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Reliability Studies on Reinforced Concrete Column Subjected to Axial Load with Natural Stone as Coarse Aggregate

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Abstract

This paper presents the reliability assessment of a reinforced concrete column subjected to Axial loading. Locally available natural aggregate (NA) was used in concrete production, the results of preliminary tests revealed the aggregate was adequate for concrete production. A typical column cross section of 230 × 240 × 3000mm was adopted and probabilistically assessed. First Order Reliability Method (FORM) was employed to estimate the implied probabilities of failures. The results of the sensitivity analysis showed that the reinforced concrete column is structurally safe at length, breadth and depth of 3200, 240 and 230 mm with Probability of Failures of 1.14×10^{-3}, 8.45×10^{-4} and 8.45×10^{-4} respectively.

Keywords: *Axial load, column, Concrete, Natural stone, Reliability.*

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I. INTRODUCTION

Concrete is a heterogenous substance made up of numerous materials that influence its properties both in its fresh and hardened states. It is obtained by mixing cement, water and aggregates (in some cases with admixtures) in the right proportions. This mixture is then placed in a form and allowed to harden into a rock-like hard mass referred to as concrete. The hardening occurs as a result of chemical reactions between water and cement, it continues for a long time resulting in higher strength with age (Alhaji, 2016). Aggregates constitute about 75 percent of the body of concrete; hence their influence is extremely important in the quality of resulting concrete. The aggregates must be of proper shape (rounded or approximately cubical), clean well graded, strong, possess chemical stability, exhibit abrasion resistance and possess significant resistance to freezing and thawing (Gambhir, 2004).

According to Alhaji, (2016) concrete compressive, flexural and tensile strengths define the amount of resistance a structural element can offer to deformation. They are the most important properties of concrete from an engineering perspective. Concrete properties especially its strength are determined by the properties of the hardened mortar, coarse aggregates and the aggregates/mortar interfacial zone.

Reliability is the probability of a system performing its intended purpose for a certain period of time under defined operating conditions. The application of reliability and probabilistic methods in modern structural engineering analysis is being advocated. This is to ensure structures that are safe, elegant and meet client specifications are achieved (Aguwa, 2013).

In conducting the reliability assessment of reinforced a concrete column (RCC), two basic models exist in capacity or resistance calculations. First, the analytical formulas in codes are used while the second uses finite element analysis (Jiang *et. al.,* 2019). Structures designed before the introduction of the seismic code in the early 1970's are generally prone to damage and could even collapse in the event of occurrence of natural disasters or seismic waves. Hence it is important to retrofit structures which were not designed in line with the modern BS codes or reinforced concrete columns erected with deficient materials (Flores, 2007).

The absence of reliability entails probability that failure will occur. Hence the concepts of reliability and probability of failure form two extremes in the safety of a structural system. According to the probability theory, the sum of reliability and probability of failure is unity (Adewunmi *et al.,* 2017). This makes it easy to determine one variable when the other is known. The reliability index (β) is related to the probability of failure P_f by equation (1):

$$P_f = ø(-β) \qquad (1)$$

ø(-β) is the cumulative distribution function of the standard normal distribution.

Researchers have employed various methods in determining probability of failure of reinforced concrete columns. First-order reliability method (FORM) (Au et al., 2007; Katafygiotis and Zuev, 2008; Adewunmi *et al.,* 2017), Monte Carlo Simulation (MCS) (Paik *et al.,* 2009; Basaga *et al.,* 2012). FORM simplifies tasks and will be employed in determining the reliability indices and failure probabilities in this research.

The natural aggregate (NA) utilised in the production of concrete in this research was locally sourced (depicted in Plate I). It was sourced from Bida and its environs in Niger state, Nigeria. It has been used for several concrete construction purposes especially among the locals where it is sourced (Kolo *et el.,* 2019). However, there is need to know the reliability and level of performance of this material in reinforced concrete columns. This will provide adequate guidance for its use for specific structural purposes (columns) other than just knowing the compressive strengths. Kolo *et al.* (2019) conducted reliability studies on RC beam utilising this NA subjected to shearing forces, here washed and unwashed NA were used. Furthermore, Kolo *et al.* (2020) performed reliability analysis on RC beam with this NA, washed and unwashed NA were utilised also. Currently no research exists on reliability analysis with this NA on reinforced concrete column, hence this research is timely and justifiable.

