Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2018, 5(11): 907-926

Research Article **ISSN: 2394 - 658X**

Analysis of Mechanical Properties of Steel Rod as it Relates to Structural Failure Using Finite Element Method

LAWAL, Monsuru Olawale[1], M.T. Lilly [1] & B.E. Ngekpe[2]

[1]Department of Mechanical Engineering, Rivers State University, Port Harcourt, Nigeria
[2]Department of Civil Engineering, Rivers State University, Port Harcourt, Nigeria
ebenezer.ngekpe@ust.edu.ng

ABSTRACT

This research presents an investigation of mechanical properties of 12mm diameter steel rods from three different construction sites in Nigeria using finite element method. The main focus is to evaluate the level of conformity of locally manufactured/used steel rods in Nigeria with relevant local and international standards. Three samples A, B, and C, selected from the different construction sites were machined to standard sizes and tensile tests were performed using a tensometer. Basic strength of materials equations was used to determine the various parameters for the mechanical properties and values were compared with the internationally acceptable standards from the British Standard Institution BS 44449, the American Society for Testing and Materials (ASTM) – A706, and the Nigerian Steel standards NST.65-Mn. The results of the analysis showed that the ultimate tensile strength (UTS), yield strength (YS) and the percentage elongation (% E) are 604.71N/mm^2, 493.32N/mm^2 and 18.87 respectively for sample A; 550.81N/mm^2, 437.10N/mm^2 and 19.79% respectively for sample B; and 483.55N/mm^2, 353.64N/mm^2 and 4.27% respectively for sample C. The use of finite element method also allowed further test to be carried out on the steel rods such as the total deformation, elastic strain, stress, directional deformation and factor of safety.

Key words: Finite element method, rod, stress, strain, elastic, tensonmeter

INTRODUCTION

Lives of engineering components especially that of iron rod/steel are always being threatened by a phenomenon called failure, which happens to be one of the greatest problems facing the engineering world. Failure generally, is an unacceptable difference between expected and observed performance, a component fails when material strength is exceeded as applicable from the law of elasticity. Engineering failure is frequently caused by the misuse or wrong application of materials. When a plastic tea spoon buckles as you stir your tea, when a building collapses or when aircraft is grounded because cracks have appeared in the tail plane, this is probably because the Engineer who designed them used the wrong materials or did not understand the properties of those materials used. Thus, modern research has shown the need of constant monitoring and evaluation of materials in other for standards to be maintained.

There are lots of materials available to the engineers, each of which has unique characteristics, applications, advantages, limitations and cost. The challenging task of knowing the properties and behaviors of this material becomes very essential as adequate knowledge of the materials and its properties will aid the engineers and designers to avoid or minimize mistakes that may lead to engineering failure [22]. Often, materials are reinforced to make them stronger when improved strength is the major goal, the reinforcing components must have its length- diameter ratio to be high so that the load is transferred across potential points of fracture, this is why iron rods is preferred in concrete structures as reinforcing components.

Iron is one of the most abundant metals on the earth. It is probably one of the most important, being used on a larger scale that any other metal. It is less brittle than stone, yet compared to wood or copper, extremely strong, thus its popular usage in the construction of buildings and other edifices. Iron is the basis of many types of steel. The iron rod is a length of iron that is often the major ingredient in heavy construction works. It is used by intertwining reinforced concrete with the rods (rebar) to strengthen the tension of the build. Iron rod is a dark grey metal whose major constituent ranges from materials including wrought iron, cast iron, carbonised iron (carbon steel) and steel, [12].

The strength of concrete will be enormously increased if a concrete slab be "reinforced" with a network of small steel rods is placed under surface where the tensile stresses occurs. Unreinforced concrete, although have a great compressive strength, is very weak in tension, it is this lack of strength that leads to the necessity for reinforcement which carries the tensile forces present in the structure.

An understanding of the properties of materials is essential in both design and applications in any engineering project if it is to prove satisfactory for its intended purpose [22]. [18] stated that the numerical stress values that may be obtained from a tension test are the proportional limit, yield stress, ultimate stress, and rupture (breaking) stress. They further stated that modulus of elasticity, percentage elongation and percentage reduction in cross-sectional area may also be obtained. They concluded that these values define the mechanical properties or qualities of a material that are significant in the applications of strength of materials.

Since steel bars are vital and integral part of any structure, they are ought to possess certain mechanical properties for optimal performance. It therefore follows that the mechanical properties of steel must meet up with the quality specifications and standards of standard codes of practice on which designs are based for effective utilization. In Nigeria, the steel bars used for construction purposes are produced partly by the country inland rolling mills and the rest are imported from both international Organization for standards ISO member manufacturers and non member countries [24].

The study by [4] on the properties of reinforcement rods in the Nigerian markets asserts that bars delivered are produced by different manufacturers, often without adequate and reliable information regarding their structural properties; this may be a deliberate attempt to increase profits by the merchants. This therefore provides grounds for questioning the veracity of the strength of these bars. He further revealed that steels of recognizable origin satisfied both local and ISO requirement for strength and ductility, whereas those from unrecognizable sources failed to satisfy these requirements. In order to close the gap arising from uncertainties in the sources of rods and their corresponding strengths, [4] recommended that bars obtained from open market must be tested to confirm their conformance with the relevant requirements before use or an alternative proactive action such as the use of all ribbed bars from non-recognizable sources as plain bars with associated structural properties may be adopted.

As the population and economic activities continues to explode, the demand for structural projects becomes more pressing globally. In Nigeria, this justified the massive housing and infrastructural development that has been going on in the urban and rural areas of the country in the recent times. But an embarrassing feature of our building and infrastructural developmental strive is the failure rate verified among the existing structures and those under construction. The cost of these collapses, in terms of human life and economic waste, cannot be over emphasized**.** There are factors which are responsible for these failures which include the utilization of inferior quality and substandard steel rods.

Due to the problem as stated above a proactive measure is required as to predict material characteristic under specific loading before application of the steel rod in Engineering projects, Hence the analysis of the steel rod using finite element method provide certain parameters which aid engineers predict if failure is ineluctable or not which indicates the project is vital providing a sustainable and reliable innovative approach for failure reduction structurally as low as reasonably possible.

The aim of this research is to analyze mechanical properties of steel rods using finite element methods.

This study covers the assessment of available steel rods of diameter 12mm in Nigeria with mechanical properties such as yield strength, toughness, ductility and elongation using the universal testing machine / Tensometer.

Also, to use finite element method to determine other properties of the steel rods such as total deformation, elastic strain, stress, directional deformation and factor of safety when the rod is subjected under specific load and carry out a comparative examination of the experimental and finite element result graphically.

Nomenclatures

A_f	Final Cross-Sectional Area	mm^2
A_o	Original Cross-Sectional Area	mm^2
ASTM	American Society for Testing and Materials	
BS	British Standard	
ΔL	Extension (Change in Length)	mm
ϵ	Modulus of Elasticity	N/mm^2
ε	strain	
L_f	Final Length	mm
L_o	Original Length	mm
NBRRI	National Building and Road Research Institute	
NST	Nigerian Steel Standards	
σ	Stress	N/mm^2
P	Applied Load	N
P_B	Breaking Load	N
P_{max}	Maximum applied Load	N
P_Y	Yield Load	N

	Percentage Elongation	% E
UTS	Ultimate Tensile Strength	
YS	Yield Strength	

MATERIALS AND METHODS

Materials Adopted for the Comparative Analysis of a Steel Rod

Three samples A, B, & C of 12mm diameter steel rods were collected from three different construction sites in Nigeria. This was necessary for comparative investigation and analysis.

The mechanical properties tests were carried out at the Civil Engineering Laboratory of the Rivers State University, Port Harcourt. The yield strength, ultimate tensile strength, and percentage elongation were the properties investigated. The samples were machined to standard sizes and the tensile test was performed using a Tensometer and in accordance with ASTM A706.

A Tensometer is a device used to evaluate the tensile properties of materials such as their young modulus (i.e. the degree to which they stretch under stress) and tensile strength. It is usually loaded with a sample between two grips that are either adjusted manually or automatically to apply force to the specimen, the type used in this project is adjusted manually.

Methods Adopted in the Comparative Analysis

The steel rod samples were cut to a shape that fits the grips (jaws), most usually in the form of a dog-bone shape and great care were needed in machining the sample in order to create a smooth edge, the samples were secured at both ends and load is gradually applied until the samples breaks into two pieces, the measurements taken are plotted in a graph as the load extension curve and not the stress-strain curve, however, the stress-strain curve were calculated from the cross-sectional area and the original length of the specimen. From the curve, specific identifiable points such as elastic limit, yield point and fracture can be seen.

Experimental Analysis (Tensometer test)

Justification of the Application of Tensometer Test and its Relevance to Steel Analysis

Tensile Tests using a tensometer are performed for several reasons. The results of tensile tests with the aid of a tensometer are used in selecting quality grade steel for engineering applications in accordance to Quality Management system in ISO 9001. Tensile properties frequently are included in steel specifications to ensure quality.

The sample to be tested must fairly represent the body of steel to be applied in question. In other words, it must be from the same source and have undergone the same processing steps. Test samples must be prepared properly to achieve accurate results.

