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Cooling Tower Basin Leakage Assessment & Mitigation

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INTRODUCTION

Collection and retention of cooling water fluids is an integral feature of reinforced concrete Cooling Tower Basins, regardless of being associated with Natural or Mechanical Draft Cooling Technology. Concrete may be thought of as an impervious manmade building product such as that associated with polymer technology, but it is in fact more closely related to ceramic chemistry. Concrete is classified as being a "sub-vitreous" construction product as opposed to fired pottery and dishware being "vitreous". Composed of multiple constituents including mineral aggregates of varying size, Portland Cement and water, the resultant hardened "man-made stone" product can be looked upon as a "hard sponge". This hard sponge has inherent porosity that includes a network of drying capillaries contributing to its relative permeability.

Typically, construction details associated with reinforced concrete water retention structures incorporate:

- The use of low water-to-cement ratio (w/c) dense concrete (efforts made to minimize long-term material volume shrinkage)
- Maximize the amount of embedded reinforcing steel according to ACI-350 (increases the amount of embedded reinforcing steel to restrain cracking associated with material volume shrinkage)
- Implement concrete placement Formwork Systems that don't employ full Wall section thickness Form Ties (minimizes the potential of full Wall section thickness "conduits")
- Minimize or exclude the installation of expansion joints (maintenance is regularly required to keep Expansion Joints functioning adequately)
- Reduce the amount of Construction Joints and detail proposed Construction Joints to seal along the formed edges of daily placements by the installation of redundant Water-Stops
- Provision of Quality Assurance/Quality Control (QA/QC) on-site to reduce to probability of Construction Defects that would affect the "Water-tightness" of the Cooling Tower Basin (i.e., porosity associated with unconsolidated concrete, misplacement of Water-Stop glands, full width structural section cracking)

Construction Defects - Many times the most significant factor(s) associated with Cooling Tower Basin leakage comes in the following forms:

- Unconsolidated concrete (i.e., honeycomb) that can provide a direct conduit through the reinforced concrete Wall/Floor Slab section, between the process water and the outside environment (Figure No. 3)

- Misplacement of embedded reinforcing steel bars within a concrete mass that could prove to be ineffectual at material volume shrinkage crack control
- Misplacement and/or the absence of Water-Stop glands at Expansion Joint locations (Figure No. 3)
- Form-Ties, inadequately prepared/sealed that can initiate embedded steel corrosion of the Form-Tie, in the presence of moisture and oxygen as well as behave as a process water egress location

Even in the best situations, reinforced concrete can crack within Basin Walls and/or Floor Slabs creating conditions conducive for leakage (Figure No. 1). It's at times like these that Repair Professionals are employed by Operators/Owners to address the current need to stop process water egress and provide means and methods to detect and address future Basin Wall and/or Floor Slab leakage opportunities.

Process Fluid Leakage Mitigation - Positive Side Waterproofing - Typically when we say waterproofing, it's implied that these features will be installed at the time of original construction or at a time that allows complete dewatering, interior basin cleaning and excavation along exterior regions of the Basin Wall/Floor Slab perimeter. Typically, in the case of a Cooling Tower Basin, "positive-side" waterproofing would include the installation of an interior immersion service environmental coating/lining that's resistant to chemical exposure consistent with the Cooling Tower Process environment. Besides chemical exposure, mechanical properties such as elasticity of the coating/lining and its ability to bridge "cracking" whether existing or newly formed during service, are important facets to consider during the selection process.

Negative-side waterproofing includes repair means-and-methods that are implemented once the Cooling Tower is placed in-service and repairs to observed leakage requires that the repair be performed while the Unit is On-Line. The use of multi-component chemically activated grouts, sealants and cementitious products are available and are used successfully in controlling leakage originated from within Cooling Tower Basins.

LEAKAGE FUNDAMENTALS

When discussing leakage we have to place moisture egress into the context of weeps, seeps & leaks.

- Weeps – falling drops of water or other liquids as in condensation
- Seeps – leaking fluids through small openings or pores
- Leaks – movement of fluids through openings such as cracks, holes or other ports of egress

Regardless as to the relative severity of Cooling Tower Basin containment "compromises", process fluid lost through these "breaches' in containment integrity, must be addressed and stopped, to reduce "make-up" water additions and potential environmental consequences associated with "escaping" process fluids released into surrounding areas.

