

Contents lists available at RER

Reliability Engineering and Resilience

Journal homepage: www.rengrj.com



# **Probabilistic Strength of Steel Poles Used for Power Production and Transmissions**

# A. Mustapha<sup>1</sup>, O.S. Abejide<sup>1\*</sup>

1. Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria Corresponding author: *abejideos@yahoo.com* 

doi https://doi.org/10.22115/RER.2019.87232

## **ARTICLE INFO**

Article history: Received: 03 April 2019 Revised: 06 May 2019 Accepted: 06 May 2019

Keywords: Steel poles; Reliability analyses; Limit states; Reliability index.

## ABSTRACT

The profound changes in engineering over the last few decades were reflected by ideas of uncertainty recognized in engineering today. Civil engineering structures like steel transmission poles are to be designed for loads created by environmental actions such as wind, snow and earthquake, these actions are exceptionally uncertain in their but manifestations as one is required to quantify the risks and benefits involved. The subject of structural reliability offers a rational framework to quantify uncertainties mathematically. This study presents a probabilistic assessment of the strength of steel poles in service, the resistance of the steel poles, ultimate strength of steel, section modulus, cross sectional dimensions of the poles, distance at which the load acts on the pole and the magnitude of the load acting on the pole are treated as random variables, which can be significantly influenced by time and location. The study has been carried out to determine the structural safety levels of electric distribution steel poles under uncertain loadings using First Order Reliability Method (FORM) in MATLAB with FERUM Version 4.0. The reliability analyses in MATLAB gave lower values of reliability index,  $\beta$ , (1.4802E+00) and probability of failure  $P_f$  (6.9407E-02) for moment failure mode, while higher values of  $\beta$  (2.339E+01 and 5.1245E+01) were obtained respectively for deflection and shear failures, with negligible  $P_f$  values of 0.100E-10. The effect of variation of parameters like thickness, diameters and length of steel poles also studied, which indicates that the thickness, were diameters and length significantly affects the strength of steel poles.

How to cite this article: Mustapha A, Abejide OS. Probabilistic strength of steel poles used for power production and transmissions. Reliab. Eng. Resil. 2019;1(1):29–41. https://doi.org/10.22115/RER.2019.87232.

© 2019 The Authors. Published by Pouyan Press.

This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).



# 1. Introduction

There is considerable investment now in steel poles worldwide, and there is a need to examine the structural reliability and probability-based assessment of these power distribution poles. Given the scale of this infrastructure, it is reasonable to assume that even a small improvement in the design would lead to considerable cost savings and improved strength of these poles and safety of lives [1].

Generally, the power system includes three main components: generation, transmission, and distribution. Of these three components, the distribution systems (lines and poles) are the most susceptible to wind damage. This is due to the fact that distribution lines and poles are more exposed to winds than the generation plants and the transmission systems. Furthermore, the distribution poles are often not designed to withstand high wind speeds. However, when it comes to failure due to natural hazards, the distribution system is the most vulnerable [2].

Steel poles have several advantages over other types of poles, including reduced maintenance cost, predictability of behavior, consistent performance, insusceptible to wood-pecker attacks and rottening, light weight; factory pre-drilling is possible, environmentally friendly, recyclable, no toxic preservatives, no disposal concerns, and superior life-cycle cost [3].

Reliability analysis is a probabilistic approach to determine the safety level of a system (or a structure, in structural engineering). Reliability is defined as a probability of the system to functionally perform under given conditions. In the 1960s, [4] identified the reliability index as an indicator to represent the safety level of the system, which until today is a commonly used parameter. To perform reliability analysis of transmission structures, instead of using the deterministic capacity of the structure and applied load, it is required to utilize the statistical parameters of the load and/or resistance.

[5] Summarized the procedure to determine the reliability index as follows, Structural loading and load effect, Structural resistance and Balance between load effect and structural resistance. Depending on the limit state function, several approaches were introduced to compute the reliability index.

