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FELLING INDUCED DYNAMIC STRESSES IN SOME TROPICAL HARDWOODS FROM NIGERIAN LOWLAND RAINFOREST

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ABSTRACT

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A study was undertaken to estimate the magnitude of dynamic stresses (MDS) induced in some mature tropical hardwood species during felling operation and their effect on the harvested wood. Five areas in Shasha forest reserve, Osun State, Nigeria were selected as the study sites because of the prevalent high. Two hundred and eighty nine trees represented by nine different species were studied. The species are Afzelia africana, Nauclea diderrichii, Terminalia superba, Khaya ivorensis, and Triplochiton scleroxylon Entandrophragma angolensis, Cordia millenii, Mansonia altissima and Milicia excelsa. Using a checklist, information were collected on tree factors, terrain of the sites and experience of the operators. During felling of each tree, the duration of impact was estimated. Data collected were subjected to statistical analysis. The average content of the green wood ranged from 108% to 147% (dry basis) for all the species. The average impact force ranged from 1.498 X 10^6N to 7.588 X 10^6N, while the maximum dynamic stress ranged from 8.38 x 10^6N/m^2 for Triplochiton scleroxylon (Obeche) to 18.75 x 10^6N/m^2 for Nauclea diderrichii (Opepe). The observed values of dynamic stress are very much higher than the ultimate static stress values for all the species and this will definitely affect the wood quality of the felled trees.

Keywords: Dynamic stress, impact force, tropical hardwoods, felling operations, logging.

INTRODUCTION

The long history of tree felling operation has witnessed a steady evolutionary trend in terms of technological advancement and improved productivity. The replacement of crude felling tools, such as axes and hand saws with modern tools like powered chain saws has reduced physical stress and accidents on operatives and has also reduced felling-induced damages in timber. However, felling-induced damages are still considerably high in the tropical forests (Elias, 1998). These damages could be associated with the peculiar nature of tropical timbers. Tropical timbers are generally densely crowned, massive and bulky with girth of about Fourteen to Seventeen metres in some mature species. They also usually grow hi mixed natural forest and in most cases interconnected with wood climbers (Richard 1996). This feature including the numerous branching, with branches frequently leaning in any directions, felling of any mature tree usually result in the felled trees landing with great force. The resultant stresses of this high force on the felled trees are a function of several interrelated factors which could be broadly grouped into three, viz, the tree characteristics, environmental factors and the technique adopted in felling (Omole 2000). Upon reaching the ground, the felled tree experiences impact force and the stress-stain relationship of wood subjected to high dynamic loading has been observed to be very complex (Hearmon 1952; Dinwoodie 1989). The magnitude of the dynamic loading on wood fibres depends on wood species, crown architecture, tree height and diameter, wood density and moisture content, presence of degrades, wind speed and direction, slope or gradient, falling direction (uphill or down slope) and soil elasticity (Wackerman 1949, Hearmon 1952, Qmole 2000).

In felling tropical trees, unless great care is taken, breakage, wastage and loss of timber resulting from the impact could be near total. The damage induced is usually more pronounced and visible at the crown region, resulting hi the breaking of the branches and some of the stresses are transmitted into the main trunk. The resultant failure may or may not be readily visible to naked eye (Lausgerg *et al.* 1995). The damage incurred in felled trees has serious effect on subsequent wood utilization qualities especially when they are required for load-bearing (structural) application. Whenever there is failure resulting from the high impact, the strength characteristic of the wood is usually adversely affected. Also, veneers produced from such logs have been found to be defective because they contain numerous splits and checks caused by excessive stress (Lausberg *et al.* 1995). It therefore becomes necessary to examine the wood felling techniques in tropical forests with a view to estimating the magnitude of the dynamic stresses induced in the wood of the felled tree and force generated at impact. Also, it is necessary to design or propose an appropriate felling method which will not only lead to minimizing incidental damage but also ensure the production of good quality logs that will be structurally acceptable.

