A PROPOSAL FOR

Evaluation of Constructed, Cast-in-Place (CIP) Piling Properties

Submitted to the

Wisconsin Highway Research Program
Geotechnical Technical Oversight Committee

Submitted through the
Michigan Tech Transportation Institute
Center for Structural Durability

May 18, 2009

Dr. Devin K. Harris, Assistant Professor
Dr. Theresa M. (Tess) Ahlborn, P.E., Assoc. Prof. and CSD Director

Michigan Tech Transportation Institute
Dept. of Civil & Environmental Engineering
Michigan Technological University
1400 Townsend Dr., Dillman Hall
Houghton, Michigan 49931-1295

(906) 487-3521 and (906) 487-2625 (Phone)
(906) 487-1620 (Fax)
dharris@mtu.edu and tess@mtu.edu

1. Problem Statement

Closed-end, round, cast-in-place (CIP) tubular friction piles are commonly used in bridge and retaining wall structures in the state of Wisconsin. Installation of the CIP piles is typically performed by the contractor according to specified bearing capacities in the construction plans. These CIP piles have historically been installed at depths ranging from 30 ft to 120 ft, with nominal diameters between 10-3/4 in. and 14 in. and shell thicknesses between 1/4 in. and 3/8 in. Upon driving the tubular piles to capacity, concrete is placed by allowing it to free fall within the tubular, with care taken to minimize intermittent voids.

WisDOT practices employ a conservative approach in the design of these CIP pilings by neglecting the contribution of the steel shell and reducing the design compressive strength of the concrete core. These adjustments are used due to uncertainties in the shell integrity after long-term environmental exposure and the in-place properties of the core including compressive strength and interface composite action. WisDOT is interested in evaluating the actual behavior of CIP pilings with a specific focus on the actual compressive strength of the placed concrete and the composite action between the concrete core and steel shell.

2. Research Objectives

The overall objective of this project is to characterize the axial capacity of typical CIP tubular piles used by WisDOT in bridge and retaining wall structures. Of primary interest to this goal is the characterization of the actual compressive strength of the in-place concrete due to uncertainties in the placement method. The other key objective includes an investigation of the level of composite action between the concrete core and the steel tubular shell.

Results from this investigation will provide the information necessary for the evaluation of current design practices pertaining to CIP tubular piles. The information developed as part of this project will allow WisDOT to determine whether the current assumptions are overly conservative or if there is a potential economic benefit to a modified design approach.

This proposal, presented by Dr. Devin K. Harris and Dr. Tess Ahlborn of Michigan Technological University, will investigate the aforementioned objectives related to the CIP tubular friction piles in Wisconsin. This research will be conducted over the specified 18 month time frame.

3. Background and Significance of Work

Current WisDOT design practices are based on the AASHTO LRFD Specifications (AASHTO 2007), with modifications for inclusion of WisDOT best practices. AASHTO LRFD treats pilings as compression members, with the design procedure determined by the type of member (e.g. concrete compression member – section 5.7.4.4 or composite member – section 6.9.5.1). WisDOT practice allows for a similar treatment, but due to the potential for corrosion and uncertainty in the level of composite action, the contribution of the steel tubular is neglected. This treatment reduces the behavior down to that of a concrete compression member [*Eqn. 1*]. In addition, the allowable concrete design compressive strength is limited to 3.5 ksi based on uncertainties in the placement practice, construction difficulties, and historical consistency with the plans (WisDOT 2007).

$$P_n = 0.80\left[0.85 f'_c\left(A_g - A_{st}\right) + f_y A_{st}\right] \qquad \textbf{\textit{Eqn. 1}}$$

where:
P_n = nominal axial resistance without flexure (kips)
A_g = gross area of concrete pile section (in^2)
A_{st} = total area of longitudinal reinforcement (in^2)
f_y = specified yield strength of reinforcement (ksi)
f'_c = concrete compressive strength (ksi)

Limited research has been conducted on the behavior of CIP pilings (Jung et al. 2006), but none specifically devoted to CIP tubular friction piles. The primary focus in the investigation by Jung et al. was the influence of defects on strength of CIP concrete pilings. The defects investigated included a soft bottom resulting loose soil not removed from the hole prior to casting, segregation of the concrete resulting from free-fall, and contraction of the cross section. Jung et al. reported that the defects resulted in reductions in stiffness, significant stress concentrations, and propagation of some of the defects under loading. With the exception of the soft bottom defect, all of the defects could greatly influence strength and stiffness of the CIP tubular friction piles used by WisDOT. Especially considering the free fall heights of the concrete, the potential for tubular contraction during driving operations, and limited consolidation likely achieve downhole due to vibration of the tubular.

While limited research has been conducted on CIP pilings, numerous investigators (Baig et al. 2006; Giakoumelis and Lam 2004; Gupta et al. 2007; Han and Yang 2003; Huang et al. 2002; O'Shea and Bridge 2000; Sakino et al. 2004; Schneider 1998) have studied been performed on concrete filled tubular (CFT) columns for building applications. The key differences between these investigations and the focus of this effort lie in the length of application (column length vs. piling length), core material strength, and lateral support mechanism. For the majority of these efforts the tubular diameter to thickness ratios bounded those of interest to this investigation.

