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TEXAS AGGREGATES & CONCRETE ASSOCIATION

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Guidelines for Concrete Used in Residential Foundations in Texas

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The Texas Aggregates and Concrete Association (TACA) created Guidelines for Concrete Used in Residential Foundations on September 1, 2006, with an effective date of January 1, 2007. TACA began this work in 2003. This effort grew from the request of many Association members for a unifying document that could adequately address municipal responses to residential litigation, a general lack of clarity among specifying agents or agencies on the intricacies surrounding concrete specifications, and the general inconsistency and confusion surrounding performance based residential foundation specifications. Many Producers, Contractors, and Suppliers expressed the opinion that technical guidelines should be created by TACA where the actual experience and practical expertise is located. The goal of the guidelines is to provide the engineering, contracting, and specifying community with guidance on concrete materials aspects in their design and evaluation of residential foundations.

The committee for development of the Guidelines was composed entirely of TACA members, many of whom are licensed engineers. The dollar value of the professional services donated to the effort is conservatively estimated to exceed $100,000 with a combined industry experience level exceeding 350 years.

The Guidelines are not intended to be Standards, but are guidelines only, reflecting the opinions and practices of the committee members. They in no way replace the basic need for good and practical engineering judgment based on appropriate education, experience, wisdom, and ethics in any particular application. Thus, they are primarily suited as an aid for and use by engineers, contractors, municipal agencies, and the specifying community.

Referenced Documents

American Society for Testing and Materials (ASTM)[1]

ASTM C31/C31M-03a Standard Practice for Making and Curing Concrete Test Specimens in the Field

ASTM C39/C39M-05 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C42/C42M-04 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

ASTM C94/C94M-07 Standard Specification for Ready-Mixed Concrete

ASTM C125-06a Standard Terminology Relating to Concrete and Concrete Aggregates

ASTM C803/C803M-03 Standard Test Method for Penetration Resistance of Hardened Concrete

ASTM C805-02 Standard Test Method for Rebound Number of Hardened Concrete

ACI International[2]

ACI 301-05 Specifications for Structural Concrete

ACI 305R-99 Hot Weather Concreteing

ACI 306R-88 (02) Cold Weather Concreteing

ACI 306.1 Standard Specification for Cold Weather Concreting

ACI 308R-01 Guide to Curing Concrete

ACI 308.1-98 Standard Specification for Curing Concrete

ACI 318 Building Code Requirements and Commentary

ACI 332-04 Requirements for Residential Concrete Construction and Commentary

ACI 332R Guide to Residential Cast-in-Place Concrete Construction

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[1] For additional information or to download these specifications, please go to www.astm.org.

[2] For additional information or to download these specifications, please go to www.concrete.org

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Chapter 1

1.0 Concrete in Residential Foundations

Introduction and Overview

The purpose of this document is to provide a practical approach to specifying concrete mixtures pertinent for use in residential foundations. A quality residential foundation is the primary goal. However, practicality in construction and economic reality are also critical elements when establishing requirements for residential construction. To accomplish these three goals, the document is broken down into four main sections: Designer Qualifications, Design Criteria, Design Verification, and Curing.

As you review this document, bear in mind that it is designed to integrate with the most current concrete industry standards and technology. The majority of design professionals have only a cursory knowledge of concrete mixture technology. While many have been "specifying" concrete for numerous years, very few have a more intimate knowledge of the details of the mixture proportioning and production processes that impact those self same specifications for residential foundations. Some specifiers and/or designers may have an advanced knowledge of the concrete. While technology is a key element in producing high quality concrete, the final result is a combination of both quality materials and construction methods. To that end, sections discussing Design Criteria and Design Verification will also discuss placement, finishing and protection methods necessary to achieve maximum performance from the concrete.

While there is no guarantee that any concrete used in a residential foundation will perform to 100% of its design and function as intended by the specification, the attempt to achieve these results is always the goal. If the goal is to increase the level of quality by improvement both in materials and methods, certain changes to the process will have to be made. Some of the more traditional and legacy industry practices have brought the industry to the point where it has become necessary to create such a document for its own protection and improvement.

Chapter 2

2.0 Designer Qualifications

Introduction and Overview

The purpose of this section is to list qualifications necessary for the individual responsible for designing a residential foundation. The requirements that follow are intended as minimums. A builder, specifying agency, or municipality may require additional qualifications.

2.1 Minimum Qualifications

2.1.1 All residential foundations should be designed by a currently licensed Professional Engineer in the State of Texas.

