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DETERIORATION EVALUATION OF COOLING TOWER UNIT 28 IN MOBAREKEH STEEL COMPLEX AND PROVIDING ITS REPAIR PROCEDURES

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ABSTRACT

It is generally supposed that concrete is one of the best durable materials but, it is a fact that all concrete structures will deteriorate with time, though the rate at which they deteriorate varies considerably, as it is affected by many factors. Deterioration will change the performance and appearance of structure, which may affect its performance under normal working conditions.

Cooling tower unit 28 is one of the concrete structures in the Mobarekeh Steel Complex which was observed with various remarkable deteriorations. This concrete structure was directly subjected to circulation of industrial water and under aggressive sulfates, corrosion reinforcement, lack of timely attention and periodical investigations at regular time intervals were found responsible for serious deteriorations.

In order to have an optimal use of the structure and its stability and to achieve an adequate repair procedure, a thorough and logical investigation of distress causes was carried out. The survey includes information collection and visual sketching of distress locations, several in-situ NDT tests, the determination of various aggressive ions in depth of concrete, and some other laboratory tests on core specimens taken from selected components of the structure. Based on studies carried out, different deterioration mechanisms were determined and then concrete removal methods and appropriate repair procedures were suggested. Finally, durability and the remaining service life of repaired structure is predicted.

Keywords: distress evaluation, concrete, inspection, durability, maintenance strategies

1. INTRODUCTION

Worldwide concrete with Portland cement is the most widely used construction material in buildings and civil engineering structures. There are several reasons such as appropriate resistance to water, easily flexibility on various shapes and dimensions, inexpensive and easy availability of its materials constituents. Over the years, the type and quality of concrete materials and construction methods have varied considerably. In parallel, there has been an increased understanding of the mechanisms underlying the behavior of concrete and its performance in service. It is an unfortunate, but inescapable fact that all concrete structures will deteriorate with time, though the rate at which they deteriorate varies considerably, as it is affected by many factors. Deterioration changes the performance and the appearance of the structure, and as a final consequence it may affect its safety and behavior under normal working conditions on exploitation. Usually in the past, some maintenance actions were taken into consideration when already visible traces of deterioration were observed. Where periodical inspections were not carried out at regular time intervals, serious damages might be already presented at the first inspection [4, 5, 6].

Cooling tower unit 28 is one of the concrete structures in the Mobarekeh Steel Complex which was seriously damaged. This structure is used for cooling and decreasing water temperature circulated in the steel production lines. The concrete was subjected to circulation of industrial water and under aggressive sulfates, corrosion of reinforcement, without periodical inspections at regular time intervals and thus serious deteriorations were presented. Damages owing to corrosion of reinforcement have caused expansion and eventually resulted in cracking, delaminating and spalling of concrete.

In order to have an optimal use of the structure and its stability and achieving an adequate repair procedure, a thorough and logical investigation of distress causes was carried out. The survey includes information collection and visual surveying and sketching of distress locations, several in-situ NDT tests, determination of various aggressive ions in the depth of concrete, and some other laboratory tests on core specimens taken from selected components of the structure. Considerations and visual investigation and inspections of the structure, surface impairments, NDT tests and collecting core samples for laboratory tests are shown in Figure 1. Based on the results of preliminary inspections and in-situ and laboratory tests, various deterioration mechanisms were determined and then concrete removal methods and adequate repair procedures were suggested. At the final stage of this study, durability and the remaining service life of the repaired structure is predicted [1].

2. OBSERVATIONS, VISUAL SURVEYING AND INSPECTIONS

In order to investigate the performance of the cooling tower structure which is in a propagation phase of deterioration, an assessment of the current condition of the structure is necessary. This investigation is also necessary because of several other factors such as current maintenance, rehabilitation, serviceability conditions changes, investigation of structural stability and its function, and a study of current environmental conditions. Current state could include rapid assessment and visual inspection up to complex considerations which are taken into account in long time planning and performance. The main purpose of visual surveying and investigation is the diagnosing of probable causes of any visual deterioration and ensuring that the structure remains in its integration and satisfactory conditions. An instance of visual surveying of distress locations is shown in Figure 2 [1].