These paper establish a probabilistic approach to determine the implied safety level of steel poles under uncertain loading conditions with a view to improve and enhance the use of steel poles for power distributions and transmissions to conventional wood and concrete poles, since reliability index is a common worldwide used indicator to evaluate the safety level of structures [6].

# 2. Background of study

The collapse of transmission poles is not a well understood phenomenon, because these poles are subjected to various loads like wind, snow, icing and earthquake. Comparatively, wind loads are more complex for these poles due to high geometric non-linearity and randomness of wind turbulence [7], but [8] reported that wind speeds are characterize by the mean and fluctuating wind components which affects transmission poles.

In the past, naturally occurring events such as earthquakes have also caused massive damages to poles and disruption of power supply, in addition to direct loss to property and lives inflicted by earthquake by damaging the infrastructure; disruption in electricity supply results in huge loss of revenues and interruption of industrial activities. The reliability and safety of electrical transmission and distribution systems after earthquake depend on the seismic response of individual components such as substation equipment, poles, etc. [8].

For steel transmission poles, the cause of failures is not usually the material strength but rather ground line corrosion at the base of the pole [9].

The rate of corrosion of steel poles depends on several factors such as quality of initial corrosion prevention measures, soil type, mechanical damage, atmospheric chemical attack, fatigue, height of water table, metallurgical structure of galvanized layer, protective painting, duration of storage, and the presence of bacteria in soil. These parameters cannot be described with adequate accuracy and consequently, any corrosion rate model can only be a rough estimate [10].

[11] Reported that in order to estimate the load carrying capacity of structure it is necessary to identify all the parameters associated with the material, however, they reported that due to difference in environmental conditions of these parameters, which are inherently random in nature, therefore, to have a proper perception of the parameters, the statistical approach can be deliberated to estimate the mean and variance of the mentioned uncertainty factors. And one of the most appropriate approaches for improving failure rates for poles is probabilistic assessment. Probability-based methods provide essential asset management tools in other areas of civil engineering, such as road management, bridge management, dam designs etc., due to the ability to incorporate, quantify uncertainty and variability across an infrastructure network [12]. Surprisingly, however, there is little research utilizing probabilistic methods to examine the structural reliability of steel power distribution poles. This represents an important gap in the existing literature as probabilistic analysis is highly appropriate to the management of steel power poles, which exhibit high variations within other types of material poles due to differences in strength characteristics, durability, loading and deterioration conditions poles are subjected to, since it is recognized that all materials are susceptible to environmental degradation in service. The degradation processes for various pole materials are such that it is very difficult to develop accurate predictive models that can be used to modify design strength factors [1]. And properly estimating the reliability of a transmission pole structure is a complex problem. It requires knowledge of the joint Probability Distribution Function (PDF) of the load-producing events such as ice, wind, temperature, wind direction, and the PDF of the strength properties of the pole, and the evaluation of multiple correlated failure modes including bending, buckling, connections failures, and foundation failures [13].

It is for this reason that the strength of these steel poles in service need to be assessed in a probabilistic manner, while accounting for all the parameters associated with their performance in service during their design life.

## (a) Limit states

The limit state function is usually expressed in the form of an equation [5]. It can be defied in two states: safe and unsafe. The boundary between these two states is represented by a limit state function (g). There are two types of limit states. Ultimate limit states (ULS), related to the bending capacity, shear capacity and stability. Serviceability limit states (SLS), related to gradual deterioration, user's comfort or maintenance costs. The serviceability limit states include fatigue, cracking, deflection or vibration [14].