Plate I: Cluster of Natural Aggregate

The aim of this research was to conduct structural reliability studies on reinforced concrete column subjected to axial load with Natural aggregate as coarse aggregate. The objectives were; determine the physical properties of the coarse aggregate, determine the 28 days compressive strength of the concrete produced and to conduct structural reliability studies on the reinforced concrete column.

II. MATERIALS AND METHODS

2.1 Materials

The following materials were utilised in the concrete production:

i. Cement: Grade 42.5N cement was purchased from local retailers in Minna, Niger state.
ii. Fine aggregate: The fine aggregate was sourced from a river bed in Chanchaga, it conformed to stipulations in BS EN 12620 (2019).
iii. Natural aggregate: The Natural aggregate was obtained from Bida environs in Niger state. Result of preliminary test showed it conformed to stipulations as stated in BS EN 12620 (2019).
iv. Water: The water used for concrete production was sourced from the civil engineering departmental laboratory. It met stipulations as enumerated in BS EN 1008 (2002).

2.2 Compressive Strength Test

Concrete cubes measuring 150 mm × 150 mm × 150 mm were cast and cured for 28 days in a curing tank. The cube casting was performed in accordance to BS EN 12390-2 (2009). The cubes compressive strengths were thereafter determined with the aid of the ELE 2000 kN capacity compressive testing machine.

2.3 Reliability Assessment

First order reliability method (FORM) was utilised in order to ascertain the level of safety in the reinforced concrete column. FORM assumes all input variables to be normally distributed (Barambu *et al.,* 2017; Aguwa, 2013).

2.4 Column in Compression

A column is considered to be a short column when the ratios $\frac{L_{ex}}{h}$ and $\frac{L_{ey}}{b}$ are less than 15 (braced) and 10 (unbraced). It is otherwise considered to be a slender column.

Where:

L_{ex} = Effective height in respect of the major axis

L_{ey} = Effective height in respect of the minor axis

h = depth of cross section measured in the plane under consideration

b = Width of column

Consider a reinforced concrete column with the dimensions 240 × 230 × 3000 mm:

For an axially loaded short braced column;

According to BS 8110 (1997), the ultimate loading capacity is:

$$U_L = (0.67 \frac{fcu}{\gamma mc})\, A_c + (\frac{Fy}{\gamma ms})\, A_{sc} \quad (2)$$

Where:

U_L = Ultimate load capacity of column

f_{cu} = Characteristic strength of concrete

f_y = Yield strength of steel

γ_{mc} = Factor of safety for concrete = 1.5

γ_{ms} = Factor of safety for steel = 1.05

A_c = Net cross-sectional area of concrete in column = bh

A_{sc} = Area of vertical reinforcement = $\frac{\rho bh}{100}$, ρ = Reinforcement ratio,

b = smaller dimension of the column, h = larger dimension of the column

The Limit State equation for the column is:

$$R - S \quad (3)$$

R = Resistance, S = Load

Equation (2) can further be transformed into;

$$U_L = 0.45fcubh + 0.0095bhfy \quad (4)$$

Substituting all values in (4) gives:

Ultimate load, U_L = 4,158.75 kN. The U_L value is assumed to be the demand (D) on the column (that is D = 4,158.75 kN). Let Capacity (C) = Ultimate load a column can carry according to BS 8110 (1997), which is:

$$C = 0.45bh\,(f_{cu} + 2.11 \times 10^{-2} f_y\rho) \quad (5)$$

For a typical column, the conditions for checking its performance are:

G = C – D = 0 (Limit state)

G = C – D > 0 (Safe state)

G = C – D < 0 (Failure state)

With G = Performance function

The probability of failure in the column can be computed thus:

$$P_f = P\,(G = C\text{-}D < 0) \quad (6)$$

Equation (6) can further be transformed into:

$$P_f = P[0.45bh\,(f_{cu} + 2.11 \times 10^{-2} f_y\rho) - U_L] \quad (7)$$

$$G = C - D$$

$$G = 0.45bh\,(f_{cu} + 2.11 \times 10^{-2} f_y\rho) - U_L \quad (8)$$

Table 1 presents a summary of the input parameters generated for a particular column design. The input parameters are normally distributed because first order reliability method (FORM) was used for analysis. All dimensional properties are treated as normal distribution.

