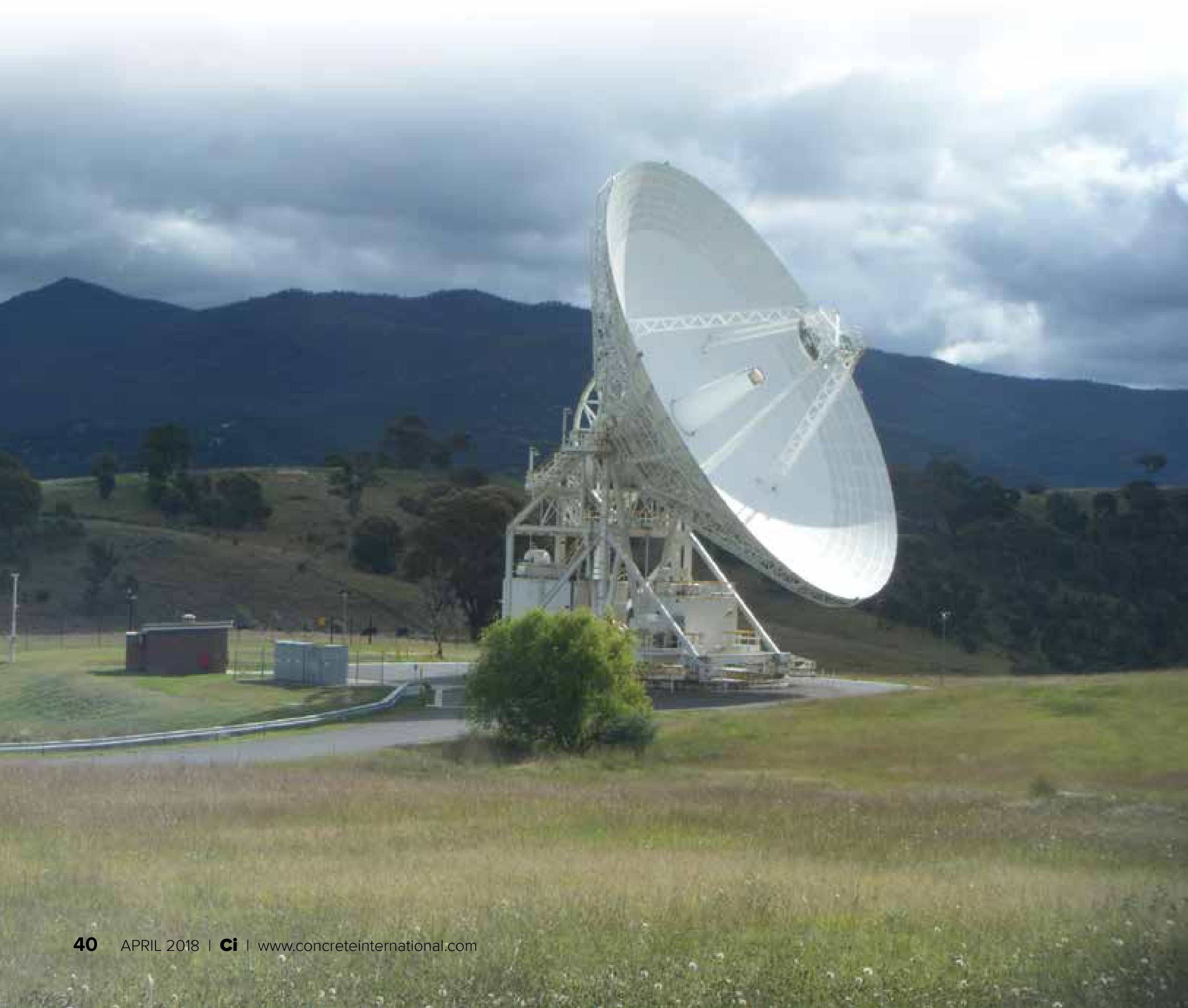
Reinforced Concrete Antenna Pedestal

Evaluation of concrete consolidation using nondestructive testing and statistical analysis

by Benjamin P. Saldua, Ethan C. Dodge, Peter R. Kolf, and Carlton A. Olson



The Deep Space Network (DSN) is a National Aeronautics and Space Administration (NASA) entity managed, technically directed, and operated by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology (Caltech). Designed to maintain communications with spacecraft, the DSN consists of three facilities spaced equidistant from each other—about 120 degrees apart in longitude—around the world. These sites are near Barstow, CA; Madrid, Spain; and Canberra, Australia.