The purpose of design is to achieve acceptable probabilities that a structure will not become unfit for its intended use, that is, it will not reach a limit state. Thus, any way in which a structure may cease to be fit for use will constitute a limit state and the design aim is to avoid any of such conditions being reached during the expected life the structure [15]. The limit state function can be written as follows:

$$g(x) = g(x_1, x_2, x_3, \dots, x_n) = R - Q$$
(1)

Where; R represents the resistance (carrying capacity), Q represents the load effect and  $x_n$  represents the random variables of load and resistance such as dead load, wind load, length, depth, thickness etc. while probability of failure, P<sub>f</sub>, is equal to the probability that the undesired performance will occur. Mathematically, this can be expressed in terms of the limit state function as equation (3):

$$P_f = P(R - Q < 0) = P(g(x) < 0)$$
(2)

## (b) Structural reliability analysis

Recent research in the area of structural reliability and probabilistic analysis has centered on the development of probability based design procedures. These include load modeling, ultimate and service load performance, and evaluation of current level of safety/reliability in design [16,17]. In a reliability-based approach, uncertainty associated with material properties, loads, environmental conditions, models etc; are taken into account by treating these parameters as random variables. The condition of a structure is assessed by probability of failure,  $P_f$  or related to the reliability index,  $\beta$ , given by:

$$Reliability = 1 - P_f \tag{3}$$

## (c) Methods of structural reliability analysis

Madsen *et al.*, (1986) [18] identified methods to measure the reliability of a structure into four groups as follows:

- (i.) *Level I methods*: The uncertain parameters are modeled by one characteristic value, as for example, in codes based on the partial safety factor concept.
- (ii.) Level II methods: The uncertain parameters are modeled by the mean values and the standard deviations, and by the correlation coefficients between the stochastic variables. The stochastic variables are implicitly assumed to be normally distributed. The reliability index method is an example of a level II method.

- (iii.) *Level III methods*: The uncertain quantities are modeled by their joint distribution functions. The probability of failure is estimated as a measure of the reliability.
- (iv.) *Level IV methods*: In these methods the consequences (cost) of failure are also taken into account and the risk (consequence multiplied by the probability of failure) is used as a measure of the reliability.

### (d) First order reliability method (FORM)

First Order Reliability Method (FORM) is an analytical approximation in which the reliability index is interpreted as the minimum distance from the origin to the limit state surface in standardized normal space and the most likely failure point (design point). In all special cases where the failure surface is linear and all basic variables are normally distributed, it is easy to show that there is a direct relationship between the failure probability and reliability index, that is, [19]:

$$P_f = \varphi(-\beta) \tag{4}$$

Thus,

$$\beta = -\varphi^{-1}(P_f) \tag{5}$$

Where  $\varphi$  is the standardized normal distribution function.

## 3. Methodology

## 3.1. Finite element reliability using Matlab (FERUM)

FERUM is a general purpose structural reliability method whose first developments started in 1999 at the University of California at Berkeley. Finite Element Reliability is used to carry out analysis Using MATLAB. FERUM 4.x now offers Reliability-Based Design Optimization (RBDO) capabilities. It offers new features, such as simulation-based techniques (Directional Simulation, Subset Simulation), Reliability-Based Design Optimization, Subset Simulation and global Sensitivity Analysis can be carried out either using the original physical model or a Support Vector Machine surrogate. If the physical model is really computationally demanding, then distributed computing is available, either virtually through vectorized calculations in MATLAB or for real with multi-processor computers, provided that a suitable interface is developed [20].

(a) Development of the MATLAB program

MATLAB program language can be used to develop the program for the reliability analysis. The program flow chat of the MATLAB based program used in this study is as follows. After that, it reads the other parameters which are also supplied by the user. FORM is subsequently called to calculate the reliability index for the data provided.

(i.) *Main Directory*: The main directory contains the main program. This program is developed to perform the reliability analysis in this study. While running this program, the user is required to select the failure mode in question with its input and the capacity of execution of specific function.

- (ii.) *FORM directory*: The form directory contains subroutines that calculate the safety index for each of the failure mode considered.
- (iii.) Distribution Model Setup Directory: The distribution model setup directory contains the MATLAB function files that assign appropriate distribution model to each random variable. The distribution model includes normal, lognormal, gumbel, weibull distribution etc.
- (iv.) Coefficient of variation directory: The coefficient of variation directory containing the function file that store the values of the coefficient of variation of each random variable based on the test result and data for the steel pole.
- (v.) *Probability of failure and safety index directory*: Probability of failure directory contains the MATLAB function that computes probability of failure with safety index as an output.

