EFECTS IN REINFORCED CONCRETE DUE TO ENVIRONMENTAL CONDITIONS, AND CONCRETE TREATMENT: A CASE STUDY AT THE UNIVERSITY OF DAR ES SALAAM

I. A. Rubaratuka and D. Mulungu
Civil Engineering Department, University of Dar Es Salaam
P. O. Box 35131, Dar Es Salaam, TANZANIA

Abstract

Concrete is produced by mixing together cement, water and aggregates (i. e. sand and coarse aggregates) in specified proportions. It can do well with compressive forces but it is very weak under tensile forces. To overcome this problem, steel reinforcement are normally added to produce reinforced concrete which can also withstand tensile forces. Experience shows that environmental conditions may have a negative impact on the durability of reinforced concrete structures resulting in development of defects if not properly assessed and appropriate measures adopted to arrest the same at the design and construction stages.

The severity of damages for the investigated reinforced concrete structures at the University of Dar es Salaam depended on the influence of the environmental conditions and the quality of concrete. Corrosion to the reinforcement was mainly associated with the influence of the environmental conditions including carbonation, action of sulphates and to small extent chlorides due to contaminated humid air.

1.0 INTRODUCTION

Reinforced concrete(RC) structures such as buildings, bridges, water tanks, retaining walls, etc. are designed and constructed to perform definite functions for estimated periods of time. While in use, these structures are subjected to different environmental conditions.

Undesirable environmental effects on structures may result from inadequate attention to environmental influence at the project design stage to lack of the knowledge and information necessary to predict environmental effects in order to take into account their influence. Experience shows that most of the reinforced concrete structures are affected by environmental conditions. Regardless of whether the structural systems are designed to withstand the environmental conditions, still the environmental effects are experienced due to either inaccuracy of determining the extent of the environmental conditions during the design stage, the cost effectiveness of the structural systems and lack of quality control during construction [1,2]. Environmental effects are influenced by winds, rainfall, atmospheric pollution, sunlight, chemical action, etc. The durability of reinforced concrete is also influenced by sunlight, abrasion and impact, chemical action such as corrosion, exposure to sulphates, acids or salts, etc. Acids of all kinds attack concrete made with portland cement. Sources of acids are flue gases, carbon dioxide dissolved in water and acids formed from sewer gas. The process of carbon dioxide dissolving in water to form carbonic acid which reacts with concrete is known as carbonation. Although carbonation is useful in plain concrete since it strengthens the material and also useful in reinforced concrete if adequate cover is provided as initially it inhibits porosity and becomes a hindrance to future carbonation, but it affects the durability of reinforced concrete by causing progressive spalling and cracking if adequate cover is not provided. Carbonation starts at the surface and proceeds inward at a decreasing rate depending on the type of concrete, its quality, its density and strength with time as shown in Figure 1. The figure also shows the measured points at the University of Dar Es Salaam buildings. Normally reinforced concrete structures are designed for a certain life span with a minimum negative influence of environmental conditions on their durability[2].

In this paper effects of environmental conditions on the durability of reinforced concrete with reference to buildings at the University of Dar Es Salaam are outlined and measures aimed at minimizing durability problems and strengthening reinforced concrete are recommended