MATERIALS AND METHODS

Site selection/study area

Surveys were carried out in four Natural Forest Reserves in Southwestern Nigeria where intensive logging operation was being carried out. Shasha natural Forest Reserve (SNFR) in Osun State was eventually selected because it was found to be a typical exploitation site in the rain forest area of Nigeria. Shasha Natural Forest Reserve (SNFR) lies between latitude 7° - 7.3°N and longitude 4° - 5°E and it covers an area of about 310.80km^2. The Forest Reserve falls within the lowland rainforest region. The forest type is characterized by highly deciduous tree species in the *upper* story. The reserve is bound on the South by Omo Forest Reserve, on the West by Ago-Owu Forest Reserve and on the Northwest corner by Ife Forest Reserve. Kio (1978) described the geology of the reserve as being dominated by rocks consisting mainly of granites, gneisses and schists of the basement complex with the rocks occasionally seen exposed in the river beds or as rocks outcrops. Bada (1877) described the geology of the reserve as crystalline rocks which are undifferentiated.

Selection of areas of exploitation and tree species

Taking into account the logging intensity, five different areas within the forest reserve were selected for the research. The five selected areas are: *Idi-ahun, Olomu, Alaagan, Laroka* and *Onigbin.* With utilization potentials and economic value as criteria, nine different tree species were selected for the study. The species selected include *Afzelia africana, Nauclea diderrichii, Terminalia superba, Khaya ivorensis, Triplochiton scleroxyhn, Entandrophragma angolensis, Cordia millenii, Mansonia altissima* and *Milica excelsa.*

With the aid of a checklist, information were recorded for individual trees on tree standard parameters such as species, total height, crown shape, diameter at three levels (stump, middle and top), initial lean position and defects were all recorded on the data form. Also noted on the checklist were the prevailing environmental conditions like terrain features, ground density, soil characteristics, etc. During falling, the time taken from first take-off of the tree to landing and duration of impact was measured with the aid of a stop watch. The manner of fall, the nature of damage and the magnitude of the damage were assessed to be able to qualify and quantify the damage.

Tree volume estimation

In determining the tree volume, the diameter of each tree was measured at three different levels with the aid of Spiegel relaskop. The volume of each tree was estimated before felling operation using Newton's formula which states thus:

$$V = \frac{\pi H}{24}(A_b + 4A_m + A_t)$$

Where,

V = Volume of tree (m^3)
H = Height or tree (m)
Ab = Cross-sectional area of the base of the tree (m)
A_m = Cross-sectional area of the middle of the tree (m)
A_t = Cross-sectional area of the top of the tree (m^2)

Maximum dynamic stress (MDS) induced

In estimating the magnitude of the MDS for each tree, equations were employed for calculating the angular velocity, angular acceleration, momentum, force generated at impact and the dynamic stress induced. Duration of impact was experimentally determined with the aid of a stop watch. Stress is force per unit area, the cross-sectional area of the top was used for dynamic stress estimation because the stress will be highest at the top. The cross sectional area A of the tree is calculated from the diameter D using the formula:

$$A = \pi\frac{D^2}{4}$$

Where,

A = to cross sectional area of the tree (m^2)
D = diameter of the tree at the top
π = constant

Data analysis

Data were analysed using a combination of descriptive statistics, simple percentages, frequency distribution, and multiple linear regression.

RESULTS AND DISCUSSION

Impulse and dynamic stress

It was observed that a wide variation exists between and within species in terms of total height of tree (Table 1). Almost all the species (83.8%) have an average total height of about 50 metres indicating that most of the trees of the studied species are very tall (Table 1). These heights are not strange for the mature trees in tropical rainforests. Richard (1996) reported that trees in rainforests are extremely numerous in species composition ranging from treelets of one or two metres to giants of over 50m or even up to 80m high. Pires and Prance (1977) reported an average height of taller tree in rainforest of between 48-58m with individual sometimes above 60m. These observations can then be taken to be in order with the existing figures recorded in the studied area. The average volume for the nine species ranged between 13.68m^3 for *Mansonia altissima* and 46.25m^3 for *Entandrophragma angolensis* (Table 1). However, majority of the species (77.78%) recorded an average volume of more than 30m^3 (Table 1). Four species, *Afzelia africana, Nauclea diderrichii, Terminalia superba* and *Milicia excelsa* have average volume ranged between 30.72m^3 and 37.82m^3 while three species *Khaya ivorensis, Triplochiton scleroxylon* and *Entandrophragma angloensis* have volume over 40m^3 (Table 1). The high values of the estimated volumes are indications of the massiveness of tropical timbers. The high volumes of the trees will lead to higher weights which in turn manifest in heavy landing forces on the wood of the trees at impact.

