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Material-Based Ultimate Moment of Resistance of a Rectangular Concrete Section

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ORIGINAL ARTICLE

ABSTRACT: The incessant collapse of buildings in Nigeria in recent years has been a major concern. This paper addresses one of the major possible causes of building collapse. The minimum compressive strength of concrete using pit-sand as a fine aggregate in Akure, Nigeria was statistically estimated. On the basis of the estimated nominal concrete strength, an implied ultimate moment of resistance of singly reinforced concrete rectangular sections is proposed. The proposal shows that the recommended resistance of concrete given by BS8110 (1997) may be reduced by as much as 50% in order to accommodate the minimum concrete strength for a 1:2:4 mix. A numerical design example based on the proposal showed the necessity of additional compressive reinforcement to justify the use of the current BS 8110 (1997) requirement if Akure pit-sand must be used as fine aggregate.

Keywords: Pit-sand, Concrete, Compressive Strength, implied Ultimate Moment of Resistance.

1. INTRODUCTION

In Nigeria, building collapse has become a common problem well reported in cities such as it Lagos, Port Harcourt, Abuja, Enugu and Ibadan. It is indeed a development that has added another chip to the jigsaw of urban decay (Fasakin, 2002; Ayininuola and Olalusi, 2004). Chinwokwu (2000) reported about 126 lives lost between 1980 and 1999 as a result of building collapse in one of the states in Nigeria. Table 1 gives a summary of recorded building collapse in Nigeria between 2004 and 2012.

However, in Nigeria, professional engineers design reinforced concrete structural elements without paying proper attention to the properties of available materials. Consequently, the ultimate moment of resistance of reinforced concrete section has always been over-estimated. However, buildings are to be designed and constructed with acceptable probability that they remain fit for the use for which they are required (Kingsley, 2010).

Baldrigde and Humay (Baldrigde and Humay, 2003) suggested that a structure should also be designed in such a way that it will not be damaged by events like explosions, impact or consequences of human errors, to an extent disproportionate to the original cause. The incessant collapse of buildings in Nigeria in recent years has been a major concern.

Pugsley (1973) identified eight parameters that seem to affect the occurrence of structural failure in which unusual materials used in construction is one of them, which in turn influences ultimate moment of resistance. Allen (1983) discovered that some structural failures are due to normal overloading or understrength such as tornado damage, some are due to accidental loads or weakness like fire and explosion in which most are due to human error. Most design errors resulting in structural failure other than deterioration are due to new or unusual materials, overloading, misplacement and omission.

Several causes of building failure had been attributed to either natural or man-made phenomena. A natural phenomenon may be attributable to earthquakes and typhoons while man-made phenomena consist of disaster which may be borne out of man's negligence in giving consideration to soil type and planning for extra loads and stress from strong winds and earthquake for tall buildings, foundation works, quality of building materials, lack or inadequate monitoring of craftsmen and poor quality of workmanship (Oloyede et al., 2010).

Ayedun et al. (2012) examines the increasing incidences of building collapse in Nigeria. They attributed the rising incidents of building collapse to the use of substandard building materials and incompetent professionals in construction activities; the refusal of the wider society to recognize professionalism and pay for the services and the attitude of the building contractors and other stakeholders as the major problem. Ede (2010a) asserts that promoting or achieving an enduring safety culture in building involves designing, constructing and using buildings, in such a manner as to make the building safe for occupation and for carrying out all desired activities. Strategies for ameliorating the trend are suggested and he posits that stakeholders in the building development have great roles to play to reduce and avert this trend.

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Table 1. Some of Recent Building Collapses 2004 – 2012

Date of incident	States	Types of buildings	No of lives lost/injured	Remote causes
Oct. 2004	Abia, Umuahia	Collapse of Bridge	4 dead, many injured	Structural defect/poor building materials.
May. 2005	IIudun, Ogun State	4 Storey Building	10 dead, many injured	Structural defect/poor building materials.
June. 2005	Aba	4 Storey Building	25 dead, many injured	Structural defect/poor building materials.
June. 2005	Lagos	3 Storey	20 dead, many injured	Structural defect/poor building materials.
July. 2005	Port-Harcourt	4 Storey	25 dead, many injured	Defective Foundation
July. 2005	Lagos	3 Storey	30 dead, many injured	Defective Foundation
July. 2005	Port-Harcourt	5 Storey Office Building	30 dead, many injured	Deviation from Approved Play / Addition of Floors
August. 2005	Adamawa	Collapse of Bridge	45 dead, many injured	Defective Foundation
August. 2006	Oworonshoki, Lagos	2 Storey Building	4 dead, many injured	Defective Foundation
August. 2006	Lagos	4-storey building	50 dead, many injured	Deviation from Approved Plan
April. 2012	Benue	Church Building	22 dead, 31 injured	Heavy down pour
January. 2012	FCT Abuja	Naval officer's quarter	Many Injured	Structural Defect