The most important deteriorations which were obviously seen in the exposed concrete in cooling tower unit 28 are longitudinal cracking due to corrosion of reinforcement in beams and columns and also severe sulfate and frost attacks (see Figure 3). Nevertheless, the essential distresses which are manifested in this structure is classified as follows:

a) Longitudinal cracking in direction of steel bars in beams and columns (Figure 3).
b) Severe corrosion of reinforcement (Figure 4).
c) Severe removing of cement paste and exposed aggregates (Figure 5).
d) Sulfate and frost attack.
e) Delamination of concrete walls.
f) Leakage and efflorescence (Figure 6).
g) Low concrete cover over reinforcement.
h) Spalling of concrete cover due to corrosion.
i) Disintegration and scaling.

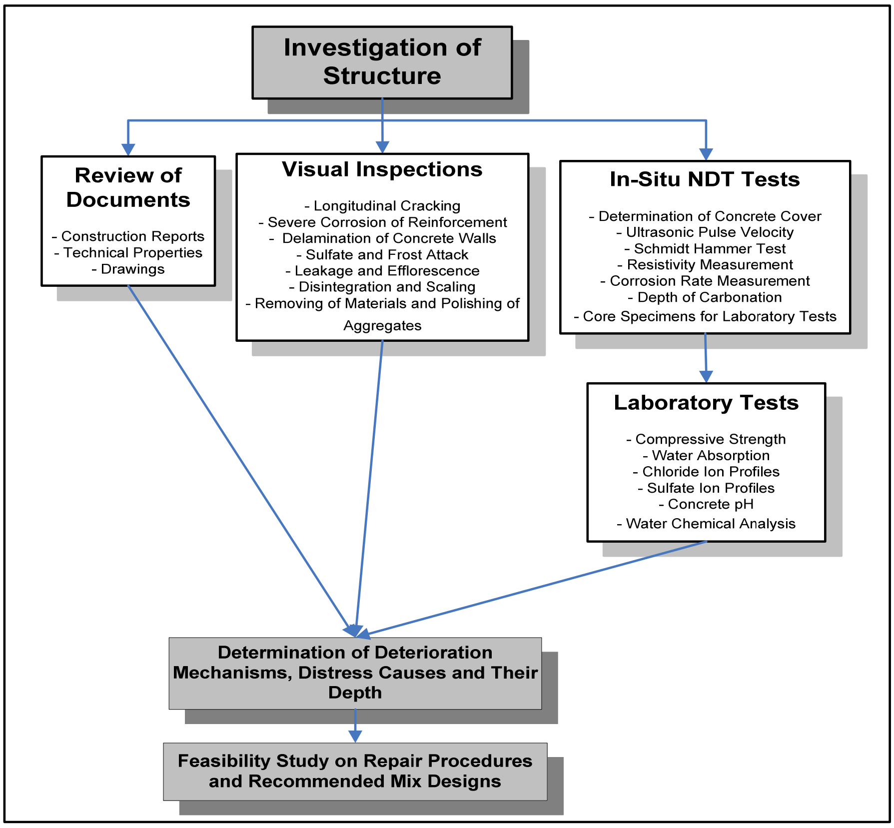

Figure 1. Flowchart of various stages of diagnosing distresses in cooling tower unit 28.

3. IN-SITU TESTS

In the first stage of the inspection and evaluation of the structure and according to visual surveying and inspections, various non destructive tests (NDT) comprising the determination of concrete cover, pulse velocity measurement, concrete strength by Schmidt hammer, resistivity measurement, determination of corrosion rate and depth of carbonation (Figure 7) were carried out. In continuing of the completion of quality and quantity of studies in laboratory, 17 core specimens were taken from selected beams, columns and concrete walls at different levels of the cooling tower [1].

