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STRUCTURAL RELIABILITY STUDIES ON PULVERIZED GLASS POWDER CONCRETE SUBJECTED TO BENDING FORCES WITH NATURAL AGGREGATE

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Abstract

The shortage of housing and basic infrastructure in Nigeria is increasing with a continuous rise in the price of construction materials. Cement is a major component in concrete production. Its production, however, is accompanied by huge carbon dioxide emissions. This research presents the results of structural reliability analysis conducted on reinforced concrete beam produced with pulverized glass powder as partial replacement for cement with Natural aggregate (NA) as coarse aggregate by subjecting it to bending forces. First order reliability method (FORM) was employed to determine the level of safety of the beam. The result of the sensitivity analysis showed that the pulverized glass powder beam with NA as coarse aggregate is structurally safe at a span of 3000 mm and depth of 600 mm with probabilities of failure of 1.00×10^{-3} and 1.04×10^{-3} respectively.

Keywords: ***Beam, Bending, Concrete, Natural Aggregate, Pulverized Glass, Structural Reliability***

I. INTRODUCTION

Cement is a very vital component of concrete production. The industry is a leading source of carbon dioxide emissions along with burning of fossil fuels and deforestation. Emission of these gases into the atmosphere results in global warming with CO_2 contributing about 65% to global warming. The cement industry worldwide is believed to be the source of about 7% of the entire greenhouse gas emissions on planet earth. Sequel to this premise, there exist an urgent need to identify alternative binders to make concrete. The reality of this has resulted in extensive research and analysis into the possibility of using waste materials and industrial by-products as partial cement replacement in concrete production [1].

Several efforts have been made by researchers in the construction industry into the use of waste glass powder as partial replacement of cement [6,8]. In this study finely powdered pulverized

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waste glass was used as partial replacement of cement in the production of concrete incorporating locally sourced Natural aggregate (NA) as coarse aggregate.

Deposits of the NA used in this research are found in abundance in Bida, Niger state, Nigeria. The use of this naturally occurring aggregate is common among the locals of this area. This is because it is cheaper and involves less energy and resources when compared to the process of producing the conventional crushed granite. [5] performed structural reliability analysis on reinforced concrete beam with washed and unwashed NA, currently no research exists on reliability studies of the NA and Pulverized glass as cement replacement, this research produces timely and justifiable results.

All structural engineers design structures with safety, aesthetics, and economy as factors of paramount importance. Hence the load carrying capacity of such structures must exceed the imposed demand on it. See Eq. 1:

$$\text{Capacity} > \text{Demand} \quad (1)$$

As long as the conditions in Eq. (1) are satisfied, structural safety is assured for all reinforced concrete structures [4].

According to Ali Mirza [5], uncertainties in the resistance of reinforced concrete members are as a result of variabilities in reinforced concrete constituent material strength and densities, the member geometry, the errors in calculations for strength, and the imposed loads. These result in difficulties in determining the absolute safety of reinforced concrete structures with deterministic approach. Hence, one of the most reliable approaches in determining the level of safety inherent in such a structure is by utilizing reliability analysis or by computing its probability of failure [6].

II. MATERIALS AND METHODS

The fine aggregate (FA) was sourced from a river bed in Chanchaga, Minna, Niger state. It was clean and free from impurities. It was ensured that the FA met guidelines as enshrined in BS 882 (1992). The water used was sourced from the Civil Engineering departmental laboratory, Federal University of Technology Minna, Niger state. The water was clean and fit for drinking; it met standards stipulated in [8]. The cement was Ordinary Portland cement (OPC) categorized as CEM 1 in [9]. The Natural aggregate (NA) was sourced from Bida local government in Niger state

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(Latitude N9˚55' E and Longitude N5˚52'E). It is a brownish-red aggregate. It conformed to stipulations in [7]. Waste glass from local glass/aluminum retailer in Minna was obtained and transported to the Civil Engineering departmental laboratory where it was further processed to pulverized form. The Natural aggregate and pulverized glass powder are presented in Fig. 1 and 2, respectively.