Source: Madu (2006) and Sunday Tribune (2012)

Ede (2010b) traced the causes of building collapse in Nigeria to abnormal factors not obtainable in many other developing nations. Apart from the generally known causes of collapse such as design flaws, ageing, material fatigue, extreme operational and environmental conditions, accidents, terrorist attacks and natural hazards, the Nigerian factor becomes a prominent issue to contend with. The Nigerian factor in the building industry rears up its ugly head in different forms such as corruption, lawlessness and our presumptions that any engineer or professional in the built environment can assume all forms responsibility in a building process without the basic skill required for it. Corruption is made manifest in greed and tendency to cheat in virtually every aspect, starting from poor materials and quality of work to the quantities we adopt. The use of unskilled labor, inexperienced professionals, and tendency of some professionals to cross-carpet to lucrative specialist duties where they lack the skill, ignorance and the abundance of quacks in the building industry are all facts to contend with. Excessive rain falls and poor drainage systems pose a serious problem to structures along the Nigerian coastlines (Ede, 2010b).

The Lagos State Government identified the principal causes of collapse within the Lagos area as: deficient foundations, inadequate steel reinforcement, poor materials and workmanship and inexperienced professionals, hasty construction, no soil test, greed, poor supervision, flooding, ignorance, lack of maintenance, overloading, conflicts among professionals and tendency of some professionals to step into some lucrative technical fields without the appropriate skill, corruption and tendency to cheat and non-adherence to the building codes.

Olanitori and Olotuah (2005) achieved a concrete of compressive strength between 8 N/mm^2 and 12 N/mm^2. This gives a reduction in strength of about 40% to 60%. In the design of building structures in Nigeria, standard mix according to BS5328 (British Standard Institution, 5328-1, 1997) is normally used. This method of mix is definitely not suitable for our local materials. The incessant collapse of building structures in Nigeria might not be unconnected with the reduction effect of fines such as silt in sand, on concrete.

Previous studies have not made any attempt to understudy the applicability of the ultimate moment of resistance in BS8110 (British Standard Institution, 8110, 1997) in a developing economy. Therefore in this present study, detailed experimental investigations on locally available materials were conducted to enable proper evaluation and possible modification of ultimate moment of resistance recommended by BS8110 (British Standard Institution, 8110, 1997) for use Akure, one of the major cities in the south western Nigeria.

Moreover, the characteristic strength of concrete produced in Akure was found to be about 50% less than the one provided on Table 3 of BS8110 (British Standard Institution, 8110, 1997). Therefore, there is need for the modification of ultimate moment of resistance of reinforced concrete section used in the design of reinforced concrete.

2.0 MATERIALS AND CONCRETE STRENGTH CHARACTERISATION

Pit-sand instead of sharp sand is commonly used as fine aggregate in concrete works in the study area. This is often mixed with granite and ordinary Portland cement. In the following section, physical properties of materials used to characterise the strength of concrete in this investigation are discussed.

2.1 Grading of aggregates

Sample of pit-sand was oven dried for 24 hours before carrying out sieve analysis according to BS 812-103 (British Standard Institution, 812, 1985). Sieves of various sizes were arranged in decreasing aperture from top to bottom and 500 g of soil sample were placed in a set of sieve and shaken vigorously for about 10 minutes. After this, the sample left in each sieve was poured and measured using digital weighing balance to determine the percentage passing on each sieve.

The results for the wet and dry sieve analyses are in Tables 2 and 3 respectively. The overall grading limit as given by BS882 (British Standard Institution, 882, 1992) requires percentage mass passing to be between 0 –

15% for sieve size 150 µm. The results in Table 2 show that sample does not satisfy the overall grading limit as given by BS882 (British Standard Institution, 882, 1992). The percentage mass passing is 17.84%, which indicates that the sand contains finer particles than the one recommended by 2.84%.

