Study on durability evaluation of concrete structure constructed over 60 years ago in cold region*1

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Abstract

Concrete structures constructed in cold region suffer from many cycles of freeze-thaw in winter. Especially concrete structures which were constructed before 1930s and which did not contain air entrained (AE) agent suffer remarkably from frost damage due to freeze-thawing. Some of them, however, are of good designs and harmonize well with the surrounding environment. So some campaigns to preserve the structures are in progress, for example, in Kamishihoro, Shyari and so on in Hokkaido. Furthermore, the maintenance and management for long term service of these structure is important for efficient public investment.

The purpose of this study is basically to :

1) Investigate the change in time of concrete arch bridge constructed in cold region 60 years ago by researching at the site and to look up design plan report of that time.
2) Analyzing the freeze-thaw cycles of section on member toward direction of depth as an external factor.
3) Evaluate the safeness and performance of the structure influenced by change in time by analyzing with finite element method (FEM) and look up design plan report of that time in order to predict remaining serviceable years.

1. Introduction

Concrete structures constructed in cold region suffer from many cycles of freeze-thaw in winter. Especially concrete structures which were constructed before 1930s and which did not contain air entrained (AE) agent suffer remarkably from frost damage due to freeze-thawing. Some of them, however, are of good designs and harmonize well with the surrounding environment as Photo-1 and Photo-2. So some campaigns to preserve the structures are in progress, for example, in Kamishihoro, Shyari and so on in Hokkaido. Furthermore, the maintenance and management for long term service of these structure is important for efficient public investment.

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*1 Parts of this report were presented in a course on steel corrosion in concrete structure in Hokkaido Branch JSCE in January 1998 and Symposium on concrete arch bridges of former Kamishihoro Japan National Railway in July 1997.

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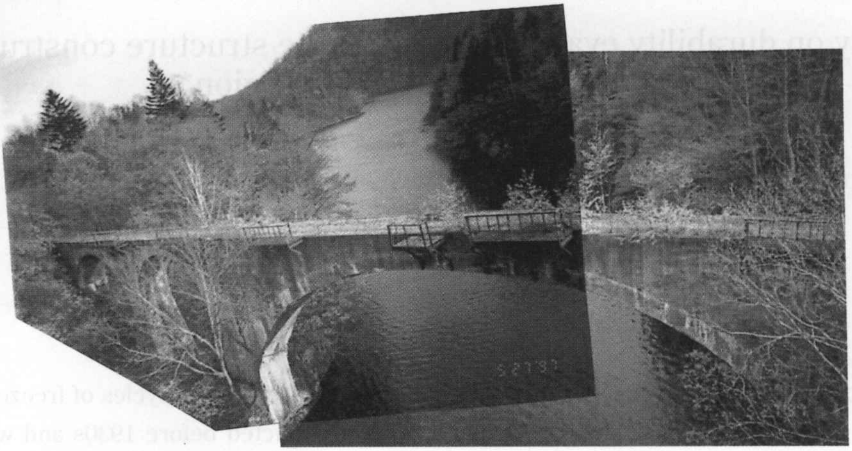

