Malaysian Journal Of Civil Engineering

RELIABILITY-BASED INVESTIGATION ON THE COMPRESSIVE STRENGTH OF COMMONLY USED NIGERIAN TIMBER SPECIES

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Article history
Received
07 June 2021
Received in revised form
30 November 2021
Accepted
03 December 2021
Published online
31 March 2022

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Abstract

This paper considers the compressive strength both parallel and perpendicular to grain of not less than twenty Nigerian-grown timber species out of which, six commonly used ones were selected and their compressive resistance assessed under certain loads. First, it was found out that the basic compressive stress perpendicular to the grain of timber is about 22% of the basic compressive stress parallel to grain. A reliability assessment was then carried out using the First Order Reliability Method (FORM) to investigate the performance of a column section of 250 x 250mm and 300 x 300mm for the six Nigerian-grown timber species. *Lophira alata* was found to be the most reliable with a Probability of failure $P_f = 2.78 \times 10^{-3}$ and 7.1×10^{-2} under an axial load of 1000kN and 2000kN respectively. This was followed by *Anogeissus leiocarpus* with $P_f = 2.53 \times 10^{-2}$ and 5.26×10^{-3} under an axial load of 1000kN and 1500kN respectively. Others that followed were 'Iroko'*(Chlorophora excelsa),*'Abura' *(Mitragyna ciliata),*'Afara' *(Terminalia superba),* and 'Obeche'*(Triplochiton scleroxylon),* in the order of descending performance. It can been established from this study that, 'Ekki' (*Lophira alata*) and African birch (*Anogeissus leiocarpus*) could be suitable for bridge piles and piers, railways or related structures that require compressive members with high axial capacity whereas, 'Abura', 'Obeche', 'Afara' and 'Abura' would be best suitable for buildings.

Keywords: Axial capacity, Compressive members, First Order Reliability Method, Nigerian-grown timber, Probability of failure, Reliability assessment.

1.0 INTRODUCTION

One of the common building materials nature has endowed humankind with is timber. Beech *et al.* (2017) submitted that 60,065 tree species have been currently known and identified. This represents 20% of all angiosperm and gymnosperm plant species. Nearly 58% of all trees are single-country endemics (that is, they can be found in one country) and about 300 species have been identified as critically endangered. Botanical Gardens Conservation International (BGCI) have reported that the number of trees on its GlobalTreeSearch list is not expected to remain static as about 2000 plants were newly subscribed each year.

The use of structural timber in the Nigerian construction industry is a wide scope for research owing to the vastness and diversity in the species of timber available in Nigeria. Oluyege, (2007) submitted that that amongst the numerous tree species available in Nigeria, only 2,300 tree species have been identified to be commercially important. It is also worthy to note that the rate at which these timbers are used cannot be overemphasized. FAO (2010) estimated that Nigeria loses about 3.7% of its forest area yearly and this makes it to have the highest net loss from 2000 to 2010 due to over-exploitation of wood for timber production.

The fact that a few of these species have been characterized for structural engineers to find readily useful for their day to day design, poses a great challenge as to the suitability of some of these timber species for certain structural purposes. Some of the commonly used timber species which have been tested and characterized are 'Abura' *(Mitragyna ciliata),* 'Afara' *(Terminalia superba),* 'Iroko' *(Chlorophora excelsa),* 'Obeche' *(Triplochiton scleroxylon),* 'Ekki'*(Lophira alata),* African birch or 'chewing stick tree' *(Anogeissus leiocarpus)* and many others (NCP 2 1973). From literature, 'Abura' has been classified as an N4 timber with a basic compressive stress parallel to grain of 17.41N/mm^2, 'Afara' has been classified as an N5 timber with a basic compressive stress parallel to grain of 9.62N/mm^2. 'Iroko' has been classified as an N3 timber with a basic compressive stress parallel to grain of 18.21N/mm^2, 'Obeche' belongs to the class N5 timber with a basic compressive stress parallel to grain of 9.22N/mm^2, and 'Ekki' has been classified under-strength class N1 timber with a basic compressive stress parallel to grain of 28.01N/mm^2 all in accordance to the Nigerian Code of Practice NCP 2 of 1973 (Aguwa 2016). The African birch timber which has a basic compressive strength of 19.62N/mm^2 belongs to strength class N2 grade timber by the NCP 2 (1973) system of grading. According to the European structural timber strength classification system (EN 338 2009), *Ceiba pentandra, Vitex doniana and Pseudocedrela kotschyi* were assigned to strength class C16, D30 and D35 respectively (Jimoh and Ibitolu, 2018). While *Azadirachta indica* was graded into strength class D40 and *Xylopia aethiopica* was graded into strength class D70 in accordance with BS 5268 (Jimoh and Aina, 2017).

These common timber species have been used for several construction purposes but there is the need to know their reliability and level of performance which could provide suitable guidance for specific structural purposes other than simply knowing their strength classes. Certain researches have been reported on some timber species to investigate their performance in flexure under certain limit state conditions. For instance, Aguwa and Sadiku (2011) revealed from a reliability assessment that the Nigerian 'Ekki' *(Lophira alata)* timber is structurally satisfactory for timber bridge beams at depth of 400mm, breadth of 150mm and span of 5000 to 7000mm under the ultimate limit state of loading. It showed a probability of failure in flexure under the specified operating conditions of 1.1 x 10^{-7}. If optimization studies were to be carried out, a more economical section and span would possibly have been found.

