Global Journal of Engineering and Technology Advances
eISSN: 2582-5003
Cross Ref DOI: 10.30574/gjeta
Journal homepage: https://gjeta.com/

(RESEARCH ARTICLE)

Check for updates

Design and production of a tiltable extension ladder on a trolley for engineering workshop and warehouse

Whyte Asukwo Akpan [1,*], Stephen Ishandi Beshel [2], Ukemeobong Enefiok Akpan [3] and Agnes Essien Oboh [2]

[1] *Department of Mechanical Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Ikot Abasi, Nigeria.*
[2] *Department of Mechanical and Aerospace Engineering, Faculty of Engineering, University of Uyo, Nigeria.*
[3] *Department of Mechanical Engineering, Faculty of Engineering, Topfaith University Mkpatak, Akwa Ibom State, Nigeria.*

Global Journal of Engineering and Technology Advances, 2024, 20(02), 090–099

Publication history: Received on 25 June 2024; revised on 06 August 2024; accepted on 08 August 2024

Article DOI: https://doi.org/10.30574/gjeta.2024.20.2.0146

Abstract

There are always needs to carry loads of many forms in workshops and warehouses in industries to different heights. which makes conventional ladder not suitable. A tiltable extension ladder on a trolley satisfies this requirement and above all possess the compactness of its kind. The tiltable extension ladder on a trolley was designed using the principle of a beam fixed at both ends with a point load acting at the centre of the beam, The system has two major parts, the trolley and tiltable extension ladder. The designed load was 150kg. The machine was produced and put to use with acceptable machine performance.

Keywords: Trolley; Extension ladder; Tiltable; Foldable; Height; Workshop; Warehouse

1. Introduction

A ladder can be defined as a working space for persons elevated above the surrounding floor or ground such as a balcony or platform for the operation of machinery and equipment or some tasks. Depending on the type, ladders are generally used in performing of jobs at elevated height which cannot be easily accessible, and where the safety of the workers and equipment is of utmost importance.

A tiltable extension ladder is a type of elevated working steps that comprises a vertical or inclined set of rungs or steps that can be leaned against a surface such as a wall, and rope on which the workers stand on when working, which is properly secured on all sides for the safety of the worker

A ladder is a vertical or inclined set of rungs or steps. There are two types of ladders: rigid ladders-that can be leaned against a vertical surface such as a wall, and rope ladder that are rung from the top. The vertical members of a rigid ladder are called stringers or rails or stiles. Rigid ladders are usually portable but some types are commonly made of metal, wood or fibre-glass but they have been known to be made of tough plastic. Ladders are very essential and find usage in areas such as in conveying of workers, tools and materials up to elevated work location. Rigid ladders are usually portable, but some types are permanently fixed to buildings

Ladders are commonly used for working at elevated heights. Every year, a considerable number of workers are injured whilst working at elevated height. Some are seriously injured or lose their lives. Detailed analysis reveals that the accidents are either caused not using these ancillary tools or workers fail to use them properly. Tiltable ladders are one of the handiest, simplest tools that is commonly used. Because of their effectiveness, ladders are used by many people

* Corresponding author: Whyte Asukwo Akpan

to perform many tasks. Although ladders are much uncomplicated, planning and care are still required to use them safely. Each year in the US, accidents involving ladder cause an estimated 300 deaths and 130,000 injuries requiring emergency medical attention.

Ladders are ancient tools and technology. A ladder is depicted in a Mesolithic rock painting that is at least 10,000 years old, depicted in a cave in Valencia, Spain. The rock painting which shows two naked humans carrying baskets or bags that are employing wobbly ladder which appears to be made out of some kind of glass, to reach a wild honey bee nest to extract honey. Modern ladders are believed to have been conceived by Hebrews and Egyptians.

