The Wet Curing System of Concrete "AQUA CURTAIN"

1. Background

In the fabrication of concrete structures, role of curing in optimizing the performance of the concrete is crucial. The desired concrete performance and durability, as measured by strength and mass-transfer resistance for example, will be obtained only if the cement is properly hydrated during curing. That is, it is crucial to maintain the appropriate temperature and moisture level for hydration over the necessary period. Suitable curing conditions are set in various published standards.

According to Committee 308 of the American Concrete Institute (ACI), specific levels of moisture and temperature—crucial factors for hydration—are specified for concrete curing. In Japan, the period for wet curing is specified in the standard specifications published by the Japan Society of Civil Engineers (JSCE), as shown in **Table 1**.

Table 1 Curing periods (JSCE)

Daily mean temperature	Ordinary portland cement	Blended cements (Blast-furnace slag cement[typeB])	High-early-strength portland cement
15	5days	7days	3days
10	7days	9days	4days
5	9days	12days	5days

However, while it is easy to supply moisture to a horizontal surface, where ponding or a curing mat soaked with water can be used, it is extremely difficult to attain appropriate curing conditions on a vertical surface. As a result, at actual construction sites, curing is likely to cease before the end of the curing period considered necessary for full hydration.

To remedy this, the authors have developed a novel wet curing system named AQUA CURTAIN (AC). This system makes it possible to supply curing water to vertical concrete surfaces and to the interior of tunnel linings after the formwork has been removed.

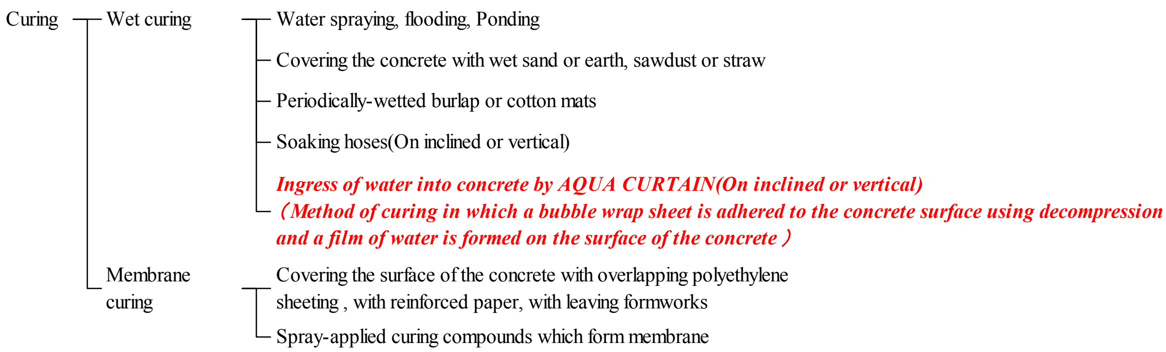
2. Overview of the AQUA CURTAIN curing system

2.1 Background

A. M. Neville has discussed the principles of the major curing methods [1], categorizing as “wet curing” and “membrane curing,” respectively, those curing methods that actively supply water to the concrete and those that simply prevent water loss.

Wet curing, which not only prevents moisture dissipation but also actively supplies water to the concrete being cured, has a significant effect on concrete performance. As already noted, however, at actual construction sites it is difficult to wet cure under perfect conditions, particularly in the case of vertical and inclined surfaces after the formwork has been removed. In the AC system described here, a water film is created on any concrete surface, including the vertical walls of structures and the interior surface of tunnel linings, ensuring that appropriate wetness conditions are maintained.

Figure 1 shows a modification of Neville’s categorization diagram to incorporate the AC curing method.



* Italics indicate the amendments made by the authors to Neville’s paper.

Fig. 1 Categories of curing (modified)

2.2 Work technique for AC curing

2.2.1 System configuration

The system consists of a curing sheet, suction equipment, and water supply equipment. Air is evacuated from the gap between the curing sheet and the concrete surface using the suction equipment. The resulting decompression brings the curing sheet into close contact with the concrete surface. Water is then supplied between the two surfaces to form a water film over the concrete.

