

Development and Finite Element Analysis of a Cantilever Beam Apparatus used in Strength of Materials Laboratory

ALIEMEKE, B. N. G. EHIBOR O. G.
Department of Mechanical Engineering, Auchi Polytechnic, Nigeria
[1]aliemekebng@auchipoly.edu.ng, [2]gregotech2007@gmail.com

Abstract
The development of a cantilever beam apparatus for the teaching of undergraduates students in Strength of Materials laboratory is successfully presented. This development of the laboratory apparatus is targeted at building a local content in the production of equipment. It tends to eliminate the dependence on foreign technology which appears to be challenging in the face of scarce foreign exchange. The laboratory apparatus was designed using engineering formulae to determine the maximum bending moment, maximum shear stress, factor of safety and the Von Misses stress of the beam to be749.95Nm, 11.26Mpa, 2.36 and 112.28Mpa respectively. The apparatus was designed to have a strength to weight ratio of 5.3Mpa/N. A graphical modeling was carried out using AutoCAD and Finite Element ANSYS Workbench which yielded an equivalent Von Misses stress of the apparatus to be 115Mpa.
Keywords: Cantilever beam, apparatus,Von Misses stress, finite element and materials
DOI: 10.7176/JIEA/13-1-01
Publication date: February 28th 2023

1. Introduction

Cantilever beam apparatus basically test for shearing forces, bending moments, support reactions and deflection angle on materials. It is necessarily applied in determining the ability of material to withstand various stresses inherent in the field of engineering (Tarsicio , Cristian & Augusto, 2003). The beam apparatus consist of steel beam, angle bars, steel ruler, weights, dial gauge and deflection indicator. The structural members offers resistance to the applied load directed sideways along the path of the beam. Cantilever beams can be referred to as a kind of structural support fixed at one end and free at the other end. They are mainly horizontal in placement and consist of either concrete or steel materials. This laboratory equipment is rigid in nature and often subjected to vertical loading and force application (Vinod & Ajit, 2015).

A cantilever beam may be subjected to various kind of loadings which includes uniform, point load and varying loads (Srivathsan,2019). This has made it possible to understand the format of the materials by simulation of the components in an ANSYS software so as to understands its ability to withstand various loads during application. The strength of engineering materials is often determined by their ability to withstand tensile, compressive and fatigue stresses (Cui & Roven, 2015). The construction of a Cantilever beam apparatus in our laboratory is necessary in ensuring that the study of materials applications is given a boost in terms of information, quality control and general engineering practice. The application of the requisite knowledge in the elastic and plastic behaviour in steel has contributed in greatly to the usage of the material in the automotive and building industries in supporting quality control experts in assessing the standard of the materials deployed to building sites and their form of application (Olufemi & Ademola, 2018).

In engineering practice today, there exists few locally produced laboratory equipment that is readily applied in the study of materials science. The imported material testing machines are expensive, rarely available and beyond the reach of poor researchers. In a bid to promote local content it will be important to resort to locally produced engineering materials and machines. This will certainly attract foreign investment and global attention (Shashidar, Ravishankar, & Padmayya, 2018).

The development of a Cantilever beam apparatus in our laboratory is a necessary step to ensuring that the study of materials applications is given a boost in terms of information, quality control and general engineering practice (Vinod & Ajit, 2015). The application of the requisite knowledge in the elastic and plastic behavioural pattern in steel has contributed in no small measure to the usage of the material in the automotive and building industries in helping quality control experts in assessing the standard of the materials deployed to building sites and their form of compliance and application

In Nigeria today, there exist few locally produced laboratory equipment that is readily applied in the study of strength of engineering materials. The commercial material testing machines are expensive, rarely available and beyond the reach of the researchers. In a view to promote local content it will be pertinent to resort to made-in-Nigeria engineering materials and machines. This will certainly bring about a boost in our national growth (Aliemeke, Okwudibe, & Ehibor, 2022).

