Transportation Literature Search

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Effectiveness of Fiber-Wrapping Concrete Columns for Corrosion Protection

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Transportation Literature Searches are prepared for WisDOT technical staff in highway development, construction and operations. The bibliography below is representative, rather than exhaustive, of available studies on the topic. Primary online resources for the literature searches are the Transportation Libraries Catalog (TLCat), the Transportation Research Information Service (TRIS Online), and various academic and scientific databases. Online copies of publications are noted when available. ***Hard copies of all cited literature may be obtained through the WisDOT Library.***

KEYWORDS

In a search of academic and transportation databases, we used the following search terms: fiberglass, concrete, pier, column, wrap, support, fiber, deterioration, corrosion, FRP.

CITATIONS

Title: Durable Repairs of Marine Bridge Piles
Author(s): P. Thaesler, L. Kahn, R. Oberle and C.E. Demers
Date: Feb. 2005
Doc ID/URL: *Journal of Performance of Constructed Facilities*, vol. 19, no. 1 (Feb. 2005): 88-92.
Description: 5 pages
Contents: Durable repairs of bridge piles exposed to a marine environment require a proper repair design, which includes understanding and preventing the deterioration mechanism in such environments and proper construction methods. To understand how repair systems work, it is important to recognize which deterioration mechanism the system prevents and controls. Conversely, to understand why a system does not work, one must determine the deterioration mechanisms that the system failed to control. The deterioration mechanism should be addressed before repair construction starts so that an appropriate solution can be achieved. Also, construction practices that accelerate deterioration mechanisms should be recognized and avoided. This paper describes efficient construction methods that can be incorporated in the construction of bridge pile repairs. It also gives recommendations to increase the life of a bridge pile repair by analyzing deterioration of repaired structures, defining the cause of deterioration, providing suggestions to enhance the performance of the repair by practical and feasible actions, and giving an integrated approach to bridge repair construction processes.

Title: Detailed Evaluation of Performance of FRP Wrapped Columns and Beams in a Corrosive Environment
Author(s): C.L. Shoemaker, P.N. Quiroga, D.P. Whitney, J.O. Jirsa, H.G. Wheat and D.W. Fowler
Date: May 2004
Doc ID/URL: Texas Department of Transportation: Austin, 2004. FHWA/TX-05/0-1774-3.
http://www.utexas.edu/research/ctr/pdf_reports/0_1774_3.pdf
Description: 76 pages
Contents: The objective of this project is to evaluate the long-term effectiveness of fiber reinforced plastic (FRP) composite wraps in preventing corrosion of reinforced concrete elements in severe environments. The experimental program was established to help determine if FRP wraps provide barriers against the transportation of chlorides into the concrete or if impermeable wraps trap chlorides and moisture beneath the wrap and thereby accelerate the corrosion process. The focus of this report is on the development of procedures for understanding data collected from 13 specimens that were removed from exposure testing and studied in detail. The specimens represent typical rectangular (beam) and cylindrical (column) elements in reinforced concrete bridges. Partially wrapped versus unwrapped elements were studied. Other parameters of interest in design and construction included: cast-in

chlorides to represent specimens already exposed to a corrosive environment prior to wrapping, cracked versus uncracked elements, addition of corrosion inhibitors, and materials of repair for damage to concrete due to corrosion or to construction traffic prior to wrapping.

Title: Effective Structural Concrete Repair: Use of FRP to Prevent Chloride Penetration in Bridge Columns
Author(s): F.W. Klaiber, T.J. Wipf and E.J. Kash
Date: March 2004
Doc ID/URL: Final Report, Iowa Project TR-428. Iowa Department of Transportation: March, 2004. http://publications.iowa.gov/archive/00002506/01/tr428vol2.pdf.
Description:
Contents: Due to changes in the design specification for bridges, increases in legal loads, potential for over-height vehicle impacts, and general bridge deterioration, there is need for new procedures for strengthening and/or rehabilitating existing reinforced and prestressed concrete bridges. In this investigation, strengthening and rehabilitating are considered to be specific means of repairing. The problems previously noted occur in the superstructure as well as in the substructure and are commonplace for state bridge engineers, county engineers and consultants. In the past, several different materials and procedures have been used for strengthening/rehabilitating structural concrete with varying degrees of success. Some of the procedures used may be effective initially, however, they may not be effective long term especially if the deterioration is due to chloride contamination. Thus, research was needed to develop successful repair methods/materials for strengthening/rehabilitating various structural concrete bridge elements.

