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The Economics, Performance, and Sustainability of Internally Cured Concrete, Part 2

ACI Fall 2012 Convention
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ACI
WEB SESSIONS

SP 290-2
History and Evolution of Internal Curing of Concrete

12 Case Studies using 9 Different Absorptive Aggregates from Texas and Oklahoma to Eastern Canada

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The Genesis, Evolution and Accelerated Use of Internal Curing How it Provides Improved Life Cycles at Reduced Cost

- **Abstract**
- First noticed by T.C. Powers et al in 1948, and then described by Bloem, Gaynor and Meininger in 1965 as beneficial for hydration by supplying water internally, construction users in 2012 have grasped how the process is implemented, how the hydration behaves and how the improvements in mechanical properties, durability and cost may be beneficial. Since external curing does not meet the time dependent hydration needs of the concrete except near the surface, having sufficient water internally available, when as and where needed, is vital for achieving optimum characteristic qualities. There is lower life cycle cost with internal curing (IC) and frequently lower first cost. In 2012, the number of projects using internal curing is increasing at an escalating rate because the process is simple and economically implemented. Pavements, bridges, buildings and pervious parking lots are being started now, in this recession, because construction users are saving dollars as they build longer lasting structures when costs and interest rates are low. Developed by hundreds of researchers and innovators initially to reduce autogenous shrinkage in low water-cement ratio and high performance concrete, users have found that it reduces drying shrinkage in medium water-cement ratio concrete. Other attributes have been found that include permeability reduction (with consequent less corrosion of reinforcing steel), greater compressive, flexural and mortar strength, less warping, stronger interfacial transition zones, greater durability, and lower carbonation. The amount of absorbed water needed in normal weight aggregate was ascertained by Dale Crowl in 2002 and proven by Eric Mack and Norbert Delatte in 2004. The amount of lightweight aggregate needed as a normal weight sand replacement was reported by Dale Bentz, et al in "Concrete International", February, 2005.

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Self-Curing Concrete, Why Not?

by Bryant Mather

In a letter in the September 2000 issue of *Concrete International, D. Srinivasan asked, "Will there be a self-curing concrete?" My answer to this is strongly affirmative for three reasons. First, most of the concrete that is produced and placed each year all over the world already does self-cure. Some of it wasn't intended to have anything done to its exterior surface. But finishing did in fact take place, and yet the concrete's ability to serve its intended purpose had not been significantly reduced.*

It was this fact that prompted Russell Fling, when he became ACI President, to ask the Technical Activities Committee (TAC) to re-establish the Institute's Curing Committee. The charge to the committee arose from President Fling's experience that a lot of the concrete with which he was concerned received no treatment under the label of "curing," yet seemed to be no worse for that having been the case. I was given the job of chairing that committee. The committee's report stated in its Section 1.2:

"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. No action to this end is required, however, when ambient conditions of moisture, humidity, and temperature are sufficiently favorable to curing. Otherwise, specified curing measures shall start as soon as required."

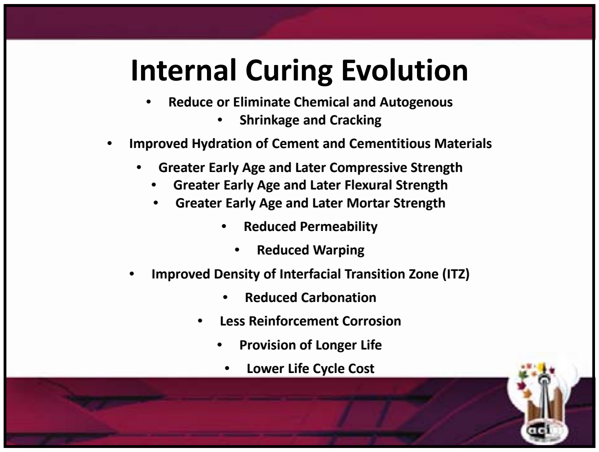
Second, most of the concrete in the world is placed in quantities that are of sufficient thickness such that most of the material will remain in satisfactory conditions of temperature and moisture during its early stages. This is so regardless of what steps are taken, or not taken, to ensure that such conditions are maintained in the exterior layer.

