Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 73/1/73/2 (1995)

Artikel: Improved durability of concrete structures in hot spring districts
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DOI: https://doi.org/10.5169/seals-55190

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Improved Durability of Concrete Structures in Hot Spring Districts

Amélioration de la durabilité des ouvrages en béton dans les stations thermales

Verbesserung der Dauerhaftigkeit von Betonbauten in Gebieten mit heissen Quellen

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SUMMARY

There are many bridges and other concrete structures in hot spring districts in Japan, despite harshness of corrosive environments in those areas. This paper reports on the results of a series of tests in which concrete specimens of various mixtures were exposed to different hot springs environments. The paper also discusses methods for extending the life of concrete structures built in hot spring areas.

RÉSUMÉ

Au Japon, de nombreux bâtiments et ponts sont construits dans les régions thermales malgré l'intensité de la corrosion dans cet environnement. Cet article rend compte des résultats d'une série de tests qui ont été effectués sur des échantillons de béton provenant de mixages variés et exposés à différents types de sources d'eau chaude. Cet article traite aussi des diverses méthodes appliquées pour prolonger la durée de vie des constructions en béton dans les stations thermales.

ZUSAMMENFASSUNG

Es gibt in Japan viele Bauten und Brücken aus Beton in Gegenden mit heissen Quellen, trotz der korrosiven Umgebung in solchen Gebieten. Es wird über eine Reihe von Versuchen berichtet, in denen Betonproben diverser Mischverhältnisse verschiedenen heissen Quellen ausgesetzt wurden. Die Arbeit diskutiert ausserdem Möglichkeiten zur Verlängerung der Lebensdauer von Betonbauten in derartigen Gebieten.

1. INTRODUCTION

There have been practices in Japan since olden days to take advantage of hot springs not only for medical purposes, but for social and recreational purposes, and people would get together around a hot spring and form a town. It is for this reason that the investment in social overhead capital including railways and roads is often found accumulated leading to the town where there is a hot spring. Included among the Japanese bridges since olden days were arch-type bridges built of stone, those built of wood and so on. In particular, they were overwhelmingly made of wood. Generally speaking, however, permanent bridges made of steel and concrete are quite common today. In this connection, hot-spring areas are no exception in that concrete is used for the construction of bridges. A concrete bridge in the hot-spring areas where a wooden bridge used to be free of any problem is laden today with a problem of chemical deterioration caused by substances contained in the hot spring. Thus, very harsh conditions prevail with respect to the durability of concrete structures in the hot-spring area in Japan and there exist many problems.

Therefore, this paper deals with measures for prolonging the life of concrete structures in the hot-spring district that have been taken on the basis of the result of a hot-spring exposure test involving concrete specimens.

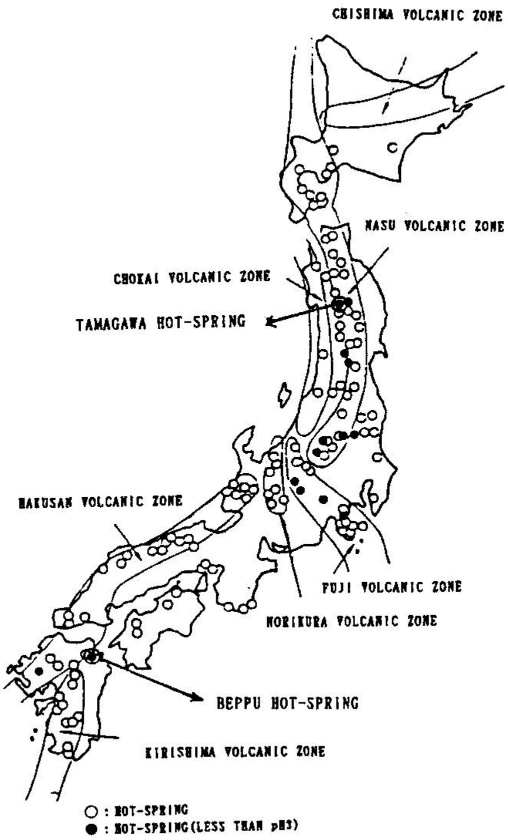


Fig. 1 VOLCANIC ZONE AND HOT-SPRING IN JAPAN

2. ON HOT SPRINGS

When the temperature of the water which gushes out is over 25℃ or when it contains higher than a specific level of dissolved substances, it is defined as a hot spring in Japan. There are many methods of classifying hot springs. When classified by principal negative ion, they will be as Bicarbonate springs, Chloride springs, Sulfate springs. [1]

Furthermore, Fig. 1 [2] shows a distribution of hot springs in Japan, indicating hotsprings with less than pH 3 by ● and hot springs dealt with in this paper by ◉.

