Prediction of repair needs in weathered concrete façades and balconies

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ABSTRACT: Degradation mechanisms of concrete are fairly well known, but systematic maintenance and repair of concrete structure vary a lot. Consequently the condition of structures may surprise unpleasantly the property owners and the service life of concrete structure can be much shorter than planned. Therefore the building management needs better proceeding to control their real estate. Concerning this problem a research project called Repair Need in Concrete Facades and Balconies has started. The target of the ongoing research is to create data source of detailed information of facades and balconies. Based on this data prediction model will be developed. Using the model property owners can compare their real estates and predict the progress of condition and arrange the stock of buildings into order of repair need. The prediction model gives possibilities to prepare technically and economically to the coming operations beforehand. It enables the building management to plan their maintenance and repair strategies. The data base for this model consists of large number of condition investigations done in Finland.

1 BACKGROUND

1.1 *The origin of problem*

Since 1960's, a total of over 30 million square metres of concrete-panel facades has been built in Finland as well as over half a million concrete balconies. Especially in 1970's the urbanization caused urgent need for housing production and exponentially growing construction. Concrete and prefabrication became the leading method to construct new centre of population and it became a solution for the settlement of people to the cities. Suburbs were born. Fast and mostly uncontrolled development didn't always lead to good solutions and quality of concrete structures suffered. The quality of concrete itself was poor, details were not properly designed and the deficiency of workmanship affected the final result. Also lack of regulations led to variability in construction. The first Finnish building regulations were created 1976 and have ever since been improved according to the latest and prevailing knowledge of construction. Before that there were more separate directions, like directions concerning the production and use of prefabricated units (1963) and official concrete code, the first one date back to 1954 (Suomen Betoniyhdistys 2002).

Most of the Finnish apartments are privately owned, but there are also big real estate owners, who are possessing relatively large number of apartment houses. During the maintenance and repair of these buildings several problems have occurred. Due to above mentioned issues, the structures have required often unexpected, technically and economically significant repairs sometimes less than in 10 years after their completion. Plenty of new technology and methods for maintenance and repair of concrete structures have been developed in Finland during the last 15 years. These are systematic condition investigation method, different kind of repair alternatives for all kind of damage, high-quality repair products and functional and well-designed structural details among others.

Over one million inhabitants live in concrete buildings in Finland and the renovation of concrete facades affect their cost of living significantly. The target in predicting the repair need of concrete structures is that the condition of Finnish real estates won't make an unpleasant surprise for property owner or people responsible for the building management and that the value of property is preserved.

1.2 *Estimation of Residual Service Life*

Concrete structures deteriorate by several different degradation mechanisms, whose progress depend on many structural, circumstantial and material factors. Hence the service lives of structures vary in practise a lot. The variable structural condition in different houses and the fact that it is often impossible to observe the most significant damage visually before they have progressed too far, makes a thorough condition investigation necessary in most facade repair cases.

Condition investigation means a systematic procedure to find out the condition and performance of a structure or a group of structural parts (e.g. facades and balconies) and their needs for repair, taking into account different degradation mechanisms and using different kinds of research methods. These are field examination, sampling and laboratory tests as well as gathering information from documents, constructions drawings and possible earlier observation data of target. The existence, degree and extent of damage for different degradation mechanisms are determined by condition investigation. Hundreds of condition investigations have been done in Finland during the past 15 years (Suomen Betoniyhdistys 2002).

2 DEGRADATION MECHANISMS

The degradation of concrete structures with age is primarily due to weathering action which deteriorates material properties. Degradation may be unexpectedly quick if used materials or the work performance have been of poor quality or if the structural solutions have been deficient from the beginning. Weathering action may launch several simultaneous deterioration phenomena whereby a facade is degraded by the combined impact of several adverse phenomena. Degradation phenomena proceed slowly initially, but as the damage propagates, the rate of degradation generally increases.

