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Structural Performance of the Nigerian Grown Abura Timber Bridge Beam Subjected to Compression and Shearing Forces

J. I. Aguwa*

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Abstract

There is the need to subject some Nigerian timber species to reliability analysis in order to establish their structural usefulness. It is on this basis that the Nigerian grown Abura timber was studied and structurally assessed to understand its performance as timber bridge beams. This was achieved by preparing some test specimens of it from naturally seasoned samples at moisture content of 18%.and determining its strength properties, which were subjected to statistical analysis to obtain the mean, standard deviation as well as the coefficient of variation. Structural analysis, deterministic design and structural reliability analysis were performed on the Abura timber bridge beam at the Ultimate Limit State of loading. A computer programme developed in FORTRAN language and First-Order Reliability Method (FORM) were used in the reliability analysis. In order to study the effect of geometry and loading on the reliability index, sensitivity analysis was performed by altering the geometrical dimensions of the beam as well as the magnitude of the loadings on the beam. Satisfactory level of reliability indices were recorded at depth of 400 mm, breadth of 150 mm and span of 5000 mm under the ultimate limit state of loading. The Abura bridge beam depicted very low level of safety when subjected to only shearing forces under the specified design conditions. The probabilities of failure of the Abura bridge beam in compression and shear are 0.68×10^{-5} and 0.023 respectively, under the specified design conditions.

Keywords: *compression and shearing, Nigerian grown abura, strength, structural reliability, timber bridge beam*

1. Introduction

Abura with botanical name *Mitragyna ciliata* is a non-durable, tropical hardwood classified under the strength group of N4 in accordance with NCP 2 (1973) It is also in the strength group C30 grading in accordance with BS 5268 (2002). It grows commonly in swamp forests. Its resistance to impregnation is moderate with medium density as well as moderate resistance to attacks by insects and decay. It is used mostly for roofing, flooring, wall sheeting, formworks and furniture. The environment, the weather conditions and the soil affect the growth of trees which are the sources of timber for engineering applications. Most of the timber strength properties recorded in British and European codes were based on timber obtained from trees in those areas and the laboratory tests were conducted there. In order to have confidence in the use of Nigerian grown timber species, their strength properties should be subjected to structural reliability analysis (Aguwa, 2010). This reliability analysis will help in the proper identification of the specific areas of structural usage of these locally available timber. The only challenge in timber as structural material is that it has high degree of variability in texture within and between members and this makes its reliability studies very difficult, unlike steel or reinforced concrete that maintain the same texture throughout.

Honjo *et al.* (2002) used the First-Order Reliability Method (FORM) for estimation of partial factors for axially loaded piles and reported that the factors depend on resistance distribution and soil parameters' uncertainties. Also Haldar and Babu (2008) used the pile load-settlement data to develop a framework for the estimation of resistance factors for axially loaded piles based on probability theory. The fundamental aim of engineering design is to produce a stable, safe, economical, aesthetic and functional structure. Timber is a natural structural materials that does not go through much factory procession before use unlike other materials such as steel. Park *et al.* (2012) reported that for a given target reliability index, their developed LRFD method using the resistance factors calibrated in their study could contribute to cost savings when compared with Allowable Stress Design (ASD) case using a safety factor of 3.0. The variability within a timber member is not considered in engineering design, whereas each member is treated under assumption that it is homogeneous, that is, the strength is assumed to have a constant low value along the member (Hanson, 2001). The use of locally available raw materials such as timber in structures is a way of industrialization, economic advancement and creation of jobs for the teeming jobless people.

Han (2011) stated that the most important processes in structural analysis are the determination of the structural behaviour based

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*Senior Lecturer, Dept. of Civil Engineering, Federal University of Technology, Minna 920001, Nigeria (Corresponding Author, E-mail: jiaguwa@yahoo.com)

on structural types and variables and the sufficient examination of the effects on the whole structure. Usually it is difficult to understand the actual behaviour of structures with the uncertainties built into the design variables through deterministic analysis. The essence of structural design is to evaluate the expected performance of the entire structure or structural elements in terms of safety and functionality. The limit states of the structure are generally described in terms of the strength, stiffness, loads, cross-sections and geometry of the structure under consideration. These parameters are described as random variables and as such the result of design in limit state is full of uncertainty. It is the duty of the Engineer to employ a design approach that will guarantee high level of reliability. Ranta-Maunus (2004), reported that most structural failures occur as a result of gross human errors related to improper information accounted for during the theoretical analysis of the structure and such human errors cannot be resolved by structural reliability analysis. The beams or girders of the timber bridge deck which are major structural members of a timber bridge are considered. In order to verify the safety of timber bridge, Cheung *et al.* (2008) carried out a study of the reliability in a stress-laminated timber bridge considering real actions supplied by the Central Vias Highway Concessionaire. The aim of the work is to research the structural reliability of stress-laminated timber bridges with special focus on bending strength and stress losses. It was demonstrated that some types of truck can be dangerous for the wood bridges and the effect of those trucks must be considered in design procedures.