Third, there are cases in which concrete has been greatly assisted in moving toward a self-curing status either inadvertently or deliberately through actions taken in the selection and use of materials.I think it may have been Rudy Valore who told me the following story about concrete in Dallas,TX. Cedric engineers and contractors to use structural low-density Wilson, at Texas Industries, was trying to encourage (lightweight) aggregate concrete. He arranged for its experimental use in half of the construction of the second floor slab of a small motel on a street corner; the other half was placed using normal-density aggregate. The low-density aggregates were batch wet. When the time came, in the late afternoon, to apply the white pigmented curing compound that would form a protective membrane, the contractor's representative at the site decided to skip this step since the wind direction was such that, had he applied it, a lot of effort would have been spent getting membrane material off the cars parked downwind. The next morning, Cedric went to see how his low-density concrete had turned out and was surprised and pleased. The normal-density concrete was virtually destroyed by drying shrinkage cracks. On the other hand, the low-density concrete had practically no cracking enough absorbed water had been brought to the concrete, though not included in the water-cement ratio, to effectively compensate for the contractor's failure to apply forming curing compound.

We at the Corps of Engineers Concrete Laboratory used this

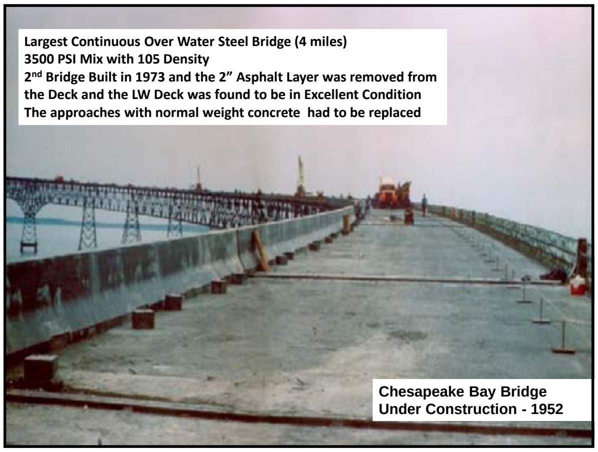
Concrete International

- **Curing, internal** - supplying water throughout a freshly placed cementitious mixture using reservoirs, via pre-wetted lightweight aggregates, that readily release water as needed for hydration or to replace moisture lost through evaporation or self-desiccation.
  - **ACI Terminology 2011**



Internal Curing Evolution

- Reduce or Eliminate Chemical and Autogenous
- Shrinkage and Cracking
- Improved Hydration of Cement and Cementitious Materials
- Greater Early Age and Later Compressive Strength
- Greater Early Age and Later Flexural Strength
- Greater Early Age and Later Mortar Strength
- Reduced Permeability
- Reduced Warping
- Improved Density of Interfacial Transition Zone (ITZ)
- Reduced Carbonation
- Less Reinforcement Corrosion
- Provision of Longer Life
- Lower Life Cycle Cost

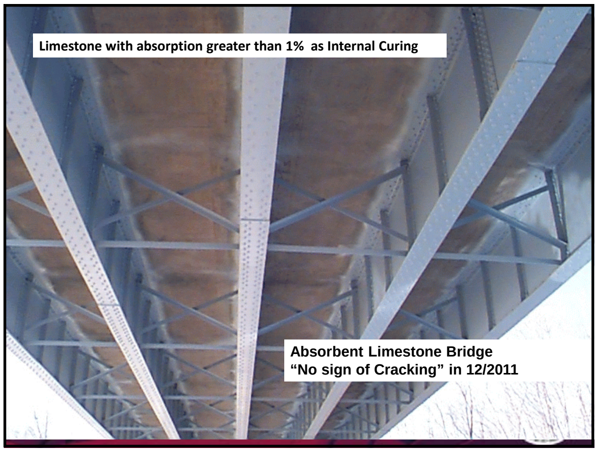


Largest Continuous Over Water Steel Bridge (4 miles)
3500 PSI Mix with 105 Density
2nd Bridge Built in 1973 and the 2” Asphalt Layer was removed from the Deck and the LW Deck was found to be in Excellent Condition
The approaches with normal weight concrete had to be replaced

