit : m)
I. P. EL. : Intersection Point Elevation
(theoretical main cable elevation) (unit : m)

Fig. 2 General arrangement of “Wakato Bridge” (unit : mm)

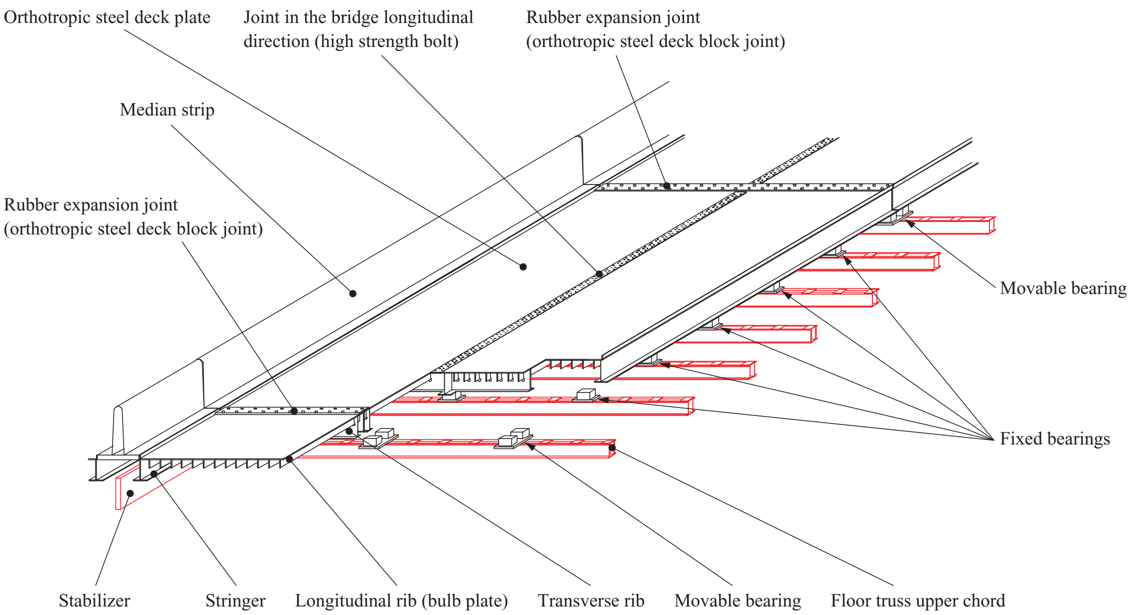


Fig. 3 Detail of orthotropic steel deck before continuation work

Fig. 4 Corrosion condition at upper chord of floor truss

management. In order to eliminate these issues, several works were executed in this project, including: ① continuation of the orthotropic steel decks; ② reinforcement of the floor truss upper chords; ③ replacement of the anchor bolts for the fixed bearings supporting the orthotropic steel decks; and ④ asphalt pavement replacement. This chapter reports on the continuation of the orthotropic steel decks.

2.1 Continuation of the orthotropic steel decks

In order to improve the environment that caused water leakage resulting from damage to the rubber expansion joints leading to corrosion, as mentioned above, it was decided to remove the rubber expansion joints, and continue the orthotropic steel decks. The continuation of orthotropic steel decks in this project was configured so that only the orthotropic deck plates between existing orthotropic steel deck blocks were connected by connection plates, rather than being configured to render the stringers or longitudinal ribs of adjacent blocks continuous with each other. **Figure 5** illustrates the structure of the orthotropic steel decks after continuation, and **Fig. 6** provides a side view of an orthotropic steel deck block joint.

As a result of the recent orthotropic steel deck continuation work, the continuous span length of orthotropic steel deck with 84 continuous spans would be 367 m, so we conducted

