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CONCRETE CONVERSATIONS

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Concrete Conversations, the ACI Alberta Chapter Newsletter is published twice per year.

In this Issue

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Sadegh Kazemi
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David Impey

Message from the President

Welcome to the spring 2011 edition of *Concrete Conversations*. The objective of the newsletter is to inform you about the ongoing activities of ACI Alberta chapter and provide articles and technical information of interest to our members.

It has been a number of years since we published a full newsletter and we hope you will find the content both enjoyable and of interest. We welcome your feedback on the newsletter and encourage you to submit articles and information that you think would interest our members. In this edition we will highlight the winning entries from the *2011 Awards of Excellence in Concrete* in the Spring 2011 category. Future editions will feature summaries of the information presented at our luncheons and seminars. Finally, we would like to highlight the professional accomplishments of our members and we encourage you to submit information on accomplishments, promotions and career transitions.

About ACI Alberta Chapter

The *American Concrete Institute* (ACI) is a nonprofit technical and educational society. Organized in 1904, ACI is one of the world's leading authorities on concrete technology, acting as a round-table for the discussion of all concrete-related matters and a forum for the development of problem resolution. ACI conducts this forum in a several ways: through conventions and meetings; the ACI Structural Journal, ACI Materials Journal, Concrete International and technical publications; chapter activities; and technical committee work.

The Alberta Chapter of the American Concrete Institute is an affiliated chapter of ACI International. We are a not-for-profit organization dedicated to advancing the use and technology/science of concrete across the industry through education, technical practice and networking. Our members come from a variety of academic, construction, engineering and industrial organizations in the province.

David Impey

David Impey

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Awards of Excellence in Concrete 2011

The ACI Alberta Chapter celebrated its 2011 Awards of Excellence in Concrete competition in a gala event at the Delta Lodge in Kananaskis on Friday, May 13, 2011.

This is a biennial event run by the chapter, soliciting entries in various categories for concrete-related projects completed in the previous few years. This year there were six categories in which a project could be entered. Twenty-five submissions were received by the end of January 2011, for projects either completed or substantially complete in 2008, 2009, and 2010 in the following categories:

Category	Description
Buildings	all types involving concrete construction
Bridges	all types and sizes involving concrete construction
Civil	all other structures that are not Buildings or Bridges
Restoration	any restoration involving concrete, or repair to concrete
Sustainable	projects advancing sustainable construction design and construction techniques
Advanced Concrete Construction	projects demonstrating advancement in concrete construction techniques

This type of event is dependent on the support of the industry in terms of sponsorship, submission of projects and attendance at the gala event. We were successful in all three areas, having excellent support from our sponsors, a record number of entries in the six categories and a sold-out attendance of 144 people to celebrate the winning entries.

All of our judges are senior members of the engineering/design/construction industry in Alberta. They all have very busy work schedules and we thank them for taking time out of these schedules for us. Our thanks to our judging team of:

Mr. David Woodall of David C Woodall Structural Engineering Ltd., representing the design side of concrete

Professor Robert Day of the University of Calgary, representing both the materials aspects and academia, and

Mr. Jeremy Sturgess of Sturgess Architecture, representing the Architectural community.

The Master of Ceremonies Team of Donavan Workrun and Graham Neil, both from Atomic Improv entertained the attendees with their repartee throughout the evening. They were aided by brief video clips

Awards of Excellence in Concrete 2011 *continued*

on each project in a category, followed immediately by a live announcement of the winning category and the presentation of a trophy to each team member of the project team.

Rather than the more traditional marble trophies awarded previously, this year we are excited about our new Award Trophy – a concrete precast image of Alberta provided by armtec. A concrete award trophy for an Awards of Excellence in Concrete competition seems far more appropriate & meaningful.

The winning projects were as follows:

Building	St Joseph Seminary
Bridge	Fort Edmonton Footbridge
Civil	The Bow Raft Slab
Restoration	Dunvegan Suspension Bridge Deck Replacement
Sustainable	Ralph Klein Park and Environmental Education Centre
Advanced Concrete Construction	Clark Builders Floating Stairs

Congratulations to all the winners.

The posters of all the projects can be viewed on our website.

We acknowledge the following sponsoring companies:

Gold Sponsors: Bird Construction Company; Graham Group; Inland Heidelberg Cement Group; Lafarge

Trophy Sponsor: armtec

Silver Sponsors: BASF the Chemical Company; Grace Construction Products; Northland Construction Supplies, PCL Construction Leaders, Read Jones Christoffersen Consulting Engineers and Sika

Bronze Sponsors: Burnco, Concreate USL, Concure Restoration, Dynamic Pumping and Holcim

In Memorium

In June 2010 the concrete industry lost an exceptional professional, and I personally lost a good friend, when ACI board member Alex Bakshan passed away. Alex, as many of you will know, was originally from Moldavia. He and his wife Tanya immigrated to Canada and lived for many years in Calgary. Alex was the well-respected QC Manager for Inland Concrete in Calgary. I had the privilege of working with Alex on many projects as the industry pushed the boundaries of concrete into SCC, high-strength concretes and high-performance mixes.

Alex was very bright and highly experienced but he remained humble and open to learning from other people. He always realized there was more to learn and never believed he had all the answers. He was fair, honest, hardworking and very accepting of others in all their diversity. He served his customers, colleagues and his organization well. He set an example for all of us to follow in his professional life.