An antenna pedestal recently constructed at the Canberra Deep Space Communications Complex is the subject of this article. The pedestal is a cylindrical structure with a suspended roof slab. After the formwork had been removed, evidence of poor concrete consolidation was visible in the slab soffit. The general contractor contracted with several local testing firms to identify other deficiencies. These firms deployed ground penetrating radar (GPR) and ultrasonic pulse velocity (UPV) test methods, and they removed and tested concrete cores. However, they could find no correlation between the results of the core tests and the observations made using nondestructive test methods. Due to the inconsistency of the results, JPL decided to conduct its own investigation. CTLGroup, Skokie, IL, was contracted to conduct the investigation using alternative nondestructive test methods.

Antenna Pedestal

The subject structure is a circular reinforced concrete pedestal with one level below grade and a roof slab at approximately grade elevation. The pedestal contains an outer track wall with an inner radius of 9365 mm (31 ft), a width of 900 mm (35 in.), and a height of about 360 mm (14 in.) above the roof slab. The pintle wall at the center of the roof structure has an inner diameter of 2743 mm (9 ft), a width of 600 mm (24 in.), and a height of 790 mm (31 in.). The roof slab of the structure is 600 mm thick at the perimeter track and thickens toward the pintle to provide a 1% drainage slope. The roof slab is reinforced with radial and circumferential reinforcing.

The contractor reported that concrete placement of the roof slab and outer track wall began by filling the outer track forms and adjacent main roof slab to near the roof slab final elevation. Placement then continued from the center outward, in wedge-shaped sections (Fig. 1). After the concrete in the outer track had stiffened enough to be filled above the main slab elevation, the final layer was placed and the lifts vibrated together. Experience has shown that the most likely problem areas would be the lift line between outer perimeter lifts and below the lap splices of the upper and lower reinforcing mats in the roof slab. This was at least partially confirmed by reports that the slab soffit had exhibited zones of poor concrete consolidation at the lower mat lap splices. These locations had been chipped to sound concrete by the time our investigation commenced.

Project

The scope of work included evaluation of concrete consolidation, development of a conceptual repair design, and observation of repairs during execution. This article discusses the application of nondestructive testing to identify areas with concrete deficiencies, including a statistically based analysis for interpretation of the data. This article also discusses the repair procedures that were developed based on the nondestructive test results, the observed concrete deficiency types, and the structural requirements.

Test program

An orthogonal grid spacing of 300 mm (12 in.) was used to investigate the topside and underside of the roof slab (Fig. 2). Some locations with soffit voids were superimposed onto the top surface using blue paint. About 7000 impulse-response (IR) tests, according to ASTM C1740,[1] were conducted on the top surface and most of the soffit.

Fig. 1: Concrete placement of the antenna roof slab. Note that the concrete vibrator is not being applied near either delivery point

Fig. 2: Test grid marked on roof slab topside (blue lines outline underside concrete removal areas)

The IR test method uses a low-strain impact from a 1 kg (2.2 lb) hammer with a built-in load cell to excite the structure. The maximum compressive stress at the impact point in the concrete is directly related to the elastic properties of the hammer tip. The response to the impact stress is normally measured by a velocity transducer (geophone). The geophone velocity spectrum is divided by the force spectrum to obtain a transfer function, referred to as the mobility of the element under test.

Based on the IR test results and visual observations, locations were selected for the application of the ultrasonic shear-wave tomography (UST) testing technique (commonly known as "MIRA"). MIRA is a phased array system applicable for nondestructive concrete testing using low-frequency ultrasonic waves (20 to 100 kHz) and advanced methods of signal processing. This system represents one of the most advanced techniques currently available in diagnosing defects in concrete. This equipment is used to image the internal condition of a concrete structure using pulse-echo technique, conducted from one side of the test element. It detects presence of internal defects such as cracks and voids, and it evaluates their approximate depths and extents.