Photo. 1 The shape of Dai San Otofuke Bridge

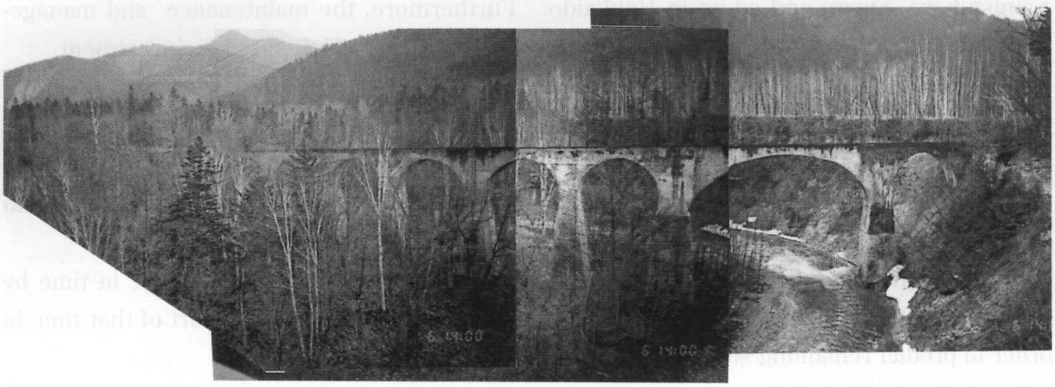

Photo. 2 The shape of Dai Go Otofuke Bridge

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2. Method

2. 1 Structures at study

The main structures of study are Dai San Otofuke Bridge and Dai Go Otohuke Bridge which are on the Shihoro-line between Kamishihoro and Tokachi Mitsumata of the former Japan National Railway and are built on Otofuke river. Outline of the shape and size of Dai San Otofuke Bridge constructed in 1936 is shown in Fig. 2. 1. Since the structure is constructed in the cold region at eastern part of the Taisetsu mountain system on inland of Hokkaido Island, it suffered many cycles of freezing-thawing, which is an external factor of deterioration, during the winter for a very long time. The concrete of the bridge must be non-AE concrete because the technique of AE agent had not been imported in Japan at that time.

2. 2 Measuring method of non-destructive strength test

As shown in Fig. 2. 2, ultrasonic velocity by PUNDIT and coefficients of repulsion by Schmidt hammer for non-destructive strength test at each point of mesh on the surface of

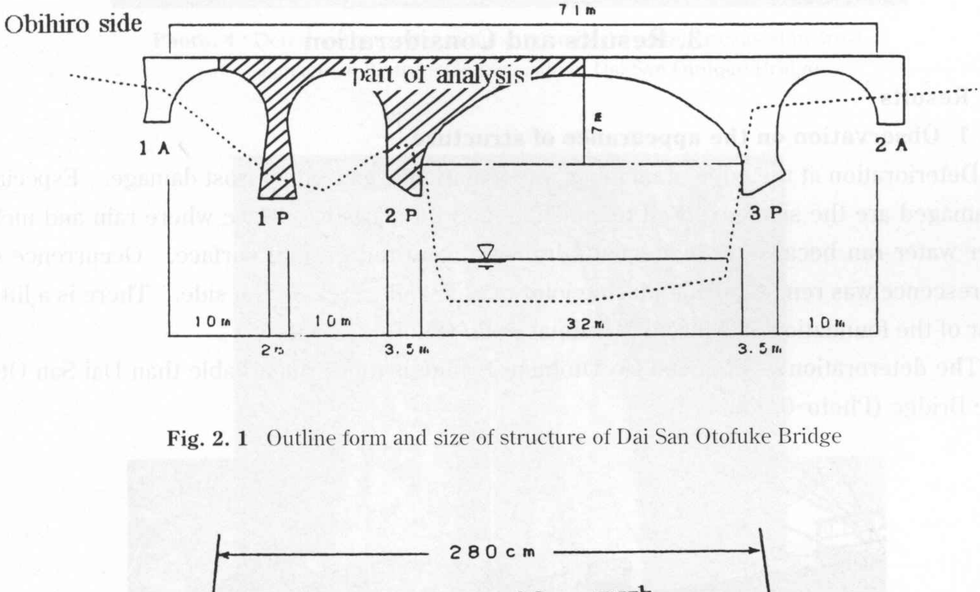

Fig. 2. 1 Outline form and size of structure of Dai San Otofuke Bridge

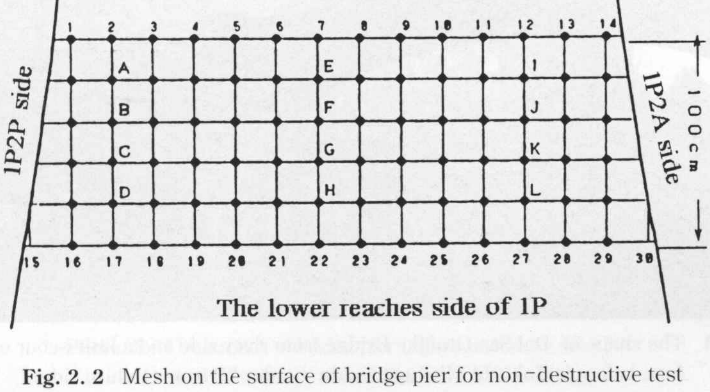

Fig. 2. 2 Mesh on the surface of bridge pier for non-destructive test

bridge pier were carried out. Compressive strength at each point was estimated from both data of ultrasonic velocity and coefficients of repulsion with method of Facaoaru and so on.

2. 3 Measuring method of depth of cover

The diameter, total sectional area, and cover depth of reinforcing steel were measured and estimated with RC radar. The neutralization depth of concrete was measured with alcohol solution of 1 % phenol-phthalene.