With typical piling lengths of interest between 30 to 120 ft, the range of interest in member length is significantly greater than those in typical column applications. Typical column designs result in members with unbraced section lengths, which would not be the case for a fully embedded piling. This difference is recognized within the AASHTO LRFD (section 10.7.3.13) by an assumed slenderness parameter (λ) of zero for fully embedded piles. However, this assumption would not preclude local buckling effects.

Much of the research on concrete filled tubular columns has focused on the axial capacity of the tubular sections with consideration of the strength enhancement from confinement of the concrete core, core compressive strength, and buckling behavior. The general consensus has been that the behavior of a concrete filled tubular section is highly dependent on the loading conditions of the member due to the difference in the Poisson's ratio of the core and shell materials. As a result of the difference in Poisson's ratio between the materials, members with the core and shell loaded simultaneously did not experience the strength enhancement due to core confinement because the shell tended to expand more freely than the core.

O'Shea and Bridge (2000) demonstrated that the greatest confining effects were observed when loading was applied to the core only, but no additional enhancement was observed for higher strength concrete. This lack of enhancement due to increased compressive strength was also demonstrated by Gupta et al. (2007). The use of higher strength concrete would likely be immaterial for pilings from a cost-benefit perspective, but the influence on behavior warrants consideration due to the unknowns in down-hole properties of the core material in CIP pilings. Schneider (1998) concluded that for a section with the core and tubular shell loaded simultaneously, the effects of confinement were not realized until the shell approached yielding, upon which only minimal enhancement was observed. Similar findings were also presented by Baig et al. and Brauns (2006; 1999). Schneider also observed that the enhancement of confinement was only present for non-slender columns. Giakoumelis and Lam (2004) studied the influence of core compressive strength and bond on the axial capacity of CFT columns concluding that the bond does not significantly influence the capacity for normal strength concrete, but does for high-strength concrete.

While the parameters for CPT columns are not identical to those of pilings, it is expected that the findings from these efforts will provide insight since both at their core are simple compression members. These findings will be especially useful in the initial information gathering stage because bond strength is expected to correlate directly with concrete placement. Similarly, load application is expected to be directly related to pile cap construction.

4. Benefits

This investigation will provide WisDOT with a firm understanding of the behavior of axially loaded CIP pilings installed using current procedures. The current installation approach is believed to be conservative because the contribution of the steel shell is neglected in design and the strength of the concrete is reduced. Results from this proposed research program are expected to provide validity to the assumed conservative design approach. This research program will also provide an evaluation of current installation practices and investigate potential improvements in the process. The outcome of this project will provide WisDOT with the critical information necessary to adjust current design and placement practices, if necessary.

5. Implementation

The proposed research program will include a detailed review of literature related to the installation and design of CIP pilings, coupled with experimental and analytical analyses of the behavior. The results from the program are expected to affect both the design method and construction practices of CIP pilings in the state of Wisconsin. It is expected that this project will lead to a validation of current practices with the potential of reducing the degree of conservativeness in the design. <u>The original plan called for an investigation of best practices for placing the concrete in tubular sections which will no longer be performed.</u>

6. Detailed Work Plan

This proposal describes the investigation of the strength and behavior of cast-in-place pilings. The following tasks describe the planned work to be undertaken as part of this research program.

Task 1: Literature Review

An extensive literature review will be performed with a primary focus on cast-in-place tubular pilings. The emphasis of the literature review will be on the behavior and composite action of tubular sections filled with concrete. While the focus will be on pilings, the search will also include tubular type compression members. The literature search will evaluate current design practices within the LRFD specifications. Per TOC recommendations, efforts will not focus on building practice in the United States. The object of this review will be to gather all pertinent information related to concrete filled tubular sections that might be considered analogous to CIP tubular pilings. As part of this literature search, information related to testing and modeling of these members will be gatherer. In addition to the investigation on behavior, the literature search will also focus on construction practices used in the implementation of these piles.

Task 2: Installation Site Survey

During the course of Task 1, a construction site will be visited for observation of the installation methodology. It is expected that this site survey will provide the project team with a better understanding of the details involved in the installation process and also allow for the opportunity to discuss issues related to the installation procedures with an experienced contractor.

Task 3: Refinement of the Research Plan

Per the RFP, an interim summary report will be provided to the Technical Oversight Committee (TOC). Included in this summary report will be a refined project plan based on the findings from Tasks 1 and 2. The project team will meet with the TOC to review Tasks 4-6 and discuss the findings of the report. *Modifications to the original plan based on discussions with the WisDOT will be evaluated with consideration of the available budget.*

Task 4: Pile Fabrication

Upon refinement of the proposed research plan, 3-4 full-scale test piles will be constructed. These test piles will be constructed in conjunction with an ongoing bridge construction project. This phase of the project will require coordination with a contractor. Coordination of the construction will be handled by the PI, but assistance from WisDOT will be required to help find suitable construction sites where the piles can be fabricated. WisDOT will provide contractor contacts for the PI to locate potential fabrication sites. Due to the uncertainty in contractor participation, the proposed timeline for this task will depend primarily on contractor assistance and may potentially shift into the 2010 construction schedule, if necessary.

