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Incessant Collapse of Buildings in Nigeria: The Possible Role of the Use of Inappropriate Cement Grade/Strength Class

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Abstract**—**The use of low quality concrete has been identified as one of the main causes of the incessant collapse of buildings in Nigeria. Emphasis has been on the use of poor quality aggregates, poor workmanship and the use of lean concrete mix with low cement quantity as the reasons for the low quality of concrete used for building construction in Nigeria. Surveys conducted revealed that in the construction of most privately owned buildings where concrete trial mixes and concrete compressive strength quality assurance tests are not conducted, concretes used for building constructions are produced using the 1:2:4 mix ratio irrespective of the cement grade/strength class. In this paper, the possible role of the use of inappropriate cement grade/strength class as a cause of the incessant collapse of building in Nigeria is investigated. Investigation revealed that the compressive strengths of concrete cubes produced with Portland-limestone cement grade 32.5 using 1:2:4 and 1:1.5:3 mix ratios are less than the 25MPa and 30MPa cube strengths generally recommended for building superstructures and foundations respectively. Conversely, the compressive strengths of concrete cubes produced with Portland-limestone cement grade 42.5 using 1:2:4 and 1:1.5:3 mix ratios exceed the 25MPa and 30MPa generally recommended for building superstructures and foundations respectively. Thus, it can be concluded that the use of inappropriate cement grade (Portland-limestone cement grade 32.5), particularly for the construction of building foundations is a potential cause of the incessant collapse of buildings in Nigeria. It is recommended that the Standards Organisation of Nigeria should embark on creating awareness for Nigerians, particularly, the home owners and the roadside craftsmen that Portland-limestone cement grade 32.5 should not be used for the construction of building load-carrying members, particularly, building foundations in order to reduce the incessant incidence of collapsed building.

Keywords**—**Cement grades, Concrete strength class, Collapsed building, Concrete mix ratio, Portland-limestone cement.

I. Introduction

THE incessant collapse of building in Nigeria and its attendant/associated loss of life, loss of properties and injuries to the survivors of collapsed building incidents have become worrisome to the extent that the Council for the Regulation of Engineering Practice in Nigeria (COREN) has recently advocated for a death penalty for the owners of collapsed buildings [1]. The incidence of building collapse is common in all regions and all major cities of Nigeria such as Lagos, Abuja, Port Harcourt, Ibadan etc and the frequency of the incidence of building collapse is so high to the extent that no six months go by without at least one incidence of collapsed building somewhere in Nigeria [2]. As stated by the Nigerian Building and Road Research Institute (NBRRI), the government agency in charge of research and development of building and construction materials, the cases of building collapses are so numerous that it has become overwhelming to conduct a detailed investigation at every site of collapsed building [3]. The reported incidences of collapse of building have occurred in buildings under construction, buildings under renovation as well as buildings in service (i.e. buildings with occupants) [4].

Several authors such as [3]-[13], amongst others have identified various reasons for the failure of buildings in Nigeria. The reasons these authors amongst others identified include: lack of structural design, bad/faulty design, faulty design implementation, faulty construction methodology, foundation failure, excess loads on buildings due to unauthorised increase in number of storeys, use of unqualified/incompetent contractors and craftsmen/artisans, quackery, and poor workmanship. Other reasons identified by these authors include: poor project supervision and monitoring, lack of enforcement of building codes/non-compliance with specifications/standards, the use of low quality/substandard building materials, change of use of building, aged buildings, poor maintenance culture, failure to conduct site investigation to obtain geotechnical data/properties (such as the load-bearing capacity) of the soil of the building site and structural defects. Other technical causes of failure identified by these authors are: the adoption of wrong foundation, inadequate depth of placement of foundations, poor concrete mix ratio, poor concrete strength, improper walling, poor building material specifications, hasty construction and inadequate maintenance, The overturning and sliding of building by lateral loads such as heavy wind loads; deterioration of building, particularly, the corrosion of the reinforcement and fire inferno have also been identified as causes of collapse of buildings.

