NDTitans

In the beginning there was nothing, no light, no land and no sea, no God´s and no human beings.

From Chaos sprang Mother Earth – Gaia – and Uranus – the Heaven, the Mountains, the Forest, and the Sea. The lights spread everywhere. Uranus embraced Gaia and gave birth to six sons and six daughters – THE TITANS.

Among the TITANS was Cronus, the leader, overthrowing his tyrant father Uranus. One of descendants, Zeus, fought Cronus and the TITANS in a large battle, which lasted for 10 years. The Gods headed by Zeus finally won and the TITANS were imprisoned in Tartarus – the depth of the Earth.

Now the TITANS are back – the NDTitans, specialized in Non-Destructive Testing (NDT) of materials from the crust of the Earth.

NDTitans is an international group of highly specialized, skilled, and dedicated engineers, scientists, and companies with many years of structural engineering and testing experience related to all aspects of concrete and reinforced concrete structures. The NDTitans are from Denmark, Finland, Poland, Greece, Ireland, India, Mexico, USA and Canada.

The group is driven by a culture of collaboration and entrepreneurial spirit, internally and in relation to clients.

NDTitans offer educational workshops, see Main Menu, relating concrete science to advanced methods for evaluation of concrete structures. Relevant ASTM standards, ACI guidelines and European standards are covered.

Furthermore, the group offers testing services, professional advice, training, and implementation of a wide range of test systems, worldwide.

Examples of services the NDTitans provides:

1. **Workshops.** Twenty workshops have been conducted so far, worldwide, latest from Athens, Greece (see WORKSHOP in man menu). The workshops provide a unique blend of in-depth concrete science with the underlying principles, advantages, and limitations of various test systems. Included are cases and demonstrations and opportunities for hands-on practice with selected systems. The original instructional team - **The Three Musketeers** -, Dr. Nicholas Carino, Dr. Andrzej Moczko and Mr. Claus Germann Petersen, has been augmented by teachers and instructors specialized in subjects such as in-situ cover layer quality and implications on service life, injection of cable ducts and corrosion of strands, safe and early loading operations, further loading of structures, integrity of structures and the application of drones for visual inspection.

2. **Professional testing services** for clients to ensure that testing is performed correctly, e.g. related to service life, corrosion, permeability, strength, GPR, delaminations, injection quality of cable ducts, voids in cable ducts an floors, NDT evaluations, rheology, air voids and operation of drones.

3. **Supporting clients with interpretation and calculations, e.g. of chloride diffusion characteristics**

4. **Recommend efficient implementation procedure** as stated in “Reflections” on the Main Menu.

5. **Train technicians** until they are proficient with the fundamentals of testing. Specimens with known defects are available for this purpose at the Chicago and Copenhagen offices of Germann Instruments.
6. **Assist clients** in cases where the testing by others was executed improperly

Scope of available testing methods

1. **FRESH CONCRETE AND MIXTURE EVALUATION**
   - **1.1** Rheology
   - **1.2** Chloride content of concrete and its components
   - **1.3** Resistance to chloride penetration
   - **1.4** ASR, reactivity of sand and aggregates
   - **1.5** Alkali content (equiv. Na_2O/m^3) for evaluating the potential risk of ASR
   - **1.6** Adiabatic heat development
   - **1.7** Temperature simulation during construction
   - **1.8** Air-void structure (spacing factor and specific surface)
   - **1.9** Autogenous shrinkage of the mortar fraction

2. **HARDENING STRUCTURES**
   - **2.1** Temperature recording
   - **2.2** Maturity measurement
   - **2.3** In-Place strength for safe and early loading
   - **2.4** Cover layer quality
   - **2.5** Curing effectiveness
   - **2.6** Grout injection quality, e.g., in cable ducts and joints
   - **2.7** Cracking evaluation
   - **2.8** Crack depth

3. **FINISHED STRUCTURES**
   - **3.1** Strength for production control QA/QC
   - **3.2** Bond strength
   - **3.3** Tightness of casting/construction joints
   - **3.4** Water permeability
   - **3.5** Chloride content
   - **3.6** Cover layer quality
   - **3.7** Resistance to chloride penetration of the cover layer
   - **3.8** Reinforcement location
   - **3.9** Petrography sample preparation

4. **EXISTING STRUCTURES**
   - **4.1** Thickness of elements
   - **4.2** Chloride ion profiling for remaining service life
   - **4.3** Depth of carbonation
   - **4.4** Corrosion activity
   - **4.5** Corrosion mitigation
   - **4.6** Remaining alkali content (equiv. Na_2O/m^3)
   - **4.7** Integrity of cable duct injection and corrosion of strands
   - **4.8** Strengthening of structures by CFRP
   - **4.9** Voids, e.g., behind slabs, industrial floors and tunnel lining elements
   - **4.10** Membrane failure
   - **4.11** Strength for structural capacity
   - **4.12** Cracking evaluation
   - **4.13** Water tightness of joints
   - **4.14** Air-Void structure

4.15 Crack movement
4.16 Bond strength
4.17 Internal defects
4.18 Delamination detection
4.19 Asphalt overlay de-bonding of bridge decks
4.20 Curling
4.21 ASR
4.22 Reinforcement location and size
4.23 Pile integrity
4.24 Removal of cores

TEST SYSTEMS

- ICAR Rheometer
- AVA (Air Void Analyzer)
- Auto-Shrink
- RCT (Rapid Chloride Test)
- Profile Grinder
- RAT (Rapid Alkali Test)
- MERLIN Bulk Electrical Conductivity Test
- PROOVE´it Rapid Chloride Permeability Test
- Heat Box (adiabatic heat)
- Coma-Meter
- VAKKA maturity and humidity
- Pullout test, LOK-TEST, new structures
- Pullout test, CAPO-TEST, existing structures
- BOND-TEST
- MIRA Tomography (ultrasonic echo)
- DOCter Impact-Echo
- s´MASH Impulse Response
- UPV (Ultrasonic Pulse Velocity)
- Surfer (surface ultrasound velocity)
- GWT (Germann´s Water Permeation Test)
- CoverMaster
- GPR (Ground Penetrating Radar)
- Rainbow Indicator for carbonation
- GalvaPulse (corrosion rate, potentials and electrical resistance of the cover layer)
- RapidAir (air-void structure)
- Corecase (precision core drilling)
- Drones for visual inspection.

Details on **www.germanninstruments.com**


Dr. Nicholas Carino, USA


Mr. Guy Rapaport, Finland


Dr. Andrzej Moczko, Poland


Mr. Nikolaos Zoides, Greece

Test Right –Sleep Tight

NDTitans

An international group of highly specialized, skilled, and dedicated engineers and scientists with many years of structural engineering and testing experience related to all aspects of concrete and reinforced concrete structures


Mr. Claus G. Petersen, Denmark


Dr. Thomas Callanan, Ireland


Mr. Parampreet Singh, India


Mr. Sal Fasullo, Canada

Educational workshops
Training on-site
Implementation support
Professional Testing Services


Mr. Bernie H. Hertlein, USA


Mr. Oliver Aguirre, Mexico

Covering the most advanced test systems for concrete and concrete structures

www.germanninstruments.com


Mr. Malcom K. Lim, USA


Mr. Hugo D. Orozco, Denmark


Mr. Todd Allen, USA


Mrs. Kirsten Eriksen, Denmark


Mr. Jesper Clausen, Denmark

NDTitans

1. **Dr. Nicholas Carino**, ncarino@roadrunner.com
Concrete Technology Consultant, USA

Dr.Nicholas J. Carino *is an internationally recognized researcher, author and educator on NDT and standard test methods. He retired from NIST after 25 years of service and is an independent consultant. He has served in many leadership positions on ACI and ASTM Committees.*

Dr. Carino received many awards from ACI and ASTM for his contributions in research and standards development. He is an Honorary Member of ACI and a Fellow of ASTM.

Dr. Carino is responsible for the technical content of the highly-acclaimed NDT Workshops organized by Germann Instruments and international partners. These workshops are a unique blend of fundamental concrete science and the principles of advanced NDT methods.

2. **Dr. Andrzej MOCZKO** andrzej.moczko@pwr.edu.pl
Professor at Faculty of Civil Engineering
Wrocław University of Science and Technology
Poland

Dr. Andrzej Moczko *is a Specialist in nondestructive testing and evaluation of reinforced concrete structures. He has more than 25 years of experience in the practical application of the DOCter Impact-Echo system for flaws and thickness, and the s'MASH Impulse-Response system for rapid screening of flaws, LOK-Test and CAPO-Test for in-place compressive strength assessment; the Bond-Test for bond strength evaluation; the maturity method for estimation of strength development; GWT water permeability testing, Rapid Chloride Test; and corrosion evaluation.*

Among other projects, Dr. Moczko was responsible for the Polish government's project regarding the structural assessment of Polish concrete bridges for modernization and continued safe use. The project involved extensive CAPO-TEST pullout testing together with core testing and rebound hammer testing on more than 50 bridges.

Dr. Moczko is a frequent teacher and instructor on modern NDT test systems, including the European testing standards. In addition, he authored several publications on modern NDT systems and their practical application. He is also a Senior Member of RILEM and a Member of the Polish National Standard Committee responsible for NDT techniques for concrete structures.

3. **Mr. Claus Germann Petersen,** germann-eu@germann.org
In-Situ Test of Copenhagen Ltd
Denmark

Claus Germann Petersen *founded Germann Instruments in 1974, operating out of Copenhagen and Chicago, and In-Situ Test of Copenhagen in 1980. Mr. Petersen holds a B.Sc. diploma from the Danish Engineering Academy and is M.Sc. in economics from the Copenhagen Business School (CBS).*

Mr. Petersen designed the LOK-TEST pullout instrument and invented the CAPO-TEST pullout system. He has been the central person in development and marketing of Germann Instruments test systems, including RCT (Rapid Chloride Testing), RCPT, RAT (Rapid Alkali Test), GalvaPulse for corrosion rate, DOCter Impact-Echo, s´MASH Impulse-Response, MIRA tomography, GWT Water Permeability, AVA Air Void Analyzer and ICAR Rheometer.

He has 25 years of extensive, practical testing experience on-site with pullout, maturity, adhesion/tensile strength, chlorides and chloride profiling, electrical conductivity, carbonation, corrosion activity, impact-echo, impulse-response, MIRA tomography, water permeation and air-void analysis.

He is a member of ACI committee 228 on Nondestructive Testing of Concrete and has received a number of awards for his work in the NDT field, e.g., the Professor Ostenfeld Gold Medal from the Danish Society for Structural Science and Engineering. Mr. Petersen has lectured and conducted workshops on NDT methods worldwide.

4. **Mr. Parampreet Singh**
Avantech Engineering Consortium Pvt. Ltd. (AEC)
New Delhi, India

Parampreet Singh *has gained extensive experience in India on pullout testing for compressive strength, bond-strength evaluation, corrosion assessment, electrical conductivity testing including the chloride migration test, and testing for water permeation.*

He is also specialized in homogeneity and integrity testing using ultrasound, impact-echo, impulse-response, MIRA tomography, and ground penetrating radar.

Mr. Singh is a frequent teacher and instructor in testing systems and has conducted several NDT workshops in India.

He is doing training on site with his experienced group of testing engineers, operating in India and the adjacent countries.

5. **Mr. Bernhardt Hertlein,** bhertlein@geiconsultants.com
GEI Consultants
USA

Bernhardt H. Hertlein*, Senior Consultant at GEI Consultants, Inc., in Vernon Hills, Illinois, has specialized in geophysics, inspection and nondestructive testing methods for concrete structures and deep foundations, and construction-related vibration issues, for more than 35 years. He was half of the team that introduced Crosshole Sonic Logging (CSL), Parallel Seismic and Impulse-Response testing for deep foundations to the United States in the early 1980s, and he developed the Impulse-Response test (s´Mash) for plate-like concrete structures such as pavements, bridge decks, building façades and tunnel linings. His work experience has included projects throughout the US and Canada, and in Algeria, Guam, Hawaii, Hong Kong, Puerto Rico, Venezuela and several European countries.*

Bernie is the principal author of the book "Non-destructive Testing of Deep Foundations", published by John Wiley & Sons in 2006. He is a past chairman of the Test and Evaluation Committee of the Deep Foundations Institute. He is also Secretary of ACI Committee 228 Nondestructive Testing of Concrete, past chairman of ACI Committee 336 Footings, Mats and Drilled Piers, and past chairman of ASTM Subcommittee C09.64 on Nondestructive and In-Place Testing.

He was elected a Fellow of the ACI in 2012, presented with the DFI Distinguished Service Award in 2015, and was elected into The Moles in May 2018.

6. **Mr. Guy Rapaport,** guy.rapaport@ramboll.fi
Ramboll Finland OY
Finland

Guy Rapaport, *Civil Engineer, has 25 years of professional experience in the field of bridge engineering. He is acting at present as a Leading Consultant, NDT Business Manager and Project Manager in Ramboll Finland Oy.*

Mr. Rapaport is specialized in bridge repair planning, bridge- and concrete structures inspections and in state-of-the-art Nondestructive Testing (NDT) of concrete structures and bridges, including validation of NDT results.

Mr. Rapaport's special expertise and extensive experience (about 100 test cases) is in special inspections and NDT evaluations of post-tensioned structures including tendon duct grout injection evaluation using MIRA ultrasound tomography and Impact-Echo, corrosion evaluation of prestressing steel and condition evaluation of bridge decks with Impulse-Response testing.

KEY QUALIFICATIONS: Certification of Qualifications of Bridge Chief Inspector, Bridge Chief Repair Planner and Bridge Inspector of the Finnish Transport Infrastructure Agency.

7. **Mr. Nikolaos Zoides, CEO,** nzoidis@geotest.gr
GEOTEST SA
Greece

Nikolaos Zoides, *after finishing his M.Sc. studies at the Technical University of Crete, started his professional career in the construction industry as a QA/QC engineer on large infrastructure projects in Greece.*

In 2003, he co-founded Geotest SA offering services in quality control testing of construction materials, nondestructive testing and inspection of concrete structures, especially industrial floors. He has been the company CEO ever since.

In 2011, Mr. Zoidis participated in the 1st International Workshop on NDT at Germann Instruments in Copenhagen. He organized two highly successful international NDT workshops in Greece in 2016 and 2019.

Mr. Zoidis has more than 10 years of on-site testing experience with LOK-TEST and CAPO-TEST pullout tests, Impulse-Response, Impact-Echo, RCPT and RCT testing. He has also been involved with integrity and corrosion evaluation of bridge decks, and with using drones for visual inspection of large structures, e.g., wind turbines

8. **Mr. Sal Fasullo, Principal, C.E.T.** sfasullo@davroc.com
   Davroc Testing Laboratories Inc.
   Ontario, Canada

Sal Fasullo *has over the years provided his expertise on many high profile and technically challenging projects such as the CN Tower, Royal Bank Plaza, Scotia Plaza, BCE Place, the Bay Adelaide Centre, Simcoe Place, the Humber River Bridge Project and many more projects across North America where high-performance concrete was used.*

Furthermore, Mr. Fasullo participated in the introduction of new advanced concrete testing systems in Canada such as LOK-Test, maturity method, ultrasonic pulse velocity testing, rapid chloride permeability testing, Impact-Echo and Impulse-Response testing, chloride ion diffusion testing and many others.

Mr. Fasullo has, over the years, been in charge of and responsible for more than 50,000 LOK-TEST pullout tests for safe formwork removal and early loading of slabs of high-rise buildings.

Mr. Fasullo is a member in good standing of the Ontario Association of Certified Engineering Technicians and Technologists (OACETT), the American Concrete Institute (ACI), the Ready Mix Concrete Association of Ontario (RMCAO), and several CSA and ASTM Committees related to concrete technology.

9. **Dr. Thomas Callanan, tom@infrastruct.ie**
INFRASTRUCT ltd
Ireland

Dr. Thomas Callanan *is a Chartered Engineer with 22 years of experience in Civil Engineering. He previously worked as a Consulting Engineer and was the Director of a materials testing laboratory in Ireland.*

Dr Callanan's primary focus is on Principal and Special Inspections of Bridges including Post-tensioning Special Inspections, on-site structural testing and investigations, and condition assessment of all types of civil engineering structures.

He has extensive experience using and interpreting information from a variety of test systems including the MIRA ultrasonic-echo tomographer, s'MASH Impulse-Response, DOCter Impact-Echo, GWT Water Penetration, RCT Rapid Chloride Testing, UPV, GalvaPulse, Half-Cell Potential, and many other test systems.

10. **Mr. Oliver Aguirre,** oaguirre@neodexndt.com
NEODEX
USA/MEXICO

Oliver Aguirre*, Civil Engineer, has 11 years of experience in the field of advanced nondestructive testing and is currently the technical manager and co-founder of NEODEX, with main operations in USA and Mexico.*

Mr. Aguirre's career started in 2009 as a Sales Engineer for Germann Instruments. Inc., where he was trained to become an expert in advanced NDT systems. Oliver was deployed many times within the Americas to provide on-site training and technical assistance with data interpretation during structural evaluation projects, both with commercial and government institutions.

Since 2014, as the technical manager of NEODEX, he has conducted numerous condition assessment projects of existing commercial and residential structures.

Mr. Aguirre has vast experience with the implementation of the pullout test (LOK-Test and CAPO-Test) to determine the strength of concrete in structures, GPR and covermeter to quantify structural reinforcement, the use of stress-wave techniques such as Impact-Echo and MIRA (ultrasonic-echo) to examine localized internal cracking of concrete and Impulse-Response to determine overall structural integrity of massive plate structures. He has conducted structural assessments of bridges, light-rail structures, residential buildings, water treatment and commercial warehouse facilities.

11. Mr. Jesper Stærke Clausen, JECA@cowi.com
COWI
Denmark

Mr. Clausen has since 1994 been working worldwide with NDT and has wide experience and detailed knowledge of the techniques used on different types of concrete constructions, such as buildings, bridges, tunnels, foundations, harbor structures, industrial /housing floors and nuclear plants. The techniques are used on both new structures for quality assurance and existing structures to determine the current state and precense of defects, or dimensions or localization of hidden or hard to reach construction parts

Mr. Clausen has conducted General and Special inspections on more than 1000 bridges and is working with the Management System for Infrastructure Assets.

More specifically, Mr. Clausen´s on-site experience coves visual inspection, extensive testing with pullout and bond-test, impact-echo, impulse response, RCT, corrosion instruments as well as GPR and cover meters.

He has published many papers in the practical approach and application using the NDT methods, presented at international conferences through-out the world.

12. Mr. Tasos Gotzamanis, gkotzaman@yahoo.gr
Geotest SA
Greece

***Tasos Gotzamanis**, MSc Civil Engineer, has 10 years of professional experience in the field of civil engineering and nondestructive testing of concrete structures.*

Tasos is currently an engineer with Geotest SA and is involved in projects such as visual inspections and performing NDT tests, such as Impulse-Response, Impact-Echo, MIRA Tomographer and ground penetrating radar, in concrete structures.

In addition, he has extensive and practical experience with CAPO-TEST and BOND-TEST testing. Tasos is a specialist in using drones for visual inspection of structures (bridges, wind turbines) and he is an expert in the application of Artificial Intelligence in engineering and specially in recognizing defects in concrete structures, automatically.

KEY QUALIFICATIONS: Seismic engineering of structures, project management, inspection of structures with drones.

13. Mr. Malcolm, Lim, PE, President, mlim@adeptgp.com
MLIM Consulting, Inc.
USA

***Malcolm Lim**, licensed Professional Engineer, is a nationally recognized expert in the evaluation of structures and has more than thirty years of on-site experience. He has evaluated conventionally reinforced, prestressed and post-tensioned concrete structures in over ten different countries and has performed over two thousand forensic structural assessments covering both sub and superstructures. Mr. Lim Master's Thesis emphasized the use of NDT to determine material properties of bridge decks and he is well versed in all NDT techniques including GPR, Impact-Echo, Impulse-Response, corrosion assessment and ultrasonic testing of concrete.*

Mr. Lim has authored and co-authored 22 technical publications and has published a book on nuclear power plant assessment. Additionally, Mr. Lim holds one United States and one international industry-related patent. He has been the main speaker at seminars in the United Kingdom, United Arab Emirates, Saudi Arabia, Switzerland, and Singapore, and lectures a graduate-level class at a local university.