According to Park *et al.* (2006), it is not easy to accurately examine the safety of structures through evaluation method that uses safety factors selected based on experience and as such reliability method, which takes into account the uncertainties is better in the assessment of the safety of structures. Afolayan (2001) developed a reliability model for estimation of post-construction reliability of wooden floor subjected to human-induced vibrations. The effect of variability of materials and geometrical properties in addition to the impulse unit load on the reliability of the initial design is considered in the model.

This research aims at studying the structural performance of the Abura timber grown in Nigeria when used as bridge beams and girders. In order to realize the set goal, the following objectives were accomplished; determination of the strength properties which were statistically analysed, deterministic structural design of an Abura bridge beam subject to structural reliability with sensitivity analysis. According to Aguwa (2012), the local content and economic activities of Nigeria will greatly increase if Abura can be used as bridge beams and girders due to their abundance in Nigeria. In addition, the use of Abura grown in Nigeria as bridge materials will reduce importation of foreign construction materials.

2. Materials

2.1 Abura

Sawn Abura wood was bought from Sapele timber market in Delta state in Nigeria.

3. Method of Testing

Sawn pieces of 50 mm × 75 mm × 3600 mm of Abura samples were purchased and subjected to natural seasoning for eight months to be in the equilibrium moisture content range before the preparation, testing of the test specimens in accordance with BS 373 (1957). The natural seasoning was preferred to artificial seasoning which is faster because the proposed timber structure is bridge, which is always completely exposed to natural weather conditions (Aguwa and Sadiku, 2012) Twenty (20) test specimens

Fig. 1. Test Samples of Nigerian Timber

Fig. 2. Test Samples of Nigerian Timber

Fig. 3. Electronic Weighing Balance

Fig. 4. Testing Set-up for Compression Parallel to the Grain

Fig. 5. Test Set-up for Compression Perpendicular to the Grain

Fig. 6. Test Set-up for Shear Parallel to the Grain

were used each for compression and shear respectively. The Universal Testing Machine (UTM) used has a capacity of 50kN and was in good working condition. Proper care was taken to ensure that the test specimens were positioned according to the guidelines.

Figures 1-6 show the photographs of the test specimens of some Nigerian grown timber species including Abura, electronic weighing balance and different testing setups under the Universal Testing Machine (UTM) respectively.

4. Compressive Test

Standard size of specimen for compression parallel to the grain is 20 mm square in cross-section and height of 60 mm. The direction of application of load was longitudinal to the grain at a rate of 0.625 mm/minute as shown in Fig. 4. Proper alignment of the specimens with the axis of the machine was ensured during the operation. The basic compressive stress parallel to the grain for the Abura was determined by using Eq. (1) from Ozelton and Baird (1981):

$$c_{b\ par} = \frac{c_m - 2.33\,\sigma_c}{1.4} \tag{1}$$

where, c_m is the mean of the failure compressive stresses of the Abura parallel to grain and σ_c is the standard deviation for the failure compressive stresses from tests.

4.1 Compressive Strength Perpendicular to the Grain

Specimen used for determination of compressive stress perpendicular to the grain is a cube of 50 mm side. The loading was applied perpendicularly to the direction of the grain at a constant head speed of 0.625 mm/minute as shown in Fig. 5. Using Eq. (2), the basic compressive stresses perpendicular to the grain for the Abura was determined:

$$c_{b\ per} = \frac{c_m - 1.96\,\sigma_c}{1.2} \tag{2}$$

where, c_m is the mean of the failure compressive stresses perpendicular to the grain and σ_c is the standard deviation for the failure compressive stresses perpendicular to the grain from tests.