The socio, economic and political habits of Nigerians that contribute to the incessant collapse of building includes: “Corner cutting by the client or the contractor”, “Owner Constructor Syndrome”, building cost minimisation/control and corruption in the Nigerian construction industry. “Corner cutting by the client or the contractor” involves a deliberate

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use of sub-standards materials and/or the use of lower quantity of materials (e.g. lower quantity of cement and reinforcement bars). "Owner Constructor Syndrome" involves the owners engaging direct labour (basically roadside craftsmen or quacks) as they are not will/able to pay the professional fees; buying building materials without any idea of what type of materials is suitable for the construction of the different parts buildings [10], and deciding the quantity of materials (e.g. cement) to be used for their building). Corruption caused by poverty, excessive love for money (greed), politics in the award of contract, professional indiscipline, profit maximization by contractor, quackery, "godfatherism" and favouritism leads to a compromise on the quality of workmanship and on the quality and quantity of materials used for building constructions [11].

Of all the various causes of collapsed building identified by these authors amongst others, the use of low quality building materials was ranked: first [5], second to "quackery" [9], second to "Poor Workmanship by Contractors" [7], second to "improper supervision" [10] by the experts in the Nigerian building industry. The high ranking of the use of low quality building materials demonstrates that it is a major cause of collapsed building in Nigeria. The two strength given materials in reinforced concrete are the steel and the concrete. Most of the causes of collapsed building ascribed to the use of low quality building materials is ascribed to the use of low quality concrete. The low quality of concrete used for building construction has largely been ascribed to poor workmanship in terms of poor mixing and placement of concrete, and to the use of low quantity of cement [4], [12]. The low quality of concrete has also been blamed on the use of low quality materials such as fine and coarse aggregates with high silt content [8].

Another main cause of the incidents of collapsed building ranked high by the cited authors and by the experts in the Nigerian building and construction industry is the construction of buildings by quacks. As stated by NBBRI [14], 70% of building failures is caused by the engagement of quacks. The Nigerian construction industry consists of what can be termed the formal and the informal sectors. The formal sector consists of professionals such as architects, engineers, technicians, technologist, craftsmen/artesian, builders/contractors, quantity surveyors etc with formal education whose professional practices are regulated by their relevant professional bodies. The informal sector consists of roadside craftsmen/artisans such as bricklayers, draftsmen, iron benders, welders etc without any formal technical education, training, certification or license, whose professional practices are barely regulated by their various voluntary associations. The roadside craftsmen/artisans which are referred as quacks undergo informal training and/or learn the various crafts/trades such as bricklaying/masonry on the job. They have the practical skills required for mixing and placing concrete but without any theoretical understanding of the strength of materials, such as the grade/compressive strength of concrete and the factors that affect it such as mix ratios, water cement ratios, purity of the aggregates etc.

Conservatively, at least 70% of the buildings in Nigeria are owned by private individuals, 70% of which are poor (survive barely on an income that is less than one dollar per day) [11] and cannot afford to pay professionals for the design and construction of their buildings. Consequently, most of the building constructions in Nigeria are done by the roadside craftsmen who construct various types of buildings ranging from one storey building/bungalow to three/four storey buildings. The professionals in the formal sector of the construction industry only construct building owned by the government, corporate organisations (banks, industries etc), and a few educated and very wealthy individuals.

In the construction of building owned by government and corporate organisations, which are handled by the professionals, adequate structural designs are done and detailed material specifications; particularly the required concrete grades/compressive strength are specified. Trial mixes to achieve the specified concrete grades/strength class are conducted by the contractors and quality assurance tests are conducted on the samples of the concrete used for the building construction to ascertain that the concrete of the required strength are used for the building construction. Conversely, in the projects handled by the roadside craftsmen in, many or all of the necessary professional steps (designs, material specifications, trial mixes and quality assurance tests) are not conducted and the necessary professional supervisions are not provided. For example, in the construction of privately owned buildings, even majority of those owned by very wealthy Nigerians, no trial mixes, no concrete compressive strength quality assurance tests and no complete supervision by qualified professionals are done as the private individuals are not willing/able to pay for the quality assurance tests and/or complete professional supervision. This explains why as stated by NBBRI, 70%, 23.3% and 6.7% of collapsed buildings in Nigeria belong to private, public and corporate organizations respectively [3]. Since no trial mixes or concrete compressive strength quality assurance tests are conducted in the construction of most privately owned buildings in Nigeria, the roadside craftsmen as well as many qualified professionals usually construct privately owned buildings with concrete produced using 1:2:4 cement-fine aggregate-large aggregate mix ratio. Furthermore, the 1:2:4 cement-fine aggregate-large aggregate mix ratio is used for the construction of privately owned building by the roadside craftsmen and many qualified professionals irrespective of the strength class/grade of the cement as they are unaware of the presence of different cement grades in Nigeria.