2. 4 Method of analysis

Young's modules was estimated from result of non-destructive test. The stress in member of bridge was analyzed with finite element method (FEM) using programs MARK · MENTAT. The freeze-thaw cycles per year was analyzed with Conventional analysis of differential analysis equation on non-stationary boundary conditions which was developed by the author[1].

3. Results and Consideration

3. 1 Results

3. 1. 1 Observation on the appearance of structure

Deterioration at the edge of member was remarkable caused by frost damage. Especially damaged are the sides exposed to sunshine and the parts of surface where rain and melt-water water ran because of inadequate drainage from rail ground surface. Occurrence of efflorescence was remarkable at placing joint of arch and crack of the side. There is a little scour of the foundation at Tokachi Mitsumata side (Photo-3, 4 and 5).

The deteroration level of Dai Go Otohuke Bridge is more remarkable than Dai San Otohuke Bridge (Photo-6, 7 and 8).

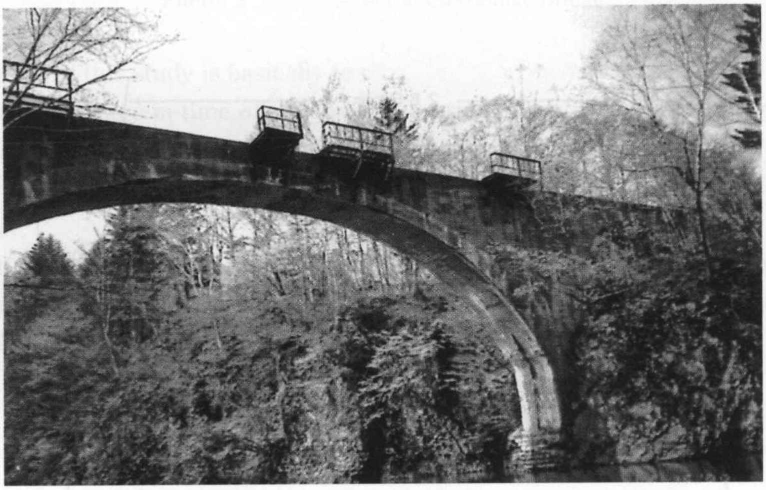

Photo. 3 The shape of Dai San Otofuke Bridge from river side and a little scour of the pier foundation at Tokachi Mitsumata side (under 3P from Obihiro side)

Photo. 4 Deterioration and scaling at the edge of member caused by frost damage on 2P from Obihiro side of Dai San Otofuke Bridge

Photo. 5 The surface of bridge pier (1P from Obihiro side) for non-destructive test of Dai San Otofuke Bridge

Photo. 6 A complete view of deck of Dai Go Otofuke Bridge from Obihiro side and the edge of deck is deteriorated.

Photo. 7 Deterioration and crack at a part of repair on 1P from Tokachi Mitsumata of Dai Go Otofuke Bridge

Photo. 8 Scour of the foundation at Obihiro side (1P from Obihiro side) of Dai Go Otofuke Bridge

3. 1. 2 Result of non-destructive strength test

The estimated compressive strength at a section of concrete bridge pier is shown in Fig. 3. 1. There are parts which are below the strength of design standard, 180 kgf/cm^2. Especially decrease at the sides exposed to sunshined were much. The compressive strength estimated at a section of member toward direction of depth by non-linearly analysis is shown in Fig. 3. 2. The Young's modules were estimated from the result to input in analyzing by FEM.

3. 1. 3 Result of depth of cover

Though the depths of concrete cover were not confirmed on design plan report, RC radar showed a auffcient depth 10～12.5 cm. The neutralization depths of concrete are within several millimeter except where these are crack. If there are no exposed steel due to frost damage and cracking, the reinforcing steel inside concrete would be well for some time. The spacing between 19-mm diameter longitudinal reinforcing steel are 50 cm. The spacing of of rectangular reinforcing steel is longer than the standard of specification of concrete design for earthquake resistance of JSCE, which space is 12.5 times the diameter of the reinforcing steel ; the spacing was calculated to be 37.5 cm.

3. 1. 4 Result of analysis

The result of horizontal stress of RC main span analyzed is shown in Fig. 3.3. Longitudinal principal stress is shown in Fig. 3. 4 and Fig. 3. 5. They were all compressive. The absolute value of the stress at the root of span was smaller than at the center of span. Because the area of section at the root of span is larger and the stress is spread at parts connected to the bridge pier.

