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NON-DESTRUCTIVE MATERIAL TESTING POSSIBILITIES OF REINFORCED CONCRETE STRUCTURES AFTER A FIRE

Abstract

Supporting structures play a particularly important role among building structures. From the point of view of fire protection, they must ensure the stability of buildings in the event of a fire for a specified period. During post-fire recovery, it should be verified that the supporting structure still has the required static and fire resistance performance. The use of reinforced concrete structures as a supporting structure is typical, where the degree of damage is closely related to the heat load caused by the fire. Renovation after a fire requires special expertise, as a starting point it is essential to be able to determine the extent of damage to building structures. In our paper, we present the non-destructive material testing possibilities of fire-damaged reinforced concrete structures and its limitations.

Keywords: reinforced concrete structures, fire, non-destructive diagnostics

VASBETONSZERKEZETEK TŰZ UTÁNI RONCSOLÁSMENTES ANYAGVIZSGÁLATI LEHETŐSÉGEI

Absztrakt

Az épületszerkezetek között kiemelten fontos szerepet töltenek be a tartószerkezetek. Tűzvédelmi szempontból meghatározott ideig biztosítaniuk kell az épületek állékonyságát tűzeset során is. Tűzesetet követő helyreállítás során vizsgálni kell, hogy a tartószerkezet továbbra is rendelkezik-e az előírt statikai és tűzállósági teljesítménnyel. Tartószerkezetként jellemző a vasbetonszerkezetek alkalmazása, ahol a károsodás mértéke szorosan összefügg a tűz által előidézett hőterheléssel. A tűzeset utáni felújítás speciális szaktudást igényel, kiindulásként elengedhetetlen, hogy meg tudjuk határozni az épületszerkezetek károsodásának mértékét. Közleményünkben a tűzkárt szenvedett vasbetonszerkezetek roncsolásmentes anyagvizsgálati lehetőségeit és annak korlátait mutatjuk be.

Kulcsszavak: vasbetonszerkezetek, tűz, roncsolásmentes diagnosztika

1. INTRODUCTION

The general requirement for structures and their parts is to equally meet the requirements of function, energy saving, life and health protection, economicality, safety and fire protection.

In addition to their functional role (girder, space delimiter, rain barrier, etc.), building structures must also serve fire protection aspects, for which purpose they must comply with 54/2014. (XII. 5.) Decree of the Ministry of the Interior on the issuance of the National Fire Protection Regulations (hereinafter: NFPR) and the relevant requirements of the Fire Protection Technical Directive 11.2:20.01.22 (hereinafter: FPTD) entitled Fire Protection Characteristics of Building Structures.

According to the provision of Section 1.4 of the FPTD, fire safety compliance of building structures within the scope and extent of the conversion must be verified in all cases, even in the event of the conversion, modernization, renovation and restoration of a building, regardless of whether it requires a permit procedure or not.

The reinforced concrete building structures discussed in this paper are dimensioned with a design primarily for compliance with static and fire protection requirements, the main parameters of which are structure thickness, concrete material quality, steel insert quantity and minimum concrete coverage. The latter is primarily responsible for the fire resistance of the structure.

2. DAMAGE EFFECTS OF FIRE ON REINFORCED CONCRETE STRUCTURES

As a consequence of fire, reinforced concrete structures undergo a number of changes, which will have an effect on the behavior and load-bearing capacity of the structure. During the increase of the temperature of the structure and the subsequent cooling, the following changes can lead to a decrease of the load capacity of the structure (*Balázs [et. Al.] 2017*):

- Deformation due to the temperature and the load;
- Longitudinally and cross-sectionally different temperature change;
- Nonlinear rise in air temperature;
- Different thermal expansion of cement and additive;
- Changes in the strength of concrete and steel;
- Different thermal expansion of concrete and rebar.
- The failure of reinforced concrete structures can basically be traced back to the following two causes (*Balázs, Lublóy, 2009*):
- Chemical and physical transformation of concrete components,
- layered detachment of the concrete surface.

The extent of the damage is closely related to the heat load under the fire, therefore the maximum temperature formed during the fire should be determined primarily. This is facilitated by knowing the ignition and melting temperatures of the various materials (*Table 1*). With the help of the table, we can deduce the maximum temperature in the building from the degree of damage to the materials in the building.

Material	Ignition or Melting Point
lead	327°C
paper	100°C
wood	300°C

aluminum	658°C
glass	800°C
concrete	1300°C
basalt	1426°C
ceramics	1500°C
steel	1535°C
chamotte	1700°C

Table 1 - Ignition and Melting Temperatures of Solids

3. CASES PRESENTING THE DAMAGING EFFECTS OF FIRE

In this chapter, we present some fire sites that illustrate the damage of fire to reinforced concrete structures.

Figure 1: Grocery store sales area after a fire

Source:
http://www.hirado.hu/Hirek/2011/10/17/07/Szinte_teljesen_a_kiegett_CBA_arutere__fotok.aspx

Figure 1 shows the condition of a grocery store after a fire. The store burned on 600 square meters during the fire. The picture clearly shows that the suspended ceiling was damaged in some places, and is significantly discolored from the smoke. However, the paper boxes in the store did not burn, so the temperature along the walls did not reach 300°C. Of course, during the inspection of the building, it must be checked whether chloride ions have entered the reinforced concrete structure during the burning of the plastics, but in this case, the building can be restored after a possible replacement of the ceiling and a painting.