#### (b) Limit state equations

The following limit states equations were considered for this study,

(a) Moment 
$$G(x) = [M_{per} - M_a]$$

- (b) Deflection  $G(x) = [\delta_{per} \delta_{max}]$
- (c) Shear  $G(x) = V_{res} V_{app}$

#### (i.) Moment

The condition to be satisfied here is that the actual applied moment due to load effect should not exceed the maximum permissible resistance moment.

$$G(x) = [M_r - M_a] \tag{6}$$

$$M_r = 0.66 f_y Z \tag{7}$$

$$M_a = \frac{-WL^2}{2} \tag{8}$$

Where;  $M_r$  = resistance moment of the pole;  $M_a$  is the applied moment due to load;  $f_y$  = steel strength; Z = section modulus given by

$$Z = \frac{\pi (D_o^4 - D_i^4)}{32D_o}$$
(9)

$$D_i = D_o - 2t \tag{10}$$

 $D_0$  = outer diameter of the pole;  $D_i$  = inner diamter; t = thickness of pole; w = design load; L = pole length

#### (ii.) Deflection

The condition to be examined here for the steel pole designed as a cantilever is given as

$$G(x) = P[\delta_{per} - \delta_{max}]$$
<sup>(11)</sup>

$$\delta_{per} = \frac{Span}{250} \tag{12}$$

$$\delta_{max} = \frac{wl^3}{3El} \tag{13}$$

Where;  $\delta_{per}$  = permissible deflection;  $\delta_{max}$  = maximum deflection; w = design load; l = pole length; E= modulus of elasticity and I = moment of inertia.

(iii.) Shear

The limit state equation for shear is given by

$$G(x) = P[V_{res} - V_{app}]$$
<sup>(14)</sup>

 $V_{res}$  = ultimate shear resistance and  $V_{app}$  = applied shear force due to applied load given by

$$V_{res} = \varphi 0.66 f_y A_v C_v \tag{15}$$

$$V_{app} = W \tag{16}$$

Thus, the basic variables for the design are  $[t, l, G_k, W_k, d, f_y]$ , where  $\varphi_R$  = shear resistance factor; t = thickness of pole; l = pole length;  $A_v$  = shear area;  $C_v$  = shear coefficient;  $G_k$  = dead load and  $W_k$  = wind load.

The basic variables are identified, while their statistical parameters are obtained from literature.

- (c) Load data analysis (Dead and Wind Load)
- (i.) Dead load

Weight of steel =  $78.5kN/m^2$ 

Bracket arms and Insulator =  $0.15kN/m^2$ 

Street Lamp =  $0.005kN/m^2$ 

The self-weight of aluminum =  $0.86kN/m^2$ 

Total dead load =  $79.515kN/m^2 = 0.0795N/m^2$ 

(ii.) Wind load

BS 6399-2 (1997) Code of Practice for wind loading was used for the analysis of wind load; the dynamic pressure is given as:

$$q_e = k V_e^2 \tag{17}$$

$$V_e = V_s K_1 K_2 \tag{18}$$

Where; k = 0.613,  $k_1$  is the risk coefficient taken as 1.0,  $k_2$  is the terrain factor taken as 1.0 for flat terrain, the wind speed is taken as 3m/s.

According to Adaramola and Oyewola [21] the average wind speed across Nigeria is about 3.0m/s with the northern part of the country having higher wind speed values than the southern part; therefore, the average wind speed of 3.0m/s is adopted in this study.

Therefore,  $q_s = 0.613 \times 3.0^2 = 5.512 N/m^2$ 

## 4. Results and discussion

## 4.1. Results

The failure of any structure can be measured in terms of the probability of failure; on the other hand, the reliability of a structure is measured by the safety index. Reliability analyses were conducted for electric power distribution steel poles based on the derived limit states equations. The reliability levels were calculated using the deterministic and statistical parameters to the developed computer program in MATLAB in order to compute the safety indices based on the limit states equations. The program in MATLAB is used to examine and simulate the behavior of the steel poles at distances above the ground level, the length, diameter, and thickness of the poles were all varied simultaneously, the thickness was varied from 3.6mm, 4.5mm, 5.4mm and 5.9mm respectively, For each of the length considered, the thickness was varied in order to check the effect of the steel poles in service, while resisting the effect of moment, deflection and shear. The stochastic design variables used in calculating the capacity of the steel poles is shown in Table 1.

