KIM – BEST PRACTICES GUIDE

Cast-in-place concrete

CONTENTS

1. OVERVIEW

This document is a summary of guidelines given by concrete authorities, such as the American Concrete Institute (ACI) and the Portland Cement Association (PCA), that are relevant to waterproofing structures using Kryton's Krystol Internal Membrane (KIM) Waterproofing System. Kryton has inserted additional instructions that are specific to using KIM successfully. The instructions given by ACI and PCA should be followed on all construction projects. The additional instructions given by Kryton should be followed on all KIM projects. On projects that have been approved for the Krystol Assurance Program, strict adherence to this guide is mandatory.

IMPORTANT: You are using the KIM system to make a waterproof membrane out of the concrete. This is different from traditional construction where the concrete forms the structure only. The KIM concrete you are placing will be the only barrier to water penetration. This means that common defects found in typical concrete cannot be tolerated in KIM concrete. Poor consolidation, unplanned cold joints, cracks, penetrations, contaminations, etc. will all result in a leaking structure. To avoid leakage and achieve success you must follow the critical instructions outlined in this document.

NOTE: Instructions appearing in *blue italics* are taken directly from guidelines set out by ACI and the PCA. Sections in black text are supplementary requirements based on Kryton's firsthand knowledge and experience.

2. SCHEDULING

Kryton's KIM Waterproofing System will require alternate planning and scheduling considerations. The contract documents should specifically address the following items:

CONCRETE SUPPLY:
An on-site test pour should be performed to ensure that the concrete will meet the contractor's expectations for slump, air content, finishing properties and setting time. This step may be omitted if the concrete supplier and contractor have previous experience with a concrete mix containing KIM.

JOINT SPACING AND CRACK CONTROL:
An experienced engineer must review the project and, if required, recommend procedures to reduce and control cracking through the use of control joints, reinforcing or other appropriate measures. To control cracking, slabs may need additional reinforcement to limit crack widths to tolerable levels. Walls will usually need closer control joint spacing compared to typical construction to prevent random cracking.

FORMWORK:
Concrete forms must be designed and constructed to allow the Krystol Waterstop System to be installed and inspected at all specified joints and penetrations.

CURING:
Construction schedules must allow for adequate protection and curing of the concrete for 7 days or as specified.

FILLING JOINTS:
Construction schedules must allow joints to be left for 28 days before being filled to allow for initial concrete shrinkage to take place first before the final waterproofing materials are installed.

WATER TESTING:
Before the structure is put into service, a period of water tightness testing must be provided to identify leaking cracks and allow them time to self-seal. Typical self-sealing times are 2-4 weeks provided the cracks are continuously exposed to a source of water. If construction schedules do not allow for a sufficient period of self-sealing, the contract documents must include provisions to repair leaking cracks at an

earlier time. This is particularly important for water containment structures where extended periods of water testing prevent other construction operations from proceeding.

LEAK REPAIR:
Allow time to repair leaks using Krystol Leak Repair System before the structure is handed over. If an area will become inaccessible due to the installation of equipment (elevator, mechanical or HVAC equipment) the leak repair system should be installed to all cracks in that area, regardless of whether they are leaking or not. This will protect against future leaks and reduce difficulties with access.

COSMETIC PATCHING AND PAINTING:
Do not allow cosmetic patching and painting of concrete to proceed until all components of the KIM waterproofing system have been installed and inspected, including the leak repair system as required.

3. CONCRETE MIX DESIGN GUIDELINES

KIM is not a replacement for a well-proportioned concrete mix and good construction practices. Concrete mixes must be designed to meet all structural requirements and be suitable for the expected exposure conditions. This section outlines Kryton's recommended guidelines for designing a normal weight, reinforced concrete mix that will be waterproof and resistant to severe conditions, including continuous exposure to moisture, freezing and thawing, and chemicals such as chlorides and sulfates.

Unless otherwise noted, mix design guidelines are from ACI 201.2R (Guide to Durable Concrete), ACI 301 (Specifications for Structural Concrete for Buildings) or Design and Control of Concrete Mixtures published by the Portland Cement Association.

Table 1: Mix Design Guidelines

Property	Requirement
Total Cementitious Content	*Minimum 335 kg/m³ (565 lb./cu. yd.) - Portland Cement Association*
Portland Cement Content	Minimum 250 kg/m³ (420 lb./cu. yd.)
Supplementary Cementitious Materials (SCM) Content	*Portland Cement Association Adapted from ACI 318* *Fly Ash / Natural Pozzolans: Max 25%* • *Silica Fume: Max 10%* • *Slag Cement: Max 50%* • *Total SCM: Max 50%*
KIM Dosage	2% by weight of total cementitious content to a maximum of 8 kg/m³ (13.5 lb./cu. yd.) Dosage may be varied for specific projects in consultation with Kryton's Technical Services Department.
28 Day Compressive Strength	Minimum 27.5 MPa (4000 psi)
Air Content	*5-7% or as specified**
Water-Cement Ratio (based on total cementitious content)	*Max 0.45*

*Air content range is suitable for most exposure conditions and maximum nominal aggregate sizes up to 20 mm (0.75 in.) based on guidelines in ACI 212.1. Alternate air contents may be specified by the project engineer, when appropriate for the exposure conditions and selected aggregate size.

In some cases, it may be appropriate to use Portland cement contents, SCM contents, KIM dosages or water-cement ratios outside of the above guidelines. Consult with Kryton's Technical Services Department for project specific guidance.

4. PROPORTIONING STRUCTURAL CONCRETE

(ACI 301 – Specifications for Structural Concrete for Buildings / ACI 211.1 – Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete)

COARSE AGGREGATES:

- *To minimize shrinkage, the largest possible nominal maximum size should be selected that allows for proper consolidation and meets all other strength and workability requirements.*
- *Maximum nominal aggregate size shall not exceed:*
    - *1/5th the narrowest dimension between the sides of forms.*
    - *1/3rd the depth of slabs.*
    - *3/4th the minimum clear space between reinforcing bars.*

WORKABILITY & SLUMP:

The workability of concrete is of critical importance as it affects consolidation, voids, and structural integrity.

- *Appropriate slumps for concrete consolidated by vibration:*
    - *Minimum slump: 25 mm (1 in.)*
    - *Maximum slump:*
        - *Foundations, walls and footings: 75 mm (3 in.)*
        - *Beams and columns: 100 mm (4 in.)*
        - *Pavements and slabs: 75 mm (3 in.)*
        - *Mass Concrete: 50 mm (2 in.)*
- *Concrete of lower slump may be used if it is properly placed and consolidated and accepted by the general contractor.*
- *Admixtures should always be added separately. Adding admixtures at the same time can cause unwanted reactions.*
- *Chemical admixtures may be used for higher slumps provided the admixture treated concrete has the same or lower w/c ratio and does not exhibit excessive segregation or bleeding.*
- The most efficient use of superplasticizer can generally be achieved by adding the majority of superplasticizer after KIM is fully mixed into the concrete. This is usually accomplished by adding the KIM at the central batch plant, and adding superplasticizer on-site to adjust the slump immediately prior to placement. An initial dose of superplasticizer or other water reducing admixture may be used at the batch plant to aid with initial mixing as required. The ready mix producer should determine the optimal batching sequence based on previous experience or with a test pour.

    NOTE: *Excessive workability, whether achieved with unnecessarily high slump, over sanding, small aggregate, or even excessive air content (which may reduce strength), is always popular and in demand on the job. However, it must be discouraged if the best concrete for the work (i.e., having adequate workability, handling and vibration properties and having minimum shrinkage factors) is to be obtained. Slumps of greater than 100 mm (4 in.) are rarely needed excect for perhaps conditions of high temperature where slump and moisture are lost rapidly (ACI 224R – Control of Cracking in Concrete Structures).*

ADMIXTURE COMPATIBILITY:

Consult your Ready-mix Concrete Producer and/or Kryton International Inc. for information related to compatibility of admixtures with KIM concrete. Most superplasticizers and non-chloride accelerators are compatible with KIM concrete at the manufacturer's recommended dosages and are acceptable provided the Ready-mix Concrete Producer approves of their use.