Figure 2. Location of a fire in a 9th floor apartment of a panel residential building, 2020.

Source: Metropolitan Disaster Management Directorate, Fire Inspectorate General

During the fire shown in *Figure 2*, the largest room and the anteroom of the 9th floor panel apartment suffered the greatest damage. In both rooms, the equipment and objects were completely burned, which indicates a long-term, intense free burning. The maximum air temperature can be set to 800°C and the flame temperature reaching the ceiling can be set to 1000°C. With the opening of the front door and the destruction of the windows facing the balcony, the resulting draft contributed to the development of intense burning and high damage in these two rooms. The discoloration seen on the reinforced concrete wall and slab structures, as well as the layered detachment on the slab, indicate severe damage, which necessitated a static examination of the slab and, consequently, the reinforcement of it.

Figure 3. Fire scene of a car parked in an underground garage, 2017.

Source: MDMD Fire Inspectorate General

During the fire shown in *Figure 3*, a BMW-type vehicle parked in the underground garage of a residential building in the 2nd district of Budapest burned in its entirety. The entire underground garage was contaminated with soot. Plastic elements (plastic parts of pipes, fittings) have melted. The reinforced concrete slab and pillar in the area next to the car were significantly damaged, and the concrete cover was detached from the reinforcing steel mesh from the contiguous area above the engine compartment. The extent of the damage was caused by the closed space, the proximity of the slab and the lack of heat and smoke extraction at the flame temperature of 1200-1400°C.

It is clear from the figure that all the combustible parts of the car were destroyed in the fire, the aluminum wheels melted, despite being located at floor level, in the lowest temperature air layer.

Figure 4: Location of a fire in a cosmetics warehouse, 2009.

Source: MDMD Fire Inspectorate General

At the fire site shown in *Figure 4*, cosmetic products were stored on a shelf system in a warehouse system in the 9th district of Budapest on about 3,000 m^2. As a result of the fire, the combustible materials stored inside were largely destroyed, and the metal storage racks collapsed and deformed. Reinforced concrete pillars and beams were damaged due to the formed temperature of about 800°C and a heat load lasting for more than 1 hour. The heat load was reduced by the fact that the plate roof structure of the cold storage collapsed due to the fire, therefore the high-temperature combustion products, heat and smoke flowed into the open air.

Following the fires presented, it became necessary to carry out tests in order to determine the extent of the damage and to determine the procedure for repairing the reinforced concrete structures.

4. NON-DESTRUCTIVE METHODS OF MATERIAL TESTING AND THEIR USE IN FIRE DAMAGED BUILDINGS

When surveying a building damaged during a fire, it is advisable to carry out non-destructive tests if possible. Table 2 provides an overview of the options that can be used in the inspections.

Based on the Average Reaction of the Concrete Cover	Small Sample Per Dot	Special Technologies
Schmidt Hammer	Mechanical Testing of a Small Sample	Impact Echo
Windsor Probe Test	DTG	Sound Tomography
Capo Test	Dilatometry	MASW (Modal Analysis of Surface Waves)
BRE Internal Fracture	Thermoluminescence	Electrical Resistance
Ultrasonic Examination	Porosimetry	
Drilling Resistance	Colorimetry	
	Microcracking Density Analysis	
	Chemical Tests	

Table 2 - Overview of Non-destructive Testing Methods (fib bulletin 46)

4.1 Based on the Average Reaction of the Concrete Cover

4.1.1. Schmidt Hammer

The most common tool for measuring the surface hardness of concrete is the Schmidt hammer (Figure 5). Based on the rebound values obtained during the Schmidt hammer tests, the compressive strength of the structural concrete is estimated from empirical relationships. The actual condition (age, moisture content, etc.) and composition of structural concrete significantly affect the measured rebound values, so taking them into account is an important step in evaluating the results *(Szilágyi, Borosnyói, 2008).*

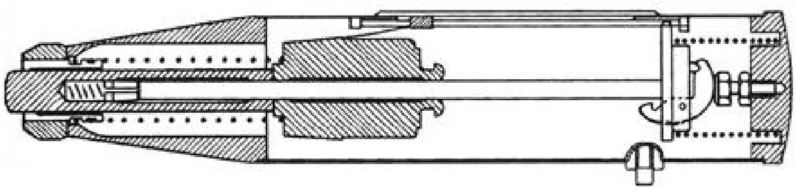


Figure 5. Schmidt Hammer *(Szilágyi, Borosnyói, 2008)*

The most common tool for measuring the surface hardness of concrete nowadays is the Schmidt hammer. The principle of the test is that the spring in the device moves an impact mass, which strikes the test surface with a given energy through an impact probe perpendicular to the surface, and after the impact, the rate of rebound of the impact mass is recorded by the device. The rebound value (R) is a dimensionless number: the ratio of the distance traveled by the moving mass during impact (x_0) to the distance traveled after rebound (x_r) expressed as a percentage ($R=x_r/x_0 \cdot 100$). It is also a measure of surface hardness.