The most common degradation mechanisms causing the need to repair concrete facades, and concrete structures in general, are corrosion of reinforcement due to carbonation or chlorides as well as disintegration of concrete. Disintegration can ensue from freeze-thaw exposure, formation of late ettringite or alkali-aggregate reactions. The most common reason for disintegration in northern Europe is insufficient frost resistance of concrete which can lead to frost damage (Pentti et al., 1998).

These degradation mechanisms may result in, for instance, reduced bearing capacity or fixing reliability of structures. Experience tells that defective performance of structural joints and connection details generally causes localised damage thereby accelerating local propagation of deterioration.

2.1 *Reinforcement Corrosion*

Reinforcing bars within concrete are normally well protected from corrosion due to the high alkalinity of concrete pore water. Corrosion may start when the passivity is destroyed, either by chloride penetration or due to the lowering of the pH in the carbonated concrete

Carbonation of concrete is a phenomenon that decreases the naturally high alkalinity of concrete, that is, neutralises it. Neutralisation begins at the surface of a structure and propagates as a front at a decelerating rate deeper into the structure. The speed of propagation is influenced foremost by the quality of concrete (proportion of cement and density) as well as rain stress. Heavy rain stress slows down neutralisation by blocking carbon dioxide from penetrating into the structure.

The high alkalinity of concrete protects the reinforcement within from corrosion. When the carbonation front proceeds in concrete to the depth of the reinforcement, the surrounding concrete neutralises and corrosion of re-bars can begin, if there is enough moisture and oxygen available. The rate of corrosion clearly depends on the moisture content of concrete and advances significantly only at over 80 % RH. Corrosion decreases the tensile and bond strength of reinforcement while the corrosion products cause pressure to the concrete cover around the reinforcement, inducing cracking.

Figure 1. Damage caused by reinforcement corrosion in the window frame

The passivity of steel may also be destroyed by the presence of chlorine ions derived either from the environment or from the use of contaminated constituents of concrete. It is possible that chlorides have been added to the concrete mix during preparation to accelerate hardening. Chlorides were used mainly in the 1960’s in connection with in-situ concreting and in prefabrication plants during the cold season when concrete hardens slowly. Often the amount of salt used as accelerator was multiple compared to steel's corrosion threshold. Chlorides may also penetrate into hardened concrete if the concrete surface is subjected to external chloride aggression, for instance, on bridges where de-icing salts are used. Strong pitting corrosion is typical to chloride corrosion of re-bars, and it may propagate also in relatively dry conditions. Chloride-induced corrosion becomes highly accelerated when carbonation reaches reinforcement depth whereby the extent of visible damage may increase strongly in a short time (Pentti, 1999 and Tuutti, 1982).

2.2 *Frost Damage in Concrete*

As earlier mentioned, the other main degradation mechanism of concrete is disintegration. Because the most common cause is the freeze-thaw exposure in Finland and other cold countries, it is reviewed here.

Concrete is a porous material whose pore system may, depending on the conditions, hold varying amounts of water. As the water in the pore system freezes, it expands about 9 % by volume which creates hydraulic pressure in the system (Pigeon & Pleau, 1995). If the level of water saturation of the system is high, the overpressure cannot escape into air-filled pores and thus it damages the internal structure of the concrete resulting in its degradation. A typical sign for frost damage is widening map cracking. Far advanced frost damage leads to total loss of concrete strength.

Figure 2. In this case water has exposed the structure to freeze-thaw action. Thus the structure has disintegrated.

The frost resistance of concrete can be ensured by air-entraining which creates a sufficient amount of permanently air-filled so-called protective pores where the pressure from the freezing dilation of water can escape. Finnish guidelines for the air-entraining of facade concrete mixes were issued in 1976 (Suomen Betoniyhdistys 2002).

Moisture behaviour and environmental conditions have a strong impact on stress caused by frost. For instance, the stress that affects balcony structures depends on the existence of proper waterproofing or protecting balcony glazing.

