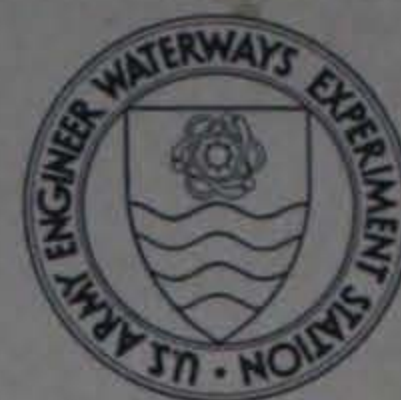
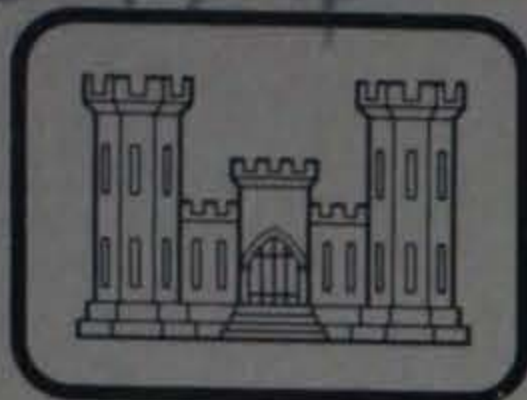


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MISCELLANEOUS PAPER SL-79-4

QUALITY CONTROL DURING HOT AND COLD WEATHER CONCRETING

by

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Final Report

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PREFACE

This paper was prepared for presentation at the Educational Symposium on Hot and Cold Weather Concreting. This conference, sponsored by the American Concrete Institute, was held 29 November - 1 December 1978 in Kansas City, Missouri.

Funds for the publication of this paper were provided from those made available for operation of the Concrete Technology Information Analysis Center (CTIAC). This is CTIAC Report No. 36. The paper was prepared by John M. Scanlon, Chief, Engineering Mechanics Division, Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES). The paper was prepared under the general supervision of Mr. Bryant Mather, Acting Chief, SL.

The Commander and Director of WES during the preparation and publication of this paper was COL J. L. Cannon, CE. Mr. F. R. Brown was Technical Director.

QUALITY CONTROL
DURING HOT AND COLD WEATHER CONCRETING

by

John M. Scanlon^{*}

INTRODUCTION

Quality control, or what I like to refer to as "Construction Quality Management," is a very controversial subject among contractors, owners, and producers, or for that matter any group of professionals trying to obtain the quality of construction desired by the eventual owner. Too often in the past the owner or the owner's representative spent too much time interfering in a contractor's business by trying to tell him how to construct. When a contractor bids on a project and bases his bid on the quality requirements established in the project specifications, the contractor becomes responsible for using materials, procedures, equipment, and workmanship which will result in a product complying with those specifications. If an owner desires more, he should pay for the increased quality and effort required of the contractor.

In order that we can communicate effectively, we should have a good understanding of "Construction Quality Management" and the meaning of the particular terminology used during this discussion. We - contractors, producers, and owners - need to know where we fit under the construction quality management (CQM) umbrella. The three words which have caused many problems with implementing an effective CQM policy are defined as follows:

- a. QUALITY: Degree of Excellence.
- b. CONTROL: To Regulate.
- c. ASSURANCE: Degree of Certainty.

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Now let us try to put these words together into the real subjects of our discussion.

CONSTRUCTION QUALITY MANAGEMENT (CQM). CQM is a system involving the joint but independent efforts of the contractor and the owner to achieve the level of quality desired by the user and established in the project specifications.

CONTRACTOR QUALITY CONTROL (CQC). CQC is that part of the CQM system by which the contractor regulates, tests, and inspects his procedures, equipment, materials, and manpower so that the completed function will most likely comply with the requirements of the project specifications.

OWNER QUALITY ASSURANCE (OQA). OQA is that part of the CQM system by which the owner or his representative verifies (1) that the contractor's quality control system is actually working and (2) that the end results for each of the completed functions comply with project specifications and design criteria.

It is very important that we understand these functions because they are basic to the overall understanding of how quality is controlled and verified during engineering and construction.

QUALITY CONTROL DURING HOT WEATHER

As you have discovered, during hot weather temperature is not the only hindrance to quality concrete. We have to be very concerned with relative humidity and wind velocity. In order to establish good quality control procedure, we need to know when the conditions are detrimental to the production of quality concrete construction. Concrete is a material which can be used and should be used during all periods of the year: there isn't any reason for a 50 percent reduction of concrete production during the winter and absolutely no excuse for placement of poor quality concrete during hot summer conditions. In hot weather we must cause the concrete to feel that it is being placed under ideal conditions. During my career I have caused concrete manufacturers to do many things against their will; but many times I have been told afterwards that the requirements placed on them actually saved them money and allowed them to produce a quality product under extreme weather conditions. We all realize that the reduction

of technical problems during construction saves money and increases efficiency; it also increases the morale of the worker, the owner, and the contractor. Quality control (CQC) is very important under all conditions but even more important during hot and cold weather concreting conditions.

As you have heard, hot weather effects on concrete in the plastic state may include:

- a. Increased water demand.
- b. Increased rate of slump loss.
- c. Increased rate of setting.
- d. Increased tendency for plastic cracking.
- e. Increased difficulty in controlling entrained air content.

