ECONOMIC ASPECTS OF CURING MASS CONCRETE

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Published by U. S. Army Engineer Waterways Experiment Station
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On 30 November 1971 Dr. Jack W. Hilf of the U. S. Bureau of Reclamation, acting as chairman for the Engineering Foundation Conference on Economical Construction of Concrete Dams, requested Mr. Bryant Mather to lead Session II of Workshop A in a discussion of economic aspects of curing mass concrete. This session was held during the conference at Pacific Grove, California, on 15 May 1972. At the conclusion of the conference, a resolution was passed requesting the discussion leaders to prepare manuscripts for publication. This manuscript was cleared by OGE on 26 June for publication.

Director of the WES during the preparation of this paper was COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.
The most recent authoritative document on curing concrete is ACI Standard 308-71, "ACI Recommended Practice for Curing Concrete," notice of the adoption of which appeared in the January 1972 ACI Journal, page 1. The full text—which was not later amended—was published in the April 1971 ACI Journal, pages 233-243.

This standard recognizes that curing involves two principal elements: (a) maintaining a satisfactory moisture content and (b) maintaining a favorable temperature—in concrete during hydration of the cementitious materials, so that desired properties are developed.

For the purpose of this discussion, attention will be primarily directed to the maintenance of a satisfactory moisture content, since the topic of maintaining a favorable temperature in concrete in dams is a major subject in its own right and usually is considered apart from "curing."

The ACI Standard notes that two basic systems are used for maintaining a favorable moisture content: (a) application of water and (b) prevention of excessive loss of water by use of sealing materials. The principal cost
reduction that appears to be feasible, with regard to curing, in the con-
struction of dams, lies in the selection and use of the most economical
methods of maintaining favorable moisture content.

The ACI Standard includes the following statements regarding duration
of curing:

a. Paragraph 2.10, "For establishing the termination time for curing,...
test specimens made in the field and cured as nearly as possible like the
concrete they represent are used."

b. Paragraph 3.3.3, "Mass concrete: For unreinforced massive sections
containing no pozzolans, curing should be continued for not less than 2 weeks.
Where pozzolan is included as one of the cementing materials, the minimum
time for curing should be not less than three weeks. For construction joints,
curing should be continued until resumption of concrete placement or until
the required curing period is completed. For heavily reinforced massive
sections, curing should be continuous for a minimum of 7 days."

Regarding curing methods, it says:

a. Paragraph 1.2.1, "The amount of mixing water in the concrete at the
time of placement is normally more than the quantity that can combine
chemically with the cement."

b. Paragraph 2.9, "Curing by means of direct application of water... is
generally considered to be the ideal method."

c. Paragraph 2.3, "Although not necessarily as effective as the appli-
cation of water throughout the curing period, there are advantages in the
use of sealing materials for curing that make their use preferable under
many conditions."
The seventh edition (1963) of the USBR Concrete Manual says (page 399):

a. "The object of curing is to prevent or replenish the loss of necessary moisture during the early, relatively rapid stage of hydration."

b. "...concrete made with Type I, II, or V cement be kept moist at least 14 days, and that concrete made with Type IV cement or a combination of any type of cement and pozzolan be kept moist for at least 21 days."

c. "Surfaces of ceilings and walls inside buildings require no curing other than that resulting from forms being left in place for at least 14 days."

The Corps of Engineers Standard Guide Specifications for Concrete (CE-1401.01, April 1971, with Amendment -1, January 1972) provide:

- 16. CURING AND PROTECTION.

- 16.1 General. All concrete shall be cured for the period of time given below corresponding to the cementing materials used in the concrete:

<table>
<thead>
<tr>
<th>Type of Cement</th>
<th>Curing Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type III portland cement</td>
<td>3 days</td>
</tr>
<tr>
<td>Type I portland cement</td>
<td>7 days</td>
</tr>
<tr>
<td>Type II or V portland cement or portland-blast-furnace-slag cement</td>
<td>14 days</td>
</tr>
<tr>
<td>Type IV portland cement or blends containing pozzolans, natural cement or slag cement *(except in navigation locks)</td>
<td>21 days</td>
</tr>
<tr>
<td>*(Type IV portland cement or blends containing pozzolans, natural cement or slag cement in navigation locks)</td>
<td>28 days</td>
</tr>
</tbody>
</table>

