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Structural Design of Concrete Bench Using Bamboo as Replacement to Steel

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ABSTRACT
Environmental management basically known as the idea which entails practices that encourages sustainable development and reduction of environmental impact within the natural world. Thispaper is aimed at reduction of environmental degradation which results from iron ore mining and encourages the use of environmentally friendly material Bamboo in construction activities. Ultimate limit state method is used to structurally design a concrete bench with bamboo as replacement to Steel,The method helps determine the stability of a concrete bench at maximum loading, this means the design can determine safest load expected of the bench to accommodate without failure when using bamboo as reinforcement. Fresh green fully grown bamboo are sliced into four pieces and used as reinforcement for the footing,legs (column) and the slab respectively. the structural the design determined soil bearing capacity of approximately 198kpa, column load was 840kn while footing is $1.42m^2$alsothe legs (column) and slab using bamboo as reinforcement has load capacity of 14.38kn. Practical illustration of the design was carried out with wooden formwork, casted in-situ and finally tested to confirm the structural design. It can be deducted that bamboo has a good bonding with concrete and can be a perfect replacement to steel reinforcement in construction work.

Keywords: Environmental management, Reinforcement, Bamboo, Ultimate limit state,

I. INTRODUCTION

Construction is one of the direct indicators of physical development within every locality or human settlement, Due to the increasing need for structural development, there is rapid increase in construction materials cost. This material may include concrete, steel and cement.

Concrete and steel are universally accepted construction material that are vital to construction project everywhere in the world, this means Concrete and steel work hand in hand in order to stabilize a structure with strength and durability. Due to the increasing cost of this materials, There is need to explore more materials in order to have alternative to each and every one of them.

Steel reinforcement has been used in a variety of structural concrete applications decades; However, its susceptibility corrosion is the major drawback. Corrosion is often initiated by either concrete carbonation or exposure of the concrete element to chloride ions, as discussed in many studies (Broomfield, 2002 and Benturet al., 2017).

The concrete matrix creates a layer around the steel member by providing an alkaline environment with a pH level of 12 to 13, where a thin oxide layer forms on the steel reinforcement prevents iron atoms from dissolving. Hence, steel reinforcement remains in a passive state and the corrosion is prevented or largely reduced (Almusallam, 2001 and Yoon et al., 2000).

Grantham et al., (2011)made emphasis to thevarious methods used to investigate corrosion of steel by researchers worldwide in order too overcome that in concrete. Methods like Improving the quality of concrete, employing protective coating on reinforcement bars, and the application of non-ferrous and non-metallic reinforcement materials are some of the many ways to reduce the problems that are associated with corrosion of steel reinforcement bars in concrete.

Corrosion is one of the basic shortcomings of steel in construction while cost and environmental degradation during extraction of the raw materials contributes to its disadvantages. The need for alternative material which will have similar properties to steel is highly recommended.

Allot of researchers tried to identify the potential of bamboo as a replacement to steel in reinforced concrete or in construction work at large, This will help reduce construction cost and also eliminate the case of corrosion or even environmental degradation of raw material.

An Overview of Bamboo

Bamboo belongs to the botanical family of grasses and it has relatively high tensile capacity, thus making it a potential reinforcement alternative for steel (Liese, 1985 and Ardle, 2005). Some species of bamboo have shown tensile strength of up to 600 MPa and single bamboo fibers can reach a tensile strength as high as 2000 MPa (Osorio, et al., 2011).

The idea of employing bamboo for concrete applications is not new,In 1914, Hou-kun Chow, at MIT tested for the very first time small diameter raw bamboo as reinforcement materials for concrete members (Chow, 1914). Later on, in 1935, Datta and Graf from Stuttgart investigated the potential applications of raw bamboo in concrete, However, they were not successful in implementing full-scale applications due to problems that are associated with debonding of natural bamboo from the concrete matrix as a result of water absorption and swelling (Hidalgo-Lopez, 2005).

