Erika Holt, Hannele Kuosa, Markku Leivo & Erkki Vesikari

DuraInt-Project Workshop

Effect of interacted deterioration parameters on service life of concrete structures in cold environments

ISBN 978-951-38-7177-2 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 1459-7683 (URL: http://www.vtt.fi/publications/index.jsp)

JULKAISIJA – UTGIVARE – PUBLISHER

VTT, Vuorimiehentie 3, PL 1000, 02044 VTT
puh. vaihde 020 722 111, faksi 020 722 4374

VTT, Bergsmansvägen 3, PB 1000, 02044 VTT
tel. växel 020 722 111, fax 020 722 4374

VTT Technical Research Centre of Finland, Vuorimiehentie 5, P.O. Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 4374

Cover photo is taken by Markku Laksio.

Series title, number and report code of publication

VTT Working Papers 116
VTT–WORK–116

Author(s)

Erika Holt, Hannele Kuosa, Markku Leivo & Erkki Vesikari

Title

DuraInt-Project Workshop

Effect of interacted deterioration parameters on service life of concrete structures in cold environments

Abstract

The workshop was held at VTT as part of the Finnish project "Effect of interacted deterioration parameters on service life of concrete structures in cold environments". The 3-year project began in 2008 and is funded by Tekes. The goal of the workshop was to share results and experiences on current concrete durability research, especially with regard to correlation of accelerated laboratory tests with real-time field exposure sites. Presentations were given on topics of frost resistance, abrasion, chloride ingress and existing field station data. International researchers were invited to share their expertise and collaboration ideas for future partnerships.

ISBN
978-951-38-7177-2 (URL: http://www.vtt.fi/publications/index.jsp)

Series title and ISSN		Project number
VTT Working Papers 1459-7683 (URL: http://www.vtt.fi/publications/index.jsp)		26848
Date March 2009	Language English	Pages 32 p.
Name of project DuraInt	Commissioned by	
Keywords chloride, concrete, deterioration, durability, field station, frost resistance, service life	Publisher VTT Technical Research Centre of Finland P.O. Box 1000, FI-02044 VTT, Finland Phone internat. +358 20 722 4520 Fax +358 20 722 4374	

Contents

1. Workshop Flyer

DURAINT-PROJECT WORKSHOP

Dates: March 2-3, 2009

Hosts: VTT Technical Research Centre of Finland and Helsinki University of Technology (TKK)

Location: VTT campus in Espoo, Finland

In association with the Finnish project "DuraInt: Effect of Interacted Deterioration Parameters on Service Life of Concrete Structures in Cold Environments", 2008-2011

Over the past years various field stations have been established in the Nordic countries and worldwide to assess the real-time performance of concrete. Evaluation of material performance in actual environments is necessary for comparison to accelerated laboratory tests to assess the validity of deterioration models. By obtaining better data on deterioration with the field to laboratory correlations, along with incorporating local weather data, it is possible to improve calculation tools, computer models and service life models to predict concrete behavior. Existing tools typically account for limited deterioration mechanisms, such as frost or chloride alone. The current need is for evaluating interaction of deterioration, such as carbonation, frost and chlorides together, to assess how actual combined forces create a total impact. This need leads to requirements for further laboratory-based research of interacted deterioration to provide for accurate modelling of concrete durability.

The goals of the workshop are to share experiences on recent and on-going concrete durability research with regard to predicting service life utilizing concrete field station results together with possible laboratory results or other information on interacted deterioration. Special attention will be given to addressing the needs for interacted deterioration research. Participants will be expected to submit a short abstract prior to the workshop and then give a 20 minute presentation on a relevant topic. Anticipated presentations include topics such as:

- Summary of existing field station data from earlier projects, Finland and abroad
- 10 year results from Swedish field exposure projects (assessing chloride attack in roadway and marine environments)
- Current Norwegian study on concrete abrasion resistance in harsh environments
- Needs for updating service life prediction models

An expected outcome of the workshop is to strengthen the international cooperation plans between Finland and the participants. During the workshop a clear roadmap will be formulated, detailing how the Finnish DuraInt-project will incorporate knowledge and results from other related international projects, as well as how the Finnish project can assist other researchers and countries. Discussions will focus on how to optimize the test programs to achieve maximum benefits on an international scale with regard to concrete durability modelling and service life prediction tools. Planning of interactive researcher visits between Finland and other countries will also be addressed.

VTT

TKK

1. Workshop Flyer

DURAINT-PROJECT WORKSHOP

Tentative Agenda:

Monday March 2, 2009

noon	Opening Session
1-5pm	Presentations
7pm	Evening Dinner & Program

Tuesday March 3, 2009

9-11am	Presentations
11am-1pm	Laboratory tour and lunch
1-3pm	Cooperation Road-mapping
3:30pm	Workshop Closed

A detailed agenda will be sent in early February 2009.
The language of the workshop is English.
There is no cost associated with the workshop; coffees, lunch and dinner will be provided.
Participants are expected to cover their own of airfare and accommodations.

Suggested Accommodations, using code DURAINT09 before February 20, 2009:

Phone: +358 20 1234 700
e-mail: groups.finland@radissonsas.com,
on-line www.radissonsas.com

(VTT can provide arrangements assistance if needed):

- Radisson SAS Hotel, Espoo
  114 euros single room (10 min walk to VTT)
- Radisson SAS Royal Hotel, Helsinki
  129 euros single room (15 min direct bus to VTT)

Workshop registration by e-mail confirmation along with a 250 word abstract by February 9, to:

Erika Holt
VTT Technical Research Centre of Finland
P.O. Box 1000
FI-02044 VTT, Finland
E-mail: erika.holt@vtt.fi
phone: +358 40 536 5543

More information

Finnish Tourist Board
www.visitfinland.com

City of Helsinki
www.hel.fi/english

City of Espoo
http://english.espoo.fi

Invited participants:

Finland:

- Technical Research Centre of Finland (VTT)
  Dr. *Markku Leivo*, Dr. *Erika Holt*, M.Sc. *Hannele Kuosa*, Lic. *Erkki Vesikari*
- Helsinki University of Technology (TKK)
  Professor *Jari Puttonen*, Lic. *Esko Sistonen*, Lic. *Fahim Al-Neshawy*

Norway

- Norwegian University of Science and Technology (NTNU)
  Professor *Stefan Jacobsen*, Professor *Øystein Vennesland*, *Egil Møen*, *Ueli Angst*

Sweden

- Chalmers University of Technology
  Associate Professor *Tang Luping*
- Swedish Cement and Concrete Research Institute (CBI)
  Dr. *Peter Utgenannt*

Portugal

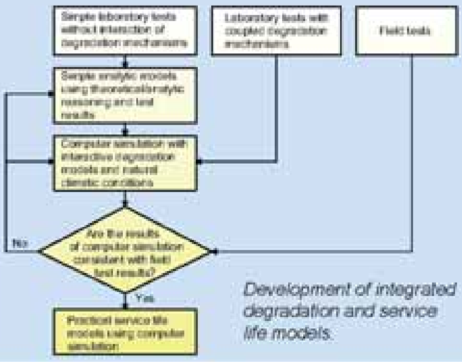
- University of Coimbra
  Assistant Professor *Fernando J. Branco*

Canada

- Laval University, Department of Civil Engineering
  Professor *Jacques Marchand*,
  Associate Professor *Marc Jolin*
- University of Toronto, Department of Civil Engineering:
  Professor *Doug Hooton*

USA

- Michigan Technological University
  Professor *Larry Sutter*
- Federal Highway Administration Turner-Fairbank Highway Research Center
  Richard Meininger
- Cold Regions Research and Engineering Laboratory (CRREL), R&D Center of US Army Corp of Engineers
  Lynette Barna



Development of integrated degradation and service life models.