The curing medium and method, or the combination of mediums and methods used, shall be approved in writing... All galleries, conduits and other formed openings through the concrete shall be closed during the entire construction period.
16.2 Moist Curing. All concrete shall be moist-cured by maintaining all surfaces continuously (not periodically) wet for the duration of the entire curing period with the exceptions listed below. If water is used which stains or discolors concrete surfaces which are to be permanently exposed, they shall be cleaned. Where forms of tongue-and-groove or shiplap sheathing are left in place during curing, the sheathing shall be kept wet at all times. Horizontal surfaces shall be cured by ponding, by covering with a minimum uniform thickness of 2 inches continuously saturated sand, or by covering with saturated non-staining burlap or cotton mats. The following exceptions to the requirements for moist curing are permitted:

(1) Horizontal construction joints may be allowed to dry for twelve hours immediately prior to the placing of the following lift.

(2) Designated surfaces may be cured by application of curing compound.

(3) Between specified dates concrete may be cured by the appropriate one of the following procedures:

(a) Where cold weather protection is provided entirely by insulation, all joints in the insulation may be sealed to prevent moisture loss and maintained sealed throughout the curing period.

(b) A curing compound may be used except that curing compounds may not be used when free steam is applied to concrete surfaces.

16.3 Membrane Curing. Concrete may be cured with an approved curing compound as indicated below in lieu of moist curing. Membrane curing will not be permitted on any surface to which concrete, paint or sack rubbed finish is to be applied.
__-16.3.1 A pigmented-type curing compound conforming to CRD-C 300 may be used in the designated structures or portions of structures.

__-16.3.3 The curing compound shall be applied to formed surfaces immediately after the forms are removed and prior to any patching or other surface treatment except the cleaning of loose sand, mortar, and debris from the surface. The surfaces shall be thoroughly moistened with water and the curing compound applied as soon as free water disappears. The curing compound shall be applied to unformed surfaces as soon as free water has disappeared. The curing compound shall be applied in a 2-coat continuous operation by approved power-spraying equipment and at a uniform coverage of not more than 400 sq. ft. per gallon for each coat. Concrete surfaces which have been subjected to rainfall within 3 hours after curing compound has been applied shall be resprayed by the method and at the coverage herein specified. All concrete surfaces on which the curing compound has been applied shall be adequately protected for the duration of the entire curing period from pedestrian and vehicular traffic and from any other cause which will disrupt the continuity of the curing membrane.

Under "Contractor Quality Control" the following is specified:

Moist Curing. At least once each shift an inspection shall be made of all areas subject to moist curing. The surface moisture condition shall be noted and recorded. When a daily inspection report lists an area of inadequate curing, the required curing period for that area shall be extended by one day.
Curing Compound. No curing compound shall be applied until the Contractor's authorized representative has verified that the compound is properly mixed and ready for spraying. At the end of each operation he shall estimate the quality of compound used and the area of concrete surface covered and compute the rate of coverage in square feet per gallon. He shall note whether coverage is uniform. When the coverage rate of curing compound is less than that specified or when the coverage is not uniform, the entire surface shall be sprayed again.

The Corps Engineer Manual, EM 1110-2-2000, "Standard Practice for Concrete," 1 November 1971, with Change 1, 1 February 1972, provides in the section on preparation of plans and specifications:

3-9. Curing.

a. General. Any drying of young concrete significantly reduces the rate of hydration and consequently the rate of gain in strength and development of other desirable properties of hardened concrete. Thin sections dry out more rapidly than thick sections; hence, adequate curing is especially important for thin sections. Even though no appreciable drying may occur in the interior of a thick section, drying of the surface may produce a nondurable surface. Therefore, special attention should be given to surfaces which will be subject to wear or weathering. The Standard Guide Specifications stresses the need for continuous rather than periodic wetting of the surfaces. Periodic wetting not only permits drying, but alternate cycles of wetting and drying might also produce some deterioration.
b. **Staining.** The Standard Guide Specifications does not require that water be nonstaining. However, there must be no permanent staining of surfaces where appearance is important. For these surfaces the contractor has the option of using nonstaining water or of cleaning the surfaces after completion of moist curing. No cleaning should be required on surfaces which will not be permanently exposed, or which will subsequently become stained when the structure is in service.

