Field tests and in-service performance of the new glulam tied arch roadway bridge "Hyakume-ishi"

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ABSTRACT

Field tests were conducted on the new glued laminated timber (glulam) tied arch bridge “Hyakume-ishi” located on a forest roadway in Akita, Japan. Results showed that the bar force loss already reached almost the maximum 60% level within less than a year. One reason is the use of a water-borne preservative for the preliminary pressure treatment of the glulam members. There were large variations in the humidity within 24-hr spans which resulted to corresponding changes in the bar force. The maximum deflection under the test truck positioned longitudinally at the center of each span in the downstream lane was 8.4 mm (L/2400) on the downstream side tie member which is smaller than L/500, the maximum allowable deflection for steel bridges. The deflections are greater when the truck is positioned at the downstream side than those when the truck is positioned at the longitudinal centerline. There is a good agreement between measured and the estimated values using FEM. The maximum deflection under the test truck positioned longitudinally at the center of each span in the downstream lane was 2.72 mm which is equal to 1/1.56 of the design deflection value of the deck.

INTRODUCTION

Japan has about 25 million hectare (250 billion m^2) of forest which is about 70% of its land area. Their growing stock is about 3500 million m^3 with about 700 different tree species. Of these, the Japanese cedar (*Cryptomeria japonica* D. Don) contains about 1100 m^3 which is equal to approximately 30% of total growing stock. Japanese cedar is one of the representative plantation softwood species among the trees that compose the Japanese forests. It is necessary to consider wider use of Japanese cedar because the stock is increasing every year. Japanese cedar has been used primarily for housing construction as sawn lumber products, but recently a number of attempts to utilize Japanese cedar for large scale timber construction such as dome structure, building structure and timber bridges have been done in many prefectures (Komatsu 1997).

The glued laminated timber (glulam) tied arch bridge “Hyakume-ishi” located on a forest roadway in Akita Prefecture, Japan was completed in March 1999. The bridge also used Japanese cedar grown in the prefecture. This paper introduces the detail of structure of the bridge and results of field test which were performed on the bridge.

OUTLINE OF THE BRIDGE

Fig. 1 shows a general view of “Hyakume-ishi” bridge. The bridge length is 20.9m with span length is 20.0m. The clear roadway width is 5m. The bridge was designed in compliance with the “Japanese Specifications and Commentaries for Roadway Bridge for A-live loading (one axle load of 196kN)”. Specific design requirements for the stress-laminated timber (SLT) was based on the “Manual for Design and Construction of Timber Bridges” guided by the Technical Advisory Committee on Timber Bridges organized by the Foundation of Japan Housing and Wood Technology Center. Almost all of structural members except for the tie, floor beam and hanger members are glulam made of Japanese cedar grown in Akita Prefecture. All of glulam members were preliminary pressure treated with a water-borne preservative didecyldimethylammonium chloride (DDAC) (Eaton and Hale 1993) before the laminae gluing. Further, almost all end surfaces of glulam members were spread with a thin coat of coal tar. The arch ribs consisting of two longitudinal curved

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glulam members with interconnecting steel boxes are independent without lateral bracing and covered by a copper plate along the longitudinal direction to protect the arch rib surfaces from rain fall and direct sunshine. By these chemical treatment and additional elements, durability of the bridge was expected to be more than 30 years. The 50mmφ round steel hangers are spaced 2.8m along the bridge length. The ties and floor beams are suspended by the hangers. For the ties and floor beams, weathering steels were used. The SLT deck which was supported by the floor beams was employed for the deck of the bridge. The SLT deck was also composed of Japanese cedar glulam members except both edges for transverse direction of the deck. For both edge members, Japanese oak glulam were used taking bearing stress into consideration. The details of SLT deck will be described in the latter section. The SLT deck of the bridge contains end-to-end butt joints. At any cross section of the deck, the joints are placed in a regular pattern, with one butt joint in a group of four adjacent lamination, namely, “one-in four” (1 in 4) within a 2m distance along the deck length. This frequency of butt joints was decided according to the table of butt joint factor which was provided by Ritter (1990). The 21mm diameter high strength steel stressing bars with a design tension force of 190kN are spaced 1m along the SLT deck length.