4.2 Shear Stress

The test specimen for shear parallel to the grain is a cube of 20 mm. The rate of loading was 0.625 mm/minute in the direction of shearing parallel to the grain as shown in Fig. 6. The machine jig is designed to shear the test piece into two and the failure shear stress was read directly from the dial gauge. The basic shear stress parallel to the grain for the Nigerian grown Abura was calculated using Eq. (3):

$$v_{b\ par} = \frac{v_m - 2.33\,\sigma_v}{2.25} \tag{3}$$

where, v_m represents the mean value of all the failure shear stresses parallel to grain and σ_v denotes standard deviation for all the failure shear stresses parallel to the grain from tests.

4.3 Modulus of Elasticity

Equation (4) was used to calculate the statistical minimum value of modulus of elasticity, E_N depending on the number of species acting together, N:

$$E_N = E_{mean} - \frac{2.33\sigma}{\sqrt{N}} \tag{4}$$

If the number, $N = 1$, the minimum value, E_{min} is used as E_N, E_{mean} denotes mean of the moduli of elasticity while σ is their standard deviation determined from tests.

Figure 7 shows the direction of testing timber specimens in accordance with the BS373 (1957).

4.4 Analysis and Design of the Abura Bridge Beam

The goal of analysis and design of timber structures is to ensure that the existing stresses or deformations caused by loadings are below the permissible limits for the material.

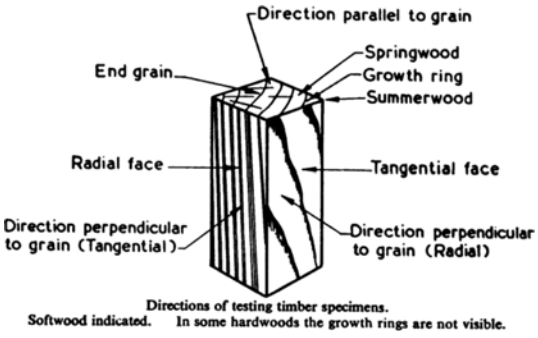

Fig. 7. Direction of Testing Timber Specimens

Table 1. Specifications for the Abura Bridge Beam Analysed

Bridge carriageway width (m)	7
Number of notional lanes (No)	2
Width of notional lane (m)	3.5
HA live load per notional lane (BS 5400) (kN/m)	30
Uniformly distributed load due to HA live load (kN/m)	8.57
Knife Edge load (KEL) per notional lane (BS 5400) (kN)	120
Uniformly distributed load due to KEL (kN/m)	34.20

Timber structures such as bridges are cost-effective, structurally stable, durable and aesthetically good if properly designed and protected from factors that cause defects. Defects in timber are generally avoided due to the fact that they reduce the strength and other good properties of the timber resulting in their rejection.

In order to subject the designed Abura timber bridge beam to the same conditions of loadings as any other types of bridge, specified standard loads from BS 5400; Part 2; 1978 were used in the analysis as shown in Table 1.

The geometrical properties of a typical Abura bridge beam and the determined parameters from tests on the Abura timber were used as input parameters in the analysis. These values are shown in Table 2.

4.5 Reliability of the Abura Bridge Beam

Reliability of the Abura bridge beam is the probability of its adequate performance throughout its designed life span. The main purpose of structural reliability analysis is to ensure that failure does not occur within the designed life span and even beyond while the bridge structure is in service. Mathematically, Reliability = Failure-Free. From Melchers (1987):

$$R = 1 - P_f \tag{5}$$

where, R is reliability and P_f is the probability of failure.

First-Order Reliability Method (FORM), which is a simplified reliability model first introduced in structural steel design is used in this analysis. It uses only the mean values and standard deviations for the load and resistance parameters in a particular limit state to obtain the reliability index. It does not require the knowledge of the type of probability distribution of the random variables. Eq. (6) linear performance function with a_i (i = 1, 2, ...n) as constants and X_i are random variables that are not correlated:

$$g(X_1, X_2, \ldots, X_n) = a_0 + a_1X_1 + a_2X_2 + \ldots a_nX_n = a_0 + \sum_{i=1}^{n} a_iX_i \tag{6}$$

Applying the three-step procedure for determining the Hasofer-Lind reliability index, we would obtain the following expression for β:

$$\beta = \frac{a_0 + \sum_{i=1}^{n} a_i\mu_{xi}}{\sqrt{\sum_{i=1}^{n}(a_i\sigma_{xi})^2}} \tag{7}$$

where, a_0, a_i are constants, μ is the expected mean of the variables and σ is the standard deviation.