Chesapeake Bay Bridge
Under Construction - 1952

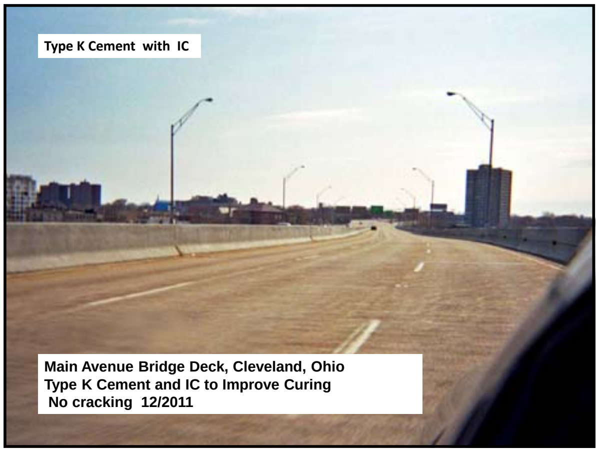
The LW aggregate in the concrete in 1952 was batched at SSD

Chesapeake Bay Bridge
60 Years Later - January 2012



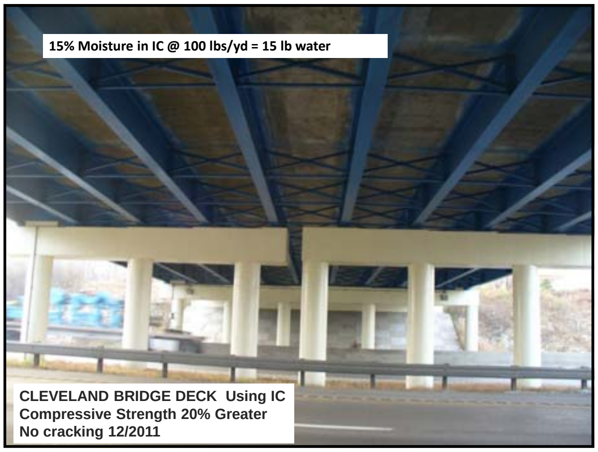
Limestone with absorption greater than 1% as Internal Curing

Absorbent Limestone Bridge
“No sign of Cracking” in 12/2011



Type K Cement with IC

Main Avenue Bridge Deck, Cleveland, Ohio
Type K Cement and IC to Improve Curing
No cracking 12/2011



15% Moisture in IC @ 100 lbs/yd = 15 lb water

CLEVELAND BRIDGE DECK Using IC
Compressive Strength 20% Greater
No cracking 12/2011

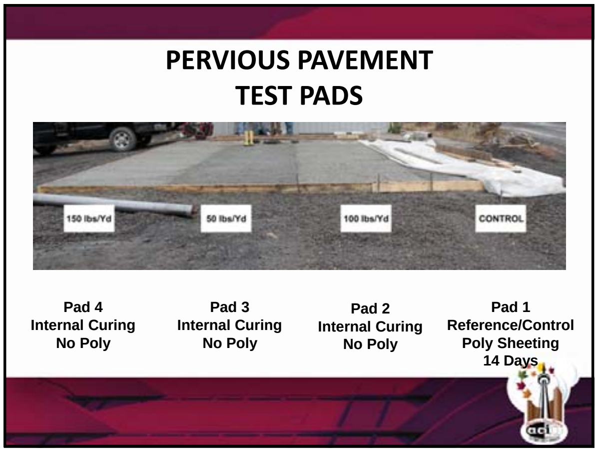
Lightweight Aggregate
Infiltration Base Prior to
Placement of Pads 1-4

