Nigerian Journal of Technology (NIJOTECH)
Vol. 32. No. 2. July 2013, pp. 241-252

University of Nigeria, Nsukka, ISSN 1115-8443
www.nijotech.com

STRUCTURAL RELIABILITY OF THE NIGERIAN GROWN ABURA TIMBER BRIDGE BEAM SUBJECTED TO BENDING AND DEFLECTION FORCES

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Abstract
Structural reliability analysis was carried out on the Nigerian grown Abura timber, to ascertain its structural performance as timber bridge beams. Samples of the Nigerian grown Abura timber were bought from timber market, seasoned naturally and their structural/strength properties were determined at a moisture content of 18%. The determined strength properties were subjected to statistical analysis to determine some statistical parameters used in the design. Structural analysis and deterministic design of a timber bridge beam using the Nigerian grown Abura timber in accordance with BS 5268 were carried out under the Ultimate Limit State of loading. A computer programme in FORTRAN language was developed and used for reliability analysis of the Nigerian grown Abura timber bridge beam so designed, to ascertain its level of safety using First-Order Reliability Method (FORM). Sensitivity analysis was carried out by varying the depth of beam, imposed live load, breadth of the beam, unit weight of the Abura timber, span of the beam as well as the end bearing length. The result revealed that the Nigerian grown Abura timber is a satisfactory structural material for timber bridge beams at depth of 400mm, breadth of 150mm and span of 5000mm under the ultimate limit state of loading. The probabilities of failure of the Nigerian grown Abura timber bridge beam in bending and deflection are 0.23×10^{-2} and 0.27×10^{-15} respectively, under the design conditions.

Key words: Bending and deflection, Nigerian grown Abura, Strength, Structural reliability, Timber bridge beam.

1. Introduction

Abura with botanical name *Mitragyna ciliata* is one of the tropical hardwoods classified under the strength group of N4 in accordance with [1] and it is non-durable. 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. Structural uses include flooring, roofing, wall sheeting, formwork 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. Since all our timber structures are constructed of timber from Nigeria, there is the great need to determine their strength properties and subject them to structural reliability analysis in order to prove their degree of structural performance.

Structural reliability and probabilistic methods have continued to develop a growing importance in modern structural engineering practice especially when it involves naturally occuring materials such as timber. They are currently used in the development of new generation design codes, evaluation of existing structures and probability risk assessment [2]. The primary goal of engineered construction is to produce a structure that optimally combines safety, economy, function and aesthetics. Timber, like other building materials, has inherent advantages that make it especially attractive in specific applications [3]. The question of reliability is especially complicated for timber because of the large natural variability of the material. A significant element of uncertainty is also introduced through lack of information about the actual physical variability. The variability of strength between elements is significantly larger than for steel or reinforced concrete members. The coefficient of variation is of the order of 20-40%, with higher values for brittle type of failure modes [4].

Structural timber is the timber used in framing and load-bearing structures, where strength is the major factor in its selection and use. Trees are the only sources of timber and those that carry naked seeds are called softwoods, while those with seeds inside a fruit are termed hardwoods and Abura is one of them. Most timber used in the building construction are softwoods but in structures like bridges and railway sleepers, hardwoods are specially used [5]. Construction activities using vast quantities of locally available raw materials are major steps towards industrialization and economic independence for developing countries that are emphasizing more interest in local and affordable materials such as timber.

One of the objectives for structural design is to fulfill certain performance criteria related to safety and serviceability. One such performance criterion is usually formulated as a limit state that is, a mathematical description of the limit between performance and non-performance [4]. Parameters used to describe limit states are loads, strength and stiffness parameters, dimensions and geometrical imperfections. Since the parameters are random variables, the outcome of a design in relation to limit state is associated with uncertainty. The main issue is to find design methods ensuring that the relevant performance criteria are met with a certain desired level of confidence or reliability. That means that the risk of non-performance should be sufficiently low.

This study focuses on current reasoning and the integration of advanced technologies to suit the available climatic, natural and human resources to solve the problem of transportation, by making cheaper, better and more reliable structural system in highways [6]. The beams or girders of the timber bridge deck which are major structural members in the structural system of a timber bridge are considered. When timber structural systems are made safe and reliable in road bridges, then we will not only improve the nation's economic base but also contribute immensely to the economic activities and peoples well-being of the areas where they are abundantly sourced and used [7].

The aim of this study is to evaluate the performance of the Nigerian grown Abura timber as structural material for timber bridge beams. The specific objectives are; to conduct experiments on the Nigerian grown Abura timber with a view to establishing their strength properties, to utilize the strength properties of the Nigerian grown Abura timber so obtained to determine its conformity to the International Standard, to determine the structural reliability index for the Nigerian grown Abura timber, to establish safety standard in the use of the Nigerian grown Abura timber as bridge beams and to add value to our locally available and affordable structural material thereby increasing the local content of the construction industry in Nigeria, resulting in less dependence on foreign materials [8].