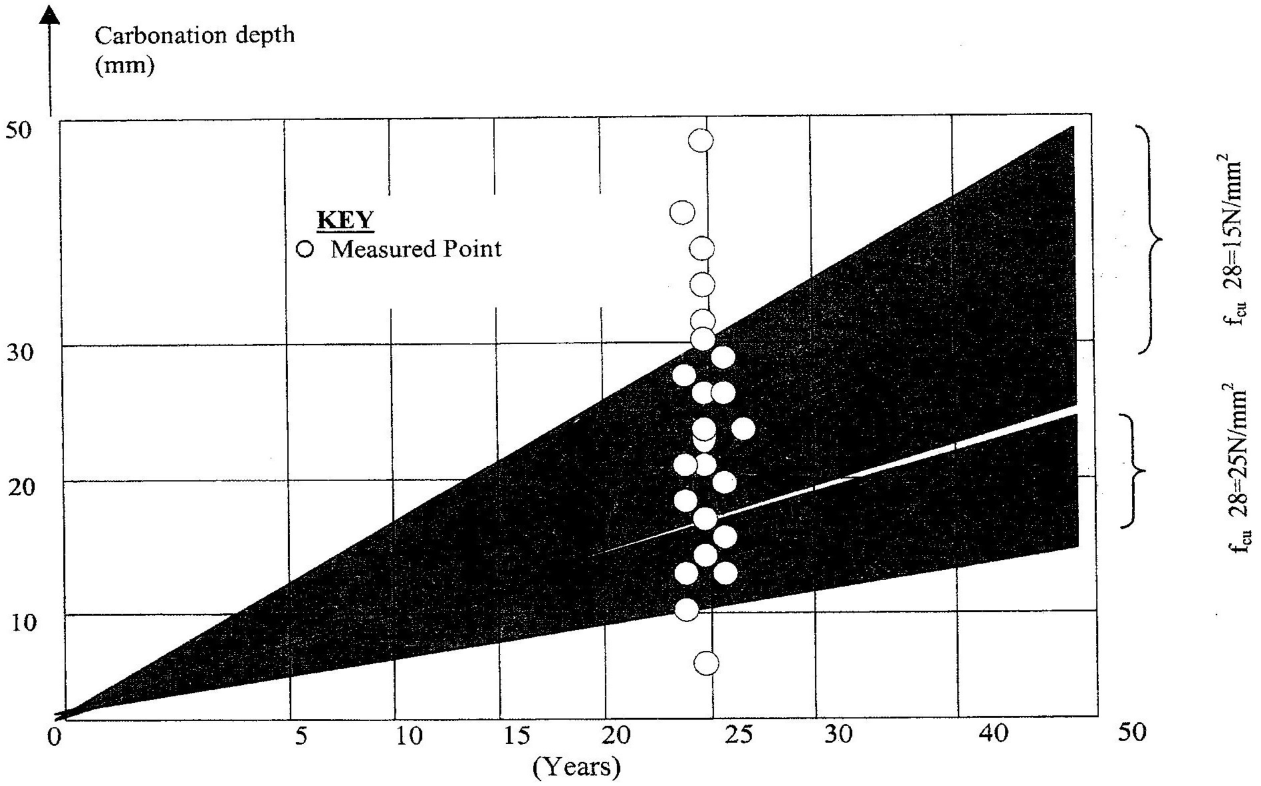

Figure 1. Depth of carbonation according to the resistance of 28 days old concrete.

2.0 INVESTIGATION

2.1 Tests

In order to assess the environmental impact on reinforced concrete buildings at the University of Dar Es Salaam, the following tests were carried out[3]:

(a) visual inspection,
(b) determination of carbonation depth from selected points by drilling or coring,
(c) measurement of the concrete cover above reinforcement,
(d) determination of concrete granulometry,
(e) determination of cement content,
(f) microscopic analysis of the concrete micro structure,

(g) porosity, and
(h) strength tests.

2.2 Investigation Results

The results of the investigations were as follows:

2.2.1 Visual Inspection, Concrete Cover and Carbonation Depth

Columns and walls for some of the buildings were found to be in a very poor condition, which may contribute to impair their long term load bearing capacity and structural strength. Signs of rusting and in some places considerable spalling were evident on concrete facade slabs. Measurements revealed carbonation depths exceeding 65mm at a steel concrete cover of up to 30mm hence indicating the rusting of reinforcing steel in many places. Results are shown in Table 1.

Table 1. Concrete cover and carbonation depth

Location	Carbonation depth (mm)	Concrete cover (mm)	
		Stirrups at the top at the bottom	Horizontal rods at the top at the bottom
Kileleni	>65	16 – 23	26 – 30
		16-19	28 – 30
		24 - 30	22 –24
Hall 1	40		48 – 50
		19 – 35	> 60
Hall 2	15 – 20	9 – 11	28 – 36
		16 – 21	33 – 36
Hall 3	50	14 - 18	27 – 29
		6 – 21	25 –30
Hall 5	20 - 25	5 – 7	20 – 24
		6 – 15	13 – 16
Cafeteria	45	12 – 13	30 –34
Tower building (Faculty of Arts and Social Siences)			
West side	30 40	22 – 26	34 – 41
		26 – 30	32 – 34
East side	20	39 – 54	62
		22 – 30	
Sinza staff flats			
South side	20 – 25	15 – 20	30 – 33
North side	20 – 30	11 – 20	28 – 31
Hall 6 bock B South	30 – 35	2 - 20	18 – 20
			22 - 25

2.2.2 Granulometry

Aggregate particles distribution of the sand /gravel material was determined. The aggregate grading curve clearly shows the high fraction of 0/1 mm sand in Figure 2. Due to the high sand fraction, the concrete mix requires more water, thus being the cause of the high w/c ratio and the inadequate concrete quality.