Folding wooden ladders have been employed at least since the 1800s as a convenient way to store then use as a ladder when needed. Different styles serve varying uses such as ladders to rescue people from an icy lake or ones to climb to get into a small attic. Although a range of materials such as aluminium are now used, the folding wood ladder is still being manufactured today

One of the earliest records of a folded wooden ladder dates to 1828. The Register of Arts and Journal of Patent Inventions, Mr. Green of London designed a ladder that allowed each step to pivot that the two sides of the ladder could be brought together to form a round pole. According to the Register, Green constructed the ladder to assist in rescuing people who had fallen into icy body of water. The design was approved by the Society of Arts.

Wooden ladders were common among firefighting crews until the late 1940s. Fire crews still use some wooden ladders, either made from Douglas fir and Hickory or wood beams with metal rungs. The extension ladders, which collapses for storage is still sometimes made of wood, due to tradition and to the fact that it can hold more weight than some metal ladders. Small folding ladders are still used by fire fighters as they are simple to transport and manoeuvre.

In house with small attics or lofts, wooden folding ladders come in handy. These ladders are often attached to the ceiling between the attic and the floor below and extend or collapse by pushing or pulling the end. Straight, non-folding ladders also be used to get into such spaces, but if the cost is too small, the folding ladder provides a simple storage and use solution. Wooden loft ladders often hold more weight than their aluminium counter parts and do not conduct electricity.

A frame folding ladders are free standing but fold to take up less space whether they are short or tall. The original material for this type of ladder was wood and while some still that, the weight of the wood can be prohibitive when compared to lightweight option like aluminuim. This type of ladder a wider to provide more stability.

The extension ladders are fixed ladders divided into two or more lengths for more convenient storage, the lengths can be slid together or slid apart to maximize the length of the ladder, a pulley system may be fitted so that the ladder can be easily extended by an operator on the ground then locked in place using the dogs and pawls. It is retractable and extendable and suitable for high and medium place for maintenance job. However, it I s heavy to lift, difficult to carry to other places, must be tilted to the wall for use.

A telescopic ladder consist of concentric or rectangular tubing that can be inside each other for storage of slid apart to expand the length the length of the ladder, a pulley system may be fitted so that the ladder can be easily extended by an operator on ground then locked in place using the dogs and pawls. It is adjustable for high and medium place for maintenance job, foldable, stable to use because the base part is more wide and light in weight. It is however is large and hard to keep or store and difficult to lift to another place

A step ladder has hinge in the middle to form an inverted V, with stage to keep the two halves at fixed angles. It is stable to use, foldable and durable. It is heavy to lift and not good for high place maintenance job, difficult to carry, use a lot of space to store, only one side can be used and fixed for one angle.

Fixed ladder has two side members joined by several steps, affixed to structure with no moving parts, it is a vertical ladder mounted permanently to a structure. The ladders are primarily used to access roofs or some other structures for industrial purposes with side members and standing brackets and layers. It is cheap, durable and simple in construction. However, it is not adjustable high, cannot be moved, fixed shape and always fixed to the wall.

There is a multipurpose ladder. This ladder should be able to fold to make it easier to store. It is also portable. A folding ladder is also a ladder in the step ladder style with one or (using no more than three) one-way hinges ideal for use on an even ground (stairs) as a trestle or when fully extended a fixed ladder. It is foldable, stable, adjustable and requires little storage space. However, it is heavy and difficult to transport.

Rigid ladders are available in many forms such as ;Orchard ladder-three lagged step ladder with third leg made so that it can be inserted between tree branches for fruit picking; Hook ladder – this is also known as a pompier ladder, is a type of a single beam ladder with pairs of rungs projected outward on both sides of the beam, Hook ladder can be used to scale from floor to floor on multi-story buildings by way of extension windows, a rigid ladder with a hook at the a hook at the top grip a window is still used by fire fighters; Sectional ladder-this is also known as a builder's ladder that has sections that come apart and are interchangeable so that any member of the sections can be connected; Bridge ladder- a bridge ladder lay horizontally to act as passage between two points separated by a drop [1].

