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PROBABILITY-BASED CALIBRATION OF LOAD DURATION MODIFICATION FACTORS FOR THE NIGERIAN GROWN TIMBER

Aguwa, J. I.[1]; Sadiku, S.[2]; Afolayan, J. O.[3]; Aliyu, A.[4]; Abubakar, M.[5]; and Kolo, D. N.[6]

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ABSTRACT

All along, load duration modification factors used in Nigeria for design of timber structures were based on BS 5268 of 2002 and this is not a good engineering practice since the strength of timber depends so much on the soil as well as on the environment. There is the need to localize the modification factors based on our environment since Nigerian grown timber is generally used for all timber structures designed and built in Nigeria. Probability-based calibration of load duration modification factors for the Nigerian grown timber was successfully carried out. The results showed significant difference between the calibrated factors and those from BS 5268 of 2002. The calibrated modification factors are; 1.25 for long-term, 1.35 for medium-term, 1.70 for short term, and 2.0 for very short-term duration. This paper recommends the use of these calibrated load duration factors based on Nigerian grown environment.

Keywords: Calibration, Load duration factors, Nigerian, Probability-based, Timber

INTRODUCTION

The term timber refers to wood in the form that is suitable for construction, carpentry, joinery or reconversion for manufacturing purposes. This definition includes all standing trees or felled trees capable of being converted for the above-mentioned uses. Timber has been playing very important roles in the history of man. In the primitive age, timber was used to provide shelter for example huts, for weapons like spears and bows and for transport such as canoes, ships and log-bridges. Timber remains a very important structural material and technological advances, developments and high-level engineering production have led to more innovative methods of working with timber (Aguwa, 2016). Wood is produced by harvesting forest plantations or natural forests (primary and secondary forests). In 2020, the plantation area was 132 Mha (i.e., 8% of global cropland area (1595 Mha) and only 4% of global natural forest area (3629 Mha) but it likely contributed more than 33% to global industrial roundwood production (Mishra et al, 2022)

The strength of timber depends on the moisture content. It is important to know the moisture content of green wood because it allows fine tuning of the drying schedule and grading by air-dried density before drying. However, it is difficult to non-destructively determine the moisture content with accuracy when the moisture content is well above the fibre saturation point (FSP), as in green wood (Fukui et al., 2023).

Timber is very durable as a structural material when well-treated and protected from rain or adverse effects of weather and can withstand fire for sometimes before total failure. Experience and fire endurance tests have shown that the tendency of a wood member to ignite in a fire is affected by its cross-sectional dimensions. In a fire, large-size wood members form a protective coating of char which insulate the inner portion of the member. Thus, large wood members may continue to support a load in a fire long after uninsulated steel member has collapsed because of elevated temperature (Lowden and Hull, 2013). Buildings made from timber act as a long-term carbon sink of harvested wood (Pomponi et al, 2020). Engineered wood used for the construction of buildings can substitute conventional hard to decarbonize building materials This helps to avoid considerable c02 emissions from the manufacturing of cement and steel.

Using the principle of structural reliability, the level of reliability of an existing structure, which is designed as per the existing structural standards, can also be evaluated. It can also be used for developing a reliability-based design criterion in the form of code calibration to compute the partial safety factors and load combination factors for a targeted level of reliability (Abubakar, 2019).

Modification factors are used in structural design of timber to take into account some of the uncertainties arising from the service condition such as geometrical properties, exposure properties and duration of loading. This is because the conditions in the laboratories where the timber stresses are determined are quite different from the actual service conditions.

All the modification factors (in British and European Codes) used in structural design of timber structures in Nigeria were calibrated using foreign grown timber species. However, the strength of timber depends mostly on the soil and environment in which it is grown. Using these recommended modification factors from foreign codes to design timber structures in Nigeria is not a good engineering practice. It is on this basis that this research is initiated so that our structural design in timber structures will be completely indigenous.

Duration of loading factor (K_3) is used in design of timber structural elements and it depends on the duration as well as the type of loading. Values of stresses given in Tables 8, 9, 10, 11, 12, 13, 14 and 15 of BS 5268 of 2002, are for long-term loading and should be multiplied by modification factor, K_3 for short term loads such as snow and wind. Table 17 of BS 5268 (2002) shows values of K_3 presented herein in Table 1.

