Condition assessment of a Johannesburg skyscraper

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Abstract. This paper presents a condition assessment conducted on a Johannesburg skyscraper. It had become apparent that concrete spalling occurred in areas of the top 11m of the Southern and Western facades of the reinforced concrete skyscraper constructed in the 1970's. However, the extent of the problem was unknown. The only information available were twophotographs showing spalled concrete and severely corroded reinforcement bars. Some literature search pertaining to the structure was conducted after which, visual inspection and mapping of spalled areas and cracks were conducted. This was followed by a cover meter survey, a half-cell potential survey, and the removal of 20 (twenty) cores for laboratory testing. It was found that the typical problems associated with carbonation and insufficient cover resulted in the corrosion of reinforcement which then led to the spalling observed.

Keywords. Reinforced concrete, spalling, carbonation, cover, site supervision

Introduction

This paper illustrates the significance, methods and processes of conducting assessments in order to diagnose deterioration mechanisms in ageing infrastructure. Ageing of any structure leads to the need for repair and maintenance that has to be conducted with the intent to prolong the structure's lifetime. Concrete structures typically undergo numerous processes that lead to its deterioration, right from early age defaults to gradually developing physical or chemical attack processes. Corrosion of steel is the most widespread form of deterioration in reinforced concrete (RC) structures. Two attack processes, consisting of chloride attack and carbonation are responsible for steel corrosion in RC structures. The sources of chlorides may be external such as sea water, de-icer salts, salty groundwater and soils. Internal sources of chlorides may include chemical admixtures or construction materials, especially aggregates. Carbonation on the other hand arises from the ingress of atmospheric carbon dioxide into concrete. In both cases (of chloride attack and carbonation,) protection to steel reinforcement is provided by the concrete cover which normally has a high pH of about 12.5, as in the rest of the concrete material mass. At such a high pH, steel forms a protective passive film at its surface but once chlorides or carbon dioxide penetrates through the full cover depth to the level of steel, the alkalinity of concrete decreases, the protective passive film breaks down and steel corrosion ensues [1-2].

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As the infrastructure which is essential for conduct of economic activities continues to be amassed worldwide, attention will in future shift more towards repair and maintenance of existing structures rather than new construction. However, prior to conduct of any meaningful repair actions, it is essential that the damage or active deterioration process(es) occurring in the structure is/are properly diagnosed through condition or structural assessment methods. The assessment usually involves insitu non-destructive testing (NDT) along with limited physical laboratory testing or analyses done on core or dust samples [1-3]. This paper is limited to a case study involving the use of various methods of condition assessment including visual inspection, insitu strength grade determination, ultrasonic pulse velocity (UPV), covermeter survey, half-cell potential, core testing and optical microscopy.

1. Background

The multi-storey reinforced concrete skyscraper in Johannesburg, estimated to have been constructed in the 1970's, is a multi-functional structure used for office and residential purposes, and a shopping precinct within the inner city. The owner was concerned of the severe concrete spalling that had occurred mainly at the south and west facades, causing speculation that chemical attack on concrete may have risen as a result of windblown dust from nearby mine dumps. Accordingly, engineering expertise was called upon to examine the condition of the structure and suggest the required repair and/or rehabilitation options. In the investigation, emphasis was placed on determining the structural integrity and material characteristics of the in-situ concrete. The engineering team then conducted the following assessments

- A condition survey entailing on-site inspection
- Laboratory testing and optical microscopy

Some past literature indicated that concrete mixes tested and used throughout the structure had compressive strengths of 40 MPa at 28 days, which at the time of construction, was considered to be high-strength concrete. The mixtures consisted of 37.5 mm Juskei granite stone and rod-milled reef quartzite sand of standard grading. However, no information was available regarding the cover to steel reinforcement, sizes of the structural members and steel reinforcement bars used in design or construction. The outer façade finishing consisted of sandblasted, exposed aggregate surface. The sandblasting operation was conducted in the early ages of insitu concrete placement. The main issues of concern that were identified for conduct of the investigation were:

(a) Presence of severe cracking and exposed corroded steel bars on the outer surfaces of building walls
(b) Uncertainty over the active deterioration processes, given the 40-year age of the structure
(c) Potential environmental effects arising from extensive presence of previous and/or existing gold mining activities, to the South-West of the structure
(d) Unknowns regarding the type of aggregates used. Some of the aggregates in Johannesburg are reactive and could cause alkali-silica reaction attack. This

phenomenon and its implications may not have been known during the time of construction of the structure.