Test Set Up and Procedures

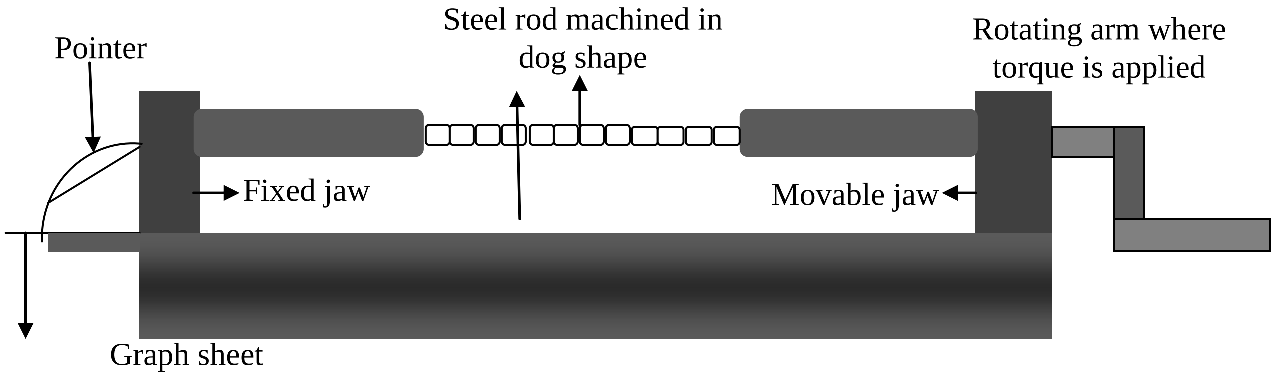


Fig. 1 Test Set Up Procedure

It is essential to note that the tensometer have similar operational principle as the iosipescu shear test fixture with both having an arm which upon rotation causes a resultant rotation of the movable jaw with specimen firmly fixed between the fixed jaw and the movable jaw; the applied torque causes a twist of the specimen till failure occurs while plotting results on the attached graph. It is essential to highlight the procedures as below:

- The steel specimen is measured with the aid of a measuring instrument and machined into the dog shape.
- The dog shape dog is fixed firmly between the jaws of the tensometer.
- A graph sheet is placed in the tensometer for recording of values while carefully ensuring there is no zero error recorded.
- Torque is applied on the arm to cause a turning effect of the specimen till failure occurs.

Theoretical Analysis

Tensile Strength and Tensile Stress

One of the most natural test of a material's mechanical properties is the tension test, in which a strip or a cylinder of the material, having length L and cross-sectional area A, is anchored at one end and subjected to an axial load P- a load acting along the specimen's long axis as shown in Figure 2.

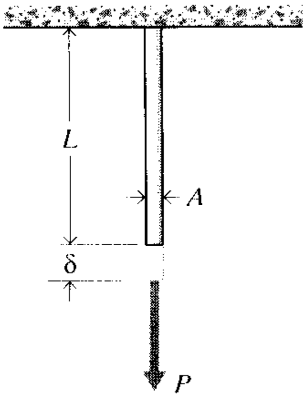


Fig. 2 The Tension Test

Many materials display linear elastic behaviour, defined by a linear stress–strain relationship, as shown in Figure 3 point 2 up to point 3.

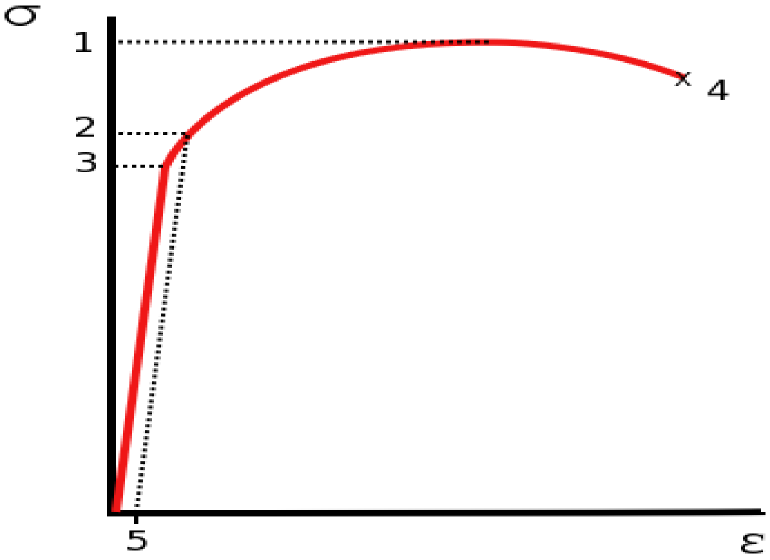


Fig. 3 The Stress-Strain Curve

Analytical Model

From the results of the mechanical test and analysis of the various specimens, the stress, strain, yield strength (YS), ultimate tensile strength (UTS), breaking strength and percentage elongation were determined employing the principles of strength of materials using the following standard structural equations:

Stress (σ) = $\frac{P}{A_o}$ (1)

Strain (δ) = $\frac{\Delta L}{L_o} = \frac{L_f - L_o}{L_o}$ (2)

Yield Strength (YS) = $\frac{P_Y}{A_o}$ (3)

Ultimate Tensile Strength (UTS) = $\frac{P_{max}}{A_o}$ (4)

Breaking Strength (BS) = $\frac{P_B}{A_o}$ (5)

Percentage Elongation (% E) = $\frac{L_f - L_o}{L_o} \times 100\%$ (6)

Percentage Reduction in Area (% R) = $\frac{A_o - A_f}{A_o} \times 100\%$ (7)

Where: P = Applied Load (N), P_{max} = Maximum applied load (N),P_Y = Yield load (N), P_B = Breaking Load (N), A_o = Original Cross-sectional Area (mm^2), A_f = Final Cross-sectional Area (mm^2), L_f = Final length (mm), L_o = original length (mm), ΔL = Extension (Change in Length) (mm).

Numerical Simulation Using Finite Element Analysis.

Nonlinear finite element analysis (NLFEA) implemented in MIDAS FEA, a commercially available finite element software was adopted. The VonMises failure criterion was adopted to model the tensile behaviour of the steel rod. The basis of Von Mises failure criterion is presented below.

Von Mises Yield Criterion.

The tensile failure of the steel bar was defined using the Von Mises yield criterion. The model is formulated on the basis that yielding occurs when a regular octahedral shear stress, τ_{oct} reaches the limit, which is formulated as,

$$f(\tau oct) = \tau oct - \sqrt{2/3}\,k \qquad (8)$$

In terms of principal stresses $\sigma 1$, σ_2 andσ_3 equation (8) can be written as,

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 6k^2 \qquad (9)$$

K denotes yield stress under pure shear

For uni-axial case

$\sigma_2 = 0\ \sigma_3 = 0$

Equation(9) reduces to

$\sigma_1^2 + \sigma_1^2 = 6k^2$

$2\sigma_1^2 = 6K^2$

$\sigma_1^2 = 3K^2$

Simulation Procedures.

The exact specimen size as shown in figure 3 was modelled. The steel bar specimen was discretized into 2921 elements and 894 nodes as shown in Figure 3.

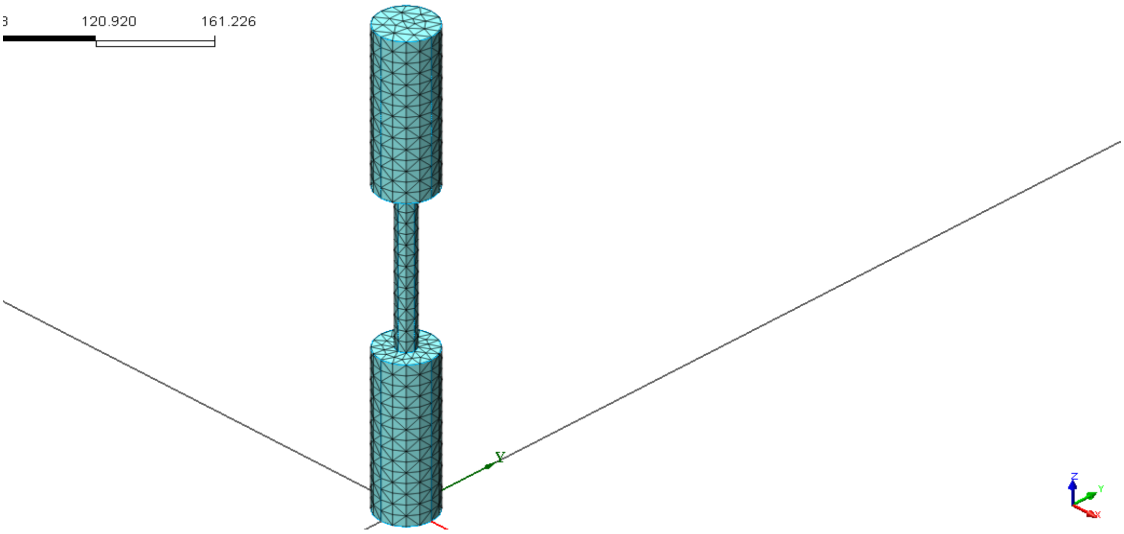


Fig. 4 The Tension Test Specimen

The specimen was modelled with 3D- solid element. The steel bar was defined using Von Mises Criterion. The material parameters used in the model is presented in Table 3.0.

Table-1 Parameters of the Modelled Material

Elastic constants	Young Modulus (N/mm^2)	Poisson's ratio	Yield Stress (N/mm^2)
	210,000	0.3	460

The yield stress measured was used to calibrate the numerical model.

Solution Phase

Solve a set of linear or non-linear algebraic equations simultaneously to obtain nodal results, such as displacement values at different nodes or temperature values at different nodes in a heat transfer system.

Therefore displacement at nodal points are

$\delta = Kg^{-1}F$ (10)

Postprocessor Phase

Obtain other important information including stress values, strain values, in some cases the magnitude of the primary unknowns, that is the nodal displacements, will be all that is required for an engineering solution. More often, however, the other quantities derived from the primary unknown like stresses, strains must be computed.

Force acting on each element is, $F_1 = K_1\delta$ (11)

Principle Governing a Steel Rod Structural Behaviour/Analysis

The hooks law of elasticity which states that except the elastic limit of a component such as the composite pipe is not exceeded the extension of an elastic component is directly proportional to the Load (P) applied. The reinforcements imbedded in the matrix of a composite pipes and the matrix obeys this principle due to subjected impacts from external and internal forces.

The stress the composite pipe is subjected to is important to analyze as it gives room for mitigations towards avoiding fatigue or failure, the expression for stress is the ratio between the external or internal force to the cross sectional area as mathematically illustrated below;

$stress\ \sigma = \frac{Force}{Area}$ (12)

Also the strain sustained as a result of deformation is of essence to identify in a composite pipe, the ratio of the deformation to the original size of the composite pipe.