Aguwa (2012) in another work showed from a reliability study that the Nigerian-grown 'Apa' *(Afzelia bipindensis)* timber is a satisfactory structural timber for bridge beams at depth of 400mm, breadth of 150mm and span of 5000mm under the ultimate limit state of loading. The possible chances of failure of the Nigerian Apa timber bridge beam in flexure and deflection are $2.062{\times}10^{-3}$ and $2.673{\times}10^{-14}$ respectively, under specified design conditions.

Some columns could be subjected to different load types at the same time depending on the type and purpose of the structure. Osama and Hassan (2019) investigated the load-bearing behaviour of timbers subjected to both compression and flexure specially referred to as beam-columns. Two design approaches namely the effective length method and the second-order analysis were used to account for the flexural buckling. In an attempt to develop an alternative interaction formula to check the stability of beam-columns with the risk of buckling failure, the second-order analysis was found as an alternative tool for structural engineers to measure the stability of axially loaded members subjected to the risk of flexural buckling failure.

Jimoh et al. (2017) studied the compressive strength characteristics of the Nigerian grown Apa (*Afzelia bipindensis*) and Opon (*Lannea schimperi*) timber species for certain nominal lengths of 200, 400, 600 and 800mm and a nominal width and thickness of 50mm by 50mm. The data revealed that Apa and Opon have average densities of 652.74 and 472.60 kg/m^3 respectively. From the findings, the mean moisture content (MC) of both species were less than the fibre saturation point (FSP) recommended value of 25-30% and the average strength at a yield of Apa and Opon are 35.65 N/mm^2 and 14.00N/mm^2. From the compressive strength test, the relationship which between the compressive stress and slenderness ratio resulted in the design model for Apa (*Afzelia bipindensis*) and Opon column (*Lannea schimperi*) given by $\sigma = 47.882^{-0.009\lambda}$ and $\sigma = 17.221^{-0.007\lambda}$ respectively where σ is the experimental yield stress of the timber gotten from the ratio of the column specimen load to its cross-sectional area and λ is the slenderness ratio of the timber column. This is the ratio of the effective length of the column to its radius of gyration as shown in Equations 1 - 4, (when making reference to true slenderness ratio) or the ratio of the length of the column to its breadth (when referring to its false slenderness ratio).

The slenderness ratio λ was computed from the relation

$$\lambda = \frac{L_e}{r} \quad (1)$$

Where

$$r = \sqrt{\frac{I}{A}} \quad (2)$$

$$A = BD \quad (3)$$

and

$$I = \frac{BD^2}{12} \quad (4)$$

Where I- moment of inertia

- A- Cross-sectional area of column
- B- Breadth of column section
- D- Depth of column section

This is strongly in conformity with Benu *et al.* (2012) showed that, the reliability of a column can be improved by choosing adequate section dimensions since the reliability was affected by varying the slenderness and load ratios. The time-based reliability analysis result shows the fact that Apa and Opon timber species have reliability indices of 0.64 and 0.65 respectively for a service life of 50 years, assuming other serviceability conditions are met.

Wiesner and Bisby (2019) in an attempt to evaluate the performance of a laminated timber column under fire attack, reviewed and assessed available data and methods to design timber compression elements for fire resistance as a laminated column mass. Collected data from history for certain fire resistance tests were compared against the available design calculation methods. The resulting meta-analysis suggested that the available methods are all able to make reasonable predictions (with an average mean absolute percentage error (MAPE) of 22% across methods) of the fire resistance of glued-laminated columns exposed to standard fires; however, the available methods for Cross Laminated Timber walls give inconsistent (MAPE of 46% across all methods and 30% excluding extreme outliers) and potentially non-conservative results (up to 88% of investigated cases are statistically non-conservative).

Wilson *et al.* (2018) reported that the Nigerian-grown African-birch is adequate as a structural material for use as solid timber columns at a depth and breadth of 150mm, an effective length of 3600mm and an axial load of 260kN; with a probability of failure of 8.85 x 10^{-3}. Furthermore, it was discovered that a column of similar effective length can support an axial load of 1000kN with a probability of failure of 4.85 x 10^{-2} at a depth of

400mm, breadth of 200mm. In the reliability by failure rate method, the Nigerian-grown African birch showed a higher failure rate at an interval of 10 years over a 100-year expected lifespan under flexure when compared to compression and this can be attributed to their respective basic compressive and static bending strength values.

The compressive strength is selected and considered amongst all other structural/mechanical properties for this research because it is most relevant to the compressive resistance or the axial load capacity of the various timber species considered. The basic compressive stress is a function of the respective mean compressive stresses of the individual timber species. This basic compressive strength or stress could either be parallel or perpendicular to the grain of the timber considered. Aguwa (2016) investigated about twenty structural timber species for compressive stress perpendicular and parallel to grain all in accordance with BS 373 (1957) using small clear test specimens. For each of the species, the basic stress, and the various available grade stresses of timber (grade 80, grade 63, grade 50 and grade 40) were evaluated according to NCP 2 (1973). These grades or classes are meant to account for defects or other strength-reducing features associated with the timber to various degrees (Aguwa, 2016).

Getting the information about the class and performance of different timber species is necessary but not absolutely sufficient. In this study, a reliability-based method is to be employed in the investigation of the compressive strength of some Nigerian timber species. This is carried out using certain data on the mechanical properties of some Nigerian-grown timber species to which statistical analysis would be applied. The probability distributions of the relevant parameters would be used for the First Order Reliability Method to determine their capacity and performance in sustaining several axial loads.
The aim of this study is to carry out a reliability assessment which aids to study and compare the performance of some commonly used timber species when used as columns under certain loads for the purpose of subsequently categorising the timber species for specific structural uses considering the available commercial sizes of solid sections in Nigeria.