The inability to develop local content in the design and construction of relevant laboratory equipments has been a major challenge in Nigerian research world. Some of the commercial available laboratory equipments come with incomprehensive manuals and numerical codes which are difficult for our technologists to comprehend. All these have adverse effect on the rate of technology transfer (Aliemeke *et al*, 2022). This present study will address this shortcomings by developing indigenous capacity.

The aim of this research is to develop a cantilever beam apparatus applied in strength of materials laboratory in Nigeria. The study will promote indigenous capacity in the development of a cantilever beam apparatus used in the strength of materials laboratory .

2. Materials and Methods

The Cantilever beam apparatus which comprises of a base frame, steel meter rule, dial gauge, frame support and strain gauge was fabricated in the Department of Mechanical Engineering workshop, Auchi Polytechnic, Auchi.

2.1 Component parts of the beam apparatus

2.1.1 *Base frame*

The cantilever beam apparatus consist of a mild steel base which measures 1000mm × 450mm in area with a thickness of 70mm. The base frame acts as a support to other components of the apparatus. The frame is made of mild steel angle bar and sheets.

2.1.2 *Dial gauge*

The Dial gauge is an instrument that indicates the deflection obtained during experimentation. It is placed in between the scale rule and the base frame. The gauge measures 0.25mm in every 0.1mm division (Buliaminu, 2012)..

2.1.3 *Dial gauge support*

The support are linkages which holds the gauge firmly to the metallic base. It ensures that the dial gauge is positioned in a way and manner to sense the required deflection.

2.1.4 *Cantilever test beam*

The cantilever test beam is a vertical rigid support attached by mechanical joining to the base frame. The test beam offers a platform for the scale rule. It is made up of mild carbon steel or corrosion resistant stainless steel.

2.1.5 *Steel Scale rule*

The measuring device is clamped to the test beam so as to effectively bear the load hanger and the variable loads. The 1m steel rule is graduated in mm

2.1.6 *Load hanger*

The beam apparatus is fitted with hanger which bears the variable loads that causes the requisite deflection. The hanger is made of a steel material fitted with a sensor or cursor to sense accurate positioning and the effect of a load which in turn produces deflection that is noticed on the dial gauge.

2.1.7 *Beam clamp*

The beam clamp located at the top of the cantilever beam ensures that the steel rule is firmly attached to the vertically erected beam. It is made up of steel.

2.2 Design specification

The design specifications applied in our course of study are:
Density of mild steel=7700kg/m^3
Ultimate tensile strength of steel=400Mpa
Yield strength of steel=270Mpa
Acceleration due to gravity=9.81m/s^2

2.3 Design for maximum shear force and bending moment

The free body, maximum shear force and the bending moment diagrams are shown in Fig1. The free body diagram of the cantilever beam apparatus has overhang weights of 750N and 250N at 0.667m and 1.0m from point A.