3 CONDITION INVESTIGATION

The basic aim of the condition investigation is to produce information about the factors affecting the condition and the performance of the structure and consequently about the need and the options of repair for the building management. Condition investigation report gives information about the present state of damage and investigator’s estimation about the residual service life of structure and maintenance and possible repair alternatives. A systematic condition investigation consists of fairly simple and clear phases as mentioned later on. The phases are not totally separate and successive, but rather partly overlapping. They also deal more with principles and ideologies than practical actions of condition investigation (Suomen Betoniyhdistys 2002).

3.1 *Determining the Structures and Materials*

The first phase of the condition investigation is to study what kind of structure or structures are under investigation. This is done by visual inspection and examining the documents and its idea is to get to know what kind of a structural system the object is and what the materials it has been constructed of are. It is self-evident that no successful investigation can be carried out if the investigator does not know the type and the nature of the object. Thus also the person who does the investigation work has to possess wide experience about the behavior of structures under investigation.

The information is gathered from original construction documents and by visual inspection. The information that old documents provide needs to be considered carefully. The structures have not always been constructed exactly according to the original documents. In certain cases the dissimilarity between the structure and the document may be remarkable.

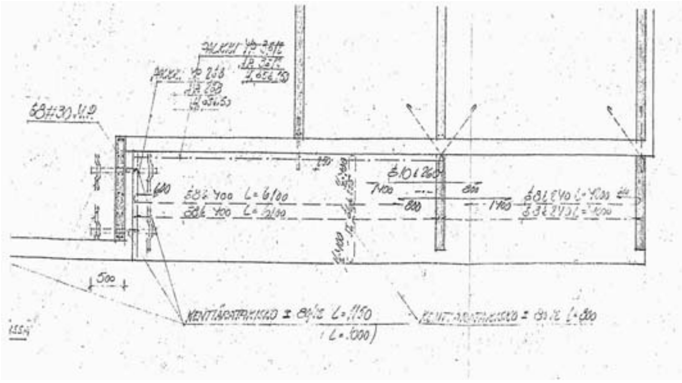

Figure 3. Old construction documents are not always found, often slightly obscure and their reliability is arguable.

It is also important that different types and parts of structures as well as structures in different exposure conditions are distinguished from each other and that they are also investigated as separate groups of objects. A fairly common error is to examine only some part of the building, for example concrete facade panels, and then generalize the conclusions to apply also to the other parts of the structure, for example to the concrete balconies in the facade. It is important to realize that the results apply only to the structure which they have been obtained from. However, the results between separate groups can be utilized so that if there is no damage in the structures under severe exposure conditions there probably will not be any in the lighter conditions either (Mattila 1998).

3.2 *Evaluation of Possible Deterioration Mechanisms*

The second phase of condition investigation is to recognize the problems that may exist in the structure. This is received from field and laboratory tests. The information is considered on the basis of the type of structure and materials used in it as well as the exposure conditions of the structure. The possible problems may be caused either by different kinds of deterioration mechanisms or by malfunction of structures, for example problems with moisture. A list of problems and ways of malfunction for example in a concrete panel facade may be as follows:

- reinforcement corrosion due to carbonation of concrete cover or due to chlorides in concrete
- disintegration of concrete due to freeze-thaw exposure, formation of late ettringite or alkali-aggregate reactions,
- decrease in the bearing capacity of structural members or weakening of fixings or ties in a structure (for example weakening of the ties in sandwich panels due to corrosion),
- malfunction in the moisture behavior of the structure including defects in joints, malfunction of the ventilation inside the structure,
- defects and degradation of paints and coatings,
- defects in facade tiling (ceramic, clay brick or natural stone tiles)
- harmful cracking or deformations in concrete,
- defects due to the use of the structure (for example normal wearing)

All the deterioration mechanisms and types of malfunction have to be considered at least to some extent when aiming at a reliable condition investigation. It is important to notice that the items to be investigated vary widely between different investigation cases, and no fixed set of investigation measures can be used.

The mutual importance and the combined effects of different deterioration mechanisms should also be evaluated carefully. It is self-evident that the factors related to the bearing capacity and safety of fixings is the most important items to be investigated (Mattila 1998).

