Research on evaluation of durability and preservation of concrete structures with cultural assets in cold regions*1

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Abstract

When concrete structures in cold regions are in service for many years, the sever winter conditions of freeze-thawing and the large variations in temperature though the year cause deterioration in the durability of the concrete structure such as its load resistance the performance, damage the caused by third party influence, functionality, appearance and safety. Damage includes scaling, peeling off, and cracking caused by frost damage. However, some concrete structures have come to considered landmarks in an area. Citizens wish to preserve some concrete structures as cultural assets, part of their historical civil engineering heritage, and so on.

This research combines assessment methods for investigation and quantitative assessment of the condition of concrete structures with cultural value, and methods for their maintenance and management by non-destructive tests. When structures were not damaged by huge earthquakes or floods, the structures were stabilized for standing themselves by analysis of FEM and estimation of freeze-thawing cycles at each depth.

1. Introduction

When concrete structures in cold regions are in service for many years, their durability in terms of load resistance, third party influence, functionality, appearance and the safety from scaling, peeling off, and cracking by frost damage tends to fall off. Deterioration occurs due to great differences in temperature and the cycles of freeze-thawing during severe winters. However, some concrete structures become to the landmarks in an area. Citizens wish to preserve some concrete structures as cultural assets, historical civil engineering heritage, and so on.

The porpose of this study is to examine the possibility of quantitatively assessing the healthy and determining maintenance and management methods for concrete structures

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with a high level of cultural worth by combining non-destructive surveys data with analysis comprehensively.

2. Method

2.1 Structural safety

2.2.1 Method of analysis theory

A quantitative method of studying the durability and maintenance and management methods of concrete structures with the cultural assets in cold regions is to assess structural safety and durability comprehensively by combining non-destructive surveys with analysis. The cases examined were constructed in 1931 as part of a now abandoned railroad of the former Japan National Railways. The Daisanotofukegawa bridge, the diagonal part shown in Fig. 2.1 of which is analyzed. And the Dairokuotofukegawa bridge, as shown in Fig. 2.2 were selected. They are in a cold region with inland environment. Citizens have asked that they be preserved.

Finite element analysis (FEM) with the MARK MENTAT II system using thermal and stress coupling analysis is carried out.

PHOTO.2.1 The main span of Daisannotofukegawa Bridge

PHOTO.2.2 The main span of Dairokuotofukegawa Bridge

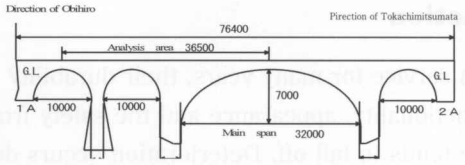

Fig.2.1 Analysis part of Daisanotofukegawa Bridge

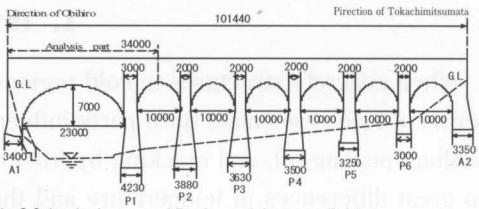

Fig.2.2 Analysis part of Drokuotofukegawa Bridge

2.2.2 Analysis condition estimating and setting

The strength data to demand for the analysis and to evaluate load resistance is estimated from the non-destructive test result by combining. Ultrasonic transit speed by PUNDIT and repulsion hardness by Schmidt hammer are converted to the compression strength in reference of Facaoaru's research. It is estimating the concrete strength from the concrete surface of a pier in the sectional direction by regression analysis with an our development model in SAS software. The strength is set in 3 stages from the surface in quest of the modulus of elasticity of the sectional direction of concrete member converting from the relation equation between strength and the modulus of elasticity.

