



**ASSESSMENT OF ASSOSA BAMBOO (*Oxytenanthera abyssinica*) AS AN
ALTERNATIVE SCAFFOLDING MATERIAL**

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Abstract

The local construction industry exploits indigenous material like timber for different construction activities following the many development activities. Timber is a major building material that is frequently used for key activities like scaffolding system in construction. This demand of timber is creating a considerable gap between demand and supply and this is threatening the remaining meager forest resources of Ethiopia. In contrary, use of environmentally friendly and sustainable building material promotes conservation of declining timber resources locally. Bamboo is one of a renewable natural resource used for many purposes in many parts of the world. Bamboo as a construction material is also popular in Southeast Asia. Even if Ethiopia is among those countries with abundant bamboo population, the utilization of the Bamboo is limited to construction of house, fences, some ordinary furniture's and household utensils. Since, the absence of material standards and local engineering methods has restrained the use of bamboo in the construction industry and limited its use for non-engineered construction in rural areas of the country. Bamboo is being used in structural works as well as for temporary structures like scaffolding in other parts of the world. The use of bamboo for scaffolding in other countries demonstrated advantages over other types of scaffolding systems due to its flexibility, low cost and speed of construction. The rational of this research is detail evaluation of the physical and mechanical characteristics of Assosa bamboo and its utilization potential with regard to scaffolding. Assosa bamboo is selected for this study considering its lowland, abundant, and solid to semi-solid nature of culm. Based on the findings of this study, bamboo is found comparable to other conventional structural materials in terms of most material properties. Therefore, this research demonstrates the versatility and ability of Assosa bamboo (*Oxytenanthera abyssinica*) for scaffolding and similar structural purposes which could pave away to standardization pursuing wider acceptance and use as a structural material.

Key Words: Assosa, Bamboo, Scaffold, Culm, Structure, Sustainable

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Chapter One

Introduction

1.1 Overview of the study

The local construction industry exploits industrial products and natural indigenous natural resources like timber for many development activities. Timber is a natural resource harvested to meet society demand for different purposes. The decline in resource of timber through deforestation has a negative impact on the environment and reducing the demand of timber for construction through other alternative is necessary. The need to identify an alternative material which is sustainable, environmentally friendly and widely available promotes conservation of dwindling timber resources locally. One species that is natural resource is bamboo, using it as a construction material can reduce the pressure on use of local timber.

Bamboo is fast growing woody grass and natural resource, used for construction extensively for many centuries by people all over the world. It also has a long history of usefulness in the field of construction, particularly in Asian countries. The properties of bamboo such as resilience, shape and strength make it an ideal material for construction purposes (Chan, 2002). In recent years bamboo has also become an industrial raw material and substitute for soft and hard wood in most Asian countries (Aiyin, 2010). However, it is not a popular industrial material in Ethiopia and its application has been limited to traditional household use. Ethiopia is one of the Countries with large bamboo coverage.

Bamboo plants are indigenous to the tropical and temperate regions only, found in abundance particularly in Southeast Asia (Banik, 1995). It is reported that more than 1500 bamboo species are found in the world, covering more than 14 million hectares (Ohrnberger, 1999). It is estimated that bamboo coverage of Ethiopia accounts for 67% of Africa's entire bamboo resources with about 1 million hectares of bamboo forest and also constituting 10 % of Ethiopia's total forest coverage (Luso, 1997).

According to African Bamboo (2011), there are two bamboo species namely; the *Yushania alpina* "highland bamboo" comprising 20% of the bamboo resource and the *Oxytenanthera abyssinica* "lowland bamboo" constituting 80% of the Ethiopia's bamboo resources.

Bamboo is widely used in other parts of the world for construction purposes either in its natural form or as a processed/enhanced material. The reasons for this are the low cost of production as well as the outstanding durability and strength of bamboo culms. Traditionally bamboo is used extensively in handicraft, making of chopsticks, blinds, mats, carpets, and furniture but its true market potential is in industrial processed products like flooring and panels (African Bamboo, 2011).

The physical and environmental properties of bamboo make it an exceptional economic resource for a wide range of uses. Bamboo has high strength, low weight and easily worked using simple tools. This characteristic can be attributed to its hollow stem and nodes. In addition, it can be harvested within short periods of time in comparison to timber and has a good influence on the climate of the region which helps control erosion. Bamboo used in the construction industry can be either in the form of full culms or splits. It may be used in any one of the following building construction areas: Scaffolding, Foundations, Framing, Flooring, Walls and Roof Trusses (Aiyin, 2010).

In Ethiopia, bamboo in the construction industry is mainly used for building traditional houses and fences. But unlike other countries with large bamboo resources it is rarely used as an input to produce various industrial and construction products (Haile, 2008). Recent studies conducted by local researchers have shown bamboo to be an ideal material for many construction applications. This research explores Assosa bamboo (*Oxytenanthera abyssinica*) as scaffold material; assess the physical and mechanical properties; adopt design procedures; discuss scaffold erections, maintenance, and dismantling. It also adapts the best international standards and practices to suit the local application of bamboo as a scaffold material thereby integrating into local standards and practices.

In view of this, locally available and sustainable material should be considered as alternative construction material which reduces the environmental impact associated with the use of timber (eucalyptus) and provide a means to use this vast resource. Hence, this study tries to investigate the potential and application of Assosa bamboo (*Oxytenanthera abyssinica*) as an alternative scaffolding material.

1.2 Statement of the problem

In recent periods, vast construction undertakings are being carried out by both government and private firms that consumes large quantities of non-renewable resources. Majority of these construction activities involves use of Eucalyptus tree, non-renewable natural resource, as a scaffolding material. Exploiting indigenous renewable resources and to benefit from local resources with better or equal option as Eucalyptus tree has a great importance. Among the renewable resources, bamboo is quick growing and abundantly available in the country, using it for scaffolding material can be taken as a possible solution to rectify such problem. And ultimately reduce the current pressure on natural forests.

In addition, considering its abundance, bamboo can help alleviate rural poverty and promote justified application like other construction materials as the technology develops.

1.3 Objectives

The objectives of this study are:

- 1) To study the use of Assosa bamboo as an alternative scaffolding material.
- 2) To assess the type of scaffolding systems in use by the local construction industry,
- 3) To investigate the physical and mechanical properties of Assosa bamboo,
- 4) To adopt structural design procedures for Assosa bamboo scaffolds from well established procedures.
- 5) To assess the performance of Assosa bamboo as scaffolding system.

1.4 Significance of the research

The outputs of this study will pave a way to integrate bamboo with local building materials and recognise as a substitute for timber (eucalyptus) and steel as a scaffolding material. It also introduces Assosa bamboo scaffold in the construction industry of Ethiopia in general.

1.5 Scope of the research

This research will only cover the assessment of Assosa bamboo for its potential as an alternative scaffolding material. Assosa bamboo is selected for this study considering its lowland, abundant, and solid to semi-solid nature of culm. The rational of this research is detail evaluation of the physical and mechanical characteristics of the Assosa bamboo and draw parameters to be used as

an input in design. Following the results obtained, adopting appropriate design principles from Ethiopian Building Code Standard and British Standard. Based on the outcome of the design, demonstrate its potential as a scaffold material.

1.6 Research methodology

The methodology employed for achieving this research work has focused on review of relevant literature by different authors and relevant data is collected from previous related research studies. Further, bamboo processing facilities around Assosa area was visited to appreciate local use and conducted interview of local people on the use of this material.

To achieve the above mentioned objectives, nine bamboo culms from Assosa area were collected to conduct laboratory tests and assess the physical properties (diameter, thickness, water content, and radial shrinkage) and mechanical performance (compression and flexure). Three culms were used for preliminary identification of physical properties and compressive strength test. Four Culms were used for conducting flexure test. The other samples were used for connection test. In preparation and testing ISO standards were used as a guideline. Following the experimental tests, the results are analyzed and the parameters determined are used as an input for design of safe scaffold system in accordance with well recognized practices.

Chapter Two

Bamboo and Its Application

2.1 Introduction

The term Bamboo is a common name for a wide range of perennial, wood like, usually shrubby or treelike plants of the grass family. Bamboo is a tall perennial grass that can grow up to 30 m in height and 35 cm in diameter (Kassahun, 2003). Bamboo grows mostly in tropical and subtropical areas ranging from sea level to mountain peaks, with a few species reaching into temperate areas. They are most abundant in southeastern Asia, with some species in the Americas and Africa (Figure 2-1).



Figure 2-1: Different Bamboo Species (Source: Janssen 2000)

The bamboo plant is mainly characterized by two parts: the main stem above ground called the culm and the underground part called rhizome as shown in Figure 2-2 (David, 1984). The bamboo culm is characterized as a cylindrical shape divided by lateral diaphragms called nodes (David, 1984). Bamboo culm grows and matures rapidly. Most new culm production is achieved through the expansion of the rhizome system. The culm initially emerges as a shoot and grows every rainy season from rhizome buds that attain full height and diameter in about 3 months. The full development of a rhizome-root system takes 3 to 7 years after seeding (Kassahun, 2003). The culm matures and retains strength for harvest after 2 to 3 years. The part of bamboo this research focus is the culm.

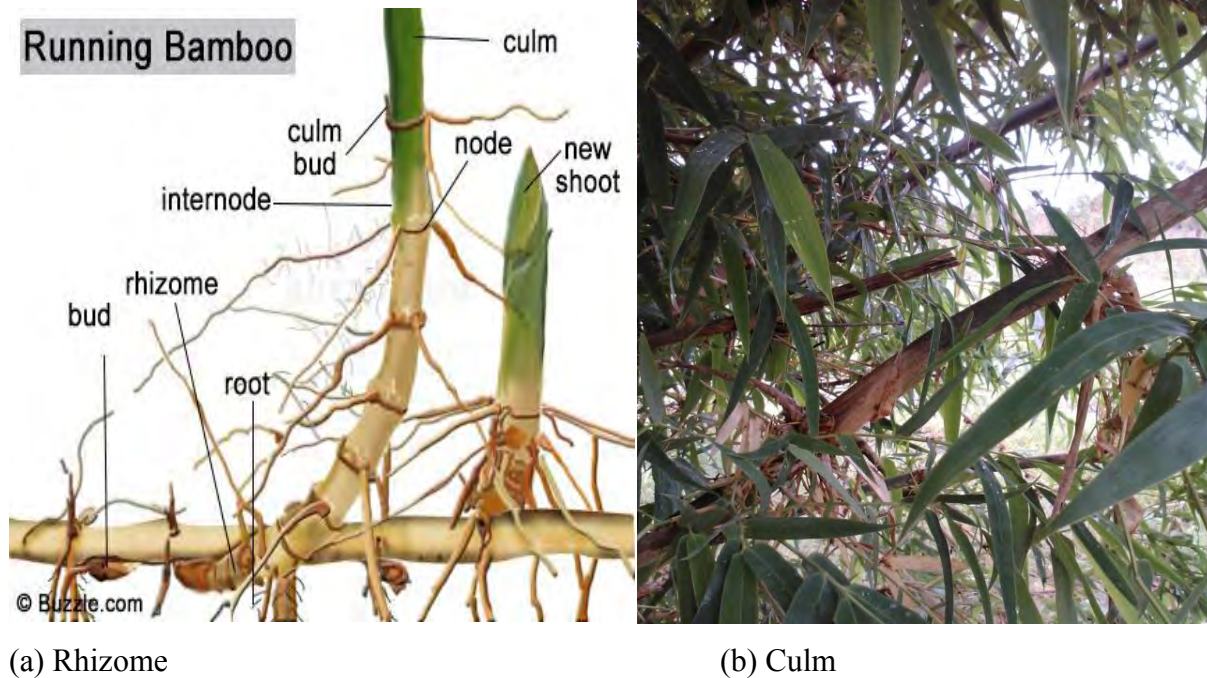


Figure 2-2: Bamboo Rhizome and Culms (Source: Banik 1995)

Bamboo culm grows with enormous growth rate and with great density per square meter. For example, bamboo shoots in tropical countries grow up to 30 meters within six months. A plantation of a typical giant bamboo will take less than 10 years to mature while the equivalent for a plantation of timber tree like Eucalyptus may take 15 years. This shows that bamboos are competitive or better than wood alternatives in terms of annual yield, this shows their potential for the future. The underground rhizome of a bamboo clump produces new above ground culms annually so that there is a continuous production of new culms that enable harvesting of older mature culms. Thus, unlike a timber tree which requires replanting after harvesting, bamboo can be harvested sustainably throughout its entire life (Shantha, 2009).

Bamboo culm is a natural organic material with material combining strong high modulus fibers of cellulose with a low-modulus plastic matrix lignin (David, 1984). It also has independent mechanical properties in three mutually perpendicular planes: longitudinal, radial, and tangential to the fibers making it orthotropic material. In general, a large variation of physical properties along the length of bamboo culms is observed: external and internal diameters, dry density and moisture content (Chan, 2002).

Currently, the absence of local material standards and engineering methods have restrained the use of bamboo and limited its use for non-engineered activities in rural areas of the country. In the contrary, bamboo has been used in architectural works as well as for temporary structures such as scaffolding in other parts of the world. Contemporary research on bamboo needs to investigate the structural benefits of the material's fibrous composition. As a structural material, bamboo is comparable to other conventional materials in terms of most material properties. Showing the versatility and ability of bamboo for structural purposes could pave away to standardization pursuing wider acceptance and use of bamboo as a structural material.

2.2 Bamboo culm

Bamboo culm is long visible stem composed of solid circular bundle forming structures or nodes separating hollow circular inter-nodal parts along the length. The culm varies greatly in physical characteristics depending on species, age, and climate. Unlike other hard and softwood species, the maximum attainable diameter of the culm is limited by its primary growth only and do not increase in diameter or height through secondary growth (David, 1984). As seen from the preliminary characterization, the diameter of the culm decrease from bottom to top for Assosa bamboo. The culm of Assosa bamboo is characterized as solid to semi-solid which makes it native to Ethiopia.

The long, slender and elastic characteristic of culm is ideally suited for the structural framework of the plant because bamboo have shallow root. The circular cross section is a composite material combining strong high modulus fibers of cellulose with a low-modulus plastic matrix lignin enabling to absorb loading stresses which would rupture the weaker part (David, 1984). This has made bamboo to resist its own self- weight and the lateral loading effects of wind (Michael, 2013). As observed in Assosa bamboo, the wall thickness is solid at the base of the culm and decrease with height up the culm which demonstrate a naturally efficient use of material to resist overturning due to wind while reducing gravity loads.

The culm is composed of approximately 40% cellulose fibers, 10% vessels and 50% parenchyma tissue (Janssen, 1981). The fibers are mainly responsible for bamboo's strength. The fibers gradually decrease in length, maturity, and wall thickness towards culm tip (David, 1984). Hence, it can be concluded that Bamboo fibers, are sources of strength and vary considerably in shape, size and wall thickness.

2.3 Bamboo harvesting and preservation

Bamboo is harvested after three years old or above. The harvesting technique differs from traditional to mechanized. In the former harvesting the local villagers cut down bamboo culms by hand from local stands near the village as needed. In the later harvesting large organized plantation with industrial equipment and large outputs are used. The basic process of harvesting bamboo is composed of cutting, treatment, and seasoning.

David (1984) noted the following general rules to be followed for bamboo harvesting:

- 1) Cut no culms younger than three year or in rainy season or from a flowering grove,
- 2) No cuts lower than second node or higher than 50 cm or one node above ground,
- 3) Remove branches, culms tips, and all harvest trash from the clump,
- 4) Leave leaves for long, It help culms to retain and gain hardness,
- 5) A minimum of six mature culms should be left uncut in each rhizome to ensure sustainable growth.

Harvesting is done manually with hand cutting tools. In Assosa area, a machete is used to harvest culms of lowland bamboo and culms are cut to standard 7 meter lengths. It is usual practice to harvest Assosa culms at around 4 years of age from January till March when the bamboo has the least water and starch. Harvesting in this period benefits the culm to be durable against insects and fungi attack. Air drying is required after harvest to maintain the strength and avoid cracking of the culm while drying. According to David (1984) the drying period ranges from six to twelve weeks staked vertically or staked horizontally with protection from rain by shade and by avoiding soil contact as shown in Figure 2-3. The bamboo is stacked on high platforms to allow ventilation and prevention of termite attack. At Alpha bamboo production facility located in Assosa the culms are stacked on a platform in an open air to air dry as shown in Figure 2-4.



Figure 2-3: Vertical and Horizontal Stacking



Figure 2-4: Air Drying

As organic material with high moisture content than conventional wood, bamboo culms are easily exposed to deterioration and insect and fungi attack (Liese, 1987). The natural durability of bamboo varies based on species, age, and conservation actions taken (Ghavami, 2008). The duration of untreated bamboo ranges from 1 to 3 years in the open with soil contact and 4 to 6 years under cover and free from soil contact (Janssen, 1981). Untreated bamboo under very good condition is estimated to last 10 to 15 years. Therefore, treatment processes are required to extend the life and improve the durability and performance of bamboo culms.

There are different techniques ranging from traditional methods to chemical preservation methods as shown in Figure 2-5. Traditional methods are simple and cost-effective which do not use of supporting equipment and chemicals. But these methods are not appropriate for long-term protection of bamboo. The other method is use of chemical preservatives to protect the culm from degradation. These are modern methods providing desired protection in extent of harsh conditions. The techniques used by Indian Standards for Preservation of Bamboo (NMBA, 2006) are presented as follows:

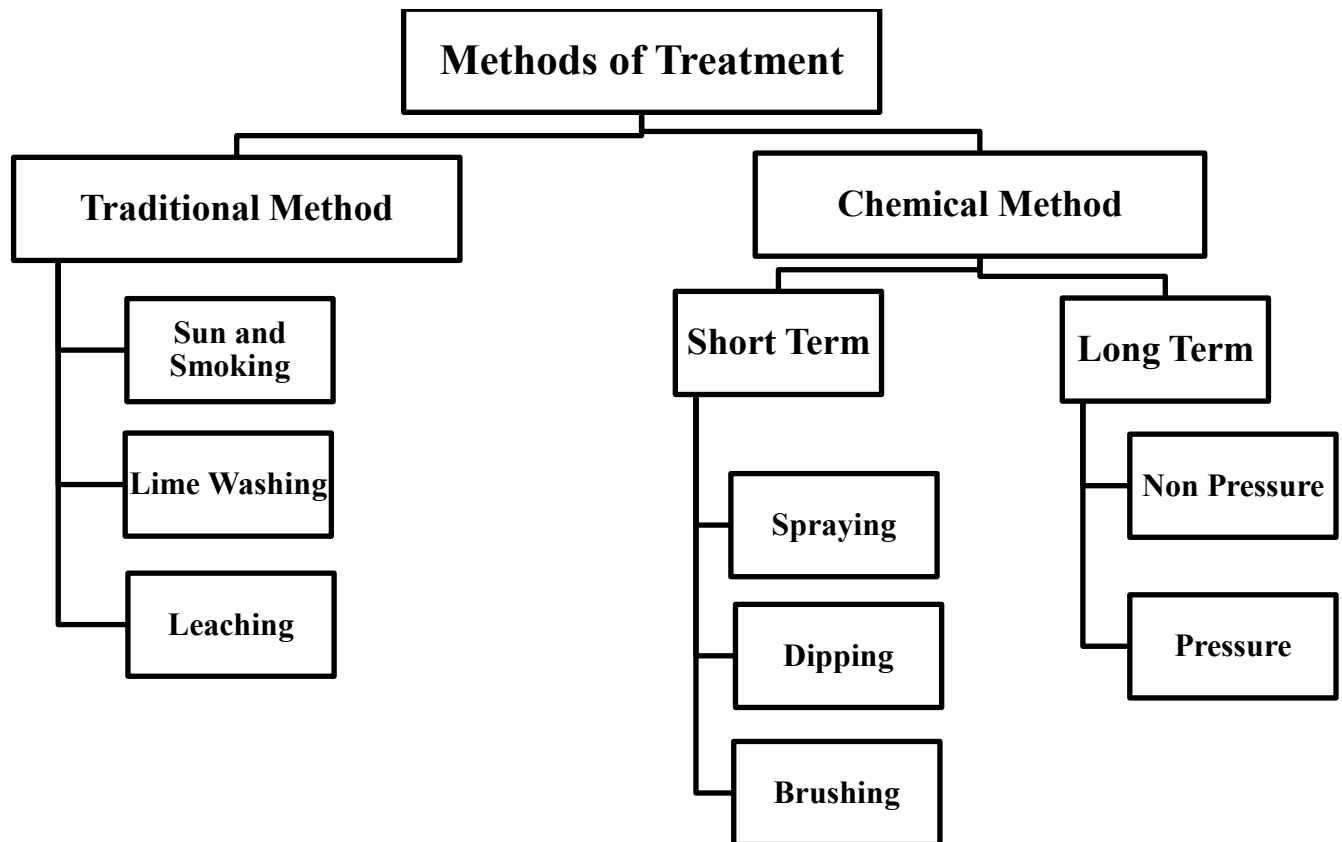


Figure 2-5: Bamboo Treatment Methods(Source: NMBA, 2006)

1) Sun and Smoke Exposure

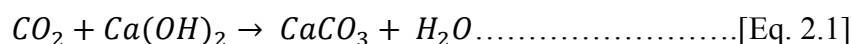
This method is a traditional and simplest of all methods. Sun exposure is used to drive of the moisture and soluble starch. Heat and smoke is also used to season the bamboo which have similar effect to that of sun exposure. The water and soluble starch is destroyed by the action of heat.

