ANALYSIS & DESIGN OF A LOW – COST TIMBER PEDESTRIAN BRIDGE FOR RURAL AREAS: A CASE STUDY OF UTARU STREAM IN AKPO TOWN, AGUATA LGA, ANAMBRA STATE.

BY

OKPALANNEBUAKU EKENE AUGUSTINE

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DEPARTMENT OF CIVIL ENGINEERING

FACULTY OF ENGINEERING

NNAMDI AZIKIWE UNIVERSITY, AWKA

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CERTIFICATION

This is to certify that this project work titled "Analysis & Design of A Low – Cost Timber Pedestrian Bridge for Rural Areas: A Case Study of Utaru Stream in Akpo Town, Aguata Lga. Anambra State" was carried out by Okpalannebuaku Ekenedilichukwu Augustine with Registration Number NAU/2017/224/031 in the Department of Civil Engineering, Faculty of Engineering, Nnamdi Azikiwe University, Awka. Anambra State.

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Okpalannebuaku E. Augustine   **Date**

APPROVAL PAGE

This is to certify that this project titled "Analysis & Design of A Low – Cost Timber Pedestrian Bridge for Rural Areas: A Case Study of Utaru Stream in Akpo Town, Aguata Lga. Anambra State" an authentic academic work undertaken by Okpalannebuaku Ekenedilichukwu Augustine with Registration Number NAU/2017/224/031 in the Department of Civil Engineering, Faculty of Engineering, Nnamdi Azikiwe University, Awka. Anambra State.

_____   _____
Prof. C.A. Ezeagu   **Date**
(Project Supervisor)

_____   _____
Prof. C.A. Ezeagu   **Date**
(Head of Department)

_____   _____
Engr. Prof. D.O. Onwuka
External Examiner   **Date**

DEDICATION

This project work is dedicated to God Almighty for his continual loving kindness and sole assistance in wisdom, strength and guidance throughout the period of this work.

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ABSTRACT

This study aimed to analyze and design an alternative low cost pedestrian bridge using Nigeria timber specie *Milicia excelsa* generally known as Iroko or OJI tree. The permissible stress method of analysis was used for analyzing the bridge components (beam & slabs). For overall stability, the abutments was designed using reinforced concrete. Iroko was used for the analysis. Results obtained indicate that Iroko is suitable for the design of pedestrian bridges owing to its strength and durability properties. The use of timber in low cost pedestrian bridges can be a cost – effective and sustainable alternative to other construction methods especially in economically disadvantaged rural areas

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LIST OF SYMBOLS

S	effective deck span
A_S	Area of reinforcement
M_{DL}	Deck dead load moment (KN m)
w_{DL}	Dead load of the deck
M_{LL}	moment due to pedestrians load
w_{LL}	Pedestrian live load
f_{pb}	Permissible bending stress
f_{gb}	Grade bending stress
δ_l	Deflection of loads
δ_p	Permissible deflection
w	UDL on the bridge
L	span of the bridge
E	Modulus of elasticity
I	Moment of area
F_v	Maximum shear force
f_{av}	Maximum shear stress at neutral axis
$f_{pv\ par}$	Permissible shear stress parallel to the grain
f_{gv}	Grade shear parallel to grain

K_3	Duration of load factor
K_2	Wet exposure factor
k_4	Length of bearing (mm)
k_7	Depth factor
k_8	Load-sharing system factor, k_8
Z	Section modulus
b	Breadth
h	Depth
f_{ab}	Applied bending stress
f_{pb}	Allowable bending stress
f_{gb}	Grade bending stress
$f_{ac\,per}$	Applied compressive stress perpendicular to the grain
$f_{pc\,per}$	Permissible compressive stress perpendicular to the grain
$f_{gv\,per}$	Grade compressive stress perpendicular to the grain
F_r	End reaction
L_b	End bearing length
γ	Soil Density
H	Height of wall
t	Thickness of wall
φ	Angle of Internal Friction

f_c Design Strength of Concrete

f_y Design Strength of Reinforcement Steel

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CHAPTER ONE
INTRODUCTION

1.1 Background of Study

Kathy (2023) stated that a pedestrian bridge is "Simply a bridge also called a footbridge, whether over land or water, that is designed for foot traffic as opposed to vehicle traffic. Often, footbridges are constructed to give pedestrians a safe way to cross from one side of a busy road to the other". Nwakire (2021) elaborated that "The obstacle to be crossed may be river, a road, a railway, or a valley. In other words, a pedestrian bridge is a structure for carrying the road Traffic or other moving loads over a depression or obstruction such as canal, road, or railway without closing the way beneath".

Nwakire (2021) also stated that "Bridge has been a necessary tool in every civilization through history. Bridges depict the culture that developed them, depending on the knowledge of the creator and material on his disposal".

In this work we will examine timber as low cost bridge construction material with emphasis on using of Nigerian grown timber specie Iroko that is suitable to be used in construction of composite timber - reinforced concrete bridges to withstand imposed pedestrian loads and as well as their own self weights.

Nigeria as a country has vase supply of timber trees which can compete favorable with other materials of construction like steel, concrete in terms of costs, availability, and strength to weight ratio, fire resistance and many more. Though Ezeagu et al. (2021) concluded that "timber has been found to be underutilized, undervalued and less appreciated in Nigeria". Ezeagu (2005) also noted that "not much attention has been given to the exploitation of timber materials in Nigeria. It is disappointing that research institutions, universities, polytechnics, industrial timber users and markets have not developed this materials that is of vast benefits and unlimited availability compared to other materials". As not much information about this timbers is put out to the general public so this has hindered clients such

as Government institution and private bodies to shy away from considering its use in important constructions like pedestrian bridges and bridges in general even for the rural areas.

Based on the rapid advances in the construction materials technology over the recent years, civil engineers have been enabled to produce new solutions of built structures to serve the common needs of the society. In that line, this research work seeks to exploit the use of composite timber-reinforced concrete for pedestrian bridge design and construction.

1.2 Statement of Problem

In our modern time the use of timber especially locally obtainable timbers called 'Nigeria timber' as the main structural material either for bridge or any structural construction is on the decline owning to lack of knowledge of the structural advantages that timber especially locally sourced ones have over the most utilized ones such like steel. Furthermore, due to the cost of constructing pedestrian bridges with conventional materials, residents are forced to go through hard times trying to cross through streams and rivers alike. This has adverse economic, social, and environmental impacts.

1.3 Aim and Objectives

The aim of this work is to Analysis & Design of A Low – Cost Timber Pedestrian Bridge for Rural Areas: A Cast Study of Utaru Stream in Akpo Town, Aguata Lga. Anambra State. The aim is achieved following these objectives:

1) Carrying out full structural design of timber bridge deck
2) Designing thoroughly the bridge girders
3) Designing the concrete abutment like a cantilever retaining wall

1.4 Scope of Study

This work is limited to structural design of composite timber-reinforced concrete pedestrian bridge, considering reinforced concrete bridge abutment design, timber bridge deck design and timber bridge beam/girder design.

1.5 Justification of the Design

- To provide a relatively cost – effective alternative pedestrian bridge for use in rural areas.
- To solve the problem associated with make-shift bridges found in the rural areas.
- Timbers relative light weight reduces the need for foundation capacity and associated costs
- Sustainability as the use of timber to replace conventional materials is sustainable.

CHAPTER 2
LITERATURE REVIEW

2.1 Timber as a Civil Engineering Material

Timber has be defined as a natural structural material from matured trees which serves various purposes in construction and furniture industry (Aguwa et al., 2015). Rahmon (2018), further defined timber as wood in the form that is suitable for construction of carpentry, joinery or for reconversion for manufacturing purposes. Wood can be said to be a heterogeneous conglomeration of large number of cells which are hollow, spindle shaped and parallel to each other exhibiting hydroscopic and anisotropic tendencies (Aleru and David-Sarogoro, 2016) Furthermore, Jimoh et al. (2017), opined that timber is a complex building material owing to its heterogeneity and species diversity. This calls for a high degree of scientific, engineering and technological understanding of its properties (Aleru and David-Sarogoro, 2016)

Diego et al. (2013) observed that wood has been used as a raw material for several centuries for housing construction, roofing and structures such as bridges and walkways to overcome natural obstacles. They argued that besides being a sustainable product, for presenting great absorption and fixation of carbon dioxide during its production, wood is easy to work and requires low power consumption in its processing. Thus, they concluded that, wood is widely used in construction of formwork and shoring and for roof structures, window frames and floors. However, for proper wood, it is necessary to know its properties of strength, stiffness and anisotropy due to its characteristics and variability

Ataguba et al. (2015) pointed out that wood is the oldest material used by humans for construction after stones and argued that in spite of wood's complex chemical nature, it has excellent properties that lend it selves to human use and further stated that wood is readily and economically available, can easily be machined,

and amenable it fabrication into an infinite variety of sizes and shapes using simple on-site building techniques.

Similarly. Ogunbajo et al. (2016) stated that wood is a very versatile raw material and is widely used in construction, especially in this nation where there is an abundance of good quality timber. They reasoned that timber is the most sustainable building product available and naturally renewable, it can be used in a range of structural applications including marine works: construction of wharves, piers, cofferdams, and heavy civil works: bridges, piles, shoring, pylon, domestic housing roofs, partitions, shuttering for precast and in situ concrete, for brick or stone construction.

