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# Reliability Assessment of the Nigerian Timber – An Environmental Sustainability Approach in the 21<sup>st</sup> Century

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## Abstract-

An important component of environmental sustainability is how we can continue improving human welfare within the limits of the earth's natural resources. With recent research showing that carbon dioxide levels in the air are at their highest in 650,000 years and thus an alarming depletion of the ozone layer, the challenge currently facing many countries is how to respond to the issue of climate change. Steel, reinforced concrete and timber are the most commonly used structural materials worldwide. However, carbon dioxide emissions from steel and cement production have been found to be the first and second largest sources of industrial CO<sub>2</sub> emissions worldwide and this has prompted the inclination towards timber as a structural material. Timber is decomposable or biodegradable as well as renewable and its production does not require the use of high energy fossil fuels as in the production of some other building materials such as steel or even brick. Nigeria is blessed with several timber species in different wood classes but despite the environmentally sustainable and obvious advantages of timber, it is being grossly underutilized as a structural material in Nigeria because there is limited information on the reliability of timber considering the wide property variability between and even within, timber species. This paper addresses the need for reliability analysis of various Nigerian timber species with a view to determining and establishing their structural strength to encourage the use of the Nigerian Timber as a structural material. The need to revise the Nigerian Code of Practice for the structural design of Timber is also emphasized in this paper.

**Keywords:** Nigerian Timber; reliability; structural material; environment.

## 1. Introduction

Sustainable development is mostly concerned with meeting the needs of the present without compromising the flexibility of future generations to meet their own needs (Cunningham, 1992) [1]. Based on availability, strength and durability properties, timber ranks top amongst the foremost versatile construction materials globally. It is the proper example of an environmentally sustainable and friendly material because of its renewability, energy efficiency and naturally occurring nature as compared to structural materials like steel and concrete.

Timber has many great advantages; it is extremely machinable and can be used to fabricate all kinds of shapes and sizes to suit practically any construction need. Also, unlike marble, glass or steel, timber features a comparatively low heat conduction. and it maximizes the potency of



insulation materials and as a result, wood never gets cold or dissipates heat, therefore less energy is needed to keep up heat or warmth in a building, and the less energy used, the less the environmental damage. In terms of resistance to high temperature, timber has an edge over steel because while steel expands or even collapse in high heat; timber becomes stronger in high heat by actually drying out (Chanakya, 2009) [2]. Timber is also the ideal material for electrical insulation because of its resistance to electrical currents. Another vital characteristic of timber is its tensile strength, which is its ability to bend under stress without breaking. Timber is today easily transformed into a durable and insect resistant structural material through several cost efficient treatments.

## 2. Grading and Characterization of Timber

Timber is a variable raw material hence some form of grading is introduced in order to utilize it to the best advantage (Aguwa, 2010) [3]. However, the properties and quality of Timber vary from specie to specie. The quality of timber refers to the characteristics that make it suitable for use. Quality can be considered with respect to differences between species and variation within a specie.

Characterization and grading in accordance with relevant codes are necessary criteria for the utilization of timber in infrastructural construction. Several codes for the design of timber exist. These codes take into consideration the unique environmental conditions in the region under consideration. According to Aguwa and Sadiku (2012) [4], the requirement for native contents in construction of infrastructure is a serious engineering challenge for developing countries. However, every country needs to develop its design codes because of diversity in geographical and environmental conditions.

### 2.1 Nigerian Timber Species

Nigeria is blessed with a large number of timber species; hardwoods and softwoods. Hardwoods, in addition to possessing complex grain structure are heavier and more expensive than softwoods. Oak, mahogany, teak and walnut are some of the most notable hardwoods worldwide and their application and usage include walls, ceilings and floors construction. Softwoods are commonly used to make doors, window frames and furniture. Examples of common softwoods include pine, ash, beach and cedar. The Nigerian Code of Practice for Timber Structural Design (NCP 2, 1973) [5] features several timber species all of which are hardwoods because of the wide application of hardwoods in infrastructure construction.

Nigeria is endowed with a variety of timber species that would compete well in terms of structural strength with timber species from other parts of the world. Nigerian Iroko (*milicia excelsa*) for instance, is a great substitute for Asian or Australian Teak because of the high cost of Teak and despite being cheaper, it has an average life span of about two hundred years. In addition to having great compressive strength, it is rot and insect resistant and like teak, it is suitable for exterior use.



Fig 1: Nigerian Iroko Timber.



Figure 2: Australian Teak wood

Apart from Iroko, there are several other Nigerian timber species that are yet to be explored for structural use.

### 3. The Future of Engineered Woods in Nigeria

Countries like Australia, Netherlands and even Canada have gone a step further to create engineered woods out of their local timber species. For ages, engineered wood products like plywood and glulam timber have existed. More products like the Cross Laminated timber CLT and Nail Laminated Timber NLT came up a while later. Engineered woods are manufactured by arranging dimensional lumber boards in interchanging directions and bonding them with structural adhesives.



