Concrete NEWS

FORCE TECHNOLOGY

No. 9 A newsletter from FORCE Technology on inspection and examination of concrete April 2009

This issue

Editorial

Welcome to the latest edition of Concrete News, in which we deal with three subjects, namely fire in concrete structures, our work at the Xiang´an tunnel in China, and our agreements with foreign partners on distribution of systems for corrosion monitoring in concrete structures.

When reinforced concrete structures are exposed to fire, very serious and devastating damages may occur, which especially for reinforcement may have vital consequences for the durability of the structure. In this edition of Concrete News, you can read more about damage development, forensic examination methods and failure investigation.

Furthermore, we have chosen to present our first major assignment in China. In connection with the construction of the Xiang'an tunnel, which is China's first subsea tunnel, tying the mainland with the island of Xiamen, FORCE Technology introduced their system for surveillance/monitoring of the reinforcement corrosion. A series of CorroWatch probes and ERE 20 reference electrodes were later installed in the upper part of the tunnel section.

Subsequently, FORCE Technology was invited to participate in an International Conference in Hang Zhou in November 2008 to present our experiences with corrosion monitoring. The presentation from the conference may be downloaded from our web page: www.forcetechnology.com

Please enjoy your reading.

The next edition of Concrete News is expected to be published by the end of 2009.

Brián Kofoed
Editor

Corrosion monitoring
– now in China!

FORCE Technology presented their unique system for monitoring of reinforcement corrosion in concrete structures in connection with the building of China's first subsea tunnel.

The entrance to the new Xiang'an tunnel.

As part of the development of China's infrastructure, a new tunnel, the Xiang'an tunnel, connecting Xiamen to the mainland, is under construction. The tunnel, which is 7 kilometres long with two tubes is the first subsea tunnel in China, cf. Figure 1.

Figure 1: Illustration of how the tunnel will connect the island of Xiamen to the mainland.

To optimise the maintenance strategy and ensure a long service life, the owner has decided to install a corrosion monitoring system in the tunnel.

Corrosion monitoring systems are not widespread in China

In China, corrosion monitoring systems have generally not been considered or used in concrete structures. Therefore, there is no significant experience with the various techniques and systems.

In order to choose the optimum corrosion monitoring system, Xiamen University Department of Materials, Science and Engineering were chosen as expert advisors. They ordered the newly developed fully automatic corrosion monitoring system from FORCE Technology and a number of CorroWatch sensors and ERE 20 reference electrodes for embedding in the concrete. The sensors will be used to test and evaluate the system both in the laboratory and in the tunnel prior to a complete installation of the corrosion monitoring systems. Apart from the sensors from FORCE Technology, as an experiment, a sensor developed at the Shanghai Jiao Tong University was also installed in the Xiang'an tunnel.

The CorroWatch sensors and ERE 20 reference electrodes from FORCE Technology

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were mounted in the upper part of the tunnel sections, i.e. 'under the ceiling', in an area where the casting for a section was primed and which was to be performed a few hours after the installation, cf. Figure 2. The sensors were installed by Professor Xuan Cheng, Xiamen University, Department of Materials, Science and Engineering and Peter V. Nygaard, FORCE Technology. Because of the major public interest in the tunnel project, the installation of sensors was followed closely by a local television crew.

Figure 2: Design draft of the Xiang'an tunnel.

Demonstration of built-in corrosion sensors

In the role as expert advisor, the Xiamen University arranged and hosted a workshop titled 'Corrosion of oceanic structures'. Here, FORCE Technology presented their data logger system and sensors for embedding in concrete. Apart from a large number of employees and students at the Xiamen University, people from the Shanghai Jiao Tong University and large consultancy and contracting companies also participated in the workshop.

In connection with the workshop, a visit was paid to the suspension bridge which today is the primary connection between the island of Xiamen and the mainland. Next stop on the tour was the Xiang'an tunnel where all the various corrosion sensors from FORCE Technology had been installed.