Table 2. Grain size distribution (Wet) for pit-sand in Akure

Sample No.	Pit-Sand (Akure)			
Weight of Sample	500 g			
Sieve Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	% Retd	% Passing
4.75	0.00	0.00	0.00	100.00
2.36	0.86	0.86	0.17	99.83
1.70	0.66	1.52	0.13	99.70
1.18	3.46	4.98	0.69	99.00
0.60	59.36	64.34	11.87	87.13
0.50	111.36	175.70	22.27	64.86
0.425	3.66	179.36	0.73	64.13
0.212	193.46	372.82	38.69	25.44
0.150	37.96	410.78	7.59	17.84
0.075	19.26	430.04	3.85	13.99
Pan	69.96	500.0	13.99	0.00

Table 3. Grain size distribution (Dry) for pit-sand in Akure

Sample No	Pit-Sand (Akure)			
Weight of Sample	500 g			
Sieve Diameter (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	% Retd	% Passing
4.75	0.00	0.00	0.00	100.00
2.36	4.00	4.00	0.80	99.20
1.70	4.10	8.10	0.82	98.38
1.18	7.20	15.30	1.44	96.94
0.60	97.90	113.2	19.58	77.36
0.50	178.70	290.90	35.74	41.62
0.425	9.20	301.10	1.840	39.78
0.212	153.30	454.40	30.66	9.12
0.150	27.50	481.90	5.50	3.62
0.075	13.40	495.30	2.68	0.92
Pan	4.70	500.00	0.92	0.00

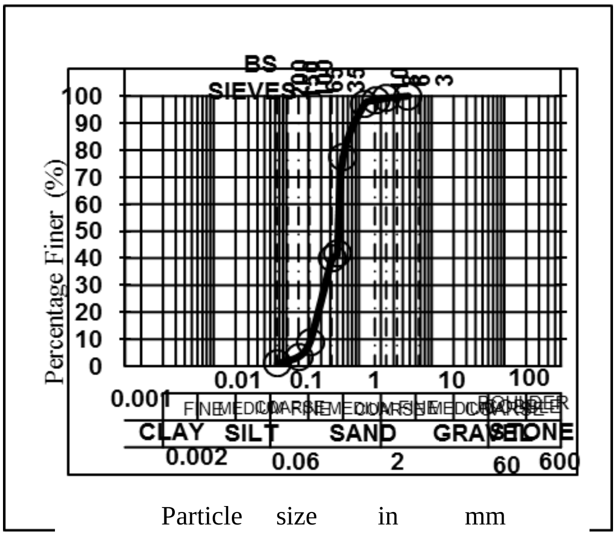

Figure 1. Particle size distribution curve for Akure pit-sand (dry)

2.59 and 1.06 respectively. Since, $C_u < 4$ and $C_z = 1.06$ which is between 1 and 3 in the Unified Soil Classification System, the soil is classified as poorly graded sand. More than half of the coarse fraction is not retained on the No 4 sieve showing that the aggregate is poorly distributed.

According to the unified soil classification system, the sand sample is a fine – grained soil (sand) because more than half of the coarse fraction is between the No 4 (4.75 mm) and No 200 (0.075 mm) sieve size (Tables 2 and 3).

2.2 Coarse aggregate (Granite)

The type and source of coarse aggregate used in the production of concrete can have considerable influence on the compressive strength of concrete. Crushed coarse but smooth aggregate of size 14 mm is commonly used in the study area and it is the same that is employed in this investigation. Table 4 displays the coarse aggregate properties and Figure 2 shows the coarse aggregate grading.

Table 4. Coarse aggregate properties

Coarse aggregate properties	Coarse
Fineness modulus	5.78
Specific gravity, G_s	2.65
Bulk Density (kg/m^3)	1635
Absorption	1.86