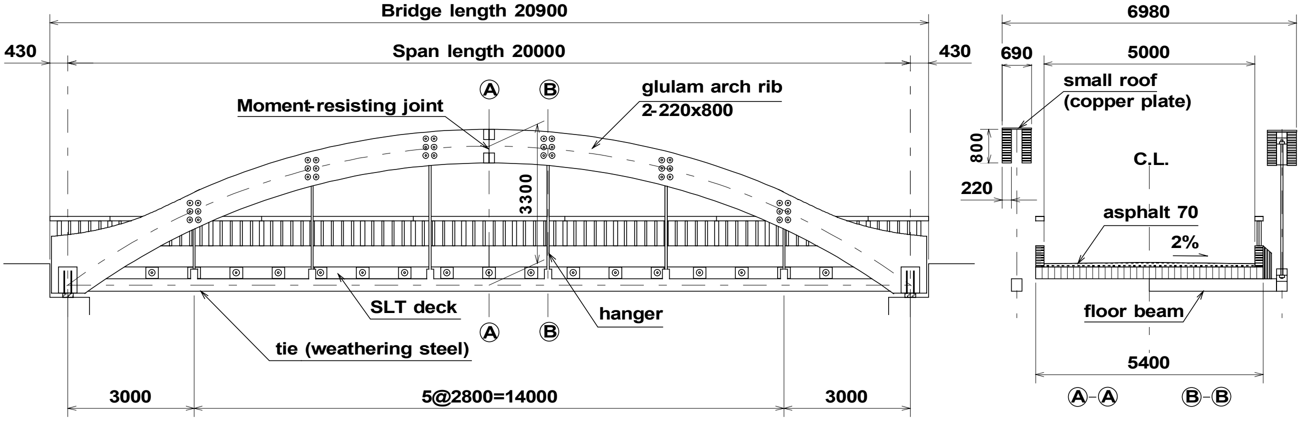


Fig. 1 General view of the “Hyakume-ishi” bridge.

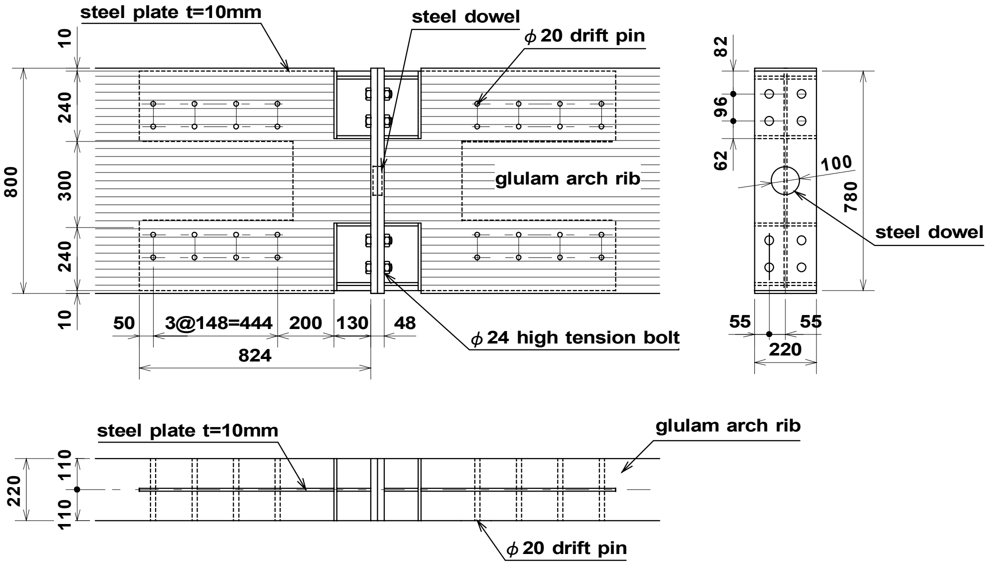


Fig. 2 Moment-resisting joint of arch rib.

Each arch rib was constructed in two parts corresponding to two halves along the longitudinal direction then transported to the construction site. Insert steel plates with drift pin and epoxy resin injection were used for the joints. The parts were then joined using high tension bolts at the site. The details of the joints and the insert steel plates are shown in Fig. 2. The flexural properties of this type of moment-resisting joint system was evaluated previously by Usuki et al (1998).