The information contained in Aguwa (2016) is relevant to investigate the relationship between the compressive stress parallel to grain and that perpendicular to grain.

Table 1 shows the compressive stress parallel to grain of twenty different species of Nigerian-grown timber at 18% moisture content. While Table 2 shows the compressive stresses perpendicular to grain for some timber species at 18% moisture content available in Nigeria.

Table 1. Compressive stresses parallel to grain at a moisture content of 18% for some Nigerian timber species (Adapted from Aguwa 2016).

S/N	Specie	Mean Failure Stress (N/mm²)	Standard Deviation (N/mm²)	Basic Stress (N/mm²)	Grade 80 Stress (N/mm²)	Grade 63 Stress (N/mm²)	Grade 50 Stress (N/mm²)	Grade 40 Stress (N/mm²)
1	Abura	39.99	3.57	17.41	13.93	10.97	8.71	6.96
2	Afara	24.31	2.92	9.62	7.70	6.06	4.81	3.85
3	Apa	47.46	2.51	22.86	18.29	14.40	11.43	9.14
4	Ara	29.86	4.33	10.87	8.70	6.85	5.44	4.35
5	Araba	21.84	3.60	7.39	5.91	4.66	3.70	2.96
6	Ayo	39.83	2.84	18.25	14.60	11.50	9.13	7.30
7	Danta	58.97	7.81	22.39	17.91	14.11	11.20	8.96
8	Ebony	54.13	5.70	22.45	17.96	14.14	11.23	8.98
9	Ekki	74.17	9.95	28.01	22.41	17.65	14.01	11.20
10	Gmelina	45.22	10.74	11.10	8.88	6.99	5.55	4.44
11	Iroko	39.51	2.74	18.21	14.57	11.47	9.11	7.28
12	Lagos Mahogany	44.47	10.47	11.03	8.82	6.95	5.52	4.41
13	Mansonia	46.48	6.04	17.81	14.25	11.22	8.91	7.12
14	Obeche	24.53	3.33	9.22	7.38	5.81	4.61	3.69
15	Okan	58.47	2.76	30.14	24.11	18.99	15.07	12.06
16	Okwen	50.16	7.11	18.46	14.77	11.63	9.23	7.38
17	Omu	49.21	6.74	18.42	14.74	11.60	9.21	7.37
18	Opepe	65.26	5.25	29.13	23.30	18.35	14.57	11.65
19	Sapele Mahogany	51.68	7.72	18.52	14.82	11.67	9.26	7.41
20	Walnut	48.92	9.66	14.54	11.63	9.16	7.27	5.82

Table 2. Compressive stresses perpendicular to grain at a moisture content of 18% for some Nigerian timber species (Adapted from Aguwa 2016)
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S/N	Specie	Mean Failure Stress (N/mm²)	Standard Deviation (N/mm²)	Basic Stress (N/mm²)	Grade 80 Stress (N/mm²)	Grade 63 Stress (N/mm²)	Grade 50 Stress (N/mm²)	Grade 40 Stress (N/mm²)
1	Abura	8.65	1.57	3.20	2.56	2.02	1.60	1.28
2	Afara	5.50	0.96	2.09	1.67	1.32	1.05	0.84
3	Apa	9.67	0.91	5.05	4.04	3.18	2.53	2.02
4	Ara	6.94	1.60	2.05	1.64	1.29	1.03	0.82
5	Araba	8.47	2.55	1.62	1.30	1.02	0.81	0.65
6	Ayo	6.81	0.45	3.69	2.95	2.33	1.35	1.48

7	Danta	9.14	0.65	5.05	4.04	3.18	2.53	2.02
8	Ebony	9.70	0.80	5.02	4.02	3.16	2.51	2.01
9	Ekki	14.31	2.25	6.34	5.07	3.99	3.17	2.54
10	Gmelina	5.54	0.90	2.21	1.77	1.39	1.11	0.88
11	Iroko	9.04	1.12	4.38	3.50	2.76	2.19	1.75
12	Lagos Mahogany	5.53	0.88	2.23	1.78	1.41	1.12	0.89
13	Mansonia	8.94	1.19	4.23	3.38	3.67	2.12	1.69
14	Obeche	5.64	0.99	2.13	1.70	1.34	1.07	0.85
15	Okan	12.54	1.36	6.34	5.07	3.99	3.17	2.54
16	Okwen	7.13	0.33	4.08	3.26	2.57	2.04	1.63
17	Omu	8.98	1.20	3.96	3.17	2.50	1.98	1.58
18	Opepe	10.34	0.25	6.32	5.06	3.98	3.16	2.53
19	Sapele Mahogany	8.99	1.20	3.97	3.18	2.50	1.99	1.59
20	Walnut	8.65	1.67	3.21	2.57	2.02	1.61	1.28

2.0 METHODOLOGY

In this section, the compressive stresses parallel and perpendicular to grain of the twenty timber species from literature are compared. Since the strength in timber depends on the angle between the line of action of the load and the direction of the grain (Aguwa 2016), hence the greater compressive stress parallel to grain than the compressive stress perpendicular to grain. This was confirmed by Song and Hong (2019) when they established in their study that timber tends to be weak against load applied perpendicular to grains when loads were applied perpendicularly to a larch cross-laminated timber (CLT) made up of multiple larche laminae. Table 3 shows the different species of timber, their basic compressive stresses perpendicular and parallel to grain as well as the ratios of the compressive stresses perpendicular to that parallel to grain. The average of these ratios shows that the basic compressive stress perpendicular to the grain of timber is about 22% of the basic compressive stress parallel to grain provided the tests are done following the specifications provided in BS 373 (1957). For the six commonly used timber being considered in this paper namely, 'Abura' *(Mitragyna ciliata),* 'Afara' *(Terminalia superba),* 'Iroko' *(Chlorophora excelsa),* 'Obeche' *(Triplochiton scleroxylon),* 'Ekki'*(Lophira alata),* and African birch or 'chewing stick tree' *(Anogeissus leiocarpus)*, their actual and permissible stress values were used to form limit state equations with which the reliability-based assessment of the individual timber was carried out when used as a column member. A FORTRAN-based First Order Reliability Method software was used to carry out the reliability analysis following the flow chart represented in Figure 1.