2. Materials and Methods

2.1 Abura

The Nigerian grown Abura timber was bought from Sapele timber market in Delta state, Nigeria.

2.2. Preparation and Testing of the samples

Four pieces of 50mm x 75mm x 3600mm of the Nigerian grown Abura samples were bought and naturally seasoned for eight months for the samples to attain moisture content equilibrium environmentally. The natural seasoning was preferred to the artificial seasoning which is faster because the proposed timber structure is bridge, which is always completely exposed to natural weather conditions [9]. The Abura timber samples were prepared and tested in accordance with British Standard [10], Methods of Testing Small Clear Specimens of Timber. A total of 40 test specimens were used for the testing, that is, 20 specimens for bending and the other 20 for tension The seasoning and preparation of the samples were carried out at African Timber and Plywood (AT & P) Sapele while the testing using Universal Testing Machine (UTM) of capacity 50kN was performed at National Centre for Agricultural Mechanization (NCAM) in Ilorin, Kwara State, Nigeria.

2.3 Bending strength parallel to the grain

The basic bending stress parallel to the grain for the Nigeria grown Abura timber was determined using the failure bending stresses from tests, from [11]

$$f_{b\,par} = \frac{f_m - 2.33\sigma}{2.25} \qquad (1)$$

where $f_{b\,par}$ = basic bending stress parallel to the grain

f_m = mean value of the failure stresses

σ = standard deviation of the failure stresses

2.4 Tensile strength parallel to the grain

The basic tensile stress parallel to the grain for the Nigerian grown Abura timber was determined using the failure tensile stresses from tests, from [11],

$$t_{b\,par} = \frac{f_m - 2.33\sigma}{2.25}. \qquad (2)$$

2.5 Modulus of elasticity

Equation (3) below gives the relationship between the E_{mean} and the statistical minimum value of E appropriate to the number of species acting together, from [11],

$$E_N = E_{mean} - \frac{2.33\sigma}{\sqrt{N}} \qquad (3)$$

where E_N is the statistical minimum value of E appropriate to the number of pieces N acting together (where N=1, E_N becomes the value for E_{min}) and σ is the standard deviation.

2.6 Structural analysis and design of the Nigerian Abura timber bridge beam

Structural members should be so proportioned that the stresses or deformations induced by all relevant conditions of loading do not exceed the permissible stresses or deformation limits for the material or the service conditions, determined in accordance with [12]. When properly designed and protected from elements such as water, insects and fire, timber is a structurally capable, cost-effective and aesthetically pleasing material suitable in many structural applications such as in bridges [6]. However, when not properly designed or protected, timber structures are susceptible to deterioration, which can result in a decrease in structural capacity [13]. Table 1 shows the design information for the Nigerian grown Abura timber bridge beam under the ultimate limit state of loading. The input parameters for the structural reliability analysis of the Nigerian grown Abura timber bridge beam are shown in Table 2.

Table 1: Design information for the Nigerian grown Abura timber bridge

Width of bridge carriageway (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

Source: [14]

Table 2: Input parameters for the design of the Nigerian Abura timber bridge beam

Input Parameter	**Value used**	**Input Parameter**	**Value used**
Unit weight (Uw)	5.62	Breadth of beam (b)	150
COV_{UW}	6	Mean bending Stress ($f_{m\ par}$)	74.06
Depth of beam (h)	400	Std. deviation for bending stress (σf_{par})	7.10
Spacing of beam (Sp)	400	Coefficient of variation ($COVf_{par}$)	10
Plank depth (hpl)	100	Grade bending stress ($f_{g\ par}$ 80%)	15.50
Plank breadth (bpl)	250	Std deviation for modulus of E (σ_E)	1047
Span of beam (L)	5000	Beam Self Weight (SWBM)	0.34
bearing (L_b	300	Plank dead load (PDL)	0.23
Minimum E (E_{min})	6368	Total live load on beam (TLL)	6.17
Mean E (E_{mean})	8806		

2.7 Reliability analysis for simply supported Nigerian grown Abura timber bridge beam

The design procedure for timber beams where the direction of the grain in the wood is parallel to the span is to ensure that;

(i) The design bending strength parallel to the grain is not reached or exceeded and the bending stresses do not cause lateral torsional buckling of the beam leading to a premature instability failure.

(ii) The beam's deflection meets the Serviceability Limit State of deflection criteria.