By assuming an empirical relationship between the surface hardness and strength of materials, the compressive strength of concrete can be estimated using a tool based on the principle of elastic rebound. From the value of the hardness, we can also deduce the compressive strength of the material from the conversion table (diagram) characteristic of the tested material, which also takes into account the direction of impact. With the digital version, the direction of impact and the age of the concrete are corrected automatically, and with the average values of 10-10 measurements on pre-sanded surfaces, the device displays the most probable values of the compressive strength of the concrete as well, based on a pre-selected conversion table.

The Schmidt hammer is an indispensable tool, but if we measure with it solely, the results are primarily suitable for judging the strength homogeneity of individual elements of a concrete structure based on relative variance (*Vértes, 2001*). Values converted to strength should be treated as informative data. When classifying the strength of concrete *(according to MSZ 4720)*, the non-destructive compressive strength determined by statistical evaluation can only be considered to be as reliable data as the expected strength value of the breaking of standard cylindrical specimens if the Schmidt hammer measurement was combined with ultrasonic measurement (*Ódor, 2002*). The rebound value R measured with a Schmidt hammer, which can be converted to strength (*Proceq*) using a comprehensive, comparative destructive and non-destructive test database, taking into account the ultrasonic measurement performed in the hardness measurement environment. Schmidt hammers should not be used if the concrete is surface-treated (e.g. with thin resin) (*Ódor, 2002*), partially or incompletely surface-improved (*Orbán, 2001*), if the ambient temperature is below 5°C or above 30°C (error caused by the change of the spring constant) (*Vértes, 2001*), or if the surface layer of the concrete is frozen (*Mohácsi, 2004*). This already suggests that application can be problematic in the case of heat-loaded concrete as well.

While examining a heat-loaded concrete, the elastic and plastic deformability of the concrete, the changed porosity of the surface, the cracking and the escape of free water play an important role in the accuracy of the measurement with a Schmidt hammer. Measurement with a Schmidt hammer can provide reliable results (*Figure 4*) if the decrease in strength of the concrete does not exceed 30-50%. *However, Schmidt hammers should not be used if the concrete surface is significantly cracked or the concrete surface has suffered layered detachment, i.e. it can be used up to a maximum temperature of about 500°C.*

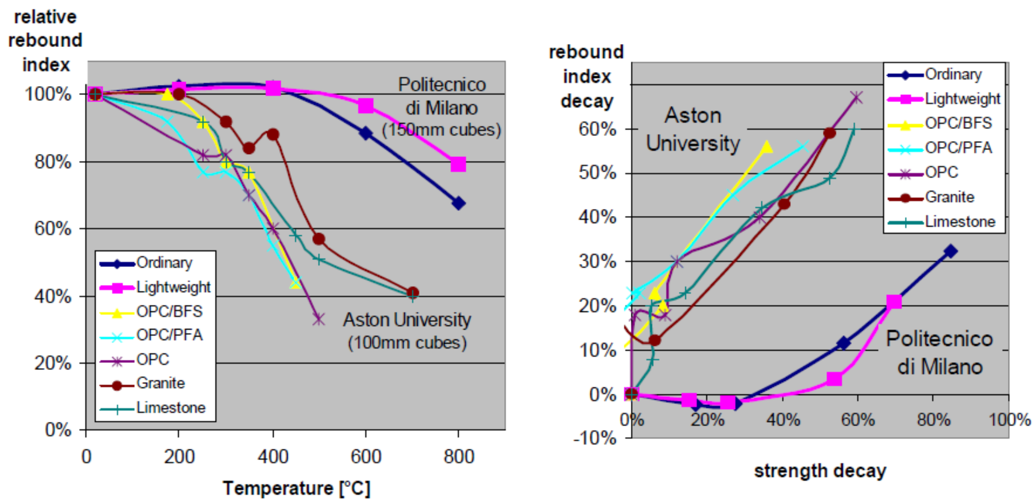


Figure 6. Bounce value measured with a Schmidt hammer depending on temperature

(*fib* bulletin 46)

4.1.2. Adhesive strength measurement

Determination of the adhesive strength is necessary when the surface of the concrete structure is coated for protection or reinforcement, or when the damaged surface needs to be repaired. The measurement is carried out prior to repair, since the surface is prepared for the application of the repair layer in the knowledge of the tensile strength of the original surface, then the adhesive strength of the repaired layer is checked as well *(Bindseil, 2002)*. Given the frequency of coating the surface of fire-damaged concrete and reinforced concrete buildings arises, we describe the steps of the measurement: the test layer is pre-drilled to a depth of more than 5 mm with the concrete core drill, the steel test stamp is glued to the designated and cleaned surface with a two-component adhesive of a higher adhesion strength than the one to be tested, and after hardening the tensile force is applied until fracture (*Figure 7*). The tensile force per unit area is the surface tensile strength of the concrete or the adhesive strength of the investigated layer, depending on the purpose of the study *(Bindseil, 2002)*. Since this method only directly measures the strength of the top layer, this method is not recommended for testing fire-damaged buildings, but is a good method for determining the method of reconstruction. If the degree of damage to the concrete also needs to be determined, methods based on measuring the extraction force will give results that are more reliable.