Ladder accidents usually are caused by improper selection, care or use, not by manufacturing defects. Some of the more common hazards involving ladders such as instability, electrical shocks and falls can be predicted and prevented. Prevention requires proper planning, correct ladder selection, good work procedures and inadequate ladder maintenance [2].

Portable ladders are designed as 'one –man' equipment with the proper strength to support the worker as well as his tools and materials. Ladders are produced under three general classes: Type I Industrial-Heavy duty with a load capacity not more than 550 kg; Type II Commercial-medium-duty with a load capacity not more than 495kg and Type III-household-light duty with a load capacity of 440 kg. There the certification classes solely apply to ladders that are portable such as step ladder and extension ladders and are broken down into three kinds of certification. Each certification is colour-coded to indicate the amount of load the ladder is designed to carry, the certification class and it use. The colour can be found on the rubber feet of each ladder and on the certification symbol; Class 1 ladder is for heavy-duty, industrial uses, maximum load of 175kg-colour coded blue to identify; Class 11 ladder is for commercial uses maximum load of 150kg –colour coded green or yellow to identify and Class III ladder is for light, domestic uses, maximum load of 125kg-colour coded red to identify..

Ladder maintenance is very essential. Wood ladders should be protected with a clear scalar sealer varnish, shellac, linseed oil or wood preservative. Wood ladders should not be painted, because the point could hide defects. Checks for cracks, rot, splinters, broken rungs, loose joints and bolts are necessary. For aluminium or steel ladders, it should be inspected for rough burrs and sharp edges before use. It should be inspected for loose joint and bolts, faulty welds and cracks, hooks and locks on extension ladders should be in good condition. Worn or flayed ropes on extension ladder should be done; for fiberglass ladder-It should have a surface coat of lacquer maintained. If it is scratched beyond normal wear. It should be lightly sanded before applying a coat of lacquer [3].

Trolley is important equipment to move loads from one place to another. It can reduce the human burden in their daily lives. This device is commonly used by a large number of industries to transport physical products. Trolley is often used by those who organize and stock merchandise in retail store restock. When used properly, trolley can protect people from having back injuries and other health problems that can result from lifting and carrying heavy loads.

Trolleys are of many types-Multiple trolley hand four wheels are easy to use, strong and easy to operate. These trolleys have four wheels. The total of trolley size 1450mm x 550mm x 460mm and the total plate width is 189mm, this trolley can handle the load of 250kg and below.

The disadvantage of this trolley are light weight, durable, top grade and easy to operate. It is extensive suitable for warehouse and office and the disadvantage of this trolley is loads fell freely. The materials used to manufacture this product consist of light-duty wheels (front wheels); tough moulded polypropylene centres fitted with ribbed types and it especially designed for trolley and other light horticultural applications. The hollow bar (main body) is used to make the main body. This part must be made from hand material so it can support heavy load. In addition, this material has a property with light in weight so it can reduce the weight of the trolley. The rubber (holder) is suitable to serve as the holder because of the gripping and can prevent the hand from slipping.

The multipurpose metallic trolley four wheels are foldable and easy to use. This trolley has four wheels where the front diameter of 225 mm and the rear time is about one time smaller than the front wheel. Height of this trolley is 1320 mm and width of 460mm, this trolley can handle a load of 60kg and less. The advantage of this trolley is foldable to convert functions. It also can carry many types of equipment. The disadvantages of this trolley is equipment fell off early when filled with a larger quantity. Stainless steel is used to manufacture this product. The hand trolley aluminium dual purpose- Manufacture from robust aluminium extrusions, this is the ultimate trolley for delivery trucks, light in weight, but with high strength, the two wheels are easily converted by the pull of the spring. It is simple to load and highly manoeuvrable featuring an ergonomic handle in either position with safe operation. Again fitted with the highest quality pneumatic wheels and polyurethane tyre castors, designed to minimize performance, safety, reliability and efficiency.