2.8 Beam in bending parallel to the grain

Considering under the Ultimate Limit State (ULS), for the moment capacity of the timber bridge beam, the performance function can be formulated for the beam bending, by considering the elastic section modulus ($Z=bh^2/6$, for a rectangular section), the applied bending moment, M and the permissible bending stress, f_b. For a beam considered to be freely hinged at its ends and carrying a uniformly distributed load of intensity w, the maximum bending moment at the mid-span of the beam due to distributed loads is; from [15]

$$M = \frac{WL^2}{8} \qquad (4)$$

It is assumed that the dimensions and support conditions of the beam are adequate to prevent instability, that is, deflections occur only in the loading plane. Then in according with strength of materials, the bending stresses in the beam are given by, from [16],

$$f_b = \frac{MY}{I} \qquad (5)$$

where M is the bending moment acting on the beam as a result of external loads, I is the second moment of area of the beam cross-section, Y is the distance from the neutral axis and f_b is the bending stress at a distance Y.

The maximum bending stress at the extreme fibre is given by, from [16],

$$f_b = \frac{M}{Z} \qquad (6)$$

where Z is the section modulus for the timber

Since BS 5268 (2002) allows the design of timber structures to be carried out on the assumption that they behave elastically, the above expression may be used for the design purposes. The design bending stress parallel to the grain, $f_{p\ par}$ of the beam is defined as, from [12]

$$f_{p\,par} = K_3K_6K_7f_{g\,par} \qquad (7)$$

where $f_{p\ par}$ = the permissible bending strength parallel to the grain, $f_{g\ par}$ = the grade bending strength parallel to the grain from tests. , given in Table 2, K_3 = modification factor for duration of loading (Table 17 of [12], K_6 = form factor (Page 35 of [12], K_7 = depth modification factor

The applied bending stress on the beam is given by

$$f_{a\,par} = \frac{M}{Z}. \qquad (8)$$

The limit state or performance function in bending parallel to the grain is given by

$$g(x) = f_{p\,par} - f_{a\,par} \quad (9)$$

2.9 Beam in deflection

Deflection in beams at a particular stage may become visually unacceptable to the occupants or leads to distortion, cracking or failure under the beam for example, violation of the serviceability limit state. In order to prevent such occurrence, deflection is limited based on past experience and observations in accordance with code recommendation. The BS 5268 (2002) recommends 0.3% of the span or 0.003L. In timber design, a total deflection of both the bending and shear deflections are calculated or considered. In steel design, shear deflections are usually disregarded except in cases of heavily loaded and deep steel plate girders [17]. This is because timber beams are frequently deep in relation to their span and have a very low G/E value. G is the modulus of rigidity usually taken as 1/16 (0.0625) compared to 0.4 for mild steel.

The bending deflection of a timber beam in simple support is given from first principles as, from [11],

$$\Delta_b = \frac{5W_eL^3}{384EI} \quad (10)$$

The equivalent uniform load, W_e may be determined for most loading conditions as

$$W_e = WK_b \quad (11)$$

where K_b is a coefficient taken from tables 4.9 - 16 [11] according to the nature of the actual load, K_b is used for bending and K_v is used for shear.

Usually the bending deflection is calculated at the mid-span and the shear deflection was determined at the same point or location. Therefore, by the method of unit load, from [11],

$$\text{Shear deflection} = F\int_0^L \frac{VV_1dx}{AG} \quad (12)$$

where F, is a form factor dependent on the cross-sectional shape of the beam (equal to 1.2 for solid rectangle), V is the external shear due to actual loading, V_1 is the shear due to a unit load at the point where the deflection is being calculated, A is the area of the cross-section and G is the modulus of rigidity (usually taken as E/16).

The shear deflection is normally added to the centre-span bending deflection; therefore it is the centre-span shear deflection in which one is interested [11]. With the unit load placed at centre-span, V_1= 0.5 and it can be shown that

$$\text{Shear deflection at mid-span} = \frac{F \times Area\ of\ shear\ force\ diagram\ to\ midspan}{AG}$$

From [11],

$$\Delta_v = \frac{FM_o}{AG} \quad (13)$$

where M_o, is the bending moment at mid-span, M_o for a simple span may be calculated as, From [11],

$$M_o = \frac{W_oL}{8} \quad (14)$$

where W_o is the equivalent uniform load to produce the moment M_o.