3.3 *Rough Evaluation of Methods for Maintenance or Repair*

The third phase of a condition investigation is to consider the potential techniques for the maintenance and repair of the structure. This is important to do as early as possible because all kinds of remedial techniques require different amount and type of information of the structure to be repaired.

There is a wide range of options for maintenance and repair of structures ranging from doing nothing to demolition and reconstruction of the structure. The technical and economical comparison between the options is extremely difficult in most cases.

Possible options of repair methods as an example in the case of concrete panel facade are as follows:

1. Doing nothing (nearly always possible at least for a while)
2. Repair by standard painting or by using special protective coatings
3. Careful patch repair by cementitious repair mortars
4. Additional thermal insulation and cladding
5. Realkalisation
6. Cathodic protection
7. Demolition and reconstruction.

The suitable repair method depends on the technical condition of a structure. Usually, the final repair is a combination of some of these options. Some of these options are more used than the rare ones.

These alternatives have to be also re-evaluated from time to time during the investigation process whenever new information about the condition and the need of repair becomes available. It is possible that on the basis of new information about the condition some lighter repair techniques can be used or simultaneously some more investigation measures is needed for evaluation of feasibility of these techniques (Mattila 1998).

3.4 *Analysis and Report from the Gathered Information*

The fourth phase of the investigation is to gather objective information concerning the deterioration processes and malfunction of the structure and analyze carefully the information.

It is important to notice that the measured values and other observations gathered during the investigation process are not the final results of the investigation, but an analysis to produce the results out of them is always needed.

Practically, the analysis means seeking answers to the following five questions:

1. What kind of problems exists in the structures?
2. What is the extent stage and location of each type of damage and malfunction?
3. What are the reasons for the problems noticed?
4. What kind of effects may the problems have on the structure itself or on the users of the building?
5. How will the damage or malfunction proceed in the future?

The final results can be settled on the basis of the answers to these five questions.

The fifth phase is to prepare a written report in which the results are presented for the client. The report should not consist only of measured values etc. but rather of practical conclusions concerning the alternative practical measures for the client to manage with the structure. There are usually several options for maintenance and repair, and all suitable methods should be evaluated shortly in the report (Mattila 1998).

4 THE PREDICTIVE MAINTENANCE

4.1 *The Data Base*

Hundreds of condition investigations have been done in Finland. The Institute of Structural Engineering in Tampere University of Technology has done over 200 condition investigation and been in a way a pacemaker developing the procedure. Nowadays there are few large and plenty of small agencies doing only condition investigations for all kinds of facades and balconies. Most of the investigations concern concrete structures as it is the most used construction material in apartment houses.

Out of each investigation a report is written. These reports contain large amount of detailed information concerning concrete structures of different ages and surface types. This information serves at the moment only individual property owner, whereas it also has all the potential to form a massive, constantly growing data base for statistical investigation. Active condition investigation and repair work could produce extensive and reliable data base, which could be used for predicting the repair need of concrete facades and balconies, but which is scattered at the moment and doesn’t actually exist, yet.

Gathering up of this database has been started in Tampere University of Technology. In 2006 March started a three-year project, called The Repair Strategies of Concrete Façade and Balconies. Its major aims are to produce above mentioned database and create a sort of predictive model for building management to systematize and add reliability to decision-making concerning maintenance and renovation. To get the information needed and to get results that really are useful in practise, this work is done together with big property owners and major condition investigation agencies, who are handing over their condition investigation reports and taking part as commentators to this project.

The condition investigation reports include plenty of very detailed information about the present condition of buildings, in a numerical and in a verbal form. To make it comparable and statistically handleable, numerical classification for verbal information has been created. As a result over 60 values per one building and over 20 individual values per one sample taken from the building are registered. The information is assorted according to the surface type of façade and balcony structure as its own file. Because there are about 350-400 reports in the use of this research, the number of values to form statistically reliable damaging and property distributions and comparison is approximately 150 000.