$strain\ \epsilon = \frac{\Delta L}{L}$ (13)

Where ΔL = Deformation

L = Original Length

Having known the stress and the strain sustained the young modulus can be deduced as the ratio between these two criteria of failure in steel rods hence;

$E = \frac{\sigma}{\epsilon}$ (14)

From equation 7 above;

$\sigma = \frac{\Delta L}{L}E = E\epsilon$ (15)

Comparing equations above

$E\frac{\Delta L}{L} = \frac{F}{A}$ (16)

$F = AE\frac{\Delta L}{L}$ (17)

$F = \frac{AE}{L}\delta$ (18)

$[F] = [K][\delta]$

where$K = \frac{AE}{L}$(Stiffness Matrix)

Analytical Application of Stiffness Matrix to the Specimen (Steel Rod)

The primary characteristics of a finite element are embodied in the element stiffness matrix. For a structural finite element, the stiffness matrix contains the geometric and material behaviour information that indicates the resistance of the element to deformation when subjected to loading.

Linear Spring Analogy Applied to the Finite Element Analysis of the Specimen (Steel Rod)

The linear spring is employed as a method of finite element analysis as it appears homologous with the stress analysis using the finite element method. For instance recall that;

The spring force

$F = Ke$ (19)

Where K can be regarded as the stiffness and e the elongation which is similar to the deformation (δ) hence the above Equation 12 can be likened to Equation 4 which is why this approach is adopted.

A linear elastic spring is a mechanical device capable of supporting axial loading only, and the elongation or contraction of the spring is directly proportional to the applied axial load. The constant of proportionality between deformation and load is referred to as the spring constant, spring rate, or **spring stiffness k**, and has units of force per unit length. As an elastic spring supports axial loading only, we select an element coordinate system (also known as a local coordinate system) as an x axis oriented along the length of the spring, as shown.

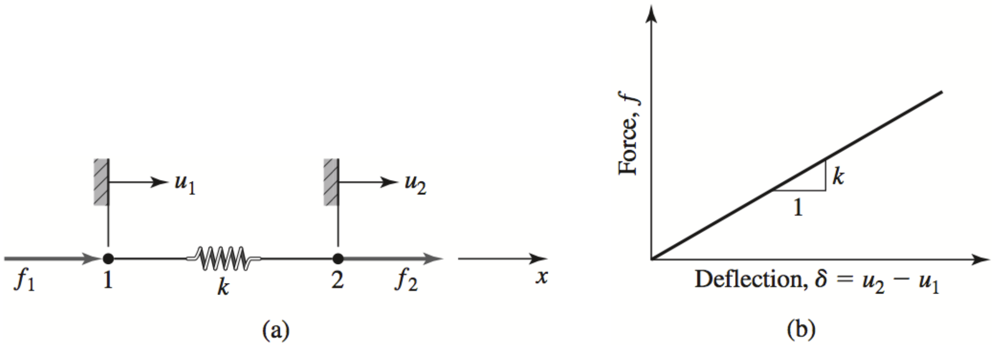


Fig. 5 Linear Spring Element with Nodes, Nodal Displacement and Nodal Force and Load Deflection Graph

Assuming that both the nodal displacements are zero when the spring is undeformed, the net spring deformation is given by

$$\delta = u_2 - u_1 \qquad (20)$$

And the resultant axial force in the spring is

$$f = k\delta = k\,(u_2 - u_1) \qquad (21)$$

For equilibrium,

$$f_1 + f_2 = 0 \text{ or } f_1 = -f_2, \qquad (22)$$

Then, in terms of the applied nodal forces as

$$\boldsymbol{f_1 = -k\,(u_2 - u_1)}$$
$$\boldsymbol{f_2 = k\,(u_2 - u_1)} \qquad (23)$$

Which can be expressed in matrix form as

$$\begin{bmatrix} k & -k \\ -k & k \end{bmatrix}\begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = \begin{Bmatrix} f_1 \\ f_2 \end{Bmatrix} \quad \text{or}$$

$$[k_e]\{u\} = \{f\}$$

where $\mathbf{k_e} = \begin{bmatrix} \boldsymbol{k} & \boldsymbol{-k} \\ \boldsymbol{-k} & \boldsymbol{k} \end{bmatrix}$ **= Stiffness matrix for one spring element**

Writing the equations for each spring in matrix form:

Superscript refers to an element in the discretized steel rod

$$\begin{bmatrix} k_1 & -k_1 \\ -k_1 & k_1 \end{bmatrix}\begin{Bmatrix} u_1^{(1)} \\ u_2^{(1)} \end{Bmatrix} = \begin{Bmatrix} f_1^{(1)} \\ f_2^{(1)} \end{Bmatrix}$$

$$\begin{bmatrix} k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix}\begin{Bmatrix} u_1^{(2)} \\ u_2^{(2)} \end{Bmatrix} = \begin{Bmatrix} f_2^{(2)} \\ f_3^{(2)} \end{Bmatrix} \qquad (24)$$

Expanding each equation in matrix form

$$\begin{bmatrix} k_1 & -k_1 & 0 \\ -k_1 & k_1 & 0 \\ 0 & 0 & 0 \end{bmatrix}\begin{Bmatrix} U_1 \\ U_2 \\ 0 \end{Bmatrix} = \begin{Bmatrix} f_1^{(1)} \\ f_2^{(1)} \\ 0 \end{Bmatrix}$$

$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & k_2 & -k_2 \\ 0 & -k_2 & k_2 \end{bmatrix}\begin{Bmatrix} 0 \\ U_2 \\ U_3 \end{Bmatrix} = \begin{Bmatrix} 0 \\ f_2^{(2)} \\ f_3^{(2)} \end{Bmatrix} \qquad (25)$$

Summing member by member

$$\begin{bmatrix} k_1 & -k_1 & 0 \\ -k_1 & k_1 + k_2 & -k_2 \\ 0 & -k_2 & k_2 \end{bmatrix}\begin{Bmatrix} U_1 \\ U_2 \\ U_3 \end{Bmatrix} = \begin{Bmatrix} f_1^{(1)} \\ f_2^{(1)} + f_2^{(2)} \\ f_3^{(2)} \end{Bmatrix} \qquad (26)$$

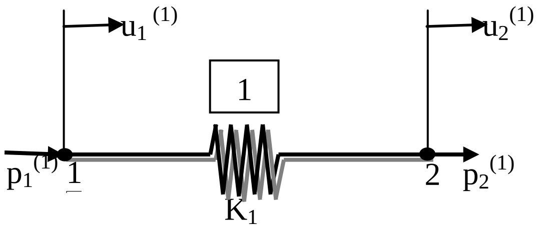
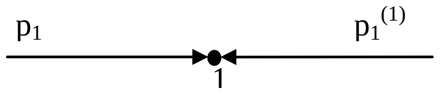
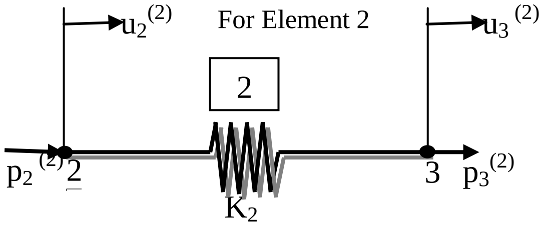
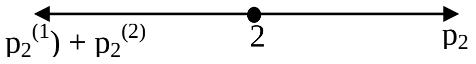
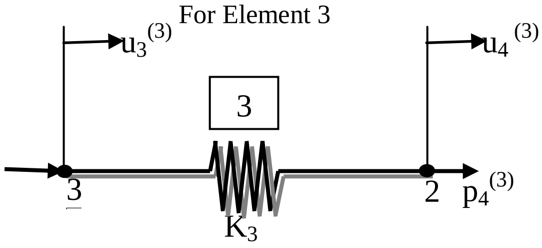
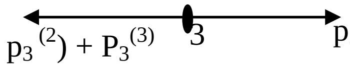
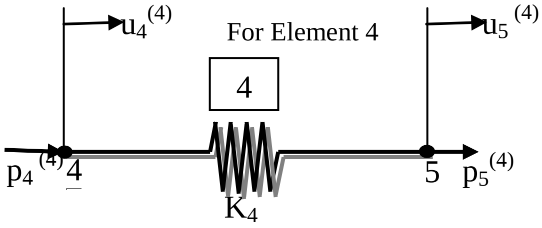
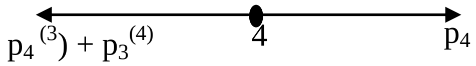
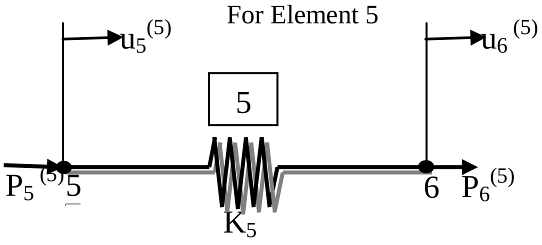
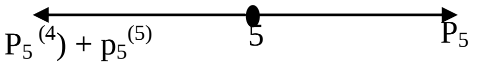
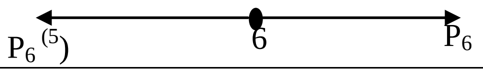
Next, we refer to the free-body diagrams of each of the three nodes

$$f_1^{(1)} = F_1 \qquad f_2^{(1)} + f_2^{(2)} = F_2 \qquad f_3^{(2)} = F_3 \qquad (27)$$

Similarly, for a five spring system with identified boundary conditions

Developing the free body diagram for each elements and maximum of two nodes as boundary conditions seen below in the table.