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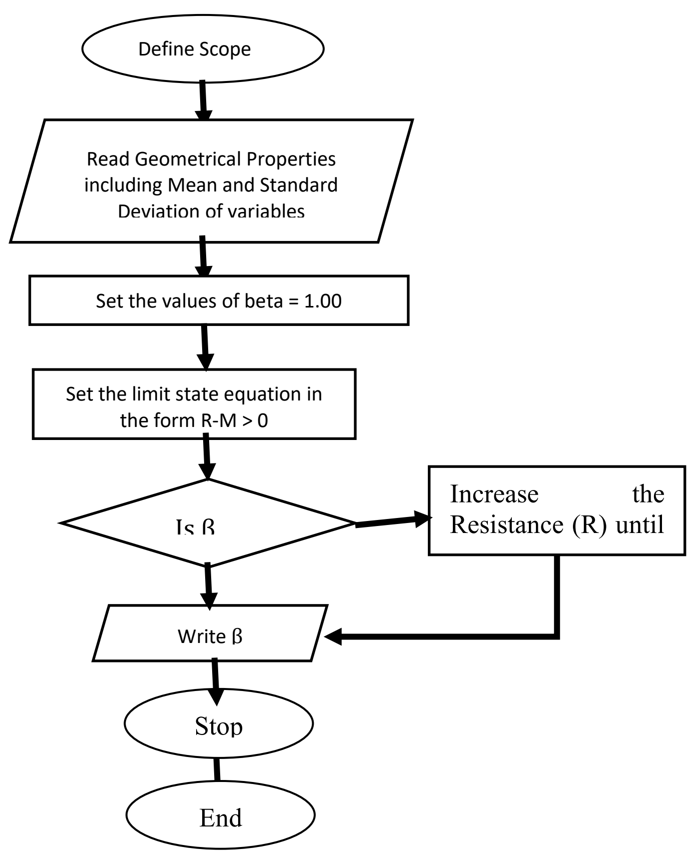

Figure 1 Flow Chart of FORTRAN Subroutine. Adapted and modified from Afolayan and Opeyemi (2010)

The First Order Reliability Method (FORM) was used as a reliability assessment technique to investigate the performance of the column section of six Nigerian-grown timbers reported in this study. This method entails establishing the performance or limit state function. FORM as a reliability assessment technique was first reported in literature by Hasofer and Neils (1974). It was considered in this study because of its flexibility to handle both linear and non-linear performance functions, as well as correlated non-normal variables. FORM is also referred to as Mean Value First order second moment method (MVFOSM), and FORM linearizes the performance function using Taylor series approximation. Hence, it results in a first order approximation. FORM uses only mean and standard deviation of the variables. The mean and standard deviation of the actual and permissible stress are used to evaluate the safety index values and subsequently, the corresponding probabilities of failure. In this work, the FORTRAN programming language was used to enhance the computation process.

3.0 RESULTS AND DISCUSSION

More often in compression members than in other members is the need for stresses perpendicular to grain. This is attributed to the application of the load on the member. A comparison between basic compressive stress perpendicular to grain and basic compressive stress parallel to grain is shown in Table 3, while a graphical representation of the basic compressive stress perpendicular to grain and that parallel to grain for the various species of timber is presented in Figure 2.

Table 3. Comparison between compressive stress parallel to grain and perpendicular to grain

Specie	Stress Parallel to grain (N/mm^2)	Stress Perpendicular to grain (N/mm^2)	Stress Perpendicular/ Stress Parallel
Abura	17.41	3.20	0.183802
Afara	9.62	2.09	0.217256
Apa	22.86	5.05	0.220910
Ara	10.87	2.05	0.188592
Araba	7.39	1.62	0.219215
Ayo	18.25	3.69	0.202192
Danta	22.39	5.05	0.225547
Ebony	22.45	5.02	0.223608
Ekki	28.01	6.34	0.226348
Gmelina	11.1	2.21	0.199099
Iroko	18.21	4.38	0.240527
Lagos Mahogany	11.03	2.23	0.202176
Mansonia	17.81	4.23	0.237507
Obeche	9.22	2.13	0.231020
Okan	30.14	6.34	0.210352
Okwen	18.46	4.08	0.221018
Omu	18.42	3.96	0.214984
Opepe	29.13	6.32	0.216958
Sapele Mahogany	18.52	3.97	0.214363
Walnut	14.54	3.21	0.220770
Average			**0.215812**

