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The owner of the buildings, which had been analysed, is the GEHAG Berlin

Method for assessment of working life of exterior concrete components

Surface components of existing structures are exposed to strong atmospherical deterioration. This accelerates the process of altern. It is important to decelerate this process in such a way, that our modern concrete buildings can be called durable in human time conceptions. The life expectation of these components can be extended by supplementary coating. The engineer is interested to find the latest acceptable time to coat the surface in order to reach exactly the aspired working life.

<u>Method with weighted carbonation coefficients</u>

In general the working life of concrete can be determined with:

$$x_k = \sqrt{2Dt} \quad (1)$$

x_k ... depth of carbonation [mm]
t ... inspection period since completion of construction [a]
D ... coefficient of carbonation [mm²/a]

The theoretical end of alkaline protection is: $t_E = \frac{c^2}{2D}$
c ... concrete cover [mm]

Tests have been carried out in 1985 within Berlin on existing structures.

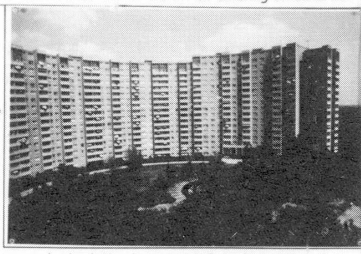
Besides the age of the building we received the following data:

a) depth of carbonation: max. value, mean value, mean value of peaks

b) concrete cover: min.-and mean value.

Additionally we took into consideration a measuring error of ±1mm and a tolerance v, equivalent the increase of carbonation of the past 5 years. The results of all value combinations give different dates of working life. For the determination of a safe value the measurement data have to be weighted.

With that we obtain 4 dates for the probable appearance of the first systematic damages:



1 - earliest date without tolerance (safe value)
2 - standard date without tolerance
3 - earliest date with tolerance (prevention date)
4 - standard date with tolerance

A surface treatment should be considered at the prevention date.

<u>Prognosis - equation</u> (latest date for coating)

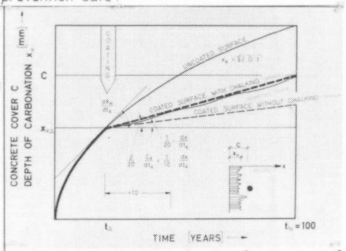
The basis is equation (1) for uncoated concrete. After coating the function between x_k and t is approximately reflected as a straight line. Including some simplifications, the derivation leads to the following equation:

$$t_A = 0{,}3 \cdot \frac{c^2}{D} + 1{,}5 \cdot \frac{c}{\sqrt{D}} - 5$$

c ... c_{MEAN}
D ... calculated with $x_{k\,MEAN-PEAK}$
t_A ... time [a] between uplift and the latest date for coating, if the working life of 100 years is to be achieved.

t_A corresponds to the prevention date.

Both of these methods of prognosis have been tested at approximately 50 existing structures within Berlin and ended up with satisfactory results. Today they are used as decisive factor for planning of finances for building maintenance. First of all, both methods are applied to central european proportions only. In future it is certainly interesting to test their quality at other locations.



Parabola - straight line - function for process of carbonation of a concrete surface coated at t_A

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Method for Serviceable Assessment of Working Life of Exterior Reinforced Concrete Components

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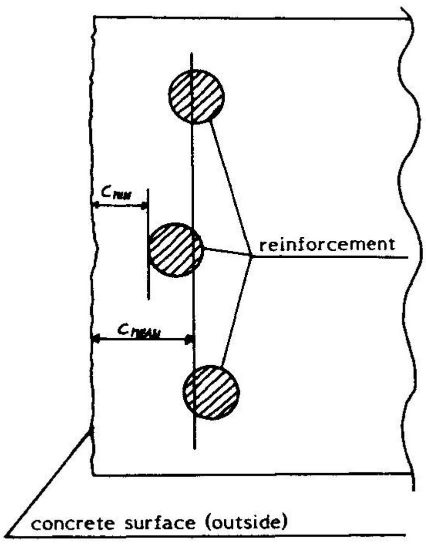
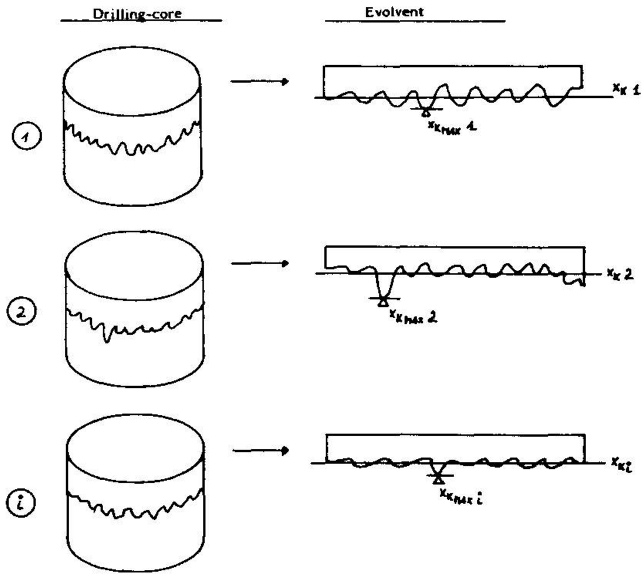
Method of weighted coefficients of carbonation