c. **Membrane Curing.** The Standard Guide Specifications contains space to list areas which may be cured with a pigmented curing compound and an optional provision for listing areas to be cured with a non-pigmented compound. Curing compounds should not be permitted on any surface to which other concrete is to be bonded, nor on any surface which is to be painted or which is to receive a sack-rubbed finish. Curing compounds may not be used for curing permanently exposed surfaces except in cold weather (see below) or horizontal construction joints of mass concrete but may be used on bulkhead faces of leading monoliths and surfaces to be backfilled. They may be permitted on small isolated structures; on long reaches of channel bottom and sideslope paving; on the undersides of bridge decks; on inside surfaces of conduits, culverts, galleries, adits, and tunnels; on ogee crests of small spillways; on concrete surfaces immediately adjacent to earth excavation or embankments; or on work where the use of moist curing would cause an undue hardship to the contractor or would be excessively costly. Pigmented compounds should be used unless they are objectionable on aesthetic grounds, in which case non-pigmented compounds may be used. The optional requirement
that concrete cured with a non-pigmented compound be shaded from direct rays of the sun for seven days should be invoked if concrete is to be placed during hot, dry, summer months. The purpose of this requirement is to prevent surface checking. In freezing weather curing water may do more harm than good. Optional paragraph \(-\)-16.2(3) is provided to take care of situations in which no artificial heat is supplied.

It is also noted that under each shift supervisor the government quality assurance organization should include one placing inspector for each location at which concrete is being placed, one mixing plant inspector, and one inspector assigned to inspection of cleanup, curing, protection, and finishing.

In the section on Construction Inspection the following is given:

5-5. **Curing.**

a. **General.** Early hydration proceeds at an acceptable rate only if the concrete is maintained at a high humidity. Thus, positive curing procedures are essential, especially for thin sections. Even in massive sections, the quality of the surface concrete is dependent upon adequate curing. The contractor should present his plans for curing for approval well before concreting begins. During construction these operations must be continually checked. "Form curing" is not an acceptable method of curing; where forms of tongue-and-groove or shiplap sheathing are left in place during curing, the forms should be kept wet at all times.

b. **Moist Curing.** Proposed methods of keeping concrete surfaces continually moist by spray-pipe or fog systems, by soil soakers, by ponding, or by covering with damp earth, saturated sand, or burlap maintained in a
damp condition in contact with the concrete are satisfactory. Galvanized or alloy pipe should be required to avoid rust stains on the concrete surfaces. Hand sprinkling is not satisfactory and should not be permitted except as an emergency measure. The contractor is not required to use nonstaining water, but he is required to clean surfaces permanently exposed to view if he elects to use water that stains.

c. Membrane Curing. Areas cured by pigmented compounds are relatively easy to inspect. Uneven distribution of the compound is readily revealed by a nonuniform appearance. In those few areas in which a clear compound is permitted, an inspector should be on hand during all spraying operations and should check closely the uniformity of the application. Spraying equipment should be of the constant pressure tank type with provision for continual agitation of the contents during application. Compressed-air lines must be trapped to prevent moisture or oil from contaminating the compound. Ordinary hand-spray outfits are not satisfactory and should not be permitted. Application by brushing should not be permitted. Pigmented compounds used in cold weather may become too viscous for proper application. In this event, the contractor should be required to heat the compound in a hot water bath to a temperature not to exceed 100°F prior to introduction of the compound in the feed tank. Pigmented compounds should be thoroughly mixed in the receiving containers by the insertion of a compressed-air pipe into and near the bottom of the container prior to withdrawing the material for use. Continuity of the membrane coating will be maintained for the duration of the full specified curing period. The membrane should be
protected by a 2 in. layer of earth or sand or other suitable means if traffic thereon is unavoidable. Any damage to the membrane during the curing period should be immediately repaired at the original specified rate of coverage.

From this review it is apparent that the continuous application of water is generally regarded as the preferable method and the application of a membrane-forming compound is regarded as an alternative to be permitted in specific special cases, particularly where water curing is not feasible. I suggest that this represents an unrealistic evaluation of the factors affecting the relative quality of the curing to be obtained by these two alternatives and that this evaluation has undesirable consequences regarding the economy of construction.

The ACI standard includes the words "Although not necessarily as effective as the application of water throughout the curing period, there are advantages in the use of sealing materials...." The Corps' Specification and Manual stress the need for continuous rather than periodic wetting. I am told that very little of the concrete required by the specifications covering its curing to be kept continuously wet for 3 or 7 or 14 or 21 or 28 days is, in fact, kept continuously wet and I note that the Corps' Specifications regarding contractor quality control only require inspection once per shift and then penalize failure to have the concrete wet when inspected by extending the period of curing one day per deficiency noted.