Table 1: Modification factor K_3, for duration of loading

Duration of loading	Value of K_3
Long-term (e.g. dead + permanent imposed load)	1.00
Medium-term (e.g., dead + snow, dead + temporary imposed)	1.25
Short-term (e. g. dead + imposed + wind, dead + imposed + snow + wind)	1.50
Very short-term (e. g. dead + imposed + wind)	1.75

Source: BS 5268 (2002)

The usage of Nigerian timber mainly in building construction has been by intuition, guess and trial-and error due to the uncertainty about their behaviour under applied loads as a result of improper prediction of their load-carrying capacity (Aguwa, 2010). Timber bridge decks were common in Nigeria in the colonial era but disappeared due to fear of high risk of failure caused by unavailable in-depth structural reliability analysis. It is not a good structural design practice to use modification factors calibrated based on foreign environment. It is justifiable that with proper reliability-based calibration of the modification factors, analysis and design of Nigerian timber structures will be based on local environment. This will bring about increased construction activities with Nigerian grown timber. Life of the numerous rural dwellers will be improved tremendously as both Government and individuals will likely embark on provision of low-cost timber bridge decks and houses with locally available and affordable structural materials. This will also create the awareness in Nigerian engineers to look inward by making use of this locally available structural material with great confidence.

Aboshio et'al. (2016) carried out reliability-based calibration of safety factors for reinforced concrete staircase designed to BS

8110 (1997). They employed reliability approach to calibrate partial factors of safety in BS 8110 for a typical half turn staircase using a Microsoft excel based reliability software developed by Joint Committee on Structural Safety (JCSS.) They determined the statistical parameters representing the model uncertainty, resistance, dead and live loads and used in the software and afterwards determined the associated safety indices and probabilities of failure. Their results however, show the design of staircase to BS 8110 (1985) is to a great extent conservative and thus recommends that the resistance, dead and live load factors be reviewed to 1.02, 1.4 and 1.31 respectively.

Nowak and Rakoczy (2012) carried out Reliability-based Calibration of Design Code for Concrete Structures (ACI 318) at Department of Civil Engineering, University of Bebraska, LINCOLN. Structural components considered are; Beams (reinforced concrete, prestressed concrete), Slabs (reinforced concrete, prestressed concrete), Columns (reinforced concrete, prestressed concrete, tied and spiral, axial and eccentric) and plain concrete. They discovered that reliability of structures designed according to old ACI 318 is higher than the minimum acceptable level and also resistance factors can be increased by 10-15%. Therefore, for the new load factors (ASCE 7), old resistance factors are acceptable.

Sorensen et al. (2005) carried out reliability-based calibration of load duration factors for timber structures. The load bearing capacity of timber structures decrease with time depending on the type of load and timber. Based on the representative limit states and stochastic models for timber structures, load duration factors are calibrated using probabilistic methods. Three damage accumulation models are considered namely; Gerhards model, Barret and Foschi's model and Foschi and Yao's model. The results show that the long-term reliability is smaller than the short-term reliability, indicating that damage reduced strength does not change the reliability compared to the long-term reliability.

The aim of this research is to calibrate load duration modification factors for structural design of timber based on Nigerian environment. The objectives of this research are; (1). to determine various strength properties of the selected Nigerian timber species. (2). to carry out statistical analysis using the results from (1). (3). to carry out deterministic design of a chosen Nigerian timber structure. (4). to Perform structural reliability analysis of the chosen timber structure, using bending failure mode and (5) to carry out calibration of the modification factors using results from (4).

MATERIALS AND METHODS

Materials

The Nigerian Standard Code of Practice NCP 2 (1973), classified some characterised Nigerian timber species into seven (7) strength groups; N_1, N_2, N_3, N_4, N_5, N_6 and N_7 based on their strengths. For the purpose of this research, representative timber species were selected from the seven strength groups in order to achieve the aim of the research with wide spread results. The Nigerian timber species used for the research are; Okan (N_1), Danta (N_2), Mansonia (N_3), Abura (N_4), Gmelina (N_5), Afara (N_6) and Araba (N_7). The whole timber species were bought from Sapele Delta State, Nigeria and transported to Civil Engineering laboratory in Federal University of Technology, Minna, Nigeria.