Alex was dedicated to his family. He was immensely proud of his daughter's accomplishments as she completed a law degree. Even when he felt the stress of work pressures he still had a ready wit and a sense of humor. Alex was a great hockey fan and he was always ready to debate the relative merits of the Flames.

ACI has plans to expand the University of Calgary scholarship and rename it in honor of Alex Bakshan. The Inland foundation has generously stepped in to assist ACI in establishing a permanent fund that will underwrite the scholarship annually.

It is fitting that at the recent Alberta Awards of Excellence in Concrete "The Bow" raft slab won an award. Alex was instrumental in the planning and execution of this record-breaking project and he will be fondly remembered by all the team members.

Bill Fitzsimmons
(Former Chapter President ACI Alberta)

Construction of the Hoover Dam Bypass

High-performance concrete used for the bridge arches

BY JEFF ST. JOHN

Since its completion in the 1930s, the roadway on top of the Hoover Dam has been a primary traffic route across the Colorado River. Increasing traffic and tourism often led to lengthy delays. Traffic volumes increased even more when U.S. 93 became a North American Free Trade Agreement corridor in the 1990s. Security concerns in the wake of the 9/11 attacks caused truck traffic to be banned from using the crossing. All of these factors motivated the design and construction of the Hoover Dam Bypass with its centerpiece river crossing, the Mike O'Callaghan–Pat Tillman Memorial Bridge.

By 2004, the Central Federal Lands Highway Division of the Federal Highway Administration had led the development of a design and the project was put out to bid. The Obayashi/PSM joint venture (JV) was awarded the contract in October 2004 with the low bid of $114 million. In early 2005, the construction team began assembling on the project site. Working near the Hoover Dam—arguably one of the 20th century's greatest engineering feats—prompted many questions about its construction: How did they handle the intense heat of a site where temperatures approach 130°F (54°C)? How did they get the workers, equipment, and materials to the site? Our team would face many of the same challenges 70 years later.

One challenge dwarfed all others: how to build the concrete arches. Our main concern was the concrete itself: mixture proportions, thermal control, concrete delivery and placement, consolidation, and possibly the chief concern—quality control.

DESIGNING THE MIXTURE

Development of the mixture proportions began 2 years before the first arch segment was cast. Many of the requirements for this high-performance concrete had been established by the design and ownership team. They included strength, aggregate selection, and thermal control requirements. Our construction team added several others to overcome delivery and placement challenges (pumpability, flowability, and long set time) and rapid strength gain to minimize form traveler cycle time.

The design strength of the concrete was 10,000 psi (69 MPa) in 56 days. The owner, the Central Federal Lands Highway Division of the Federal Highway Administration, had undertaken a detailed study of local aggregates to ensure a high-strength concrete with low permeability and low specific creep. These studies validated the design basis of the structure and reduced the amount of mixture verification required.

The specifications for the project included detailed thermal control requirements for mass concrete (primarily 4000 psi [28 MPa] concrete in the footings and 6000 psi [41 MPa] concrete in the pier caps) and also for the high-strength concrete in the arches. Figure 1 shows a typical bridge cross section. These requirements included a maximum allowable internal temperature of 155°F (68°C), and a maximum allowable temperature differential of 35°F (20°C), unless an alternate plan using an approved computer model was approved.

Operationally, we needed to achieve early strengths of 4000 psi (28 MPa) for form stripping and traveler launching and 6000 psi (41 MPa) for stressing post-tensioning tendons and erection stays. Our goals were 4000 psi (28 MPa) in 12 hours and 6000 psi (41 MPa)in 24 hours. The target slump at point of placement was 8 to 10 in. (203 to 254 mm) due to the difficult placement and consolidation conditions. Our target for setting time was at least 3 hours to allow for placing or delivery equipment failures.

Ryuichi Chikamatsu from Obayashi's Technical Research Institute in Japan consulted on the mixture proportioning. Paul Jordan of Sika Corporation lent his advice and helped with numerous trial batches. Wilbert Langley of W.S. Langley Concrete & Materials Technology, Inc., Halifax, NS, Canada, also consulted on the mixture proportioning and the thermal control requirements.

The mixture design met all of the criteria. Short- and long-term strength targets were met by a high cementitious material content (800 lb [363 kg] of cement and 200 lb [91 kg] of fly ash per cubic yard) and a very low water-cementitious material ratio (less than 0.31), typically

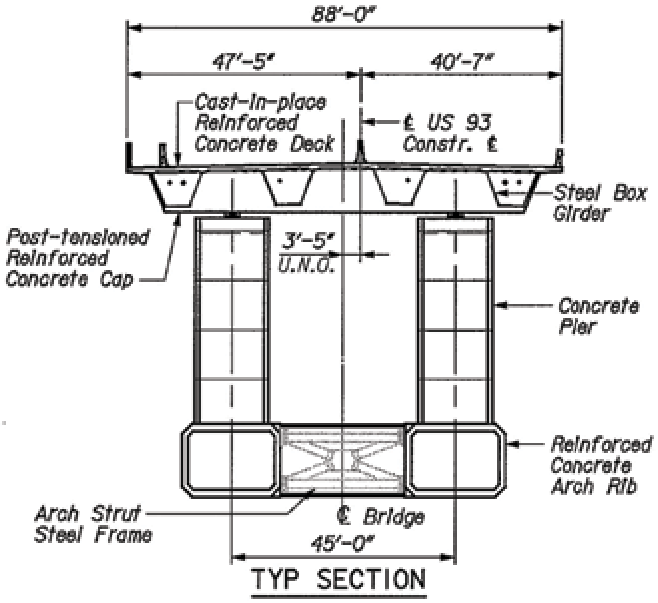

Fig. 1: A typical bridge cross section (Note: 1 ft = 0.305 m; 1 in. = 25.4 mm) *(illustration courtesy of FHWA)*

Portions of this article were originally published in *HPC Bridge Views*, September/October 2010, Issue 63; reprinted courtesy of the Federal Highway Administration and the National Concrete Bridge Council.