I happen to be convinced that concrete having a water-cement ratio greater than 0.35 by weight and not made with expansive cement does not need
externally applied curing water to develop its needed properties. I am willing to concede, primarily for the purposes of the argument, that continuous water cure may be, say, 10 percent better than membrane cure. However, I suggest that all of us would rather have 100% effectiveness of a process that was 90% of optimum, than 50% effectiveness of a process that was 100% of optimum. Consequently, I believe that, on technical grounds alone, there are reasons for preferring membrane curing.

Now to the question of relative cost--since this is the topic for this conference. Under date of 13 March 1972, I wrote to John W. Leonard, Chief Engineer, Morrison Knudsen, and asked for his comments; his reply of 13 April 1972 is quoted, with his permission, below:

"We would estimate that the membrane curing at present-day wage rates ($7.00/hour) would be six-and-a-half cents a square foot less than water curing. Water, though effective, is expensive because of 'round-the-clock operation in this high wage rate era.

"Other water disadvantages are:*

1. It's difficult to apply properly when windy.
2. High inspection costs (again, 'round-the-clock).
3. Naturally, the dumbest people on the job are the curing people - the lowest paid.
4. Hoses are stolen, workmen turn off the sprinklers.
5. It makes cleanup more difficult because of water running into low blocks, low areas.
6. Last, the problems of rust.

"*None of these are in the 6.5 cents."
Savings of $0.585/square yard of surface in bid price plus reduced inspection cost and no cost for removal of rust stains makes this a promising area for cost reduction in dam construction.

The disadvantages of using curing water that causes staining depend on the degree to which such stains develop and are required to be removed. I will show slides of a project in the St. Louis District of the Corps of Engineers where severe rust staining was encountered. Studies in this region revealed that the only curing water available for use on this job that could have been used without staining was located 12 to 13 miles from the site.

It is often stated that one major advantage of water curing is the beneficial effects of evaporative cooling in preventing excessive temperature development in concrete surfaces exposed to sunlight. This is not always true—and, when true, not always a benefit.

Experiments were conducted at an Air Force paving project in Mississippi, during a period of high ambient temperature, bright sun, and high relative humidity in which surface temperatures of concrete under wet burlap and under white-pigmented curing compound were compared. The temperature in the white-pigmented compound cured concrete was lower. The dark color of the wet burlap as contrasted with the white-pigmented curing compound more than compensated for the reduced evaporative cooling effect under the high relative humidity conditions.

An article in Concrete (London, November 1971, pages 343-347) on concreting in the Abu Simel project in Egypt noted that in that region of low relative humidity: "The concrete, which had a slump of 0.8 to 2 in (20 to
was compacted by high-frequency vibration and shaded from the sun during placing and curing. For curing the concrete was generally coated with a white membrane compound, but water was partly used where it could not damage the temple blocks or supporting sandstone. However, the use of water leads to severe superficial cooling, resulting from the marked evaporation due to the strong winds, which introduces a steep temperature gradient in the fresh concrete and may increase the risk of surface cracking. Attempts were made to limit such evaporation by covering the concrete with plastic sheets but this proved impracticable because of the need to re-wet the concrete during curing."

Orrin Riley, in the National Cooperative Highway Research Program, Synthesis 4, on Concrete Bridge Deck Durability (Highway Research Board, 1970), echoes the prevailing view that water curing is better but adds some cogent comments as may be noted from the following quotation:

"Wet curing (with burlap, cotton mats, etc.) is more desirable on bridge decks than are sprayed-on membranes, provided the burlap is kept constantly wet. Polyethylene sheets have also been used successfully. However, a fundamental factor in all curing is the importance of expeditiously applying the cure as soon as the visible bleed water has evaporated. There may be a need during hot weather to use a membrane cure to protect the surface during the time that wet curing cannot be applied without marring the surface. Probably no area of concrete construction technology is more demanding of training, experience, and forthright action than the timely application of curing."
"Curing is especially vital in the prevention of plastic shrinkage cracks. Such cracks are the result of rapid drying which, in turn, is affected by atmospheric conditions."

I hope that this review will stimulate discussion and will cause those concerned with specifications for mass concrete construction to review the requirements relating to maintenance of a satisfactory moisture content to the end that more economical procedures be permitted when circumstances allow their use without significant detriment.