Besides, Kelechi-Asumba and Uche (2015), stated that interests in designing timber structures has steadily increased in the last few years and attributed it to an increased focus of the society on environmental aspects, sustainability, positive effects and the increased architectural possibilities (Brandon, 2006). Moreover, the strength/weight ratio of timber is even higher than that of steel (Manfred, 2008). Also, research has also shown that timber products can be recycled (Zimiring, 2005)

In addition, Osuji and Inerhunwa (2017), stated that timber is one product amongst many designers can choose from and are promoted as environmentally viable options. They argued that as a natural and renewable building material, timber has excellent ecological attributes. Also, they pointed out that wood acts as a carbon sink and has low embodied energy. Moreover, they asserted that the energy needed to convert trees into wood and hence into structural timber is significantly lower than that required by steel and concrete. In addition, they concluded that timber is unique in that it does not corrode

Moreover, Jimoh et al. (2018), stated that timber is referred to as the World's only renewable resources since a new one can he grown where one has been cut down. Jimoh et al. (2017), observed that Nigeria is one of the countries that have timber in surplus quantity. In Nigeria, forest reserves take possession of approximately

10 million hectares, standing for about 10% of land area of approximately 96.2 million hectares in (Alamu and Agbeja, 2011). According to Obasi et al. (2015), the world has just less than 4 billion hectares of forest which cover approximately 20% el the world's land area. Therefore, if this natural resource is properly utilized, it will be of immense benefit to the country in terms of reduction in the cost of construction (Aguwa, 2012, Rahmon, et al., 2017, Ibitolu and Jimoh, 2017)

Furthermore, Jimoh and Adefemi (2017), opined that timber is one of the most frequently used building materials in the construction industry and argued that despite the discovery and availability of other materials, the use of timber structure keeps increasing, due to its environmentally friendly nature, sustainability and low handling cost. Nevertheless, they stated that insufficient information on the structural behavior of timber members systems cause difficulties in adequate description and reliable design of timber structure.

Similarly, Jimoh et al. (2017), pointed out that the main challenge in design with timber as structural member is to be acquainted with sufficient data about a given species of timber to ensure that the relevant performance criteria are met, as specified in relevant standards and codes. A significant element of uncertainty is associated with lack of information on the physical variability as well as structural behavior of material under load, (Aguwa, 2012). Thus, Jimoh and Aina (2017) stated that the question of strength characteristic of these timber species is therefore aimed at reducing the structural risk of using them for supporting and sustaining loads in structural systems.

2.2 Design of Timber Structure/Bridge

(Ede, A.N et al., 2014) stated that "The construction industry in Nigeria is relatively monotonous in terms of the Building material used as evidenced by the vast number of residential buildings large structures, and bridges in Nigeria made of heavy weight materials is in high concrete blocks and steel. Since Concrete is

in high demand in the society, the cost of getting concrete constituent Materials is becoming high thereby leading to high cost of living. This is largely due to the fact that alternatives to concrete for residential buildings and bridges in particular in Nigeria are not readily available or explored. It is therefore of necessity to motivate stakeholders to alternative building materials that will not only rival concrete in cost, but also serve as a viable competition in terms of sustainability, maintenance, constructability and client satisfaction in all necessary ramifications"

2.3 Timber as a Building Material

(Apu, 2003) stated that "Timber is natural and renewable. It has a high strength to weight ratio and is easy to work with, making it especially useful even where only basic technology and procedures are available". (Douglas, 1995) continued that "Timber remained the most predominant building material until the last half of 19" century". Today, proponents of timber as a building material perceive it as an alternative building material while its opponents opine that it is unreliable for construction. However, (Andreas, 2005) asserted that "architects are only limited not by the material but their knowledge of how the material works".

The physical properties of timber as a building material according to **Prof. Dr. Ramazan Ozen:**

Thermal Properties: Materials change in size and volume as the temperature changes. They expand with increasing temperature and contract with reducing temperature. The expansion cause decrease in the strength of materials. Timber does not practically expand against heat. On the contrary, by the effect of heat, it dries out and gains strength, the only time wood expands a little is when the humidity level is below 0% and this only scientifically significant. In practice, the humidity level of wood does not drop under 5% in the driest climate. Specific

heat of wood is high. That means high amount of energy is needed to increase and decrease the temperature of one kilogram of timber material.

Acoustic Properties: Sound isolation is based on the mass of the surface. Timber, as a light material, is not very perfect for sound absorption. Timber prevents echo and noise by absorbing sound. For this reason it is extensively used in concert halls. Sound energy loss as a result of friction is also significantly low in timber due to its lightness and structure.

Electrical Properties: Resistance to electrical current of a completely dry wood is equal to that of fhenol for maldehit. An oven dried timber is a very good electrical insulator. To some extent, air-dried wood is the same. Unfortunately, electrical resistance of timber is lowered by increasing the moisture content. Static electricity that is dangerous for human health is not observed in timber unlike metal, plastic and other building materials. For this reason, timber is preferred as a healthy building material.

Mechanical Properties: Although timber is a light material, its strength is quite high. For instance, while the tensile strength of timber with 0.6cm specific gravity is 100 N/mm", the tensile strength of steel with 7.89cm° specific gravity is 400N/mm.

Dividing tensile strength by specific gravity gives the breaking length and quality of material, when hung as a result of its own weight. While the breaking length of steel used for construction is 5.4km, chrome mobile steel is 6.8km, harden bow steel is 17.5km, the breaking length of spruce timber is 19.8km, and laminated timber made of beech is 28.3km. For this kind of property, timber and laminated timber is used in wide-gap constructions like health centers and sport halls.

Aesthetic Properties: Timber on its own is a decorative material when considered as an aesthetic material. Each tree has its own color, design and smell.

The design of a tree does change according to the way it is sliced. It is possible to find different timber materials according to color and design preference. It can be painted to darker colors or vanished, and can be given bright or mat touches.

Oxidation Properties: Although timber has oxidation characteristics in some way, it is not the kind of oxidation seen in metals. Metals get rust, timber does not for such characteristics, and use of timber is preferred to avoid rust when and where necessary.

Working Properties: (Also known as timber workability). Timber is easy to repair and maintain. While old timber can be renewed by special touches, other materials are costly to maintain and to repair, therefore, they are usually disposed of.

Variation: There are more than 5000 kinds of timber species in the world. Their specific gravity, macroscopic and microscopic structures are different. Accordingly, their physical, thermal, acoustic, electrical and mechanical properties are also different. Because of this variety, it is possible to find timber suitable for needs. For instance, for heat isolation and sound, absorption timbers in light weight are used. Similarly, heavy ones are used for construction purposes.

2.4 The Nigerian Timber and its use in Nigerian Bridges

(Abubakar Idris et al., 2014) stated that "The current Nigerian code of practice for timber design, **NCP2 (1973),** which is a permissible stress design code, is largely based on **BS 5268 (2002).** Today, the replacement of BS 5268 (2002) with **Eurocode 5 (EC5)** has been a major problem in design with NCP2 (1973). EC5, on the other hand, is based on limit state format". However, (Kaura J.M et al., 2015) maintained that "The properties of timber materials are not designed or produced, when compared to other building materials such as steel and concrete,

by means of some recipes but may be ensured to fulfill given requirements only by quality control procedures known as grading. (NCP2, 1973) stated that Grading refers "To the established classification of timber and certain manufactured products (e.g. plywood) according to quality". The exact quantity of wood and non-wood forest products in Nigeria cannot be easily estimated (Alamu and Agbeja, 2011). (Abubakar and Nabade, 2013) opinioned that "The flexible use of timber in construction of bridges especially in the beam fabrication has made it famous and popular". (Ezeagu and Nwokoye, 2009) decried that "Nigeria as a nation is spending her huge resources on importation of steel which is not necessary even in fabrication of long span trusses for sophisticated structures because timber can be used to achieve economy, strength, durability, aesthetic and time saving". Nevertheless, the competitive challenges posed by modern architecture encourage the development of timber constructions. (Natherer, 2001) added that "The different research, teaching, development and marketing programme should aim not only at the quality of material used, but also at the manifold quality of material stability, section variability, material diversity as well as widespread usage of new techniques in timber engineering construction".

2.5 Traditional Bridges in Nigeria

The traditional bridge, bridges constructed by the locals especially in remote areas majorly in the riverine parts of Nigeria built from strong bamboo sticks and Timber woods like Abura. Most times built directly on top of water so as to enable the locals especially children and woman cross those difficult terrains.

The Nigerian grown Abura timber which play major role in such construction by locals was studied by (James Isiwu Aguwa, 2014) and founded that satisfactory level of reliability indices were recorded at depth of 400mm, breath of 150mm and span of 5000mm under ultimate limit state of loading.

(Osasona, 2015) observed that "The riverine architecture is found among the people of ljaw, Nigeria where the majority bridges is constructed solely from timber".

2.6 Wood Processing and Storage Techniques adopted in Nigeria

This project work is concerned with wood lumbering as means of wood processing. It involves sawing of woods in different sizes namely log (4x6x12f), (2 in x 6 x l2ft) and so on as the market demand. This size may be for immediate use or for drying for those who have dryer chambers or kiln. The dried wood is further processed into finished product like floor tiles and ceiling board. There two major means of storing/removing the excess moisture from wood namely: air seasoning (natural) and kiln seasoning (Artificial).

- **Air Seasoning:** This is done by pilling the converted timber into stacks, separating the boards by using skids or stickers, so that the moisture is evaporated by the free circulation of air by natural convection. A good dry site with a firm foundation is necessary. This is the prevalent situation in Nigeria. The seasoning processes are usually joined with wood storage to the time of common practice like piling and stacking under a roof cover, piling, stacking and covering with cellophane; piling, stacking and left open soaking in water, and treated with chemical; piling, stacking under a cover roof.

- **Kiln Seasoning:** A kiln is a drying room with heating pipes arranged in the floor and ceiling, fans to circulates the hot air and jets to allow the introduction of steam. Most kilns in Nigeria are of the compartment type in which the load of timber remain in the kiln throughout the drying and the air conditions are regulated in accordance with a suitable schedule. Kiln-dried timber will normally be of a lower moisture content than air-dried material and may be 6 and 15% depending on the set objectives of

kiln drying. For proper kiln operation, the kiln environmental conditions must be known-that is the temperature and humidity of the circulating air. A careful record should be kept for the progress of every run so as to provide information when undertaking drying of a similar wood type or as a sort of validation of the drying processes.