Table.2.1 Set of properties of Concrete

Properties	unit	Setting rate
Young's modulus	kgf/cm^2	①$2.38 \times 10^5$ ②$2.43 \times 10^5$ ③$2.48 \times 10^5$
Density	kg/cm^3	0.0023
Poisson's ratio	———	0.2
Heat conductivity	Kcal/cm・s・℃	6.111×10^{-6}
Heat transfer	$kcal/cm^2$・s・℃	4.167×10^{-7}
Specific heat	kcal/kg・℃	0.25

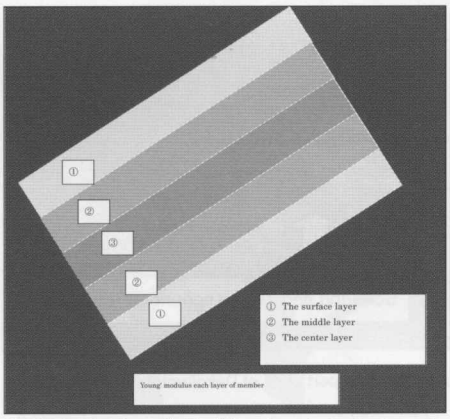

Fig.2.1.B .The Young's Modulus at each depth of member

2.2.3 Load conditions

The Daisanotofukegawa Brige and the Dairokuotofukegawa bridges are analyzed in consideration of the dead load itself and the snow load, without considering the live load of train because the line closed. Because these bridges are located in an area of much snowfall, the snow load reaches 300 kg/m² over 50 cm in the most heaviest month of snowfall in Nukabira district.

2.2.4 Outside air temperature

The outside air temperature taken from AMEDAS meteorological data for the coldest period in the most severe recent winter in 1991 is inputted as the boundary condition.

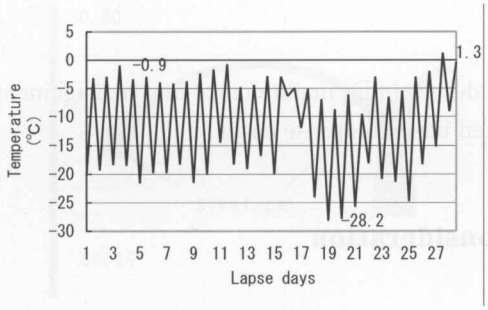

Fig.2.3.A .The outside temperature in Feb.

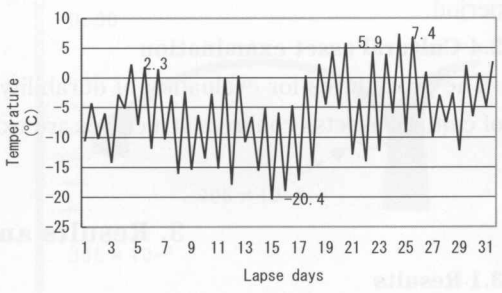

Fig.2.3.B .The outside temperature in Mar.

2.2.5 Support condition

Although Daisanotofukegawa bridge supports are close to full healthy, the foundations of the Dairokuotofukegawa bridge has been washed away and the scour protection of the pier foundation of the has washed out. It is result the base of abutment basement on the Obihiro side is exposed to air. Then the analysis condition at the present make the support condition to be removed enough. The pier support situation is determined that the looseness on the foundation is 80 cm and more from the river side by measuring and consideration. For comparison, a foundation in the original scour protection in place is analyzed regarding each case's healthy level.

Photo.2.3 Scouring part of A1 of Dairokuotofukegawa Bridge

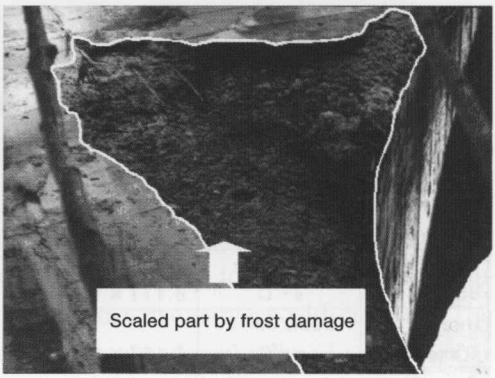

Photo.2.4 Deficit part by frost damage of Dairokuotofukegawa Bridge

2.3 Examination of durability

2.3.1 Damage area measurement

The damage area to required repair are measured by photograph taken.