From a quality control standpoint, what can we do to prevent these problems? (a) and (b) can be controlled by proportioning your concrete for the conditions to which it will be exposed in the field. A concrete mixture which in February gave you a 3-in. (76 mm) slump and 4000 psi (27.5 MPa) concrete may, when controlled by slump in August, give you a 3-in. (76 mm) slump and 3200 psi (22 MPa) due to the increased concrete temperature which requires an increase of approximately 40 pounds (18 kg) of water to maintain the same slump (see Figure 1). If concrete is going to be placed at 90 F (32 C), it should be proportioned for placement at that temperature. Hot-weather concrete requires a higher water requirement than cold-weather concrete to maintain the same slump. Either one of two adjustments can be made. You can (1) increase the cement content in order to maintain the same water-to-cement ratio as the cold weather concrete or (2) decrease the hot weather concrete temperature to the temperature used during the winter. I personally believe the answer is a combination of these two adjustments: adjust the mixture by slightly increasing the cement and water content, and decrease the placing temperature to reduce the increased water demand and slump loss. (c), (d), and (e) can be controlled by reducing concrete placing temperatures, using a retarder and employing protection from the wind, combined with the use

of adequate curing (see Figure 2). Setting time decreases with increased temperature; plastic cracking increases due to increased water demand and rapid evaporation; quantity of air-entraining agent increases with increased temperature.

Questions I normally receive from frantic callers during September always include, "Why am I not getting my 28-day strength until 90 days? Why has my concrete strength dropped 15 to 20 percent?" Invariably the caller had been controlling his concrete on slump and did not realize that his 3-in. (76-mm) slump in July and August required approximately 25 pounds (11.4 kg) more water than the 3-in. (76-mm) slump in April or May, thereby increasing his water-to-cement ratio by about 0.05 and reducing strength accordingly.

Field Test Conditions and Methods

As discussed above, a technician who controls concrete during changing seasons by use of the slump test is asking for trouble; a 3-in. (76-mm) slump concrete in August will not have the same water content as a 3-in. (76-mm) slump concrete in April. For good quality control, adjustments should be made to the mix, including increasing the amount of cement and water so that the original acceptable W/C ratio is maintained. The slump test should be performed as required in ASTM C-143, Standard Test Method for Slump of Portland Cement Concrete. When slumps are measured, the temperature of the concrete should be determined by a temperature measuring device which will permit 3-1/2 in. (89 mm) of concrete cover around the sensor. Under normal conditions, the sensor should be buried in the concrete for a minimum of two minutes; but when cool or cold mixing water has been used, the time should be extended to five minutes. Temperature-measuring devices should be used and the results recorded with the results of the slump test, which of course should be recorded with the concrete strength data.

Many times a technician will make an air-content test early in the morning when the concrete is relatively cool; and, if the results comply with the requirements, he may not make another all day. Air-content tests should be randomly performed during the period of concrete placement and especially during the heat of the day. For concrete containing

relatively dense aggregates, ASTM C-231, Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method, should be followed in determining the air content of the concrete. For concrete containing lightweight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity, ASTM C-173, Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method, should be used. The use of small meters which check the air content of the mortar is not recommended for good concrete control.

As previously mentioned, the initial temperature of the concrete is very important: the higher the initial temperature, the greater the final temperature drop during the cool of the night. The thicker the section, the higher the ultimate temperature and the longer the concrete takes to cool. Concrete placed 20 F (11 C) below ambient will have approximately 20 fewer degrees F (11 fewer degrees C) of temperature to drop. The strain capacity of concrete, especially young concrete, varies greatly but normally will not permit more than a 40-F (22-C) drop during 24 hours. The thicker the section, the smaller the permissible temperature drop. If dissipation does not take place during early hydration, the concrete can gain approximately 15 F (8 C) for each hundred-weight of cement used per cubic yard. Concrete containing 500 pounds (227 kg) of cement placed at 90 F (32 C) can generate enough heat to cause the concrete temperature to become 180 F (82 C) within a day. Even with normal dissipation this 90-F (32-C) concrete could reach 140 F (60 C) before the cold of the night. A cool 60-F (16-C) night would force rapid cooling which would cause cracking, and in this case, the thinner the section, the more rapidly the concrete will cool.

The use of insulation during the first night for relatively thin sections is not a bad idea: when the concrete is weak, insulation helps to keep it warm and prevents the rapid cooling. During the second day, the heat of the day allows the concrete to cool more slowly and its strain capacity is also increased due to increased age.

Inspection Before Concreting

Good quality control includes the three-step approach to inspection. These three steps include:

(1) Preparatory Phase. This phase should be performed prior to beginning any work and should include a review of contract requirements. Check to verify that all materials or equipment have been tested and approved and a plan established for completing the work as required.

(2) Initial Phase. This phase should be performed as soon as work begins on a representative portion of the job and should include assurance that the decisions made during the preparatory phase are being implemented and are working satisfactorily.

(3) Follow-up Phase. This phase should be performed daily to assure continued compliance.

Ideally all possible problems should be anticipated during the preparatory phase, but, if they are not, the system should be flexible enough to correct problems as they arise.

During the preparatory phase of anticipated hot-weather concreting, we should follow the stipulations below.

PROVISIONS FOR PLACING

(1) A relatively low-heat cement should be used; do not use Type III or a finely ground cement unless absolutely necessary.

(2) The concrete should be mixed at the coolest temperature economically possible.

(3) The haul distance should be the shortest possible.

(4) The waiting time to unload should be the shortest possible.

(5) The placement should be ready for concrete as soon as it arrives.

(6) The placement should occur during the coolest part of the day.

(7) The subgrade should be as cool as possible.

(8) The concrete should be placed and consolidated as rapidly as possible.

PROVISIONS FOR CURING

(1) Plan for fog curing, if possible. Water curing, membrane curing and water, and membrane curing alone are listed in order of decreasing effectiveness.