Equation (8) was used to determine the probability of failure, P_f, from the reliability index, β and the standard normal distribution function, Φ (zero mean and unit variance):

$$\beta = -\Phi^{-1}(P_f) \quad \text{or} \quad P_f = \Phi(-\beta) \tag{8}$$

A simply supported uniformly loaded Abura bridge beam was subjected to structural reliability analysis to ascertain its performance. The analysis involves ensuring that existing shear and compressive stresses (bearing stress) are below the permissible values specified by the code.

Equation (9) from Ozelton and Baird (1981),was used to calculate the applied compressive stress at the support of the beam with breadth, b, end bearing length, L_b and the shear force, V:

$$c_{a\,per} = \frac{V}{b \times L_b} \tag{9}$$

The permissible or design compressive stress is calculated by Eq. (10):

$$c_{p\,per} = K_4K_7c_g \tag{10}$$

where, K_4 is the modification factor for bearing stress, K_7 is the

Table 2. Parameters used for the Analysis and Design of the Abura Bridge Beam

Design parameter	Value	Design parameter	Value
Unit Weight (UW) (kN/m^3)	5.62	Breadth of beam (b) (mm)	150
Coef. of variat. unit wt. COV$_{UW}$	6	Plank dead load (PDL) (kN/m)	0.23
Depth of beam (h) (mm)	400	Total live load (TLL) (kN/m)	6.17
Spacing of beam (Sp) (mm)	400	Mean failure shear stress (v$_{m\,par}$) (N/mm^2)	30.32
Depth of plank (hpl) (mm)	100	Std. deviation for shear stress ($\sigma_{v\,par}$) (N/mm^2)	10.31
Breadth of plank (bpl) (mm)	250	Grade shear stress ($\nu_{g\,par}$ 80%) (N/mm^2)	1.9
Span of beam (L) (mm)	5000	Coefficient of variation for shear stress (COVν_{par})	34
End bearing length (L$_b$) (mm)	300	Mean failure compressive stress (c$_{m\,per}$) (N/mm^2)	8.65
Minimum E (E$_{min}$) (N/mm^2)	6368	Std. deviation for comp. stress ($\sigma_{c\,per}$) (N/mm^2)	1.57
Mean E (E$_{mean}$) (N/mm^2)	8806	Coefficient of variation for comp. stress (COVc$_{per}$)	18
Std deviation for E (σ_E) (N/mm^2)	1047	Grade compressive stress (c$_{g\,per}$) (N/mm^2)	2.85
		Self weight of beam (SWBM) (kN/m)	0.34

Table 3. Statistical Parameters for the Basic Variables and Probability Distribution

Basic Variables	Probability Distribution	Coefficient of variation
Unit Weight of the Abura (UW)	Lognormal	11
Modulus of Elasticity of the Nigerian grown Abura timber (E)	Lognormal	12
Live Load on the Nigerian Abura bridge beam (LL)	Lognormal	20
Span of the Nigerian grown Abura bridge beam (L)	Normal	3
Breadth of the Nigerian Abura bridge beam (b)	Normal	6
Depth of the Nigerian grown Abura bridge beam (h)	Normal	6
Grade shear stress of the Nigerian Abura timber (v_g)	Normal	24
Grade Compressive stress of the Nigerian Abura timber (c_g)	Normal	9
Length of end bearing for Abura bridge beam (L_b)	Normal	9

depth modification factor and c_g is the grade compressive stress determined from test

The limit state or performance function in compression perpendicular to grain is given by:

$$g(x) = c_p - c_a \tag{11}$$

Equation (12) from Ozelton and Baird (1981), was used in calculating shear stress, v at any level of a build-up section based on elastic beam theory. The shear force is *V*, a is the area of the beam above the level at which *v* is required:

$$v = \frac{va\bar{y}}{IB} \tag{12}$$

I is the complete second moment of area of the beam at the cross-section being considered and *B* is the breadth of the beam at the level at which *v* is being calculated.

Since the Abura beam has a rectangular cross-section, the maximum shear stress occurring at the neutral axis was calculated from Eq. (13), from Ozelton and Baird (1981):

$$v_{a\,par} = \frac{3V}{2A} \tag{13}$$

V represents shear force, while A is the total area of the beam.

The design or allowable shear stress in the Abura beam was calculated using Eq. (14):

$$v_{p\,par} = K_3K_4v_g \tag{14}$$

K_3 and K_4 are the modification factors as defined in Tables 17 and 18 respectively of BS 5268.