Do not use admixtures that delay setting time with KIM without prior testing. For example, based on ASTM C494, admixtures that meet Type-B (set retarding) or Type -D (water reducing and set retarding) will often cause long set delays with KIM. These admixtures usually contain lignosulfonates which are known to cause long set delays. Instead, use water reducers that meet Type-A (water reducing) or Type-F (high range water reducing, or superplasticizing). These admixtures usually contain polycarboxylates, which provide more efficient performance with much less set delay.

Some regions use different admixture classifications. In Europe, avoid set retarding admixtures classified under EN 934-2 Tables 8 (set retarding, similar to Type B) and Table 10 (water reducing and set retarding, similar to Type D). Instead use admixtures that meet Table 2 (water reducing, similar to Type A) or Tables 3.1 and 3.2 (high range water reducing, similar to Type F).

Consult with Kryton Technical Services for further advice.

In very hot weather, for long delivery distances, it may be necessary to use a set retarding admixture with KIM to provide the required working time. Only use set retarding admixtures with KIM if prior testing shows they are needed.

5. CONCRETE FORMWORK

(ACI 347 – Guide to Formwork)

Formwork design and construction must be sufficient to support the concrete within the specified tolerances before and after placement until the concrete has gained sufficient strength to support itself. Shoring and reshoring must be employed at the direction of an experienced engineer to prevent overloading the structure during subsequent construction.

FORMWORK DESIGN AND CONSTRUCTION:

- *Forms must be able to withstand the lateral pressure of vibrated, liquefied concrete. Forms with external vibrators must also be able to withstand repeated stress of vibration, and be able to transmit the vibration uniformly over a large area.*
    - KIM may increase form pressure due to its plasticizing and set retarding properties. Care should be taken not to fill forms too quickly, or formwork should be constructed with sufficient strength account for the increased form pressure.
- *Forms must be mortar tight to prevent leakage that would otherwise lead to rock pockets or entrapped air. Forms should be sealed or caulked at the bottom to prevent mortar leakage during vibration.*
- *Formwork drawings must provide appropriate details for construction joints, contraction joints, expansion joints, waterstops, keyways, penetrations, etc.*
    - Formwork design must account for the installation and inspection of the Krystol Waterstop System.
- Ensure all form penetrations (form ties, pipe penetrations etc.) can be waterproofed and are compatible with the Krystol Waterstop System
    - For walls – do not use internal bracers or “form spreaders” that will fully penetrate the concrete or disrupt the waterstop.
    - For slabs – do not use metal mesh “stay-in-place” forms at construction joints. Water can migrate along the metal mesh and cause leaks. Use traditional, removable formwork.

PREPARATION:

- *Unless otherwise specified, before placing reinforcing steel concrete forms shall be coated with a suitable material to prevent absorption of moisture and prevent bond with the concrete. Excess coating material shall not stand in puddles in the forms or come in contact hardened concrete to which fresh concrete is to be placed.*
- *Removal of forms – Forms and shoring supporting forms shall be left in place until the concrete has reached the minimum specified strength for their removal or for 7 days as required for initial curing, whichever is greater.*

RESHORING AND BACKSHORING:

- *Reshoring and backshoring is one of the most critical operations in new construction, and must be planned well in advance and approved by the engineer/architect. All operations must ensure that the new construction is not imposed to loads in excess of its capacity as determined by the engineer/architect during form removal, reshoring and backshoring.*

NOTES FOR MULTISTORY STRUCTURES:

- *Multistory construction has special considerations due to the speed of construction and the desire to reuse formwork as quickly as possible on upper floors. Shoring for green concrete is necessarily supported by lower floors that may not be designed to support these loads. Therefore, shoring must be supplied for a sufficient number of floors to support the applied loads without excessive stress or deflection.*

6. CONCRETE JOINTS, WATERSTOPS, AND DEFECTS

(ACI 224R - Control of Cracking in Concrete Structures / ACI 504R – Guide to Sealing Joints in Concrete Structures, Design and Control of Concrete Mixtures – Portland Cement Association / ACI 301 - Specifications for Structural Concrete for Buildings, Design and Control of Concrete Mixtures – Portland Cement Association)

Joints, Embedded items and Control of Cracking in Concrete:

- *Cracking due to drying shrinkage is one of the most serious problems encountered during construction. Good design and construction practice can minimize the amount of cracking by the use of adequate reinforcement and contraction joints.*
  - *If a sizeable length or expanse of concrete, such as walls, slabs or pavements, is not provided with adequate joints to accommodate shrinkage, then it will make its own "joints" by cracking.*
  - *The use of contraction joints is the most effective method of preventing uncontrolled cracking in concrete elements, and allows cracking to be isolated to areas that can be conveniently repaired.*
  - It is particularly important to reduce or eliminate cracking when external waterproofing membranes are not being installed. Cracks in the concrete will cause immediate leaks that require corrective measures. Cracks that develop in predetermined joint locations can be repaired faster and at a reduced cost compared to uncontrolled cracking that develops in random locations.
- *Joints must be provided for at stopping places in concrete construction, or as needed to control and isolate cracking. Each job must be studied individually to determine where joints should be placed.*

CONTRACTION JOINTS (CRACK CONTROL JOINTS):

These are purposely made planes of weakness designed to regulate cracking that might otherwise occur due to the unavoidable, often unpredictable, contraction of concrete structural units. They are appropriate only when the net result of the contraction and any subsequent expansion during service is such that the units abutting are always shorter than at the time the concrete was placed. They are frequently used to divide large, relatively thin structural units, for example, pavements, floors, canal linings, retaining and other walls into smaller panels. Contraction joints in structures are often called control joints because they are intended to control crack location.

Contraction joints in walls can be made by fastening wood or rubber strips to the forms which leave narrow, vertical grooves in the concrete. Cracking should be isolated to the grooves, relieving stress on the wall and preventing uncontrolled cracking.

Contraction joints are recommended at all locations prone to cracking, such as abrupt changes in concrete height, thickness or direction. The following recommendations are a guide only and may not be suitable for all projects.

CONCRETE WALLS:

- Place crack control joints at a maximum spacing of 20 times the wall section thickness.
- Additionally, place joints should be provided at all abrupt changes in thickness or height, box outs and beam intersections, and within 3 meters of corners on either side
- See Kryton Application Instruction 4.14 - Waterproofing Horizontal and Vertical Control Joints
- Cracks will form more reliably within crack control joints if the reinforcement is designed to help induce a crack within the joint. This can be done by reducing the reinforcement passing through the joint, or but cutting up to 50% of the horizontal reinforcing at the joint. Seek the guidance and approval of the project's structural engineer to determine if this practice is suitable for your project. If bars are cut, ensure cuts are aligned with joint keyways, and tie all loose bar ends so they are secure.

SPECIAL CONSIDERATIONS FOR WATERPROOFING SLABS:

Cracking must be controlled for slabs. Unlike walls, slabs cannot be easily jointed to control cracking. To control cracking for slabs, follow these important guidelines:

1. Use a low shrinkage mix design. Use the largest aggregate size that is compatible with the reinforcement spacing, and use the lowest possible water content.
2. Include a shrinkage reducing admixture (SRA) or fiber reinforcement if possible.
3. Use fly ash or GGBS (slag) to reduce heat generation and reduce cracking from thermal expansion and contraction.

   NOTE: There must be enough reinforcement to control crack widths to less than 0.4mm. To achieve this, average crack width should be targeted at 0.2mm or less. This ensures the cracks stay within KIM's self-sealing tolerance. The engineer should design and reinforce the slab as a water retaining structure, because that is what it will be expected to do. This may require increasing the reinforcement compared to the minimums required by standard structural codes. Even though improving the reinforcement will increase the initial cost, this cost will be much less than the cost of repairing cracks later.