In recent years, there has been a renewed interest in bamboo as a sustainable and eco-friendly material for construction, furniture, and consumer products. The environmental benefits of bamboo, such as rapid growth, minimal resource consumption, and carbon sequestration, have led to its adoption in green building practices and sustainable development initiatives (Ding, 2018). Moreover, the cultural heritage and aesthetic appeal of bamboo continue to inspire architects, designers, and artists worldwide (Stiles, 2017).

Bamboo is a woody herbaceous plant which is found in Asia, South America and Africa. Its culms present large variations of its physical properties along the length and cross-section, inducing variation of its mechanical properties. The analysis aims to determine the longitudinal culms Young's modulus along its radius and to investigate the effect of different structural parameters in order to explain its natural efficiency. Bamboo is an excellent resource because it has been used and known to the world due to its origin, its way of usage both economically and industrially (Ghavami, 2005).

Bamboo has a rich history spanning thousands of years. It's been used for various purposes, from construction and medicine to art and cuisine. In Asia, especially China, bamboo has been integral to daily life for centuries. Its strength, flexibility, and rapid growth make it a versatile resource. Bamboo has also gained popularity globally for its sustainability and eco-friendliness (Liese and Kohl, 2015). Bamboo's history is extensive, dating back thousands of years. It has been integral to the cultures and economies of various regions, particularly in Asia. Bamboo's use dates back to ancient times, with evidence of its utilization in China over 7,000 years ago. It was used for construction, weaponry, and even as a medium for writing. Bamboo's strength-to-weight ratio makes it an excellent construction material. Throughout history, it has been used to build houses, bridges, scaffolding, and even musical instruments (Haig, 2012).

Bamboo as used for reinforcement in Concrete

Zhang and Han (2019) conducted experimental test on bamboo-reinforced concrete beams and found that bamboo reinforcement provided comparable strength and ductility to steel reinforcement, demonstrating its potential as a viable alternative in structural applications.

Similarly, Li et al., (2020) investigated the flexural behavior of bamboo-reinforced concrete beams and concluded that bamboo reinforcement exhibited satisfactory load-carrying capacity and deformation characteristics, highlighting its suitability for use in concrete structures.

Studies by Ariffinet al., (2018) and Liu et al., (2021) explored the bonding characteristics between bamboo and concrete interfaces. They found that proper surface treatment of bamboo and the use of appropriate bonding agents improved the bond strength and durability of bamboo-reinforced concrete.

Furthermore, research by Duanet al., (2017) investigated the effect of different bamboo species on the mechanical properties and bond strength of bamboo-reinforced concrete, providing valuable insights into material selection and compatibility.

Hu et al., (2019) proposed a design methodology for bamboo-reinforced concrete structures based on analytical models and finite element analysis. Their study highlighted the importance of optimizing reinforcement layout and spacing to maximize structural performance.

Additionally, Liang et al., (2022) developed innovative construction techniques for integrating bamboo reinforcement into concrete elements, including prefabrication methods and

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specialized formwork systems, to enhance construction efficiency and quality.

Research by Zhang et al., (2020) evaluated the durability of bamboo-reinforced concrete under various environmental exposures, including moisture, freeze-thaw cycles, and chloride ingress. Their findings indicated that bamboo reinforcement enhanced the durability and resistance of concrete against degradation mechanisms.

Furthermore, studies by Wang et al., (2018) and Liu et al., (2020) investigated the long-term performance of bamboo-reinforced concrete structures in real-world applications, demonstrating their resilience and sustainability over extended service life.

Analysis by Yang et al., (2019) compared the cost-effectiveness of bamboo and steel reinforcement in concrete structures, considering material procurement, fabrication, and construction costs. Their findings suggested that bamboo reinforcement could offer significant cost savings and environmental benefits, particularly in regions with abundant bamboo resources.

Moreover, studies by Yu et al., (2021) and Liu et al., (2019) assessed the environmental sustainability of bamboo-reinforced concrete through life cycle assessments, highlighting its potential to reduce carbon emissions, energy consumption, and resource depletion compared to steel reinforcement.

Overall, the literature indicates that bamboo holds promise as a sustainable and cost-effective alternative to steel reinforcement in the design and construction of concrete bench, offering comparable structural performance, enhanced durability, and positive environmental impacts. However, further research is needed to address challenges related to material standardization, construction practices, and market adoption to fully realize the potential of bamboo-reinforced concrete technology.