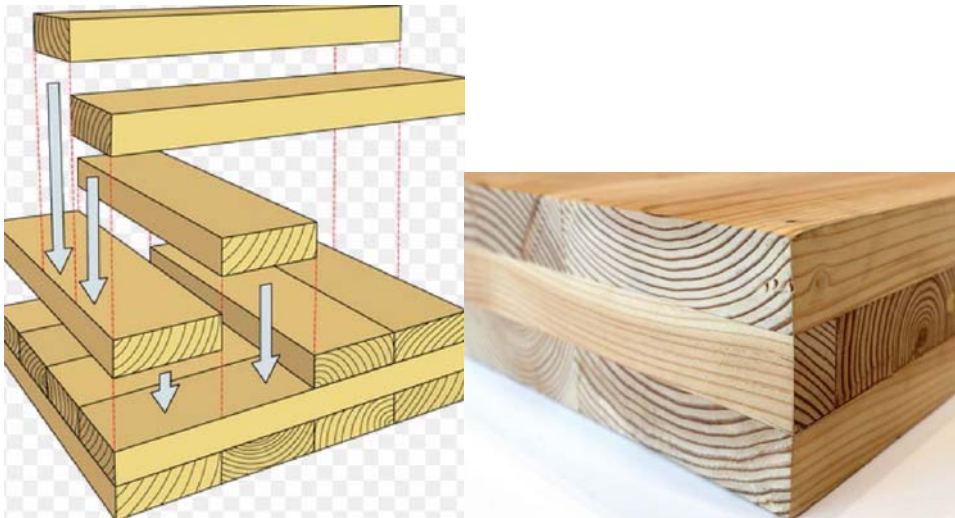


Fig 3. Engineered wood layup (cross laminated timber CLT)

As a Structural material, engineered wood products are known to have excellent fire and seismic attributes and great performance under lateral loads. Structurally, they have better structural properties than ordinary wood such as having higher load-carrying capacities than solid wood of the same size. This is so because the manufacturing process of the engineered wood product addresses and removes deficiencies in the wood such as knots and cracks and the manufacturing process also takes into consideration the principal failure modes in solid timber such as shearing, splitting or even crushing. In fire, unlike wood, engineered wood forms a char layer that protects the layers of fibres by slowing down combustion through reducing the amount of oxygen reaching each fibre and unlike wood that easily collapses in fire, engineered wood products can be found standing in the building even after the fire is put out thereby saving the lives of the occupants and the building life itself.

### 3.1 Timber and Sustainability

Demographers believe that the planet's urban citizenry will double in 36 years thereby increasing the demand for taller structures. The world is increasingly looking towards timber as a structural material for the construction of high rise structures. This interest is partly due to the environmentally friendly nature of timber and also due to the development of new engineered products that have overcome the previous disadvantages of solid wood such as fire. Environmentally, wood is a carbon sink, sequestering the carbon dioxide it absorbed during growth and even once it has been turned into lumber. Carbon compounds have adverse effects on climate change and the role of carbon sinks in protecting our environment by acting like sponges to soak up the carbon compounds cannot be overemphasized. Beyond the lumber form, a building made of engineered wood products sequesters carbon and enhance the performance of the building, especially in energy use. Engineered wood products also cut back the employment or use of forest resource by using a higher percentage of fibre, which previously was burned or left to rot.

Structurally and Environmentally, engineered woods have great benefits and advantages. However, despite the several timber species across Nigeria and the huge advantages of timber, Nigerian timber is still on a long way to being developed into engineered wood products. Timber

is even grossly underutilized in Nigeria because of the ambiguity about its varying properties as well as the reliability of timber. The reliability of timber is a complicated subject because of the massive natural variability of timber. Furthermore, every country needs to develop its design codes because of diversity in geographical and environmental conditions and the Nigerian Timber code NCP 2 is long overdue to be revised.

### 3.2 The Problem Associated with the Reliability Analysis of Timber in Nigeria

The need for reliability analysis as a tool for predicting the ability of a system to fulfill its design purpose under specified conditions cannot be overemphasized. There is a great uncertainty about the behavior of Nigerian timber under applied loads hence the usage of Nigerian timber in construction has been by intuition and guess. The issue of the reliability of Nigerian timber species should be taken seriously with a view to exposing their strengths and unique properties as well as the reliability indices and probabilities of failure of each.

One of the hinderances towards carrying out proper timber reliability analysis in Nigeria is the Nigerian Code of Practice for timber Structural design NCP 2 (1973) [6] which is based on the permissible stress approach and long overdue for a revision. The NCP 2 (1973) [7] was developed with reference to the British CP 112 code; a permissible stress approach code. In 1984 [8], the CP 112 was withdrawn and subsequently replaced with the BS 5268. In 2010 [9], with a view to meeting up with new civil engineering advancements in the design of timber structures, the Eurocode 5 was introduced to replace the BS 5268. The Eurocode is based on the limit state design philosophy and it is the globally accepted design approach for timber structures. Unfortunately, the Nigerian timber code was never revised and is now left without a basis.