(2) Plan to cure in a way which will reduce heat buildup in the concrete.

(3) If membrane curing is used, use the white-pigmented type so extreme heat will be reflected.

(4) If feasible, use insulation during evenings and nights in environments where the temperature drops considerably at night.

PROVISIONS FOR PROTECTION

(1) If possible, shade placed concrete from the sun and wind. Exposure to either can adversely affect the finished product.

(2) Protect it from rains, especially relatively cold fall rains which cause rapid cooling.

(3) See (4) immediately above.

Inspection During Concreting

In the three-phase system of inspection, two phases, initial and follow-up, occur during concreting. All of the problems which come up during concreting should have been anticipated during the preparatory phase. During concreting operations, the time period during which you can effectively bond new concrete to older concrete is significantly decreased. Therefore, if you are placing a wall, you may have to reduce the lift size so that the timelapse between lifts can be reduced. Otherwise, cold joints will occur.

The slump of hot-weather concrete can disappear quickly due to the temperature of the concrete, the ambient temperature, the wind, and relative humidity; therefore, the concrete should be placed and consolidated as soon as possible. After the quantity of water proportioned for the mix has been mixed into the concrete, retempering--the addition of more water--should never be attempted unless you are willing to

accept the resulting loss of strength and durability and increase in cracking and shrinkage. Do not control your concrete on slump alone; make certain that the W/C ratio is not exceeded if you want quality concrete. Maximum time periods between mixing and placing are not technically desirable. If the concrete is workable and has not been re-tempered, it should be acceptable.

Uniformity of the concrete is very important for hot-weather concreting. This includes uniformity of temperature of the ingredients, mixture proportions, quantities of ingredients, mixing time, W/C ratio, and air content. Some of the other conditions which should be uniform include: delivery time, placing time, finishing, curing, and protection. The use of a retarder normally allows greater flexibility in the uniformity of these conditions. The greater the uniformity, the fewer the problems encountered and the better the quality obtained.

Frequent air-content tests should be made. Too often a slump test may come up low and water is mistakenly added when the mixture really needed additional air entrainment.

Inspection After Concreting

Young concrete needs tender loving care, especially during extreme weather conditions. This care is not complete immediately following placement and finishing. As mentioned above, you may want to insulate the surface during reduced evening and nighttime ambient temperatures. Curing is one of the most important yet ignored phases of concrete construction. Under hot-weather conditions concrete can dry very rapidly and shrinkage cracking can result. If moisture is driven out and not replaced, the concrete can become dormant and stop acceptable strength gain. Cement requires moisture to hydrate and grow stronger. Normally the mix water is ample moisture for the hydration process; but during hot arid weather, especially in the case of thin concrete sections, this moisture may evaporate and not be available to the cement.

Conclusion (Hot Weather)

1. Do a good job of quality control.
2. Anticipate problems.
3. Plan to alleviate these problems.
4. Obligate yourself to a good evaluation program.
5. Use a mixture proportioned for the hot weather and other ambient conditions.
6. Assure uniformity of concrete, mixing, delivery, placement, finishing, curing, and protection.

QUALITY CONTROL DURING COLD WEATHER

During the previous two sessions, we have discussed construction quality management and quality control during hot weather. Many of the statements made in those discussions are also appropriate for cold-weather concreting. Uniformity of concrete and its surroundings are very important and cannot be over-emphasized. Good quality control establishes good uniformity; without uniformity, the product is out of control. During the introduction, we defined cold weather as "a period when for more than 3 successive days the mean daily temperature drops below 40 F (4.5 C)." As you can see, the temperature does not need to be below freezing for us to be concerned with cold-weather concreting. The concern for safety is much greater during cold weather because concrete does not gain strength as rapidly in cold weather as it does in warmer weather. Cold weather is an ideal time to place concrete if the work is adequately controlled and protected. The ultimate strength of concrete placed during cold weather, not permitted to freeze, and allowed to gain strength slowly, exceeds the same concrete exposed at higher temperatures (see Figure 3).

As in hot weather, good quality control includes the preparatory, initial, and follow-up phases of inspection; in other words:

Plan ahead. Check with the weather bureau to obtain the latest forecasts for temperature, relative humidity, and wind velocities.

Be prepared. Make sure all necessary materials and equipment are on hand to prevent delays during mixing, transporting, placing, finishing, and protection.

Be concerned. Anticipate potential problem areas; make certain that the batching plant is prepared for winter; think about what needs to be done.

Schedule work. Establish the work schedule to take advantage of warmth during the daytime and insulate before evening.

Instruct and assure. Instruct the foremen and workmen on how the concrete has to be controlled and protected. Assure by personally delegating inspection responsibilities that the concrete is being controlled as you have instructed.

Test Specimens

There are normally two purposes for fabricating and testing specimens for strength during the cold weather. These are: (1) to verify that the mixture used has the ability to obtain the designed strength and (2) to determine the strength of the in-place concrete. Specimens made for each of these purposes should be fabricated as required in ASTM C-31, "Standard Method of Making and Curing Concrete Test Specimens in the Field." As we know, concrete exposed to low temperatures does not gain strength as rapidly as concrete exposed at higher temperatures; therefore, the in-place strength is very important. Cold-weather exposure extends for safety purposes the period of time required before form removal. In my estimation, strength-test results of small specimens stored at the project site in the same temperature environment as a large placement are not representative of the strength of the in-place concrete. The temperature effect on small specimens is much greater than on the larger in-place concrete structure. If you were placing 6-in. (150-mm) diameter columns, the 6-in. (150-mm) diameter test specimen would be representative. A few organizations measure the temperature of the in-place concrete and control the temperature of the test specimen accordingly. If this procedure is followed, the strength of the test specimen should be representative of the strength of the in-place concrete.