14. Mr. Todd Allen, todd.allen@radarviewllc.com
Radarview LLC / Universal Construction Testing, Ltd
USA

***Todd Allen** is President of Radarview/Universal Construction Testing (UCT), headquartered in Houston, TX with offices in Dallas, Austin/San Antonio, Chicago, and Miami.*

His background includes 26 years as an NDT practitioner, NDT applications designer, expert witness, and manager. He is also an honorably discharged veteran of the US Navy. Mr. Allen is a published *author in professional trade journals/magazines and has presented numerous times for engineering and trade associations. He currently serves as a voting member of ACI Committee 228 (NDT) and ICRI Committee 210 (Evaluation).*

Radarview/Universal Construction Testing is a group of engineers, geologists, and NDT specialists in determining concrete/steel/wood as-built construction and condition parameters as well as an array of subsurface examination and testing services, such as: field and laboratory forensic examination and testing services including concrete, masonry, steel, wood, and soils. The company has extensive experience in performing field NDT, specimen collection, and laboratory analysis. Radarview LLC was established in 2002 and acquired UCT (est.1983) in 2013

15. **Mr. Hugo Orozco,** hugo@germann.org

Germann Instruments A/S
Denmark

Hugo Orozco *is a Civil Engineer and MBA with 16 years of experience in the assessment of reinforced concrete structures. He is specialized in various NDT techniques, the science of concrete deterioration, and the implementation of strategies for damage prevention, protection, repair and structural strengthening, especially with fiber reinforced polymers (FRP composites).*

He worked for Sika Mexico as a Product and Market Manager in charge of the marketing, development and technical support for the portfolio of solutions for concrete repair and protection, grouting, structural bonding, chemical anchoring and structural strengthening with FRP.

Hugo has participated in many projects providing advice, on-site training, supervision and technical assistance, dealing with existing and new structures such as buildings, highways, bridges, piers, tunnels, foundations, silos, power plants, industrial and commercial facilities, for private companies and governmental agencies.

16.

Mrs. Kirsten Eriksen, **kie@cowi.com**
COWI A/S
Denmark

Associate NDTitan

Kirsten Eriksen*, MSc, Chem. Eng. has expert knowledge on cement, concrete, and road building materials. She has more than 40 years of experience using and interpreting results from advanced concrete test methods, and she has performed numerous specialist investigations of damaged concrete structures in Europe and working abroad. She is a specialist in concrete petrography and use of SEM/EDX for evaluation of deterioration mechanisms. Preparation of concrete specifications for infrastructure projects is another part of her core competences, being updated on material standards in various countries.*

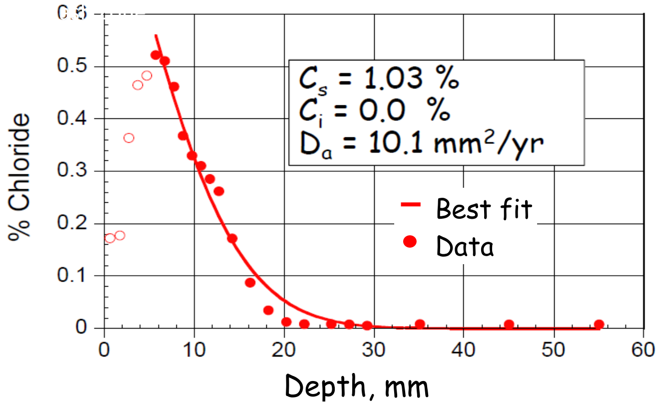
A primary focus has been evaluation of concrete condition and expected future durability / residual lifetime for concrete structures in various environments (marine and splash zone, underground structures, hot and cold climate zones). Special interest areas cover mechanisms as Alkali Aggregate Reactions (AAR), Delayed Ettringite Formation (DEF) and chemical attack (sulphate; thaumasite etc.).

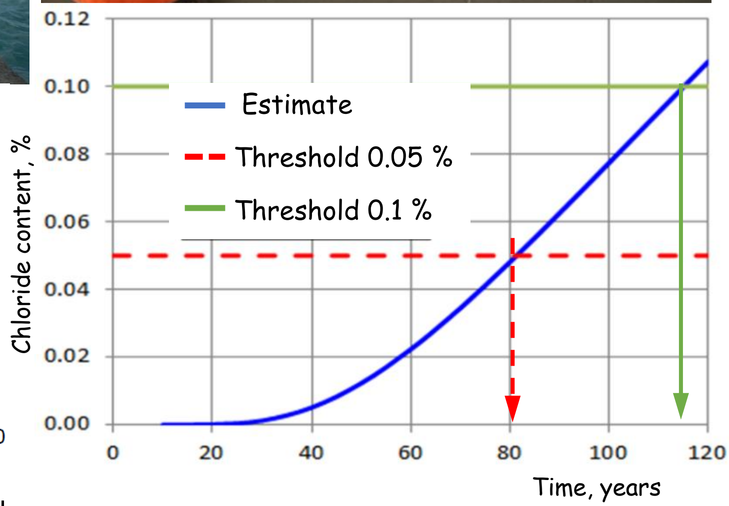
The following pages 14-51 illustrates for a quick review typical testing cases, and from page 52 training examples.

For the comprehensive testing cases go to the Main Menu

NDTitans in action, testing cases, examples

Chloride Profiling and Service Life estimation of a Bridge in the Mediterranean Sea, Greece





With the objective of estimating the remining service life of the structure, testing for chlorides was done in a bridge in the Mediterranean Sea using the **Germann Instruments' RCT** (Rapid Chloride Test).

At the time of testing, the concrete under investigation had been exposed to the sea water for 5 years and the cover of the reinforcement was in average 80 mm.

Powder samples were collected by grinding the concrete at controlled depths towards the reinforcement in the splash zones by means of the portable **Profile Grinder** device. The acid soluble chloride content of each sample was determined directly in-situ with the RCT equipment and the chloride profile was plotted.

The solution for the Fick's second law of diffusion was applied to the chloride profile to obtain the apparent diffusion coefficient, D_a, by regression analysis. The low value of D_a = 10.1 mm^2/year is indication of a good quality concrete.

With the calculated parameters of the best fit line, the chloride content was extrapolated over time, assuming that the concrete is saturated and that the surface chloride content and D_a remain constant.

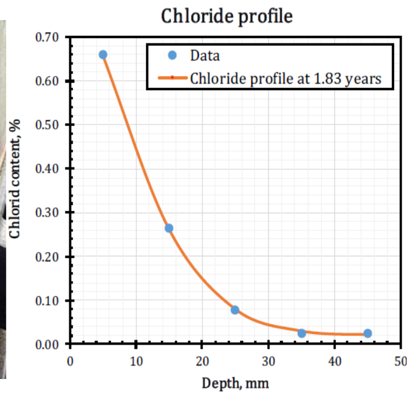
Depending of many variables, the threshold chloride content at the depth of the reinforcement to initiate active corrosion is normally in the range of 0.05% to 0.1% (by weight of concrete). For a content of 0.05%, the remaining service life was calculated to be about 80 years. For a threshold level of 0.1 %, which might be a more reasonable value for saturated concrete, active corrosion was estimated to start at a time of 115 years.

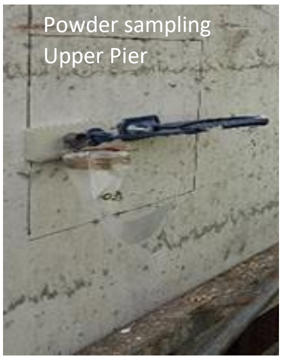
This is a good example of how a combination of good quality concrete, deep cover layer for the reinforcement and proper construction procedures that prevent anomalies in the quality of the concrete surface, provides a long service life to a structure subjected to challenging exposure conditions.

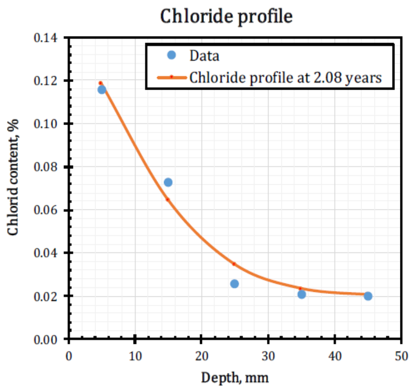
Testing shown is performed by NDTitan Nikolaos Zoides.

NDTitans in action, testing cases, examples

Service life estimations, the Nuuk Container Terminal, Greenland







In 2013 the construction began of the new 47,000 square meter container terminal in Nuuk, Greenland, and was opened to operation in 2017. Some months later, under suspicions of low strength concrete in some elements of the piers, investigations of chloride penetration in the cover layer were carried out using the **Germann Instruments' RCT** (Rapid Chloride Test).

In a few elements, concrete powder samples were extracted by drilling at five different depths towards the reinforcement at 50 mm depth: 0-10, 10-20, 20-30, 30-40, and 40-50 mm. The chloride content by weight of concrete at each depth was determined with the RCT method, and this chloride profile was used to estimate the service life of the steel reinforcement, understood as the estimated time at which a chloride threshold reaches the depth of the reinforcement and accelerated corrosion might initiate.

The solution for Fick's second law of diffusion was applied to the chloride profiles to obtain the apparent diffusion coefficient by regression analysis. According to the concrete mix design, the chloride threshold value was calculated by means of the HETEK Model proposed by Frederiksen J.M., Mejlbro, L. & Poulsen, and under some simplifying assumptions, the approximate remaining service life was obtained.

It turns out that the average of the estimated service life for the concrete not exposed to splashing of sea water was higher than 100 years, but the average service life for the concrete in the splash zone was 23 years.

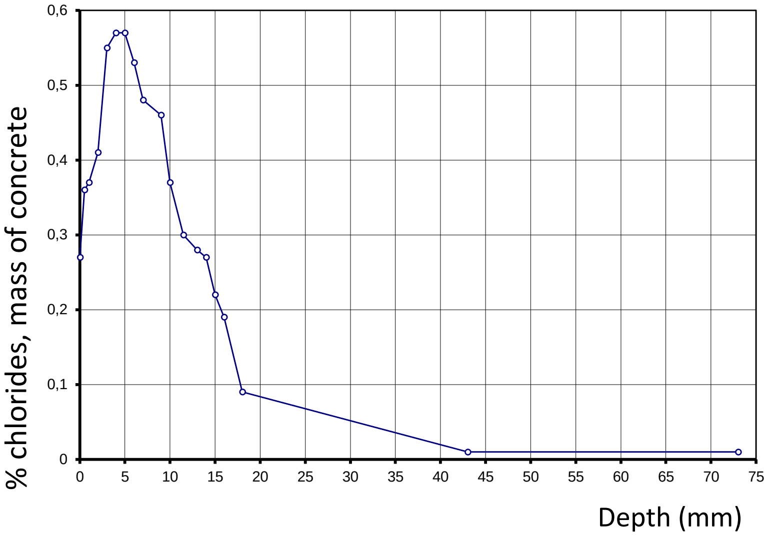
Reviews applying other models with different assumptions also gave service lives ranging from 20 to 24 years in the splash zones.

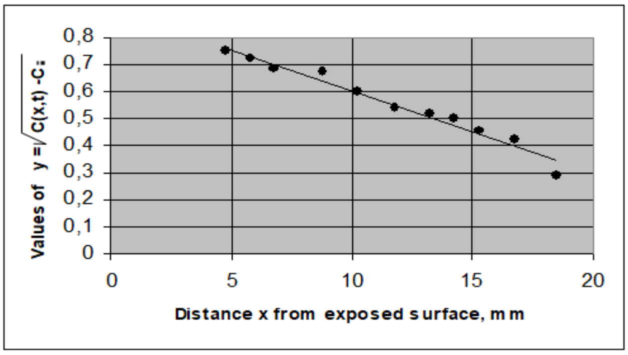
The conclusion seems to be that, despite the low concrete water-cement ratio of 0.37, the concrete design was improper for the exposure conditions. Simulations of predicted service life for the same concrete mix showed that additions of about 10% to 12% of silica fume or fly ash would have resulted in a service life above 50 years.

A solution for protecting the exposed concrete could be the application of high-performance coatings or silane based hydrophobic impregnations in order to limit the ingress of more chlorides and ensure a longer service life of the structure.

Report made by **NDTitan Hugo Orozco**

Remaining Service Life of one-year old sea wall, at the splash zone, Denmark





The quality of the one-year old seawall´s cover layer was questioned. The owner wanted an estimation of the remaining service life before corrosion would take place in the reinforcement based on the first year's ingress by diffusion of chlorides.

The cover was 50 mm.

Profile grinding for every 0.5 mm depth was performed with the **Profile Grinder** on the wall close in the splash zone. In parallel the **RCT** was used to measure the (light) acid soluble chlorides in percentage of concrete mass. To get the initial chloride content a masonry drill bit 18 mm in diameter was used to get a powder sample at 43 mm depth and 72 mm depth, respectively, behind the reinforcement.

The profile obtained is illustrated above. As shown the maximum peak is at a depth of ~5 mm, the depth of the carbonation – measured by the **Rainbow Indicator**.

Fick´s Second Law of Diffusion was applied to the data:

$$C(x,t) = C_i + (C_s - C_i) \cdot erfc \frac{x}{2 \cdot \sqrt{t \cdot D_0}}$$

D_O being the apparent diffusion coefficient, C_s the surface concentration of chlorides and C_i the initial chloride content (0.0094 Cl^-/mass)

Linear regression analysis of the data was performed

Producing the following relationship y = 0,9060 – 0,0302 Ax and the chloride concentration at the surface as:

Cs = 0,90602 + 0,0094 = 0,830 % Cl^- by concrete mass

and the apparent chloride diffusion coefficient of

$$D_0 = \frac{\left(\frac{0,9060}{0,0302}\right)^2}{12 \cdot 1,0} = 75 \ mm^2 / year$$

First year ingress:

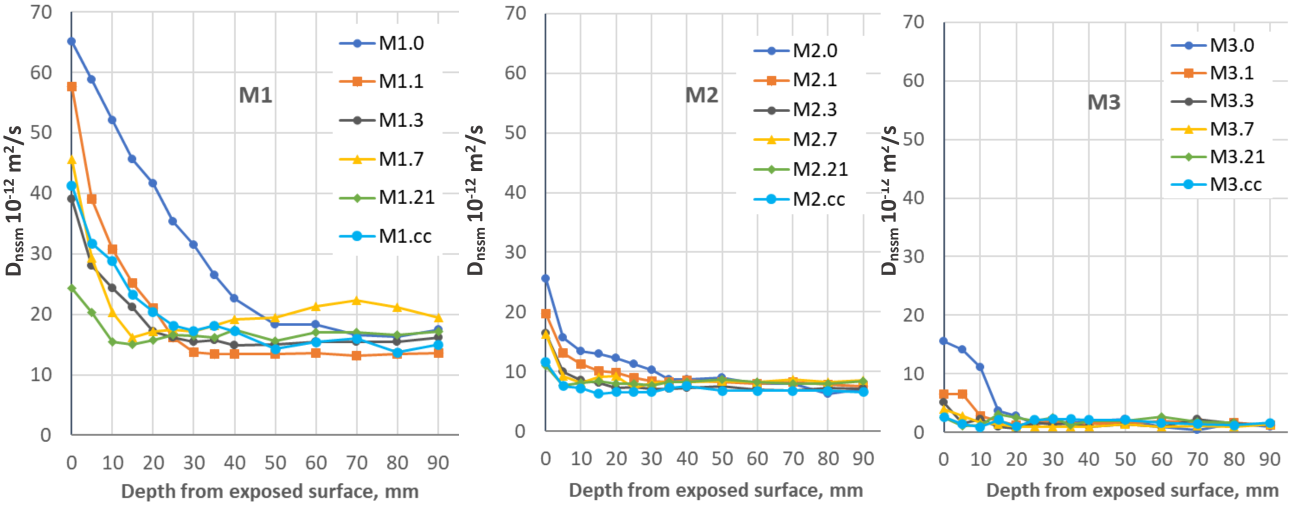
$$K_1 = \left(1 - \sqrt{\frac{0,0500 - 0,0094}{0,8300 - 0,0094}}\right) \cdot \sqrt{12 \cdot 75} = 23,3 \ mm \ per \ \sqrt{year}$$

And the remaining service life for a critical concentration of 0.050% Cl^- /mass for corrosion to start out, and a cover layer of 50 mm:

$$t = \left(\frac{50}{23,3}\right)^2 = 5 \ years$$

Case prepared by NDTitan Claus Germann Petersen

LOK-TEST / CAPO-TEST for rapid in-situ screening of bad curing and its implication on durability and cost of structures.



It is well known that bad curing conditions affect not only the potential strength of the concrete, but also its durability in terms of penetration of deleterious ions such as chlorides that causes corrosion of the steel reinforcement in structures exposed to marine environment or deicing salts.

While durability evaluation of concrete mixes is a common practice in the concrete industry for important projects, the evaluation is very seldom done in-situ once the concrete has been cast. This would indicate what the effect of the real curing conditions is in the expected service life of the structure, in contrast with the well curing conditioning of lab specimens.

One example of the severe implications of bad curing in service life is the experiment presented by R. D. Hooton et al[(1)]. In this lab study, 3 mortar mixtures were subjected to 6 different curing regimes: 0, 1, 3, 7 and 21 days under moist curing (100% RH) and 1 case with no moist curing but treatment with a common curing compound. After their curing time, the specimens were exposed to low air flow at 20°C and 65% RH.

Mortar	Cement	w/c	f'c (21 days, moist curing)
M1	Portland	0.5	45 MPa
M2	Portland	0.35	62 MPa
M3	73% Portland + 20% FA + 7% SF	0.35	67 MPa

At day 21, migration chloride diffusion coefficients, D_{nssm}, were then estimated as a function of depth using a modification to the rapid migration test (NT Build 492). The figures above show the variation of coefficients with depth from the exposed surface and the affected depths are presented in the next table (the range in millimeters where the diffusion coefficients are at least 15% higher than the average value in the interior part of the specimen).

A model to simulate service life prediction, in terms of the time for initiation of corrosion of the steel reinforcement, was applied using the data and assuming, among other things, a chloride corrosion concentration threshold of 0.2% by weight of concrete. For a 50 mm thick cover layer, the reduction in service life between 21 days and 0 days of curing resulted to be about **30% for M2 and M3 and almost 50% for M1.** These high values might actually be conservative if we take into account that lower chloride corrosion threshold values have been commonly reported and that the real in-situ conditions can be easily worse than low air flow exposure with 65% RH and 20°C.

Depth of curing-affected zone (mm)			
Type of Curing	**M1**	**M2**	**M3**
0 d	40 to 50	30 to 35	20 to 25
1 d	25 to 30	20 to 25	15 to 20
3 d	20 to 25	15 to 20	10 to 15
7 d	5 to 10	5 to 10	5 to 10
21 d	0 to 5	0 to 5	0 to 5
Compound	40 to 50	5 to 10	0 to 5

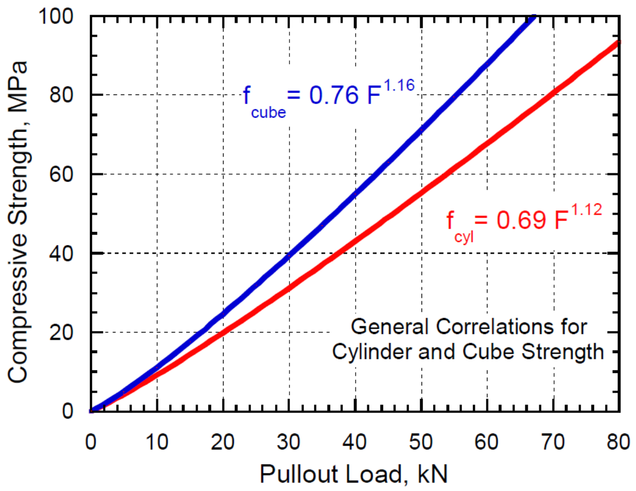
Assuming that the effect on strength of poor curing was acceptable, the economic implication in maintenance, repairs or early replacement of a given structure along its actual life would be quite important with such reductions. If a proper evaluation is made in time, as an integral part of the construction plan, corrective actions can be taken both to improve curing procedures and to implement protective actions for the affected concrete (e.g. application of sealers, plasters or coatings).