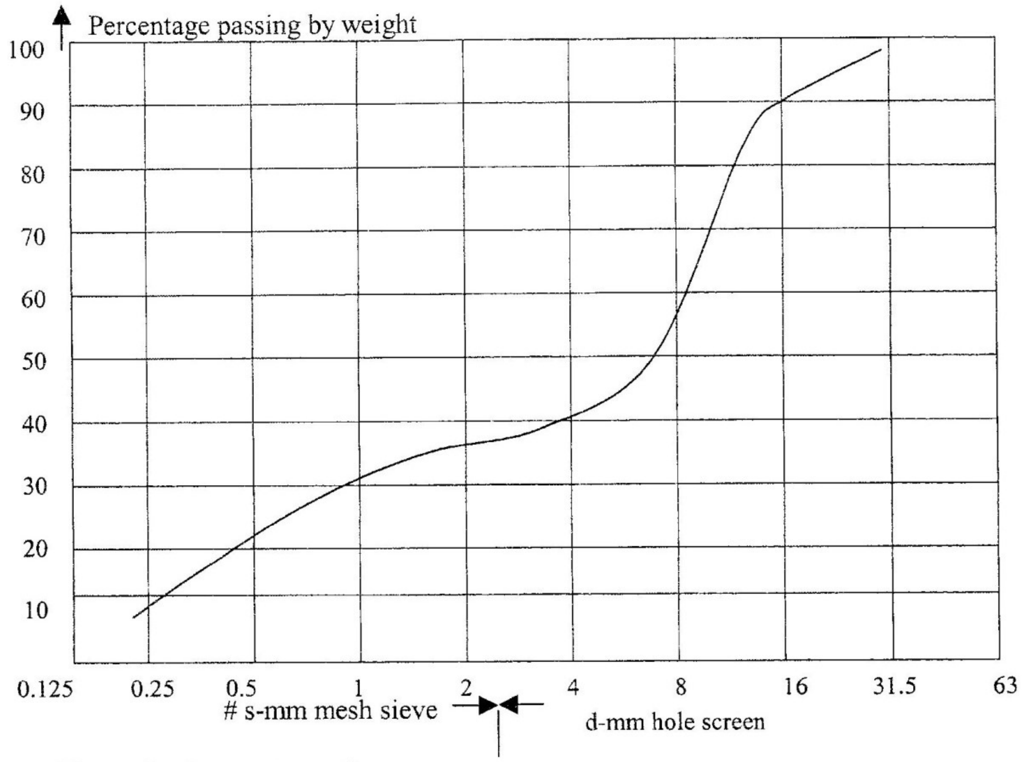

Figure. 2 Aggregate grading curves

2.2.3 Cement Content

By assuming that the composition of the cement used during construction is approximately the same as that of cement used at present, the test results yielded the following cement content: 320 ± 35 kg/m^3.

This value seem to be high particularly considering the otherwise unfavorable concrete properties. The normal value for concrete grade 15 of nominal maximum size of aggregate of 20mm is about 280 kg/m^3

2.2.4 Microscopic Analysis

Microscopic analysis yielded the following results:

(a) the aggregate fraction less than 2mm are mainly composed of quartz and feldspar,
(b) the bonding between aggregate and cement in hardened concrete is often inadequate,
(c) surface pores and voids are abundant,
(d) due to high water content characterised by voids and reduced strength , the density is low.

2.2.5 Porosity

The concrete porosity results revealed a gross density of 2145 kg/m^3 for concrete with 16.6% in volume of pores which can be filled with water while similar values for well compacted concrete with a w/c ratio of 0.5 are approximately 2390 kg/m 3 and 11% respectively. This shows that the tested concrete has a relatively high content of pores, prone to be filled with water and resulting in a high degree of capillarity which in turn is significant for the carbonation process. According to the above results, the w/c ratio of the used concrete is approximately 0.7, thus very high. The low gross density can be explained by the high w/c ratio as well as by the low density of the used aggregate.