3. A FEW EXANPLES OF INPROVEMENT IN DURABILITY OF CONCRETE STRUCTURES IN HOT-SPRING DISTRICTS

3.1 Summary

Concrete structures have been constructed in Beppu and Tamagawa Hot Springs shown by ◉ in Fig. 1 mentioned earlier. When there is no countermeasure taken, concrete will be destined to degradation due to hot-spring ingredients. Thus, various measures have been taken against erosion based upon the result of an exposure test of concrete and anti-erosion concrete specimens. The following is a discussion on the measures for improving durability of concrete structures:

3.2 Examples of bridge substructure on sulfuric-acid, hot-spring foundation

A new road network has been installed in the Beppu hot-spring district, and concrete structures such as bridges, tunnels, and box culverts have been constructed. Measures taken to improve durability of the substructure of a bridge will be a discussed as follows:

	UNIT	BEPPU HOT-SPRING GROUP				TAMAGAWA HOT-SPRIG WATER
		M-SPRING WATER	M-SPRING SOIL *	T-SPRIG WATER	H-SPRIG WATER	
pH	—	2.25	1.7~2.6	1.5	6.5	1.3
Water Temp	℃	82	97~50	75~12	64~31	65
Cl^-	mg/ℓ	1.07	———	0.49	16.70	2147~2470
SO_4^{2-}	mg/ℓ	550	78400~3310	3700	63	857~1296

* SURFACE~40(cm)

Tab.1 The analysis results of hot-spring water and soil

3.2.1 Erosive environment
Beppu Hot Spring is a term applied in general to M, T and H Hot Springs. A comparison of chemical components of Beppu Hot Spring with those of Tamagawa Hot Spring, which will be discuss-ed later, will be as shown in Table 1. The acidity of T Hot Spring is high with a pH of 1.5, while that of H Hot Spring is almost neutral with a pH of 6.5. M Hot Spring is under such environments with various factors contributing to deterioration of the soil.[3]

3.2.2 Method of examining preventive structure
Cyrindrical specimens of concrete, $\phi 10\times 20$ cm (M, T and H hot-spring water soaking test specimens) and prism specimens of concrete, $10\times 10\times 80$ cm (no n-painted M hot spring soil exposure test specimens), mixed respectively as shown in Table 2, were produced and a hot-spring water tank test and a soil exposure test were conducted.

No	W/C	S/a	A UNIT WEIGHT		TEST RESULTS			USED CEMENT	ADMIXTURE
	(%)	(%)	W kg/m3	C kg/m3	Slump (cm)	Air (%)	*σ_{28} (kgf/cm^2)		
I	31.0	30	155	500	19	0.2	600 (577)	POLTLAND CEMENT	HIGH WATER REDUCING AGENT
II	40.0	38	160	400	6	4.0	439 (411)	POLTLAND CEMENT	WATER REDUCING AGENT
III	52.3	39	157	300	6	4.0	347 (316)	POLTLAND CEMENT	WATER REDUCING AGENT
IV	79.0	41	190	240	6	1.2	153 (134)	POLTLAND CEMENT	WATER REDUCING AGENT
V	46.4	39	158	340	7	4.0	342 (328)	SULFATE RESISTING CEMENT	WATER REDUCING AGENT

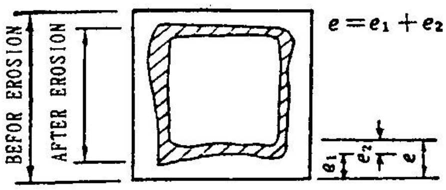
*σ_{28} UPPER LINE: STADARD CURING AT 20℃
UNDER LINE: CURING IN THE FIELD