Task 5: Experimental Testing Program

Of primary interest to this project is the investigation of axial behavior of CIP pilings with a specific focus on the composite behavior of the core/shell interface and the compressive strength of the core. To investigate this behavior a series of physical tests will be performed. The testing program will utilize the full size test piles and also the simulated defect pile sections to investigate the strength of CIP tubular piles, bond strength between the concrete core and steel shell, and also the compressive strength of the as-cast concrete core under axial loading conditions.

Full-Scale Pile Sections

a) Due to the uncertainty in contractor and site selection, the following is a tentative plan for pile casting. A preliminary plan is presented, but final details of this task will be revised based on the participation and recommendations of the selected contractor. In an effort to mimic the as-built conditions, 3-4 identical piles (~40 ft each) will be constructed and cured (above ground) in conjunction with a WisDOT bridge construction project. Construction of these piles will allow for simulation of the placing technique used in a typical application. These piles will be partially driven to provide stability allowing for the concrete to be placed vertically. The piles will positioned out of the critical construction path and removed after sufficient strength is achieved such that the piles can be lowered from a vertical position. Due to the piles being above ground, it is likely that continuous pouring of the concrete is may not be feasible and casting may require the use of buckets. Another recognized shortcoming of these simulations is the inability to mimic down-hole curing conditions with portions of the pile being above grade. Efforts will be made to ensure that curing conditions do not adversely affect properties by wrapping the piles and evening casting. After sufficient set, the piles will be laid down and covered with moist burlap. The pilings will be transported back to the Michigan Tech campus for physical testing and evaluation.

b) All of the pilings will be sawn into smaller cross sections (12-24 in. each) along the length of the piling to allow for compression testing [Figure 1]. Sawing of the specimens will also allow for a visual inspection of concrete material for consolidation, voids, and other defects. All of the piling sections will be externally instrumented to measure axial deformation and strain response during loading.

c) One series [*Series 1*] of piling will be tested in compression to failure by loading the entire cross-section (i.e. loading plate and core simultaneously) [Figure 1b and Figure 2a]. This series of testing will allow for evaluation of the true axial capacity of the CIP tubular sections including the contribution of the tubular shell with no section loss. The second series [*Series 2*] of piling sections will be tested in compression to failure by loading only the core cross-section [Figure 1c and Figure 2b]. This testing will demonstrate the capacity of the cross-section with the influence of confinement from the tubular shell. Series 2 will also allow for evaluation of the bond strength through push-off testing. To address the TOC comments on assessment of composite behavior, longer pile (10-15 ft) sections will be tested third-point bending to assess composite behavior of the pile sections. The final series [Series 3] of piling sections will first be cored to extract test cylinders from the concrete core [Figure 1d]. The cored cylinders will then be tested in compression to failure to demonstrate the placed strength of the concrete [Figure 2c]. The coring process will also allow for further visual inspection of the placed concrete.