Migration tests are however expensive and time-consuming procedures that make them impractical for this purpose. But because bad curing also negatively affects the compressive strength of the concrete, testing this property is useful to do the job.

It is clear that coring is useless in this case because getting results from cores takes a couple of weeks and the interest is testing the cover layer only, but that is exactly what the **LOK-TEST and CAPO-TEST** do (pull-out tests): measuring the compressive strength of the outermost 25 mm of the

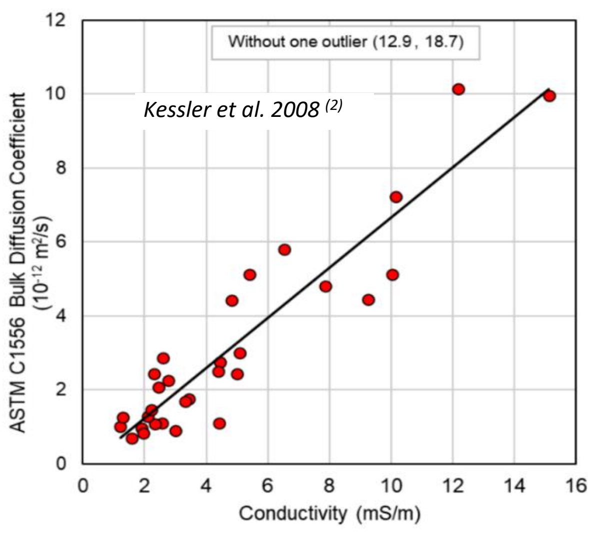
(1) R. D. Hooton, M. R. Geiker and E. C. Bentz. "Effects of Curing on Chloride Ingress and Implications on Service Life". ACI Materials Journal No. 99-M20, 2002

cover layer within a few minutes at any accessible location. Unlike any other indirect test methods, the LOK-test (for inserts in fresh concrete) and CAPO-test (for inserts in hardened concrete) have been extensively proven to have a robust general correlation with compressive strength which can be used to quickly estimate the actual value of the strength of the cover layer. So, if this value is found to be significantly lower than the expected one, not only this is an alarm for investigating the inner strength of the concrete, but it is also an immediate indicator of poor quality of the cover layer and of the potential risk of an important reduction in durability of the structure.



Even though there is no fixed correlation to infer the value of the increase of the chloride diffusion coefficient based on the reduction of strength, LOK and CAPO test will quickly indicate the affected areas for further evaluation.

For instance, one property that does have a fundamental relationship to chloride diffusion is the electrical conductivity (or its inverse, resistivity). In the literature, one can find published relationships between the chloride bulk diffusion coefficient determined by ASTM C1556 vs. conductivity, and this property can be easily measured in the cover layer if a core is extracted from the suspicious area and the top end is sliced away for testing with the **MERLIN** conductivity/resistivity meter.



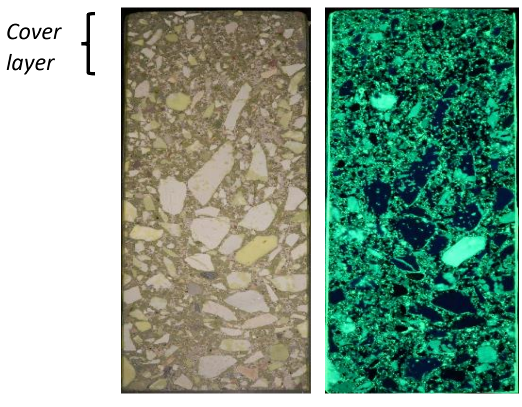
This conductivity value can be compared with the one obtained from the inner part of the core. The difference finally allows us to estimate the increase of the diffusion coefficient caused by the affected cover layer as well as the inherent implication in service life and future maintenance costs.

One practical example of this approach was done over the concrete of four slabs produced by people of the CEE department at University of Illinois, within the project "Evaluation of PCC Pavement and Structure Coring and In-Situ Testing Alternatives (ICT R27-137)". All 4 slabs were designed with the same mix proportions of a typical road construction and delivered by the same mix-concrete company.

Compressive strengths were determined for each slab with the average of 8 cast in-place cylinders extracted and tested at day 16 after casting, and in parallel with the average of 3 CAPO-tests performed at the same day 16. The pull-out force was transformed to compressive strength of standard cylinders with the equation of the General Correlation $f_{cyl} = 0.69\ F^{1.12}$

Slab	f'c Cylinders (MPa)	f'c CAPO (MPa)	Difference
R1	34	22.6	-33.5 %
R2	38	26.6	-30.0 %
R3	43	29.8	-30.7 %
R4	39	25.7	-34.1 %
Avg.	38.5	26.2	-32.1 %

The comparison between cylinders and CAPO tests revealed an average reduction of strength of 30% between the top 25 mm thick layer and the bulk concrete, indicating the potential effect of bad curing or other defects in the cover layer.



(2) Kessler, Powers, Vivas, Paredes, Virmani, 2008, "Surface Resistivity as an Indicator of Concrete Chloride Penetration Resistance," 2008 Concrete Bridge Conference, St. Louis MO, USA. Transportation Research Board.

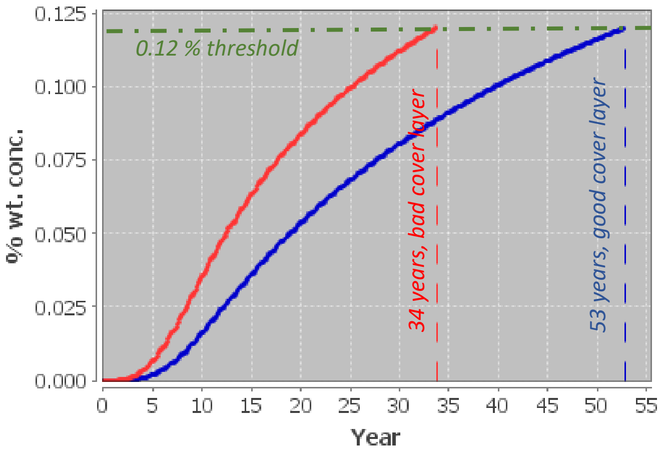
NDTitans in action, testing cases, examples

This was indeed corroborated by a microscope inspection of a 1 mm thin section of one of the cores that found high porosity, bleeding and lack of gravel in the cover layer, which in turn demonstrates that CAPO-tests results detected these anomalies accurately and are not a product of a "different strength correlation" as one may erroneously infer.

In order to evaluate the consequences in durability, two cores, 100 mm in diameter and 230 mm long, were drilled out. A 50 mm thick slice was cut from the top end of the cores (the cover layer) and conductivity measurements with MERLIN were performed on these slices and compared to measurements of the center part of the cores (bulk concrete).

Core:	C1	C2	Avg.	D_{cl} (10^{-12} m^2/s)
Cond. cover layer (mS/m)	13.5	13.9	13.7	9.3
Cond. bulk concrete (mS/m)	9.8	10.2	10.0	6.0
Difference	-27.4 %	-26.6 %	-27.0 %	

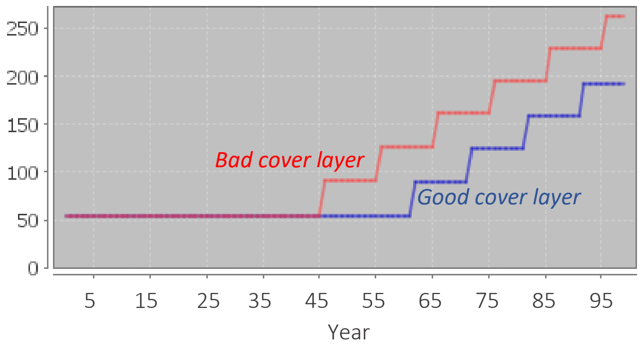
The average values of conductivity were converted to Chloride Diffusion Coefficients, D_{cl}, with the correlation published by Kesler et al., and with these coefficients, a simulation for predicting service life and life-cycle cost was made using the Life-365™ Software, available free at www.life-365.org, assuming a cover layer thickness of 60 mm, typical exposure conditions of chlorides coming from deicing salts used on bridges[(3)] and a chloride concentration threshold value of 0.12 %.



The simulation shows that the reduction of 27% of conductivity might represent a reduction **of 36% of service life**, 34 vs. 53 years (time for initiation of corrosion of the steel reinforcement).

If we assume that the Owner pretends that the structure lasts 100 years, the resultant increase of costs at present value of construction and repairs during that life **would be 37%, about $70 USD/m² more** than if corrective measures are taken.

Cumulative Present Value ($USD/m²)



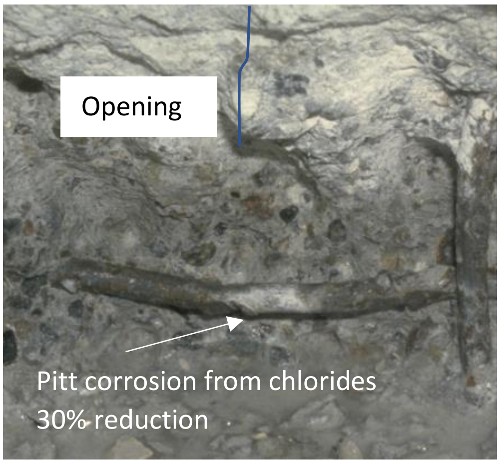
The outcome of this example makes clear for Owners how important the effect of the cover layer is in relation to durability and future costs during the service of a reinforced concrete structure.

In practice, the easiest way to specify in a project a quality control of durability is to leave **LOK-test inserts** embedded in the fresh concrete while casting so they serve as a rapid screening of the strengths of the cover layer. If desired for a detailed evaluation, the suspicious areas detected can be later cored for further evaluation of chloride permeability with the MERLIN device.

Case prepared by **NDTitan Hugo Orozco**

(3) L. Nilsson, A. Andersen, T. Luping & P. Utgenannt, Chloride Ingress Data from Field Exposure, Chalmers University of Technology, REPORT P-00:5, Sweden.

Electrical resistance and potentials for corrosion evaluation, Denmark



Electrical Resistance (kOhm)						*level*
25	21	20	14	18	26	*75 cm*
20	26	20	8	10	19	*60 cm*
18	19	15	6	10	20	*45 cm*
10	8	6	4	7	10	*40 cm*
2	0	5	2	2	1	*25 cm*
0	0	0	1	0	0	*10 cm*

crack

Potentials, Ag/AgC, (mV)					
-10	-8-	7	-90	-9	-11
-40	-32	-34	-110	-21	-24
-100	-89	-110	-288	-288	-80
-150	-143	-180	-400	-190	-200
-250	-192	-195	-450	-210	-220
-300	-390	-490	-600	-500	-340

crack

A 5-year old highway bridge column, close to the traffic lane, exhibited a crack (width 0.2 mm) vertically in the column. Suspecting corrosion of the rebars from splash water with chlorides, the following investigation was made.

Reinforcement was located near the ground, and electrical connection made at one location, using sloping edge Allen bolts, twisted, and cutting into the reinforcement for perfect electrical connection.

Testing was made, after water spraying the column in the selected test points, with the **Mini Great Dane** for electrical resistance of the cover layer and half-cell potentials of the reinforcement, circumferentially, starting from the ground and moving upwards in steps of 15 cm.

First, the electrical resistance in kOhm is measured, and if reasonably low, the half-cell potential is registered in mV.

The electrode used is a self-contained Ag/AgCl electrode. Compared to the ASTM C 876 cell, the Cu/$CuSO_4$ cell, the potential measured is 110 mV higher, so if a -190-mV value is measured with the Ag/AgCl cell, the corresponding value on the Cu/CuSO4 cell would be -300 mV.

The ASTM C 876 states there is a 90% risk of corrosion if the potentials are lower than -300 mV on the Cu/$CuSO_4$, equivalent to -190 mV on the **Mini Great Dane**. However, the standard is not mentioning any requirement for moistening, as with the case of the Mini Great Dane, where the moisture and the presence of chlorides is measured, reflected in the electrical resistivity.

Evaluation: From 40 cm height and downwards the electrical resistance of the cover layer is low, indicating presence of moisture and chlorides.

The potentials are low in the same region with the lowest potentials at the footing, close to the crack, -600 mV. The cover was opened at the location at the lowest potential and the reinforcement was corroded in pits, as illustrated above.

Chlorides were measured at the footing with **RCT,** showing 0.95% Cl-/mass and further up, at level 60 cm, 0.04 % Cl-/mass.

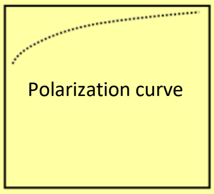
Reporting by **NDTitan Claus Germann Petersen**

Corrosion rate, Electrical resistance, and Potentials for corrosion evaluation, Denmark

Highway bridge with deteriorating columns at the footings

M: \galva\44

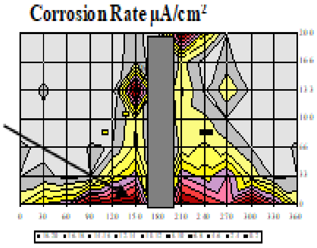
X,Y - point 8 , 1
E-corr. -388.0 mV
Icorr 15.85uA/cm2
Resistance 0.2 KOhm
Measured 61



i_{corr} = 15.9 µA/cm² or ≈ 190 µm/year

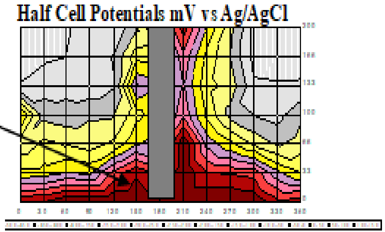
Loss of steel

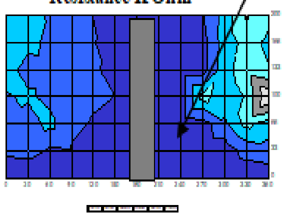
210 to 230 µm/yr



0 to 2 kOhm

-450 to -500 mV





The columns of a 30-year-old highway bridge were investigated at the lower parts for corrosion of the rebars with a cover layer of ~40 mm.

The **GalvaPulse** was used for half-cell potentials, corrosion rate and electrical resistance of the cover layer.

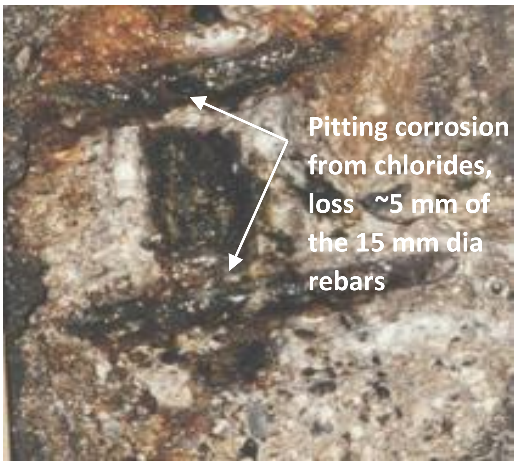
Above is shown the **GalvaPulse** electrode and computer with signal box and one readout for illustration.

The Ag/AgCl potential is -388 mV and the electrical resistance 0.2 kOhm, indicating high corrosion risk and a moist cover layer, probably contaminated by chlorides. The polarization curve is regular and the corrosion current, calculated from this curve, 15.9 µA/cm², equivalent to a loss of steel, following Faraday's Law, of 190 µm/year, ~0.2 mm/year, highly active corrosion.

The amount of chlorides measured by the **RCT** was 0.9%/mass at the footings. Carbonation ~65 mm.

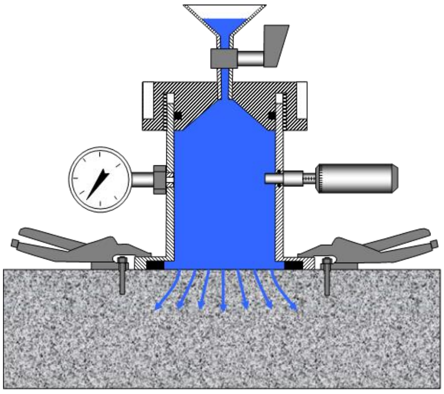
Assuming 20 years of corrosion, the corresponding loss of reinforcement cross section would be 20 x 0.2 mm = 4 mm, quite close to the actual reduction of ~5 mm.

Opening



Report made by **NDTitan Claus Germann Petersen**

Water Permeation evaluated by the GWT Test, Poland



Masonry Permeability

After finishing 2000 m^2 brick walls in a newly constructed high-profile insurance buildings main office, it was observed that water penetrated the walls when it rained and when there was wind pressure on the walls.

First it was believed that the penetration of rainwater was related to highly permeable mortar joints.

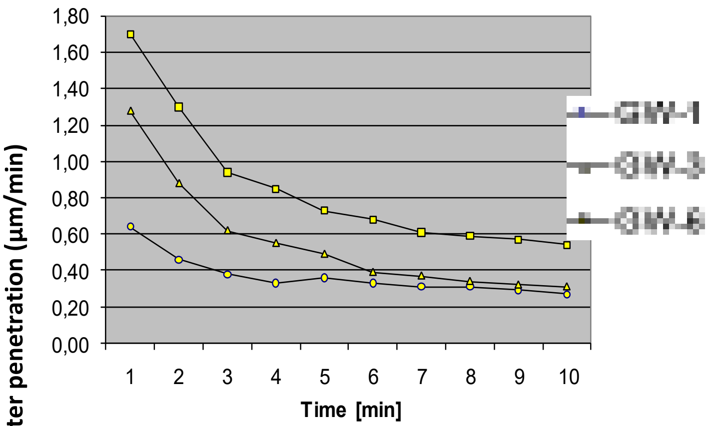
Testing with the GWT was performed as illustrated. The pressurized water very quickly penetrated the walls. In fact, it was not even possible to establish any constant water pressure on the surface.

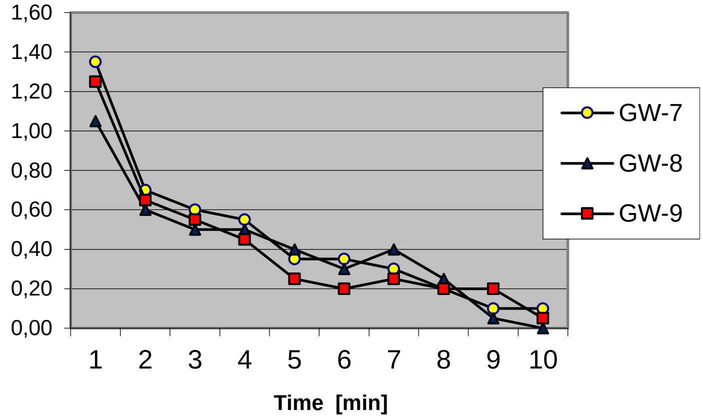
Separate testing was made on the bricks. They were highly permeable. The mortar joints were not the problem. The bricks had been burned with higher than normal heat to achieve the "right" color of the bricks, specified by the architect. The increased temperature during production had caused the bricks to become highly permeable.

A "water-proof" invisible sealer was applied to the walls and re-tested to make sure rain would not penetrate at high wind pressures. It was recommended to renew the sealer every year, and perform re-testing.

Water tightness of sewer pipes

Correlations have been established between the speed of the GWT piston travel and the depth of water penetration using EN 12390-8 "Testing Hardened Concrete, Part 8: Depth of Penetration of Water under Pressure". It has been found that the definition "watertight" concrete of <50 mm penetration depth (EN 12390-8) 72-hour pressure test relates to a GWT water flux of < 0.32 µm/min [#)] after 10





As will be seen, all sewer pipes passed the watertight requirement of a GWT flux <0.32 µm/min, except pipe GW-1.