2.3.2 Freeze-thawing cycles

The differential calculus equation of the two-dimensional thermal conduction equation owing to calculate with enough capacity to execute and appropriate accuracy is used to estimate the cycles of freeze-thawing in the depth direction of the main member over a winter. This is the main external deterioration factor needed to analyze and predict frost damage. The boundary condition to estimate the cycles of freeze-thawing number for a year at each depth is AMEDAS data to input as the outside and surface temperature in the freeze-thawing period.

2.4 Cultural asset examination

The procedures for evaluation of durability and determining maintenance and management of cultural assetss concrete structures are examined based on these cases.

3. Results and consideration

3.1 Results

3.1.1 Stability and safety by FEM

Under the present conditions of dead load and snow load only, the stress acting on the arch members of the Daisanotofukegawa Bridge and the Dairokuotofukegawa Bridge are all compressive.

(1) Daisanotofukegawa Bridge

As a result, no large change of critical strain and critical stress are seen in the supposing condition that temperature data are analyzed on the temperature data in 2 months of severe cold period from February 1 to March 31 in 1991. The safety factor of Daisanotofukegawa Bridge is 5 or more as compared with the estimated concrete strength. Also, the strain had not reached dangerous zone 2000×10^{-6} in generally as eaven the value of the largest main strain. It is conceivable that there is little occurrence of cracks due to the thermal contraction

of concrete. But Daisanotofukegawa Bridge at present is that the third party influence degree etc. are serious serviceability limit condition by scalling, peeling off and so on. Now the load resistance is adequate to support only the dead load and the snow load. Accordingly, in the case of Daisanotofukegawa bridge, unless the river scour piers by flood or a large earthquake occurs, there is little risk of the bridges reaching extremely limit state.

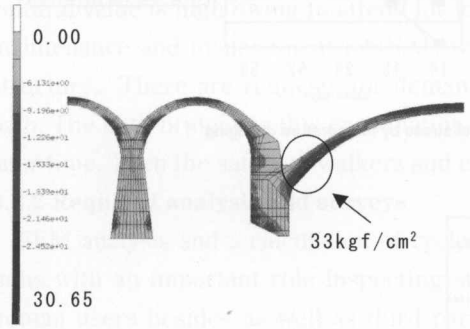

Fig.3.2 Principal strain of Daisanotofukegawa Bridge

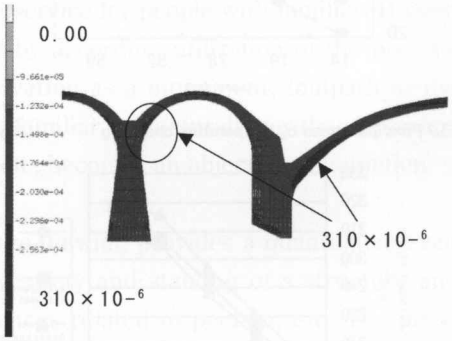

Fig.3.2 Principal strain of Daisanotofukegawa Bridge

(2) Dairokuotofukegawa Bridge

Dairokuotofukegawa bridge, if scaring at present and its original design state is compared, the large value part of stress and strain moves to the side of a pier in the river from the side of the support of abutment on the bank. Repair of the base foundation and scour protection is required to preserve cultural asset. If all the vertical supports were removed from the foundations, it is natural that the strain would become dangerous over 2000×10^{-6} by FEM analysis.

