The Kintaikyo Wooden Bridge

— spanning as evidence of relationship between human being and nature —

Contents

Kintaikyo World Heritage Promotion Office
City of Iwakuni

1. Background of Bridge Construction

1) Location

① Unique Town Planning

Immediately after defeat in the Battle of Sekigahara (1600), Hiroie Kikkawa, the first feudal lord of the Iwakuni Domain, planned to construct a strong castle town that would be easy to defend against the expected enemy attack. Having discovered that the Nishiki River flowed in a U curve around a mountain, the Lord Kikkawa decided to locate his castle on that mountain, since the River surrounding the mountain could serve as an ideal outer moat. At the foot of the mountain, he ordered upper-class warriors to build their residences. On the River's opposite shore, the lord constructed a town for middle and lower-class warriors, as well as for the merchants who would support residents' daily life. As a result, the castle town comprised two districts bisected by the River, which necessitated some means of linking the two districts.

Fig. 1: Map of Iwakuni Domain (1688)

Photo 1: Aerial photo of Kintaikyo Bridge and Mt. Shiroyama

Photo 2: Castle town viewed from Mt. Shiroyama

② Need for a Bridge

Although the original town plan conceived by Hiroie Kikkawa was excellent from the perspective of defense in war, which he believed would break out shortly, the area of land surrounded by the River was very narrow. Since not all his vassals were able to build their houses there, many were obliged to find land on the opposite shore. To assemble them at the castle for important decisions, a bridge was necessary, since only a bridge could ensure access for his vassals regardless of weather conditions. Accordingly, it is reasonably concluded that a bridge was constructed concurrently with the town. There is no evidence, however, that proves the existence of such a bridge at the time, since the oldest extant document indicating the presence of a bridge was written in 1639. However, this first known bridge, an ordinary girder bridge with many piers, was washed away by a storm. After losing the girder bridge, commuters to the castle used ferryboats for many years.
The ferryboat, however, was out of service whenever the water level became too high. During periods of continuous bad weather, vassals were unable to gather at the castle, a state that interfered with policy making and administrative procedures. It is in this context that people in Iwakuni were impatient to have a durable bridge that could withstand storms.

③ System for Guaranteeing the Bridge's Long Life

In response to the growing demand for a durable bridge, the first Kintaikyo Bridge — a five-span arch bridge — was constructed in 1673. (The present Kintaikyo is the fourth.) For the initial 195 years, until 1868, the Kintaikyo Bridge was used only by successive feudal lords of the Domain and their vassals. Since 1868, however, local residents have been using the Kintaikyo Bridge as an essential means of crossing the River. Today, the bridge having been designated a national cultural property, the City of Iwakuni, home of the Kintaikyo Bridge, bears the responsibility of preserving the Bridge for present and future generations.
Despite the Bridge's unique five-span arch structure, which is designed to enhance durability, the Kintaikyo, which is primarily made of wood, is vulnerable to natural disaster. As a way of long sustaining the Kintaikyo, the City of Iwakuni decided to establish a unique system: instead of reinforcing the existing Bridge structure, the City decided to guarantee the succession of Bridge building technology, so as to ensure repeated rebuilding of the Bridge. This solution is indeed unprecedented and unique in the history of bridges in the world.

2) Natural Disasters

① Storms and Floods

The Nishiki River

The Nishiki River, spanned by the Kintaikyo, is Yamaguchi Prefecture's longest river, with a total length of approximately 110 km and a total catchment area of approximately 884 km^2. (The River is 200-meter wide at the point of the Kintaikyo Bridge.) Today there are three dams upstream of the Kintaikyo, and an additional dam is under construction. In 1950, when the Bridge was washed away, however, there was only one dam (designed catchment area: 152.2 km^2; total storage capacity: 7,031,000 m^3).

Photo 3: An arch being washed away following the collapse of the fourth pier, due to the erosion of its stone footing

Collapse of the Bridge during the Showa Period (1926 - 1989)

The Kintaikyo Bridge was washed away on September 14, 1950, when the River's flow volume increased to 3,700 m^3 /s at the point of the Bridge. This flow volume exceeded the design high water discharge of 2,470 m^3 /s. Over the preceding two days, average precipitation in the catchment area had been 328.8 mm (Photo 3).
During the dry season (November to April), flow volume decreases as shown in Photo 4. Once flooding occurs, however, the water level rises as shown in Photo 3.