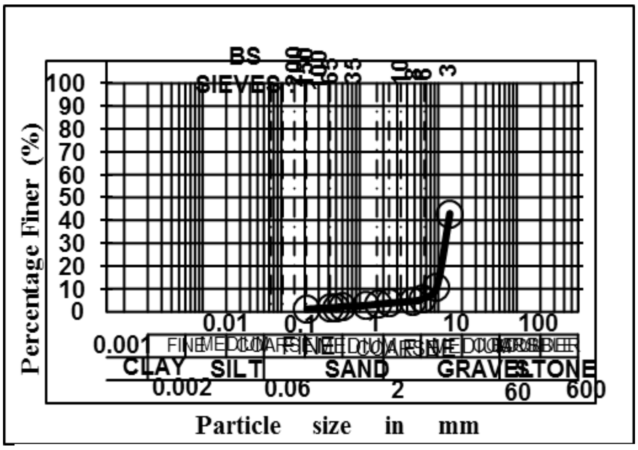

Figure 2. Particle size distribution curve for granite

2.3 Mean compressive strength

The characteristic compressive strength, f_{cu} for the concrete made from the aggregate discussed in section 2.1 and 2.3 respectively at different ages was calculated using

$$f_{cu} = f_m - 1.64\sigma \qquad (1)$$

In Equation (1), f_{cu} is the characteristic compressive strength of the concrete, at any age,

f_m is the mean target strength of the concrete at any age and σ is the standard deviation of the sample values.

From Table 5, the characteristic strength at 28 days for different concrete mix ratios are displayed. Different mix ratios were investigated to probe into optimum proportioning of the aggregates.

It is obvious from the result that 1:2:4 mix is more consistent. However, the characteristic f_{cu} is much lower than the minimum recommended, indicating the poor quality of the constituent materials.

Table 5. Characteristic compressive strength, f_{cu} of concrete

Mix	Mix Ratio	Characteristic Compressive Strength, f_{cu} (N/mm^2)			
		7 days	14 days	21 days	28 days
A	1:2.1:1.8	7.73	12.36	7.59	10.53
B	1:2:4	10.56	10.15	10.40	10.13
C	1:2:4.5	7.72	9.63	9.84	8.32
D	1:2:5	7.33	7.03	5.18	10.44
E	1:2.5:6	6.30	7.38	8.36	6.91
F	1:3:5	7.93	8.33	10.70	8.26

3.0 IMPLIED ULTIMATE RESISTANCE

3.1 Basic consideration

Ultimate moment of resistance of concrete section in compression given by BS8110 [16] is used to examine resisting capacity of concrete produced in Akure, Nigeria. This moment of resistance is taken as:

$$M_{ult(c)} = 0.156 f_{cu(c)} bd^2 \quad (2)$$

where $f_{cu(c)}$ is the characteristic compressive strength usually taken as 20 N/mm^2 [19], b is the width and d is the effective depth of a rectangular section.

Hence, substituting $f_{cu(c)}$ = 20 N/mm^2 [4] into Equation (2) will give

$$M_{ult(c)} = 3.12bd^2 \quad (3)$$

Using the characteristic compressive strength, $f_{cu(m)}$ = 10.13 N/mm^2 obtained for the locally available materials in Akure for mix ratio of 1:2:4 in Equation (2) yields;

$$M_{ult(m)} = 1.58bd^2 \quad (4)$$

where $M_{ult(m)}$ is the corresponding ultimate resistance.

From Equation (3) and (4), the proposed modified ultimate moment of resistance for a rectangular section, M^i_{ult}, is given

$$M^i_{ult} = \frac{f_{cu(c)}}{f_{cu(m)}} * M_{ult(m)} \quad (5)$$

so that, $M^i_{ult} = 1.98M_{ult(m)}$ (6)

In order words, if in the design process, f_{cu} = 20 N/mm^2 must be used, the actual resistance of the section based on the available material (pit-sand) should be taken a $M^i_{ult} = 0.156\lambda_o f_{cu} bd^2$ (7)

In which $\lambda_o = \frac{1}{1.98}$. That is,

$$M^i_{ult} = 0.08 f_{cu} bd^2 \quad (8)$$

Equation (8) shows a 50% reduction of concrete resistance recommended in BS8110 [16].

3.2 Implication of the proposed resistance

The consequence of the proposed resistance is that the use of pit-sand will lead to weaker concrete sections. To buttress this fact, the following design example is given.

A simply supported rectangular beam of 7 m span carries characteristic dead (including self-weight of beam), g_k, and imposed, q_k, loads of 10 kN/m and 8 kN/m respectively. The beam dimensions are breadth, b = 275 mm and effective depth, d = 450 mm.

