



## Reliability Assessment of a Solid and Nail-jointed Box-Section African Birch (*Anogeissus leiocarpus*) Timber Column

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### ABSTRACT

In an attempt to study the performance of a box-section timber column, a structural reliability analysis was carried out on the Nigerian-grown African birch to ascertain its usability for columns under several axial loads. Samples of the timber were bought, sawn and used to prepare small clear specimens of box columns after which their compressive strengths were obtained. Results of corresponding solid square sections of the same timber specie were used as the control. Some statistical parameters were established for the deterministic design of the timber column. A FORTRAN-based program was also developed and used for the reliability analysis of the Nigerian-grown African birch columns designed to ascertain their level of safety using First-Order Reliability Method (FORM). From the reliability analysis, both sections were found adequate to support the design load however, it was found out that only beyond 100kN is there an advantage of the box-section above the solid. The compressive capacity of the box-section (150 x 150mm) was found to be 1.5 times that of the solid section and this margin increases to more than two times that of the solid section as the design load was successively increased to 1000kN. Also, the box section has a higher capacity to bear its Euler load with a greater length than the solid section because of its greater radius of gyration and rigidity. Therefore the box section would be preferable for long columns than the solid section. Lastly, the box-section is also economically advantageous considering the area of the design section- 10,400mm<sup>2</sup> over the solid section offering a cross sectional area of 22,500mm<sup>2</sup>.

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### INTRODUCTION

The application of built-up timber is a growing phenomenon which serves as an alternative in timber construction. It entails the application of wood plates that are built-up as beam, column, floor, and wall elements. In some loading situations, the performance of box-based timber under loading could be structurally efficient. Box timber section can reduce structural weight without significant loss of strength or stiffness. It is also cost competitive. This makes the box timber section a reliable structural member.

Reliability can be defined as the ability of a system to perform a required function under stated conditions for a stated period of time in a designated environment (Ireson, 1996; Gyrna, 2007 cited in Juran and DeFeo, 2015). Peng Shang *et al.*, (2018) carried out an experimental investigation on the flexural performance of hollow glulam beams. Comparative analysis of solid glulam beams and

hollow glulam beams of various sizes of rectangular holes were conducted. It was concluded that the apparent flexural stiffness and ductility of hollow glulam beam were lower than those of solid glulam beam. It was realized that the apparent modulus of elasticity obtained through empirical investigation is 0.86 times the theoretical value. Karyadi *et al.*, (2018), conducted an empirical study on square hollow-section columns in order to examine the strength of the columns under axial load. Thirty test columns were built-up with laminated Asian bamboo glued together by urea formaldehyde. The thirty columns were made up of nine samples of short columns, twelve samples of intermediate columns and nine samples of long columns. The results obtained from the investigation show that all the short columns failed by crushing when subjected to a pressure of 59.08 MPa. Three of the intermediate columns failed by crushing or inelastic buckling or splitting wall of the columns, while all the long

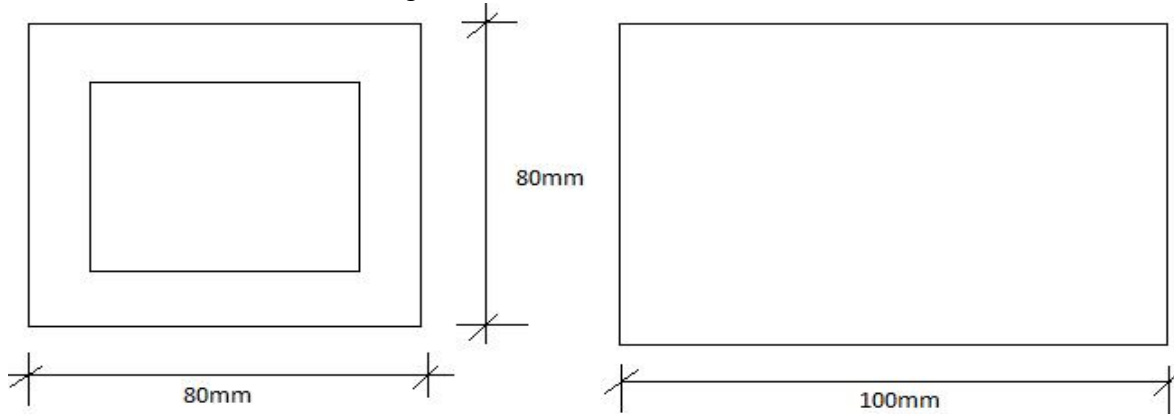
columns samples failed by buckling. The built-up columns exhibited good structural performance under the applied load.