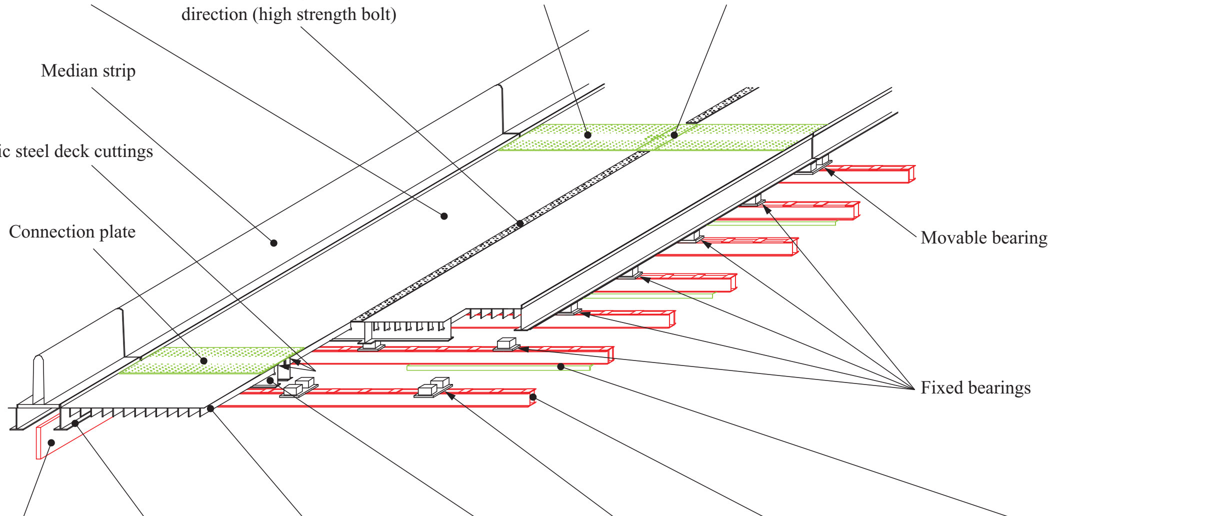


Fig. 5 Detail of orthotropic steel deck after continuation work

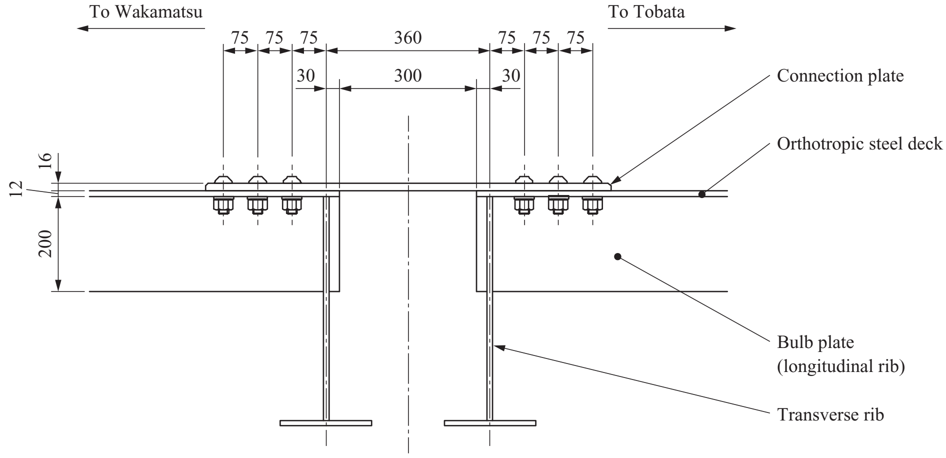


Fig. 6 Side view of orthotropic steel deck joint (unit : mm)

a structural analysis, thereby confirming that such structural change would not affect the behavior of the entire suspension bridge.

2.2 Execution of the orthotropic steel deck continuation work

The orthotropic steel deck continuation work was executed while the suspension bridge was in service. In order for the bridge to maintain its capacity to accommodate a daily traffic volume of approximately 30 000 vehicles, the work was executed on two of the four lanes first and then on the remaining two lanes within the 24-hour fixed traffic restriction zones established over the entire length of the inbound and outbound lanes, for a total length of 1 700 m.

The asphalt pavement was dismantled beforehand and the rubber expansion joints were removed next. Since the orthotropic steel deck block joints were so close together you could not even put your hand between them, the joints were removed from the top surfaces of the orthotropic steel deck plates along with the ribs of the orthotropic steel decks in order to allow space for rust-proofing work, and then the joints were repainted. **Figure 7** shows repaint work being performed on an orthotropic steel deck block joint.

The orthotropic steel deck continuation work was executed first on the driving lanes of the inbound and outbound lanes and then on each of their passing lanes. New connection plates were simultaneously installed at four panel points — on the inbound and outbound lanes of the Tobata side, and on the inbound and outbound lanes of the Wakamatsu side — from the central part of the center span toward each anchorage in order to prevent the girder and orthotropic steel decks in service from being affected by temperature changes and from being subjected to overtwist or overstress attributable to the live load. The orthotropic steel decks were then sequentially connected by using the new connection plates and high strength bolts to make them continuous. **Figure 8** shows the orthotropic steel deck continuation work being performed by using new connection plates.