EVALUATION OF GLULAM

For the glulam arch members, high stiffness and rigidity were required, because these members are subjected to the bending moment and axial force at the same time. The Japanese Agricultural Standards (JAS) series of structural glulam is divided into two main classes, the same mechanical property class and the different mechanical property class. The same mechanical property glulam classification E85-F300 for the arch rib members was used. This stress grade for the arch rib is difficult to attain with Japanese cedar, therefore the logs were graded before sawing. Only laminae cut from 16~40cm diameter graded logs from plantation thinnings with 6 GPa modulus of elasticity (MOE) or more were used using the longitudinal vibration grading technique (Arima et al 1993). The mean MOE of 1047 pieces of graded logs was 8.2 GPa. From these, stress graded lumbers with MOE of more than 9 GPa and 5~8 GPa were used for the laminae for the arch rib and the SLT deck, respectively (Fig. 3). 90mm and 130mm laminae were side jointed to form the 220 width of the arch rib. It was possible to get high quality laminae at high efficiency and high yield rate by the longitudinal vibration grading of logs.

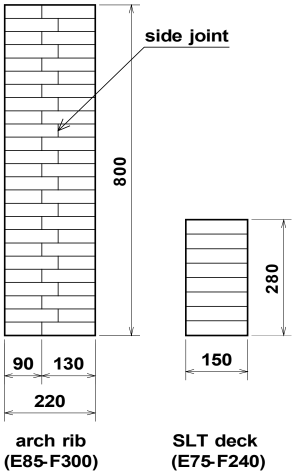


Fig.3 Dimensions of cross sections of glulam for arch

BAR FORCE MONITORING

In this study, a remote monitoring system for the long term measurement of the stress losses under environmental changes of the bridge in service was developed and shown in Fig. 4. The data from the measuring device that consists of six load-cells, a thermometer and a hygrometer are sent to a central station about 100 kilometers away automatically using a telephone line and modem at constant time intervals. These measured data were corrected using the remote monitoring control program M-SYSTEM/SFDN Ver.1.60D. The load cells to measure the bar force are positioned between the bearing and anchorage plates of the 3rd, 6th, 9th, 12th, 15th, and 18th stressing bars. The details of the placement of a load cell are shown of Fig. 5. Temperature and humidity of the backside of the bridge are simultaneously monitored. The data are analyzed to determine the characteristics of this type of bridge during actual service. Results will be used in the development of Japanese Manual for the Design of Timber Bridges.

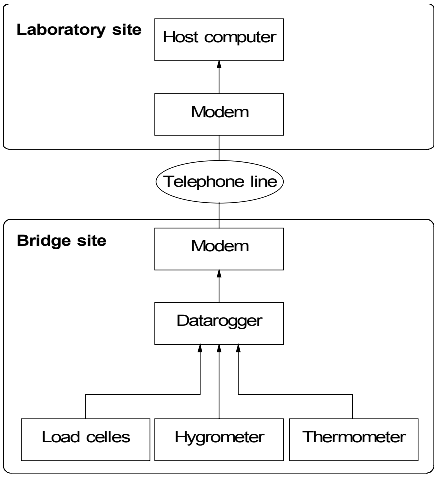


Fig. 4 Schematic diagram of the remote monitoring system.

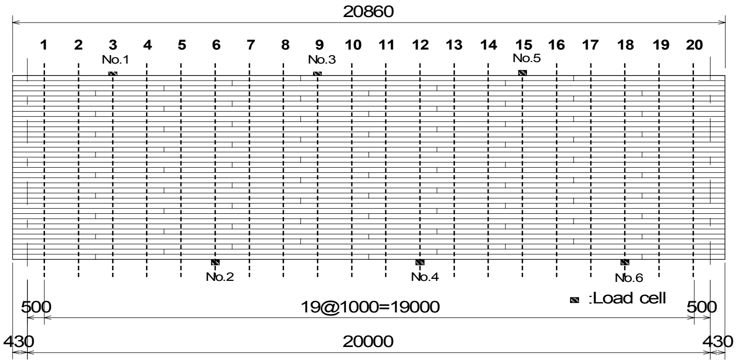


Fig. 5 Configuration of load cells.