<u>Investigation Methods</u>

Depending on the form of notification, (i.e., Operator Notification, Security Drive-by, Periodic Inspection by Reliability Team Member, etc.) Equipment and Techniques exist to establish to presence of leakage which can include:

- Listening Devices
- Leak Noise Correlators
- Tracer Gas Technique
- Dye Location Tracers
- Thermography
- Ground Penetrating Radar
- Remote Camera Video Photography

<u>Listening Devices:</u> The most common of these devices include listening rods, aquaphones and geophones (i.e., ground microphones). Sensitive circuitry relying on piezoelectric elements can sense leak-induced sound or vibration. Improvements in the devices have involved employing signal amplifiers and noise filters to highlight leak signal signatures. Effectiveness of listening-type devices depends on the training and experience of the user.

<u>Leak Noise Correlators:</u> Portable microprocessors that pinpoint leaks use cross-correlation techniques where acoustic leak signals are measured by vibration sensors/hydrophones at two contact points that bracket the suspected leak location. Leak signals are transmitted wirelessly. The location of the leak is calculated based on the algebraic relationship between the time lag, sensor-to-sensor distance and the propagation velocity of sound waves.

<u>Tracer Gas Technique:</u> A non-toxic, water-insoluble and lighter-than-air gas such as helium or hydrogen is injected into an isolated segment of the water source. The gas escapes at a leak opening and then, being lighter-than-air, permeates to the surface through the soil and/pavement. The leak is detected by "sniffing" the ground surface directly above the leak source with a highly sensitive gas detector.
<u>Dye Detection Tracers:</u> As with Tracer Gas methodologies, colored dyes are placed into the water source and visible flowing water sources are viewed in pre-excavated Test Pits or along suspected ground surface egress points. Dyes are usually fluorescent in

color and easily “picked up” with specially tinted eyewear once dye-colored fluids emerge from leak egress points.

Thermography: Thermography is based on the principle that as leaking water egresses from a containment structure, the adjacent soil is changed thermally making it a more effective heat sink than the surrounding dry soil. These resulting thermal anomalies are detected with handheld, cart-wheeled or aircraft-mounted infrared cameras.

Ground-Penetrating Radar: Impulse Radar can be used to detect leaks by detecting voids in the soil created by leaking water as it circulates around a subsurface containment breach. The principal basis is the recording of information based on differences in dielectric constants of soils and construction materials. Ground-Penetrating Radar waves are partially reflected back to the ground surface when they encounter an anomaly in dielectric properties, such as a void. An image of the size and shape of the object is formed by radar time-traces obtained by scanning the ground surface. The time lag between transmitted and reflected radar waves determines the depth of the reflecting object.

Remote Camera Video Photography: This method includes both manned (i.e., divers) and unmanned (i.e., robot-actuated) means of capturing video processed images of subsurface containment conditions by implementing waterproof and well-lit photographic documentation. This method is well established for piping and can also be applied to Cooling Tower Basins.

Repair Methodologies

Depending on the size of the leak and volume of process fluids exiting a structure, several repair techniques are available that include:

- Grouting (Interior & Exterior Repair Response)
- Joint/Surface Seals (Interior & Exterior Repair Response)

- Coatings (Interior Repair Response)
- Membranes (Interior Repair Response)
- Re-route Flow (Exterior Repair Response)

Grouting: Grouting involves the practice of pressure injecting water-stopping materials, into, behind or around a structure or structural member, to form a barrier against water and/or process fluids. Most grouts solidify when cured ranging in consistency from semi-gelatinous to “rock” solid. Grouting barriers are designed to close off passageways within a structure or structural member. Materials can range from specially formulated micro-fine cementitious products to water-activated, expansive chemical grouts.

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Materials generally include Type 1 Portland Cement, Cement & Silicate, Bentonite Cement, Acrylate, Urethane Gel and Urethane Foam. (Figure Nos. 2 & 3)

Joint/Surface Seals: Sealing of Joints and/or Cracks involves the process of installing materials into or overtop of an opening within a structure or structural member to form a barrier to water and/or process fluids. The surface seals must be capable of absorbing/transmitting energy and loads. Essentially the seal design and materials must be able to absorb movement while in service. Materials generally include Silicone, Urethane elastomers, low modulus Epoxies and Polysulfide elastomers. (Figure Nos. 2 & 4)

Coatings: Coating applications involve the installation of "bonded" film-producing materials to a prepared concrete surface. The application requires a significant level of concrete surface preparation/cleanliness in order to achieve required substrate bonding. Impregnation of concrete surfaces is a common technique which is generally used to control the flow of moisture into and out of concrete. Coating materials can be fiber-reinforced to resist reflective concrete substrate cracking and are usually matched to the exposure conditions that the coating will be subjected to during service. Materials can include Epoxies, Epoxy/Aggregate blends, Urethanes, and Polyurea.