Figure 7. Devices for measuring adhesive strength

(http://www.minden-korr.hu/contents/muszereink_eszkozeink)

4.1.3. Measurement of Extraction Force

4.1.3.1. Windsor Probe Test

During the measurement with the Windsor Probe Test *(Figure 8)*, a 6.3 mm diameter, 79.5 mm long metal pin probe is shot into the concrete using a spring-loaded device and the depth of penetration is measured. Surface hardness can be deduced from the depth of penetration, from which the strength of the concrete can be determined. The instrument can be used for concrete compressive strengths between 20 N/mm^2 and 110 N/mm^2. It can be used in fire-damaged buildings even if the layered detachment of the concrete surface has occurred, but only if the concrete surface has remained sufficiently flat.

Figure 8. Apparatus used for the Windsor Probe Test

(https://www.ndtjames.com/News-releases_a/Redesigned_Windsor_Probe_Press_%20Release_a/295.html)

4.1.3.2. CAPO Test

In the CAPO test, an undercutting fastening element is fixed in the concrete and then a 55 mm diameter ring is placed on it (*Fig. 9*). The fastening element is pulled out and the force associated with the pullout is measured. The maximum pull-out strength is directly proportional to the concrete strength.

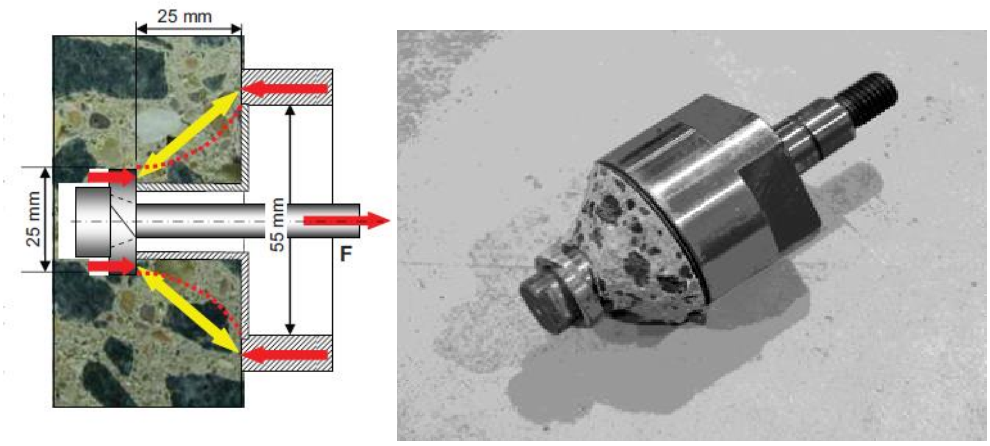
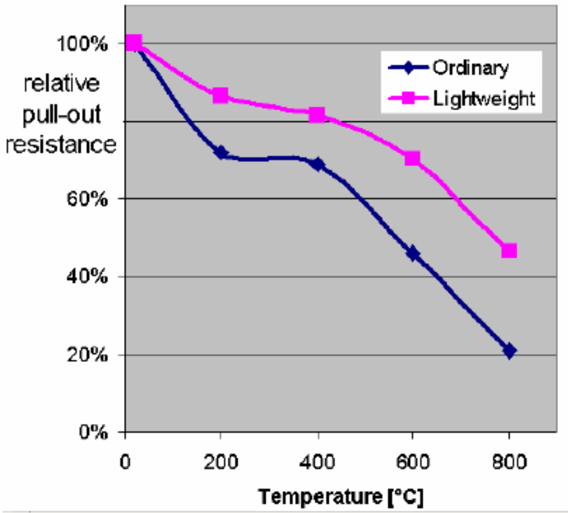


Figure 9. Working principle of CAPO Test

(https://www.germann.org/TestSystems/CAPO-TEST/CAPO-TEST.pdf)

After a fire, the CAPO test is suitable for estimating the average strength of the upper 10–15 mm layer (*Fig. 10*). It provides more accurate data than the Windsor Test, due to the dimensions of the torn out cone.



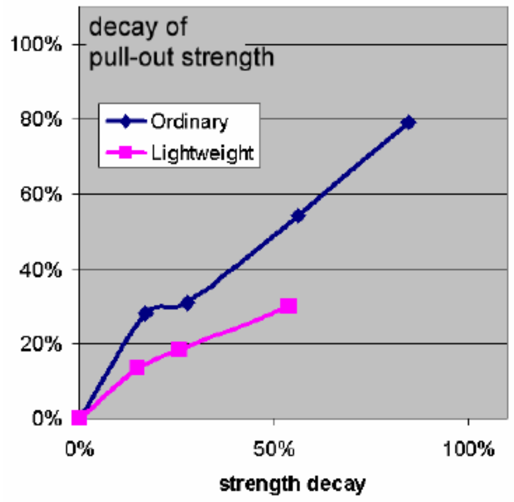


Figure 10. Correlations between temperature and readings of CAPO test (*fib* bulletin 46)

4.1.3.3 BRE Internal Fracture Test

During the test, a tensioned dowel is fixed to the test piece at a depth of 20 mm. The torque for the dowel to pull out is determined. This method, like the CAPO test, gives results for the strength of the upper 10-15 mm. The BRE test gives more accurate results than the CAPO test because the failure is much more controlled.

