Investigation of the Long Term Effects of Magnesium Chloride and Other Concentrated Salt Solutions on Pavement and Structural Portland Cement Concrete

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PROBLEM STATEMENT

Keeping roads safe and passable are key concerns for any State Highway Agency (SHA), especially during the winter season when ice and snow accumulation on roads and bridges can create hazardous driving conditions. To accomplish these goals, SHAs are constantly seeking out, evaluating, and adapting new winter maintenance strategies that can accomplish these safety goals while being cost effective and environmentally friendly. One such area where new strategies are being employed is the broad area of deicing and anti-icing. Deicing is defined as any effort to remove ice from roads and bridges after ice deposition on those surfaces has occurred. This is in contrast to anti-icing, which is defined as a surface treatment applied prior to ice deposition that eliminates ice accumulation or facilitates ice removal by lessening the bond between the ice and the pavement surface. In general, deicing and anti-icing are accomplished through the use of various chemicals including aqueous solutions of various chlorides (e.g. magnesium chloride, sodium chloride, and calcium chloride) or other chemicals such as calcium magnesium acetate (CMA), urea, or others. Although the efficacy of these chemicals for deicing and anti-icing has been clearly demonstrated, possible detrimental effects to concrete pavements or bridge decks have not been fully examined and documented. In this sense, the cost effectiveness has not been determined as chemical attacks on concrete structures are a strong possibility and in turn, the resulting deterioration of the structures from these chemical attacks may lead to costly pavement rehabilitation or replacement. Based upon published research, the most problematic chemicals appear to be the chlorides of magnesium, calcium, and sodium and other chemicals containing calcium and magnesium (e.g. CMA). Use of these chemicals has increased given their cost, ease of use, and effectiveness for deicing and anti-icing. Use of alternative chemicals such as propylene glycol and ethylene glycol, which are not commonly viewed as harmful to concrete, has not occurred given concerns about their environmental impact. In the end, chlorides appear to be the best choice if they can be used in such a way as to minimize possible chemical attacks to concrete structures.

The degradation of concrete used in pavements and bridges that may occur as a result of chemical attack by problematic deicing chemicals is the result of an increase in concentration of dissociated calcium and magnesium ions in the concrete pore water. In theory, these free ions are available to combine with materials in the concrete to form expansive or weak products such as brucite or magnesium silicate hydrates, respectively. Also, researchers have suggested that increased concentrations of calcium ions in the concrete pore water solution may result in dedolomitization of dolomite or dolomitic limestone aggregates. Of course, the dissociation of chlorides into ionic species also increases the concentration of chloride in the pore water solution, which has been well documented as a primary cause of scaling and corrosion of reinforcing steel. These possible and known effects must be fully understood if these chemicals are to be used as a mainstay of any deicing or anti-icing strategy. The goal of this proposed research is to examine the effects of deicing and anti-icing chemicals on portland cement concrete and to recommend dosage levels and/or changes to concrete mix designs that will make these solutions non-detrimental to concrete durability.

OBJECTIVES

The objectives for this project are the following:

1) To determine the long-term effects of concentrated solutions of magnesium, sodium and calcium chloride as well as CMA or other alternative liquid deicers on durable portland cement concrete.

2) To estimate the potential for reduction in performance and service life for pavements (jointed plain, reinforced and continuously reinforced) and structures subjected to various concentrated deicing brines.

3) To identify alternative protective or deicing/anti-icing strategies which minimize potential impacts to durable portland cement concrete while providing acceptable winter maintenance results.

To accomplish the first objective, a research program is proposed that includes both field and laboratory evaluation of in-service concrete that has been exposed to deicers, along with a focused laboratory study to qualify and quantify the effect of various deicer/anti-icing chemicals on concrete. From the field study, baseline data for in-service structures will be obtained to help assess concrete quality, permeability, and any deleterious alteration due to deicing/anti-icing chemicals. In turn, this data will be used to guide and benchmark laboratory studies investigating the effect of deicers on various concrete mixes. It is also proposed that the field study data be useful for establishing relationships between concrete material properties and field performance. The laboratory study will provide a statistically valid experimental method for determining the effect of concrete mixture parameters and coatings on the ingress of deicer into concrete and the potential for concrete degradation resulting from high-concentration applications of various deicing/anti-icing chemicals.