Tab.2 Specification of concrete specimens in BEPPU

Moreover, an exposure test was carried out to the soil of M Hot Spring, using 6 prism specimens, $10\times 10\times 80$ cm, of concrete mixed as Mixture III shown in Table 2, the surface of which were coated with 6 kinds of anti-erosion measures as shown in Table 3 after a material age of 28 days. The conditions of deterioration of the soaking specimens and soil exposure test specimens were judged from factors such as external appearance observation, weight changes and erosion depths. As shown in Fig. 2, the depth of erosion has been defined as a combination of the part lost and the depth of carbonation.

	KIND OF ANTI-EROSION MATERIAL AND METHOD	THICKNESS
E	COATING WITH EPOXY-AROMATICPOLYAMIDE	1.2mm
AS	GLASS-CLOTH COATING WITH ASPHALT-EPOXY	3.0mm
EM	MORTAR LINING WITH EPOXY-AROMATICPOLYAMIDE	10.0mm
PM	MORTAR LINING WITH UNSATURATED POLY-ESTER	10.0mm
AM	MORTAR LINING WITH ASPHALT-EPOXY	10.0mm
CM	POLYMER-CEMENT MORTAR LINING	10.0mm

Tab.3 Specification of anti-erosion in BEPPU



e :DEPTH OF EROSION (mm)
e_1:DEPTH OF LOST (mm)
e_2:DEPTH OF CARBONATION (mm)

Fig.2 The definition of cprrosion depth

3.2.3 Relationship between concrete mixtures and deterioration

5 kinds of concrete specimens were soaked and exposed in 3 hot springs each with a different pH chosen from among the Beppu hot-spring group, after which weight changes and erosion depths were determined, the result of which is as shown in Fig. 3. The result has revealed that the deterioration of concrete is dictated more heavily by the kind of soaked hot-spring water rather than the kind of cement and its mixture used for the concrete used.

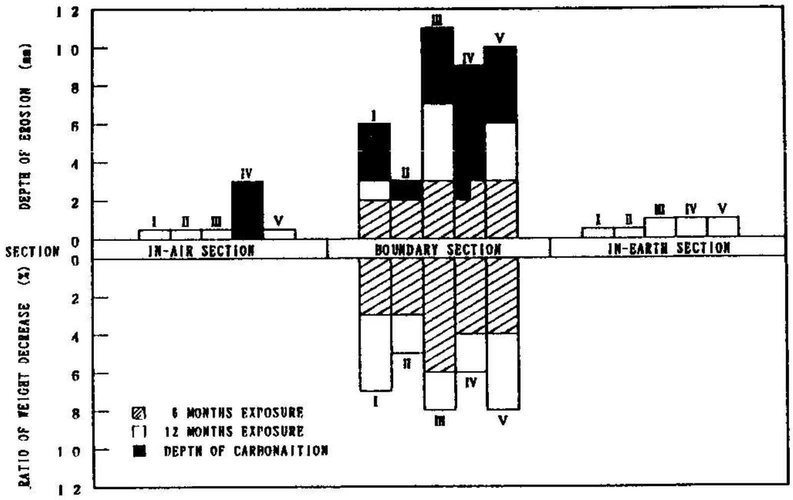


FiG. 3 Depth of errosion and ratio of weight decrease at soaked spacimens

As a next step, the result of a soil exposure test of non-coated prism specimens from M Hot Spring is as shown in Fig. 4. The degree of deterioration was conspicuously higher near the surface (5 cm above and 10 cm below the ground surface), whereas the section more than 5 cm above the ground surface showed not so much deterioration. Subsequently, Fig. 5 shows the depths of erosion and the rates of weight decrease with the specimen divided into the in-air section, boundary section, and in-earth section. The result indicates that the deterioration in the boundary section is the most conspicuous and the degree of deterioration is just about the same as the specimen soaked in the M hot-spring water. The depth of erosion in the in-earth section is about 1/7 that of the boundary section, and the deterioration in the in-air section is almost negligible. From above, the pH of the soil, the period of exposure, and the depth of erosion have been estimated as shown in Formula below:

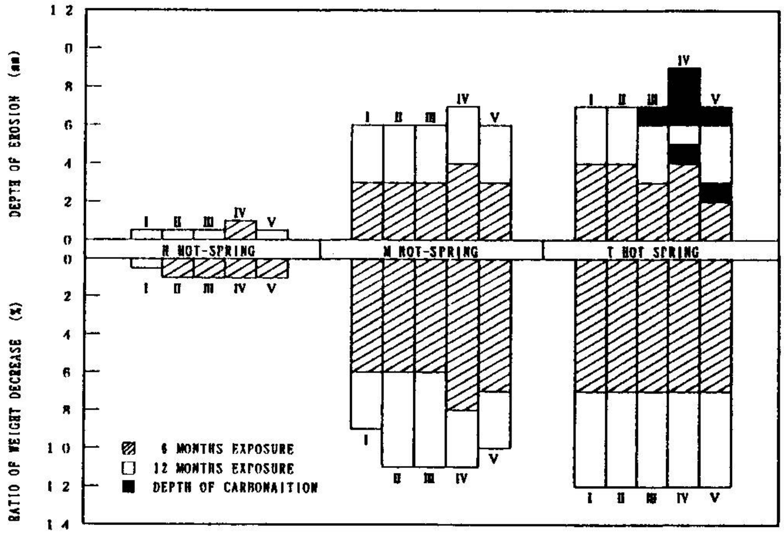


FiG. 4 Depth of erosion and ratio of weight decrease at soil exposur test spacimens

$\delta = K \cdot (7-pH) \cdot t$ ------(1) [4]

Where d: Depth of erosion (mm)

K: Coefficient corresponding to structural section (boundary section; 1.4, in-earth section; 0.4)

pH: Hydrogen ion concentration at exposed section

t: Years exposed

3.2.4 Samples coated with anti-erosion methods of construction

3.2.4 Samples coated with anti-erosion methods of construction

The result of measurement obtained from a 3-year exposure test to the M hot-spring soil of the concrete specimens coated with the anti-erosion material shown in Table 3 is as shown in Table 4. With the boundary section, the anti-erosive material was deteriorated other than EM and the anti- erosive function of concrete ceased to exist. In the case of the in-earth section, a 10-mm-thick lining specification was recognized as effective. However, the result was variable from specification to specification when the film was thin, and this coating cannot be adopted under existing erosive environments.

	SECTION	THE RESULT OF OFSERVATION	ADHESIVE	WEIGHT CHANGES	Carbonation (mm)
E	IN-AIR	No problem expect change of color	▲	+2.0	0
	BOUNDARY	Coating film damaged in 3.5years	▲		0
	IN-EARTH	No problem expect change of color	▲		0
AS	IN-AIR	Partial Blister	◎	-3.4	0
	BOUNDARY	Scaling (depth of erosion:9mm)	×		25
	IN-EARTH	Softening, mixing to soil	◎		0
EM	IN-AIR	No problem expect change of color	◎	+1.8	0
	BOUNDARY	No problem expect change of color	◎		0
	IN-EARTH	No problem expect change of color	◎		0
PM	IN-AIR	No problem expect chalking	◎	+0.5	0
	BOUNDARY	Thermal deterioration crack	△		0
	IN-EARTH	No problem expect change of color	◎		0
AM	IN-AIR	Fall down	×	-7.1	0
	BOUNDARY	Scaling (depth of erosion:13mm)	×		2
	IN-EARTH	No problem expect change of color	×		0
CM	IN-AIR	Fall down	×	10.7	0
	BOUNDARY	Scaling (depth of erosion:10mm)	▲		3
	IN-EARTH	No problem expect change of color	◎		0

REMARK: ◎ VERY GOOD, △ GOOD, ▲ NO GOOD, × BAD

Tab. 4 The result of a soil exposure test

3.2.5 Preventive measures [4]

Based on the above-mentioned result, preventive measures have been determined as follows:

1) Boundary section ... Thickness-added method of construction plus use of anti-erosive material

2) In-earth section ... Thickness-added method of construction

The thickness-added method of construction means that the cover concrete on the outside is increased in thickness for placement in one-piece, expecting that the erosion by hot spring will not reach the effective cross-section of the concrete itself, and the thickness to be added on was obtained from Formula (1) mentioned above.