#### Table 1

Stochastic Model Parameters and Their Statistical Values for Steel Poles, [22,2	23	ij.
---	----	-----

S/No	Design Variables	Unit	Distribution type	Coefficient of variation (C.O.V)	Mean E(x)	Standard deviation S(x)
1	Steel Strength ( $f_y$ )	N/mm <sup>2</sup>	Normal	0.15	500	61.50
2	Pole Thickness	mm	Normal	0.03	3.65	0.109
3	Diameter of Pole	mm	Normal	0.03	114.3	3.429
4	Dead load $(G_k)$	N/m <sup>2</sup>	Lognormal	0.10	0.0795	0.00795
5	Height above ground	mm	Normal	0.03	7500	225
6	Wind load $(W_k)$	N/m <sup>2</sup>	Lognormal	0.3	$5.51 \times 10^{-3}$	$1.653 \times 10^{-3}$

The results obtained from the probabilistic evaluations are discussed. Table 2 gives the summary of the result obtained in the program for moment, shear and deflection failures for a 9m length pole.

Table 2Results obtained by FERUM in MATLAB (R2015b) for 9m pole.

Failure mode	Time to complete Analyses (secs)	Reliability Index $\beta$	Probability of Failure $P_f$
Moment	0.979544	1.4802E+00	6.9407E-02
Deflection	0.771579	2.3390E+01	0.100E-10
Shear	0.719422	5.1245E+01	0.100E-10

## 4.1.1. Sensitivity study

Sensitivity analyses refer to the evaluation of the response when a design parameter is modified or changed. Thus, to identify the behavioral strength of the steel poles, design parameters such as the diameter and thickness were varied simultaneously on the variability of the reliability indices; the study was carried out to assess the relative impact of the variability and uncertainty of the parameters on the overall model output. This was achieved by varying the two most important parameters that affect the strength of steel poles, since in steel power poles design; the strength is derived by varying the thickness and diameters. The sensitivity study results for each of the two parameters are presented in Table 3 below.

## Table 3

Pole length				
Pole length (m)	Reliability Index ( $\beta$ )	Probability of Failure $(P_f)$		
7.0	1.5541	4.0085E-02		
8.0	1.6943	4.5106E-02		
8.5	1.5935	5.5524E-02		
9.0	1.4802	6.9407E-02		
10.0	1.304	9.6114E-02		

Reliability values for different pole length.

## Table 4

Reliability values for different pole thicknesses and diameters

Thickness and diameters of the poles				
Thickness (m)	Reliability Index ( $\beta$ )	Probability of Failure $(P_f)$		
3.6	2.7142	3.3097E-03		
4.5	2.3713	3.3100E-03		
4.8	2.0867	3.3104E-03		
5.9	2.0781	3.3107E-03		
5.9	1.7153	3.3115E-03		

Figures 3, 4 and 5 show the relationship between reliability indices to various pole lengths, thicknesses and diameters. The discussions arising from these findings are also given in section 4.2.



Fig. 3. Relationship between reliability index and pole length.



Fig. 4. Relationship between reliability index and pole Thickness.



Fig. 5. Relationship between reliability index, diameter and length of steel poles.

## 4.2. Discussion

Based on the result output generated in MATLAB for the steel poles, it was observed from Table 2 that for moment failure mode the reliability index value was very low ( $\beta = 1.4802$  and  $P_f = 6.9407E-02$ ) as compared to that for deflection and shear failure modes, which had higher values (2.339E+01 and 5.1245E+01) respectively with both negligible  $P_f$  values of 0.100E-10.

