Construction and Building Materials 24 (2010) 898–902

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Compressive strength loss and reinforcement degradations of reinforced concrete structure due to long-term exposure

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ARTICLE INFO

Article history:
Received 19 June 2009
Received in revised form 3 December 2009
Accepted 3 December 2009
Available online 4 January 2010

Keywords:
Compressive strength
Tensile strength
Reinforcement corrosion
Rebound hammer
Ultrasonic pulse velocity
Half-cell potential
Abandoned projects

ABSTRACT

Degradations due to long-term weathering actions on a reinforced concrete structure were investigated. Compressive strength and reinforcement corrosion developments of a prototype RC structure were monitored for 6 years using destructive and non-destructive tests which include periodic coring, compressive strength, rebound hammer, ultrasonic pulse velocity, carbonation, half-cell and tensile strength tests. Eventually, results have shown that more than a quarter of peak compressive strength can be lost within 5 years of continuous exposure. Corrosion of the exposed bars within the range of the testing period was also observed to be quite alarming. Thus, defects caused by prolonged actions of environmental factors may pose serious threats on the integrity of partially completed structures especially abandoned projects.

1. Introduction

Civil infrastructures are generally the most expensive investments in a country. Concrete has been used extensively in the construction of these infrastructures so much that its usage signifies the growth and development of a nation [1,2]. However, the act of abandoning concrete structures in the midst of construction activities might jeopardize design efforts towards achieving a strong, safe, durable and economical structure. One of the major factors for deterioration of concrete structures in this situation is the attack from surrounding environment. This is obvious since both strength development and durability status of reinforced concrete depends not only on the compositional constituents but also on the characteristics of the immediate environment, specifically exposure conditions [3,4].

Principal factors of deterioration associated with surrounding environments include; rainfall, alternate wetting and drying, temperature variations, ground moisture and presence of aggressive chemicals in the soil. Continuous actions of these agents affect weak spots on the concrete surface and the reinforcing steels, thereby, rendering both materials vulnerable to deteriorational defects with possible irreversible damages [5–8]. The formation and gradual propagation of cracks for instance, can easily weaken concrete and instigate reinforcement corrosion with eventual deflections as well as partial or total collapse. In addition, dissolution of atmospheric carbon dioxide (CO_2) in the pore water often forms carbonic acid. This reduces pH value of concrete to a level at which the passive layer surrounding the steel reinforcement is no longer sustained [9,10]. As a result, the reinforcing steels are exposed to corrosive activities with consequent loss in general performance [11]. Furthermore, the formation of salt deposits on the surface of exposed concrete, known as efflorescence is another form of attack, at least rendering the concrete surface aesthetically undesirable and making it difficult to achieve desired bonds between the affected surfaces and finishes [12–14]. In fact, the appearance of efflorescence on concrete surfaces was fully attributed to environmental circumstances [15].

The present investigation therefore seeks to evaluate the performance of concrete and reinforcement after being subjected to bare environmental conditions for 6 years. The aim is to expose the level of detriment caused on reinforced concrete structures especially in an abandoned situation. However, in order to achieve and maintain both structural and environmental similarities between the structure erected for this investigation and structures in the real situation, physical inspections on some abandoned projects were conducted and reports substantiated accordingly.

2. Experimentation

2.1. Model structure

A prototype structure representing elements in an abandoned situation was constructed in an open space besides a structural laboratory. Fig. 1 shows the model structure which consisted of a slab 1.5 m length and 1.0 m width. The slab is

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doi:10.1016/j.conbuildmat.2009.12.003

Fig. 1. RC model structure exposed to natural environment.

150 mm thick and the corner columns are square 150 × 150 mm with a height of 600 mm. All reinforcing bars are mild steel 10 mm in diameter. The reinforcing bars were allowed to project beyond the concrete surfaces of the structural members. A 20 mm concrete cover to reinforcements was maintained throughout.

OPC, river washed sand and crushed granite of maximum size 20 mm were used. The designed mix proportions are 1:2:4; cement, sand and coarse aggregate. A water/cement (w/c) ratio of 0.5 was employed. The structure was left fully exposed to the natural outdoor environment without any form of protection or maintenance throughout the investigation period.

2.2. Abandoned projects

Inspection visits were conducted on selected abandoned projects in some areas of Malaysia. The sites chosen were located in the high acidic rainfall zones with average acidity of less than 6.0 [16]. These include Seven Storey Apartment, Mukim Pulai which has been abandoned for more than 10 years and a Double Storey Shop Complex in Taman Teratai both of Johor Bahru, Malaysia. During the inspection structural menace to the immediate vicinity as well as the surrounding community were also noted.