Data collection

Contour maps displaying the average mobility values were generated from the IR data. Combined with MIRA test results, visual observations, and hammer sounding, these maps were used to select areas for concrete coring and investigative concrete removal.

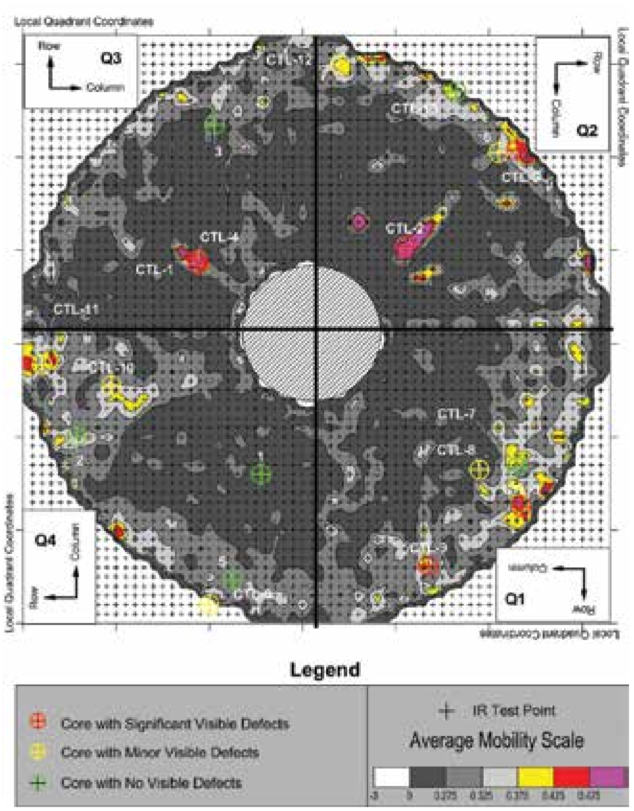


Fig. 3: Topside impulse response (IR) average mobility results and core locations/condition

GPR was used to lay out the locations of reinforcing bars prior to coring. GPR uses high-frequency electromagnetic energy, typically 900 to 2600 MHz, for rapidly and continuously assessing a variety of characteristics of the subsurface being tested. A single contacting transducer (antenna) is used for transmitting and receiving radar signals. High frequency, short pulse electromagnetic energy is transmitted into the tested medium (usually concrete or soil); each transmitted pulse travels through the element being tested and is partially reflected when it encounters a change in dielectric constant. The dielectric constant will change when the material type changes—for example, at a void or reinforcing steel.

Because IR is a relative test method that measures the response of a structure to a known force input, measured changes in structural response are evaluated by performing statistical analyses, additional testing such as impact-echo (IE) testing or MIRA, and by destructively opening areas and/or removing core samples for visual inspection. A total of 17 concrete cores were removed to confirm the IR test results and to support the visual observations. IR average mobility test results for the top surface combined with core locations that are color coded for observed conditions are shown in Fig. 3. The four quadrants have been combined to show the test results for the entire roof slab.

IR data analysis

For the data analysis, the roof slab was divided into four separate designated quadrants (Q1 through Q4), shown in Fig. 3. Given that the computed IR average mobility values from each quadrant were statistically similar, it was decided to perform the analysis on the ensemble of the combined data set. The basic assumption used to interpret the IR data is that portions of the structure do not contain defects or changes in structural condition. It is the sound uniform portion of the structure that is used to establish the expected structural response and appropriate standard deviations. Experience has shown that, typically, sufficient sound areas are present to perform this analysis even when significant defective regions are also present. Application of the statistical analysis method to average mobility values outlines the following general guidelines for comparison with the expected structural response[2]:

- Average mobility values within 2 standard deviations of the mean indicate no significant changes in concrete condition;
- Average mobility values between 2 and 4 standard deviations of the mean are indicative of material changes such as lower strength, increased entrapped air voids, surface deterioration, or other minor localized defects; and
- Average mobility values greater than 4 standard deviations from the mean indicate significant concrete deficiencies.