2.2.6 Compressive Strength

The test results range between 28.2 - 35.3 N/mm^2 . Using the rebound impact hammer on site, much higher results were obtained. This is due to the fact that the hammer measures surface hardness which due to carbonation can increase significantly. Relevant for the effective compressive strength are therefore laboratory test results. Though very low, they seem sufficient for adequate strength of the buildings.

3.0 CONCRETE TREATMENT

3.1 Introduction

Concrete is produced by mixing together cement, water and aggregates in specified proportions as previously explained. The severity of damages for the University of Dar Es Salaam buildings depended on the both environmental influence and concrete quality as explained above. Test carried out indicated that chloride had no significant effect as a cause of damage. Corrosion to reinforcement was mainly associated with the carbonation process which resulted to rusting of reinforcement. In this case, the area of carbonated concrete has to be submitted for treatment to reinstate the protective system of the reinforced concrete structures to aggressive environmental conditions as presented below[1].

3.2 Treatment (Repairs)

The basic operations involved in repairing concrete damages are as follows: preparing the concrete substrate, preparing the steel reinforcement and protecting it against corrosion, restoring the affected structural member to its original section with new concrete or patching mortar and possibly applying some form of protective coating to the finished concrete surface[4].

3.2.1 Preparing the Concrete Substrate

Before the structural member can be restored to its original section and before the application of any protective coatings or the attachment of additional reinforcement, the concrete substrate must satisfy certain requirements: the surface must be sound, free from cement grout, laitance, loose or segregated material, voids and substances which could interfere with the bond between old and new concrete(e.g. curing agents and traces of old paint). All requirements must be satisfied to ensure a sound, permanent bond between the existing substrate and the new repair material. In most cases the substrate was specially pretreated before it conforms to these requirements.

Most of the techniques used for preparing the substrate also serve to roughen up the surface, effectively increasing the area of the bond face. At the same time they create a mechanical cogging between the substrate and the newly applied material, thus making the bond more resistant to shearing stresses. The techniques used for preparing the substrate were: sand blasting, high-pressure water jet and Grit/Water blasting.

3.2.2 Protecting the Steel Reinforcement Against Corrosion

A lasting and successful repair can only be effected if the reinforcement is free from rust. Unless rust formed on the reinforcement is removed or stabilized by some special treatment, the cycle of corrosion will continue, even if the surface of the concrete is protected by coating impervious to air and water and sooner or later this is bound to lead to a recurrence of the damage. Anti-corrosion coatings can be applied either directly to the reinforcement bar or if the reinforcement shows no sign of rusting as yet, and if the surrounding concrete is still uncarbonated and contains no critical concentrations of harmful substances to the surface of concrete. Two types of system are available for protecting the steel itself, based either on reactive resins or on polymer-modified cements. Whichever system is used, it is essential to expose the reinforcement bar completely on all sides and along its entire rusted length. The protection process involves:

(i) De-rusting

The sandblasting is used to remove rust from the steel. Where the reinforcement is directly exposed to the jet of sand, i.e. on its outward-facing side, it is certainly possible to de-rust it very effectively. But it is not so easy to clean the back of steel using this method. Each bar need a careful check and has to be given further treatment where necessary. This is rust removal by hand, using angle grinders or wire brushes. It is vital to ensure that all thickly encrusted rust is removed by scraping or chipping away with chisel. It is to be noted that, de-rusting the back of steel effectively is often extremely difficult. When the reinforcement has been cleaned back to the bright metal and is free from all substances which could form an electrolyte, the application of a good quality sealer to prevent the access of moisture and acts as a barrier against harmful substances(carbon dioxide, chlorides, sulphates, etc.) can provide lasting protection against corrosion. The type of sealer material used was Sika Mono Top 610, which is cementitious, silica fume containing polymer modified 1-component coating material as a bonding slurry and corrosion protection for reinforcement. These Sika products were manufactured by Sika AG and were imported from Switzerland.