Characteristics of Bamboo and Its Strength

According to research conducted, experimentally bamboo tensile strength varies from 140 N/mm2 - 280 N/mm2 which is comparable to that of mild steel. This together with other characteristics has made Bamboo a more visible option as a construction material (Lakkad, and Patel, 2011). It has also been found that bamboo acts very well in buckling but due to low stresses than compared to steel and due to it not being straight it may not be very good. Further, it has been established that in seismic zones the failure of bamboo is very less as the maximum absorption of the energy is at the joints.

Cellulose is the main component present in bamboo which is the main source of mechanical properties of bamboo (Mehra and Ghosh, 2015).

Some specific properties of Bamboo according to Lakkad, and Patel, (2011), are as given below:

Specific gravity - 0.575 to 0.655
Average weight - 0.625 kg/m
Modulus of rupture - 610 to 1600 kg/cm2
Modulus of Elasticity - 1.5 to 2.0 x105 kg/cm2
Ultimate compressive stress - 794 to 864 kg/cm2
Safe working stress in compression – 105 kg/cm2
Safe working stress in tension - 160 to 350 kg/cm2
Safe working stress in shear - 115 to 180 kg/cm2
Bond stress - 5.6 kg/cm2
Source: Lakkad, and Patel, (2011)

Properties of Bamboo Reinforcement

Bamboo is mainly a tropical and subtropical plant which is found adequate in China. Many studies find that the physical as well as mechanical attributes vary with respect to diameter, length, age, type, position along culms, and moisture content of bamboo. The use of bamboo as a reinforcement in concrete is a comparatively new concept but has been evolved because of increases in demand of low-cost building material. One of the significant properties that would make bamboo an attractive alternative to steel in reinforced concrete is its tensile strength. The tensile strength of bamboo is greater than most timber products which are advantageous, but it is approximately half the tensile strength of steel. Bamboo is very light in weight compared to steel. This is the fact that the ratio of tensile strength to specific weight bamboo is six times greater than that of steel (Xiao et al., 2009). Due to its low modulus of elasticity, bamboo can crack and deflect more than steel reinforcement under the same conditions. A list of the positive mechanical properties of bamboo reinforcement is given below (Xiao et al., 2009).

(1) High tensile strength
(2) Light weight-to-strength ratio (compared to steel)
(3) High shock absorbing and seismic building material
(4) Free-cutting and processing

These above properties put bamboo on the list of viable structural materials. These properties when combined, suggest that bamboo will make a fine addition to the selection of potential reinforcement bar materials. Bamboo reinforced concrete design is similar to steel reinforced

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concrete design. Bamboo reinforcement in concrete structures can be assumed to have the mechanical properties (Matsuo, and Takami, 2009) as shown in Table I. Steel reinforcement in concrete structures can be assumed to have the mechanical properties as shown in Table II.

Mechanical Properties of Bamboo Reinforcement used in Concrete Structures

Mechanical Property	Value (SI)
Allowable curve compressive stress	65 Mpa
Allowable axial compressive stress	50 Mpa
Ultimate tensile stress	600 Mpa
Allowable tensile stress	400 Mpa
Allowable shearing stress	4.5 Mpa
Allowable bond stress	0.35 Mpa
Modulus of elasticity	14000 Mpa
Density	700 kg/m3

Key: Mpa = megapascals
Source: Matsuo, andTakami, (2009)

Mechanical Properties of Steel Reinforcement used in Concrete Structures

Mechanical Property	Value (SI)
Allowable yield stress	400 Mpa, 600Mpa for high-strength steel
Ultimate tensile stress	400 – 600 Mpa, 1000Mpa for high-strength steel
Allowable elongation	20%
Modulus of elasticity	200 Gpa
Ductility	20%

Key: Mpa = megapascals, Gpa = gigapascals
Source: Neville, (2011).

II. METHODOLOGY

The methods used in order to achieve the result include, structural design using ultimate limit state in accordance to BS 8110, a step by step design was carried on each component of the bench which include the footing, the legs and the slab. Soil bearing capacity was calculated using terzaghi's formula for shallow foundation which directly relate to the base of the our concrete bench.

