A Bridge Made of Wood

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Utilization of Wood

The recent trend in departmental naming at Japanese universities is the disappearance of the word "civil engineering". One reason behind this trend may be that our territory is expanding and the concept of "mounding earth and assembling wood" has become too narrow to cover the entire civil engineering discipline. Yet, it would be a pity to forget our roots that are the "earth" and the "wood".

Compared with the "culture of stone" in the West, Japanese "culture of wood" has used timber as the main material not only for shrines, temples and houses but also for bridges. However, today, cast iron, wrought iron, steel and concrete have become the main materials for bridge parts, and in many cases, wood is used in a limited range such as for landscaping or temporary materials. Wood, as a material consumes far less energy in its production process compared to other materials. Moreover, its use enables the maintenance of forests and therefore is an excellent material for the environment. Also, timber utilization is expected to not only activate the forest industry, but also make a great contribution to the development of the local economy, which has been experiencing a considerable downturn.

In Miyazaki Prefecture, the top cedar-producing region in Japan, the "Great Karikobozu Bridge" which takes advantage of the above-mentioned characteristics of timber, was planned, designed and constructed. And in the spring of 2003, the largest timber road bridge in Japan was completed successfully.

With the increase in demand for environment-friendly timber, its manufacturing costs will decrease and will enable the construction of more economical bridges.

Forms of Wooden Bridges

As in steel or concrete bridges, timber bridges come in various forms including girder bridges, truss bridges, arch bridges, cable-stayed bridges and suspension bridges. Because wood has lower strength that steel or concrete, it has shorter applicable span and is often used in pedestrian bridges. Some of the typical timber bridges that are used as road bridges are shown in Table-1. In the case of a structure that has each spot joint like a truss bridge, spans become longer, and when connection of parts becomes necessary, steel material is used at the joints.

Wood as a Material

Wood as a material demonstrates considerable strength and little deformation when forces such as tension, compression and bending are applied in the direction of its fiber. Moreover, as wood has little weight, strength of the equal mass is very large compared to other materials. Among various strengths in the direction of the fiber, tension is the largest, next is bending, and compression is about 1/3 ~ 2/3 of the tension. Shear strength is of very small value compared to that of the compression. On the other hand, values of Young's modulus and the tension strength, perpendicular to the fiber direction are about 1/10 ~ 1/20 of those in the fiber direction. Wood is visco-elastic, and therefore it demonstrates the creeping phenomenon in which deformation increases with time, when a certain load is added to it. However, it is one of the materials with small creep strain among other high polymer materials. Nevertheless, it has a tendency of remarkable increase in creep strain when its moisture content changes during the creep process.

Glued laminated timber is generally used as the material for main structural member of bridges. It is a material that consists of layers of lamina (a plate material that constitutes each layer of the glued laminated timber) that are adhered together with the directions of their fibers in approximate parallel to each other.

Advantages gained by using glued laminated material are as follows;

① It has greater strength than solid timbers

When timber is used as a log, force transmission cannot be prevented through its fiber, whereas, when the work is done in a prim and stiff way, it generates fiber declination in the timber and lowers its strength. On the other hand, with glued laminated timber, it is possible to arrange thin lamina artificially and rationally. Especially when they are used in a beam that undergoes bending, it becomes possible to form a section rationally by arranging lamina with larger strength on the outer edge that receives larger stress, and those with smaller strength in the center of the section (near the neutral axis) where they would receive smaller stress.

② Cracks and measurement errors can be decreased.

Since glued laminated timber is fully dried in a state of lamina, there are few cracks and member measurement errors even in a large section. Furthermore, measurements are stable because there is hardly any dry contraction, so it becomes possible to use it securely as an industrial product.

③ Changing forms and sizes voluntarily becomes possible

With glued laminated timber, production in various forms such as large section, length, curvature, and varying cross sections become possible.