Other drying methods includes:

- **Radio-Frequency Heating**: In this method, the wood is placed between two metal plates to which is applied an electric current oscillating at a very high frequency. The high frequency current causes the moistures in the wood to heat up at a more or less uniform rate throughout. Eventually boiling point is reached and, if the steam that then forms can escape freely, the drying rates may become very great indeed depending upon the power input

- **Temperature Gradient Method:** In this method of drying, the core of the wood is heated by radio-frequency and the surface deliberately cooled by moist air, thereby inducing moisture movement from the hotter centre to the colder surfaces. This method is very expensive.

- **Chemical Drying:** In this method, the surface of the timber are caused to absorb, when in the green state, certain hygroscopic salts such as urea or even the common eating salt. The presence of such salts in the surface tends to keep these damp and inhibit shrinkage while moisture from within is able to diffuse outwards into and out of the surface layers into the atmosphere. The main difficulty in this method is to know the amount of chemical that should be introduced and to what depth, also in ensuring that the timber is not badly discolored.

2.6.1 Unit Operation of a Typical Timber Saw Mill

- Extraction: The log will be extracted from the forest

- Log Yard: Here all logs are measured and calibrated in three dimensional measuring systems.

- Saw,Mill: Here the log are cut into different size that is 12 to 80cm in diameter and 3 to 5 in

    length.

- Drying Chamber: Here energy is required for the drying of wood (drying process)

- Planner Mill: Here, timber can be further processed in a high-performance planner (that is further

    cut the wood to a desired size)

- Storage or Delivery: Here the finished product will be stored until it is sold

- Execution:

2.7 Building with Nigerian Timber in Nigeria

As one of the fastest growing economics in the world, it is saddled with so many on-going projects, both technological and infrastructural, executed by Governments and by the private sector, in the form of small scale and large scale projects, all competing to meet up with the high demand created by the nation's large population and the high rate of rural-urban migration. (Ede and Okundaye, 2014). Not minding all the efforts that have been put in place and the massive urbanization taking place, the ultimate goal of making affordable houses available for the masses remain mirage due to high cost of building materials. This high cost of building materials have been severally confirmed by many researchers as

the leading cause of sharp practices that have been responsible for the frequent building collapse that occurs in Nigeria (Simuna and Ede, 2010). With this reason in mind, there is need to explore new idea that seeks to encourage the adoption of locally available building materials which will lead to cheaper rural and urban structures accessible to the masses. This project work therefore explores the possibility of providing a reliable alternative (the timber) to the labor intensive/environmentally not friendly concrete technology that has been predominantly adopted in the country for residential building construction, especially for low cost housing programs needed to curb the acute housing deficits (Ede and Okundaye, 2014).

2.8 Design of timber-concrete composite (TCC) bridges with under-deck stay cables

Timber-concrete composite (TCC) bridges represent an attractive structural system due to the synergistic use of its wood and reinforced-concrete constituent components. However, their relatively large flexibility limits their application for larger spans. This paper presents an alternative solution for TCC bridges involving the implementation of post-tensioned under-deck tendons. Based on a series of design and numerical studies, the advantages of the newly proposed system for 30-m, 60-m and 90-m spans are evaluated. This paper shows that the incorporation of under-deck post-tensioning changes the critical limit states governing the design of TCC bridges, and allows for a significant increase in their slenderness's at medium and long spans. Timber's shear-deformation contribution to the vertical deflection of TCC bridges is significant and should be accounted for, especially when the span/depth ratio (l/h) is less than 20. However, this additional deformation can be neglected when stay cables are implemented, especially for bridges with medium and long spans. In order to achieve a more efficient structure, it is proposed that concrete-to-timber shear connections with an efficiency coefficient (y) greater than 0.8 be used. Finally, the best practical

eccentricity of the under-deck tendons and the best location of the deviators are determined on the basis of parametric analyses. (Lyu, Christian and Ruiz-teran, 2019)

2.9 Performance evaluation of innovative composite pedestrian bridge

Light and slender pedestrian bridges which emerged as a result of new material technology and advanced computational techniques, are increasingly used to cater to the architectural and aesthetic demands of the communities. It is a very challenging task to satisfy the current code requirements on the dynamic performance of such bridges which are made of lighter composite materials. This paper attempts to explore new and innovative lighter and durable composite material compositions for a simply supported pedestrian bridge deck by considering hybrid Carbon fiber reinforced polymer (CFRP)/Glass fiber reinforced polymer (GFRP) as a bottom layer and cement composite/laminated glass as top layer. Features such as aesthetics, light weight, cost effectiveness, durability and ease of installation were considered during the selection of different composition of composite material. The overall performance of the developed innovative pedestrian bridge with the proposed materials and composition satisfy all the requirements of standard bridge design codes for safety and serviceability, and hence will contribute towards efficient and cost-effective pedestrian transport.

(Saima, David, Xuemei, and Sabrina F, [a]2020)

2.10 Design of Timber Building and Bridges Based on Other Countries Codes of Practice

All countries design standards or codes of practice must follow one or a combination of some design philosophies.

2.10.1 Design Philosophies (According To Roy Beardmore, 2009).

A design philosophy is a set of assumptions and procedures which are used to meet the conditions of serviceability, safety, economy and functionality of a structure. Several design philosophies have been introduced from different parts of the world. Some of the design philosophies that have been used by engineers are:

- Working stress method (WSM)/ Load Factor Method (LFM)
- Limit State Method (LSM)
- Probabilities Design Method (PDM)
- Permissible stress design (PSD)

Working Stress Method: This is also known as allowable or permissible stress method. Using this criterion, the strength of a timber structure involves determining the stresses induced under working conditions and comparing them with the permissible/admissible stress. The permissible stresses are obtained as the product of the grade stress for the timber and various modifying factors.

Therefore, $f_{pb} = f_{gb} \ k_2 \ K_3 \ K_6 \ K_7 \ K_8$ .... (i)

Where

f_{ab} =calculated bending stress parallel to grain

f_{gb} =Grade bending stress parallel to grain

K_2 Modification factor for moisture content of the timber

K_3 Modification factor for duration of the load

K_6 Modification factor for shape of the cross section

K_7 Modification factor for the depth of the section

K_8 Modification factor for load sharing.

Ultimate Load Method: This is also known as load factor method or ultimate strength method. Using this criterium, the strength of a timber structure involves determining the ultimate load stresses i.e the working stress X a factor of safety. This is compared to the ultimate capacity of the timber sections at yield. Plastic methods are required to determine the timber section capacities. Working Load X Factor of Safety ≤ Ultimate Strength of timber at failure.

Limit State Design: When using limit state design, the load at structural collapse is divided by selected margin of safety to determine the ultimate capacity of the structure. The ultimate design load is determined as the product of the working load and a second select safety margin. The ultimate design load should be less or equal to the ultimate capacity of the structure. Ultimate design load ≤ ultimate capacity. Also, working (characteristic) load X partial factor of safety ≤ Failure/collapse load X partial safety facto

Probability Design: When using a probabilistic approach to design, the designer no longer thinks of each variable as a single value or number. Instead, each variable is viewed as a probability distribution. From this perspective, probabilistic design predicts the flow of variability (or distributions) through a system. Adjustments are made to reduce the flow of random variability, and improve quality. Many quality problems can be predicted and rectified during the early design stages and at a much reduced

Cost. The goal of probabilistic design is to identify the design that will exhibit the smallest effects of random variability. This could be the one design option out of several that is found to be most robust. Alternatively, it could be the only design option available but with the optimum combination of input variables and parameters. This second approach is sometimes referred to as robustification, parameter design or design for six sigma.

Some methods that are used to predict the random variability of an output include;

- The Monte Carlo method (including Latin hypercube)

- Propagation of error

- Design of experiments (DOE)

- Statistical interference.

Permissible stress design (PSD): Permissible stress design (PSD) is a traditional approach used in civil engineering for the design of structures such as buildings, bridges, and dams. It involves calculating the maximum allowable stress that a material can withstand without failure and then designing the structure based on this permissible stress. The PSD approach is simple and straight forward and has been used for many years in the construction industry.

In the PSD approach, engineers determine the loads that the structure will experience, such as dead load, live load, and wind load. They then design the structure based on the allowable stress of the material used for construction. One of the advantages of the PSD approach is that it is simple and easy to use. It allows engineers to quickly design structures based on the allowable stress of the material used for construction. The approach also provides a high degree of confidence in the structure's safety since it is based on the strength of the material.

However, there are several limitations to the PSD approach. One limitation is that it does not take into account the variability in the strength of the material. Materials can have a wide range of strengths, and the PSD approach assumes that the material has a uniform strength throughout. This can lead to overdesign or under design of the structure, depending on the variability of the material strength.

Another limitation of the PSD approach is that it does not consider the loadings that the structure will experience over its lifetime. The approach assumes that the loads are constant and do not change over time. However, loads on structures cary vary over time, leading to fatigue and failure of the structure.

In conclusion, the permissible stress design approach has been a traditional approach used in civil engineering for many years. It involves calculating the maximum allowable stress that a material can withstand without failure and design the structure based on this permission stress (www.simplecivil.com, 2023)

2.10.2 Design of Timber Structures To Eurocode 5

This is abbreviated as EN 1995 or informally, EC5. It describes how to design buildings and civil engineering works in timber using the limit state design philosophy. It was approved by the European committee for standardization (CEN) on April 16, 2004. It applies for civil engineering works from solid timber or wood-based structural products, (e.g LVL) or wood-based panels jointed together with adhesives or mechanical fasteners and is divided into the following parts.