The insitu investigation was therefore conducted to determine the cover to steel reinforcement, establish the condition and integrity of the existing structure. Considering the complexity of gaining access to conduct measurements, it was quite difficult to do several field measurements except those tests that were considered to be most essential, which included the cover to steel reinforcement and the half-cell potential measurements. Some rebound hammer measurements were also done.

In the laboratory investigation, different assessment methods were used to conduct the tests based on cores drilled from all four walls of the building. Firstly, the depth of carbonation that occurred over the past service life of the structure was measured along with compressive strengths, rebound hammer readings, and UPV. The UPV technique is a versatile method capable of establishing concrete characteristics to determine the soundness of concrete quality; it enables accurate estimation of elastic modulus, strength and crack depth. Excellent concrete quality typically gives a propagation speed of 4000 to 4800 m/s. A velocity of 3000 to 3500 m/s is satisfactory while < 3000 m/s indicates poor quality and lack of integrity.

2. Survey and field tests

2.1. Photographic survey and crack mapping

Photographic surveys, mapping of cracks wider than 0.3mm and mapping of areas of spalling were conducted. The surveys provided strong evidence that the problems were localized. **Photo 1** to **Photo 3**shows some of the problematic areas.

Photo 1 Exposed rebar and spall

Photo 2 Exposed rebar and apparent honeycombing

Photo 3 exposed rebar and spall

2.2. Extraction of cores

A total of 5 (five) cylindrical cores, from preselected locations, were extracted from each of the four facades. These 100mmdiameter cores of approximately 200mm length were sent for laboratory testing. **Photo 4** shows the coring process while **Photo 5** and **Photo 6** show some of the core samples.

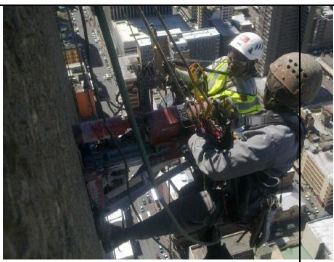

Photo 4 Lifting & core cylinder

Photo 5 Sample of cores

Photo 6 Exposed aggregate finish

2.3. Cover meter survey

The survey was conducted by scanning the facade with a cover meter instrument. A grid system was used to position the recordings and map the results. Vertical gridlines were spaced at 2m intervals and the horizontal construction joints were used as the horizontal gridlines. **Photo 7** shows a technician carrying out the cover meter survey.

The lowest cover reading for each block was recorded, thereby giving conservative measurements. The survey was able to identify areas that would require repair and maintenance in the short to medium term. The results of the South facade cover survey, which contained by far the most area of low cover, is shown in **Figure 1**.