2. Agenda

Monday March 2, 2009

noon Opening Session

- *Markku Leivo: Welcome from VTT*
- *Jari Puttonen: Welcome from TKK*
- *Group Introductions*
- *Leivo (VTT): Overview of DuraInt project plan & goals (including history of Finnish concrete durability research)*

1–5 pm Presentations – Research Reviews (20 minutes each)

- *1 Branco (Coimbra): A review on experimental tests for chloride migration and chloride/freeze-thaw interaction in concrete*
- *2 Jacobsen (NTNU): Ice abrasion on concrete: available field experiences and coupling to testing*
- *3 Al-Neshawy (TKK): Long term monitoring of frost deterioration of building facades*
- *4 Utgenannt (CBI): 10 years of frost experience at 3 Swedish field exposure sites*

(Coffee Break)

- *5 Sutter (Michigan Tech): Deleterious chemical effects of deicing solutions on PCC*
- *6 Luping (CBI): Chloride ingress and corrosion from the Swedish field exposure sites*
- *7 Hooton (Toronto): Predictive Model Validation from Long-Term Chloride Penetration Resistance of Bridge Decks Made With Silica Fume Concretes*
- *8 Vesikari (VTT): Methods for Generating Reliable Service Life Models*

Discussion

7 pm Evening dinner, Ravintola Loiste
Address: Kaivokatu 3, 10th floor (above Sokos department store), Helsinki

Tuesday March 3, 2009

9–11 am Presentations – DuraInt project specific (including others' experiences & opinions)

- *9 Holt (VTT): Earlier field station project results (Conlife & YmpBetoni)*
- *10 Kuosa (VTT): Initial lab and field results from DuraInt project, including test methods (first 1 year)*
- *11 Sistonen (TKK): Review of future plans for DuraInt interaction testing and FEM modeling (next 2 years)*
- *12 Vesikari (VTT): Life Cycle Management Tools Developed in VTT*

Discussion

11 am – noon VTT Laboratory tour

12–1 pm Lunch at VTT

1–3 pm Cooperation Road-mapping

- *Leivo (VTT): Review of cooperation ideas from Finland*
    - *Our researchers visiting abroad*
    - *Guest researchers coming here*
    - *Option for exchange of testing samples*
- *All participants: please share ideas/goals:*
    - *What projects you have going on or planned where cooperation may be possible?*
    - *How would you like to benefit from cooperation with Finland & DuraInt project?*
    - *Other ideas*

4 pm Workshop summary and closing remarks (Holt – VTT)
Distribution of slides & any relevant papers to all participants

Wednesday March 4, 2009 (optional)

10 am TKK Tour

2–4 pm Meeting at Finnish Road Administration (Tiehallinto)
Discussion about Management Systems

3. Abstracts

Title: Overview of DuraInt Project plan & goals

Presentation by Markku Leivo (Technical Research Centre of Finland)

The 3-year DuraInt project began in 2008 with the objecting of evaluating the effect of interacted deterioration parameters on the service live of concrete in cold environments. Here the deterioration parameters include both accelerated laboratory testing and real-time field exposure for freeze-thaw resistance, frost-salt resistance, carbonation and chloride ingress. The project was born from the Durafield project, a Finnish industry-driven project aimed at establishing a new field testing area (Highway 7) and starting long term field testing and parallel initial testing and laboratory studies with about 30 mixes/cases with Finnish binding materials. The DuraInt project is funded by TEKES (Finnish Funding Agency for Technology and Innovation) and has a strong objective to increase international cooperation on the topic of concrete durability. This workshop is one aspect of improving knowledge sharing with research leaders from Canada, Norway, Portugal, Sweden and the U.S.A.

1 Title: A review on experimental tests for chloride migration and chloride/freeze-thaw interaction in concrete

Authors: Fernando G. Branco (Department of Civil Engineering, University of Coimbra, Portugal) and Maria de Lurdes B. Reis (Department of Civil Engineering, Polytechnic Institute of Tomar, Portugal)

Presentation given by Esko Sistonen, TKK

The occurrence of freeze-thaw cycles is one of the contributing factors for concrete deterioration in cold climates. The presence of chloride and chloride migration within concrete also contribute to the life-span reduction of reinforced concrete elements. The effect of these two factors in concrete durability has been studied by different research teams along the years. A number of laboratory setups have been developed, and some of them have been upgraded to standard documents.

The present communication aims to present the different experimental techniques available to test chloride migration and/or the influence of freeze-thaw cycles in concrete. A literature review was carried out; the available published data was collected and will be analyzed, correlated and commented on this presentation.

2 Title: Ice Abrasion on Concrete: Available Field Experiences and Coupling to Testing

Authors: Egil Møen and Stefan Jacobsen (Department of Structural Engineering, Norwegian University of Science and Technology - NTNU) and Kjell Tore Fosså (Aker Solutions Engineering & Technology)

Ice abrasion is known as a very severe deterioration mechanism acting on concrete offshore structures under sub-arctic conditions. In a previous workshop we gave an overview of the current state in this field [1, 2]. Based on this, a research program is currently in progress on development of ice abrasion resistant concrete. As a part of the program an accelerated ice abrasion test method is developed. In order to validate this test, calibration towards at least one or two concrete structures exposed to real, known, ice abrasion is required. It is also an ambition of the program to take initiative to foundation of an international standardization committee on the subject.

Field data on ice abrasion for well known concrete compositions exposed to well-defined ice load regimes are rare. Laboratory data indicate that the rate of deterioration correlates with the concrete quality, but that there is a general lack of coupling between ice abrasion measurements in lab and in field. Therefore we discuss further research possibilities within this field for the development a reliable test for assessing and producing competitive concrete structures for sub-arctic conditions. Specifically we have reviewed ice abrasion data on 7 field exposed concrete structures we consider relevant for sampling and further testing under controlled laboratory conditions as well as one arctic natural rock: The Finnish light houses Oulu 1, 2, 3 and Raahe [3], the Canadian Confederation Bridge, [4] the Field track of the “Super CID-platform” that has been operating in the Arctic for around 20 years [5] and finally a natural igneous rock in Spitsbergen Norway where the coastal cliff retreat rate has been examined by terrestrial photogrammetry [6].