2.2.2 Main equipment

(1) Curing sheet

Two types of material are used as the curing sheet: material with an uneven surface (used for decompression sections) and material with a smooth surface (used for airtight sections). The reasons for choosing certain materials for the curing sheet are explained below.

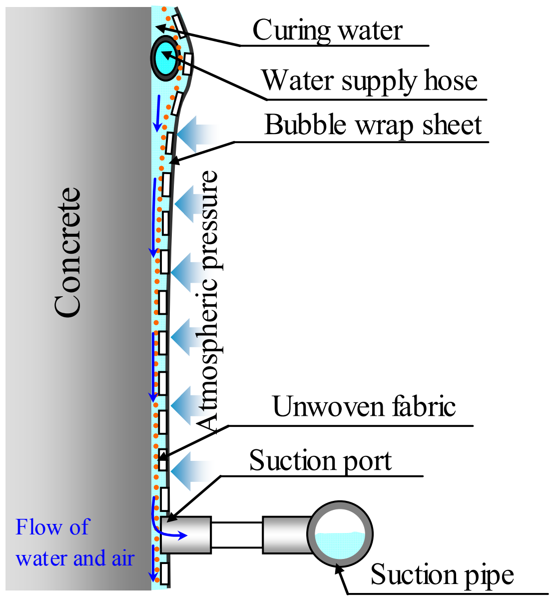


Fig. 2 Section through AC system during curing

- In order to expand the decompression area, it is important to secure an adequate air flow between the sheet and concrete. For this reason, a sheet with an uneven surface is required.
- Bubble wrap is chosen as the curing sheet because it is lightweight, inexpensive, and has good heat-retention properties.
- The water holding properties of the curing sheet can be improved by covering the concrete surface with a hydrophilic unwoven fabric before applying the bubble wrap.

(2) Water supply

Water should be supplied through a hose that is approximately 70–100 m long.

2.2.2 Work process

The curing process is described below.

- The formwork, support members, and binding wires are removed from the structure.
- The water supply hose is positioned at the high point of the concrete surface to be cured and the curing sheet is temporarily attached.

- Suction ports are positioned at the lower edge of the curing sheet at intervals of approximately 4 m.
- The suction equipment and suction pipes are connected.
- After ensuring that the edges of the curing sheet are airtight, the suction pumps are switched on.
- The water supply pump is switched on to supply curing water through the water supply hose, thereby starting the wet curing process.
- The water supply is regulated on an intermittent basis so that water is supplied at a specified rate throughout the curing process in accordance with the water absorption rate of the concrete.

3. Effects of AC wet curing

3.1 Purpose and overview of tests

To ascertain the effects of wet curing using the AC system, the authors have previously investigated the development of compression strength in normal Portland cement. It was found that wet curing improved compression strength over an extended period. However, strength is not the only important measure of expected performance; mass-transfer resistance is also important to attaining durability.

In this study, in order to investigate the effect of wet curing on durability, freeze-thaw resistance, pore size distribution tests, and carbonation resistance tests were conducted so as to evaluate quantitatively the mass-transfer resistance.

The mix proportions for the concrete used in the investigation are shown in Table 2. The cements used were normal Portland cement (N) and Portland blast furnace slag cement (BB). In addition to simulations run for general structures, a simulated case (BT) using for tunnel lining concrete that had the formwork removed at an earlier stage than usual and on which it is difficult to apply wet curing was conducted. The target values for slump and air volume at the time of pouring the concrete were 8±2.5 cm and 4.5±1.5%, respectively.

Details of the curing conditions are shown in Table 3. With AC curing, the concrete surface is always in a water-wet condition. Therefore, in the case of freeze-thaw resistance and pore size distribution tests using small specimens, AC curing in table-3 assumed itself standard water curing.