2) Leaching

It is the most common traditional preservation treatment for bamboo to leach out the soluble starch and water soluble materials wanted by insects. This is done by submerging the bamboo culms in running water for three days to seven days. However, excessive leaching is not recommended since it results in strains and brittleness of bamboo. This method is commonly used around Assosa area.

3) Lime washing

This traditional method is mainly used for decorative purposes. The culms are painted with slaked lime (Ca(OH)_2) which is then transformed into calcium carbonate, CaCO_3 , and ultimately inhibits water absorption and delays fungal attack as shown in the formula below:



4) Short term Chemical Treatments

This method is used to prevent immediate attack when the bamboo is stored for a few days or during transportation through use of slight amounts of chemicals. Under this treatment method spraying, brushing and dipping are used for effective protection under short period. The chemicals used for short term treatments includes 2% Boric acid and Borax (50:50) solution for protection against fungal attack. 2.1% solution of Thio-cyanomethyl-thio-benzothiazole (TCMTB): Boric acid: Borax in ratio of 0.1 to 1:1 for total protection against stain fungi, decay fungi, borers and termites, where use of Sodium Pentachlorophenate is not permissible. For insect attack emulsion of Lindane formulation is advisable (NMBA, 2006).

5) Long-Term Chemical Protection

This method adopts techniques for preservation of bamboo culms for long periods. The preservative should penetrate the protective lignin and hard cover to provide protection over long periods of time. Long term protection is achieved through the use of pressure to drive the preservative or without pressure. The method is determined by moisture content in bamboo, type of preservative and end-use (NMBA, 2006).

Among the methods for non-pressure treatment of bamboo are butt end treatment, soaking, hot and cold treatment, and sap replacement. Pressure methods are suitable for dry bamboo and

ensure quick and uniform penetration of the preservative deep inside. The principle of the process is to force the preservative into the bamboo tissue. This is achieved either by evacuation of the air inside the culm, or by increased pressure upon the preservative in a pressurized cylinder, or a combination of both. Treatment under pressure increases the durability of bamboo. Bamboo treated by this method will last for about 15 years in ground contact and 50 years for building components. Water-borne preservatives and sometime creosote are used for the treatment(NMBA, 2006). The bamboo facility in Assosa has a preservation chamber which uses borax as preservative as shown in the Figure 2-6.



Figure 2-6: Pressurized Chemical Treatment Chamber

2.4 Bamboo resources of Ethiopia

Bamboo plants are indigenous to the tropical and temperate regions only, found in abundance particularly in Southeast Asia (Banik, 1995). It is reported that more than 1500 bamboo species are found in the world, covering more than 14 million hectares (Ohrnberger, 1999). The worldwide distribution of bamboo is shown in Figure 2-7. Out of these species, Africa holds about 43 species and over 1.5 million hectare of the land (Kigomo 1988). Of these, 40 are mainly

found in Madagascar while the remaining 3 are in mainland Africa. Two out of three species are indigenous to Ethiopia: *Oxytenanthera abyssinica* (lowland bamboo) and *Yushanealpina* (highland bamboo). The lowland bamboo forest of Ethiopia is characterized as multi-stemmed species with solid culm. And, the highland bamboo forest is characterized as single-stemmed species with hollow culm. The experimental portion of this study concentrates on specimens collected from Lowland bamboo, specifically Assosa bamboo.

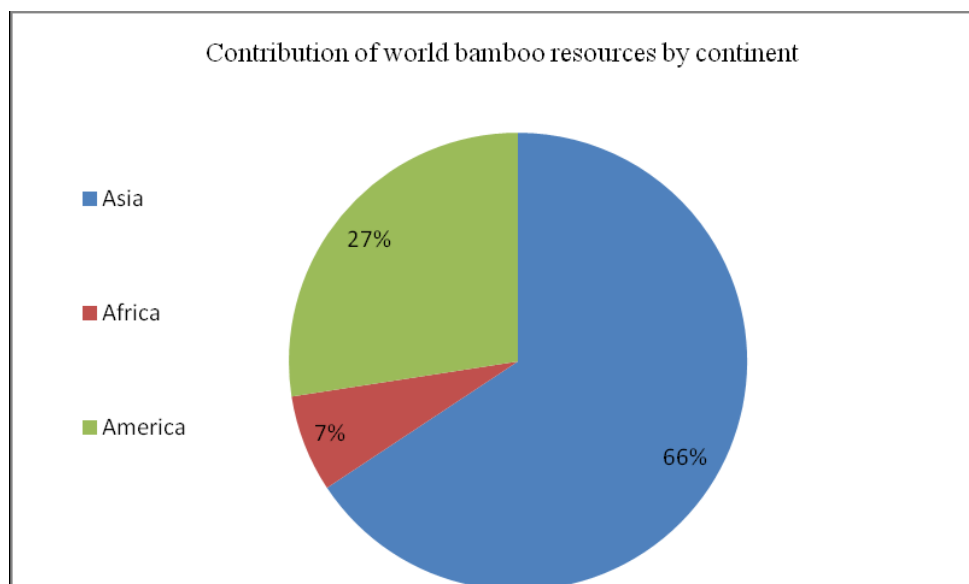


Figure 2-7: Distribution of Bamboo along the continent (Source: Ohrnberger 1999)

Being one of the tropical regions, Ethiopia has an estimated 1 million hectares of high and lowland bamboo (Luso, 1997), the latter being the dominant specie with an estimated area of 850,000ha. Thus 67% of African bamboo resources and more than 4.69% of the global total are found in Ethiopia. Hence, Ethiopia can be considered as a country with large bamboo resource.

The bamboo resources are mainly found in the South-West, South and Central part of the country. The following table no.1 shows the major bamboo areas in Ethiopia and their estimated coverage is reported in the following table by International Network for Bamboo and Rattan (INBAR, 2000).

Table 2-1: Major Bamboo Areas in Ethiopia by INBAR (2000)

Bamboo location	Region	Type	Area in ha
para	Amhara	Highland, farmed	2,380
Hinde	Amhara	Lowland, natural	8,670
Assosa	Benishangul/Gumuz	Lowland, natural	77,947
Bambesi	Benishangul/Gumuz	Lowland, natural	64,245
Begi	Benishangul/Gumuz	Lowland, natural	21,509
Demi	Benishangul/Gumuz	Lowland, natural	27,612
Dibate	Benishangul/Gumuz	Lowland, natural	14,200
Guba	Benishangul/Gumuz	Lowland, natural	7,757
Kamashi	Benishangul/Gumuz	Lowland, natural	33,723
Pauwe	Benishangul/Gumuz	Lowland, natural	53,830
Agaro	Oromiya	Highland, Farmed	1,500
Gera	Oromiya	Highland, Farmed	37,250
Bale mountains	Oromiya	Highland, Farmed	56,851
Shenen.Jibat mount	Oromiya	Highland, Farmed	1,774
Gimbi	Oromiya	Lowland, natural	29,125
Guten	Oromiya	Lowland, natural	6,044
Gera bamboo Forest	Oromiya	Highland, Farmed	1,052
Gera-lola	Oromiya	Highland, Farmed	34,493
AgereSelam- Bore	South Nations Nationalities	Highland, Farmed	-
Chencha	South Nations Nationalities	Highland, Farmed	-
Indibir-Jembero	South Nations Nationalities	Highland, Farmed	-
Jima-Ameya	South Nations Nationalities	Highland, Farmed	-
MizanTeferi-Kulish	South Nations Nationalities	Highland, Farmed	-

Bamboo location	Region	Type	Area in ha
Wushwush-Bonga	South Nations Nationalities	Highland, Farmed	-
Bonga-Ameya	South Nations Nationalities	Highland, Farmed	7,997
Masha	South Nations Nationalities	Highland, Farmed	18,652
Shashmene	South Nations Nationalities	Highland, Farmed	4,183

The two bamboo species are found in few African countries but no other place. They are in more or less pure, fully stock natural forest conditions. These forests until recently were protected by their remote and inaccessible locations. However, as noted from the site visit and interview with local people indicates that bamboo forests are disappearing due to population growth, demand for land, migration, forest fires, accessibility and improvement of road networks and establishments of villages within them and their vicinities.

2.5 Application of Assosa bamboo

Bamboo has traditionally been used throughout the world as a raw material for different applications ranging from traditional buildings, fences, roof panels to furniture, household utensils, basketry and handcraft. It is suitable for handcrafting with simple tools and techniques. In many parts of Asia, bamboo is also used for domestic housing and small building construction material and extending to domestic household applications.

It is evident that Ethiopia has abundant bamboo population but its use is limited in construction of traditional houses, fences, traditional furniture and household utensils (Luso, 1997) as shown in Figure 2-8. It is used as full-culm or splits for wall and partition construction; often as framing paired with an infill material in the form of whole or halved bamboo culms, bamboo mats, split bamboo, woven bamboo and bamboo panels. However, recently few bamboo production facilities like African Bamboo PLC have been established to transform bamboo for use in modern construction materials. This is an indication of the gap for use of this ideal resource exclusively with the aim of integrating with local need and quality.

The majority of bamboo consumption and use is related with traditional and rural community needs in this country. This traditional application of bamboo dominates modern application. Few

small scale workshops around towns use bamboo to manufacture modern furniture. In recent years, bamboo has sought use in making particle board and floor parquet for the local construction industry.



Figure 2-8: Bamboo Fence

There have been few efforts by the local industry to promote bamboo for wider use despite its abundant availability (Kassahun, 2003). One of the establishments in this regard is Alpha bamboo products association, established in August 2013 with the anticipation of promoting use of bamboo for different modern house hold furniture (Figure 2-9 and Figure 2-10). The production facility located inside the compound of Assosa Rural Technology Promotion Center has adequate man power and machinery such as cutting tools, preservation chambers and molds for producing wide range of modern furniture (Figure 2-11).



Figure 2-9: Alpha bamboo products association



Figure 2-10: Inside Alpha Facility



Figure 2-11: Bamboo Furniture

As appreciated from other Asian countries, application of bamboo as construction material is vast. Here in the local context it is usual to think of bamboo as inferior material, but the material is used in a range of temporary and permanent structures in both natural and engineered forms globally. Bamboo structures have the ability to perform during extreme loading conditions such as seismic events and hurricane. Bamboo has also been used in major architectural works as well as for temporary structures such as scaffolding. Recent researchers are studying the structural and sustainability benefits of bamboo from the material's biological composition (Michael, 2013). The experience of Asian countries with plentiful bamboo resources showed that bamboo is used traditionally as structural members in low-rise houses, short span foot bridges, long span roofs and construction platforms. Furthermore, different studies have indicated bamboo to be an ideal and safe structural material for many construction applications (Chan, 2002).

Bamboo used in the construction application can be either in the form of full culms or splits. It may be used in any one of the following building construction areas: Scaffolding, Foundations, Framing, Flooring Walls, Roof and Trusses. Furthermore, it is a material source for furniture, building, pulp, particleboard, bio-energy, food, forage and medicine (Liese, 1987).

As a structural material, bamboo has a great potential as sustainable alternative to conventional construction materials. However, to fully utilize the potential of bamboo as a construction material requires further study in key areas of preservation, jointing, structural design and codification. Since there is little knowledge of engineering and materials standards of bamboo, it is most often associated with non-engineered or marginal construction associated with under-developed rural areas. According to Jayanetti and PR Follett (1998), the gap for use of bamboo as an engineering material attributed to two main issues;

- a) The formulation of structural design guidance is governed to a large extent by practical, engineering experience. In case of bamboo information in this regard is limited.
- b) Basic mechanical properties of bamboo have been dealt with many authors but bamboo properties do not relate to species unlike timber and factors such as age and geographical area affect it highly.

In general, it is believed that the mechanical property of bamboo is likely to be at least similar, if not superior, to those of timber (Chan, 2002). As mentioned above the fast growing ability of bamboo and the short period of time it takes to harvest make it an ideal substitute of timber in construction. The effective use of structural bamboo will mitigate the pressures on the ever-shrinking natural forest resources of the country, and thus, facilitate the conservation of the local environment. However, a major constraint to the development of bamboo as a modern construction material in the world is the lack of design standards for structural bamboo (Chan 2002). In overcoming this challenge, research institutions have to conduct series of studies focused on formalizing and standardizing bamboo application by integrating with local knowledge. Reverting the stigma and promote greater engineering recognition and acceptance of bamboo requires formal quantification of this natural fiber material with respect to performance, standardization, and sustainability. In addition, socio-economic and technical studies will be essential to identify factors which govern current bamboo usage and those which will influence its use in the future. To this end, the studies conducted need to address these issues and integrate bamboo with the local construction industry for wider acceptance and application in the future.

Chapter Three

Scaffolding System

3.1 Introduction

Scaffolding is a temporary structure used to support working people and material in the construction or repair activities of buildings and other large objects. The purpose of scaffolding remains the same i.e. to provide a safe, temporary platform from which all types of construction, repair and maintenance work is performed (McGraw-Hill, 2003).

According to McGraw-Hill (2003), scaffolds are usually made up of the same basic different structural members namely:

- a) Main posts: are primary vertical members which support the whole weight of the scaffold
- b) Standards: are secondary vertical members which acts as a secondary support and bracing to the scaffold,
- c) Ledgers: are horizontal members which provide support to transoms and tie vertical members together,
- d) Guard rail: are ledgers put at working level for the protection of workers using the scaffold,
- e) Transoms: are bars put perpendicular to the building which provide support for the platforms,
- f) Bracing members: are members put where necessary in the diagonal directions, so both to stabilize post to ledger and ledger to transom planes.

The various members of a scaffold are connected by means of materials like nails, plastic strip and bamboo strip. Structural members of a typical bamboo Scaffolding is shown in Figure 3-1.

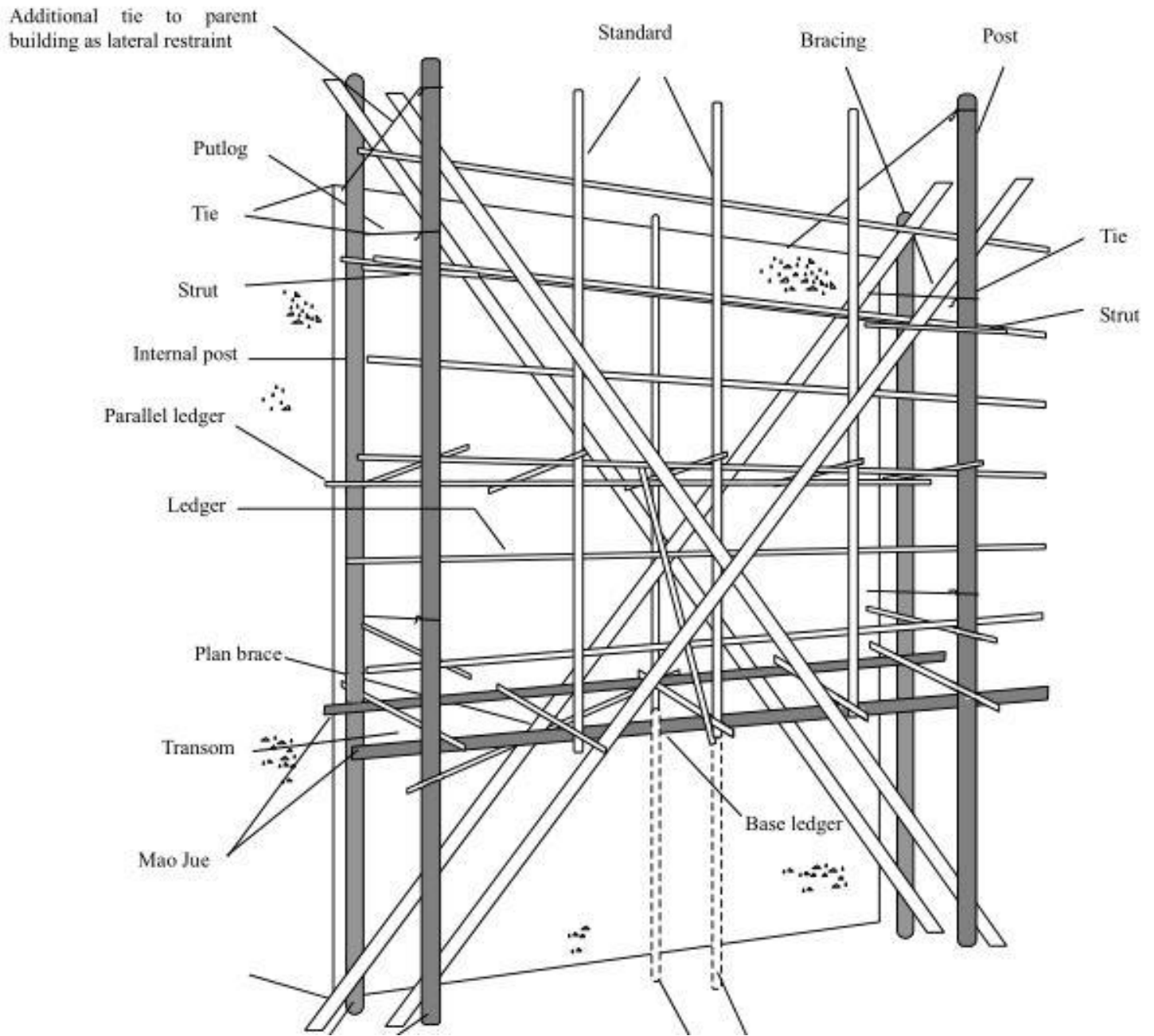


Figure 3-1: Main Elements of Bamboo Scaffolding(Source: Guidelines on the Design and Construction of Bamboo Scaffolds, 2006)

3.2 Types of scaffolding

There are many materials used for scaffolding around the world. Among the materials used for construction of scaffolds are steel tubes, aluminum tubes, wood, and bamboo. The most common scaffold material is prefabricated, modular system of metalpipes or tubes. However, in Ethiopia, wood is frequently used as scaffolding material with few exceptions of metal scaffolds. The following are the most common types of scaffolding made of wood, steel and composite materials:

3.2.1 Single scaffolding

This scaffolding system frame consists of a single row of standards set away from the wall at a distance that will accommodate the required width of the working platform. It is the simplest type made of wood or bamboo and steel. It is also widely used in the construction of light work as shown in Figure 3-2. It consists of a single layer of standards placed at an interval of 1.2meters from the structure. The ledgers are fixed to the standards at vertical interval of 1.2 meters to 1.8 meters. The transoms are placed one end on the ledger and the other on the wall of a structure with an interval of 1.2 meters to 1.8 meters (Rangwala, 2008).

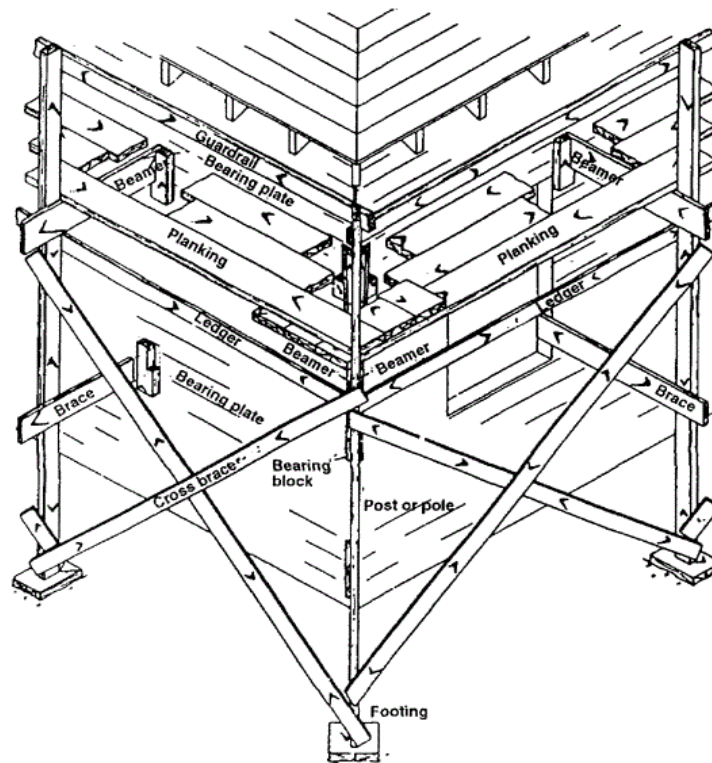


Figure 3-2: Single Scaffolding(Source, Rangwala 2008)

3.2.2 Double scaffolding

This scaffolding is stronger than the single scaffolding and it is used in the construction of heavy work. The framework is similar to the single scaffolding except now the standards are doubled and act as independent of the structure to be build or repaired. Double scaffolding is made of steel or wood or bamboo(Rangwala, 2008). Typical steel scaffold is shown in Figure 3-3.