Placement

PERVIOUS PAVEMENT

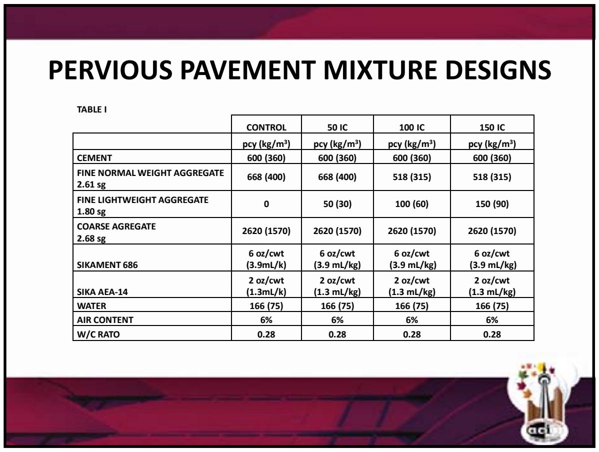
Control Texture

Addition of 100# of LWAS Texture



PERVIOUS PAVEMENT TEST PADS

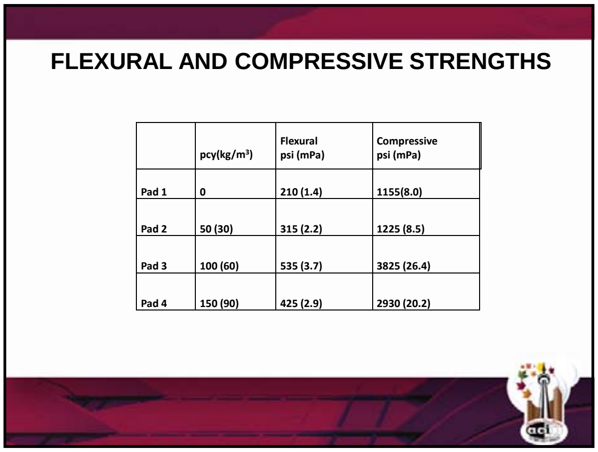
Pad 4	Pad 3	Pad 2	Pad 1
Internal Curing No Poly	Internal Curing No Poly	Internal Curing No Poly	Reference/Control Poly Sheeting 14 Days



PERVIOUS PAVEMENT MIXTURE DESIGNS

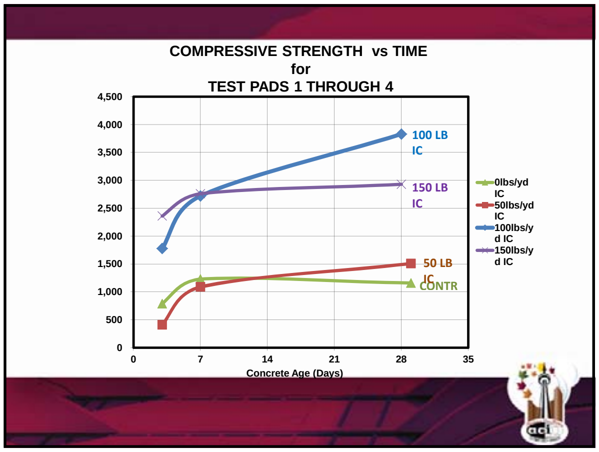
TABLE I

	CONTROL	50 IC	100 IC	150 IC
	pcy (kg/m³)	pcy (kg/m³)	pcy (kg/m³)	pcy (kg/m³)
CEMENT	600 (360)	600 (360)	600 (360)	600 (360)
FINE NORMAL WEIGHT AGGREGATE 2.61 sg	668 (400)	668 (400)	518 (315)	518 (315)
FINE LIGHTWEIGHT AGGREGATE 1.80 sg	0	50 (30)	100 (60)	150 (90)
COARSE AGREGATE 2.68 sg	2620 (1570)	2620 (1570)	2620 (1570)	2620 (1570)
SIKAMENT 686	6 oz/cwt (3.9mL/k)	6 oz/cwt (3.9 mL/kg)	6 oz/cwt (3.9 mL/kg)	6 oz/cwt (3.9 mL/kg)
SIKA AEA-14	2 oz/cwt (1.3mL/k)	2 oz/cwt (1.3 mL/kg)	2 oz/cwt (1.3 mL/kg)	2 oz/cwt (1.3 mL/kg)
WATER	166 (75)	166 (75)	166 (75)	166 (75)
AIR CONTENT	6%	6%	6%	6%
W/C RATO	0.28	0.28	0.28	0.28