Table 2 Mix proportions

Symbol	W/C (%)	s/a (%)	Unit content （kg/m³）					
			Water W	Cement C	Fine aggregate		Coarse aggregate G	Admixtures
					S1	S2		
N	55.0	43.1	157	286	561	241	1073	2.86
BB	55.0	43.4	153	279	567	243	1073	2.97
BT	60.0	46.5	164	274	600	275	1001	2.92

*Cement Type N: Ordinary portland cement, BB and BT : Blast-furnace slag cement(TypeB)

Table 3 Curing conditions

Categories	Symbol	Method of curing
Ponded in water	W	**Curing for the study of concrete performance standards** -Remove the formwork after 2 days of material aging and then conduct the standard water curing (20ºC). -After completing curing (28 days), conduct air curing.
Wet curing	A1	**Verification of the AC curing effects** -Remove the formwork after 3 days of material aging (15 h for BT) and then conduct AC curing. -Curing period (N, BB: 1/2/3 weeks, BT: 1/2/3 months) -After completing curing, conduct air curing.
	A2	
	A3	
Sheathing curing (Kind of Membrane Curing)	S	**Curing for actual structures (Curing according to the JSCE curing methods)** -After the curing period described in the specifications, remove the formwork and conduct air curing. -Curing period (N: 5 days, BB, BT: 7 days) -After completing curing, conduct air curing.
	P	**Curing with a shortened curing period (60% of the JSCE curing period)** -Shorten the curing period to 60% of the specifications and conduct curing. -Curing period (N: 3 days, BB: 4.2 days, BT: 15 h) -After completing curing, conduct air curing.

3.2 Effects on freeze-thaw resistance

Freeze-thaw resistance was measured for normal Portland cement specimens according to JIS A 1148 (Method A), which is similar to ASTM C 666(A). Specimen size was 100mm x 100mm x 400mm.

The relationship between the number of freeze-thaw cycles and mass change ratio is shown in Figure 3. The mass at the time of pouring is taken as the basis for the mass change ratio. A difference in mass according to curing method was already discernable after 30 cycles. At 300 cycles, the mass change ratio of specimens subjected to sheathing curing (S, P) was greater than that of water-cured and AC-cured specimens (A1 to A3) by 1.5%–4.5%. It is thus clear that the freeze-thaw resistance of concrete that has been sheath-cured is lower than that of concrete that has been AC-cured.

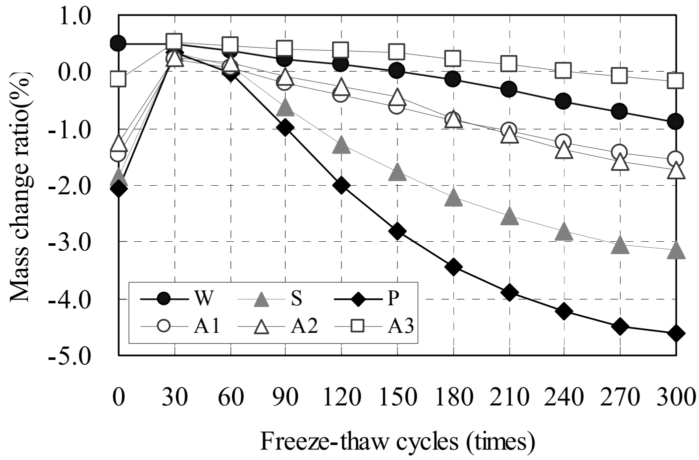


Fig. 3 Relationship between freeze-thaw cycle and mass change ratio

3.3 Effect on pore structure

The pore size distribution (mercury intrusion porosimetry) was measured to ascertain the effect of AC curing on the pore structure of concrete. In order to eliminate the influence of the coarse aggregate in making these measurements, a mortar specimen (φ5 mm x 10 mm) that had been crushed to a size smaller than 5 mm by wet screening using a 5 mm sieve was used as a sample.

The measured pore size distribution is shown in Figure 4. For each type of mortar, the pore size distribution shifted in the direction of finer pores (that is, a more dense pore structure) as the AC curing period was extended.