Equation (15) is the performance function for the Abura beam in shear:

$$g(x) = v_p - v_a \tag{15}$$

Table 3 shows statistical parameters and their probability distribution of the basic variables used as input into the FORTRAN programme for reliability analysis.

5. Method of Analysis

The deterministic designed simply supported Abura bridge beam was subjected to reliability analysis using FORM5, which is a reliability software for evaluating the safety index (β) of structures. Table 4 shows design loads and geometrical properties of the Abura beam.

Table 4. Design Loads and Geometrical Properties of the Abura Beam

Span of the Nigerian Abura bridge beam (mm)	5000
Depth of the Nigerian Abura bridge beam (mm)	400
Breadth of the Nigerian Abura bridge beam (mm)	150
Design dead load on the Nigerian Abura bridge beam (kN/m)	0.66
Design live load on the Nigerian Abura bridge beam (kN/m)	9.26

6. Discussions

Tables 5 and 6 show the determined strength properties of the Abura grown in Nigeria at 18% moisture content and the values are in conformity with those in BS 5268 (2002).

Grade stress is the stress which can safely be permanently sustained by timber of a particular grade. There are four main grade stresses in Nigeria (NCP, 2: 1973) as shown in Table 6. It is very rare to get a timber without any defect, hence the grading is to provide allowance for strength reduction due to defects. For example, Grade 80% allows strength reduction of 20% due to any of the common defects associated with timber.

Table 5. Determined Strength Properties of Abura Timber at Moisture Content of 18%

Mean failure compressive stress along the grain (N/mm^2)	39.99
Mean failure compressive stress across the grain (N/mm^2)	8.65
Mean failure shear stress along the grain (N/mm^2)	30.32
Basic compressive stress along the grain (N/mm^2)	17.41
Basic compressive stress across the grain (N/mm^2)	3.20
Basic shear stress along the grain (N/mm^2)	2.37
Minimum modulus of elasticity (E_{min}) (N/mm^2)	6368
Mean value modulus of elasticity (E_{mean}) (N/mm^2)	8806
Density of Abura (kg/m^3)	573

Table 6. Standard Deviations and Grade Stresses for Nigerian Abura at Moisture Content of 18%

Type of stress	Standard deviation N/mm^2	Grade 80% N/mm^2	Grade 63% N/mm^2	Grade 50% N/mm^2	Grade 40% N/mm^2
Compression stress parallel to grain	3.57	13.93	10.97	8.71	6.96
Compression stress perpendicular to the grain	1.57	2.85	2.85	2.53	2.53
Shear stress parallel to grain	10.31	1.90	1.49	1.19	0.95

Table 7. Verified Mean of the Failure Stresses for the Abura

Type of stress	95% Confidence Limits (N/mm^2)	99% Confidence Limits (N/mm^2)	Mean from Tests (N/mm^2)
Compressive stress parallel to grain	38.27 and 41.71	37.63 and 42.35	39.99
Compressive stress perpendicular to grain	7.89 and 9.41	7.61 and 9.69	8.65
Shear stress parallel to grain	25.35 and 35.29	23.51 and 37.13	30.32

Table 8. Verified Standard Deviation of the Stresses for the Abura

Type of stress	95% Confidence Limits (N/mm^2)	99% Confidence Limits (N/mm^2)	Standard deviation from Tests (N/mm^2)
Compressive stress parallel to grain	2.78 and 5.33	2.57 and 6.10	3.57
Compressive stress perpendicular to grain	1.22 and 2.35	1.13 and 2.68	1.57
Shear stress parallel to grain	8.03 and 15.41	7.42 and 17.59	10.31

To verify the authenticity of the mean and the standard deviation from the tests, they were subjected to confidence limits analysis at 95% and 99% and the results are presented in Tables 7 and 8 respectively. Eqs. (16) and (17) were used for the mean, while Eqs. (18) and (19) were used for the standard deviation.

For the mean,

$$\text{95\% Confidence Limits} = \mu \mp t_{0.975}\frac{\sigma}{\sqrt{N-1}} \tag{16}$$

$$\text{99\% Confidence Limits} = \mu \mp t_{0.995}\frac{\sigma}{\sqrt{N-1}} \tag{17}$$

where, μ is the mean failure stress, $t_{0.975}$ and $t_{0.995}$ are the percentile values for students distribution with v degrees of freedom, σ is the standard deviation and N is the number of test specimens.

