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Dennis Mertz Symposium on Design and Evaluation of Concrete Bridges

SP-340

Editors:
Andrzej S. Nowak and Hani Nassif

American Concrete Institute
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Dennis Mertz Symposium on Design and Evaluation of Concrete Bridges

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Editors:
Andrzej S. Nowak and
Hani Nassif

Associate Editor:
Victor Aguilar

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PREFACE

Dennis Mertz Symposium on Design and Evaluation of Concrete Bridges

Professor Dennis Mertz passed away after a prolonged battle with cancer. He spent a large portion of his professional career working on advancing of the state-of-the-art of bridge engineering. He was a great friend and colleague to many at ACI and ASCE. Joint ACI-ASCE Committee 343, joined with ACI Committees 342 and 348, sponsored four sessions to honor his contributions and achievements in concrete bridge design and evaluation. These sessions highlighted the important work and collaborative efforts that Dr. Mertz had with others at ACI and ASCE on various topics. These sessions also combined the efforts among ACI and ASCE researchers and practitioners in addressing various topics related to the design and evaluation of concrete bridges. The scope and outcome of the sessions are relevant to ACI's mission. They raise awareness on established design methodologies applied for various limit states covering topics related flexure, shear, fatigue, torsion, etc. They address problems related to emerging design and evaluation approaches and recent development in design practices, code standards, and related applications. The Symposium Publication (SP) is expected to be an important reference in relation to design philosophies and evaluation methods of new and existing concrete bridges and structures.

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Updating AASHTO Concrete Design Provisions - Prof. Mertz's Final Major Contribution to AASHTO LRFD

John M. Kulicki, Ph.D., P.E., NAE and Gregg A. Freeby, P.E.

Synopsis: Dr. Dennis Mertz was involved with the *AASHTO LRFD Bridge Design Specifications* [1] for 30 years. Starting with the original development of the specifications and continuing with maintenance and related course development and presentations. His last major contribution to the Specifications was to serve as Principal Investigator for the reorganization of Section 5, Concrete Structures. This presentation summarizes the changes to the structure of the Section including the increased emphasis on design of "B" and "D" regions of flexural members and introduces new and expanded material on beam ledges and inverted T-caps, shear and torsion, anchors, strut and tie modeling and durability. The product of this work was included in the 8th Edition of the Specifications as a complete replacement of Section 5.

Keywords: concrete bridge design**,** STM, disturbed beam regions, concrete anchors, beam ledges, node efficiency factors

Load and Resistance Factors for Concrete Bridges and Buildings

Olga Iatsko and Andrzej S. Nowak

Synopsis: In the new generation of design code, safety of structures is provided in form of load and resistance factors. Safety is measured in terms of the reliability index. The acceptability criterion in the selection of load and resistance factors is closeness to the target reliability index which can be different depending on limit state. The paper presents a procedure to determine these factors using the concept of "design point". The coordinates of design point are equal to factored load or factored resistance. The required input data includes for each load component and resistance: mean values, bias factor (ratio of mean to nominal), standard deviation or coefficient of variation. The procedure is demonstrated on example of bridge design code (AASHTO[1]) and design code for concrete buildings (ACI 318[2]) for prestressed concrete girders and reinforced concrete beams in flexure and shear.

Keywords: load factor, resistance factor, design point, reliability index, dead load, live load, resistance, statistical parameters, bias factor, coefficient of variation.

Calibration of Service I Limit State for Reinforced Concrete Bridge Deck Designed using AASHTO Empirical Method

Dan Su and Hani Nassif

Synopsis: Service I limit state in the AASHTO LRFD Bridge Design Specifications (BDS) is applied for the control of cracking in reinforced concrete elements in order to maintain its normal functionality and to achieve its design life. There are two methods specified in AASHTO LRFD BDS: 1) equivalent strip design method and 2) empirical method. For the empirical method, no exhaustive design calculation are needed and the reinforcement area is obtained as a percentage of the concrete section. However, usually, the reinforcement area designed using empirical method is less than that designed using the equivalent strip method, which could result in shortened service life and excessive crack width. Albeit arching action effects were considered in the empirical method which improves the flexural resistance of concrete deck after cracking, the effects of arching action on crack control of reinforced concrete deck were not studied. In addition, different exposure conditions and different design sections (positive moment vs. negative moment regions) were not considered in the empirical design method. Thus, it is extremely important to investigate and calibrate the Service I limit State for reinforced concrete decks designed using the AASHTO empirical method.

In this study, the Service I limit state function is formulated and the load and resistance models are developed. The arching action effects are integrated into the resistance model. Detailed calibration is performed to ensure uniform target reliability will be achieved for different design parameters including exposure conditions, span lengths, deck thickness, and positive moment and negative moment regions.