Another research by (Harries *et al.*, 2000) on built-up box columns had deductions that axially loaded specimens having a clear height of 3,048mm (120 in.) and an estimated effective height of  $3,048 \times 0.8 = 2,438$  mm (96 in.) showed capacities of at least 1.7 times the capacities predicted by the National Design Specification of Wood construction (NDS) for these members. Also, that the ultimate behavior of these columns was generally governed by elastic buckling. Second, for flexure-critical specimens loaded at midpoint for flexure over a span of 2,438 mm (96 in.), it was discovered that flexural capacities obtained was approximately 3.7 times those predicted by the NDS specifications for these members. Third, shear-critical specimens loaded at midpoint for flexure over a span of 2,438 mm (96 in.) showed a shear capacity of approximately 2.4 times the capacities predicted by the NDS specifications for these members. Lastly, the work indicated a significant advantage in load-carrying capacity of the laminated built-up box sections over solid timber sections for columns having dimensions

greater than 127x 127 mm (5 x 5 in.). In other words, beyond 127 x 127mm section, solid timber becomes inadequate in resisting axial loads hence, the need for the use built-up sections. Wilson *et al.*, (2019) showed that an 'I'- section was found unsafe to bear a design load of 260kN unlike its corresponding solid section. But an identified I- section (100 x 400mm) was found adequate (with  $P_f = 1.22 \times 10^{-02}$ ) whose compressive capacity corresponds to (200 x 100mm) of the solid section (with  $P_f = 7.76 \times 10^{-02}$ ) which is practically half the dimension of the I-section. This therefore established that the solid section has a capacity twice that of the 'I'- section of equal dimension.

#### METHODOLOGY

A total of ten specimens each of I and box sections of 'Ayin' (*Anogeissus leiocarpus*) timber were prepared for testing by being sawn into specified sizes of 45 x 85 x 100mm and 80 x 80 x 100mm for the compressive strength test. The specimens were systematically mounted on the machine, clamped and gradually loaded as readings were automatically taken by the machine.



**Figure 1:** A Front and Side Elevation of Box-Section Specimen for Bending Strength Test



**Plate 1:** Showing Solid-Section Test Specimen Plate 2 Showing Box Section Test Specimen

Table 1. Probability distribution and statistical parameters for the Basic Variables.

Parameter	Distribution	Mean	Standard deviation	COV
Load (N)	Log	250	35	0.14
Breadth(mm)	Normal	150	9	0.06
Depth (mm)	Normal	150	9	0.06
Young's Modulus (N/mm <sup>2</sup> )	Log Normal	10,500	315	0.03
Length (mm)	Normal	3600	432	0.12
Radius of gyration (mm)	Normal	28.57	1.44	0.05

Wilson et al., (2018)

Table 2. Design Parameters for the Nigeria- grown African birch

Timber Specie	Span(mm)	Depth(mm)	Breadth (mm)	Design Load kN
Africa Birch	3600	150	150	260

Wilson et al., (2018)

**Table 3:** Probability distribution and Statistical parameters for the basic variables for Box Section of Timber.

S/N	Parameter	Distribution	Mean	Standard deviation	COV
1.	Load (N)	Log	250	35	0.14
2.	Breadth(mm)	Normal	150	9	0.06
3.	Depth (mm)	Normal	150	9	0.06
4.	Young's Modulus (N/mm <sup>2</sup> )	Log Normal	10,500	315	0.03
5.	Length (mm)	Normal	3600	432	0.12
6.	Radius of gyration (mm)	Normal	53.70	2.69	0.05

The limit state or performance function in compression as given by (Nowak and Collins, 2000) is

$$g(x) = f_{pp} - f_{ap} \quad (1)$$

$f_{pp}$  = Permissible stress parallel to grain

$f_{ap}$  = Actual stress parallel to grain

From the basic stress gotten for the solid timber, the limit state function can be written as:  $g(x) = 16.25 - \frac{N}{bh}$  (2)