3. Large-scale reinforcement works for the “Bosphorus Bridge”

The “Bosphorus Bridge” is a suspension bridge spanning the Bosphorus strait, which divides Istanbul, Turkey into eastern and western parts. Forty-six years have passed since its completion in 1973. **Figure 9** provides a panoramic view of the “Bosphorus Bridge.”

Key specifications

Length of bridge	1 560 m
Span length	231 m + 1 074 m + 255 m
Width	33.4 m (three lanes in each direction)
Year of completion	1973

This suspension bridge, situated on a major arterial road in Istanbul and having a traffic volume of approximately 200 000

Fig. 7 Painting situation for joint of orthotropic steel deck

Fig. 8 Orthotropic steel deck continuation situation by new connection plates

Fig. 9 Panoramic view of “Bosphorus Bridge”

vehicles daily, was frequently experiencing local damage attributable to aging. Faced with these circumstances, the road administrator, namely, the General Directorate of Turkish Highways (KGM) of the Ministry of Transport asked PARSONS (U.S. consulting firm) to investigate the degree of soundness of the "Bosphorus Bridge." As a result of this investigation, the decision was made to execute various reinforcement works, including replacement of the hangers of the suspension bridge, as well as reinforcement of the orthotropic steel decks against cracking and installation of a dehumidification system on the main cables. Since the "Bosphorus Bridge" was one of only a few long-span suspension bridges anywhere in the world, the work for replacing the inclined hangers with vertical hangers was an unprecedented endeavor. **Figure 10** provides a general drawing of the "Bosphorus Bridge" and the details of reinforcement.

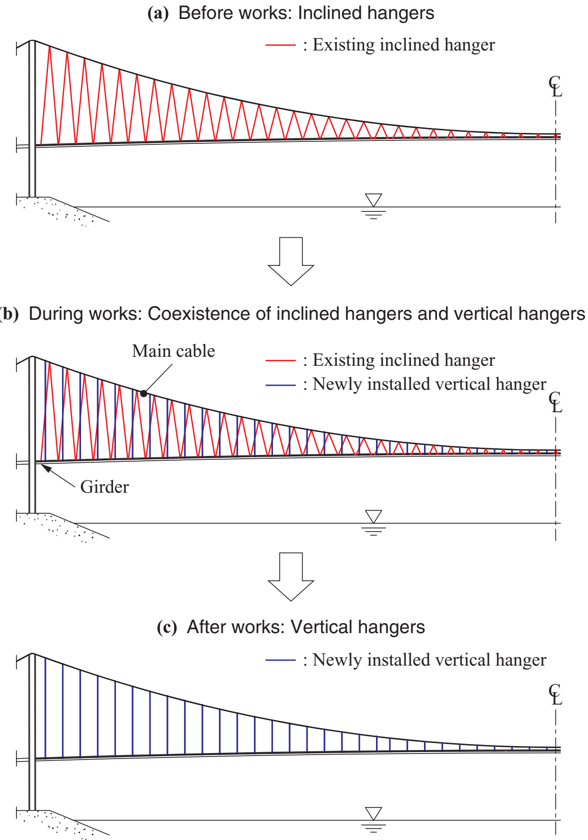
In 2013, IIS received orders for these works as a member of the Joint Venture (JV) established with MAKYOL (a major Turkish general construction contractor); the works were started in April 2014 and completed two years later in March 2016. This chapter reports on the hanger replacement.

3.1 Hanger replacement method

Figure 11 illustrates the procedure that was followed to replace the inclined hangers with vertical hangers. Before the adoption of this method, PARSONS conducted a study on another method as well, whereby the original inclined hangers would have been replaced with new inclined hangers. Whereas this method required a 42-month work period because step ④ in **Fig. 11** was followed by two additional steps, i.e., the installation of new inclined hangers and the removal of vertical hangers, the adopted method was expected although a 20-month work period. The study resulted in the conclusion that the method of replacing the original inclined hangers with vertical hangers would be more economical and enable the works to be completed in a shorter period of time. For this reason, this method was adopted. Given that the traffic volume on this bridge was particularly high, the shortest duration of traffic restriction, one advantage of this method, was a key factor. **Figure 12** shows the situations before and after the removal of the inclined hangers.