Ladder accidents usually are caused by improper selection, care or use. Some of the more common hazards involving ladders such as instability, electrical shocks and falls can be predicted and prevented. Prevention requires proper planning, correct ladder selection, good work procedures and adequate ladder maintenance **[**4].

Among the safe practices for use of ladder is not moving or shifting it while a person is on the ladder **[**5].It is a good practice to climb down to make the adjustment and latter climb up again for the task [6].

The various platform types are determined either by their function, drive mechanism or modes of operation [7]. They include aircraft platform-is a type of a platform that moves both vertically through the aid of hydraulically powered pantographs and horizontally through the aid of the castor tyres attached to the bases of the platform. They are used for carrying out maintenance on aircrafts. The oil platform-also refereed as an offshore platform. It is large in structure with facilities to drill wells to extract and process oil and natural gas, and to temporary store product until it can be brought to shore for refining and marketing. In many case, the platform contains facilities to house the workforce as well. Depending on the circumstances, the platform may be fixed to the ocean floor, may consist of an artificial island or may float. Temporary suspended working platforms is temporarily assembled on a building or a structure. It will be dismantled at the end of the work for which it was installed. This type of temporary suspended working platform is generally used for painting and installing work, cladding, repairs and refurbishment on buildings, bridges, chimneys, silos and other structures. They carry workers, site personnel or engineers for working at height during the installation of certain walls and windows and external renovation.

Aerial work platform is a mechanical device used to provide temporary access for people or equipment to inaccessible areas, usually at height. They are generally used for temporary, flexible access purposes such as maintenance and construction work or by fire-fighters for emergency access, which distinguishes them from permanent access equipment such as elevators. They are used to lift limited to weight usually less than a ton,

We also have scaffolds, a scaffold is any temporary elevated platform and it is necessary vertical, diagonal and horizontal members are used for supporting workmen and materials. It is also known as a scaffold tower. They are employed when building of houses, etc.

Work platforms by their nature are designed for works and therefore frequently required transportation between sites. For this reason, they are almost all designed for easy movement, The motive mechanism may be unpowered, self-propelled or vehicle mounted,

Unpowered- these usually small units have no motive drive and require external force to move them. Depending on size and whether they are wheeled or otherwise supported, this may be possible by hand or may require a vehicle for towing or to transport. Small non-powered work platform can be light enough to be transported in a pickup truck bed, can usually be moved through a standard doorway. Self –propelled –These units are able to drive themselves (on wheel or tracks) around the site, for reason for safety and economy. In some instances, these units will be able whilst the job is in progress, although this is not possible on units which require scare outriggers and therefore most common on the scissors lift types. The power can be almost any form of standard mechanical drive system, including electric or gasoline powered in some cases, a hybrid.

Improvement in joint mechanism in which a resilient leaf spring (knuckle joint) is mounted at its end on a first joint member at a location adjacent to one side of a locking piece engaged in notches disk of a second joint member and its free end being provided with a bent portion good enough to retain the front end of the locking piece. While the locking piece is being lifted up from the associated notch operation on the first front member the belt portion at the front end of the resilient leaf spring automatically swiftly move under its own elasticity into the front end of the locking piece to lock it from engaging again in the angular position of the joint to be made. In other to attain the locking and releasing purpose in the locking piece only when the two joint members pivotably connected together are folded in an opposite direction relative to one another, where one edge of the notch is will push in the blocking bent portion of the locking be able to fall into the notch. The commonly available joints are the lap, butt and knuckle join t [9], [10],[11],[12]. The objective of this research is to design and produce an extension ladder mounted on a trolley to assist in climbing up to reach heights in workshops and warehouses to perform some tasks.