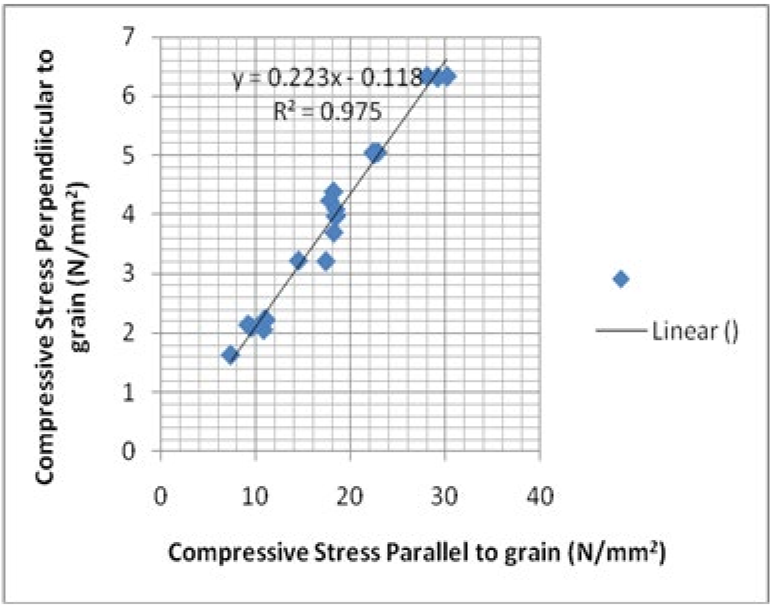

Figure 2. A graph of compressive stress perpendicular to grain against compressive stress parallel to grain

From the Figure 2, a model which can be used to compute the basic compressive stress perpendicular to the grain (minor compressive stress) given the basic compressive stress parallel to grain (major compressive stress) or vice versa for other timber species which have not been completely characterised can be expressed according to Equation 5.

$$f_{bcper} = 0.2235\, f_{bcpar} - 0.1186 \qquad (5)$$

where

f_{bcper} connotes the basic compressive stress perpendicular to grain.

f_{bcpar} connotes basic compressive stress parallel to grain.

The correlation coefficient value of $R^2 = 0.9759$ indicates a very strong relationship between the two parameters and hence validates the model formulated.

A reliability assessment is necessary to evaluate their performances especially with regards to their respective safety indices. Table 4 shows commonly used timber species in Nigeria, their compressive stresses parallel to grain and corresponding grade stresses since the compressive stresses parallel to grain is what is relevant in assessing the compressive resistance of timber when used as a column member. The basic stress values are used to form the limit state equations for the reliability assessment. The probability distributions (which is a function that gives the probabilities of occurrence of possible outcomes for an experiment) is shown in Table 5 with the statistical parameters of the basic variables, where load is assumed to have a lognormal distribution while breadth and depth have a normal distribution (Aguwa and Sadiku, 2011). The statistical parameter, particularly the coefficient of variation is the ratio of the standard deviation to mean.

Table 4. Compressive stress parallel to grain and grade Stresses of Some Commonly used Nigerian Timber species

Timber Specie		Mean Failure Stress (N/mm²)	Standard Deviation (N/mm²)	Basic Stress (N/mm²)	Grade 80 Stress (N/mm²)	Grade 63 Stress (N/mm²)	Reference
1.	Abura	39.99	3.57	17.41	13.93	10.97	Aguwa (2016)
2.	Afara	24.31	2.92	9.62	7.70	6.06	Aguwa (2016)
3.	Iroko	39.51	2.74	18.21	14.57	11.47	Aguwa (2016)
4.	Obeche	24.53	3.33	9.22	7.38	5.81	Aguwa (2016)
5.	Ekki	74.17	9.95	28.01	22.41	17.65	Aguwa (2016)
6.	African Birch	57.15	5.04	32.43	25.95	20.43	Bello and Jimoh (2018)

Table 5. Probability Distribution and Statistical Parameters for Basic variables

Parameter	Distribution	Mean	Standard Deviation	Coefficient of Variation
Load (kN)	Log	250	35	0.140
Breadth (mm)	Normal	250	9	0.036
Depth (mm)	Normal	250	9	0.036

For the reliability study reported in this study, a limit state or performance function was written for the column using the basic compressive stress of each timber species mentioned in Table 4 for the reliability to be considered in terms of compression. This is done to ensure that the permissible stress of the column is neither reached nor exceeded. A uniform section of 250 x 250mm column for all the species at different loads was considered and also for 300 x 300mm section which is the maximum section commercially available. These analyses were done using FORM- First Order Reliability Method to determine the probabilities of failure and the safety index values for the different conditions.

The limit state or performance function in compression as given by (Nowak and Collins 2000) in Equation 6;

$$g(x) = f_{ppar} - f_{apar}. \quad (6)$$

f_{ppar} = Permissible stress parallel to grain
f_{apar} = Actual stress parallel to grain

Figure 3 shows the graph of the safety index against the load supported by a 250 x 250 mm section of all the six timber species. The degree to which the structural element is safe is the Safety index, β. Theoretically, the safety index is calculated as the distance between the origin and the reliability curve. The 'Ekki' timber (*Lophira alata*) shows the highest performance amongst the other timber species judging from its safety index of 3.45 and a probability of failure of 2.78×10^{-3} for loads as much as 1000kN. It was found out that a further increment of the load to 1500kN, the 'Ekki' timber showed a safety index of 1.0, which is still regarded safe and economical by the Nordic Committee on Building (NKB 1978). This implies that sections slightly greater than 250 x 250 mm of that timber can be used for a bridge pier. This performance is followed by the African birch which supports 1000kN load with a safety index of 2.8 and a probability of failure of 2.53×10^{-2}. In the order of decreasing performance, the 'Iroko'*(Chlorophora excelsa)* follows with a safety index of 0.85 and probability of failure of 0.20, and 'Abura'*(Mitragyna ciliata)* showing a safety index of 0.58 with a probability of failure of 0.28 which are certainly not safe to support a load of 1000kN.