Table 1: Statistics of design variables for a short-braced column

Input Parameter	Mean	C.O.V	STD. DEV.	Distribution
Compressive Strength of concrete, f_{cu} (N/mm^2)	19.94	0.05	1.00	Normal
Tensile Strength of steel, f_y (N/mm^2)	460	0.05	23	Normal
Breadth of column cross-section, b (mm)	240	0.05	11.5	Normal
Depth of column cross-section, h (mm)	230	0.05	11.50	Normal
Length of column, L (mm)	3000	0.05	150.00	Normal
Imposed Load on column, q (kN)	215.96	0.3	64.79	Normal

Std. Dev: Standard Deviation C.O.V: Coefficient of Variation

III. RESULTS AND DISCUSSION

Fig. 1 presents the plot of reliability index (β) against the length of axially loaded column. It can be observed that a short braced reinforced concrete column under pure axial load is structurally safe at length not exceeding 3200 mm. The column is deemed unsafe at lengths exceeding this value with reliability index values falling below the target reliability index (β_T) of 3.0. The reliability indices generally reduced with an increase in the length of the column.

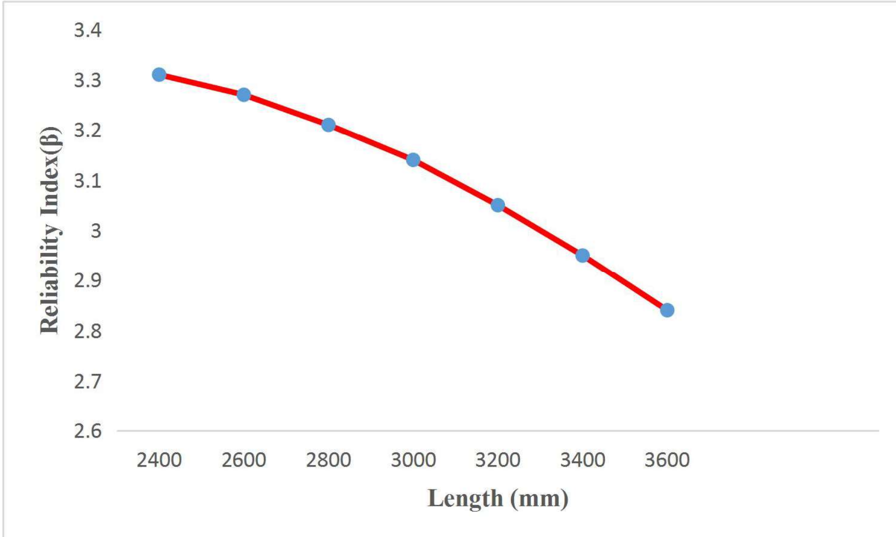

Fig.1: Relationship between Column Length and Reliability Index

Fig.2 presents the plot of reliability index (β) against the Breadth (b) of the Reinforced concrete column under axial load. It was observed that the reinforced concrete column under pure axial load is safe at a breadth of 240 mm with reliability index and probability of failure values of 3.14 and 8.45×10^{-4} respectively. A decrease in safety index was observed with decrease in the breadth of the column.