Fig. 1. Natural aggregate

Fig. 2. Pulverized glass powder

First order reliability method (FORM) was employed as the method of reliability analysis of the reinforced concrete beam. It is a simplifies method in which only the mean and standard deviations for load and resistance values ae used to compute reliability indices. All input variables are taken to be normally distributed [4].

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For a simply supported reinforced concrete beam, the performance function is represented by Equation 2:

$$Z = R - I \qquad (2)$$

Where R represents the resistance of the beam and I is the imposed load

Equation (2) can further be transformed into Equation (3):

$$g_1(x) = 0.156 f_{cu} b d^2 - \frac{W}{8} L^2 \qquad (3)$$

The input data for the various parameters used for reliability and sensitivity analysis is presented on Table 1, all variables are assumed to be normally distributed.

Table 1: Bending failure reliability analysis data

Parameter	**Value**	**COV**	**STD**
Thickness of slab, h_s (mm)	150	0.07	10.50
Height of Beam, h (mm)	400	0.05	20.00
Beam width, b (mm)	225	0.05	11.25
Beam effective depth, d (mm)	359	0.05	17.95
Diameter of tension bar, Φ (mm)	16	0.04	0.64
Area of tension reinforcement A_s (mm^2)	402	0.04	16.08
Shear reinforcement, A_{sv} (mm^2)	101	0.04	4.04
Concrete compressive strength f_{cu} (N/mm^2)	16.45	0.25	4.11
Concrete unit weight	24	0.04	0.64
Dead load, DL (kN/m)	17.70	0.10	1.77
Live load, LL (kN/m)	3.33	0.18	0.60
Yield strength of steel, f_y (N/mm^2)	460	0.05	23.0
Span of Beam, L (mm)	4000	0.22	880

COV: Coefficient of variation STD: Standard deviation

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III. RESULTS AND DISCUSSION

Tables 2, 3 and 4 present the results of the specific gravity tests conducted on the fine aggregate, pulverized glass powder and coarse aggregate (NA). The fine and coarse aggregates were found to have specific gravities of 2.60 and 2.68 respectively. These values are in line with BS requirements for 2.60 – 3.0 for fine aggregates and 2.4 – 2.8 for coarse aggregates. The specific gravity of PGP was found to be 2.45. this value is however lower than the specific gravity of 3.15 for cement.

Table 2: Specific gravity of Fine aggregate

Trials	**1**	**2**
Weight of empty cylinder (g) W_1	116.50	116.70
Weight of cylinder + water (g) W_4	436.30	404.00
Weight of cylinder + sample (g) W_2	204.60	175.30
Weight of cylinder + sample + water (g) W_3	482.00	430.90
Specific gravity	2.59	2.61
Average Specific gravity	2.60	

Table 3: Specific gravity of Pulverized Glass (PGP)

Trials	**1**	**2**
Weight of empty cylinder (g) W_1	116.50	116.70
Weight of cylinder + water (g) W_4	436.30	404.00
Weight of cylinder + sample (g) W_2	166.40	163.90
Weight of cylinder + sample + water (g) W_3	445.10	413.90
Specific gravity	2.55	2.35
Average Specific gravity	2.45	

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Table 4: Specific gravity of Coarse aggregate (NA)

Trials	**1**	**2**
Weight of empty cylinder (g) W_1	116.50	116.70
Weight of cylinder + water (g) W_4	257.80	231.70
Weight of cylinder + sample (g) W_2	446.20	430.40
Weight of cylinder + sample + water (g) W_3	358.00	358.60
Specific gravity	2.67	2.69
Average Specific gravity	2.68	

Table 5 presents the proportions of the various constituent materials used in the production of the PGP concrete.