Corrosion monitoring system from FORCE Technology

The fully automatic corrosion monitoring system from FORCE Technology monitors corrosion activity (active/passive) – of each of the 4 anodes on the CorroWatch probes embedded in the concrete. As the CorroWatch probes are placed in the concrete cover and the 4 anodes at various depths under the concrete surface, the corrosion front may be monitored through the concrete. When active corrosion is detected in the CorroWatch probes' deepest installed anode, close to the main reinforcement, repair strategies, such as traditional repair or cathodic protection can be prepared and implemented. Corrosion monitoring thus supplies an early warning of reinforcement corrosion.

Determination of the individual anodes' corrosion activity is based on measurements of their electrochemical potentials and a 5 second macro cell current. For each CorroWatch probe, the electrochemical potential of each of the 4 anodes is measured prior to the macro cell current being determined. This is done by connecting the individual anodes on each CorroWatch, one at a time, to the Ti-mmo cathode mounted on the probe body through a precision 0-Ohm ammeter. Exactly 5 seconds after an anode has been connected to the Ti-mmo cathode, the current running between the two is measured and the result is recorded in the corrosion monitoring system computer. The anode is then disconnected and the next anode connected and the procedure repeated after 5 seconds. This procedure is reiterated until the macro cell current for all 4 anodes in the CorroWatch probe have been determined.

The anodes' corrosion activity is primarily evaluated based on the measured 5 second macro cell currents. Based on examinations in the laboratory, it has been determined that 5 second macro cell currents above 12-15 $\mu A/cm^2$ signify active corrosion. Depending on the concrete saturation degree and thus the oxygen content/supply, the measured electrochemical potentials may also be applied for interpreting the corrosion condition of the anodes. This is possible when the concrete is not saturated and the electrochemical potential of the anodes is not under cathodic control due to low oxygen content in the concrete. If, on the other hand, the concrete has been exposed in the atmosphere, and the oxygen content has not been limited by high water content, the potentials of the anodes may also be applied for determination of the anodes' corrosion activity.

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Agreements abroad help establish our leading position within corrosion monitoring

During 2008, the Concrete Department has entered into co-operation agreements with companies representing China, Australia, New Zealand, Portugal and Spain about distribution of systems for corrosion monitoring in concrete structures.

CorroWatch probe and ERE 20 reference electrode

These agreements include all our products such as ERE 20 reference electrodes, CorroWatch and CorroRisk probes and also GalvaPulse equipment. Furthermore, our new handheld equipment for measuring by ERE 20 reference electrodes and CorroWatch/CorroRisk probes as well as data logger systems for automatic data collection is also included. The agreements also include assistance for interpretation of measurements and reliability as regards repair needs and remaining service life.

Leading global position

Such agreements ensure distribution of our products to areas experiencing increasing growth in new construction (China) and to areas with rather much need for maintenance of existing construction and structures (Australia/New Zealand and Portugal/ Spain). Similar agreements with other countries in and outside Europe are up-coming. This way we expect to become the world leading supplier of corrosion monitoring for concrete structures over the next few years.

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How fire affects concrete

Fire damage on buildings and other structural parts may influence the structural integrity and resistance towards other secondary deterioration mechanisms. Thus, it is important to determine the degree of damage caused by the fire in order to ensure that a collapse does not occur after the fire has been extinguished. It is furthermore important in order to plan a financially realistic restoration.

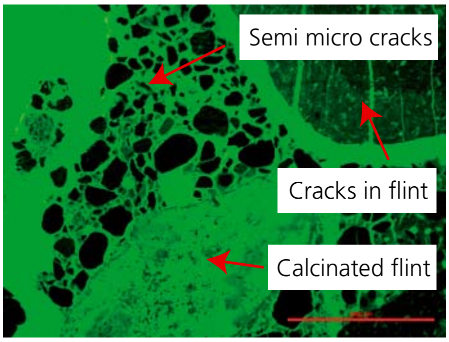
Repercussions of a massive fire impact on concrete surrounding a window opening.

Primary impact

In order to map out the extent of failures/damages after a fire, it is important to understand the anatomy of the construction/structure, as detailed as possible. In many cases it is crucial to understand the structure's initial state of health to be able to differentiate between damages/failures that occurred due to the fire and damages that can be related to the original condition. Furthermore, it is very important to get a relatively clear view on where, how and especially for how long the structure has been exposed to the fire. Information on which materials that burned and the extinguishing task may also be of great importance to how any secondary, long-term effects of the fire may arise.