SLAB PLACEMENT:

1. Pour large slabs in square sections that are as small as possible and acceptable to the project's engineer.
2. Treat each construction joint as described in the next section.
3. Ensure slabs are well consolidated, especially at joint locations (see section of Consolidation)
4. Ensure slabs are properly cured (see section of Curing and Protection for Freshly Placed Concrete)

CONSTRUCTION JOINTS (STOPPING POINTS IN CONCRETE WORK):

Construction joints are made at the surfaces created before and after the interruption of concrete placement. Locations are usually predetermined by agreement between the engineer and contractor so as to limit the work that can be done at one time to a convenient size with the least impairment to the finished structure.

- *Joints not indicated on the contract documents shall be located and constructed to minimize the impact on the strength of the structure. Joint types and locations shall be acceptable to the architect/engineer.*
- *All reinforcement shall be continued across construction joints. Longitudinal keys at least 40 mm (1.5 in.) deep shall be provided in all joints in walls and between walls and slabs or footings. Other keys and inclined dowels shall be acceptable to the architect/engineer.*
- *The surface of the concrete at all joints shall be thoroughly cleaned and all laitance removed prior to placing adjoining concrete.*
- *Bond shall be obtained with one of the following methods:*
  - *The use of an acceptable chemical retarder which delays but does not prevent setting of the surface mortar. Retarded mortar shall be removed within 24 hr. after placing to produce a clean exposed aggregate bonding surface.*
  - *Roughening the surface of the concrete in an acceptable manner which will expose the aggregate uniformly and will not leave laitance, loosened particles of aggregate or damaged concrete at the surface.*
  - Surfaces should be roughened and Krystol Waterstop Treatment applied as per Kryton Application Instruction 4.11 - Waterproofing Horizontal Construction Joints - Internal Grout Method, 4.12 - Waterproofing Horizontal and Vertical Construction Joints - External Grout Method, 4.13 - Dampproofing Construction Joints, 4.14 – Waterproofing Horizontal & Vertical Control Joints, 4.15 – Waterproofing Construction Joints – Swellstrip Method, 4.16 - Waterproofing Horizontal & Vertical Control Joints – Triple Protection Method, as applicable.

EMBEDDED ITEMS:

- *All sleeves, inserts, anchors, and embedded items required for adjoining work or for its support shall be placed prior to concreting.*
- All penetrations (pipes etc.) through the concrete structure must be prepared as per Kryton 4.17 - Waterproofing Tie Holes and Pipe Penetrations as applicable, prior to placing concrete so that they are compatible with the Krystol Waterstop System.

TREATMENT OF JOINTS WITH THE KRYSTOL WATERSTOP SYSTEM:

Table 2: Summary of Joint Option Procedures

Joint Type	Method	Application Instruction	Installation Notes
Horizontal Construction Joints	Internal Grout	4.11	Grout and Treatment installed prior to placing additional concrete.
Horizontal & Vertical Construction Joints	External Grout	4.12	Treatment installed prior to placing additional concrete, Grout installed after 28 days.
Horizontal & Vertical Control (Contraction) Joints	Crack Inducing Waterstop / External Grout	4.14	Crack Inducing Waterstop, and or Grout installed after 28 days.
Horizontal & Vertical Construction Joints	Internal Swelling	4.15	Treatment and Krytonite installed prior to placing additional concrete.
Horizontal & Vertical Construction Joints	Triple Protection	4.16	Treatment and Krytonite installed prior to placing additional concrete, Grout installed after 28 days.
Penetrations	External Grout	4.17	Prepare surface as required prior to placing concrete, Grout after 28 days.

- Except when following Kryton Application Instruction 4.11 – Waterproofing Horizontal Construction Joints - Internal Grout Method, all joints must be left for a minimum of 28 days to allow initial concrete shrinkage to take place first before installing Krystol Waterstop Grout.
- Localized shrinkage cracking at control joints may produce initial seepage of moisture. Simulation of expected hydrostatic conditions or shutting off of dewatering system will assist to determine seepage prone cracks.
- KIM concrete has the inherent ability to self-seal leakage through minor cracking including shrinkage cracks. Joints that self-seal after 28 days shall be filled with Krystol Waterstop Grout as per Kryton Application Instructions 4.12 – Waterproofing Horizontal and Vertical Construction Joints - External Grout Method, 4.14 – Waterproofing Horizontal and Vertical Control Joints, 4.15 – Waterproofing Construction Joints – Swellstrip Method, 4.16 - Waterproofing Horizontal & Vertical Control Joints – Triple Protection Method, as applicable, or 4.17 - Waterproofing Tie Holes and Pipe Penetrations, as applicable.
- If substantial cracks develop (i.e., width exceeds Krystol's ability to self-seal), the contractor will be responsible for the installation of Kryton Application Instruction 5.12 - Waterproofing Cracks, Holes and Joints for repairing leaks from the negative side (interior or accessible side) prior to final inspection.
- For joints that are found to be moving, use a flexible sealant or joint filler such as urethane injection.

HOLES, ROCK POCKETS AND DEFECTS

Any holes, honeycombs, rock pockets or defects that result either intentionally or from inadequate consolidation should be repaired after a 28 day waiting period in accordance with Kryton Application Instructions

a) 5.12 - Waterproofing Cracks, Holes, and Joints
b) 5.21 - Patching and Parging Defective Concrete and Masonry

Curing of patching materials for a minimum of 7 days is required. Patching materials must be kept damp and protected from drying out; appropriate curing methods include damp coverings or impermeable sheeting to retain moisture.

7. LEAKAGE TEST

(ACI 305R – Environmental Engineering Concrete Structures / ACI 504R – Guide to Sealing Joints in Concrete Structures)

It is normal practice to test liquid-retaining structures for water tightness. The leakage test should be performed while the tank walls are exposed so that leaks can be easily found and repaired. Thus, leakage tests usually are performed prior to backfilling or cladding the tank. For potable water facilities, the leakage test is often done in conjunction with the disinfection in order to save water. The acceptance leakage criteria and method of test should be specified in the construction contract. Tanks generally are filled to full overflow level. If the structure has dried out, the water should be left standing for a period to allow for absorption. Tanks are usually considered acceptable if:

a) There are no visible leakage or visible damp areas, and
b) The volume of leakage in a given time period (after correcting for evaporation losses) is less than a specified amount.

Water tightness testing should be performed for a sufficient period of time to allow for the self-sealing of minor cracks to occur. An appropriate time period is generally 2-4 weeks. If constructions schedules will not accommodate the self-sealing period, the contract documents should include provisions for crack repairs as per Kryton Application Instruction 5.12 (Waterproofing Cracks, Holes and Joints) and Application Instruction 5.32 (Waterproofing Pipe Penetrations) to ensure the structure is watertight before proceeding with construction.

8. REINFORCING STEEL

(ACI 301 - Specifications for Structural Concrete for Buildings)

- *Refer to ACI 301 (Specifications for Structural Concrete for Buildings) for detailed reinforcement standards and placements tolerances.*
- *Reinforcement, at the time concrete is placed, shall be free of mud, oil, or other materials that may adversely affect or reduce the bond.*
- *All reinforcement shall be supported and fastened before concrete is placed and shall be secured against displacement.*
- *Reinforcement supported from the ground or mud mat shall rest on precast concrete blocks not less than 4 inches and having a compressive strength equal to or greater than the specified compressive strength of the concrete being placed.*

Other means of support are not acceptable for KIM concrete placement. Plastic “chairs” or other devices provide an unacceptable path to water penetration.

- *Reinforcement supported from formwork shall rest on bar supports made of concrete, metal, plastic, or other acceptable materials.*
- *Where the concrete surface will be exposed to weather in the finished structure, the portions of all bar supports within 12.5 mm (0.5 in.) of the concrete surface shall be noncorrosive or protected against corrosion.*
    - Rebar supported from formwork should be supported from the inside or interior face only. Rebar supported from the outside or exterior face may cause leaks by providing a path for water to penetrate to the rebar mat.

