CONCRETE DETERIORATION, DIAGNOSIS, MAINTENANCE AND MAINTENANCE RELIABILITY IN BUILDINGS IN HOT CLIMATES

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ABSTRACT

This paper identifies types of deterioration in concrete structures and analyses their causes, examines methods of repair and maintenance and assesses the effectiveness of the maintenance with age.
The findings in this study have showed that maintenance reliability depends on (a) quality of materials (b) the proffered technical solution (c) supervision (d) regularity of inspection and (e) management procedure.

KEYWORDS: Building, Concrete, Deterioration, Diagnosis, Maintenance, Reliability, Strengthening, and Underpinning

1.0 INTRODUCTION

Concrete is a versatile construction material which consists of water, cement, fine and coarse aggregates and sometimes a fifth ingredient called admixture may be added to modify the property of concrete. Concrete uses a large proportion of naturally occurring and highly variable material (aggregates) and because of site conditions, there is limitation on the degree of quality control that can be exercised during the production of concrete. As a result of the effects of these conditions, concrete is prone to deterioration when in service. Deterioration is a phenomenon of becoming impaired in quality or value by a process where degradation of material is involved. Warner et al [1] have shown that there are three major ways in which structural concrete may deteriorate; namely, (i) Surface deterioration of the concrete (ii) Internal degradation of the concrete and (iii) Corrosion of reinforcing steel. Sjostrom (2) reported that most examples of early deterioration of exterior materials leading to unexpected maintenance are caused by faulty design. He further noted that deterioration processes are controlled by micro environment, which can be defined as the precise condition of the solid material and immediate layers of liquid or gas prevailing at the site where chemical or physical deterioration is taking place. Generally buildings are prone to deterioration with age. Falade (3) reported that the susceptibility of buildings to deterioration is traceable to the materials used in construction, geographical location and environmental conditions. He further noted that several defects associated with reinforced concrete are due to poor quality control during construction.
A lot of money is spent to erect imposing and monumental buildings but they are left as soon as commissioned to face premature and rapid deterioration. The author acknowledges the need for construction of new housing stock particularly in developing countries where there is acute shortage of housing but maintaining the existing ones is equally very important. Where efforts have been made, to maintain these edifices, they have been on corrective basis, that is, making repairs only when faults have occurred as opposed to planned, routine and preventive maintenance. The role of building maintenance is mainly to keep the structure in a serviceable state on a continuous basis in a cost effective manner. But in general, new construction is preferred to maintenance of existing housing stock with the result that buildings are left to waste, deteriorate and decay at alarming rate. Maintenance is a function which can be used effectively to control reliability and cost. The life span of concrete structures depends on proper

design, detailing, quality of materials, workmanship, environmental conditions, method of construction and the appropriateness of the maintenance approach.
The aims of this paper are to: (i) examine different causes of deterioration (ii) method of arresting deterioration and (iii) examine the effectiveness of the existing maintenance methods.

2.0 CAUSES OF DETERIORATION

Deterioration may be due to any of the following:

2.1 Quality of Materials

Concrete consists of cement, fine and coarse aggregates and mixing water. The conditions in which these materials are batched determine their durability and proneness to deterioration. When cement is stored on site or transported in ships over a period of time, partial hydration of cement commences in humid conditions resulting in formation of air-set lumps. When these lumps are allowed in concrete during mixing, the strength of concrete produced is somewhat lower than the specified strength. Fine and coarse aggregates may contain impurities such as silt, clay or dust. The presence of these impurities in concrete hinders effective bond between the coarse aggregate and the paste leading to reduction in compressive strength of concrete. Water that contains impurities, if used for mixing concrete components results in reduction of strength.

2.2 Inappropriate Combination of Concrete Constituents

The strength of each concrete batch varies depending on the ratios in which its constituents are proportioned. Inadequate or excess water in a mix produces concrete with reduced strength. While inadequate water results in lower strength and dry segregation, excess water in concrete produces reduced strength and wet segregation. Low fine aggregate content results in inadequate paste to coat the coarse aggregate thus producing harsh mix with reduced strength. Excess fine produces concrete mix of wet constituency with lower strength.