Maturity Concept

The recently published ACI 306 Committee Report on Cold Weather Concreting introduces the strength-maturity factor relationship, which is rapidly being accepted as a means of quality control for establishing the in-place strength of the concrete. Basically, the maturity concept compares the temperature-and-time relationship of the in-place concrete to an equivalent relationship for a laboratory-cured specimen (see Figure 4). This relationship has been established by the use of a maturity factor, M , expressed as

$$M = \sum (C+10) \nabla t$$

where

C = temperature, deg C

∇t = duration of curing at a particular temperature C , in hours.

The 10 represents -10 C, the temperature at which cement normally stops hydrating. Critical to this concept is the location of the temperature-measuring devices in the structure. It is my recommendation that such devices be placed on the surface of the concrete immediately inside the forms, or on an exposed surface. Equipment is available which will provide a running total of the maturity factor ($\sum (C+10)\nabla t$).

Additional quality control measures include the normal slump and air content tests, and they should be performed on the concrete at the time of placement and as discussed in the hot weather section of this document. Again, it is very important to measure and record the temperature of the as-placed concrete. The ACI Committee Report on Cold Weather Concreting recommends minimum concrete placing and maintenance temperatures for various structural section thicknesses; these are:

<u>Section Size</u> <u>Minimum Dimension</u>	<u>Minimum Concrete Temperature</u> <u>As Placed and Maintained</u>
< 12 in. (300 mm)	55 F (13 C)
12-36 in. (300-900 mm)	50 F (10 C)
36-72 in. (900-1800 mm)	45 F (7 C)
> 72 in. (1800 mm)	40 F (5 C)

Please do not use these exact figures in project specifications: concrete should not be rejected if it varies from these temperatures. Instead, these temperatures should be established as control points. A concrete temperature within ± 10 F (6 C) of those shown above is sufficient for good control.

Temperature Records

Good QC of cold weather concreting operations is never complete without continuous records of temperature. The temperature records should include the following:

- (1) Periodic accounting of temperatures of all ingredients.
- (2) Temperature of concrete after mixing (normally about 2 minutes or so following mixing).
- (3) Temperature of concrete as placed.
- (4) Either a periodic or continuous accounting of the temperature of concrete at the surface of placement (exposed surfaces or below forms).
- (5) Continuous recording of ambient temperature at the project site.

These records should be maintained as diligently as you maintain your strength-tests reports because they are just as important. They should also include the date and hour, as well as the other weather conditions (calm, windy, clear, cloudy) present. Temperature-measuring devices embedded in the concrete surface are ideal, but satisfactory accuracy and greater flexibility may be obtained by using a normal pocket thermometer. This temperature history should be included in the permanent records for the project.

Insulation

One of the most important phases of quality control is to assure the adequacy of insulation. Table 1 is one of the insulation tables extracted from the ACI Committee Report on Cold Weather Concreting. It establishes the insulation requirements for various thicknesses of walls or floor slabs above ground when exposed at various ambient temperatures. For example, if your wall thickness is 12 in. (300 mm) and your concrete has a cement content of 500 lb/cu yd (296 kg/m³) and the lowest ambient

temperature is expected to be 18 F (-8 C), according to the table you will need to use an insulation with an R value of 4 (0.70). Table 2 gives us the thermal resistance, R value, for each 1-in. (25-mm) thickness of various materials. From Table 2, we can see that one of the solutions to our example problem would be the use of 1-in. (25-mm) plywood forms plus about an inch of mineral fiber blankets. Figure 5 is a graphical presentation of Table 1. From a QC standpoint, it is necessary to assure that the insulation necessary to shield the concrete during the protection period is provided and that the corners and edges have ample overlaps. If you are unwilling to provide insulation and the extra care needed to do a good quality job during cold weather, you should not be placing concrete during that period of the year: lives are too precious, and inadequate winter protection invariably costs lives.

SUMMARY

1. Very little concrete is ever placed under ideal laboratory conditions.
2. Concrete should be proportioned for the conditions under which it will be placed.
3. Hot weather concrete should be protected from high temperature, low humidity, and wind.
4. Concrete placed at relatively high temperatures should be protected from rapid cooling, especially during late summer.
5. Concrete placed at relatively low temperatures has the ability to gain higher ultimate strength than concrete placed at high temperatures.
6. Temperature-measuring devices should be used frequently, especially during hot and cold weather concrete construction.
7. It may be feasible and economical to insulate concrete even during warm weather, especially during relatively cool nights.
8. It is very important to test concrete in such a way that the tests results are representative of the in-place concrete.
9. Quality control which does not include the preparatory phase is insufficient.