Wilson et al., (2018)

To consider the reliability of the timber with an interest in considering the length in response to the performance, the limit state function formulated from the Euler load formula and can be given by:

$$g(x) = 16.25 - \frac{9.8 E r^2}{l^2} \quad (3)$$

E= Young's Modulus of elasticity

r= radius of gyration

l= length of the column

Wilson et al., (2018)

### The Column Analysis

The axial stress on the column is given by the expression

$$\sigma = \frac{F}{A} \quad (4)$$

Where P is the load supported by the cross-sectional area A. For long columns, the equation given by Euler for the load is:

$$P = \frac{\pi^2 E I}{L^2} \quad (5)$$

Where P is the maximum critical or failure load, E is the elastic modulus and I the moment of Inertia.

The radius of gyration is given by

$$r = \sqrt{\frac{I}{A}} \quad (6)$$

The corresponding Euler stress experienced by the slender column can consequently be expressed by the expression

$$\sigma = \frac{\pi^2 E}{(L/r)^2} \quad (7)$$

Jimoh (2005)

## RESULTS AND DISCUSSION

### Results of Reliability Using a FORTRAN-Based First Order Reliability Method Program for Both The Solid And Box-Section Column

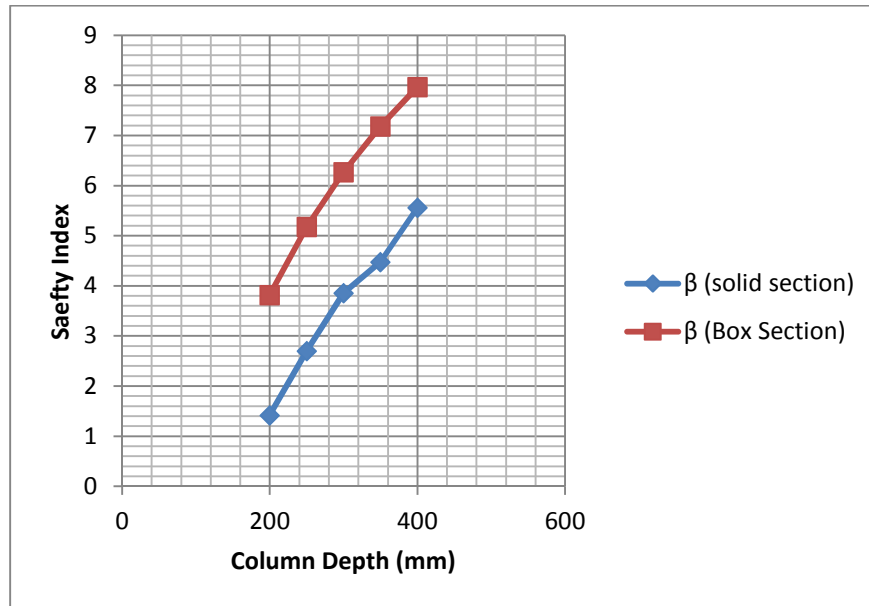


Figure 2 Safety Index-Column Depth Graph for Design Load of 260kN

The safety index-column depth relation shown in the figure 2 above depicts the performance of the two section geometries: the solid section and the box section under the design axial load of 260kN and a constant breadth of 100mm. The solid section can support the design load with an adequate depth of 200mm (that is a 100 x 200mm section) at a probability of failure of 7.76 E-02. The box-section

can also safely support this design load with a depth of 200mm (that is 100 x 200mm section) but with a much lower probability of failure value of 6.66 E-05 (that is a higher chance of success than the solid section). This invariably implies that, the design load can be supported by a smaller section than 100 x 200mm of the box section judging from their safety indices.