Report prepared by **NDTitan Claus Germann Petersen**

[#)] *Moczko, A. & Moczko, M.: "GWT-New Testing System for In-Situ Measurement of Concrete Water Permeability", Elsevier, Procedia Engrg. 153 (2016), 483-489*

Development of CAPO-TEST, testing for strength at the "Hestetorvet" slab in Roskilde, Denmark

Professor, emeritus Mogens Peter Nielsen, DTU, Denmark

Early one sunny Saturday morning in the spring of 1974, Professor Mogens Peter Nielsen called and asked us to come IMMEDIATELY to Roskilde – the Viking town in Denmark – for testing the strength of a large slab called "Hestetorvet", in the middle of the town.

We went, met with Professor Mogens Peter Nielsen on the slab. He ordered us to measure the strength with the LOK-TEST in the upper part of the slab, "no matter what", as he said.

— "Champs, YOU can do it. Send me the results ASAP", he said before leaving.

We drilled from below of the slab, 80 cm thick, to ~28 mm from the surface.

Broke the core and drilled a center hole, 8 mm in diameter, planed the surfaces for a 25 mm distance, inserted a LOK-TEST disc from below and threaded it into a pull bolt from above, connected to the LOK-TEST pull machine. Tested to failure and got 28 kN as the pull force. One test lasted 1 day.

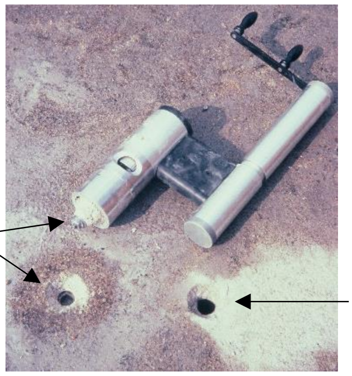
Then, I started thinking of making another system, like LOK-TEST, but with testing from the top surface. Being a dedicated mechanical engineer specialized in diesel engines, at that time, with particular reference to its pistons and piston rings, I took the piston ring technology (slicing the ring and expanding it for position in the piston groove) and did the opposite. Make a ring, slice it, compress it for expansion into a groove.

Hestetorvet, Roskilde, Denmark

At the dentist I saw how their tools had a slim axel with a larger diamond bit at the end, perfect for making a groove in a pre-cored hole. The parts, included the expansion tool, were designed, and made rapidly.

We went back to the slab, cored a hole, planed the surface, recessed the groove, inserted the compressed ring on the expansion tool, expanded the ring to full insertion in the groove, and loaded the ring to failure of the concrete, similarly as with LOK-TEST.

First CAPO-TEST in the world, 1974



LOK-TEST after coring from below

It worked! And one test only lasted 20 minutes. On 6 tests we got pullout forced ranging between 25 kN and 30 kN, averaging 27.0 kN (equiv. to 27.7 MPa cylinder strength based on the general correlation).

Asking Professor Mogens Peter Nielsen what he wanted to use the test results for, he answered: "The shear capacity of the slab is low due to corrosion of reinforcement. However, the slab has a lot of concrete around it, making it act as an arch, that is why I want the strength at the top of the slab for calculations".

Thank you very much to Professor Mogens Peter Nielsen for his immense inspiration to develop the CAPO-TEST.

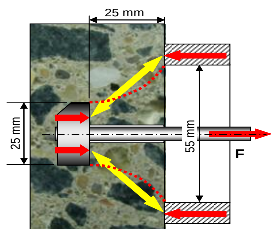
What a Professor!

Reported by: **NDTitan Claus Germann Petersen**

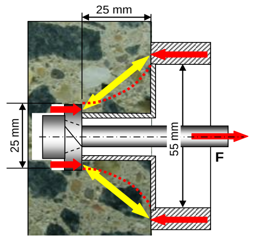
NDTitans in action

Correlation between Pullout force and Compressive Strength

The pullout systems:



LOK-test



CAPO-test

The first major correlation between LOK pullout force and standard cylinder strength was made at DTU (where LOK-test was designed), in the early 1970´ties:

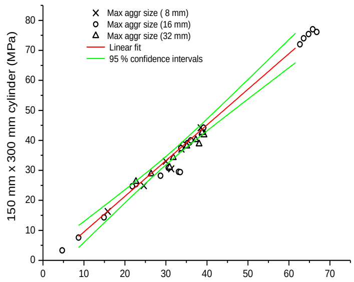


Fig.1 First experimantal found correlation between LOK-force and standard cylinder compressive strength, 1974

More experimental correlations were made at DTU in Denmark for different parameters producing the same relationship, making the pullout system interesting, one straightlined 45 degree relationship, close to 1 MPa compressive strength to 1 kN pullout force, indicating the same property being measured, the compressive strength.

For understanding this relation, three major studies were made: one by means of plasticity theory, one by a non-linear finite elements analysis, and one by fracture analyses to explain the failure mechanism, in:

1976: *Jensen, B.Chr. & Bræstrup. M.W.: "LOK-test determine the Compressive Strength of Concrete", Nordisk Betong, nr. 3-4 , Sockholm, Sweden*

1981: *Ottosen, N.S. "Nonlinear Finite Element Analysis of a Pull-Out Test",Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, Vol. 107, NO ST4, USA*

1985: *Krenchel, H. & Shah, S.P.: "Fracture analysis of the pullout test", Dept. of Structural Engineering, Technical University of Denmark, RILEM, Materials and Structures, Dunod, Nov-Dec. 1985 no 108*

The results from the two theoretical studies, in 1976 and in 1981, are shown in fig. 6, comparing the uni-axial compressive cylinder strength to LOK-test pullout force

For details click the link:

- Section 1: Theoretical Analysis, Fracture Mechanism and Correlations

In the following years, many major correlation were performed in Denmark, Sweden, Norway, Holland. Canada, USA, Poland, England and KSA, investigating the following parameters: types of cementitious materials, water-cementitious ratio (w/cm), age, air entrainment, use of admixtures, curing conditions, stresses in the structure, stiffness of the member tested, carbonation, as well as shape, type, and maximum size of aggregate up to 40 mm.

Ref:

- ACI publication: CAPO-TEST to Estimate Concrete Strength in Bridges.

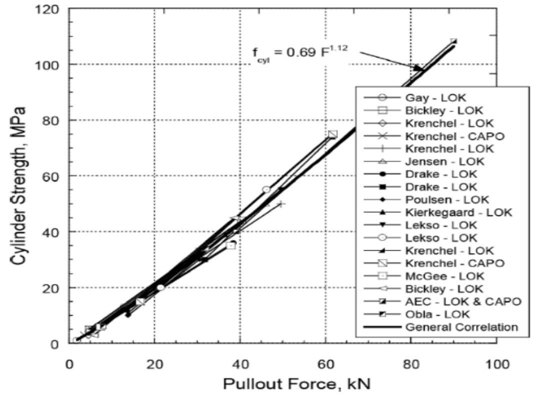


Fig.2. Eighteen correlations between pullout force and standard cylinder compressive strength.

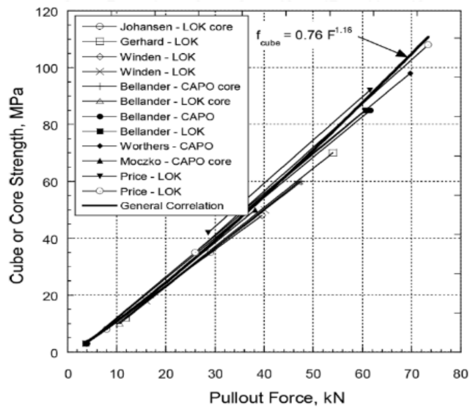


Fig.3. Twelve correlations between pullout force and standard cube / core compressive strength.

NDTitans in action

And, it was found that the pullout forces by LOK-test and CAPO-test had a 1:1 relationship.

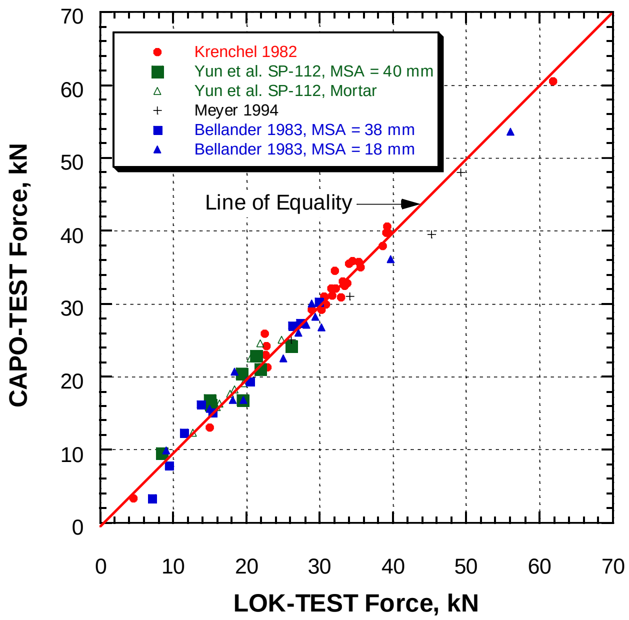


Fig.4. Relationship between LOK-test and CAPO-test pullout force, relationship being 1:1

From the experimental correlations found, fig.1 and fig.2, the following general correlations can be deducted:

1. For standard cylinders (150 mm x 300 mm) compressive strength f_{cyl} in MPa related to pullout force F in kN, shown in fig.5:

   $f_{cyl} = 0.69\ F^{1,12}$

2. For standard cubes (150 mm x 150 mm x 150 mm) compressive strength and cores (100 mm dia x 100 mm) compressive strength in MPa related to pullout force F in kN, also shown in fig.5

   $f_{cube} = 0.76\ F^{1.16}$

It should be noted that all correlations were done by different laboratorties each with their own compression machine.

The procedure for the correlation can be found in:

Petersen, C.G. & Poulsen, E.: "Pullout testing by Lok-Test and Capo-Test with particular reference to the in-place concrete of the Great Belt Link", Dansk Betoninstitut A/S, Birkerød, Denmark, 1991

Appendix 2. Relation of pull-out force versus compressive strength (p. 85-99)

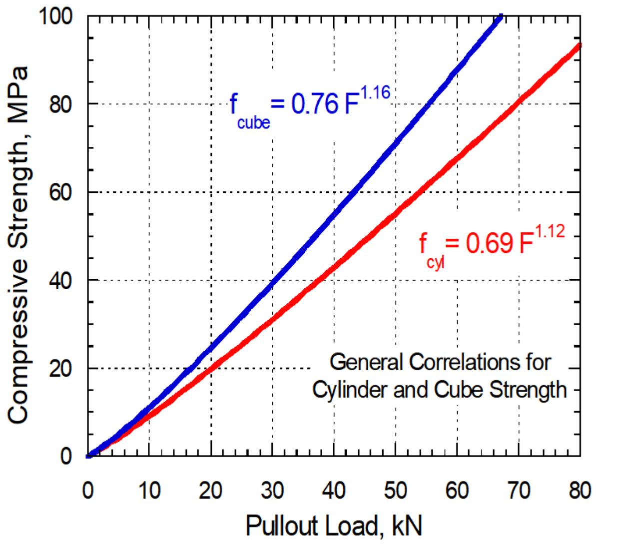
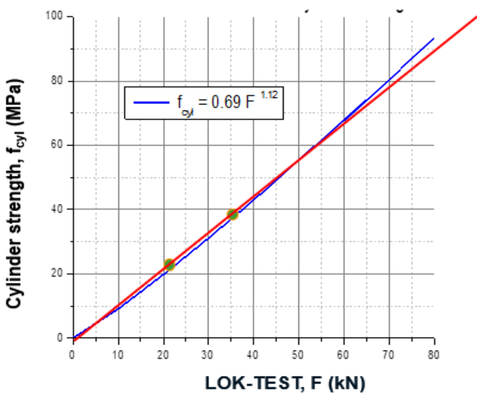


Fig.5. General correlations between pullout force (LOK or CAPO) and standard cube – and core - and standard cylinder compressive strength

Note: For the same concrete, the cube compressive strength is ~28% higher than the cylinder, as the stress distribution in standard cubes is tri-axial, while uni-axial in standard cylinders.

Comparing the general correlation for cylinder to pullout force to the two theoretical studies mentioned previous page from 1976 and 1982:



Fig, 6. The theoretical studies results (red line and dots) compared to the experimental found general correlation for uni-axial stress, the standard cylinder compressive strength (blue curve).

Reporting by **NDTitan Claus Germann Petersen**

In-Situ compressive strength testing of quarantined precast concrete tunnel lining segments using CAPO-TEST, UK

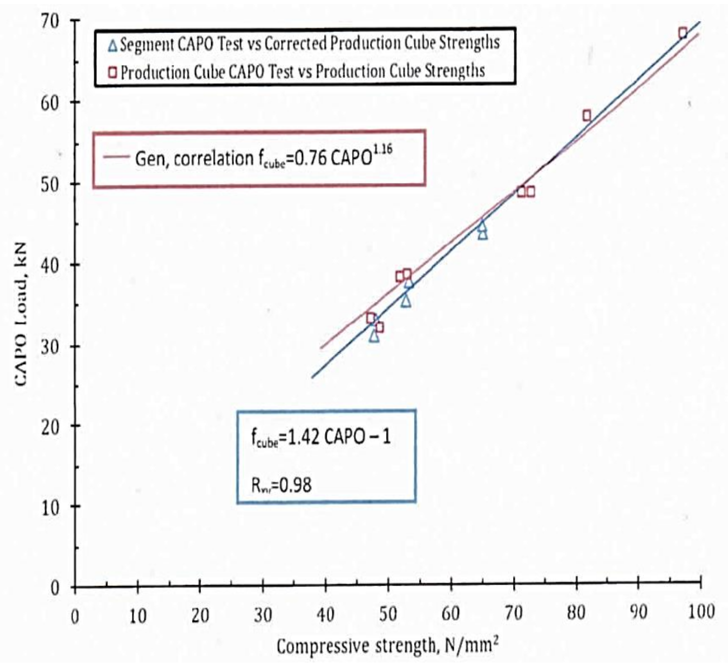
Tunnel elements were produced at the TransLink Joint Venture site, Isle of Grain, UK, and hardened in a heating tunnel on a moving conveyer belt.

For strength estimation, cubes were placed alongside. The production took place in large numbers, automatically. The cube strength, after heating, was specified to be 60 MPa. During a period, the cube strength dropped, but production continued until the drop was realized.

All the elements produced in that period were quarantined.

After scrutinizing, it was later established that the reason for the drop was a change in the cement used in the mix. The gypsum component in the cement had been changed.

To test the final strength of the quarantined elements, two systems were selected as candidates, coring or CAPO-TEST. Elements tested with cores could not be used in the tunnel as the coring would have to be through-going. CAPO-TEST was selected.



The correlation obtained (blue), matched perfectly the general one between CAPO-TEST and cube strength (red)

A calibration program was conducted in relation to cube strength ranging from 35 MPa to 100 MPa, partly between production cured cubes and CAPO-TEST, and partly between standard cured cubes and CAPO-TEST.

Testing was made in relation to maturity at 4, 7, 28, 154 and 329 actual days.

Subsequently, the quarantined elements were tested at random in a statistically valid manner with three CAPO-TEST´s in each element.

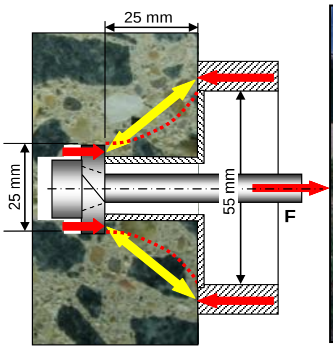
All quarantined elements, >2-month-old, were accepted for erection in the tunnel, as the strength with CAPO-TEST related to cube strength showed strength > 60 MPa from 150 days and onwards.

Certified CAPO-TEST technician Henrik Kristensen performing the CAPO-TEST on the tunnel elements.

Reported by **NDTitan Claus Germann Petersen**

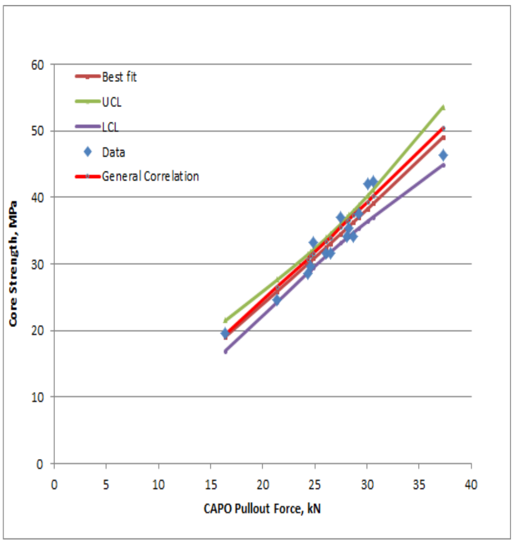
Strength testing with CAPO pullout of old bridges for upgrading, Poland

CAPO-TEST



As part of strength testing 50 old bridges to be upgraded, fifteen bridges, ranging in age from 25 to 52 years, were investigated initially, for establishing a correlation curve between cores and the CAPO-TEST (ASTM C-900 and EN 12504-3), with special focus on the effect on carbonation. The depth of carbonation varied from 2 mm to 35 mm. The strength of the bridges ranged from 20 MPa to 50 MPa.

The number of cores and CAPO-TEST´s for each bridge are reported in the referenced ACI publication. The average values are plotted below.



As will be seen, the best fit curve (purple) matched almost identically the general correlation for cubes (red):

$$f_{cube} = 0.76\ F^{1.16}$$

with a COV on the cores of 7.4% and 8.8% on the CAPO-TEST, on average.

Most interestingly, the effect of carbonation was only minimal on the CAPO-TEST. More importantly, there was no correlation between the depth of carbonation and the relative error of the estimate based on the CAPO-TEST.

Schmidt Hammer was also performed. The estimated strength from this test showed about 80% higher strength than cores, using the correlation recommended by the manufacturer of the Schmidt Hammer.

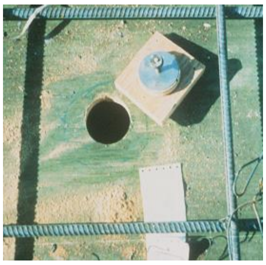
Subsequently testing of the remaining bridges was made with CAPO-TEST, only

The project was organized

by **NDTitan Dr. Andrzej Moczko**

Ref: Andrzej Moczko., Nicholas J. Carino and Claus Germann Petersen: "CAPO-TEST to Estimate Concrete Strength in Bridges" ACI Materials Journal, Nov. Dec. 2016, Technical Paper, title no. 113-M76 by Bridges" ACI Materials Journal, Nov. Dec. 2016, Technical Paper, title no. 113-M76.

Safe and early form stripping with LOK-TEST pullout for strength, Canada


Not only for accelerating construction schedules, but also for safety, the LOK-TEST pullout system is being extensively used for testing the strength of slabs on high rise residential and office structures. The system is used in conjunction with optimized concrete mixes, by which a scheduled time of construction can be reduced, saving interest, costs on formworks, reshoring, winter heating and earlier rental.

In a 100 m^3 slab pour 10 to 15 LOK-TEST inserts are installed equally distributed in the bottom of the slab as illustrated above through prepared port holes. Inserts can also be installed as floating inserts in the top, but the bottom installation is preferred due to simplicity.

At the time of testing, e.g. evaluated by maturity, a couple of inserts are tested, and if meeting the expectations, the remaining inserts are tested. 10 inserts can be tested in about 1 hour.

The LOK-TEST pullout force is converted to equivalent cylinder strength in MPa by means of a pre-established relationship, or the general correlation is used. The standard deviation is calculated, followed by calculation of the "Minimum in-place strength" as: Average Strength less a K-factor times the Standard Deviation. The "K" factor relates to the 10% fractal of the T-distribution.

If the "Minimum in-place strength" is higher than 75% of the f'c, stripping / reshoring takes place. Otherwise, testing of remaining inserts is performed later, e.g. after another half-a-day, and the "Minimum in-place strength" re-calculated.