④ Fireproof

With large sections, as the outer edges of the section burns and becomes carbonated, the combustion of timber is delayed and thus the material's fireproof capability is enhanced.

Thus, by using glued laminated timber, homogenization of the material as well as its reliability are enhanced. Furthermore, it becomes possible to meet the strength required. In addition, it is possible to produce large section members that have been hard to obtain with natural material, and therefore its usage potentiality is remarkably expanded. However, sizes of glued laminated timber that can be produced continue to be restricted due to the factory facilities.

When using timber as a structural member of a bridge, treatments against decay or against ants are indispensable in order to improve the durability of the bridge. The agents for these purposes are generally injected by pressurized injection.

Verification of Material Performance

Just as the qualities of steel or concrete that are used as bridge materials are guaranteed by standards like JIS, it is necessary to guarantee the quality of timber. To test the quality of glued laminated timber, there is a JAS Standard, which stipulates the testing method and the judgment method of the test results for the test items below:

① Bending test

・Verification test of bending strength of glued laminated timber.

② Shear test

・Verification test of shear strength of glued laminated timber.

③ Soak peel test

・Verification test of peel ratio of samples after 24 hours of soaking

④ Boiling peel test

・Verification test of peel ratio of samples that were soaked in boiling water for 4 hours.

⑤ Moisture ratio test

・Verification test of moisture ratio of glued laminated timber.

Glued laminated timber has already treated against decay and against ants. Therefore, verification tests should be carried out using sample pieces that are already treated with anti-decay and anti-ant agents.

Great Karikobozu Bridge

The Great Karikobozu Bridge is a timber road bridge constructed at the upstream of Hitotsuse River that flows along Furusato Forest Road of Nishimera Village, Koyu County in Miyazaki Prefecture.

As Miyazaki Prefecture is the number one producer of cedar timber in Japan, cedar glue laminated timber is used as the material for the main structural member of this bridge to promote the local industry of forestry, as well as to preserve the landscape and the environment. As consideration for the landscape, on top of preserving the landscape with the warmth of the timber, harmony with the surrounding environment was sought by creating king-post truss structures after the image of the three surrounding mountains of Mera. The cutting area of timber that was used for the bridge was approx. 21.2 ha, the raw wood bulk was approx. 4,100 m^2, and approx. 1,335 m^3 was used as glued laminated timber.

"Karikobozu" is a forest spirit, whose tale has been passed down orally in Nishimera Village. It is the symbolic character of the village that is said to live in Hitotsuse River, just like the imaginary creature called Kappa. It was derived from "Kariko," who were in charge of chasing out the games during hunting in the Mera Mountains. As it has been worshipped as the god of mountain and water, the name has been familiar to the local residents.

"Karikobozu Bridge" (Photo-1), with its total length of 140 meter and its longest span of 48.2 m, is the largest timber road bridge in Japan. Its superstructure consists of simple structures which were determined based on the condition of the river and structural examination results. The adopted structures were a span of simple girder, two spans of king-post truss and a small truss. Moreover, steel material joints are used for the truss panel points (Photo-2).

Photo-1 The nightscape inside the dome.　The beams seem sucked into the wall.