Fig. 2: Liquid nitrogen being injected into a concrete truck *(photo courtesy of Obayashi/PSM JV)*

Fig. 3: The concrete slickline wrapped in burlene. Soaker hoses inside the burlene delivered chilled water to the exterior of the slickline in an effort to reduce concrete heat gain during pumping *(photo courtesy of Obayashi/PSM JV)*

Fig. 4: Concrete truck discharging into the concrete pump *(photo courtesy of Obayashi/PSM JV)*

achieving strengths of 4000 psi (28 MPa) in just over 12 hours (during the summer) and over 12,000 psi (83 MPa) in 56 days. Pumpability and flowability were addressed by the use of a high-range water-reducing admixture, which resulted in concrete slumps exceeding 10 in. (250 mm). During our extensive trial batch process, it was observed that segregation could occur if the slump approached 11 in. (280 mm); thus, the slump was continuously monitored by our Batch Plant Operator and Quality Control Manager. Setting times in excess of 2-1/2 hours were achieved using a retarder.

COOLING

The very rich concrete mixture, however, did have a negative aspect. Without mitigation efforts, the internal curing temperatures of the concrete would have exceeded 190°F (88°C), far above the 155°F (68°C) limit specified by the contract. Mitigation methods—such as using chilled batch water or ice chips, shading the aggregate stockpiles, and placing at night—couldn't come close to reducing the maximum curing temperature to within the target range. Only two realistic options remained: circulating cold water through pipes embedded in the concrete or cooling the concrete with liquid nitrogen.

Miles of cooling tubes had been used to control temperatures during the construction of the Hoover Dam. Cooling tubes were also used for much of our bridge's substructure and pier caps. Unfortunately, for construction of the arches, the location, cycle time, installation, repair, and maintenance issues involved with cooling tubes ruled them out. Only the liquid nitrogen option remained.

The injection of liquid nitrogen into the concrete truck mixing drums shortly after batching (Fig. 2) allowed us to reduce the temperature of the concrete during the summer from 85°F (29°C) to 40°F (4°C). The initial temperature at point of placement was about 60°F (16°C), resulting in peak curing temperatures of less than 150°F (66°C). During the southern Nevada summer, the cost of the nitrogen required for cooling often exceeded $100 per cubic yard. These costs were mitigated, however, by the minimal effort needed at the point of placement and during the initial curing period. No maintenance (such as water supply or form insulation) or mitigation (grouting of cooling tubes or leaving forms in place for an extended duration) was required.

The precooling results in a "cool-and-forget" product and—with the unique structure and difficult access—offered the only viable option. An additional benefit of the nitrogen cooling is that it likely helped prevent problems with the placement system and consolidation efforts during the very warm summer months, when even at night, temperatures did not always fall below 100°F (38°C). During the hottest portions of the summer, it was necessary to precool the concrete pumping slickline by