References

1. Ice Abrasion on Concrete Structures, Proceedings Nordic Concrete Research Workshop. Helsinki, October 25 and 26, 2007, Editors: S. Jacobsen, E. Møen, K. T. Fosså, T. Myrland Jensen and E. Sistonen, Nordic Concrete Federation 2008. 181 p.
2. Møen et al. Ice Abrasion Data on Concrete Structures – State-of-the-art – COIN Proceedings Nordic Concrete Research Work Shop, Ice abrasion on concrete structures, Helsingfors, October 25 and 26, 2007. Pp. 59–103.
3. Huovinen, S. Abrasion of concrete by ice in arctic sea structures, Espoo, VTT Publications 62 (Doctoral Thesis). 110 p. + app. 31 p.
4. Newhook, J. P. and McGinn, D. J. Ice Abrasion Assessment – Piers of Confederation Bridge, Confederation Bridge Engineering Summit, August 19–22, 2007. Charlottetown, PEI.
5. LaFraugh, R.W. Design and Placement of High Strength Lightweight and Normalweight Concrete for Glomar Baufort Sea 1. Proceedings Symposium Stavanger, Norway, June 15–18, 1987. Pp. 497–508.
6. Wangensteen, B., Eiken, T., Ødegård, R. S. and Sollid, J. L. Measuring coastal cliff retreat in the Kongsfjorden area, Svalbard, using terrestrial photogrammetry. Polar Research 2007(26), pp. 14–21.

3 Title: Long term monitoring of frost deterioration of building facades

Author: Fahim Al-Neshawy (Helsinki University of Technology, TKK)

Frost damage to building facades is common throughout the Scandinavian countries because of the temperatures may drop below freezing point from the end of September to the beginning of May. The degree of saturation, the freezing rate, the minimum freezing temperature, and the frozen time are the external factors which cause the frost damage of materials. One of the objectives of the research was to develop and test a thermal and moisture monitoring network system. The continuous monitoring of temperature and relative humidity provides a good piece of information about the frost deterioration of buildings facades. The results of the research will help the building construction industry by providing methodologies and systems for monitoring the frost deterioration of building facades.

4 Title: 10 years of frost experience at 3 Swedish field exposure sites

Author: <u>Peter Utgenannt</u> (Swedish Cement and Concrete Research Institute, CBI)

Concrete samples made from different cement/binder types, including secondary cementitious materials, have been exposed at three different field test sites for over ten years. All the sites are situated in Sweden: one in a highway environment, one in a marine environment and one in an environment without salt exposure. The resistance to internal and external frost damage has been regularly evaluated by measurements of change in volume and ultrasonic pulse transmission time. The results after ten years' exposure clearly indicate the highway environment as being the most aggressive with regard to external frost damage. The influence of climate on the internal frost damage is less pronounced. The results after ten years' exposure show that concrete with CEM I, CEM II/A-LL, CEM II/AS, CEM I + 30% slag and CEM I + 5 % silica as binder, with entrained air and a water/binder ratio of 0.5 or below, has good resistance to internal and external frost damage. Results show that concrete containing large amounts of slag in the binder (CEM III) have the severest scaling, whether with or without entrained air. For concrete without entrained air, qualities containing CEM I + 5% silica as binder seem to be more susceptible to internal damage than do the other qualities. Carbonation depth was measured on specimens exposed for eleven years at the test site without salt exposure. Results show a small carbonation depth for all concrete qualities, except for concrete with CEM III as binder, for which the carbonation depth was markedly greater.

5 Title: Deleterious chemical effects of deicing solutions on PCC

Author: <u>Larry Sutter</u> (Michigan Tech Transportation Institute)

This research project investigated the effects of concentrated brines of magnesium chloride, calcium chloride, sodium chloride, and calcium magnesium acetate on portland cement concrete. Although known to be effective at deicing and anti- icing, the deleterious effects these chemicals may have on concrete have not been well documented. The degradation of concrete used in pavements and bridges that may occur as a result of exposure to these chemicals is the result of an increased concentration of calcium and magnesium ions in the concrete pore water. These free ions are available to combine with materials in the concrete to form expansive or weakened cementitious phases. The possible deleterious effects of these chemicals on concrete must be fully understood if these chemicals are to be used as a mainstay of any deicing or anti- icing strategy.

6 Title: Chloride ingress and corrosion from the Swedish field exposure sites

Authors: Tang Luping and Peter Utgenannt (Swedish Cement and Concrete Research Institute, CBI)

This paper presents the results from several Swedish national research projects dealing with durability of concrete structures. In the beginning of 1990's, some 40 types of concrete specimens were exposed to seawater at the field station at the western coast of Sweden to investigate the chloride resistance of concrete under marine environment. In the middle of 1990's, a large number of reinforced concrete specimens with different qualities have been exposed at the field station by Highway 40, where de-icing salts were intensively used, to investigate the chloride resistance of concrete under the road environment. Chloride profiles were measured after certain periods of exposure from 0.5 to more than 10 years. Moisture profiles were also measured from some of samples. Up to now some 400 chloride profiles and 200 moisture profiles have been collected. These collected data supply unique opportunities for validation of the rapid test methods and the prediction models for chloride ingress and corrosion of reinforcement steel in concrete.

7 Title: Predictive Model Validation from Long-Term Chloride Penetration Resistance of Bridge Decks Made With Silica Fume Concretes

Authors: Doug Hooton & E. Bentz, (University of Toronto, Department of Civil Engineering), and T. Kojundic (Elkem Materials, Pittsburgh PA)

With support from the US Silica Fume Association, cores were obtained in 2001 and 2002 from four concretes from bridge decks in New York State and one in Ohio which were 15 years old and which had been exposed to de-icing salts. The bridge in Ohio was 15 years old and made with silica fume concrete (477 kg/m^3 cementitious materials with 14.3% silica fume, 0.33 w/cm). The New York bridges included a 6 year old Portland cement concrete (0.42 w/c, 400 kg/m^3), a 6 year old, 0.40 concrete with 20% F-fly ash and 6% silica fume (400kg/m^3), a 7 year old, 11% silica fume, 0.37 w/cm concrete (455 kg/m^3), and a 12 year old silica fume concrete repair overlay (6% silica fume, 0.40 w/cm, 400kg/m^3).

The cores were tested for chloride penetration profiles using mm profile grinding, while deeper parts of the cores were tested for chloride bulk diffusion by ASTM C1556 (Nordtest NT Build 443), rapid chloride penetration resistance (ASTM C1202). The depth of cover was noted, where visible.

The results show that all of the silica fume concrete decks had high chloride penetration resistance, with all full depth decks having ASTM C1202 values between 290 and 690 coulombs on average, while the portland cement concrete had 3900 coulombs. Predicted time-to-corrosion service life, using the Life-365 program (using default diffusion and time-dependant values, assumed in the program for each mix design), indicated residual service-life estimates of between 30 and 61 years for the silica fume concretes. A portland cement concrete, used as a control, was found to be likely subject to corrosion at the time of coring (using an assumed depth of cover). Predicted residual service lives based on extrapolation from existing chloride penetration profiles gave longer estimates by 10-years on average for the 3 new bridge decks (the overlay repaired deck was not included) made using silica fume concrete, thus indicating that the model predictions are conservative, yet not overly so.

