QUALITY CONTROL AND MAINTENANCE OF CONCRETE IN BUILDINGS IN HOT CLIMATES

Funso Falade
Department of Civil Engineering
University of Lagos
Akoka - Lagos
Nigeria
ffalade@hotmail.com

Abstract:

This paper examines the use of concrete as mass and/or reinforced concrete in buildings. It identifies defects associated with concrete as a result of poor quality control during its preparation. It shows that high level monitoring is necessary on construction sites in hot climates to determine the physical condition of the concrete constituents in order to ascertain the appropriate proportions for a mix to achieve the specified concrete strength for each project. The paper further noted that a close monitoring is required to determine the method of maintenance required to keep the concrete structure in a serviceable state during its service life. It concludes that the use of good quality concrete reduces the necessity for monitoring and lowers maintenance costs while assuring high reliability of buildings.

Key Words: Building; Concrete; Constituents; Defects; Maintenance; Monitoring; Proportions; Quality Control

INTRODUCTION:

Concrete surpasses the other construction materials with respect to flexibility of shape, strength, durability, and response to its environment and economy. However, its quality is not easily controlled. The quality of concrete is usually assessed by its cube strength obtained by testing field-cast cubes in the laboratory under controlled conditions. It is then assumed that the value of compressive strength so obtained is representative of the concrete in the structure itself.

The variation in the strengths of concrete and allied products may be attributed to high variation in the aggregate used, quality of cement, batching procedure and environmental conditions. Batching error accounts for the larger percentage of variability of concrete strength. Amonoo –Neizer and Solomon – Ayen [1] reported that concrete samples taken from construction sites they visited showed considerable variation in the quality of aggregates particularly, fine aggregate. According to them, the variations in most of the cube strength values obtained were between a standard deviation of 4.0N/mm^2 and 8.5N/mm^2 with about 15% having standard deviation of less than 4.0 N/mm^2. Muzaffer et al [2] reported that among other factors, water/cement ratio and curing conditions have significant effects on concrete specimens tested. Studies by Jalali and Abyaneh [3] and Falade [4] revealed that increasing the temperature above normal decreases the strength. Tamin et al [5] showed that concrete exposed to hot climatic conditions soon after casting is prone to plastic shrinkage cracking. Jackson [6] provides factors that affect the properties of fresh and hardened concrete.

Construction work in hot climates spans two seasons - dry and wet with more construction in the dry season. Heavy rainfalls constitute a major source of water penetration into buildings through the pore of poorly compacted concrete leading to dampness. When the quality of concrete is poorly controlled the stress-strength ratio is increased and the reliability of the structural unit is low and when the ratio is increased and the reliability of the structural unit is low and when the ratio exceeds unity the structure is highly susceptible to collapse. In Nigeria, the recent cases of collapsed buildings during construction are indicative of poor quality control and lack of proper supervision.

The objectives of this study are:

(1) Examine those factors that affect the quality of concrete
(2) Assess the effects of poor quality control on performance of concrete in service
(3) Present quality control measures necessary to produce good quality concrete, and
(4) Examine the level of maintenance required to restore concrete with defects to a serviceable state during its lifetime.

QUALITY CONTROL:

Cristofolini et al [7] reported that quality measurement is critical in a quality system to evaluate production process reliability, defectiveness and non-quality cost. Proper assessment of the condition of each component of concrete is a prerequisite to production of good quality concrete. Usually, the locally manufactured cement appears fresh when being batched at jobsites. The imported cement would normally have complied with the relevant specifications in its country of origin but due to long period of shipment and storage before arriving on site, they are usually in an uncertain condition. Some would appear fresh and perform excellently well in the mix while others would contain hardened nodules or lumps. When these cement nodules or lumps are allowed in the concrete mix, they tend to behave like aggregate thereby reducing the actual quantity of cement available in the mix for hardening process. Since the nodules or lumps cannot withstand the stress which real coarse aggregate would normally withstand they may disintegrate under pressure thereby contributing to poor strength. Freshly dredged sand contains high moisture and both fine and coarse aggregate stored on site over a period of time may be extremely wet on the day of casting concrete as a result of heavy rainfall and if they have to be used, the water/cement ratio must be adjusted accordingly otherwise low quality concrete is produced. The water for concrete work may contain some impurities that if allowed in concrete may impair strength development.