3.2 Tension introduction to hangers

Given that the design tension introduced to the new vertical



(Note) Hanger replacement procedure
① Installation of the connections of the vertical hangers on the main cables and girder
② Installation of the vertical hangers
③ Tensioning of the vertical hangers
④ Removal of the inclined hangers
⑤ Tension adjustment of the vertical hangers

Fig. 11 Replacement sequence from inclined hanger to vertical hanger

hangers was approximately 500 kN, we conducted a structural analysis, thereby confirming that introducing this tension to each of the hangers would relieve the existing inclined hangers of tension. On site, the design tension was introduced to the vertical hangers by using tensioning equipment as shown in **Fig. 13**, and after tension had been introduced to all hangers, it was confirmed that the tension of inclined hangers

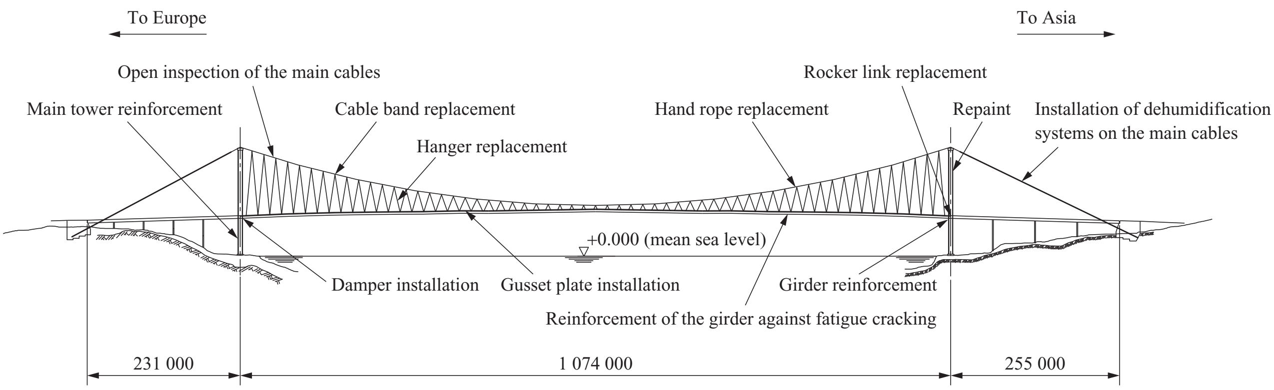


Fig. 10 General arrangement of "Bosphorus Bridge" and reinforcement item (unit : mm)

(a) During works: Coexistence ofinclined hangers and vertical hangers

(b) After works: Vertical hangers only

Fig. 12 Situation before and after dismantling inclined hanger

Fig. 13 Jacking equipment of hanger

were almost completely released and then the inclined hangers were removed. After removal of the inclined hangers, the tension on the new hangers was measured again and it was adjusted at the panel points to be greater than the allowable limit, which is the design tension $\pm 5\%$. In addition, the tension was remeasured on the hangers adjacent to the hangers at the panel points on both sides, as they were also affected by the tension adjustments, and it was confirmed that the remeasured tensions were within the allowable limits. Thus, the inclined hangers were completely replaced.

4. "Matadi Bridge" Maintenance Program

The "Matadi Bridge," situated in Matadi City, Congo Central Province in the western part of the DRC, was constructed by a JV led by Ishikawajima-Harima Heavy Industries Co., Ltd. (the present IHI Corporation) with Japan's loan assistance and was completed in 1983. It is a 3-span continuous stiffened suspension bridge with a bridge length of 722 m. **Figure 14** provides a panoramic view of the "Matadi Bridge" and **Fig. 15** provides a general drawing of the bridge.