Part 1-1: General -Common rules and rules for buildings

EN 1995-1-1 gives general design rules for timber structures together with specific design rules for buildings. The contents include:

- General

- Basis of design

- Materials

- Durability

- Basis of structural analysis

- Ultimate limit states

- Serviceability limit states

- Connection with metal fasteners

- Components and assemblies

- Structural detailing and control

Part 1 -2: General - Structural fire design

EN 1995 - 1 - 2 deals with the design of timber structures for the accidental situation of fire exposure and is intended to be used in conjunction with EN 1995 - 1 -1 and EN 1991-1-1-2: 2002. EN 1995-1-2 only identifies differences from, or supplements normal temperature design and deals only with passive methods of fire protection. Active methods are not covered.

Part 2: Bridges

EN 1995 - 2 gives general design rules for the structural parts of bridges, i.e structural members of importance for the reliability of the whole bridge or major parts of it, made of timber or other wood-based materials, either singly or compositely with concrete, steel or other materials.

Manual for Engineered Wood Construction, 2015 Edition

The 2015 manual for Engineered Wood Construction contains, design information for structural lumber, glued laminated timber, structural-use panels, shear walls and diaphragms, poles and piles, 1-joists, structural composite

lumber, cross- laminated timber, and over 40 details are included in the chapter on connections.

The manual proves design information on structural application of most wood-based products and their connections that meet the requirements of the referenced standards. The manual is a dual format document incorporating design provisions for both allowable stress design (ASD) and load and resistance factor design.

(LRFD). Each product chapter contains information for user with this manual and the National Design specification (NDS) for Wood Construction. Chapters are organized to parallel the chapter format of the NDS.

CHAPTER THREE
MATERIAL AND METHOD

3.1 Materials

Nigeria timber specie Iroko was consider in this work due to its structural quality and availability and accessibility within the proposed area for the project.

Iroko

Plate1:Iroko timber of varying sizes

Iroko (also known as *ọ́jị̀* in Igbo language, '*uloho*' in the Urhobo language of Southern Nigeria, and as odum in the Kwa languages of Ghana) is a large hardwood tree from the west coast of tropical Africa that can live up to 500 years. This is the common name for the genus *Milicia*, in which there are two recognized species, which are closely related: *Milicia excelsa* and *Milicia regia* Iroko has a botanical name of chiorophoraexcelsa, Christine and Nestor (26 July 2010) stated that "Iroko is a large deciduous tree up to 30-50m height, with a diameter of 1.70-2m, with high crown, umbrella-like and growing from a few thick branches" and grade as an N3 timber material by NCP and it is mostly common in rain forests in Nigeria. It has a basic stress of bending parallel to the grain as 23.61 N/mm^2 , min modulus of elasticity at 18% moisture content as 5652 N/mm^2 and density of 734 Kg/m^3 .

3.2 Site Description

Otaru stream located at the boundary between Akpo town and Aguluezechukwu town both located at Aguata local government of Anambra state.

The area is partly vegetative as it is surrounded by lots of trees, shrubs and grasses and vase surrounding of barren land made up of mostly sharp sands.

Temperature is relatively average throughout the year as there are little variations in temperature.

The wetter season last 7.2 months from April 1 to November 6, also the chance of a wet day varies very significantly throughout the year.

The area experiences extreme seasonal variation in the perceived humidity and likewise the average hourly wind speed.

The stream has served as a very important site and source of quality fine aggregates for various construction work within those axes. Both towns comes in from opposing side of the stream

There is also an increase on religious activity on the location from both towns and either sides most have to pass through the water to get to either side of the stream.

Plate 2: Utaru stream

3.2.1 Site Access

Due to relative business activities already going on in the said location, as the area has abundance of sharp sand that brings in tipper drivers to buy these sands from the owners access Road can be said to already be in existence.

3.2.2 Site preparation

The stream width was determined to ascertain the effective span of the bridge. The surround soil boundary of the stream was also examine to determine their ability bear the loads that could result from the pedestrian bridge.it was determined that surface soil boundary the bridge on both ends of the width of the river are loss and can't safely suppose the load without additional strengthen.

Setting out is to be carried on   site to mark out the required area for the proposed pedestrian bridge marking out the four corners of the bridge and also the intended bridge wall embankment that would support the bridge.

Plate 3: Surrounding of proposed site

3.3 Design analysis

In analysis on loads on a bridge and the moments, shearing force, and any form of actions that might result from that load or been generated in the bridge and also in selecting proper sections for various structural members of the bridge, various codes of practice like eurocode 5, Nigeria codes of practices, standard AASHTO will be referenced for various sections of the design.

Referenced sections in any of the mentioned codes of practice we be indicated.

3.3.1 Dimensional considerations for the bridge

The design bridge is a pedestrian bridge of total length of 7 meters and width of 3 meters passing over a stream of 6.6 meters wide and a retaining wall of thickness of 0.3meter, width of 3 meters and height of 2.3 meters would be constructed on both entrance of the bridge to embank the surface soils from collapsing due to slight tendency of the weak soil to collapse due to loading of the bridge and washing off by run offs and over flow stream water.

The superstructures in this bridge are the bridge deck and girders and are made with timber as the project is conserved with a low budget in mind but still looks toward to having a structural stable bridge. Timber been a low cost material and easily accessible within the site environs but most importantly of high structural strength

The bridge sub-structure is basically a retaining wall that is met to support the super structures and the surrounding surface vertical soil in both entrances to the bridge.

3.3.2 Loading considerations

Loading consideration according to En 1991 Eurocode 1 Actions on structures will be followed.

An imposed uniformly distributed load of $5KN/m^2$ will be assumed as the maximum pedestrian load that could occur on bridge in reference to EN 1991-2-2003(E) clause 4.3.4 load model 4 (crowd loading).`

A permanent load estimated with the dimension of the bridge component considered and the density of the timber species used

3.4 Design method

Permissible load method of analyzing loads will be used in determining bending moment, deflection and shear checks

The method involve checking bending moment, deflections and horizontal shear force produced by the structure against the allowable or permissible ones.

In the event the acting forces and moment from structure in more than the allowable or permissible, the depth or thickness of the structural member is increased.

3.4.1 Design of nail laminated timber deck

Transverse nail laminated timber decks consist of series of dimension lumber laminations placed on edge and nailed together on their wide faces. The deck is constructed by progressively nailing laminations to the preceding section to form a continuous surface over the bridge length. Load transfer between laminations is done mechanically by nails. The laminations are generally nominal 50mm by 100mm (2" by 4") or 50mm by 150mm (2" by 6") sawn timber for spans up to approximately 1828.8mm (6 feet) under standard AASHTO highway loads.
Steps

Define deck span, configuration, and loads: The effective deck span S is the clear distance between supporting beams plus one-half the width of one beam. The deck width is equal to the roadway with plus additional width required for curbs and hand rails. A UDL of 5KN/m is assumed for pedestrians load on the bridge.

Estimate deck thickness: Deck thickness must be estimated for initial calculation. Estimation for a known species and grade of timber based on bending, deflection or shear

Compute dead load and dead load moment: Uniform dead load moment for the effective deck section can be computed:

$$M_{DL} = \frac{w_{DL}S^2}{8}$$

Where M_{DL} = Deck dead load moment (KN m), w_{DL} = dead load of the deck and wearing surface over the pedestrian load distribution width, b_d (KN/m) and S = effective deck span (m)

Determination of live load moment: Live load for pedestrians is assumed to be a UDL of 5KN/m

$$\text{M}_{LL} = \frac{W_{LL}S^2}{8}$$ Where S = effective deck span.

Compute bending stress and select a deck combination symbol: When deck panels are continues over two spans or less, bending stress is based on simple span moments and is computed by: $f_{ab} = \frac{M}{S_y}$ Some characterized and graded timber and basic stresses of timber is gotten from the table 2.0 and 2.1 below extraction from Nigeria timber structures (by Aguwa James Isiwu, 2016, Nigeria code of practice, 2000.

Table 3.0: Some characterized and graded Nigerian timber species Aguwa (2016)

S/No	Standard name	Botanical name	Grade	Other Nigeria common names	Availability
1	Abura	Mitragynacilliata	N4	Bini : Eben Efik :Uwem Igbo : Uburuinu	Common in swamp forests
2	Afara	TerminaliaSuporba	N5	Bini : Egboninnofua Efik :Atiaeto Igbo, Edo and Ijaw : Gbarada	Very common in high forest
3	Apa `	Afzeliabipindensis	N2	Bini : Arinyan, orodo Hausa : kawa Igbo : Akpalata, Aja Yoruba : Olutoko, Apaigbo	Common in the savannah, secondary forest and in high forest
4	Lagos mahagony	Khayalvorensis	N5	Hausa: Male Igbo : Ono Yoruba : Oganwo	Found in low land rain forest
5	Obeche	TriplochitonSclerox	N5	Igbo : Okpobo	Abundant in the rain forest

6	Iroko	Chiorophoraexcelsa	N3	Hausa: loko Igbo : Oji Nupe : Roko	Common in rain forests
7	Ekki	Lophiraalata	N1	Igbo :Aba , Akufo	Low land rain forests

Table 3.1: Basic stresses of some Nigeria timber at moisture content of 18% Aguwa (2016)

