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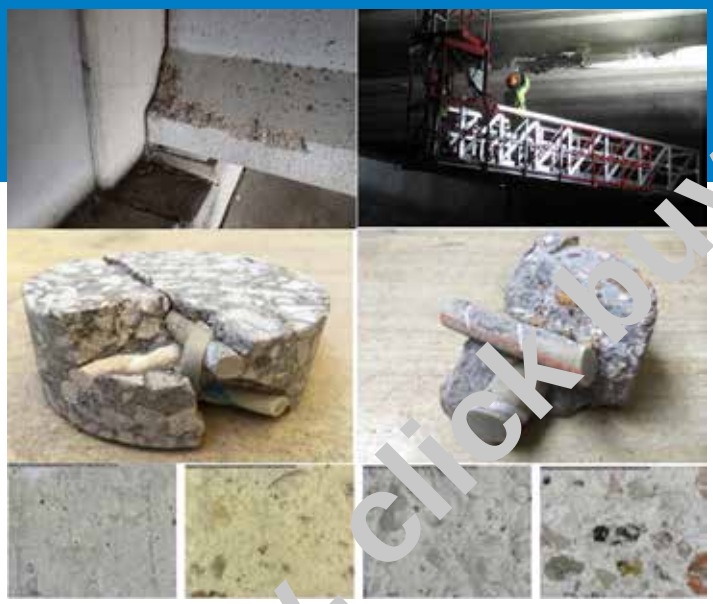

Durability of Concrete Structures Incorporating Conventional and Advanced Materials

Editors:
Yail J. Kim, Isamu Yoshitake,
and Mark F. Green

SP-331

American Concrete Institute
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Preface

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Sustainability is one of the salient requirements in modern society. Structures frequently deteriorate because of aggressive service environments; consequently, federal and state agencies expend significant endeavors to maintain the quality of the structures. Among many factors, durability plays a major role in accomplishing the concept of sustainability. Extensive research has been conducted to understand the deterioration mechanism of concrete and to extend the longevity of concrete members. Over the past decades, the advancement of technologies has resulted in durable construction materials such as advanced composites. This Special Publication (SP) contains nine papers selected from two technical sessions held in the ACI Spring Convention at Detroit, MI, in March 2017. All manuscripts were reviewed by at least two experts in accordance with the ACI publication policy. The Editors wish to thank all contributing authors and anonymous reviewers for their rigorous efforts. The Editors also gratefully acknowledge Ms. Barbara Coleman at ACI for her knowledgeable guidance.

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Thermal Detection of Subsurface Delaminations in Reinforced Concrete Bridge Decks Using Unmanned Aerial Vehicle

Tarek Omar and Moncef L. Nehdi

Synopsis: Bridge deck condition assessment is commonly conducted through visual inspection by bridge inspectors. Considering the colossal backlog of aging bridge structures, there is a need to develop cost-effective and innovative solutions to evaluate bridge deck conditions on regular time intervals, without interrupting traffic. This makes remote sensing technologies viable options in the field of bridge inspection. This paper explores the potential for applying infrared thermography (IRT) using unmanned aerial vehicle (UAV) to detect and quantify subsurface delaminations in concrete bridge decks. The UAV-borne thermal sensing system focuses on acquiring thermal imagery using a UAV and extracting information from the image data. Two in-service concrete bridge decks were inspected using a high resolution thermal camera mounted on a UAV. The captured images were then enhanced and stitched together using a tailored procedure to produce a mosaic view of the entire bridge deck, indicating the size and geometry of the detected delaminated areas. The results were validated by conducting hammer sounding and half-cell potential testing on the same bridge decks. The findings reveal the capability of the technology to provide measurements comparable to those derived from traditional hands-on inspection methods. Thus, it can be an excellent aid in efficient bridge maintenance and repair decision-making.

Keywords: bridge deck, condition assessment, delamination, infrared, thermal image, unmanned aerial vehicle

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Bond Behavior of Concrete Strengthened with FRP Laminates and NSM Bars Subjected to Accelerated Aging using Freeze-Thaw Cycles

Ian Shaw, Hang Zhao and Bassem Andrawes

Synopsis: Fiber reinforced polymer (FRP) composites have emerged as a lightweight and efficient repair and retrofit material for many concrete infrastructure applications. FRP can be applied to concrete using many techniques, but primarily as either externally bonded laminates or near-surface mounted bars or plates. This paper presents the results of direct shear pull-out tests performed on aged concrete specimens reinforced with glass FRP (GFRP) and carbon FRP (CFRP) externally bonded laminates and near surface mounted (NSM) bars. An accelerated aging scheme consisting of freeze/thaw cycling in the presence of a deicing salt solution is implemented to determine the effect of long-term environmental exposure on the FRP/concrete interface in regions that experience aggressive winter environments. The results show that the NSM bar technique is superior to externally bonded laminates in terms of efficiency in the use of FRP material and the effects of accelerated aging. Generally, the performance of GFRP is affected less than CFRP after freeze/thaw cycling for both externally bonded laminates and NSM bars. For high strength NSM FRP bar applications, a spalled or cracked concrete surface caused by freeze/thaw cycling may drastically reduce the capacity of the FRP/concrete interface by inducing failure at the concrete/epoxy filler interface.