FLEXURAL AND COMPRESSIVE STRENGTHS

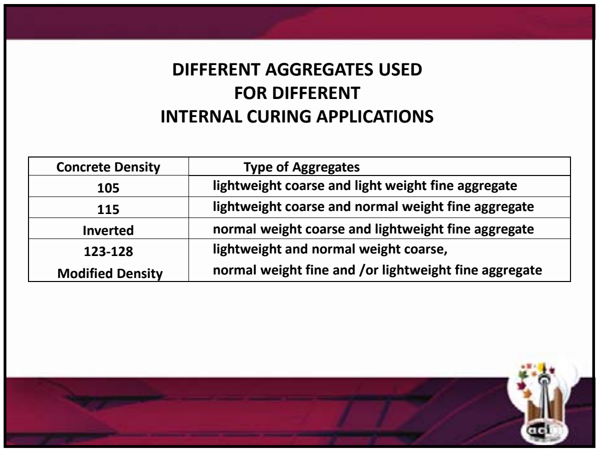
	pcy(kg/m³)	Flexural psi (mPa)	Compressive psi (mPa)
Pad 1	0	210 (1.4)	1155(8.0)
Pad 2	50 (30)	315 (2.2)	1225 (8.5)
Pad 3	100 (60)	535 (3.7)	3825 (26.4)
Pad 4	150 (90)	425 (2.9)	2930 (20.2)



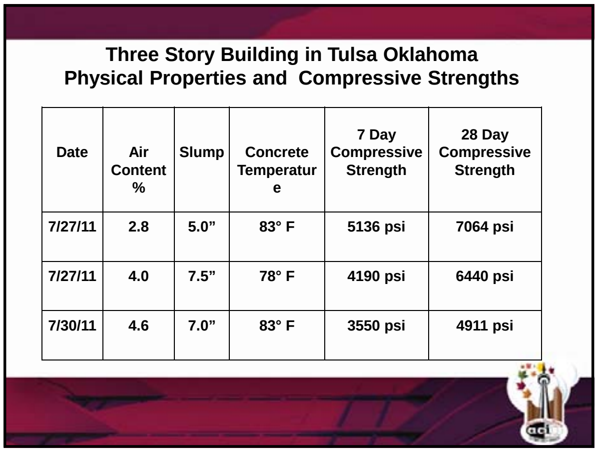

DENVER WATER
IC SLAB
PLACEMENT
10 Million Gallon
Water Storage
Tank with 285 lb IC
= 43 lb/yd (5 gal)


DENVER WATER Monolithic Pour
Contractor also used IC walls &
columns – No shrinkage cracks