The second objective will be accomplished in part through the field and laboratory evaluation of in service structures, through the proposed laboratory experiments, and through a comprehensive review of the literature. In addition, predictive models will be developed linking mixture design and material characteristic parameters and sealers/coatings to the rate of deicer ingress and concrete degradation. Also, a life cycle cost analysis will be performed to establish cost models for the various deicer strategies, mix design and maintenance recommendations.

The last objective will be accomplished by the proposed laboratory experiments and a comprehensive review of the literature. Additionally, if appropriate field sites can be identified, in-service protective strategies can be evaluated and contrasted to similar structures in the same geographic region that have not been so maintained. To aid in implementation, the research will also result in development of guidelines for use by the SHAs to assist them in mitigating damaging effects to concrete resulting from the increasing use of liquid deicing/anti-icing chemicals. These guidelines will be based on sound engineering principles and be broadly applicable over a wide geographical area.

Brief statements of qualifications for key individual team members are presented below.

Lawrence L. Sutter, Ph.D., Project Principal Investigator

Dr. Sutter is an Associate Professor of Civil Engineering Technology at Michigan Tech University where he instructs on a variety of subjects including concrete technology, soil engineering, water and wastewater engineering. He has an extensive background in materials characterization and has done research on the characterization of construction materials including both concrete and asphalt. He is currently involved in a number of projects for the Michigan DOT, Wisconsin DOT, the Federal Highway Administration, the National Cooperative Highway Research Program, and the National Science Foundation investigating concrete durability and performance. Dr. Sutter's dissertation subject was the identification of materials-related distress in portland cement concrete pavements. He is co-director of the University's *Facility for Analysis of Non-Conductive/Volatile Materials*, which includes a complete petrography lab, environmental scanning electron microscope, and newly developed x-ray microscope. He is an Officer of the International Cement Microscopy Association, Member of ASCE, ACI, and ASTM and an ACI Level 1 Concrete Technician Examiner.

As the project principal investigator, Dr. Sutter will be involved in the management of all facets of the project. He will spend considerable efforts directing the laboratory phases of the study, where his material science background and extensive experience in cementitious material characterization will be fully utilized.

Thomas J. Van Dam, Ph.D., P.E., Project Co-Principal Investigator

Dr. Van Dam is an Associate Professor in transportation engineering and construction materials, having specific interest in pavement materials, evaluation, design and performance. He is currently involved in a number of projects for the Michigan DOT, Wisconsin DOT, the Federal Highway Administration, the National Cooperative Highway Research Program, and the National Science Foundation investigating concrete pavement durability and performance. Dr. Van Dam is the Director of the Michigan Tech Transportation Materials Research Center and is the Co-Director of Michigan Tech's *Facility for Analysis of Non-Conductive/Volatile Materials*. Dr. Van Dam conducted doctoral work at the University of Illinois studying the design and performance of general aviation airport pavements. As a Project Manager for four years at ERES Consultants, Inc., he supervised the airport pavement evaluation and design services area. Dr. Van Dam's international experience includes two years of service in Tanzania, East Africa, as a U.S. Peace Corps volunteer and more recently working as a consultant to the Asian Development Bank in Malaysia. He is also co-director of the Peace Corps Masters International program in the Department of Civil and Environmental Engineering at Michigan Tech. He is an active member of ACI Committee 201, *Durability of Concrete*, and is Chairman of TRB Committee A2E01, *Concrete Durability.*

Dr. Van Dam will assist Dr. Sutter in managing the project, and thus will participate in all project tasks. He will take a more prominent role is working with APTech on the field evaluation, in the statistical analyses conducted, and the development of the guidelines.

Dr. R. Douglas Hooton, Co-Principal Investigator

Dr. Douglas Hooton is a Professor of Civil Engineering at the University of Toronto, where he has been since 1986, after working as a research engineer at Ontario Hydro. His research is focused on the properties and performance of cements and supplementary cementing materials, as well as on fluid transport properties, and the durability of concrete to various aggressive environments, such as chlorides, sulfates, freezing and thawing, deicer salt scaling, and alkali-aggregate attack.