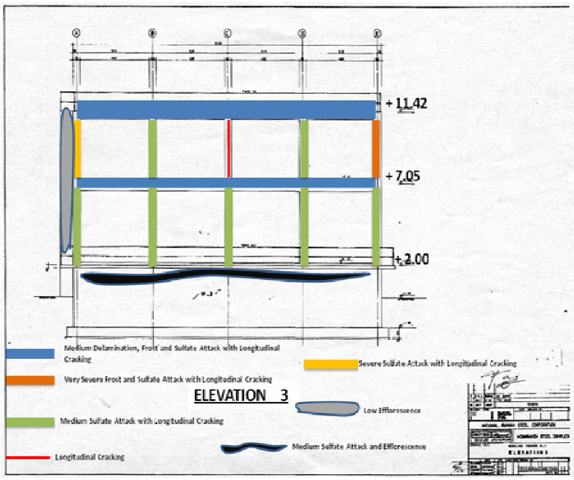

Figure 2. Schematic and sketching of distress locations in the western view of cooling tower unit 28

Figure 3. Longitudinal cracking and sulfate attack

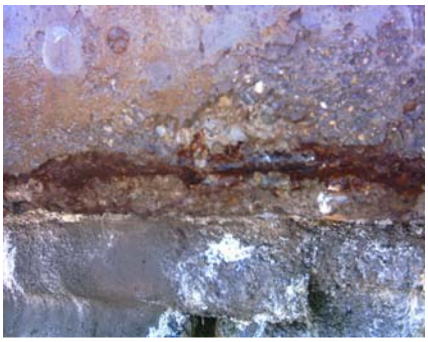

Figure 4. Severe corrosion of reinforcement

Figure 5. Removing of cement paste and exposed aggregates

Figure 6. Leakage and efflorescence

Figure 7. Determination of carbonation depth

4. LABORATORY TESTS

In the laboratory, compressive strength, water absorption, chloride and sulfate ion profiles and concrete pH in different depths of core samples are implemented. During taking of core specimens it was seen that the cover of concrete in all samples taken from concrete walls and some of those taken from beams is separated due to the corrosion of reinforcement.

Water could be considered as one of the most important reasons which cause impairments in concrete and concrete structures. Water is the initial compound of life and decomposes the most natural materials and also causes most of the difficulties for concrete durability. Water also is one of the reasons of decrease in quality in porosity materials and is responsible for the intrusion of aggressive ions into concrete and is one of the resources for chemical processes causing quality reduction.

One sample from circulated water in the cooling tower unit 28 was taken for chemical analysis. Chloride and sulfate ions contents in this sample were less than the allowable limit which is in the Iranian code of practice. Nevertheless, these ion contents in a constant volume of concrete are more than the allowable limit; therefore, the concrete of cooling tower's structure was subjected to aggressive ions. Its intensity depends on concrete quality, concrete cover, and permeability of concrete and on how the structure is maintained during its service life [1].

5. CONCLUSION OF EVALUATION STUDIES AND TECHNICAL RECOMMENDATIONS

Concrete is one of the most widely used construction materials alike other materials with a life time. Concrete deteriorations, due to several causes could considerably affect the technical life time of concrete structures. Therefore, the awareness of deteriorations and their mechanisms, their prevention and/or decreasing the intensity of damages, creating delay in their progress, and considering appropriate requirements afterwards are one of the most important duties of civil engineers who deal with concrete works. On the other hand, the concept of innovative construction materials and also innovative concretes is not only considered as its own materials. But the concept of life time and durability design is also one of the essential parts which must be taken into account .Life time and durability design concepts, along with its deep and wide considerations are surrounded by all material parameters, environmental conditions, construction, conditions, human resources and technological conditions [8, 9, 10].

Nevertheless, all concrete structures are always subjected to deteriorations which is affected by many factors. In addition, considering the concepts of life time and durability design for such structures, maintenance planning during physical service life of the structure is one of the most important factors increasing the life time of concrete structures.

