Technology for Enhancing Concrete Durability by Continuous Drainage and Moist Curing

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1. Background of development

In anticipation of increasing maintenance costs for social infrastructure in the future, a construction technology that uses concrete of long-term durability is required to curb the maintenance costs for new structures. The technology for enhancing concrete durability has been studied chiefly from the viewpoints of preventing initial cracking and increasing concrete quality, and a variety of technologies has been developed in each process of design, materials selection, transportation, casting, compaction, and curing. Of these, curing is a vital process for eliciting concrete performance. Commercialized curing systems are available. These include permeable forms that discharge excess water and air bubbles immediately after concrete is cast by placing fabrics and special sheets inside the forms, as well as moist curing mats that are placed on the concrete surface to keep the surface moist after removing the forms. However, even when using an aggressive curing method that goes beyond simple drying prevention, most methods either drain excess water before the concrete sets or supply water after the concrete sets.

The developed technology produces more highly durable concrete by combining permeable-form curing, which continuously discharges the excess water and air bubbles that are produced immediately after the concrete is cast, and moist curing (W curing), which supplies water immediately after the concrete has set with the forms in place. This curing technology is designed to reduce the water-cement ratio on the concrete surface by draining excess water immediately after concrete casting, and then after the concrete has set and without removing the forms, immediately initiating moist curing. This produces a very tight void structure in the concrete surface, which significantly improves durability.

2. Overview of continuous drainage and moistening curing method

2.1 Form structure and curing procedures

The structure and appearance of the forms and curing procedures that were used during the development of this technology are described below and illustrated in Figs. 1-3.

[1] Using a permeable resin plate with a hollow structure capable of supplying water inside is used as a sheeting plate, assemble a formwork with a permeable sheet covering and contacting the surface of the concrete.

[2] Cast the concrete. During or immediately after casting, open the drain valve installed in the lower part of the form to release the excess water and air bubbles present on the concrete surface. This will lower the water-cement ratio on the surface.

[3] After the concrete is completely set, close the drain valve and supply water to the permeable plate to perform moist curing.

The hollow, high-strength permeable plate has fine pores about 1 mm in diameter at 10 mm intervals on the side in contact with the cast concrete. Water is supplied to and drained from the concrete through a commercially available permeable sheet that combines a fabric and a non-fabric and was developed for use with permeable forms. Moreover, a water vent in a lower part of the permeable plate drains the water that collects within the permeable plate.