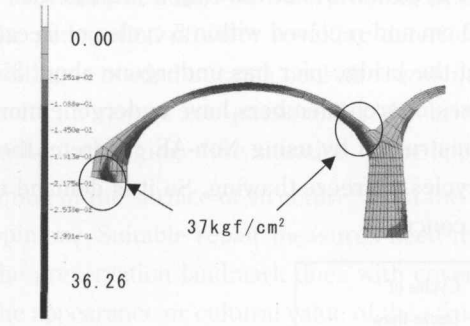

Fig.3.3 Principal strain of Dairokutofukegawa Bridge at present

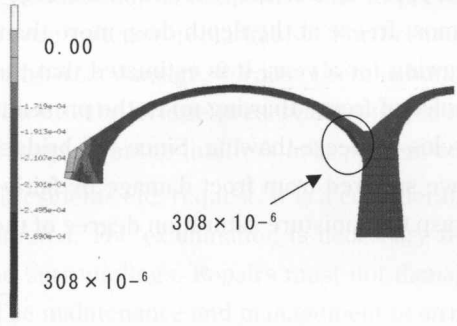

Fig.3.4 Principal strain of Dairokutofukegawa Bridge at present

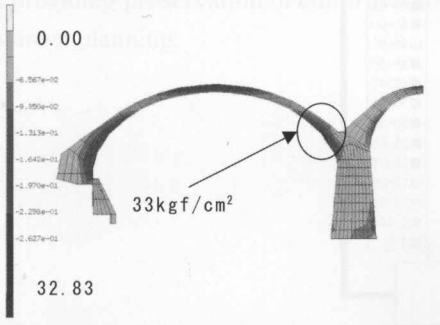

Fig.3.5 Principal stress of Dairokutofukegawa bridge not scouring

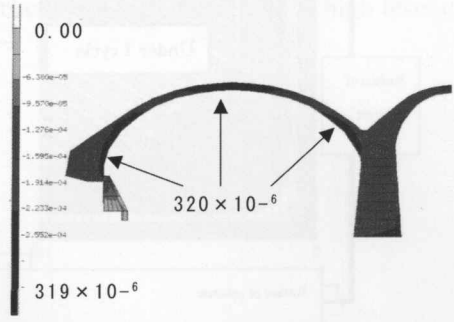

Fig.3.6 Principal strain of Dairokutofukegawa Bridge without scouring

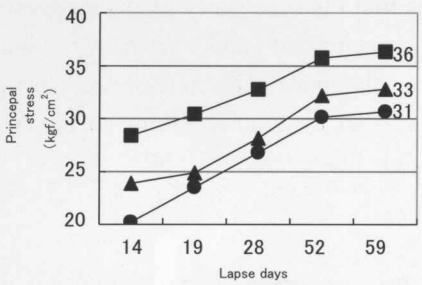

Fig.3.7 Principal stress by temperature changing

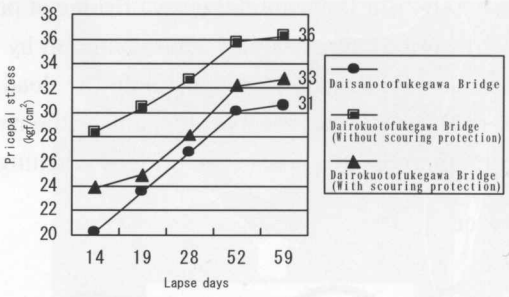

Fig.3.7 Principal stress by temperature changing

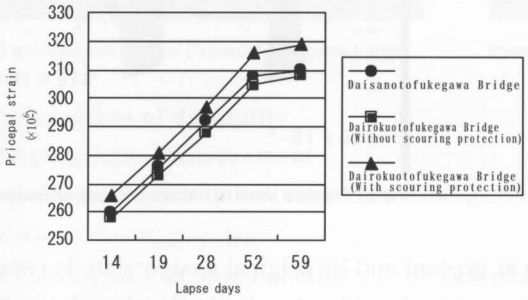

Fig.3.8 Principal strain temperature changing

3.1.2 Estimation of cycles of freeze-thawing and strength

When the temperature of pier part with the outside air temperature for example in 1991 is analyzed, the surface it found to undergo about 60 cycles of freeze-thawing a year, just as it almost freeze at the depth deep more than 35 ~40 cm and received within 5 cycles of freeze-thawing for a year. It is estimated that the core of the bridge pier has undergone about 350 cycles of freeze-thawing up to the present. The cores of arch members have undergone more cycles of freeze-thawing. Since the bridges are constructed by using Non-AE concrete, they have suffered from froct damage by fairly many cycles of freeze-thawing. So it is demand to grasp the moisture saturation degree of the inside concrete.