2.3 Inadequate Estimation of Load

In reinforced concrete design, a material partial safety factor γ_m =1.15 is provided for steel while for concrete the factor is γ_v=1.5. The value for concrete is higher than the value for steel because of the non-uniformity and variability of the aggregate obtained from earth crust and the quality control in making the concrete. It is believed that when these partial safety factors for materials are applied to both the steel and concrete, realistic design strengths are obtained in both cases. Partial safety factors are also used for the applied load. The dead and imposed loads are multiplied by 1.4 and 1.6 respectively to accommodate the inadequacies in the estimation of the applied load. When these loads are underestimated, the structural element is susceptible to stress that is higher than its strength leading to early deterioration of the element.

2.4 Error in Design and Detailing

The effects of improper design and /or detailing range from poor appearance to lack of serviceability to catastrophic failure. These problems can be minimised only if a thorough understanding of structural behaviour is known and adequate reinforcement and proper detailing are ensured.

2.5 Poor Construction Practice

When only water is added to concrete to improve workability, this may result in cracking. Added water has the effect of reducing strength, increasing settlement and increasing ultimate shrinkage. Inadequate consolidation and placement of construction joints at the points of high stress may result in cracking.

2.6 Corrosion of Reinforcement

Steel corrosion is the most common form of deterioration in concrete structures and it is the main issue in the durability requirements provided in most codes of practice for concrete structures (BS 8110,4). It has been shown by Yeomans and Cook (5) that corrosion process of reinforcing steel in concrete is essentially an electrochemical oxidation process and that it takes place on the surface of the steel in the presence of water and dissolved oxygen. Reinforcement corrosion is one of the most important causes of poor reinforced concrete durability.

Improved quality attracts increased cost in labour and supervision, however the careless construction of reinforced concrete structures attract disproportionate penalty in unnecessary maintenance and repair costs during the life of a building. Of all the concrete deterioration problems corrosion of reinforcing steel outweighs, that due to other forms of distress.

2.7 Climatic Conditions

In tropical climate, deterioration arises as a result of (i) high temperatures (solar radiation) and (ii) heavy rainfall moisture penetration. For example the cause of plastic cracks is the rapid evaporation of water from the surface of the concrete. Changes in temperature also cause dimensional changes in building materials especially in those materials in which the coefficient of expansion is high. Rainfalls on the sun-heated surfaces apply severe tensile stress higher than that of concrete resulting in appearance of crack. These damages are more evident in building with concrete flat roof. The wind also transports degradation stimulators such as salts in coastal areas and other air contaminants in industrial regions. High humidity and warmth encourage the growth of lichens and mosses on the walls of the buildings. This has discolouring effect on them with the external wall, sometimes turning black. This defect heightens the need for frequent deterioration repairs of the buildings.

2.8 Heavy Traffic

Concrete floor deteriorates under heavy traffic especially in warehouses, commercial building floor surfaces in the markets. There is frequent presence of abrasive dust, sand, dry chemical and food ingredients, all of which are destructive to concrete and concrete finishes.

3.0 CONCRETE IN BUILDINGS

Generally, certain parts of buildings are more vulnerable to failure than others and this, frequently, under adverse conditions leads to deterioration. Table 1 provides the most commonly encountered deterioration features in some parts of building.

Table 1: Deterioration, Diagnosis, Causes and Repair

Element	Deterioration	Diagnosis	Causes	Repairs
a) Foundation	i) Uneven Settlement	Movement Cracks on Superstructure	Inadequate foundation thickness inadequate foundation depth, overloading, poor concrete mix. Poor workmanship, ground movement due to geological faults.	Take foundation to a greater depth of adequate bearing capacity by underpinning
	ii) Sinking	Reduction in the height of plinth of the building.	Inadequacy of foundation types, size and depth.	Strengthening by simple underpinning or piled underpinning as the case may be. If this will endanger life and properties demolish and rebuild using appropriate foundation on stratum of adequate bearing capacity.