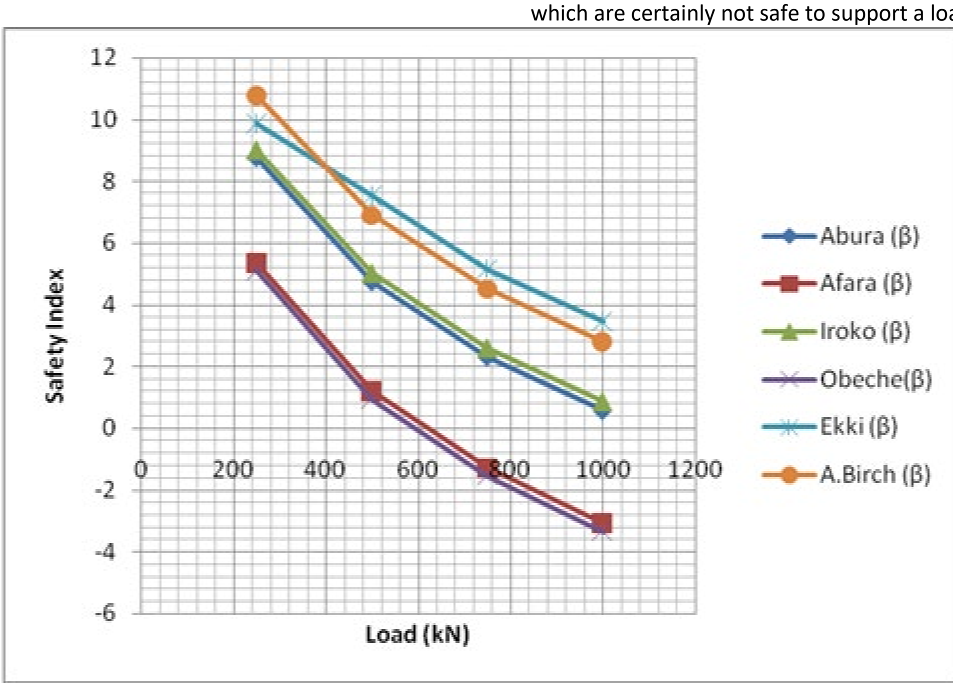

Figure 3. Safety Index-Load (kN) relation for a (250 x 250mm) of Nigerian Timber Species for Load between 250 and 1000kN

'Afara' (*Terminalia superba)* and 'Obeche'(*Triplochiton scleroxylon*) come last in the order showing their abilities to safely bear a maximum load of 500kN with safety indices of 1.19 and 0.93 and probability of failure values of 0.12 and 0.18 respectively beyond which, failure is expected. The performance of each timber can be traceable to their compressive stresses parallel to grain.

In Figure 4, it can be seen that only 'Ekki' (*Lophira alata*) and African birch (*Anogeissus leiocarpus*) can safely support a load to as much as 1500kN and this is what makes it different from Figure 3.

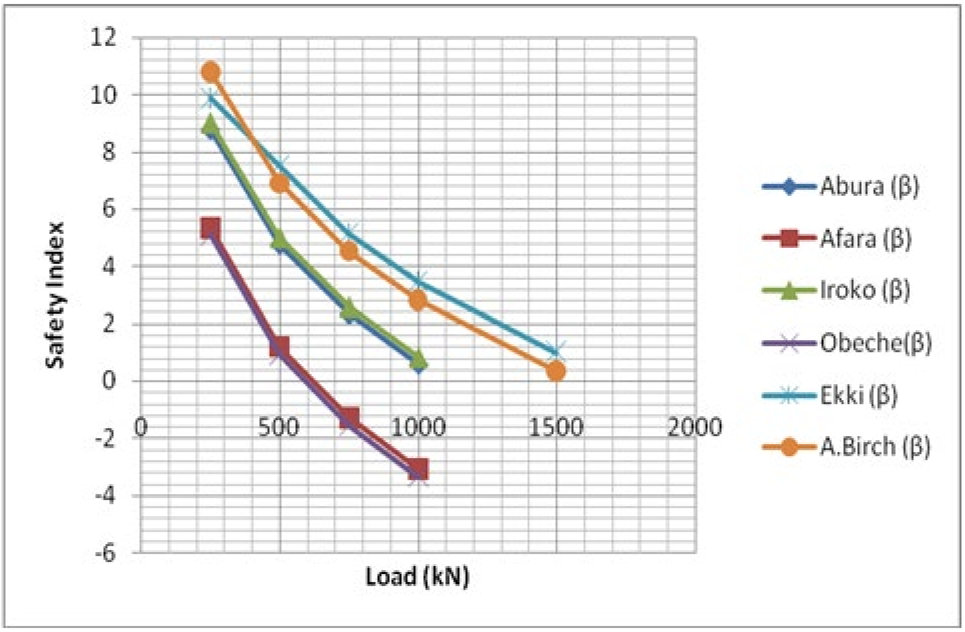

Figure 4. Safety Index-Load (kN) relation for a (250 x 250mm) of Nigerian Timber Species for Loads greater than 1000kN

It can be observed that their margin of safety in supporting the load of 1500kN is very slim. 'Ekki' (*Lophira alata*) supports the load with a safety index of 1.0 and a probability of failure of 1.58 x 10^{-1}, while African birch (*Anogeissus leiocarpus*) does with a safety index of 0.34 and a probability of failure of 3.7 x 10^{-1} which is close to failure.