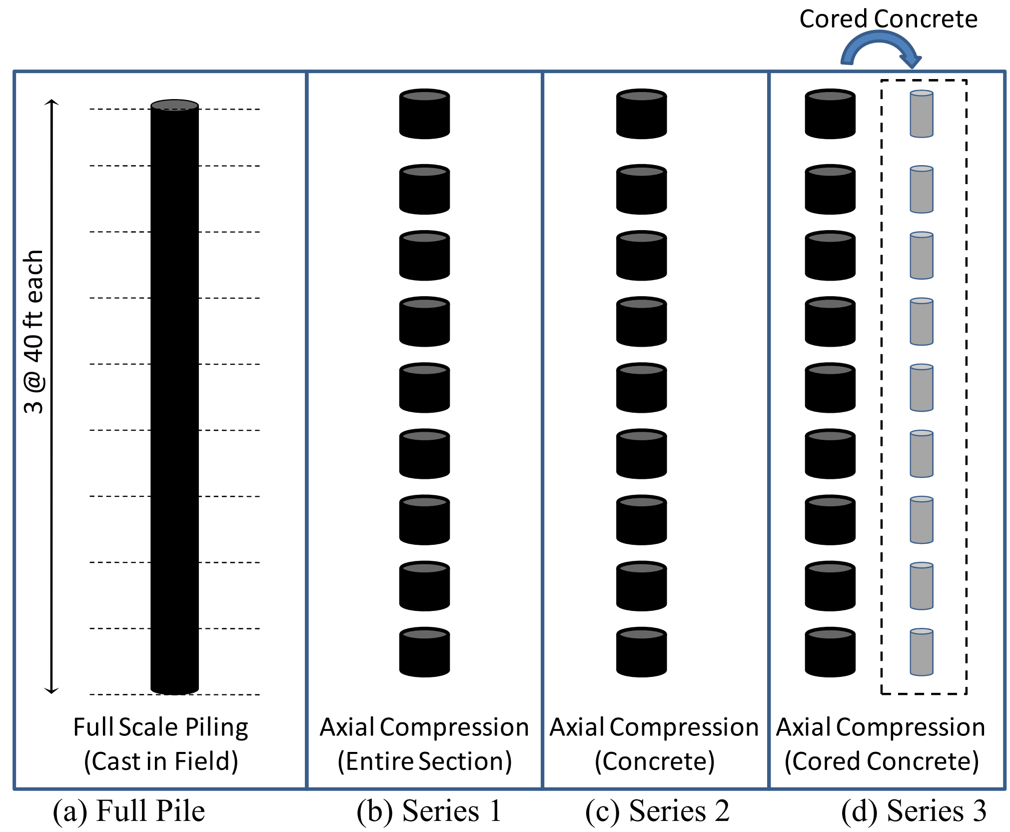

Figure 1 – Summary of Full Scale Pile Section Testing Program

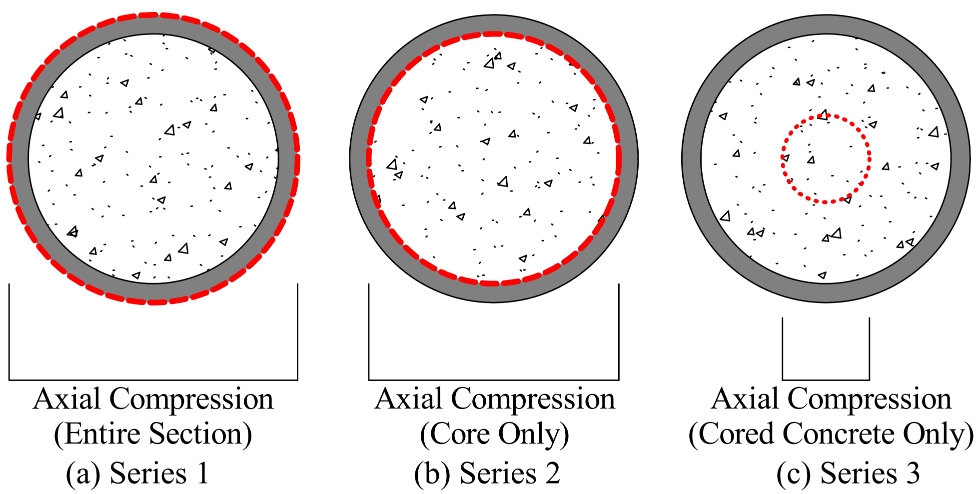

Figure 2 – Loading Areas of CIP Tubulars

Pile Sections with Simulated Defects

TOC noted that this phase was not of interest to WisDOT and has been removed from the proposed research program.

Task 6: Finite Element Analysis Program

Finite element modeling will be used in this research program. The objective of the modeling will be to expand the scope of parameters that could not be investigated experimentally due to budget constraints in the experimental program. A series of linear elastic finite element models would first be developed and validated with the results from the experimental program (Task 4). Upon validation, the model would then be expanded to investigate other parameters such as improper consolidation and voids, concrete segregation, section loss of the tubular shell.

Task 7: Preparation of Reports and Deliverables

Throughout the duration of the project the research team will keep the TOC apprised of progress and issues related to project. In addition, the team will also develop and maintain a website for to allow progress to be observed. Upon completion of the experimental program a final report will be provided to the TOC as specified in *Section 8 - Reports*.

7. Work Time Schedule

The project duration for this study is eighteen (18) months. It is anticipated that the official start date will be July, 1 2008. Table 1 shows a summary of the planned timeline for the six tasks outline in Section 6.

Table 1: Schedule of Tasks

	Month																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Task 1: Literature Review																		
Task 2: Installation Site Survey																		
Task 3: Refinement of Research Plan																		
Task 4: Pile Fabrication									alt	alt	alt	alt						
Task 5: Experimental Testing Program																		
Task 6: Finite Element Analysis Program																		
Task 7: Preparation of Reports and Deliverables																Review	Review	Review Final Report

Regions highlighted by a dashed border represent a window time frame with the planned time designate in a dark shade
**alt represents and alternative time frame for completing the task*

10. Qualifications of the Research Team and Management Plan

Devin K. Harris, Ph.D.

Dr. Harris is the Donald F. and Rose Ann Tomasini Assistant Professor in structural engineering in the Civil and Environmental Engineering Department at Michigan Technological University. He is also a member of the Michigan Tech Transportation Institute, which supports transportation related research related addressing national and global needs. Dr. Harris received his M.S. and Ph.D. at Virginia Polytechnic Institute and State University in 2004 and 2007, respectively and his B.S. from the University of Florida. His research interests include all aspects of structural engineering, with a main focus on bridge related issues. Previous research experiences have focused primarily on innovative materials in civil infrastructure, including the Sandwich Plate System (SPS) technology and the Ultra-High Performance Concrete (UHPC). Dr. Harris has expertise in bridge design and behavior, finite element modeling, experimental testing in both the laboratory and field environments. He also has a strong background in subsurface exploration and development as a result of his oil industry drilling experience.

Theresa M. (Tess) Ahlborn, Ph.D., P.E.

Dr. Ahlborn is an Associate Professor in structural engineering in the Civil & Environmental Engineering Department at Michigan Technological University and currently serves as the Director of the Center for Structural Durability with the Michigan Tech Transportation Institute. She has an active research program in the area of structural concrete materials related to prestressed concrete bridges and bridge decks, including rapid construction and ultra-high performance concrete (UHPC) applications. She has worked extensively with the Michigan Department of Transportation to seek solutions related to long-term durability of concrete structures. She also conducts research on other transportation structures including steel bridge deterioration, overhead sign support structures under fatigue duress, and full scale bridge testing. Dr. Ahlborn has advised over 20 graduate students to completion and currently has 8 more under her direct supervision. She has published more than 30 papers in various journals and conference proceedings. She has served as an active technical committee member in the Prestressed/Precast Concrete Institute (including the Committee on Bridges, PCI Technical Activities Committee, and PCI Sustainability Committee), TRB and the American Concrete Institute. She is also a national panelist for NCHRP projects (12-60, 12-77, and 20-07) and the National Science Foundation. Current projects include Development of Rapid Construction Solutions Using Prefabricated Prestressed Concrete Systems – Phase I and II, Ultra-High Performance Concrete for Michigan Bridges – Material Properties, and Condition Assessment and Methods of Abatement of Prestressed Concrete Box-Beam Deterioration – Phase I and II.