Often, at the design stage of a building project, the quality of constituents, proportions and strength of concrete are specified. On job sites, however, variations do occur in the quality of constituents of concrete, which may adversely affect the quality, and durability of concrete produced, if the proportions specified are used. In order to reduce these inevitable variations to a minimum and ensure that concrete for structural work is uniform both in workability and strength a good quality program must be put in place. This ensures design reliability and guarantees conformance with construction specifications (The cement is to comply with the requirements in BS 12 [8] and both fine and coarse aggregates are to conform with the grading requirements in BS 882 [9] while the water must be free from impurities).

Table 1 shows the characteristics of mixtures with inappropriate proportions of its constituent materials while Fig. 1 is a schematic representation of quality control measures as a tool for the production of good quality concrete.

MAINTENANCE:

British Standards Institution [10] defines maintenance as "Work undertaken in order to keep or restore facilities i.e. every part of a site, building and contents to an acceptable standard". All buildings are prone to deterioration and thus require adequate maintenance to prolong their life spans. The susceptibility of buildings to deterioration is traceable to the materials used in construction, geographical location and environmental conditions. Several defects associated with reinforced concrete are due to poor quality control during construction. The effect of high temperature (solar radiation) and heavy rainfall (moisture penetration) cannot be over-emphasized. At the construction stage if the condition of concrete constituents are well assessed and appropriate precautions are taken to ensure that components are batched keeping in view the site conditions, deterioration will be minimal and less maintenance work will be required during the service life of the structure. The causes of failure in buildings include bad engineering design, faulty construction, poor workmanship, improper use and inadequate or lack of protection against excessive environmental stress. Usually, reinforced concrete forms the structural fabric of building structures, so un-rectified structural defects may result in the collapse of a building thus endangering lives and properties.

Two significant periods with regard to rectification of building defects are;

(1) the defects liability period, usually 6 months after the completion of the construction and

(2) beyond 6 months period. Those defects occurring within 6 months liability period are carried out by the contractor at no cost to the client but defects arising beyond this period are undertaken at full cost to the client except in the case of extremely new materials and components with little history of exposure where the manufacturers could still be held liable.

Table 1: Characteristics of Concrete Mixtures with inappropriate Content of Constituents

Proportion of Constituents	**Characteristics of Mixture**
Low water	Results in loss of mobility and compatibility. It gives rise to dry segregation, which results in crumbly mixture that can cause unnecessary delay and difficulty during mixing, placement and compaction. -
High water	Provides greater fluidity and decreases friction within the concrete matrix. It gives rise to weak concrete that cannot retain individual aggregate particles in a homogenous dispersion. It results in wet segregation and bleeding. Increases settlement and shrinkage.
Low cement	Leads to low adhesion between the paste and coarse aggregate. Produces weak concrete. It increases the water/cement ratio and workability of the mixture.
High cement	Gives sticky and sluggish mixtures particularly in the normal range of slump for cast-in-place concrete. It results in lower water/cement ratio and higher content of hydrating material thus reducing the workability of rich mixes. It increases shrinkage and cracking.
Low Fine Aggregate	Insufficient paste to lubricate the coarse aggregate. It results in increased workability and voids within the coarse aggregate fraction.
High Fine Aggregate	Increases the cohesion and causes the mixture to be sticky and difficult to move. It causes an increase in surface area of particles within the mixture, which increases the amount of water required to coat these surfaces. This can result in increased drying shrinkage and cracking.
Low Coarse Aggregate	Gives poor stability and increases workability. Provides weak concrete, segregation and bleeding.
High Coarse Aggregate	Mixture lacks sufficient mortar to fill the void system resulting in loss of cohesion and mobility. Results in honey combing due to incomplete compaction. Strength and impermeability of such mixture will be less than those for a well proportioned mixture