Figure 3-3: Double Scaffolding made of steel around Lagar area

Steel tubes used in place of timber are effectively used for scaffolding work. The thickness of steel tubes ranges from 4cm to 5cm. The steel tubes are available in standard lengths with special couplings and set-screws. The steel scaffolding has no height limit and is strong and more durable. It has advantage of easy erecting and dismantling. It has high scrap value and fire resistant characteristics. However, the disadvantage is high initial cost and routine maintenance and skilled labour for assembling and dismantling (Rangwala, 2008).

Wood scaffolding is used when steel scaffold is not available. It is common around the world and the oldest temporary structure. The use of timber as a scaffold is now rarely encountered in the developed world, although it is extensively used in the developing countries. It is made of wood and secured with rope knots or nails. The timber used is structural-quality wood in either putlog or independent format. Wood is readily available in the local market and made it popular scaffolding material than steel. Wood scaffolding used for buildings around Addis Ababa is shown in Figure 3-4.



Figure 3-4: Wood Scaffold of Building around Arat Kilo

3.2.3 Cantilever or needle scaffolding

The general layout of this type scaffolding work may be of single or double scaffolding type. The commonly used material is steel or aluminum members. The basic difference from other types of scaffolds is the standards are supported by a series of needles or ties which are taken out at floor levels or through openings or through holes kept in the masonry (Rangwala, 2008). The hard ground is not available for the standards to rest and to clear obstructions on the face of the wall by scaffolding as shown in Figure 3-5.



Figure 3-5: Cantilever or needle scaffolding (Source: WWW.hdwalls.xyz)

3.2.4 Suspended scaffolding

The working platform provides optimum level for working. It is suspended from the roofs of the structure by rope or wire and the platform is arranged to be raised and lowered. The platform is made of wood or steel. It is very light type of scaffolding and used for light construction or maintenance works (Rangwala, 2008). As seen in Figure 3-6, this type of scaffolding does not impose obstruction on the ground and it is the most efficient.



Figure 3-6: Suspended Scaffolding(Source: WWW.wti-scaffold.com)

3.2.5 Trestle scaffolding

This type of scaffolding is mobile, the platform being supported by moveable apparatuses mounted on frame structures or tripods as shown in Figure 3-7. This scaffold is commonly made of steel or aluminum. It is used for minor repairs and paintworks. The purpose of this scaffold has limitation of working height from the supporting device and restricted to internal use (Rangwala, 2008).



Figure 3-7: Trestle Scaffolding(Source: WWW.Sunlitemitre10.com)

3.3 Bamboo scaffolding

Bamboo scaffolds have been used in building construction in South East Asia for many generations. To date, people still use the traditional bamboo scaffolding in Asia. For example, as shown in Figure 3-8, it is a common sight in Hong Kong to see these bamboo structures spanning the entire height of buildings. It is commonly employed in building construction to provide temporary access and working platforms for construction workers and supervisory staff.



Figure 3-8 Bamboo high-rise scaffolding in Hong Kong, China (Source: Chan 2002)

As shown in the picture above, bamboo scaffolds can be constructed in any layout to follow various irregular architectural features of a building due to its high flexibility, lightness and speed, within short period of time. Nowadays, in spite of open competition with many metal scaffolding systems, bamboo scaffolds remain one of the most preferred systems for access in building construction in South East Asia (Chan, 2002).

The main deficiency of bamboo scaffolding is safety and effectiveness of the bamboo scaffolds which depends primarily on skill of workers. The knowledge of assembling and dismantling such structures depends on the skills passed down to younger workers through an apprenticeship system and on-the-job training from the senior workers (Chan, 2002).

Most of the scaffolds are generated from the following basic scaffolding systems in general building construction which includes (Chan, 2002):

- Single Layered Bamboo Scaffolds: used for light duty work such as exterior decoration. It is highly adaptable to site conditions with both easy erection and dismantling.
- Double Layered Bamboo Scaffolds: used for working platform for heavy duty worksuch as masonry work, installation of curtain walls. This provides safe working platformsfor complicated operations to be carried out at heights.

According to Chan (2002), the other applications of bamboo scaffolds which are derived from single layered bamboo scaffolds and double layer bamboo scaffold in construction are the following:

- Demolition scaffolds
- Truss-out scaffolds
- Cantilever scaffolds
- Platform scaffolds
- Foot-bridge scaffolds
- Civil engineering scaffolds

The obvious advantages of bamboo as a scaffolding material are high strength-to-weight ratio, simple erection, and easy adaptability to building forms and site conditions. Due to the ease of handling, bamboo scaffolds are easily and efficiently erected and dismantled. It is reported that, where installation and dismantling take the same amount of time, bamboo scaffolds can be dismantled in a tenth of the time it takes to install. Machinery, power-driven tools and tightening equipment are not necessary, as simple hand tools and nylon or wire ties suffice to erect the bamboo scaffolds (Chan, 2002).

The height of bamboo scaffold depends on the codes of practice and may also depend on quality and species of bamboo used. For instance, the Chinese mainland has limited the use of such scaffolds on buildings shorter than six stories because of fears that the quality of bamboo has deteriorated in recent years. However, in Hong Kong such scaffolds are used in a vast majority of construction projects with 50 or 60 stories high (Landler, 2002).

Bamboo is rarely used in the construction industry of Ethiopia with few exceptions in some parts of the country where bamboo is available. Figure 3-10 illustrates some of the application of bamboo-wood composite scaffolding system in Assosa town, showing the arrangement of bamboo ledgers and transoms and wood posts.



Figure 3-9: Bamboo-wood composite scaffolding system in Assosa Town

Therefore, Assosa bamboo can be a candidate for scaffolding material due to its history of structural use in traditional construction and use as a scaffolding material and natural abundance.

Chapter Four

Bamboo Scaffold Design

4.1 Recent studies on Assosa bamboo

Until recently, the structural use of bamboo has been limited to traditional construction and only few researches have conducted studies in the past in this regard. The Recent study focused on the application of Assosa bamboo for reinforcement material in concrete structure as reported by Markos in 2005. His study has reported mechanical parameters of Assosa bamboo for the first time. The tests were carried in dry condition either on small split specimens or on a full size specimen as per the outlined procedures in ISO/DIS 22157. The reported mechanical parameters of Assosa bamboo are represented as the average mechanical properties of the Assosa bamboo species. It is also reported that the strength at the internode is critical. However, as shown in Table 4-1 below some ranges of values were provided concerning the physical and mechanical properties of Assosa bamboo.

Table 4-1: Summarized Values of Test Results as reported by Markos (2005)

No	Mechanical Properties	Value (MPa)
1	Ultimate tensile Strength	127 ± 10
2	Ultimate Compressive Strength	40 ± 3
3	Ultimate Bending Strength	84 ± 34
4	Modulus of Elasticity	15,600

Accordingly, this study targets to confirm the results obtained from previous studies and study further the magnitude of mechanical properties of Assosa bamboo resulting from systematic tests and analysis procedures.

Since bamboo culms are biological, non-homogenous materials demonstrating large differences of physical properties along the length of bamboo members such as: external and internal diameters, dry density and moisture content. The representative mechanical values of bamboo are obtained from tests of bamboo culm after checking the presence of no obvious flaws such as knots, splits and cracks on the bamboo culm.

The potential of Assosa bamboo could be extensive and requires proper testing to substantiate its utilization in structural applications. The main setback for the use of Assosa bamboo for structural purpose is lack of standards and understanding of the potential mechanical qualities. However, in view of the structural potential of Assosa bamboo from recent studies and the experience gained from south Asian countries using bamboo for structural purposes has inspired this study to do the same with support from scientific study. In line with this, experimental investigation is to be carried out to examine the variation of compressive strength along the length of bamboo culms for Assosa bamboo. Moreover, a series of combined tests with a large number of compression and bending tests will be conducted to establish characteristic values of both the strengths and the Young's moduli for limit state structural design.

The other critical characteristic of Bamboo member is effect of slenderness and column buckling resulting from use of vertical element in bamboo scaffolds. Based on the recent study by Chan (2002) on Kao and Mao Jue bamboo species, column buckling behavior of structural bamboo is studied over a wide range of practical member lengths. Chan determined column buckling characteristics through careful calibration and analysis of test data. He has developed a general design method implementing steel design principles of Perry-Robertson formula for column buckling. In this study, the same principle is adopted and derived for Assosa bamboo column design. Moreover, the physical variation of Assosa bamboo along the culm and the non-prismatic effect is considered in assessing axial buckling resistances of the culm.

To this end, this study focuses on the investigation of Assosa bamboo which is used as a traditional construction material around Assosa area. Later, the outcome of this study is used to determine the structural adequacy of Assosa bamboo as a scaffolding material.

4.2 Design philosophy

The philosophy of any structural design is to provide economical and adequate structure capable of carrying the specified load without compromising the intended purpose. In achieving this, structures are designed considering either ultimate limit state or serviceability limit states. For the purpose of this study, ultimate limit state design is used considering the limit state beyond which the members become unfit for their intended purpose and proved by serviceability limit state.

Scaffolding system is designed to behave as an integrated structure. The layout of its constituent members, such as posts, ledgers, and other structural parts are made as one and stable structure. Thus, each member of the structure should be sufficiently strong and withstand the effects of applied load during service without compromising the safety of other parts. In general, it implies that ultimate limit state is concerned with the safety of the entire or part of the structure before failure.

In order to achieve structural adequacy and safety, the ultimate limit state capacities and resistances determined in this study is set as limiting values, and the purpose of the design is to reach these limits in vertical and horizontal parts of the scaffold to adopt a layout such that maximum structural efficiency is attained and obtain the optimum combination of members and workmanship, consistent with the overall requirements of the scaffold.

In this section, the same design principles of steel scaffolds are applied as reported in British Standard (BS5950-1:2000); Structural Uses of Steelwork in Building and Ethiopian Building Code Standard (EBCS-3); Design of Steel Structures, since the cellulose fibers in bamboo act as reinforcement similar to reinforcing steel bars in concrete or glass-fiber in polyester-resin . Bamboo exhibits elastic behavior because the plastic behavior is considered to be insignificant as that of steel hence, the design principles of bamboo can be derived from steel according to the local and standard practice (Janssen, 2000).

The basic configurations and orientation of bamboo scaffolds have been reported by Chan (2002). He reported that the main posts for the outer and inner part of the scaffold are placed at a minimum spacing of 0.75 to a maximum of 1.2 m in the horizontal direction, and main ledgers are placed at a minimum spacing of 1.8 to a maximum of 2.25 m in the vertical direction for both parts.

The design assumptions and procedures of a number of typical structural members and scaffolding systems and consideration of various arrangements of lateral restraints for practical applications are presented as follows (Chan, 2002):

- Bamboo scaffolds exhibit high degree of structural redundancy,

- Primary members such as the posts and standards experience compression and ledgers and transoms experience bending,
- Entire structural stability is achieved through vertical supports and lateral restraints,
- Additional restraints are provided to the primary members through secondary members such as standards, ledgers, and diagonal members,
- All the joints of bamboo scaffolds are assumed not to develop moments and considered as pin connections. However, due to the continuity of the ledgers over the post-ledger connections, the ledgers are designed as continuous beams with simple supports,
- The construction loads under consideration for design of structural members is controlled at 1.5kN. Moreover, as stipulated in EBCS-2 the dead load and live load is multiplied by a safety factor of 1.3 and 1.6 respectively.
- Additional posts are placed at a spacing of 0.3 to 0.6 m in the horizontal direction,
- Additional ledgers at a spacing of 0.6 to 0.75 m in the vertical direction,
- All main posts are supported at the bottom of the members.
- Typical height of the double layered bamboo scaffolds is about 10 to 15 m.

In order to simplify the design process of bamboo scaffolds, the first step is to determine the minimum configuration of the scaffolds for overall stability and structural adequacy. Then the primary load paths within scaffold are identified i.e. exposed to compression and bending members.. Finally, bracing members are provided to increase the stability of the overall scaffold. For this particular study, the design procedures of double layered bamboo scaffolds are discussed with the details below:

- i) Design of a bamboo transom supporting a working platform and ledgers supporting the transom
- ii) Design of the posts in both the inner and the outer layers
- iii) Connection design
- iv) Design of supports
- v) Column buckling design of Assosa bamboo as a post in the inner layer and the outer layer

4.2.1 Loading requirements

Scaffolds functions many purposes which imposes different point and uniform loads and requires consideration same. In general applications BS5973:1993 recommend platform loadings for access and working scaffolds as shown in Table.4-2.

Table 4-2: Access and working Scaffold (Source: BS5973:1993)

Duty	Use of platform	Distributed load on platforms (kN/m ²)	Maximum no of platforms	Commonly used widths using 225mmboards	Maximum bay length (m)
Inspection and very light duty	Inspection, painting, stone cleaning, light cleaning and access	0.75	1 working platform	3 boards	2.7
Light duty	Plastering, painting, stone cleaning, glazing and pointing	1.50	2 working platforms	4 boards	2.4
General purpose	General building work including brickwork, window and mullion fixing, rendering, plastering	2.00	2 working platforms + 1 at very light duty	5 boards or 4 boards + 1 inside	2.1
Heavy duty	Block work, brickwork, heavy cladding	2.50	2 working platforms + 1 at very light duty	5 boards or 5 boards + 1 inside or 4 boards + 1 inside	2.0
Masonry or special duty	Masonry work, concrete block work, and very heavy, cladding	3.00	1 working platform + 1 at very light duty	6 to 8 boards	1.8

4.2.2 Partial safety factor

Safety is broadly defined as a state without a risk. Consideration of safety concept is very important in any structural engineering to determine the risks or uncertainties to acceptable level. Determination of safety factors must meet the requirement of economy and safety (Proske, 2008).

In modern structural codes the safety coefficient γ is determined through consideration of partial safety factors that affect the load values γ_f and the characteristic values of the material properties γ_m . The combination of the partial safety factors of load and material yield a more homogenous level of safety. It is current practice to define a global safety coefficient γ that augments the service value of the actions until failure as follows:

$$\gamma = \gamma_f \gamma_m \dots \dots \dots [\text{Eq. 4.1}]$$

Where: γ_f are partial safety factor for loads,

γ_m are partial safety factor for material,

Norton (1996) has established rules for determination of the global safety factor as presented in Table 4-3:

Table 4-3: Partial safety factor determination (Source: Norton 1996)

Safety Factor	Knowledge of Load	Knowledge of Material	Knowledge of Environment
1.3	Extremely well-known	Extremely well-known	Likewise tests
2.0	Good approximation	Good approximation	Controllable environment
3.0	Normal approximation	Normal approximation	Moderate
5.0	Guessing	Guessing	Extreme

The load partial safety factors are adopted from Ethiopian Building Code Standard (EBCS-1) for dead load as 1.3 and live load as 1.6 since the loads that are carried by the scaffolding system are extremely well known.

According to Proske (2008) the material safety factor of bamboo when used as a building material is 1.5. However, bamboo is a naturally occurring composite material and its mechanical properties depend upon several factors such as species, moisture content, cross sectional variation etc. Among the factors, the moisture content of bamboo is the decisive factor for its use as structural element as all mechanical and physical properties are functions of it. The moisture

content of bamboo varies vertically from the bottom to the top portions. In addition, in the dry condition (less than 15% m.c.) the strength is higher than in the green condition (more than 30% m.c.) by approximately 50% (Chan 2002). Therefore, in order to take account of mechanical variations against moisture content and other factors a partial safety factor of 2.0 is recommended.

4.2.3 Design of a bamboo transom and Ledger

The transom is part of the scaffold that carries the working platform. It is subjected to bending and shear force and the section should sustain these loads without structural failure. The load which comes from the working platform is uniformly distributed along the transom.

In the design of transoms we use the design principle set out in EBCS-3: Design of steel structures, section 4.6.1.1, the design moment resistance M_{cRd} of the cross section of bamboo shall exceed the design bending moment M_{sd} as follows:

$$M_{sd} \leq M_{cRd} \dots\dots\dots [\text{Eq. 4.2}]$$

Where: M_{cRd} is the design moment resistance of the cross section of bamboo

$$M_{cRd} = \frac{W_{pl} \times f_b}{\gamma_{mo}} \dots\dots\dots [\text{Eq. 4.3}]$$

Where; W_{pl} , section modulus = $\frac{\pi \times (D_e^4 - D_i^4)}{32 \times D_e} \dots\dots\dots [\text{Eq. 4.4}]$

γ_{mo} , partial safety factor for bamboo, 2.0,

f_b , Design bending strength of bamboo,

The design shear resistance V_{Rd} of the cross section of bamboo shall exceed the design shear force V_{sd} as follows:

$$V_{sd} \leq V_{Rd} \dots\dots\dots [\text{Eq. 4.5}]$$

$$V_{Rd} = \frac{2A/\pi \times (\frac{f_{cd}}{\sqrt{3}})}{\gamma_{mo}} \dots\dots\dots [\text{Eq. 4.6}]$$

Where; A, is area of the cross section of bamboo,

f_{cd} , Design compressive strength,

γ_{mo} , partial safety factor for bamboo, 2.0.

Ledgers are horizontal members that provide structural support to transom members and subsequently transfer the load to vertical posts. It is a simply supported continuous beam under point load. Design of ledgers follows the sample design principle as that of transoms. However, for simplicity of statical calculation, structural adequacy of a ledger under one point of load is considered.

4.2.4 Design of posts and standards

Bamboo is long and slender natural material with large differences in diameter and cross section thickness along the culm. The use of bamboo as a vertical member demands analysis of column buckling against the compressive load. The compressive buckling strength of bamboo can be determined by following the same principle to that of steel column buckling method given in BIS 5950: Part 1: 2000 where a Perry- Robertson interaction formula. In Perry- Robertson interaction formula a number of buckling curves are available with different values of Robertson constant for selection and design.

Robertson constant, a , is related with column type which has been adjusted according to the tests on practical proportions with realistic lack of straightness and residual stress. Hence, $a = 0.28$ is considered following the calibrated column buckling test results (Chart 4-1) obtained by Chan (2002) for Kao June which is similar in cross section and initial imperfection as of Assosa.