From [11],

$$W_o = WK_v \quad (15)$$

where W = wL, is actual load and K_v is a coefficient taken from Tabes 4.9-16 [11], according to the nature of the actual load. Where more than one type of load occurs on a span, W_o is the summation of the individual WK_v values. Therefore, the deflections due to uniformly distributed load are, from [11],

$$\Delta_b = \frac{5W_eL^3}{384EI} = \frac{5W_eL^3 \times 12}{384Ebh^3} \quad (16)$$

and from [11],

$$\Delta_v = \frac{FM_o}{AG} = \frac{1.2 \times W_oL \times 16}{8Ebh} \quad (17)$$

Therefore, total deflection at the centre-span of the beam is

$$\text{Total deflection} = \Delta_t = \Delta_b + \Delta_v \quad (18)$$

where Δ_b = bending deflection and Δ_v = shear deflection, F = 1.2, G = E/16 and

$M_o = wL^2/8$

The modulus of rigidity or bulk modulus is given as

$$G = \frac{E}{16}\ and\ AG = \frac{EBD}{16} \quad (19)$$

For the purpose of calculating deflection, the mean value of the modulus of elasticity should be used for rafters, floors, joists and other system where it can be shown that transverse distribution of load is achieved [12], from [11],

$$E_N = E_{mean} - \frac{2.33\sigma}{\sqrt{N}} \quad (20)$$

where E_N, is the statistical minimum value of the modulus of elasticity for the number of pieces acting together, E_{mean} is the mean value of modulus of elasticity and N is the number of pieces acting together at a cross-section. In a special case when one section acts alone, N = 1 and E_N becomes the E_{min} value.

Table 3: Probability distribution and the statistical parameters for the basic variables

Basic Variables	Probability Distribution	Coefficient of variation	Basic Variables	Probability Distribution	Coefficient of variation
UW	Lognormal	11	H	Normal	6
E	Lognormal	12	f_g	Normal	13
LL	Lognormal	20	ν_g	Normal	24
L	Normal	3	c_g	Normal	9
b	Normal	6	L_b	Normal	6

Source: From test results on the Nigerian grown Abura timber analyzed statistically

By substituting the known values of E_{min}, E_{mean} and N in the formula, the value of 2.33σ can be calculated. E_{min} is used in this case and the beam is regarded as a principal member. The limit state or performance function for deflection can be written as

$$g(x) = 0.003L - \Delta_t \quad (21)$$

The statistical parameters and their probability distribution of the basic variables used as input into the FORTRAN program are shown in Table 3.

2.10 Method of Analysis

The results obtained from the deterministic design of the simply supported timber bridge beam were used to carry out a reliability analysis of the beam using FORM5. FORM5 is reliability software used to estimate the probability of failure or safety index (β) of structures. The design parameters used in the analysis are shown in Table 4.

3. Results and Discussion

3.1 Structural/Strength properties of the Nigerian Abura timber

Tables 5 – 7 show the determined structural/ strength properties of the Nigerian Abura timber at 18% moisture content. The Nigerian Abura timber has basic and grade strengths that conform to International Standards [12].

3.2 Confidence Limits for mean and standard deviation

Table 8 shows the confidence limits for the mean for the Nigerian grown Abura and the results are satisfactory for both 95% and 99% confidence limits. The results were calculated using equations (22) and (23) from [18],

$$95\%\ \text{Confidence Limits} = \mu \mp t_{0.975}\frac{\sigma}{\sqrt{N-1}} \quad (22)$$

$$99\%\ \text{Confidence Limits} = \mu \mp t_{0.995}\frac{\sigma}{\sqrt{N-1}} \quad (23)$$

where μ is the mean failure bending 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 for the failure bending stresses and N is the number of test specimens.

Table 4: Design parameters for the Nigerian grown Abura timber bridge beam

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

Table 5: Basic stresses of Nigerian grown Abura timber at moisture content of 18%

Bending parallel to grain (N/mm²)	20.62
Tension parallel to grain (N/mm²)	19.78

Table 6: Mechanical/Physical properties of Nigerian Abura at moisture content of 18%

Mean value modulus of elasticity (N/mm²)	8806
Minimum value modulus of elasticity (N/mm²)	6368
Density (kg/m³)	573

Table 7: Mean failure Stresses, Standard deviation, Basic stresses and Grade Stresses for Abura

Type of stress	Bending stress parallel to grain	Tensile stress parallel to grain
Mean failure stress (N/mm²)	74.06	88.58
Standard deviation (N/mm²)	7.10	14.76
Basic stress (N/mm²)	20.62	19.78
Grade stress (80%) (N/mm²)	16.50	15.82
Grade stress (63%) (N/mm²)	12.99	12.46
Grade stress (50%) (N/mm²)	10.31	9.89
Grade stress (40%) (N/mm²)	8.25	7.91

Table 8: Confidence Limits for the mean of the failure bending stresses for Nigerian Abura

95% Confidence Limits (N/mm²)	99% Confidence Limits (N/mm²)	Mean from Test (N/mm²)
70.14 and 77.48	69.37 and 78.79	74.06