2.3. Test details

At 120 days old, 100 mm diameter cores were drilled and tested for compressive strength. Electromagnetic cover meter was used to identify suitable coring locations so that reinforcing bars are avoided. However, 7 and 28 days compressive strength of 150 mm cubes prepared from the concrete used in the prototype structure were also tested. Representative samples of steel bars were obtained from the exposed portions and these are subjected to tensile strength tests. These serve as reference values for the subsequent tests. Similar operations were conducted at the end of the first, third and sixth years of exposure.

An average strength of two cored samples at each of the four testing ages was translated into equivalent cube strength by using the relationship contained in BS 1881-120:1983 [17]. However, in order to provide supporting evidence for the concrete strength obtained from the core tests, rebound hammer and ultrasonic pulse velocity (UPV) tests were also carried out during the final observations. The rebound hammer test was carried out in accordance with BS 1881-203:1986 [18]. Twenty suitable locations; two on each of the four columns and 12 on the slab were selected in accordance with BS 1881-202:1986 [19]. Nine readings were taken from each location within an area of 150 mm^2.

In addition to tensile strength test conducted on the exposed bars, carbonation and half-cell potential tests were also performed during the final testing age (6 years). Depth of carbonation was determined by spraying phenolphthalein solution on 50 mm diameter concrete cores removed from the slab. On the other hand, half-cell potential readings were taken at the intersection points of 100 mm square grid lines in accordance with ASTM C876-91 [20].

3. Results and discussion

3.1. Compressive strength

Fig. 2 shows the compressive strength results of the structural model during the 6 years duration. Initial strength development especially within the first 28 days was quite normal, but turns out to be slow until a peak of 32.1 N/mm^2 was reached at exactly 1 year. Beyond this limit, gradual decrease was observed within the next two subsequent years and a much higher strength loss of about 27.6% was recorded at 6 years old. However, in order to further ascertain whether the strength obtained by coring at this stage is a true representative of the current strength level of the model structure both rebound hammer and UPV were conducted as mentioned earlier.

Observations using rebound hammer yielded a global average of 39.07 and a standard deviation of 5.0 against tested locations. Using calibration chart, this corresponds to a cube's compressive strength of 23.74 N/mm^2 as against the core strength of 23.35 N/mm^2. UPV tests however resulted in an average of 3.66 km/s and a standard deviation of 0.20 which equates to 25.2 N/mm^2. Thus, the minimum compressive strength loss as suggested by the use of UPV is 21.5%, against the core strength loss of 27.6%. In addition, non-instrumental assessments further revealed leaching of cement and minor hairline cracks.

Ideally, concrete should progress in compressive strength with time. However, in this case, it is clearly demonstrated by the three strength assessment techniques that strength loss was inevitably registered. Obviously, environmental factors of destruction such as acidic rain, conditional fluctuations associated with cycles of

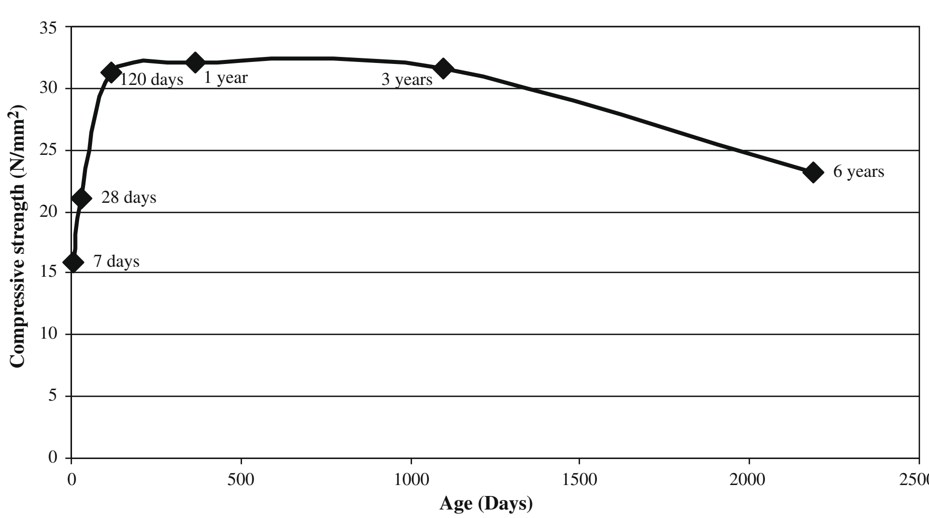

Fig. 2. Impact of exposure time on compressive strength.