For the standard deviation,

$$\text{95\% Confidence Limits} = \frac{\sigma\sqrt{N}}{x_{0.975}} \text{ and } \frac{\sigma\sqrt{N}}{x_{0.025}} \tag{18}$$

$$\text{99\% Confidence Limits} = \frac{\sigma\sqrt{N}}{x_{0.995}} \text{ and } \frac{\sigma\sqrt{N}}{x_{0.005}} \tag{19}$$

where, $x_{0.975}$, $x_{0.025}$, $x_{0.995}$ and $x_{0.005}$ are the percentile values for the Chi-Square distribution with v degrees of freedom, σ is the standard deviation and N is the number of test specimens.

Structural reliability analysis on Abura bridge beam under the maximum loading conditions subject to both compression and shearing forces with target reliability index of 2.5 indicates that the beam has satisfactory performance only in compression as shown in Table 9. It is in good agreement with the report by Melchers (1987) which stated that timber members have target reliability index, (β) in the range between 2.0 and 3.0 with strong mean of 2.5. However, it is obvious that the Nigerian grown Abura timber is not safe in shear as bridge beam under the stated design conditions. This explains why each timber specie should be subjected to structural reliability analysis because Aguwa and Sadiku (2012) reported that the Nigerian grown Ekki timber in shear is reliable under the same design conditions. The reliability of the Nigerian grown Abura timber in shear can be improved if satisfactory dimensions are chosen by decreasing the span and increasing the depth of the beam. This also agrees with the report by Benu and Sule (2012) that the safety of the timber column can be enhanced if adequate and suitable dimensions are chosen to have a lower slenderness ratio.

Table 9. Reliability Indices for the Abura Bridge Beam

Beam subjected to compression perpendicular to the grain (β)	4.37
Beam subjected to shearing parallel to the grain (β)	1.94

Structural failure is imminent if the load is greater than the resistance and this can be expressed as, $g < 0$.

Applying Eq. (20) from Melchers (1987), for probability of failure,

$$P(failure), P_f = P(g<0) = \Phi(-\beta) \tag{20}$$

Φ and β are as defined earlier.

The probabilities of failure of the Abura bridge beam subjected to compression and shearing forces are 0.68×10^{-5} and 0.023 respectively.

In order to study the effect of the design parameters on the reliability index, sensitivity analysis was performed on the Abura beam subjected to compression and shearing forces under the design load. It can be seen from Fig. 8 that increase in the depth of the beam from 300 to 500 mm resulted in an increase in reliability index, (β) This was so because of the increase in the stiffness, EI of the beam. The performance of the beam compression at a depth of 400 mm and span of 5000 mm, was satisfactory but very poor in shear. For economical design and to