Table 9: Confidence Limits for the standard deviation of the failure bending stresses for the Nigerian grown Abura

95% Confidence Limits (N/mm²)	99% Confidence Limits (N/mm²)	Standard deviation from Test (N/mm²)
5.53 and 10.61	5.11 and 12.11	7.10

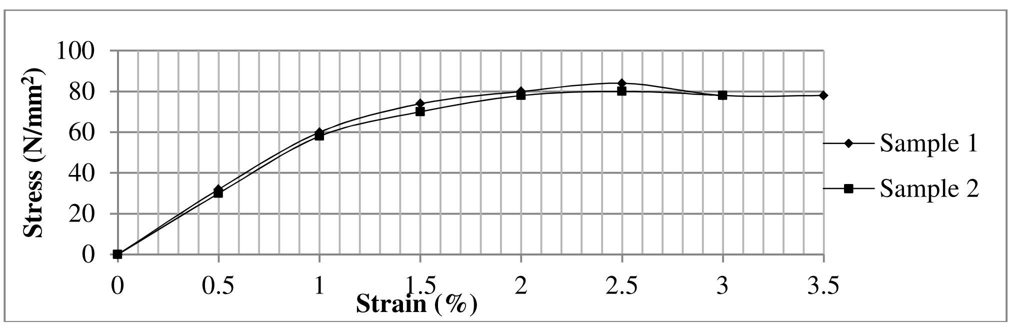

Fig. 1: Stress-Strain relation for the Nigerian grown Abura timber

Table 9 shows the confidence limits for the standard deviation for the Nigerian grown Abura and the results are satisfactory for both 95% and 99% confidence limits. The results were calculated using equations (24) and (25) from [18],

$$95\% \text{ Confidence Limits} = \frac{\sigma\sqrt{N}}{\chi_{0.975}} \text{ and } \frac{\sigma\sqrt{N}}{\chi_{0.025}} \quad (24)$$

$$99\% \text{ Confidence Limits} = \frac{\sigma\sqrt{N}}{\chi_{0.995}} \text{ and } \frac{\sigma\sqrt{N}}{\chi_{0.005}} \quad (25)$$

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

3.3 Stress-Strain relation for the Nigerian Abura timber

Fig. 1 shows the stress-strain relationship for the Nigerian Abura timber in bending parallel to the grain. Limit of proportionality is exhibited, thereby confirming that the Nigerian Abura timber is an elastic structural material.

3.4 Load-Deflection Relation for the Nigerian Abura Timber

The relationship between load and deflection for Nigerian grown Abura timber in bending parallel to the grain is shown in Fig.2. A coresponding increase in deflection with increase in applied load was observed and it can be seen that timber does not move into plastic stage of deformation.

3.5 Reliability Assessment

The results of the reliability assessment of the Nigerian grown Abura timber bridge beam are shown in Table 10. The reliability analysis was carried out on the Nigerian Abura timber bridge beam at the ultimate limit state of loading subjected to bending and deflection forces. Using 2.5 as the target reliability index, the Nigerian grown Abura is safe as timber bridge beam subjected to bending and deflection forces, under the specified design conditions of loading and geometrical properties. This result agrees with [19] who stated that target reliability index (β) for timber members ranges from 2.0 to 3.0 with strong mean of 2.5. However, the degree of reliability in bending is not high and this can be improved if suitable cross-section is chosen by reducing the span and increasing the depth of the beam. This also conforms to the report by [20] that the safety of the timber column can be enhanced if adequate and suitable dimensions are chosen to have a lower slenderness ratio.

Table 10: Safety Indices for the Nigerian grown Abura timber bridge beam

Beam in bending (β)	2.84
Beam in deflection (β)	8.08

3.6 Probability of Failure (P_f)

Failure occurs when the demand exceeds the capacity. Mathematically denoted as, $g < 0$.
From [19],
Probability of failure, $P(failure), P_f = P(g < 0) = \Phi(-\beta)$ (26)
where Φ is the standard normal distribution function (zero mean and unit variance)
The probabilities of failure of the Nigerian grown Abura timber bridge beam in bending and deflection are 0.23×10^{-2} *and* 0.27×10^{-15} respectively.

3.7 Sensitivity Analysis

Fig. 3 shows the relationship between safety index (β) and depth (h) for the Nigerian grown Abura timber bridge beam subjected to bending and deflection forces. A general increase in safety index (β) was noted as the depth was increased from 300 to 500mm. This increase in safety index (β) could be attributed to the increase in EI values which increased the rigidity of the beam. At the ultimate limit state of loading and at a depth of 400mm and span of 5000mm, the Nigerian Abura timber is safe in bending and deflection. It is to be noted that at large depth, the structure may be reliable but not economical because drying and lifting will be a problem. Since structural safety must recognize financial burden involved in project execution and general utility, the derived factors of safety are improved to balance conflicting aims of safety and economy [21].