10. Using the preparatory phase without the initial and follow-up phase is also insufficient.

11. Concrete needs to be handled with tender loving care.

12. Concrete is almost human and if controlled thusly will always perform as intended.

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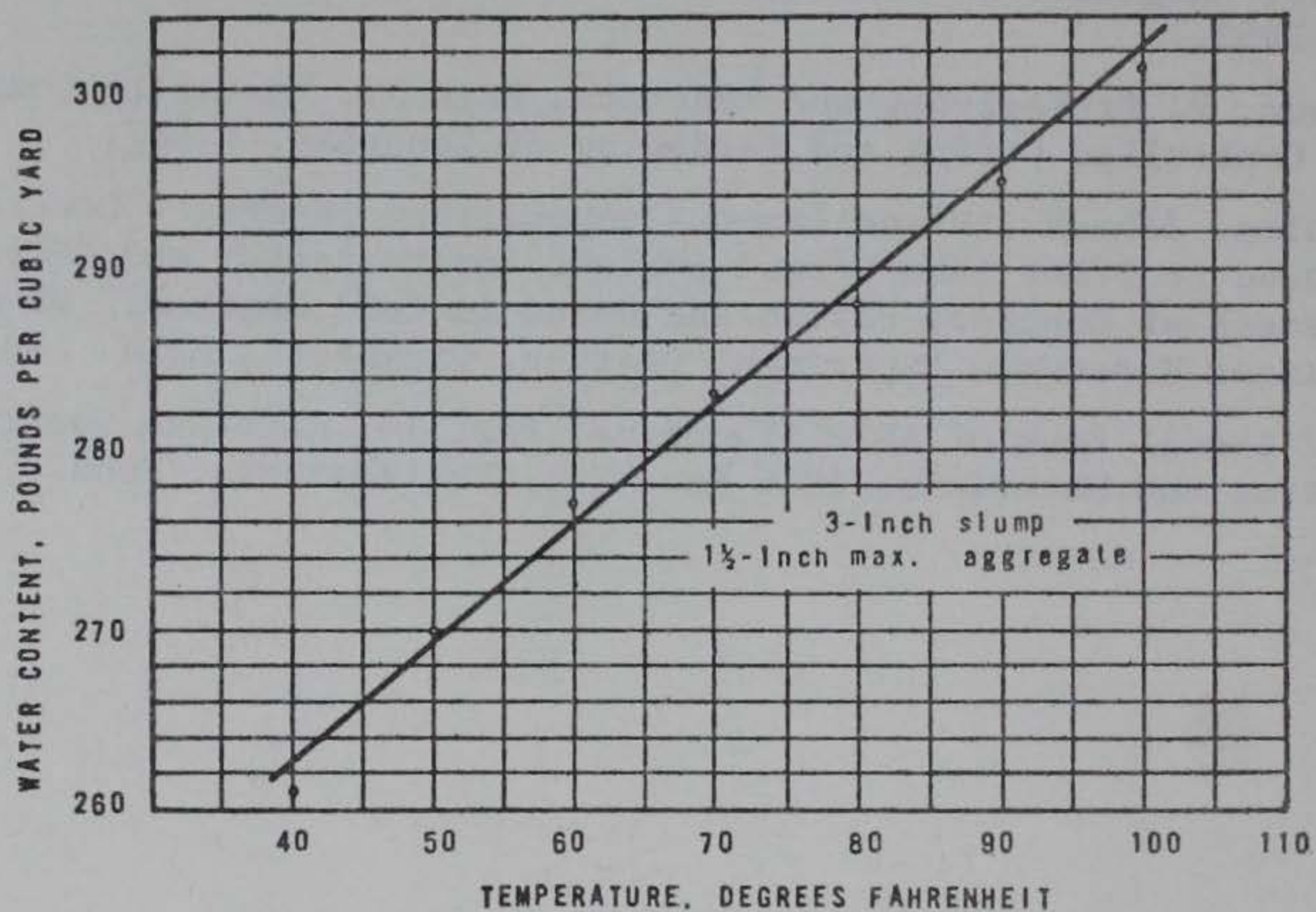


Fig 1. —Water requirement for a typical concrete mix as affected by temperature. The increase of water content accounts in part for greater shrinkage of concrete that is mixed and cured at high temperatures. 288-D-2653.