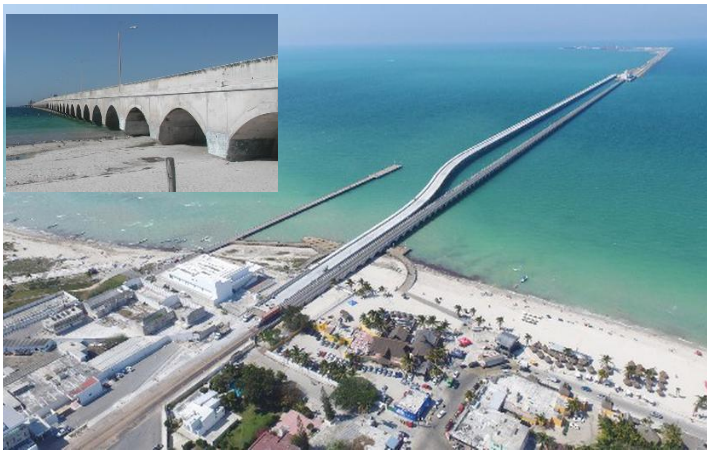
This procedure has been adhered to in many cases for safe and early loading of slabs in high rises such as the one above (Scotia Plaza – Toronto, Canada) where earnings due to speeding up the construction schedule was reported to be 1.5 M Dollars

Optimized concrete mixes are used, allowing forms to be removed as quickly as after 1.5 actual days, even in cold winter conditions. On the other hand, in the substructure, strength is not needed that quickly. Here e.g. fly-ash, Slag Cement, or other supplementary materials may be is used in the mix, reducing the costs of the concrete mix.

The Canadian Standard CSA-A23.2-15C outlines in detail the testing procedures, and the calculations.

NDTitan Sal Fasullo is shown above performing a **LOK-TEST**

Structural Strengthening of the Old Viaduct of Progreso
Measuring bond strength of CFRP strips



The port city of Progreso, in the Mexican state of Yucatán, boasts one of the longest piers in the world. The long length is necessary to allow large ships to dock because the Yucatán coast is shallow.

The Danish company Christiani & Nielsen built the pier at Port Progreso in 1941. The old Progreso pier consisted of a 1.7 km long viaduct and a 205 × 50 m dock platform. The viaduct comprises 145 concrete arches supported by 145 girders, which in turn, are supported by two massive circular concrete piles.

It is one of the first high-durability-performance structures in the world because the project design considered not only the environmental loads, but also the characteristics of the local construction materials (porous limestone aggregate) and the environmental exposure to corrosive chlorides (e.g., stainless steel reinforcing bars were used).

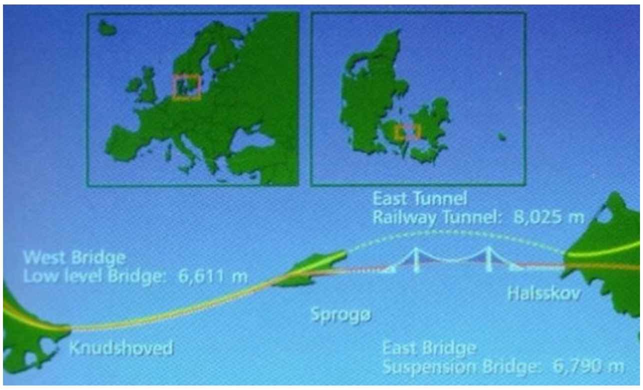
During the 80s, the Mexican government initiated the construction of a Remote Terminal, to which the old Progreso pier was joined by a 4-lane, 4.5 km long viaduct. This addition transformed the Progreso port into a deep port, which resulted in heavy traffic on the old, 2-lane viaduct, subjecting it to loads several times greater than the design service loads according to the Mexican Institute of Transportation.

Inspections carried out in 2001 found no important effects of chloride-induced corrosion over the stainless-steel reinforcing bars. However, they identified cracking in several arches, parallel to the direction of the viaduct, due to tensile stresses produced by settling induced by the heavy loads.

In 2003, 54 arches were externally reinforced with Carbon Fiber-Reinforced Polymer (CFRP) composites, but because of budget restrictions, the cracks were only “stitched” locally. In 2008, inspectors found that the cracks had “moved” to non-reinforced areas within the same arches and other arches also began to exhibit cracking. In 2009, the authorities managed to secure the needed resources and CFRP strengthening of all the arches was carried out. Since then, the viaduct has performed well but, in 2019, due to the increased traffic volume, a modern high-performance prestressed concrete viaduct was built parallel to the 80-year old structure. Today, both structures give access to the port simultaneously.

The **Germann Instruments’ Bond-Test** was used by the manufacturer of the CFRP strips to perform **pull-off tests** and verify that the required adhesion to the concrete surface was achieved (tensile bond strength > 1.5 MPa). In the bottom right photo, **NDTitan Hugo Orozco** is shown performing a pull-off test.

Production control of the cover layer at The Great Belt Link project, Denmark



The Great Belt Fixed Link runs between the Danish islands of Sjælland and Fyn (eastern and western Denmark). The 18 km long project consists of three structures: a road suspension bridge and a railway tunnel between Sjælland and the small island Sprogø located in the middle of the Great Belt, and a box girder bridge for both road and rail traffic between Sprogø and Fyn. The "Great Belt Bridge" (Danish: "Storebæltsbroen") commonly refers to the suspension bridge, officially known as the East Bridge, which has one of the world's longest main spans (1.6 km). The construction work took place between 1988 and 1998 and because of its size and importance, implied that aspects of durability were studied in an unprecedented scale in Denmark to keep the risk level at a minimum for a 100-year service life design period. One important objective was, therefore, to specify the requirements to prevent deterioration from alkali-silica reactions, frost attack, and reinforcement corrosion due to chloride ingress.

Both concrete strength and durability are influenced by the curing conditions. Inspection of potential compressive strength with companion well cured lab specimens, however, gives no guarantee of safety against failure of the concrete structure or quality of the cover layer. Therefore, it was of major importance to specify that, in addition, the achieved characteristic compressive strength at the cover layer was to be controlled using in-situ testing with LOK and CAPO tests.

The decision rule for acceptance was: $\{f_c\} \geq 0.8\ k_n\ f_{ck}$, where $\{f_c\}$ is the mean value of the strengths measured, and k_n is a factor that depends on the number of tests and the coefficient of variation.

In-situ strength testing had never before been used for production tests in Denmark, but on the Great Belt Link LOK-test inserts were used for all structures (in average 1 test for every 25 m^3) except the slip-formed caisson walls (West Bridge) and the tunnel lining segments, where CAPO-test rings were inserted at the time of testing.

The general correlation shown in the next page, recommended by Germann Instruments and based on data from international research and construction projects, was used for the East tunnel and East bridge as it matched reasonably well with the actual correlations obtained (dotted lines). However, during full-scale trial castings for the West Bridge, it was realized that the in-situ CAPO strengths determined by the general correlation were significantly lower than the LOK strengths. The obtained values also indicated a potential risk of rejections, so it was decided to carry out a correlation test for the actual West Bridge concrete. For this purpose, several 400 x 200 x 200 mm blocks were prepared with four LOK-test inserts (hand poked vibration and air curing outside the lab was done). After each 4, 7, 28 and 56 maturity days, six blocks were tested with LOK and CAPO along with 18 lab cylinders for standard strength tests. The West Bridge correlations found and used for the project are shown with the blue and green solid lines.

The main characteristics of the concrete mixes tested with LOK or CAPO were:

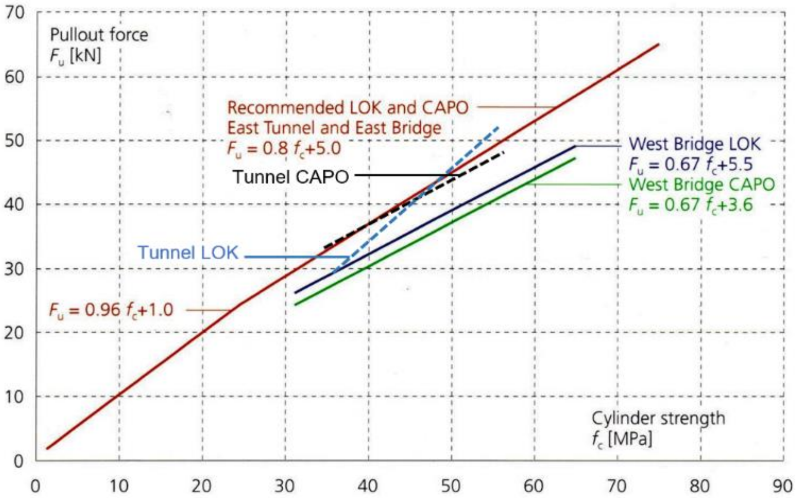
Structure	Tunnel	East Bridge		West Bridge	
Concrete ID	A1 [a]	A	B	A	B [b]
28-day f'$_c$, MPa [c]	76	56	53	58	57
w/c	0.33	0.34	0.37	0.34	0.36
Fly ash, %	10	12	13	10	17
Microsilica, %	5	5	5	5	5
Density, kg/m^3	2,485	2,340	2,348	2,323	2,280
D_{max}, mm	16	25	25	32	32
Air content, %	0.8	1.4	1	6	6
Superplast. kg/m^3	1.8	7.6	6	8.8	5.7

[a] *segments* [b] *caissons* [c] *from standard cylinders*

The structures were subdivided into inspection sections, each of which was accepted or rejected after the statistical

Ref.: Extracts from Concrete Technology, A/S Storebæltsforbindelsen, Copenhagen, Denmark, 1999

NDTitans in action, testing cases, examples

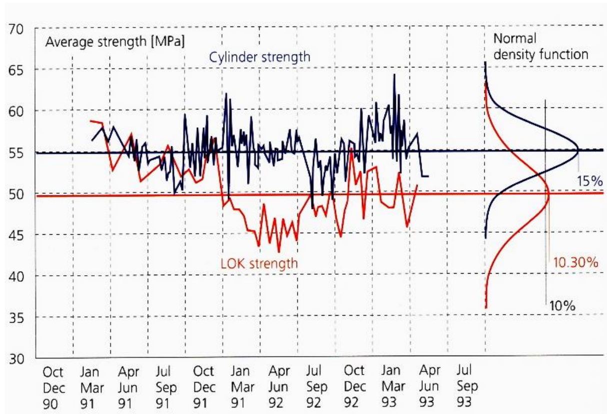


CAPO-testing on the Caissons of the GBL West Bridge

evaluation. The main quantities and number of required strength tests for one of the inspection sections in the West Bridge are presented in the following table.

Figures per inspection section in the West Bridge			
	Concrete, m³	No. of LOK/CAPO tests	No. of test cylinders
Caissons (walls)	2,500 - 2,900	100 - 116	50 - 58
Pier shafts	700 - 1,200	28 - 48	14 - 36
Road girder	2,300	92	46
Rail girders	1,700	84	34

As an example of production testing, the West Bridge rail girder inspection sections were tested by LOK-test inserts. In the beginning, the cylinder and in-situ strengths were almost identical until November 1991. From then on, the LOK-strength was about 10% lower because of poorer concrete, but the concrete cover complied with the requirements if the characteristic 28-day's LOK-strength was above 36 MPa.



The final results of the comprehensive statistical evaluation of the major part of the project shows the differences between the strength and coefficient of variation, CV, obtained under lab conditions (cylinders) and under in-situ conditions, which in turn, proved how important the control of transport, casting, compaction, and curing is in order to maintain a proper level of quality of the cover layer. Without quantitative monitoring of the cover layer, the works would have run blind.

		28-d LOK/CAPO strength, $f_{L/C}$		28-d cylinder strength, f_c		Ratio
Structure / Concrete ID		Avg., MPa	CV, %	Avg., MPa	CV, %	$f_{L/C}$ / f_c
East Tunnel	A1	58.2 C	16.3	76.4	6.0	0.78
East Bridge	A	55.4 L	11.6	55.8	7.6	0.99
	B	51.8 L	13.3	53.0	6.9	0.98
West Bridge	A	53.7 L	9.7	57.6	4.9	0.93
	B	51.9 C	19.5	57.4	4.9	0.90

Well-planned pretesting and trial castings for the actual work methods, and prior certified training of the workforce, were key. Training and technical follow-up during all this Danish iconic project was made by NDTitan Claus Germann Petersen

Slab cracking due to improper depth of reinforcement, USA

Cracking of a slab was visible in one bay of an older building on the top surface of the elevated slab.

Other bays exhibited no cracking.

The Radarview team was brought in to investigate the reinforcement placement.

First, a crack-free area was examined, then the cracked area. Both areas were centered on columns and were large enough to capture the slab reinforcement around the columns, middle strip, and column strip areas for comparison.

Collection of larger 3D **Ground Penetrating Radar (GPR)** data sets allows practitioners a bird's eye view and allows clearly identifying problems compared to rudimentary cross section only GPR scans.

A 1600 MHz **GPR** frequency was used, and the area is 25 feet x 25 feet in size (in yellow on the photo, right).

Crack-free slab: The two images below are the top reinforcement (fig.1) and bottom reinforcement (fig.2)

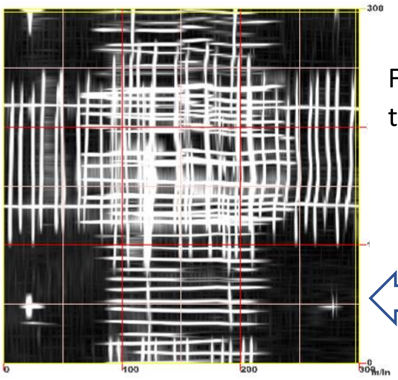


Fig. 1 Crack-fee slab, top reinforcement

Compare

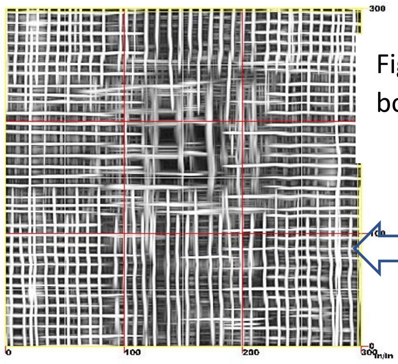


Fig.2 Crack-fee slab, bottom reinforcement

Compare

Cracked Slab: Both images, fig. 3 and fig.4 below are shown at the same depths as fig.1 and fig.2. The image fig.3 reveals that the column strip reinforcement was not present at the required shallow depth which would have prevented the cracking as in fig.1. The image fig. 4 reveals that the column strip reinforcement was present, but had also dropped lower during concrete placement

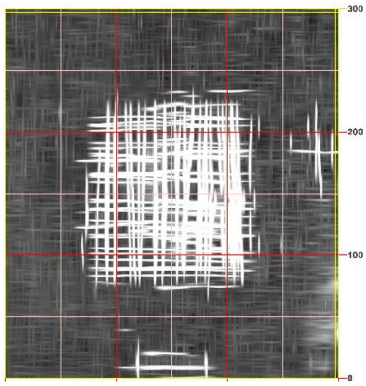


Fig.3 Cracked slab, top reinforcement

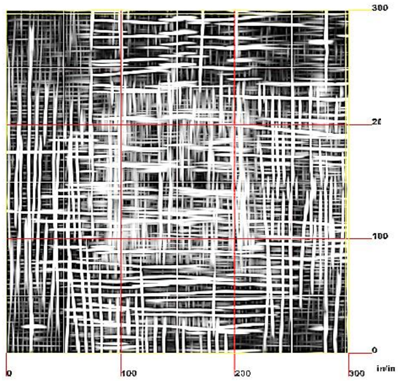
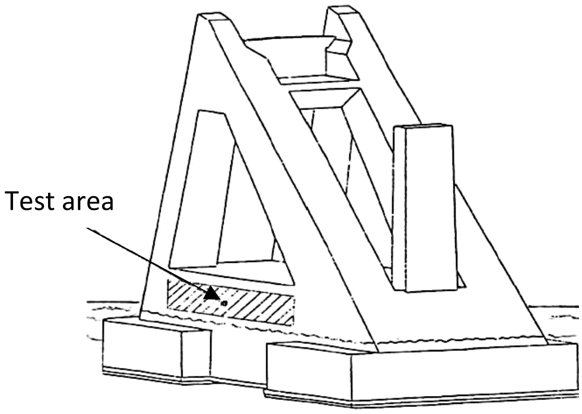
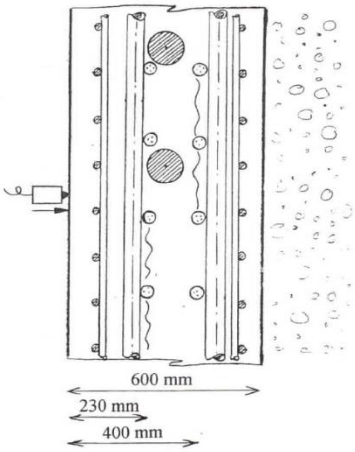


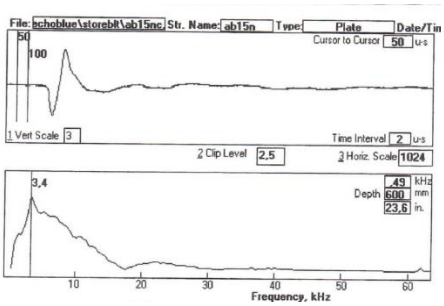
Fig. 4 Cracked slab, bottom reinforcement

Testing and reporting by **NDTitan Todd Allen**

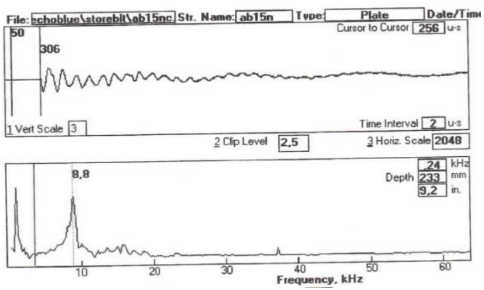
Impact-echo testing for delaminations of walls in two anchor blocks, Denmark



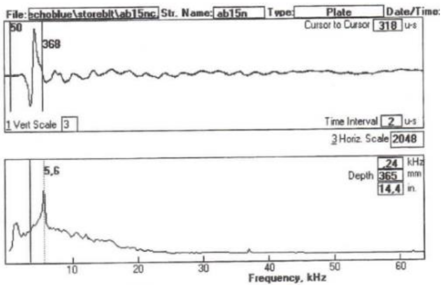




3.4 kHz, Solid 600 mm



8.8 kHz, Delamination 233 mm deep

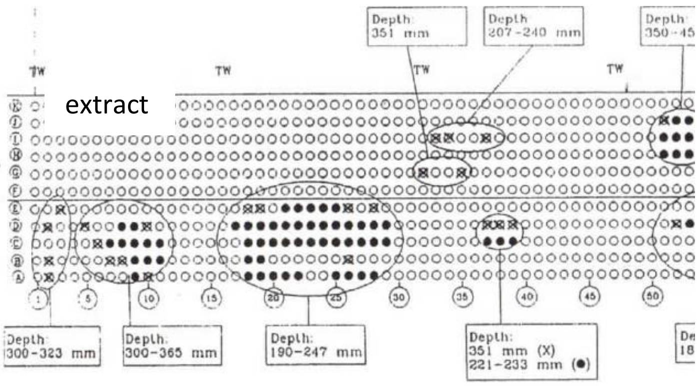


5.6 kHz, Delamination 365 mm deep

Cooling of the interior of 600 mm thick walls in two huge anchor blocks was performed during hardening to avoid temperature cracking due to too large temperature differences between the interior and the surface. The cooling water was partly left in the cooling tubes placed at 1/3 and 2/3´s of the depth in the 600 mm thick walls. The ambient temperature dropped to -15 Degree Celsius. The formed expanding ice cracked the walls vertically.

The walls were heavily reinforced with post-tensioning in both directions. It was decided to inject the cracking, but how to find the delaminations? GPR was attempted without success.