2.1.2 Design engineer should carry a minimum of $1,000,000 Errors, Omissions, and Liability policy.

2.1.3 Design engineer should be identified as Engineer of Record for documentation purposes.

Chapter 3

3.0 Design Criteria

Introduction and Overview

The purpose of this section is to list the minimum design criteria for a concrete residential foundation. The minimum design requirements are performance based. Prescriptive requirements are often in direct conflict with the purpose of improving levels of quality in both construction methods and material supply. Testing methods for verification are included in Chapter 4.0.

3.1 Minimum Design Criteria

3.1.1 The Engineer of Record should furnish to the governing municipality, specifying agency, or builder, a letter stating:

3.1.1.1 Address, lot, block, & sub-division.

3.1.1.2 The reference number of the geotechnical report used to determine the foundation design. Criteria should include necessary data, including but not limited to PVR, PI, swell, and soil bearing capacity.

3.1.1.3 The builder has engaged the Engineer of Record to design the structure and write project specifications for the requirements of concrete, including inspection and testing requirements in accordance with local building codes. Testing should be in accordance with pertinent ASTM standards.

3.1.2 The Engineer of Record should submit a written report of the foundation inspections and applicable verification tests of the design performance requirements to the governing municipality, specifying agency, builder, or owner, when necessary.

3.1.3 The Engineer of Record should specify the curing methods and protection methods (see Chapter 5.0) for the ambient conditions at the time of placement. Guidance on curing procedures are covered in ACI 308R, ACI 308.1 and guidance on protective measures in hot and cold weather construction are covered in ACI 305R, ACI 306R. The EOR should ensure adherence to standard curing procedures for concrete test specimens in accordance to ASTM C31.

3.1.4 The Producer supply concrete in accordance with ASTM C94.

3.1.5 Compressive strength requirements should be based on the following performance minimums for residential foundations[3]:

Limit (Day)	Post-Tensioned	General Reinforcement[4]
Partial stressing of post tension cables	As specified by design engineer[5]	N/A
Full stressing of post-tension cables	As specified by design engineer[2]	N/A
28	3000 psi	3000 psi

Table 3.1 Residential foundation compressive strength performance minimums[6],[7].

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[3] A 28-day specification is an incomplete specification. Many of the residential house foundations in Texas use post tension cable reinforcement systems. This type of reinforcement can require compressive strength requirements before 28 days. Performance specification of the strength required in the time frame required for partial stressing, and full stressing is essential in designing performance concrete. For this purpose the performance requirements reflect the additional time and strength requirements.

[4] If early age strength is required, this need to be explicitly specified by the Design Engineer of Record, i.e. 2000 psi in 7 days minimum before loading occurs.

[5] The Engineer of Record needs to explicitly specify the strength value at what age, i.e 2000 psi in 7 days for full stressing

[6] Compressive strengths are based on concrete that has been sampled and tested according to ASTM C31, C39 (which includes proper initial curing between 60F and 80F, if this is not performed, the test results will be invalid and result in additional costs for in-situ testing.),

[7] Engineer of Record may specify additional compressive strength requirements for design purposes.

3.2 Prescriptive Specifications to Avoid

3.2.1 **Maximum slump or slump limitations**. With current technology, slump of concrete is not an indicator of the quantity of water in the mix. Slump of concrete can be varied significantly with the use of chemical admixtures, and supplementary pozzolanic materials. The project specification should not place limitations on slump as this will restrict proper constructability. Further it limits the use of innovative technologies like self consolidating concrete. (Note that these are recommendations and not code requirements)

The use of a slump test will only indicate consistency from load to load, or the movement of concrete under its own self weight. Workability concerns are an issue for the Contractor during placement. Depending on the formwork, slopes, and placement techniques, the slump can vary widely on any given job. As long as the performance requirements are met, limitations on slump are unnecessary and irrelevant.

3.2.1 **Limitations on water addition at the jobsite.** The Contractor is responsible for achieving the performance requirement set forth by the Engineer of Record. As such, water addition on the job site to facilitate required workability becomes the responsibility of the Contractor. The resulting impact to other specified performance properties also becomes the responsibility of the Contractor. Explicit specification of performance properties will guarantee results in the field, prescriptive specifications are no guarantee of performance and might likely detract from quality construction.

While additions of water have historically been linked to decreases in concrete performance, with the use of admixtures and supplementary pozzolanic materials, it is possible to design concrete to minimize the requirements for job site addition of water. As a consequence, the relationship between water addition and decreasing performance may not be as direct.