Photo 4: The Nishiki River during dry season

Heavy Rainfall

In 2005, Typhoon 14, which was formed between the night of September 6 and the dawn of September 7, 2005, brought heavy rainfall (maximum precipitation: 59 mm/hour) over the upper reach of the Nishiki River. The daily precipitation reached 472 mm, the heaviest rainfall in recorded history in Japan. At the observing station situated 600 meters downstream from the Kintaikyo Bridge, the water level reached 7.32 meters at 1:00 a.m. on September 7, as compared to the danger level of 6.4 meters. The flow volume at that time was approximately 5,400 m^3 /s (Photo 6), which was much greater than the level recorded when the Bridge was carried away in 1950. The heavy rainfall indicated that the three dams were insufficient to control flooding of the Nishiki River, thereby demonstrating the strategic importance of the Bridge design, including its spans and height of piers.

Damage

The typhoon inflicted extensive damage on Kintaikyo Bridge. The drift from upper reaches destroyed two piers of the first span (Photo 7), causing damage to the fifth span as well (Photo 8). After the typhoon, approximately 40 million yen was needed to restore the Bridge. Damage inflicted on all of Iwakuni City amounted to approximately 14.8 billion yen.

Photo 5: A flood downstream of the Kintaikyo Bridge (for reference)

Photo 6: The flood of September 2005

Photo 7: The first span after losing two piers in the flood of 2005

Photo 8: Drift that blocked the water flow under the fifth span

Despite the loss of the two piers from the first span, its superstructure remained intact. The superstructure was protected by the design of a special tenon called *hozo* (projection left by cutting away the wood around it for insertion into another member to make a joint) (Photo 9). Unlike typical tenons, which are designed to join members firmly, the *hozo* used in the Bridge had been tapered to allow members disjoint easily, so that substructural damage would not impact the superstructure. In other words, the *hozo* was designed to function in a way similar to a fuse in an electric circuit. This unique *hozo* design was developed over the long history of the Bridge, which experienced frequent storms and floods. Although the great flood of 2005 occurred 55 years after the similarly great flood of 1950, slightly less serious floods strike every few years. The Kintaikyo would have been carried away more frequently, had its central portion been a girder bridge equipped with many piers.

Photo 9: Tapered *hozo* tenon, a design to enhance the ease of disjointing

② Earthquakes

In December 10, 1685 by the lunar calendar then in use (January 4, 1686 by the present solar calendar), the region was struck by an earthquake thought to have exceeded 7.0 on the Richter scale. A document of the time indicates that during the quake, piers submerged slightly. More recent earthquakes in the region include one measuring 6.9 on the Richter scale in 1905 and another measuring 6.2 in 1949. There is, however, no record that the Bridge was damaged by either quake.

Still more recently, the West Tottori Earthquake occurred on October 6, 2000 (7.3 on the Richter scale), and the Geiyo Earthquake on April 24, 2001 (6.4 on the Richter scale), both causing extensive damage to many structures in the nearby region. At the time of the Geiyo Earthquake, the Kintaikyo Bridge swayed so violently that pedestrians crossing it were extremely frightened. The Bridge, however, remained intact. The Bridge was free from deformation because the over 20,000 members comprising it absorbed the stress of the quake.

Thus, a storm definitely poses a greater threat to the Bridge than does an earthquake.

2. Bridge Construction System

1) Passing down Traditional Technology

① Passing down the Secrets of Technology to Only One Successor

During the Edo Period (1603 - 1868), important technologies were primarily handed down from the father to the eldest son, or sometimes from the master to his first disciple. This system is indicated by old documents that list the chief carpenters' names.

During the Edo Period, the Kintaikyo Bridge projects were implemented by the Iwakuni Domain. Carpenters engaged in the projects were vassals of the lord of Iwakuni. Among the vassals, those who belonged to a specific family succeeded to the role of bridge construction. Accordingly, the bridge building technology was inherited in that family.