Preparation and Testing of Samples

Seven different timber species were cut into transportable size of 50mm x 100mm x 1200mm, stacked and naturally seasoned for six months. Forty (40) test specimens for each specie and for each test were prepared in accordance with BS 373 (1957), making a total of 1400 test specimens. The bending stress parallel to the grain tests were carried out in accordance with BS 5268 (2002) at the seasoned moisture content. The results at moisture content of 18%, which is recommended for Nigerian environment by NCP 2 (1973) are shown in Tables 3-5.

Statistical Analysis

Statistical Analysis was carried out using the failure stresses determined, yield and mean stresses, standard deviations and coefficients of variation. The results are shown in Tables 3-5.

Basic Stresses

The basic bending stresses were determined using the mean failure stresses and the standard deviations and the results are shown in Table 3

Bending stress parallel to the grain

The basic bending stresses parallel to the grain for the species were determined using forty failure bending stresses from tests by NCP 2 (1973)

$$f_{bb\ par} = \frac{f_{mb} - 2.33\sigma}{2.25} \quad (1)$$

Where $f_{bb\ par}$ = basic bending stress parallel to the grain

f_{mb} = mean value of the forty failure bending stresses

σ = standard deviation of the forty failure bending stresses

Then the grade bending stresses were determined for 80, 63, 50 and 40 respectively The 80% grade bending stresses for the species were determined using Equation. (2)

$$f_{gb,par} = f_{bb,par} \times 0.8 \quad (2)$$

Other grades were obtained by multiplying the $f_{bb,par}$ by 0.63, 0.50 and 0.40 respectively.

Modulus of elasticity

The formula below shows the relationship between the E_{mean} and the statistical minimum value of E appropriate to the number of species acting together,

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

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.

Choice of structure and the failure Modes

One of the most important requirements of structural reliability analysis and design of structural systems is the identification of the possible modes of failure (Faber and Sorensen, 2002). BS 5268 (2002) like other design codes is based on single component performance, where each permissible limit is related to mode of failure of a single component (Hansson and Ellegaard, 2006). From Figure 1, the components considered for the analysis are: Column AB, Beam BC and Column CD. The five cases corresponding to fives modes of failure are:

i. Beam bending failure at the mid-span
ii. Beam compression failure at the bearing ends
iii. Beam deflection failure at the mid-span
iv. Beam shear failure at the mid-span
v. Column axial compression failure

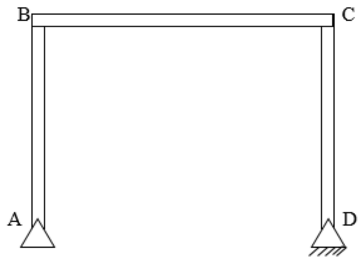

Figure 1: A simple timber structure

Limit State Functions

The Limit State Functions for failure criterion of the timber portal frame were developed for each failure mode based on the following generalized BS 5268 (2002) design criteria. A traditional notion of the "Safety Margin" or Margin of Safety" is associated with the ultimate limit states. For example, a mode of beam failure could be when the moment due to loads exceeds the moment-carrying capacity. Let R represents the resistance (moment-carrying capacity) and Q represents the load effect (total moment applied to the considered beam). It is helpful to think of R as the "Capacity" and Q as the "Demand". A performance function, or limit state function, can be defined for this mode of failure as

$$g(R, Q) = R - Q \quad (4)$$

The limit state corresponding to the boundary between desired and undesired performance, would be when g = 0. If g ≥ 0, the structure is safe (desired performance), if g < 0, the structure is not safe (undesired performance), (Nowak and Collins, 2000). The probability of failure, P_f is equal to the probability that the undesired performance will occur. Mathematically,

$$P_f = P(R - Q < 0) = P(G < 0) \quad (5)$$

Generalizing the above concept of failure, all realizations of a structure can be put into one of two categories:

Safe (Load Effect ≤ Resistance)
Failure (load Effect > Resistance)