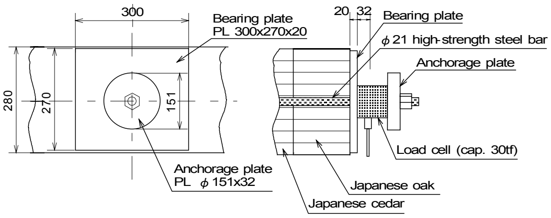


Fig. 6 Details of the anchorage system and institution of load cells.

FIELD TESTS

Field-test on the performance of the glulam tied arch bridge having the SLT deck, the "Hyakume-ishi" bridge, under static loads characteristics were conducted six months after construction in order to verify the adequacy of the design values and to collect initial data for bridge maintenance purposes. Another objective of this study is to investigate the performance of continuous stress laminated timber deck. The SLT deck of the bridge can be considered a seven-span continuous deck, because the deck is supported by eight floor beams.

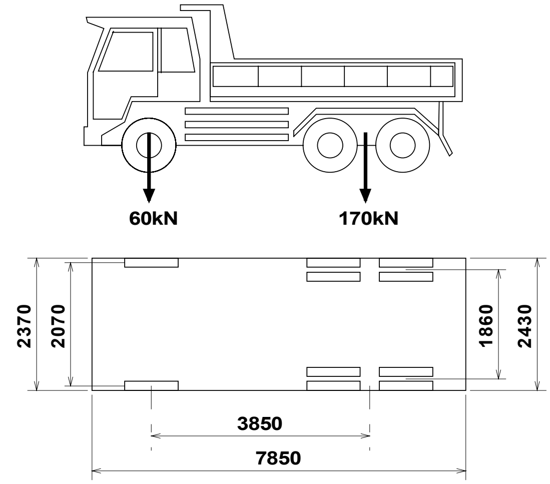
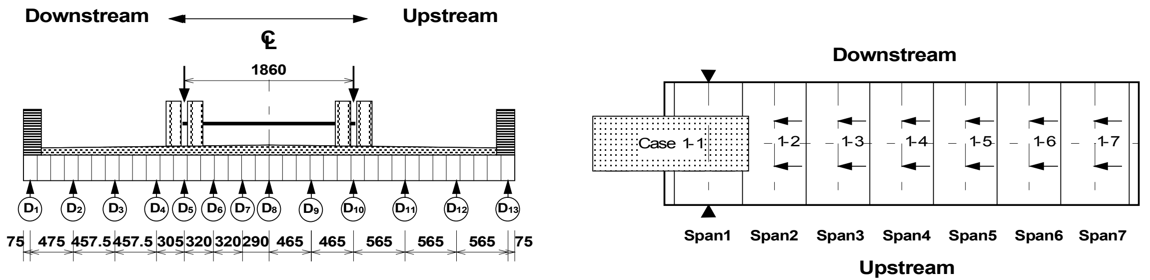
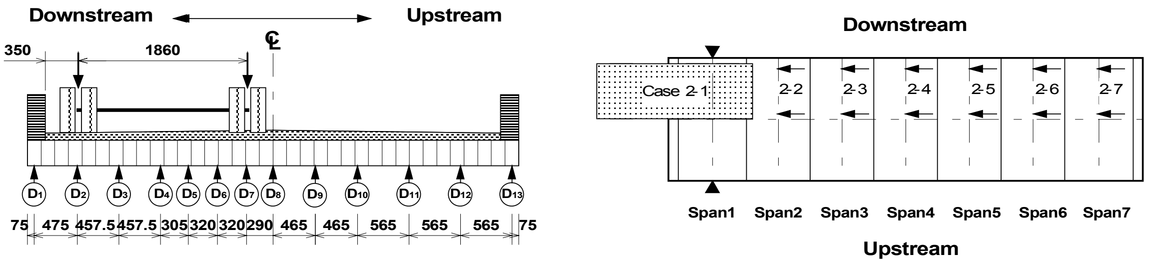


Fig. 7 Test truck configuration and axle loads.