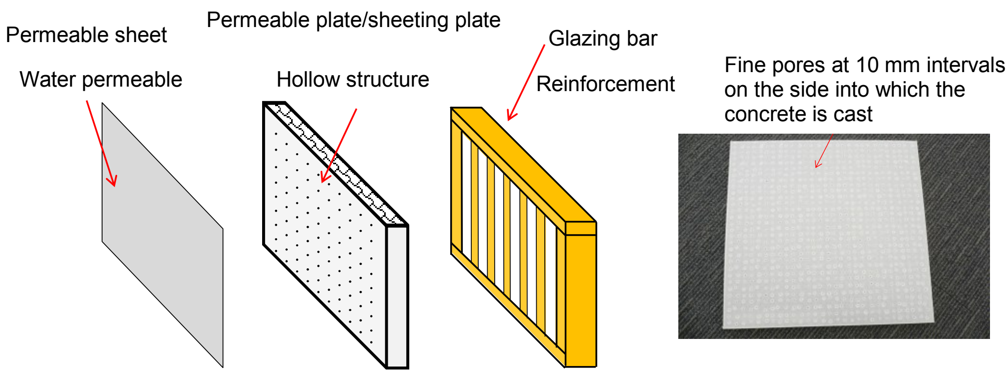


Figure 1. Structure of form used for continuous drainage and moistening curing

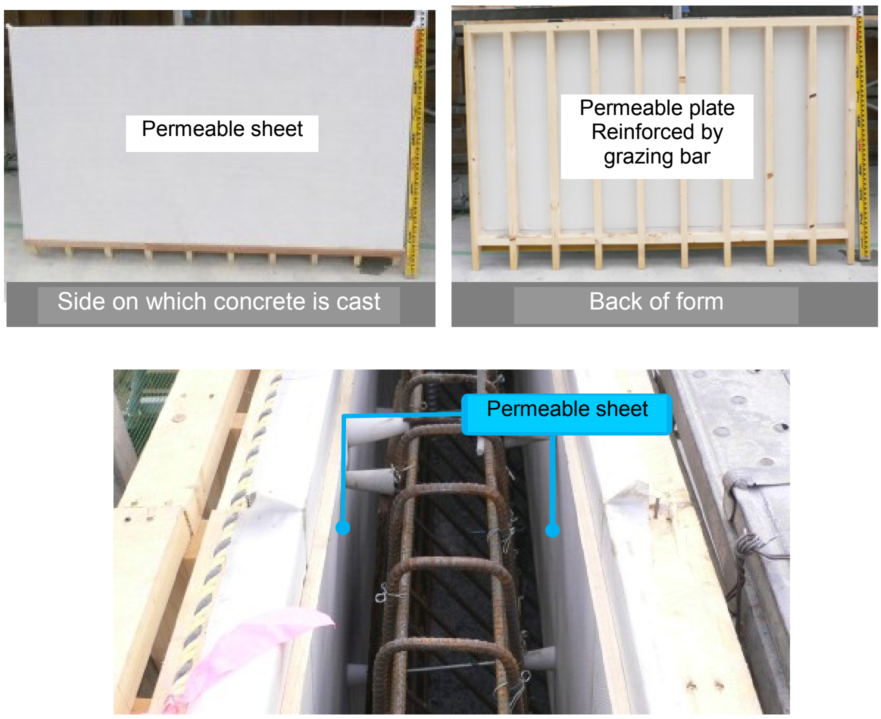


Figure 2. Appearance of form

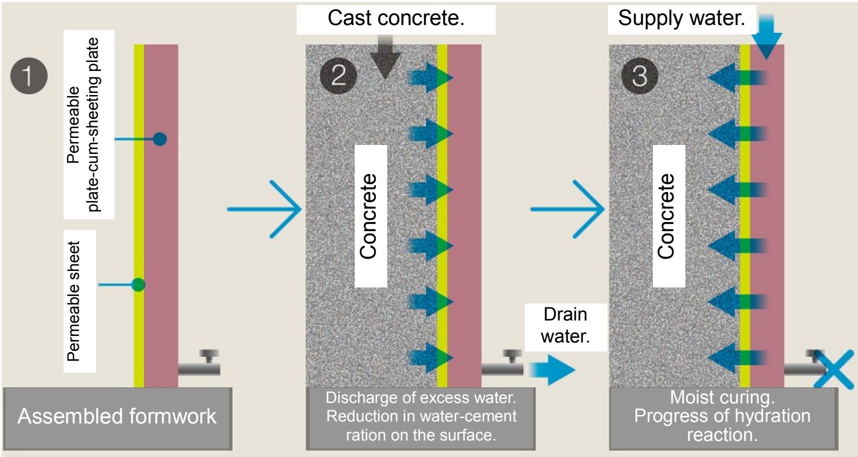


Figure 3. Continuous drainage and moistening curing processes

2.2 Effect of curing technology

The developed special forms permit continuous drainage immediately after concrete casting and continuous water supply after concrete is set without removing forms. The result is a synergetic effect beyond simply the combined effect of the two operations. The effect is summarized below from a mechanical aspect.

[1] The water-cement ratio on the concrete surface is reduced by releasing excess water. This diminishes the voids among the cement particles, which are filled by hydrate, resulting in narrowed cement particle intervals.

[2] Curing water can be supplied to the concrete surface promptly after the concrete has set without waiting for the concrete to develop sufficient strength to remove the forms. Because of this, the consumption of mixing water is promoted by brisk hydration reaction of the cement during the initial few days. The resultant self-drying phenomena enables efficient water absorption into the concrete surface. Hence, a much greater effect is produced than that produced by conventional moist curing, which is performed after the forms are removed.