The state of the structure can be described using various parameters $X_1, X_2 \ldots Xn$, which are load and resistance parameters such as dead load, live load, length, depth, compressive strength, yield strength and moment of inertia. A limit state function or performance function, is a function $g(X_1, X_2 \ldots Xn)$ of these parameters such that

$g(X_1, X_2 \ldots Xn) > 0$ for a safe structure
$g(X_1, X_2 \ldots Xn) = 0$ border or boundary between safe and unsafe
$g(X_1, X_2 \ldots Xn) < 0$ for failure

Failure Mode One: Beam bending failure at mid-span

The beam BC can fail under bending forces at the mid-span. The applied bending stress parallel to the grain caused by the external loads is

$$f_{a\,par} = \frac{M}{Z} \quad (6)$$

But $M = \frac{wl^2}{8}$ *and* $Z = \frac{bh^2}{6}$

By substituting in Eq. (4),

$$f_{a\,par} = \frac{3wl^2}{4bh^2} \quad (7)$$

where l is the span of the beam, Z is the section modulus, b is the breadth of the beam, h is the depth of the beam and w is the uniformly distributed load on the beam. The permissible or design stress in bending parallel to the grain is

$$f_{p\,par} = f_{g\,par} K_3 K_7 \quad (8)$$

where K_3 is the modification factor for duration of loading, K_7 is the depth modification factor and $f_{g\,par}$ is the grade bending stress parallel to the grain.

The Limit State Equation is

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

$$= f_{g\,par} K_3 K_7 - \frac{3wl^2}{4bh^2} \quad (9)$$

Table 2: Statistical parameters for failure mode one: Beam bending failure at the mid-span

Description	Variable	Mean	COV	Std Dev.	Pdf
Grade bending stress of timber (N/mm²)	X_1	28.88	0.3	8.66	Normal
Load duration factor K_3	X_2	1.0	0.3	0.3	Normal
Depth factor, K_7	X_3	1.05	0.3	0.315	Normal
Live load, LL (kN/m)	X_4	1.5	0.3	0.45	Normal
Span of beam, L (mm)	X_5	3825	0.1	382.5	Normal
Beam width, b (mm)	X_6	150	0.1	15	Normal
Beam depth, h (mm)	X_7	200	0.1	20	Normal
Dead load, DL (kN/m)	X_8	0.6	0.3	0.18	Normal

Using Advanced First Order Second Moment method (AFOSM)

The numerous reliability analyses were performed using Advanced First Order Second Moment method (AFOSM), Equation 9 becomes;

$$G(X_1 X_4 X_5 \ldots X_8) = 1.05X_1 - 1.05X_5^2 X_6^{-1} X_7^{-2} X_8 - 1.2X_4 X_5^2 X_6^{-1} X_7^{-2} \quad 10)$$

Therefore, the first-order approximate mean and variance of g can be shown,

$$G(X_1X_4X_5 \ldots X_8) = 1.05(\mu_{x1} - \alpha_{x1}\beta\sigma_{x1}) - 1.05((\mu_{x5} - \alpha_{x5}\beta\sigma_{x5})^2(\mu_{x6} - \alpha_{x6}\beta\sigma_{x6})^{-1}(\mu_{x7} - \alpha_{x7}\beta\sigma_{x7})^{-2}(\mu_{x8} - \alpha_{x8}\beta\sigma_{x8}) - 1.2(\mu_{x4} - \alpha_{x4}\beta\sigma_{x4})(\mu_{x5} - \alpha_{x5}\beta\sigma_{x5})^2(\mu_{x6} - \alpha_6\beta\sigma_{x6})^{-1}(\mu_{x7} - \alpha_{x7}\beta\sigma_{x7})^{-2} \quad (15)$$

respectively (Ayyub 2014), as.

$$\mu_G = 1.05X_1 - 1.05X_5^2 X_6^{-1} X_7^{-2} X_8 - 1.2X_4 X_5^2 X_6^{-1} X_7^{-2} = 24.3985969$$

Substituting for the values of the gradients, $\partial g / \partial xi$ and the standard deviations gives:

Substituting for the values of the gradients, $\partial g/\partial xi$ and the standard deviations gives:

$$\sigma_G^2 = \sum^{n} \sigma_{Xi}^2 \left(\frac{\partial g}{\partial xi}\right)^2 = \sigma_{X1}^2 \left(\frac{\partial g}{\partial x1}\right)^2 + \sigma_{X4}^2 \left(\frac{\partial g}{\partial x_4}\right)^2 + \sigma_{X_5}^2 \left(\frac{\partial g}{\partial x_5}\right)^2 + \sigma_{X6}^2 \left(\frac{\partial g}{\partial x_6}\right)^2 + \sigma_{X7}^2 \left(\frac{\partial g}{\partial x_7}\right)^2 \quad \sigma_{X_8}^2 \left(\frac{\partial g}{\partial X_8}\right)^2 \quad (11)$$

$$\sigma_G = \sqrt{\sigma_{X1}^2 \left(\frac{\partial g}{\partial x1}\right)^2 + \sigma_{X4}^2 \left(\frac{\partial g}{\partial x_4}\right)^2 + \sigma_{X5}^2 \left(\frac{\partial g}{\partial x_5}\right)^2 + \sigma_{X6}^2 \left(\frac{\partial g}{\partial x_6}\right)^2 + \sigma_{X7}^2 \left(\frac{\partial g}{\partial X_7}\right)^2 + \sigma_{X8}^2 \left(\frac{\partial g}{\partial X_8}\right)^2} = 9.373645$$

$$Initial\ value\ of\ \beta = \frac{\mu_g}{\sigma_g} = \frac{24.3985969}{9.373645359} = 2.602893$$

The direction cosine is given by

$$cos\theta_{xi} = cos\theta_{ui} = \alpha_{xi} = \alpha_i = \frac{\left(\frac{\partial G}{\partial X_i}\right)\sigma_{Xi}}{\left[\sum_{i=1}^{n} \left(\frac{\partial G}{\partial Xi}\right)2\sigma_{Xi}^2\right]^{1/2}} = \frac{\nabla G(u^i)}{|\nabla G(u^i)|}$$

The initial design or failure points are assumed at the mean values,
The new design point is thus given by

$$X_i^* = \mu_{xi} - \alpha_{xi}.\beta\sigma_{xi} \quad (13)$$

$$\frac{\partial y}{\partial x_1}\sigma_{x1} = 9.10\ and\ \alpha_{x1} = \frac{\frac{\partial y}{\partial x_1}\sigma_{x1}}{\sigma_G} = 1.000 \quad (14)$$

Equation (13) is repeated for all variables X_2, X_4, X_5, X_6, X_7 and X_8.

$$Puting\ X_i^* = \mu_{xi} - \alpha_{xi}.\beta\sigma_{xi}\ in\ Equation\ 15\ gives$$

Substituting for μ_{x1}, μ_{x4}, μ_{x5}, μ_{x6}, μ_{x7}, μ_{x8}, α_{x1}, α_{x4}, α_{x5}, α_{x6}, α_{x7}, α_{x8} and σ_{x1}, σ_{x4}, σ_{x5}, σ_{x6}, σ_{x7}, σ_{x8} in the Equation and solving for β by numerical method (secant method) with excel the value of new safety index (β) is obtained. A new estimate of the design point is computed after re-evaluating the gradients, direction cosines and by substituting the new reliability index (β) into Equation 13. Repeat the process until the reliability index, β, converges (Ayyub 2014). After six iterations, the reliability index converges to β = 2.53342. Hence, the probability of failure is calculated as:

$$P_f = \emptyset(-\beta) = \emptyset(-2.53342) = 1 - \Phi(-2.53342) = 0.06045\ or\ 6.045\%$$

Similarly, the reliability index is found to be low with the beam span of 3825mm and depth of 200mm. The target reliability of 2.73 is satisfied when the depth of the beam was increased to 250mm, giving reliability index of 2.89.