It has been 10 years since the facilities were constructed in the anti-erosive method of construction discussed so far and there seems to have been no problem in the absence of conspicuous abnormality in appearance.

3.3 Examples of facilities to process neutralization of chloric hot-spring water

In order to construct a dam in the upstream of Tamagawa Hot Spring, it was decided to build a neutralization facility because the ingredients of the hot-spring water on the up-stream-side were highly acid as shown in Table 1. The following is a discussion on the measures to improve durability of the facility.

Slump	W/C	Air	S/a	UNIT WEIGHT (kg/m^3)				
(cm)	(%)	(%)	(%)	W	C	S	G	AE WATER REDUCING ADMIXTURE
8	55	4.5	45	160	291	819	1053	0.728

Tab. 5 Specification of concrete specimens in TAMAGAWA

3.3.1 Erosive environment

In Table 1 mentioned above, the ingredients of Tamagawa hot spring are shown. The carbonation facility at stake was designed to take in the hot-spring water with a pH of 1.1 and neutralizes it prior to discharging. This was due to the fact that the hot-spring water was chloric, calcium chloride produced from the hot-spring water reacting to a cement hydrate was easily soluble and it was feared that there might be deterioration with the concrete flowing out.

3.3.2 Examination of anti-erosive construction method

In view of the result in the foregoing item, concrete specimens, 30×30×10 cm, were prepared in accordance with the mixture shown in Table 5. After the specimens were cured for more than 28 days, they were coated with the anti-erosive material shown in Table 6 and made anti-erosive specimens.

	KIND OF ANTI-EROSION MATERIAL AND METHOD	THICKNESS
E	COATING WITH EPOXY-AROMATICPOLYAMINE	3.0mm
E C	GLASS-CLOTH COATING WITH EPOXY-POLYAMIDE	2.0mm
E M	MORTAR LINING WITH EPOXY-AROMATICPOLYAMINE	6.5mm
P	GLASS-FLAKES WITH UNSATURATED POLY-ESTER	2.5mm
S	SEAT LINING WITH PLLYVINYL-CHLORIDE	3.0mm
N	NON-COATING	–

Tab. 6 Specification of anti-erosion

The result of observation of external appearance in a 2-year exposure test is as shown in Table 7.

The results discussed so far have led to the adoption of the paint group EM for the structures which come in contact with the raw water or diluted water mixture and the paint a group P for the facilities which come in contact with the water (pH 5 or higher). An observation in 2 years after construction has revealed nothing unusual about the paint group EM, but swelling or rising has been witnessed with the paint group P.

	THE RESULT OF OFSERVATION
E	Change of color Blistering (φ5mm)
E C	Change of color Blistering, (partial)scaling, cracking
E M	No problem expect change of color
P	Chalking Blistering(φ8~20mm)
S	Chalking Blistering(φ10~30mm)
N	flows out severely from the surface

Tab. 7 The result of a exposure test

4. CONCLUSIONS

This paper mainly deals with the experiments performed by the author as regards the measures for improving durability that have been applied in the hot-spring district of strong acidity in Japan. The ingredients are variable from hot spring to hot spring, and so are the erosive environments. In either case, many of them contain harmful ingredients flowing out of concrete. It can, at least, be said that in the case of hot springs with strong acidity, the kind of cement or the blending of concrete alone can not contribute to solve problems as seen from the standpoint of durability. Subsequently, it has been made clear that there will have to be anti-erosive measures taken in one way or another. The anti-erosive material itself is required to be durable and adhesive, apart from the ability to intercept any elements to facilitate the deterioration of concrete. It is hoped that this report will be able to contribute to the designing of durability in concrete structures in the hot-spring district.

In the preparation of this paper, several pieces of literature have been referred to. At the end of this report is a list of reference materials used, and the author would like to express appreciation to all those concerned for the opportunity given to refer to such data.

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