8 Title: Methods for Generating Reliable Service Life Models

Author: Erkki Vesikari (Technical Research Centre of Finland)

Reliable service life models are needed in today's design practices: service life design, life cycle analyses, predictive maintenance design, risk based approaches etc. In this paper the methods for providing degradation and service life data and generating reliable degradation and service life models are discussed. The methods may be categorized as follows:

1. long-term aging tests,
2. tests performed in laboratories as combined with long-term aging tests, and
3. analytical calculation methods as combined with long-term aging tests and laboratory tests.

Long-term aging tests are a prerequisite for reliable degradation and service life data as eventually only the data obtained by field tests can be considered as "firm ground". The validity of the results of long-term aging tests for the exposed materials and in the actual test conditions can hardly be denied. However, there may be serious problems in the application of these data to other materials and to different environmental conditions. To extend the application of these data beyond the limits of the actual field test may require supplementary tests and analytical calculation methods. In spite of this, by establishing one or more firm points in the design models of durability the field tests are invaluable in the development process.

There are also serious problems with field tests resulting from the fact that field tests are long-lasting and expensive. That is why the need of service life data can never be satisfied by field tests only. Other methods should be developed to produce usable service life data more quickly. Such more rapid methods may be accelerated tests performed in laboratories and theoretical and analytical calculation methods. Both of them must be verified and calibrated with observations from the field.

Many kinds of accelerated tests have been widely used for the evaluation of durability in laboratories. However, in order to be applicable for service life evaluation these tests must be calibrated with long-term aging tests. When developing accelerated test methods for service life prediction the procedure of ISO 15686-2 is recommended.

Theoretical calculation methods should also be calibrated with long-term aging tests when used for service life prediction. They can be grouped as follows:

1. Simple theoretical/analytic models
2. Computer simulation.

Simple theoretical/analytic models are based on general theories of diffusion, dissolution, convection, erosion, abrasion, chemical reaction, electrochemical corrosion, phase transition etc. Parameters to the theoretical framework are usually searched by experimental research both in laboratory and in field. To be practical the parameters of the models should be those commonly used in the design of structures. The weak point of this kind of simple models is that they are usually based on fairly rough exposure classification and fail to consider the interaction of degradation mechanisms.

Computer simulation which is able to simulate weather, heat and moisture transfer in concrete and several degradation mechanisms at the same time could serve as a solution for the above mentioned problem. By computer simulation momentary moisture and temperature states which are relevant e.g. for frost attack can be simulated. Also the interaction of different degradation mechanisms such as frost attack and carbonation/ chloride penetration can be studied

It is evident that all the above mentioned methods, long-term aging tests, laboratory tests and theoretical calculation methods are needed for development reliable prediction methods of service life. To be able to combine these data full understanding on the degradation mechanisms is necessary.

9 Title: Earlier field station project results

Presentation by <u>Erika Holt</u> (Technical Research Centre of Finland)

The first two Finnish field stations were established in 2001 and 2002 for evaluation of frost resistance. The northern Sodankylä station in Lapland has severe low temperatures where the southern Otaniemi, Espoo station has more moderate winters. Both stations have about 50 freeze-thaw cycles per winter. There are approximately 40 different concretes at each location, with various amounts of slag, fly ash and silica fume in mixtures with w/b_{eff} from 0.27 to 0.62. There are both air entrained and non-air entrained mixtures and some mixtures have been heat treated after casting. The field performance of all mixtures has been monitored and evaluated in comparison to accelerated laboratory test. Some of the mixtures, especially those that are non-air entrained, have shown internal damage. The results are utilized for long-term durability and service life models.

10 Title: Initial lab and field results from DuraInt project, including test methods

Presentation by <u>Hannele Kuosa</u> (Technical Research Centre of Finland)

In the Durafield-project (from March 2007) a new field and laboratory testing program was started, which is now continued within the DuraInt project (2008–2011). Two field testing areas are located in southern Finland; one of them is a new field beside Highway 7. So far 27 Finnish industrial concretes have been included; more will be included later on, e.g. some high strength concretes autumn 2009. Field testing of frost-salt scaling, internal frost deterioration, carbonation and chloride penetration without and partly with protective impregnations or the use of mould lining is going on. Weather data and concrete temperature and relative humidity/moisture content data is monitored. The laboratory program includes: fresh concrete properties, compressive strength, frost-salt or frost testing without and with ageing, chloride diffusion coefficient, accelerated and natural carbonation, thin section studies and air void analysis. The first field testing results (2007–2008) are available and the results include also a lot of comparable laboratory testing data. A documentation database will be established. Information on other similar projects will be included. This database will be maintained for decades to serve as a basis for future service life modeling and normative regulations. Applicable quality control systems and methods can also be based on the results.

11 Title: Review of future plans for DuraInt interaction testing and FEM modeling

Presentation by Esko Sistonen (Helsinki University of Technology, TKK)

Laboratory testing is needed to get data and verify deterioration models with interaction. An extensive laboratory program is underway to model interaction between different deterioration actions. Interacted deterioration parameters to study for DuraInt interaction testing are: Part A. Frost-Salt and Carbonation (FS-Carb) (and reverse); Part B. Frost and Carbonation (F-Carb) (and reverse) – both 2007 and 2008 samples; Part C. Carbonation and Chloride penetration (Carb-Cl) (and reverse); Part D. Frost and Chloride (F-Cl); Part E. Chloride and Moisture (Cl-Moist). The quantification in order to make deterioration models with interaction will be made using FEM modeling.

There is reasonable doubt that conventional methods do not have the capability to describe the deterioration of structures accurately enough, as the interaction of various deterioration mechanisms is not considered. Thus, the fundamental questions to be clarified are the effect of interaction between different mechanisms on the ageing of reinforced concrete, and possible difference of results between conventional methods and the mathematical model, that takes into account the mechanisms interaction.

The developing mathematical model is constructed to take into account coupling of the relevant deterioration mechanisms needed for an estimation of concrete degradation. The mechanisms recognized and studied are: carbonation of concrete, moisture ingress, chloride penetration, frost damage, and frost salt damage. The results will be obtained by implementing the model into a finite element program simulating test concrete mixes compared with the values obtained from the experiments and conventional calculation methods.

12 Title: Life Cycle Management Tools Developed in VTT

Presentation by Erkki Vesikari (Technical Research Centre of Finland)

Several life cycle management tools have been developed in Finland during the years 2002–2008. The tools were designed applicable to bridges, roads, building envelopes and nuclear power plants. All these systems were based on the basic ideas of the European Union Project LIFECON in 2001–2003. The objective of the LIFECON project was to develop a model of a predicted and integrated life cycle management system for infrastructures. The basic ideas can be expressed by the following characteristics of the system: predictive, integrated, life-cycle based and probabilistic.

The structures whether bridges, roads, buildings or nuclear power plants are divided into smaller structural parts which can be treated as homogenous with respect to materials, structural features and environmental stresses. These structural parts are called “modules” and they serve as basic structural units in the analysis and planning processes of the system. The structural databases which serve as initial data sources in the calculation processes are consistent with the modular breakdown of structures. The modular database consists of identification data, history data (dates of manufacturing and repairs), structural data, material data, measuring data, exposure data, observed damage data (inspection data) and specification data for the future maintenance and repair actions. Another database consisting of data on costs, environmental impacts, degradation rate and service life etc. pertaining to maintenance, repair and rehabilitation (MR&R) actions is also produced.