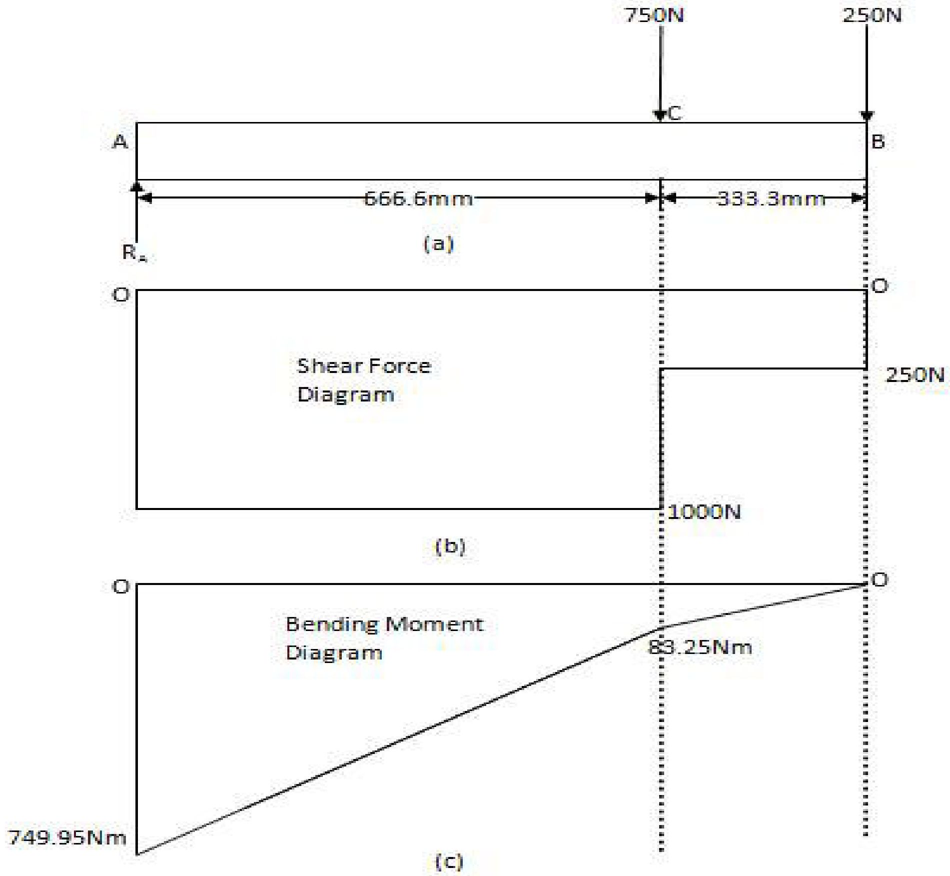

Fig. 1: The shearing force and Bending Moment diagram of the Cantilever beam apparatus

Since $$\sum F_y = 0 \quad (1)$$

Where Fy = vertical forces

From equation (1) the reaction at point A, R_A in Fig. 1is 1000N.

The bending moment at point B, M_B=0

The bending moment at point C, M_C in Fig. 1, is M_C=250×0.333=83.25Nm

While the bending moment at point A, M_A in Fig. 1c is M_A=250×1.0+750×0.667=749.95Nm.

Also the maximum shear force as shown in Fig. 1 is 750N.

2.4 Design for Von Misses Stress

The Von Misses stress was calculated using equation (2) obtained from (Buliaminu, 2012).

$$\sigma_v = \sqrt{\sigma_m^2 + 3\tau_m^2} \quad (2)$$

Where σ_v =Von Misses stress

σ_m= Maximum bending stress

τ_m =maximum shear stress

The maximum bending stress was determined using equation (3) obtained from Sharma & Aggarwal (2018).

$$\sigma_m = \frac{M_b \times L}{2 \times I} \quad (3)$$

Where M_b= Maximum bending moment which has been determined to be 749.95Nm

L= length of steel bar taken to be 1m

I=Moment of inertia

The moment of inertia was determined by equation (4) obtained from (Khurmi & Gupta, 2015)

$$I = \frac{bd^3}{12} \quad (4)$$

Where b= width of the steel bar taken to be 500mm

d= depth of the bar taken to be 200mm

The moment of inertia was calculated to be $3.33 \times 10^{-6} m^4$.

The calculated moment of inertia was substituted into equation (3) to yield the value of 112.61N/mm^2 as maximum bending stress.

$$\sigma_m = \frac{749.95 \times 1}{2 \times 3.33 \times 10^{-6}} = 112.61 \text{N/mm}^2.$$

Also,a value for the maximum shear stress was calculated using equation (5)

$$\tau_m = \frac{V \times A_m}{I} \quad (5)$$

Where V=shear force

A_m=Moment of area

The moment of area was determined by equation (6) obtained from (Khurmi & Gupta, 2015)

$$A_{,m} = b \times \frac{d}{2} \quad (6)$$

The moment area was calculated to be $5 \times 10^{-2} m^2$.