On increasing the sections of the timber columns to 300 x 300mm which is the maximum section commercially available in the market, their compressive resistance/capacity is invariably increased and the performance of the timber species can be seen in Figure 5.'Ekki' (*Lophira alata*) could support as much as 2000kN with a safety index of 1.47 and a probability of failure of 7.1 x 10^{-2} which is safe. African birch (*Anogeissus leiocarpus*) of that section does not reflect a safe condition, but for a load of 1500kN, African birch supports it with a safety index of 2.56 and a probability of failure of 5.26 x 10^{-3} which is reflective of safe status. 'Iroko'*(Chlorophora excelsa)* and 'Abura'*(Mitragyna ciliata)* are safe enough to support a load of 1000kN as they show safety index values of 3.02 and 2.34 respectively and probabilities of failure of 1.12 x 10^{-3} and 2.266 x 10^{-3} respectively.

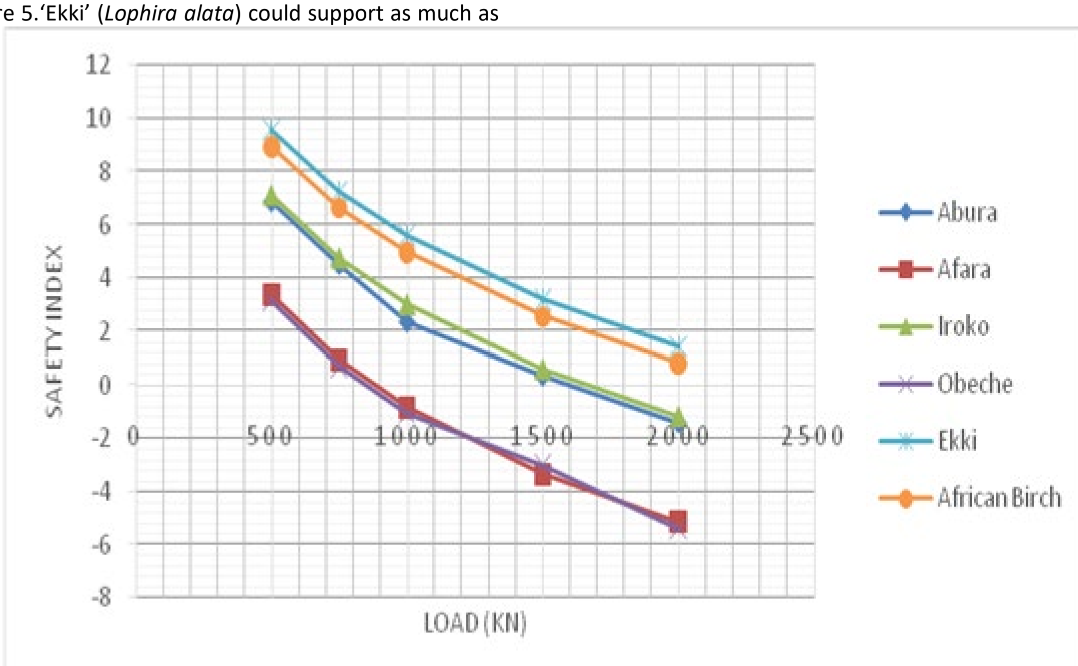

Figure 5. A Safety Index-Load (kN) relation for a (300 x 300mm) of Nigerian Timber species.

'Afara' (*Terminalia superba)* and 'Obeche'(*Triplochiton scleroxylon*) with column section of (300 x 300mm) would safely support a load of 500kN as can be seen from the various safety index values of 3.39 and 3.13 respectively and their probabilities of failures 3.5 x 10^{-4} and 8.7 x 10^{-4}. These performances of the various timber species under the specified loadings are traceable to their basic compressive strengths parallel to grain which is the key determinant mechanical property for the behaviour of compressive members like columns or piers in timber design.

The safe load that can be supported by the various sections of the different timber species as summarized in Figure 6. The various grade stresses of the compressive stress/strength parallel to grain for the selected species considered are as summarized in Figure 7.

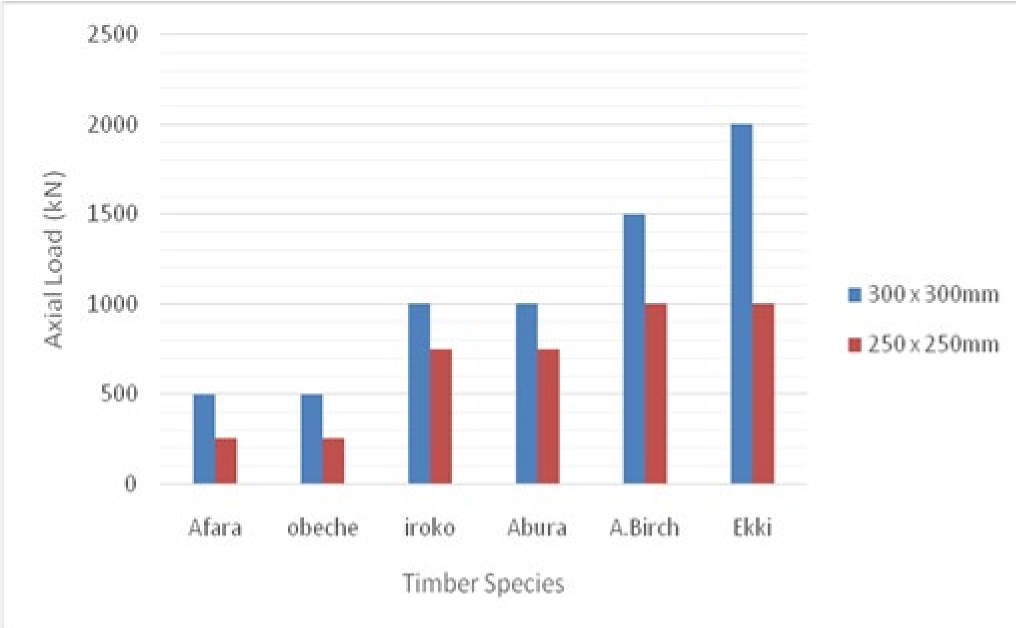

Figure 6. Graph of axial load safely supported by 250 x 250mm and 300 x 300mm sections of various timber species