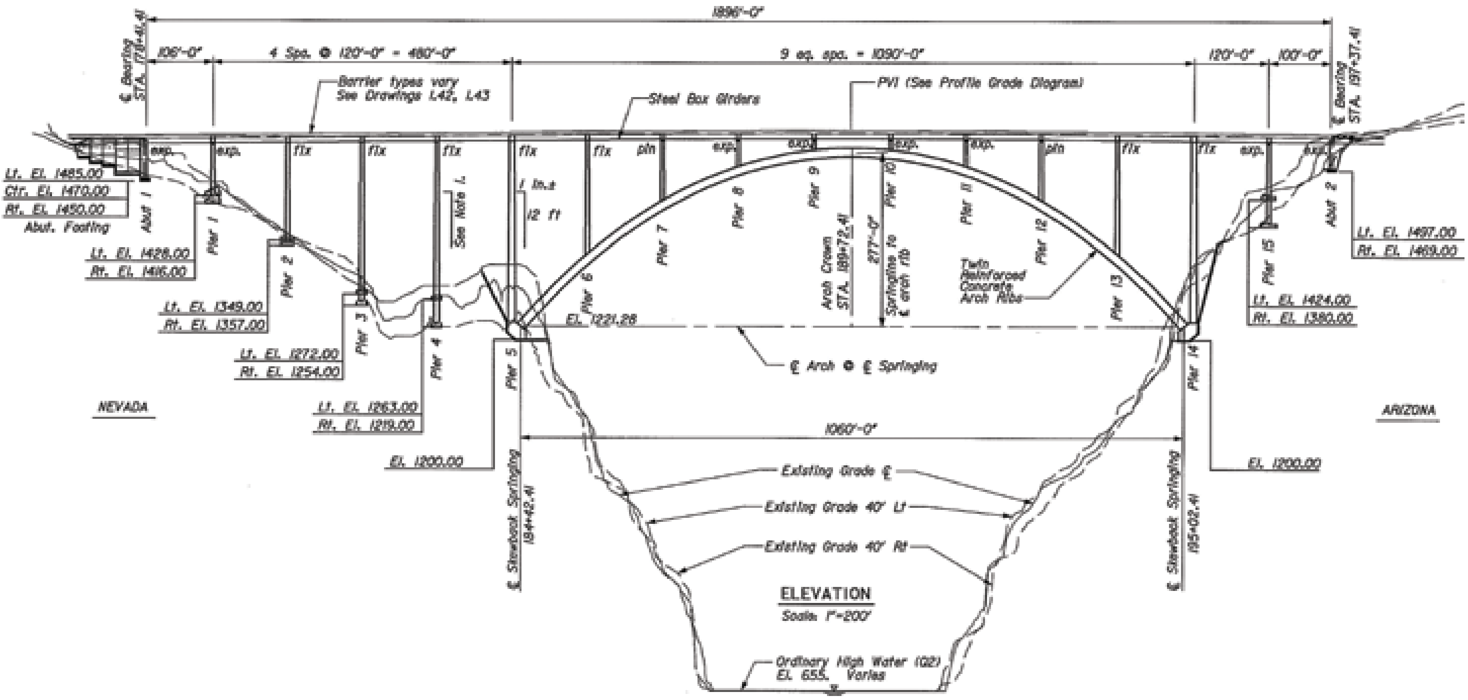

Fig. 5: Elevation drawing of the bridge (Note: 1 ft = 0.305 m; 1 in. = 25.4 mm) *(illustration courtesy of FHWA)*

filling it with chilled water prior to placement and also wrapping it with burlene soaked with chilled water to reduce heat gain through the placement system (Fig. 3).

PLACEMENT

Two options were apparent to get the concrete to the point of placement: use of a pumping system or delivery by cableway (hi-line) concrete bucket. Delivery by bucket to the point of placement (the same methodology used for construction of the Hoover Dam) was rejected to avoid tying up critical resources for several hours nearly every day and also due to the size of buckets required to maintain precise control of discharge into a very small target area (placement windows in the arch cover forms). The decision was made to use a concrete pumping system (Fig. 4).

Challenges for pumping included the harsh aggregates of the concrete mixture, the long slickline to be pumped through, the means to place in the restricted placement windows previously mentioned, and delivery of concrete to the pump. Trailer pumps, specially modified to handle the harsh local aggregates, were selected due to their ability to fit in the tight areas available for setup.

Delivery to the pump was easy on the Nevada side of the gorge; the pump could be set up on the roadside near the arches and the concrete could be delivered by truck. The Arizona side, with its tremendously steep cliffs, was another story (Fig. 5). There, the trailer pump was set up on the base of the arch in conjunction with a 5 yd^3 (3.8 m^3) remixer. Concrete was discharged from the delivery truck into 8 yd^3 (6 m^3) concrete buckets supported by the cableway, lowered to the base of the arch, and then discharged into the remixer. Use of the remixer allowed the buckets to be rehoisted nearly immediately to receive the next load of concrete. Tying up the cableways for half of the arch placements was a significant issue, but no other realistic option was discovered.

Fig. 6: A view up the Arizona-side cantilevers. The concrete slickline can be seen just off-center of the cantilever on the right *(photo courtesy of Obayashi/PSM JV)*

From the trailer pump, the concrete was pumped up the arch through a 5 in. (127 mm) diameter heavy wall slickline (Fig. 6) up to 600 ft (185 m) horizontally and 250 ft (77 m) vertically to a 32 m (105 ft) placing boom

Fig. 7: (a) The placing boom and platform on the Nevada-side arch cantilevers; and (b) placing boom being relocated *(photos courtesy of Obayashi/PSM JV)*

(Fig. 7) mounted atop the arch near the form traveler. The placing boom allowed precise control of discharge. A typical arch segment placement took 4 to 5 hours. All major concrete placements took place at night (Fig. 8) to avoid delivery delays due to traffic. During the warm months (April through October), this was also a requirement of the thermal control plan.

CONSOLIDATION AND QUALITY CONTROL

Consolidation of the concrete in the forms was another major concern. The geometry of the arch (many segments were placed at 45-degree angles) required the use of top surface forms for all placements. Placement windows were established in the cover forms, not only for placement, but also to allow use of high-cycle concrete vibrators. In addition, external vibrators were mounted under the bottom soffit and along the sides

ARCH SPAN DESIGN

High-performance concrete (HPC) is at the core of the successful construction of the Hoover Dam Bypass. The nearly 5 mile (8 km) long project comprises eight separate and significant bridges, including the centerpiece Colorado River Bridge at the Hoover Dam. This monumental 1905 ft (581 m) long structure includes twin rib arches that are the longest in the western hemisphere. The arches span 1060 ft (323 m) and rise nearly 900 ft (274 m) above the Colorado River.

HPC was the designer's focus from the beginning, according to David Goodyear, Senior Vice President, T.Y. Lin International (from *HPC Bridge Views*, September/October 2010, Issue 63). There are many characteristics of HPC that provide advantages for a long-span arch, including superior durability, strength, and stiffness. The arch form is an ideal application for concrete owing to the primary compressive strength of a simple concrete box section typically used for the arch rib.

In the case of the Colorado River Bridge at the Hoover Dam, the arch span required more than just strength. Several aspects of design were controlled by both immediate and time-dependent arch deflections. So, the stiffness of HPC surpassed strength in importance.