However, this does not relieve the Contractor of their responsibility to provide concrete that meets the performance specifications from the Engineer of Record. Additionally, this does not mean that the addition of water at the jobsite cannot cause harm and means should be taken to ensure that the quantity added does not exceed that required as per the concrete mix design.

Water addition at the jobsite is necessary for a variety of reasons and should be done with full knowledge that the addition of water will impact the performance of the concrete. The final impact cannot be determined by knowing the volume of water that was added.

3.2.3 **Cementitious content minimums or supplementary pozzolanic material replacement limitations.** As this document is based on performance standards, it would seem contradictory to use/specify minimum cement content or maximum supplementary pozzolonic replacement. With an optimized combination between cement, admixtures, and supplementary cementitious materials, multiple performance objectives (strength, permeability, workability retention, shrinkage, etc.) can be obtained. Minimum cement content does not necessarily guarantee any performance parameter; it only guarantees a minimum cost per yard.

3.2.4 **Water to cementitious materials ratios (w/cm) have long been associated with strength and durability.** Unfortunately, a w/cm limit is no guarantee of either. Even though the durability of a structure is proven by its longevity in service, there are other performance parameters that can be used to predict durability. Specification of performance parameters related to durability (shrinkage, permeability, durability factor) increases the potential for longer service life.

Specification of w/cm limit only increases the restrictions on mix designs, eliminates innovation, and ultimately results in higher costs without direct links to improved or actual performance.

However, it should be noted that several building codes will include a maximum limit on w/cm with regards to chemical attack, etc. Please be sure to check the direct applicability of these codes and required w/cm for these specific cases.

3.2.5 **Maximum concrete temperatures.** ACI 305 Hot Weather Concrete is generally referenced as the guidelines for use of concrete during hot weather conditions and is referenced in almost all commercial specifications. In Section 2.3.1, it states,

> *"In the more general types of hot weather construction (as defined in Section 1.2), it is impractical to recommend a maximum ambient or concrete temperature because the humidity and wind speed may be low, permitting higher ambient and concrete temperatures. A*

> *maximum ambient or concrete temperature that will serve a specific case may be unrealistic in others."*

Section 3.2.1 goes on further to state,

> *"Concrete can be produced in hot weather without maximum limits on placing temperature and will perform satisfactorily if proper precautions are observed in proportioning, production, delivery, placing, and curing."*

However, this has not prevented many specifiers, engineers, and architects from using 90°F as a limit for concrete temperature. This is a misinterpretation of ACI 305. There is no graph, table, chart, or statement within ACI 305 that shows that a limitation of concrete temperature exists at 90°F. This value stems back from an earlier definition of when "hot weather" conditions were thought to exist, i.e. when the ambient temperature goes above 90°F hot weather conditions exist, and certain precautions should be taken.

The ACI 305 document does not support a maximum temperature specification, and gives clear and suggestive guidelines on numerous precautionary measures that should be taken under hot weather conditions, but there is no upper limit of recommend concrete temperature within ACI 305. Any attempt to claim otherwise is incorrect. The 90°F temperature specification is arbitrary and NOT based on the ACI 305 guidelines.

However, some specifiers will reference ACI 301 Section 5.3.2.1.c that states,

> *"The temperature of concrete as placed shall not exceed 90F unless otherwise permitted. Loss of slump, flash set, or cold joints due to temperature of concrete as placed will not be acceptable. When temperature of concrete exceeds 90°F, obtain acceptance, when required, of proposed precautionary measures."*

Or ACI 301 Section 4.2.2.7, which states,

> *"Unless otherwise specified or permitted, the temperature of concrete as delivered shall not exceed 90°F."*

What is unclear is where the authority lies for the acceptability of concrete whose temperature exceeds 90°F. In both parts of the standard, it clearly allows for the concrete temperature to exceed the 90°F limit as long as it is permitted. The challenge is to find the decision maker responsible to give that permission. For Residential Construction that responsibility could reside with the Engineer of Record, the Builder, or a Municipality. Ultimately, is should be the decision of the Owner or the Owners representative. Under no circumstances should this be the responsibility of the concrete producer or contractor.

The typical approach to reducing concrete temperature to this level or below is the use of ice as an ingredient in concrete. The use of ice represents an increased cost for the owner and the potential benefit is generally questionable relative to alternative mixture options or protective measures that can be utilized.