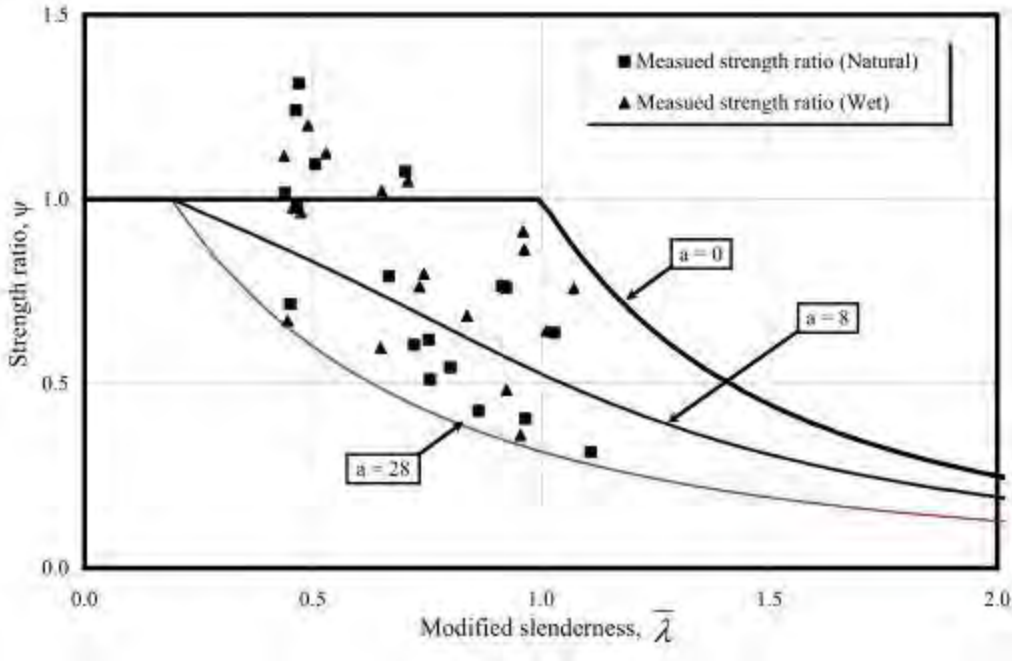


Chart 4-1 Column Buckling Analysis (Chan, 2002)

The bamboo column is assumed to be light, straight, slender, non-uniform, pin –ended column of length L , with cross-section property I . Hence, to entertain the physical variations along bamboo culm a non-prismatic parameter, α is introduced to the elastic Euler buckling load of the bamboo member. Chan (2002) has determined the non-prismatic parameter α through the minimum energy method. The proposed design method is presented below:

a) The section properties of lower part (l , larger diameter) and upper part (s , smaller diameter) of bamboo column are calculated;

$$\text{Cross sectional area, } A_l = \frac{\pi}{4}(D_e^2 - D_i^2) \text{ and } A_s = \frac{\pi}{4}(D_e^2 - D_i^2) \dots \dots \dots [\text{Eq. 4.7}]$$

$$\text{Second moment of area, } I_l = \frac{\pi}{64}(D_e^4 - D_i^4) \text{ and } I_s = \frac{\pi}{64}(D_e^4 - D_i^4) \dots \dots \dots [\text{Eq. 4.8}]$$

Slenderness ratio for larger section (λ_l) and smaller section (λ_s) respectively,

$$\lambda_l = \frac{h_E}{r_l} \text{ and } \lambda_s = \frac{h_E}{r_s} \dots \dots \dots [\text{Eq. 4.9}]$$

Where radius of gyration for larger section (r_l) and smaller section (r_s) respectively,

$$r_l = \sqrt{\frac{I_l}{A_l}} \text{ and } r_s = \sqrt{\frac{I_s}{A_s}} \dots \dots \dots [\text{Eq. 4.10}]$$

b) The Elastic critical bulking strength of the bamboo culm P_{cr} is calculated;

$$P_{cr} = \alpha \frac{\pi^2 E_b}{\lambda_s^2} \dots\dots\dots [\text{Eq. 4.11}]$$

Where α , non- prismatic parameter, and if α lies between 1.0 and 2.35, defined as,

$$\alpha = 1.005 + 0.4751\rho - 0.011\rho^2 \dots\dots\dots [\text{Eq. 4.12}]$$

Where section change,

$$\rho = (I_l/I_s - 1) \dots\dots\dots [\text{Eq. 4.13}]$$

c) The compressive strength of the bamboo column, P_c is given by;

$$P_c = \frac{P_{ck}}{\gamma_{mo}} \dots\dots\dots [\text{Eq. 4.14}]$$

d) The compressive buckling strength of the bamboo column, $P_{c,c}$ is given by;

$$P_{c,c} = \frac{P_{cr}P_c}{\phi + (\phi^2 - P_{cr}P_c)^{1/2}} \dots\dots\dots [\text{Eq. 4.15}]$$

Substituting the following expression with ϕ

$$\phi = \frac{P_c + (1 + \eta)P_{cr}}{2} \dots\dots\dots [\text{Eq. 4.16}]$$

Where Perry factor, η , defined as,

$$\eta = 0.001a(\lambda_s - \lambda_o) \dots\dots\dots [\text{Eq. 4.17}]$$

Where limiting slenderness ratio λ_o ,

$$\lambda_o = \sqrt{\frac{\pi^2 E_b}{P_c}} \dots\dots\dots [\text{Eq. 4.18}]$$

Where Robertson constant, $a = 0.28$ is considered following the results obtained by Chan (2002)

Modified slenderness ratio $\bar{\lambda}$,

$$\bar{\lambda} = \sqrt{\frac{P_c}{P_{cr}}} \dots\dots\dots [\text{Eq. 4.19}]$$

Modified strength ratio ψ ,

$$\psi_c = P_{c,c}/P_c \dots\dots\dots [\text{Eq. 4.20}]$$

Axial load resistance P ,

$$P = P_{c,c}A_1 \dots\dots\dots [\text{Eq. 4.21}]$$

4.2.5 Design of bracing members and lateral restraints

Bamboo scaffold is a structure with several structural redundancies. The structural stability of bamboo scaffold is achieved through bracing members and lateral restraints. Bracing construction is applied in many constructions to provide stability and resists lateral loads. In bamboo scaffolds vertical, horizontal and diagonal bracing is provided. The diagonal bracing between two lines of posts is shown in Figure 4-1.

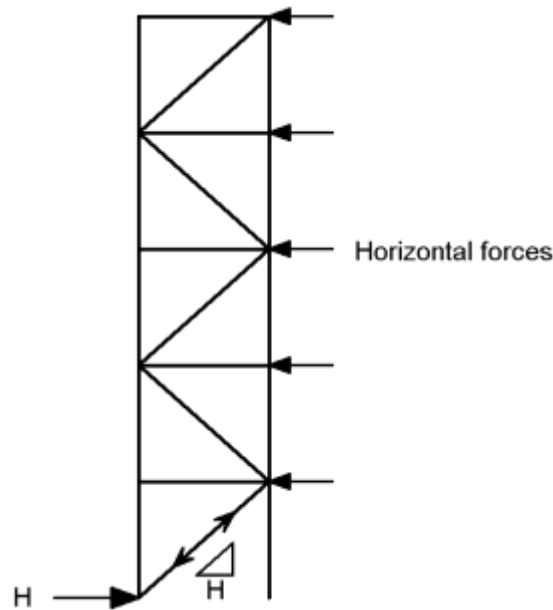


Figure 4-1: Horizontal force and Bracing

The vertical and diagonal bracing must be designed to resist the forces due to the following:

- Wind loads
- Equivalent vertical and horizontal forces, representing the effect of initial imperfections
- Second order effects due to sway

Chan (2002) has given guidance on the determination of individual members of the bracing system as follows:

- Standards at a horizontal spacing of 0.3 to 0.6 m centers,
- Ledgers at a vertical spacing of 0.4 to 0.75 m centers,
- Lateral restraints are provided to the scaffolds at the post – main ledger connections, at the post spacing of 1.5 to 2.4 m in the horizontal direction and 1.8 to 2.25 m in the vertical direction.
- Cross Diagonal bracings are provided to increase the lateral stability of the structure.
- The configurations of bracing members for bamboo scaffolding systems are presented in Figures 4-2

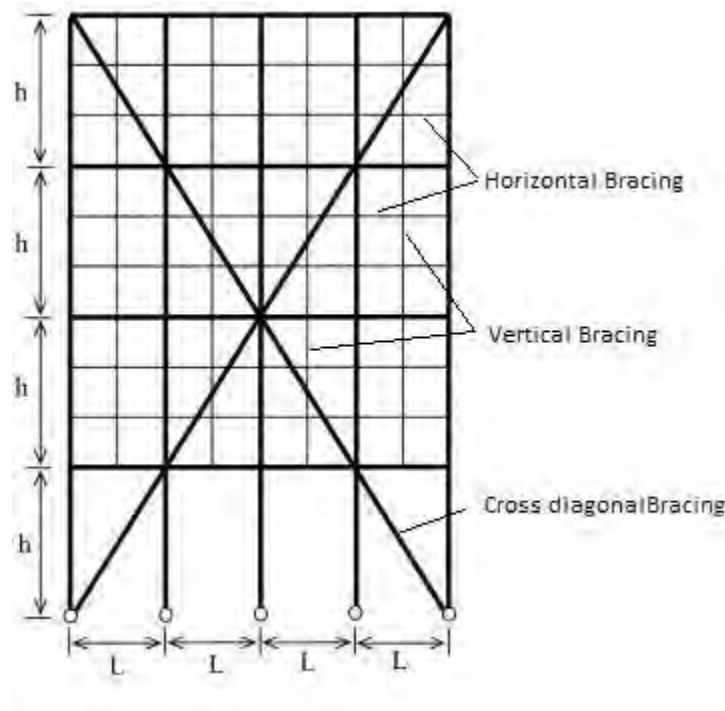


Figure 4-2: Bracing Configuration of bamboo scaffold system

Lateral restraints are provided to efficiently achieve overall structural stability of the bamboo scaffolds. The number of lateral restraints to be provided depends on the availability of strong supports. Many structures do not have adequate supports to provide lateral restraints to bamboo scaffolds.

Through advanced non-linear analysis, both the local buckling of bamboo posts between ledgers and the global instability of the entire structures with regular and staggered lateral restraints are accurately incorporated. It is reported that out-of-plane buckling of the posts is critical, and the deformed shapes of double layer bamboo scaffolding system for regular and staggered lateral restraint are also presented in Figures 4-3 and 4-4.

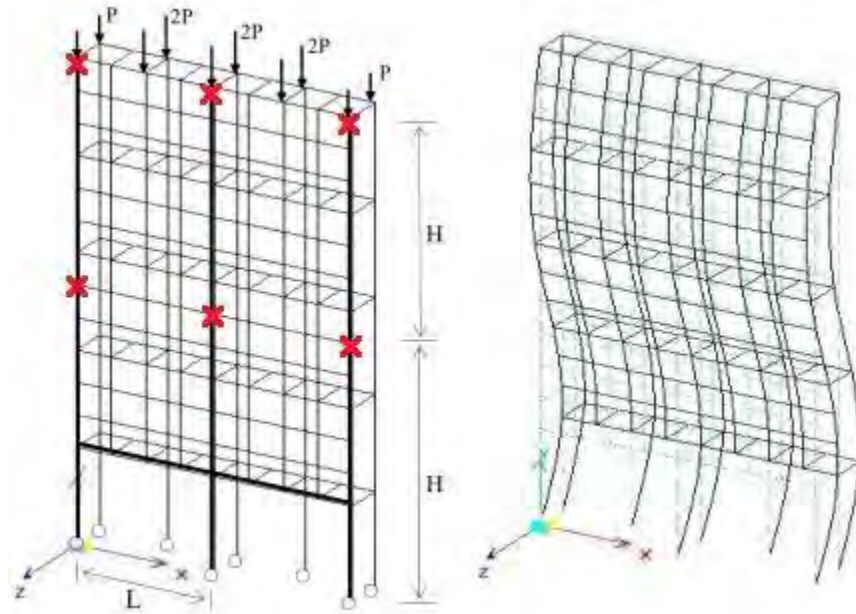


Figure 4-3: Regular Restraint and Deformed Shape

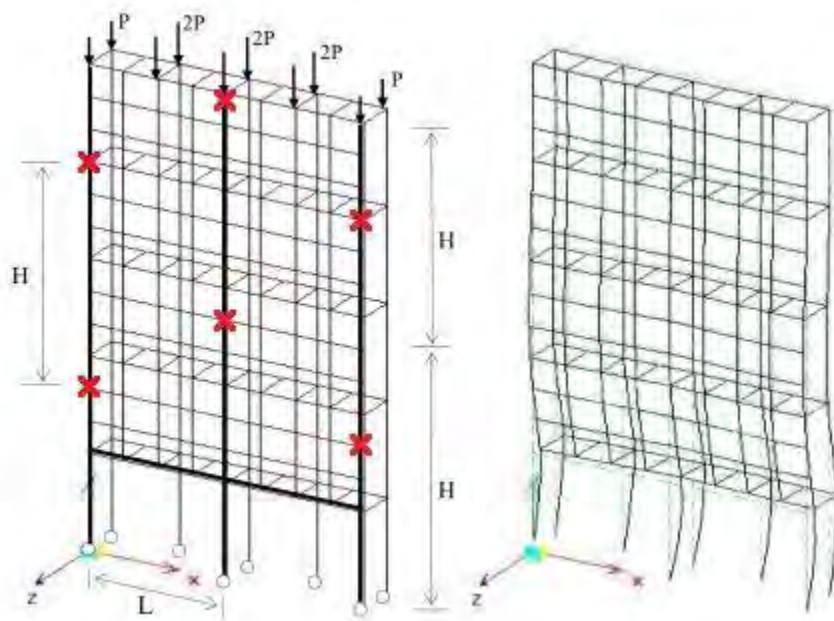


Figure 4-4: Staggered Restraint and Deformed Shape

The design guidance is provided by Chan (2002) after analyzing efficiently the results of providing lateral non-linear finite element and sway analysis using Nonlinear Integrated Design and Analysis software (NIDA) as shown in Table 4-4. He assigned a typical distance between lateral restraints, H ; to be $2.0 h$, $2.667 h$ and $3.0 h$ in various arrangements where h_i is the height of a platform, or the vertical distance between two platforms.

Table 4-4: Load resistances and effective length coefficients

Distance between lateral restraints H (m)		Regular Restraint			Staggered Restraint		
		P_c (kN)	h_e (m)	k_e	P_c (kN)	h_e (m)	k_e
$H=h$	2.0	2.156	2.0	1.0	-	-	-
$H = 2 h$	4.0	0.776	3.796	0.949	2.655	1.736	0.434
$H = 2.667 h$	5.33	0.535	4.720	0.885	1.521	2.512	0.471
$H = 3 h$	6.0	0.380	5.736	0.956	1.068	3.132	0.522

In addition, Chan (2002) has recommended the effective length of the post in double layered bamboo scaffolds for inner layer, h_{ei} , as follows:

$$h_{ei} = k_e \times h_i \dots \dots \dots [\text{Eq. 4.22}]$$

where; k_e = the effective length coefficient = $k_i \times k_b$,

k_i = secondary effective length coefficient which depends on the restraint arrangement provided at the posts of the outer layer as shown in Table 4-5:

Table 4-5: Secondary Effective Length Coefficient

H / h	1.0	1.5	2.0	2.667	3.0
k_i	1.0	1.10	1.25	1.50	1.75

$k_b = 1.0$ for double layered bamboo scaffolds with regular lateral restraints, or

0.7 for double layered bamboo scaffolds with staggered lateral restraints,

H = the system length between lateral restraints,

h_i = the height of a platform, or the vertical distance between two platforms.

With the same assumption, the effective length of the post in double layered bamboo scaffolds for outer layer, h_{eo} as follows;

$$h_{eo} = k_e \times H \dots\dots\dots [\text{Eq. 4.23}]$$

where; k_e = the effective length coefficient = $k_o \times k_b$

k_o = 0.7 for double layered bamboo scaffolds with $H = 1.0$ h to maximum of 2.667 h to

allow for the restraint effect provided by both ledgers and standards,

k_b = 1.0 for double layered bamboo scaffolds with regular lateral restraint or

0.7 for double layered bamboo scaffolds with staggered lateral restraints,

H = the system length between lateral restraints,

h = the height of a platform, or the vertical distance between two platforms.

4.3 Bamboo connections and joints

Connections are important features of any structural element. Structures like scaffold consist many members connected together to act as a system. These structural elements are put together with adequate and sound connections. Connections require cautious design and consideration of many factors. Unlike timber the physical characteristic of bamboo makes it difficult to use conventional nail for connection since splitting is inevitable due to longitudinal fiber material. Bamboo is also susceptible to crushing particularly of open ends results in reduction of strength.

Among the different types of connections, the preferred connection is tying the entire bamboo culm cross section through bearing by using bamboo strips, rattan, iron wire and plastic strips. This connection preserves the entire bamboo without imposing any physical inferiority. There are different connection types as discussed by Janssen (1981). He explained the difficulty of making connections with bamboo despite good mechanical properties for the following reasons:

- a) Round shape of bamboo makes it difficult to create connections with round profiles leading to difficult geometric structures at the knot,
- b) Fibers of bamboo only grow in the longitudinal direction,
- c) Bamboo is hollow at the center and no material is available to add strength to the culm,
- d) Bamboo surface is hard and slippery,
- e) Variable diameter, length and quality,

f) No cross fibers to sustain cross-sectional loads,

Bamboo connections were first studied and developed in a proper way by Janssen (2000). According to him, bamboo jointing techniques are classified into eight groups based on force transmission between culm and joint. In general, bamboo connections are classified into two; namely traditional and modern connections. Group one involves tying the entire bamboo culm cross section through bearing by using bamboo strips, rattan, iron wire and plastic strips (Figure 4-5). Group two connects members by joints which transfer load from the inside hollow of the culm to a parallel element through a fill material (e.g. wood or cement mortar) as shown in Figure 4-6. Group three connections transfer loads from inside the culm to a perpendicular element and it has similarity with group two connections. Group four connections use parallel elements to transfer loads from the cross section often by pins shown in Figure 4-9. Group five connection use pins or bolt elements perpendicular to the culm to transfer load from the cross section as shown in Figure 4-7. Group 6 connections use parallel elements that transfer load between the outside of the culm and the joint Figure 4-8. Group 7 connections transfer from outside to an element perpendicular and are not often seen according to Janssen (2000) while category 8 is reserved for split bamboo connections.

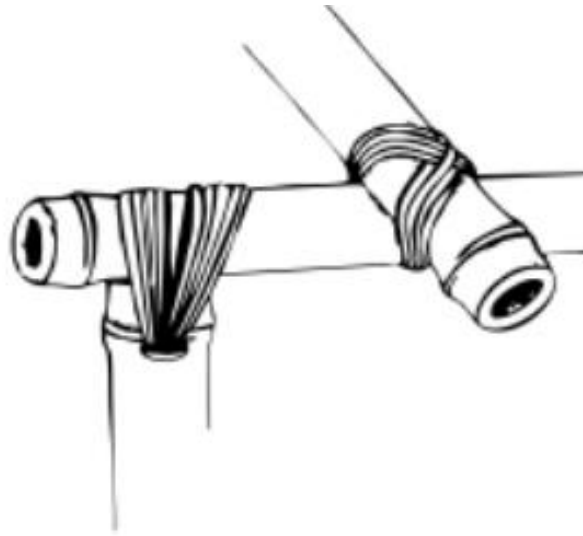


Figure 4-5: Group One example; Lashed connection (Source: Janssen 2000)

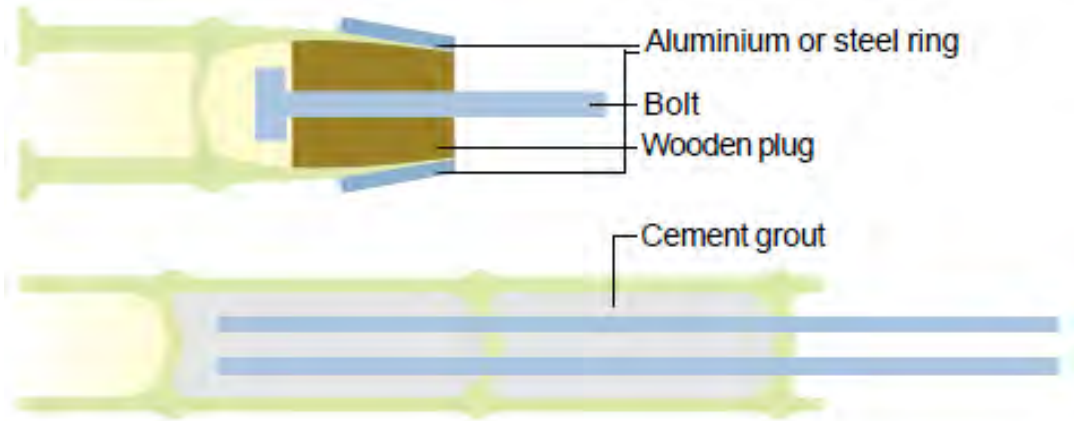


Figure 4-6: Group two example plug (top) and grouted dowel (bottom) connections(Source: Janssen 2000)

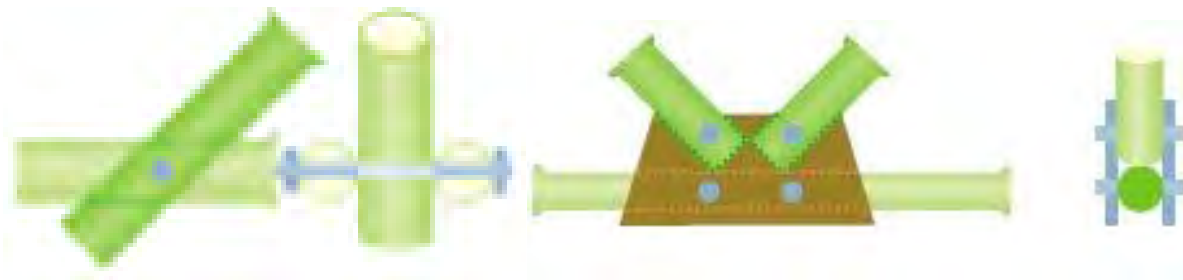


Figure 4-7 Group 5 examples: pinned or bolted connection(Source: Janssen 2000)

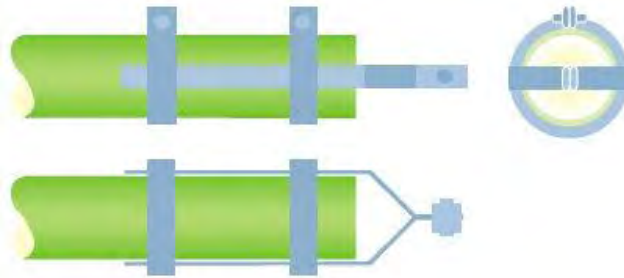


Figure 4-8: Group 6 example: 'swaged' connection (Source: Janssen 2000)

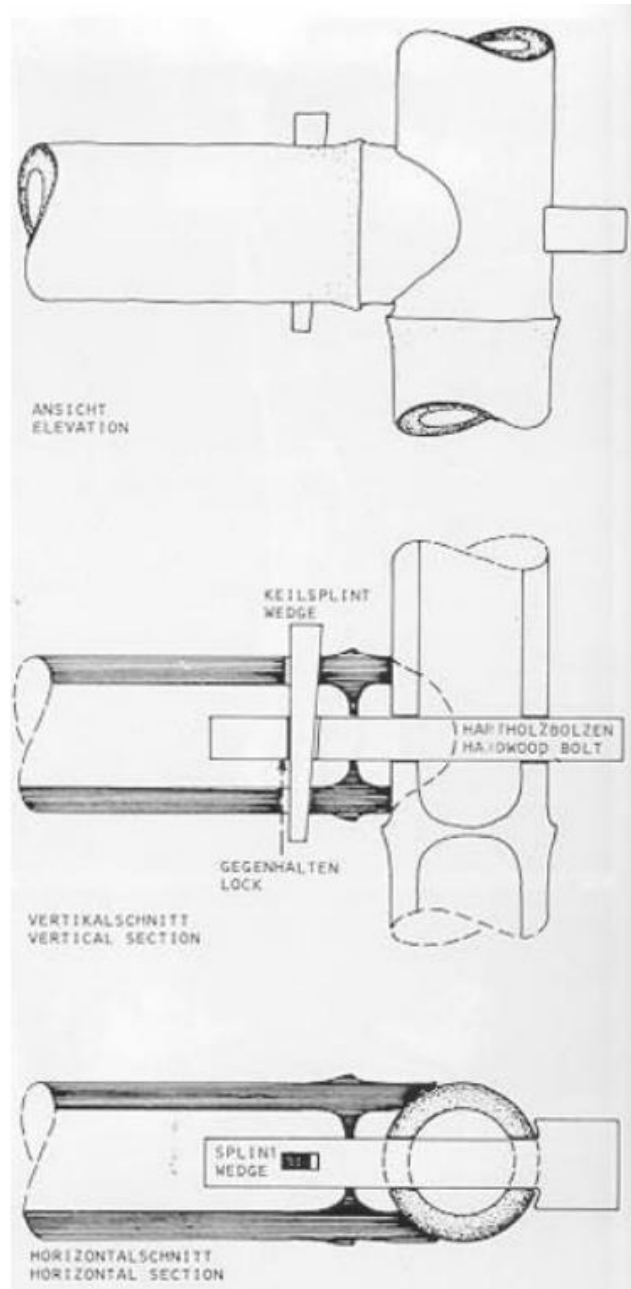


Figure 4-9: Category 4 example: taper-wedged fishmouth connection(Source: Janssen 2000)

Chapter Five

Determination of physical and mechanical properties of bamboo

In this section sample preparation and test methods used for the determination of physical and mechanical properties of Assosa bamboo are discussed. The standard ISO 22157-1 is followed in the preparation of samples and conducting tests.