(ii) Patching or resurfacing

Patching involves repairing relatively small areas of localized damage. The damaged area is restored to the profile of the surrounding. Undamaged concrete and in most cases the patched surface is then given a suitable protective coating. Resurfacing or reinstatement refers to the application of mortars or grouts to large surface areas, against with the aim of restoring the concrete to its original section(or in some instances increasing its original section) substances designed to protect against further damage are often incorporated into the repair material itself. Two basic categories of products were available for this kind of work, depending on the type of binder material on which they are based. These are cement based products and mortar based epoxy resins. The material or product mostly used was cement based namely; Sika Mono Top 615 (repair mortar) and Sika Mono Top 620 (pore sealer/finishing coat).

3.2.3 Preventive Action to Protect the Steel Reinforcement

If the embedded reinforcement shows no signs of rusting as yet, and the concrete cover can still provide an adequate degree of protection against corrosion, then it makes sense to apply a suitable coating to the surface of the concrete in order to preserve its protective function.

4.0 CONCLUSION

Although it is not easy to design and construct reinforced concrete structures which are absolutely free from environmental effects, but investigations have revealed that it is still possible to minimize environmental effects at the design and construction stages. The main cause of damage of the University of Dar Es Salaam buildings is the porous concrete structure which, in turn, is due to the high w/c ratio, inadequate granulometry and partly to aggregate porosity. These are among the reasons of the carbonation penetration to and beyond the reinforcing steel, thus eliminating the passivation of steel and its resistance against rust. There is a need to establish the impact of environment on reinforced structures so that appropriate measures can be taken at the design stage i.e. adopting the appropriate concrete cover taking into account the influence of environmental conditions. At this stage appropriate materials may be selected. The concrete deterioration process can be minimized by incorporating protective measures at the design and construction stages. Protective measures for the durability of reinforced concrete structures may be established by considering the following:

(i) the good quality concrete composition

(ii) the reinforcement detailing including concrete cover. From the results of carbonation depths in Figure 1, if the c over is 30 mm under the same conditions of exposure and concrete quality, the carbonation front will reach the reinforcement in more than 50 years which may be beyond the design service life of most of structures. Concrete quality requirements for the concrete cover should also be satisfied for concrete spacers as they can be the sources (points) for carbonation.

(iii) addition protective measures such as coatings, including coating of reinforcement.

(iv) specified inspection and maintenance operations during in - service operations of the structure, including monitoring procedures.

Complexity in structural form, as well as inappropriate construction technology and use , usually influence the sensitivity of the structure to deterioration, shorten service life, or require increased efforts in maintenance. For example, around out-going edges and corners, aggressive substances can penetrate the concrete from more than one side, thus leading to local concentrations at these corners. Damage may occur first in these areas, i.e. so called corner effects develop. In such cases, rounded corners and edges may reduce the concentration effects and thus enhance durability of the structure. Near in-going sharp edges and corners, stress singularities in loaded structural components occur, and the risk of cracking is increased. This may increase the rate at which aggressive substances or environment, including water, locally penetrates into the concrete. Congestion of reinforcement may lead to difficult casting conditions where the concrete is segregated by being sieved through the reinforcement, thus causing bad compaction and honey-combing. A closed 3-dimensional reinforcement cage provides confinement of the concrete, and can increase the structural reliability in the case of any deleterious expansive reactions within the concrete causing delamination and splitting of the concrete. In slabs, that may need no shear reinforcement a minimum number of uniform distributed links should be provided in case of any splitting or delamination of the bulk concrete. Investigations have revealed that most of the negative environmental effects also are due to lack of quality control during construction[3].

Experience shows that the cost of concrete treatment or treating the corroded reinforcement as a result of the carbonation process is extremely high as compared to the cost of taking precaution measures during the design and construction stages so as to minimize the carbonation process. Therefore reinforced concrete structures should be designed, constructed and operated in such a way that, under the expected environmental conditions, they maintain their safety, serviceability and acceptable appearance during an explicit and implicit period of time without requiring unforeseen high costs for maintenance and repair.Explicitly, construction process plays an essential role in providing the quality needed for a structure to resist its environment. Good workmanship is a crucial element of the service life concept. All good intentions laid down in a rational design will fail if not supported by quality workmanship during construction. Therefore it is very important to engage qualified, competent and committed consultants and contractors for construction projects.

5.0 REFERENCES

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