Membranes: Membranes can incorporate either bonded or unbonded surface-applied sheet systems with welded seams that provide barriers to the passage of contained process-fluids. Membranes are typically only successful as a positive-side waterproofing measure, requiring a high level of Quality Assurance and Quality Control (QA/QC) during installation. Materials can include Butyl Rubber, Neoprene, Hypalon, PVC and Bituminous hybrids.

Re-Route Flow: Heavy leakage process flows are many times "by-passed" in emergency situations, such as in cresting process fluid surges during "monsoon-like" rainfalls in form of sand-bags and/or re-circulating pumps with associated piping. Many times the leakage flows can't be stopped until flow pressures are reduced by installation of flow-bypass piping installed directly into cracked or jointed concrete members.

Industry Best Practices – Pressure Injection of Water-Activated Chemical Grout

The most popular method of stopping process fluid flow out of Cooling Tower Basins is pressure-injected, water-activated Chemical Grouting. Water-activated expansive Chemical Grouts are really split into two types:

1. **Hydrophobic** – Literally means "Water-Hating"
2. **Hydrophilic** – Literally means "Water-Loving"

Hydrophobic Chemical Grouts, early generation crack leak sealing technology, initiates upon contact with water generating a reaction with these grouts actually pushing water away as they react. However, the surrounding water isn't absorbed into the grout, but instead is forced through the crack and deep into the micro-fractures. Since the micro-fractures are filled with water, the hydrophobic grout can't flow in and establish a significant bond with the surrounding concrete surfaces.

Once a hydrophobic grout cures, it forms a rigid foam structure. Due to its rigidity, it's unable to re-expand to its original size, once compressed. When temperature change or other pressures cause the crack to close, the foam compresses/deforms under load. When the applied load experiences a reduction, and the crack reopens, the poorly bonded rigid foam structure will break away from the surrounding concrete surfaces. In many instances, leakage conditions return, however the repair of a previously grouted Crack/Joint provides even more challenges due to "impacted" cured foam structures along crack fissure interfaces.

Hydrophilic Chemical Grouts, recent generation crack leak sealing technology, have two properties that make them best for sealing leaks in reinforced concrete structures. Initially, they develop a tight bond with concrete by chasing and absorbing the water in the cracked concrete and in all of the micro-fractures that stem from the main Crack/Fissure. Additionally, as hydrophilic grouts cure, a tight flexible seal forms that has elastic characteristics allowing it to expand and contract as load or temperature changes cause the Crack/Joint to open or close.

Repair Case History

Structure: Multi-cell, Mechanical Draft Cooling Tower with a Wooden/Composite Superstructure and Fill Arrangement

Age & Location: 30+ Years Old located within a Petrochemical Facility in the Mid-Western USA

Concerns: Significant Process Water Leakage occurring along Cooling Tower Basin Wall surfaces requiring regular "make-up" water additions due to losses. A Root Cause Analysis was performed on structural details and correlated with existing site conditions revealed the structure was adequately designed however the placed concrete materials had a high water-to-cement ratio (w/c) initiating material shrinkage cracking due to excessive volumetric changes (concrete material mass reductions restrained by embedded reinforcing steel bars) in the concrete, upon drying/hardening. Non-faulted, fine to medium width (i.e., 0.005" to 0.025") vertical cracking at regular intervals along the Cooling Tower Basin Wall exterior perimeter. Unable to shutdown this critical asset for even a short-duration outage, the Operator/Owner decided to initiate a Chemical

Grout injection program at leaking crack locations in an effort to slow/stop further process water egress.

Repair Technique: All exposed exterior concrete surfaces of the Cooling Tower Basin Walls were sounded with a geologist's hammer with delaminations (i.e., internal separations) marked and removed where possible, assuring that cracked, partially detached, concrete pieces would not be incorporated into the repair. Once marked, locations were drilled at staggered positions apart, approximately the width of the Basin Wall and adjacent to but at a 45 degree angle in order to intercept subsurface crack fissures. Once drill holes were cleaned, mechanically expansive injection ports were installed and the cracks flushed with water. Arranging mechanized, high-pressure pump lines to chemical resin pots and injection gun-head, pressure injection of the Hydrophilic Chemical Grout began at the lowest crack leakage location. Using port-to-port communication techniques, Chemical Grout was injected until partially reacted grout was seen emerging from adjacent grout port locations and/or crack shoulder surfaces (Figure No. 5). Following a systematic progression - working from lowest to highest port, once the highest port was injected and crack location filled, the chemical grout was allowed to catalyze, crack surfaces cleaned of excess grout, injection ports were "pulled", drill holes cleaned and then patched with repair mortar.