4.2 *Building Management*

Building management and the work contribution in building maintenance has essential role on the development of building’s condition. With properly timed and right kind of maintenance, it is possible to prolong the service life of structure by postponing or stopping deterioration and protecting structure beforehand. Advanced deterioration happens when there are unidentified problems and numerous buildings to take care of.

By regular maintenance the property owners know better what the state of condition is and are able to budget for bigger operations beforehand. The most important affect is that the service life extends by small-case service operations like coating using protecting products and ensuring the function of flashings and other associated systems. To avoid unexpected renovations, building management needs more preventive maintenance and help to predict coming repair needs.

The substantial factor making systematic building management to success is the identification of damage. A model to identify the damage can be established on the grounds of earlier mentioned data base and it will help to direct the condition investigations' and repair works' timing optimal.

4.3 *A Predictive Model*

A model to identify damage is actually a large number of distributions of different kind of states of damage and the relation of the damage and other factors. Distributions are classified by surface types and year of construction. One distribution serves as a prediction model of certain structure to which building management can compare their own structure and thus see the odds for what's going on. The property owners use the prediction model as comparative data to their own buildings of similar age and surface types. From the data base the owners find different kind of distributions concerning for example the depths of carbonation front and the average depth of reinforcement.

The distributions help them to estimate what might be going on in buildings of different construction year and surface types. Buildings can be arranged to a rough order of repair urgency. After that they can consider what kind of deterioration might be going on in what kind of structures. They get information, where should they start their inspection and how it is done. Is the expected condition so good that visual evaluation and checking are enough to verify the present condition or is thorough condition investigation needed?

This enables the transition to pro-active maintenance in building management. With that it is possible to estimate the incoming repair needs before damage is visual even for the large number of real estates. Thereby house managers can prepare enough beforehand both technically and financially, by systematization and directing the building management and repair planning. Thus repair work can be optimally timed out taking into consideration the service lives of old structures.

The aim is also to reduce the amount of heavy repair work and at the same time to reduce the need for demolition of deteriorated structure and thereby also reduce the waste that demolition generates. With optimally timed light repair, the heavy repair work can be entirely avoid or at least move to a later point in time. Pro-active building management extends residual service lives of present structures, develops and maintains good, healthy residential environment and prevents the risks of reduced bearing capacity and safety that deterioration causes.

It is important to remember, that using the predictive model does not replace the condition investigation as clarification of the present state of individual structure and building. Condition investigation which is done before engaging to repair operations is the best method to avoid oversized or too risky repair. This predictive model is based on statistical probabilities and function as a help for building management to lead the resources to right targets.

5 CONCLUDING REMARKS

Building management definitely needs technical help organizing their property in the order of repair need. To make sustainable renovation and to ensure continuous safety also between the renovations and service operation, there needs to be reliable information where the decision-making can rely on.

The predictive model is based on over 350 condition reports. Therefore after its completion this model gives reliable data for the use of building management.

REFERENCES

Mattila J. et al. 1998: Condition Investigation Prior to Renovation Process – a Systematic Approach in Saving Buildings. In Central and Eastern Europe IABSE Colloquium Berlin June 4-5, 1998, Pp.68-71.

Pentti M et al. 1998: Repair of Concrete Facades and Balconies. Part 1: Structures, degradation and condition investigation. Tampere. Tampere University of Technology, Structural Engineering. Publication 87. 157 p. (In Finnish)

Pentti, M. 1999. The Accuracy of the Extent-of-Corrosion Estimate Based on the Sampling of Carbonation and Cover Depths of Reinforced Concrete Façade Panels. Tampere, Tampere University of Technology, Structural Engineering, Publication 274. 105 p.

Pigeon M. & Pleau R.1995: Durability of Concrete in Cold Climates. Suffolk. E & FN Spon. 244 p.

Suomen Betoniyhdistys r.y. 2002: Condition Investigation of Concrete Facades by 42. Helsinki, Suomen Betoniyhdistys r.y. 178 p. (In Finnish)

Tuutti K. 1982: Corrosion of Steel in Concrete. Stockholm. Swedish Cement and Concrete Research Institute. CBI Research 4:82. 304 p.