2. Materials and methods

2.1. Theory of operation

The tiltable extension ladder works on the same principle similar to that of a beam fixed at both ends with a point load at the centre of the beam. The load here represents the weight is acting at the centre of the beam, then there will be equal and opposite reaction at the base of the ladder and at the wall when the ladder is inclined to the wall at an angle suitable for working.

2.2. Design Criteria

The design criteria is to determine the bearing load of the trolley capable of supporting and inclined extension ladder**,** when load is applied.

2.3. Design Analysis

The tiltable ladder is assumed to be a beam of uniform length at an angle θ ,to the floor and resting on the wall. In this design, since the ladder does have to rst on the wall before the design, the angle is neglected and it is regarded as a beam supported at both ends and a vertical point load is acting at the centre. If the length of the beam is L and the weight is W acting at the centre of the beam, and the weight of the rung of the ladder is neglected. The reactions and weight is expressed in Equation 1.

$$R_A + R_B = W \quad \text{.....1}$$

Since the load is acting at the centre, then the effect of the load has to be shared equally at both ends, thus we have in Equations 2 and 3

$$R_A + R_B = R \quad \text{.....2}$$

Hence,

$$2R_A = W \quad \text{.....3(a)}$$

$$R_A = \frac{W}{2} = R_B \quad \text{.....3(b)}$$

The bolts and nuts on the hinged parts of the ladder should have adequate strength to withstand the applied load. These are the likely failure points. The direct stress due to axial load on the bolts may be determined from Equation 4.

$$\sigma_t = \frac{W}{A_C} = \frac{W}{\Pi \frac{d_C^2}{4}} \quad \text{.....4}$$

where W is the total acting load on each bolt (N)

d_C is the core diameter of bolt (mm) for a bolt of 20mm, the core diameter is 18mm

The torsional shear stress is given in Equation 5.

$$\tau = \frac{16T}{\Pi (d_C)^2}) \quad \text{.....5}$$

where τ is the shear induced on the bolt N/mm^2, T is the torque in N-mm and d_C is the core diameter of bolt (mm), this is put in a better form in Equation 6.

$$\frac{T}{J} = \frac{C\theta}{L} \quad \text{, ……6}$$

where C is the modulus of rigidity and J is the second moment of area of the screw bolt about its polar axis and θ is the twist angle in radians, and L is the length of the bolt.

The principal shear stress is given in Equation 7 as:

$$\tau_{\max} = \frac{1}{2\sqrt{\sigma_t^2 + 4\tau^2}} \quad \text{……7}$$

The factor of safety is given in Equation 8.

$$F_S = \frac{Y_s}{W_S} \quad \text{……8}$$

where Y_S is the yield strength and W_S is the working stress and F_S, the factor of safety.

2.4. Design of the Trolley

The trolley part is designed like a platform with a rectangular shape. It is the trolley that the ladder is folded into and conveyed to the work site. The load analysis is similar to that of the ladder.

The bending moment for a triangular section loaded from the vertical vertex is shown in Equations 9 and 10.

$$M_A L = -\frac{1xLWL}{2x4} \quad \text{…… 9}$$

$$M_A = \frac{-WL}{8} = M_B \quad \text{……10}$$

where M_A and M_B are bending moments at ends A and B of the base of the triangle.

The shear force is similarly given in Equation 11.

$$R_A = R_B = \frac{W}{2} \quad \text{……11}$$

The moment of inertia of a rectangular section about an axis through its centre of gravity is shown in Equation 12.

$$I = \frac{bd^2}{12} \quad \text{……12}$$

where b is the breadth of rectangular section (mm)

d is the depth of rectangular section (mm),

Sectional Modulus is shown in Equation 13.

$$Z = \frac{bd^3}{6} \qquad \text{……13}$$

Where d is diameter of rectangular section (mm) .

In the design of the ladder structure, the materials used in the production is 50mmx 25mm x3mm mild steel rectangular pipe with pawls (articulate joint attached).