For the static loading test, a dump truck with a gross vehicle weight of 230 kN was used (Fig. 7). In Test Cases Nos. 1-1 – 1-7, the test truck was positioned longitudinally at the center of each span of the bridge at various positions shown in Fig. 8-a. In Test Cases Nos. 2-1 – 2-7, the test truck was positioned longitudinally at the center of each span in the downstream lane with the center of the outside wheel line 350mm from the curb face shown in Fig. 8-b. The measurement points of deflections of framework are shown in Fig. 9. The longitudinal deflections along both sides of the arch rib (A_{11}~A_{27}) and the tie (T_{11}~T_{27}) were measured using optical levels and strain gauge type displacement transducers respectively at each loading condition. The floor beams deflections at the center of each floor beam (F_1~F_6) were measured using a non-contact optical micrometer. The relative deflections (D_1~D_{13}) along the transverse center of the Span 1 of the SLT deck were also measured. This loading and measurement method for field testing were also used in our previous investigations on the forest roadway timber bridge "Ki-no-Kakehashi" (Usuki et al 1998) and the π-rigid frame timber bridge "Midori-bashi" (Sasaki et al 1999).



(a)Case 1



(b)Case 2

Fig. 8 Details of static loading positions (Test cases 1-1~2-7) and measurement points for relative deflections (D_1~D_{13}).

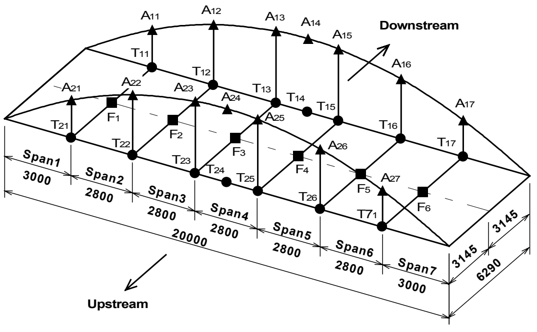


Fig.9 Geometry of the framework and details of deflection measurement points (A_{11}~A_{27}, T_{11}~T_{27}, F_1~F_6).

RESULTS AND DISCUSSION

Bar force monitoring

The stressing bars were initially tensioned on February 5, 1999 using hydraulic jack and pump. A second and then a final tensioning were done approximately two weeks and six weeks, respectively after the initial stressing. The trend of the average bar tension force measured by the load cells on six stressing bars is shown in Fig. 10. The data is for the first 330 days after installation. The mean daily temperature and humidity taken at the same period are shown in Fig. 11. Continuous loss of bar force was recognized for the first 250 days. Large decrease in tension which corresponded with decrease in humidity and increase in temperature was noticed at around August. This is the summer period in Japan when it was warm and dry with no rains at the site.

Based on the design manual for the stress-laminated deck (Ritter 1990), the maximum expected loss over long service time in prestress from creep will be limited to 60 percent of the initial level in design when the restressing sequence used in the construction of this bridge is applied. However, the loss already reached almost the maximum 60% level within less than a year. One possible reason is the used of a water-borne preservative, didecyldimethylammonium chloride (DDAC) for the preliminary pressure treatment of the glulam members. The use of a water-borne preservatives causes larger changes in the moisture content of the members compared to oil-based preservatives such as creosote and pentachlorophenol (Caccese and Dagher 1991). Investigations on the existing timber bridges with oil-based preservative treated members showed no significant losses (Wacker and Ritter 1992, Usuki et al 1996). The "Hyakume-ishi" is the first timber bridge having the SLT deck in Japan with water-borne preservative-treated members. It is necessary to consider the maintenance program for decks with these type of members.

Changes in humidity, either increase or decrease, cause creep in wood and wood products. This effect is known as mechano-sorptive creep (Morlier 1992). An example of this effect on the bridge is shown in Fig. 12-a and 12-b. A 5-day data of the changes in daily humidity and temperature and the

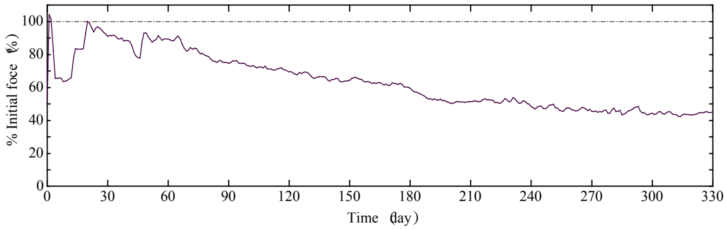


Fig. 10 Trend of the average bar force obtained from the load cells installed in six stressing bars.