Solution

Ultimate load $(w) = 1.4g_k + 1.6q_k$ (9)

Design moment $(m) = \frac{wl^2}{8} = \frac{26.8 \times 7^2}{8}$ $= \mathbf{164.15\ kNm}$

$(M_u) = 0.156 f_{cu} bd^2$ (10)

$= 0.156 \times 20 \times 275 \times (450)^2 \times 10^{-6}$

= 173.7 kNm

Since $M_u > M$, design as a singly reinforced beam

$$K = \frac{M}{f_{cu}\,bd^2} = \frac{164.15 \times 10^6}{20 \times 275 \times (450)^2} = 0.147$$

$$Z = d\left[0.5 + \sqrt{\left(0.25 - {}^{K}/_{0.9}\right)}\right] \quad (11)$$

$$Z = 450\left[0.5 + \sqrt{\left(0.25 - {}^{0.147}/_{0.9}\right)}\right]$$

= 357.5 mm ≤ 0.95d (= 427.5 mm)

$$= \frac{M}{0.95 f_y Z} = \frac{164.15 \times 10^6}{0.95 \times 460 \times 357.5}$$

$A_s = 1050\ mm^2\ (4T20, A_{sprov} = 1260\ mm^2)$

Using the same example given above for the result obtained based on the material we have

Implied ultimate resistance $(M^i_u) = 0.08 f_{cu} bd^2$

$= 0.08 \times 275 \times (450)^2 = \mathbf{89.1\ kN/m}$

Since $M^i_u < M$, design as a doubly reinforced beam and compression reinforcement will be required.

Compression reinforcement

Assume diameter of compression bars$(\emptyset) = 16\ mm$. Hence

$$d^I = cover + {}^{\emptyset}/_{2} = 25 + {}^{16}/_{2} = 33\ mm$$

$$K = \frac{M^I_U}{f_{cu}\,bd^2} = \frac{89.1 \times 10^6}{20 \times 275 \times (450)^2} = 0.666$$

which leads to $K^I = 0.156$. Therefore,

$$Z = d\left[0.5 + \sqrt{\left(0.25 - {}^{K^I}/_{0.9}\right)}\right] = 375.5\left[0.5 + \sqrt{\left(0.25 - {}^{0.156}/_{0.9}\right)}\right]$$

= 277.7 mm

and

$$x = \frac{d - Z}{0.45} = \frac{357.5 - 277.7}{0.45} = 177.3\ mm$$

Thus,

$\frac{d^I}{x} = \frac{33}{177.3} = 0.186 < 0.37$ given in BS8110 (1997),

signifying that the compression steel has yielded. (7)

But

$$A^I_s = \frac{M - M^i_u}{0.95 f_y (d - d^I)} = \frac{(164.2 - 89.1) \times 10^6}{0.95 \times 460\ (450 - 33)} = 412.1\ mm^2 \quad (8)$$

Provide 3T16 $(A_{sprov} = 603\ mm^2)$

Consequently, the required tension reinforcement becomes

$$A_s = \frac{M_u}{0.95 f_y Z} + A^I_s = \frac{89.1 \times 10^6}{0.95 \times 460 \times 357.5} + 412.1$$

Provide 4T20, $A_{sprov} = 1260\ mm^2$

From this illustrative beam example, it is clear that if pit-sand must be used as fine aggregate, there will be need for compression reinforcement to ensure safety. Reinforced concrete beam designed to BS8110 [16] and constructed using pit-sand from Akure, the study area, will definitely not perform as expected.

4.0 CONCLUSION

The minimum compressive strength of concrete using pit-sand as a fine aggregate in Akure, Nigeria was statistically estimated. On the basis of the resulting nominal strength, an appropriate modification to the ultimate moment of resistance of singly reinforced rectangular concrete sections is proposed. The proposal shows that the recommended resistance of concrete given by BS8110 (British Standard Institution, 8110, 1997) may be reduced by as much as 50% in order to accommodate the minimum concrete strength for a 1:2:4 mix using pit-sand as fine aggregate.

Since the compressive strength of the concrete at 28 days used in the design of reinforced concrete sections could not be obtained using locally available material (pit-sand) in Akure, Nigeria as recommended by BS8110 British Standard Institution, 8110 (1997), therefore, the implied ultimate moment of resistance suggested in this study is recommended. A reinforced concrete beam designed based on the modification are compared with the required resistance in BS8110 (British Standard Institution, 8110, 1997) showed that compression reinforcement must be added to achieved a desired performance.

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