Bamboo is characterized as natural non-homogenous organic material with differences in physical properties along the length of bamboo culms. In order to study these physical and mechanical variations the experimental investigation is divided into the following parts:

5.1 Preliminary study

A primary study is conducted to study the variation of compressive strength against a number of physical properties along the length of bamboo culms in air dry condition. The physical test relevant to this study includes; external diameter D , wall thickness t , cross-sectional area A , mass by volume (density ρ), and moisture content m.c. All the physical properties of the test specimens are measured before and after the compression tests as necessary.

5.1.1 Selection and specimen preparation

Three Bamboo culms were selected from different matured clumps with different sizes and free from any defects in the standing condition. The age of all culms is between 3-4 years. Immediately after selection, the bamboo is marked as Assosa Bamboo (ASB) followed by culm and position number.

The culms are felled according to good local practice which is one node above the ground. The height of the culms felled range from 6 meters to 7 meters. A length of 0.5 meters from bottom of the culms is cut. After that, a 4.5 meter culm is prepared and each culm marked into three parts as bottom (B), middle (M) and top (T) at a distance of about 1.5 m above the bottom as shown in Figure 5-1. The test specimens are prepared with a diameter ranging from 50mm to 25mm and a height twice the diameter. A number of test specimens were cut out from the bamboo culms at height twice the diameter, each marked with a label indicating its position from the bottom of the bamboo culm as shown in Figure 5-2.

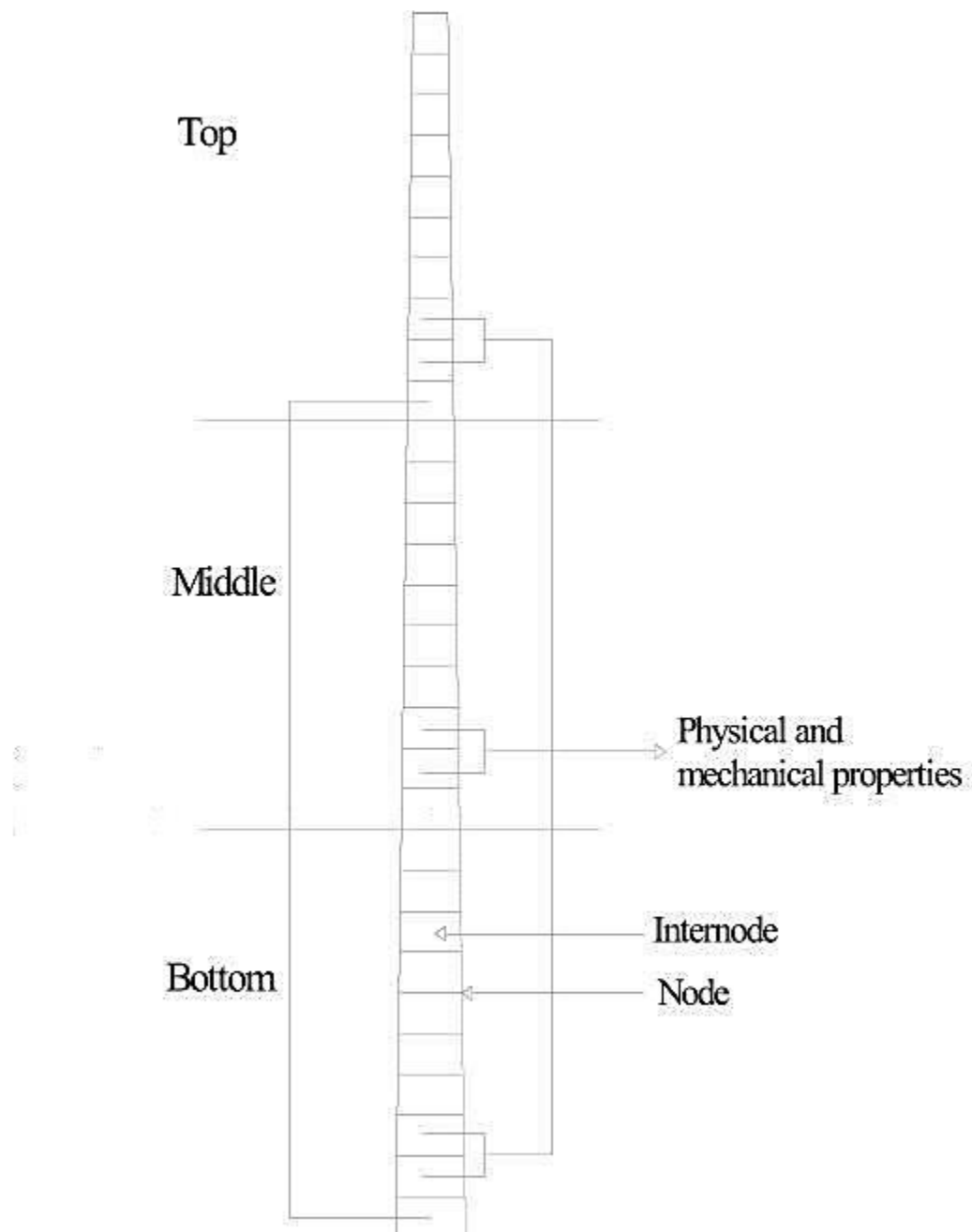


Figure 5-1: Bamboo Culm Sampling Location



Figure 5-2: Sample Prepared for Compression

5.1.2 Moisture content

As natural organic material, the mechanical property of bamboo largely depends on moisture content of bamboo culms. The sample for moisture content is prepared after each compression test.

The moisture content m.c. of each test piece is calculated as the loss in mass, expressed as a percentage of the oven dry mass, according to the equation below:

$$MC = \{(m - m_o) / m_o\} \times 100 \dots\dots\dots [Eq. 5.1]$$

Where; m = mass of the test piece before drying,

m_o = mass after drying,

The arithmetic mean of the results obtained from the individual test pieces is reported as the mean value for the moisture content of the test pieces.

5.1.3 Mass by volume

The mass by volume is calculated by dividing the oven dry mass by the volume of the specimens. The density is to be reported at the natural moisture content of the test specimen. Here the mass is taken as the oven-dry mass and only the volume is taken by measurement of its dimensions at the natural moisture content of the specimen. The calculation of mass by volume is calculated as follows:

$$\rho = (m / V) \times 10^6 \dots\dots\dots [\text{Eq. 5.2}]$$

Where; ρ = mass by volume in kg/m^3 ,

m = mass in g of the test piece, oven-dry,

V = green volume of the test piece in mm^3 .

5.1.4 Radial Shrinkage

For determination of shrinkage, the procedure set out in ISO 22157-1 is followed. The internode section of bamboo culm is considered by measuring outside diameter, wall thickness and height before and after drying. The apparatus used is electric oven and digital calliper. Specimens are prepared from full bamboo culms, internode sections; with a height of 100 mm. Shrinkage is observed in the outer diameter D , in the wall thickness t and also in the length L of the specimen. On each specimen, 4 diameters, 4 wall-thicknesses (two on either end) and 2 lengths shall be measured as shown in Figure 5-2. The specimens are allowed to dry slowly under gradually decreasing humidity and increasing temperature. The specimens are put into an oven at about $103 \pm 2^\circ\text{C}$ temperature, and after a while their dimensions are taken and the change is measured from time to time until no change is observed and finally the last measurement is taken. Shrinkage is calculated using the following formula:

$$\text{shrinkage} = \frac{(I - F)}{I} \times 100 \dots\dots\dots [\text{Eq. 5.3}]$$

Where; I = initial reading,

F = final reading,



Figure 5-3: Shrinkage Measurement

5.2 Compression Test

Compression test is carried out as per the procedure outlined on ISO 22157-1. The test is performed parallel-to-the-axis of specimens made from bamboo culms without node. Specimens are taken from the bottom part, middle part and top part of each culm. These specimens are marked indicating the location from the bottom of the culm. The length of the specimen is taken as twice the outer diameter. The end planes of the specimen are made at right angles to the length of the specimen to reduce friction between the plates and specimen.

For this study, Controls Automatic Compression testing machine with model 50-C36V is used to determine the compressive strength of bamboo culms. The load is applied at an average rate of 0.01mm/sec (1N/mm²/s). The specimen is placed so that the center of the movable head is vertically above the center of the cross section of the specimen. Then the final reading of the maximum load, at which the specimen fails, is recorded as shown in Figure 5-3(a-c). The maximum compressive stress is determined by the following formula:

$$\sigma_{ult} = F_{ult} / A, \text{ in MPa (or N/mm}^2\text{)} \dots\dots\dots [\text{Eq. 5.4}]$$

Where; σ_{ult} =the ultimate compression stress, rounded off to the nearest 0.5 MPa,

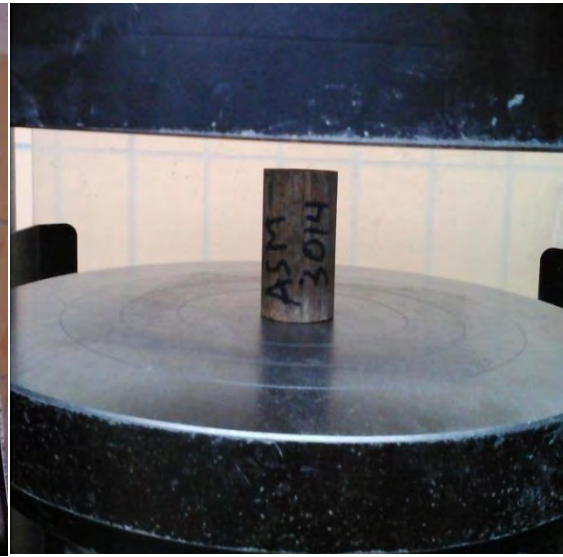
F_{ult} = the maximum load at which the specimen fails, in N,

A = the cross sectional area.

The mean ultimate stress of the tested specimens shall be calculated to the nearest 0.5 MPa as the arithmetic mean of the test results of the individual test specimens.



(a)



(b)



(c)

Figure 5-4 (a-c): Compression Test Setup

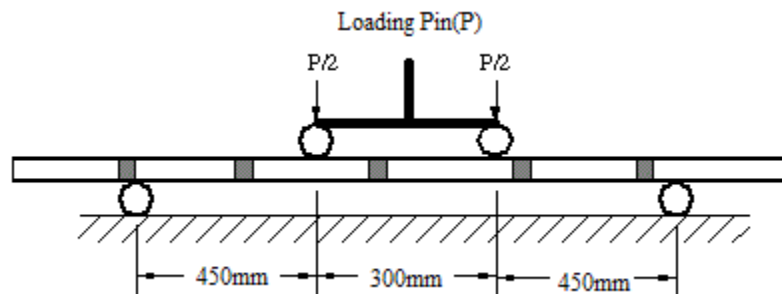
5.3 Bending (Flexure) Test

A four-point bending test is conducted as per the procedure outlined on ISO 22157-1. This test ensures a region of constant moment and is performed to determine bending capacity, load versus vertical deflection curve and the nominal modulus of elasticity of the culm.

The load of the device is divided into two halves by means of an appropriate beam. To avoid crushing of the culm, the half loads and the reaction forces at the supports are applied near to the nodes. At the supports the bamboo culm are allowed to rotate freely as shown in Figure 5-4.



(a)(b)



(c)

Figure 5-5 (a-c): Flexure Test Setup

The length of the specimen culms ($L_{\text{total}}=1200\text{mm}$) are at least 30 times the outer diameter (D) and without any visual defects. This specimen length ensures a flexure-dominated behaviour thereby minimizing the effects of perpendicular shear. The moment of inertia for the bamboo culm is calculated as follows:

$$I(mm^4) = [\frac{\pi}{64} (D^4 - (D - 2t)^4)] \dots\dots\dots [Eq. 5.5]$$

The ultimate strength σ_{ult} in static bending at the moisture content at the time of the test is given by the formula:

$$\sigma_{ult}(Mpa) = \frac{F \times L \left(\frac{D}{2}\right)}{6 \times I} \dots\dots\dots [Eq. 5.6]$$

The modulus of elasticity E is calculated with the formula:

$$E = \frac{23 \times F \times L^3}{1296 \times \delta \times I} \dots\dots\dots [Eq. 5.7]$$

Where; F is the applied maximum load in N, (the total load applied in the two points of load),

L is the clear span in mm,

D is the outside diameter in mm,

I is the moment of inertia in mm⁴,

δ is the deflection mid-span in mm.

This test is performed on Controls universal testing machine (UTM) model No. 70-0820/C with a four point bend fixture. The rate of the load is maintained at a rate of 0.5mm/sec (0.5MPa/Sec) and the load is measured to the nearest 1 %, and that of deflection to the nearest mm.

5.4 Connection Test

Strong and reliable bamboo connections are very important for achieving structural stability and integrity. Connections require proper attention and consideration in the overall design. An experimental investigation was carried out on the resistances of the beam-column connections in bamboo scaffolds where the connections are formed.

In assessing the connection resistances in bamboo scaffolds, two sets of tests were conducted. In each test two representative connection types were tested. For tight connections green bamboo strips and iron wire are used separately. The bamboo strip is made from green bamboo by hammering the wet bamboo until it is changed to threads and left to dry. The bamboo strip is known by the name of “Fesho” and is available from the local market in Assosa area (Figure 5-

5). The bamboo strip is watered before tying around the bamboo and after drying, the fibers shrink and becomes stronger.

The first set of beam-column connections are fastened with bamboo strips of 5 rounds with nodes and without nodes. For the second set of beams 5 round iron wire is used same as first connection test. The configuration of the vertical member or column was hold in position by a fabricated metal holder and the loading was applied vertically to the horizontal member in two points equally spaced at $L_1=150\text{mm}$. Typical test setup is shown in Figure 5-7(a-c). The applied load is recorded during test.

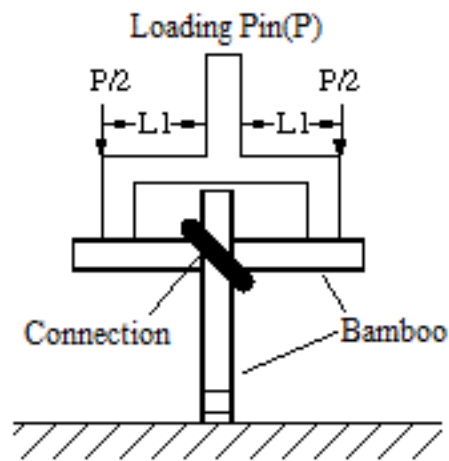


Figure 5-6: Assosa Bamboo strip (Fesho)



(a)

(b)



(c)

Figure 5-7 (a-c): Test Configuration of beam-column connection tests for bamboo strip (a), iron wire (b) and Test setup dimensions

Chapter Six

Discussion and Analysis on Experimental Results

In this section the result of experimental tests on bamboo culms are reported and discussed. Initially, the changes observed on diameter, wall thickness, moisture content and compression tests varied along the sections from bottom to top are reported. Following, the compressive strength is studied against moisture content of saturated bamboo culm specimens. Then, four point flexure tests on twelve full bamboo culms were conducted to study the bending strength and deflection characteristics. Both the compressive and bending tests are carried out with UTM machine and the moduli of elasticity were analyzed. The experimental results are illustrated here using a representative set of specimen data. A complete set of experimental test results are presented in the Appendix A.

6.1 Results of primary study

Reporting of the primary study results are organized into four sections. First, the diameter and wall thickness changes observed along the culm length are discussed and illustrated. Next, moisture content data of the culms along the culm length are observed. Following, mass by volume changes is discussed. Finally, radial shrinkage experienced is discussed.

6.1.1 Diameter and wall thickness

Assosa bamboo can be characterized as solid to semi-solid cross-section. This property is believed to be found in Ethiopia only. The diameter and wall thickness difference for selected samples along the culm length are presented from Table 6-1 to 6-3.