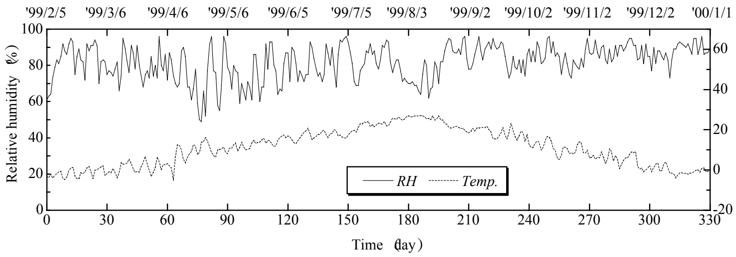
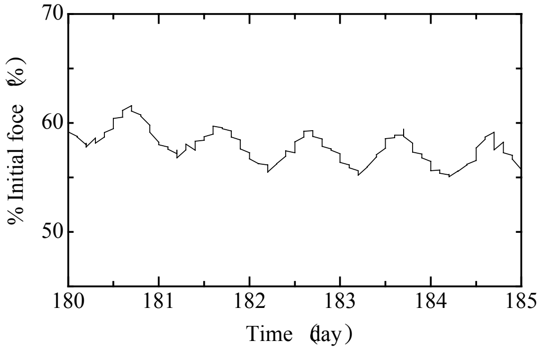
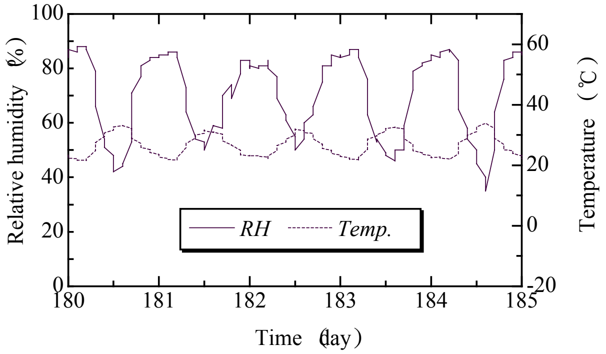


Fig. 11 Trend of the mean daily temperature and humidity changes around the deck.