Figure No. 5 Following Port-to-Port Communication techniques, Chemical Grouting begins from the lowest to the highest injection port elevation.

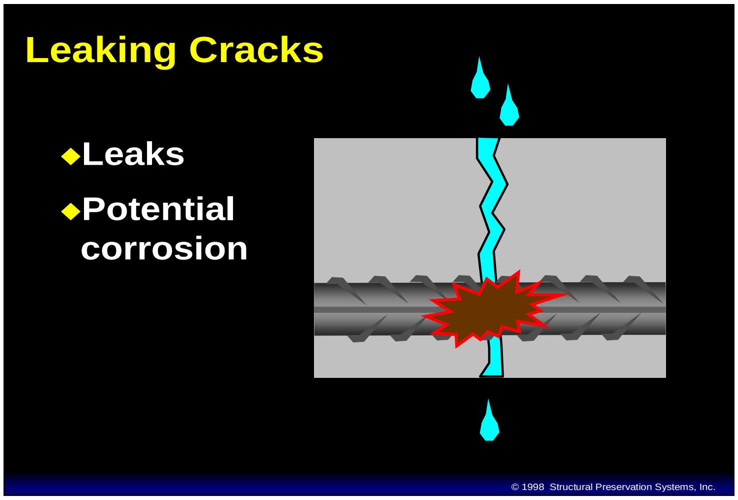

Figure No.1 Besides loss of process fluids, the egress of the fluids across reinforcing steel can initiate embedded metal corrosion processes.

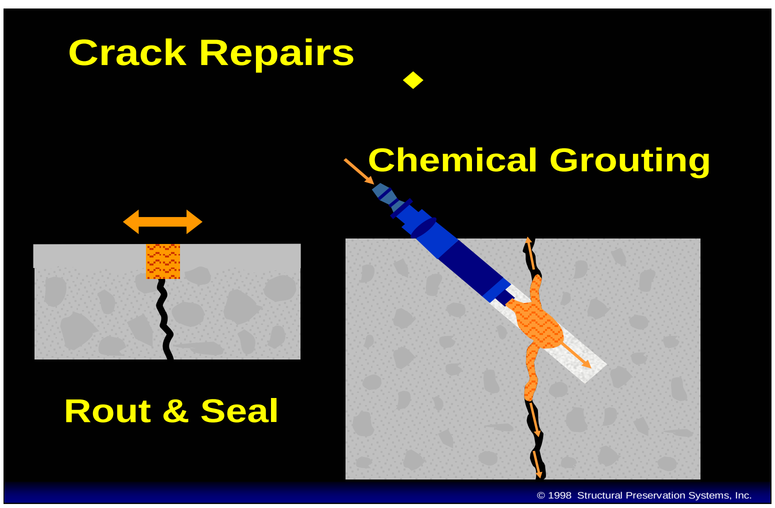

Figure No. 2 While “Routing & Sealing” can provide an adequate “positive-side” Off-line waterproofing repair, “Chemical Grouting” can be performed On-line, in the presence of Cooling Tower process water.