In handing down technologies, it is essential that successors have first-hand experience. Regarding the technologies involved in building wooden structures, there are aspects that even the best drawing or book cannot record. Without experiencing actual bridge construction, no carpenter can build a wooden bridge like the Kintaikyo.

② Historic Materials

Many historic documents remain regarding the Kintaikyo Bridge. Of them, the oldest extant material is the drawing prepared in 1699 (Fig. 2). (There are 12 additional drawings that remain intact today.) The oldest drawing indicates in detail the types, dimensions and production centers of the timbers used for the Bridge; types and number of necessary metal fittings; primary dimensions and gradients of beams used for the three arches in the Bridge's central portion etc. Without these documents, it would have been impossible to rebuild the Bridge each time it was carried away.

To long sustain the bridge building technology, we must also prepare and preserve such records for future generations.

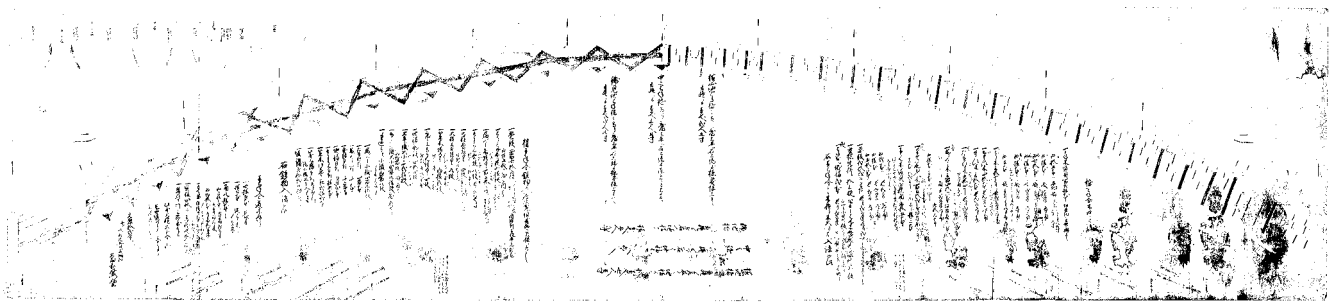

Fig. 2: The oldest extant drawing of the bridge, prepared at the time of rebuilding in 1699

③ To Learn from Wood to Know Wood

Since the Edo Period, carpenters have passed down verbally the secrets of their technology, or aspects that are difficult to express either in text or drawing. Among such secrets is the method of learning from wood the nature inherent in each respective wood type. Each timber has a different and unique nature, which can be learned only by viewing and touching the timber, and using all five senses. Without knowing the nature of each timber, carpenters cannot use it for the appropriate purpose (Photo 10).

Unfortunately, the wide spread of laminated lumber provides contemporary carpenters with few opportunities to learn from wood. In this environment, rebuilding the Kintaikyo Bridge, which employs authentic timbers, is a golden opportunity for carpenters to acquire the skill of learning from wood the nature inherent in each type of wood.

Photo 10: Marking on timbers

2) Establishing a New Order Placement System

① The Order System Prioritizing Technological Transfer

Since the construction of the first bridge, the Kintaikyo has been rebuilt and maintained by local people. To long sustain the traditional bridge building technology, it is best that such technology be passed down to local people. With this view, in selecting builders the local authority adopts a single tendering method rather than a competitive tender, which is the most common way of ordering public works. Although use of the single tendering method is rare, in the case of the Kintaikyo projects it is most effective in transferring traditional technology.

A drawback of the single tendering method, however, is that project expenses can become higher due to the lack of competitive bidding. Even so, this system is essential for passing down traditional technologies to future generations in the Iwakuni region, as well as for maintaining local carpenters' enthusiasm for inheriting their predecessors' high technical expertise.