9. CONCRETE COVER

(ACI 301- Specifications for Structural Concrete for Buildings, ACI 201.2R - Guide to Durable Concrete).

Effective concrete cover can protect reinforcing steel from chemical attack and reduces the risk of cracking. Cracks running parallel to reinforcing steel in particular should be avoided as they allow a direct path for chemicals to attack the steel.

- *Minimum concrete cover for reinforcement, except for extremely corrosive atmospheres, other severe exposures, or fire protection, shall be as noted in table 3 (from ACI 301):*
- All tie wires must be cut to a length of no more than 13 mm (0.5 inches) and turned so that they do not protrude into the concrete cover.

Table 3: Minimum Concrete Cover

Type	*Minimum Cover mm (in.)*
Concrete deposited against the ground (includes concrete deposited at or near the waterline, concrete subject to marine environments (including spray) or other severe conditions (ACI 201.2R))…………………………………………………………………………*	*75 mm (3 in.)*
Formed surfaces exposed to weather or in contact with the ground: *Bar sizes No. 6 or larger………………………………………………………………* *Bar sizes No. 5 and smaller, and W31 or D31 wire and smaller……………………*	 *50 mm (2 in.)* *40 mm (1.5 in.)*
Formed surfaces not exposed to weather or not in contact with the ground *Beams, girders, and columns…………………………………………………………..* *Slabs, walls, and joists* *Bar sizes No. 11 or smaller……………………………………………………* *Bar sizes No. 14 and 18……………………………………………………….*	 *40 mm (1.5 in.)* *20 mm (0.75 in.)* *40 mm (1.5 in.)*

**AASHTO recommends 4 inches of cover for severe exposure*

10. BATCH PLANT INSPECTION

(ACI 311.5R – Batch Plant Inspection and Testing of Ready Mixed Concrete)

The inspector should be qualified by education, training, and experience to perform the required duties. The inspector should have a technical understanding of the principles involved in concrete batching and should know the basic operating sequence of the of the concrete batch plant. The inspector should be able to provide evidence of such training and experience. The inspector should also be furnished with and become familiar with published standards set forth by this guide and with project specification requirements.

- *The inspector should observe that the facilities, scales, and truck mixers meet the specified project requirements.*
- *The inspector should be physically present at the batching console during the first batch and should periodically (at least once per hour) observe that the specified type and amount of materials conforming to the mix design are incorporated into the mix.*
- The inspector must visually verify that KIM admixture is added to the mix at the correct dose for each truck and note the addition on the batch ticket.
- *The inspector should conduct or witness the following tests at least once daily:*
  - *Moisture content determination on the fine and coarse aggregates in accordance with ASTM C566.*
  - *Aggregate gradations, fine and coarse; in accordance with ASTM C136.*
  - *Aggregate tests should be compared to the project specifications for compliance (ASTM C33 is usually specified as the gradation requirement for both fine and coarse aggregates).*
  - *The inspector should observe that the producer is making adjustments in the mix proportions as required for the free moisture in the aggregates.*
  - *The inspector should observe that the trucks are in good working order and not loaded above capacity.*
- *The inspector should determine that the batch plant is furnishing the purchaser with a delivery ticket for each batch of concrete with the following information:*
  - *Name of batch plant*
  - *Serial number of ticket*
  - *Date*
  - *Truck number*
  - *Name of purchaser*
  - *Project designation*
  - *Class or designation of concrete*

- *Amount of concrete batched*
- Amount of KIM added and batch number(s).
- *Time batches*

- *The inspector should sign each delivery ticket to show that the concrete batch has been inspected.*
- *Daily inspection reports should be prepared detailing the inspector's observations.*

11. CONCRETE MIXING, HANDLING AND DELIVERY

(ACI 301 - Specifications for Structural Concrete for Buildings, ACI 304R – Guide for Measuring, Mixing, Transporting and Placing Concrete) (ACI 309R – Guide for Consolidation of Concrete)

PRODUCTION OF CONCRETE:

- *Ready-mixed concrete shall be batched, mixed and transported in accordance with ASTM C 94 unless otherwise specified. Plant equipment and facilities shall conform to "Certification of Ready Mixed Concrete Production Facilities (Checklist with Instructions)" of the National Ready Mixed Concrete Association.*
- All concrete shall be from a ready-mix concrete producer expressly approved by Kryton International Inc.
- The ready-mix concrete producer will proportion, mix and deliver KIM admixture in accordance with the following Kryton Application Instructions:
  - 1.11 - Instructions for Mix Design & Batch Plant
  - 1.12 - Instructions for Ready-mix Truck Driver

ADDITION OF WATER ON THE JOB:

- *The maximum water-cement ratio should never be exceeded. If all the water allowed by the specification has not been added at the start of mixing it may be permissible to add the remaining allowable water at the point of delivery. It should be noted that once part of a batch has been unloaded, it becomes impractical to determine what water-cement ratio is produced by the addition of water.*
- *The production of concrete of excessive slump or adding water in excess of the proportioned water cement ratio to compensate for slump loss resulting from delays in delivery or placing should be prohibited.*
- *Persistent requests for the addition of water should be investigated.*
- All additions of water, whether at the batch plant, wash rack or on the jobsite, must be recorded on the concrete delivery ticket. The total addition of water must not exceed the maximum specified water-cement ratio under any circumstances. All jobsite additions of water must be approved by the concrete supplier and the general contractor.

PREPARATION PRIOR TO PLACING:

- *Hardened concrete and foreign materials shall be removed from the inner surfaces of the conveying equipment.*
- *Formwork shall be completed; snow, ice and water shall be removed; reinforcement shall be secured in place; expansion joint material, anchors, and other embedded items shall be positioned; and the entire preparation shall be accepted.*
  - Construction debris and water must be removed from the bottom of formwork prior to placing concrete. Often such materials are left in place, which can causes voids and honeycombing at the bottom of walls and slabs. Proper consolidation is critical in these areas, particularly along joints, because they are the most vulnerable to leakage.
- *Semi-porous subgrades shall be sprinkled sufficiently to eliminate absorption of water from the freshly placed concrete.*
- *Concrete shall not be placed on frozen ground.*
- *Concrete shall be handled from the mixer to the place of final deposit as rapidly as practicable by methods which will prevent segregation or loss of ingredients and in a manner which will assure that the required quality of the concrete is maintained.*
- *Conveying equipment shall be acceptable and shall be of a size and design such that detectable setting of concrete shall not occur before adjacent concrete is placed.*

- *Truck mixers, agitators, and non-agitating units and their manner of operation shall conform to the applicable requirements of ASTM C 94.*
- *Belt conveyors shall be horizontal or at a slope which will not cause excessive segregation or loss of ingredients. Concrete shall be protected against undue drying or rise in temperature. An acceptable arrangement shall be used at the discharge end to prevent segregation. Mortar shall not be allowed to adhere to the return length of the belt. Long runs shall be discharged into a hopper or through a baffle.*
- *Chutes shall be metal or metal-lined and shall have a slope not exceeding 1 vertical to 2 horizontal and not less than 1 vertical to 3 horizontal. Chutes more than 7 m (20 ft.) long and chutes not meeting the slope requirements may be used provided they discharge into a hopper before distribution.*
- *Pumping or pneumatic conveying equipment shall be of suitable kind with adequate pumping capacity. Pneumatic placement shall be controlled so that segregation is not apparent in the discharged concrete. The loss of slump in pumping or pneumatic conveying equipment shall not exceed 50 mm (2 in.).*
- *Concrete shall not be conveyed through pipe made of aluminum or aluminum alloy.*

DEPOSITING CONCRETE:

- *Concrete shall be deposited continuously, or in layers of such thickness that no concrete will be deposited which has hardened sufficiently to cause the formation of seams or planes of weakness within the section.*
- *If a section cannot be placed continuously, construction joints shall be located as indicated on the contract documents or as permitted. Placing shall be carried on at such a rate that the concrete which is being integrated with fresh concrete is still plastic.*
- *Concrete which has partially hardened or has been contaminated by foreign materials shall not be deposited.*
- *Equipment should be arranged so that the concrete has an unrestricted vertical drop to the point of the placement or into the container receiving it. The stream of concrete should not be separated by permitting it to fall freely over rods, spacers, reinforcement or other embedded materials.*
- *Temporary spreaders in forms shall be removed when the concrete placing has reached an elevation rendering their service unnecessary.*
  - Temporary spreaders in forms must not be left in place regardless of their composition.
- *Segregation*
  - *Concrete shall be deposited as nearly as practicable in its final position to avoid segregation due to re-handling or flowing.*
  - *Concrete shall not be subjected to any procedure which will cause segregation.*

CONCRETE CONSOLIDATION:

Freshly placed concrete is typically poorly consolidated and contains numerous honeycombs and air voids. Without effective consolidation, the concrete will have poor properties such as low strength, high permeability, and increased cracking. Special care is needed to ensure proper consolidation around joints, Waterstops, and reinforcement. Leaks due to poor consolidation are preventable with good construction practices; however should they occur the contractor will be responsible for making the required repairs.

CONSOLIDATION METHODS:

1. Vibration is the recommended method of consolidation using either internal or external vibrators, power tampers, vibrating screeds etc.
2. *Vibration reduces the internal friction of the concrete and allows it to flow. The resulting consolidation proceeds in two stages, elimination of honeycombs and removal of entrapped air pockets.*
3. *Operators of vibrating equipment should have developed, through experience and training, the ability to determine the timing and spacing of vibration to achieve proper consolidation.*
4. *Internal vibration is generally best suited for ordinary construction except for areas with heavy rebar congestion or that are otherwise inaccessible.*
5. *For walls and deeper sections, it may be necessary to supplement external vibrators with internal vibrators to ensure full compaction.*
6. *For thin sections, particularly for precast work, external vibration should be the primary method of consolidation.*
7. *All equipment should be suitable for the required work as described in ACI 309R.*

8. Extra care must be taken to ensure the complete consolidation of concrete at the bottom of forms, particularly wall-to-slab joints for perimeter walls.

PROCEDURES FOR INTERNAL VIBRATION:

1. *Internal vibrators used shall be the largest size and the most powerful that can be used properly in the work.*
2. *The depth of the concrete should be approximately equal to the length of the vibrator head.*
3. *In walls and columns, the layer depth should not exceed 0.5 m (20 in.). The layers should be as level as possible so that the vibrator does not move the concrete laterally.*
4. *After the surface is leveled, the vibrator should be inserted vertically at uniform spacings over the entire placement area.*
5. *The distance between insertions should be about 1.5 times the radius of action, or such that the visibly affected areas overlap by several centimeters. For slabs, the vibrator should be sloped towards the horizontal as needed to operate in a fully embedded position. The vibrator should not be inserted within 0.60 m (2 ft.) of any leading (unconfined) edge.*
6. *Use of vibrators to transport concrete within forms shall not be allowed.*

ACCEPTANCE:

- *There is no quick and reliable way to judge the adequacy of consolidation; and quality control will largely depend on the operator's experience and knowledge. Inspection is generally done visually for the following indicators:*
    - *Embedment of large aggregate with a thin film of mortar at the surface and cement paste showing at the junction between the concrete and the form.*
    - *General cessation in the escape of large air pockets. Note that thick sections will take more time than thin sections for air to work its way to the surface.*
    - *The pitch and feel of the vibrator often changes during consolidation and becomes steady when the concrete is fully consolidated. An experienced operator should be able to determine when consolidation is complete.*
        - *Note: inexperienced operators tend to merely flatten the concrete without watching for the other signs of full consolidation.*
        - *If concrete cannot be reached for vibration due to rebar congestion, it may be helpful to vibrate exposed sections of rebar to carry the vibration to the concrete.*
- Full consolidation is of critical importance to the installation of the Krystol Waterproofing System, particularly around joints, waterstops, penetrations and embedded items. Poorly consolidate concrete will leak.
- *Under vibration is more common than over vibration. Well proportioned, normal weight mixes with adequate consistency are typically not susceptible to over vibration. If there are any doubts as to the adequacy of consolidation, it should be resolved with additional vibration.*
- *Over vibration may occur if an operator is careless or uses greatly oversized equipment, and can lead to segregation, sand streaks, loss of entrained air or form deflection/failure.*
- *At least one spare vibrator should be on standby for every three vibrators in use during all concrete placing operations.*

REVIBRATION:

- *Revibration is the process of vibrating concrete that was vibrated at some earlier time.*
- *Some revibration is unintentional when placing multiple layers of concrete.*
- *Revibration can be accomplished anytime the running vibrator will sink under its own weight into the concrete.*
- *Revibration usually increases the compressive strength of standard cylinders, and increase bond strength in top cast bars placed in high slump concrete. However, revibration may lower bond strength for bars cast in well consolidated, low slump concrete.*
- *Revibration is usually most effective in the top 0.5 to 1.0 m (1.5 to 3 ft.) of a placement, where air and water voids are most prevalent. Revibration of walls usually results in more uniform appearance of vertical surfaces.*
- *Revibration can be effective in minimizing cracks at the top of doorways, arches, major boxouts, etc. The best procedure is to delay concrete placement for 1-2 hours, depending on temperature, after reaching the springline of arches or headline of doors, boxouts, or*

joints between columns and floors, etc. to permit settlement shrinkage to occur before revibration of the materials placed at the resumption of placement.

- Revibration should be considered in areas prone to poor consolidation such as the tops of walls; however care must be taken to prevent cold joints from developing if concrete placement operations are delayed.

PROCEDURE FOR EXTERNAL FORM VIBRATION:

- *Vibrators must be placed to provide uniform vibration over the full surface of the form. Spacing is generally 1.3 to 2.7 m (4 to 8 ft.) unless this does not produce adequate vibration. Proper spacing requires knowledge of the distribution of frequency and amplitude over the form, and an understanding of the workability and compactability of the mixture.*
- *Concrete should be placed in layers of 25 to 40 cm (10 to 15 in.) and each layer vibrated separately. External vibration times are longer then internal, often up to 2 minutes and as much as 30 minutes in some deep sections.*
- *It is desirable to be able to vary the frequency and amplitude of the vibrators.*
- *The "in and out" movement of form vibration can pump air into the concrete, particularly in the top 0.5 to 1.0 m (2 to 3 ft.) of placement, creating a gap between the concrete and the form. In the top layer, there is no subsequent layer of concrete to help close the gap; therefore it is advisable to use internal vibration in these areas.*

SLOPED SURFACES:

- *It is difficult to consolidate concrete that has a sloping top surface. When the slope is approximately 4:1 (vertical to horizontal) or steeper, consolidation is best assured by providing a temporary holding form or slip form screed to prevent sag or flow of concrete during vibration. The holding form can be removed before the concrete has reached its final set so that surface blemishes can be removed by hand. When the sloping form cannot be removed before the concrete has set, the form should be removed as soon as possible to permit filling of the blemishes.*

NOTES FOR STRUCTURAL CONCRETE:

- *Rebar must allow space for insertion of internal vibrators. Typically spaces of 100 x 150 mm (4 x 6 in.) at 0.6 m (24 in.) intervals are used.*
- *Special attention should be directed towards member size, bar size, bar location, bar spacing and other factors that affect the consolidation of concrete. The designer should communicate with the contractor during the early concrete phase. Problem areas should be recognized early enough to take corrective measures.*
- *Slabs on Grade:*
  - *Internal vibrators should be fully immersed (vertically for thick sections, at an angle or horizontally for thinner sections). Contact between the vibrator and the sub grade should be kept to a minimum.*

12. CURING AND PROTECTION OF FRESHLY PLACED CONCRETE

(ACI 308 – Standard Practice for Curing Concrete, ACI 224R – Control of Cracking in Concrete Structures)

Curing is the maintaining of a satisfactory moisture content and temperature in concrete during its early stages so that desired properties may develop. Curing is essential in the production of concrete that will have the desired properties. The strength and durability of concrete will be fully developed only if it is cured.