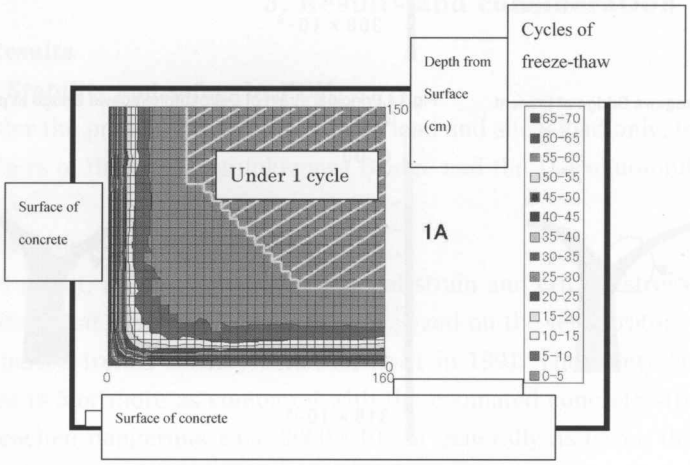

Fig.3.9 Relationship between depth from surface and cycles of freeze-thawing

3.2 Consideration

3.2.1 Cultural asset value and safety

The procedure for maintenance and management of the concrete structure with cultural assets developed from this case study is shown as a flowchart in Fig3.2.1 The preservation of such structures is demanded by residents of the area and society in the case that they have cultural value is high owing to attend for long time service for people with familiar. However, maintenance and management methods will differ by according utilization of the preserved structure. There are requests for demand preservation as a monument, footpath or cycle path. The both bridges in this examination case are familiar and naturally for the visitor at the later time. Then the safety of walkers and cyclists, etc. becomes an object of examination.

3.2.2 Required analysis and surveys

FEM analysis and a calculation of cycles of freeze-thawing provides a quantitative evaluations with an important role inspecting structural safety and stabling of a structure and a human users besides as well as third party influences related to peeling, etc. The present stress and strain value showed that the structure is stable for self standing, assuming the absence of a large earthquakes and scouring. A detailed soundness survey of the core concrete of arch member, piers and so on is demanded to verify the estimation result based on cycles of freeze-thawing. And an investigation of the supply of water to the core of arch members is now required, this will entail small-scale destructive tests of the core of the arch members.

3.2.3 Maintenance and management of concrete structures with cultural worth

Providing drainage 31 waterproofing of the bridge foundation is temporary way to prevent the penetration of water resulting deterioration of core concrete remarkably. Furthermore, netting is needed to catch peel-off fragments caused by frost damage, because there is human traffic, a canoes etc. passe under the bridge. Still more the bridge preservation is needed without changing "the situation of the appearance keeping in the limitless near present condition of the surface of structure" from the regional residents etc. request. It is a considerable opinion. Suitable repair measures need to be examined. The examination is necessary that the preservation landmark does with coverings and surroundings. Repairs must not damage the appearance or cultural value of the structure. The maintenance and management of structures with cultural value must meet the needs of the local residents near bridge and citizens. And providing preservation of cultural landmark structure is useful as a part of high level cultural town planning.