The highest density of green wood of 1958kg/m^3 was recorded for *Nauclea diderrichii* as against the least density of green samples of density of 796kg/m^3 recorded for *Triplochiton scleroxylon* (Table 1). The average density of green samples for the nine species ranges from 936.91 kg/m3 for *Cordia millenii* and 1845kg/m^3 for *Nauclea diderrichii* (Table 1) The densities of green wood for all the species were very much higher than the norminal densities (sometimes double the value). Contributory to this high value of the density is the high moisture content.

Table 1: The characteristics of nine trees study for felling induced dynamic stresses

Trees species	Mean height (m)	Volume (m^3)	Moisture content (%)	Green density (kg/m^3)
Afzelia Africana	51.23	30.72	133.77	1765.81
Nauclea diderrichii	49.90	32.29	147.05	1845.95
Terminalia svperba	54.78	37.82	126.27	1167.00
Khaya ivorensis	56.61	42.88	129.39	1263.48
Milicia excelsa	50.64	35.75	129.44	936.91
Cordial millenii	42.11	21.21	108.09	936.91
Triplochiton scleroxylon	54.78	40.79	116.39	882.27
Mansonia altissima	40.39	13.68	110.64	1268.57
Entandrophragma angolensis	56.38	46.25	137.62	1612.62
Total mean	50.76	33.48		

Table 2: Average magnitude of forces on wood of the felled trees at Impact

Trees	Impulse (Value = Ns)		
	Minimum	Maximum	Average
A. africana	11.57	102.35	53.74
N. diderrichii	21.81	108.70	58.18
T. superb	25.50	72.11	44.65
K. ivorensis	25.52	77.34	55.47
M. excels	13.93	84.89	55.09
C. millenii	6.05	30.38	17.73
T. scleroxylon	19.61	55.04	36.22
M *altissima*	9.41	20.70	14.98
E. angolensis	35.03	111.8	75.88

The average moisture content is more than 100% for the nine species with *Nauclea diderrichii* having the highest average moisture content of 147.05%. *Cordia millenii* however has the least average moisture content of 108.09% (Table 1). This high moisture content of the green wood species is responsible for the high value of the green densities of the studied species. Since it is a known fact that high moisture content leads to reduction in the static strength of the wood, the magnitude of the moisture content observed in all the species (above 100%) coupled with the induced higher weights is expected to make the wood more flexible (decreased stiffness). The response of wood to applied dynamic load is quite different from static response hence this high moisture content expectedly will impose on the wood additional quality to cope with the high dynamic stresses. The impact of toughness of green timber as reported by Lavers (1969) is considerably higher than it is in the dry state. He reported that the impact resistance of two tree species, namely; green willow and teak are approximately 30 percent and 50 percent higher respectively than values at 12 percent moisture content for the two species.