4.1.4 Concrete Scope (Ultrasonic Examination)

Ultrasonic testing (*Figure 11*) is a non-destructive testing method based on the determination of the propagation velocity of an ultrasonic frequency acoustic wave traveling in concrete. The propagation velocity of a longitudinal wave pulse is a measure for estimating concrete strength. During excitation of the longitudinal wave, the transmitter and receiver must be fitted to the opposite side of the concrete using an acoustic coupling material (e.g. machine grease). The wave propagation velocity (v) can be calculated by dividing the distance (s) between the transmitter and the receiver head by the measured propagation time (t) of the wave pulse. From the velocity of the wave propagation, the concrete strength can be estimated. The measurement can be performed both directly and indirectly *(Cioni, Croce, Salvatore, 2000).*

Figure 11. Image of concrete scope

Source: (http://sdt.sulinet.hu/Player/Default.aspx?g=30b4fc34-89a4-4ad9-8cf6-e30529fbcc5b&cid=27ce789c-3af0-4df8-82f8-edeea421596b)

The concrete scope is often used to survey fire-damaged buildings because there is a clear relationship between concrete strength and ultrasonic propagation velocity *(Figure 12)*. In our opinion, however, if there are many cracks on the concrete surface, this measurement will not give reliable results.

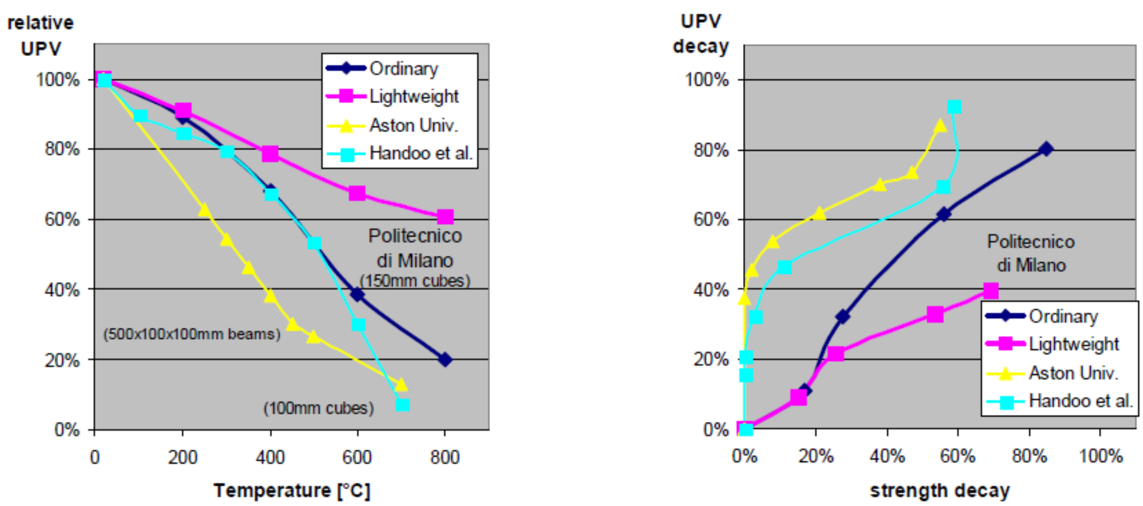


Figure 12: Velocity of ultrasonic propagation depending on heat load *(Felicetti, 2003)*

4.1.5. Drilling Resistance Measurement

To measure the drilling resistance, a modified drill is used (*Figure 13*), which measures the drilling resistance (J/mm) for drilling to a given depth. The relationship between concrete strength and drilling resistance cannot be given unambiguously because compressive strength also depends on a number of other parameters. This method can be used to detect the extent of damage after a fire. The measurement can only be used up to a 70% strength deterioration, which means a thermal load of about 800°C.