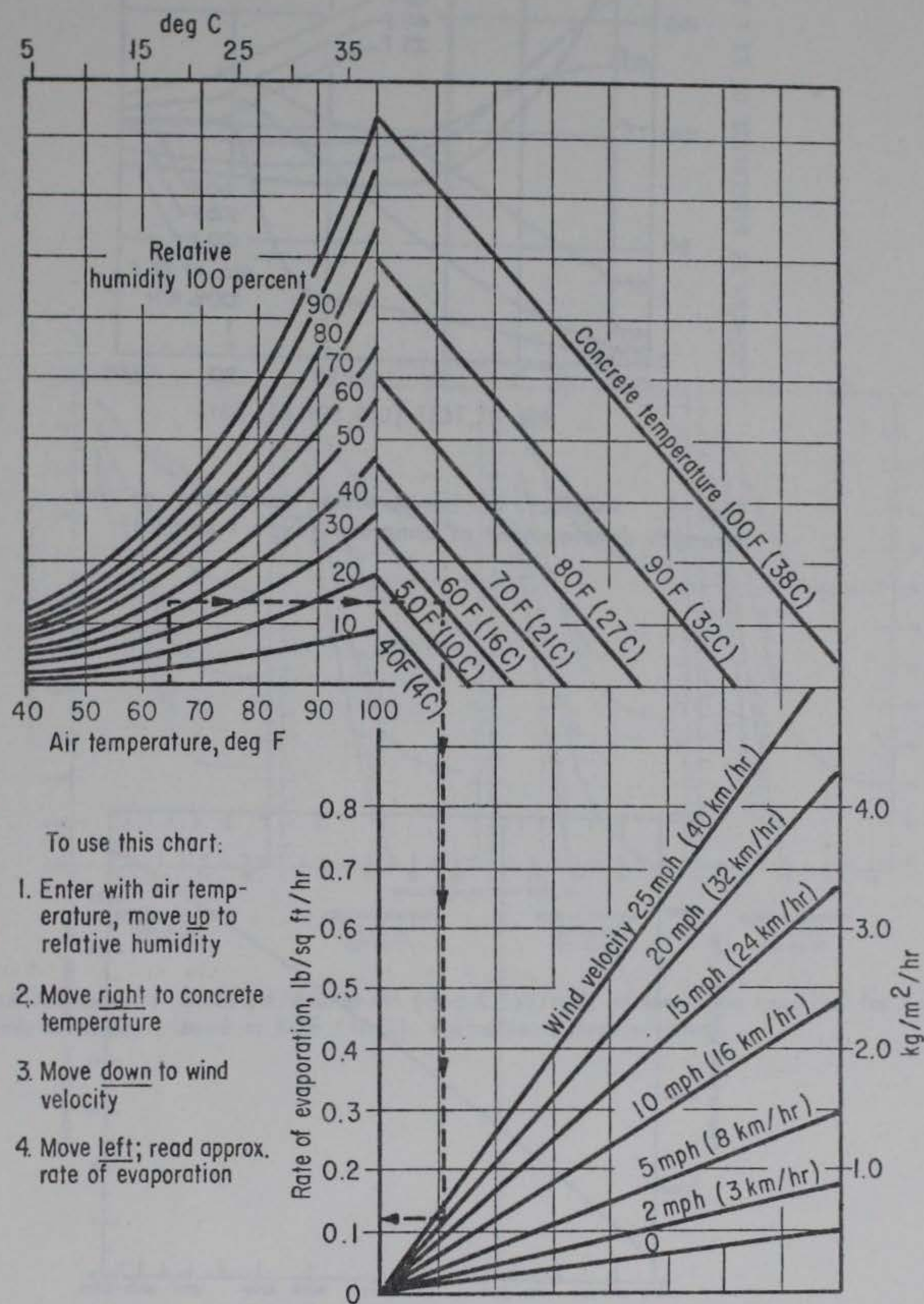


Fig. 2. —Effect of concrete and air temperatures, relative humidity, and wind velocity on the rate of evaporation of surface moisture from concrete. This chart provides a graphic method of estimating the loss of surface moisture for various weather conditions. To use the chart, follow the four steps outlined above. If the rate of evaporation approaches 0.2 lb/ft²/hr (1.0 kg/m²/hr), precautions against plastic shrinkage cracking are necessary.

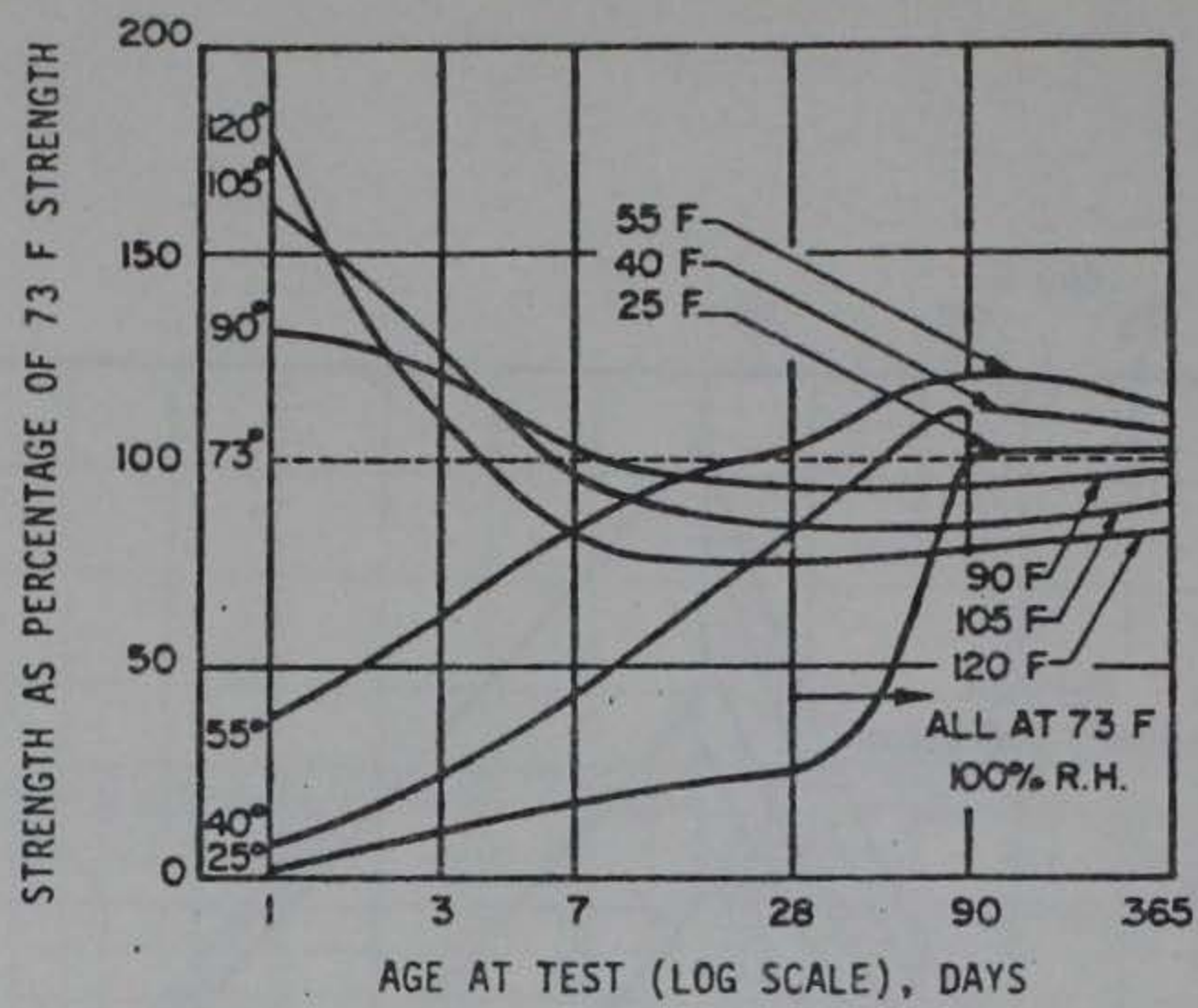


Fig. 3. —Effect of temperature conditions on the strength development of concrete (Type I cement)