Table-2 Free Body Diagram for a Five Spring System

Element	**Node**
For Element 1 	For Node 1 
For Element 2 	For Node 2 
For Element 3 	For Node 3 
For Element 4 	For Node 4 
For Element 5 	For Node 5 
	For Node 6 

From the developed free body diagram; developing an equation for each of the spring elements in a 2 x 2 matrix form;
From Element 1 on the table:

$$\begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix} \begin{bmatrix} u_1^{(1)} \\ u_2^{(1)} \end{bmatrix} = \begin{bmatrix} p_1^{(1)} \\ p_2^{(1)} \end{bmatrix}$$

From Element 2 on the table:

$$\begin{bmatrix} K_2 & -K_2 \\ -K_2 & K_2 \end{bmatrix} \begin{bmatrix} u_2^{(2)} \\ u_3^{(2)} \end{bmatrix} = \begin{bmatrix} p_2^{(2)} \\ p_3^{(2)} \end{bmatrix}$$

From Element 3 on the table:

$$\begin{bmatrix} K_3 & -K_3 \\ -K_3 & K_3 \end{bmatrix} \begin{bmatrix} u_3^{(3)} \\ u_4^{(3)} \end{bmatrix} = \begin{bmatrix} p_3^{(3)} \\ p_4^{(3)} \end{bmatrix}$$

From Element 4 on the table:

$$\begin{bmatrix} K_4 & -K_4 \\ -K & K \end{bmatrix} \begin{bmatrix} u_4 \\ u_5^{(4)} \end{bmatrix} = \begin{bmatrix} p_4^{(4)} \\ p_5^{(4)} \end{bmatrix}$$

From Element 5 on the table:

$$\begin{bmatrix} K_5 & -K_5 \\ -K_5 & K_5 \end{bmatrix} \begin{bmatrix} u_5^{(5)} \\ u_6^{(5)} \end{bmatrix} = \begin{bmatrix} p_5^{(5)} \\ p_6^{(5)} \end{bmatrix}$$

Expanding each of the Equation in matrix form:

$$\begin{bmatrix} K_1 & -K_1 & 0 & 0 & 0 & 0 \\ -K_1 & K_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} p_1^{(1)} \\ p_2^{(1)} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & K_2 & -K_2 & 0 & 0 & 0 \\ 0 & -K_2 & K_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ u_2 \\ u_3 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ p_2^{(2)} \\ p_3^{(2)} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & K_3 & -K_3 & 0 & 0 \\ 0 & 0 & -K_3 & K_3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ u_3 \\ u_4 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ p_3^{(3)} \\ p_4^{(3)} \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & K_4 & -K_4 & 0 \\ 0 & 0 & 0 & -K_4 & K_4 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ u_4 \\ u_5 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ p_4^{(4)} \\ p_5^{(4)} \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & K_5 & -K_5 \\ 0 & 0 & 0 & 0 & -K_5 & K_5 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ u_5 \\ u_6 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ p_5^{(5)} \\ P_6^{(5)} \end{bmatrix}$$

Summing member by member

$$\begin{bmatrix} K_1 & -K_1 & 0 & 0 & 0 & 0 \\ -K_1 & K_1 + K_2 & -K_2 & 0 & 0 & 0 \\ 0 & -K_2 & K_2 + K_3 & -K_3 & 0 & 0 \\ 0 & 0 & -K_3 & K_3 + K_4 & -K_4 & 0 \\ 0 & 0 & 0 & -K_4 & K_4 + K_5 & -K_5 \\ 0 & 0 & 0 & 0 & -K_5 & K_5 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \end{bmatrix} = \begin{bmatrix} p_1^{(1)} \\ p_2^{(1)} + p_2^{(2)} \\ P_3^{(2)} + p_3^{(3)} \\ p_4^{(3)} + p_4^{(4)} \\ P_5^{(4)} + p_5^{(5)} \\ P_6^{(5)} \end{bmatrix}$$

ANSYS Parametric Design Language as a Material Adopted in the Stress Analysis of the Steel Rod

ANSYS which is a computer aided engineering software was used to stimulate the interactions of the composite pipe structure relative to the solid properties such as the force or pressure, heat transfer, stresses etc. The ANSYS mechanical interface uses the method of finite element analysis for its structural analysis and has been programmed adopting the above out line steps of finite element method to obtain results such as the deformation and stresses; pictorially illustrating areas of more intense stress or deformation on the steel rod and areas with minimal stress or deformation intensity when the specimen is simulated for results.

Element Type Used in ANSYS for the Analysis

The element used from the library for the analysis in ANSYS is the Axisyn 4 node 272.

Material Characterization

The following properties are generally accepted values for steel;
The young modulus E = 200KN/M
Poisson ratio $\nu = 0.3$
Weight density $\rho = 878 Kg/m^3$

Failure Criteria

The Maximum distortion energy criterion or Von mises criterion was applied in this analysis. This is so as this criterion aids engineers check weather a design will withstand certain load conditions. This theory is most suitable for ductile materials such as steel, Material response is usually linear elastic behaviour. In engineering application, the von mises yield criterion can also be formulated in terms of von mises stress σ_v; a steel start yielding when the von mises stress reaches a value known as the yield stress. Mathematically the von misses failure criterion is expressed as;

$$J_2 = k^2 \qquad (28)$$

where k is the yield stress of the steel in pure shear.

Analysis Type

The linear elastic analysis was utilized in the analysis of steel,Structural analysis of steel is concerned with the evaluation of deformation and stresses arising within a component under the action of applied load. If time is not explicitly considered as an independent variable, the analysis will be static else it is structural dynamic analysis. Under the assumption of small deformation and linearly elastic steel behaviour, three dimensional formulations result in a set of fifteen linear first order partial differential equations involving displacement field, the stress field and strain field.

RESULTS AND DISCUSSION

Test Results, Analysis and Discussion

The tensile tests as well as the mechanical properties analysis results for the three samples A, B and C are shown in Tables 3 to 12 and Figures 6 to 9, whereas, the summary of the results from the analysis is displayed in Table 12 and Figure 9.

Table 3 shows the tensile test results for the steel rod sample A. It is observed that increase in the applied loads results to a corresponding total change in lengths until the material is loaded to failure at 7500N, 7400 and 7300N for test 1, test 2 and test 3 respectively.

Table-3 Tensile Test Results for Steel Rod Sample A

Nature of Test	Test 1		Test 2		Test 3	
	Load(N)	Extension (mm)	Load(N)	Extension (mm)	Load(N)	Extension (mm)
Elastic load	5900	2.2	5800	2.0	5700	1.8
Yield load	6300	2.6	6200	2.5	6100	2.4
UTS-maximum load	7700	5.9	7600	5.8	7500	5.7
Breaking load	7500	7.2	7400	7.0	7300	6.8
Initial length (mm) L_1	21.3		21.2		21.1	
Initial diameter(mm) D_1	4.0		4.0		4.0	
Final length(mm) L_2	25.3		25.2		25.1	
Final diameter(mm) D_2	3.6		3.7		3.7	

Table 4 is a display of the tensile test results for steel rod sample B. The results show a variation in extensions for every change in load. It indicates the maximum load the materials could bear before rupture as 8100N, 8000N and 7900N for test1, test 2 and test 3 respectively.

Table-4 Tensile Test Results for Steel Rod Sample B

Nature of Test	Test 1		Test 2		Test 3	
	Load(N)	Extension (mm)	Load(N)	Extension (mm)	Load(N)	Extension (mm)
Elastic load	6100	3.8	6000	3.6	5900	3.4
Yield load	6500	4.0	6300	3.8	6100	3.5
UTS-maximum load	8100	7.0	8000	6.8	7900	6.6
Breaking load	7900	9.0	7700	8.8	7500	8.6
Initial length (mm) L_1	22.5		21.5		20.5	
Initial diameter(mm) D_1	4.3		4.3		4.3	
Final length(mm) L_2	26.4		25.5		25.3	
Final diameter(mm) D_2	4.0		3.9		3.6	

Table 5 is the tensile test results for steel rod sample C. It shows a direct proportional relationship between applied loads and extensions. The % difference between the yield load and breaking load is 33.3% with a corresponding extension of 4.0mm.

Table-5 Tensile Test Results for Steel Rod Sample C

Nature of Test	Test 1		Test 2		Test 3	
	Load(N)	Extension (mm)	Load(N)	Extension (mm)	Load(N)	Extension (mm)
Elastic load	4600	2.8	4700	2.9	4800	3.0
Yield load	4800	3.0	4900	3.1	5000	3.2
UTS-maximum load	6600	6.0	6700	6.1	6800	6.2
Breaking load	6400	7.0	6500	7.1	6600	7.2
Initial length (mm) L_1	22.4		22.4		23.0	
Initial diameter(mm) D_1	4.2		4.2		4.2	
Final length(mm) L_2	23.3		23.3		24.1	
Final diameter(mm) D_2	4.0		3.9		3.9	

Table 5 whose plot is shown in Figure 6 shows the tensile test analysis for steel rod sample A. The results obtained indicate, values of 461.45N/mm^2, 493.32N/mm^2, 604.71N/mm^2 and 588.80N/mm^2 for elastic limit, yield strength, ultimate tensile strength and breaking strength respectively with 18.87% percentage elongation and 15.96% percentage reduction in area.