Particular to this project, he has numerous publications on deicer salt scaling resistance, concrete permeability, and resistance to chloride penetration. He is also a member of ACI C201 on Durability and ASTM C09.67, which covers ASTM test method C672.
He is or has been Chair of several committees including ASTM C09 on Concrete and Concrete Aggregates (to 2001), ASTM C09.66 on Resistance to Fluid Penetration, ASTM C01.31 on Volume Change of Cements (to 2001), ACI C234 on Silica Fume (to 2000), and CSA Committee A3000 on Hydraulic Cements. He is a past-president of the ACI Ontario Chapter, a Fellow of both the American Concrete Institute and The American Ceramic Society, and an honorary member of ASTM C01 on Cements.

Dr. Hooton brings his extensive practical and academic experience to this project as a technical resource and manager of the experimental work to be conducted at the University of Toronto. Of particular interest is the profile grinding and bulk diffusion testing, which offers some unique capabilities to fully understand the phenomena under study. Dr. Hooton will be advising the graduate student working on this project at the University of Toronto.

Dr. Neeraj Buch, Co-Principal Investigator

Dr. Buch is an Associate Professor of Civil Engineering at Michigan State University, where he directs the Pavement Research Center of Excellence. He currently is involved in research studies for the Michigan DOT, the National Cooperative Highway Research Program, and the Innovative Pavement Research Foundation. Recent research work has been focused on performance modeling of rigid and flexible pavements and analytical and experimental characterization of portland cement concrete mixtures. Current research includes (i) the characterization of transverse cracks in jointed concrete pavements as a function of aggregate type and various pavement design parameters, (ii) the development of rut and fatigue models for flexible pavements and their subsequent inclusion into MICHPAVE, (iii) the development of temperature correction model for asphalt concrete and its subsequent inclusion into MICHBACK, (iv) and the development of concrete mixtures for fast track full depth patches that exhibit sound durability properties. Other research interests include the development of mechanistic pavement design procedures for jointed concrete pavements and non-destructive testing of pavements.

Dr. Buch will use his expertise on concrete pavement design and performance to play a major role in the development of the life cycle cost analyses, coordinating his efforts with APTech.

Russ Alger, Senior Research Engineer

Russ Alger is the Head of the Institute for Snow Research at KRC and has over 16 years experience working with soils and snow as an engineering material. His projects have included studies of mobility in virgin snow as well as methods to manipulate snow layers to produce a desired surface. Mr. Alger was one of the primary engineers on the Wheels versus Tracks program with the Army and was also chosen as one of two snow experts on a Traverse in Antarctica. He has a BS and MS degree in Civil Engineering from Michigan Technological University. His work has brought him to locations across the US and Canada, as well as to Antarctica. The major emphasis is the study and manipulation of snow and ice properties for use as engineering materials, as well as in the modes of both chemical and mechanical removal from pavements. He has conducted extensive research on the ability of various chemical deicing/anti-icing to either remove or prevent the formation of ice on concrete. He has recently completed a North American survey of transportation agencies for the U.S. Army Corps of Engineers Cold Regions Research Engineering Laboratory on deicing/anti-icing practices. He has also conducted research on coatings, and is currently investigating proprietary methods to enhance deicing/anti-icing effectiveness through the use of specialized coatings.

Mr. Alger brings to the project team the expertise on ice removal from transportation structures. He is very familiar with the various chemicals and practice used for deicing/anti-icing, and has extensive laboratory experience in evaluating the effectiveness of such practices. He will contribute to the literature review and site selection process. He will also assist in the laboratory evaluations and will contibute his expertise in coatings and practices.

Karl Peterson, Research Scientist

Mr. Karl Peterson is a Research Scientist with a focus on the microstructure of building materials. He is currently involved in a number of projects for the Michigan Department of Transportation, the Federal Highway Administration, the National Cooperative Highway Research Program, and the National Science Foundation focusing on concrete pavement durability and performance. Mr. Peterson is a well-published and respected concrete petrographer whose creative talents and endless curiosity are of unmeasureable value to the Michigan Tech's research efforts. His Master's research focused on development of a methodology for performing ASTM C-457 with a high-resolution flatbed scanner.

Mr. Peterson will contribute to various tasks, but will be primarily focused on the conduct of laboratory characterization of materials in Michigan Tech's *Facility for Analysis of Non-Conductive/Volatile Materials*. In addition to hands on analytical work, Mr. Peterson will supervise the hourly and graduate students in the laboratory, and will coordinate efforts with Russ Alger at KRC.