11. Facilities Available

The research team has available to it a wide array of equipment and facilities for researching durable and sustainable structural systems. The equipment listed below is predominantly situated in laboratories in Dillman Hall, on the first floor of the Minerals and Materials Engineering Building and in *Benedict Laboratory*. The *Peter Grant Structural Engineering Laboratory* is located in the confines of Dillman Hall and offers almost 800 square feet of dedicated space for structural load testing with a 30-ft high bay space. In addition, another 800 square feet is available for material and specimen preparation and storage. The recently acquired *Benedict Laboratory* offers 15,000 square feet of space dedicated to cement and concrete research, including structural concrete. A 5-ton overhead crane services the 80x60ft structural high-bay testing area. Equipment for mechanical testing is available for compression, tension, bending, and fatigue testing of many engineering materials. A variety of computer operated mechanical test equipment is available including twin 55-kip servo-hydraulic structural actuators with 10 in. total stroke. A self-reacting load frame can apply single or double vertical or horizontal loads. Data acquisition is available to collect information from component testing. Additional mechanical testing frames are available through tunnel access from *Benedict Laboratory* with load capacities up to one million pounds for isolated testing of material properties.

The following is a more detailed listing of available research facilities and equipment at Michigan Technological University for conducting research in the area of structural durability. Facilities for material characterization are also available to support such research.

Mechanical and Dynamic Testing

Mechanical and dynamic testing facilities are available for compression, tension, bending, and fatigue testing of all engineering materials. A variety of computer operated mechanical test frames are available including:

- MTS 55 kip servo-hydraulic stiff-frame system with Test-Star II digital control and a 6 g.p.m. hydraulic pump with Russell temperature control cabinet (-40^{o} to 200^{o} C).
- MTS 55 kip servo-hydraulic structural actuators (2) with 10 in. stroke with 30 g.p.m. hydraulic pump. Especially suitable for the testing of very ductile materials or large specimens.
- MTS 407 digital controllers with function generator, AC and DC conditioning, PC communication links, load or displacement control, and cabling.
- Self-reacting load frame with several configuration options for large scale testing.
- Tinius Olson 120 kip compression/tension screw-driven testing machine.
- Saytec 20 kip and 50 kip electromechanical systems with digital control and accessories.
- Additional mechanical test frames are available with load capacities up to 1,000,000 pounds.
- Split-Hopkinson Pressure Bar for testing aggregates/portland cement concrete and determination of dynamic fracture characteristics for 3-in diameter specimens.
- V-meter ultrasonic testing system.
- Portable Pentium computer with digital oscilloscope and arbitrary waveform generator couple with a 400 watt bipolar power supply for control of dynamic testing.

- Resonant column device for soil, asphalt, concrete and rock.
- AET5000 acoustic emission instrument with four channels of data acquisition.
- IOtech DaqBook 200 for dynamic acquisition, capabilities include vibration measurements, accelerator conditioning, load cell measurements, temperature, and low pass filtering.
- Ten Mark L1 geophones, 1Hz (1 volt/g) accelerometer, and two 3-D Hz geophones.
- Six single axis and two tri-axial accelerometers with voltage output conversion boxes.

Concrete Preparation Laboratories

All necessary facilities are available for the preparation of mortar and concrete to prepare specimens for characterization and mechanical test analysis including:

- Fully equipped concrete laboratory for mixing and performing wet concrete tests, including slump, air content, and maturity
- 10 ft^3 mortar type mixer, 7.5 HP electric motor, 220V / 3 phase/ 60 Hz, rubber blades, duo tread retractable axle with 16-in tires.
- 3 ft^3 four-paddle rotating drum mixer, 1/3 HP motor, portable.
- 4 ft^3 Croker RP100 CUMFLOW XD pan mixer.
- 60 quart mixer, Doyon Model BTF060.
- 2-20 Hobart quart mixers.
- 20 in square vibrating table, item #HM-140 from Gilson.
- Moist cure room (without temperature and humidity control).
- Lime water baths with temperature control.

Ultra High Performance Concrete Facilities

State-of-the-art facilities for casting, curing, and test specimen preparation are available for UHPC including: (note – testing facilities are listed separately)

- Doyon BTF060 10 amp, 60Q high shear capacity mixer.
- Syntron UP-SI-DI vibrating table.
- 64CF Insulated Cure Chamber (up to 100°C, 100% RH).
- Fosdick M.T. CO-3hp Coring Machine.
- Clausing 2276 1.5hp Coring Machine.
- REID 618PF 1.25hp Surface Grinder.
- 1-Million pound MTS mechanical testing machine with Instron 8500 Controllers.