In many cases the addition of ice can reduce concrete temperature by a maximum of about 10°F, at a rather high cost per yard. Because the temperature reduction is so small, the actual benefits or perceived improvements to the performance of the in-place concrete does not actually exist. Often there are more effective and economical methods that may be employed to reduce initial concrete temperatures.

Finally, there is concern by some specifiers that the temperature of the concrete is really a discussion centered on the relationship between water demand and finishing. None of the referenced documents actually make that connection. The basic assumption is that temperature drives setting time and setting time drives water demand and finishing.

With the chemical technologies available (which are significantly less expensive than the use of ice) it is entirely possible to achieve a desired setting time in hot weather regardless of the concrete temperature. These options can also minimize the requirement to retemper concrete to maintain slump.

The Contractor is ultimately responsible for delivering a residential foundation that conforms to the performance specifications suggested in Table 3.1. As long as those performance specifications are met, the temperature of concrete at placement should not be an issue.

3.2.6 **Minimum concrete temperature.** ACI 306R Cold Weather

Concrete is generally referenced as the guidelines for use of concrete during cold weather conditions and is referenced in almost all commercial specifications. Table 3.1 in ACI 306R give the appropriate concrete and air temperatures for placement. Nowhere in this table is there any indication given that the ambient air temperature must be above a certain limit to produce or place concrete. In fact, Table 3.1 gives guidelines on concrete temperature at placement and to be maintained based on the ambient temperature and the thickness of the section, but does not limit whther or not concrete can be placed based on ambient temperature.

Therefore, as with maximum temperature, the burden is still upon the Contractor to deliver a residential foundation that conforms to the performance specifications suggested in Table 3.1. As long as those performance specifications are met, the temperature of concrete at placement should not be an issue.

3.2.7 **Use of a chloride based accelerator.** Use of a chloride-based accelerator should have approval of the Design Engineer of Record prior to use. Chloride based admixtures are the most effective and economical accelerating admixture for setting time of concrete and should be acceptable for use in plain concrete foundations and footings that do not have structural reinforcement. This situation is rare in Texas as the majority of residential foundations in Texas contain structural reinforcement.

3.3 Minimum Concrete Supplier Requirements

3.3.1 Ready-mixed concrete suppliers shall:

- Supply concrete from concrete plants and trucks certified by the National Ready Mixed Concrete Association (NRMCA) Plant Certification Program or equivalent;
- Have a current and valid air quality and storm water permit registered with the Texas Commission on Environmental Quality (TCEQ).

3.4 Minimum Concrete Finisher Requirements

3.4.1 At least one member of the concrete contracting crew finishing the concrete foundation being placed at the time should be a Certified Concrete Finisher in the American Concrete Institute Concrete Craftsman Certification Program.

3.4.2 If the structure is post-tensioned, at least one member of the crew should be certified as a Level 2 Superstructure Ironworker administered by the Post-Tensioning Institute.

Chapter 4

4.0 Design Verification

Introduction and Overview

The purpose of this section is to provide a listing of the non-destructive and destructive testing methods that can be used to verify the minimum performance standards outlined in Chapter 3.

4.1 Sampling and Preparing Specimens for Compressive Strength testing

4.1.1 ASTM C31 Standard Practice for Making and Curing Concrete Test Specimens in the Field

a.) This is for standard compressive strength cylinders sampled from the truck in the field. It should be noted that ASTM C31 Section 6.1 does allow for the use of 4x8 cylinders,

> *"For acceptance testing for specified compressive strength, cylinders shall be 6 by 12 in. [150 by 300 mm] or 4 by 8 in. [100 by 200mm]"*

b.) Particular attention should be paid to ASTM C31, Section 6.3 that states,

> *"The field technicians making and curing specimens for acceptance testing shall be certified ACI Field Testing Technicians, Grade I or equivalent. Equivalent personnel certification programs shall include both written and performance examinations, as outlined in ACI CP-1."*

And Section 10.1.2 which states,

> *"Immediately after molding and finishing, the specimens shall be stored for a period up to 48 h in a temperature range from 60*

> *and 80°F [16 and 27°C] and in an environment preventing moisture loss from the specimens."*

The testing technicians should ensure that there are adequate facilities at the jobsite to protect and store the strength test specimens in accordance to ASTM C 31. This includes a process by which the maximum and minimum temperatures the specimens are exposed to are recorded. One of the best ways for initial curing is to immerse test specimens in water that is maintained at the required temperature. The test specimens should be transported to the laboratory for subsequent curing in a moist room or immersion in lime water at 73°F for the remainder of the standard curing period.