Tree and wood properties evaluation revealed that the study species are characteristically different in height, volume, density and moisture content. These observations however are in line with various tree and wood property analyses carried out by previous researchers (Bada 1977). Cown *et al.* (1991) confirmed that there are pronounced between and within trees variation in wood quality and properties such as density, moisture content and response to application of stress. Richard (1996) also wrote that some tree species have the tendency to grow bigger than others while there are wide variations in density, strength and other physical and mechanical properties of tree and wood. Hence, trees have traditionally been selected for harvesting based upon visual qualities of the tree and species. Visual quality important in tree selection includes diameter, height, observable defects and age. All these have been reported to contribute significantly to the quality of wood from the trees. The force at impact in a felling deciduous tropical timber is considerable. This impulse varies from one species to the other with bigger trees species having higher impact force than smaller trees. Due to the small size of *Mansonia altissima* it has the least force at impact of between 9.41 10^5Ns and 20.70 10^5Ns with average of 14.98 x 10^5Ns (Table 2). *Afzelia africana, Milicia excelsa, Khaya ivorensis* and *Nauclea diderrichii* recorded average maximum impact force of 53.74 x 10^5Ns, 55.09 10^5 Ns, 55.47 x 10^5Ns and 58.18 x 10^5Ns respectively (Table 2). *Terminalia superba* and *Triplochiton scleroxylon* have an average impact force of 44.65 x 10^5Ns and 36.22 x 10^5Ns respectively, *Entandrophragma angolensis* has the highest maximum impulse which ranged from 3.50 x 10^5Ns to 11.80 x 10^5Ns with a mean impulse of 7.588 x 10^5Ns (Table 2). The wide variations in the impact force on the landing trees could be associated with factors such as tree height and diameter (which dictate the volume) the moisture content and the density or the green wood in the tailing tree. This high force coupled with the tree diameter will to a great extent determined the magnitude of the dynamic stresses induced in the wood and the associated mechanical damages. Soil effect on the impact force may be variable, in rigid soils such as rocky area, the impact force is entirely transmitted into the wood leading to severe damages while in softer soils, there is better dissipation of force, onto the earth. The ground condition (on which the tree lands) therefore has effect on the magnitude of the dynamic stress induced. But in the case of this study, the ground was assumed to be level and soft for all the felling sites. Hence the effect was assumed to be uniform.

The least mean induced dynamic stress of 8.38 x 10^6N/m^2 was recorded for *Triplochiton scleroxylon* as against the maximum of 18.75 x 10^6N/m^2 for *Nauclea didderrichii* (Table 3). *Ajzelia africana* and *Entandrophrama angolensis* were subjected to very high dynamic stress of 18.18 x 10^6N/m^2 and 17.84 x 10^6N/m^2 respectively (Table 3). Medium average dynamic stress of 14.29 10^6N/m^2, 13.46 x 10^6N/m^2 and 12.66 x 10^6N/m^2 were induced in *Terminalia superba, Khaya ivorensis* and *Milicia excelsa* respectively (Table 3). However, *Triplochiton scleroxylon, Mansonia altissima* and *Cordia millennii* were subjected to lower dynamic magnitude of 8.38 x 10^6N/m^2, 9.08 x 10^6N/m^2 respectively (Table 3). Although the calculated values of dynamic stress on the wood of the trees could be considered to be quite high, it should be realized that the stress distribution will not be uniform throughout the whole tree. There would be areas of stress concentration and these areas will be first to suffer mechanical failure and the stress in those areas will be higher than the estimated stresses.

Impact force and dynamic stresses

Additional explanation on this is that since stress is force per unit area, heavier tree with small cross-sectional area is subjected to higher stress value than wood of lighter density with big cross-sectional area. *Nauclea diderrichii* had average volume of 32.29m^3 and MDS of 18.75 x 10^6N/m^2 as against species with higher volumes such as *Terminalia superba, Khaya ivorensis, Triplochiton scleroxylon, Milicia excelsa* and *Entandrophragma angolensis* with volumes and MDS of 37.82m^3 and 14.29 x 10^6N/m^2, 42.88m^2 and 13.46 x 10^6N/m^2, 40.79m^3 and 10.01 x 10^6N/m^2, 35.75m^3 and 12.66 x 10^6N/m^2 and 46.25m^3 and 17.84 10^6N/m^3 respectively (Table 4).

When a falling tree hits the ground, the impact induced will be higher in the material around the crown region than in other parts of the tree. This is because the stress waves are dampened before reaching the parts away from the crown region (i.e. away from the point of impact). Also the taper in the tree diameter from the butt to crown area makes the girth at the crown and smaller, hence the increased stress there. This was observed in all the trees tested, with greater breakages and fibre tearing away from the woods around the crown region than in the other parts. The maximum dynamic stresses induced in the trees at impact were all well above the ultimate stresses in static loading.