Table-6 Tensile Test Analysis for Steel Rod Sample A

Nature of strength	Test 1	Test 2	Test 3	Average
Elastic Limit (N/mm^2)	469.45	461.49	453.53	461.49
Yield strength, YS(N/mm^2)	501.27	493.32	485.36	493.32
Ultimate tensile strength, UTS(N/mm$^{2)}$	612.67	604.71	596.75	604.71
Breaking strength (N/mm^2)	596.75	588.80	580.84	588.80
% Elongation (%E)	18.78	18.87	18.96	18.87
% Reduction in Area (%)	19.00	14.44	14.44	15.96

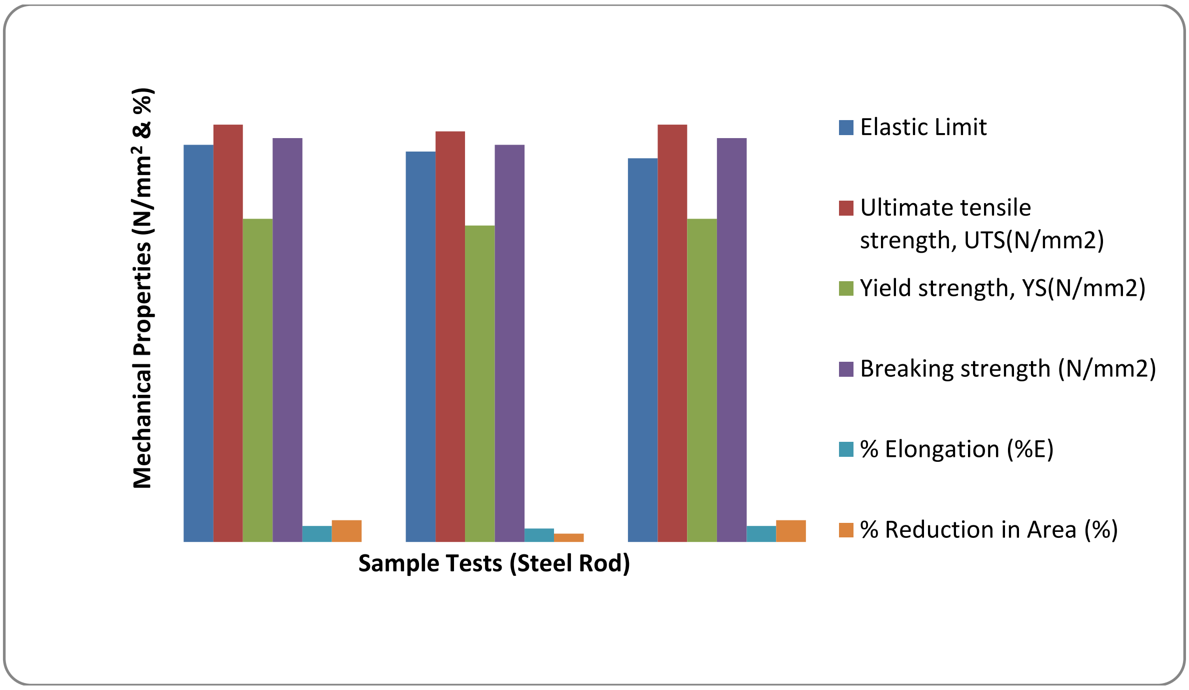


Fig. 6 Tensile Test Analysis for Steel Rod Sample A

From Table 5 plotted on Figure 7 shows the tensile test analysis for the steel rod sample B. It indicates the average values of the different mechanical properties. It is observed that the material yielded at a stress value of 437.10N/mm^2 which causes a permanent set of 19.79% reduction in cross-sectional area.

Table-7 Tensile Test Analysis for Steel Rod Sample B

Nature of strength	Test 1	Test 2	Test 3	Average
Elastic Limit (N/mm^2)	420.00	413.11	406.22	413.11
Yield strength, YS(N/mm^2)	477.53	443.77	420.00	473.10
Ultimate tensile strength, UTS(N/mm$^{2)}$	557.70	550.81	543.93	550.81
Breaking strength (N/mm^2)	543.93	530.16	516.39	530.16
% Elongation (%E)	17.33	18.61	23.42	19.79
% Reduction in Area (%)	13.47	17.74	29.91	20.37

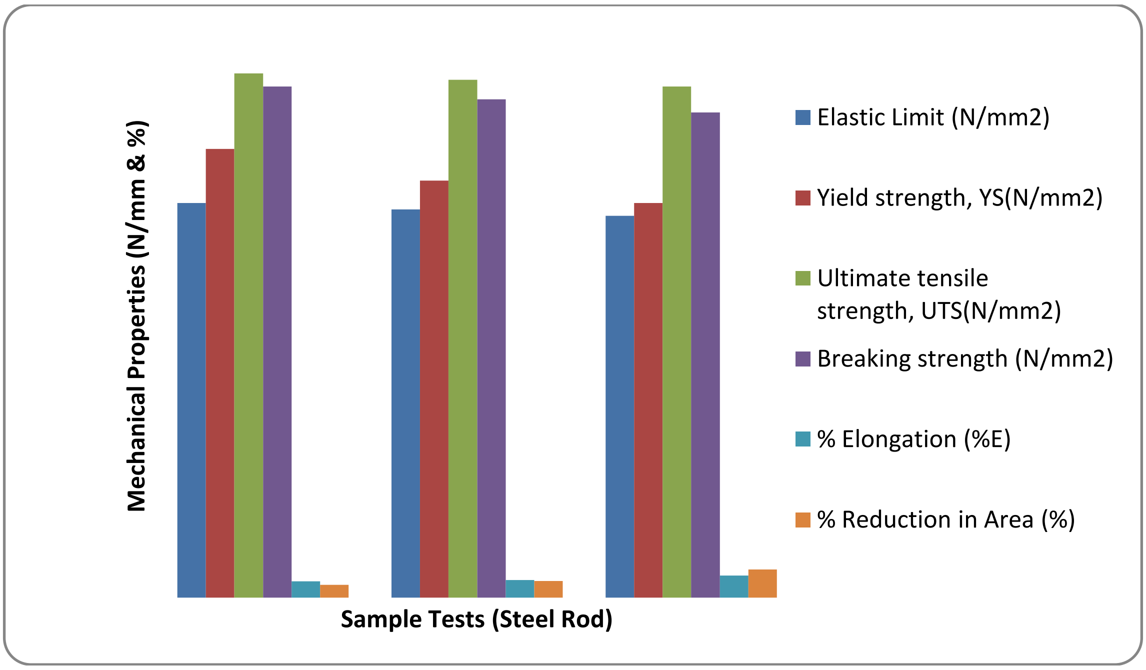


Fig. 7 Tensile Test Analysis for Steel Rod Sample B

Table 6 whose plot is shown in Figure 8 is a display of the tensile test analysis for the steel rod sample C. The numerical average values of the proportional stress limit, yield strength, ultimate tensile strength and breaking strength are 339.20kmN/mm^2, 352.64N/mm^2, 483.55N/mm^2 and 469.11N/mm^2 respectively and also determined as 4.27% and 13.74% respectively.

Table-8: Tensile Test Analysis for Steel Rod Sample C

Nature of strength	Test 1	Test 2	Test 3	Average
Elastic Limit (N/mm^2)	331.99	339.20	346.42	339.20
Yield strength, YS(N/mm^2)	346.42	353.64	360.86	353.64
Ultimate tensile strength, UTS(N/mm$^{2)}$	476.33	483.55	490.76	483.55
Breaking strength (N/mm^2)	461.90	469.11	476.33	469.11
% Elongation (%E)	4.02	4.02	4.78	4.27
% Reduction in Area (%)	9.30	13.78	18.14	13.74

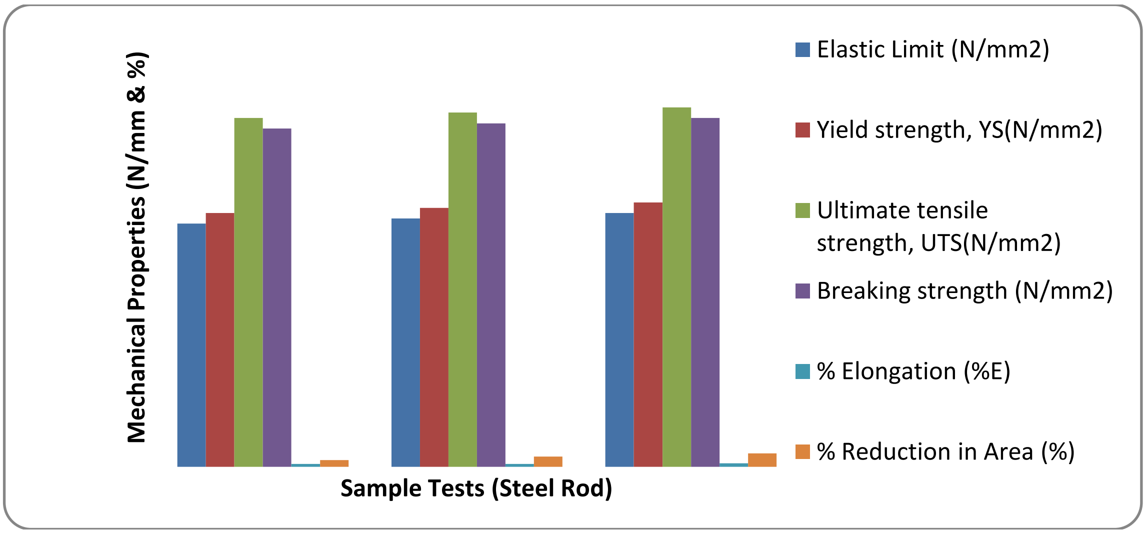


Fig. 8 Tensile Test Analysis for Steel Rod Sample C

Tables 7, 8, 9 displayed on Figures 6, 7, 8 show the mechanical properties test results indicating the stress-strain relationship. It is observed that there is a direct proportional relationship between the stress and strain values from the elastic limit to the UTS in line with Hooke's law.

After the UTS, there is a decline in stress value accompanied with a sharp increase in the extension. This results from the visible decrease in diameter with an increase in length over a localized segment of the steel. This necking progresses rapidly until the steel suddenly ruptures at 588.80N/mm^2, 530.16N/mm^2 and 469.11N/mm^2 for sample A, B, and C respectively.