Keywords: code calibration; limit state; reinforced concrete deck; crack control

Establishing Baseline Performance of a Segmental-Concrete Cable-Stayed Bridge

Michael J. Chajes, Harry W. Shenton III, Hadi T. Al-Khateeb, and Christos Aloupis

Synopsis: The maintenance and management of segmental-concrete cable-stayed bridges represents a major investment of human and financial capital. One possible approach to reducing this cost while simultaneously improving the process, is by using structural health monitoring (SHM) systems. The Delaware Department of Transportation (DelDOT), working collaboratively with the University of Delaware (UD) Center for Innovative Bridge Engineering, installed a comprehensive SHM system on the 1,749 ft (533 m) long Indian River Inlet Bridge (IRIB) during construction. The SHM system is fiber-optic based with more than 120 sensors of varying type distributed throughout the bridge. Within the first year of service, a series of three controlled diagnostic load tests were conducted utilizing the installed SHM system. The test results have been used to establish a standard set of truck passes for future tests, and the recorded response has been used to establish a baseline against which future test results can be compared. These comparisons will yield a quantitative measure of how the bridge is performing, and in combination with the more qualitative biennial inspections, will enable DelDOT to better manage this critical infrastructure asset.

Keywords: load test; structural health monitoring; baseline performance; cable-stayed bridge

Performance of Latex-Modified Concrete (LMC) Overlays on Bridge Decks Under Laboratory and Field Conditions

By Nakin Suksawang and Hani Nassif

Synopsis: For many decades, latex-modified concrete (LMC) overlays have been successfully used in the United States, inclusive of providing protection for many bridge decks and their steel reinforcements. LMC remains one of the most desirable rehabilitation materials for concrete bridge decks because it is easier to place and requires minimal curing. Nevertheless, as is the case with any cement-based material, LMC overlays are susceptible to plastic shrinkage and delamination. These problems are often solved by proper curing and better surface preparation. Yet, despite these solutions, many questions have been raised regarding the best practices for placing LMC overlays and the proper curing and placement conditions. The current curing practice for LMC in most states simply follows the latex manufacturer's recommendation because very little information on the proper curing methods is available. There is a need to establish detailed technical specifications regarding curing and placement conditions that will provide more durable LMC overlays. This paper provides an in-depth laboratory-based experimental study of the effect of curing methods and duration on the mechanical properties and durability aspects of LMC. Four different curing methods were examined: (1) dry curing, (2) 3 days of moist curing, (3) 7 days of moist curing, and (4) compound curing. Based on the results from the laboratory tests, technical specifications were developed for field implementation of LMC. Various types of sensors were installed to monitor the behavior of the LMC overlays on bridge deck. Results show that extending the moist-curing duration to a minimum of 3 days (and a maximum of 7 days) significantly improves both the mechanical properties and durability of LMC.

Keywords: curing, durability, latex-modified concrete, structural health monitoring, shrinkage, permeability, bond strength

Autogenous Shrinkage in Self-Consolidating Concrete

Maria Kaszynska and Adam Zielinski

Synopsis: The research paper presents an analysis of autogenous shrinkage development in self-consolidating concrete (SCC). The first stage of the study involved an evaluation of concrete susceptibility to cracking caused by shrinkage of SCC with natural and lightweight aggregate. The shrinkage was tested on concrete rings according to ASTM C 1581/C 1581M- 09a. The influence of aggregate composition, the water content in lightweight aggregate, and SRA admixture on the reduction of concrete susceptibility to cracking, due to the early-age shrinkage deformation was determined. In the second stage of the research, the innovative method measurement of autogenous shrinkage was developed and implemented. The tests were performed on concrete block samples, dimensions 35x150x1150 mm, that had the same concrete volume as ring specimen in the ASTM method. Linear deformation of the concrete samples was measured in constant periods of 500 s using dial gauges with digital data loggers. The investigation allowed evaluating of the influence of water/cement (w/c) ratio of 0.28, 0.34, 0.42, and of aggregate composition on the development of autogenous shrinkage in different stages of curing SCC. The results were compared to existing material models proposed by other researchers. The conducted study indicated a significant influence of the w/c ratio and composition of aggregate on the concrete susceptibility to crack caused by the autogenous shrinkage deformation.