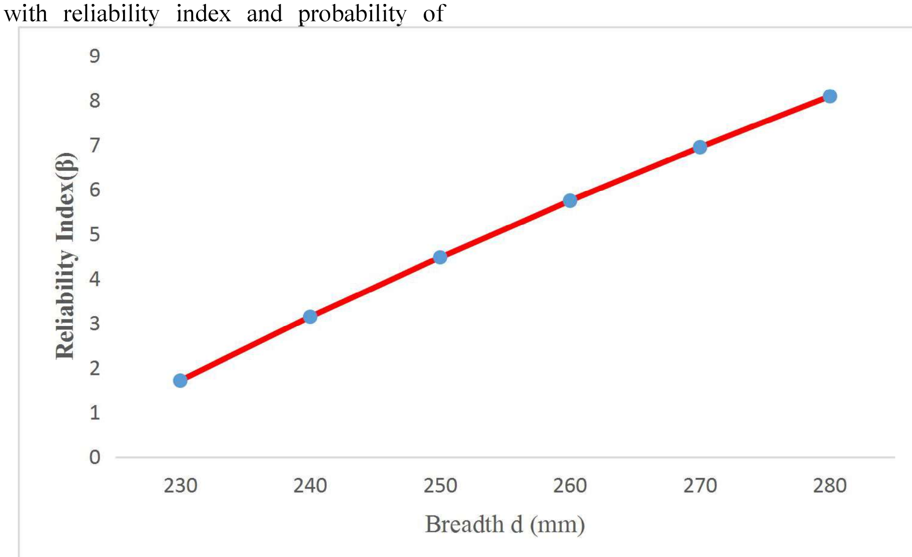

Fig.2: Relationship between Column Breadth and Reliability Index

Fig.3 presents the plot of reliability index (β) against the Depth (h) of the reinforced concrete column under axial load. It was observed that the reinforced concrete column under pure axial load is safe at a depth of 230 mm with reliability index of 3.14. A general increase in the column depth returned higher reliability indices. It should be noted that at larger depths the structure may be more reliable but not economical. This is because structural safety most put into consideration the financial implications involved in construction project execution and general utility of the structure (Aguwa and Sadiku, 2011).

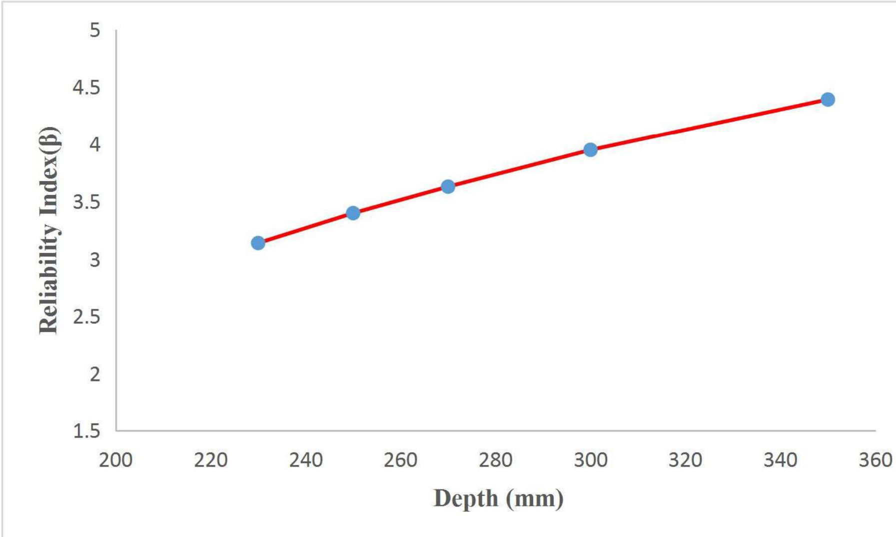

Fig.3: Relationship between Column Depth and Reliability Index

IV. CONCLUSION

A reinforced concrete column produced with locally sourced Natural aggregate under pure axial loading has been probabilistically examined in this research. The First Order Reliability Method (FORM) was employed in determining the level of safety of the column. The research concludes that the reinforced concrete column is structurally safe at length, breadth and depth of 3200, 240 and 230 mm with Probability of Failures of 1.14×10^{-3}, 8.45×10^{-4} and 8.45×10^{-4} respectively.

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