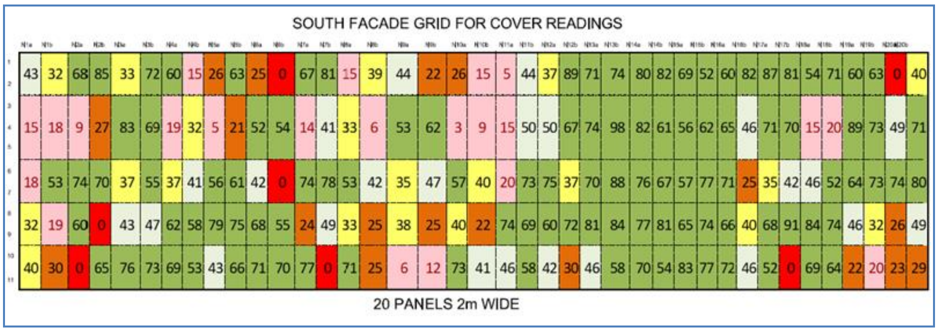

Figure 1. Minimum cover meter readings taken on the South Facade

2.4. Half-cell potential tests

Half-cell potential measurements were conducted to assess the likely presence of corrosion activity, whether hidden or visible. Typically, readings of less than -350mV imply a 95% probability of corrosion occurring, whilst readings higher than -200 mV suggest less than 5% probability of any presence of corrosion[1-3]. Half-cell readings that were obtained, varied between -170mV to +180mV. The results indicated that no corrosion activity was occurring at the locations where measurements were taken[4].**Photo 8** shows a technician performing the half-cell tests while the data was being captured at a safe location, as in **Photo 9**.

Photo 7 Cover meter survey

Photo 8 A technician performing half-cell tests

Photo 9 Technicians capturing readings at a safe location

Half-cell readings were taken at random locations and also near cracks. **Figure 2**indicates the locations and readings of half-cell measurements taken on the South facade.

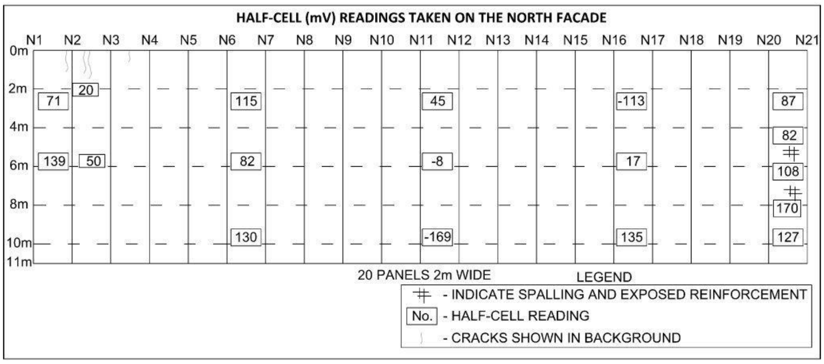

Figure 2. Half-cell potential measurements taken on the South facade

3. Laboratory tests

Several tests were conducted on the 20 core samples extracted from the building facades, as subsequently discussed.

3.1. Core compressive strength and quality tests

A minimum of three cores per facadewere used for concrete tests consisting of density, compressive strength, Ultrasonic Pulse Velocity, and rebound hammer. The tests were conducted in accordance with BS 1881:Part 203 and EN 13791[5-7].

The density of the concrete was determined to be 2384 kg/m^3, which is typical of normal concretes. The insitu strength results were in the range of 35 to 44 MPa, averaging 38 MPa i.e approximately 40 MPa. The results obtained were in agreement with the literature information indicating that concrete mixtures of 40 MPa strength were used.

Ultrasonic Pulse Velocity measurements conducted on visually assessed defect-free cores gave velocity readings ranging from 4500 to 5000 m/s, which would indicate excellent quality characteristics[1].

3.2. Carbonation attack

The depth of the carbonation front was determined on cores samples selected from each of the four façades. Carbonated concrete has a significantly lower pH than non-carbonated concrete. The samples were sprayed with phenolphthalein indicator solution. The carbonated concrete retained its natural colour while the non-carbonated concrete turned purple. The carbonation front was then measured and found to vary from 13mm to 24mm with an average of 19.3mm.Note that due to the rough exposed aggregate finish and the presence of stone aggregates inside the concrete, significant variability in the carbonation front measurements would be expected.

3.3. Concrete analysis for chlorides

Dust samples, obtained from the core samples, were analysed for chloride concentrations. The total chloride contents were determined in accordance with the ASTM C1152 test method [8]. The chloride contents were found to be between 50 and 170 ppm, well below the 500ppm threshold beyond which chloride corrosion attack would normally occur [4].