Table-9 Mechanical Properties Test Result for Steel Rod Sample A

Nature of strength	**Diameter (d) mm**	**Original Length (L_o) mm**	**Extension (ΔL) mm**	**Stress (σ)** (N/mm^2)	**Strain (ε)**
Elastic Limit (EL)	4.00	21.20	2.00	461.49	0.09
Yield strength (YS)	4.00	21.20	2.50	493.32	0.12
Ultimate tensile strength (UTS)	4.00	21.20	5.80	604.71	0.27
Breaking strength	3.70	25.30	7.00	588.80	0.28

Table-10 Mechanical Properties Test Result for Steel Rod Sample B

Nature of strength	**Diameter (d) mm**	**Original Length (L_o) mm**	**Extension (ΔL) mm**	**Stress (σ)** (N/mm^2)	**Strain (ε)**
Elastic Limit (EL)	4.20	21.50	3.60	413.11	0.17
Yield strength (YS)	4.20	21.50	3.80	437.10	0.18
Ultimate tensile strength (UTS)	4.20	21.50	6.80	548.52	0.32
Breaking strength	3.80	25.70	8.80	530.16	0.34

Table-11 Mechanical Properties Test Result for Steel Rod Sample C

Nature of strength	**Diameter (d) mm**	**Original Length (L_o) mm**	**Extension (ΔL) mm**	**Stress (σ)** (N/mm^2)	**Strain (ε)**
Elastic Limit (EL)	4.20	22.60	2.90	339.20	0.13
Yield strength (YS)	4.20	22.60	3.10	353.64	0.14
Ultimate tensile strength (UTS)	4.20	22.60	6.10	483.55	0.27
Breaking strength	3.90	23.60	7.10	469.11	0.30

Table 12 displayed in Figure 8 is a summary of the results of the mechanical properties analyses for the three samples A, B and C as compared with universally acceptable standards which include BS 4449, 1997, ASTM A706, and NsT. 65-Mn.

The results of the analysis of mechanical properties (UTS, YS and % E) are 604.71N/mm^2, 493.32N/mm^2 and 18.87 respectively for sample A; 550.81N/mm^2, 437.10N/mm^2 and 19.79% respectively for sample B; and 483.55N/mm^2, 353.64N/mm^2 and 4.27% respectively for sample C. These values are compared with the internationally acceptable values from the British Standard Institution BS 44449 of 600.00N/mm^2, 460.00N/mm^2 and 12% respectively, the American Society for Testing and Materials (ASTM) standard with values of 580.00N/mm^2, 415.00N/mm^2 and 10% and the Nigerian Steel Standards NST.65-Mn with values of 600.00N/mm^2, 353.64N/mm^2 and 14% for UTS, YS and % E respectively.

The result from the comparison shows that for UTS only sample A with values 604,71N/mm^2 meets up the required standard. For YS, Sample A and B with values of 493.32N/mm^2 and 437.10N/mm^2 meet up the standard while sample C with 353.64N/mm^2 falls below standard.

For % E, all the three samples are within acceptable range of standards. These results therefore imply that only Sample A will be acceptable in the international community where standards are respected and adhered to.

Table-12 Summary of Test Results as Compared with International Standards

Standards/Samples	**UTS(N/mm^2)**	**YS(N/mm^2)**	**%E**
BS 4449	600.00	460.00	12.00
ASTM A706	580.00	415.00	10.00
NST.65-Mn	600.00	420.00	14.00
SAMPLE A	604.71	493.32	18.87
SAMPLE B	550.81	437.10	19.79
SAMPLE C	483.55	353.64	4.27

Source: Awofadeju *et al*., 2013; BS 4449 (1997); ASTM A706 (1994); NST.65-Mn (1994)