No	Species	Bending parallel to grain	Tension parallel to grain	Compression parallel to grain	Compression perpendicular to grain	Shear parallel to grain	Modulus of elasticity E_{mean}	Modulus of elasticity E_{min}	density
		$\frac{N}{mm^2}$	$\frac{N}{mm^2}$	$\frac{N}{mm^2}$	$\frac{N}{mm^2}$	$\frac{N}{mm^2}$	$\frac{N}{mm^2}$	$\frac{N}{mm^2}$	$\frac{kg}{m^3}$
1	Abura	20.62	19.78	17.41	3.20	2.37	8806	6368	573
2	Afara	16.90	15.90	9.62	2.09	1.64	7487	5147	499
3	Apa	29.92	28.85	22.86	5.05	3.61	12429	9024	814
4	Ara	9.98	10.98	10.87	2.05	1.50	6284	3088	882
5	Araba	8.56	10.44	7.39	1.62	1.22	5365	3598	363
6	Ayo	22.15	21.00	18.25	3.69	2.96	10559	9000	702
7	Danta	33.19	31.20	22.39	5.05	3.75	12675	10302	770
8	Ebony	32.90	30.65	22.45	5.02	3.73	12662	9411	830
9	Ekki	37.45	36.75	28.01	6.34	4.80	17135	13990	1156

10	Gmelina	13.90	13.46	11.10	2.21	1.84	7480	5721	704
11	Iroko	23.61	22.75	18.21	4.38	2.82	10797	5652	734
12	Lagos mahogan	15.00	14.84	11.03	2.23	1.87	7566	5265	604
13	Mansonia	23.27	21.73	17.81	4.23	2.84	10845	8496	741
14	Obeche	15.39	14.67	9.22	2.13	1.96	7577	5692	386
15	Okan	36.10	34.94	30.14	6.34	4.64	15455	14048	1104
16	Okwen	21.90	21.72	18.46	4.08	2.86	10434	8050	716
17	Omu	22.84	21.73	18.42	3.96	2.86	10587	8127	625
18	Opepe	36.91	36.22	29.13	6.32	4.69	16026	14305	813
19	Sapele Mahog	22.31	22.16	18.52	3.97	2.84	10587	8810	700
20	Walnut	14.68	14.38	14.54	3.21	2.23	8365	7014	518

$f_{pb} = F_{gb} K$

f_{pb} is Permissible bending stress

f_{gb} Is the grade bending stress

K is modification factors relevant to the design

If $f_{ab} \leq f_{pb}$ the initial deck thickness and combination symbol are satisfactory in bending. When F_b is significantly lower than f_{pb}, *thinner* deck or lower

grade combination symbol may be more economical; however no changes in the panel thickness or combination symbol should be made until the live load deflection is determined.

$f_{ab} > f_{pb}$, the deck is insufficient in bending and the deck thickness or grade must be increased, or effective deck span reduced. If deck thickness or span is changed, the design sequence must be repeated. In some cases, it may be more economical to increase deck thickness to the next higher standard size, rather than use a higher-grade combination symbol.

Check for deflections

δ_l =deflection of loads $= \dfrac{5wl^4}{384EI}$ $< \delta_p$ =permissible deflection $= 0.003 *$ span

w=udl on the bridge

L=span of the bridge

E=Modulus of elastic

I=Moment of area

Check for maximum shear

Maximum shear force, $F_v = \dfrac{W}{2}$

Maximum shear stress at neutral axis $f_{av} = \dfrac{3F_v}{2A}$

Permissible shear stress $f_{pv\ par} = f_{gv}k_3$

W=total load

A =Area of section

f_{gv} =grade shear parallel to grain

k_3=duration of load factor

3.4.2 Modification factors

Timber shrinks or swells due to change in moisture content. Geometrical properties of timber in this work will be those at a moisture content 18%. For wet use of timber a modification factor is needed and so is other conditions of use. Some list of modification factor relevant for this work includes:

Wet exposure strength characteristics, k_2

Table 3.3 (table 16 BS 5268)

Property	Value of k_2
Bending parallel to the grain	0.8
Tension parallel to the grain	0.8
Compression parallel to the grain	0.6
Compression perpendicular to the grain	0.6
Shear parallel to the grain	0.9
Mean and minimum modulus of elasticity	0.8

Duration of loading factor, k_3

Short term loadings are multiplied by this factor as most of stresses are assumed for long term loads

Table 3.4 (table 17, BS 5268)

Duration of loading	Value of k_3
Long-term(e.g dead + permanent imposed load)	1.00
Medium-term (e.g dead + snow, dead + temporary imposed)	1.25
Short-term(e.g dead + imposed +wind, dead + imposed + snow + wind)	1.50
Very short-term (e.g dead + imposed + wind)	1.75

Bearing stress factor, k_4

Table 3.5 (table 18 0f BS 5268)

Length of bearing (mm)	Value of k_4
10	1.74
15	1.67
25	1.53
40	1.33
50	1.20
75	1.14
100	1.10

150 or more	1.00
Interpolation is permitted	

Depth factor, k_7: bending stresses are determined using depth of 300mm. for other depth the grade bending stresses are multiplied by the depth factor k_7

Table 3.6 (table 14.6 of BS 5268)

Depth of beam	Value of k_7
For solid beams having depth of h < 72mm	1.17
For solid beams with 72mm < h < 300mm	$(300/h)^{0.11}$
For solid and glued laminated beams with h > 300mm	$0.81(h^2 + 92300)/(h^2 - 56800)$

Load-sharing system factor, k_8: The grade stresses are for individual members such as isolated beams and columns assemblies. When four or more members such as rafters, joints or wall studs, spaced a maximum of 610mm center to center act together to resist a common load, the grade stress should be multiplied by k_8. Load-sharing stress modification factor, which has a value of 1.1 m

3.4.3 Design of timber beam

Bending stress, not to exceed the permissible stress

Resisting moment=section modulus * allowable beading stress =z x f_{gb}

$Z = \dfrac{bh^2}{6}$

b = breadth

h = depth

$f_{ab} = \dfrac{M}{Z} < f_{pb} = f_{gb} \, xk$

f_{ab} = applied bending stress

f_{pb} = allowable bending stress

Z = section modulus

f_{gb} = grade bending stress

K = applicable modification factors

Prevention of lateral buckling that h/b must be less than the permissible

h/b permissible = 5

for a beam to safe from lateral buckling its depth/breadth ratio should be less than 5

Maximum horizontal shear stress at the neutral axis, not to exceed the permissible

$f_{av} = \dfrac{3F_v}{2A} < f_{pv\ par} = f_{gv\ par} \, k_3$

f_{av} = acting maximum horizontal shear stress for a rectangular beam

F_{av} = acting vertical shear force

A = area of the beam

$f_{pv\ par}$ = permissible shear stress parallel to the grain

$f_{gv\ par}$ = grade shear stress from table 2.1 above

k_3 = duration factor

Deflection: both the bending and shear deflections added together should not exceed the permissible deflection δ_t = total deflection = deflection caused by bending + deflection caused by shear $\qquad \delta t = \dfrac{5wL^4}{384 E_{min} I_x}$

$+ \dfrac{12wL^2}{5 E_{min} A} < \delta_p$ = permissible deflection = 0.003 * span

w = uniform distributed loading

L = span

E_{min} = minimum modulus of elasticity

I_x = Second moment of inertia

Bearing stress at the supports and under any point loads should not exceed the permissible

$$f_{ac\ per} = \frac{F_r}{bL_b} < f_{pc\ per} = f_{gv\ per} * k_3 * k_8$$

$f_{ac\ per}$ =applied compressive stress perpendicular to the grain

$f_{pc\ per}$ =permissible compressive stress perpendicular to the grain

$f_{gv\ per}$ =grade compressive stress perpendicular to the grain

F_r =end reaction = $\frac{wL}{2}$

b = breadth

L_b = end bearing length

K_3 =duration factor

K_8 =load sharing factor

L = span

w = uniformly distributed load

3.4.4 Design of the bridge embankment wall

The reinforced concrete embankment wall will be designed as a cantilever retaining wall. The design of the wall will be based on the Nigerian Building and Road Research Institute (NBRRI) code.

The following assumptions will be made for the design:

Thickness of the wall = 300 mm

Height of the wall = 2 m

Soil Density (γ) = 18 kN/m³

Angle of Internal Friction (φ) = 30°

Design Strength of Concrete (f_c) = 25 MPa

Design Strength of Reinforcement Steel (f_y) = 460 MPa

The reinforcement steel for the wall will be selected based on the following factors:

Maximum Design Moment (M): $M = (1/2) k_a \times \gamma \times H^2$

Where, γ = soil density (kN/m³) and H = height of the wall (m)

Area of Steel Required (A_s): $A_s = (M \times 10^6) / (0.87 \times f_y \times I_a \times d)$

Where, d = effective depth (mm)

Spacing of Steel (s): $s \leq \min (3d, 300 \text{ mm})$

3.4.5 Design of Base Slab

The base slab will be designed as a simple supported slab. The thickness and reinforcement of the base slab can be determined using the Nigerian Building and Road Research Institute (NBRRI) code.

The design of the base slab will be based on the following assumptions:

Thickness of slab = 200 mm

Soil bearing capacity = 120 kN/m²

Design Strength of Concrete (f_c) = 25 MPa

Design Strength of Reinforcement Steel (f_y) = 460 MPa

The design of the base slab will include the following steps:

Calculation of Dead Load: Dead load = (wall thickness x height x density of concrete) + (slab thickness x density of concrete)

Calculation of Live Load: Live load

Calculation of Total Load: Total load = Dead load + Live load

Calculation of Required Area of Steel (A_s): $As = (M \times 10^6) / (0.87 \times f_y \times d)$

Where, $M = (wL^2) / 8$, w = total load per unit area, L = span length of slab, and d = effective depth of slab

Spacing of bars, $s = (1000 \times L) / (Lx L- 1) = 500$ mm

Check for Shear: The shear force acting on the slab can be determined using the following formula:

V = (wL) / 2 Where, w = total load per unit area and L = span length of slab

3.4.6 Railings design

Geometrical requirements according to AASHTO rules:

Rail height: The minimum height of the railing measured from the top of the walk way surface to the top rail is 1097.28mm (AASHTO 2.7.3.2.1) and 1402.08mm for bicycle railing (AASHTO 2.7.2.2.1)

Rail spacing: Within a vertical band bordered by the walk way surface and a horizontal line 1097.28mm above the surface for pedestrian railing. And 1402.08mm above the surface for bicycle railing, the maximum clear vertical opening between horizontal rail elements is 400mm (AASHTO 2.7.1.2.4 and 2.7.2.2.2). Vertical elements of the railing assembly shall have a maximum clear spacing of 300mm within this band. If the railing uses both horizontal and vertical elements, the spacing requirement apply to one or the other, but not both.