Keywords: autogenous shrinkage, self-desiccation shrinkage, self-consolidating concrete, natural aggregate, lightweight aggregate

Modeling Material Response of Fiber Composites used for the Retrofit of Existing Concrete Structures under Blast Loadings

Sary A. Malak, Ph.D., P.E., Assistant Professor, Department of Civil and Environmental Engineering, Notre Dame University, Louaize, Lebanon

Neven Krstulovic-Opara, Ph.D., P.E., FACI, Engineering Associate at Exxon Mobil, Spring, Texas

Synopsis: This paper provides an overview of simplified methods for dynamic blast analysis of structural members. The presented approach focuses on the use of a general simplified non-linear single degree of freedom dynamic model commonly used for typical flexural members such as slabs, beams or columns. The presented approach also allows modeling of members retrofitted against blast loading using fiber composites. The fiber composites considered in this paper include conventional Steel Fiber Reinforced Composites (FRC) as well as High Performance Fiber Composites (HPFRC). HPFRC's include Short Steel Slurry Infiltrated Concrete (SIFCON), Long Continuous Slurry Infiltrated Steel Fibers Mat Concrete (SIMCON), and Fiber Reinforced Polymers (FRP).

The model identifies different material parameters that affect the response of the structure. The effect of the material properties on the composite response is discussed within the framework of the existing blast-resistance guidelines and standards. Different retrofit techniques for existing concrete structures using fiber reinforced composites and the effect of varying the composite material properties on the response is presented. Final conclusions and recommendations are provided in terms of composite material's properties, modeling performance and response. Specific limitations on their use is also discussed.

Keywords: ductility, rotation, high-performance concretes, blast pressures, blast impulse, steel fibers, ultimate resistance, mitigation, threat

Development of a New Short-Span Bridge System — A Comprehensive Approach

Tevfik Terzioglu, Dongqi Jiang, Mary Beth D. Hueste, and John B. Mander

Synopsis: A new bridge system was recently developed for short span bridges in low clearance areas. This system uses the same concept as spread box beam bridges in which standard TxDOT precast prestressed slab beams are spaced apart. The deck is composed of stay-in-place precast concrete panels spanning between beams with a cast-in-place reinforced concrete deck. This paper presents a comprehensive approach for the investigation and development of this alternative spread slab beam bridge system including design, construction, field testing, modeling, and derivation of live load distribution factors (LLDFs).

A parametric design study was conducted to evaluate the potential bridge spans when considering the four standard TxDOT slab beam types, a range of beam spacings, and potential bridge widths. One of the challenging geometries with widely spaced slab beams was constructed at full-scale to assess constructability and in-service behavior. The full-scale test bridge and a recently constructed on-system bridge with more closely spaced slab beams were tested under static and dynamic truck loads to obtain important insight into their structural performance and live load distribution behavior, while also providing data to guide analytical and computational modeling studies. Finite element models were developed to investigate an array of possible bridge geometries and determine the effect of key parameters on the load sharing behavior.

Based on the research findings, it was concluded that spread slab beam bridges with a topped panelized deck provide a viable construction method for short-span bridges. For both tested bridges, the desired performance was achieved for in-service loading. Experimental and computational LLDFs were evaluated, and LLDF equations for spread box beams were reviewed for applicability to spread slab beam bridges. The AASHTO LRFD spread box beam LLDFs range from being unconservative to very conservative. Unique moment and shear LLDFs were developed for use in design of spread slab beam bridges.

Keywords: precast prestressed concrete, bridge girders, spread slab beams, live load distribution factors

Design Developments for Extradosed Prestressed Bridges

Steven L. Stroh

Synopsis: This paper provides a description and design developments of the extradosed prestressed bridge concept. The development of the extradosed prestressed bridge concept is discussed, drawing upon the differences with a cable-stayed bridge type. Proportioning parameters used for initial concept development or verification are provided. This includes recommendations on span ranges, structure depth, tower height and multi-span applicability. Stay cable design considerations are discussed. These proportioning parameters are applied to a prototype design, the Pearl Harbor Memorial Bridge. Aesthetic opportunities for this new bridge type are discussed.

Keywords: aesthetics, bridges, construction, extradosed, fatigue, post-tensioning, proportioning parameters, stay cables

Analysis of a Fire Damaged and FRP Laminate Strengthened Reinforced Concrete Bridge

Santosh Timilsina, Nur Yazdani, Eyosias Beneberu, and Abel Mulenga

Synopsis: Fire is a possible hazard on highway bridges which causes significant economic damage, and it is also one of the least investigated of all hazards. There is a lack of knowledge on the long term performance and structural integrity of fire damaged and fiber reinforced polymer (FRP) laminate retrofitted bridges. One such rare in-service bridge was selected for this study. The fire damaged cast-in-place non-prestressed girders were previously repaired with mortar and strengthened with FRP wrapping. The girders were instrumented with strain gages and displacement transducers, and a non-destructive live load test was carried out to evaluate the structural response. The results from the load testing were used to compare two identical girder spans with and without CFRP strengthening. A full-scale non-linear finite element model of the overall bridge superstructure was created, and the test results used to calibrate the model. The carbon (CFRP) strengthened girder exhibited similar stiffness compared to the undamaged girder as evidenced by almost equivalent mid-span deflection. The girder moment capacity decreased significantly due to fire damage, and the CFRP strengthening plus mortar repair was successful in restoring the moment capacity. The finite element model provided good correlation with load test results.