Table 6-1: Representative Diameter and Wall Thickness of Assosa Culm Number One

Item No.	Sample Code No	Specimen position along the culm	Sample Position	Height from Bottom (mm)	Specimen dimension			Cross Sectional Area (mm ²)
					Sample Length (mm)	Average Diameter (mm)	Average Thickness (mm)	
1	ASB1001	B	Internode	580.0	80.7	39.2	Soild	1206.9
2	ASB1007	B	Internode	1019.0	68.4	35.6	Soild	995.4
3	ASB1013	B	Internode	1357.0	63.7	32.8	Soild	842.4
3	ASB1018	B	Internode	1677.0	64.4	31.8	Soild	794.2
4	ASM1019	M	Internode	1741.0	60.3	31.1	Soild	757.2
5	ASM1026	M	Internode	2165.0	56.6	29.5	Soild	683.5

Item No.	Sample Code No	Specimen position along the culm	Sample Position	Height from Bottom (mm)	Specimen dimension			Cross Sectional Area (mm ²)
					Sample Length (mm)	Average Diameter (mm)	Average Thickness (mm)	
6	ASM1031	M	Internode	2455.0	58.0	28.6	10.0	583.3
7	ASM1035	M	Internode	2679.0	54.2	27.7	9.67	547.7
8	AST1036	T	Internode	2735.0	52.1	27.6	9.45	538.8
9	AST1041	T	Internode	3005.0	54.7	27.1	9.36	521.7
10	AST1045	T	Internode	3213.0	49.3	26.2	9.15	490.1
11	AST1049	T	Internode	3417.0	49.4	25.5	8.6	456.6

Table 6-2: Representative Diameter and Wall Thickness of Assosa Culm Number Two

Item No.	Sample Code No	Specimen position along the culm	Sample Position	Height from Bottom (mm)	Specimen dimension			Cross Sectional Area (mm ²)
					Sample Length (mm)	Average Diameter (mm)	Average Thickness (mm)	
1	ASB2001	B	Internode	592.0	89.9	46.4	Soild	1690.9
2	ASB2003	B	Internode	882.0	88.7	44.1	Soild	1527.5
3	ASB2007	B	Internode	1370.0	81.2	42.7	16.12	1346.1
4	ASB2010	B	Internode	1746.0	85.1	41.65	14.6	1240.9
5	ASM2011	M	Internode	1920.0	84.9	40.95	14.0	1186.5
6	ASM2015	M	Internode	2245.0	79.3	39.4	12.1	1037.8
7	ASB2020	M	Internode	2633.0	76.1	38	11.4	952.7
8	ASB2024	M	Internode	3039.0	75.9	34.95	10.3	797.6
9	AST2025	T	Internode	3267.0	70.0	34.15	10.2	765.3
10	AST2028	T	Internode	3477.0	70.7	35.45	10.4	819.8
11	AST2032	T	Internode	3851.0	68.0	33.95	9.725	740.1
12	AST2035	T	Internode	4183.0	66.0	33	9.5	701.0

Table 6-3: Representative Diameter and Wall Thickness of Assosa Culm Number Three

Item No.	Sample Code No	Specimen position along the culm	Sample Position	Height from Bottom (mm)	Specimen dimension			Cross Sectional Area (mm ²)
					Sample Length (mm)	Average Diameter (mm)	Average Thickness (mm)	
1	ASB3001	B	Internode	628.0	75.5	39	Soild	1194.6
2	ASB3003	B	Internode	784.0	75.6	39	Soild	1194.6
3	ASB3006	B	Internode	1116.0	74.4	37	Soild	1075.2
4	ASB3008	B	Internode	1425.0	71.0	36	Soild	1017.9

Item No.	Sample Code No	Specimen position along the culm	Sample Position	Height from Bottom (mm)	Specimen dimension			Cross Sectional Area (mm ²)
					Sample Length (mm)	Average Diameter (mm)	Average Thickness (mm)	
5	ASM3009	M	Internode	1495.1	69.4	35.85	13.45	946.5
6	ASM3013	M	Internode	1773.1	68.2	33.5	11.0725	780.1
7	ASM3017	M	Internode	2213.1	67.1	33.1	10.85	758.4
8	ASM3022	M	Internode	2659.1	63.6	31.4	10.41	686.5
9	AST3023	T	Internode	2838.1	61.3	30.75	10.825	677.6
10	AST3026	T	Internode	3028.1	58.7	30	10.18	633.9
11	AST3030	T	Internode	3489.1	55.8	28.6	9.5125	570.4
12	AST3033	T	Internode	3657.1	55.4	28.45	9.2025	556.5

In addition, Chart 6-1 and Chart 6-2 presents the physical properties of the three culms which are remarkably different among each other. The external diameter of Assosa bamboo decreases from bottom to top of culm. The external diameter of bamboo remains the same once it has reached its full height. The external diameter decreases from an average diameter of 40mm at bottom to average diameter of 29mm at upper part of the culm. As a result, the average cross-sectional area is found to be 1690mm² with a large variation of more than 1000mm² along the whole member length. This cross sectional area change (ρ) is a non-prismatic characteristics and Chan 2000 has determined the non-prismatic factor (α) through the minimum energy method as indicated in Equation 4-12.

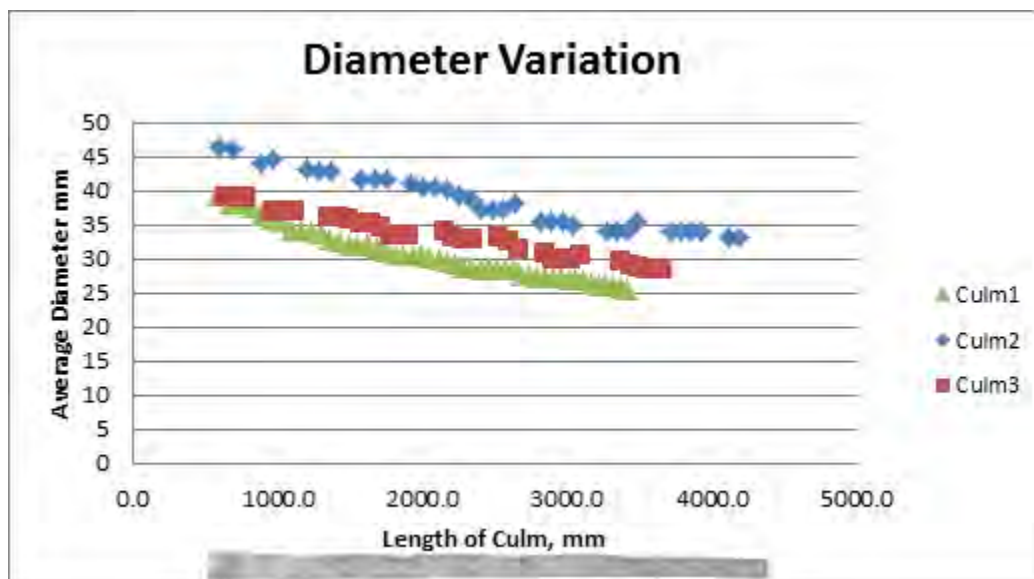


Chart 6-1: Variation of external cross sectional diameter

The wall thickness of Assosa bamboo varies from bottom to top of culm as shown in chart 6-1. It is indicated in the tables 6-1 to 6-3 that the bottom part of the culm is solid up to an average height of 1,700mm. In addition, Chart 6-2 indicates zero thickness which means bottom part of the culm is solid for all the three culms. Bottom part of the culm next to the solid part has an average wall thickness of 13mm and upper part of the culm has an average wall thickness of 9mm. The Bamboo culm on average comprises about 50-60% parenchyma, 30-40% fibers and 10% vessels and sieve tubes. The percentage of fibers is higher in the outer portion of the wall and in the upper part of the culm. Strength and slenderness of bamboo is mainly attributed to fibers (Liese 1987).

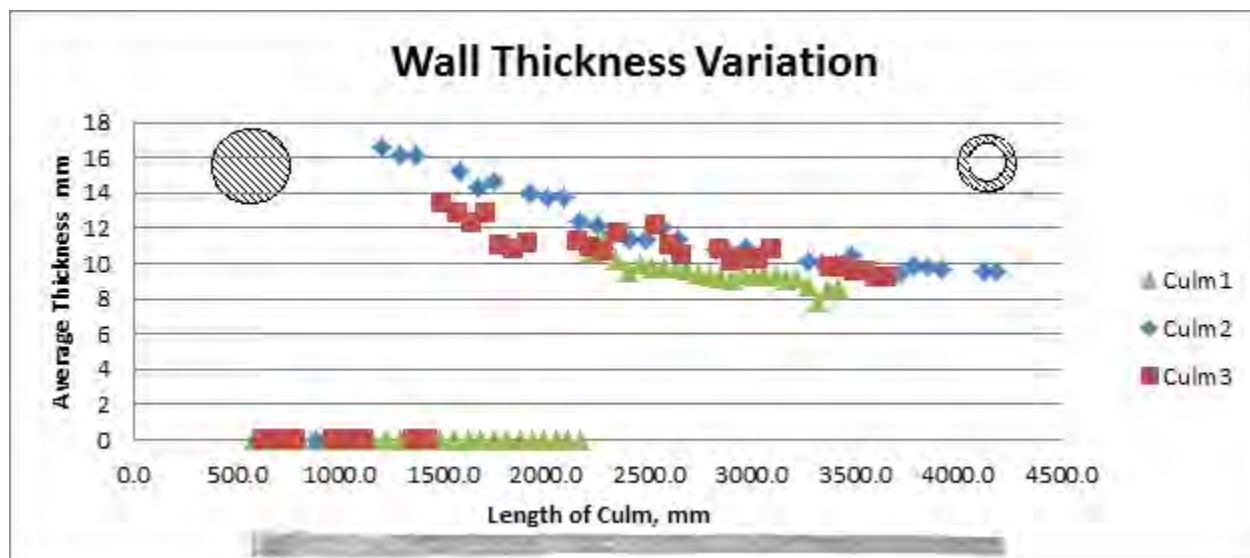


Chart 6-2: Variation of Wall thickness

6.1.2 Moisture content

As natural organic material, moisture content is an important factor in governing the mechanical properties of bamboo. The samples collected were in air dry condition after harvest for three months. The moisture content of bamboo varies vertically from the bottom to the top portions of the culm (Chart 6-3).

The moisture content of bamboo is the decisive factor as all mechanical and physical properties are functions of it. Also, the duration of bamboo may depend upon the moisture content because of its high water soluble nutrient content and can be attached by fungi and borer insects.

The moisture content varies from one culm to another. It is also influenced by age, the season of felling and the species of the bamboo culm. In younger culms a high relative moisture content of about 120 - 130% both at bottom and top is observed. In older culms of 3 - 4 years the base has higher moisture content than the top (Liese, 1987).

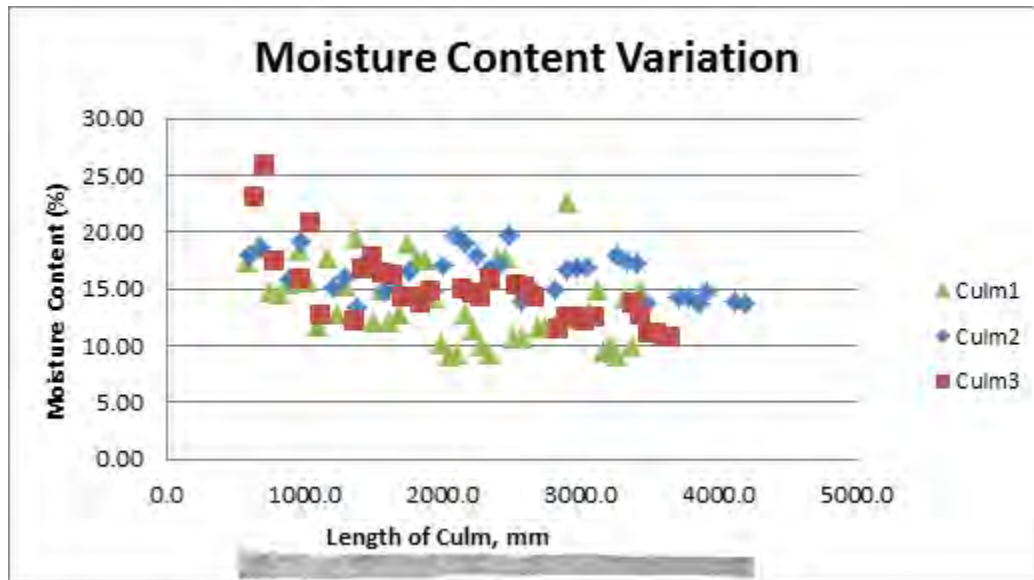


Chart 6-3: Variation of Moisture content

As presented in Chart 6-3 the trend of moisture content along the height of bamboo culm is not constant along the length of culm. It is not strictly decreasing as other physical properties but slightly decreasing. Ninety five percent of moisture content range of air dry Assosa bamboo is 9-20%. However, as shown in chart 6-3 there are few outliers in the results obtained where moisture content is higher than the range of 9% to 25%. The solid nature and larger diameter of the culm at the bottom contributes for the high moisture content of the culm. The arithmetic mean of the results obtained from the individual test pieces is reported as 14.8%.

6.1.3 Mass by volume (Dry Density)

The trend of mass by volume (dry density) of bamboo decreases from the top portion to the bottom as shown in Chart 6-4. The top portions have higher dry density than the bottom portion of the culm. The dry density range of Assosa bamboo is 670 Kg/m³ to 980 Kg/m³. The mean value of dry density is 830 Kg/m³. Liese (1987) had explained the total number of vascular bundles within the wall decreases from bottom towards the top, while their density increases at the same time. The vascular bundles are composed of vessels, sieve tubes and fibers. The number

of fibers increases with height which contributes to 40-50% of the total culm tissue and 60-70% by weight of the culm. For this reason, density of bamboo culm increases with height.

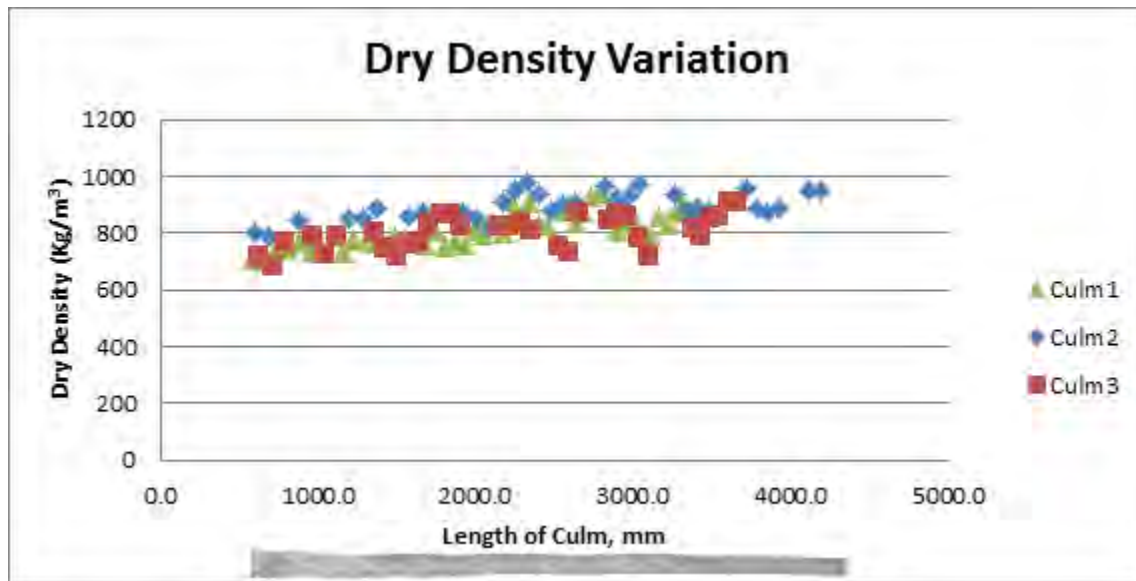


Chart 6-4: Variation in Dry Density (Kg/m³)

6.1.4 Radial Shrinkage

The shrinkage effect makes a great difference to the usage of bamboo for structure. It may cause the bamboo split or crack. Bamboo requires longer period of curing and drying than conventional timber due to its variable moisture content. The loss of moisture content during seasoning results in shrinkage that affects both the thickness of the culm walls and the circumference. During the seasoning period, it begins shrinking primarily in the radial direction of the cross section and get more susceptible to cracking with large wall thickness. Seasoning of mature bamboo from green condition to about 20% moisture content leads to a shrinkage of 4 to 14% in the wall thickness and 3 to 12% in diameter (Liese, 1987).

Bamboo fibers shrink mainly in the radial direction, and the minimum deformation occurs in the axial direction. The shrinkage of the cross section appears to be governed by the shrinkage of the outermost portion, which possesses also the highest specific gravity. The outer portion has high fiber content than the inner side. Shrinkage starts simultaneously with the decrease of moisture content but does not continue regularly (Liese, 1987).

Assosa bamboo known for its semi-solid to solid cross-section shows large variations of radial shrinkage along the length of culm. The bottom solid portions have higher radial shrinkage than the top hollow portion of the culm as shown in Chart 6-5. The value of radial shrinkage from freshly felled to the oven-dry state range from 0.12 to 1.01%.

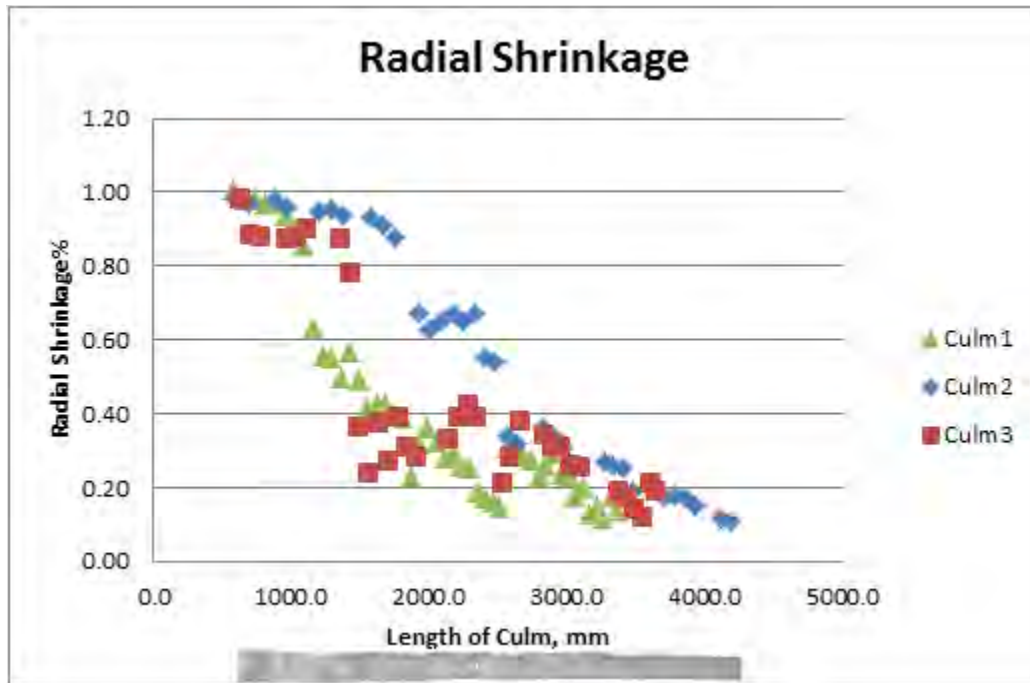


Chart 6-5: Variation in radial shrinkage

6.2 Compression test

The compressive stress (σ_{ult}) data parallel to the longitudinal direction of bamboo are presented in Chart 6-6 and 6-7. The compression capacity is found to be at its maximum of about 115kN at the bottom of the culm which is reduced suddenly to about 35kN at the top. After dividing with the cross-sectional areas, the lowest recorded compressive stress at the bottom of the culm is 55 MPa and the highest recorded compressive stress at the top of the culm is 92MPa. The reason for increase of compressive strength while the compressive load decreases along the length of culm is attributed to decrease in cross section area and increase in number of fibers to the upper part of the culm. The top portion of bamboo had the highest compressive stress. Hence, the compressive stress of bamboo parallel to the longitudinal direction increased with height. Also, the compressive stress of bamboo in the longitudinal direction is inversely proportional with moisture content. From the results obtained, compressive strength of Assosa bamboo at fifth percentile is determined as 62.5MPa.

It is also observed that no large difference is recorded in compressive strength between bottom and middle location. Markos (2005) had determined the mean value of modulus of elasticity by direct tension test and was found out to be 15,600MPa. Since the elastic behavior of bamboo is dominant than plastic behavior the same modulus of elasticity of tension is adopted for the compressive elastic modulus of elasticity.