As the proposal for high-strength HPC was advanced, questions were raised about the ability to produce consistent, high-strength concrete and deliver it over the canyon. Additionally, the typical questions about material properties, creep, and shrinkage were highlighted due to the 1060 ft (323 m) long span of the arch.

As a result, the project design team retained CTLGroup to develop a demonstration program for HPC using the local materials that would be available to the contractor. This allowed comprehensive testing for the key properties of strength, durability, workability, creep, and shrinkage to better inform the design team, as well as give the prospective bidders a reference point for their own mixture design work under the construction contract.

The topography of the site required a high rise to the arch. The high rise of the arch ribs, the use of composite deck construction, and the logistics of form traveler construction led to the use of an open spandrel crown as opposed to an integral crown. This meant that arch stability for asymmetric live load would not rely on integral deck framing at the crown.

This geometry also affected the earthquake response of the arch ribs, allowing a more flexible framing system with greater deformation along the bridge. The period of response was therefore increased and the seismic demands were reduced. The reduced seismic demands are most significant at the arch springing, where traditional arch rib design would require increasing the section size to resist higher moments. HPC allowed for a smaller arch cross section and mass while maintaining requisite strength and stiffness.

Arch deflections also controlled spandrel column design and articulation. Secondary moments in the spandrel columns due to long-term arch deflection were a considerable portion of total demand. The superior stiffness of the HPC was key to using the same prismatic section down to the springing and the integral framing of the end spandrel columns.

Fig. 8: A typical night-time concrete placement on the arches using the placing boom *(photo courtesy of Obayashi/PSM JV)*

Fig. 9: An overview of the nearly completed bridge on August 20, 2010 *(photo courtesy of Obayashi/PSM JV)*

to improve consolidation. Very little honeycombing was observed when forms were removed.

As mentioned previously, quality control was our greatest concern. One bad load of concrete could plug up the placement system and lead to a half-completed segment that would need to be removed. In addition, if a load of concrete failed to reach the required strength, we might not find out until several additional segments had been cast. The implications for cost and schedule would be staggering. Thus, our quality control efforts needed to go far beyond the usual industry standard.

Our experience with the footing construction demonstrated that traditional ready mixed concrete batching methods would not meet our quality requirements for the arch. There were too many sources of variability, such as the batching efficiency of the truck's mixing drum and the drive time. We elected to purchase a portable batch plant incorporating a 5 yd^3 (3.8 m^3) pan mixer for the project site.

Pan mixers use high-speed paddles to mix the concrete prior to discharge into the truck. Although they are traditionally used only in precast yards, they were perfect for our application, where quality—not production rate—was paramount. The Batch Plant Operator was able to maintain the slump of the concrete within ±1/2 in. (±13 mm) during a placement. Our Quality Control Manager checked the slump of every load of concrete prior to sending it to the job site. Every third truck was tested at the job site prior to pumping. The proximity of the plant to the site made it extremely easy to make adjustments during a placement.

The result of all of these efforts can be seen in the finished structure (Fig. 9), which opened to traffic on October 19, 2010. No delays were encountered during arch construction due to pumping or placement, nor were any quality problems encountered. The arch construction actually went faster than anticipated and resulted in a monument that rivals the beauty of its neighbor.

Selected for reader interest by the editors.

PROJECT CREDITS

Owner: Central Federal Lands Division, Federal Highway Administration
Design Team: T.Y. Lin International, HDR Engineering, and Sverdrup Civil, Inc.
General Contractor: Obayashi Corporation/PSM Construction USA, Inc., a JV partnership
Concrete Suppliers: Obayashi/PSM JV for the twin arches and superstructure; Casino Redi-Mix and Silver State Materials for foundations and precast column segments
Concrete Admixture Supplier: Sika Corporation
Post-Tensioning Supplier: Schwager-Davis
Bridge Bearings: R.J. Watson

ACI member **Jeff St. John** was the Engineering Manager, and later the Project Manager, for the Obayashi/PSM JV, the general contractor of the Mike O'Callaghan–Pat Tillman Memorial Bridge over the Colorado River at the Hoover Dam. He is currently the Engineering & Planning Manager for Shimmick/Obayashi, the general contractor for the Phase IIIA seismic retrofit of the Golden Gate Bridge in San Francisco. St. John received his BS in civil engineering from Southern Illinois University, Carbondale, IL. He is a licensed professional engineer in Illinois and a member of the American Society of Civil Engineers and the American Segmental Bridge Institute.

Scholarships

A summary of all the scholarships currently supported by ACI Alberta is as follows:

School	Scholarship Name	Amount
University of Alberta	Alberta Chapter ACI Prize in Civil Engineering	$1,000
NAIT	American Concrete Institute Scholarship	$1,000
University of Calgary	Alex Bakshan Memorial Scholarship	$1,000
SAIT	American Concrete Institute	$1,000
Please contact each institution directly for further details about scholarship eligibility requirements and application procedures.		

Membership

An ACI, Alberta Chapter membership is a solid investment in your career.

Benefits

For a nominal yearly fee you will receive:

- Numerous networking opportunities with peers and industry experts
- Opportunities for professional advancement through:
- A variety of seminars held in both Edmonton and Calgary that boast excellent speakers and timely topics
- A full day Spring Seminar featuring a number of industry experts and many international ACI members as speakers
- Discounted registration fee for the Spring Seminar
- A fun-filled annual golf tournament held in Red Deer
- Additional single topic seminars and workshops, often in partnership with other organizations
- The opportunity for industry recognition via the renowned and well attended bi-annual Awards of Excellence in Concrete
- Access to student library

For more information, please see the Membership section on the website.