Keywords: Accelerated aging; Concrete; Durability; Freeze-thaw; FRP; NSM.

SP-331-3

Cyclic Loading Behavior of CFRP-Wrapped Non-Ductile Beam-Column Joints

Ali S. H. Zerkane, Yasir M. Saeed, and Franz N. Rad

Synopsis: Use of fiber reinforced polymer (FRP) material has served as a proper solution to overcome the weakness of concrete members caused by substandard design, changes in the load distribution, or to correct the weakness of concrete structures subjected to hostile weather conditions. Concrete beam-column joints designed and constructed before 1970s were characterized by weak joints. Lack of transverse reinforcement within the joint reign, hence lack of ductility in the joints could be one of the main reasons that many concrete buildings have failed during earthquakes around the world. In the present work, carbon fiber reinforced polymer (CFRP) sheets were used as Externally Bonded FRP System to compensate for the lack of transverse reinforcement in the beam-column joints in order to retrofit the joint region and to transfer the failure to the concrete beams. Six specimens of approximately one-third scale were designed, constructed, and tested. A new technique of rehabilitation scheme is proposed for retrofitting. The scheme proved to be effective in improving the behavior of non-ductile beam-column joints, and to change the final mode of failure. The comparison between beam-column joints before and after retrofitting is presented by load versus deflection, load versus CFRP strain, energy dissipation, and ductility.

Keywords: durability of concrete, cyclic loading, retrofit, CFRP, non-ductile, beam-column joints

SP-331-4

Implications of High Plasticity Soils in Bridge MSE Wall Embankments

Mark E. Williams

Synopsis: Bridge embankments serve a vital role in raising the roadway profile to the bridge deck elevation for passage of vehicles. It is common practice to construct embankments utilizing compacted lifts of soil obtained from nearby borrow pits. Soil borrowed from regions of predominantly expansive clay soils can be problematic for bridge embankment construction. High plasticity soils swell in contact with moisture, inducing vertical and lateral pressure on embankments. Mechanically Stabilized Earth (MSE) walls are particularly susceptible to soil expansion as they try to confine high soil expansion pressures through soil reinforcement and mobilization of a stabilized volume behind the face of the wall. This paper provides insight into the investigation of MSE wall movement, abutment movement and corresponding bridge beam distress, and reinforced concrete failures resulting from high plasticity soil backfill in existing bridge embankments. Remediation strategies are discussed which are directed at the expansive soil behavior within the embankment.
.

Keywords: bridge embankment, MSE wall, expansive soils

SP-331-5

Long-Term Durability of GFRP Internal Reinforcement in Concrete Structures

Omid Gooranorimi, Doug Gremel, John J. Myers, Antonio Nanni

Synopsis: Glass fiber reinforced polymer (GFRP) bars are emerging as a feasible, economical solution to eliminate the corrosion problem of steel reinforcements in concrete structures. Confirmation of GFRP long-term durability is crucial to extend its application especially in structures exposed to aggressive environments. The objective of this study is to investigate the performance of GFRP bars exposed to the concrete alkalinity and ambient condition in two bridges with more than a decade old located in the City of Rolla, Missouri: i) Walker Bridge (built in 1999), which consists of GFRP-reinforced concrete box culverts; and; ii) Southview Bridge (built in 2004), which incorporates GFRP bars in the post-tensioned concrete deck. In order to monitor the possible changes in GFRP and concrete after years of service, samples were extracted from both bridges for various analyses. Carbonation depth, chloride diffusion, and pH of the concrete surrounding the GFRP bars were measured. Scanning electron microscopy (SEM) imaging and energy dispersive X-ray spectroscopy (EDS) were performed to monitor any microstructural degradation or change in the GFRP chemical compositions. Finally, GFRP horizontal shear strength, glass transition temperature (T_g) and fiber content were determined and compared with the results of similar tests performed on pristine samples produced in 2015. SEM and EDS did not show any sign of GFRP microstructural deterioration or existence of a chemical attack. Horizontal shear strength and T_g showed slight improvements while the fiber content was similar to the pristine values. The results of this study suggest that GFRP bars maintained their microstructural integrity and mechanical properties during years of service as concrete reinforcement in both bridges.

Keywords: Box-Culvert; Bridge Deck; Corrosion resistant; Durability; Glass fiber reinforced polymer; Reinforced concrete; Scanning electron microscopy.