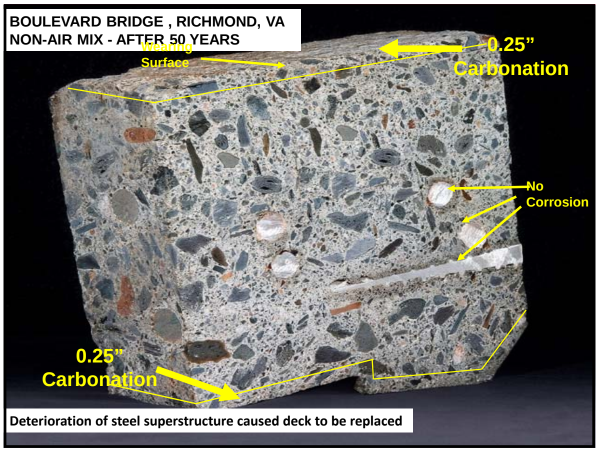

DENVER WATER
IC ROOF
PREPARATION


DIFFERENT AGGREGATES USED
FOR DIFFERENT
INTERNAL CURING APPLICATIONS

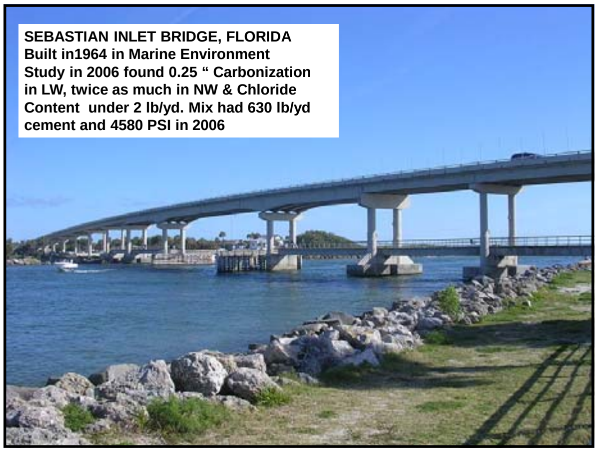
Concrete Density	Type of Aggregates
105	lightweight coarse and light weight fine aggregate
115	lightweight coarse and normal weight fine aggregate
Inverted	normal weight coarse and lightweight fine aggregate
123-128 Modified Density	lightweight and normal weight coarse, normal weight fine and /or lightweight fine aggregate

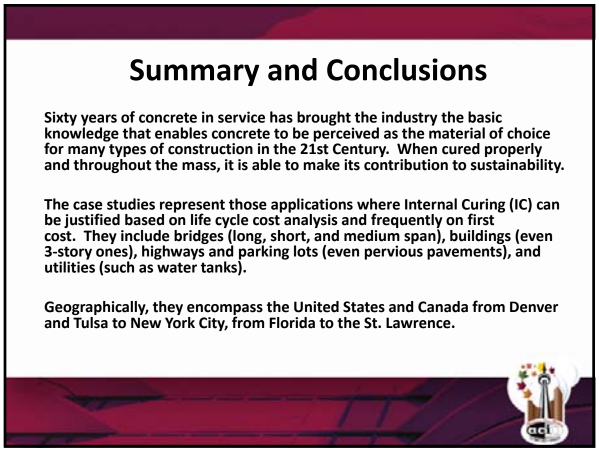

Three Story Building in Tulsa Oklahoma
Physical Properties and Compressive Strengths

Date	Air Content %	Slump	Concrete Temperature	7 Day Compressive Strength	28 Day Compressive Strength
7/27/11	2.8	5.0”	83° F	5136 psi	7064 psi
7/27/11	4.0	7.5”	78° F	4190 psi	6440 psi
7/30/11	4.6	7.0”	83° F	3550 psi	4911 psi


BOULEVARD BRIDGE , RICHMOND, VA
NON-AIR MIX - AFTER 50 YEARS

Deterioration of steel superstructure caused deck to be replaced

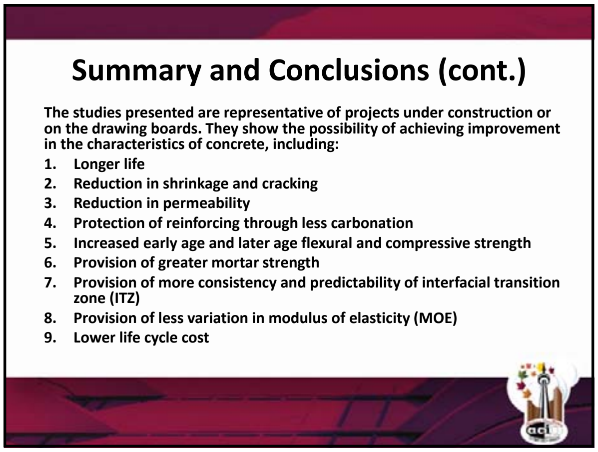

SEBASTIAN INLET BRIDGE, FLORIDA
Built in1964 in Marine Environment
Study in 2006 found 0.25 “ Carbonization in LW, twice as much in NW & Chloride Content under 2 lb/yd. Mix had 630 lb/yd cement and 4580 PSI in 2006