Loading requirement for pedestrian and bicycle railing are based on the uniformly distributed load acting on rail elements. Minimum requirements for rail and post loads are as follows:

Rail loads: the minimum design loading for each pedestrian and bicycle rail element is w =50lb/ft, applied simultaneously in the transverse and vertical directions (AASHTO 2.7.3.2.2 and 2.7.2.2.3). When rails are located more than 1524mm above the walkway for pedestrian railing, or 1402.08mm above the walkway for bicycle railing, AASHTO loading is not required and loads are left to designer judgment (AASHTO 2.7.3.2.2 and 2.7.2.2.4)

Post loads: post loads are designed for upward transverse load wL, where L is the post spacing and w= 50ft/ft, (AASHTO 2.7.3.2.3 and 2.7.2.2.5). The load is

applied to the post at the center of gravity of the upper rail member, but not more than 1524mm above the walkway for pedestrian railing or 1402.08mm above the walkway for bicycle railing.

3.4.7 Connections

A connection consists of two or more members joined with one or more mechanical fasteners. Connections are one of the important considerations in timber bridge design because they provide continuity to the members as well as strength and stability to the system. There are two basic types of connections in timber bridges: lateral (shear) connections and withdrawal (tension) connections. In lateral connections, forces are transmitted by bearing stresses developed between the fasteners and the members of the connection and friction between members though not considered in design.

In the withdrawal connections, the mechanism of load transfer depends on the type of fastener, for screw-type fasteners, load transfer is by a combination of friction and thread interaction between the fastener and the wood. For driven fasteners such as nails, load transfer in withdrawal is entirely by friction developed between the fastener and wood.

Types of fasteners

Bolts: are the most common timber fastener for lateral connections where moderately high strength is required.

Lag screws: are pointed threaded fasteners with square or hexagonal head that are placed in wood members by turning with a wrench. They are of advantageous when an excessive bolt length is required or when access to one side of a connection is restricted.

Timber connectors: are steel rings or plates placed between members held by a bolt or lag screw. They are used in lateral connections only and provide the

highest lateral strength of all fasteners because of the large bearing area provided by the connector   .

Nails and spikes: are driven fasteners used in bridges primarily for nonstructural applications.   They are susceptible than other fasteners to loosening from vibrations and from dimensional changes in the wood caused by moisture content variations.

Drift bolts and drift pins: are long unthreaded bolts or steel pins that are driven in prebored holes. Drift bolts have a head on one end, but drift pins have no head

CHAPTER 4

INTRODUCTION

Design of structures (bridge) is define as the planning, determination of sizes, and arrangement of structural members so that external forces or loads on the structure are transmitted to the foundation in the most economical manner consistent with the purpose of the structure (V.O OYENUGA, 2011).

References	Calculations	Outputs
According to En 1991	Deck design Deck (Bridge)width = 3m Assume the deck is supported by 3 beams of depth 200mm and breath 100mm spaced at 1350mm to each other Deck span =Clear distance between beams $+\frac{1}{2}$ one of the beam width =1400mm	
Table 2.1 Nigeria timber structures (by AGUWA JAMES ISIWU,2016)	Imposed loads Pedestrian load 5KN/m Wind load 0.95 KN/m Total imposed loads 5.95KN/m Moment due to imposed load$=\frac{wl^2}{8}$ $$=\frac{5.95x1.4^2}{8}$$ =1.458KNm	Total imposed load: 5.95KN/m Moment:1.458KNm

Table 7.1 Nigeria timber structures (by AGUWA JAMES ISIWU,2016	Timber specie : Iroko Grade : N3 Modulus of elasticity: E_{min} =5652N/mm^2 Grade stress parallel to grain: f$_{gb}$ =23.61N/mm^2 Section modulus for deck , S: $\frac{M}{f_{gb}}$ $$\frac{1.458x1000x1000}{23.61}$$	
	=62X10^3 mm^3	Section modulus required 62x10^{3}mm^3
Table 2.3 Nigeria timber structures (by AGUWA JAMES ISIWU,2016	Choose a section 50mm depth by 130mm breadth Provided section modulus 130x10^{3}mm^3 Estimate dead load of deck Specific unit weight of Iroko =734kg/m^3 Length =1.4m Thickness =0.05m Estimated total dead of deck =734x10x1.4x0.05 =3.721N/mm Total estimated UDL on the deck: 5.95N/mm+3.721N/mm =9.671N/mm	Section modulus provided 130x10^{3}mm^3

	Total moment $=\dfrac{9.671\,x1400^2}{8}$	
	$= 2369395$Nmm	
	$f_{gb} =23.61$N/mm^2	
	Section modulus $= \dfrac{2369395}{23.61}$	
	$=100355.5697$Nmm^3	
	$= 101x10^3$Nmm^3	
	Section modulus required $= 101x10^3$Nmm^3	Provide sections depth
	Provide sections depth 75mm and breadth 125mm	75mm and breadth 125mm
	Section modulus provided $=$ 195x10^{3}Nmm^3 about x-x	Section modulus provided $=$
Table 7.1 Nigeria timber structures (by AGUWA JAMES ISIWU,2016		195x10^{3}Nmm^3 about x-x
	Acting bending stress, $f_{ab}=\dfrac{M}{S_x}$	
	$f_{ab}=\dfrac{2369395}{195x10^3}$	
	$f_{ab}=12.151$ Nmm^{-2}	$f_{ab}=12.151$ Nmm^{-2}
	$f_{pb} =f_{gb}$ x k	
	f_{pb} is Permissible bending stress	
	f_{gb} is the tabulated bending stress	
	K is modification factors relevant to the design:	
	$K_2 =$wet exposure strength characteristics $=0.8$	
	$K_3 =$ duration of loading factor $=1.25$	
	$K_7=$ depth factor $=(\dfrac{300}{h})^{0.11} = (\dfrac{300}{75})^{0.11} =1.165$	

Table 16 BS 5268	$f_{pb} = 23.61 \times k_2 \times k_3 \times k_7$	
	$f_{pb} = 23.61 \times 0.8 \times 1.25 \times 1.165$	
Table 17 BS 5268	$f_{pb} = 38.96 \text{ Nmm}^{-2}$	$f_{pb} = 38.96 \text{ Nmm}^{-2}$
	$f_{ab} < f_{pb}$ deck is said to be safe against	
Table 14.6 BS 5268	bending	
	Check for deflections:	
	δ_l =deflection of loads $= \dfrac{5wl^4}{384EI}$	
	W=udl on the bridge =9.671N/m	
	L=deck span of the bridge =1400mm	
	E=Modulus of elastic =	
	E_{min} =5652N/mm^2	
	I=Moment of area $= \dfrac{bh^3}{12}$	
	$= \dfrac{125 x 75^3}{12}$	
	$= 4394531.25\text{mm}^4$	
	δ_l =deflection of loads	
	$= \dfrac{5 x 9.671 x 1400^4}{384 x 5652 x 4394531.25}$	
	δ_l =deflection of loads = 19.476	
		$\delta_l < \delta_p$ =permissible
	δ_p =permissible deflection =0.003 * span	deflection= 42mm
	$< \delta_p$ =permissible deflection =0.03 * 1400mm	δ_l =deflection of loads
	$= 42\text{mm}$	= 3.58mm deflection
	$\delta_l < \delta_p$	satisfied

Check for maximum shear

Maximum shear force, $F_v = \dfrac{W}{2}$

$$F_v = \dfrac{9.671 x 1400}{2}$$

$$F_v = 6769.7N$$

Maximum shear stress at neutral axis $f_{av} = \dfrac{3F_v}{2A}$

A =75mm x125mm

A=9375mm^2

$f_{av} = \dfrac{3x6769.7}{2x9375}$

$f_{av} = 1.083Nmm^{-2}$

Permissible shear stress $f_{pv\ par} = f_{gv}k_3$

$\qquad f_{pv\ par} = 2.82\ x1.25$

$f_{pv\ par} = 3.525\ Nmm^{-2}$

$f_{av} = 1.083Nmm^{-2} < f_{pvs\ par} = 3.525\ Nmm^{-2}$

shear requirement satisfied

$\qquad$ W=total load

$\qquad$ A =Area of section

$\qquad$ f_{gv} =grade shear parallel to grain =2.82

$\qquad$ k_3=duration of load factor =1.25

$f_{av} = 0.709Nmm^{-2} < f_{pvs\ par} = 3.525\ Nmm^{-2}$

shear requirement

satisfied

Table 2.1: Basic stresses of some Nigeria timber at moisture content of 18% Table 2.1 Nigeria timber structures (by AGUWA JAMES ISIWU,2016)	**Beam design** Timber species : IROKO Grade stress parallel to grain: f_{gb} =23.61N/mm^2 f_{gv} =grade shear parallel to grain =2.82 f_{gc} =grade compressive stress perpendicular to grain=4.38 E=Modulus of elastic = E_{min} =5652N/mm^2 Length of beam = 7m Beam dimension according to deck requirements = depth 200m and breadth 100mm **Deck dead load and dead load moment** Specific unit weight of Iroko =734kg/m^3 Deck thickness =0.075m Dead load =734kg/m^3 x 0.075m x10ms^{-2} =550.5Nm^{-2} For interior beams, each beam supports a tributary deck width of 0.1m Deck dead load UDL, w_{DL}= 550.5Nm^{-2} x 0.1m w_{DL} = 550.5Nm^{-1} deck dead load moment, M_{DL} =$\frac{w_{DL} x\ L^2}{8}$

$$M_{DL} = \frac{550.5 \text{N}m^{-1} \, x \, (7m)^2}{8}$$

$$= 3371.81 \text{Nm} = 3371812.5 \text{Nmm}$$

For outside beams, each beam supports 0.05m of deck surface only and 0.05m of deck and 0.5 Nm^{-2} of rail