Maximum height is 3000mm and minimum is 750mm, width of the ladder is 350mm. The maximum designed load is 150kg- weight of workmen and some tools.

Figure 1 shows the diagram of the extension ladder on a trolley, while Figure 2 is the diagram of the completed project in the foldable form.

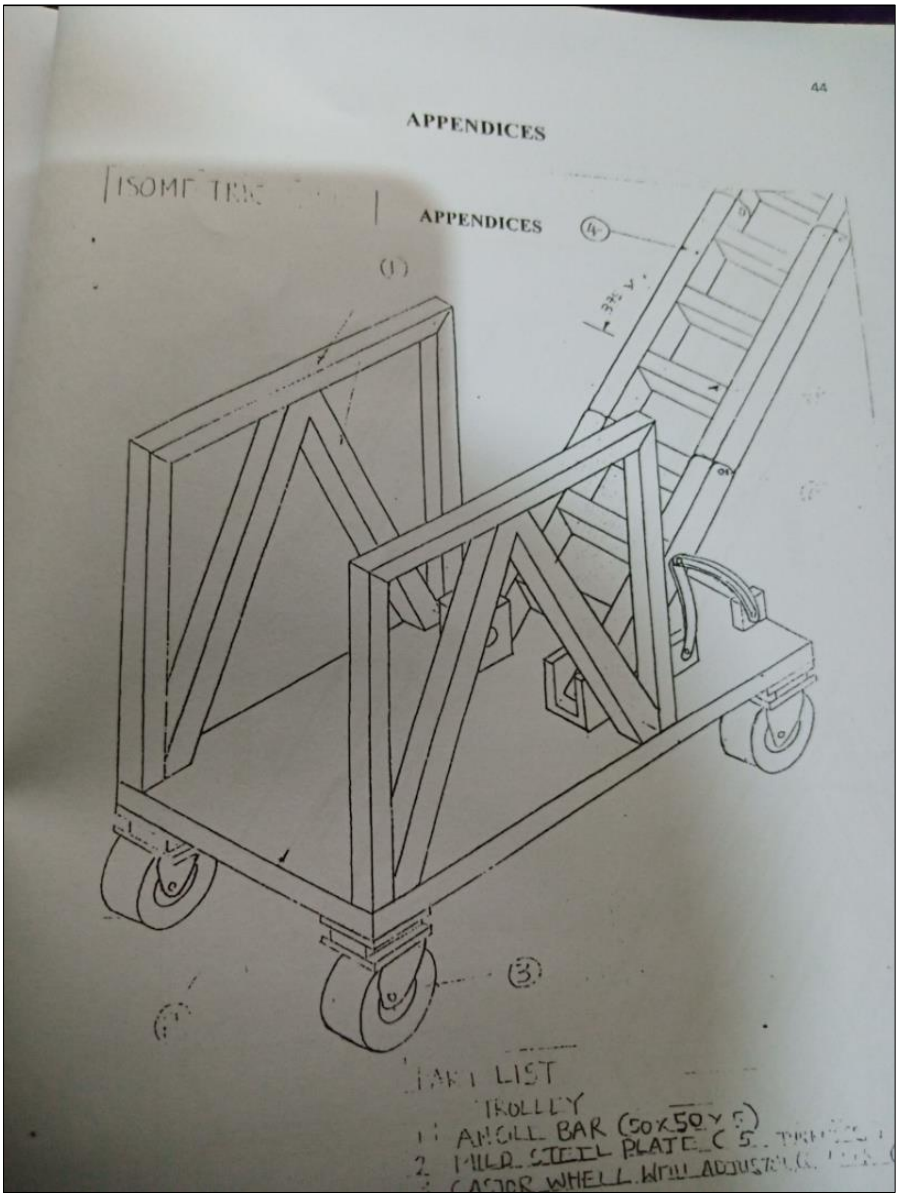

Figure 1 Isometric Sketch of the Trolley with Extension Ladder Mounted on it

Figure 2 Final Produced Trolley with Extension Ladder in the Foldable Form

3. Results

For a mass of 150kg and acceleration due to gravity taken as $10m/s^2$, W=1500N.