Fires

Each fire has its own anatomy. A fire is controlled by the availability of combustible material, the type of material and the availability of oxygen for combustion. Thus, the most massive fire damage is not necessarily linked to the location where the highest concentration of combustible material is placed. It is not un-common that the combustible material gasifies somewhere while the high temperature zones are around openings in the structure with oxygen excess for combustion of the gases. Beside the lateral variations in the fire damage, huge vertical variations are seen, as the heat surges upwards. This means that the low-lying parts of a structure may be almost unmarked by the fire, even in the fire's epicentre.



Micro photo of surface of heavily fire damaged concrete. The surface is seen to the left.

What happens?

When concrete based products are exposed to fire, a number of processes occur in paste and aggregates that control the disintegration. The first thing to happen is that free water in paste evaporates from the surface in a temperature range between 100-200 °C. When the free water has evaporated, the crystal water in the hydration products starts to evaporate. When the temperature reaches approx. 200°C, the flint particles start to change. Flint contains some water that may evaporate, which again may cause colour change in some types of flint and consequently at higher temperatures the particles start to crack and spall.

In the temperature interval from 500 to 600°C, the hydration products will undergo severe changes, as free calcium hydroxide will convert into calcium oxide and water, and the gel will lose its crystal water. Within the same interval, structural changes will occur in certain types of quarts, which results in an increase in volume. This may lead to cracks in the adjacent paste and aggregate. At temperatures above 600°C, limestone particles and carbonated paste start to decompose into calcium oxide and carbon dioxide.

Depending on the fire exposure, these processes will affect the overall strength of the concrete in a negative direction. The loss of strength depends on how deeply the fire related alterations penetrate into the concrete.

As the fire exposure on the concrete involves a number of phase changes, a change in volume also takes place. Within the first 100 to 200°C the concrete volume increases, which is a consequence of the segregation of free water. At temperatures above 200°C, the concrete starts to contract as the phases have lost their water. However, these processes depend on the water-cement ratio and the presence of pozzolanic material. The positive element in the segregation of water is that the heat conductivity of the concrete decreases and the effect of the fire on the inner parts is somewhat delayed.

The segregation of water may involve explosive spalling in dense concrete as the steam cannot escape at the same rate as it is generated. To compensate for this, it is possible to add polypropylene fibres to the concrete that will work as drainage channels for vapour during fires. Concrete types with high water cement ratios above 0.45 are less susceptible to explosive spalling as the capillary pore structure is sufficiently open so that the vapour can escape freely. However, this is also dependent on the heating gradient.

Temperature indicator	Temperature interval
Carbonate decomposition	600-880˚C
C-S-H gel decomposition	500-700˚C
Quartz inversion (expansion due to phase change)	573˚C
Calcination of flint	350-450˚C
Discoloration of certain flint types	ca. 200˚C
Semi micro cracks along fine aggregates and air voids	150-250˚C
Decomposition of ettringite	150-200˚C

Table 1: The relation between the concrete temperature and the transformation of by-products.

Reality

When the extent of fire damages is to be assessed, it is important to get an overview as to which parts of the structure that are most affected. The degree of burning of paint, wall paper, woodwork melting of aluminium panels and bending of steel elements may be good indicators of cold and hot areas. Furthermore, in some cases, the colour of the concrete may be an indicator of the damage level. However, one should

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always look out for filler material, pigmented concrete or alternative concrete compositions, cf. Table 2 below.

Temperature interval	Colour
0-300˚C	Normal grey
300-600˚C	Purplish
600-1000˚C	White grey
1000-˚C	Brownish yellow

Table 2: The colour indicates the temperature impact on concrete.

Strength probing

As mentioned, the fire affects the paste structure, which again influences the concrete strength and its speed of sound in the material. This can be utilised for identifying various damage zones.

This may be done by 'acoustic probing', which is basically a systematic tapping on the structure, whereby the change in pitch reveals the most affected areas. Damaged parts will be characterised by a hollow sound whereas intact concrete will have a much harder ringing sound. Since this method is not quantifiable, ultrasonic equipment is applied in many such cases, for measuring the speed of sound on the surface. Alternatively, a Schmidt hammer, that measures the recoil values of individual measuring points can be used.