	iii) Corrosion/ rusting of reinforcement	Cracks and spalling of concrete	Poor workmanship Loss of alkalinity, infiltration of water to reinforcement. Inadequate concrete cover.	Cut back concrete to the other side of the reinforcement, wirebrush, apply antirust and patch
b) Ground floor	i) Cracks	Visible fine and/or structural cracks.	High rate of hydration. Disproportionate concrete mixture, poor workmanship Heavy traffic especially warehouse and commercial buildings, presence of abrasive dust, sand, and dry chemical and food ingredient in sailing and markets.	Use appropriate proportion of components. Sweep regularly to keep dust and particles out of the pores and crevices of the floor. Scrub with appropriate detergent solutions to remove sticky, adherent soilage such as oil, greases and other dirts.
	ii) Dusting	Opening on the floor with particles of accumulated dust	Surface exposure and breakdown. Inappropriate mix	Remove the soft chalky material, clean the surface thoroughly then allow the surface to dry. Apply the hardener treatment then patch appropriately.
	iii) Tilting	Sloping of the floor	Improper construction, Inadequate compaction Lack of bearing on walls (for slab that is cast within the walls)	Demolish and reconstruct. Cut the block back from room to room to provide bearing for the slab and recast.
c) Wall	i) Cracks	Cracks on wall	Uneven settlement of foundation, failure of ground support, lintel or beams within the walls being too flexible which causes overstressing of masonry.	Strengthen foundation and then rebuild wall partially or totally in the affected area, seal with stiff mortar (I:3 mix). Stitching of the cracks together by inserting short length rods at interval.
	ii) Efflorescence	Leaching of lime compounds when water percolates through poorly compacted		Mix hydrochloric acid with water and then scrub the deposits.

		concrete.		
	iii) Tilting	Cracks, leakages, shift in vertical alignment of the building.	Inadequate flashing and tooling of joint.	Cut the defective mortar and point all joints in the affected areas.
	iv) Internal cavitation	No external sign of defect. It can only be detected by sounding the wall with hammer.	Improper compaction	Replace the affected blocks with solid blocks.
	v) Fracture of wall at roof level	Cracks on the wall	Spreading of roof, sagging of roof produces a horizontal thrust on the external supporting wall.	Provide adequate bracing to the roof
	vi) Shift in wall position	Thermal movement of blockwall.	Lack of provision of expansion joint. Variation in temperature.	Construction of expansion joint in accordance with the design code of practice
	vii) Dampness	Discoloration of wall surface and fungi growth	Poor quality block, osmotic and capillary action. Moisture penetration due to climatic condition (e.g. during heavy rainfall), leakages from roof gutters, rainwater pipes and plumbing pipes, rain penetration due to blockage of roof drains (flat roof) by debris.	Provision of damp proof course on block wall. Use good quality block. Repoint cracked and/or weak mortar joints. Seal the leaking roof, plumbing pipes and clear debris from roof gutter.
d) Beams, columns, staircases and lintel	Shrinkage cracks	Fine cracks	High rate of hydration. Inappropriate proportioning of concrete constituents.	Seal crack, use appropriate concrete constituents.
	Cracks (structural)	Cracks on the structural element	i) Structural movement due to uneven settlement of foundation ii) Low strength of structural member due to inappropriate proportion of constituents iii) Corrosion	Strengthening of structural members .

			induced crack iv) Inadequate concrete cover	
e) Roof and gutter slab	Cracks and leakage	Infiltration of water to the underside of the roof	Temperature gradient poor design, poor construction, poor supervision, poor workmanship, poor quality materials and blocked drain	Provision of quality bitumen felt and good quality material and proper supervision during construction.

4.0 CONCRETE MAINTENANCE

The aim of maintenance operation in building is to restore a distressed building back to its serviceable state. Two types of maintenance are distinguished namely, reactive and proactive. The former is performed in response to unplanned or unscheduled repair, usually as a result of imminent failure. Proactive maintenance may be either preventive or predictive. Preventive maintenance is usually carried out periodically during which a well-defined set of tasks, such as inspection and repair are performed. Predictive maintenance, estimates through diagnostic tools and measurements, when a part of a structure is near failure and should be repaired thereby eliminating more costly unscheduled maintenance operation. The proactive maintenance approach is preferred because it institutes a system of inspections at regular predetermined intervals and carrying out any minor repairs before they develop into tasks of some magnitude. This approach is cost effective.