The reliability indices as basic indicators of the level of reliability were determined and the results were validated using CalREL Software. CalREL (Cal-REliability) is a general-purpose structural reliability analysis programme. It is designed to compute the probability integrals of the form

$$P_f = \int_{\Omega} f(X)dX \quad (16)$$

Where X is a vector of random variables with joint probability density function f(X) and Ω is the failure domain defined

$$\Omega \equiv \{g(X) < 0\} \quad (17)$$

In addition to the above, CalREL computes the generalized reliability index defined by

$$\beta_g \equiv \Phi^{-1}(1 - P_f) \quad (18)$$

Target Reliability Index

The target reliability index was determined by averaging the reliability indices of all the sensitivity analyses for bending mode of failure and timber species respectively.

Calibration of the Load Duration Factors

In order to calibrate the load duration factor, K_3 for Long-Term loading, the Target reliability Index, β_T was determined to be 2.73. Then Equation (19) was evaluated repeatedly by varying the value of K_3 from 0.8 to 1.40 at interval of 0.05. The value of K_3 that satisfies Equation (19) is the required calibrated value.

$$(\beta_i - \beta_T)^2 \cong 0.001 \quad (19)$$

The whole procedure is repeated for calibration of load duration factors for

Medium-term, Short-term and Very short-term loadings. The results are shown in Table 6.

RESULTS AND DISCUSSION

Strength Properties of the Nigerian Timber

The strength properties of the Nigerian grown timber species characterised and classified into Strength Groups N1-N7 in accordance with the NCP 2 (1973). The results are in good agreement with Aguwa (2010), Aguwa (2012), Aguwa and Sadidku (2011), Aguwa et al. (2016). These results were used in the Reliability-Based calibration of the load duration modification factors for the Nigerian timber. The strength properties determined and used are shown in Tables 3, 4 and 5

Table 3: Basic Stresses parallel to the grain for the Nigerian timber at moisture content of 18%

S/No	Specie	Bending parallel to the grain N/mm²	Tension parallel to the grain N/mm²	Compression parallel to the grain N/mm²	Compression perpendicular to the grain N/mm²	Shear parallel to the grain N/mm²
1	Okan	36.10	34.94	30.14	6.34	4.64
2	Danta	33.19	31.20	22.39	5.05	3.75
3	Mansonia	23.27	21.73	17.81	3.20	2.84
4	Abura	20.62	19.78	17.41	3.20	2.37
5	Gmelina	13.90	13.46	11.10	2.21	1.84
6	Afara	16.90	15.90	9.62	2.09	1.64
7	Araba	8.56	10.44	7.39	1.62	1.22

3.2. Sensitivity Analysis for Various Failure Modes

The results of sensitivity analysis carried out on aspect ratio, load ratio and span of the beam for bending modes of failure considered are shown in Figures 2-4. From the Figures, it can be seen that the results are similar to those of Aguwa (2010), Aguwa (2012), Aguwa (2013), Aguwa (2016), Aguwa and Sadiku (2011), Aguwa and Sadiku (2012), Aguwa and Sadiku (2013). The safety index of Nigerian grown timber beam is dependent on the aspect ratio, load ratio and the span of the beam.

Table 5: Bending Stresses parallel to grain for Nigerian timber at moisture content of 18%

S/No	Specie	Mean failure stress (N/mm²)	Standard deviation (N/mm²)	Basic stress (N/mm²)	80% Grade stress (N/mm²)	63% Grade stress (N/mm²)	50% Grade stress (N/mm²)	40% Grade stress (N/mm²)
1	Okan	127.53	11.51	36.10	28.88	22.74	18.05	14.44
2	Danta	119.27	11.45	33.19	26.55	20.91	16.60	13.28
3	Mansonia	105.37	17.35	23.27	18.62	14.66	11.64	9.31
4	Abura	74.06	7.10	20.62	16.50	12.99	10.31	8.25
5	Gmelina	67.07	12.14	13.90	11.12	8.76	6.95	5.56
6	Afara	75.02	11.96	16.90	13.52	10.65	8.45	6.76
7	Araba	31.85	3.42	8.56	6.85	5.39	4.28	3.42

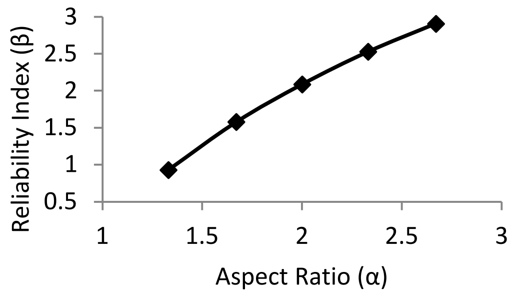

Fig. 2: Reliability Index-Aspect Ratio Relation for Nigerian Timber for Failure Mode 1