3.4. Durability tests

Six core samples were selected for durability tests. Two durability index tests were conducted on the core samples namely, oxygen permeability and sorptivity tests [9]. The objective of conducting these tests was to obtain an indication of the potential performance of the concrete under mild exposure environment. The tests revealed generally poor durability performance, as shown in **Figures 3** and **4**. This was not surprising as the desk study revealed that no extenders were used in the concrete mix design[4]. However, the results should be examined in the context of the construction period of the 1970s when current understanding of the influence of extenders in concrete was not yet fully developed. Modern concrete technology usually requires the use of extenders in order to achieve good durability performance.

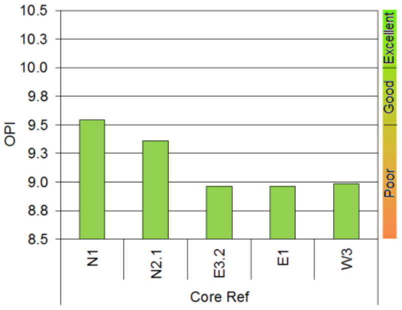

Figure 3. Oxygen permeability test results

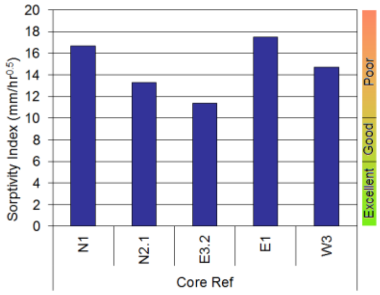

Figure 4. Sorptivity test results

3.5. Optical microscopy

The site photos gave no indication of possible alkali-aggregate reaction or sulphate attack. The desk study revealed that the stone aggregate were Jukskei granite from a quarry near Halfway House Midrand; Granite aggregate is typically non-reactive. The sand used was Rodmilled Reef Quartzite but no information could be found on the reactivity of the reef quartzite. The investigation team found no reason to suspect that the sand used could be reactive. Optical microscopy was however conducted to establish the potential for alkali-aggregate reaction. Any presence of sulphate attack would also be detected by microscopy [4].

Detailed examination of the concrete was done using thin section optical microscopy. Thin sections were prepared from different concrete cores and cut longitudinally in a direction parallel to core axis. Microscopic examination showed the aggregates to be predominantly quartz, microline, feldspars and some opaque particles as shown in micrographs of **Photo 10** to **Photo 13**.

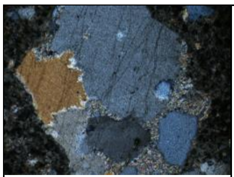	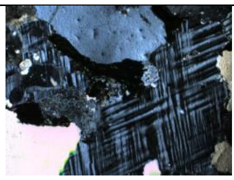	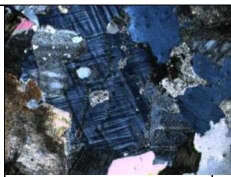	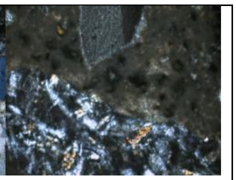
Photo 10 XPL Strained quarts 50x	**Photo 11** XPL quartz, microline 100x	**Photo 12**XPL Microline 50x	**Photo 13** XPL strained quartz and feldspar 200x

Strained particles such as seen in **Photo 10** and **Photo 13** may sometimes be associated with alkali aggregate reaction[4]. However, there was no evidence of any reactive phase(s) such as microcrystalline quartz commonly found in reactive aggregates in South Africa.

4. Conclusion

Site survey determined that the spalling was localized, in areas of very low cover. Carbonation attack was the mechanism identified to have caused corrosion of the reinforcement, which then resulted in spalling. In the 40 MPa concrete, carbonation had progressed to about 19.4 mm over the 40 years of the structure's lifetime. However, the cover in the façade varied significantly to the extent that the very low cover areas were severely affected by corrosion.

The concrete was intrinsically of excellent quality yet its durability characteristics were generally poor when evaluated based on durability indexes. This poor index performance is attributed to absence of extenders, whose use in concrete was not an established technology in the 1970's. No indication of chemical deterioration attack mechanism was found.

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