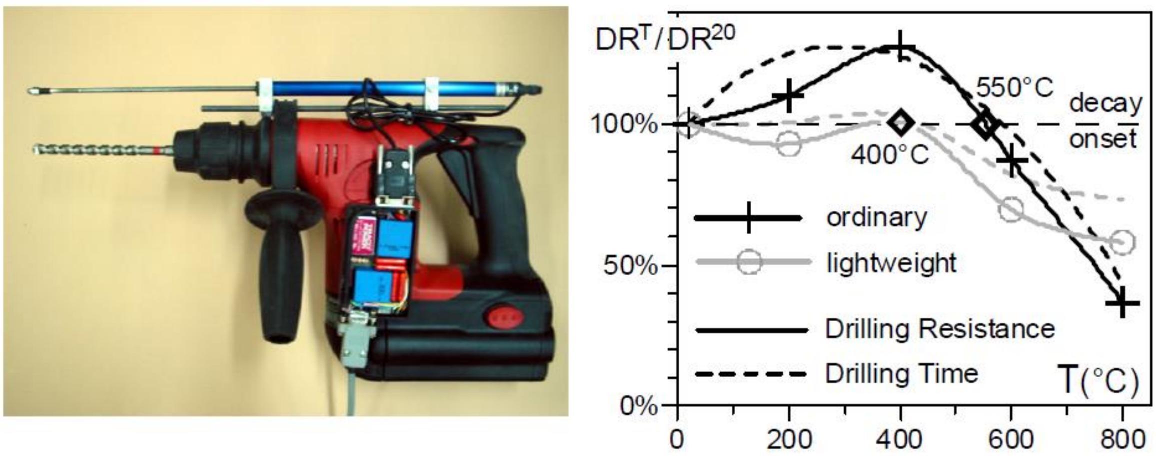


Figure 13. Methods of measuring drilling resistance *(fib* bulletin 46*)*

4.2. Small Sample per Dot

4.2.1. Mechanical Testing of a Small Sample

The best-known method for determining the strength of concrete is the core sample test, which is not a non-destructive test, but with a small amount of damage of the structure, we can get quite reliable results. In the case of fire-damaged structures, the strength test is not sufficient. Prior to the strength test, in addition to the assessment of cracks, the different layer boundaries and their thickness must be assessed, as the breaking of layers of different strengths does not give a reliable result during the compressive strength measurement. Thus, it is not suitable for determining compressive strength on its own.

4.2.2. Derivatographic Inspection

The derivatographic method is a simultaneous thermoanalytical method that simultaneously generates TG (Thermogravimetric), DTA (Differential Thermal Analysis) and DTG (Derivative Thermogravimetric) signals. A small amount of the sample is pulverized and placed in a crucible of inert material (corundum or platinum), and heated in a furnace chamber at a uniform heating rate (so-called dynamic mode). Meanwhile, an analytical balance measures the changes in the mass of the sample (TG curve) and thermocouples measure the changes in enthalpy in the sample relative to the temperature of an inert material in the furnace space (DTA curve). The first derivative of the TG curve, the DTG curve, is generated in an analogous way, which determines the location and extent of the processes involved in the mass change on the temperature scale. The test result obtained depending on the measurement time (t min), and which also contains the above three curves and the temperature (T, °C) signal, is called a derivatogram. The derivatogram can also be displayed as a function of temperature (T, ºC) *(Kopecskó, 2006)*.

4.2.3. Dilatometry

The dilatometer, or expansion meter, measures deformations due to temperature. Using a very sensitive dilatometer, the volume change of quartz between 571 and 573 °C can be measured.

4.2.4 Thermoluminescence

Thermoluminescence is based on the light absorbing ability of crystals. Because of various chemical changes, the light-absorbing ability of the crystals changes. During thermoluminescence, changes in temperature are measured. In the case of concrete, most changes occur between 300 and 500 °C, so this measurement may be suitable for determining the temperature acting on the concrete.

4.2.5 Measurement of Porosity

As a result of the temperature, the pore system and density of the concrete change. The change in pore system due to temperature can be determined. The change in pore content and density can be determined with a Mercury porosimeter. Measuring porosity is quite expensive and complicated.

4.2.6 Color Analysis

The color of the concrete changes with temperature *(Figure 14)*. The color changes are as follows:

Gray	up until 300 °C
Pink-red	300-600 °C
Greyish white	600-900 °C
Yellowish brown	from 900 °C

The pink discoloration is caused by the dehydration of the iron-bearing minerals of the admixture, and as a result, the color development of the concrete is greatly influenced by the type of admixture. This method can be used well for concretes with quartz admixture; for limestone and aggregates of volcanic origin, the applicability of the method is questionable. The measurement, on the other hand, gives reliable results if we measure and compare the degree of color change on the surface of a core sample of a hole, in which case the maximum temperature reached and thus the degree of strength loss can be estimated well.

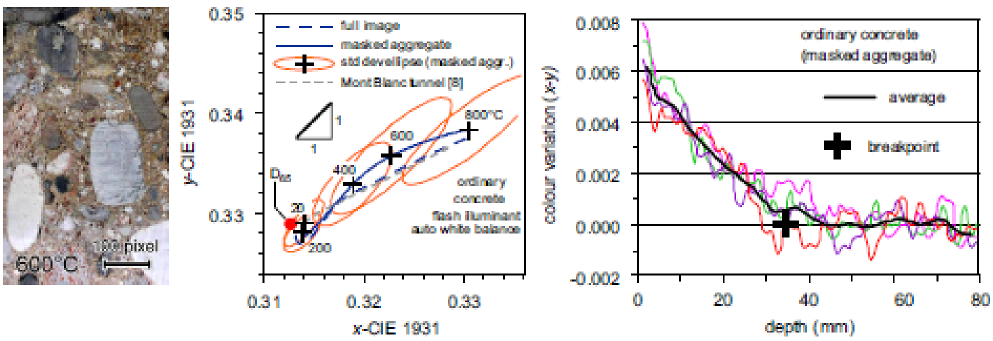


Figure 14. The extent of color change on the surface of the concrete (*fib* bulletin 46)

4.2.7. Microcracking Density Analysis

As a result of heat load, microcracks are formed in the concrete, since under heat load many chemical processes take place, therefore the number and size of the microcracks also increase with the temperature of the heat load. Modern digital technology provides an opportunity to analyze the density of microcracks.