This is an indication that the pole is too save against these failure modes. It may also be due to the fact that deflection and shear failures of steel poles are a rare event; they require the combination of a number of unusual events to occur such as corrosion at or near the ground surface. The consequence of having higher values of reliability index is a conservative design with a very high cost, that is, (uneconomical). Normally, a lower value of the reliability index  $\beta$ , implies unsafe structure as witnessed for moment failure mode. Thus, based on these findings it is noted that the most likely mode of failure of electric distribution steel poles is by moment generated at the base of the poles.

Thus, to identify the behavior and parameters that affect the strength of the steel poles, sensitivity analysis were conducted to see which parameter actually affects the poles, since the limit states equations are functions of the geometric variables of the poles, the lengths, thicknesses, diameters (both bottom and top) were varied simultaneously for each of the pole considered; it was decided to vary one variable at a time, Figures 3, 4, and 5 show the relationship between these design variables on the reliability indices, as can be inferred from figure 3. For the various lengths considered, the reliability indices decreases with increase in pole lengths or heights, whereas for all the thicknesses of the poles considered, the trend of the reliability indices values tends to be increasing as the thicknesses increased, Also from Figure 5, the reliability indices was less sensitive to the bottom diameters as compared to the top diameters, there is a slight decrease of reliability indices from the values observed, Whereas for the top diameters; higher values of reliability indices were observed, which shows a decreasing trend as the pole length was increased which is an indication that failures do not occur at the top, but rather at the bottom of the poles. Therefore, the reliability indices are sensitive to variability in structural dimensions, such as, the diameters, in all the limit state equations; the thicknesses and diameters were found to be quite significant. It should also be noted that for deflection and shear failures, higher values of reliability indices,  $\beta$ , were also obtained for the varied parameters and both negligible probability of failures. The diameters and thickness variation results are most sensitive, followed by length. Usually, the variability of the statistical parameters significantly affects the magnitude of failure associated with the poles; therefore, the uncertainty in these parameters should be considered for the steel poles design, since failures of any pole can be influenced by the variability and uncertainty of these parameters.

## 5. Conclusion

The result of probabilistic evaluation of electric power distribution steel poles using generated limit state functions and First Order Reliability Method under uncertain loading based on the provision of EC3 (2004) [24] have been presented, The reliability indices for moment had a value of 1.4802E+00, 5.1245E+01 for shear and 2.339E+01 for deflection of the pole, indicating that reliability based design can be considered as a rational measure of performance for steel poles as these meet the JCSS (2005) [25] condition for safety of structures. The shear and deflection of the pole had the highest reliability index and lower probability of failure indicating that these failure modes have low effect on the strength of steel poles. The choice of material to be used is based on several factors such as available resources and functional requirements, but steel poles provide better performance than other types of poles, However, based on the model

output highlighted, in order to obtain a more accurate insight into the strength of steel poles in service, pole maintenance scheduling must be incorporated into a structural reliability analysis before construction is carried out.