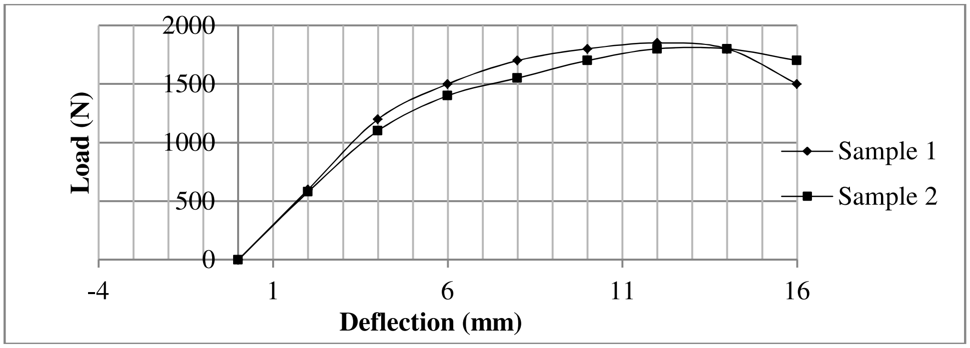

Fig. 2: Load-Deflection relation for the Nigerian grown Abura timber

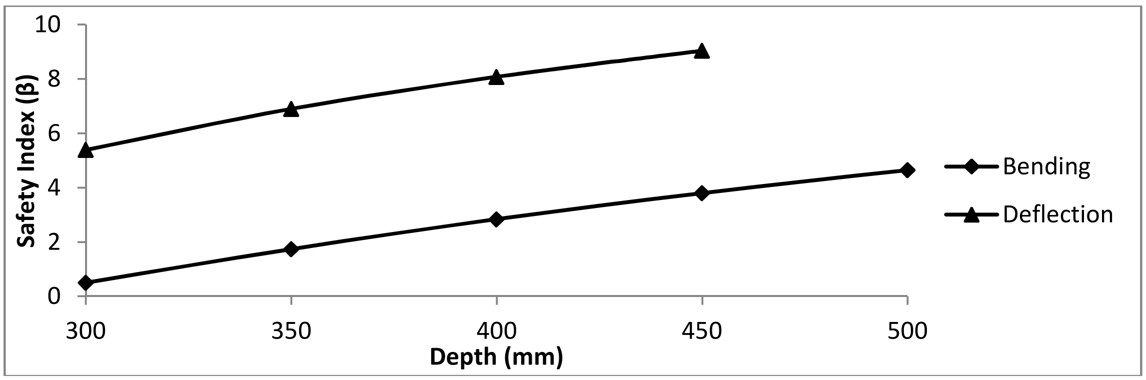

Fig. 3: Safety Index - Depth relation for the Nigerian Abura bridge beam

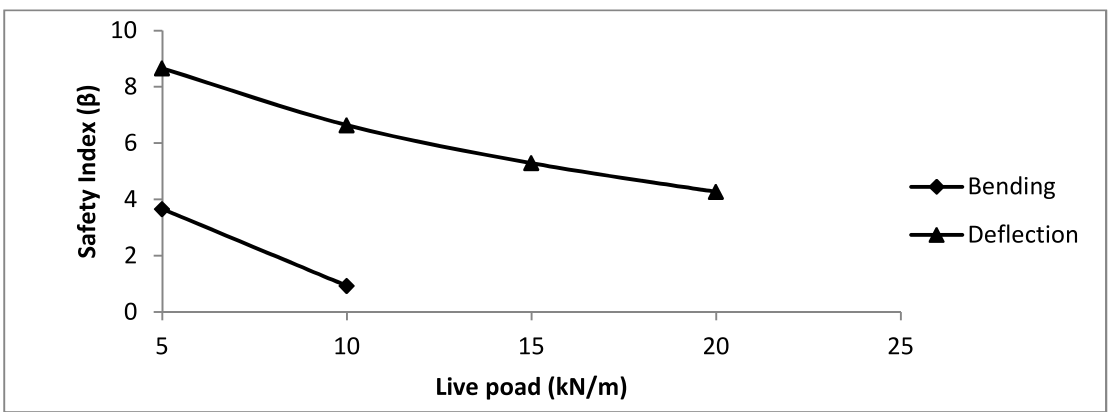

Fig. 4: Safety Index - Live Load relation for the Nigerian Abura timber bridge beam