5.0 CASE STUDY

The building has a total length of 20.695m and width of 9.390m. It is a bungalow of five bedrooms with necessary facilities. The structural fabric of the building consists of load bearing walls on a continuous strip foundation. The building is still under construction. The entire framework including the roof covering has been put in place. The building is being constructed without any supervision by consultants. Consultants were invited to the site when deterioration had set in.

5.1 Observation

Visual inspection was conducted on the building to identify the causes of the observed deterioration features. Notable among the observed defects are, deep cracks on the wall that cut across the entire width of the blockwall. Such cracks were found around the openings and at roof level. Other forms of cracks were indicative of defective mortar used for setting the blocks. Investigation revealed that the external walls were more affected by the cracks spread.
The foundation was opened up at some points. The finding revealed that the foundation was found on a shallow depth. The average thickness of the concrete in foundation was found to be 75mm.

5.1 Repair Operations

In order to ensure the proper repair of the observed deterioration, adequate precaution was taken to examine the problem and prioritize the repair procedure.

5.1.1 Cracks

The observed crack are categorized into structural and non-structural

(i) ***Structural***

Short lengths (150mm) of reinforcement were cut. The cracks width was cut back, wirebrushed and adequately wetted to enhance the effective bond of the patch with the parent wall. The repair patches were of ordinary Portland cement mortar. The short length rods were inserted at interval of 100mm along the length of the crack to bridge the cracks, later a stiff 1:3 (cement:sand) mortar was applied.

(ii) ***Non-structural***

These cracks were widened to provide sufficient surface for mortar to have adequate penetration. The finished surface was then smoothened.

5.1.2 **Defective Mortar**
In order to rectify the deterioration arising from the use of defective mortar open tuck-pointing was used. This was accomplished by cutting out the defective mortar and replacing it with mortar of good quality material mixed in the appropriate proportions. The procedure adopted consists of;
i) Removal of defective mortar to a depth of 16mm with handtool.
ii) Removal of loose material with wirebrush.
iii) Selection of appropriate mortar mix (1:3, cement:sand).
iv) Mixing of the mortar component thoroughly.
v) Adding adequate water to produce a stiff mix.
vi) To ensure good bond, the mortar joints were thoroughly wetted before applying the fresh mortar.

5.1.3 **Foundation**
The strengthening operations were limited to external wall and some minor locations internally where there were indications of structural cracks on the walls. It was also noted that the foundation has uneven settlement which was identified to be as a result of (i) shallow depth of foundation and (ii) small thickness of concrete foundation base.
The building was strengthened by a process of underpinning, which is achieved by excavating under an existing foundation and building up a new supporting structure from a lower level to the underside of the existing foundation. The aim is to transfer the load from the weak foundation to a new bearing at lower level. Underpinning can also be carried out on a foundation when there is need to increase the load on a structure and such load is likely to exceed the capacity of the existing foundation, and to permit the level of adjacent ground to be lowered especially when it is required to form a basement at a lower level. The procedure adopted was to divide the entire length and width of the building into odd number of bays. Digging and construction of new concrete in foundation commenced from the centre bay. After this, the two bays at the edges were constructed and subsequently, the remaining bays were successively constructed alternatively until the foundation of the entire length and width of the peripheral walls of the building was strengthened.

5.2 Discussion
Table 1 provides a summary of most of the deterioration features associated with some construction elements that can be found in buildings in countries located in hot climatic conditions. The Table further indicates how such defects can be analysed, causes identified and the appropriate repair methods to be used for reliable repair work. If all the shortcomings associated with constituents of concrete are not rectified on site at the mixing point, they give rise to defects such as crack, deflections, etc which result in early deterioration and maintenance. The case study presented in this paper has shown that the reasons for the deterioration in buildings are sometimes caused by ignorance or wrong evaluation of stress on the structural elements. Other factors that can result in early deterioration of buildings are the widespread use of inferior and undurable building materials and cheap labour. The example also shows that poor construction practice and inadequate supervision constitute serious factor that can necessitate early deterioration of building and expensive repair/reconstruction if care is not taken at the construction stage.