The expected structural response (average of all areas without significant defects) used was an IR mobility value of 0.275 with a standard deviation of 0.05. These values were obtained from Q4, which had very few defects, and were roughly consistent with values from the overall data after high values were removed (that is, data with mobility values less than 0.425 or approximately 3 standard deviations from the mean). Approximately 95% of the values were within 2 standard deviations, 4% were between 2 and 4 standard deviations, and 1% were greater than 4 standard deviations from the mean. The IR results showed widespread low magnitude variation without visible signs of surface deterioration, indicating that subtle defects and material variations were probable.

For this project, significant voids produced average mobility values greater than 0.475. The value of 0.475 corresponds to about 4 standard deviations from the average response which, in our experience, is commonly associated with significant defects in similar structures. All cores removed in or adjacent to areas with mobility greater than 0.475 revealed significant defects (CTL-1, CTL-2, CTL-3, CTL-5, and CTL-9). All cores removed in or adjacent to areas with mobility greater than 0.425, but less than 0.475, revealed signs of concrete irregularities (CTL-6, CTL-11, and Core 6). All cores removed in or adjacent to areas with mobility values within 2 standard deviations of the mean exhibited only minor irregularities.

MIRA test results

A significant void below the top reinforcing steel was distinguishable from the MIRA test results (Fig. 4) at the location of core CTL-2. However, in areas with material variations such as an increase in entrapped air pockets or the cold joint at the location of core CTL-3, significant defects could not be readily distinguished by MIRA.

Repairs

Results of nondestructive testing and material sampling revealed that significant defects could be identified reliably and that the pedestal structure could be effectively repaired to ensure structural integrity and long-term durability.

The repair program consisted generally of the following:

- Soffit—As expected, and as demonstrated by the IR test results, significant defects on the slab underside were primarily limited to the lap splice zones under the lower reinforcing mat. Shotcrete was selected as the repair material for the soffit repairs. Due to the presence of large diameter bars and laps, cavity areas above reinforcing steel were filled with trowel-grade mortar prior to shotcrete application. The preparation, cavity filling, and final shotcrete repair are shown in Fig. 5;
- Perimeter Track—Presence of significant reinforcing in perimeter track walls precluded the use of nondestructive testing techniques. Therefore, a combination of visual inspection and careful exploratory concrete removal was

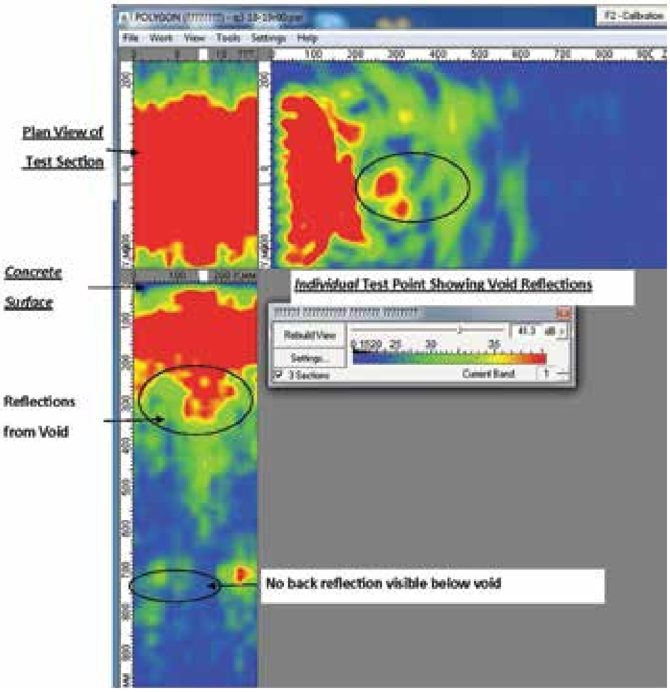


Fig. 4: MIRA data showing a void below the upper reinforcing steel near the location of core CTL-2