[3] As a result, water surrounds the cement particles on the concrete surface throughout the curing period, which efficiently produces a tight concrete surface and avoids coarse voids among the cement particles.

4. Effect of development

The effect of the developed method was studied by comparing two cases: (1) the wood forms were left for five days, and (2) continuous drainage and moist curing (one day of excess water drainage and two days of moist curing). This applicability experiment used members that simulated a wall railing (member dimensions: 3600 x 300 x 1200 mm). The specific effects are described below. The experiment used ready-mixed concrete of 30-8-20N and W/C51.8%.

[1] Improvement in appearance of concrete surface (Figure 4)

- The concrete surface was imprinted with the fine-mesh fabric marks of the permeable sheet. However, air bubbles were significantly reduced, which improved the appearance of the concrete surface.

- Compared with the wood form members, the tissues of the concrete surface became tighter, which darkened the grey color of the surface.

(1) Continuous drainage and moist curing

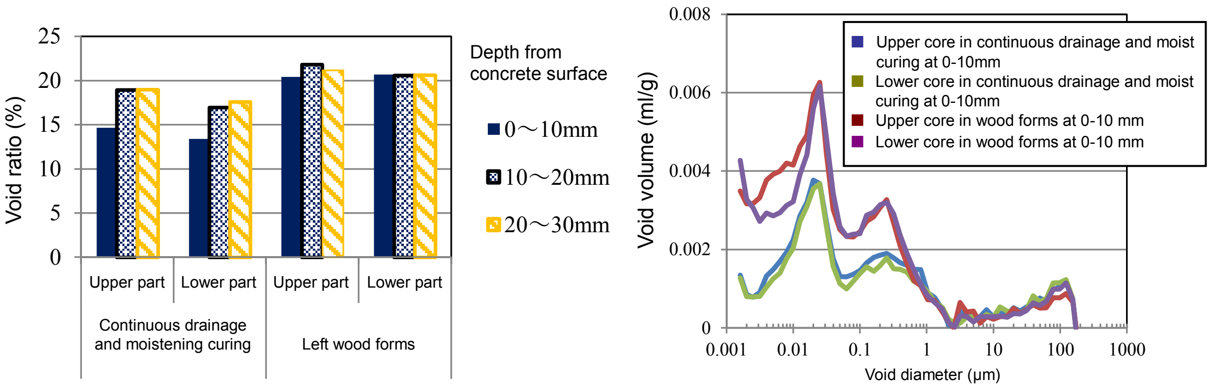
(2) Wood-form marks

Figure 4. Surface conditions of form members

[2] Tighter void structure (Figure 5)

- In moist continuous curing, the void ratio at a depth of 30 mm from the concrete surface was lower than that for the wood-form curing. The void ratio at 0-10 mm was about 14%, or about 20% less than the 20% produced by wood-form curing.

- As for fine-pore distribution, continuous drainage and moistening curing considerably reduced the number of voids of 1μm or less at a depth of 10 mm from the concrete surface as compared with wood-form curing, and formed a tight void structure.



(1) Void volume at 0-30 mm

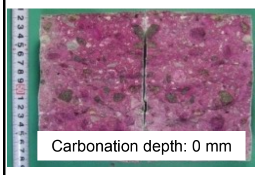
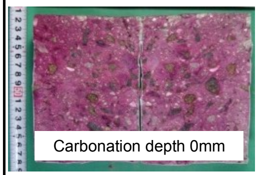
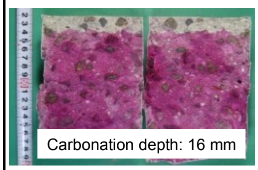
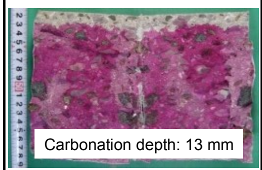
(2) Void distribution at 0-10 mm

Figure 5. Tight void structure resulting from developed technology

[3] Suppression of carbonation (Table 1)

- The concrete in the wood forms was carbonated to a depth of 10 mm or more, but continuous drainage and moistening curing produced no carbonation.