Finishing should not be done in the presence of surface water. Prior to final finishing, exposed concrete surfaces should be protected from rapid evaporation by use of liquid applied evaporation retarders or the use of fogging equipment to maintain a high relative humidity above the concrete. All required markings or grooves should be cut or molded to the specified depth.

- *After final finishing, curing must begin promptly to maintain the required internal moisture content for full strength development, and prevent moisture loss that could result in drying shrinkage before the concrete has gained sufficient strength to resist cracking.*

- *Acceptable curing methods are described in ACI 308.1, and include wet curing methods (sprinklers, web burlap, plastic sheeting etc.) or a curing compound conforming to ASTM C309. Wet curing is preferred and recommended whenever possible.*
- *In hot weather, the temperature of water used for curing must be as close as possible to that of the concrete to avoid thermal shock.*
- *Duration: When the daily mean ambient temperature is above 5 °C (40 °F), curing should be continuous for a minimum of 7 days or for the time necessary to attain 70% of the specified compressive or flexural strength, whichever period is less.*
- *If concrete is placed with daily mean ambient temperature 5 °C (40 °F) or lower, precautions should be taken as recommended by ACI 306. For some structural members, such as columns where high strength [41 MPa (6000 psi) or greater] is required curing periods may be increased to 28 days or greater to allow development of the required strength of the concrete.*
    - Curing should continue uninterrupted for a minimum of 7 days.
- *Protection and curing should not be ended abruptly; for wet curing the covering should be left in place until it and the concrete surface appear dry, particularly in arid climates. In less arid areas and for interior surfaces, the concrete form usually provides adequate protection provided they are left in place for a minimum of 7 days, after which the forms should be left in place with loosened bolts long enough to allow the surface to dry gradually.*

Construction schedules and practices should allow concrete to attain a minimum strength of 27.6 MPa (4000 psi) before being exposed to freezing conditions.

Cold, damp or rainy weather is not a replacement for proper curing.

If a curing compound is used, apply at the manufacturer's recommended coverage and ensure uniform coverage. Apply curing compounds to walls immediately after stripping forms. For slabs, apply immediately after the concrete takes its final set.

13. HOT WEATHER CONCRETING

(ACI 305R – Hot Weather Concreting)

Hot weather may lead to problems in mixing, placing, and curing hydraulic cement concrete that can adversely affect the properties and serviceability of the concrete. Hot weather is any combination of the following conditions that tend to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration, or otherwise resulting in detrimental results:

a) *High ambient temperature*
b) *High concrete temperature*
c) *Low relative humidity*
d) *Wind velocity*
e) *Solar radiation*

POTENTIAL PROBLEMS IN PLASTIC CONCRETE:

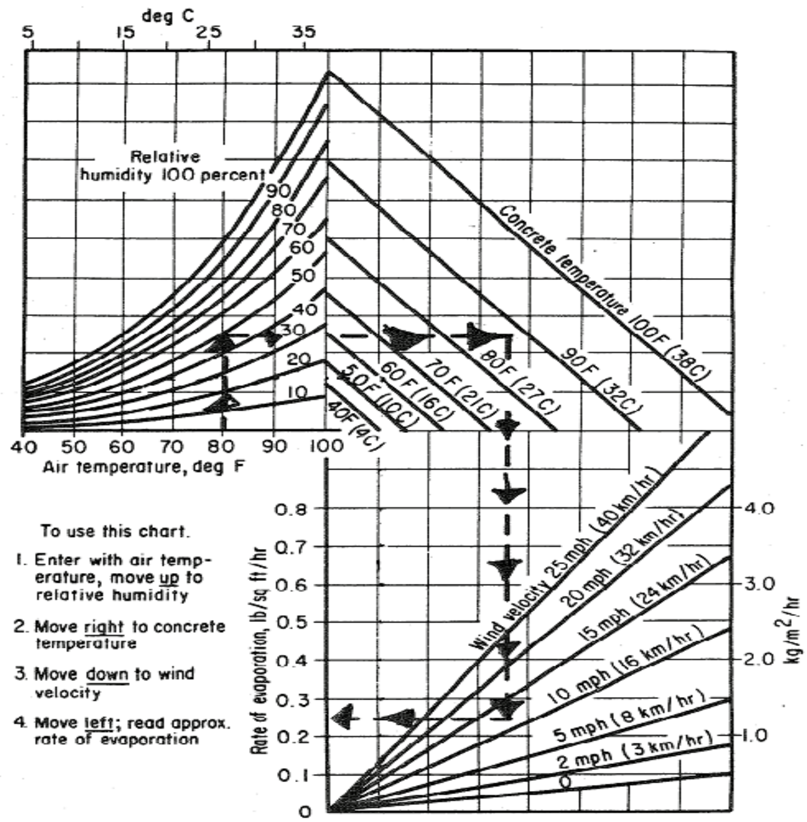
- *Increased water demand for a given slump*
- *Increased rate of slump loss*
- *Higher concrete temperatures, increased rate of setting, difficult in placing and finishing and formation of unintended cold joints*
- *Increased plastic shrinkage cracking*
- *Increased difficulty in controlling air entrainment.*

POTENTIAL PROBLEMS IN HARDENED CONCRETE:

- *Reduced 28 day strength (due to increased water content or high early temperatures)*
- *Increased drying shrinkage or thermal cracking.*
- *Increased permeability and potential for corrosion.*

The effects of high air temperature, solar radiation, and low relative humidity may be more pronounced with increases in wind velocity (see Figure 1).

Figure 1: Evaporation rate based on relative humidity, concrete, temperature and wind velocity



The potential problems of hot weather concreting may occur at any time of the year in warm tropical or arid climates, and generally occur during the summer season in other climates. Cracking due to thermal shrinkage is generally more severe in the spring and fall. This is because the temperature differential for each 24-hr period is greater during these times of the year. Precautionary measures required on a calm, humid day will be less strict than those required on a dry, windy, sunny day, even if air temperatures are identical.

- *When the evaporation rates are expected to exceed 1.0 kg/m/hr (0.2 lb./ft./hr), precautions against rapid evaporation should be taken.*
- *The occurrence of plastic-shrinkage cracks may be increased if concrete settings times are delayed due to factors such as: using slow-setting cement, an excessive dosage of retarding admixture, the use of fly ash, or cooled concrete. Fly ash is may also reduce bleeding which may contribute to a cracking tendency.*

KIM admixture has set retarding properties. When combined with other admixtures or fly ash, the set delay may require additional precautions against surface drying. Moistening the air above the concrete with fogging equipment is the recommended practice. The use of monomolecular evaporation retarders applied during concrete placement may also be used if accepted by the architect/engineer.