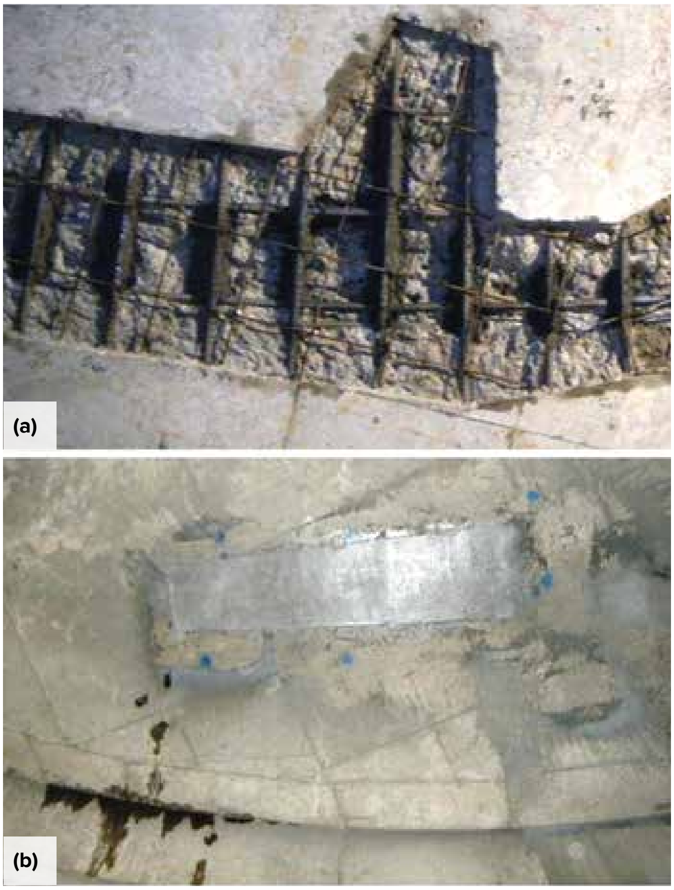


Fig. 5: Shotcrete soffit repair: (a) prepared soffit cavity and mortar packed above reinforcing steel; and (b) completed shotcrete repair

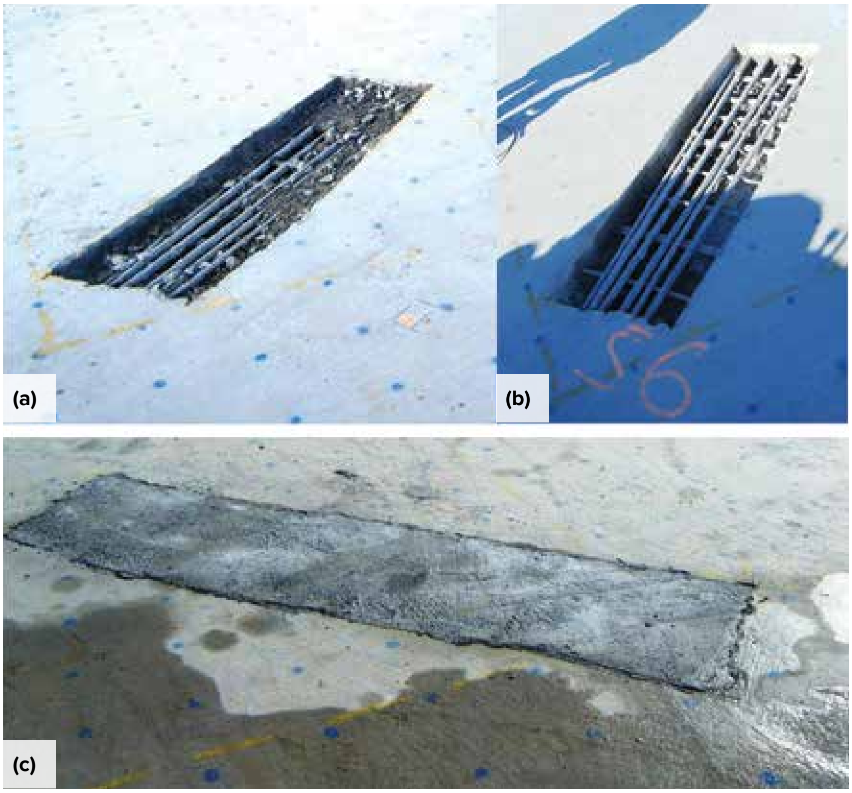


Fig. 6: Top surface repair area: (a) initial chipping of marked repair area; (b) completed chipping and inspection: and (c) completed repair