From Equation 1, 2 and 3

$$R_{A,} = 750N = R_B$$

Given:

$d_c = 18mm$ and $\prod$ known,

$$A_C = 2.5447X10^{-4}m^2$$

From Equation 4 and substituting value, the direct stress is given as;

$\sigma_t = 58.95N/mm^2$

Given:

$d_c = 18mm$, $T = \frac{11.426X10^3}{\Pi x10^3}$

From Equation 5

$\tau = 113.64N/mm^2$

For this design:

$C = 80x10^3 N/mm^2$, L=60 mm , $\theta = 0.5\Pi = 0.00873rad$, $J = 981.875mm^4$

Substituting into Equation 6 yields,

$T = 11.429kN/mm$

Given:

$\sigma_t = 29.84N/mm^2$ and $\tau = 113.64N/mm^2$

From Equation 7

$T_{\max} = 114.65N/mm^2$

Given:

W=1500N, L =750mm

From Equations 9 and 10, the bending moment is:

$M_A = -140.6Nm = M_B$

From Equation 11

$R_A = R_B = 750N$

Given: b=25mm, d=50mm

From Equations 12 and 13

$I = 2.604x10^5$ and

$Z = 1.542x10^3 mm$

4. Discussion

The tiltable extension ladder built is versatile and can be operated manually. The production process include machining, measuring, cutting, welding, drilling, grinding and painting. The ladder and trolley can carry a maximum weight of 150kg and can be folded, thus making iy portable. It is extensive for warehouse and workshop usage.

5. Conclusion

A tiltable extension ladder on a trolley designed and produced was found to be very effective. It can carry the designed load of 1500N and cost effective and in use increased the productivity in workshops and warehouses where its applications are paramount. Introduction of modern electrical and electronic components into the design will further designs.

Compliance with ethical standards

Statement of ethical approval

The research complied with engineering ethics.

Disclosure of conflict of interest

No conflict of interest among the authors.

References

[1] Universal Access Platform Guide: www.universalplatform.co.uk

[2] Petovic Z. (1995) Aerial work Platform online Available: http://www- ritc.hiewiki.com/wiks/index.php/Aerial, Access 5th May, 2023.

[3] Truessdell, Leon E. (19965) The development of Punch Tabulation in the Bureau of Census; 1890-1940. US GPO.

[4] Ritchiewiki 2011 Aerial Work Platform (Online) Available http://www.ritc.hiewiki.com/wiks/index.php/Aerial.

[5] Occupational Safety and health Administration (2011) Walking-working Surfaces (Online) Available gov. hk Accessed 15th May, 2015.

[6] Otto Mayer (1972) Cited Patent for Foldable Ladder Online Available [23rd May, 2024].

[7] Occupational Safety and Health Department (1990) Code of Practice for SFE Use and Operation of Suspended Working Platforms, Hong (Online) Available [www.lanourgov.hk Accessed 5 May, 2023.

[8] Slac (2010) Mobile Elevating Work Platforms (0nline) Available http://en.wikipedial.org/wik/oil- and-gas-platforms Accessed 20th May, 2023.

[9] Khurmi R.S. and Gupta J.K. (2010) A Textbook Machine Design, Eurasia Publication House (P) Ltd Ram Nagat New Delhi.

[10] Adikwanduala S. (2005) Technology of Properties of Engineering Materials, Kwandu's Publication, Nigeria.

[11] Adikwanduala S. (2007) A textbook of Engineering Workshop Practice and Safety, Kwandu's Publications.

[12] Hamidi B. (2007) Metal Construction in Machine Design (Online) Available :www. Metalconstruction.com Accessed 10th May, 2023.