The core of the management system consists of a combined condition, cost and environmental impact analysis. The condition analysis is produced automatically based on degradation models and predefined limit states of condition. The condition analysis is based on the Markov Chain method and is capable of predicting the probability of the structure to be at any of the condition states during the treated design period. The automatically produced life cycle action profiles can later be altered manually. When the life cycle action profile is defined the life cycle costs and the environmental impacts due to MR&R actions are calculated automatically by the side of the condition analysis.

The procedures and methods of the LCM Tools are discussed in this paper concentrating especially in the condition analysis. They include the transition methods from degradation models to Markov Chain condition analysis, accounting for protection methods in the condition prediction of structures and timing of MR&R actions.

4. Minutes & Discussions

Monday, March 2

12.00 Opening Session

Leivo, *Summary of VTT:* established 1942, 2700 employees, 76% higher academic degree, 4 domestic sites, Turnover 232 M euros. Reviewed divisions and types of research.

Puttonen, *TKK summary:* established 1849, 1500 students in 25 departments, free education system, budget 240 M euros, 42% of Finnish engineers, 60% Drs of Science, about 12% international students doing doctoral and postgrad. Staff about 3100 including 200 professors, research funded by industry. Review of divisions and laboratory facilities.

Personal introductions by all participants.

Leivo, *Quick review of DuraInt project:* Key in this project is how the deterioration mechanics work together. Want to look at how rate of degradation in field tests correlates to laboratory. Then develop deterioration models and service life calculation tools. Funding from Tekes and industry partners. Budget 1.2 M Euros over 3 years. History of Finnish research: Frost-salt for deicing applications (not marine, as sea is only 0.3% salt). Corrosion and carbonation have researched for long time and durability studies with VTT–TKK always on-going. ASR not considered a problem.

1–5 pm Presentations – Research Reviews

01. Branco (Coimbra): *A review on experimental tests for chloride migration and chloride/freeze-thaw interaction in concrete:* Presentation given by Esko Sistonen (TKK). Reviewed critical chloride concentration limits (Cl^-) reported in historic research (from 1962) and various codes (such as ACI and RILEM), i.e. range of 0.20 to 0.60 kg/m^3 – there is a high variation based on parameters such as pH, cement type, temperature, water amount, etc. Noted diffusion theories, such as Fick's 2nd Law but this theory assumed to not always accurately show penetration

process. Review of laboratory techniques for chloride diffusion quantification, with descriptions of method, history and drawbacks noted. Reviewed freeze-thaw test methods. Questions regarding which methods correlate best to field results?

Discussion: *Jacobsen* asked what methods were used to investigate internal damage? Replies were about various participants' experiences using relative dynamic modulus calculated from frequency or ultrasound, and dilation. *Hooton* commented that the ASTM standard for frost-salt may include new guideline for 3% salt water soaking for a week prior to freeze-thaw cycles, which has given preliminary results that closer match field performance of concrete flatwork (especially mixtures with secondary binders). He also noted that the ASSHTO 259 "90 day ponding" test is not really used anymore. The rapid permeability test still being used with the modification where there is an initial measurement of resistivity.

02. Jacobsen (NTNU): *Ice abrasion on concrete: available field experiences and coupling to testing:* Started by provided background review of COIN funding in Norway and NTNU's cooperation with SINTEF, the research needs from the oil industry, and the earlier workshop in Finland October 2007 on abrasion of arctic structures with publication of papers. Current review of offshore concrete structures and ice abrasion (literature from earlier tests with ice breakers and on lighthouses in Sweden and Finland). There are new international research results related to performance of the Confederation Bridge in Canada (built 1990s) along with scaling and abrasion measurements (Proceedings from Engineering Summit August 2007 meeting). Showed current NTNU laboratory equipment options for measuring abrasion on concrete along with video clips. Concluded with upcoming research plans and proposed cooperation ideas to core from Finnish lighthouses and measure interactions with frost and chloride.

Discussion: *Utgenannt* asked about building their test equipment within a freezer room. *Leivo* remembers earlier Finnish calculations about ice development rate and risk of ice build-up. *Luping* asked if there is data yet from the abrasion tests but NTNU is still doing equipment development and installing laser scanner sensors. *Luping* commented that they may need to also consider crushing pressure (and resulting microcracks and scaling) that is happening within NTNU test arrangement. *Hooton* asked what level of pressure seen in field, *Jacobsen* commented locally 5–7 MPa seen in USA research (reported in 2007 workshop).

03. Al-Neshawy (TKK): *Long term monitoring of frost deterioration of building facades:* Presentation based on two earlier projects and with earlier and ongoing thesis work. Work includes monitoring moisture state and exposure environment during

deterioration. Laboratory concrete samples stored at different RH with temperature control of freezing and then long-term measurements of RH, temperature and dilation length change. Measurements since 2004 in lab and correlated with instrumented façade measurements in field after repair/retrofit. Air entrained concrete performed well until end of test at 100 cycles, while non-air entrained cycles start to deteriorate (even after 2 freeze-thaw cycles for 95% RH samples) and failed early. Dilation of -300 to +750 microstrain with cycle from -40ºC to 20ºC for 20 MPa concrete (w/c 0.68 to 0.98). In field, monitored maximum cooling and warming rate (ºC/hr) along with total freezing time (days/yr). The results were very dependant on direction of façade pertaining to location. Work is still on-going and will be summarized in PhD (2010).

Discussion: *Holt* asked about the dependence of direction of façade exposure when modeling service life (i.e: assuming north exposure always behaves similar, though results showed different directions were sometimes performing "worst"). *Vesikari* asked about the potential to have frost damage even in sheltered (non-moisture exposed) samples. Reply that yes, results have shown that even at 45% RH there is still dilation/deterioration measurements. *Luping* asked is the moisture monitoring at the surface or at various depth and what is the long term availability of data? Reply that yes, they are measuring at various depths and want to measure more in future instrumentations. Data will be available.

04. Utgenannt (CBI): *10 years of frost experience at 3 Swedish field exposure sites:* Exposure sites initially established 12 years ago to correlate field data to lab testing. Have highway (salt and plain exposure) at Borås, and seawater at Tröslövsläge & Hirtshals harbors in Denmark. Program: 6 cement types – CEM I, II or III having 5% silica, 30% slag, 70% slag with design of w/b 0.30 to 0.75. Cured 2–3 months before exposure. Lab strength, salt-frost and air void structure measured before exposure. Initial yearly measurements of volume change (weight) and ultrasound pulse transmission time and now measured every 2 years. Roadway results at w/b 0.75: all concrete qualities with air entrained showing damage. At lower w/b ratios, all performing ok (except with high slag). Without salt and entrained air, all doing OK. Highway without air entrainment, all showing damage (failure at w/b 0.75, 0.5 w/b is showing some damage but not failure). Marine environment without air entrainment, w/b 0.75 severe failure. CEM 1 with 5% silica fume showing expansion in all environments for concrete with w/b ratio 0.50 and over and without air entrainment. They did tests to measure the effect of ageing (carbonation) on the salt-frost resistance, with carbonation (1%). For concrete with pure OPC as binder, the carbonation markedly increases the scaling resistance. For concrete with high slag content (65 %) the effect was the opposite.