(a) Bar force



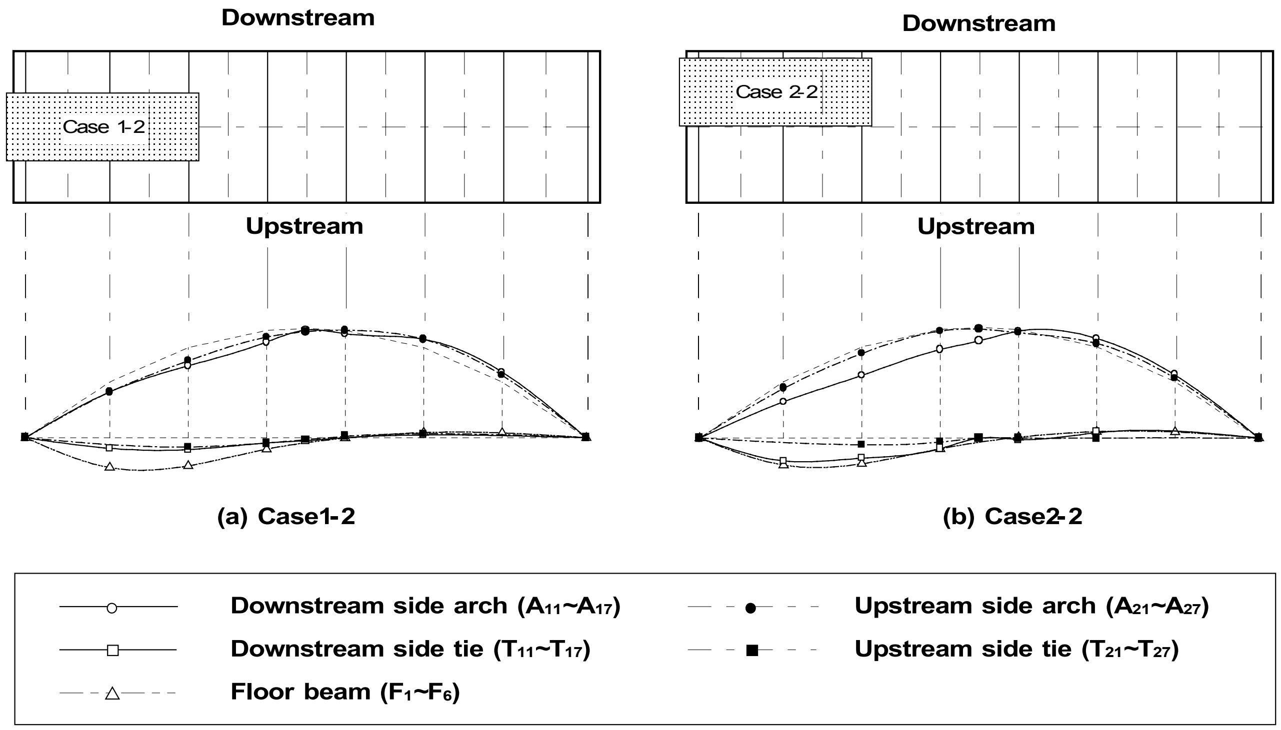
(b) Temperature and rilative humidity

Fig. 12 5-day data of the changes in daily bar force (a), and humidity and temperature (b) corresponding bar force are shown. There were large variations (30%~45%) in the humidity within 24-hr spans which resulted to corresponding changes in the bar force.

Field test

Examples of the deflections in the longitudinal direction at both sides of arch ribs and ties are shown in Fig. 13. The results from static loading conditions Cases 1-2 and 2-2 are presented. In addition, the deflections (F_1-F_6) of the floor beam measured along its longitudinal centerline are shown in the same figure. The scales in the figure were enlarged 10x for easier comparisons. Positions of the measured data in relation to the bridge are shown in the upper figure. The maximum deflection under the test truck positioned longitudinally at the center of each span in the downstream lane was 8.4 mm on the downstream side tie member. This is equal to approximately L/2400. This value is smaller than L/500 which is the maximum allowable deflection for steel bridges. The deflections are greater when the truck is positioned at the downstream side (ex. Case 2-2) than those when the truck is positioned at the longitudinal centerline (ex. Case 1-2).