In the evaluation of concrete durability of cooling tower unit 28, attention was given to the knowledge of physical-chemical processes of concrete distresses causes in real structure which have been observed and for diagnosing of these causes, several in-site and laboratory tests were carried out. However, interactions of physical and chemical causes of distresses, which are sometimes complicated, are considered. Regarding the tests results and visual inspection, the conclusion is as follows [1]:

a) Based on considerations and according to concrete Iranian code of practice, the structure of cooling tower unit 28 was subjected to moisture, wet and dry conditions, freezing and thawing, periodic cooling and warming, hence locating in very severe environmental condition.

b) The average compressive strength of concrete specimens shows very high compression strength (average: 44 Mpa on cylindrical specimens) and it is also very dense with low permeability (with 2.25% maximum water absorption).

c) In spite of high compressive strength and low permeability, the structure was always subjected to aggressive harmful ions which was available in water, so that stresses due to wet and dry conditions and periodic cooling-warming caused cracking and ingress of aggressive ions into concrete was intensified.

d) High leakage and penetration of water from inside to the outside of concrete walls of the structure caused an intensive corrosion of reinforcement and sulfatation of concrete. Low cover of concrete in some locations in concrete walls also caused corrosion and concrete delaminations.

e) As some parts of beams and columns in the structures were under 70-90% moisture and other parts were simultaneously subjected to environment and wet-dry condition, corrosion in these elements was developed as cavities. From the point of view of corrosion, increase of concrete water saturation is a useful effect in decreasing the oxygen penetration and on the other hand, it could be harmful because concrete electrical conductivity is considerably enhanced by increasing the degree of saturation. Therefore, it is not surprising that maximum corrosion and cracking in beams and columns occurred in places where there were wet and dry conditions. Getting sulfate of concrete because of aggressive sulfate ion of water and disintegration and exposure of aggregate due to freezing and thawing conditions intensified the concrete surface distresses. Sulfate ion profile in depth of a concrete core is shown in Figure 8.

f) Besides the insensitive factors of deterioration in the structure, one of the most important causes of distress development was the lack of maintenance planning during service life of the structure, lack of periodical inspection and timely prevention of distress development.

g) With chloride ion contents in the depth of concrete cores (Figure 9), corrosion of reinforcement, delamination of concrete cover, sulfatation and frost of concrete surfaces, it could be concluded that the concrete must be removed up to the minimum depth of 100 mm and replaced with a higher strength and low permeable concrete.

h) Also due to the penetration of water from the interior to the exterior, the interior surface of concrete walls must be cleaned and coated with impermeable materials. In addition, the existing joints which have caused leakage of water to the outside must be filled with appropriate resin.

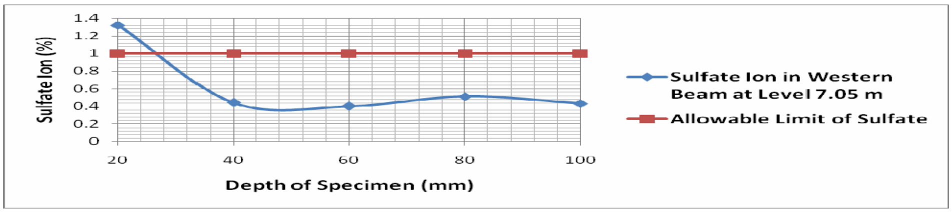

Figure 8. Sulfate ion profile in the depth of a concrete beam at a level of 7.05m.

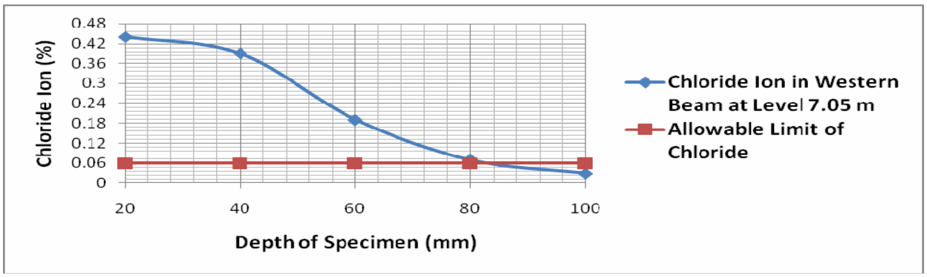

Figure 9. Chloride ion profile in the depth of a concrete beam at a level of 7.05m.