6.0 RELIABILITY OF MAINTENANCE

Ebeling (6) defines reliability to be the probability that a system will perform a required function for a given period of time when used under stated operating condition. Generally when the deterioration of concrete is well diagnosed, the conditions of the constituents of concrete are well assessed and the quality is monitored, the reliability of the building will be high with minimum maintenance cost. When defects associated with concrete e.g. corrosion, spalling of concrete and dampness as a result of infiltration of water through poorly compacted concrete are not rectified on time, the sum that will be required to restore the structure to acceptable standard may off-set the yield function and often leads to the death of the building as an economic investment. Maintenance cost must be analysed vis-à-vis the expected benefits to determine its worthwhileness. For high reliability of maintenance, there must be detailed formulation of maintenance policy for specific property, this includes:
(a) Analysis of present condition of each component of the building.
(b) Outline programme of work necessary to keep the building in satisfactory condition.
(c) Determine the method of implementing the programme.
(d) Calculate the appropriate costs:- two assessments will be required

(i) Down-time period – when the building is put in repairs and
(ii) The cost of keeping them in that serviceable state

Periodic inspection is the best method of ensuring that the right policy is being devised, implemented and adapted to meet the changing conditions. When the defects are well diagnosed and proper technical solutions are applied with quality materials and adequate monitoring and control, the reliability of maintenance will be high and vice-vérsa. Planned inspection must be undertaken in order to:

(i) Prepare a schedule of the locations in which maintenance work is to be done.
(ii) Defect deviations from pre-determined standards and incipient faults, which may result in such deviations developing before the next inspection
(iii) Ascertain the cause of deviation, the extent of remedial work necessary to restore to the required standard and prevent a recurrence of defect and the relative urgency of the work.
(iv) Check that previous work was done in accordance with the necessary specification.

7.0 CONCLUSIONS

This study has showed that;
(i) Concrete is prone to deterioration with age.
(ii) The susceptibility of concrete to deterioration depends among other things on ignorance and inadequate estimate of applied stress on structure.
(iii) Neglect of maintenance leads to severe deterioration
(iv) Poor construction practice and faulty design results in early deterioration and expensive maintenance

8.0 RECOMMENDATION

The following recommendations are made;
(i) Care must be taken to ensure that all the elements are adequately designed and during construction all the specifications must be adhered to.
(ii) Buildings must be inspected regularly to detect any signs of deterioration. Any observed defect must be diagnosed to establish the causes and then remedial solution that would cure such defects permanently would be proffered.
(iii) The observed defect(s) must be corrected promptly to prevent its degeneration to defects of a greater magnitude.

9.0 REFERENCES

1. Warner, R.F; Rangan, B.V. and Hall, A.S, (1989) ' Reinforced Concrete' Longman Cheshire, Melbourne, 3rd Edition.

2. Sjostrom, C. (1997), 'Analysis of Service Life of Materials for the Building Envelope', Proc. Ins. Civ. Engr. Structs & Bldgs, 122, pp 377-384.

3. Falade, F (2000), 'Quality Control and Maintenance of Concrete in Buildings in Hot Climates', Proc. 13th International Congress on Condition Monitoring and Diagnostic Engineering Management Houston Texas, U.S.A, pp 559-568.

4. British Standard BS8110, Part 1 (1985), 'Structural Use of Concrete – Code of Practice for Design and Construction of Concrete', British Standard Institution, London.

5. Yeomans S.R and Cook D.J (1978), 'Corrosion of Steel Reinforcement in Concrete Causes and Prevention' Proc. Int. Conf on Materials of Construction for Developing Countries, Bangkok, pp 443-451.

6. C.E. Ebeling (1997), 'An Introduction to Reliability and Maintainability Engineering', First Edition McGraw-Hill Companies, Inc. Singapore.