This is explained by the change in pore structure and thus freezable water content as a result of carbonation. The Swedish field results showed good correlation with the 25-year exposure data of slag concrete from the Treat Island exposure site in the USA. (*Hooton* commented those tests were done at exposure ages having concrete of various strengths, which is not very realistic from material suppliers/sales viewpoint). The Swedish provisions for the EN206 codes have specifications for XF classes that were modified in 2008 to include higher amounts of mineral byproducts, based on these field results. Conclusions: Highway environments are the most aggressive with regard to frost attack. At w/b 0.50 or less, scaling seen only when exposed to salt. Concrete with high slag suffered severe scaling even at w/b 0.50 and with entrained air. Internal damage was seen at all sites for mixtures without air entrainment. Results for lab tests classifies most concrete qualities correctly.

Discussion: *Kuosa* asked was the 7 days of drying prior to carbonation exposure enough? Answered that it was enough within the standard and *Kuosa* commented that in VTT tests the carbonated surface is cut away after 1 year of exposure prior to next type of deterioration exposure in lab. *Hooton* commented that Canadian requirements now say that if using 50% slag, it requires lowering w/b from 0.40 to 0.35 and cure 14 days before exposure. *Jacobsen* asked if any ternary blends (including 2+ mineral admixtures) were used but they were not included in any exposures for the Swedish tests (but *Holt* replied they were included within EU Conlife project with silica fume combined with either fly ash and slag – see presentation Number 9).

05. Sutter (Michigan Tech): *Deleterious chemical effects of deicing solutions on PCC*:

Started with background of MTU and Michigan winter environment, as describing how their research funding is often from government agencies (road administrations (DOTs), etc.). MTU’s expertise in concrete and asphalt is related to characterization (i.e: petrographic studies) and durability studies. They recently completed a large 3-year project for a group of US DOTs. The project goals were to evaluate long term effects of deicing solutions in pavements and bridges, estimate potential of service life reduction, and identify alternative methods to improve resistance. Looked at both mortar and concrete in lab, as well as characterized field specimens. If saw damage from deicers in field sampling, almost always saw poor air void structure. Laboratory: tested 5 different deicer solutions (around 15–23 wt% which is about half of concentration level used in field) and control, exposed at various times and exposed at different temperatures (5, 22, 57ºC). Samples were immersed (not freeze-thaw cycles) and left to sit to see chemical effects of exposure. Sometimes saw interesting result that w/c 0.40 mortar performed worse than high w/c 0.6 mixture. Saw formation of cracks and expansive crystal growth in voids for various deicer chemical exposures. Saw same effects in concrete compared with mortar but took much longer (500 days) and saw different morphology of oxychloride. Results showed use of secondary binders (slag and fly ash) had reduced chloride ingress. Measured data correlated with predicted by NIST (Fick's 2^{nd} Law) diffusion model. Have planned a continuation/follow-up project that will hopefully begin in 2009 (3 years and with a group of DOTs again).

Discussion: *Utgenannt* asked about use of sugar for deicing? Answered yes – sugar products like beet-juice can be mixed with calcium chloride for lowering freezing temperature (also example of one tested in their project which was an agricultural by-products, like beer-brewing residue). *Hooton* comment that storage of such agricultural products have problems with growth of mould and *Sutter* mentioned their hazardous appeal to animals (attract to road). *Sutter* commented that problems with placing the deicers as liquid brined rather than solid, which is causing greater levels of damage due to saturation. Also, there has been a large increase in cost of salt in the past few years so road administrations are concerned. *Jacobsen* asked if dealing with friction/safety? *Sutter* answered that this topic will probably be in upcoming research with driver safety for friction effect (along with service life and cost analysis).

06. Luping (CBI): *Chloride ingress and corrosion from the Swedish field exposure sites:* There were two field exposure sites and their concrete performance described. The first has concretes 12 years old at Träslövsläge harbor on floating station with 40 types of concrete, where measure temperature and chloride along with other material properties. Various binders (silica fume, fly ash) and cement types, w/b 0.25 to 0.75, air at 0, 3 or 6% (for w/b over 0.35). Sample concretes are located at different sea/moisture levels: atmospheric, splash or submerged zone. Also have various concrete cover depths to rebar for corrosion measures. The other field exposure is along a highway, with heavy deicing spray and samples there since 1996. 1.1 to 2.4 kg/m^2 of salt spread, 115 to 150 times per year (past few years spreading lowest amounts due to different techniques). They have been doing lab testing with measuring chloride profiles and new NDT method "rapid technique for corrosion mapping – RapiCor". Looking at chloride ingress, curve fitting is not suitable because each year there are different levels/curves. Results showed effect of binder type on chloride ingress, with improved resistance (lower ingress) when containing fly ash and fly ash. Yet it is not clear to establish the effect of binder on corrosion rate. The ClinCon model was developed based on cement types for predicting chloride ingress. Conclusion are that the chloride ingress after 10 years in some cases is less than in the early (1–2 year) measurements. This could be due to varying amount of salt spread (and chlorides are leaching out each year, though they are going deeper?) and snow insulation?

Discussion: *Jacoben* & *Puttonen* asked about the "dip" at the start of the chloride profile. *Luping* attributes it partially to carbonation and chloride binding. Yet there is a question for how to fit curves (or Fick's 2nd Law) to model this. It is still an "unknown" how to accurately model this. *Sistonen* asked are there results for stainless steel (most results given were for black steel)? Reply is that there was no threshold value found for the stainless steel.

07. Hooton (Toronto): *Predictive Model Validation from Long-Term Chloride Penetration Resistance of Bridge Decks Made With Silica Fume Concretes:* Gave short overview of University of Toronto (largest university in Canada). Have 4 field exposure sites (i.e. 12 & 16 yrs old) evaluating ASR, freeze-thaw and scaling with deicing agents. Worked with Silica Fume Association, also with the "Service Life-365" model to estimate chloride damage based on weather data, salting amount and material parameters (w/b, barriers, binder types, etc). Investigated with 2+ core samples from each of 5 bridge decks and 4 parking decks (6–15 yrs old). Measured RCPT (resistivity) to measure chloride permeability index and also chloride bulk diffusion, as well as surface chloride penetration profiles. On one bridge deck made with 2 types of concrete, after 6 years, mixtures with silica fume had ingress about 30 mm, yet plain mixture had ingress to 70 mm. Compared all data for measured surface penetration profiles and bulk diffusion value compared to w/b ratio (and evaluated with respect to predictions from the Life-365 model). Made modifications with Conflux software to be able to input current penetration profiles and predict residual service life assuming a diffusion value for future penetration rates. Found that Life-365 predictions were about 10 years shorter than from current profile-Conflux predictions for silica fume bridge decks, and therefore are conservative. Did not find any carbonation in any samples. Diffusion values from actual surface chloride profiles were ~10x lower than from Nordtest 443 bulk diffusion tests on the cores.