The maximum shear stress was determined to be 11.26mpa by applying equation (5)

$$\tau_m = \frac{750 \times 5 \times 10^{-2}}{3.33 \times 10^{-4}} = 11.26mpa$$

The Von Misses stress was determined to be 114.28Mpa

$$\sigma_v = \sqrt{112.61^2 \times 3 \times 11.26^2} = 114.28 \text{Mpa}$$

2.5 Design for Factor of Safety

The Factor of safety of the cantilever beam apparatus was calculated using equation (7) obtained from Khurmi & Gupta, (2014)

$$\phi = \frac{Y}{\sigma_v} \quad (7)$$

Where ϕ=factor of safety

Y= Yield strength of steel

$$\phi = \frac{270}{114.28} = 2.36$$

The factor of safety was calculated to be 2.36 which is close the value obtained in Vinod & Ajit (2015) . For this study we used a factor of safety 2.0

2.6 Design for Strength to Weight ratio

The strength to weight ratio was determined by using equation (8) obtained from Khurmi & Gupta, (2014).

$$S_w = \frac{Ultimate\ tensile\ strength}{Weight\ of\ beam} \quad (8)$$

Where S_w = strength to weight ratio

The ultimate tensile strength for structural steel material was taken to be 400Mpa. While the weight of beam, W was determined using equation (9) obtained from Vinod & Ajit (2015).

$$Weight\ of\ beam = \rho Alg \quad (9)$$

Where ρ=density of steel

A= area of beam

g =acceleration due to gravity

L =length

$$weight\ of\ beam = 7700 \times 0.02 \times 0.05 \times 1 \times 9.81 = 75.537N$$

The strength to weight ratio was determined to be 5.3Mpa/N

$$S_w = \frac{400}{75.53} = 5.3Mpa/N$$

3. Results and Discussion

The results obtained from the development of the Cantilever beam apparatus which entails the design calculations, graphical modeling and the Finite element analysis are presented in this section.

3.1 The summary of the designed values

The summary of the calculated values of the Cantilever beam are shown in Table.1.

Table 1: Summary of designed values

S/N	Parameter	Designed values
1	Maximum bending moment	749.95Nm
2	moment of inertia	$3.33 \times 10^{-6} m^4$
3	maximum bending stress	$112.61 N/mm^2$
4	maximum shear stress	11.26mpa
5	Von Misses stress	114.28Mpa
6	factor of safety	2.36
7	weight of beam	75.53N
8	The strength to weight ratio	5.3Mpa/N

3.2 Modeling of the Apparatus

The graphical modeling of the Cantilever beam apparatus was done using AutoCAD 2018 software. The Third angle orthographic projection and the isometric view of the apparatus are shown in Figures 2 and 3 respectively.

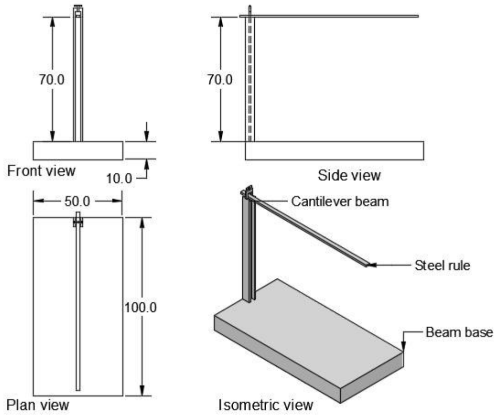

Fig. 2: Third Angle Orthographic Projection of the Cantilever beam apparatus

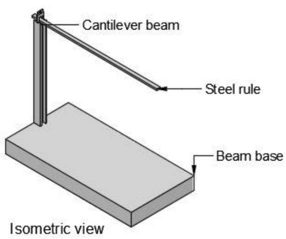

Fig. 3: Isometric view of the Appratus

3.3 Finite Element Analysis

The developed beam apparatus was subjected to finite element analysis using the ANSYS Workbench 2018. The developed apparatus was imported into the ANSYS enniviroment with a view of applying the static structural tool system to determine the various points of stress concentration. The developed apparatus in the Workbench software is shown in Fig. 4.