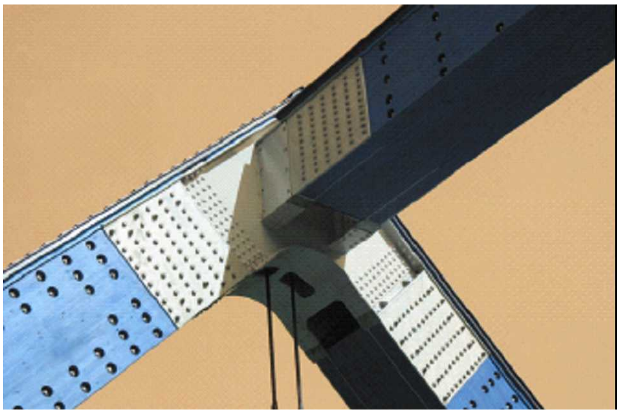

Photo-2　A view of the dome from the pier

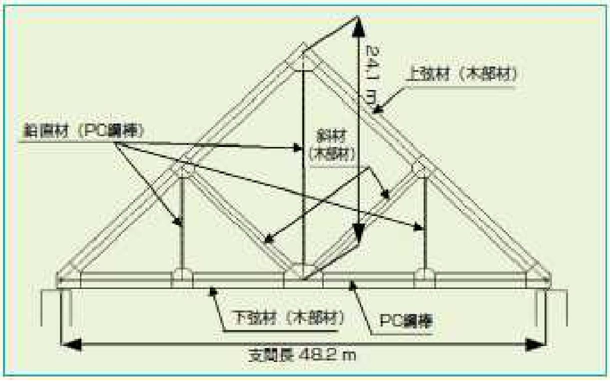

Fig.-1 the structure of the king post truss bridge

Fig.-1 shows the structure of the king post truss bridge of the Great Karikobozu Bridge. As for the structural characteristic of this bridge, considering the entire structure as a triangle truss, the load is resisted principally by the upper chord and the horizontal force that are generated at the supporting point are resisted by PC steel bars (SBPRφ23) that are placed as the lower chord. If the lower chord had been made solely of timber member, it would have been impossible to manufacture glued laminated timber because the member height would have exceeded 2 meters. Therefore, the structure in which PC steel bars in the lower chord bear the axial force of the trussing, and the timber member bears the load of the floor system that supports the bridge load was adopted.

PC steel bars (SBPRφ32) was used as the vertical member in order to facilitate configuration management by re-tensing the timber after creep deformation. At the same time, because the lower chord was shortened by the vertical member, it has become possible to reduce the maximum stress resultant that generates in the lower chord.

Although the cedar timber produced in Miyazaki Prefecture was used in the Great Karikobozu Bridge, no tests have been carried out on cedar glued laminated timber produced in Miyazaki Prefecture before. Therefore, it was necessary to verify their strength and safety. The bending stress and the compressive force work on the upper chord of the truss, and the tensile force works on the lower chord. At the joints, steel member and wooden member are connected by bolts. In order to understand the strength characteristics of these members and verify their safety, static loading tests of the material and the members (compression tests, tensile tests, simple bending tests, tensile bending tests) as well as the fatigue tests were carried out.

Maintenance

Appropriate maintenance is necessary in order to utilize structures for a long period of time, and this does not only apply to wooden structures. Moreover, compared to corrective maintenance, which is done after deterioration have been discovered, preventive maintenance is more effective. By choosing the agents for antiseptic and ant extermination in accordance with the climate and the environment of the construction site, it becomes possible to enhance its effects.

In the case of Karikobozu Bridge, besides the antiseptic and ant extermination treatments, protective coating was placed and drainer was installed to protect the wood surface (Photo-3).

Photo-3 1931, the first block's form work removal.

Furthermore, manuals for regular, periodical, and extraordinary inspections were created to grasp the conditions of the bridge at all times. Also, in order to establish the method of maintenance, it is planned to conduct the behavior observation on each members of the bridge under creep deformation and live load, and to conduct static / dynamic tests periodically.

Taught by the Wood

It has been my previous understanding that in timber bridges, slight discrepancies in the strength or the nature of the material would raise difficulties in verifying the strength and securing homogeneous materials. However, these were not the only difficulties. Every step from securing the materials and manufacturing to connection and securing the durability was an encounter with the unknown. It was the performance design in its real sense, and I have learned a lot from planning and designing this bridge.

However, after completion, people who were not even involved in the construction seem to feel a certain familiarity with the completed wooden bridge. This may be due to the fact that the wood is after all, a material imminent to Japanese people and from which we feel the warmth. It is my hope to widen the application of wood as a material that is environment friendly and that helps to preserve the forest.