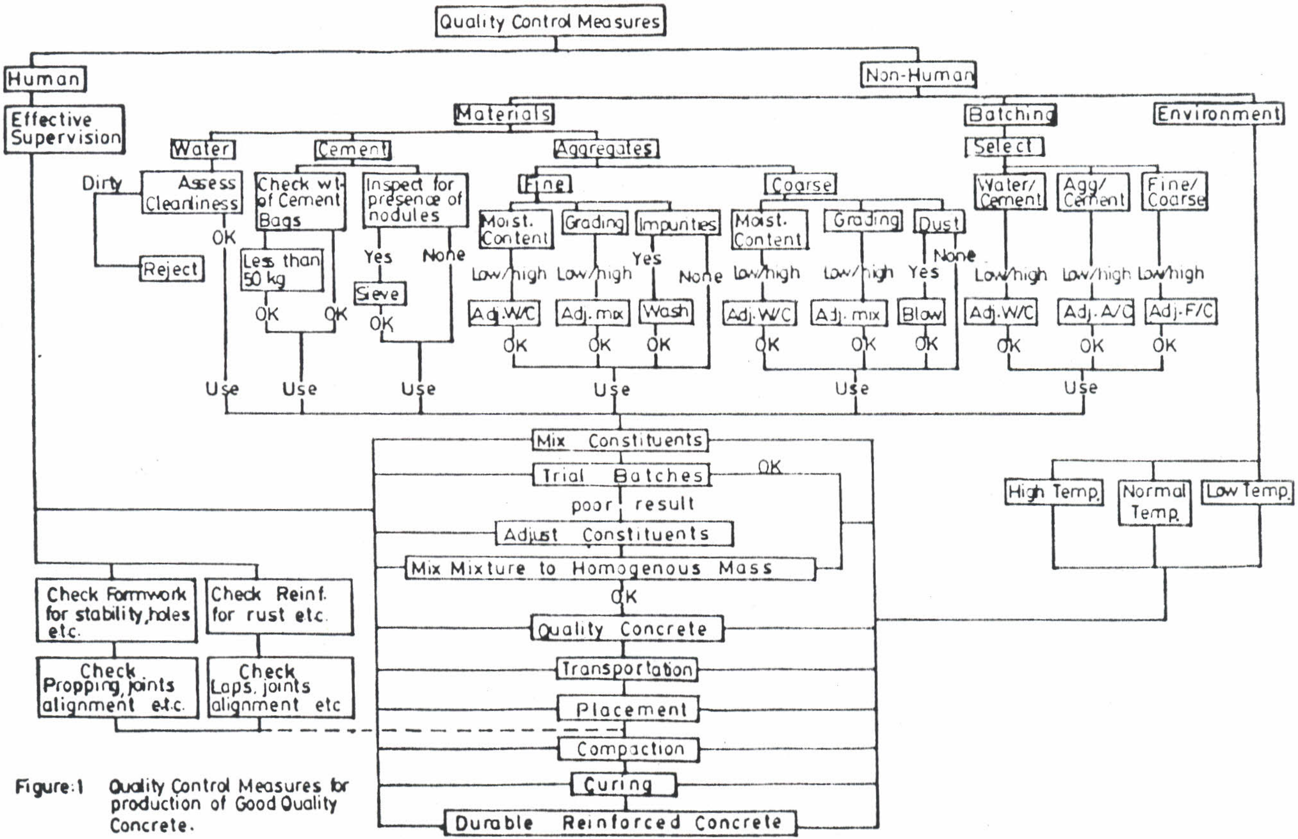

Figure: 1 Quality Control Measures for production of Good Quality Concrete.

Poor quality concrete when used in buildings results in defects listed in Table 2.
In preparing the Table 2, it is assumed that the engineering design and detailing are correct. While some of the defects can be seen and rectified within the 6 months liability period others for example, uneven settlement, excessive deflection, structural cracks may not be too obvious within this period but they become pronounced with age. Proper monitoring of the structure is required to determine the appropriate maintenance approach to adopt whether planned or unplanned. Lee [11] describes planned maintenance as "an attempt to eliminate as far as possible the need for day-to-day maintenance and to reduce the number of separately funded maintenance works by instituting a system of inspections at regular predetermined intervals and carrying out any minor repairs before they have time to develop into tasks of some magnitude". Planned maintenance can be corrective (making repairs only when faults have occurred) or preventive (work directed to prevent failure in a building or facility to ensure a continued operation in life time. Unplanned maintenance arises when unanticipated defects are observed and need to be corrected almost immediately to avert failure.