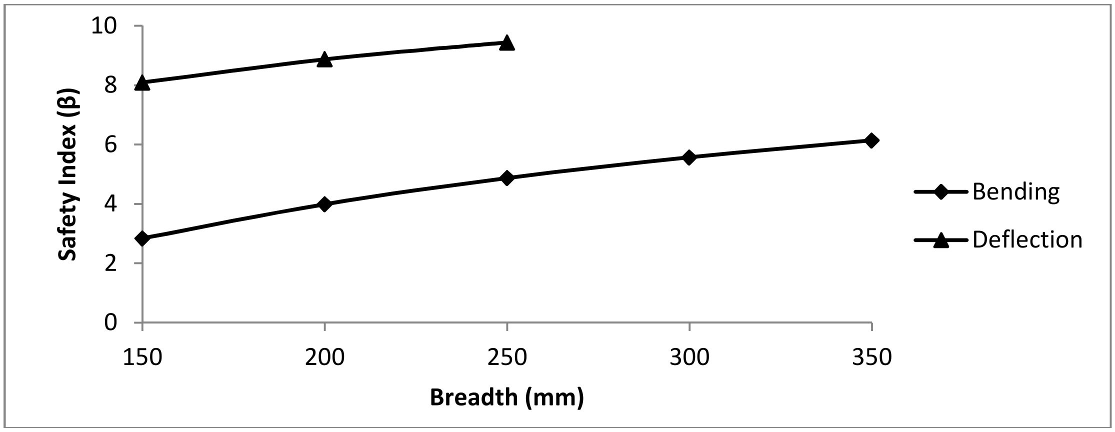

Fig. 5: Safety Index - Breadth relation for the Nigerian Abura timber bridge beam

Fig. 4 shows the relationship between safety index and live load for a simply supported Nigerian grown Abura timber bridge beam subjected to bending and deflection forces at the ultimate limit state of loading and at variable live load. A decrease in safety index (β) was recorded as the live load was increased from 5kN/m to 20kN/m. This could be attributed to the fact that the carrying capacity of the structural element is being exceeded thereby leading to the chances of failure. A maximum of 10kN/m live load can adequately be sustained by the Nigerian Abura as bridge beam at a span of 5000mm, depth of 400mm and breadth of 150mm.

In Fig. 5, a general consistent increase in safety index (β) was observed as the breadth was increased from 150mm to 350mm for the Nigerian grown Abura timber bridge beam subjected to bending and deflection forces. This could be attributed to the increase in EI values, which increased the rigidity of the beam. The Nigerian Abura timber bridge beam is safe at a minimum breadth of 150mm under the specified design conditions.

The effect of varying the unit weight of the Nigerian grown Abura timber bridge beam on the safety index is shown in Fig. 6 and slight decrease in safety index (β) was noted as the unit weight increased from 10kN/m^3 to 30kN/m^3. This trend could be attributed to the fact that dead load increases with increase in unit weight and as noted before, increase in load will definitely reduce the safety index. However, the effect of unit weight on the reliability index is not significant and this conforms to the report by [22].

Fig. 7: shows the relationship between safety index and span for simply supported Nigerian grown Abura timber bridge beam subjected to bending and deflection forces under the ultimate limit state of loading, at variable span. Sharp decrease in safety index was noted as the span was increased from 5000mm to 10000mm. This is because increasing the span implies an increase in bending moment which is a major factor that causes failure of beam (Aguwa, 2010). The Nigerian grown Abura timber bridge beam is safe in bending and deflection for span not exceeding 5000mm. The effect of span on the safety index of the Nigerian Abura timber bridge beam is more significant in bending parallel to the grain than in deflection [23].

Fig. 8: shows the relationship between safety index and end bearing length for a simply supported Nigerian grown Abura timber bridge beam and it was found that the Nigerian Abura timber is reliable even at a minimum end bearing length of 100mm.