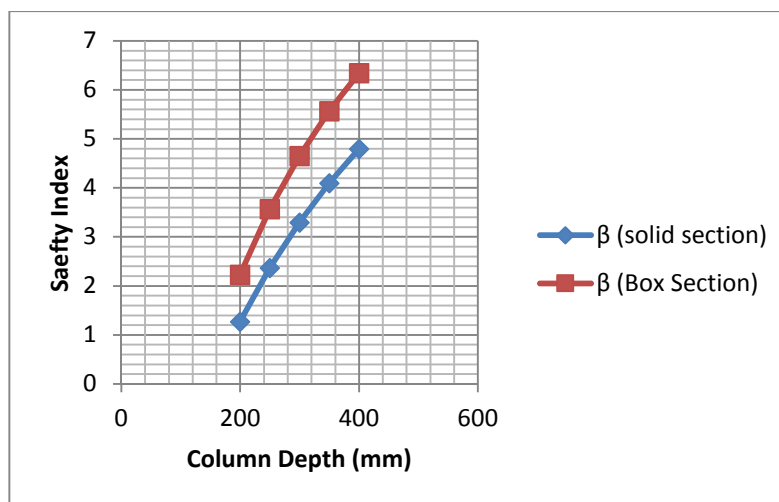


Figure 3: Safety Index-Column Depth Graph for Design Load of 500kN

For a greater design load of 500kN with a constant column breadth of 150mm, the solid section is apparently seen to be able to support this design load with a depth of 200mm but since the probability of failure at this safety index is 0.103, 300mm breadth is selected as adequate (that is, a

150 x 300mm section) having a probability of failure of 8.85 E-03. The box-section can also safely support this design load with a minimum depth of 200mm (that is, a 150 x 200mm section) at 1.28E- 02 chance of failure.

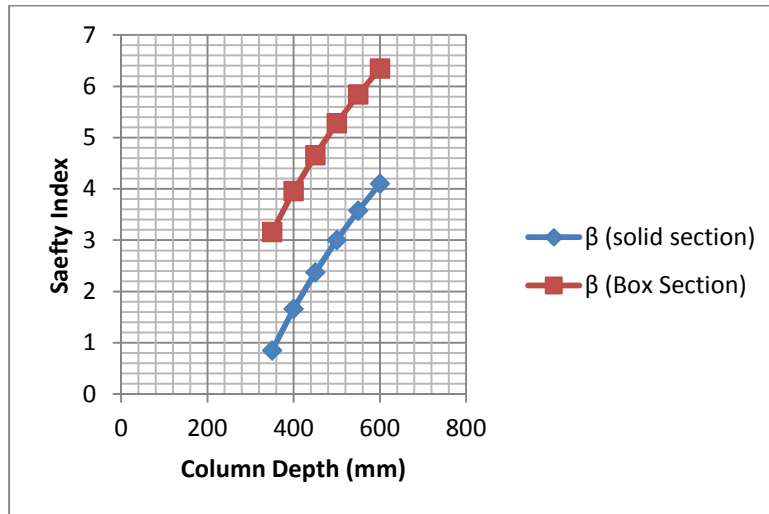


Figure 4: Safety Index-Column Depth Graph for Design Load of 1000kN

Figure 4 shows that the solid section can safely support this load with a minimum depth of 400mm (that is a 200 x 400mm section) at a 4.85 E-02 chance of failure. The box-section can also support the design load with a 200 x 350mm section

at a probability of failure of 7.87 E-04. It means that with a depth of 350mm and even less (as can be observed from the safety index values), the box-section can sustain the same load.

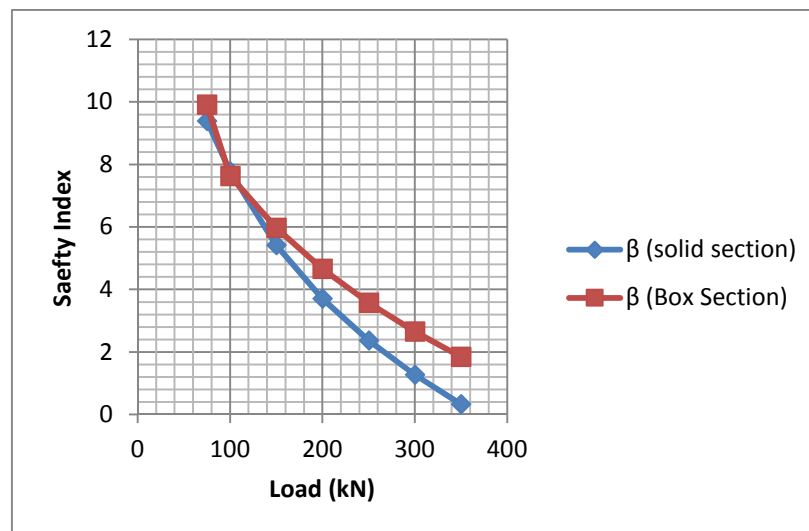


Figure 5: Safety Index-Load Relations for the Design Section (150 x 150mm)