Discussion: *Jacobsen* asked if the temperature was taken into account when adjusting the diffusion coefficient in winter (compared to total over year) and reply was that temperature was not taken into account but may be beneficial to consider in future (Temperature is accounted for in Life-365 model). *Luping* asked about curve fitting used and *Hooton* agreed that Fick's 2nd Law was used for fitting penetration profiles but not best/appropriate (However, The Life-365 and Conflux models use a finite difference approach where diffusion values can be changed at every time step). *Holt* asked if Life-365 model accounts for frost or other damage but answer was that it only accounts for chloride damage. Canada & USA generally don't see plain frost damage as long as the air content (and air structure) are OK.

08. Vesikari (VTT): *Methods for Generating Reliable Service Life Models:* Descriptions of what types of work are coming within DuraInt project. To generate service life models it is best to use a combination of long-term field tests, lab tests and theoretical models of how to combine the earlier two. It is difficult to always correlate lab data to service life models because it is unknown how well a lab test simulates field conditions. Models can be either theoretical/analytical or numeric simulations and examples were given for carbonation and chloride. The decision tree and cycle of service life modeling parameters was shown. The practical service life model to be used within DuraInt is by the factor method, as is described in Finnish codes but needing updated to account for chloride ingress. An example was given from the actual simulation program (Excel-based).

Discussion: *Luping* commented that it is correct to model mathematically. *Al-Neshawy* commented that this work is very similar to his PhD goals and looks forward to more discussions together. *Hooton* asked how is the freezing level defined, answered that it is lower than 0ºC and depends on temperature/humidity/situation (accounted for in the models).

Tuesday March 3, 2009

9–11 am Presentations – DuraInt project specific

09. Holt (VTT): *Earlier field station project results (Conlife & YmpBetoni):* An overview was given of the Conlife EU project (2001–2004) and the Finnish Ymparisto Betoni (2002–2005) projects where two field stations were established for frost attack and carbonation (non-sheltered) attack in northern and southern Finland. The 22 Conlife mixtures were high strength (over 60 MPa) and contained up to 10% silica fume (SF), 70% blast furnace slag (BFS) and 60% fly ash (FA). Only half of the mixtures were air entrained, so that some "poor" mixtures would hopefully show damage in field and laboratory testing. The 19 YmpBetoni mixtures were 30–45 MPa mixtures with up to 60% fly ash or 70% blast furnace slag, cast and prepared with either normal curing or heat-treatment. Some results from laboratory testing were shared, specifically for the poor mixtures with no air entrainment that also showed deterioration within the first winters in the field (Conlife mixtures with w/b = 0.42 and 7% SF or 7% extra fine BFS), as well as failure after the laboratory frost test. Most field mixtures showed healing and strength gain during the summer periods, with an improved relative dynamic modulus. Monitoring of the concrete performance at the 2 field stations is continuing within the current DuraInt project and the data will be used for long-term durability performance modeling and service life modeling.

Discussion: *Utgenannt* commented that in Sweden they see the same results as in Finland, where there is frost damage in concrete with w/c 0.42 and 7% silica fume (no air entrainment).

10. Kuosa (VTT): *Initial lab and field results from DuraInt project, including test methods (first 1 year):* A review was given of the first year of results from the DuraInt project. 27 mixtures have been cast with w/c_{eff} 0.42, 0.50 and 0.60, with strengths of 35–64 MPa and mostly air entrained. Testing frost & frost-salt (slab test), carbonation (1% exposure or plain with 65% RH) and chloride, doing both in lab and field. Complimentary studies include fresh properties, thin sections, temperature and RH. Gave a review of the test methods used in VTT labs. Showed results of effect of impregnation and mould lining for diffusion coefficient in chloride test for 3 months. Showed field results of chloride, for instance with chloride measurement with respect to distance from road edge. Results from carbonation k-value showed correlation with w/c and with cement type for accelerated lab test. Field results show only about 2 mm carbonation depth. Results from field frost-salt shared, with descriptions such as manual removal of snow from samples along roadway if snow depth over 1 cm. Lab testing doing combined tests, such as comparing carbonation depth with frost scaling, where carbonated samples show greater scaling compared to reference samples (especially with lower air entrainment or insufficient small pores).

Discussion: *Hooton & Jacobsen* asked about how VTT is evaluating air quality, answer is using thin-sections with manual point-count method (with air pores <0.8 mm). In chloride studies, *Hooton* asked how the measure of salt spread was given (3.8 kg/lane) – *Kuosa* needs to verify it was per m^2. *Jacobsen* asked if in Finland we are still using protective pore ratio but *Leivo* answered not used in Finland much anymore because not as valid for high strength concrete (*Jacobsen* answered it is now being used in Norway). *Jacobsen* commented that it would be good to look at carbonation "profile" with thin-sections to see shape. *Sutter* asked about how come Finland does not get spacing factor below 0.2 mm (Finnish standards are around 0.25 but the test method is different (modified NordTest method)). *Leivo* replied it is a constant uncertainty about why Finnish air spacing factor is often higher than reported in other international literature (i.e. not enough fines, cement properties, etc.). *Sutter* asked about opinions of using fresh air void analysis (Danish AVA equipment), Finland likes it and *Sutter* also finds good correlation with gravimetric (but not volumetric) pressure meter.

11. Sistonen (TKK): *Review of future plans for DuraInt interaction testing and FEM modeling (next 2 years):* Reviewed what types of interaction work are coming within the next phases of the project, such as laboratory testing of combined frost-carbonation, chloride-carbonation, frost-chloride, etc. Showed the test methods and cycles of repeating methods with boundary conditions defined. 2nd part of

presentation about FEM tools to model carbonation, moisture ingress, chloride ingress, etc. Conclusions that the interactions are needed for improving service life models. Future plans to calibrate models with concrete mix studies, both experimental and conventional calculation methods. Need to integrate frost and frost-salt results to models.

Discussion: *Luping* asked for copy of licentiate thesis availability with some of the early modeling and *Al-Neshawy* replied that he would send copy within the next months when 100% finalized by Olli-Pekka Kari ("Modelling the Durability of Concrete for Nuclear Waste Disposal Facilities"). *Vesikari* asked what types of weather modeling is accounted for in the work, and *Sistonen* replied that the models at this point are only accounting for moisture variation but in future work it will be further developed. *Luping* commented that the numeric model *Sistonen* showed for chloride does not account for binding effects and therefore the profile may not be true (it should be considered closer in future works). Yet *Jacobsen* commented that this presented chloride ingress model is good because there is the "dip" modeled at the surface.

12. Vesikari (VTT): *Life Cycle Management Tools Developed in VTT:* Presentation shared how the models of deterioration and service life can be used in management tools. 4 tools have been developed at VTT over the past 10 years in different projects: BridgeLife (including data on 100 existing bridges, implemented by Finnish Road Administration), RoadLife (for pavement, demonstrative use), MaintenanceMan (i.e. facades, balconies, roofing; prototype) and ServiceMan (for nuclear power plants, and still on-going in development). Some of these have been implemented to practice, such as use by Road Administration, but ideally they require upkeep with new data. Management tool development at VTT started with work in the LIFECON EU project in 2001, results at http://lifecon.vtt.fi. Showed procedure and data flow of life cycle management tools and how they were programmed on MS Excel. At conclusion of presentation, showed the Excel program and the parameters that can be adjusted within ServiceMan program. Showed outputs such as corrosion, cracking and protection needs. Get outputs for life cycle costs, environmental impacts and resource planning for action plan of maintenance and repair.