Title: The Mechanisms of Corrosion and Utilizing Fiber Reinforced Polymers as a Chloride Barrier
Author(s): Elizabeth Kash
Date: October 20, 2003
Doc ID/URL: http://www.ctre.iastate.edu/mtc/papers/2003/Kash.pdf.
Description: 22 pages
Contents: This report is a discussion on the mechanisms of the corrosion process and utilizing fiber reinforced polymers as a chloride barrier on reinforced concrete structures. This includes a synopsis of the current methods of repair, rehabilitation and prevention of chloride penetration. There is also a section on the characteristics and current research being conducted with fiber reinforced polymers as a rehabilitation method for chloride contaminated reinforced concrete. Finally an overview of the field and laboratory experiments that have tested both glass and carbon fiber reinforced polymers as a chloride barrier is provided. To-date the collected data has established a trend line that shows that fiber reinforced polymers are capable of keeping the chloride level below the corrosion threshold in reinforced concrete structures.

Title: New Materials in Construction: Advances in the Application of FRB for Repairing Corrosion Damage
Author(s): Rajan Sen
Date: June 2003
Doc ID/URL: *Progress in Structural Engineering and Materials*, vol. 5, no. 2, 2003: 99-113. (10.1002/pse.147)
Description: 15 pages
Contents: This paper presents an overview of the application of fibre-reinforced polymers (FRP) for repairing corrosion-damaged structures by external wrapping. The rationale, design and durability for such repairs are addressed and significant research findings highlighted. Several field applications are described and new and innovative practices identified. Recommendations are made to improve future performance.

Title: Performance Evaluation of Reinforced Concrete Bridge Columns Wrapped with Fiber Reinforced Polymers
Author(s): Ming-Hung Teng, Elisa D. Sotelino and Wai-Fah Chen
Date: May 2003
Doc ID/URL: *Journal of Composites for Construction*, vol. 7, no. 2 (May 2003): 83-92. (10.1061/(ASCE)1090-0268(2003)7:2(83))
Description: 10 pages
Contents: This study investigates the performance of new bridge columns wrapped with fiber reinforced polymers (FRP) when exposed to aggressive environmental conditions. This has been accomplished through field monitoring and laboratory tests. As part of the field monitoring, temperature data were collected at various locations of bridge columns. In addition, visual inspection of two bridges was performed periodically for over a period of two years. No evidence of deterioration of the FRP wraps was detected during that period. Laboratory tests were performed to investigate how FRP wraps protect reinforced concrete columns from corrosion, and freeze–thaw laboratory tests were conducted to study the impact of temperature cycles on the mechanical behavior of FRP-wrapped columns. From the corrosion experimental tests, it was found that FRP provides excellent protection against aggressive agents (salty water or moisture) even when a single layer is used. Compression tests were conducted on specimens

subjected to freeze–thaw cycles. It was found that minor thermal cycles have no effect on the performance of FRP-wrapped concrete specimens. However, for large thermal cycles, some degradation of ductility in the axial and the hoop directions was observed.

Title: Florida's Approach to Bridge Preservation
Author(s): Ivan R. Lasa and Rodney G. Powers
Date: unknown; 2003 or later
Doc ID/URL: http://www.pwri.go.jp/eng/ujnr/tc/g/19bws/pdf/3-5lasa.pdf.
Description: 14 pages
Contents: Corrosion of reinforcing steel in concrete bridges is a problem of major concern for entities responsible for the maintenance and safe operation of such structures. In the state of Florida in the United States, millions of dollars are spent yearly in the rehabilitation of structures due to corrosion deterioration. In this regard, the Florida Department of Transportation has adopted effective design and materials standards to delay corrosion development and has developed effective corrosion mitigation systems for older bridges where corrosion has already initiated. On older structures where corrosion has been identified as the source of deterioration, cathodic protection is used to stop the damaging corrosion effect as it is recognized that standard repairs provide only a short term solution. This paper describes the newest materials and the design criteria used for corrosion prevention as well as various cathodic protection systems used on different structures in Florida.

Title: Stress-Strain Model for Fiber-Reinforced Polymer-Confined Concrete
Author(s): Domingo A. Moran and Chris P. Pantelides
Date: Nov. 2002
Doc ID/URL: *Journal of Composites for Construction*, vol. 6, no. 4 (Nov. 2002): 233-240. (10.1061/(ASCE)1090-0268(2002)6:4(233))
Description: 8 pages
Contents: The design of fiber-reinforced polymer (FRP)-confined concrete members requires accurate evaluation of the performance enhancement due to the confinement provided by FRP composite jackets. A strain ductility-based model is developed for predicting the compressive behavior of normal strength concrete confined with FRP composite jackets. The model is applicable to both bonded and non-bonded FRP-confined concrete and can be separated into two components: a strain-softening component, which accounts for unrestrained internal crack propagation in the concrete core, and a strain-hardening component, which accounts for strength increase due to confinement provided by the FRP composite jacket. A variable strain ductility ratio described in a companion paper is used to develop the proposed stress-strain model. Equilibrium and strain compatibility are used to obtain the ultimate compressive strength and strain of FRP-confined concrete as a function of the confining stiffness and ultimate strain of the FRP jacket.