DISCUSSION:

It is observed from Table 1 that the quality of concrete is adversely affected as a result of deficiencies associated with mixtures having disproportionate quantity of each component. The constituents of concrete are proportioned to give concrete of adequate workability to assure good placement and compaction during construction and to ensure that hardened concrete gives the necessary properties during its life span. Water/cement ratio governs the strength and durability of concrete. The strength of concrete decreases as the water/cement ratio is increased above the optimum ratio for each mix. Too much water in a mix produces unstable concrete[Falade 12]. When the water/cement ratio in a mix is lower than its optimum water (cement ratio, the strength is also reduced. The higher the aggregate/cement ratio, the lower the strength because of the presence of voids and loss of cohesion between the aggregate and the paste. Aggregate must be well-graded to achieve concrete of good workability. The absence of a particular size of aggregate (gap – graded) or complete elimination of fine aggregate (no-fines) in a concrete mixture affects strength and other properties of concrete [Falade 13. When the sizes of aggregates supplied for construction deviate from those specified, necessary adjustment is required to maintain the same level of workability and strength as contained in the specifications. Usually, for construction work the ratio of fine/coarse aggregate is 0.5 for most prescribed mixes (1: 0.5: 3: 1: 2: 4: 1: 3: 6 – cement: fine: coarse). When a concrete mixture contains excess fine aggregate, cohesion increases, the mixture is sticky and difficult to work but when the fine aggregate content is inadequate the mixture lacks sufficient morter to coat the coarse aggregate resulting in the presence of voids, loss of cohesion and mobility. These adversely affect the strength and durability of hardened concrete. The reduction in strength may result in structural defect e.g. cracks, when the structure is loaded. The commonly used method of batching by volume (using headpan, wheel barrows or appropriately designed gauge boxes) on job site is very inaccurate and therefore proper supervision is essential to produce good quality concrete when the method is used.

The environmental conditions under which operations are carried out on sites cannot be controlled and these affect all the operations e.g. mixing, placing, curing etc. Proper assessment of the prevailing condition and application of appropriate measure will reduce the effect of the site conditions on hardened concrete. Some of the defects listed in Table 2, if not corrected on time may result in structural problem, which may give rise to structural failure in which lives and properties are lost. Fig. 1 indicates appropriate quality control measures that can be put in place on construction sites to produce good quality concrete and/or reinforced concrete. These measures are broadly categorised into two - Human and Non-human. The human aspect relates to effective supervision of construction tasks, ensuring adherence to specifications and good workmanship by the supervisor while the non-human measures are: the materials, batching procedure and the environmental conditions prevailing on the construction site when the work is being done. In considering these measures, supervision of all the other aspects of concrete production besides proportioning and mixing, formwork design and construction, placing concrete compaction and curing are necessary.

Equation (1) is formulated for the determination of compressive strength of field- cast concrete batches based on observed practical situations on job sites. The equation introduces 3 different coefficients that take cognisance of the conditions of the aggregates and the environment in which the work is being carried out

$$F_{28} = \frac{P}{A} (n_1 \, n_2 \, n_3) \qquad (1)$$

Where:

F_{28} - 28^{th} day compressive strength of field-cast specimen

P - Average cube failure load

A - Surface area of the cube

n_1 - Coefficient that takes cognisance of variation in fine aggregate from specified
$n_1 = 1.0 - 1.2$

n_2 - Coefficient that considers variation in coarse aggregate from specified
$n_2 = 1.0 - 1.25$

n_3 - Coefficient that takes cognisance of the environmental condition. For low and medium temperatures $n_3 = 1.0$ for high temperature $n_3 = 1.0 - 1.1$

These coefficients enable the use of some constituent materials that somehow deviate from specifications without producing poor quality concrete.

Concrete of poorly controlled quality suffers early deterioration in service as a result of the associated defects. Such concrete requires early inspection to determine the root cause, the extent of the defects and the appropriate technical solution to restore the concrete member to a serviceable condition

Table 2: Defects in concrete of poor Quality Control and their locations in Building

Location	Defects	Caused by
Foundation	Cracks, uneven settlement	Incorrect selection of materials, improper proportioning, improper mixing and compaction. Inadequate depth and thickness of foundation and poor supervision
Ground Floor	Cracks, Dusting, dampness, water seepage, abrasion shrinkage	Wrong selection of materials, improper mixing and compaction. Hot, dry and windy conditions, temperature changes and rapid evaporation of water from the surface of the concrete, foundation settlement and poor supervision.
Beams, Columns, Staircase and lintel	Cracks (fine and structural) reinforcement corrosion, spalling of concrete and excessive deflection	Incorrect selection of materials, improper proportioning, improper mixing and compaction foundation settlement, inadequate support and poor supervision.
Suspended Floor Slab	Cracks (fine and structural) Dusting, reinforcement and corrosion, spalling of concrete, abrasion and excessive deflection	Incorrect selection of materials, improper proportioning, improper mixing and compaction. Hot, dry and windy conditions, high temperature changes, foundation settlement and poor supervision.
Flat roof slab, roof gutter	Cracks (fine and structural) reinforcement corrosion, spalling of concrete, dampness infiltration of water and abrasion	Incorrect selection of materials, improper proportioning, improper mixing and compaction. Hot, dry and windy conditions, high temperature changes, heavy rainfall, temperature gradient, improper fixing of joints and poor workmanship.