4.2.8. Chemical Tests

4.2.8 1. Scanning Electron Microscopy (SEM)

Morphological examinations of concrete pieces taken from concrete cubes can also be performed by electron microscopy.

Each SEM image shows the comparative micrometer scale for that magnification. The tested samples can be attached to the sample holders with a conductive carbon adhesive tape with a double-sided adhesive strip.

4.2.8 2 Depth of Carbonation

By measuring the depth of carbonation *(Figure 15)*, the detection of the depth of $Ca(OH)_2$, i.e. the location of the isothermal line at 400-450 °C, was compared. It is questionable whether the measurement can be applied several weeks or possibly months after heat loading, or whether CaO is converted back to $Ca(OH)_2$ in concrete.

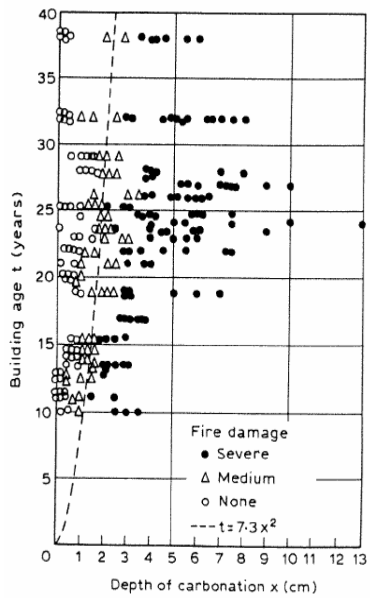


Figure 15. Measurement of the depth of carbonation on heat-loaded concrete *(fib bulletin 46)*

4.3. Special Methods

4.3.1. Seismic Tomography

Seismic tomography is an image reconstruction procedure. Its history dates back to the 1980s, when detailed image reconstruction methods developed to solve the tasks that had already arisen in the medical and technical sciences began to be applied in seismology.

Using tomography, the distribution of a physical quantity within a range can be determined from the data of screening-type measurements performed around the perimeter of the range if the measured values are line integrals of the physical quantity being examined. There is a relationship of such in seismology:

- Reciprocal of wave propagation time and velocity,
- Between the logarithm of the reciprocal of the amplitudes and the absorption.

In the case of seismic tomography, the velocity and absorption profile of the area can be calculated by measuring the propagation times and amplitudes between a large number of (in principle infinite) intersecting avenues located between the explosion points and geophones located in the perimeter of the studied area. Reliable and appropriately resolved scales in all directions therefore require uniform coverage of the test area with a large number of radii according to direction and density. The "walkability" of the area, as opposed to medical CT, is usually not feasible in seismic practice, so the image is smeared in a direction parallel to the avenues.

Seismic measurement was used at the Mont Blanc tunnel *(Abraham, De´robert, 2003)*. During the seismic measurement, the mechanical properties of the concrete depending on temperature could be deduced. As a result of fire, strength properties of the concrete deteriorate. During the measurement, 70 sensors were used per measurement site. They were able to deduce the extent of damage from the distribution of seismic waves *(Törös, 2006)*.

4.3.2. Radar

4.3.2.1. Ground Radar

The ground radar method (GPR, Ground Penetrating Radar, Ground Probing Radar, SIR Subsurface Interface Radar) is one of the newest branches of geophysics. The ground radar equipment consists of a transmitter and a receiver antenna, a control and data acquisition electronic unit, and a computer for storing data. The transmitter part of the device emits a series of high frequency (10 MHz-5 GHz) electromagnetic pulses into the medium to be tested. The reflected signals are received, digitized and stored by the computer as a function of time. The propagation of the radar signal in rocks depends on the physical properties of the medium. In practice, the dielectric constant determines the speed of wave propagation and the conductivity determines the attenuation of the signal. If either of these two parameters changes at an interface, part of the signal is reflected and another part enters the next layer. On the profile generated from the time series, layering and structure can be tracked, and recognition of underground objects is possible, if physical contrast allows.

4.3.2. Impact Echo

We distinguish two types of surface waves: Rayleigh and Love waves. Rayleigh waves travel along the surface and their amplitude decreases with distance according to the scattering of energy along the cylindrical surface. Love waves only occur when there is a layer that allows a lower propagation velocity above a layer that allows a higher propagation velocity, and multiple reflections are created at the interface between these two layers. Researchers have focused on Rayleigh waves, as 67% of the energy of mechanical stress waves propagates in this form. The propagation velocity of these waves depends on the wavelength and the modulus of elasticity of the material. The depth at which a wave penetrates the material depends on the wavelength. The velocity of a Rayleigh wave depends on the characteristics of the material it passes through: its Poisson's ratio function and approx. 0.9 times the speed of the shear wave. As a result of the longitudinal and transverse vibrations, the particle motion is elliptical. The main wave source of the SASW (Spectral Analysis of Surface Waves) method is the Rayleigh wave. Developers have taken from other research that it is best if the distance between the signal source and the first receiver matches the distance between two adjacent receivers. Similarly, previous research has been accepted that it is not appropriate to use wavelengths greater than three times the distance between receivers. To make the SASW method easy to apply, simplifying assumptions have been made *(Törös, 2006):* In the sample, the horizontal layers correspond to the layer structure of the structure and these layers are homogeneous in terms of their material properties. Waves were considered (body waves were neglected). The latter assumption does not cause disturbing inaccuracies if the signal-to-receiver distance is kept within specified limits relative to the wavelength.