② Order Placement by Type of Work

Rebuilding the Kintaikyo Bridge requires various types of work, including temporary structure construction (building footings etc.), civil engineering (preparing work yard), carpentry (timber processing and bridge building), metal processing (processing steel and copper plates), painting (painting timbers and steel members for antiseptic treatment), procurement (purchase of timber) and nail production (producing traditional Japanese nails). Since from the standpoint of managerial efficiency it is unwise to place separate orders for individual types of work, in the recent project the local authority placed orders — orders for temporary structure construction, civil engineering, carpentry, metal processing and painting — collectively with a local builders' union. However, the authority placed orders with timber merchants and nail producers on an individual basis. Instead of supplying raw materials to individual worker unions, the authority supplied them to the principal contractor, i.e. the local builders' union. As to carpentry work, the primary contractor subcontracted the work to a local carpenters' union. Since carpenters usually work by themselves, the primary contractor subcontracted the project, involving hundreds of millions of yen, to the carpenters' union rather than to individual carpenters. Similarly, the primary contractor subcontracted other types of work to selected local unions, rather than to individual workers. Since this method has been effective in passing down traditional techniques to younger generations, the authority will continue this order placement system in the future.

3) To Pass on Building Technology to Future Generations

① Fostering Carpenters

Only carpenters who have received sufficient training can process timbers and build a bridge like the Kintaikyo Bridge. To build a structure using traditional technology, carpenters must have expertise in processing timbers, as well as skills in identifying the inherent nature of individual timbers.

Recently, however, carpenters primarily use precut, laminated timbers. Contemporary carpenters therefore have fewer opportunities to use and process authentic, live timbers. Therefore, rebuilding the Kintaikyo Bridge affords carpenters a rare opportunity to learn the traditional technology of wood building. In the rebuilding project conducted during the Heisei Period (1989 -), carpenters of various generations were recruited to take part in the project, so as to transfer timber processing and bridge building technologies to younger generations. To foster future carpenters, the workers who were engaged in the most recent project are currently organizing various training programs, including seminars. The City of Iwakuni believes that such programs are essential for handing down the traditional technology to future generations. With this view, the City is considering establishing an appropriate system to support such activities.

② Timber Production System

During the Edo Period, the Bridge was built using locally available timber. In recent projects, however, including the one during the Heisei Period (1989 -), rebuilding projects had to rely primarily on a supply of timber from other prefectures. There are various, rigorous requirements for the wood materials to be used in building the Bridge, since they must withstand extremely severe climatic and weather conditions. Only timbers of large diameter can meet these requirements. In the local mountains and forests owned by the City of Iwakuni, however, no such trees were found.

The City of Iwakuni therefore has designated a special forest to grow wood for use in future Kintaikyo Bridge rebuilding projects. Since the trees planted in the forest are still young — about 80 years old —, they cannot be used now. They should be preserved, however, for use in future. To pass down the traditional bridge building technology to future generations, some suggested that the Bridge be rebuilt every twenty years. In line with this proposal, the authority has designated a new forest, where seedlings will be planted in March 2008 to prepare timbers for a project 200 years hence. Such a timber production system, however, is not new. There is a document indicating that during the Edo Period, the Iwakuni Domain planted trees for use in the Bridge. More recently, 2,000 zelkova trees were planted in 1991.

The tree-planting campaign for the Bridge has many purposes: preserving and passing down local traditional culture and technology, nourishing water sources, helping alleviate global warming, preserving biodiversity and developing a local culture of preserving the historic environment through Bridge rebuilding and tree planting on a regular basis.

③ Rebuilding Expenses

Since the Iwakuni Domain needed considerable funds to build and rebuild the Bridge in 1673 and 1674, respectively, the Domain ordered its vassals and merchants to share the expense. The share for vassals was determined in accordance with their positions; the share of merchants was based on their family businesses. This system continued until 1871. Over the subsequent 95 years, Bridge rebuilding and maintenance was funded by donations and taxes.

On April 1, 1966 Iwakuni City began collecting tolls from pedestrians who cross the Bridge. The project to rebuild the Bridge during the Heisei Period cost 2.6 billion yen. Of the amount, 2.2 billion yen was funded by the tolls, the remaining 0.4 billion yen by the national and prefectural governments. To maintain the Kintaikyo Bridge, the local authority will continue collecting tolls.