Key specifications

Length of bridge	722 m
Span length	101 m + 520 m + 101 m
Width	11.5 m (one lane in each direction)
Year of completion	1983

The Organization for Equipment of Banana-Kinshasa (OEBK), a bridge management organization, carried out maintenance of the bridge on a regular basis. With the lapse of 36 years from the completion of the bridge, however, there were concerns about deterioration in the strength of the bridge due to aging, especially the advancement of internal corrosion of the main cables. For this reason, a main cable inspection was conducted on the main cables in 2012, resulting in the conclusion that if the existing situation remains unchanged, relative humidity in the cables would

Fig. 14 Panoramic view of "Matadi Bridge"

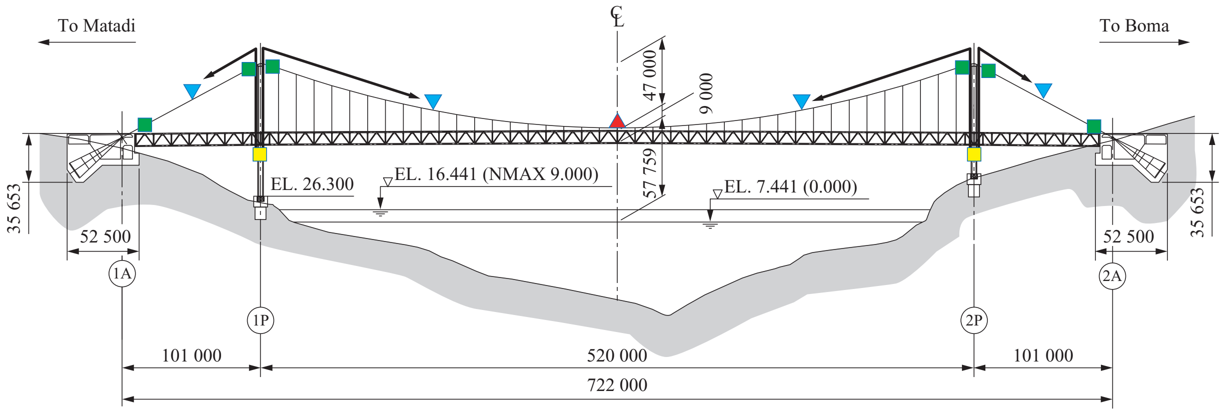


Fig. 15 General arrangement of "Matadi Bridge" (unit : mm)

affect the corrosion of the wires, posing a risk of wire fracture in the future. As a result, a reinforcement project for prolonging the lifespan of the suspension bridge called the "Democratic Republic of the Congo Matadi Bridge Maintenance Program" was implemented.

This reinforcement project was implemented with a grant-in-aid of the Japan International Cooperation Agency (JICA) and consisted of the following works: ① installation of a dehumidification system for the main cables and anchorages; ② renewal of the electric power equipment; ③ retightening and caulking of the cable band bolts; ④ reinforcement of the anchorage wall concrete against cracking; and ⑤ repainting the main cables.

OEBK was in charge of this project. The JV of Oriental Consultants Global Co., Ltd. and Nippon Engineering Consultants Co., Ltd. undertook execution management. IIS participated in this project as the contractor, engaging in the procurement of equipment and on-site installation work from January 2016 to March 2017.

This chapter reports on the installation of a dehumidification system.

4.1 Installation of a dehumidification system

The purpose of the dehumidification system is to inject dry air into the main cables or their connections, i.e., anchorage chambers, from the air inlet to reduce the overall relative humidity in the main cables or anchorage chambers and thereby prevent the advancement of corrosion of the main cable wires.

The equipment in each anchorage chamber consists of a compressor unit, a dehumidifier and a duct. We adopted a method whereby dehumidified (dry) air is injected into the bottom of the anchorage chamber through the duct and then pushed up from the bottom of the chamber. **Figure 16** provides a layout diagram of the equipment in the anchorage chamber. Before the installation of the system, the section penetrated by the main cables, ventilation hole, inlet and outlet of each anchorage were closed and cracks in the wall

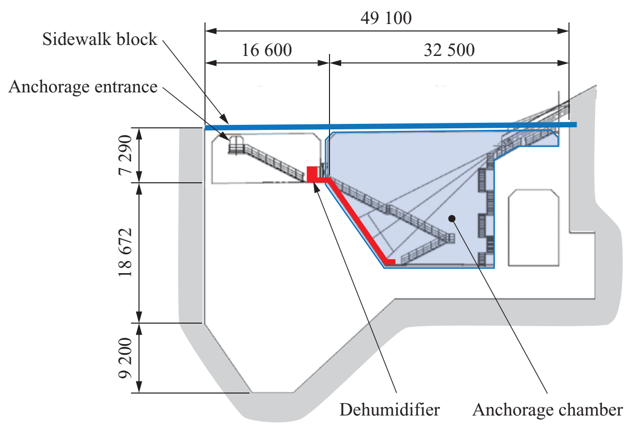


Fig. 16 Layout of dehumidification system in anchorage (unit : mm)

concrete were filled to improve the internal airtightness of the anchorage chamber. With this system, we wanted to control the relative humidity in the chambers so that it would not exceed 60%, as well as to take measurements of and record the relative humidities at the top, middle and bottom parts of the anchorage chambers during daily inspections, in order to prevent the advancement of corrosion.