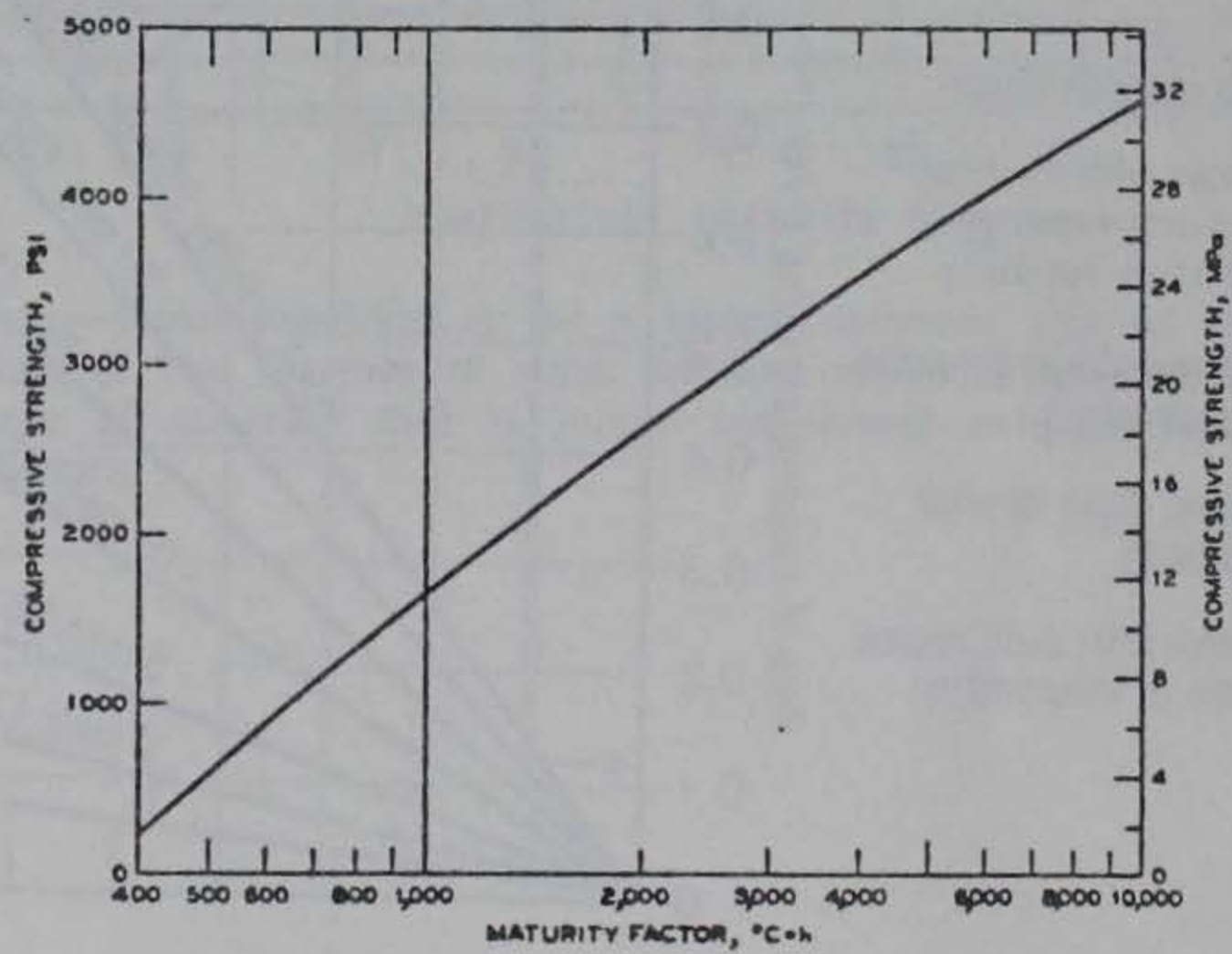


Fig. 4. —Strength-maturity factor relationship for laboratory cured cylinders (22.8 C)