Data Acquisition and Other Equipment

In addition to the data acquisition systems specifically mentioned above for use with testing equipment, the following acquisition systems and miscellaneous equipment is available for research laboratory use:

- System Characterization for a host of ASTM/AASHTO durability testing needs.
    - Scientemp Freeze/Thaw Chamber - 80 unit
    - Rapid Chloride Permeability Testing
    - Other ASTM/AASHTO tests

- OPTIM Megadac 3016, portable for field testing and monitoring
    - Dynamic sampling rate of up to 25,000 samp/sec

- 40 channels of 120-ohm resistance for ¼, ½ and full bridge
- 24 channels of voltage readout
- Voltage excitation source of +5V or ±15V
- 8 channels of vibrating wire and thermistor readout
- IEEE connection: AT-GPIB/TNT with software for DOS/Windows for fast data transfer

- Cyber Research 16 channel conditioned system
- Standard terminal junction boxes and cabling
- Backup power supplies and surge protectors
- LVDTs and DCDTs with stroke ranging from 0.1-in. to 4-in. travel, are available for PI use
- Load cells ranging from 2 kips to 1000 kips are available
- Hydraulic hand-actuators, torque wrenches, cabling for field monitoring projects, etc.

Cement and Concrete Characterization Facilities

The Michigan Tech research team has available to it a wide array of equipment and facilities for researching portland cement based materials. These facilities are AMRL inspected and CCRL accredited. The characterization equipment listed below is predominantly situated in four laboratories on the sixth and seventh floors of the Minerals and Materials Engineering Building. These laboratories are managed under the *Non-Conductive/Volatile Materials Characterization Facility.* Available facilities include the following:

- **Electron Optics Facilities**
- **X-Ray Analytical Microscope**
- **Optical Microscopy-Petrographic Facilities**
- **X-ray Diffraction and X-ray Spectrometry Facilities**
- **Digital Image Processing Capabilities**
- **Microstructural Characterization Sample Preparation Facilities**
- **Particle Characterization Equipment**

Computation and Information Resource Facilities

In addition to the above systems, the team has available to it high-speed computing facilities within the CEE Department at Michigan Tech. Design and analysis software as well as programming capabilities are available, including Mathcad, Matlab, AutoCAD, SAP 2000, ANSYS, ABAQUS, DasyLab and IDEAS.

J. Robert Van Pelt Library: on the Michigan Tech campus provides the research team with book and periodical collections, microfilms and microfiche of older scholarly material, society and governmental publications, and many current scientific and technical reports. The library also offers a wide range of computer-based information services affording the research teams world-wide access to cutting edge research, particularly that which will benefit the proposed research directly.

Outreach Facilities: Workshops, seminars and training sessions are held for K-12 and undeclared college students, engineers, contractors, and county and state agencies, through web-based and classroom settings.

12. References:

American Association of State Highway and Transportation Officials (AASHTO). (2007). "AASHTO LRFD bridge design specifications." 4th ed. (with 2008 interim revisions), American Association of State Highway and Transportation Officials, Washington, D.C.

Baig, M. N., Fan, J., and Nie, J. (2006). "Strength of concrete filled steel tubular columns." *Tsinghua Science and Technology*, 11(6), 657-666.

Brauns, J. (1999). "Analysis of stress state in concrete-filled steel column." *Journal of Constructional Steel Research*, 49(2), 189-196.

Giakoumelis, G., and Lam, D. (2004). "Axial capacity of circular concrete-filled tube columns." *Journal of Constructional Steel Research*, 60(7), 1049-1068.

Gupta, P. K., Sarda, S. M., and Kumar, M. S. (2007). "Experimental and computational study of concrete filled steel tubular columns under axial loads." *Journal of Constructional Steel Research*, 63(2), 182-193.

Han, L. H., and Yang, Y. F. (2003). "Analysis of thin-walled steel RHS columns filled with concrete under long-term sustained loads." *Thin-Walled Structures*, 41(9), 849-870.

Huang, C. S., Yeh, Y. K., Liu, G. Y., Hu, H. T., Tsai, K. C., Weng, Y. T., Wang, S. H., and Wu, M. H. (2002). "Axial load behavior of stiffened concrete-filled steel columns." *Journal of Structural Engineering-ASCE*, 128(9), 1222-1230.

Jung, G. J., Kwon, O. S., Jung, S. J., and Kim, M. M. (2006). "Evaluation of full-sized cast-in-place pile capacity with artificial defects." *Soil Mechanics 2006*(1975), 10-20.

O'Shea, M. D., and Bridge, R. Q. (2000). "Design of circular thin-walled concrete filled steel tubes." *Journal of Structural Engineering-ASCE*, 126(11), 1295-1303.

Sakino, K., Nakahara, H., Morino, S., and Nishiyama, A. (2004). "Behavior of centrally loaded concrete-filled steel-tube short columns." *Journal of Structural Engineering-ASCE*, 130(2), 180-188.

Schneider, S. P. (1998). "Axially loaded concrete-filled steel tubes." *Journal of Structural Engineering-ASCE*, 124(10), 1125-1138.

Wisconsin Department of Transportation (WisDOT). (2007). "WisDOT LRFD Bridge Design Manual." Wisconsin Department of Transportation.

Appendix A

Condensed, two-page resumes of the principal investigators are provided for panel review.

DEVIN K. HARRIS, Ph.D.