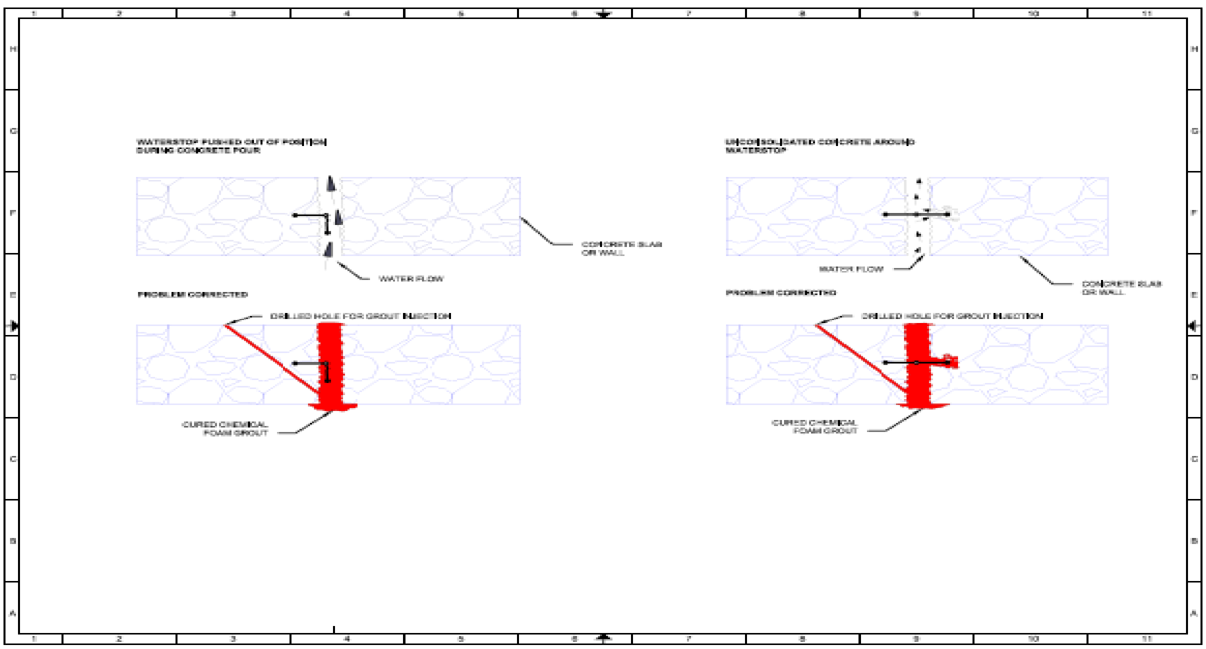

Figure No. 3 Repair of Embedded Water-Stops due to original Construction Defects in the forms of misplacement and lack of concrete consolidation (i.e., honeycomb).

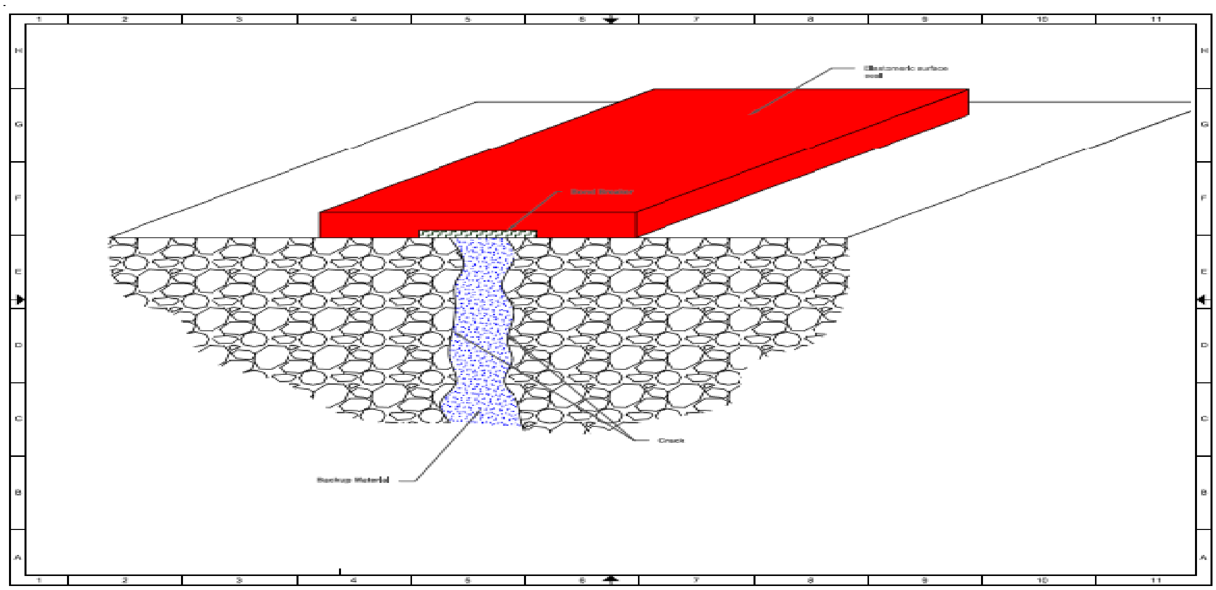

Figure No. 4 Elastomeric Surface Seal Membranes are appropriate at large Crack/Joint locations where significant horizontal and/or vertical movement can be expected yet Water-tightness is a necessary requirement.