SP-331-6

Improving the Durability of Impact Damaged PC Bridge Girders Using CFRP Rod Panel Retrofit

Abheetha Peiris and Issam Harik

Synopsis: An exterior girder of a prestressed concrete bridge over Interstate 65 in Kentucky was damaged due to an over-height truck impact. The damaged section spanned two of the three northbound lanes of the highway. Two prestressing strands were severed and two additional strands were damaged by the impact. In addition, shear reinforcing bars in the vicinity of the impact were cut-off. CFRP Rod Panels (CRPs) were deployed to restore some of the load carrying capacity lost due to the severed prestressing tendons. CRP 195, with CFRP rods of 3.96 mm (0.156 in) diameter, having a capacity of 867 kN (195,000 lbs.) per 305 mm (1 ft.) width of panel, was selected for the flexural strengthening. A triaxial braided quasi-isotropic CFRP fabric was selected for shear strengthening and served as containment of crushed concrete in the event of future over-height impacts. Since the ACI and AASHTO Codes or Guides do not directly address the design with CRPs, strain limits based on debonding of the rods similar to externally bonded CFRP (EB-CFRP) are imposed when determining the retrofitted beam capacity. The load rating evaluation of the impacted beam, the retrofit analysis and design, and the field repair stages are presented and discussed.

Keywords: CFRP, Impact Damage, Load Rating, Prestressed Concrete, Residual Capacity, Retrofit, Rod Panel

SP-331-7

Experimental Investigation of CFRP Prestressed Concrete Beams

Yasir M. Saeed and Franz N. Rad

Synopsis: This paper presents the experimental investigation of concrete beams pre-tensioned with Carbon Fiber Reinforced Polymer (CFRP) strands. Four rectangular prestressed concrete beams were fabricated and tested under cyclic loading, and then the beams were loaded monotonically until failure. All beams were prestressed with one 0.5-in. diameter (13 mm) CFRP strand. The results showed that bond failure between CFRP strands and surrounding concrete was the main cause of early and brittle failures. Adding extra steel stirrups improved the slippage resistance capacity but was not adequate to prevent slippage at higher loads. A new technique was developed and used by anchoring the CFRP strand at the ends using a steel-tube anchorage system. The new technique prevented the slippage and improved the flexural moment capacity by 39%. An analytical computer model was created to predict the load vs. deflection responses of the beams. The behavior of beams with CFRP strands were compared to beams with steel strands using the same computer program. It was found that CFRP beams had more flexural strength but lower ductility if both beams were designed to carry the same service loads.

Keywords: Beams, CFRP, Flexure, FRP Anchors, Prestressed Concrete, Pre-tensioned Concrete

SP-331-8

Behavior of Full-Scale Damaged Beams Repaired Using a Steel Reinforced Polymer (SRP) Technique

Hayder Alghazali, Zuhair Al-Jaberi, Zena Aljazaeri, John J. Myers

Synopsis: Structures may need to be repaired for different reasons, such as, construction or design defects, or service stage changing which include, ageing of structures or deterioration due to exposure to aggressive environmental conditions. New materials are emerging, such as steel reinforced Polymer (SRP) composite, which can be used to strengthen and repair structures with greater durability and less maintenance over the life of the structure.
An experimental test program was carried out to investigate the performance of repaired damaged concrete beams with (SRP) repair technique. Six full-scale reinforced concrete (RC) beams were designed and tested using 4-point load test setup to be failed in lap splice in the middle region of the beam. The damaged concrete was repaired, and SRP sheet (longitudinal soffit laminates and transverse U-wrapping strips) was applied to restore the original flexural capacity. All beams were 10 ft (3.0 m) in length, 18 in. (457 mm) in depth, and 12 in. (305 mm) in width. Different repairing configurations were investigated. The studied variables were the number of plies and the amount and distribution of U-wrapping strips. Ultimate load capacity, deflection, and mode of failure were recorded during testing. The test results were compared to beam results with continuous reinforcement. It was concluded that repairing beams with SRP plies and U-wrapping strips can restore the beam to a capacity similar to that of reinforced concrete (RC) beam with continuous reinforcement.

Keywords: Steel reinforced polymer (SRP); Damaged beams; Flexural strength; Confinement; Lap splice zone.

SP-331-9

Durability Investigations into CFRP-confined Concrete in H_2SO_4

Yongcheng Ji and Yail J. Kim

Synopsis: This paper presents the durability of concrete confined with carbon fiber-reinforced polymer (CFRP) composite sheets in sulfuric acid. An accelerated conditioning scheme is employed to comparatively assess the performance of CFRP-confined concrete relative to that of plain concrete, based on various test methods such as optical microscopy, chemical reaction with $BaCl_2$, thermogravimetric analysis, and rapid chloride penetration. Test results reveal that the cement paste of the plain concrete gradually deteriorates through acid exposure, substantiated by the detection of $CaSO_4$ and $BaSO_4$, whereas the CFRP system lessens the detrimental chemical interaction between the core concrete and sulfuric acid. The confining system is effective in preserving the integrity of the concrete and lowering the extent of chloride penetration and conductivity.

Keywords: carbon fiber reinforced polymer (CFRP); composite; durability; sulfuric acid