CONCLUSIONS:

From the foregoing, the following conclusions are made:

(1) The inevitable variations in the quality of concrete cast on job sites can be reduced by adequately monitoring the conditions of the concrete constituents

(2) Adjustment in the proportions of concrete constituents in conformity with site conditions enhances production of good quality concrete

(3) Concrete of poor quality suffers premature deterioration, requires early inspection and maintenance.

RECOMMENDATIONS:

These recommendations are considered necessary precautions for the production of good quality concrete

(1) It is a good practice to use cement from the same source for a project to reduce variation in quality of cement

(2) Proper storage of cement and using it in order in which it is delivered to site (First-In-First-Out) will help to ensure cement quality

(3) To ensure that the required grading of coarse aggregate remains sensibly the same for every batch of concrete, it is necessary to order the different single-sized aggregates and recombine them in the correct proportions at the mixer. Aggregate stockpiles on site must be adequate. When the grading of aggregates is controlled and stockpiles are adequate without adverse weather condition (e.g. heavy rainfalls), the water/cement ratio may not vary significantly. Therefore, this ratio should be kept reasonably constant during the period of casting concrete.

REFERENCES

1. K. Amonoo-Neizer And K.A. Solomon-Ayen (1987) "Variability of Concrete Strengths in Ghana," Proc. First International Conference on Structural Analysis and Modeling 14 – 16 July, 1987 Kumasi Ghana pp. 433 – 447.

2. Y. Muzaffer, F.C. Wai and N. Alvin (1983) "In-Place Flexural Strength Evaluation of Concrete" Proc. of Fourth Engineering Mechanics Division Specialty Conference on Recent Advances in Engineering Mechanics and their Impact on Civil Engineering Practice 23 – 25 May 1983. Purdue University, Indiana, pp. 1032 – 1035

3. S. Jalali and M.Y. Abyaneh (1995), "Prediction of Final Concrete Strength in Hot Climates" Magazine of concrete Research, Vol. 47, No. 173 pp. 291 – 297.

4. F. Falade (1991), "Influence of Method and Duration of Curing and of Mix Proportions on Strength of Concrete Containing Laterite Fine Aggregate" Journal of Building and Environment, Vol. 26, No. 4 pp. 453 – 458

5. A.S. Tamim, H.M. Wajahat and F.W. Faisal (1996), "Plastic Shrinkage Cracking of Normal and High-Strength Concrete: A Comparative Study". ACI Material Journal, Vol. 93 No. 1 pp. 36 – 40.

6. N.Jackson(1984), " Civil Engineering Materials" Third Edition, English Language Book Society, pp.110-209.

7. I. Cristofolini, G. Mancuso and G. Wolf (2000), Defects Monitoring Incidence on Quality Forecasting, "Proceedings of Third International Conference on Quality Reliability and Maintenance", held in University of Oxford England 30th – 31st March 2000 pp. 27 – 31.

8. British Standard BS 12 (1971), "Portland Cement (Ordinary and Rapid Hardening); Part 2". British Standard Institution, London

9. British Standard BS 882 (1974); "Aggregates from Natural Sources for Concrete, Part 2", British Standards Institutions, London

10. British Standard BS 3811 (1974), "Glossary of General Terms used in Maintenance Organization" British Standard Institution, London.

11. R. Lee (1985), "Building Maintenance Management", 2nd Edition, Crossby Lockwood Staples, London

12. F. Falade (1994); Influence of Water/Cement Ratios and Mix Proportions on Workability and Characteristics Strength of Concrete Containing Laterite Fine Aggregate Building and Environment, vol. 29, No. 2 pp 237 - 240

13. F. Falade (1999), "Effects of Separation of Grain Sizes of Fine Aggregate on Properties of Concrete Containing Granite Fines" Journal of the University of Science and Technology, Kumasi, Ghana Vol. 19, Nos. 1, 2 & 3 pp. 62 – 66.