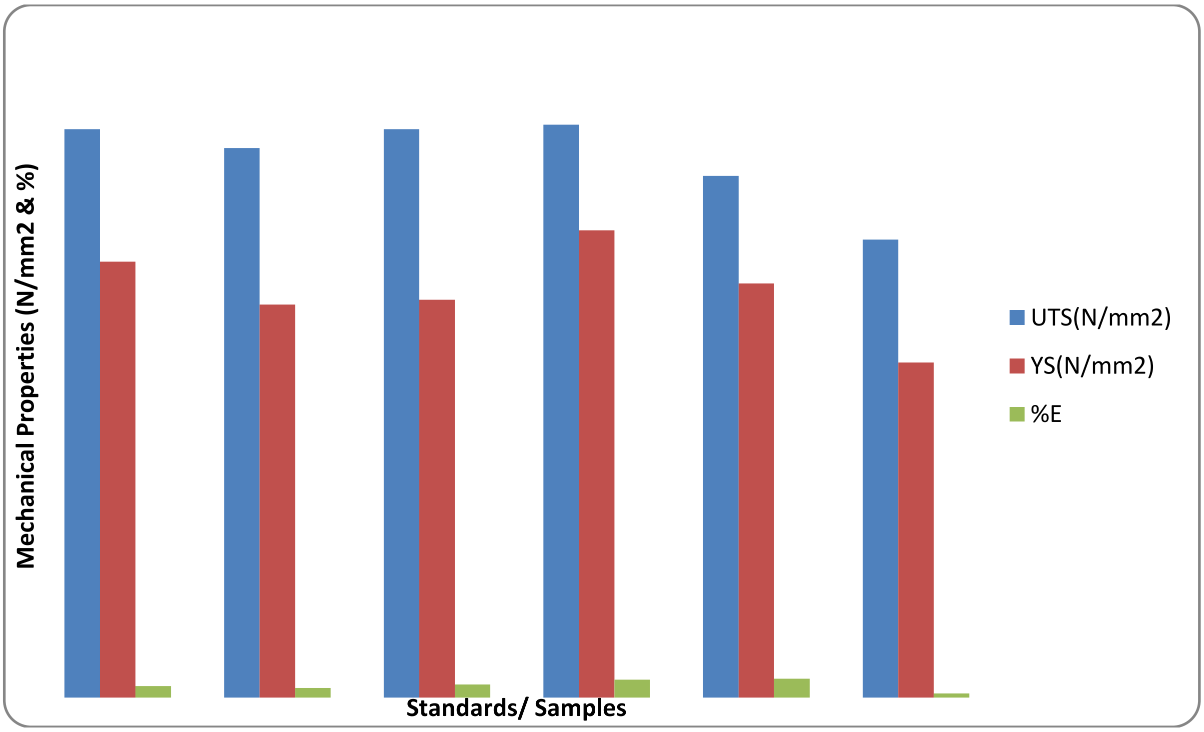


Fig. 9 Summary of Test Results in Comparison with International Standards

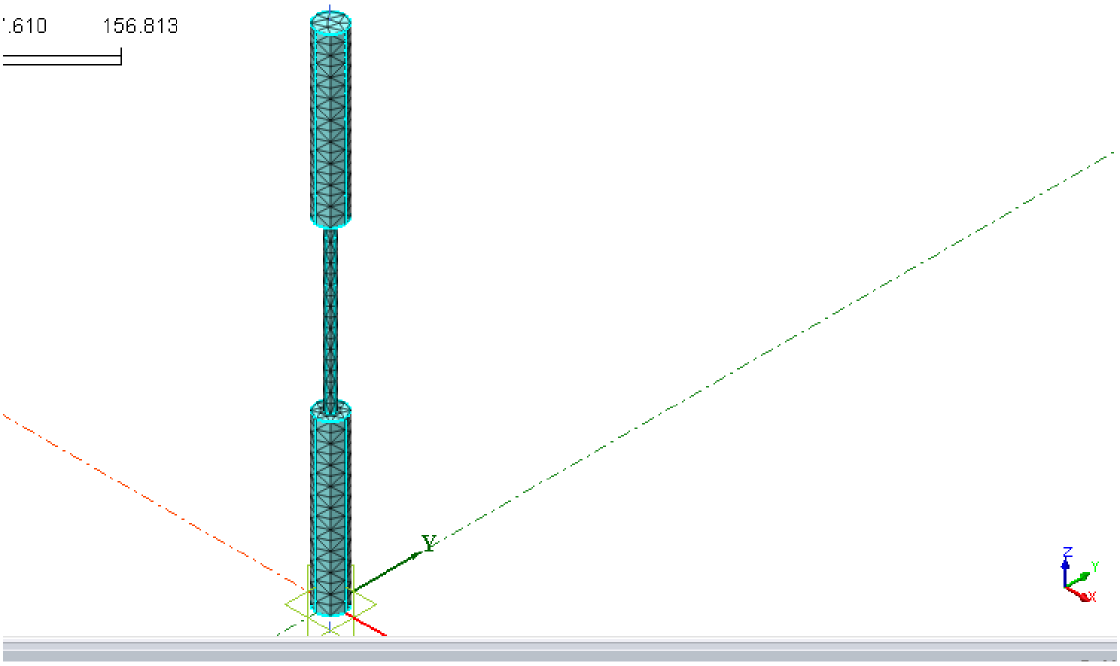


Fig. 10 Finite Element Analysis (FEA) Model of Steel Rod

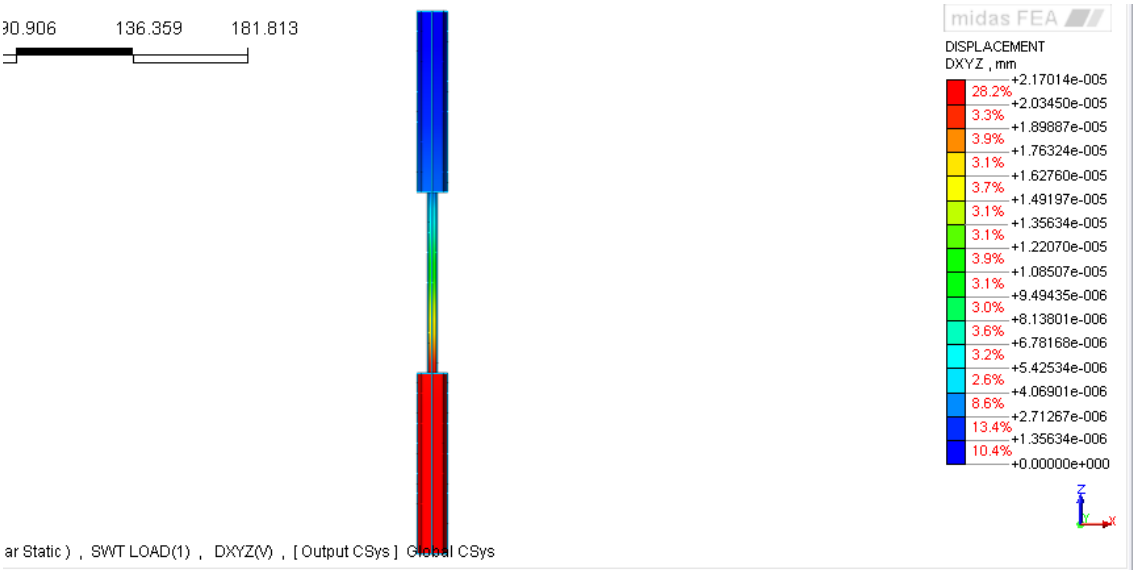


Fig. 11 Displacement contour for Steel Rod

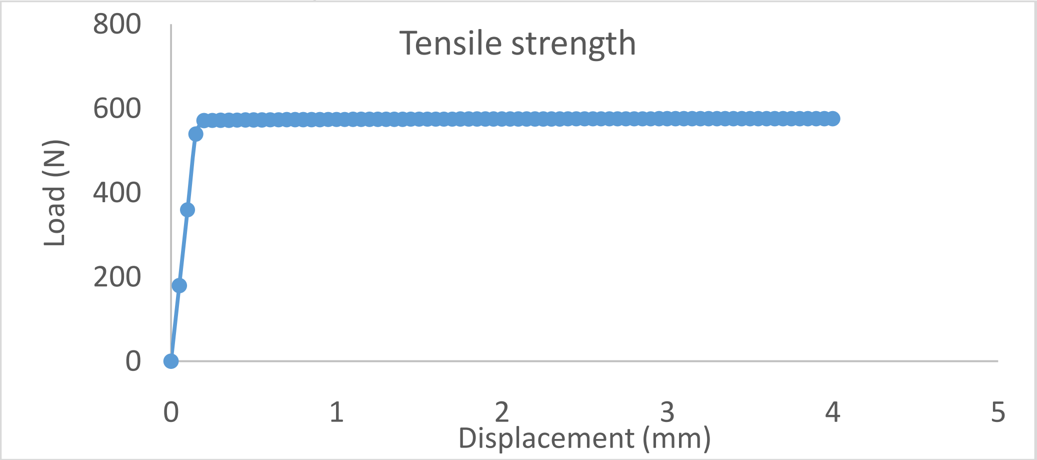


Fig. 12 Load – Displacement Curve for Steel Rod

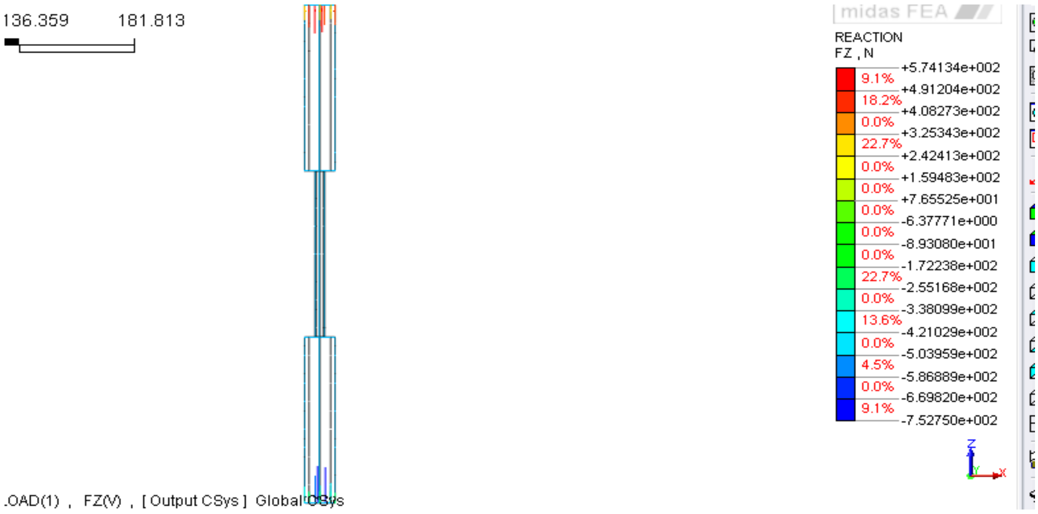


Fig. 13 Force Contour for the Steel Rod

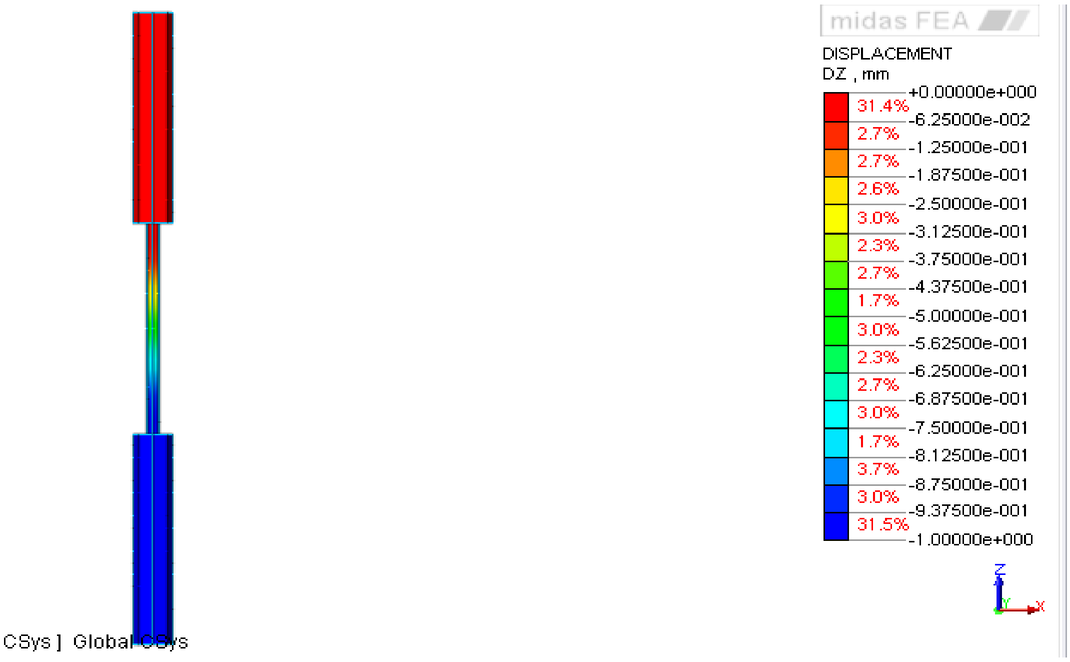


Fig. 14 Displacement Contour Steel Rod

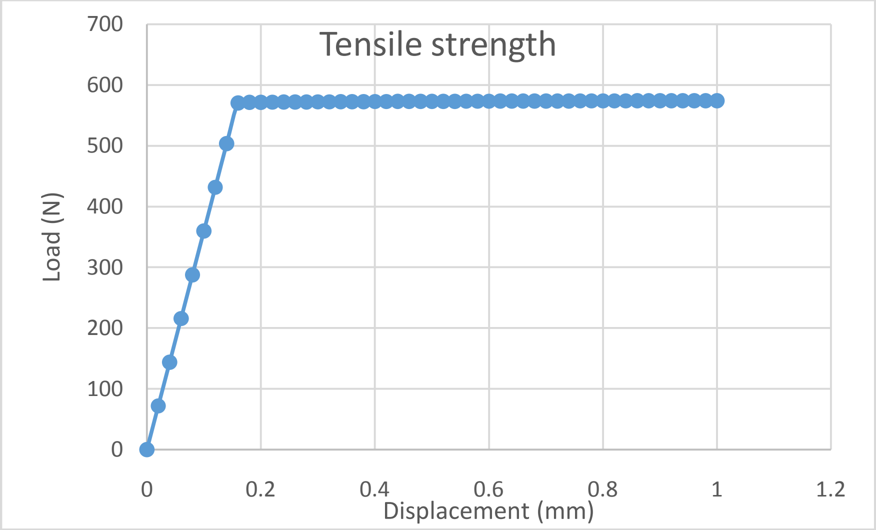


Fig. 15 Load – Displacement of Steel Rod.

The above simulation is aimed at studying the behaviour of the 12mm steel rod under varied forces in other to optimize the permissible stress within this force range as illustrated above, the steel rod is fixed at one end with a load applied on the other end for ease and precision of analysis. It is quickly evident that the steel rod under both selected load exhibited similar structural characteristics with areas of more force intensity indicated duly. From Figure 8 above, a 7500N load applied yielded a maximum deformation of 0.0073808mm with its minimum indicating no deformation along a specific cross section of the rod. Also areas with high and minimal load effect are indicated along the cross section of the bar. This deformation of the steel rod under the 4600N rod as earlier mention has similar characteristics with that of the 7500N applied force with maximum deformation value of 0.038805mm. Also the equivalent strain, equivalent stress and the factor of safety of the steel pipe under the 7500N load are seen in Figure 9, Figure 10 and Figure 12 with their maximum and minimum values duly indicated and that of the 4600N on the steel rod exhibited similar characteristics as earlier mentioned.

The external work done on the steel rod by virtue of the applied load in causing the steel member to distort form its unstressed state is transformed into stain energy, hence the strain energy which is seen as the energy stored in the steel rod under the applied load is also considered in the analysis. Fig 13 shows the strain energy of the steel rod under a 4600N load with its point of maximum and minimum strain energy density indicated as above. Along the cross section of the pipe a 0.0066002 and 0.0053257 were the predominant energy stored in the steel rod due to deformation. A close look at the experimental result indicates conformity with the hooke's law and most internationally accepted standards with obtained structural parameters duly ascertained and indicating that. In similar vein, the simulated results of the model conform to this law as that of the experimental result with both structural properties exhibiting similar characteristics as seen in their rate of deformation of both results.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The mechanical properties of 12mm diameter of Steel rods from three different construction sites in Nigeria were investigated and the level of conformity was evaluated with relevant local and international standards which include BS 4449, 1997, ASTM A706, and NsT. 65-Mn.

Only one (Sample A) out of the three samples investigated meets the international standards used in benchmarking with values of 604.71N/mm^2, 493.32N/mm^2 and 18.87% as compared with the minimum international standard of 580.00N/mm^2, 415.00N/mm^2 and 10.00% for UTS, YS and %E. Sample B is closely related to the minimum international standard above with values of 550.81N/mm^2, 437.10N/mm2 and 19.79% respectively while Sample C completely exhibit a strange behaviour as the values of 483.55N/mm^2, 353.64N/mm^2 and 4.27% deviates greatly from the minimum standard generally acceptable.