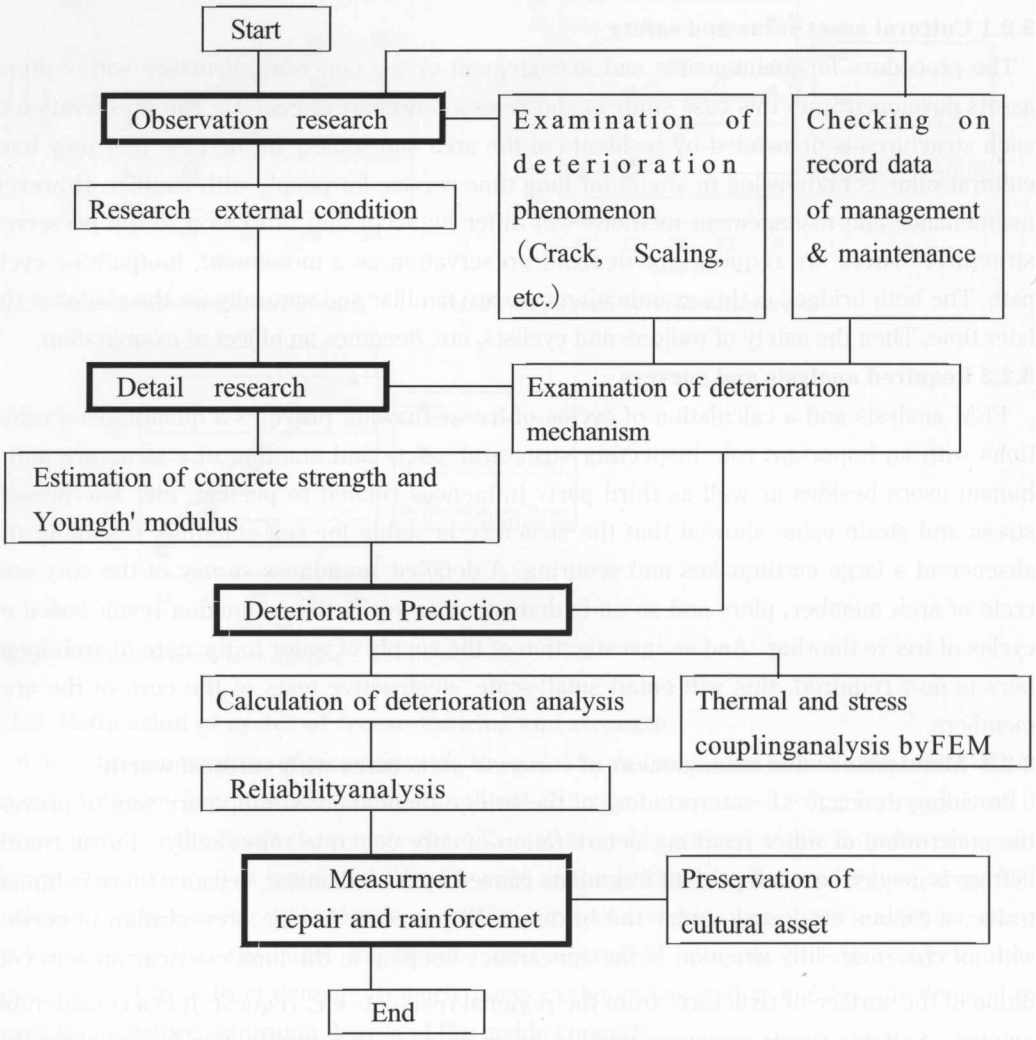

Fig.3.2.1 The flowchant of procedure for maintenante and management of concretestrnoture with cultural assets

4. Conclusion

The following conclusion can be drawn from this research on evaluation of durability and preservation of concrete structures with cultural assels in cold regions;

1) The quantitative evaluation of the health' maintenance,and management method for concrete structures with cultural value in cold regions is possible by combining surveys with non-destructive test, analysis by FEM, and estimating the cycles of freeze-thawing by differential calculus at each depth in main member.

2)In the absence of large earthquakes and scouring of foundations by floods, the stability and deterioration of concrete strength within members of Daisanotfuke Bridge are assured according to the

results of non-destructive testing, finite element method, and estimating freeze-thawing cycle in unsteady constant difference equation analysis. These concrete structures are evaluated as the serviceability limit state and demanded to repair prevention of peel-off and put in place drainage to prevent frost damage of the concrete as soon as possible.

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