Mr. Kurt Smith, P.E., Project Manager

Mr. Kurt Smith will be the APTech project manager for this project, overseeing the APTech work efforts and working closely with Michigan Tech University in coordinating assigned work activities. Mr. Smith earned his B.S. and M.S. degrees in Civil Engineering from the University of Illinois and has over 17 years of experience in the area of pavement engineering, with an emphasis in concrete pavements. During those 17 years, he has been involved in a number of prominent concrete pavement research studies. For example, between 1986 and 1990 and between 1991 and 1995, Mr. Smith served as Co-Principal Investigator and Principal Investigator, respectively, on two major FHWA studies of concrete pavement performance and rehabilitation. In both studies, extensive field studies of existing concrete pavements were conducted, and guidelines were developed for the improved design and construction of concrete pavements. Mr. Smith has also served on several other major national research efforts, including studies on the use and performance of pavements constructed with recycled concrete aggregate, smoothness specifications, and performance-related specifications.

Mr. Smith will manage APTech's role in spearheading the field inspections to be carried out. He will also be actively involved in the life cycle costing analyses conducted, where his expertise on using Monte Carlo simulation for such applications will be invaluable.

Mr. Smith is currently serving as the Principal Investigator on two on-going FHWA projects: *Portland Cement Concrete Overlays* and *Technical Reports on Pavement Technology* and is currently Co-Principal Investigator on *Repair and Rehabilitation of Concrete Pavements*, which is developing guidelines for practicing pavement engineers to aid in identifying and selecting repair or rehabilitation strategies for distressed concrete pavements. He is also assisting in the conduct of an ongoing NCHRP project, *Aggregate Tests for Portland Cement Concrete Pavements* (NCHRP 4-20C). His level of commitments are such that they will not impact his ability to meet his commitments to this project.

FACILITIES

The combined facilities of the research team are very well suited for the tasks described. First, because materials engineering is a recognized university-wide thrust area at Michigan Tech, our materials research facilities are state of the art and uniquely suited for a wide variety of materials characterization and testing activities. The Transportation Materials Research Center (TMRC) at Michigan Tech will be the central laboratory facility for most of this work. These labs include aggregate processing, concrete mixing, and curing. These testing facilities are all available for this project. The TMRC is also well equipped for materials characterization with its petrography laboratory, chemistry laboratory facilities and the Facility for Characterizing Non-Conductive/Volatile phase materials (NC/VP). The NC/VP lab was funded in part by support from the National Science Foundation (NSF) and includes an environmental SEM with an energy dispersive spectrometer (EDS) and a crystallographic orientation imaging system (OIM), an analytical x-ray microscope, and a high-resolution flatbed scanner.

The Concrete Materials Laboratories at the University of Toronto are fully equipped to carry out a wide range of standard and specialized tests on cement, mortar, concrete and associated materials. These facilities include a mercury porosimeter, high-pressure triaxial permeameters, low-pressure water permeameters, chloride migration cells, a custom fitted milling machine for “mm” chloride profiling of concrete, and a Nordtest NTBuild 443 Bulk Diffusion test

Applied Pavement Technology (APTech) is a woman-owned business enterprise (WBE) and a professional corporation that was incorporated to offer a broad range of pavement engineering services to clients in the public and private sector. APTech’s facilities include a Dynamic Cone Penetrometer (DCP), a pachometer to locate and measure depths to steel embedded in concrete, and a digital faultmeter. Several of APTech’s engineers and technicians are certified construction inspectors. APTech has also developed an extensive library database that includes nearly 10,000 publications, which includes reports from the Federal Highway Administration, the Federal Aviation Administration, the National Cooperative Highway Research Program, the Transportation Research Board, the Strategic Highway Research Program, various State highway agencies, as well as numerous conferences proceedings.

The Keweenaw Research Center (KRC) is a research, development and testing agency of Michigan Technological University (MTU) and is totally supported by contract research from government and industry. KRC has four basic research areas, which encompass a broad range of research and development from the basic design stage to the final testing stage. One major research area is directed by the Institute for Snow Research (ISR) which is heavily involved in studying the properties of snow and ice. This group has performed a broad range of research including snow removal techniques, de-icing, anti-icing, winter road maintenance, snow drifting, using snow to build runways in Antarctica as well as traction and braking studies of snow and ice. Their cold room facilities and other climate control facilities will be a key resource in this research.