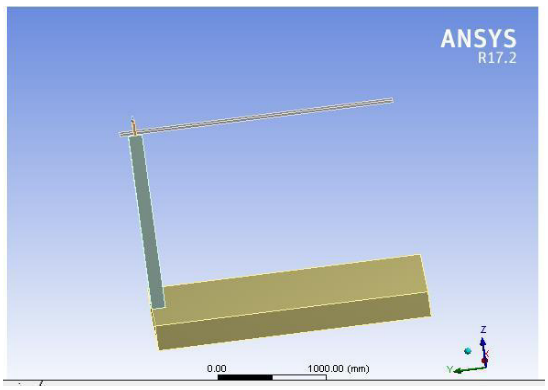

Fig.4: The developed apparatus in the workbench environment

The apparatus was meshed into minute sizes to allow for an easy solution and modeling. The meshed apparatus is shown in Fig. 5. The meshed structure had 4255 nodes and 628 elements.

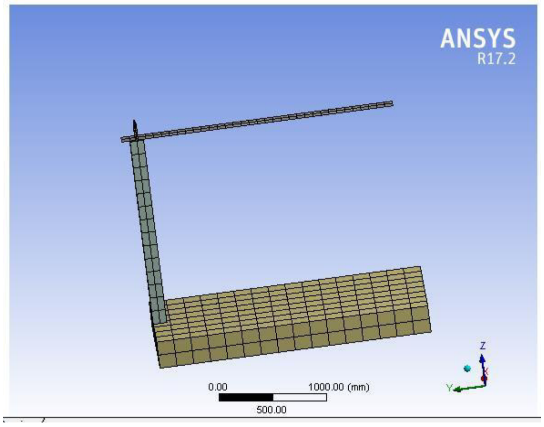

Fig. 5: Meshed Cantilever beam apparatus

The meshed apparatus was subjected to various forces and displacements to determine the effect of the equivalent Von Mises stress on the beam. The result as shown on Fig. 6, indicates that an equivalent Von Mises stress was maximum at 375.24Mpa from a 1mm displacement of the x,y and z axes. It implies that a stress of 375.24Mpa could cause a rupture of the apparatus. While between 0 and 120Mpa depicts a comfortable condition for the apparatus. This buttresses that fact that the calculated value of 114Mpa in this study is an effective result.

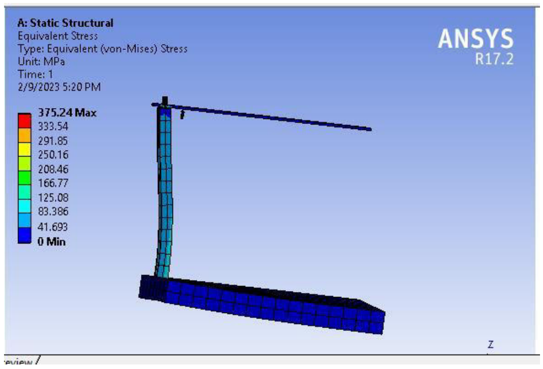

Fig. 6: The equivalent Von Mises stress output

3.4 Design/Fabrication Procedure

The cantilever beam apparatus was designed. The beam length was 0.7m meters and fixed support were inserted. The beam was investigated under point loads. The steel was fixed to the wall at one end and made to be free at the other end. A pivot and specimen holder was installed to have an avenue to load the system with specimen for the experimentation (Srivathsan, 2019). A beam was used to attach the counterweights. Electric arc welding was applied in welding the steel materials.