References:

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2 – Guidebook of Wooden Bridge Design and Construction, New Era of Wooden Bridge Construction, Japan Housing and Wood Technology Center, January 1995

3– Wooden Bridge Design and Construction Handbook, Japan Institute of Construction Engineering,1998

4 – USUKI, Seizo, The Era of Modern Wooden Bridges, Ryugen-sha, 1995.3

Table-1: The typical wooden road bridges in Japan

Name	Location	Structural Type	Bridge length	Design Load	Date of Completion	Material Type
Bokawa Forest Road No. 2 Bridge	Takanosu-cho, Akita Pref.	Simple girder	6.0	TL-14	1987.10	Cedar glued laminated timber
Meoto Bridge	Akita City, Akita Pref.	Through arch	23.0	TL-14	1994.12	Akita cedar
Uyo鵜養Bridge	Kawabe-cho Akita Pref.	Simple girder	14.0	TL-14	1988.8	Akita cedar
Yunomata Bridge	Gojome-cho Akita Pref.	Tied-arch	13.5	TL-14	1990.3	Akita cedar
Akagi Bridge	Tajima-machi Fukushima Pref.	Three-span simple girder	18.0	TL-14	1991.7	Norway spruce
Yokura Bridge	Hongo-cho. Hiroshima Pref.	Three-span consecutive cable-stayed	145.0	TL-14	1992.10	Norway spruce
Chuo Bridge	Hongo Town, Hiroshima Pref.	Deck lohse girder	34.0	TL-14	1993.3	Norway spruce, cedar, Red Pine
Zennyuji 善入寺 Bridge	Hongo-cho Hiroshima Pref.	Three-span simple girder	23.0	TL-14	1993.3	Norway spruce
Hirokusada 広草田 Bridge	Hongo-cho Hiroshima Pref.	Simple girder	10.7	TL-14	1993.3	Norway spruce
Agenosawa Bridge	Takanosu-cho Akita Pref.	Pre-stressed slab	8.0	TL-14	1993.10	Larch, cedar. Japanese oak
Kuriito 栗飯戸 Bridge	Kurotakimura Nara Pref.	Tied-arch	24.0	TL-20	1994.2	Japanese cypress, Norway spruce
Kaminomori Bridge	Hirotamura Ehime Pref.	2 hinge-arch	26.0	TL-20	1994.5	Cedar, Yellow southern pine
Kinokake Bridge	Kisofukushima, Nagano Pref.	4 span consecutive pre-stressed slab	40.5	A live load	1996.10	Larch, Yellow southern pine
Midori Bridge	Mitakemura Nagano Pref.	Π type rigid frame bridge	30.0	A live load	1996.12	Larch
Suginoki Bridge	Kobayashi-shi Miyazaki Pref.	2 hinge arch (deck)	38.6	A live load	1997.3	Cedar
Nijinoki Bridge	Tsuru-shi Yamanashi Pref.	Half through arch	23.0	A live load	1998.12	Cedar glue laminated timber
Asobou Bridge	Namino-mura Kumamoto Pref.	Lattice truss	41.6	A live load	1998.5	Kumamoto Cedar, Japanese cypress, イタジイ
Haykumeishi Bridge	Kyowa-cho Akita Pref.	Tied arch	20.9	A live load	1999.3	Akita cedar glue laminated timber
Tashiro Bridge	Azumi-mura Nagano Pref.	Simple slab	22.9	A live load	1999.4	Larch glue laminated timber
Kinpou 2000-nen Bridge	Kinpou-cho, Kagoshima Pref.	Deck arch	42.0	A live load	2000.1	Kagoshima Cedar glue laminated timber
Bouchu Bridge	Fujisato-mura, Akita Pref.	2 span consecutive stiffening truss wooden girder	55.0	A live load	2000.9	Akita cedar glue laminated timber
Karikobozu Bridge	Nishimera-mura Miyazaki Pref.	4 span king post truss	140.0	A live load	2003.4	Miyazaki cedar glue laminated timber