The lack of awareness of the presence of different cement grades in Nigerian market is not peculiar to the roadside craftsmen and many professionals/practitioners in construction industries alone, as many Nigerian academics and researchers are equally unaware of the fact that there are different grades/strength classes of cement in the Nigerian market. This explains why the grade/strength class of the cement used by Nigerian authors such as [15]-[23], amongst others was not indicated in their published works on concrete strength. The roadside craftsmen, many professionals in the Nigerian construction industry, and Nigerian academics and researchers are only aware of the different cement brand names in Nigeria and consequently buy and use cement based on brand names rather than cement grades/strength classes.

Concrete grade/strength class C20/25 is the minimum/lowest concrete grade/strength class recommended for the construction of reinforced concrete load-bearing members (beams, slabs and columns) of building under mild exposure condition [24]. However, for durability purposes, a concrete compressive strength higher than that required for structural design is often needed. Consequently, concrete grades/strength classes C25/30 is often the recommended minimum/lowest concrete strength class for the construction of foundations that are completely buried in the soil (i.e. exposure class XC2 for reinforced concrete foundations that are completely buried in soil) [25]. Class 20/25 concrete is a concrete with a minimum cylinder crushing strength of 20MPa or a minimum cube crushing strength of 25MPa, while Class 25/30 concrete is a concrete with a minimum cylinder crushing strength of 25MPa or a minimum cube crushing strength of 30MPa [24], [25].

As earlier stated, emphasis has been on the use of poor quality aggregates, poor workmanship and the use of lean concrete mix with low cement quantity as the reasons for the low quality of concrete used for building constructions in Nigeria. The possible contribution of the use of inappropriate cement grade/strength class to the low quality of concrete used for building constructions and consequently to the incessant collapse of buildings has not been investigated. In this paper, the use of inappropriate cement grade as a possible cause of collapse of buildings in Nigeria is investigated. The investigation was conducted by comparing the strengths of concretes produced with Portland-limestone cement grades 32.5 and 42.5 using the 1:2:4 mix ratio that is generally used for building construction with the recommended minimum 25MPa and the 30MPa cube compressive strengths required for the construction of building reinforced load-bearing superstructure members and foundations respectively. The investigation also covered the determination of the cube compressive strengths of 1:1.5:3 and 1:1:2 concrete produced with the two cement grades which was conducted to establish if these richer concrete mixes would produce concrete with the recommended minimum 30MPa compressive strength required for building foundations.

II. Experimental

No experimental work to confirm the compressive strength of the Portland-limestone cement employed for this research was conducted by the authors because the Standards Organisation of Nigeria (SON), the agency in charge of standardisation in Nigeria has adjudged the cement to be of the right quality as the two grades of Portland-limestone cements used have NIS quality certificates/SON quality marks. The concrete used for this research was produced with cement grades 32.5 and 42.5 bought directly from the depots of the cement manufacturers in Ibadan which guaranteed that good quality cements (not adulterated cement and properly stored) were used for the research. The concrete used for this research was also produced with river sand (generally known as sharp sand) and 20mm crushed granites that are commonly used for concrete production in Nigeria. The particle size distribution of the sand was determined by sieve analysis. The concrete was produced with water of drinkable quality. Concrete cubes cast/moulded with three mix ratios of 1:2:4; 1:1.5:3 and 1:1:2 representing the ratios of cement to sand to crushed granite by weight and with 0.5 water-cement ratio were employed for the research. The concrete cubes were made and cured in accordance with the requirements of [26]. For each cement grade and for each of the three mix ratios considered, ten 150x150x150mm concrete cubes were subjected to compressive strength test in accordance with [27].

III. Result

The particle size distribution curve for the sand used for this work and the typical fracture or failure shape exhibited by all the concrete cubes are shown in Figs. 1 and 2 (a) respectively. The average compressive strengths for the concrete cubes made with cement grades 32.5 and 42.5 for all the three mix ratios are presented in Table I.