PLANNING AND PREPARATION:

- *Whenever possible, placing of slabs should be scheduled after the roof structure and walls are in place to minimize problems associated with drying winds and direct sunlight. This will also reduce thermal shock from rapid temperature drops caused by wide day and night temperature differences or cold rain on concrete heated by the sun earlier in the day.*
- *Under extreme hot weather conditions, scheduling concrete placements at other than normal hours may be advisable.*

- *Preparations must be made to transport, place, consolidate, and finish the concrete at the fastest possible rate. Delivery of concrete to the job should be scheduled so it will be placed promptly on arrival, particularly the first batch. Many concrete placements get off to a bad start because the concrete was ordered before the job was ready and slump control was lost at the most critical time. Traffic arrangements at the site should insure easy access of delivery units to the unloading points over stable roadways. Site traffic should be coordinated for a quick turnaround of concrete trucks. If possible, large or critical placements should be scheduled during periods of low urban traffic loads.*

CONCRETE BATCHING AND DELIVERY:

- *Common methods to control the initial temperature of concrete include*
    - *Precooling aggregates,*
    - *Use of cold water or ice in concrete batching,*
    - *Use of set retarding admixtures (Refer to ACI 305R – Hot Weather Concreting).*
- *Concrete must be delivered within the temperature guidelines established by the architect/engineer.*

SLUMP ADJUSTMENT:

- *Fresh concrete is subject to slump loss with time, whether it is used in moderate or hot weather. With given materials and mix proportions, the slump change characteristics between plant and jobsite should be established.*
- *If on arrival at the jobsite the slump is less than the specified maximum, additional water may be added if the maximum allowable water content is not exceeded. When water is added to bring the slump within required limits, the drum or blades must be turned an additional 30 revolutions or more, if necessary, at mixing speed.*

PLACING FORMED CONCRETE:

- *In hot weather, it is usually necessary to place concrete in shallower layers than those used in moderate weather to assure coverage of the lower layer while it will still respond readily to vibration.*

PROTECTION OF FLATWORK:

- *Arrangements should be made for ample water supply at the site for wetting subgrades, fogging forms, reinforcement work in progress under arid conditions, and for moist-curing if applicable.*
- *Before depositing concrete, the subgrade should be moist, yet free of standing water and soft spots at the time of concreting. It may be necessary keep the operation confined to a small area and to proceed on a front having a minimum amount of exposed surface to which concrete is to be added.*
- *A fog nozzle should be used to cool the air, to cool any forms and steel immediately ahead, and to lessen rapid evaporation from the concrete surface before and after each finishing operation.*
    - *The fog nozzles used should produce a fog blanket. They should not be confused with common garden-hose nozzles, which generate an excessive washing spray.*
    - *Pressure washers with a suitable nozzle attachment may be a practical means for fogging on smaller jobs.*
    - *Excessive fog application (which would wash the fresh concrete surface or cause surplus water to cling to reinforcement or stand on the concrete surface during floating and troweling) must be avoided.*
- *Other means of preventing moisture loss include spreading and removing impervious sheeting or application of sprayable moisture-retaining films between finishing passes.*
- *Materials and means should be on hand for erecting temporary windbreaks and shades as needed to protect against drying winds and direct sunlight.*
- *Means should also be provided to protect the concrete against thermal shrinkage cracking if it is likely to become exposed to rapid temperature drops.*
- *The materials and means for the curing methods selected should be readily available at the site to permit prompt protection of all exposed surfaces from drying upon completion of the placement.*

CURING OF FORMED CONCRETE:

- *Forms should be covered and kept continuously moist during the early curing period. Formed concrete requires early access to ample external curing water for strength development. This is particularly important when using high-strength concrete having a water-cementitious material ratio of less than about 0.40 (ACI 363R).*
- *The forms should be loosened, as soon as this can be done without damage to the concrete, and provisions made for the curing water to run down inside them. During form removal, newly exposed surfaces should promptly receive a uniformly wet cover. A continuous flow of curing water over the concrete may prevent or moderate development of high-temperature levels that would otherwise result from the heat generated by cement hydration.*

PREPARING INCIDENTAL WORK:

Due to faster setting and hardening of the concrete in hot weather, the timing of various final operations as saw-cutting joints and applying surface retarders becomes more critical; therefore, these operations must be planned in advance.

14. COLD WEATHER CONCRETING

(ACI 306R – Cold Weather Concreting)

Cold weather is defined as a period when, for more than 3 consecutive days, the following conditions exist:

a) *The average daily air temperature is less than 5 °C (40 °F) and,*
b) *The air temperature is not greater than 10 °C (50 °F) for more than one-half of any 24-hr period.*

The average daily air temperature is the average of the highest and the lowest temperatures occurring during the period from midnight to midnight. Cold weather, as defined here usually starts during fall and usually continues until spring. The temperature of concrete at the time of placement should always be near the minimum temperatures given in Table 4. Placement temperatures should not be higher than these minimum values by more than 11 °C (20 °F).

Table 4: Recommended Concrete Temperatures

Air Temperature	*Section Size, Minimum Dimension, mm (in.)*			
	<300 mm (12 in.)	*300-900 mm (12-36 in.)*	*900-1800 mm (36-72 in.)*	*>1800 mm (72 in.)*
Minimum concrete temperature as placed and maintained				
--	*13 °C (55 °F)*	*10 °C (50 °F)*	*7 °C (45 °F)*	*5 °C (40 °F)*
*Minimum concrete temperature as mixed for indicated air temperature**				
Above -1 °C (30 °F)	*16 °C (60 °F)*	*13 °C (55 °F)*	*10 °C (50 °F)*	*7 °C (45 °F)*
-18 to -1 °C (0 to 30 °F)	*18 °C (65 °F)*	*16 °C (60 °F)*	*13 °C (55 °F)*	*10 °C (50 °F)*
Below -18 °C (0 °F)	*21 °C (70 °F)*	*18 °C (65 °F)*	*16 °C (60 °F)*	*13 °C (55 °F)*
Maximum allowable gradual temperature drop in first 24 hr after end of protection				
--	*28 °C (50 °F)*	*22 °C (40 °F)*	*17 °C (30 °F)*	*11 °C (20 °F)*

**For colder weather a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place*

PLANNING:

The concrete contractor, concrete supplier, and owner (or architect/engineer) must meet in a preconstruction conference to define in clear terms how cold weather concreting methods will be used. Plans to protect freshly placed concrete from freezing and to maintain temperatures above the recommended minimum values should be made well before freezing temperatures are expected to occur. Necessary equipment and materials should be at the work site before cold weather is likely to occur.

RECORD KEEPING:

The actual temperature at the concrete surface determines the effectiveness of protection, regardless of air temperature. Temperature recording and monitoring must consider the following:

- *The corners and edges of concrete are more vulnerable to freezing and usually are more difficult to maintain at the required temperature, therefore, their temperature should be monitored to evaluate and verify the effectiveness of the protection provided.*
- *Inspection personnel should keep a record of the date, time, outside air temperature, temperature of concrete as placed, and weather conditions (calm, windy, clear, cloudy, etc.). Temperatures of concrete and the outdoor air should be recorded at regular time intervals but not less than twice per 24-hr period.*
    - *The record should include temperatures at several points within the enclosure and on the concrete surface, corners, and edges. There should be a sufficient number of temperature measurement locations to show the range of concrete temperatures.*
    - *Temperature measuring devices embedded in the concrete surface are ideal, but satisfactory accuracy and greater flexibility of observation can be obtained by placing thermometers against the concrete under temporary covers of heavy insulating material until constant temperatures are indicated.*
- *Maximum and minimum temperature readings in each 24-hr period should be recorded. Data recorded should clearly show the temperature history of each section of concrete cast. A copy of the temperature readings should be included in the permanent job records.*
- *It is preferable to measure the temperature of concrete at more than one location in the section cast and use the lowest reading to represent the temperature of that section.*
- *Internal temperature of concrete should be monitored to insure that excessive heating does not occur.*

FREEZING AND THAWING:

- *If, during construction, it is likely that the concrete will be exposed to cycles of freezing and thawing while it is in a saturated condition, it should be properly air entrained even though it will not be exposed to freezing and thawing in service.*

SLUMP AND FINISHING:

- *Concrete with a slump lower than normal [less than 100 mm (4 in.)] is particularly desirable in cold weather for flatwork; bleeding of water is minimized and setting occurs earlier.*
- *During cold weather, bleed water may remain on the surface for such a long period that it interferes with proper finishing. If the bleed water is mixed into the concrete during trowelling, the resulting surface will have a lower strength and may be prone to dusting and subsequent freeze-thaw damage if exposed. Thus, during cold weather, the concrete mixture should be proportioned so that bleeding is minimized as much as practicable.*
- *If bleed water is present on flatwork, it should be skimmed off prior to trowelling by using a rope or hose.*

METALLIC EMBEDMENTS:

- *Large metallic embedments at temperatures below freezing may result in localized freezing. The architect/engineer must determine if the project contains embedments that pose a problem and whether heating is required.*

CONCRETE PLACEMENT TEMPERATURE:

- Concrete placement temperature should be controlled to within the tolerances in Table 5. Common procedures include the use of heated water or heated aggregates.
- Temperature loss during transport should be taken into consideration. Refer to ACI 306R for additional guidance and precautions.