<u>If curing procedures outlined in the ASTM C31 are not followed and verifiable, then the results from those cylinder tests should be considered invalid.</u>

4.1.2 Compressive strength cylinders (ASTM C31 and C39) are a standard method for evaluating concrete compressive strength. Full compliance with the standard is necessary to obtain accurate and valid results. This means complete curing, transport, and storage for the cylinders during the process.

Slump, air, unit weight, and temperature **must be taken** when the compressive strength cylinders are taken according to ASTM C31, Section 8.1, 8.2, and 8.3 specifically state,

> *"Slump- Measure and record the slump of each batch of concrete from which specimens are made immediately after remixing in the receptacle, as required in Test Method C 143/ C 143M.*
>
> *Air Content— Determine and record the air content in accordance with either Test Method C 173/C 173M or Test Method C 231. The concrete used in performing the air content test shall not be used in fabricating test specimens.*
>
> *Temperature—Determine and record the temperature in accordance with Test Method C 1064/C 1064M."*

4.1.3 According to ACI 318 Section 5.6.2.4 a valid strength test result is defined by the average of two cylinders tested at the designated age. A recommended complete set for verification will total 9 cylinders (3 for 7 day, 3 for 28 day and an additional 3 cylinders are for contingency or long-term verification.) This will allow for greater confidence in interpreting strength results.

4.2 Investigations

Investigations should follow logical sequence of possible causes and effects, before any action is taken, including:

a.) Analysis of all test reports, noting any patterns relating low strength to slump, air content, temperature, or field-curing information;

b.) Confirmation that results represent actual non-compliance with specification acceptance criteria;

c.) Verification of testing accuracy. Testing Laboratories should be held accountable for procedural deficiencies, and consideration should be given to discarding invalid or incomplete test data.

d.) Acknowledgement of ACI 318-reference in specifications[8], which provides allowances for non-destructive testing of concrete prior to coring.

4.3 Non-Destructive Testing

As noted in Item 5.6.5 of ACI 318 under Investigation of Low-Strength Test Results, two major reasons for low strength test results are:

a.) Improper handling and testing of concrete test specimens, which has been found to contribute to the majority of low-strength investigations; and

b.) Reduced concrete strength due to an error in production, the addition of too much water to the concrete on the job, or high air content.

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[8] Another reason is to protect all interested parties in that ACI Guidelines are nationally and legally recognized as industry standards of practice.

There are two commonly accepted test methods for in-situ strength evaluation that are non-destructive to the concrete being tested.:

ASTM C805 Standard Test Method for Rebound Number of Hardened Concrete

a.) Rebound Hammers are required to have accuracy verified by a 3rd party at least annually per ASTM C805. Indication of calibration should be indicated on testing device or accompany device to testing site.

b.) The results generated should be used to give indication of compressive strength at the sampled location, and not used for acceptance unless permission is granted from the Engineer of Record. This test is only good as a relative indicator where results on the questionable concrete are compared to those conducted on acceptable concrete.

ASTM C803 Standard Test Method for Penetration Resistance of Hardened Concrete (Windsor Probe)

a.) Energy level and hardness value of coarse aggregate must be determined prior to testing, as these will affect the interpretation of penetration readings;

b.) The results generated should be used to give indication of compressive strength within the structure, and not used for acceptance unless permission is granted from the Engineer of Record.

c.) Relationship between actual compressive strengths of cylinders or cores and penetration resistance of concrete cylinders or cores of similar concrete must be done prior to evaluation. Alternatively, relative evaluations comparing to acceptable concrete can be conducted

4.4 Destructive Testing

Core testing (ASTM C42) is a standard method to evaluate in-situ compressive strength. It is important to condition cores as described in ASTM C 42 to achieve a uniform moisture distribution as this will significantly affect the measured strength. ACI 318 5.6.4.4 outlines parameters for evaluation and analysis which states,

> *"Concrete in an area represented by core tests shall be considered structurally adequate if the average of three cores is equal to at least 85 percent of* ***f'*** $_c$ *and if no single core is less than 75 percent of* ***f'*** $_c$*."*

As an example, if the design strength (f'$_c$) is 3000 psi. No single core can be below 2250 psi, and the average of a core set of three cores must be greater than 2550 psi. If both of these conditions are met the strength of the concrete is considered to have met its design requirements.

ACI 318 5.6.4.4 uses this criteria for acceptance of cores, it originated from empirical research included in Delmar Bloem, "Concrete Strength in Structures," *ACI Journal*, March 1968, pp.176-187.