Donald F. and Rose Ann Tomasini Assistant Professor of Structural Engineering
Michigan Technological University 1400 Townsend Dr. Houghton, MI 49931
Phone: (906) 487-3521 Fax: (906) 487-1620 e-mail: dharris@mtu.edu

PROFILE

Innovative researcher with a diverse background in research methods including experimental, analytical and field investigation. Research and teaching interests include concrete behavior, bridge behavior, polymeric materials, composite structures, and innovative materials in civil infrastructure.

PROFESSIONAL EXPERIENCE

Assistant Professor — December 2007 – present
Michigan Technological University — Houghton, MI

Graduate Research Assistant — January 2003 – December 2007
Blacksburg, VA

Sr. Project Engineer — June 2001 – November 2002
ExxonMobil Development Company – Business Planning — Houston, TX
Analyzing the performance, expenditures, and trends of the global drilling organization, forecasting expenditures and projects, and developing presentations and reports for senior management reviews. Strategic focus areas included Deepwater Gulf of Mexico, North Sea, Malaysia, Eastern Canada, Azerbaijan, Turkmenistan, Qatar, New Projects, Technology, and Operations Integrity Management Systems.

Project Engineer — December 1999 – June 2001
ExxonMobil Development Company – U.S. West Drilling — Houston, TX
Well planning/design, cost estimating/surveillance, project management, and follow-up of drilling programs in South Texas and East Texas. Additional duties as group business advisor included monitoring of US drilling organization's drilling and safety performance; development of quarterly reports, monthly highlights, and internal programs.

Project Engineer — July 1999 – December 1999
Exxon Company U.S.A. – U.S. Drilling Group — New Orleans, LA
Well planning/design, cost estimating/surveillance, project management, and follow-up of oil drilling programs in Wyoming and East Texas.

EDUCATION

Doctor of Philosophy, Civil Engineering — December 2007
Virginia Polytechnic Institute and State University
Dissertation: *Lateral Load Distribution and Deck Design Recommendations for the Sandwich Plate System (SPS) in Bridge Applications*
Dissertation Advisor: Thomas E. Cousins and Thomas M. Murray

Master of Science, Civil Engineering — December 2004

Virginia Polytechnic Institute and State University
Thesis: *Characterization of Punching Shear Capacity of Thin Ultra-High Performance Concrete Plates*
Thesis Advisor: Carin L. Roberts-Wollmann

Bachelor of Science, Civil Engineering June 1999
University of Florida

PUBLICATIONS

Harris, D.K. and Roberts-Wollmann, C.L., (2005). Characterization of the Punching Shear Capacity of Thin Ultra-High Performance Concrete Slabs. Final Contract Report VTRC 05-CR26.

Harris, D.K., Cousins, T., Murray, T.M., and Sotelino, E.D. Field Investigation of a Sandwich Plate System Bridge Deck. Journal of Performance of Constructed Facilities-ASCE. *Accepted January 2008*.

CONFERENCE PROCEEDINGS

Harris, D.K. Cousins, T., Murray, T.M., and Ferro, A., Live Load Test of a SPS Deck Bridge. 7th International Conference on Short and Medium Span Bridges 2006. Montreal, Quebec.

Harris, D.K. and Roberts-Wollmann, C.L., Characterization of Punching Shear Capacity of Thin Ultra-High Performance Concrete Slabs. 2nd International Symposium on Ultra High Performance Concrete 2008. Kassel, Germany (*accepted*).

Theresa M. (Tess) Ahlborn, Ph.D., P.E.

Associate Professor - Civil and Environmental Engineering - Michigan Technological University
Houghton, Michigan 49931 Tel: (906) 487-2625 FAX: (906) 487-1620 e-mail: tess@mtu.edu

PROFESSIONAL SUMMARY:

Dr. Ahlborn has an active research program in the area of reinforcing steels and concrete materials related to concrete structures and bridges, including high performance and ultra-high performance concrete (UHPC) applications. Her additional research interests include bond and development of reinforcing steels, inspection and repair of distressed concrete bridges, overhead sign support structures under fatigue duress, and full scale bridge testing. She is Director of the Center for Structural Durability with the Michigan Tech Transportation Institute and provides a solid research link between industry and government. She has worked extensively with the Michigan Department of Transportation to seek solutions related to long-term durability of transportation structures, including testing of stainless, stainless-clad and high-chromium reinforcing steel to reduce deterioration of bridge decks.

Dr. Ahlborn has published 30 papers in various journals and conference proceedings, directed 17 graduate students to completion in seven years, currently advises eight MS and PhD students, been PI on ten research grants and contracts totaling nearly $600,000, and has taught over 1200 students in 41 course sections at both the undergraduate and graduate levels, with courses emphasizing reinforced and prestressed concrete design, structural analysis, and construction materials. And she often ranks in the top 10% of instructors at Michigan Tech based on student evaluation results. Her industrial experience in the design of bridges, dams and hydropower support structures adds depth to the classroom experience. She is well known for her high student expectations and requires realistic projects in design courses including prestressed concrete bridge superstructure designs and reinforced concrete high-rise building designs.