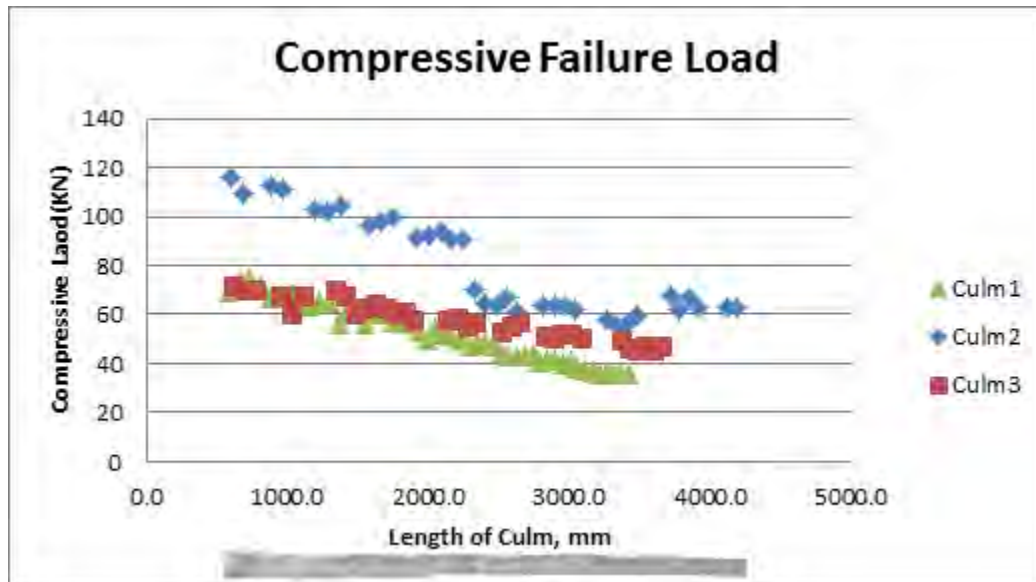


Chart 6-6: Variation in compressive failure load

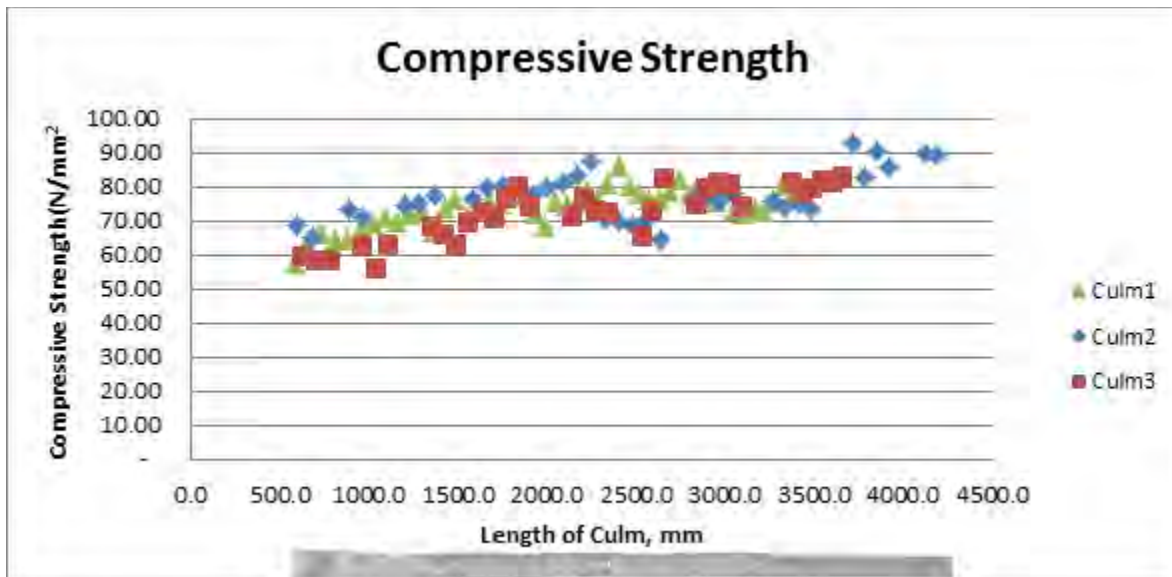


Chart 6-7: Variation in compressive strength

During the compressive strength test two fail modes, namely End bearing and splitting, were identified, as shown in Figure 6-1. It was found that almost all specimens failed in End Bearing,

especially in those specimens with high moisture contents. However, for few exceptional failures the moisture content decreased which induced cracks along fibres and caused Splitting.



Figure 6-1: End bearing and Splitting Failure

The compressive strength varies with moisture content. Chan (2002) has determined the correlation between compressive strength and moisture content. For moisture content greater than 30% reduced the compressive strength roughly by 30-50% of its original value. Therefore, in the dry condition the compressive strength is higher than in wet condition.

6.3 Bending (Flexure) test

The bending strength data of four different bamboo culms of Assosa area is presented in Table 6-4. The effect of vertical sample location along the bamboo culm was not significant while moisture had a significant effect on the bending strength. According to the study by Chan (2002) the moisture content greater than 20% reduces the bending strength by half. From the test results, the failure load is found to range from maximum of about 4.9kN to minimum of 0.6kN at the top portion of the culm.

The maximum and the lowest recorded bending stress are 105MPa and 69MPa respectively. The characteristic bending strength at fifth percentile is determined as 75.8MPa. And the bending modulus of elasticity is found to range from maximum of about 10,000MPa to about 15,900MPa. The bending modulus of elasticity at fifth percentile is determined as 11,140MPa.

Table 6-4: Bending Strength and Modulus of Elasticity of Assosa bamboo

Item No.	Sample Code No	Specimen dimension			Moment of Inertia (mm ²)	Moisture Content	Bending Force (N)	Bending Strength (N/mm ²)	Mid Span Deflection (mm)	Modulus of Elasticity (MPa)	Type of Failure
		Sample Length (mm)	Average Diameter (mm)	Average Thickness (mm)							
1	ASB4001	1500	45	Solid	201288.96	18.43	4900	100.4	42.5	13529.69748	Cracking
2	ASB4002	1500	40.6	Solid	133374.88	15.95	3700	103.2	46.5	14092.09714	Cracking
3	ASB4003	1500	39	Solid	113560.77	15.11	2900	91.3	49.3	12235.5541	Cracking
4	ASB4004	1500	37.6	Solid	98111.81	16.4	2400	84.3	51.9	11133.28933	Splitting
5	ASB4005	1500	35.5	11.2	76516.44	15.1	2000	85.1	55.4	11144.64856	Cracking
6	ASB4006	1500	34.7	10.5	69439.27	16.6	2100	96.2	53.4	13377.4637	Cracking
7	ASB4007	1500	33.4	10.1	59597.71	17.5	2010	103.3	54.9	14510.92326	Splitting
8	ASB4008	1500	31.2	9.4	45353.96	15.4	1680	105.9	52.3	16729.89693	Cracking
9	ASB4009	1500	29.8	11.2	38563.85	13.8	1490	105.5	56.9	16039.63426	Splitting
10	ASB4010	1500	27.1	9.5	26264.37	11.15	900	85.1	53.9	15017.15374	Splitting
11	ASB4011	1500	26.3	8.5	23117.93	9.8	790	82.4	57.9	13941.2121	Splitting
12	ASB4012	1500	25.6	8.2	20731.21	9.6	600	67.9	55.8	12251.6119	Splitting

As seen from the experimental results and Figure 6-2 (a-b), bamboo had high flexible rigidity and made it most effective in members such as beams in which length is far in excess of depth. In addition, comparison with other construction materials (Table 6-5), the strength-weight ratio for bamboo is very favorable for scaffold applications.

Table 6-5: Strength-Weight Ratio for Construction Materials (Source: Janssen 1981)

Item No.	Construction Materials	Strength-Weight Ratio(N/Kg*10 ⁹)
1	Concrete	0.003
2	Steel	0.020
3	Wood	0.013
4	Bamboo	0.017



(a)

(b)

Figure 6-2 (a-b): Assosa bamboo deflection before failure

During the bending test, two types of failures were observed, namely splitting and local cracking as shown in Figure 6-3 (a) and (b). Failure of bamboo is not permanent and the bond between the fibers had broken down during failure and the circular form of the cross-section had lost its

strength. Afterwards, when the load placed on it is removed, the bamboo specimen will return to its original straight form. This phenomenon has great practical importance in scaffolds.



Figure 6-3 (a): Local cracking failure of Assosa bamboo



Figure 6-3(b): Splitting failure of Assosa Bamboo

6.4 Connection test result

The cross connections formed by connecting the vertical and horizontal bamboo members using bamboo strip or iron wire. The results of connection resistances for two sets of tests are presented in Table 6-6. It is also observed that the stiffness's of both bamboo strips and iron strips are limited under loading and induced deformations to occur. The deformations that have

occurred induced slipping between bamboo members. Hence, slipping between members is the critical failure in cross-connections.

It is found that for cross-connections at the internodes using both bamboo strips and iron wire, the connection resistances are found to range from 0.9kN to 1.4kN. The cross-connections at the nodes using both bamboo strips and iron wire have shown higher connection resistances ranging from 1.45kN and 2.5kN. The connections at node have failed because of the deformation of the bamboo strip and iron wire and simultaneously slipping under loading.

The outer surface of bamboo is smooth and slippery for connection. This can be eased by removing the outer smooth surface of the bamboo culm at the cross connection which increases grip and introduce friction to resist slipping between members to provide lateral stability for horizontal member.

The cross connection test with node has resulted increase in load resistance for bamboo strip by 50% and for iron wire by 60%. The reason for higher connection resistance at the node than internode is due to the grip induced by horizontal support by lateral braces increase and increased friction between the fastening material and the lateral braces. The lateral braces at the nodes have irregularities which prevent the bamboo members from slipping. In the presence of nodes, the connection resistance is found to increase up to a value of 1.55kN and 2.5kN for bamboo strip and iron wire respectively. However, as there is little control on the provision of nodes in bamboo connections on site, the basic connection resistance of each fastening should be taken as 1.0kN. Therefore, the average value of cross resistance of node is adopted for design.

Table 6-6: Strength of connections with and without nodes

Test No.	Cross connection resistance with bamboo strip (KN)	Test No.	Cross connection resistance with iron wire (KN)
Connection Without Node			
1	0.9	1	1.2
2	1.1	2	1.4
Connection With Node			
3	1.45	3	2.1
4	1.55	4	2.5

6.5 Summary of test result

A total of 120 compressive tests and 12 flexure tests were conducted for different batches of samples and statistical analysis on all the test results were carried out to establish the characteristic mechanical properties of Assosa bamboo. Table 6-7 summarizes the ranges of the measured mechanical properties obtained from the different experimental test and compares the result with average mechanical strengths of wood and steel. It is observed from the table below that the test results that Assosa bamboo is acceptable construction materials with good mechanical properties against compression and bending in comparison to wood and steel.

Table 6-7: Comparison of design mechanical properties of bamboo and conventional construction materials (Guthrie, 2003)

No	Mechanical Properties	Bamboo (MPa)	Eucalyptus Wood(MPa)	Tubular Steel(MPa)
1	Compressive strength	62.5	55	138
2	Bending strength	75.8	68.9	165
3	Bending Modulus of Elasticity	11,140	14,197	19,995

The above mechanical strengths indicated in the table above are used for assessing the performance of Assosa bamboo as a scaffolding system in the following chapter.

Bamboo is composite material composed of soft and weak material, stiff and strong material. Composites like concrete are well known for their good properties, the properties of the whole being better than the sum of the component parts. In comparison with the mechanical performance of other composite materials, bamboo's mechanical properties are found reasonable. Concrete as a composite material use a design partial safety factor of 1.5. The dimensional and mechanical variations of bamboo depend on moisture content so it is the decisive factor for its use as structural element. Hence, in consideration of mechanical variations against moisture content and other factors a partial safety factor of 2.0 is recommended.

Chapter Seven

Detail Design of Bamboo Scaffold

7.1 Configuration and assembly of double layered bamboo scaffolds

In this section, the design procedures laid out in Chapter four are exercised for the design of two working platforms or height of 6m double layered bamboo scaffolding system to demonstrate the use of Assosa bamboo as scaffolding system. According to the design procedures set out by Chan (2002) for bamboo scaffolding can be used for a height up to fifteen meters. As a demonstration, a six meter high double layer Assosa bamboo scaffold is designed using the same procedures laid out by Chan (2002) and applying EBCS-3. The detail statical calculations for 6m double layered bamboo scaffolds are presented in Appendix B.

The intended double layered bamboo scaffold has two layers of bamboo in the inner facing the building and outer layer facing opposite to the inner layer as shown in Figure 7-1. It also supports two working platforms at a height of 2m spacing that can be used one at a time since this configuration is limited due to post axial load resistance capacity.

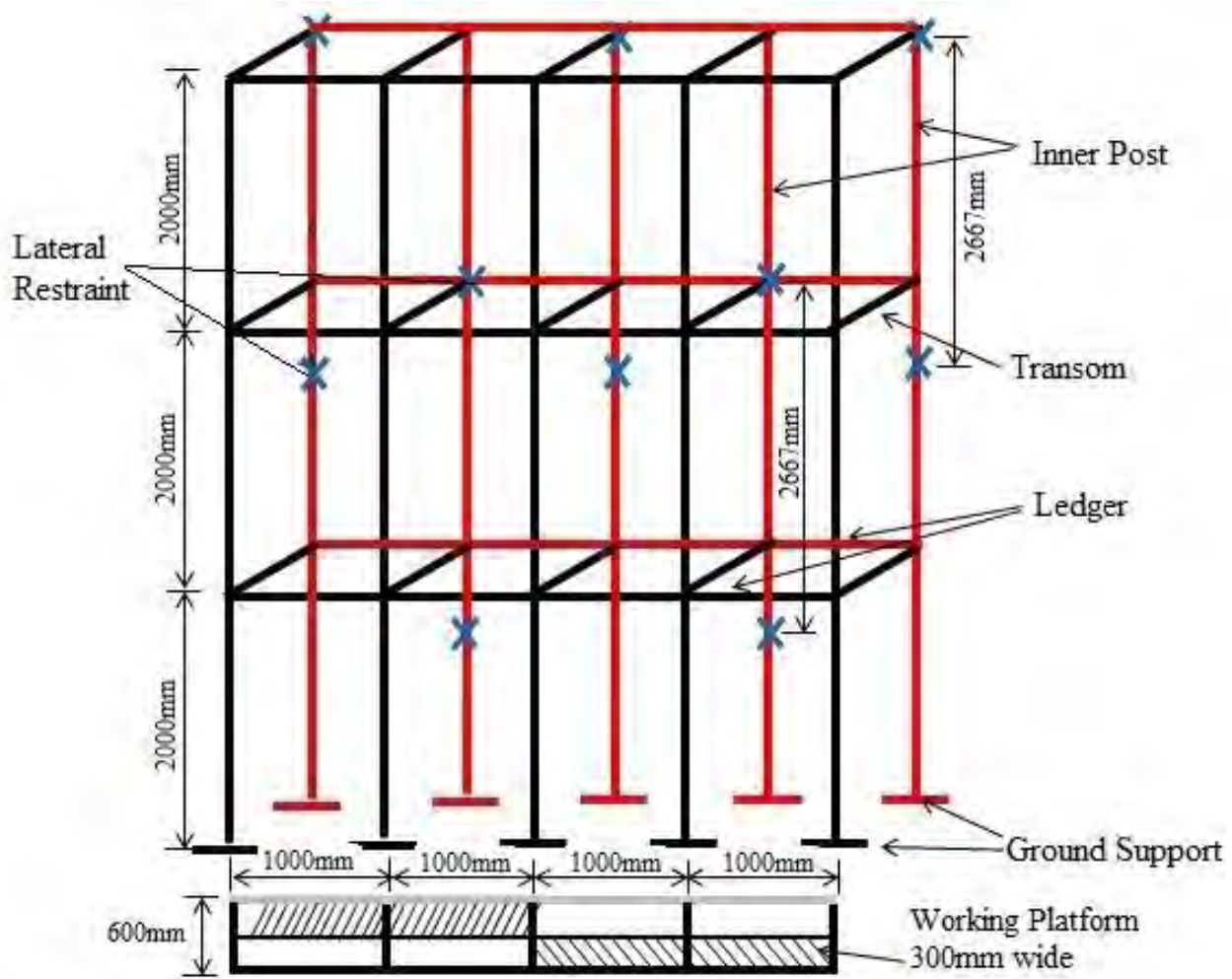


Figure 7-1: Six meters high double layered bamboo scaffolds

The configuration for scaffolds up to a height of fifteen meters in section 4.2 recommends an economical spacing of main posts on the outer and inner layer of the scaffold to be placed at a minimum spacing of 0.75 to a maximum of 1.2 m in the horizontal direction, and main ledgers to be placed at a minimum spacing of 1.8 to a maximum of 2.25 m in the vertical direction for outer and inner layer. The distance between the inner and outer layer is in a range of 0.6 to 0.75m.

For the six meter double layer bamboo scaffolding system under consideration a horizontal spacing of 1.0m for main post and vertical spacing of 2m for ledgers is used in the design. The main posts are rested on either solid ground or steel brackets and connected with horizontal ledgers in order to fix their position. The distance between the inner and outer layer is made 0.6m to increase the structural integrity and stiffness. Lateral bracing are provided at a vertical distance of 5.3m.

The same assumptions and procedures are applied for the design of six meter double layer bamboo scaffolding under consideration. Based on the output of the design, the ledgers and transoms have been found adequate to resist the loads coming from the platform. And, the 2m braced Assosa bamboo post could resist an axial load of 1.42kN. Since the bottom part of Assosa bamboo culm up to a height of 2m has solid cross section has contributed to stiffness of the post and it is recommended for use as a post. According to Chan (2002) the minimum overlap connection length between 2 post members should be 1.5m to 2m and at least 2m for ledgers and bracings. Hence, in consideration of the solid cross section at the bottom and the length of the connection between post members the culm height along the culm length up to 4m from bottom must be used as a main post with overlap of 1.5m connected at three places by bamboo strip.

The bracing members are provided to increase the structural stability of the scaffold. Along the horizontal plane, the standards are provided as secondary posts at spacing of 0.5 m with diameter of not less than 30mm and with no defects. The purpose of the standard is used as a bracing member and increase structural stability of the overall structure.

In the vertical direction, main ledgers are placed at a distance of 2m. Additional ledgers as bracing members are placed at a distance of 0.75m. The inner layer is erected in the same way and connected with 0.6m long transoms. The distance of transoms depends on the space between inner and layer of bamboo scaffold. The inner layer is tied laterally with a structure at a spacing of 2.667 times the height of one platform. Finally, two culms of Assosa bamboo are fixed in an 'X' shape at an angle of 45° to 60° as bracing to increase lateral stability. Each bracing is tied to the posts, standards and ledgers of the scaffold. Therefore, all the above members cumulatively form the basic configuration of a double-layered bamboo scaffold.

7.2 Safety management of bamboo scaffold

Bamboo scaffolds are used in different construction works. The stability and strength of bamboo scaffolds shall be justified by recognized engineering principles and standards. Bamboo is a natural material with good mechanical properties. It has few flaws as natural material subjected to insect and fungal attack. In addition with varying moisture content its mechanical properties change. It also requires due consideration to all safety factors in the design of bamboo scaffolds. So, it requires proper inspection during use. As per the published guideline of department of

occupational safety and health labor of Hong Kong (2006), the following legal requirements in relation to safe bamboo scaffolding practice is summarized:

a) Inspection and maintenance of bamboo scaffolds

During inspection and maintenance of bamboo scaffolds the following shall be observed;

- i. The scaffold shall be inspected with a report made by a competent person before use for the first time, within 14 days immediately preceding each use and after exposure to adverse weather conditions.
- ii. A qualified person should check the strength and stability of the scaffold and ascertain whether it is safe or needs to be repaired.

b) Dismantling of bamboo scaffolds

The following general procedures shall be observed for dismantling of bamboo from the work site;

- i. Work out a dismantling plan and working procedures.
- ii. Ensure that the dismantling work is done by trained workmen under the immediate supervision of a competent person.
- iii. Allow sufficient time for the dismantling work.
- iv. Install fences on the ground level and post up warning notices.
- v. Check the strength and stability of the scaffold before dismantling.
- vi. Ensure that no components, which endanger the stability of the remaining structure, are removed first while dismantling work is in progress.
- vii. Prohibit throwing or tipping scaffolding materials from height.
- viii. Ensure that no materials are stored on the scaffold.
- ix. Use personal protective equipment.

Chapter Eight

Conclusions and Recommendations

8.1 Conclusions

The research was conducted to assess the practicality of the Ethiopian lowland bamboo from Assosa area for use as scaffolding material. From the experiments conducted and design output there are several conclusions that can be derived from this study:

- 1) Considering the benefits of abundance, rapid renewability and good mechanical properties, bamboo has a great potential as an alternative scaffolding material that can add to the local construction resource list. However, absence of design procedures and standards have affected acceptance of bamboo as a substitute of choice in the construction industry.
- 2) The cross section of Assosa bamboo is solid to semi-solid characteristics for the bottom portion of the culm up to an average height of 1.7m. The thickness and cross-sectional diameter of Assosa bamboo varied along the culm length. The cross-sectional diameter ranges from 45mm to 30mm along the culm height. This showed Assosa bamboo cross-section is non-prismatic.
- 3) The moisture content of Assosa bamboo varies vertically from the bottom to the top portions of the culm. Moisture content range of air dry Assosa bamboo is 9-25%. The top portions have higher dry density than the bottom portion of the culm. And the mean value of dry density is 830 Kg/m³.
- 4) The top portion of Assosa bamboo had the highest compressive stress than middle and bottom portion. And the fifth percentile of the compressive strength for design is taken as 62.5MPa. The fifth percentile of the characteristic bending strength for design is taken as 75.8MPa. And the fifth percentile bending modulus of elasticity is determined to be 11,140MPa. Both mechanical properties had a strong inverselyproportionalrelation with moisture content.

- 5) Among the different bamboo connections only bamboo strips and iron wire cross-connection are considered for this study. It is found out that the connection resistances at the internode are found to be 0.9kN and 1.4kN for bamboo trip and iron wire respectively. The cross connection test with node has resulted increase in load resistance for bamboo strip by 50% and for iron wire by 60%.
- 6) In comparison with other conventional construction materials the mechanical properties of Assosa bamboo has been comparable to other conventional materials like wood and steel. In addition, the mechanical performance of Assosa bamboo scaffold has been found adequate for use as an alternative scaffolding material.