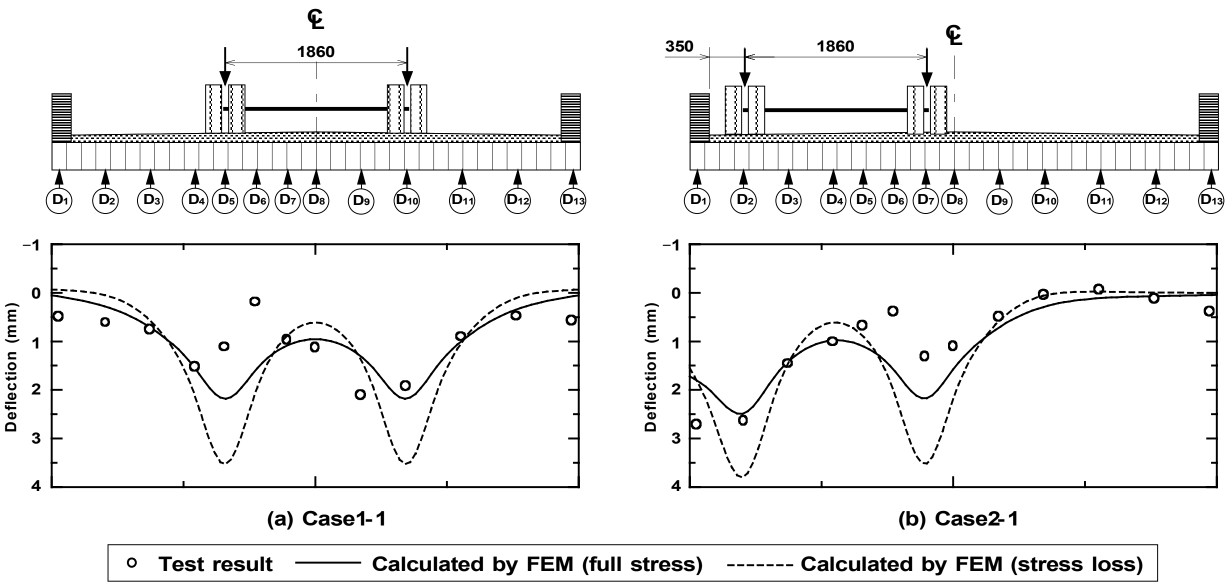
The deflections in the transverse direction at Span 1 under static load test conditions Cases 1-1 and 2-1, as well as the estimated deflections based on the results of the linear static analyses by FEM are presented in Fig. 14. Numerical analyses were performed using the general finite element program MSC/NASTRAN. The stress-laminated deck was modeled as an orthotropic plate using a modulus of elasticity (MOE) of 8.4 GPa in the longitudinal direction (E_L). For the relationships of the design values of the shear modulus (G_{TS}) and MOE in the transverse direction (E_{TS}), the equation of E_{TS} =0.013 E_L, and G_{TS} =0.03 E_L were used respectively (Ritter 1990). These relationships are obtained based on the characteristic of deck stiffness when the bar force loss reaches 60%. When the stress loss doesn't occur, it has been reported that the relationships of ordinary glulam properties can be used which are E_{TS} =0.04 E_L, and G_{TS} =0.067 E_L (Hasebe et al 1998). The two estimated lines in Fig. 14 show 60% loss condition (stress loss) and no loss condition (full stress), respectively. When the static loading test was performed the bar force level already reached almost the 50% level of initial force. However, in each loading condition, there is a good agreement between measured and the estimated values at no stress loss (full stress) condition. In the case of short span deck like this bridge, the effect of stress loss is small. D_5 and D_6 deviated from the estimated values. The maximum deflection under the test truck positioned longitudinally at the center of each span (Case 2-1) in the downstream lane was 2.72 mm which is equal to 1/1.56 of the design deflection value of the deck. This verified that the deck of the bridge has high bending stiffness.



(a) Case1-2

(b) Case2-2

Fig. 13 Examples of deflections in the longitudinal direction at two loading conditions.



(a) Case1-1 (b) Case2-1

Fig.14 Measured and estimated deflections in the transverse directions at two loading conditions.

CONCLUSIONS

Field-tests on the performance of the glulam tied arch bridge having the SLT deck, the "Hyakume-ishi" bridge, under static loads characteristics were conducted six months after construction in order to verify the adequacy of the design values and to collect initial data for bridge maintenance purposes. The glued laminated timber (glulam) tied arch bridge "Hyakume-ishi" is located on a forest roadway in Akita Prefecture, Japan. The bridge used Japanese cedar grown in the prefecture. The details of structure of the bridge were also reported. Monitoring system for the long term measurement of the stress losses under environmental changes of the bridge in service was also developed.

Results showed that the bar force loss already reach almost the maximum 60% level within less than a year. One possible reason is the use of a water-borne preservative for the preliminary pressure treatment of the glulam members. It is necessary to consider the maintenance program for decks with these water-borne preservative-treated type of members. There were large variations in the humidity within 24-hr spans which resulted to corresponding changes in the bar force.

The maximum deflection under the test truck positioned longitudinally at the center of each span in the downstream lane was 8.4 mm on the downstream side tie member. This is equal to approximately L/2400 which is smaller than L/500, the maximum allowable deflection for steel bridges. The deflections are greater when the truck is positioned at the downstream side than those when the truck is positioned at the longitudinal centerline.

There is a good agreement between measured and the estimated values using FEM. In the case of short span deck like this bridge, the effect of stress loss is small. The maximum deflection under the test truck positioned longitudinally at the center of each span in the downstream lane was 2.72 mm which is equal to 1/1.56 of the design deflection value of the deck. This verified that the deck of the bridge has high bending stiffness.

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