Evaluation of Durability of Water Distribution Reservoir with the Reinforced Concrete Structure Utilized for 90 years

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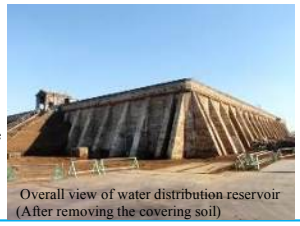
INTRODUCTION

In general, concrete structures are required to have high durability since their period of utilization is long. However, in studies on the durability of concrete structures so far, there are not many cases of detailed investigation of structures that have been used for a long time. Therefore, conducting studies of structures actually used for a long time to evaluate their durability from their materials, design, and construction is considered to be useful for construction and maintenance of waterworks facilities in the future.

The Tokyo Waterworks conducted studies to evaluate the condition of concrete and reinforcing bars of a water distribution reservoir, which had been managed and utilized by Tokyo Waterworks for 90 years when renewing the reservoir to secure water capacity and improve earthquake resistance. Survey methods included visual evaluation of external appearance, as well as measuring neutralization depth with core samples, the amount of chloride ions, compressive strength, and proportion estimation. Tests on the rebar included corrosion status, fogging, diameter checks and tensile strength tests.

From these results, it was found that there was no significant deterioration of the concrete or rebar observed even after 90 years in use, and they had durability comparable to that of modern concrete structures.

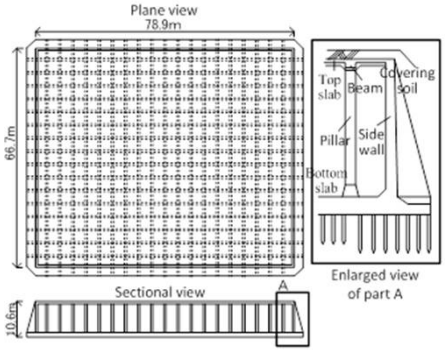


Overall view of water distribution reservoir (After removing the covering soil)

Inside the reservoir

Structure Overview

- The reservoir of the target structure entered use in 1924, and was used for 90 years until its removal for renewal construction in 2014
- The structure was a rectangular above ground structure entirely covered in earth
- Structure Overview
  Structure Dimensions
  Structure Format: Reinforced concrete structure
  Foundation Format: Pile foundation



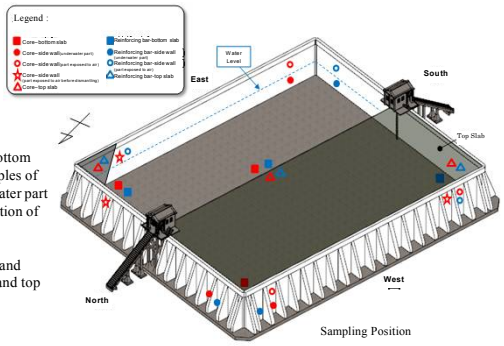
Outline of Structure

Survey Methods

- Survey items and test method

	Survey item	Test method
Concrete	Appearance	Visual inspection
	Neutralization depth	Phenolphthalein method
	Chloride ion amount	Extraction from sample with nitric acid
	Compressive strength Elastic modulus	Destructive test by specimen
	Proportion	Chemical analysis of finely ground sample
Reinforcing bars	Corrosion, covering, diameter	Measurement by visual observation and vernier caliper
	Tensile strength Elastic modulus	Tensile test by test piece

- Core samples were taken from the bottom slab, side walls, and top slab, with samples of the side wall taken for both the underwater part and the part exposed to air in consideration of the water level during use
- Surveys were conducted both inside and outside the structure for the side walls and top slab



Sampling Position

RESULTS

Status of Concrete

- In the condition of appearance, some beam parts were exposed and concrete had peeled away, but overall it was in good shape, with no cracking
- Neutralization depth and chloride ion amount had not progressed very far, and compressive strength is 30N/mm2 , so it has high durability.
- The proportion of materials is estimated to use the general proportion at the time, with a low water to cement ratio deemed to be one of the reasons for high durability.

Exposed rebar on ceiling beams

Part	Neutralization depth			
	Max.	Min.	Avg.	Predicted value
Top slab	5.5	0.0	2.5	8.8
Side wall exposed to air	0.0	0.0	0.0	7.4
Side wall underwater	9.5	4.5	6.6	
Bottom slab	5.0	0.0	2.3	4.8

Results of neutralization

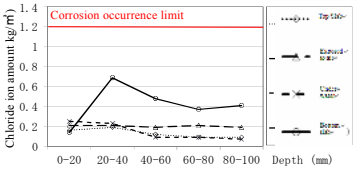


Figure 3: Measurement results of chloride ion amount

Part	Compressive strength (N/mm²)	Elastic modulus (kN/mm²)
Top slab	46.3	41.2
Side wall exposed to air	38.8	39.4
Side wall underwater	30.6	39.0
Bottom slab	53.8	39.1

Results of compressive strength test

Part	W/C (%)
Top slab	50.0
Side wall exposed to air	48.3
Bottom slab	45.3

Proportion Estimate (Water/Cement Ratio)

Status of Reinforcing Bars

- All the reinforcing bars were round steel, and some rust leachate and exposure were observed, but other s were not corroded, nor were there cross section defects. The reinforcement arrangement was favorable.
- There was also protective concrete on the inner surface of the side walls, and the covering was over 100 mm. The covering is deeper than neutralization depth, so it seems that this was a gentle environment against corrosion.
- It had standard quality for the time it was built, with no decrease in strength. It satisfies standard values even compared with current standards, so performance was adequate.

Part	Reinforcing bar diameter	Covering
Outside top slab	18.8	125
Inside top slab	16.2	29
Inside side wall	19.2	175

Actual measurement of reinforcement arrangement condition

Part	Yield load (kN)	Yield point (N/mm²)	Maximum load (kN)	Tensile strength (N/mm²)	Elastic modulus (kN/mm²)	Breaking elongation (%)
Top slab	66.9	326	94.7	462	210	26.0
Side wall exposed to air	72.8	365	106	532	206	27.7
Side wall underwater	87.7	301	126	433	209	35.5
Bottom slab	87.5	299	129	441	207	27.2
SR235	—	≧235	—	380~520	—	≧20

Results of tensile strength test

CONCLUSIONS

- The structure surveyed had sufficient durability even after 90 years in use, with little deterioration due to the passage of time except for some rebar corrosion, so it can be evaluated as being in sound condition.
- Hence, it is assumed that concrete structures which are constructed appropriately can retain their function for a long time, and it is believed that they can withstand long-term use under regular maintenance.

References
1) Survey Committee on Concrete, Japan Society of Civil Engineering. 1931. "*Standard Specifications for Reinforced Concrete* (established in 1931)".
2) Japan Society of Civil Engineering. March 2013 "*Standard Specifications for Concrete Structures established in 2012* (for construction work)".
3) Shimizu Corporation. August 2015 "*Report on Field Survey for Evaluation of Long-term Durability of Water Distribution Reservoir No. 2 of Watabori Water Station*".