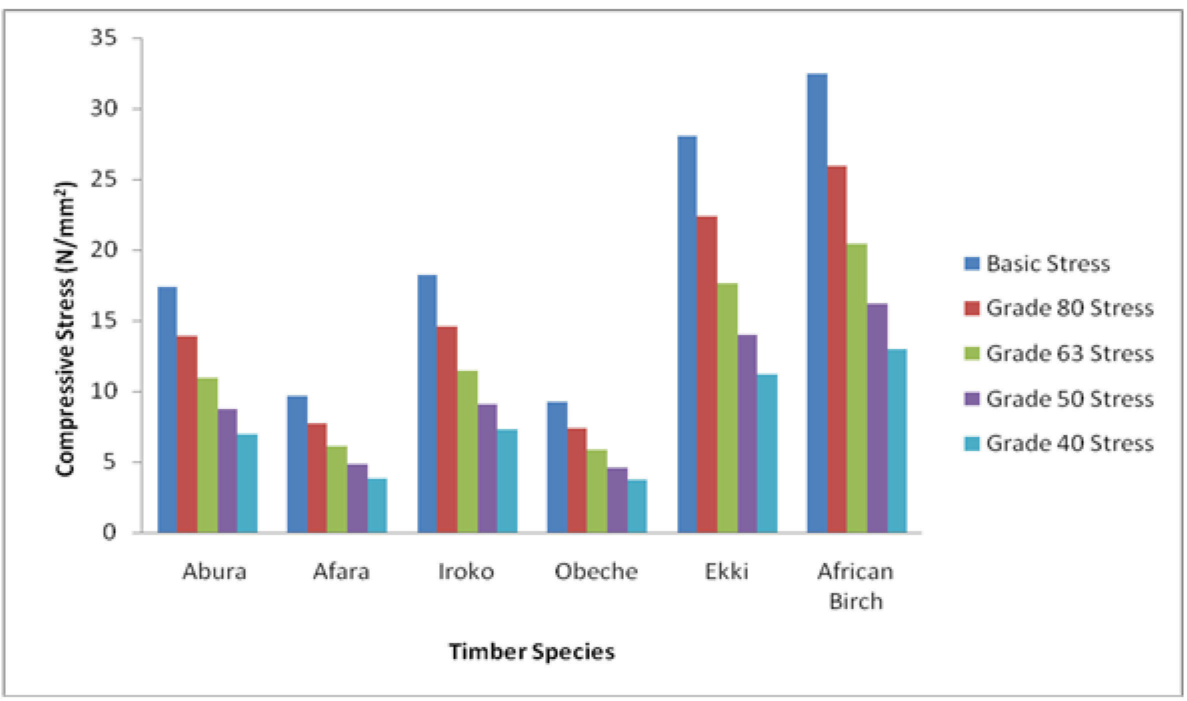

Figure 7. Graph of various grade stresses for the different timber species

4.0 CONCLUSION

From the results obtained in this study, it can be deduced that the basic compressive stress perpendicular to the grain of timber is about 22% of the basic compressive stress parallel to grain when characterization is done in accordance to BS 373 (1957). Also, the compressive strength parallel to grain can be computed provided the compressive strength perpendicular to grain is given. The reliability investigations confirmed that 'Ekki' (*Lophira alata*) and African birch (*Anogeissus leiocarpus*) can support a maximum axial load of 2000kN and 1500kN respectively with the maximum commercially available sections. Furthermore, it can be inferred from this study that 'Iroko' *(Chlorophora excelsa)* and 'Abura' *(Mitragyna ciliata)* can safely support a maximum axial load of 1000kN while, 'Afara' (*Terminalia superba)* and 'Obeche' (*Triplochiton scleroxylon*) have the compressive capacity to safely support 500kN. By implication, 'Ekki' (*Lophira alata*) and African birch (*Anogeissus leiocarpus*) could be suitable for bridge piles and piers, railway or related structures that require compressive members with high axial capacity. This is because of the high compressive capacity as well as the safety index achieved and this can invariably be corroborated by Aguwa and Sadiku (2011) which submitted that the Nigerian 'Ekki' *(Lophira alata)* timber is structurally satisfactory for use as a timber bridge beam. Also, Abubakar *et al.* (2020) showed that *Anogeissus shimperri,* a specie of the Nigerian African birch is a reliable timber bridge beam material. 'Abura', 'Obeche', 'Afara' and 'Abura' would rather be best suitable for buildings judging by their compressive strengths and safety indices. These important information obtained from this investigative study can serve as a guide in the structural usage of these timber species. The major limitation identified in this study is that the investigation was limited to the compressive stress characterization done exclusively in accordance with BS 373 (1957) and for compressive strength properties of Nigerian-grown timbers. This could be extended in future research to include the compressive stress characterization of the timber species considered following EN 338 (2009) and used as a basis of comparison with BS 373 (1957) which has not been reported in open literature.

Acknowledgement

The support and suggestions received from the members of staff of the Department of Civil Engineering, Nigerian Defence Academy (NDA) Kaduna, Nigeria for the success of this research is gratefully acknowledged. We also quite appreciate the kind contributions of late Dr Jacob O. Afolayan as we dedicate the entire work to his loving memory.

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