1. Only planar (Rayleigh) waves were considered.

The impact echo consists of the generation, measurement, and processing of scattered surface waves. The assembly consists of a signal source (12 mm diameter steel ball), two accelerometers (this is the data acquisition system), two signal conditioners and a data processing computer. The surface waves caused by the impact of the steel ball are captured by the two accelerometer receivers, converted by the signal conditioner, and the velocity distribution of the surface wave can be determined from the dispersion curves plotted over time (calculated by the system from time, frequency and power spectra):

1. It is sufficient to access one of the surfaces of the object under study.

2. When an impulse is generated by the impact of the test ball to produce the surface waves, most of the energy produced can be measured.

The velocity distribution of shear waves can be determined using the surface wave modal analysis method (SASW). Advantages of the modal analysis method of surface waves:

1. Spreads in the form of surface waves, and only a small part of it becomes a wave propagating inside the examined concrete,

2. With the geometric propagation of surface waves, the decrease in amplitude is smaller than in the case of body waves,

3. The Young's modulus or shear modulus of the test material can be determined without knowing the depth of the test layer.

A steel ball with a diameter of 12 mm is dropped from a given height onto the test surface. A low-pass filter is used to filter out noise, which eliminates the first reflections after the first strong echo. With the non-destructive SASW process, a correlation was found between the compressive strength of concretes and the speed of surface waves traveling in the material. A relationship between compressive strength and compression wave velocity has also been established *(Törös, 2006).*

4.3.3. Sound Tomography

The sound tomograph is computer controlled. During the examination, sensors are placed on the part of the building in a circle, the number and distance of which are determined by the computer. The machine and the program can be used to measure the speed of sound propagation on the examined element. The sound waves caused by knocking propagate in the concrete. If there is any change in this, such as a change in cavity or strength, the value, i.e. the time of sound propagation, changes (http://parkfavedelem.hu/index.php?option=com_content&view=article&id).

4.3.4 MASW (Modal Analysis of Surface Waves)

The method measures the propagation of seismic surface waves in a material. The system measures the change in the propagation speed of shear waves. Since shear waves directly influence the development of the modulus of elasticity, the system may also be suitable for measuring fire-damaged concrete structures *(Törös, 2006).*

4.3.5. Electrical Resistance

To some extent, all materials, such as soil and rocks, conduct electricity, so first soil mechanics developed a method based on electrical resistance measurement to measure this and utilize the results obtained. Conductivity, or its reciprocal, electrical resistance, depends significantly on the structure of the soil, the size and distribution of the pores in it, the possible water content, and the amount of salts dissolved in it. The methods for testing the surface resistance of concrete were based on the outlined principle derived from soil mechanics. To test the concrete on site, we use the so-called four-probe resistance meter, which is a much smaller version of the resistance meter used in soil mechanics converted for concrete.

Concrete is a multi-component, microporous, microstructure-sensitive building material. Porous materials absorb water from the air. The balance of the water content (relative humidity) of the porous material and the air is given by the adsorption isotherm. Up to 40% relative humidity, water uptake occurs during a "pure" adsorption process. The water absorbed in this way does not move, it is not free, and is strongly bound to the inner surface of the cement stone. At relative humidity above 40%, the material absorbs additional water through the capillaries, open pores. This part of porosity is called apparent porosity.

The pores in the concrete are randomly arranged, of different sizes and connected to each other irregularly. The flow of water and various ions through these tortuous channels is controlled by water permeability, adsorption, and various diffusion mechanisms. Cement-based materials contain air-filled cavities, microcracks, and internal surface gaps between the CSH gel. The electrical resistance of mortar and concrete depends on the microstructure of the cement paste (pore volume, distribution of pore radii), moisture and salt content, and temperature. The microstructure is influenced by a number of factors, such as the water/cement factor, the binder, the degree of hydration, the quality and quantity of additives *(Simon, Vass, 2011).*

5. SUMMARY

Reinforced concrete is a widely used building material in today's architecture. Many of its advantages include high load-bearing capacity, the possibility of designing various structures, universal usability, suitability for prefabrication and on-site construction, etc.

From the point of view of fire protection, its indisputable advantage is that it forms a non-combustible building structure, and with its appropriate sizing it is suitable for the construction of a structure with high fire resistance.

In our paper, we have shown that, despite the favorable fire protection properties of reinforced concrete, it is capable of being damaged by fire, even to the extent that it becomes unfit for its original function.

In such case, if the structure is to be restored, the extent of the damage must be examined using special methods to ensure the original and prescribed parameters of the structure (static, fire protection, etc.) and to determine the repair technology.

Extensive professional methods and advanced instrumental background are available to perform diagnostic tests to avoid the need to significantly increase the rate of secondary fire damage by disassembling and re-constructing the structure.

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