3. Architectural Value of the Bridge

1) Structural Characteristics

Each arch of the bridge consists of smoothly curved skeleton lines, its end support points restrained so that when a vertical load is applied to the curved surface of an arch, a horizontal reaction force is generated in the support points. When subjected to free vibration, each arch prominently shows the symmetric mode of deformation inherent to an arch structure, as well as the asymmetric mode of deformation. In view of these characteristics, each of the central three spans of the Kintaikyo Bridge is considered to have an arch structure, and is the prototype of an arch bridge made of large-section, glue-laminated timbers. Each arch, resiliently retained at the end support points, provides different rigidities against small rotation and large rotation.

2) Materials

① Timber

As mentioned in Section 2-1)-②, the kinds of timbers used for this bridge, locations of their use, sizes, and other details are specified in the ancient drawing created in 1699. These specifications are followed even today.

The skill of identifying timber characteristics, cultivated over years through the Japanese wooden culture, enabled the use of appropriate types of timber in the right places, taking advantage of the characteristics of hard timber, flexible timber, decay-resistant timber, smooth timber and so on. The resulting Kintaikyo Bridge represents the essence of the wooden culture.

② Stone

The stones for the substructures of the Kintaikyo Bridge were taken from quarries on Mt. Iwakuni. Though the substructures were washed away by a flood in 1950, most of the stones were collected and reused for restoration, together with the stones of substructures that had escaped destruction. As a result, most of the stones in the present bridge substructures are those of the original bridge.

③ Iron

The Kintaikyo Bridge is valued as an artifact of wood, stone and iron. When the bridge was renovated recently (in work called the Heisei era renovation), engineers attached particular importance to nails (Japanese nails). Each nail was carefully manufactured by forging a special metal (i.e., heating and hammering metal material), developed for use in crafting the nails to be used in the latest reconstruction of Yakushiji Temple. The developed metal has low concentrations of carbon, manganese etc. and provides the anti-corrosion property of old Japanese iron.

3) Bridge Engineering

① Girder assembly technique

The Kintaikyo Bridge, a five-span wooden bridge, is 193.3 m long and 5 m wide (4.3 m effective width of road). The three central spans are arch bridges, and the two end spans are warped girder bridges. The span of each arch bridge is 35.1 m; that of each girder-bridge is 34.8 m.