Table 5: Mix proportions for various constituents of PGP Concrete

S/No	**Cement Content (%)**	**PGP (%)**	**Cement (kg)**	**PGP (kg)**	**Water (kg)**	**Fine Aggregate (kg)**	**Coarse Aggregate (kg)**
1	100	0	7.20	0.00	3.96	14.76	31.83
2	95	5	6.84	0.36	3.96	14.76	31.83
3	90	10	6.48	0.72	3.96	14.76	31.83
4	85	15	6.12	1.08	3.96	14.76	31.83
5	80	20	5.76	1.44	3.96	14.76	31.83

Fig. 3 presents the result of sensitivity analysis conducted on the beam span (L) for the Pulverized glass powder concrete beam subjected to bending forces. An increase in the span resulted in lower safety index values, these values were lower than the target reliability (β_T) value of 3.0. A general decrease in the beam span; however, produced increased safety index values. The beam was found to be safe at a span of 3000 mm with reliability index of 3.09 and Probability of failure (P_f) of 1.00 $\times 10^{-3}$.

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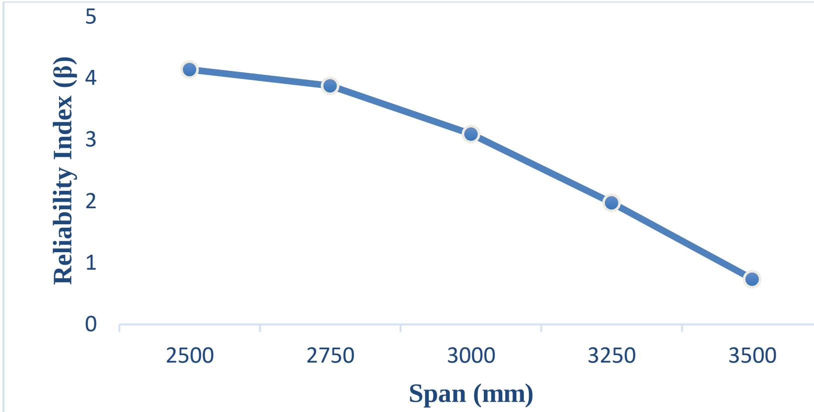

Fig. 3. Relationship between span and reliability index in bending

Fig. 4 presents the sensitivity analysis conducted on the beam depth. A general increase in safety index (β) was recorded as the depth was increased. The Pulverized concrete beam was adjudged to be structurally safe at a depth of 600 mm with corresponding safety index of 3.08 and probability of failure (P_f) of 1.04×10^{-3}.

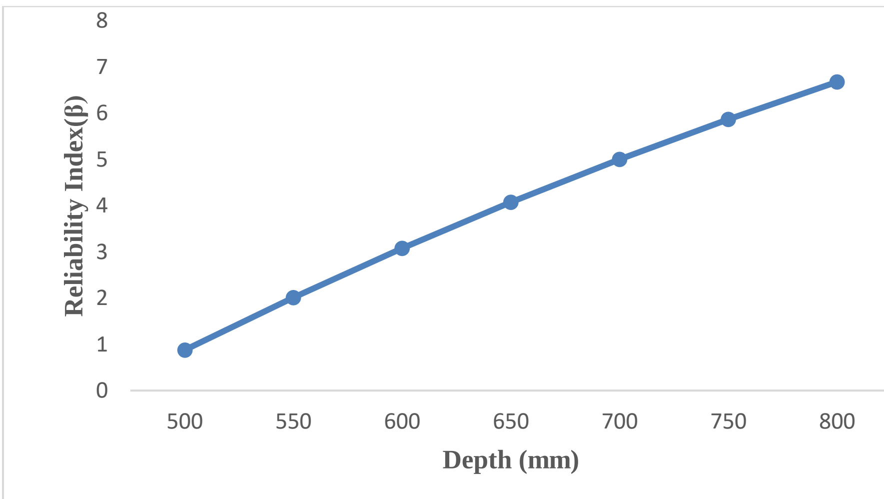

Fig. 4. Relationship between depth and reliability index in bending

The result of varying the dead load on the beam is presented in Fig. 5. A general increase in safety index was recorded as the design dead load (g_k) was reduced. The beam was deemed safe at an applied dead load of 7.70 kN/m with safety index of 3.37 and corresponding probability of failure (P_f) of 3.76×10^{-4}.