It is imperative to shed light on the actual structural/strength properties of the Nigerian timber so that these actual properties can be used in structural design instead of using foreign values from codes that are always at variance with the locally available ones. With this, modification factors can be properly calibrated and performance functions can be articulately generated thereby obtaining the reliability indices and probabilities of failure of each structural element under consideration.

## 4. The Concept of Structural Reliability

Reliability is a tool in structural engineering employed to assess the performance or functionality of a structural system, thus, measuring of the safety of the structural components and subsequently that of the entire system. Structural reliability addresses key global construction issues such as the safety of buildings, bridges, towers and other structures and has recently become a discipline of international interest.

Structural reliability calculates and predicts the probability of a structural system to violate the limit state at any stage during their life. Here, the limit state is understood to be the requirement of the structure against any form of damage, deflections or ultimately, collapse.

### The Basic Reliability problem

The basic structural reliability problem considers the existence of only one load effect,  $Q$  resisted by one Resistance,  $R$ . Each of  $Q$  and  $R$  is described by a known probability density function,  $f_Q$  and  $f_R$  respectively. The load effect can be obtained through structural analysis. The reliability of a

structural element is analyzed by considering the structural element to have failed if its resistance,  $R$  is less than the stress resultant  $Q$  acting on it.

$$R - Q \leq 0 \quad (4.1)$$

Limit state functions are often stated for given requirements of a structure. It takes into consideration the load and resistance effects, which has to do with the effects of applied loads, example moment and shear force. The resistance effect has to do with the material properties of the structure such as bending strength. State variables are the basic load and resistance parameters used to formulate the performance function (Melchers, 1987) [9].

A performance function, or limit state function can be defined as

$$M = R - Q \quad (4.2)$$

$R$  is defined as the resistance effect while  $Q$  is known to be the resultant load effect.

When Resistance effect equals load effect, the limit state has been reached i.e  $M = 0$  is the limit state.

The probability  $P_f$  of failure of the structural element is defined as below:

$$P_f = P(R \leq Q) \quad (4.3)$$

Thus,

$$P_f = P(R - Q \leq 0) \quad (4.4)$$

$$P_f = P\left(\frac{R}{Q} \leq 1\right) \quad (4.5)$$

Equation 1.5 can thus be expressed as

$$= P(\ln R - \ln Q \leq 0)$$

Or, in general

$$= P(G(R, Q) \leq 0) \quad (4.6)$$

where  $G(\cdot)$  is defined as the *limit state function*. The probability of failure is thus defined as the probability of violating the limit state.

The limit state corresponding to the boundary between desired and undesired performance, would be when  $g = 0$ . The probability of failure,  $p_f$  is equal to the probability that the undesired performance will occur. Mathematically,

$$P_f = P(R - Q < 0) = P(g < 0) \quad (4.7)$$

where  $g$  is termed the limit state function.

A structure is considered safe when the load effect is less than resistance. On the other hand, failure is when load effect is greater than the resistance effect.

The state of the structure can be described using parameters  $X_1, X_2, \dots, X_n$ , 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

$g(X_1, X_2, \dots, X_n)$  of these parameters such that

$g(X_1, X_2, X_n) > 0$  for a safe structure

$g(X_1, X_2, X_n) = 0$  boundary between safe and unsafe

$g(X_1, X_2, X_n) < 0$  for failure

For  $n$  state variables, the limit state function is a function of  $n$  parameters.

#### 4.1 Reliability-based Methods

The two most employed methods of structural reliability assessment are the deterministic measures of limit state and the probabilistic measures of limit state violation. Several methods of calculating the probability of failure exist. Some of these methods include the Monte Carlo Simulation, the First Order Reliability Method (FORM) and the Second Order Reliability method (SORM).

The First Order Reliability Method, (FORM), is a semi-probabilistic reliability analysis method devised to evaluate the reliability of a system.

#### Reliability Index

Reliability Index is a very important measure of reliability. It is the reciprocal of the coefficient of variation, that is the ratio between the mean and standard deviation of the safety margin of the system.

Reliability index,  $\beta$  for a linear limit state function,  $g = R - Q$  and  $R$  and  $Q$  both being normal random variables.

$$\beta = \frac{(\mu_R - \mu_Q)}{\sqrt{\sigma_R^2 + \sigma_Q^2}}$$

$\mu_R$  = Mean resistance.

$\mu_Q$  = Mean load.

$\sigma_R$  = standard deviation of resistance

$\sigma_Q$  = standard deviation of load.

#### Conclusion

The environmental advantages of timber over reinforced concrete and steel has been highlighted by many researchers. Timber is a sustainable structural material because in addition to being environmentally friendly, it is durable, readily available and renewable. Reliability studies of the Nigerian timber would reveal the unique properties of each specie as well as the estimated reliability indices and probabilities of failure of each, thereby encouraging its use as a structural material.

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