## References

- Ryan PC, Stewart MG, Spencer N, Li Y. Reliability assessment of power pole infrastructure incorporating deterioration and network maintenance. Reliability Engineering & System Safety 2014;132:261–73. doi:10.1016/J.RESS.2014.07.019.
- [2] Davidson RA, Liu H, Sarpong IK, Sparks P, Rosowsky D V. Electric Power Distribution System Performance in Carolina Hurricanes. Natural Hazards Review 2003;4:36–45. doi:10.1061/(ASCE)1527-6988(2003)4:1(36).
- [3] Lacoursiere B. Steel utility poles: advantages and applications. 1999 Rural Electric Power Conference (Cat. No. 99CH36302), IEEE; n.d., p. B2/1-B212. doi:10.1109/REPCON.1999.768681.
- [4] Basler E. Untersuchungen über den Sicherheitsbegriff von Bauwerken 1960. doi:10.3929/ETHZ-A-000099666.
- [5] Nowak AS, Collins KR, Collins KR. Reliability of Structures, Second Edition. CRC Press; 2012. doi:10.1201/b12913.
- [6] Ghasemi SH, Nowak AS. Reliability index for non-normal distributions of limit state functions. Structural Engineering and Mechanics 2017;62:365–72. doi:10.12989/sem.2017.62.3.365.
- [7] Dua A, Clobes M, Höbbel T, Matsagar V, Dua A, Clobes M, et al. Dynamic Analysis of Overhead Transmission Lines under Turbulent Wind Loading. Open Journal of Civil Engineering 2015;05:359–71. doi:10.4236/ojce.2015.54036.
- [8] Yang SC, Liu TJ, Hong HP. Reliability of Tower and Tower-Line Systems under Spatiotemporally Varying Wind or Earthquake Loads. Journal of Structural Engineering 2017;143:04017137. doi:10.1061/(ASCE)ST.1943-541X.0001835.
- [9] Tapia-Hernández E. Tubular Steel Poles Under Lateral Loads Pattern. Adv Steel Constr 2016;12:428–45.
- [10] Fu X, Li H-N. Uncertainty analysis of the strength capacity and failure path for a transmission tower under a wind load. Journal of Wind Engineering and Industrial Aerodynamics 2018;173:147–55. doi:10.1016/J.JWEIA.2017.12.009.
- [11] Zamanzadeh M, Kempkes CD, Aichinger D, Riley D. Laboratory and Field Corrosion Investigation of Galvanized Utility Poles. Electrical Transmission Line and Substation Structures, Reston, VA: American Society of Civil Engineers; 2006, p. 235–49. doi:10.1061/40790(218)22.
- [12] Ghasemi SH, Kalantari H, Abdollahikho SS, Nowak AS. Fatigue reliability analysis for medial tibial stress syndrome. Materials Science and Engineering: C 2019;99:387–93. doi:10.1016/J.MSEC.2019.01.076.
- [13] Dagher HJ. Reliability of poles in NESC grade C construction. 2001 Rural Electric Power Conference. Papers Presented at the 45th Annual Conference (Cat. No.01CH37214), IEEE; n.d., p. C4/1-C4/6. doi:10.1109/REPCON.2001.949521.
- [14] Ghasemi S. Target reliability analysis for structures. 2015.
- [15] Mosley W, Hulse R, Bungey J. Reinforced concrete design: to Eurocode 2. 2012.
- [16] Afolayan JO. The Tower of Babel: The Secret of the Birth and But of Structural Integrity. Inaugural Lecture Series 67. Akure: 2014.
- [17] Opeyemi D. Stochastic Modelling of Structural Elements. Stochastic Modeling and Control, InTech; 2012. doi:10.5772/45951.
- [18] Madsen H, Krenk S, Lind N. Methods of structural safety. 2006.
- [19] Ditlevsen O, Madsen HO. Structural reliability methods. Wiley; 1996.

- [20] Bourinet J, Mattrand C, Dubourg V. A review of recent features and improvements added to FERUM software. Proc. of the 10th International Conference on Structural Safety and Reliability (ICOSSAR'09), 2009.
- [21] Muyiwa S Adaramola, Olarenwaju M. Oyewola. Wind speed distribution and characteristics in Nigeria. Journal of Applied Sciences and Environmental Management 2018;22:119–23.
- [22] Ajibola Ibrahim, Joseph Olasehinde Afolayan. Probability-Based Assessment of Electric Power Distribution Concrete Poles in Southwest of Nigeria. International Journal of Advanced Scientific Research and Management 2016;1:102–10.
- [23] Salman A. Age-Dependent Fragility and Life-Cycle Cost Analysis of Timber and Steel Distribution Poles Subjected to Hurricanes. 2014.
- [24] Simões da Silva L, Simões R (Rui AD., Gervásio H. Design of steel structures : Eurocde 3: Design of steel structions. Part 1-1, General rules and rules for buildings. n.d.
- [25] Probabilistic Model Code Recommended for Structural Safety, Part 1 Basis of Design. Joint Committee on Structural Safety (JCSS); 2005.