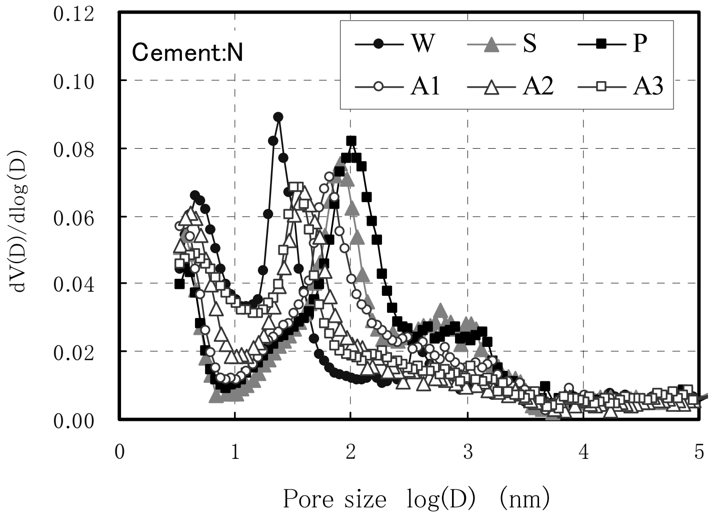


Fig. 4 Pore size distribution

3.4 Effect on carbonation resistance

An accelerated carbonation test was conducted to ascertain the improving effect of AC curing on the quality of the concrete surface layer.

To test five of the curing methods (A1 to A3, S, P) shown in Table 3, large specimens (thickness 300mm x height 1200mm x length 7200mm) were fabricated. Core specimens were taken from these test specimens at the age of 26 weeks for use in accelerated carbonation tests (JIS A 1153) up to an accelerated period of 13 weeks.

The differences in carbonation depth for the two cements and the various curing methods are shown in Figure 5. These findings, which show that the carbonation depth with AC curing is less than that with sheathing curing, indicate that the concrete structure at the surface becomes denser with AC curing as a result of sufficient water absorption.

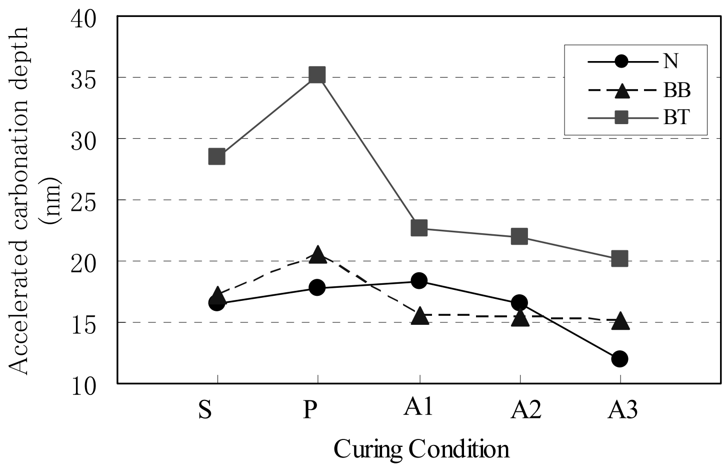


Fig. 5 Comparison of carbonation depth for various curing conditions

4. Examples of on-site applications

This curing method can be applied during the construction of various types of concrete structure. It has already been applied many times in Japan, such as in the construction of tunnels, bridge piers, box culvert walls, prestressed concrete tank walls, external walls of water treatment plants, and retaining walls. Photographs of these various application examples are shown below.

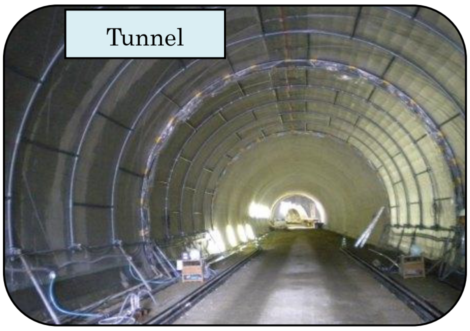

Water treatment plant


PC tank


Tunnel


Tunnel


Bridge pier


Tunnel


Watercourse

Reference

[1] A.M.Neville : Properties of concrete, Fourth and Final Edition Standards update to 2002, pp323-326.