As the surface has to be maintained, the number of drilling-samples can not be sufficient to get statistically safe values.

Therefore, the measurement data are weighted to obtain a usable prediction as help for decision. The basic idea is a reflection of probability and of followup damages.



minimum and mean concrete cover



mean value	$x_{K_{MEAN}} = \frac{\Sigma(x_{K_1} + x_{K_2} + \ldots + x_{K_i})}{n}$
mean value of peaks	$x_{K_{MEAN-PEAK}} = \frac{\Sigma(x_{K_{MAX}1} + x_{K_{MAX}2} + \ldots + x_{K_{MAX}i})}{n}$
maximum value	$x_{K_{MAX}} = x_{K_{MAX}2}$

combination	remarks	weighting
c_{mean} with x_{Kmean}	this combination is unreliable because it is afflicted with a large error. Damages are too severe for a promising restoration.	1/7
c_{mean} with $x_{Kmean-peak}$	Most damages arise when the front line of carbonation with its peaks meet the reinforcing steel. This combination is rather probable.	5/7
c_{min} with x_{Kmax}	This case certainly leads to the first damage but is not likely. Its appearance brings only locally restricted damage.	1/7

These factors produce four numbers of years for the likely appearance of the first systematic damages:

1) earliest date without tolerance (safe value)
2) standard date without tolerance
3) earliest date with tolerance (date of prevention)
4) standard date with tolerance

The earliest dates consider total reduction of error; the standard dates are calculated without reduction of error. The expression "systematic damages" means that in case unfavourable circumstances meet, little damages may show up locally restricted at single places. This remaining uncertainty can be accepted. Is the earliest date without tolerance far in future, for example about 100 years after construction the facade may supposed to be durable. Otherwise surface treatment should be considered not later than the earliest date with tolerance.

Method to determine a latest date for surface coating (prognosis-equation)

Today a facade coating ought to be renewed every 10 years. Lowest costs are achieved by coating at the possible latest date before the appearance of systematic damages (earliest date with tolerance).

Within the derivation of the prognosis equation we proceeded from a desired service life without damages of 100 years.

The function between depth of carbonation and coated concrete is approximated by a straight line with the gradient: $\frac{dx}{dt}(\text{straight line}) = \frac{1}{10}\frac{dx}{dt}$

For uncoated concrete the gradient at time t_A can be obtained with the function $x = \sqrt{2 \cdot D \cdot t}$:

$$\frac{dx}{dt} = \sqrt{\frac{2D}{t_A}} \cdot \frac{1}{2} \quad ; \quad t_A \neq 0 \quad \curvearrowright \quad \frac{dx}{dt} = \frac{1}{20} \cdot \sqrt{\frac{2D}{t_A}}$$

statement: $c = x_A + \frac{dx}{dt}(t_N - t_A)$ with $x_A = \sqrt{2 \cdot D \cdot t_A}$ and $t_N = 100$ years

$$\curvearrowright \quad c = \sqrt{2 \cdot D \cdot t_A} + \frac{1}{20} \cdot \sqrt{\frac{2 \cdot D}{t_A}} \quad (100 - t_A)$$

After some transformations this leads to the following equation:

$$t_A = \frac{c^2}{3{,}6 \cdot D} - 5{,}3 + 1{,}7 \frac{c}{\sqrt{D}} \sqrt{\frac{c^2}{39D} - 1}$$

With the results measured in Berlin the statistic interpretation of the term $\sqrt{\frac{c^2}{39D} - 1}$ of equation (5) in consideration of c_{mean} with $D_{mean\text{-}peak}$ as also with D_{max} leads to the factor 0,9 at an average. Therefore the last term of equation (5) comes to:

$$1{,}7 \frac{c}{\sqrt{D}} \cdot 0{,}9 \approx 1{,}5 \cdot \frac{c}{\sqrt{D}}$$

Including these simplifications and specialities of the previous listed results, the approximation ends in:

$$t_A = 0{,}3 \frac{c^2}{D} + 1{,}5 \cdot \frac{c}{\sqrt{D}} - 5$$