PROTECTION:

Protection from early freezing does not assure a satisfactory rate of strength development, particularly when followed by considerably colder weather. Protection and curing should continue long enough (and at a temperature sufficiently above freezing) to produce the strength required for form removal or structural safety.

- *To prevent early-age freezing, protection must be provided immediately after concrete placement. Arrangements for covering, insulating, housing, or heating newly placed concrete should be made before placement.*
- *The protection that is provided should be adequate to achieve, in all sections of the concrete cast, the temperature and moisture conditions recommended in this guide and ACI 306R.*
- *Heated Enclosures:*
  - *Heated enclosures must be strong enough to be windproof and weatherproof. Otherwise, proper temperatures at corners, edges, and in thin sections may not be maintained despite high energy consumption.*
  - *Combustion heaters should be vented and they should not be permitted to heat or to dry the concrete locally.*
  - *Fresh concrete surfaces exposed to carbon dioxide resulting from combustion heaters that exhaust flue gases into an enclosed area, may be damaged by carbonation of the concrete. Additional health and safety concerns are discussed in ACI 306R.*
- *The length of the required protection period depends on the type and amount of cement, whether an accelerating admixture is used, and the service conditions (loaded, unloaded, etc.).*
- *Protection must be left in place until the concrete has reached a degree of strength acceptable to the architect/engineer.*
  - Concrete surfaces should be protected from freezing for at least the first 72 hr. after placement.

One method used to verify attainment of sufficient in-place strength before support is reduced, changed, or removed, and before curing and protection are discontinued, is to cast at least six field-cured test specimens from the last 75 m^3 (100 cu. yd.) of concrete. At least three specimens should be cast for each 2 hr of the entire placing time, or for each 75 m^3 (100 cu. yd.) of concrete, whichever provides the greater number of specimens. The specimens should be made in accordance with ASTM C 31, following the procedures given for "Curing cylinders for determining form removal time or when a structure may be put into service". The specimens should be protected immediately from the cold weather until they can be placed under the same protection provided for the parts of the structure they represent. After demolding, the cylinders should be capped and tested in accordance with the applicable sections of ASTM C 31 and ASTM C 39.

For flatwork, field-cured test specimens can be obtained by using special cylindrical molds that are positioned in the formwork and filled during the placement of concrete in the structure (ASTM C 873). Since the test specimens are cured in the structure, they experience the same temperature history as the structure. When a strength determination is required, the molds are extracted from the structure and the cylinder is prepared for testing according to ASTM C 39. The holes remaining in the structure would be filled with concrete.

REMOVAL OF PROTECTION:

At the end of the protection period, concrete should be cooled gradually to reduce crack-inducing differential strains between the interior and exterior of the structure. The temperature drop of concrete surfaces should not exceed the rates indicated in Table 5. This can be accomplished by slowly reducing sources of heat, or by allowing insulation to remain until the concrete has essentially reached equilibrium with the mean ambient temperatures. Insulated forms, however, can present some difficulties in lowering the surface temperatures. Initial loosening of forms away from the concrete and covering with polyethylene sheets to allow some air circulation can alleviate the problem.

Table 5: Maximum allowable temperature drop during first 24 hr after end of protection period

Section Size, Minimum Dimensions, mm (in.)			
<300 mm (12 in.)	*300 to 900 mm (12 to 36 in.)*	*900 to 1800 mm (36 to 72 in.)*	*>1800 mm (72 in.)*
28 °C (50 °F)	*22 °C (40 °F)*	*17 °C (30 °F)*	*11 °C (20 °F)*

FORM REMOVAL:

During cold weather, protection afforded by forms, except those made of steel, is often of great significance. In heated enclosures, forms serve to evenly distribute the heat. In many cases, if suitable insulation or insulated forms are used, the forms, including those made of steel, would provide adequate protection without supplemental heating. Thus it is often advantageous to keep forms in place for at least the *required minimum period of protection. However, an economical construction schedule often dictates their removal at the earliest practicable time. In such cases, forms can be removed at the earliest age that will not cause damage or danger to the concrete.*

CURING:

Concrete exposed to cold weather is not likely to dry at an undesirable rate; however, this may not be true for concrete that is being protected from cold weather. As long as forms remain in place, concrete surfaces adjacent to the forms will retain adequate moisture. However, exposed horizontal surfaces are prone to rapid drying in a heated enclosure.

- *When concrete that is warmer than 16 °C (60 °F) is exposed to air at 10 °C (50 °F) or higher, it is essential that measures be taken to prevent drying. The preferred technique is to use steam for both heating and preventing excessive evaporation. Water curing may be used, but can be undesirable in cold weather since it can cause icing problems and increases the likelihood of the concrete freezing when protection is removed.*
- *If water or steam curing are used, they should be terminated 12 hr before the end of the temperature protection period, and the concrete should be permitted to dry prior to and during the period of gradual adjustment to ambient cold weather conditions.*
- *When dry heating is used, the concrete should be covered with an approved impervious material or a curing compound meeting the requirements of ASTM C 309.*

15. JOBSITE QUALITY CONTROL AND FIELD TESTING

(ACI 311.5R – Batch Plant Inspection and Testing of Ready Mixed Concrete)

The technician must at minimum have ACI certification as a Concrete Field Testing Technician-Grade I. The technician should also be furnished with and become familiar with published standards as set forth in this guide and with project specification requirements.

- *Perform control tests (slump, air content, unit weight, and temperature) on every batch of concrete delivered.*
- *Cast two compressive strength cylinders to be kept by Kryton International Inc. every for each project or 1000 m^3 (1300 cu. yd.).*
- *Cast compressive strength cylinders every 76 m^3 (100 cu. yd.) or as specified.*
- *Perform control tests using the specified ASTM or CSA standards.*
- *Report all deviations from the specification immediately to the supervisor.*
- *Prepare daily inspection reports with observations made during the day.*
- *The technician should complete a concrete data report for each set of concrete compressive strength specimen results to be reported by the testing laboratory, showing all related quality test results.*

CONCRETE TESTING LABORATORY:

All required laboratory acceptance tests (laboratory curing and compressive strength testing of concrete cylinders) should be performed by an independent testing laboratory. The laboratory must meet the concrete inspection and testing section requirements of ASTM C 1077. The laboratory should provide evidence to the architect/engineer that its facilities have been inspected by an independent agency within the last three years, and show that any deficiencies mentioned in the report of that inspection have been corrected.

The testing laboratory should pick up compressive strength test specimens from the project site within 16 to 48 hrs. and store in a moist condition at 23 ± 1.7 °C (73.4 ± 3 °F) until the moment of test in accordance with ASTM C 31, "Making and curing of concrete test specimens in the field". The testing laboratory should test compressive strength specimens in accordance with ASTM C 39, "Compressive strength of cylindrical concrete specimens". Two specimens should be tested al 28 days for acceptance and two should be tested at 7 days for information. The acceptance test results should be the average of the strengths of the two specimens tested at 28 days.

The testing laboratory should issue timely reports with the following information:

- *Project name*
- *Client*

- *Concrete supplier*
- *Date sampled*
- *Sampled by (with certification number, if applicable)*
- *Truck number and/or ticket number*
- *Time batched and time sampled*
- *Air temperature and concrete temperature at time of sampling*
- *Slump and air content*
- *28-day compressive strength requirement*
- *Concrete mix designation*
- *Location of placement and location of sample batch*
- *Date tested, concrete age, and compressive strength results*
- *Any remarks that may affect concrete quality, such as water added at the project site, elapsed time between start of mixing to completion of placement, and any variation in curing requirements.*

-- The End of Section --