Deck dead load UDL, w_{DL}= 550.5Nm^{-2} x 0.05m +0.05(550.5Nm^{-2}+ 0.5 Nm^{-2})

$$= 55.075 \text{Nm}^{-1}$$

deck dead load moment, $M_{DL} = \frac{w_{DL} \, x \, L^2}{8}$

deck dead load moment, M_{DL}

$$= \frac{55.075 \text{N}m^{-1} \, x \, (7m)^2}{8}$$

$$= 337.33 \text{Nm} = 337334 \text{Nmm}$$

Assumed a beam of depth 200mm and breath 100mm and

Self-weight of beam w_b = Specific unit weight of Iroko =734kg/m^3 x 0.2 x 0.1 x 10

$$= 146.8 \text{Nm}^{-1}$$

Estimated beam dead load moment = M_{DL}

$$= \frac{w_{DL} \, x \, L^2}{8}$$

$$= M_{DL} = \frac{146.8 \, x \, 7^2}{8}$$

$$= 899.15 \text{Nm} = 899150 \text{Nmm}$$

Estimated live load on moment on beam M_{LL}=

$$\frac{w_{LL} \, x \, L^2}{8}$$

$$= \frac{5 \times 7^2}{8}$$

=30625000Nmm

In interior beam carrying larger load

Total moment = 3371812.5Nmm + 899150Nmm + 30625000Nmm

=34895962.5Nmm

Estimated section modulus, $S_y = \frac{bh^3}{6}$

$$\frac{100 \times 200^3}{6}$$

=133333333.3 mm^3

$$f_{ab} = \frac{M}{S_y}$$

$$f_{ab} = \frac{34895962.5Nmm}{133333333.3 \, mm3}$$

$f_{ab} = 0.261$

$f_{ab} = 0.261$

$f_{pb} = f_{gb} \times k_2 \times k_3 \times k_7$

$f_{pb} = 23.61 \times 0.8 \times 1.25 \times 1.165$

$f_{pb} = 38.96 \, Nmm^{-2}$

$f_{ab} < f_{pb}$ beam is said to be safe against bending

$f_{pb} = 38.96 \, Nmm^{-2}$

$f_{ab} < f_{pb}$ beam is said to be safe against bending

Prevention of lateral buckling that h/b must be less than the permissible

h/b permissible =5

	$\frac{h}{b}$ = $\frac{200}{75}$ =2.667 <5	$\frac{h}{b}$ = $\frac{200}{75}$ =2.667 <5
	Beam is said to be safe from lateral buckling that is h/b is less than the permissible	Beam is said to be safe from lateral buckling that is h/b is less than the permissible
from table 2.1 Nigeria timber structures(by AGUWA JAMES ISIWU,2016	**Shear check** Maximum horizontal shear stress at the neutral axis, not to exceed the permissible $f_{av} = \frac{3F_v}{2A} < f_{pv\ par} = f_{gv\ par}\ k_3$ $f_{av} = \frac{3F_v}{2A}$ F_{av} =acting vertical shear force = $\frac{wL}{2}$ $= \frac{5.6973\ x\ 11.1\ x1000}{2}$ = 19940.55 N A=area of the beam =75mm x 200mm = 15000 $f_{av} = \frac{3\ x\ 19940.55\ N}{2\ x\ 15000}$ f_{av} =acting maximum horizontal shear stress for a rectangular beam =1.994Nmm^{-2} $f_{pv\ par}$ =permissible shear stress parallel to the grain = $f_{pv\ par} = f_{gv\ par}\ k_3$ $f_{gv\ par}$ = grade shear stress = 2.82Nmm^{-2}	

k_3 =duration factor =1.25

$f_{pv\ par}$ =permissible shear stress parallel to the grain =2.82 x 1.25

=3.525 Nmm^{-2}

f_{av} = 1.994Nmm^{-2}< $f_{pv\ par}$ = 3.525 Nmm^{-2}

shear okay

Deflection check

both the bending and shear deflections added together should not exceed the permissible deflection

δ_t =total deflection = deflection caused by bending + deflection caused by shear

$$\delta t\ =\ \frac{5wL^4}{384E_{min}I_x}+\frac{12wL^2}{5E_{min}A}\ <\delta_p$$

=permissible deflection =0.03 * span

$$\delta t\ =\ \frac{5wL^4}{384E_{min}I_x}+\frac{12wL^2}{5E_{min}A}$$

w   =uniform   distributed   loading

=5.6973Nmm^{-1}

L = span =7m =7000mm

E_{min} = minimum modulus of elasticity =E_{min}

=5652N/mm^2 x k3 x k$_7$

= 5652N/mm^2 x 1.25 x 1.165

=8230.725 N/mm^2

I_x = Second moment of inertia =$\frac{bh^3}{12}$

---

f_{av} = 1.994Nmm^{-2} < f_{pv}

$_{par}$ = 3.525 Nmm^{-2}

shear okay

	$=\dfrac{100\ x200^3}{12}$	
	$=66666666.67\text{mm}^4$	
	A=area of the beam =75mm x 200mm = 15000	
	$\delta t\ =\ \dfrac{5\ x\ 5.6973\ x\ 11100^4}{384\ x8230.725\ x\ 66666666.67}$	
	$+\dfrac{12\ x\ \ 5.6973\ x\ 11100^2}{5\ x\ 8230.725\ \ x\ 15000}$	
	=330.03	
	permissible deflection =0.03 * span	
	=0.03 x 7000	
	=201	
	Deflection check failed, we increase the timber depth and breadth to 200mm to 3000 and redesign	
Table 2.1: Basic stresses of some Nigeria timber at moisture content of 18%- Nigeria timber structures (by AGUWA JAMES ISIWU,2016	$I_x =$ Second moment of inertia $=\dfrac{bh^3}{12}$ $=\dfrac{200\ x300^3}{12}$ $=450000000\text{mm}^4$ $\delta t\ =\ \dfrac{5\ x\ 5.6973\ x\ 7000^4}{384\ x8230.725\ x\ 450000000}$ $+\dfrac{12\ x\ \ 5.6973\ x\ 7000^2}{5\ x\ 8230.725\ \ x\ 60000}$ =49.446 permissible deflection =0.03 * span =0.03 x 7000 =210 Applied deflection $<$ permissible deflection Deflection satisfied	Applied deflection $<$ permissible deflection Deflection satisfied

Bearing stress

Bearing stress at the supports and under any point loads should not exceed the permissible

$$f_{ac\ per} = \frac{F_r}{bL_b} < f_{pc\ per} = f_{gv\ per} * k_3 * k_8$$

$f_{ac\ per}$ =applied compressive stress perpendicular to the grain

$f_{pc\ per}$ =permissible compressive stress perpendicular to the grain

$f_{gv\ per}$ =grade compressive stress perpendicular to the grain = 4.38

F_r =end reaction =$\frac{wL}{2}$ = $\frac{5.6973 \ x \ 7000}{2}$

=19940.55N

b = breadth =300mm

L_b = end bearing length = 300mm

K_3 =duration factor = 1.25

K_8 =load sharing factor = 1.1

L = span =7000

w = uniformly distributed load=5.6973

$f_{ac\ per} = \frac{19940.55}{300 \ x \ 300}$

=0.222

$f_{pc\ per} = 4.38* 1.25 * 1.1$

=6.0225

$f_{ac\ per}$=0.351 < $f_{pc\ per}$ =6.0225

$f_{ac\ per}$=0.222 < $f_{pc\ per}$

=6.0225

bearing satisfied

66

bearing satisfied

Design of Reinforced Concrete Enbankment Wall:

Design Loads:

a. unit weight of concrete = 24 kN/m^3

b. Live Load: Pedestrian and cyclist load = 5 kN/m²

Design of Reinforced Concrete Wall:

The reinforced concrete embankment wall will be designed as a cantilever retaining wall.