6. MIX DESIGN OF REPAIR MATERIALS

Each repair work has its exclusive conditions and its own requirements in identifying the necessary criteria for repair since in many cases more than one appropriate material for use is available. Concrete repair materials can be formulated to provide a wide variety of properties. Final selection of material or combination of various materials has been implemented by consideration of several factors such as ease of application, cost, skill availability and necessary equipments for their usage. Information about the service life of materials, which were used in previous repair works, plays an essential role in the selection, usage and maintenance of such materials [2, 3].

In selection of repair materials, emphasis is on those which might have higher performance and durability. Therefore, selection of these materials must be on the basis of awareness of their physical and chemical properties, the purpose of their usage and the natural condition of environment in places where they are used.

On the basis of usual inspections, in-site and laboratory tests results in previous sections and knowing the distresses causes such as corrosion of reinforcement, sulfate and frost attacks, with the intension of providing repair mix design and its planning, the following items are carried out [1]:

a) Methods for removal of damaged concrete and surface preparation.
b) Mix design alternatives on the basis of various tests on concrete material constituents.
c) Repair procedures alternatives based on various concrete deteriorations.
d) Prediction of durability and service life of repaired structure.

7. REPAIR PROCEDURES

Concrete is one of the multiple applied construction materials which is used with reasonable cost, having appropriate strength and durability and flexibility on shapes and dimensions. In concrete structure of cooling tower unit 28, some problems such as lack of timely maintenance, environmental conditions, aggressive chemical components on passage of time, were the causes of concrete deteriorations and serious distresses. Therefore, repair of damaged places by replacing with appropriate concrete under various procedures which depend on distress depth, its severity and extent, is necessary [2, 3, 7].

In the repair works of this structure, improvement and provision of concrete appearance acceptance in terms of their color and texture between repair zones and other parts are considered. In addition, repair zones must be permanently bonded with main concrete and also have enough low permeability, without shrinkage and crazing cracking and enough resistance against freezing and thawing. Therefore, repair of this structure needs more attention and necessary design and plan as compared to other buildings in the Mobarekeh Steel Complex. With consideration of impairments of the structure and its severity and extent, the following repair procedures alternatives are recommended [1]:

a) Formwork and pouring of concrete in beams and columns.
b) Patch repair of minor deteriorations.
c) Shout Crete for concrete walls.
d) Repair of cracks by injection.
e) In the result of water penetration from inside to outside, the interior surface of concrete walls must be cleaned and coated with impermeable materials.

8. CONCLUSION

It is generally accepted that in the design of concrete structures, durability properties of materials must be considered along with their other characteristics, such as mechanical properties and costs. In the evaluation of concrete durability and the durability of concrete structures, attention must be paid to the point in which most information about physical-chemical processes causing concrete deteriorations is obtained from actual structure history because the simulation of long term status in laboratory is very difficult. Although in reality, the concrete distress is rarely found due to a unique cause. Usually in advanced stages of material degradation, more than one harmful phenomenon is observed. In general, physical and chemical causes of distresses are so complicated and so intensified together that often the separation of cause and effect is not even feasible.

Permeability is one of the most important concrete parameters affecting durability. Most aggressive materials which are generally soluble in water penetrate through concrete capillary pores. Also, concrete with low porosity is dense and has better quality in terms of durability and strength. Water absorption is due to low water pressure in concrete. Hydration and concrete drying could decrease water pressure in concrete and increase absorption. In some parts of cooling tower unit 28, periodic water absorption and drying caused deposition of water harmful ions in concrete thereby resulting in increasing of sulfate and chloride ion contents in concrete. After absorption of chloride in water by concrete, it contaminates in depth and chloride gradually penetrates in concrete. Ingress of chloride ion continues in concrete where it reaches reinforcing bars and results in the progress of corrosion.

Therefore, it is important that the concrete surface condition should be improved by replacement with high strength concrete up to 100 mm in depth and also by applying impermeable coating materials so that the service life of cooling tower could be considerably enhanced (minimum 30 years). In addition of the concept of structural life time and durability design consideration, maintenance planning, periodic inspection activities and timely prevention of the progress of deterioration during service life of the structure are necessary precaution actions.

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