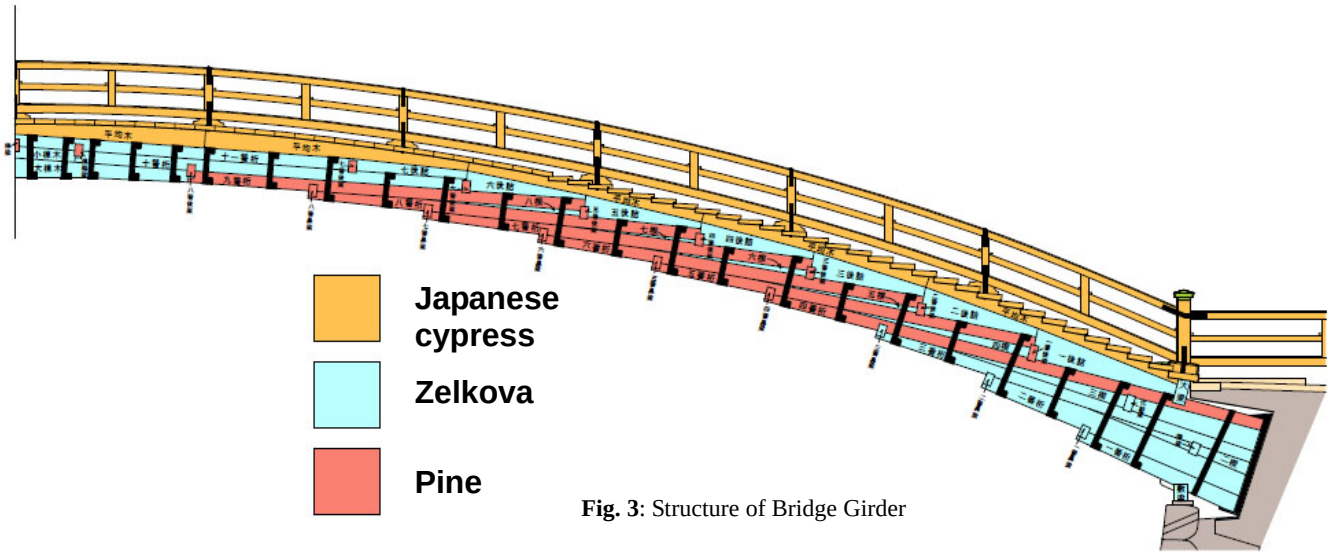

Fig. 3: Structure of Bridge Girder

The girder of each span comprises 1st through 11th girder members, a large ridge board and a small ridge board (see Fig. 3). The rear ends of the 1st through 4th girder members are inserted and bolt-clamped in the iron shoe mounted on the upper part of the substructure. The 5th through 11th girder members are longitudinally staggered so that each member protrudes by approximately one-third of its length from the girder member immediately beneath it. Girder members are sequentially installed in this way from each end of the span. A large ridge board is mounted between the 9th girder members from both ends; a small ridge board is mounted between the 10th girder members which are installed on the large ridge board. A long thin wedge is inserted between each overlapping girder member, causing the front-end portion of each member to bend slightly downward, so that an arch is formed by all girder members. To prevent girder member displacement, dowels (Photo 11) are placed in the surface of each girder member that contacts other girder members. The overlapping girder members are bound together using pairs of C-shaped hoop irons, called girder binders, which are positioned on the lateral sides of the girder members. This assembly technique, unique to the Kintaikyo Bridge, is called voussoir arch method.

Fig. 3 shows the girder assembly structure adopted for the original bridge, constructed in 1673. Ten years later, in 1683, V-shaped saddle bars (unique to the Kintaikyo Bridge) were installed, and auxiliary bars were installed along each arch rib (Photo 12), to complete the present girder assembly structure.

Photo 11: Installed Dowels

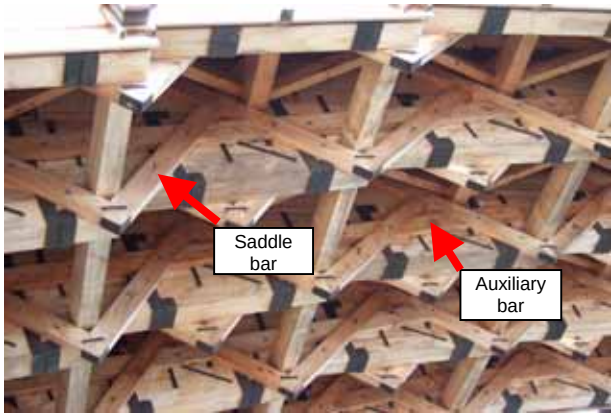

Photo 12: Saddle Bar and Auxiliary Bar

② Construction process

Full-scale drawing

Prior to timber-working, a full-scale drawing is created (Photo 13) based on the actual arch dimensions; all girder members and other members are drawn on it. The templates for respective members are then produced from the full-scale drawing (Photo 15).

Photo 13: Girder Members Are Drawn

Photo 14: Template Produced in 1929 (For Reference)

Timber-working

After template production, each timber intended for a girder beam, marked with an appropriate template applied to the timber, is cut and machined to produce a girder beam (Photo 16).

Photo 16: Marking on Timbers

Photo 15: Templates Produced for Heisei Era Renovation

Temporary assembly on land

Upon completion of timber-working, a bridge girder is temporarily assembled on land. Temporary assembly on land was also conducted before construction of the original bridge, as well as before each subsequent renewal project. The objective is to make fine adjustments to the assembly, so as to facilitate and expedite site work (Photo 17).