Report on Early-Age Cracking

A summary of the latest document from ACI Committee 231

BY WILL HANSEN

ACI Committee 231, Properties of Concrete at Early Ages, defines "early age" as the period after final setting, during which properties change rapidly. For a typical Type I portland cement concrete moist-cured at room temperature, this period is about 7 days, but it can extend beyond 7 days for other mixtures and curing conditions. Early-age volume changes induced by temperature change, hydration, and drying shrinkage can lead to cracking, and this can have lasting effects on strength, serviceability, and durability.

As is indicated in the title "Report on Early-Age Cracking: Causes, Measurement, and Mitigation (ACI 231R-10)," the latest report from ACI Committee 231 discusses the measurement and mitigation of early-age cracking.[1] The following is a summary of the report. References are provided only for the report itself and the figures used in the summary. The committee report contains numerous additional references.

CAUSES OF EARLY-AGE CRACKING

Early-age cracking arises from restraint of volume changes associated with thermal deformation, shrinkage due to hydration reactions, and shrinkage due to drying.

Thermal deformation

A hypothetical example of the effects of thermal deformation is provided in Fig. 1, which shows air and concrete temperature, stress, and tensile strength as functions of time.

Upon final setting (Time A), concrete begins to develop resistance to compressive and tensile strains. After Time A, the combined effects of hydration and, in this example, increasing air temperature cause the concrete temperature to increase until it reaches a peak (Time B). From Time A to Time B, the increasing concrete temperature causes thermal expansion. Restraint of this expansion by adjacent concrete or structures generates increasing compressive stress in the concrete.

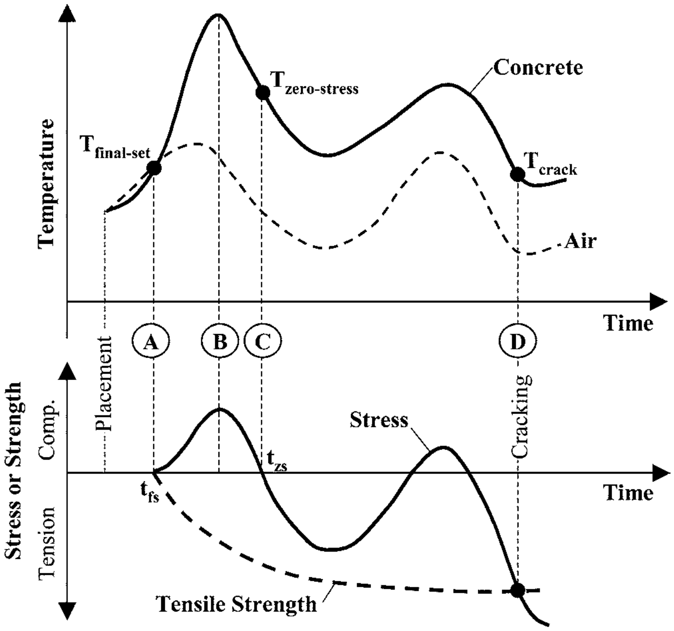

Fig. 1: Schematic of the development of thermal stress and tensile strength in concrete[2]

The compressive stress in the concrete is relieved as the concrete temperature decreases after Time B. When the temperature has dropped sufficiently, the stress in the concrete will be zero (Time C). After Time C, further decreases in concrete temperature will result in tensile stresses in the concrete if the concrete is restrained against contraction. If the tensile stresses exceed the tensile strength, the concrete will crack (Time D).

The concrete temperature at Time C may be significantly higher than the concrete temperature at Time A, particularly for hot weather placements, so mitigation techniques may be needed to reduce heat development. In massive concrete members, large temperature gradients can develop because the exterior concrete loses heat even as the core of the member continues to gain heat due to hydration. The interior concrete restrains thermal contraction of the exterior concrete, so tensile strains and cracking can develop in the exterior concrete. In terms of Fig. 1, the exterior of the concrete can be at Time D while the interior concrete is still between Times A and C.

Shrinkage due to hydration reactions

Autogenous shrinkage is volume change that occurs when there is no moisture loss to the surrounding environment. When water reacts with the clinker minerals in cement, the resulting reaction products take up less volume than the original minerals. This is termed chemical shrinkage, and before setting, autogenous shrinkage equals chemical shrinkage. Upon setting, however, a solid skeleton forms, and chemical shrinkage is restrained significantly. Autogenous shrinkage becomes much smaller than the underlying chemical shrinkage (Fig. 2). This is due to self-desiccation as the hydration reactions draw water from the concrete pores. Shrinkage due to self-desiccation can be quite significant in mixtures with a low water-cementitious material ratio (*w*/*cm*).

Drying shrinkage

Drying shrinkage is a time-dependent contraction caused by loss of moisture to the surrounding environment. Drying shrinkage is only partially reversible—dried concrete does not fully regain its original dimensions if its moisture content is restored. Drying shrinkage is greatest at surfaces exposed to air with low relative humidity, and the internal mass of the concrete will effectively restrain shrinkage that occurs at and near exposed surfaces. This can lead to serviceability issues, such as curling and cracking. Concrete slabs-on-ground, for example, will tend to dry from the top surface only, causing a nonlinear shrinkage profile to develop through the thickness. The resulting differential strains can cause axial and bending stresses.