The **DOCter Impact-echo** was used in a blind pilot test and based on these results all the walls were tested with this system. A total of 6,000 DOCter Impact-Echo were performed, clearly detecting the

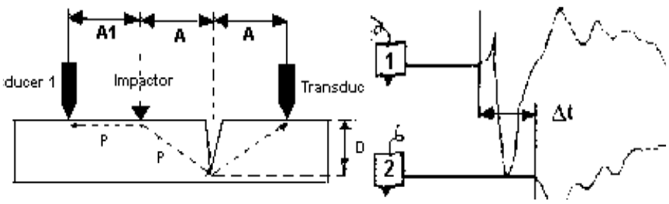


cracking despite the presence of the dense reinforcement and the cable ducts.

75 cores were drilled out for confirmation. All the core results matched 100% with the impact-echo findings. Injection was performed in the cracked areas to the full satisfaction of the owner.

Testing was headed by **NDTitan Claus Germann Petersen**

Crack depth estimation with Impact-Echo on a bridge deck in Medaryville, USA



A concrete overlay cast over the existing deck of a bridge located in Medaryville, Indiana, USA, exhibited generalized cracking. The available documents and drawings showed that the thickness of the overlay was specified to be 1-¾". However, after drilling some cores, the thickness was found to be up to 6" in some areas.

The cracking was evenly distributed along the length of the bridge, even in both ends of the bridge where the overlay had different conditions. There was concern about knowing how deep the cracks were in order to make decisions on the best way to solve the problem.

Impact-Echo tests with the **Germann Instruments DOCTer** system were carried out to quickly estimate the average depth of the cracks and avoid having to drill too many cores.

The P-stress wave velocity in the concrete was first measured with two displacement transducers placed at a certain distance. With this value, the transducers were positioned as shown in the bottom right picture with a distance A = 50 mm. The P-wave produced by the impactor travels on the surface to transducer 1, but cannot pass the surface opening crack, so it travels down along the side face of the crack. It is refracted at the bottom of the crack and returns as a tension wave to transducer 2. The geometry of the travel paths and the time intervals measured with the transducers allow calculating geometrically the estimated depth of the target crack.

The testing was divided into two locations. The average depth of cracking was found to be 59 ± 9 mm in location 1 and 85 ± 7 mm in location 2.

Two cores were taken to corroborate the results and the actual measured depth matched reasonably well with the results obtained. In the top right photo, the crack is 65 mm deep while Impact-Echo calculated 67 mm at that particular point.

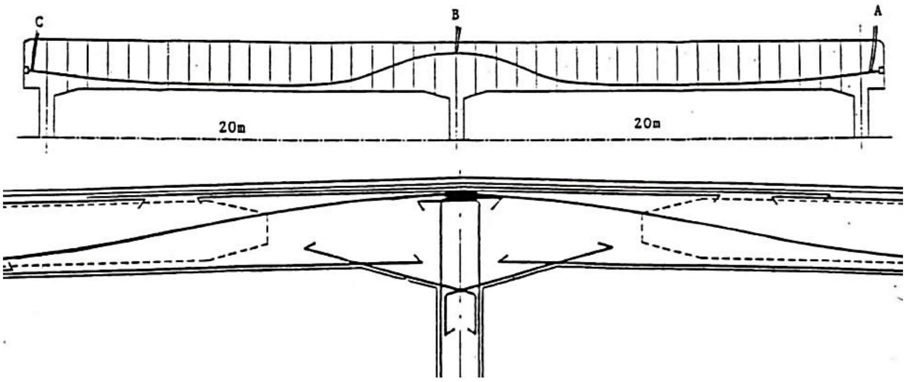
In the second core, the crack was long enough to reach one rebar of the existing reinforcement and this exhibited corrosion even though Impact-Echo did not detect delamination at that depth.

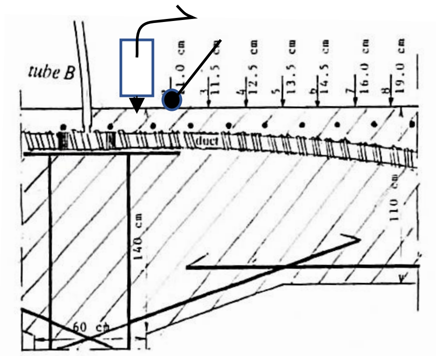
It was confirmed that the DOCter test system based on the Impact-Echo method, using two displacement transducers on the surface, offers a reliable estimation of the depth of surface opening cracks once the P-wave speed has been measured.

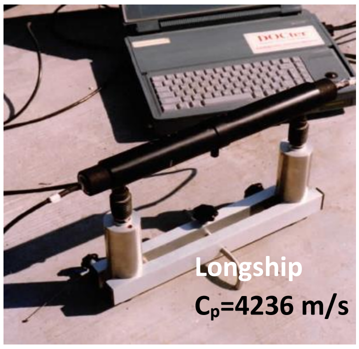
Testing and reporting by **NDTitan apprentice Andrea Godoy**

NDTitans in action, testing cases, examples

Injection quality of new cable ducts







In the Eastern part of Denmark, a large bridge slab was constructed, the slab being 110 cm thick with 40 cable ducts installed in the 40 m span of the slab. After tensioning of the strands injection with a grout was performed, partly by pressurizing the grout from tube “A” shown in the cross section and partly by pressurizing from tube “B”.

Filling up of the mortar in the corrugated steel tube is quite important, not only because of stress transfer from the strands through the mortar to the slab, but also for protection of the strands from corrosion in the future.

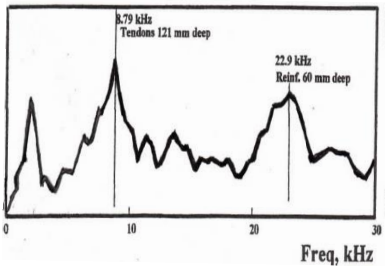
After injection, the “B” tubes were bend and secured with a steel wire. It was noticed that the mortar sludge, after injection, seeped out through the anchor ends, naturally causing a vacuum at the highest point in the cable duct, around the tube “B” inlet.

The DOCter impact-echo was used to test the injection mortar quality after hardening, filled out or not filled out.

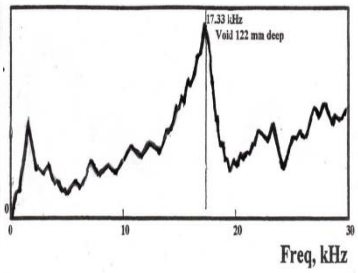
First, the wave speed C_p was estimated using the Longship illustrated above. The $C_{p\ was}$ measured to be 4236 m/s.

Secondly, testing took place with the Mark IV impact-echo transducer in the line of the ducts, 4 m to each side from tube “B”, on all the cable ducts.

Typical signals are shown below, for an injected and for a not injected duct



First peak at ~2 kHz, backwall reflection. The P-wave runs through the cable duct and is also reflected from its strands at 8.79 kHz, related to a dept D of the strands D=Cp/4f=4236 m/s/(4x8.79kHz) = 121mm. **SOLID, FULL INJECTED DUCT**, NO VOID (reinforcement at 22.9 kHz)



First peak has dropped, the P-wave is running around an air interface. Second peak 17.33 kHz is related to the air interface, depth D=C_p/2f=4236m/s/(2x 17.33 kHz)=122 mm, the depth of the void. **VOIDED DUCT, DUCT NOT INJECTED**

After hardening of the grout, all tubes were cut at the surface of the slab and inspection made through the “B” hole. Of the cable ducts investigated 25% were not injected, matching 100% the DOCter Impact-Echo findings. Re-injection was recommended to be done through the “B” tube hole.

Testing/reporting by **NDTitan Claus Germann Petersen**

NDTitans in action, testing cases, examples

Non-Destructive Testing of a Cement Silo´s RCC Wall, India

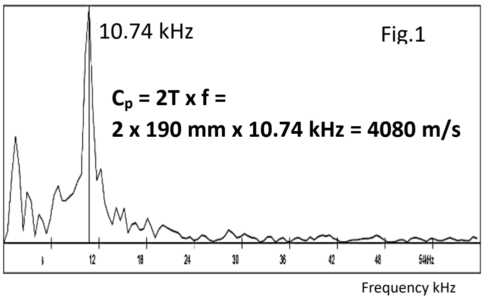
Avantech team carrying out Impact Echo test on wall of silo using the DOCter Impact Echo Test System.

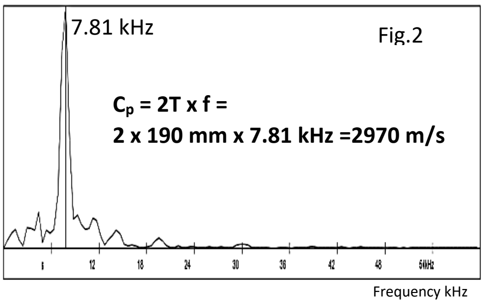
The cylindrical RCC 190 mm thick wall of an in-use cement silo, in the state of Rajasthan - India was recommended for Non-Destructive Testing after the in-house inspection team at the cement plant observed deterioration in the silo wall during routine inspections.

DOCter Impact Echo Test equipment manufactured by Germann Instruments A/S Denmark was used to inspect the silo's RCC wall using the impact echo test method.

The impact-echo signals were classified in four different groups, solid (high and low wave speed), delaminations and honeycombs. In each group one core was drilled out for confirmation:

Solid

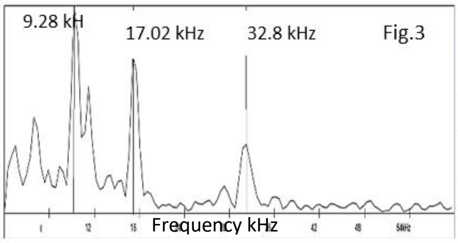


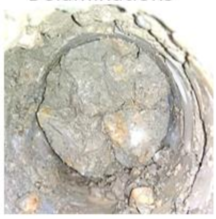


One distinct frequency peak indicating a solid wall, but with different wave speeds (different concrete qualities), for 190 mm thickness.

Confirmed by coring.

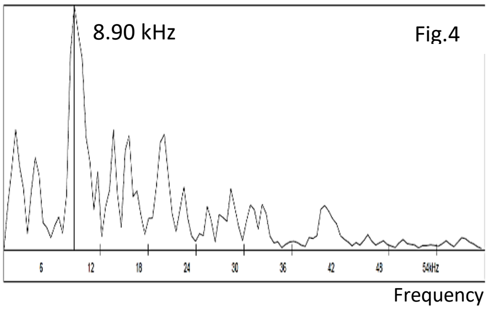
Delaminations





The 9.28 kHz represents a drop from the 10.74 kHz "solid" frequency in fig.1. Hence, the P-wave is running longer than 190 mm – the thickness of the wall, as It is running around air interfaces. At the same time, the P-wave is being reflected from those air interfaces at 17.02 kHz and 32.8 kHz, indicating smaller delaminations, confirmed by coring.

Honeycomb/Delam.



The solid frequency has dropped to 8.90 kHz. Multiple peaks appear in the frequency spectrum indicating a honeycomb, confirmed by coring.

A total of 600 impact echo tests were conducted at different levels on the silo.

18% of test locations exhibited delaminations/honeycombs and 8% reduced wave speed. The results were handed over to the inspectors for further action.

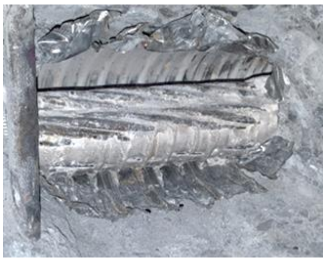
Testing organized and reported by **NDTitan Parampr**

NDTitans in action, testing cases, examples

Inspection of a three-span bridge in the West of Ireland.

Conducted by Infrastruct Ireland, a Special Inspection was first performed to examine the condition of the concrete elements forming the bridge (designed in 1966), incl. surveys for cover, half-cell potential, resistivity, UPV and localized breakouts to examine the type and condition of the reinforcement and concrete sampling to establish the compressive strength of the concrete, the carbonation depth, the cement content of the concrete and the chloride ion content.

During the Special Inspection, post-tensioning ducts were located using GPR and a couple of exposures were made to the ducts and tendons. In two of the four ducts opened, fully voided ducts with corroded tendons were found. There was no evidence of water ponding within the ducts.



Left, partially injected duct. The right figure shows a voided duct with corroding tendons in the down stand beam of the bridge. Corrosion on the tendons was visible but no pitting was evident.

The main cause of structural concern was that several tendons were found to be loose (the Infrastruct team were able to easily move the tendons with hand tools and little effort). This indicated to the team on site that the tendons were not stressed as would be expected for post tensioned strands.

The Special Inspection raised serious concerns about the overall structural integrity and capacity of the bridge and the long-term durability of the post-tensioned system. Further PTSI investigations were carried out and included:

High resolution GPR to locate and map the duct profiles on the external faces of the post-tensioned down stand beams.

Impact echo testing using the DOCter Impact-Echo system carried out above the post-tensioned ducts to quantify the extent of voiding in the ducts.

Selected duct and tendon exposures to confirm the findings of the Impact-Echo testing.

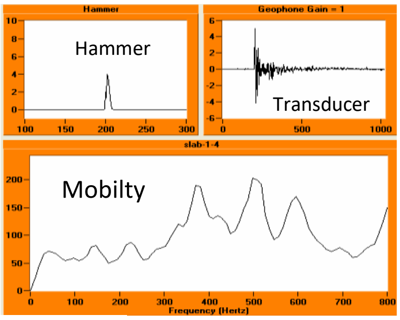
Impact Echo testing underway using the DOCter Impact Echo system to determine the ducts condition.

2000 Impact Echo tests were completed. 50% of the ducts were partially voided, 4% of the ducts were fully voided and only 46% of the ducts were found to be fully grouted.

The bridge was replaced after the findings of the PTSI.

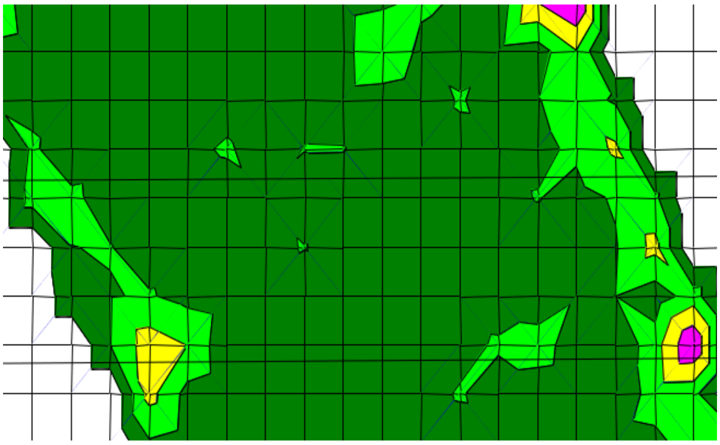
Testing supervised/reported by NDTitan Tom Callanan

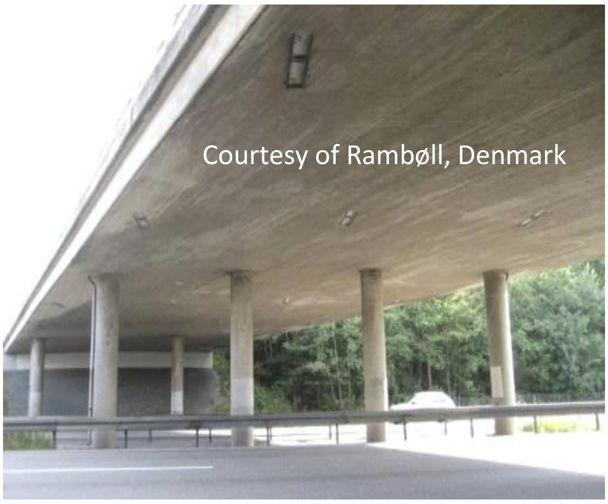
Delamination of bridge deck, Denmark



Average Mobility

□0-4 ■4-8 ■8-12 ■12-16 ■16-20





The soffit of a bridge slab showed starting deterioration at the edges. **Germann Instruments s´MASH** Impulse Response system was applied from the top of the slab.

Above is shown the instruments, a rubber tipped hammer with built-in load cell and a velocity transducer. A hammer stroke to the surface makes the member bend in a flexural manner, and e.g. the average mobility of the member is plotted.

In the bridge case above delaminations were suspected.

Tests were performed all over the bridge slab in a 1 m x 1 m grid, in 5 sections. The testing lasted 5 hours.

The software allows different options to be presented in contour plots for illustration, e.g. the stiffness, the mobility slope, the voids index, and the average mobility.

The contour plot of the average mobility showed low mobility in the center part of the slab (green color) and higher mobility at the edges, (yellow / red color).

Cores were drilled out at three locations. The three cores confirmed that low mobility (rigid response), green color, correspond to a sound slab and higher mobility (flexural bending), red / yellow color, corresponded to the presence of delaminations, at the edges as shown.

The bridge was load tested, and it was finally decided to demolish it.

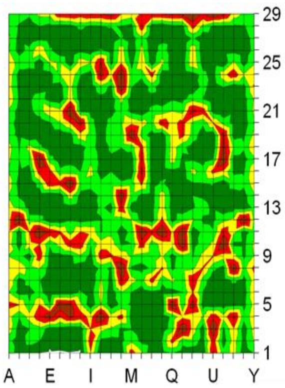
Report prepared by **NDTitan Claus Germann Petersen**

Cracked and delaminated industrial floor tested by NDT, repaired, and re-tested for soundness , Greece

A 36,000 m^2 industrial floor suffered from cracking and needed repair.

Initial testing with the DOCter Impact-Echo established that the thickness of the floor was less than specified with an airgap between the floor and the substrate. This combination of reduced thickness and voids below the floor had caused the cracking.

For speedy testing, the entire floor was tested with s´MASH Impulse Response, using its voids index option. Spacing between test points 1 m x 1 m. A section is shown below.

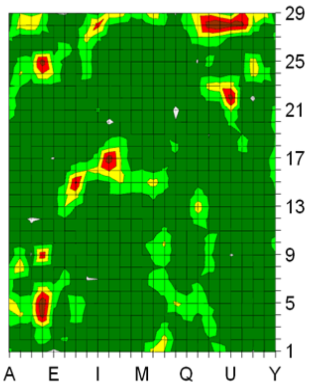


NDTitan Nikos Zoides doing the s´MASH testing and checking the voids index. The Voids Index is the maximum mobility peak divided by the average mobility, and if >1.6, a void is present (red and yellow color).

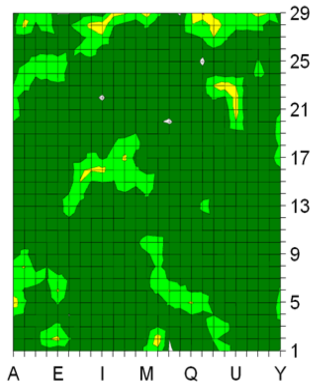
Coring confirmed the voids:

Subsequently, injection was made with a grout with a W/C ratio of 0,7 to 0,9 (under pressure of 2bars at the maximum) through 26 mm holes.

After hardening of the grout, re-testing was made with the sMASH Impulse Response.



After 1st injection



After 2nd injection

The voids-index´s had changed dramatically from the first testing, shown to the left.

Still there were red/yellow areas present. Final injection was made, again in the red/yellow areas. Re-testing made after hardening of the grout. The result for the voids index is shown at the right, only green colors were now present indicating a solid floor.

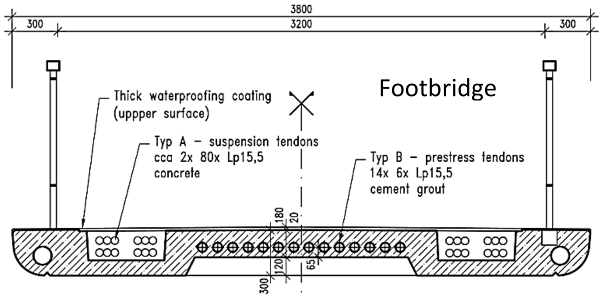
Cores were drilled out for confirmation in light green areas.

Filled out grout

The industrial floor was evaluated as sound, ready to be put back into service with no further cracking happening. The existing cracking was filled out with bitumen.