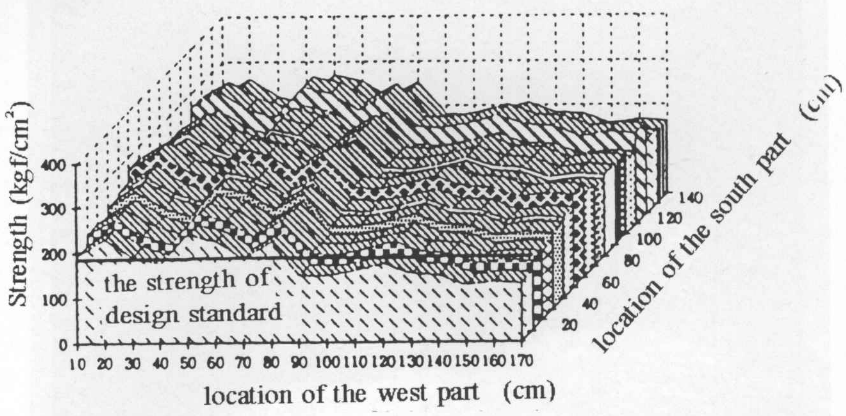

Fig. 3. 1 Result of non-destructive test of bridge pier of Dai San Otofuke Bridge (1P)

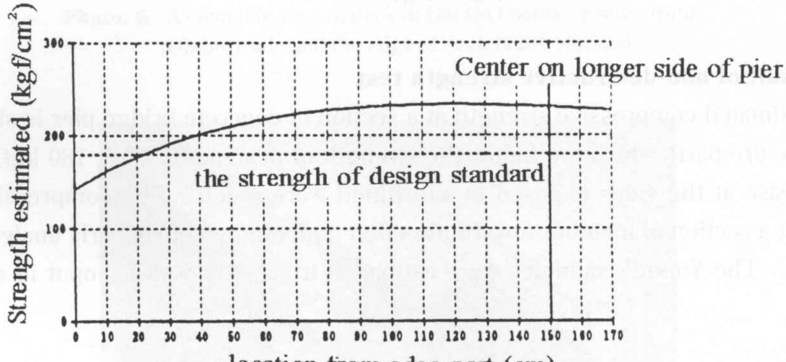

Fig. 3. 2 Strength estimated by non-linearly analysis

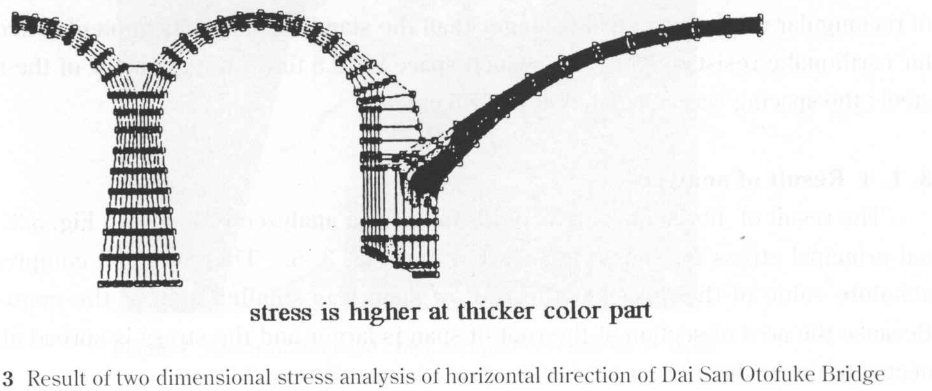

Fig. 3. 3 Result of two dimensional stress analysis of horizontal direction of Dai San Otofuke Bridge

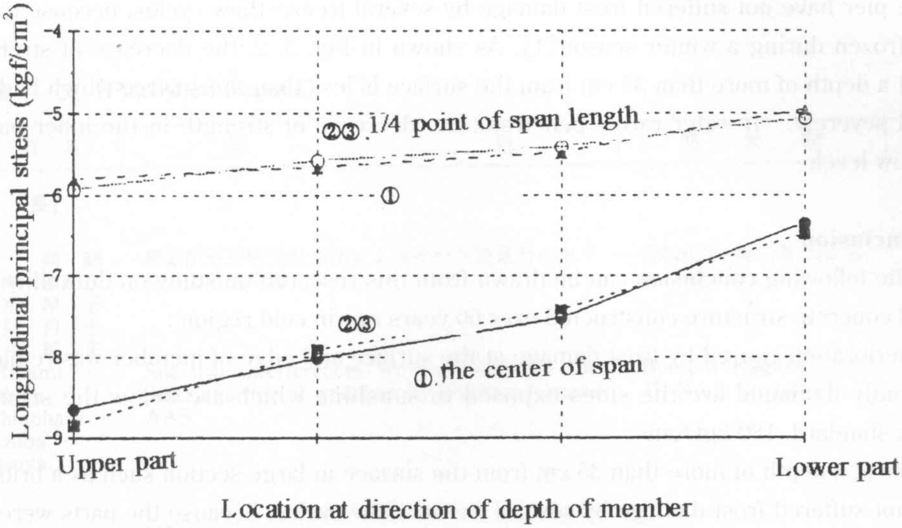

Fig. 3. 4 Longitudinal principal strength at the center of span and 1/4 point of span length of Dai San Otofuke Bridge