Moreover, in order to improve the airtightness of the main cable surfaces, additional painting of the cables and sealing of the cable bands were performed before equipment installation. The system consists of two parts: the 1P part (southern anchorage – 1P main tower – center) and the 2P part (center – 2P main tower – northern anchorage). As illustrated by **Fig. 15**, dry air is delivered from the dehumidifiers located in the horizontal members at the bottoms of main towers 1P and 2P to the tops of the main towers through piping and is then delivered to the central and side spans through the manifolds at the tops of the towers. After the dry air reaches each injection unit through the piping, it is delivered into the main cables and then discharged from a tower top saddle, an anchorage, or the exhaust unit located at the center of the central span. The target relative humidity in the main cables was set to 60% or less, equal to the target relative humidity in the anchorage chambers. Air feed pressure was set to 3.0 kPa or less in consideration of the seal durability of the cable bands. The monitoring units located in immediate proximity to each anchorage and those located on both sides of the tower top sections, as well as the exhaust unit located at the center of the central span were specified as locations for acquisition of relative humidity data.

4.2 Monitoring of the dehumidification system

The planning of the dehumidification system was conducted on the assumption that start-up of the system, operation adjustments, and acquisition of data (e.g., relative humidity, temperature) would be performed manually. Monitoring is performed at each measurement point — 12 points on the anchorages and 14 points on the main cables — on a daily basis by members of OEBK's staff carrying a thermometer and hygrometer. Acquired data is graphed on site and transmitted to Japan on a weekly basis. After a lapse of about half a year from its installation, the system is gradually showing signs of its effects. The data transfer to Japan will be continued until the stability of the results of relative humidity measurements at each measurement point is confirmed.

5. Conclusion

It is anticipated that as the number of Japanese and overseas suspension bridges that have been in service for over 30 years increases, an increasing number of reinforcement works will be executed on large suspension bridges in order to prolong their lifespans.

An expansion joint is a member necessary to absorb the motion of a bridge, but it is prone to damage and is disadvantageous in terms of maintenance. For ordinary bridges as well, it is thought that making the number of joints as low as possible or even designing a no-joint bridge are measures that can be taken to prolong the lifespans of bridges. The purpose of the orthotropic steel deck continuation work we recently executed on the "Wakato Bridge" was also to achieve a no-joint bridge. As a result of the work, the bridge administrator has been relieved of the maintenance of rubber expansion joints, and at the same time, the corrosive environment surrounding the girder has been improved. Moreover, the flatness of the road surface has been improved; thus, the work has had the side-effect of improving the driving comfortability for passing vehicles and the reduction of road noise as well. It can therefore be said that the work was extremely significant renovation work.

In the large-scale reinforcement works for the "Bosphorus Bridge," IIS changed the type of hangers of the suspension bridge from inclined hangers to vertical hangers. Although this work was an unprecedented undertaking, we overcame technical challenges and successfully completed the work. Since a suspension bridge with inclined hangers is rare, it seems to be unlikely that inclined hanger replacement work will be planned in the future; however, we expect our achievements in this work to be of great help when replacing vertical hangers of ordinary suspension bridges as well.

Main cables are critical components of suspension bridges and cannot be replaced. Hence, the improvement of the durability of main cables is effective for prolonging the lifespans of suspension bridges. A dehumidification system as introduced in the "Matadi Bridge" Maintenance Program is very effective as a means of remedying a corrosive environment surrounding main cables and is applicable to both new bridges and existing bridges. It is expected that an increasing number of works of this type will be executed particularly on existing suspension bridges now and into the future. We therefore believe that we will have plenty of chances to take advantage of this experience.

— Acknowledgments —

We received a great deal of cooperation for the execution of the works described in this article from many parties involved in the works, including Kitakyushu City Road public corporation, KGM, OEBK and JICA. With such cooperation, we were able to successfully carry them out. We would like to express our sincere gratitude for their cooperation.