Discussion: *Utgenannt* commented that the LCM tool does a good job (already) of combining different types of deterioration. *Leivo & Holt* commented that the tool has various types of deterioration attack types, but each is acting individually (one type is controlling) and in the DuraInt project the goal is to get new data about how the attacks are working together (adjusting rate of deterioration when more than one affect type). *Jacobsen* asked how the correlations are used with the factorial method and *Vesikari* commented that it is used but improvements are needed to include more of the maintenance aspects. *Utgenannt* asked which of these programs are ready and used in practice, *Vesikari* commented about ServiceMan still being developed and BridgeLife was ready but not up kept as well as hoped by the Finnish Road Administration.

1–3 pm Cooperation Road-mapping

Leivo (VTT): *Review of cooperation ideas from Finland:* DuraInt project has financing for international cooperation (about one year of time), which includes a wide range of options:

- knowledge and data sharing, workshops, visits,
- exchange test samples or materials,
- test arrangements shared to compare methodology,
- possible for our researchers to go abroad and also can host guests here in Finland.

Example is that with Norway we will likely cooperate to sample from Finnish lighthouses for testing of ice abrasion. Portugal would like to have exchange of researchers with development of test methods. We are open to ideas and suggestions for others about how to benefit each other with international cooperation.

All participants sharing ideas/goals

Hooton: Is very active in standardization methods (ASTM, etc.), working on implementing standards for resistivity, chlorides (Luping's work), and new test for scaling (modifying ASTM method). Need field data to show relation of field to lab procedures. Would be interested in exchange of samples. Could host researchers and modeling with results would be with Bentz. Compared to Finland, the Canadian issues are mostly frost and chloride, as carbonation is considered to not be a problem (maybe due to higher binder contents, even no problems with about 20–30% slag as used in most of Ontario's concrete; rarely over 10 mm, usually only 2–3 mm after many years). Also do not see much plain frost damage with concrete having "good" air systems. Carbonation research may be coming because of use of limestone blends in cement.

Regarding service life modeling, the Life365 program (2nd version, 2008, see http://www.corrosioninhibitors.org/life365intro.htm) is the main/only one used in the USA but accounts for only chloride and corrosion. It will not likely be updated to include other deterioration – carbonation is not considered to be a risk. Assume plain frost is also not a problem as long as it is properly air entrained (max. w/b = 0.50 for exposure to freezing and 0.45 for all concrete exposed to frost with salt). Frost-salt is a surface scaling problem, which typically happens only as a fault of inadequate concrete design or over finishing, or poor curing. *Leivo* commented that this is different than the Finnish approach where the many deterioration types are put together in the service life model.

Jacobsen (Norway): Main concrete research concerns are with corrosion in seawater environments. 3 PhDs within COIN project: ASR, chloride threshold values with marine salt exposure, and ice abrasion projects. Frost-salt deterioration is a concern. They are enthusiastic about cooperation proceeding for sampling from Finnish lighthouses for investigations of ice abrasion. Conversations will continue with Leivo for arranging coring from one location (prior to the lighthouse's scheduled maintenance in May 2009). Carbonation usually only seen in houses (often built in 1970s).

Sutter (USA): Shared a few slides with photos about problems with concrete pavements – staining, cracking and deterioration/spalling at joints. They are in the end stages of planning the continuation of earlier project for chemical investigations of deicing solutions on concrete (roads & bridges). Expect funding to be coming for the project, about $600,000 over 3 years with about 10 state DOTs and starting in 2009. Need to have the physical models that have been described here in Finland, but they need service life models that have both chemical and physical models together. *Vesikari* commented that Finland uses mainly sodium chloride brines and *Sutter* warned that Finland may see more damage in next 10 years. Problems with understanding the rate of chemical attack (i.e. with magnesium chloride), and it is very dependent on spreading rate (location, winter conditions, type of deicer, etc.). *Leivo* commented that here in Finland have to think about the other chemicals and maybe discuss with the Finnish Road Administration (and check with VTT team member *Liisa Salparanta's* earlier research projects on deicers) about the use of alternative deicers. It could also be a research topic with the Airport Authorities for the deicing chemical studies and environmental impacts. There is the potential for future studies and cooperation on this topic with deicer chemicals, though we need to keep discussing in what specific aspects.

Luping (Sweden): There seem many avenues for cooperation, such as in the nearly-completed project "Frost induced chloride transport" where water uptake was studied (thesis ready June 2009). Possible to exchange data from that work. Another new project is related to developing better methods for measuring threshold values (thesis project). Proposal for new RILEM technical committee for investigating chloride and corrosion criteria, to be discussed at RILEM week in September 6–10, 2009 (http://www.rilem.net/eventDetails.php?event=244). They always have a need for improving models and incorporating data (question how will *Vesikari* and *Sistonen* combine their models together, which still needs to be decided). *Vesikari* commented that in Finland we do not have much real-data from chloride attack in monitored environments, and therefore would hope to have cooperation from Swedish chloride studies, hoping to get data from their longer experiences. He plans to take cores from seawater structures (maybe 2010) and could share that data after analysis.

Utgenannt (Sweden): Have the 3 field stations on-going and some large samples where cores can be taken. Some are almost 15 years old and plan to continue monitoring after 1–2 years. The highway field station has some Finnish samples (from 1996 with 1–2 Finnish cements) and there is still free space for adding more samples. Maybe new work with different modern admixtures or different crushed aggregate that is coming into use, and always an interest in more environmental issues of concrete production (by-products). There is the option for Finnish samples to be put at the Borås highway field station in the future. They are interested in following the DuraInt project results, especially with regards to frost-salt. Happy to host visiting researchers, hope to continue working together and we should all pay attention to possible research funding options.

Leivo commented that it is interesting that we all have durability issues with concrete, but there are different attack types. Maybe it is because of the traditions of practice. In Finland we typically have lower that the target air contents and high w/c ratios, which gives different types of deterioration problems than other countries (i.e. compared to the USA where there is typically 6% air specified). If the cement contents are lowered (for CO_2 reductions with respect to Kyoto Protocol goals), then it is critical to evaluate the service life and show that the performance is maintained.

Hooton suggested it may be beneficial to design a few mixtures in the DuraInt project that are different than Finnish practice and test in lab and with field exposure for comparison. These data could be used for inputs or evaluation in the service life models (to evaluate realistic mixtures from Canada/US compared to Finland's practice).

4 pm Workshop summary and closing remarks

Holt concluded by summarizing the workshop and thanking everyone for their time and significant contributions. Follow up e-mail and discussion will continue with all partners through out the duration of the DuraInt project. VTT hopes to meet many of the participants at future international conferences and meetings. We will continue to plan for researcher exchanges. A second DuraInt project workshop at the conclusion of the study (expected early 2011).

ISBN 978-951-38-7177-2 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 1459-7683 (URL: http://www.vtt.fi/publications/index.jsp)