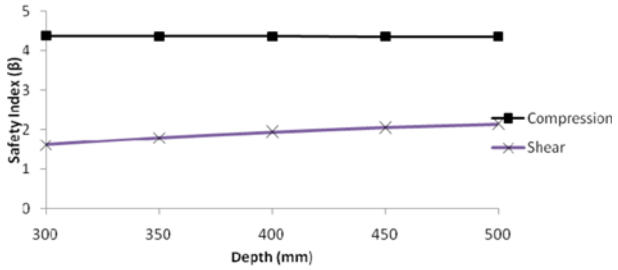

Fig. 8. Reliability Index and Depth of Abura Beam Relation

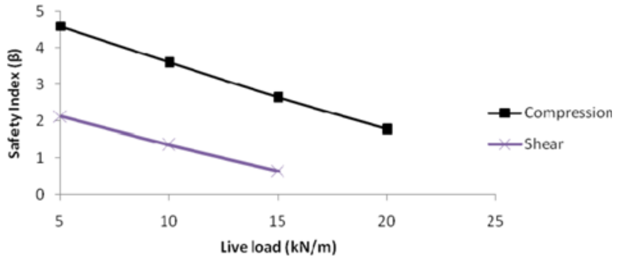

Fig. 9. Reliability Index and Live Load on Abura Beam Relation

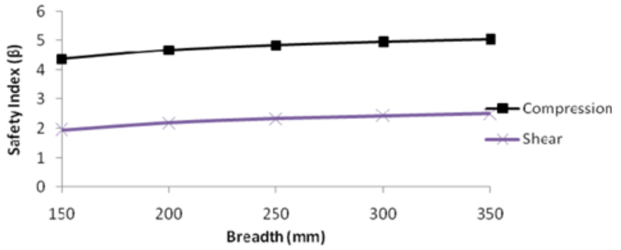

Fig. 10. Reliability Index and Breadth of Abura Beam Relation

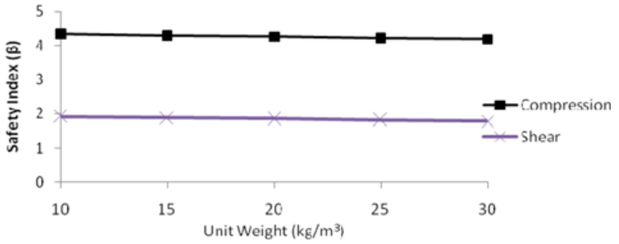

Fig. 11. Reliability Index and Unit Weight of Abura Relation

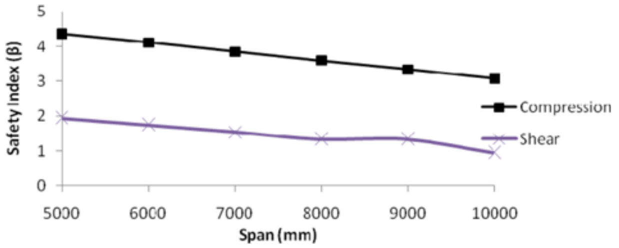

Fig. 12. Reliability Index and Span of Abura Beam Relation

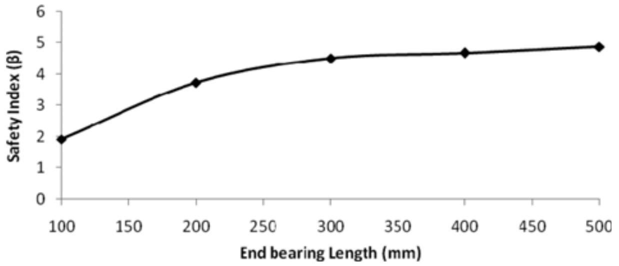

Fig. 13. Reliability Index and End Bearing Length of Abura Beam Relation

avoid problem of lifting as well as drying the beam, the depth should not be too large.

As the live load on the Abura beam was varied from 5 kN/m to 20 kN/m, the reliability index, (β) started decreasing as shown in Fig. 9 and this could be due to overloading beyond the carrying capacity of the beam resulting in gradual failure. Abura bridge beam is reliable when subjected to compression forces but failed under shearing forces within the design conditions and geometrical properties.

As shown in Fig. 10, reliability index (β) increased with increase in the breadth of the Abura beam between 150 mm and 350 mm and it could be due to the increase in rigidity of the beam. It is obvious that the degree of performance of Abura as bridge beam material is satisfactory under the action of compression forces but not reliable when subjected to shearing forces at a minimum breadth of 150 mm.

The unit weight of the Abura grown in Nigeria was varied from 10 kN/m^3 to 30 kN/m^3 in order to see the effect on the degree of structural performance of the bridge beam and as can be seen in Fig. 11, the safety index, (β) slightly decreased with increase in unit weight. It could be due to increase in self weight of the beam. This result is in agreement with the report by Nowak and Eamon (2008), that the safety index is insignificantly affected by the unit weight of the structural material.

There was sharp decrease in reliability index as the span of the Abura beam was varied between 5000 mm and 10000 mm as shown in Fig. 12. It is justifiable that the shearing force is one of the causes of beam failure and it depends much on the span. However, the structural performance of Abura bridge beam subjected to compression forces is satisfactory but the beam failed under shearing forces for spans considered. Also Hanson (2001) reported that the strength of timber members depends on the length of the member as well as the type of loading, because timber is inhomogeneous in nature.

The effect of varying the length of the end bearing of the Abura beam was examined and found to be structurally reliable when subjected to both compression and shearing forces as shown in Fig. 13.

7. Conclusions

Based on the findings from this research, it can be concluded that Abura grown in Nigeria has satisfactory performance when used as bridge beam material subjected to compression forces, for moderate span, depth and breadth. The span and depth of the Abura bridge beam affect significantly its reliability index when subjected to compression and shearing forces and as such moderate span and depth are recommended. The Abura bridge beam failed to perform satisfactorily under the action of shearing forces even at the designed span. The structural performance under shearing forces can be improved by choosing smaller span and larger depth.

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