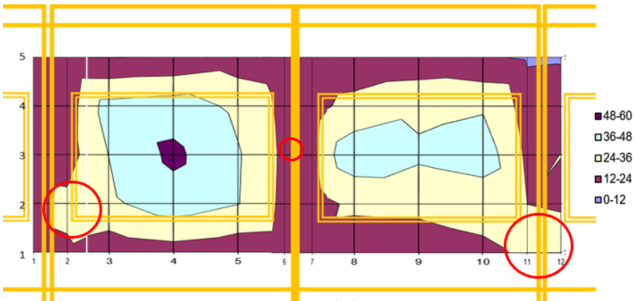
Testing and reporting by **NDTitan Nikos Zoides**

Non-destructive evaluation of a Stress Ribbon Czech Bridge



After the collapse of the Troja stressed ribbon concrete footbridge in Prague, Czech Republic, due to corrosion of the prestress steel strands, **NDTitans Claus Germann Petersen, Malcolm Lim and Hugo Orozco** were invited to demonstrate the feasibility of utilizing different nondestructive testing techniques to evaluate the current condition of similar stress ribbon bridges located in the country.

A visit to the salvage yard, where several damaged pieces of the 34-year old Troja bridge could be inspected, allowed the team to identify the possible causes that led to deterioration of the tendons. It was noticed that some of the ducts for the Type B tendons were only partially grouted and that there were signs of water leaking through the joints between the precast segments. Also, it was evident that the quality of the concrete was bad used to cast the gutters where the Type A tendons were embedded without ducts. There was honeycombing in several locations and, also, excessive shrinkage of this concrete produced cracking, especially along the perimeter in contact with the concrete of the precast elements, allowing the water leaking from the joints to easily flow into contact with the tendons. With this experience, the ND testing was then carried out over the three-span, 200 m long, Nymburk bridge, located on the Elbe River at about 45 km east of Prague. The structure, construction process and age of this bridge is similar to the Trojan bridge.



Dynamic Mobility

Suspicious areas identified by s'MASH

A preliminary visual inspection found moisture stains on the underside of the bridge caused by the water leaking through the joints as well as a few spots with minor spalls and reinforcing bar corrosion. Additionally, it was found that a thin repair overlay cast over the deck of the bridge had debonded in many areas which made it impossible to use the NDT systems without removing it. Thus, it was decided to perform the testing from the underside of the bridge.

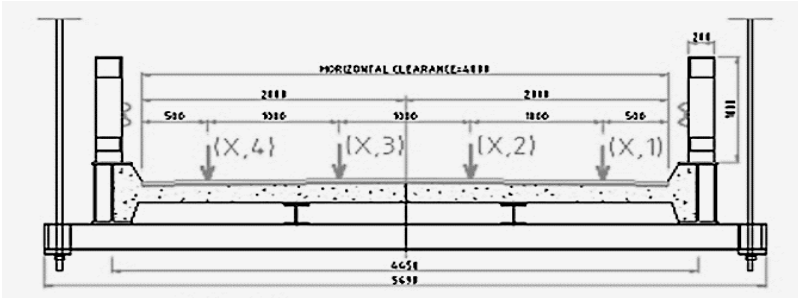
The **MIRA** Ultrasound-Echo tomographer and the **DOCter** Impact-Echo system were used to try to find poorly grouted ducts for the type B tendons. However, the MIRA signal could not penetrate and reach the ducts because of the heavy layer of reinforcing bars below the ducts. With an adequate selection of the impactor, the DOCter could apparently do the job by identifying some suspicious points where the ducts could have voids (dropping of the solid resonance frequency).

For the case of the Type A tendons, the purpose was to identify the defective (cracked, voided) concrete in the gutters by using the **s'MASH** system based on the Impulse-Response method. With this quick method, it was expected to find higher mobility values in cracked or voided concrete than in sound concrete. The mobility contour plot shows the areas of potentially defective concrete where the tendons might have started an active corrosion process.

The findings were recommended to be confirmed by drilling of some cores or by using endoscopy.

Testing and reporting by **NDTitan Hugo Orozco**

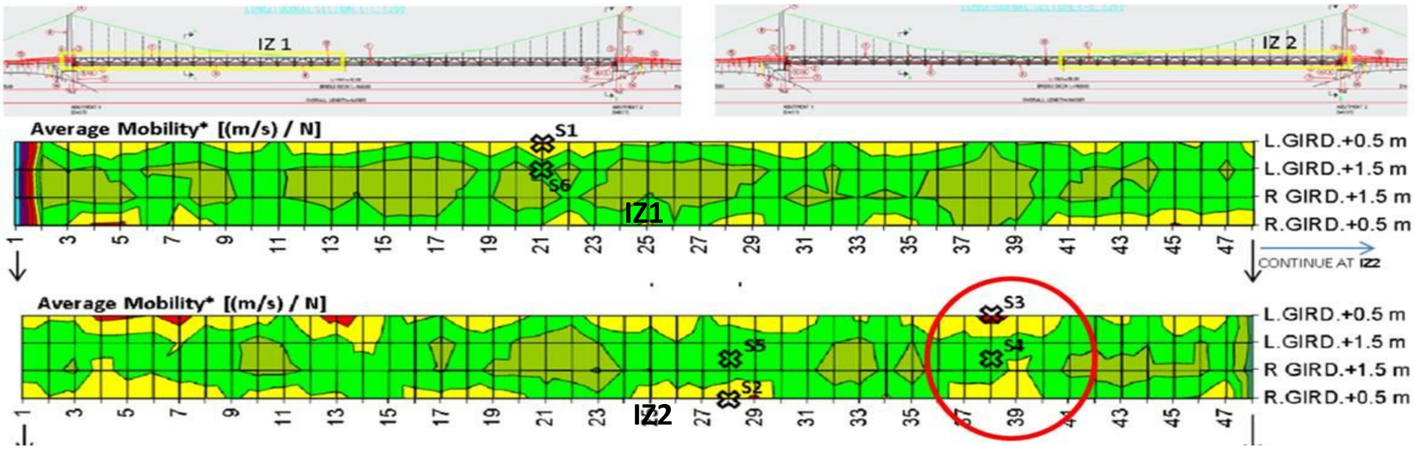
Quality Assurance of newly repaired bridge deck, Finland



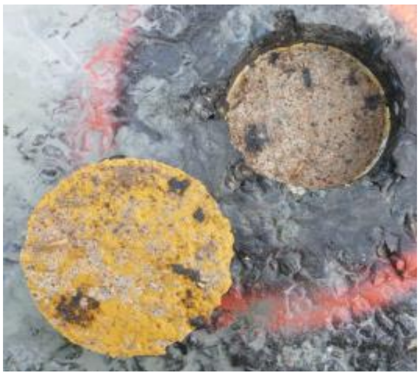
Cross section of the bridge. Deck: 50 mm asphalt on 250 mm concrete slab with waterproofing layer in between, area 350 m^2 Arrows indicate the s´MASH test points.

One year after completion of renewal (repair planning by G. Rapaport) the deck surface of the suspension bridge at the Åland islands (Finland) showed localized minor damages.

s`MASH Impulse Response testing was selected as the primary test system to detect defects, followed up by BOND-TEST of cores in areas pin-pointed by the s´MASH. Results: below showing the s`MASH Average Mobility maps.



Green areas have the relatively low mobility (sound) and the yellow-red (or higher) mobility (suspicious, i.e. not sound). For calibration of the NDT results, cores were taken and BOND-TEST´s were performed at several test points.



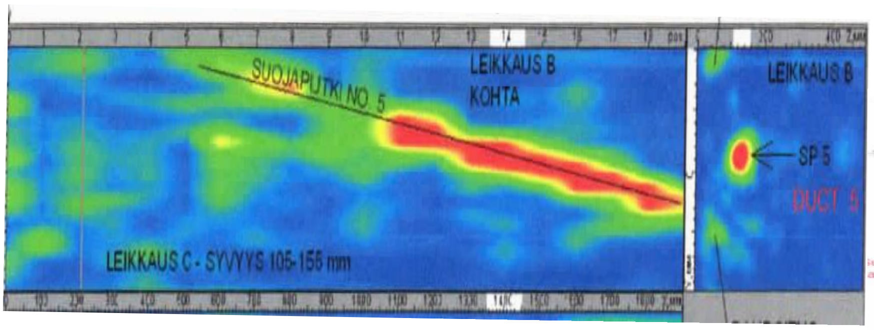
Validation points S4 and S3

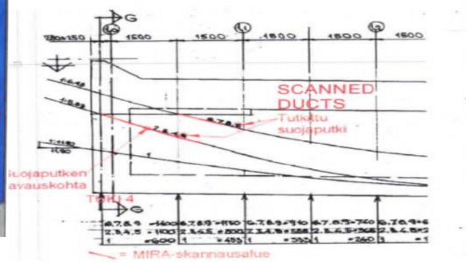
S4 (green area) bonded waterproofing, BOND-Strength ft=1.0 MPa (req. ≥ 1.0 MPa)
S3 (red area) waterproofing debonded.

Conclusions & Recommendations: Good correlation between NDT and validation.
Unsuccessful repair at the yellow / red areas (to be re-repaired). Performed by:
NDTitan Guy Rapaport

Injection quality of existing cable ducts tested by NDT

NDTitan Guy Rapaport





Evaluation of prestressing duct´s condition (Ramboll Finland Oy) at various locations along the bridge, mostly at the anchoring zones and mid spans was performed by using the MIRA ultrasound tomography and Impact-Echo on the Leiviö over bridge in Finland for the Finnish Road Administration.

The bridge constructed in 1971 is a continuous prestressed concrete box girder bridge 102 m long.

At several investigation zones intensive and continuous reflections were detected at the locations and depths of the ducts (red color). Accordingly, similar findings were made with Impact Echo investigations (dominant peaks at depth of ducts).

At one location it was decided to open the suspicious duct at a distance of 1 m from the head of the anchor holding the strands, carried out by coring to the corrugated tube, which was opened as well.

The finding is illustrated below.

The duct was empty of injection grout and the strands were severely corroded, yet only mildly pitted.

In comparison, in another area, where the MIRA did not show intensive reflections (red color), but only slightly green/yellow color (non-suspicious), another similar opening was made.

As seen, the strands were fully encapsulated by injection grout, well protected. The strands are in good condition with no signs of corrosion.

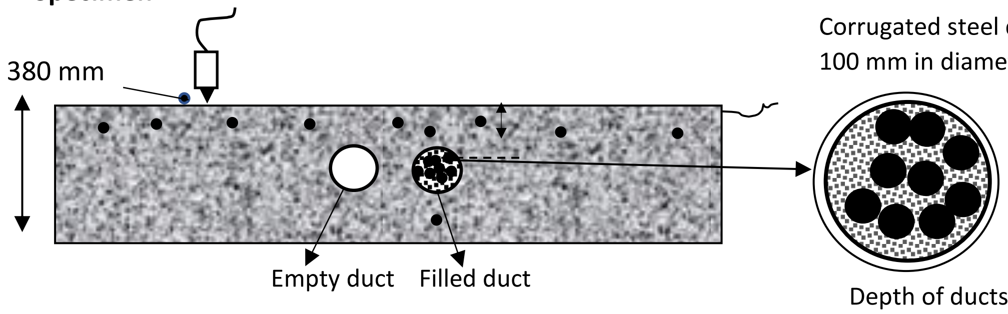
The case shows how important it is to evaluate the injection of the ducts during and after completion, e.g. with MIRA and DOCter Impact-Echo, including verification of the results by invasive means.

Testing and report made by **NDTitan Guy Rapaport**

NDTitans in action, testing cases, examples

Injection the quality of cable ducts, tested with DOCter Impact-Echo and MIRA Tomography on a controlled specimen

Specimen



Corrugated steel ducts, 1 mm wall thickness, 100 mm in diameter

Duct containing 10 strands (ea 16 mm dia.) and injected with non-shrink mortar. Duct is 2 meter long.

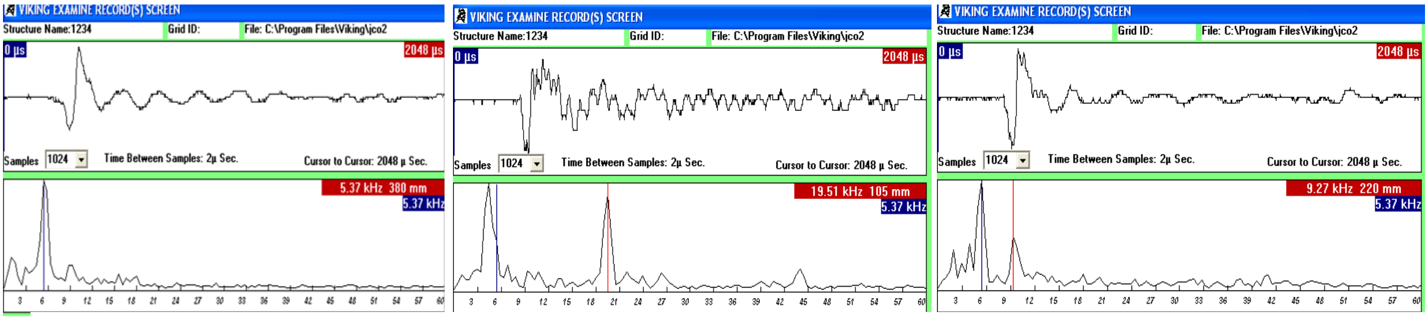
Depth of ducts ~ 105 mm

$f=C_p/2T$ &

$f=C_p/4T$

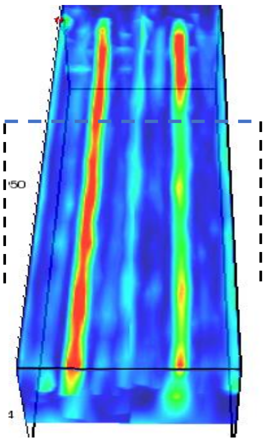
C_p=4080 m/s

DOCter Impact-Echo

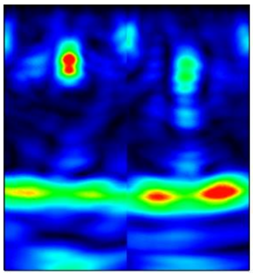


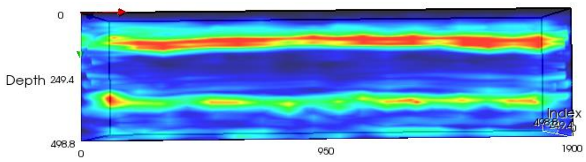
Solid	Empty duct	Filled duct
f=5.37 kHz	f=4.39 kHz (drop) & f=19.51 kHz (depth 105 mm)	f=5.37 kHz & f=9.27 kHz (strands 110 mm deep

MIRA Tomographer



Empty duct Injected duct





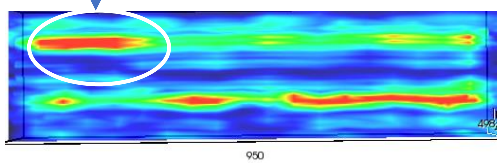
Empty duct

Backwall

Partly injected

"Injected" duct

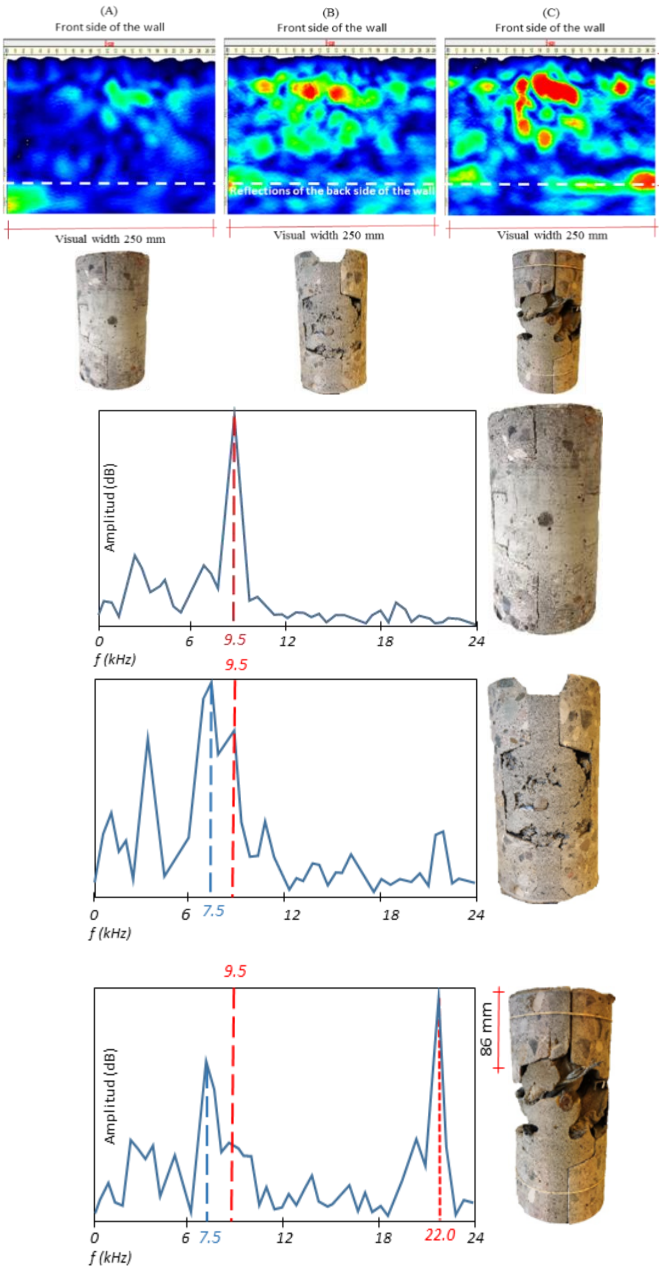
Backwall



DOCter Impact-Echo and the MIRA identified the same conditions of the injection of the cable ducts as well as in the first area of the injected duct (the red color) found to be partly injected.

Testing and report made by **NDTitans Hugo Orozco and Claus Germann Petersen**

Non-destructive testing of joints in precast walls



In 2015, a new building complex in the Technical University of Denmark, DTU, was under construction. A demonstration of quality inspection of grouted joints reinforced with looped wire ropes was performed in the Life Science & Bio Engineering multi-story building where precast concrete walls were used. Knowing that the grouting process is very susceptible to human error, looking for possible defects is critical. Two instruments were used, the **DOCter,** which is based on the Impact-Echo method, and **MIRA**, an ultrasonic-echo tomographer. These stress wave, NDT assessment methods, are well known to be sensitive to these types of defects.

The joints were grouted with a fluid mortar, but there were suspicions that a bad procedure of grouting could have been done.

A vertical column of 17 to 18 testing points, with 100 mm spacing in between, were made for inspecting each of two randomly selected joints. The tested concrete walls were 200 mm thick. By analyzing the changes in the value of the resonance frequency compared to that of a solid part of the joints (9.5 kHz), Impact-Echo was able to identify the position and depth of several voids. The 2D images or B-scans made with MIRA corroborated the findings.

The contractor also extracted some cores and verified that the position and extent of the defects matched very well with the NDT results. It was later discovered that many joints had the same problem and that it might affect the structural performance and durability of the elements. Drilling and reinjection of most of the joints had to be done to repair them.

The **Germann Instruments' NDTitans Claus Petersen and Hugo Orozco** are shown performing Impact-Echo and MIRA tomographer, respectively.

NDTitans in action, testing cases, examples

Non-Destructive evaluation of overhead water tanks in Punjab, India

The water tanks that supply potable water to a part of city were built in the late 1970s/ early 1980s. During this period, concrete was generally produced in small batches using portable mixers on the project location itself. The concrete was transported from the mixer and placed on site using manual labor.

This resulted in high variability and less than desired quality and durability of concrete in the RCC structures built during that period.

Avantech Engineering of India was assigned the task of investigating the health of concrete and reinforcement in four water tanks.

The objective of the investigations was to assess the in-situ concrete compressive strength, concrete homogeneity, surface hardness, corrosion risk, concrete cover and depth of carbonation using Non-Destructive and minimally destructive techniques to diagnose the type and cause of distress in these structures.

This information would then be utilized by the owner for validation of structure design and carrying out repair/ rehabilitation.