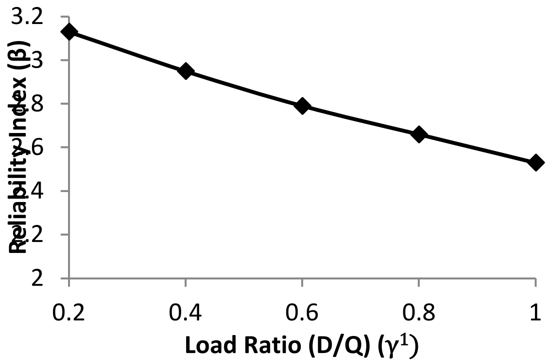

Fig. 3: Reliability Index-Load Ratio Relation for the Nigerian timber for Failure Mode 1

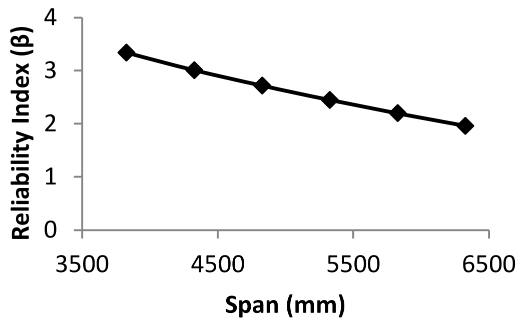

Fig. 4: Reliability Index-Span Relation for the Nigerian Timber for Failure Mode 1

Calibrated Load Duration Factors

Table 6 shows the Reliability-based calibrated modification factors for the Nigerian grown timber species. It can be seen that most of them differ from those of BS 5268 (2002), hence the need for this research. The soil type, the environment as well as the timber species affect the strength properties of timber. The load duration factors of timber depend on the strength and density of the timber. These results are clear demonstration that the load duration factors should be calibrated based on the particular environment. This also a pointer for the need for production of well researched code of practice for Nigerian timber structural design.

Table 6: Modification factor K_3, for duration of loading

S/No	Duration of loading	
1	Long-term (e.g. dead + permanent imposed load)	1.25
2	Medium-term (e.g. dead + snow, dead + temporary imposed)	1.35
3	Short-term (e. g. dead + imposed + wind, dead + imposed + snow + wind)	1.70
4	Very short-term (e. g. dead + imposed + wind)	2.00

CONCLUSION

The following modification factors have been successfully calibrated based on Nigerian environment; K_3, load duration factor for Long-term, Medium-term, Short-term and Very Short-Term loadings. It is highly recommended that these calibrated values should be used for design of timber structures in Nigeria and environs to conform with the local environment.

REFERENCES

Aboshio, A.; Uche, O. A. U. and Ogork, E. N. (2016). Reliability based calibration of safety factors for reinforced concrete staircase designed to BS 8110 (1997). Proceedings of the 2ND National Engineering Conference, ACICON 2016, Faculty of Engineering, Bayero University, Kano, 4-8

Abubakar, M. (2019). Reliability based calibration of partial factors of safety design of reinforced concrete structures to BS 8110, PhD Thesis submitted to the Postgraduate School, Federal University of Technology, Minna.

Aguwa, J.I. (2010). Structural performance of the Nigerian grown Abura timber bridge beam subjected to compression and shearing forces. *KSCE J Civ Eng* 19**,** 974–981 (2015). https://doi.org/10.1007/s12205-013-0164-9

Aguwa, J. I. (2010). *Reliability studies on the Nigerian timber as an orthotropic, elastic structural material*, PhD Thesis, Post Graduate School, Federal University of Technology, Minna, Nigeria.

Aguwa, J. I. (2012). "Reliability assessment of the Nigerian apa (afzelia bipindensis) timber bridge beam subjected to bending and deflection under the ultimate limit state of loading." *International Journal of Engineering & Technology (IJET) UK*, Vol. 2, No. 6, June 2012, pp. 1076–1088.