Chapter 5

5.0 Curing Methods

Introduction and Overview

The purpose of this Chapter is to provide a listing of curing methods that are applicable for both foundations and cylinders. These are not all of the methods or means available. These are the most practical and cost effective methods currently used. Alternate methods can be specified and are left to the discretion of the Design Engineer of Record. (Refer to ACI 308R and ACI 308.1 for curing)

5.1 Evaporation Control and Curing Methods

5.1.1 Evaporation retarders (also referred to as a mono-molecular film) are used on the surface of concrete to slow down the evaporation rate of moisture from the concrete. If rapid evaporation is allowed to occur, plastic shrinkage cracks may appear, or the surface may prematurely dry which leads to early finishing operations which can cause surface defects such as delaminating, blistering, or spotty setting which can cause the surface to be wavy or uneven.

Evaporation retarders should be applied between each finishing operation. Complete coverage with an adequate sprayer is necessary for this product to be effective. Once the surface of the concrete is disturbed with a float or trowel the evaporation retarder dissipates and needs to be re-applied. Once the finishing operation is completed, immediate curing should proceed.

5.1.2 Curing compounds (also referred to as liquid membrane-forming compounds) are used to reduce the loss of water during the early hardening period of concrete. There are several types of curing compounds available from Type 1, clear or translucent without dye, Type 1-D, clear of translucent with fugitive dye, or Type 2, white pigmented. There are also curing compounds that are manufactured to work for 4-6 weeks then start breaking down so they will not inhibit the bond of flooring materials such as tile or vinyl.

Type 2 white pigmented compound is typically used for sitework and paving because it is easy to see while applying so you can ensure that all concrete is getting the proper coverage rate and the white pigment reduces the temperature rise in concrete exposed to radiation from the sun.

Curing compounds can be sprayed, brushed, or rolled on. It should form a continuous film when applied at the specified rate of application. If a continuous film is not applied then the compound that has been applied is doing nothing. Curing compounds should be applied as soon as the water sheen disappears. Delaying the application could mean the difference between having cracks or not having cracked concrete. However, applying the curing compound while the concrte is still bleeding can lead to an inconsistent finish, as well as random variations in set characteristics.

5.1.3 Moist curing is the most preferred tried and true method, but is usually more labor intensive. Moist curing can be accomplished by ponding, spraying or fogging, and saturated wet coverings.

Ponding can be accomplished by constructing earthen dikes around the perimeter of the foundation to retain a pond of water. The ponding method could cause some staining or discoloration from the materials used to create the dikes.

Spraying or fogging can be accomplished through the use of lawn sprinklers or soaker hoses. The concrete must be prevented from alternate cycles of wetting and drying which could cause surface crazing or cracking.

Saturated wet coverings are probably the easiest and least messiest way to moist cure. The use of cotton curing blankets, burlap, burlene (burlap impregnated on one side with polyethylene), impervious paper, or plastic sheet materials. Caution should be used with burlap if it has not been used before because some burlap can cause discoloration. Thoroughly rinse burlap if it has not been used before. Plastic sheet materials can cause patchy discoloration especially if the film becomes wrinkled.

5.1.4 Thermal Curing. During cold weather concrete should be protected from freezing. This can be accomplished by leaving forms in place and covering the surface of the foundation with dry cotton curing blankets, polyethylene, or polyethylene with straw or hay on top. Failure to protect the concrete could result in significant damage to the foundation in the form of thermal shock.

5.2 Curing for Cylinders

5.2.1 If compressive cylinders are taken for strength verification, they must be stored and cured according to ASTM C39 Section 10.1.2 which states,

> *"Immediately after molding and finishing, the specimens shall be stored for a period up to 48 h in a temperature range from 60 and 80°F [16 and 27°C] and in an environment preventing moisture loss from the specimens."*

This means that a designated curing facility must be located on site, where the temperature within the facility is maintained between 60 and 80F. The cylinders after a period not to exceed 48 hours the cylinders must be transported to a laboratory curing environment (as outlined in ASTM C39).

If curing procedures outlined in the ASTM C31 are not followed and verifiable, then the results from those cylinder tests should be considered invalid.

In addition to the issues of non-compliance, there are other issues associated with curing temperature outside the specified range. Those impacts create lower strengths at both early and later ages[9].

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[9] Frank Kozeliski, "Curing Test Cylinders in Hot Weather." Concrete International, May 2005, pp 26-28