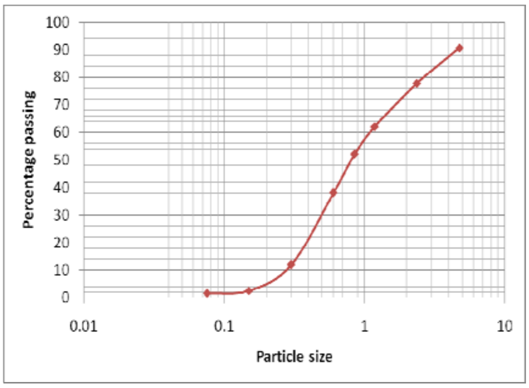
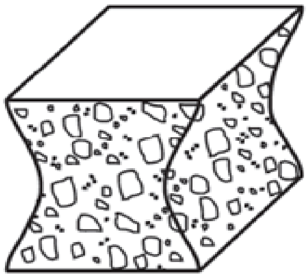


Fig. 1 Sand particle size distribution curve

(a) Fractured experimental specimen



(b) Acceptable cube fracture shape

Fig. 2 Fractured concrete cube

TABLE I
CONCRETE CUBES COMPRESSIVE STRENGTHS

Mix ratio	Strength N/mm^2	
	Cement grade 42.5	Cement grade 32.5
1:2:4	29.8	24.5
1: 1½: 3	30.1	27.0
1:1:2	30.6	29.6

IV. DISCUSSION

The shape of the fractured experimental cubes shown in Fig. 2 (a) agrees with the acceptable fracture shape specified in [27] shown in Fig. 2 (b). The good agreement between the fracture shape of the experimental cubes and the acceptable fracture shape establishes the validity of the compressive strength tests conducted in this work as it demonstrates that the compressive strength tests conducted in this work proceeded satisfactorily as specified in [27].

From Table I, the 24.5Mpa average strength of the 1:2:4 concrete cubes moulded with cement grade 32.5 compares well with the 23.8MPa reported by [23] who evaluated the compressive strength of concrete used in typical construction sites in Nigeria. The 24.5MPa cube compressive strength of the 1:2:4 concrete produce with Portland-limestone cement grade 32.5 is less than the 25MPa minimum cube compressive strength required for the construction of the reinforced concrete load-bearing building superstructure members. This result demonstrates that the concrete with the minimum 25MPa cube compressive strength required for the construction of building superstructure load-carrying members cannot be produced with Portland-limestone cement grade 32.5 using the 1:2:4 concrete mix ratio that is generally used for concrete production in Nigeria. Also from Table I, the 27.0MPa cube compressive strength of the 1:1.5:3 concrete produce with Portland-limestone cement grade 32.5 is more than the 25MPa minimum cube compressive strength required for the construction of the reinforced concrete load-bearing building superstructure members. This result demonstrates that a mix ratio of 1:1.5:3 which is richer than the 1:2:4 mix ratio that is generally used for concrete production in Nigeria is required to produce concrete with Portland-limestone cement grade 32.5 that will meet the 25MPa minimum cube strength required for the construction of building superstructure load-carrying members. Also from Table I, the 27MPa and the 29.6MPa cube compressive strengths of the 1:1.5:3 and 1:1:2 concretes produced with Portland-limestone cement grade 32.5 respectively are less than the minimum 30MPa cube compressive strength required for the construction of the reinforced concrete building foundations. These results demonstrate concrete with the minimum 30MPa cube compressive strength required for the construction of building foundations cannot be produced using Portland-limestone cement grade 32.5 as obtaining the minimum 30MPa strength will require concrete with a mix ratio richer than 1:1:2, which will be expensive (as it requires more cement) and beyond the reach of common Nigerians.

From Table I, the 29.8MPa cube compressive strength of the 1:2:4 concrete produce with Portland-limestone cement grade 42.5 is more than the 25MPa minimum cube compressive strength required for the construction of the reinforced concrete load-bearing building superstructure members. This result demonstrates that concrete with the minimum 25MPa cube compressive strength required for the construction of building superstructure load-carrying members can be produced with Portland-limestone cement grade 42.5 using the 1:2:4 concrete mix ratio that is generally used for concrete production in Nigeria. However, the 29.8MPa cube compressive strength of the 1:2:4 concrete produced with Portland-limestone cement grade 42.5 is less than the minimum 30MPa cube compressive strength required for the construction of the building reinforced concrete foundations. This result demonstrates that concrete with the minimum 30MPa cube compressive strength required for the construction of building foundations cannot be produced with Portland-limestone cement grade 42.5 using the 1:2:4 mix ratio that is generally used for concrete for building construction in Nigeria. Also from Table I, the 30.1MPa cube compressive strength of the 1:1.5:3 concretes produced with Portland-limestone cement grade 42.5 is more than the minimum 30MPa cube compressive strength required for the construction of the building reinforced concrete foundations. This result demonstrates that concrete with the minimum 30MPa cube compressive strength required for the construction of building foundations can be produced with Portland-limestone cement grade 42.5 using 1:1.5:3 concrete mix ratio.