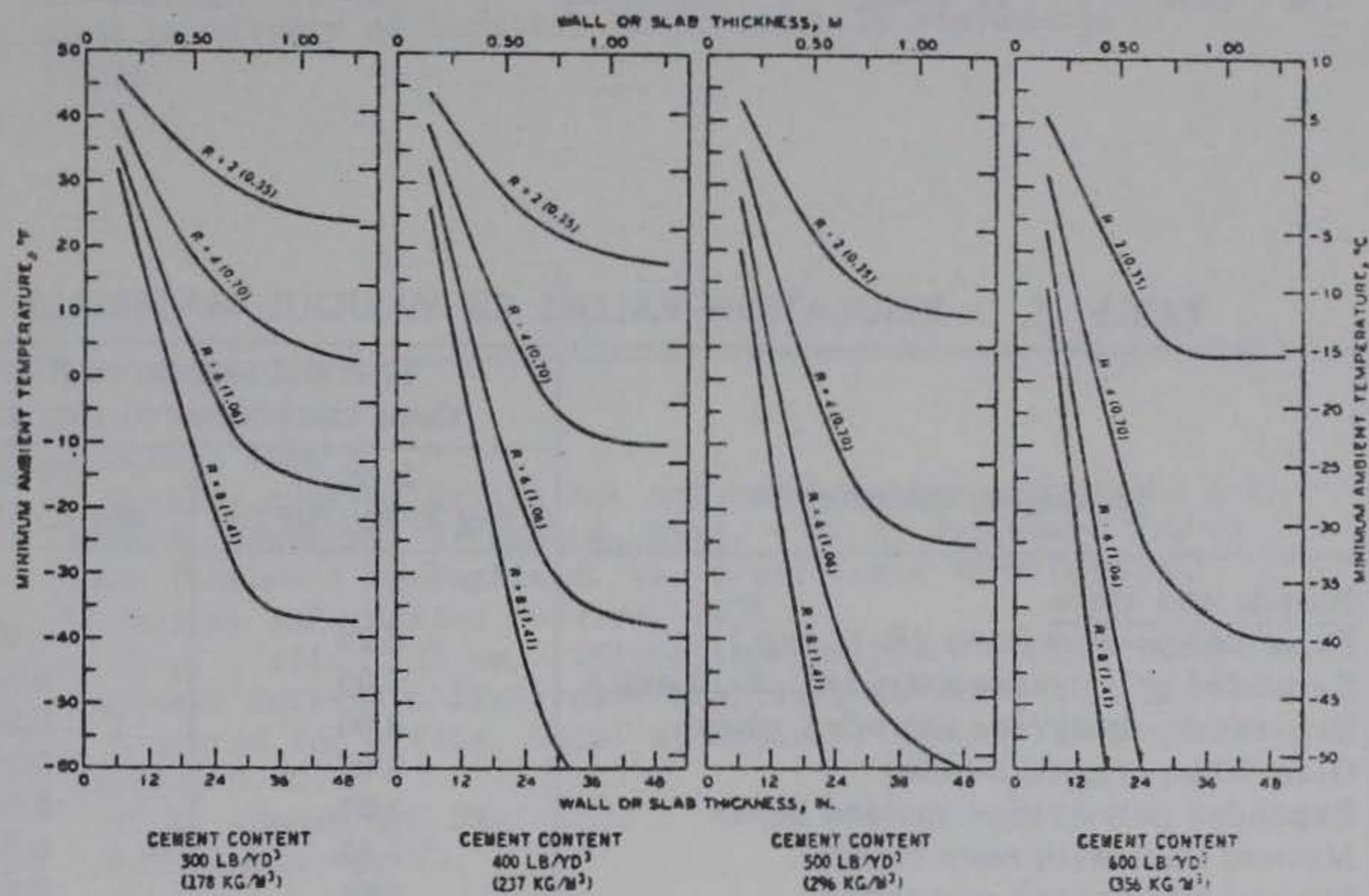


Fig. 5. Thermal resistance R , in deg F/Btu/hr ft² (deg C/W/m²), of insulation required for concrete walls and slabs above ground. Concrete placed at 50 F (10 C). Protection 3 days minimum

TABLE 1. —THERMAL INSULATION PROVIDED FOR CONCRETE WALLS
AND SLABS ABOVE GROUND

Concrete placed at 50 F (10 C). Protection 3 days minimum

Wall or slab thicknesses, in. (m)	Minimum ambient air temperature, deg F (C) allowable when insulation having these values of thermal resistance R deg F/Btu/hr ft ² (deg C/W/m ²), is used			
	$R = 2$ (0.35)	$R = 4$ (0.70)	$R = 6$ (1.06)	$R = 8$ (1.41)
Cement content = 500 lb/yd ³ (296 kg/m ³)				
6 (0.15)	43 (6)	35 (2)	28 (—2)	20 (—7)
12 (0.30)	34 (1)	18 (—8)	3 (—16)	—12 (—24)
18 (0.46)	25 (—4)	2 (—16)	—21 (—29)	—44 (—42)
24 (0.61)	18 (—8)	—10 (—23)	—38 (—39)	—68 (—56)
36 (0.91)	12 (—11)	—23 (—31)	—60 (—51)	*
48 (1.2)	10 (—12)	—25 (—32)	*	*
60 (1.5)	10 (—12)	—25 (—32)	*	*

TABLE 2. —INSULATION VALUES OF VARIOUS MATERIALS

Insulating material	Thermal resistance R for these thicknesses of material*	
	1-in., deg F/Btu/hr ft ²	10 mm, deg C/(W/m ²)
<u>Boards and slabs</u>		
Expanded polyurethane (R -11 exp.)	6.25	0.433
Expanded polystyrene extruded (R -12 exp.)	5.00	0.347
Expanded polystyrene extruded, plain	4.00	0.277
Glass fiber, organic bonded	4.00	0.277
Expanded polystyrene, molded beads	3.57	0.248
Mineral fiber with resin binder	3.45	0.239
Mineral fiber board, wet felted	2.94	0.204
Sheathing, regular density	2.63	0.182
Cellular glass	2.50	0.173
Laminated paperboard	2.00	0.139
Particle board (low density)	1.85	0.128
Plywood	1.25	0.087
<u>Blanket</u>		
Mineral fiber, fibrous form processed from rock, slag, or glass	3.23	0.224
<u>Loose fill</u>		
Wood fiber, soft woods	3.33	0.231
Mineral fiber (rock, slag, or glass)	3.12	0.216
Perlite (expanded)	2.70	0.187
Vermiculite (expanded)	2.27	0.157
Sawdust or shavings	2.22	0.154

*Values from ASHRAE Handbook of Fundamentals, 1972, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, New York.