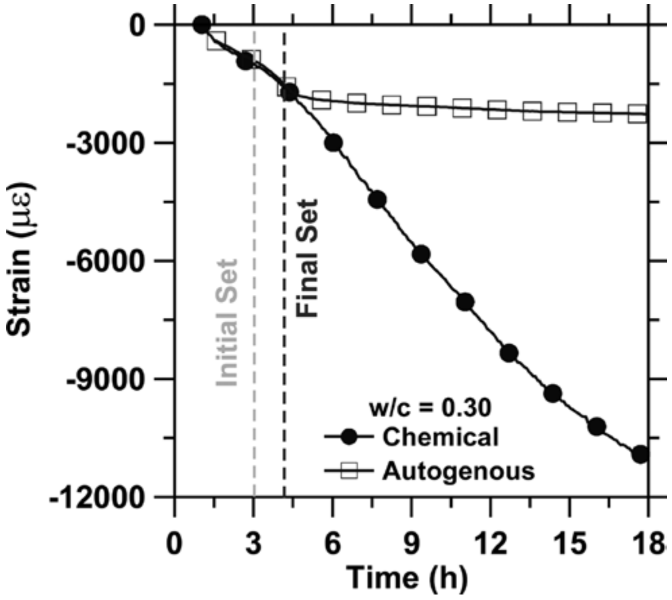

Fig. 2: Test results for chemical and autogenous shrinkage showing that chemical and autogenous shrinkage are identical until the concrete has set[3]

TEST METHODS AND ASSESSMENT

While it's difficult to separate the effects experimentally, test methods have been developed for evaluating thermal effects, chemical shrinkage, autogenous deformation, and drying shrinkage. Methods and commercial software useful for assessing the effects of restrained volume changes are discussed in detail in the committee report. A summary follows:

Thermal effects

The rate of thermal expansion of concrete is particularly difficult to measure at early ages due to the confounding influence of hydration, but a provisional test method—AASHTO TP 60—has been developed. This test method determines the coefficient of thermal expansion of concrete. A test consists of subjecting a saturated concrete specimen to temperature cycles (called segments) and measuring the length change using a linear variable differential transformer. The specimen is placed in a water bath and tested in the saturated condition to eliminate the effects of the changing moisture conditions of the sample.

Chemical shrinkage and autogenous deformation

Chemical shrinkage is an internal reduction in absolute volume of solids and liquids associated with the hydration of cementitious materials. Chemical shrinkage occurs at a microscopic scale as long as hydration takes place. It can be measured by two methods: dilatometry and weighing reduced buoyancy. An external water source is used in both of these methods. In the dilatometry test (ASTM C1608), an Erlenmeyer flask or glass vial containing a cement paste sample is connected to a pipette in which the dropping water level is monitored. The reduced buoyancy test is based on Archimedes' principle that a water-submerged sample will register a volume reduction by a mass increase. Autogenous deformation (shrinkage) is the macroscopic volume reduction (visible dimensional change) of cement paste or concrete caused by internal stresses due to self-desiccation.

Because autogenous shrinkage occurs in the hardened paste structure, it causes a much smaller reduction in absolute volume than chemical shrinkage. Autogenous shrinkage can be measured either as a volume or length change. In the volume change method, variations in the volume of the cement paste sample (submerged in water and sealed) are determined from mass measurements. But re-absorption of the bleed water, which reduces the self-desiccation of the sample, may be an important factor affecting this method.

In the length change measurements, the cement paste sample is placed in a mold with low friction. The length change is recorded by a displacement transducer. The measurements will be affected by the geometry of the sample, the friction between the sample and mold, and the state of the sample (fluid or set). One of the methods for measuring the linear length change of the sample is being standardized by the ASTM C09-68 Subcommittee on volume change. Although in autogenous shrinkage tests the samples are sealed, the so-called impermeable membranes that are commonly used are actually permeable to water during the course of the test.

Restrained drying shrinkage

The ring test (AASHTO PP34-98 and ASTM C1581) is used to evaluate cracking sensitivity or time-to-cracking due to restrained drying shrinkage. A concrete (or cement paste) annulus is cast around a stiff steel ring that restrains shrinkage, resulting in the development of tensile stresses.

Strain is generally measured using four strain gauges mounted on the inner surface of the steel ring, and the measured strain can be used to compute residual stress and creep or relaxation.

Shrinkage cracking can also be assessed by using a frame composed of two mild-steel crossheads connected by two stiff nickel-steel-alloy side bars. The concrete specimen is fixed at both ends by placing the fresh concrete directly into the dovetails in each crosshead. The alloy side bars are designed to minimize temperature-induced length change. Each bar is equipped with strain gauges to measure the combined thermal and autogenous shrinkage.

Analysis tools

Commercial finite element analysis software programs can be used to analyze and predict the effects of strain due to shrinkage and changes in temperature. Many programs can include the effects of changes in strength, modulus, and cracking tendency at early ages.

MITIGATION

The committee report provides recommendations for reducing the risk for early-age cracking of concrete. Some of the recommendations include:

Placement temperature

Cracking susceptibility is highly sensitive to the placement temperature. Low placement temperatures reduce the heat of hydration, thereby reducing the zero-stress temperature. Lowering the zero-stress temperature decreases the subsequent temperature drop during cooling, which in turn reduces tensile stresses.

Aggregate selection

Thermal deformations may be drastically reduced by using aggregates with a low coefficient of thermal expansion. Properties such as density, heat capacity, and thermal conductivity also influence heat transfer and thermal stresses. Crushed aggregates with a rough surface increase the tensile strength of the concrete.