Summary and Conclusions

Sixty years of concrete in service has brought the industry the basic knowledge that enables concrete to be perceived as the material of choice for many types of construction in the 21st Century. When cured properly and throughout the mass, it is able to make its contribution to sustainability.

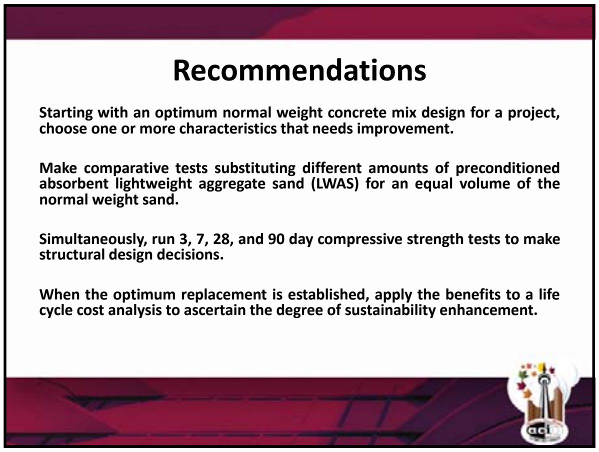
The case studies represent those applications where Internal Curing (IC) can be justified based on life cycle cost analysis and frequently on first cost. They include bridges (long, short, and medium span), buildings (even 3-story ones), highways and parking lots (even pervious pavements), and utilities (such as water tanks).

Geographically, they encompass the United States and Canada from Denver and Tulsa to New York City, from Florida to the St. Lawrence.


Summary and Conclusions (cont.)

The studies presented are representative of projects under construction or on the drawing boards. They show the possibility of achieving improvement in the characteristics of concrete, including:

1. Longer life
2. Reduction in shrinkage and cracking
3. Reduction in permeability
4. Protection of reinforcing through less carbonation
5. Increased early age and later age flexural and compressive strength
6. Provision of greater mortar strength
7. Provision of more consistency and predictability of interfacial transition zone (ITZ)
8. Provision of less variation in modulus of elasticity (MOE)
9. Lower life cycle cost

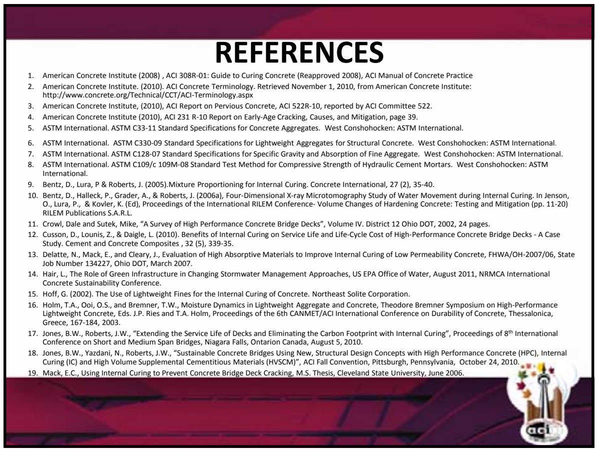

Recommendations

Starting with an optimum normal weight concrete mix design for a project, choose one or more characteristics that needs improvement.

Make comparative tests substituting different amounts of preconditioned absorbent lightweight aggregate sand (LWAS) for an equal volume of the normal weight sand.

Simultaneously, run 3, 7, 28, and 90 day compressive strength tests to make structural design decisions.

When the optimum replacement is established, apply the benefits to a life cycle cost analysis to ascertain the degree of sustainability enhancement.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Thank You

Questions