In both methods, however, the influence of filler material, roughness and other surface treatments or structures should be taken into consideration, as this may influence the measuring results. It is also important to bear in mind that these measurements are only representative of the outermost mm to cm, and thus these methods do not supply any information on the strength of the inner parts of the concrete.

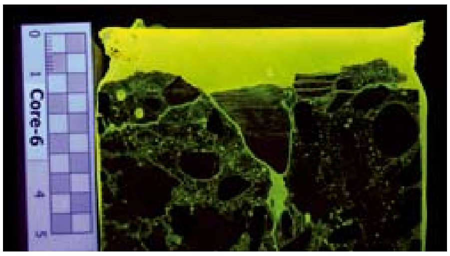
Materials analyses

Based on the survey and strength probing samples may be taken from the concrete to determine how deeply the concrete is damaged. This is done in order to assess any reduction in the compressive strength and to determine whether the reinforcement has been affected by the heat. Basically, it is always a good idea to take samples of both damaged and non-damaged concrete to have a basis for reference.

The temperature impact is based on macro- and microscopic changes of paste and aggregate, according to Table 1, as can be seen in ground surfaces and polished sections. When the depth and degree of fire damage has been determined, it can be assessed whether the reinforcement has been damaged. Thus, it is important to perform a measurement of cover layer thickness in the various fire zones in order to correlate the temperature profile from the samples with the reinforcement location.

Various types of reinforcement and steel are more or less sensitive to fire exposure. Hot-rolled steel will begin to lose its strength at temperatures above 300°C, and at temperature at approx. 600°C, a strength reduction of 50 % will have taken place. However, at cooling, hot-rolled steel will regain its full strength but during a fire, the combination of loss of compressive strength and the reduction of steel strength may have led to structural damages on the structure.

Cold formed steel, which is typically applied in pre-stressed structures are more sensitive to high heat exposure. This type of steel starts to lose its strength already at 200°C, and at 600°C it has lost 80 % of its strength, which will not be regained at cooling. This could be very crucial for a structure during and after a fire, as regards immediate safety and restoration possibility and strategy.



Sawn through fluorescence impregnated drill core.

In serious cases, reinforcement samples may be taken for strength determination in the lab, or replica tests may be performed. At an on-site replica test a piece of steel is polished, and then a replica is made of the micro structure in the surface, and this micro structure replica is then examined in the laboratory.

Damages deriving from a structure

As previously mentioned, a fire will often cause certain parts of the structure to expand. This may lead to great tensions in the structure which again may lead to fractures elsewhere than the fire affected area. This is often seen in box girder elements in the form of 'clamps' which look as longitudinal crack offs and cracks along the edge of the elements. In some cases, these tensions may be transferred to stress-bearing walls and pillars which are then weakened.

The actual extinguishing task may result in chock scaling and cracks occurring. This will occur when cold water hits hot construction parts, and heavy thermal tension occurs. The water from the extinguishing task may also contribute to rehydration of fire impacted paste, whereby these phases again will expand tremendously.

The extinguishing task may incur significant water damage to the structure, and salts, if any, may be washed down to the reinforcement. This may result in an increased risk of corrosion, if the moisture conditions are favourable. When a structure is humidified, this may increase the risk of mould, which again may be of serious consequence to the subsequent repair work. Mapping and monitoring of moisture conditions in the fire damaged structure is thus very important to ensure that moisture is not trapped inside the structure, or that the repair work is commenced prior to acceptable humidity standards being obtained.

A review is a great investment

In general, depending on the fire damage, it is a very good investment to both the owner and the insurance company to perform a careful review of the structure after a fire, bearing in mind both a repair strategy and compensation claims.

Fact box

Force Technology has many years of experience in assessing fire damaged concrete or steel structures and other failures that have occurred due to fire damages and the consequences of the fire extinguishing task. Furthermore, we have great experience in damage and failure analyses of almost all types of material and structures, and we may be able to contribute with valuable information at damage investigations and condition assessments.

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