While it would have been more scientific to determine the strengths of the cored concrete of collapsed buildings and relate them to the mix ratio and the grade/strength class of the cement used for their production, such a relationship is difficult to establish in Nigeria. This is due to the fact that most buildings constructed by the roadside craftsmen, particularly in the south-western Nigeria where various brand names and cement strength classes exist, are not constructed from foundation to finishing with a single cement grade/strength class, as the roadside craftsmen buy and use cement based on brand name and availability and not by grade/strength class since they are not aware of the presence of different grades of cements and their effects on concrete strength.

V. Conclusion

The investigation conducted to determine the contribution of the use of inappropriate cement grade/strength class to the incessant incidence of collapsed buildings in Nigeria is presented. The investigation was conducted to establish if the concretes produced with Portland-limestone cement grades 32.5 and 42.5 using the 1:2:4 mix ratio that is generally used by roadside craftsmen for building construction in Nigeria have the minimum strength required for the construction of building foundations and superstructure members to prevent failure of buildings. This study revealed that concrete with a minimum cube compressive strength of 25MPa required for the construction of building superstructure reinforced load-carrying members cannot be produced with Portland-limestone cement grade 32.5 using the commonly used 1:2:4 concrete mix ratio. The study also revealed that a mix ratio of 1:1.5:3 which is richer than the 1:2:4 mix ratio that is generally used by the roadside craftsmen for concrete production in Nigeria is required to produce concrete with Portland-limestone cement grade 32.5 that will meet the 25MPa minimum cube strength required for the construction of building superstructure load-carrying members. The study also revealed that the cube compressive strengths of the 1:1.5:3 and 1:1:2 concretes produced with Portland-limestone cement grade 32.5 are less than the minimum 30MPa cube compressive strength required for the construction of the building reinforced concrete foundations. These results demonstrate that concrete with the 30MPa minimum cube compressive strength required for the construction of building foundations cannot be produced with Portland-limestone cement grade 32.5 as producing concrete with the minimum 30MPa strength will require a mix ratio that is richer than 1:1:2, which will be expensive (as it requires more cement) and beyond the reach of Nigerians.

This study also revealed that concrete with a minimum cube compressive strength of 25MPa required for the construction of building superstructure reinforced load-carrying members can be produced with Portland-limestone cement grade 42.5 using the 1:2:4 concrete mix ratio that is generally used for concrete production in Nigeria. However, concrete with the minimum 30MPa cube compressive strength required for the construction of building foundations cannot be produced with Portland-limestone cement grade 42.5 using the 1:2:4 concrete that is generally used by the roadside craftsmen for foundation construction in Nigeria. The study further revealed that concrete with the minimum 30MPa cube compressive strength required for the construction of building foundations can be produced with Portland-limestone cement grade 42.5 using the 1:1.5:3 mix ratio. Thus, to produce a concrete having the minimum 30MPa cube compressive strength required for the construction of the reinforced concrete building foundations with Portland-limestone cement grade 42.5, a richer concrete mix ratio of 1:1.5:3 than the 1:2:4 concrete that is generally used for foundation construction by the roadside craftsmen is required.

Thus, it can be concluded that the use of Portland-limestone cement grade 32.5 for the construction of buildings, particularly building foundations, as it is presently practiced by the roadside craftsmen in Nigeria is inappropriate and could serve as a cause of the incessant incidence of collapsed buildings in Nigeria. While the use of 1:2:4 concrete produced with Portland-limestone cement grade 42.5 is appropriate for the construction of building load-carrying superstructure members, its use for the construction of building reinforced concrete foundations as is generally done by the roadside craftsmen in Nigeria is also inappropriate. Consequently, 1:1.5:3 concrete produced with Portland-limestone cement grade 42.5 which is richer than the 1:2:4 concrete that is generally used by the roadside craftsmen for the construction of most buildings in Nigeria should be used for the construction of building reinforced concrete foundations to reduce the incessant collapse of building in Nigeria. It is recommended that the Standards Organisation of Nigeria should embark on creating awareness for Nigerians, particularly, the home owners and the roadside craftsmen that Portland-limestone cement grade 32.5 should not be used for the construction of building reinforced load-carrying members, particularly, building reinforced foundations in order to reduce the incessant incidence of collapsed building in Nigeria.

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