The following assumptions will be made for the design:

a. Thickness of the wall =300 mm
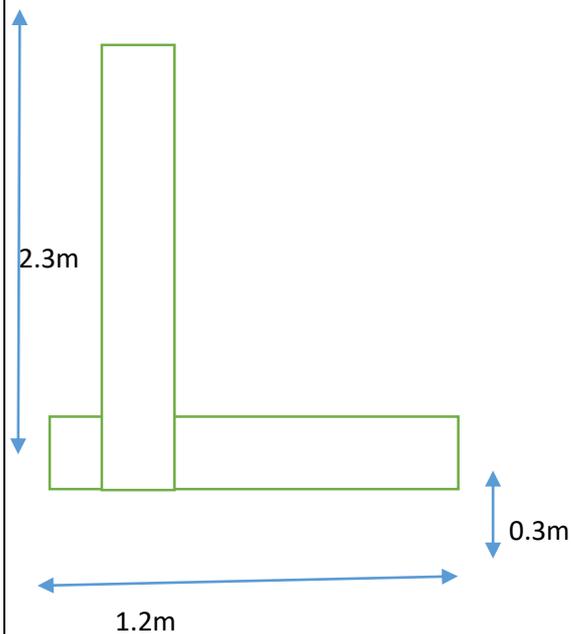
b. Height of the wall = 2.3 m

c. Soil Density (γ) = 18 kN/m³

d. Angle of Internal Friction (φ) = 35°

e. Design Strength of Concrete $(f\_c) = 25$ MPa

f. Design Strength of Reinforcement Steel (f_y) = 460 MPa

g. Soil bearing capacity = 200 kN/m²

h. coefficient of friction, $\mu = 0.5$

2.3m

0.3m

1.2m

Active pressure

$K_a = \tan^2 (45-\frac{\emptyset}{2}) = \tan^2 (45-35/2) = 0.276$

$P_a = k_a \gamma H = 0.276 \times 18 \times 2.3 = 8.94 \text{KN/m}^2$

Earth pressure$= 8.94 \times 2.3 \times 0.5 = 10.281 \text{KN}$

Surcharge$= 0.276 \times 5 \times 2.3 = 3.116 \text{KN}$

Total horizontal load$= 13.397 \text{KN}$

Total horizontal load = 13.397 KN

	Vertical load	
	Wall load =0.3x2x24 =14.4KN	
	Base=0.3x1.2x24 =8.64KN	
	Backfill =0.7x2x18 =25.2KN	Total vertical load =48.24KN
	Total =48. 24KN	
	In no heel beam case, the condition $\mu(1.0G_k+1.0Q_k)\geq \gamma_f H_k$ must be satisfied	
	Sliding force =1.35(10.28)+1.5(3.116)=18.618KN	Sliding force = 18.618kN
	For resisting effect, a factor of 1.0 is applied to the permanent load and 0.00 for variable surcharge loads	
	Frictional resisting force =1.35(1.0x48.24+0.00x5x0.7)=24.12Kn	Frictional resisting =24.12KN 24.12 > 18.618 OK!
	24.12>18.618	
	Hence, the wall is adequate against sliding	
	Overturning	
	Overturning moment	

R.C.D oyenuga	Earth =10.281x2.3/3 =7.88KNm Surcharge 3.116x2.3/2 =3.58KNm Total overturning =11.46KNm Resisting moment Taking moment about the toe Wall =14.4x0.35 =5.04KNm Base = 8.64 2.3/2 =9.936 Backfill =25.2(0.35+0.5)=21.42KNm Total = 5.04+9.936 +21.42=36.396KNm For the overturning moment, a factor of 1.1is applied to earth pressure and factor of 1.5 to surcharge pressure Overturning moment=1.1(7.88)+1.5(3.58) = 14.038 For resisting moment, a factor of 0.9 is applied to permanent load and 0.00 to the variable surcharge load. Resisting moment =0.9(36.396)+0.00(5x0.7x0.35x0.5 =32.76KNm	Total overturning moment = 14.038KNm Total Resisting Moment =32.76KNm 32.76 > 14.038 OK!

32.76 > 14.038

Hence, wall will not fail by over turning

From $P = \dfrac{W}{BD} \pm \dfrac{6M}{BD^2}$

B=1.0m, D=1.2m

Applying the various factors of safety and taking moment about base center line

M =1.35(10.281x2.3/3) +1.5(14.4x0.25) - 1.0(25.2(0.6-0.35))

M =10.64+5.375+4.86-6.3 = 14.575

$P = \dfrac{1.35(14.4+8.64)+1.0(25.2)}{1x1.2} \pm \dfrac{6x14.575}{1x1.2^2}$

46.92±72.875

P_{max} =119.795KN/m^2

P_{min} =25.9KN/m^2

Maximum pressure is less than soil bearing pressure i.e 119.795< 120 OK!

Structural design of members

Wall

P_{max} =119.795KN/m^2

P_{min} =25.9KN/m^2

119.795< 120 OK!

	Horizontal moment	
	=1.35(10.28x2/3)+1.5(3.1162/2)	
		d = 242mm
	M = 33 KNm (ULS)	
	h =300mm, d=300-50-8=242mm	
	$k = \frac{33x10^6}{25x1000x242^2} = 0.023$	
	$Ia = 0.5 + \sqrt{0.25 - \frac{0.023}{1.134}} = 0.95$	
		Provide Y_{12} @ 250 c/c
	$As = \frac{M}{0.87Xf_y I_a d} = \frac{33x10^6}{0.87x460x0.95x242} = 359mm^2$	N.F (As prov=452mm²)
	Provide Y_{12} @ 250 c/c N.F (As prov=452mm²)	
	Base	
	The base is designed using the bearing pressure at ultimate limit state	
	Taking moment about the base center line we have :	
	The pressure diagram and other forces as shown below	

Heel

$$P = 25.9 + \frac{0.7x(119.75-25.9)}{1.2} = 80\text{KN/m}^2$$

Design moment at point C

$$\frac{34x0.7}{2} + \frac{0.7x8.64x1.35x0.35}{1.2} - \frac{25.9x0.7^2}{2}$$

$$-\frac{54.1x0.7x0.7}{2x3} = 26.9\text{KNm}$$

M =26.9KNm

d =300-50-8 =242

$$k = \frac{26.9x10^6}{25x1000x242^2} = 0.018$$

$$Ia = 0.5 + \sqrt[2]{0.25 - \frac{0.018}{1.134}} = 0.95$$

d = 242mm

	$As = \dfrac{26x10^6}{0.87x460x0.95x242} = 292mm^2$	Provide Y_{12} @250 c/c top and bottom (As prov=452 mm^2)
	Provide Y_{12} @250 c/c top and bottom (As prov=452 mm^2)	
	Toe	
	$M_B \approx \dfrac{80x0.2^2}{2} = 1.6$	
	Provide same reinforcement as above	Y_{12} @ 250 c/c top and bottom
	Y_{12} @ 250 c/c top and bottom**Rail provisions**	
	according to AASHTO	
	Maximum vertical clear spacing =400mm	
	Maximum horizontal clear spacing =300mm	
	Height of rail =1100mm	
	Provide 3 (50mm x 50mm) timber for horizontal railing (spacing=366 mm)	
	Provide 22 (50mm x50mm) timber vertical railing (spacing =295mm)	

	Connections
	lag-screw is used in all connection in this design. It is used due to its long length to join slab beam and beam to bearing

4.1 Summary of design output

Timber members	Design output
Beam	200mm x 300mm
Deck	75mm x 125mm
Bearing	300mmx300mmx300mm
Railings	50mmx50mm
Deflection	Both members satisfy deflection requirement
Shear	satisfactory
Lateral buckling	satisfactory
Reinforced concrete member	
Wall	12mm diameter @250mm c/c
Base	12mm diameter @ 250mm c/c
distribution	10mm diameter @300 c/c

For abutment

Volume of concrete

Base $= 1.2 \times 0.2 \times 3 = 0.72m^3$

Wall $= 3 \times 2 \times 0.2 = 1.2m^3$

Total volume of concrete $= 1.92 \ m^3$

For two abutments, volume $= 3.84^3$

Density of concrete $= 2400kg/m^3$

Mass of concrete 2400 x 3.84 =9216kg

Mix ratio = 1: 2: 4

Mass of cement =1316kg = 27 bags of cement @ #4500 = #121500

Mass of sand = 2633.14kg = 2.6 tonnes @#10500 = #37800

Mass of coarse aggregate =5266kg =5.3 tonnes @ #6000 = #31800

Total cost of concrete = 121500+37800+31800 = # 191100

Table 4.2 Summary of abutment reinforcement cost

Bar diameter	No. of bars	Length (m)	Total length(m)	Standard length(m)	No. of standard length(m)	Price per standard length(m)	Total price (#)
Wall							
12mm	24	2.3	55.2	12	4.6	5000	23000
10mm	12	3.2	38.4	12	3.2	3800	12160
Base							
12mm	24	1.4	33.6	12	2.8	5000	14000
10mm	6	3.2	19.2	12	1.6	3800	6080
Total							#55240

Table 4.3 Cost of Timber material

Members	No. of members	Dimensions of member	Unit price (#)	Total amount (#)
Deck	50	75mm x 125mm x 3.6m	2500	125000
Beam	3	200mm x 300mm x 7m	10400	31200

Bearing	1	300mm x 300mm x 3.6m	8500	8500
Fastener	5 pounds	Length = 152.4mm	2100	10500
railing	25	50mm x 50mm	450	11250
Total				184450

Table 4.4 Summary of the bridge total cost

Materials	Price (#)
Concrete	191100
Reinforcement	55240
Timber	184450
Total Bridge cost	430790

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Wood is known for its versatility. The adoption of timber as a load bearing material for pedestrian bridges in Nigeria could bring a solution to makeshift bridges seen in most rural area.

From results obtained, it was concluded that Nigeria timber, as a load bearing material, can withstand the horizontal, vertical, overturning and shearing stresses experienced by short span pedestrian bridges.

Timber bridges are most suitable in rural area where short span pedestrian bridges are required due to their availability, cost and sustainability.

Timber pedestrian bridge is relatively cheap and easy to construct. And also Timber can be comfortably used as composite together with reinforced concrete to give even greater strength but at a lesser cost compared to when concrete or reinforced concrete is solely used for all the bridge structural members.

5.2 Recommendation

1) It is recommended based on the negative effect of the unavailability of timber Species, that government will place a ban on bush burning in order to encourage forestation and growing of sufficient tree for timber structures.

2) It is recommended based on its necessity and urgency that young engineers are equipped with adequate knowledge of the structural use of timber material to avoid restricting timber material to only interiors uses.

3) Cutting down of trees prematurely should be strictly dissuaded, to encourage production of timber with high structural strength.

4) Further research on Nigeria – timber as a structural components should be encourage by the Government, Schools and Research Institutions as timber is a more cost - effective and sustainable alternative.

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