Increasing the aggregate content generally reduces the shrinkage and potential for shrinkage cracking. This can be accomplished by favorable grading of the aggregates and by the use of larger aggregate. Lowering the amount of cement paste necessary for workability also results in lower heat of hydration. Larger aggregates, however, tend to reduce the tensile strength of the concrete.

Binder system

Low-alkali portland cements that are not too fine and have high sulfate content in relation to the C_3A content lead to low cracking temperatures; however, in high-alkali cements, an increased sulfate content does not reduce the cracking sensitivity. Minimizing the C_3S content may reduce chemical shrinkage and, consequently, autogenous shrinkage. Cracking may be reduced by modifying the particle size, altering the rate of reaction and resulting pore structure.

The cracking temperatures also decrease as the cement content decreases for concretes with a *w/cm* between 0.4 and 0.7. But when the *w/cm* exceeds 0.7, cracking temperatures increase due to the decrease in the concrete tensile strength. Fly ash as a replacement of portland cement may reduce the cracking temperature.

Slag cements work well in reducing the rate of heat development in concrete and reducing thermal deformations, but they also slow the strength development.

This causes an increase in cracking temperatures (lack of tensile strength at early ages).

Experimental observations indicate that autogenous shrinkage is increased by a reduction in *w/cm* and increase in the fineness of the cement or an addition of silica fume. Although slag cements reduce autogenous deformations at early ages due to cementitious dilution effects, the benefits are offset by low tensile strengths at early ages.

The ultimate tensile strain capacity of air-entrained concrete is approximately 20% higher than that of normal concrete. Air-entrained concretes also have lower elastic moduli, reducing restraint stresses. Adding an air-entraining agent to the concrete to achieve an air content of 3 to 6% by volume may reduce the cracking temperature by about 9°F (5°C).

Shrinkage-reducing admixtures

A shrinkage-reducing admixture (SRA) reduces shrinkage primarily by reducing the surface tension of the pore fluid. They may be mixed into the concrete or added topically. In restrained shrinkage tests, concrete is more resistant to early-age cracking if an SRA is used. SRAs have been observed to delay cracking, decrease the width of cracks that develop, and increase the spacing of the cracks.

Expansive additives

Shrinkage-compensating concretes use an expansion of the concrete matrix rather than reduction of shrinkage. These expansions may be obtained mainly through ettringite formation or calcium hydroxide formation. It's difficult to control the chemical reaction in the field. Rapid slump loss is often observed due to rapid formation of ettringite. Special precautions should be exercised to ensure the proper supply of moisture for the expansive reactions.

Internal curing

Internal curing can mitigate shrinkage by placing a material within the concrete that will release water to compensate for the water consumed by hydration. The medium used for water compensation may be lightweight aggregate, superabsorbent polymer, or a cellulose product.

PRACTICAL DEVELOPMENTS

The causes of early-age cracking include thermal contraction, autogenous shrinkage, and drying shrinkage. The restraint of these volume changes results in stresses that will lead to cracking if they exceed the tensile strength of the concrete. Creep may be beneficial in that it reduces stress, but it may also be detrimental to long-term serviceability if it leads to excessive deflections or loss of prestress.

In testing, it's difficult to separate the effects of temperature, autogenous shrinkage, and drying shrinkage. It's also difficult to determine the coefficient of thermal expansion because the response of concrete to temperature change varies during early ages.

Even so, laboratory testing—borne out by field experience—has led to a number of practical methods for evaluating and reducing the risk of early-age cracking. These include reducing the placement temperature of the concrete, selecting an aggregate with a low coefficient of thermal expansion, using a favorable grading, using a large maximum size aggregate, using a relatively coarsely ground cement with a low alkali content and a high sulfate content relative to its C_3A content, substituting fly ash for some of the cement, using entrained air, and using SRAs.

References

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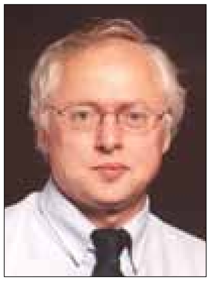
Note: Additional information on the AASHTO and ASTM standards discussed in this article can be found at **www.transportation.org** and **www.astm.org**, respectively.

Selected for reader interest by the editors.



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Calendar and Upcoming Events 2011-2012

Chapter meetings are held at the Royal Glenora Club in Edmonton on the second Wednesday of the month and at the Blackfoot Inn in Calgary on the Thursday.

Please mark these days on your calendar – topic to follow and will be posted on our Events page.

For more information please click here.

Event Description	Venue	Date
October Luncheon	Edmonton Calgary	12 Oct 2011 13 Oct 2011
November AGM Luncheon	Edmonton Calgary	9 Nov 2011 10 Nov 2011
January Luncheon	Edmonton Calgary	11 Jan 2012 12 Jan 2012
February Luncheon	Edmonton Calgary	8 Feb 2012 9 Feb 2012
Spring Seminar	Edmonton Calgary	7 Mar 2012 8 Mar 2012
April Luncheon	Edmonton Calgary	11 Apr 2012 12 Apr 2012
May Site Visit	Edmonton Calgary	9 May 2012 10 May 2012

ACI Golf Tournament

The Annual ACI Golf Tournament will be held Thursday September 22, 2011 at the Riverbend Golf Course in Red Deer. For more information please see our Events on our website.