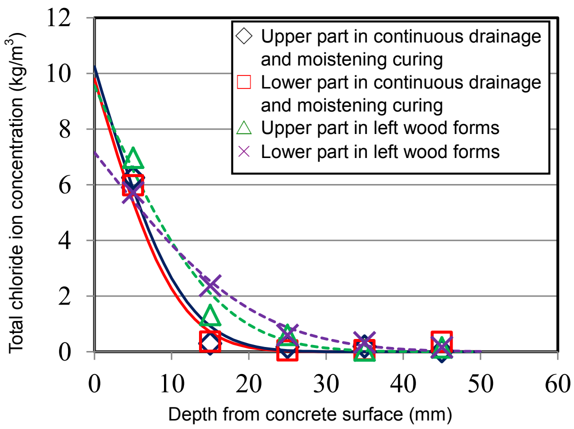
Table 1. Suppression of carbonation by the developed technology (Accelerated carbonation test: 13 weeks of exposure)

Curing	Upper part	Lower part
Continuous drainage and moistening curing		
Left wood forms		

[4] Suppression of penetration of chloride ions (Figure 6)

- The continuous drainage and moist curing method suppressed the penetration of chloride ions to depths of 10 mm or greater from the exposed concrete surface.

- The apparent diffusion coefficient was smaller by about one-half to one-third, considerably improving penetration resistance of chloride ions.



(1) Chloride ion concentration distribution

Curing	Position of coring	Chloride ion concentration on the concrete surface (kg/m^3)	Apparent diffusion coefficient (cm^2/year)
Continuous drainage and moistening curing	Upper part	10.2	1.57
	Lower part	9.8	1.40
Left wood forms	Upper part	9.6	2.99
	Lower part	7.2	5.25

(2) Apparent diffusion coefficient

Figure 6. Suppression of Cl^- ions penetration by the developed technology (3% NACL water solution: 13 weeks of immersion)

[5] Reduction in surface air permeability coefficient (Figure 7)

- The surface air permeability coefficient was reduced to about one-fifth of the mean value of all the measurements.

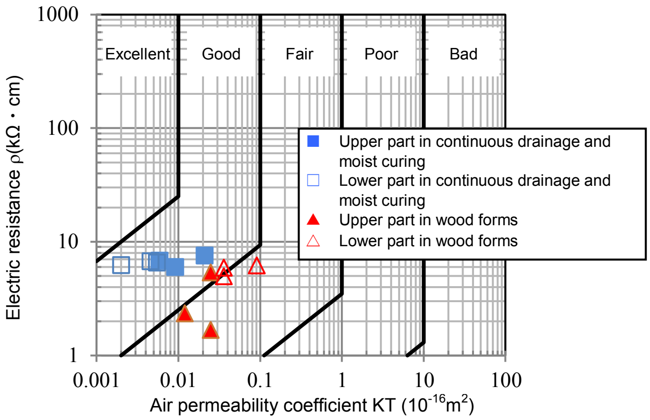


Figure 7. Reduction in surface air permeability coefficient using the developed technology (Torrent method; material age: 7 months)

7. Conclusion

This is the first curing technology that combines a form structure consisting of special resin-made forms and permeable sheets, which allows continuous drainage of bleeding water and air bubbles produced by the concrete immediately after the concrete is cast, with moist curing, which supplies water to the concrete surface immediately after the concrete has set. This method does not require the concrete to develop sufficient strength before removing the forms, unlike conventional moist curing. The result is a synergetic effect beyond simply combining the two operations.

This technology has been applied to parts of the Kihoku-higashi Road Nakatani River No. 1 viaduct superstructure in Wakayama Prefecture, the bridge wall railing on the Tohoku-Chuo Expressway Chorosawa No. 3 Bridge superstructure in Fukushima Prefecture, and the PC box girder in the Amagi-kita Road Kanogawa River viaduct PC superstructure in Shizuoka Prefecture.

Various experiments and the results of application to actual structures have demonstrated that members to which this technology has been applied become tight on the surface and have remarkably increased durability. Therefore, this development can considerably enhance the reliability of new structures, be applied to numerous types of structures, and reduce maintenance costs for social infrastructure in the future.