Photo 17: Bridge Girder Assembled on Land

Site work

Crossbeams that support the girder are installed (Photo 18); the 1st girder member is then mounted thereon at the angle of inclination shown in the ancient drawing (Photo 19). The 1st through 4th girder members are then inserted into the iron shoe and clamped with bolts (Photo 20). The 5th through 9th girder members are stagger-mounted so that each girder member protrudes forward from the girder member immediately beneath it. After installation of the 9th girder members from both ends, a large ridge board is mounted between the two 9th girder members, to connect the trains of girder members approaching from both ends. The 10th girder members

Photo 18: Installed Crossbeams

are then mounted. After a small ridge board is installed between the 10th girder members, the 11th girder member is mounted. The girder members thus mounted are bound together using girder binders. Finally, post-packing is applied, and averaging wood members are installed to complete the girder assembly.

Photo 19: Angle Adjustment of 1st Girder Beam

Photo 20: 1st through 4th Girder Members Fixed to Iron Shoe

Photo 21: Bridge Girder Assembled on Site

Photo 22: Post-Packing and Averaging Wood Members Installed on Girder Assembly

4. Bridge Data

1) History of the Kintaikyo Bridge

① The Edo Period (1603 - 1868)

On June 28, 1673 by the lunar calendar (August 10, 1673, by the present solar calendar), a groundbreaking ceremony took place to initiate construction of the first Kintaikyo Bridge (arch bridge), which was completed on September 30 (November 8 by the present calendar), and officially opened on October 3 (November 11 by the present calendar). Surprisingly, the work was completed only in three months. This first bridge, however, was carried away by a storm on May 28, 1674 (July 1 by the present calendar). The arch bridge collapsed following the loss of its three piers due to erosion of the surrounding riverbed. Bridge rebuilding commenced on June 1 in the same year (July 4 by the present calendar). The rebuilding project, in which the footing of the piers was made particularly strong, was completed on October 25 (November 22 by the present calendar); the new bridge was officially opened on November 3, 1674 (November 30 by the present calendar).

② The Showa Period (1926 - 1989)

The second bridge remained intact for 276 years. Because of insufficient maintenance during the post-World-War-II period, however, the Bridge was carried away by the typhoon that struck Iwakuni on September 14, 1950. At the meeting held in Tokyo to discuss reconstruction plans, some suggested that the new bridge be constructed using concrete. Representatives of Iwakuni, however, strongly insisted that a bridge of the original design be rebuilt.

Photo 23: Rebuilding the Bridge during the Showa Period (1926 - 1989) (for reference)

③ The Heisei Period (1989 - today)

During the Heisei Period, rebuilding was carried out to construct the fourth Kintaikyo (present bridge). Because of restrictions on the project period, which is limited to the dry season, as well as other restrictions relating to procedures for gaining governmental permission, the project was implemented in three phases, which spanned three years. Since the Kintaikyo Bridge is an essential tourist resource for Iwakuni, the long duration of the project period had serious negative impact on the tourist industry. To mitigate the anticipated loss, it was decided that an alternative bridge would be built, from which tourists and local people would be able to view the rebuilding process (Photo 24).

Photo 24: Alternative bridge installed during the first phase of the project

While the alternative bridge enabled people to cross the river, increasing numbers of tourists began visiting Iwakuni to view the project site. Their number, which was below 700,000/year immediately before initiation of the project, gradually increased, reaching over 1 million/year by the end.

2) Landscape around the Bridge

① Festivals

On and around the Kintaikyo Bridge, several events are held annually. April 29 each year marks the date of the Kintaikyo Festival (Photos 25, 26), designed to demonstrate residents' gratitude for their ancestors who built the Bridge. Every first Saturday in August, the Nishiki River Water Festival (Photo 27) is held. From June 1 to August 31, cormorant fishing, which originated during the Edo Period (Photo 28), is observed in the traditional style.

Photo 27: The Nishiki River Water Festival

Photo 25: Kintaikyo Festival

Photo 26: Families of U.S. forces participating in the procession in traditional costumes

Photo 28: Cormorant fishing, conducted below the Bridge

② The Kintaikyo Bridge in Four Seasons

Kintaikyo continues to fascinate visitors with its exceptional beauty, which changes according to the time of the day and the season of the year.

Photo 29: Kintaikyo in spring

Photo 30: Kintaikyo in spring

Photo 31: Kintaikyo on a summer night

Photo 32: Kintaikyo in autumn

Photo 33: Kintaikyo in winter