Title: Variable Strain Ductility Ratio for Fiber-Reinforced Polymer-Confined Concrete
Author(s): Domingo A. Moran and Chris P. Pantelides
Date: Nov. 2002
Doc ID/URL: *Journal of Composites for Construction*, vol. 6, no. 4 (Nov. 2002): 224-232. (10.1061/(ASCE)1090-0268(2002)6:4(224))
Description: 9 pages
Contents: The encasement of concrete in fiber-reinforced polymer (FRP) composite jackets can significantly increase the compressive strength and strain ductility of concrete columns and the structural system of which the columns are a part, be it a building or a bridge. Due to the approximate bilinear compressive behavior of FRP-confined concrete, analysis and design of FRP-confined concrete members requires an accurate estimate of the performance enhancement due to the confinement provided by FRP composite jackets. An analytical model is presented for predicting the bilinear compressive behavior of concrete confined with either bonded or non-bonded FRP composite jackets. This article describes the basis of the model, which is a variable plastic strain ductility ratio. The variable plastic strain ductility ratio defines the increase in plastic compressive strain relative to the increase in the plastic compressive strength of the FRP-confined concrete, which is a function of the hoop stiffness of the confining FRP composite jacket, the plastic dilation rate, and the type of bond between the FRP composite and concrete.

Title: Effects of Wrapping Chloride Contaminated Concrete with Fiber Reinforced Plastics
Author(s): E.W. Berver, J.O. Jirsa, D.W. Fowler, H.G. Wheat and T. Moon
Date: October 2001
Doc ID/URL: Texas Department of Transportation: Austin, 2001. FWHA/TX-03/1774-2.
http://www.utexas.edu/research/ctr/pdf_reports/1774_2.pdf.
Description: 111 pages
Contents: Damage to concrete due to corrosion of steel reinforcement is a costly maintenance problem that affects infrastructure. Reinforced concrete structures located in an aggressive environment are susceptible. Fiber reinforced

plastic composite wraps have recently been used to rehabilitate structures that have experienced damage due to corrosion. Little is known about the long-term performance of FRP composites in corrosion prevention. Corrosion monitoring of laboratory specimens and field research are discussed. A new phase of the project involving the use of corrosion inhibitors prior to wrapping with FRP composites is also described.

Title: Corrosion Damage in Composite-Wrapped Structures
Author(s): Harovel G. Wheat, James O. Jirsa, David W. Fowler and Emily Berver
Date: June 2001
Doc ID/URL: Bridge Materials 2001: High Performance Materials in Bridges, *International Conference on High Performance Materials in Bridges 2001*, Atorod Azizinamini, Aaron Yakel, Magdy Abdelrahman, eds. June 29-Aug. 3, 2001, Kona, Hawaii.
Description: n/a
Contents: Composite wrapping is being used as a means of rehabilitating corrosion-damaged reinforced concrete structures. Concern has been raised about this procedure and the potential for accelerating the problem unless provisions are made for arresting the existing corrosion. Parallel field and laboratory studies have been initiated to address some of the factors that influence the effectiveness of such procedures. In particular, the use of corrosion inhibitors as a pre-treatment prior to wrapping is being investigated. Other considerations are the types of fibers and polymer resins that are most appropriate, the severity of damage that can be accommodated, and peculiarities associated with different geometries. Preliminary results indicate that wrapping may help to retard the ingress of additional chlorides, but it may also trap moisture.

Title: Repair of Corrosion-Damaged Columns with FRP Wraps
Author(s): S.J. Pantazopoulou, J.F. Bonacci, S. Sheikh, M.D.A. Thomas and N. Hearn
Date: Feb. 2001
Doc ID/URL: *Journal of Composites for Construction*, vol. 5, no. 1 (Feb. 2001): 3-11. (10.1061/(ASCE)1090-0268(2001)5:1(3))
Description: 9 pages
Contents: Corrosion of reinforcement in bridge piers is encouraged by chloride contamination from exposure to marine environment and from deicing salts used in bridges during winter. Because corrosion products generally occupy greater volume than the original material, expansive forces are generated in concrete leading to spalling of the cover and further acceleration of the reinforcement disintegration. Jacketing of such structures by fiber-reinforced composite sheets is an effective remedy, not only as a means of slowing down the rate of the reaction, but also by confining the concrete core thereby imparting to it ductility and strength. This paper presents results of an experimental parametric study of this method as a repair alternative for corroded structures. Several small-size concrete columns with various reinforcement configurations were subjected to accelerated corrosion conditions in the laboratory. After a target level of steel loss was attained the columns were repaired using a variety of repair alternatives. Most of the repair schemes considered included jacketing the damaged specimens with glass-fiber wraps, in combination with grouting the voids between the jacket and the original lateral surface of the specimen with either conventional or expansive grouts. To protect the glass fiber material from exposure to alkali activity of the fresh grout, and to reduce the supply of oxygen and water to the mechanism of corrosion, different types of diffusion barriers were considered in the study. The efficacy of each repair system was evaluated by (1) assessing the post-repair corrosion resistance of the specimens under repeated exposure to accelerated conditions; and (2) the mechanical strength and ductility enhancement under concentric compression loading.