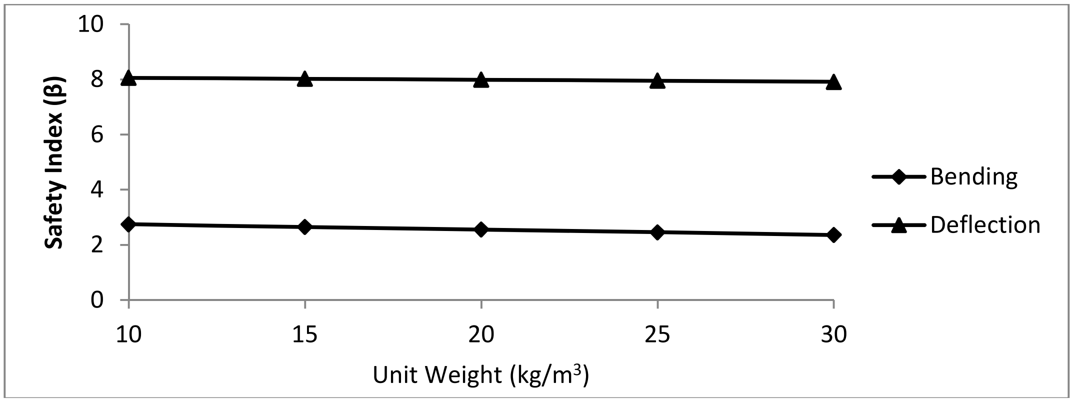

Fig. 6: Safety Index – Unit weight relation for the Nigerian Abura bridge beam

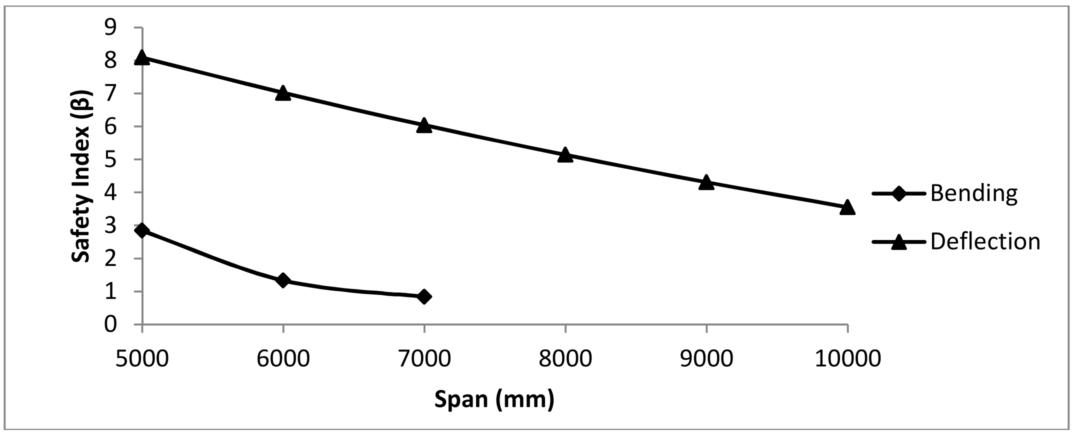

Fig. 7: Safety Index - Span relation for the Nigerian grown Abura timber bridge beam

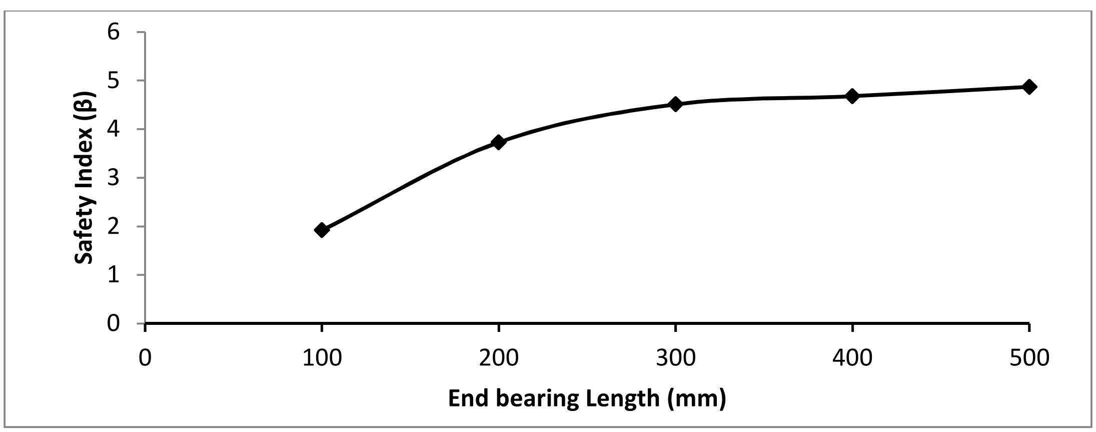

Fig. 8: Safety Index - End bearing length relation for the Nigerian grown Abura bridge beam

4. Conclusion

The over all conclusions emerging from this study are;

1. The Nigerian grown Abura timber is a reliable structural material for timber bridge beams for spans not exceeding 5000mm, depth of 400mm and breadth of 150mm.
2. The structural/strength properties of the Nigerian grown Abura timber are in good conformity to the International Standards (BS 5268)

3. The safety index of the Nigerian grown Abura timber bridge beam is highly sensitive to the depth and the span of the beam; hence they are the critical factors to be considered in design of timber bridge beams.
4. The reliability index of the Nigerian grown Abura timber bridge beam is highly sensitive to bending forces; hence these forces should always be investigated to establish the degree of reliability.

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