Keywords: bridge tests, distribution factors, evaluation, fiber-reinforced polymer (FRP) strengthening, finite element analysis, fire damaged bridge, load testing

Spatial Variation of Concrete Strength in Safety Evaluation of Existing Structures

Ming Liu, Ph.D. P.E. F.ASCE

Synopsis: The root causes of uncertainties in new concrete structures have been evidenced to be substantially different from those in safety evaluation of existing structures. Therefore, the design methodology in ACI 318 shall be re-calibrated to better reflect the effects of these significant differences, particularly for the spatial variation of concrete strength in existing structures. The degree of uncertainties that whether the testing data can reliably represent the concrete strength at the critical locations of interesting has been identified to play a vital role in developing an effective structural safety evaluation methodology. This paper presents a novel statistical procedure, where the semi-variogram modeling is used to establish the spatial variation of concrete strength so that the degree of uncertainty mentioned above can be quantified as a function of the spacing intervals of the testing points. Kriging is used to estimate the expected concrete strength with the desired confidence levels for the locations between the measurement locations to ensure the critical locations are covered. The actual concrete coring data were analyzed to illustrate how to estimate the spatial variation. The proposed methodology can also be applied to any testing data that can characterize the stochastic properties of concrete strength in existing structures.

Keywords: spatial variation; concrete strength; safety evaluation; existing structures; statistical

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How to Increase Ductile Behavior of Reinforced Concrete Structures

Piotr Moncarz, Tea Visnjic, and Peter H. Feenstra

Synopsis: This paper presents a numerical study of novel configurations in reinforced concrete wall systems that exhibit large structural ductility and increased post-ultimate strength, leading to potentially better performing structures under large and sustained loads. A Gravity-Based Structure (GBS) under extreme ice loading is used as use-case to investigate various scenarios to increase post-ultimate ductility. It is shown that the largest increase in the out-of-plane toughness of the exterior reinforced concrete walls is gained using post-tensioned tendons and mild "core" steel placed at the center of the exterior wall cross section. These structural features show promise in improving the global post-ultimate behavior, which would make them desirable to use in structures that are deployed in locations where extreme ice feature impacts pose a foreseeable risk and where designing the structure to remain elastic under ice impact may not be economically feasible. Lessons-learned from the GBS evaluation can also be applied to various reinforced concrete structures.

Keywords: concrete structures, post-ultimate behavior, gravity-based structure, OpenSees

Reliability-Based Evaluation of a 100-Year-Old Multi-Span Flat Slab Bridge

Patryk J. Wolert, Andrzej S. Nowak, and J. Michael Stallings

Synopsis: Existing road infrastructure and bridges gradually carry increasing in weight and number vehicular traffic. The objective of this study is to assess adequacy of a 100-year-old reinforced concrete framed bridge in Alabama expressed as reliability index. Geometric data about the structure was obtained using destructive and non-destructive testing methods. Material data was collected from field tests and available literature on evaluation of existing structures. Behavior of the structure was investigated during load tests performed. The most harmful load configuration for the particular bridge was established in a recent study on weigh-in-motion data for the State of Alabama. Using finite element numerical method, a three dimensional model of the bridge was developed, calibrated and used for reliability study. The statistical parameters of resistance of the bridge were obtained using Rosenblueth 2k+1 method. The reliability analysis was demonstrated on the one span structural system.

Keywords: evaluation of existing structure, finite element modelling, flat slab bridge, live load testing, non-destructive testing, non-linear material models, reliability analysis, rosenblueth 2k+1 method.

Design of FRP-Prestressed Concrete Bridge Girders

Raymon W. Nickle and Yail J. Kim

Synopsis: With over 80 years of history, it is only in the last 20 years that the use of fiber reinforced polymer (FRP) materials has become feasible for bridge applications in part due to the ever increasing requirement to make structures last longer, with the current American Association of State Highway Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications requiring that structures be designed for a 75 year design life; but also in the development of cost effective production techniques, and the introduction of FRP materials, which bring the cost and strength of FRP materials closer to traditional steel reinforcement. Published documents provide comprehensive recommendations on design methodology, predictive equations, and recommendations for strength and service limits states. In this paper, the background of FRP-prestressed concrete bridges is discussed and trial bridges are designed. Research needs to advance the state of the art are identified and delineated.

Keywords: bridges; design; fiber reinforced polymer (FRP) composites; prestressed concrete