Aguwa, J. I. and Sadiku, S. (2012). "Reliability studies on timber data from nigerian grown iroko tree (chlorophora excelsa) as bridge beam material." *International Journal of Engineering Research in Africa (JERA)*, Vol. 8, (2012), pp. 17–35.

Aguwa, J. I. and Sadiku, S. (2011). Reliability studies on the Nigerian Ekki timber as bridge beam in bending under the ultimate limit state of loading. *Journal of Civil Engineering and Construction Technology*, *2*(11), 253-259.

Aguwa, J. I.; Sadiku, S. and Abdullahi, M. (2016). Harnessing Nigeria's Forestry Potential for Structural Applications: Structural Reliability of Nigerian Grown Opepe Timber. *International Journal of Economics and Management Engineering*, *9*(10), 3658-3666.

Aguwa, J. I. (2013). Study of coir reinforced laterite blocks for buildings. *Journal of Civil Engineering and Construction Technology*, *4*(4), 110-115.

Aguwa, J. I. and Sadiku, S. (2011). Reliability studies on the Nigerian Ekki timber as bridge beam in bending under the ultimate limit state of loading. *Journal of Civil Engineering and Construction Technology*, *2*(11), 253-259.

Aguwa, J. I. (2016). The Nigerian Timber Structures. Kaduna: Ahmadu Bello University Press Limited

Ayyub, B. M. (2014). Risk Analysis in Engineering and Economics, second edition. CRC Press Taylor & Francis Group6000 Broken Sound Parkway NW, Suite 300Boca Raton, FL 33487-2742

BS 5268-2 (2002) "Structural use of Timber", British Standards Institution, London, United Kingdom

BS 8110 (1997). Structural Use of Concrete; Part 1: Code of Practice for Design and Construction. British Standards Institute, London.

BS 8110 (1985). Structural Use of Concrete; Part 2: Code of practice for special Circumstances. British Standards Institute, London

BS 373 (1957). *Methods of testing small clear specimens of timber*, British Standards Institution, 2 Park Street, London WIA 2BS

BS 5268 (2002). *The structural use of timber part 2; for permissible stresses, materials and workmanship*, 5th Edition

Faber, M. H. and Sorensen, J. D. (2002). Reliability-based Code Calibration. Joint Committee on Structural Safety

Fakui, T.; Yanase, Y. and Fujii, Y. (2023). Moisture content estimation of green softwood logs of three species based on measurements of flexural vibration, Journal of Wood Science (Springer Open), https://doi.org/ 10.1186/s10086-023-02106-0,

Hansson, M and Ellegaard, P. (2006). System reliability of timber trusses based on non-linear structural modelling. Materials and Structures, 39(6), 593-600, 10.1617/s11527-006-9098-8

Lowden, L.A. and Hull, T.R. (2013). Flammability behaviour of wood and a review of the methods for its reduction. *Fire Science Review,* 2(4), https://doi.org/10.1186/2193-0414-2-4

Mishra, A.; Humpenoder, F, Churkina, G.; Reyer, C P. O.; Beier, F.; Bodirsky, B. L.; Schellnhuber, H. J.; Lotze-Campen, H. and Popp, A. (2022). Land use change and carbon emissions of a transformation to timber cities, Nature Communications, https://doi.org/ 10.1038/s41467-022-32244-w, Accessed on 20/09/2023.

NCP 2 (1973). *The use of timber for construction*, Nigerian Standard Organization, Federal Ministry of Industries, Lagos, Nigeria

Nowak, A.S. and Rakoczy, A. M. (2012). Reliability-Based Calibration of Design Code

for Concrete Structures (ACI 318). ANAIS DO 54º Congresso Brasileira Do Concreto, 1-12

Nowak, A.S. and Collins, K.R., (2000). Reliability of Structures. 1st edition. Thomas Casson.

Pomponi F, Hart J.,Arehart J. H. and D'Amico B. (2020). Building as a global carbon sink; a reality check on feasibility limits, One Earth 3, 157 – 161.

Sorensen, J. D.; Svensson, S., and Stang, B. D. (2005). Reliability-based calibration of load duration factors for timber structures. *Structural Safety*, 27,153–169