The formula N = 0.9FcuAc - 0.85fy is used to calculate the ultimate axial load capacity (N) of a reinforced concrete column with all the variables clearly defined. Concrete Compressive strength (fc) was identified and factors like the slab's dimensions,ultimate moment capacity (Mu), ultimate moment capacity (Mu), Mbeam and maximum deflection where carefully calculated.

The practical conceptualization of the design was done using 1.8meter length by 40cm breadth by 20cm thickness for the footing while 40 wide cm by 15cm thick by 60cm as height of the bench legs. also 1.8meter length by 40cm breadth by 15cm was used as dimension for the slab. Physical demonstration was done using concrete 1:2:4 (M15) and casted in-situ in a wooden formwork.

STRUCTURAL DESIGN

The following components of a concrete bench are structurally designed in accordance to BS 8110 in similarity with the way designs are carried out for building structural components.
Column design is substituted for the legs of the bench while the slab stands for the bench top and the soil bearing capacity stand as the soil which the structure will be standing on.

- Soil bearing capacity
- Column
- Slab

1- SOIL BEARING CAPACITY(q)
Terzaghi's Formula (for shallow foundations):
$q = 1.3cNc + \sigma zNq + 0.4\gamma BN\gamma$
where:

2- COLUMN LOAD
The formula N = 0.9FcuAc - 0.85fyas is for calculating the ultimate axial load capacity (N) of a reinforced concrete column.
-Concrete properties:
- Compressive strength (f'c)

3- SLAB
1. Determine the slab's dimensions:
- Length (L),Width (W),Thickness (h)

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2. Ultimate moment capacity (Mu)
Mu = 0.45 x fck x b x d^2
3.Determine ultimate moment capacity (Mu)
-Total load (W) = 1.4GK + 1.6QK
4.Check Mbeam = Load x span / 2
5.Calculate the maximum deflection (δ)
δ = (5 × w × L^4) / (384 × E × I)

III. RESULT

The design result of structural components include soil bearing capacity which was calculated using Terzaghi's formula, giving a value of 593.3 kN, while column load was determined to be 840 kN using the formula for reinforced concrete columns.The dimensions of the footing were determined with an area of 1.42 m² and a thickness of 1.18 m. result for bending moment has a value of 26.4 kN·m and shear force was calculated to be 700 kN/m.

The column dimensions were defined with a length of 0.6 m, a width of 0.4 m, and a thickness of 0.15 m.

The moment capacity of the column was calculated to be 225.32 kN·m, higher than the moment due to the expected load of 27.07 kN·m.The slab dimensions were set at 2 m long, 0.6 m wide, and 0.15 m thick

PRACTICAL DEMONSTRATION

In order to bring out the best of this design, the dimension practical demonstration was carried out and every step was carefully conducted. The bamboo material was sliced into four strands and binding wire was used to bind the different pieces as it is done with the normal steel reinforcement even, thou the bamboo slice are thicker in size. Bamboo matt was formed with five parallel runners of 1.8-meter-long at 15cm spacing and nice short braces of 25cm spacing. Fig 1.

The legs were form worked and casted with rounded bamboo which does not need to be sliced. This bamboo was based with the bamboo footing and casted while standing in the wooden box of height 70 cm. fig2

The slab is also reinforced with bamboo matt as that of the footing was mad and also casted in wooden formwork with concrete of grad M15 (1:2:4). Fig 3.

Finally the formwork are striped and structurally designed concrete bench is reveled.fig4

Step in construction of bamboo reinforced concrete bench Fig1,2,3and 4

IV. CONCLUSION

This paper has presented the importance of bamboo as environmentally friendly materialthat can substitute the tradition steel which dominates the construction industry for decades. Factors like cost, availability, Tensile strength and durability makes it a more promising material. Structural design of structure in order to ascertain its load resistivity and strength can also be carried out on other structural material aside frombuilding and bridges., compared to steel. It can be concluded that potentials of bamboo in a built environment is still yet to be fully explored.

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