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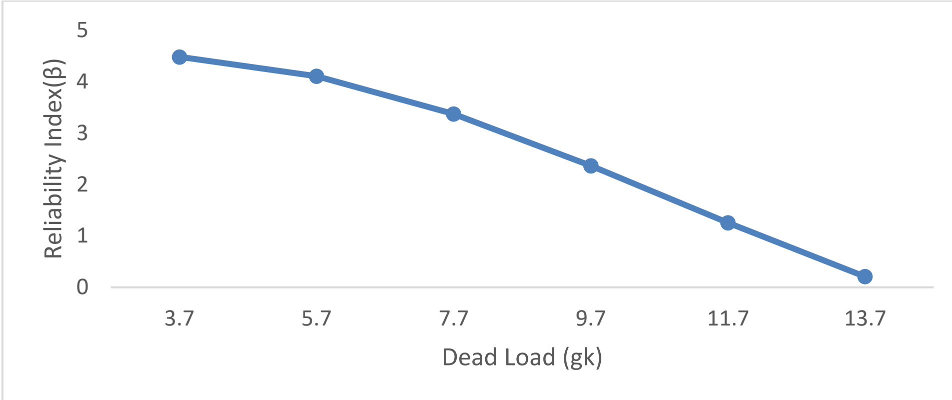

Fig. 5. Relationship between dead load and reliability index in bending

Fig. 6 presents the result of sensitivity studies conducted by varying the Area of Tension reinforcement (A_s) of the beam. The safety indices (β) increased with an increase in the area of tension reinforcement and reduced with decreasing A_s. The beam was adjudged safe with A_s value of 800 mm^2 and corresponding β of 5.04 and P_f 2.20×10^{-4}.

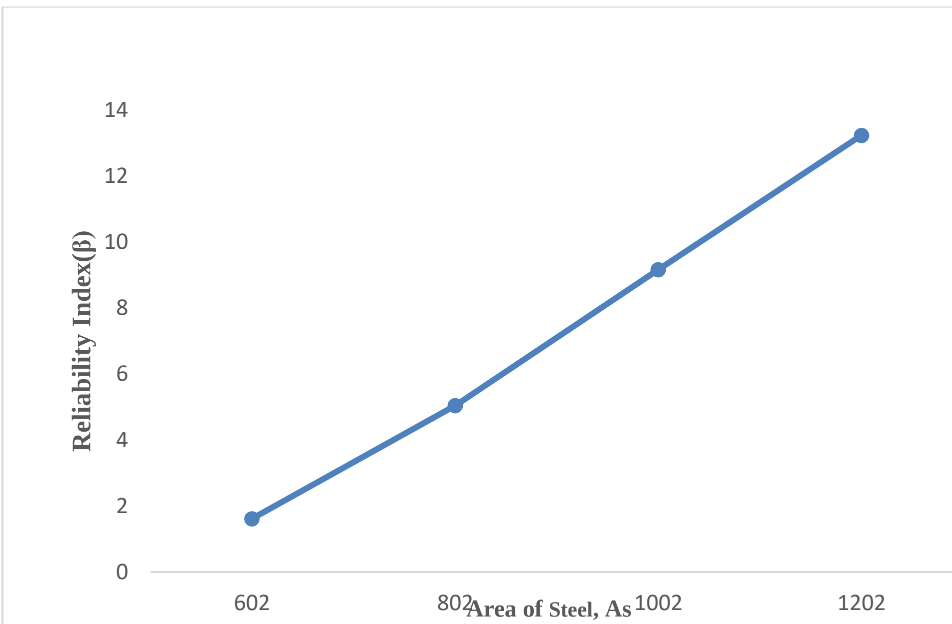

Fig. 6. Relationship between area of tension reinforcement and reliability index in bending

IV. CONCLUSION

The Pulverized glass powder reinforced concrete beam utilizing the natural aggregate as coarse aggregate is structurally safe at a span of 3000 mm and depth of 600 mm carrying a dead load of 7.70 kN/m with corresponding safety indices of 3.09, 3.08 and 3.37, respectively. The

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incorporation of this waste glass in concrete production has proven to be structurally efficient and should be encouraged as a step towards achieving sustainability in construction.

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