Concrete Strength

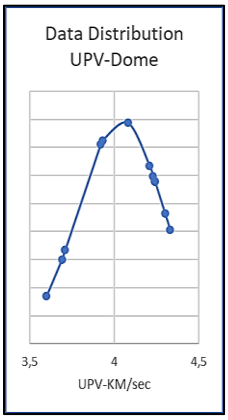
Compressive strength (MPa)	**Dome** CAPO Test ¤)	**Columns** CAPO Test ¤)	**Beams** Core Test ¤¤)	**Beams** CAPO Test (only 2 tests for core validation)
Range	24 to 50	22 to 49	16 to 39	23-33
Mean Value	38.5	39	23	26
Median	**39**	**41**	**21**	-
Standard Dev	8.5	9	6	-

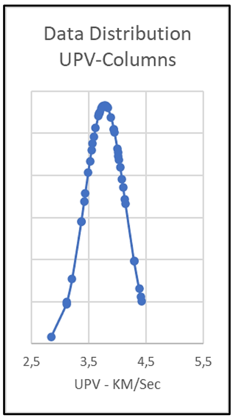
¤) Nos of CAPO-TEST: 20

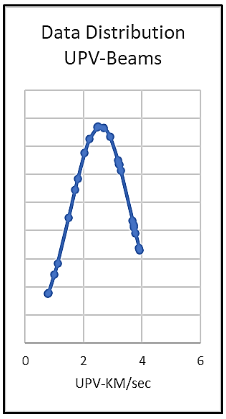
¤¤) Nos of cores: 12 (dia 68 mm, water soaked 48 hours)

Concrete Homogeneity

UPV (Ultrasound Pulse Velocity) tests were carried out to assess the general quality and homogeneity of concrete.







Aver: **km/s**	**4.0** Dome	**3.8** Columns	**2.4** Beams

Evaluated by UPV the quality of domes and columns was generally good and uniform with all UPV values above 3.5 km/sec. The beams exhibited the worst quality with about 74% readings below 3.5 km/s and average UPV only 2.4 km/s.

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Rebound Hammer

300 sets of rebound hammer data collected was not in any conformity with the UPV, CAPO and Core Test results and, therefore, not used for estimation of in-situ strength.

Corrosion

Half Cell Potential tests were conducted using the Half Cell Method and based on average -mV readings. The average risk of corrosion was observed to be 50% for most structures tested. Beams exhibited maximum average negative potentials in all tanks.

Cover

The lowest cover was on the beams (22 -27 mm), on the domes (45-67 mm) and on the columns (43-57 mm)

Carbonation

Depth of carbonation: Domes (31-53 mm), columns (36-52 mm) and beams (40-52 mm).

In almost all cases the depth of carbonation was larger than the depth of the reinforcement, causing loss of protection from the concrete´s alkalinity, and making the rebars corrode.

CONCLUSIONS & RECOMMENDATIONS

1. The in-situ strength of concrete in beams was observed to be considerably lower than concrete strength in domes and columns. This may be corroborated with original design data and suitable structural design checks.

2. Concrete homogeneity in domes and columns was adequate. However, the concrete quality and homogeneity in beams was found to be poor.

3. There is a significant risk of active corrosion in rebars in all tanks. The carbonation depths are quite significant, exceeding the cover depth in most cases and, therefore, appear to be the main cause of active corrosion. Poor homogeneity of concrete and lower cover depths as observed in beams increase the porosity and, therefore, the risk of higher active corrosion.

4. The customer was advised to take adequate remedial measures to arrest the active corrosion and draw a plan for repair/ rehabilitation of the water tanks.

Testing organized / reported by **NDTitan Parampreet Singh**

NDTitans in action, testing cases, examples

Non-Destructive evaluation of an existing industrial warehouse, Mexico

A Graphite Electrodes’ manufacturing company requested a full structural condition assessment of one of their industrial warehouses in Monterrey, Mexico. After the evaluation, a decision would be taken regarding the demolition or repair of the structure. The 50-year-old structure was fully built with cast-in-place reinforced concrete elements. The structure consisted of regular rectangular columns and beams, and a large semi-circular vaulted roof. The longest dimension of the roof from edge to edge was 124 meters. Since the owner of the structure did not allow coring, a full NDT evaluation program was conducted.

REBAR SCANNING

Ground Penetrating Radar with a 2600 MHz antenna was used to scan the structural elements and Cover Meter was used to estimate the rebar diameter. It was found that the average cover layer of all columns and beams was 20 mm.

GPR for rebar depth

Covermeter for size of bar

COMPRESSIVE STRENGTH ESTIMATION

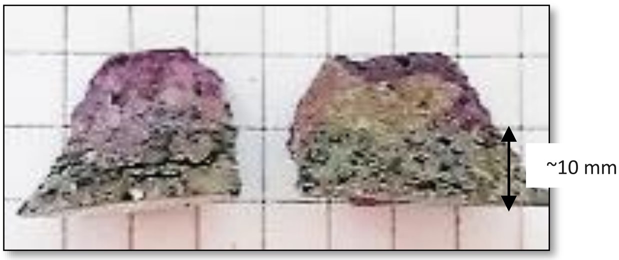
The warehouse was composed of a total of 81 structural elements among columns, beams, and vaulted roof sections. In order to obtain a representative sample of compressive strength values, ASTM 122 was used to determine the number of elements that should be tested. As a result, CAPO-TEST was conducted at 24 structural elements. And, using the statistical method suggested by ACI 228, an equivalent compressive strength was calculated for the whole structure. Coring was not allowed.

CAPO-TEST COMPRESSIVE STRENGTH SUMMARY	
Tested Elements	24
No of CAPO-TEST´s	24 (one in each element)
Strength Range (MPa)	20 to 32[#)]
Mean Strength (MPa)	25
St. Dev. (MPa)	4
C.V.	16%
Equivalent fc (MPa)	19

[#)] following the General Correlation, cylinder strength.

CAPO-TEST

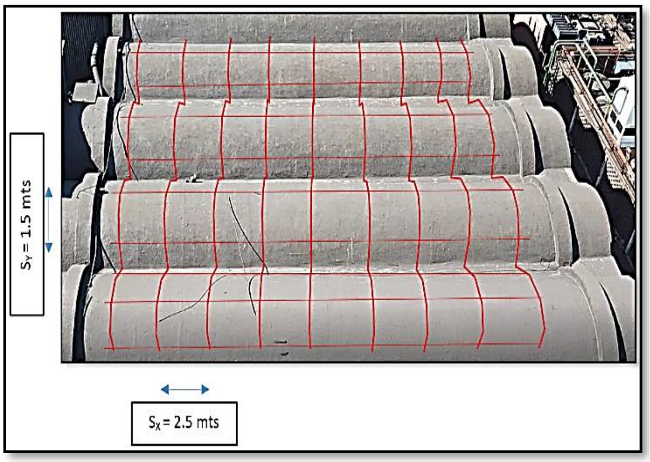
CARBONATION



The CAPO test conical pull-out cones were tested for carbonation with a pH indicator. It was found that the depth of carbonation on columns was ~10 mm and the beams and roof ranged between 15 to 30 mm. The average cover layer was 20 mm. The reinforcement of beams and roof was at high risk of corrosion.

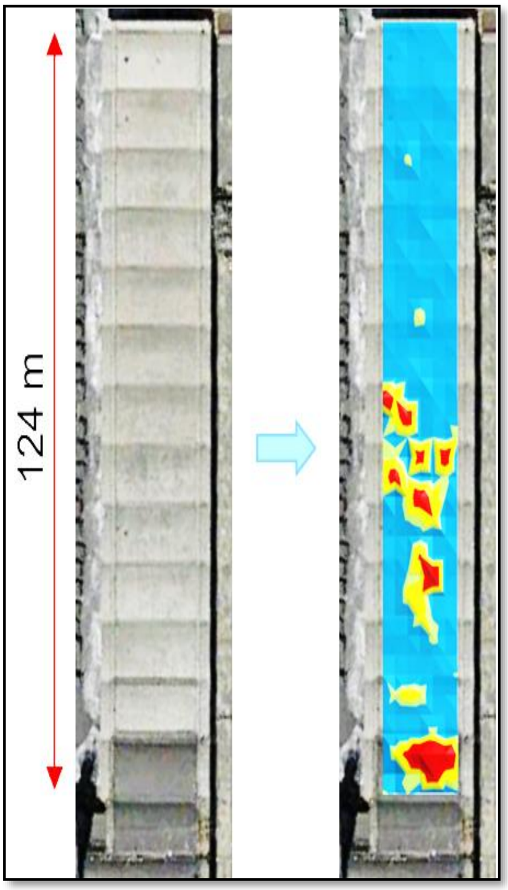
STRUCTURAL INTEGRITY ASSESMENT OF VAULTED ROOF

s´MASH Impulse-Response was conducted to quickly evaluate the structural integrity of the large concrete roof. 8,600 m^2 of roof were tested with around 1,200 points in 1 full day.



s´MASH Impulse Response on the vaulted roof

The "average mobility" value of each point was used to compute a statistically modified contour plot as shown with the "sound" areas (blue) vs "unsound" areas (red / yellow). It was found that the areas with high "average mobility" (red / yellow) coincided with heavy corrosion induced damage from carbonation.



s´MASH contour plot of average mobility on the roof

CONCLUSION

Using the calculated equivalent compressive strength as suggested by ACI 228 and the on-site rebar configuration, it was found that the structure was appropriately designed and built. However, after 50 years of service, the structure had developed localized carbonation induced corrosion deterioration on beams and especially the roof and needed repair. Columns were suffering from mechanical impact due to negligent driving of tractors within the warehouse.

A concrete rehabilitation manual was provided to the structure owner.

Testing / reporting by NEODEX team headed by NDTitan Oliver Aguirre.

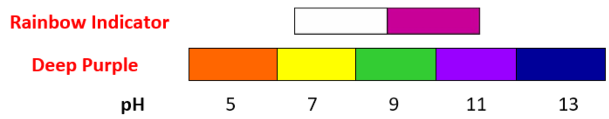
NDTitans in action, testing cases, examples

Carbonation depth with Rainbow Indicator and Deep Purple

Severe cases of carbonation damage

For new structures, the reinforcement is protected by a film caused by the alkalinity of the cement paste (pH > 11) preventing corrosion of the rebars. When Carbon Dioxide (CO_2) from the air diffuse into the concrete it reacts with the Calcium Hydroxide ($CaOH_2$) forming Calcium Carbonate ($CaCO_3$) .

By this process, the pH of the concrete decrease below its normal value at around 11-13, the reinforcement will lose its protective film at around a pH of 9 and will start corroding. To measure the pH of the concrete the Rainbow Indicator or the Deep Purple is available to be sprayed on a fresh broken piece of concrete or a core or a freshly broken CAPO-TEST failure surface.



Example

Rainbow Indicator and **Deep Purple** for depth of carbonation on a bridge girder

As part of bridge investigations in Poland the depth of carbonation was tested, both with the Rainbow Indicator and the Deep Purple indicator used, sprayed on freshly cut cores.

The Deep Purple and the Rainbow Indicator produced the same depth of carbonation, from the inside of the girder 54 mm and from the outside 25 mm. The reason for the **different** depth is that the outside is subjected to rain, slowing down the carbonation process, while the inside is relative dry.

Carb. depth 54 mm
Inside of Girder

Carb. dept 25 mm
Outside of Girder

Rainbow Indicator

Deep Purple

Reinforcement 40 mm deep

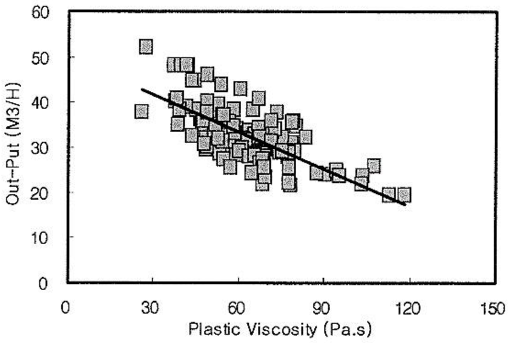
With the depth of the reinforcement 40 mm, misleading information concerning the protectiveness of the reinforcement could be given if testing was only made from the outside of the girder. The reinforcement positioned at the inside of the girder had in fact started corroding, while reinforcement at the outside had no signs of corrosion.

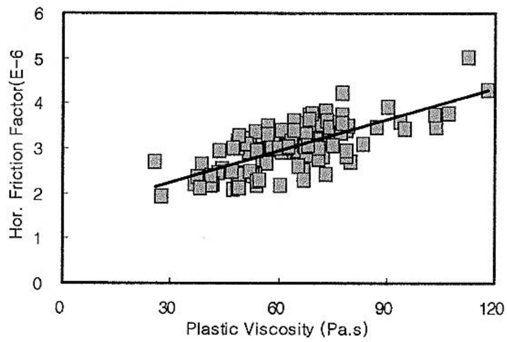
CAPO Test (pH≈4)

core (pH≈12)

Testing made by **NDTitan Andrzej Moczko**

Rheology in the Burj Khalifa Dubai Super Tall Building





Most of super tall buildings, including the revolutionary Burj Khalifa Dubai, world's tallest building, are reinforced concrete structures which have been or are being built with high performance concrete (HPC) to a greater or lesser extent. The stiffness provided by high modulus HPC has benefits in terms of limiting displacements and its high strength is necessary to keep the cross section of structural elements within reasonable slender dimensions. Also, the high early strength, along with prefabricated reinforcing cages and new slip form/climb form technologies, allow for large structures that can be constructed at rates of 2 to 3 levels per week.

On the other hand, HPC is usually more sensitive than conventional concrete during the plastic and early hardening phase. So, among many other challenges, the ability to pump and place concrete at high ambient temperatures to significant heights is crucial for the efficient and economic use of HPC. In the case of the Burj Dubai, it would not be economically viable to use HPC if large quantities are needed to be placed by crane. With the development of powerful pumps, the possibility to conduct single stage pumping to heights of more than 600 m was possible in this project.

Besides a very careful design of the concrete mixtures, the pumping setup and all the logistical issues involved, detailed monitoring of the rheological properties of the fresh concrete before and after pumping played a key role for the success of the works. Experience with pumping concrete in the Middle East had shown the potential for blockage of the pipelines due to temperature effects, so limited variation in rheology and concrete temperature had to be achieved to minimize pumping problems.

For this purpose, the **ICAR Rheometer** was extensively used both during the trials and the construction process. At the beginning, pumping through the 150 mm diameter high pressure pipes was found to be approximately half the plastic viscosity of the concrete and double the dynamic yield stress. Also, correlations of rheological properties vs. key pumping parameters like friction factor and out-put flow were developed. These findings created the ability to optimize the concrete mixtures and procedures of systematic quality control to carry out the actual works.

The success of projects such as the Burj Dubai shows the advantages of HPC in building super tall structures. The **ICAR Rheometer** was of great help to overcome the challenges faced in pumping so high under very tough climate conditions and prevent pump blockages and other problems which would severely limit the benefit of using this material.

Ref.: James Aldred. "Burj Khalifa – a new high for high-performance concrete". Proceedings of the Institution of Civil Engineers - Civil Engineering. Vol. 163-2, May 2010, pp. 66-73, "Test Right – Sleep Tight"

NDTitans in action, testing cases, examples

Inspection with Drones and Artificial Intelligence, Greece

Systematic inspection of structures play a critical role for structural safety and functionality. Defects should be recognized at their early stage of development for repair costs to be minimized

Most of modern countries have adopted Inspection Schedule for structures such as bridges, tunnels and retaining walls that have constructed in motorways. Also, a rating system of the observed defects is adopted in order to obtain a rating value for each structure that will classify in a rough way the importance of defects observed and need for further investigation.

Inspection schedule in Greek motorway demands Visual Inspection of bridges every 3 years in order to detect any significant damages and repair them as soon as possible.

Besides eye observation, photo cameras with proper lenses and binoculars Drones (UAV) can now be used to obtain photos/videos of high resolution at areas or structural elements where access is impossible by foot or ladder.

60 bridges of a major motorway in Greece were inspected lately by using drones operated by **NDTitan Tasos Gotzamanis**, Geotest SA.

The soffit of the decks was inspected, the pier caps and the elastomeric bearings. Some bridges are above river crossings and inevitably access to elements demand the use of underside platform if there were no Drones. The visual inspection comprised, furthermore, traces or moisture that could indicate deficiency of waterproofing system over deck and expansion joints.

Finally, excessive deformations, bulging and oxidation of elastomeric bearings was performed with drones in a fast and efficient way with low cost.

Artificial Intelligence will play a main role in future technological applications. Geotest SA follows this technological path in order to implement this powerful tool into Drones and specially for performing Visual Inspection of structures. By this means, automation in detection of defects will be performed faster and more efficient thus adding extra value to Management of Infrastructure.

Reporting / Piloting by **NDTitan Tasos Gotzamanis**

Training Examples

Training is offered on-site or at Germann Instruments facilities in Copenhagen or Chicago.

MIRA ultrasound tomographer

Slab with known defects, GI, USA

Joints at DTU, Denmark

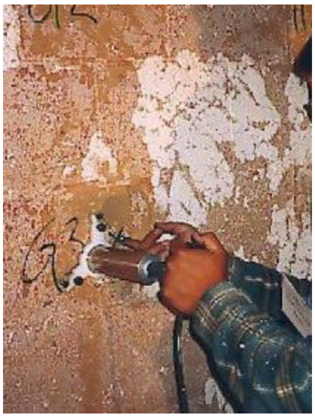
Bridge deck, FHWA, Illinois

DOCter Impact-Echo

Tunnel thickness, Germany

Slab with known defects, Denmark

Arch Bridge w. ASR, Sweden



Pulp Plant, Canada
De-bonding of tiles

Fire damaged ceiling, Germany
Depth of cracks

Sewer tubes, Denmark
Delaminations

Thickness of concrete liner inside riser column, Sweden

NDTitans in action

Training Examples

s´MASH Impulse Response

Tunnel lining, Denmark
Voids in injection

Terracotta Panels, Chicago
Cracking / debonding

Bridge Slab, Virginia
Voids / lack of support

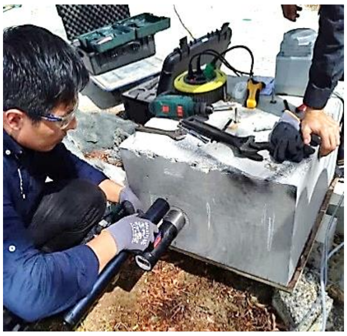
Granite Panels, New York
Missing anchoring

LOK-TEST and CAPO-TEST

Video: https://www.youtube.com/watch?v=AwgeQbCp4sQ

Industrial Floor, UK
Strength before loading

Tunnel Base, Denmark
Strength before loading



Test Specimen, Dubai
University teaching

Shotcrete, Canada
Strength

Columns, Houston
Strength before further loading

Bridge joints, Kentucky
Strength before loading

NDTitans in action

Training Examples

Great Belt Link, Denmark
LOK-TEST and CAPO-TEST training for production control with emphasis on the cover layer

BOND-TEST

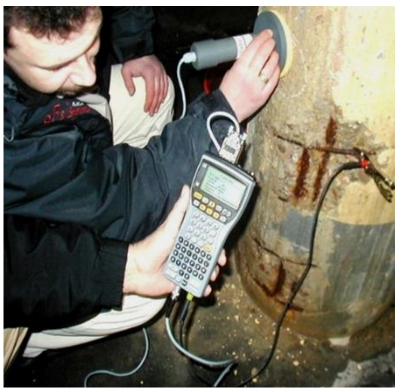
New York Metro
Tile adhesion

Joint testing at Anchorage Airport runway, Alaska
Testing of substrate before applying the joint overlay

Miscellaneous training examples

AVA-3000, FHWA, Topeka, Kansas, USA

GPR, Germann Instruments, Denmark



GalvaPulse, Luxembourg

Miscellaneous training examples

Ministry of Transport (MOT), Hanoi, Vietnam

AUD, American University in Dubai

Road & Bridge Administration, Wroclaw, Poland