4. Conclusion

The challenge of sourcing for scarce foreign exchange to buy laboratory equipment could be highly discouraging. This has made it important for developing nations like Nigeria to brace up and look inwards on how to effectively build our local content in the area of production of equipment. If developing of our local content is given a boost then so many hands will be on deck to bring about technological revolution and innovation to the fore (Anmol, Karthik, Hemanth & Naveen, 2017). Some of our foremost research institutes has been lying fallow or even moribund because much attention has not been paid to developing local content. This study has developed a Cantilever beam apparatus that is well applicable in strength of materials laboratory across Nigerian schools. The developed apparatus was carried out by the application of engineering formulae and AutoCAD graphical modeling. The apparatus has a designed beam weight and strength to weight ratio of 75.53N and 5.3Mpa/N respectively. Also, a factor of safety of 2.3 was determined for the developed apparatus with a maximum shear stress and bending stress of 11.26Mpa and 749.95respectively. This developed apparatus has the tendency to perform as well as the imported laboratory equipment. This study has efficiently developed a locally made Cantilever beam apparatus used in Strength of materials laboratory.

5. Acknowledgement
The authors of this article wish to express their profound gratitude to the Management of Tertiary Education Trust Fund (TETFund), Abuja and Auchi Polytechnic, Auchi for the prompt provision of the required Fund for this broad research. This is indeed healthy for research sustenance.

REFERENCES

Aliemeke, B. N. G. , Okwudibe, H. A. & Ehibor, O. G.,(2022) *Development of a Fatigue strength Machine,Nigerian Journal of Technology, Vol. 41, No. 2,pp. 256-262*.

Anmol S. , Karthik D., Hemanth K. J. & Naveen H. E.(2017). Design and Fabrication of Drop Weight Impact Strength Testing Machine, *Imperial Journal of Interdisciplinary Research*, Vol. 3, No. 6, pp. 1121-1128.

Buliaminu, K. (2012). Development of a Deflection Beam Apparatus from Locally Sourced Material, International Journal of Engineering and Innovative Technology, Vol. 2,No.6,pp. 343-348.

Cui, J. & Roven J. H. (2015). Recycling of Automotive Aluminium, Norwegian University of Science and Technology, Norway. International Symposium on Liquid Metal Processing and Casting, Santa Fe, New Mexico. pp. 389-396

Khurmi, R. S. & Gupta, J. K. (2015) " Theory of Machines" Fifteenth Edition, Eurasia Publishing Limited, New Delhi.

Khurmi, R. S. & Gupta, J. K. (2014) " Machine Design" Revised Edition, Eurasia Publishing Limited, New Delhi.

Olufemi, A. F. & Ademola, I. S. (2018). Effects of Melt Vibration During Solidification on the Mechanical Property of Mg-Al-Zn Alloy. International Journal of Metallurgical Engineering, Vol.1 No.3, pp. 40-43

Sharma, P. C. & Aggarwal, D. K. (2018). A Textbook of Machine design. Twelfth Edition, S. K. Kataria and Sons, Daryaganj, New Delhi, India

Shashidar, M. B., Ravishankar, K, S, & Padmayya, S. N. (2018) Design and Fabrication of Fatigue Strength Testing Machine", International Journal of Novel Research and Development, Vol. 3, No. 5, pp. 5-14.

Srivathsan, S. (2019). Comparative Study of Aluminium Alloy Pistons Manufactured by Casting and Powder Forging. International Journal of Scientific and Engineering Research, Vol. 5, No.6, pp.662-665

Tarsicio B., Cristian N. & Augusto. B. (2003). Numerical and Experimental Analysis of a Laboratory Cantilever Beam used for Geometric Nonlinearity in materials, International Journal for Engineering, Vol. 19, No. 6, pp. 885-892,

Vinod, B. S. & Ajit, D. K. (2015). Development of Constant Stress Composite cantilever Beam,International Journal of Structural and Construction Engineering, Vol.9, No. 2, pp. 117-121.