Dr. Ahlborn serves on several national committees, conference-organizing committees, and as a journal reviewer for many publications. She is a member of the American Concrete Institute and a voting member of both ACI 408 Bond and Development of Reinforcement and ACI 423 Prestressed Concrete. Dr. Ahlborn is also an active member of the Precast/Prestressed Concrete Institute with membership on the Bridge Committee, Concrete Materials Technology Committee, Student Education Committee, and most recently has been appointed as the first female to serve on the PCI Technical Activities Committee. Furthermore, she is a member in the American Society of Structural Engineers, the Structural Engineering Institute, and the Transportation Research Board. She is a panelist for NCHRP 12-60 Transfer, Development, and Splice Length for Strand/Reinforcement in High-Strength Concrete; and has been a panelist for NCHRP 20-07 Update to the Strategic Plan for Bridge Engineering, NSF – NEES Grand Challenge Panels ’04 and ’05, and numerous other NSF panels. She was recently appointed to NCRHP 12-77 High-Strength Reinforcement.

EDUCATION:

UNIVERSITY OF MINNESOTA, Ph.D. Civil/Structural Engineering, September 1998.
MICHIGAN TECHNOLOGICAL UNIVERSITY, M.S. Civil Engineering, November 1987.
MICHIGAN TECHNOLOGICAL UNIVERSITY, B.S. Civil Engineering, May 1986.

PROFESSIONAL REGISTRATION:

Professional Civil Engineer in the State of Minnesota.

WORK EXPERIENCE:

MICHIGAN TECHNOLOGICAL UNIVERSITY 1995-current

Associate Professor, Assistant Professor, Instructor

- Responsible for lectures and laboratory exercises for testing behavior of construction materials, as well as reinforced and prestressed concrete design courses and graduate structural analysis.
- Research expertise is in the area of concrete materials related to prestressed concrete bridges, including high performance and ultra-high performance concrete (UHPC) applications for structural durability. Current projects include condition assessment and

repair for adjacent box-beam bridges, and rapid repair solutions using prefabricated (decked) prestressed beams. Previous research work included structural issues related to overhead sign support structure, deteriorated steel bridge beams, and design, instrumentation, construction, and failure testing of full sized HPC bridge girders.
- Co-founder of the Michigan Tech Concrete Initiative, a campaign that has brought in over $200,000 in less than one year for facility renovations and equipment upgrades for cement and concrete research, and Director of Benedict Laboratory, a 15,000 sq. ft cement and concrete research facility established in 2005.

UNIVERSITY OF MINNESOTA 1990-1995
Graduate Research Assistant

- Conducted research on the application of high strength concrete to prestressed concrete bridge girders.
- Responsible for fabrication, instrumentation, testing and analysis of full-size specimens as well as proposal writing, budgeting, and presentation/reporting at conferences and to local funding agencies.

WARZYN/EWI ENGINEERING ASSOCIATES, Minneapolis, MN 1988-1990
Structural Engineer

- Responsible for analysis and design, development of structural plans and specifications, and shop drawing review of dams, flood control projects, hydropower facilities, and bridges.

SELECTED PUBLICATIONS (limited to 5):

van de Lindt, J.W. and T. M. Ahlborn, "Relative Fatigue/Cost Assessment of Steel Overhead Sign Support Structures Subjected to Wind Load," Wind and Structures, Vol 8, No 5, September 2005, p.343-356.

van de Lindt, J.W., T.M. Ahlborn, and S. Kethu, "Alternate Approach to Approximate Deteriorated Steel Beam End Capacity," Transportation Research Record 1928, JOURNAL of the Transportation Research Board, National Academy Press, Washington D.C., pp. 92-100.

C. G. Gilbertson and T. M. Ahlborn, "A Probabilistic Comparison of Prestress Loss Methods in Prestressed Concrete Beams, PCI JOURNAL, Journal of the Precast/Prestressed Concrete Institute, Vol. 49, No. 5, p. 52-69, (Sept-Oct. 2004).

Ahlborn, T.M., van de Lindt, J.W., Uzcategui, A.J. and Lewis, M.E., "Cost and Performance Comparison of the Nation's Overhead Sign Support Structures," Transportation Research Record 1892, JOURNAL of the Transportation Research Board, National Academy Press, Washington, D.C., 2004.

Ahlborn, T.M. and DenHartigh, T.C., "A Comparative Bond Study of Stainless and High-Chromium Reinforcing Bars in Concrete," Transportation Research Record 1845, JOURNAL of the Transportation Research Board, National Academy Press, Washington, D.C., 2003, pp. 88-95.

PROFESSIONAL MEMBERSHIPS & ACTIVITIES:

American Concrete Institute (International member and member of ACI-Greater MI Chapter)
American Society of Civil Engineers member
Precast/Prestressed Concrete Institute
Michigan Tech-Women in Science and Engineering (WISE) founding member
Structural Engineering Institute

PROFESSIONAL AWARDS:

• 2002 PCI Merit Award ● 2002 Michigan Tech Presidential Council of Alumnae: recognizes accomplishments of Michigan Tech women alums in a number of areas including profession, service to community, education, family, and University support. ●1998 CTS Research Partnership Award for "High-Strength Concrete: Applications to Bridges," an annual award recognizing research projects that have resulted in significant impacts on transportation in the state of Minnesota. ● 1994 PCI Daniel P. Jenny Research Fellowship ● 1992 Women's Transportation Seminar MN Chapter Scholarship Recipient