used to identify areas of concrete for removal and replacement. Voids encountered were generally associated with areas of laps in reinforcing bars. In addition to the repairs stemming from concrete placement delays, a poor bond between the wall placement and the roof slab placement was observed in localized areas; these areas were selected for epoxy injection repairs; and

- Top surface—Concrete repairs of the top surface were "remove and replace" operations. The repair extents and completed repair of the relatively large voided area identified at core location (CTL-2) can be seen in Fig. 6. The protocols for top surface repairs were primarily based off the IR test results:
  - A significant void or defect was presumed to exist at any location where the IR mobility test result was 0.475 or higher. These locations were marked for concrete repairs. Repair excavations were expanded as necessary to remove any defective concrete;
  - Where multiple adjacent IR test points indicated mobility values between 0.425 and 0.475, or single such IR points existed within regions with mobility values greater than 0.375 or adjacent to regions of known defects, coring was recommended to further define potential defects;
  - Where isolated IR test points with mobility values between 0.425 and 0.475 occurred adjacent to regions with mobility values less than 0.375, any potential defect was considered isolated and not in need of further investigation; and
  - No significant defect was presumed to be present where mobility values were less than 0.425.

Conclusions

Based on the information gathered during this project, the following conclusions can be made:

- Overall, it was determined that a combination of hot weather, equipment breakdown, low slump concrete mixture, and poor workmanship resulted in the concrete consolidation deficiencies;
- Nondestructive test methods can be used to evaluate and help identify and effectively repair poor concrete consolidation imperfections like those identified on this project;
- Such nondestructive testing and verification programs can be cost effective. The initial condition evaluation was completed in 4 days on the site;
- Graphical presentation of comprehensive test results and concrete core verification information allows nontechnical personnel to review the information and boosts their level of confidence in the nondestructive test methods; and
- IR statistical evaluation guidelines are effective for characterizing concrete conditions.

Acknowledgments

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Disclaimer

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Selected for reader interest by the editors.

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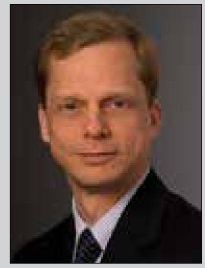

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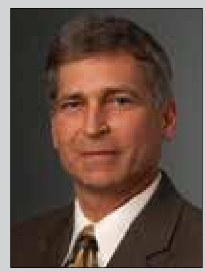

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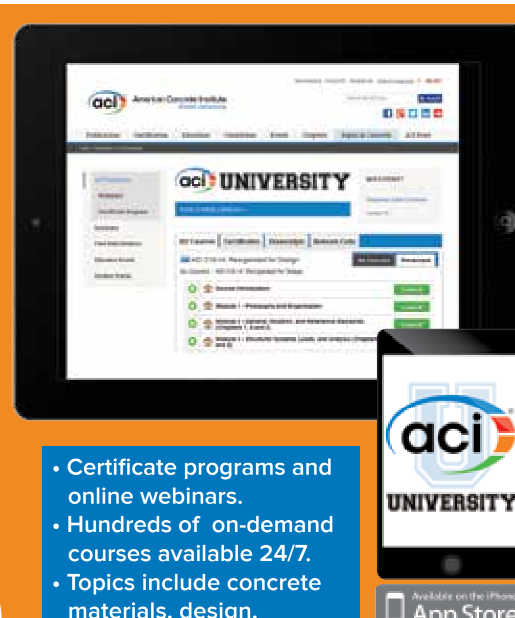

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