Table 3: Mean dynamic stresses induced in the nine species during felling operation

Trees	Dynamic Stress (x lO'TV/m^2)		
	Minimum	Maximum	Average
A. africana	6.50	29.90	18.18
N. diderrichii	11.54	31.05	18.75
T. superba	8.22	34.34	14.29
K. ivorensis	9.09	20.59	13.46
M. excelsa	5.16	12.23	12.66
C. millenii	5.61	12.24	8.38
T. scleroxylon	4.65	17.01	10.01
M. altissima	6.72	16.50	9.08
E. angolensis	14.90	21.38	17.84

Table 4: Comparison between the ultimate static strength and Maximum Dynamic Stress (MDS) induced in the wood as tree falls

Species	*MOR N/m^2(1.0x10^6)	*MOE N/m^2	*MCS N/m^2	MDS induced N/m^2(1.0x10^6	Ratio of MOR to MDS
A. africana	8.9	8700	47.0	18.18	2.04
N. diderrichii	9.4	11900	15.6	18.75	1.99
T. superba	5.2	5900	25.6	14.29	2.75
K. ivorensis	5.4	7400	26.8	13.46	2.49
M. excelsa	7.4	8300	35.3	12.66	1.71
C, millenii	3.7	4600	18.5	8.38	2.26
r. scleroxylon	5.4	1600	26.3	10.01	1.87
M. altissima	8.6	9700	44.1	9.08	1.06
E. angolensis	5.2	6900	25.4	17.84	3.43

* Values for MOR, MOE and MCS obtained from Lavers (1969)
MOR; Modulus of rapture, MOE; Modulus of elasticity, MCS; Maximum compressive strength

Hearmon (1952) and Dinwoodie (1989) have noted the much more superior strength of wood hi dynamic strength than in static. The explanation given has been consistent and it has always been linked with the theological properties of wood. This has to do with the response of the wood to an applied stress. The shock resistance of wood as observed by Green and Kretshmann (1994), and Krestschmann and Green (1996) is influenced by moisture content of the wood. The green wood has very high moisture content (sometimes up to 200%) which affects the shock resistance properties of wood materials. The high moisture content of the green wood of the study species (more than 100%), expectedly contributes significantly to the ability of the wood to absorb the greater part of the dynamic stresses without much discernible failure.

It was observed that the maximum dynamic stress induced vary considerably both between the species and with the trees of the same species. This observation cuts across the nine species selected for the study. This can be attributed to variations in trees sizes both between and with the species. *Cordia millenii* tree experienced minimum dynamic stress of 4.65 x 10^{6}N/m^2 while *Terminalia superba* had the highest maximum induced dynamic stress of 34.106N/m2. The dynamic stress range for the nine species is between 6.48 x 10^{6}N/m^2 for *Entandrophrama angolensis* and 26.12 x 10^{6}N/m^2 for *Terminalia superba.*

CONCLUSION

A moderate notch should be cut out at the butt region of a tree to be felled and the hinge should be used as control mechanism in order to reduce the falling speed of the tree. By this, the level of kinetic energy hi the system would be reduced hence the landing force and the associated stresses will be minimized. Restraining systems by means or ropes and winches should be employed to reduce impact during tree felling, especially for the those trees that are usually put into structural uses such as *Afzelia africana, Nauclea diderrichii* and *Khaya ivorensis.* The same is prescribed for veneer species, such as *Entandrophragma angolensis* and *Triplochiton scleroxylon,* the latter being in use for light structural purposes and also peeled for core and surface veneer production. The shape and size of the tree crown may be significant in influencing the magnitude of the dynamic stresses induced in the wood and the accompanying mechanical damage caused Studies should therefore be carried out on the cushioning effect of the crown of tree in protecting the wood fibres from greater damage in the trunk. For proper and quantitative categorization of the magnitude of the dynamic stresses and the associated mechanical damage, it is suggested that research work be extended to assessing the wood anatomically and also be directed at establishing an appropriate position/height along the standing tree where the centre of mass of the tree lies for different tropical timbers.

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