The result of the analysis of the three samples steel rods from the three different construction sites therefore shows that only 33% of materials used for structural purposes met up with the international standard in terms of mechanical properties. This calls for a close attention/monitoring of the steel rod manufacturing industries and marketers in the country since steel rods have been identified as one of the important materials used for construction works in virtually all sectors of the economy.

Hence from the above conducted analysis it is of essence in engineering practise and before and project which involves utilizing materials such as steel should be properly investigated; the structural reliability should be properly examined before application to prevent failure and structural collapse, early fatigue, adhesive and abrasive wear. An awareness on this practise should be conducted to enlighten young engineers of the vitality of this analysis as indicated within the frame of this project.

Recommendations

1. The Federal government and the private sector should jointly encourage further research into causes of structural failures in buildings and standardization of local construction methods in respect of unique traditional building materials available in Nigeria.
2. Technical education should be encouraged by both the Government and the private sectors, so as to ensure training of competent skilled labour for building industry in Nigeria.
3. Also, since we know that the steel manufacturing industries have been identified as one of the most important sectors that dictate the level of economic development of any nation coupled with the fact that the role iron rod play in building collapse cannot be under emphasized, then Government should as a matter of urgency introduce a strict measure in complying with the standards and quality of the iron rod being produced from our steel manufacturing industries.
4. All the professional bodies associated with the building industry in Nigeria, such as Nigerian Institute of Architects (NIA), Architect Registration Council of Nigeria (ARCON) and Nigerian Society of Engineers (NSE) as well as Council of Registered Engineers (COREN) should find a way of curbing, if not to stop quarks

operations in building industry and also work hand in hand with the Government to ensure that the culprit face the wrath of the law.

REFERENCES

[1]. J Akinpelu, The need for code of conduct, building regulations and by-laws for the building industry in Nigeria,*The Professional Builder, Nigeria institute of Building*, **2002**, 11-14.

[2]. D Allen, *Metallurgy, Theory and Practice*, American Technical Society, Chicago, **1979**.

[3]. A M Apostolopoulos, Structural Integrity of steel Bars Under Seismic Loads, *Material Physics and Mechanic, Institute of Problems*, **2015**, 22-29.

[4]. C Arum, Verification of properties of concrete reinforcement bars: Nigeria as a case study, *African Research Review Journals*, **2008,** 2 (2).

[5]. M J Ashby, *Engineering Materials I: An Introduction to their Properties and Applicatons,* 2nd Edition,Butter Worth Heineman, MG book ltd., Cirnwall, Great Britain, **1990.**

[6]. ASTM Standards, *Metals, Test Methods and Analytical Procedures, Metals – Mechanical Testing; Elevated and Low – Temperature Tests; Metallography*; 3 (1), A706 **(1990).**

[7]. British Standards Institutions,*Carbon Steel Bars for the Reinforcement of Concrete*. London, 1-17BS4449 (**1997**).

[8]. W D. Jr. Callister, *Material Science and Engineering: An Introduction*, John Wiley and Sons Inc., New York, **1997,** 108- 133, 199 – 202.

[9]. O Chinwokwo, The role of professional in Averting Buildng collapse. *In: Proceedings of 2-days seminar of NIOB(Lagos state chapter) on Building collapse, Preventon and Remedies,* Lagos, **2000**.

[10]. A. N. Ede, Measures to Reduce the High Incidence of Structural Failures in Nigeria, *Sustainable Development in Africa,* **2011**, 13 (1).

[11]. S O Folagbade, Case Studies of building collapse in Nigeria," D.R. Ogunseemi, eds., *Proc. of Nigerian Institute of Building Conf. held at Ondo State, Nigeria on Building Collapse: Causes, Prevention, and Remedies,* **2002,** 110-121.

[12]. K B Grong, *Effect of Alloying Elements in Steel*, **1986**, 27 – 48.

[13]. G T Hall, *Revision Notes on Building Maintenance and Adaptation,* Butterworths and Co., England, **1984**.

[14]. R W Hertzberg, *Deformation and fracture mechanics of engineering materials,* Wiley, New York, **1976**.

[15]. J F Knott, *Fundamentals of fracture mechanics*, John Wiley- Halsted press, New York, **1973**.

[16]. W Kumalasari and C H Fabian, Study of Recent Building Failures in United States, *Performance of Constructed Facilities ASCE,* **2003,** 17 (3), 144–150.

[17]. M Kutz, *Role of Alloying Elements in Steel, Hand Book of Materials Selection*, Kutz Myer Associates, John Wiley and Sons Inc., **2002,** 45 – 65.

[18]. K Leet and D Bernal, *Reinforced Concrete Design,*3rd Edition, The McGraw-Hill Companies Inc., New York, **1997,**1 – 36.

[19]. Limbrunner and Spiegel, *Applied Statics and Strength of Materials,* **2009.**

[20]. Mathey and Watstein, *Engineering Experiment on steel grades and Applications*, West Press Ltd, Manitoba, **1961.**

[21]. R Makinde, *Building collapse in Nigeria, A workshop paper on building collapse, Nigerian Institute of Building, Osun State Chapter,* Osun, Nigeria, **1998**, 22-24.

[22]. A K Marmi, A M Habraken andL Duchene, Multiaxial fatigue damage modelling at macro scale of Ti-6Al-4V alloy, *International Journal of Fatigue,* **2009**, 31, 2031-2040.

[23]. J Neil and K D Ravindra, *Civil Engineering Materials*, Macmillan Press Ltd, HongKong, **1996,** 187.

[24]. Nigerian Standard, *Raw Materials and Specifications for Federal Government Steel Companies,* 1st Edition, NST.65-Mn. (**1994**).

[25]. S O Nwabuokei, *The Nigerian Steel Industry*, Delta Steel Experience, **2007**, 35.

[26]. R E Olagunju,S C Aremu and J Ogundele, Incessant Collapse of Buildings In Nigeria: An Architect's View, *Civil and Environmental Research*, **2003**, 3(4).

[27]. O T Olateju, The need for quality control in the Nigeria's building industry. *Journal of Studies in Environmental Design in West Africa,* **1993**, 10, 22-25.

[28]. R. E. Peterson, Discussion of a century ago concerning the nature of fatigue, and review of some of the subsequent researches concerning the mechanism of fatigue, *ASTM Bulletin, American Society for Testing and Materials*, **1950**, 164, 50-56.

[29]. W M K Roddis, Structural Failures and Engineering Ethics, *American Society of Civil Engineering (Structural Div.),* **1993**, 5 (119), 1539-1555.

[30]. S. Timoshenko, Stress concentration in the history of strength of materials, *The William M. Murray Lecture,* SESA, **1995**, 12, 1-12.

[31]. C M Sonsino, Fatigue design of high loaded PM parts, *Metal Powder Report*, **1996,** 51(6), 36-45.

APPENDIX A
SPRING SYSTEM

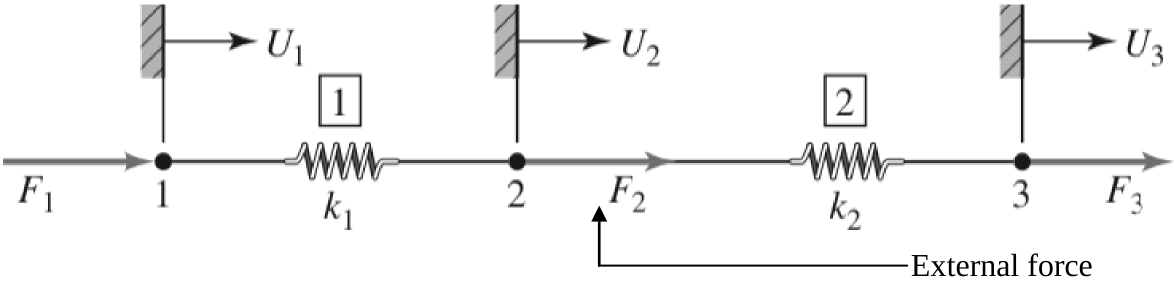


Fig. 16 Two Spring System

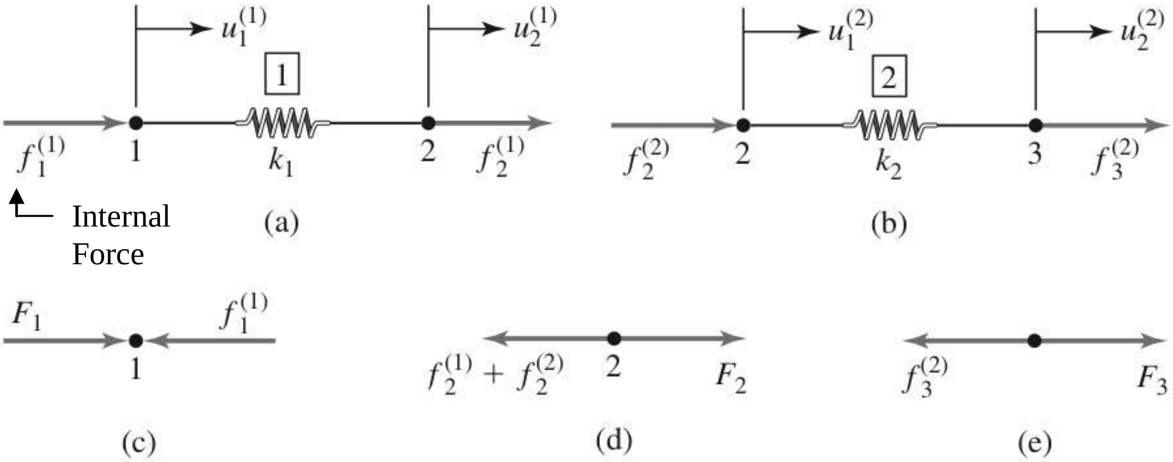


Fig. 17 Free Body Diagram