(① : Case 1 ; Supposing 3 grades of Young's modules considering the decrease to depth direction which are surface layer : E_1=2.476x10^{5}kgf/cm^2, second layer : E_2=2.568x10^{5}kgf/cm^2 and third layer : E_3=2.568x10^{5}kgf/cm^2 ② Supposing Young's modules of surface : E_s=2.343x10^{5}kgf/cm^2 ③ Young's modules for design at first : E_d=2.438x10^{5}kgf/cm^2)

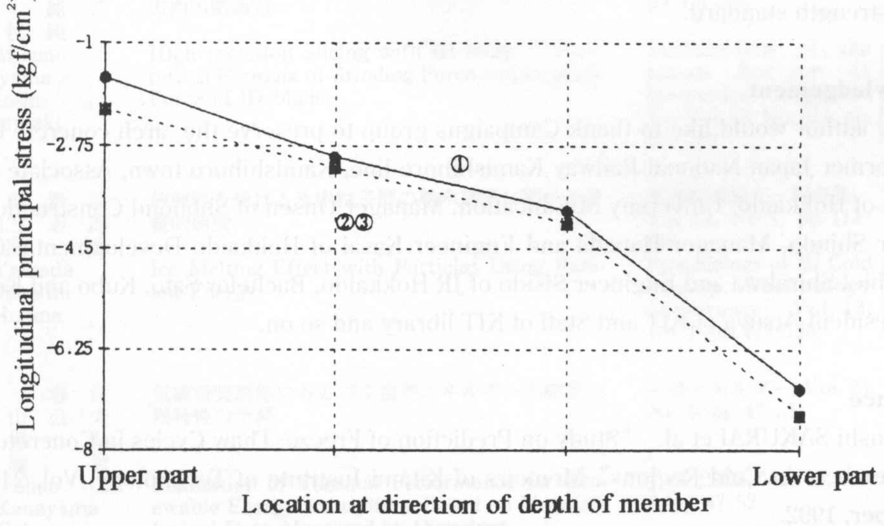

Fig. 3. 5 Longitudinal principal strength at root of span of Dai San Otofuke Bridge

(①, ② and ③ are same as Fig. 3. 4)

3. 2 Consideration

The structure of concrete arch bridge, which must have been made with non-AE concrete and constructed over 60 years ago on the inland in the cold region, suffered remarkable frost damage, especially on the surface and the edge caused by many cycles of freezing-thawing. But, parts at a depth of more than 35 cm from the surface of large section such as the bridge pier have not suffered frost damage by several freeze-thaw cycles, because the parts were frozen during a winter season[1]. As shown in Fig. 3. 2, the decrease of strength on part at a depth of more than 35 cm from the surface is less than the surface which had deteriorated severely. If water rarely penetrate, the decrease of strength in the inner part is of very low level.

4. Conclusion

The following conclusion can be drawn from this research on study on durability evaluation of concrete structure constructed over 60 years ago in cold region :

1) Deterioration caused by frost damage at the surface and edge of member was remarkable. Especially damaged are the sides exposed to sunshine which are below the strength of design standard, 180 kgf/cm^2.

2) Parts at a depth of more than 35 cm from the surface in large section such as a bridge pier have not suffered frost damage by several freeze-thaw cycles, because the parts were frozen during a winter season. The decrease of strength on the part at the depth more than 35 cm from the surface is less than that of the surface which has deteriorated severely after 60 years.

3) The Longitudinal principal stress by analyzed were all compressive. The absolute value of the stress at the root of span was smaller than at the center of span and less than the design strength standard.

Acknowledgement

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Reference

[1] Hiroshi SAKURAI et al. "Study on Prediction of Freeze-Thaw Cycles in Concrete Structural Members in Cold Regions", Memoirs of Kitami Institute of Technology, Vol. 24 No. 1, September, 1992.