The solid section can safely support as much as 300kN, which at a probability of failure of 0.103. The box-section is found to be capable of bearing as much as 450kN at a probability of failure of 0.130. It can therefore be hypothesized that the box-section can bear as much as 150% of what a corresponding solid section can, which is very economical and is traceable to its greater radius of gyration.

This closely concurs with the NDS speculation that ‘When built-up columns are nailed

or bolted in accordance with provisions in the ‘National Design Specification for Wood Construction,’ American Forest & Paper Association, the capacity of nailed columns exceeds 60% and of bolted built-up columns, 75% of an equivalent solid column for all L/d ratios’. It is also observed that, the performance margin between the box and solid section is wider in this case than observed at the design load of 500kN

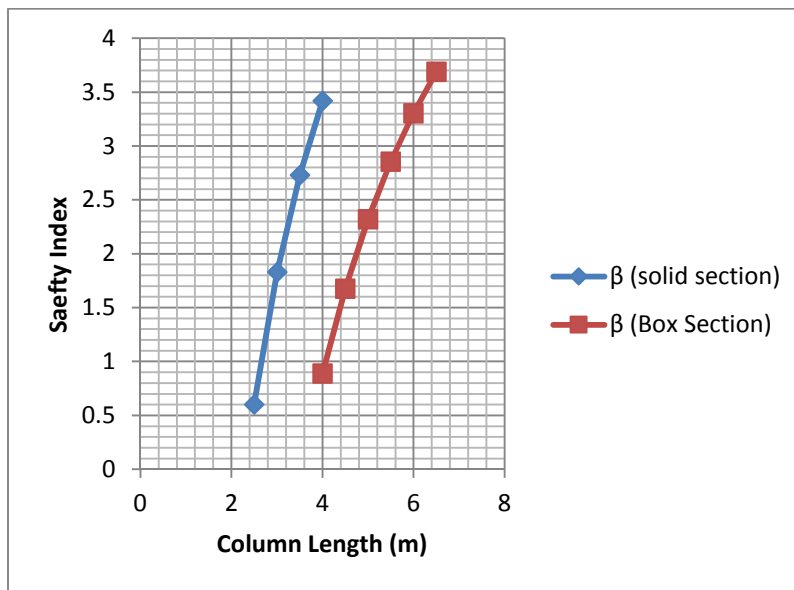


Figure 6: Safety Index- Column Length Relations for Euler Load

The figure 6 shows the relationship between safety index and the column lengths when the columns are subjected to Euler loads. It can be seen that a very safe maximum column height of up to 4.0m is possible for the solid section. It is also observed that the box-section can safely bear its Euler load to maximum length of 6.5m with a probability of failure of  $1.13 \times 10^{-4}$ . The results show that the box section has a better performance under its Euler load and would be preferable for longer columns than the solid section. This is also attributable to its greater radius of gyration than the solid section.

## CONCLUSION

It can be conclusively deduced that the box-section has a greater compressive resistance than its corresponding solid square section. Particularly, the

solid section with design area of  $22,500\text{mm}^2$  ( $150 \times 150$  mm) can safely support as much as 300kN, which at a probability of failure of 0.103. The box-section with design area of  $10,400\text{mm}^2$  (gotten from  $150 \times 150$  mm overall section) is found to be capable of bearing as much as 450kN at a probability of failure of 0.130. It is observed that as the load increases, the performance margin broadens between the box and solid section (that is to say, the capacity of the solid section drops). Specifically at 1000kN, the performance of the solid section reduces to less than half of the box section which apparently in accordance with what the National Design Specification for Wood Construction has to say about built-up sections in relation to solid section. This means that for greater loads, it is more preferable using the box section than the solid



section. Also, the box section has a higher capacity to bear the Euler load with greater lengths than the solid section because of its greater radius of gyration and rigidity value and would rather be preferable for long columns than the solid section.

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