8.2 Recommendations

From the results obtained, for future undertaking the following ideas are recommended

- ✓ Ultimately, Assosa bamboo was revealed to be adequate for the elements of scaffolding structure, but further development of enhanced design methods as well as design criteria specific to bamboo scaffolding work are needed to improve the strength and performance of all members.
- ✓ Research needs to be conducted on using Assosa bamboo in composite systems with other existing construction materials; these include timber or steel assemblies.
- ✓ Further testing and characterization of Assosa bamboo for other structural components is required to aid utilization of this promising non-conventional constructional material. In addition, development effort should be directed at key areas of preservation and effective connection methods.
- ✓ Knowledge and technology transfer from bamboo utilizing countries like India, China, Thailand, etc. And arrange knowledge dissemination programme in this regard.
- ✓ Establish micro-enterprises that process and make use of Assosa bamboo for scaffolds.

Appendix A: Experimental test results

Assessment of Assosa bamboo (*Oxytenanthera abyssinica*) as an alternative scaffolding material

Culm Number One Test Result																	
Item No.	Sample One Code No	Specimen position along the culm	Sample Location in the Culm	Cumulative Height from Bottom(mm)		Specimen dimension			Cross Sectional Area (mm ²)	Air Dry Weight (g)	Oven Dry Weight (g)	Moisture Content (%)	Dry Density (Kg/m ³)	Radial Shrinkage (%)	Compressive Force (KN)	Compressive Strength (N/mm ²)	Type of Failure
						Sample Length (mm)	Average Dia (mm)	Average Thickness (mm)									
1	ASB1001	B	Internode	580.0	580.0	80.7	39.2	Soild	1206.9	81	69	17.39	708.5	1.01	69.4	57.50	End bearing
2	ASB1002	B	Internode	656.0	76.0	73.1	38.25	Soild	1149.1	70	59	18.64	702.4	0.98	73.7	64.14	End bearing
3	ASB1003	B	Internode	730.0	74.0	73.1	38	Soild	1134.1	70	61	14.75	735.8	0.98	75.2	66.31	End bearing
4	ASB1004	B	Internode	805.0	75.0	75.0	37.5	Soild	1104.5	71	62	14.52	748.5	0.97	71.5	64.74	End bearing
5	ASB1005	B	Internode	879.0	74.0	73.1	36.35	Soild	1037.8	67	58	15.52	764.6	0.97	67	64.56	End bearing
6	ASB1006	B	Internode	949.0	70.0	73.3	35.8	Soild	1006.6	64	54	18.52	731.9	0.94	67.7	67.26	End bearing
7	ASB1007	B	Internode	1019.0	70.0	68.4	35.6	Soild	995.4	59	51	15.69	749.1	0.91	68.7	69.02	End bearing
9	ASB1009	B	Internode	1087.0	68.0	69.8	34.4	Soild	929.4	57	51	11.76	786.2	0.86	65.7	70.69	End bearing
10	ASB1010	B	Internode	1155.0	68.0	67.1	34.1	Soild	913.3	53	45	17.78	734.3	0.64	64	70.08	End bearing
11	ASB1011	B	Internode	1223.0	68.0	67.0	34.0	Soild	907.9	53	47	12.77	772.6	0.56	65.3	71.92	End bearing
12	ASB1012	B	Internode	1291.0	68.0	66.4	33.7	Soild	892.0	53	46	15.22	776.7	0.55	65.2	73.10	End bearing
13	ASB1013	B	Internode	1357.0	66.0	63.7	32.8	Soild	842.4	49	41	19.51	764.1	0.50	56.3	66.83	End bearing
14	ASB1014	B	Internode	1421.0	64.0	64.1	32.5	Soild	827.0	47	40	17.50	754.5	0.57	61	73.76	End bearing
15	ASB1015	B	Internode	1485.0	64.0	64.5	32.1	Soild	806.8	46	41	12.20	787.9	0.49	61.4	76.11	End bearing
16	ASB1016	B	Internode	1549.0	64.0	64.4	31.9	Soild	796.7	46	40	15.00	779.6	0.42	56.5	70.92	End bearing
17	ASB1017	B	Internode	1613.0	64.0	64.6	32.3	Soild	819.4	46	41	12.20	774.6	0.43	60.9	74.32	End bearing
18	ASB1018	B	Internode	1677.0	64.0	64.4	31.8	Soild	794.2	44	39	12.82	762.5	0.43	60.3	75.92	End bearing
19	ASM1019	M	Internode	1741.0	64.0	60.3	31.1	Soild	757.2	44	37	18.92	810.3	0.40	56.8	75.01	End bearing
20	ASM1020	M	Internode	1803.0	62.0	60.8	30.8	Soild	742.6	40	34	17.65	753.0	0.39	58.3	78.50	End bearing
21	ASM1021	M	Internode	1865.0	62.0	60.6	30.4	Soild	725.8	40	34	17.65	773.0	0.23	56	77.15	End bearing
22	ASM1022	M	Internode	1927.0	62.0	62.6	30.6	Soild	733.0	40	35	14.29	762.7	0.32	53	72.30	End bearing
23	ASM1023	M	Internode	1987.0	60.0	57.4	30.5	Soild	730.6	36	34	10.11	810.7	0.36	50.1	68.57	End bearing
24	ASM1024	M	Internode	2047.0	60.0	57.5	30.3	Soild	718.7	36	33	9.09	798.6	0.33	54.5	75.83	End bearing
25	ASM1025	M	Internode	2107.0	60.0	61.4	29.8	Soild	697.5	38	36	9.30	841.1	0.28	51.9	74.41	End bearing

Assessment of Assosa bamboo (*Oxytenanthera abyssinica*) as an alternative scaffolding material

Culm Number One Test Result																	
Item No.	Sample One Code No	Specimen position along the culm	Sample Location in the Culm	Cumulative Height from Bottom(mm)		Specimen dimension			Cross Sectional Area (mm ²)	Air Dry Weight (g)	Oven Dry Weight (g)	Moisture Content (%)	Dry Density (Kg/m ³)	Radial Shrinkage (%)	Compressive Force (KN)	Compressive Strength (N/mm ²)	Type of Failure
						Sample Length (mm)	Average Dia (mm)	Average Thickness (mm)									
26	ASM1026	M	Internode	2165.0	58.0	56.6	29.5	Soild	683.5	35	31	12.90	801.3	0.29	51.3	75.06	End bearing
27	ASM1027	M	Internode	2223.0	58.0	60.8	29.4	10.7	629.6	37	35	11.50	914.3	0.26	49.5	78.62	End bearing
28	ASM1028	M	Internode	2281.0	58.0	57.4	28.9	11.3	623.8	33	30	10.00	837.8	0.25	47.7	76.47	End bearing
29	ASM1029	M	Internode	2339.0	58.0	59.5	28.6	10.2	590.1	35	32	9.38	911.4	0.19	47.8	81.00	Splitting
30	ASM1030	M	Internode	2397.0	58.0	59.3	28.5	9.6	568.2	33	28	17.86	831.0	0.17	49	86.24	End bearing
32	ASM1031	M	Internode	2455.0	58.0	58.0	28.6	10.0	583.3	33	28	17.86	827.7	0.16	47	80.58	End bearing
33	ASM1032	M	Internode	2511.0	56	55.4	28.45	9.78	573.6	31	28	10.71	881.1	0.15	44.6	77.75	End bearing
34	ASM1033	M	Internode	2567.0	56	55.8	28.35	9.78	570.6	31	28	10.71	879.4	0.31	43.5	76.23	End bearing
35	ASM1034	M	Internode	2623.0	56	57.04	28.3	9.72	567.3	31	27	14.81	834.4	0.30	43.2	76.15	End bearing
36	ASM1035	M	Internode	2679.0	56	54.2	27.7	9.67	547.7	29	26	11.54	875.8	0.29	43	78.50	End bearing
37	AST1036	T	Internode	2735.0	56	52.1	27.6	9.45	538.8	29	26	11.54	926.1	0.28	44.2	82.03	End bearing
38	AST1037	T	Internode	2789.0	54	52.2	27.4	9.28	528.3	29	26	11.54	942.9	0.23	40.9	77.42	End bearing
39	AST1038	T	Internode	2843.0	54	52.3	27.4	9.18	525.5	27	24	12.50	873.3	0.26	41.8	79.55	End bearing
40	AST1039	T	Internode	2897.0	54	52.4	27.3	9.03	518.3	27	22	22.73	810.1	0.29	41.5	80.07	End bearing
41	AST1040	T	Internode	2951.0	54	54.6	27.15	9.39	523.9	27	24	12.50	839.0	0.24	39.6	75.59	End bearing
42	AST1041	T	Internode	3005.0	54	54.7	27.1	9.36	521.7	27	24	12.50	841.1	0.23	41	78.60	End bearing
43	AST1042	T	Internode	3057.0	52	55.4	27.1	9.35	521.4	26	23	13.04	796.3	0.18	38.2	73.27	End bearing
44	AST1043	T	Internode	3109.0	52	49.2	27	9.31	517.4	23	20	15.00	785.7	0.20	37.3	72.09	End bearing
45	AST1044	T	Internode	3161.0	52	49.2	26.5	9.13	498.2	23	21	9.52	856.7	0.13	36.6	73.46	Splitting
46	AST1045	T	Internode	3213.0	52	49.3	26.2	9.15	490.1	22	20	10.00	827.7	0.15	35.7	72.84	Splitting
47	AST1046	T	Internode	3265.0	52	52.3	26.25	8.73	480.5	24	22	9.09	875.4	0.12	36.4	75.75	Splitting
48	AST1047	T	Internode	3317.0	52	52	26.1	7.83	449.4	24	21	14.29	898.6	0.18	36.2	80.55	End bearing
49	AST1048	T	Internode	3367.0	50	49	25.9	8.48	464.1	22	20	10.00	879.5	0.14	36	77.57	End bearing
50	AST1049	T	Internode	3417.0	50	49.4	25.5	8.6	456.6	23	20	15.00	886.7	0.19	35.8	78.41	End bearing

Note: T- Top, M-Middle, T-Top

Assessment of Assosa bamboo (*Oxytenanthera abyssinica*) as an alternative scaffolding material

Culm Number Two Test Result																	
Item No.	Sample Code No	Specimen position along the culm	Sample Position	Cumulative Height from Bottom(mm)		Specimen dimension			Cross Sectional Area (mm ²)	Air Dry weight (g)	Oven Dry Weight (g)	Moisture Content (%)	Dry Density (Kg/m ³)	Radial Shrinkage (%)	Compressive Force (KN)	Compressive Strength (N/mm ²)	Type of Failure
						Sample Length (mm)	Average Dia (mm)	Average Thickness (mm)									
1	ASB2001	B	Internode	592.0	592.0	89.9	46.4	Soild	1690.9	144	122	18.03	802.55	0.98	115.9	68.5	End bearing
2	ASB2002	B	Internode	684.0	92.0	89.5	46.2	Soild	1676.4	140	118	18.64	786.48	0.97	109.5	65.3	End bearing
3	ASB2003	B	Internode	882.0	198.0	88.7	44.1	Soild	1527.5	132	114	15.79	841.42	0.98	112.3	73.5	End bearing
4	ASB2004	B	Internode	962.0	80.0	88.6	44.7	Soild	1569.3	130	109	19.27	783.95	0.96	111.2	70.9	End bearing
5	ASB2005	B	Internode	1198.0	236.0	79.4	43.05	16.64	1380.6	107	93	15.05	848.38	0.95	102.9	74.5	End bearing
6	ASB2006	B	Internode	1284.0	86.0	81.6	42.85	16.08	1352.3	109	94	15.96	851.83	0.96	101.7	75.2	End bearing
7	ASB2007	B	Internode	1370.0	86.0	81.2	42.7	16.12	1346.1	110	97	13.40	887.45	0.94	104.4	77.6	End bearing
8	ASB2008	B	Internode	1578.0	208.0	81.0	41.7	15.23	1266.5	101	88	14.77	857.82	0.93	96.4	76.1	End bearing
9	ASB2009	B	Internode	1662.0	84.0	81.2	41.65	14.3	1227.9	100	87	14.94	872.59	0.91	97.8	79.7	End bearing
10	ASB2010	B	Internode	1746.0	84.0	85.1	41.65	14.6	1240.9	106	91	16.48	862.14	0.88	99.9	80.5	End bearing
11	ASM2011	M	Internode	1920.0	174.0	84.9	40.95	14.0	1186.5	101	88	14.77	873.56	0.67	91.7	77.3	End bearing
12	ASM2012	M	Internode	2002.0	82.0	77.5	40.45	13.8	1153.8	89	76	17.11	849.95	0.63	92.3	80.0	End bearing
13	ASM2013	M	Internode	2084.0	82.0	85.2	40.6	13.8	1160.2	97	81	19.75	819.69	0.65	94.2	81.2	End bearing
14	ASM2014	M	Internode	2165.0	81.0	80.5	40.2	12.4	1083.0	94	79	18.99	906.18	0.67	90.3	83.4	End bearing
15	ASM2015	M	Internode	2245.0	80.0	79.3	39.4	12.1	1037.8	92	78	17.95	947.81	0.65	91	87.7	End bearing
16	ASM2016	M	Internode	2325.5	80.5	80.1	38.7	11.7	992.4	91	78	16.67	981.21	0.67	69.8	70.3	End bearing
17	ASB2017	M	Internode	2405.0	79.5	80.7	37.35	11.3	925.2	82	70	17.14	937.50	0.55	64.44	69.6	End bearing
18	ASB2018	M	Internode	2481.0	76.0	74.5	37.265	11.4	926.8	73	61	19.67	883.47	0.54	63.5	68.5	End bearing
19	ASB2019	M	Internode	2557.0	76.0	76.0	37.15	12.0	949.4	74	65	13.85	900.88	0.34	66.59	70.1	End bearing
20	ASB2020	M	Internode	2633.0	76.0	76.1	38	11.4	952.7	76	66	15.15	910.38	0.32	61.22	64.3	End bearing
21	ASB2021	M	Internode	2817.0	184.0	74.6	35.5	10.7	835.4	69	60	15.00	962.74	0.36	63.71	76.3	End bearing
22	ASB2022	M	Internode	2891.0	74.0	70.6	35.5	10.6	828.1	63	54	16.67	923.68	0.34	63.65	76.9	End bearing
23	ASB2023	M	Internode	2965.0	74.0	75.9	35.45	10.9	838.5	69	59	16.95	927.03	0.31	63.52	75.8	End bearing
24	ASB2024	M	Internode	3039.0	74.0	75.9	34.95	10.3	797.6	69	59	16.95	974.55	0.25	62.16	77.9	End bearing

Assessment of Assosa bamboo (*Oxytenanthera abyssinica*) as an alternative scaffolding material

Culm Number Two Test Result																	
Item No.	Sample Code No	Specimen position along the culm	Sample Position	Cumulative Height from Bottom(mm)		Specimen dimension			Cross Sectional Area (mm ²)	Air Dry weight (g)	Oven Dry Weight (g)	Moisture Content (%)	Dry Density (Kg/m ³)	Radial Shrinkage (%)	Compressive Force (KN)	Compressive Strength (N/mm ²)	Type of Failure
						Sample Length (mm)	Average Dia (mm)	Average Thickness (mm)									
25	AST2025	T	Internode	3267.0	228.0	70.0	34.15	10.2	765.3	59	50	18.00	933.35	0.27	57.9	75.7	End bearing
26	AST2026	T	Internode	3337.0	70.0	70.6	33.95	10.0	753.9	56	47	17.40	882.99	0.26	55.8	74.0	End bearing
27	AST2027	T	Internode	3407.0	70.0	70.6	33.95	9.9	749.8	56	47	17.30	887.90	0.25	56.22	75.0	End bearing
28	AST2028	T	Internode	3477.0	70.0	70.7	35.45	10.4	819.8	58	51	13.73	880.14	0.19	59.95	73.1	End bearing
29	AST2030	T	Internode	3715.0	238.0	70.5	33.95	9.425	726.2	56	49	14.29	957.80	0.17	67.4	92.8	End bearing
30	AST2031	T	Internode	3783.0	68.0	63.0	34.15	9.825	750.8	48	42	14.29	887.92	0.18	62.2	82.8	End bearing
31	AST2032	T	Internode	3851.0	68.0	68.0	33.95	9.725	740.1	52	44	13.80	874.26	0.17	66.7	90.1	End bearing
32	AST2033	T	Internode	3919.0	68.0	68.6	33.95	9.675	737.8	52	45	14.80	889.05	0.15	63	85.4	End bearing
33	AST2034	T	Internode	4117.0	198.0	66.0	33	9.5	701.9	51	44	13.90	949.79	0.12	62.9	89.6	End bearing
34	AST2035	T	Internode	4183.0	66.0	66.0	33	9.5	701.0	50	44	13.64	950.98	0.11	62.7	89.4	End bearing

Note: T- Top, M-Middle, B-Bottom

Assessment of Assosa bamboo (*Oxytenanthera abyssinica*) as an alternative scaffolding material

Culm Number Three Test Result																	
Item No.	Sample Code No	Specimen position along the culm	Sample Position	Cumulative Height from Bottom(mm)		Specimen dimension			Cross Sectional Area(mm ²)	Air Dry Weight (g)	Oven Dry Weight (g)	Moisture Content	Dry Density (Kg/m ³)	Radial Shrinkage(%)	Compressive Force (KN)	Compressive Strength (N/mm ²)	Type of Failure
						Sample Length (mm)	Average Dia (mm)	Average Thickness (mm)									
1	ASB3001	B	Internode	628.0	628.0	75.5	39	Soild	1194.6	80.0	65.0	23.08	720.69	0.98	70.7	59.18	End bearing
2	ASB3002	B	Internode	706.0	78.0	76.4	39	Soild	1194.6	78.0	62.0	25.81	679.33	0.88	69.3	58.01	End bearing
3	ASB3003	B	Internode	784.0	78.0	75.6	39	Soild	1194.6	81.0	69.0	17.39	764.03	0.88	69.1	57.84	End bearing
4	ASB3004	B	Internode	968.0	184.0	74.4	37	Soild	1075.2	73.0	63.0	15.87	787.54	0.87	67.1	62.41	End bearing
5	ASB3005	B	Internode	1042.0	74.0	74.4	37	Soild	1075.2	70.0	58.0	20.69	725.04	0.88	59.7	55.52	End bearing
6	ASB3006	B	Internode	1116.0	74.0	74.4	37	Soild	1075.2	71.0	63.0	12.70	787.54	0.90	67.3	62.59	End bearing
7	ASB3007	B	Internode	1353.0	237.0	71.1	36	Soild	1017.9	65.0	58.0	12.07	801.43	0.87	69.2	67.98	End bearing
8	ASB3008	B	Internode	1425.0	72.0	71.0	36	Soild	1017.9	63.0	54.0	16.67	747.21	0.78	66.7	65.53	End bearing
12	ASM3009	M	Internode	1495.1	70.1	69.4	35.85	13.45	946.5	57.0	47.0	17.70	715.51	0.36	59.2	62.55	End bearing
13	ASM3010	M	Internode	1565.1	70.0	67.6	35.105	12.8775	899.2	54.0	46.0	16.30	756.73	0.24	62.4	69.39	End bearing
14	ASM3011	M	Internode	1635.1	70.0	68.0	35.05	12.32	879.8	54.0	46.0	16.10	768.93	0.37	63.7	72.41	End bearing
15	ASM3012	M	Internode	1705.1	70.0	69.5	34.65	12.8925	881.2	57.0	51.0	14.30	832.70	0.27	62	70.36	End bearing
16	ASM3013	M	Internode	1773.1	68.0	68.2	33.5	11.0725	780.1	50.0	46.0	14.20	864.94	0.39	59.7	76.52	End bearing
17	ASM3014	M	Internode	1841.1	68.0	66.5	33.3	10.745	761.4	49.0	44.0	13.80	868.50	0.31	60.6	79.59	End bearing
18	ASM3015	M	Internode	1909.1	68.0	67.4	33.3	11.175	776.7	50.0	43.0	14.70	821.35	0.28	57.3	73.77	End bearing
19	ASM3016	M	Internode	2147.1	238.0	71.3	33.95	11.28425	803.5	53.0	47.0	14.90	820.38	0.33	56.8	70.69	End bearing
20	ASM3017	M	Internode	2213.1	66.0	67.1	33.1	10.85	758.4	47.0	42.0	14.60	825.31	0.39	57.7	76.08	End bearing
21	ASM3018	M	Internode	2279.1	66.0	67.1	32.95	10.7225	748.7	48.0	42.0	14.29	835.97	0.42	54.6	72.92	End bearing
22	ASM3019	M	Internode	2345.1	66.0	67.1	32.8	11.725	776.3	49.0	42.0	15.90	806.30	0.39	56.2	72.39	End bearing
23	ASM3020	M	Internode	2531.1	186.0	65.1	33	12.1225	795.1	45.0	39.0	15.38	753.46	0.21	51.9	65.27	End bearing
24	ASM3021	M	Internode	2595.1	64.0	62.3	32.5	11.0675	745.2	41.0	34.0	15.20	732.35	0.28	54.3	72.87	End bearing
25	ASM3022	M	Internode	2659.1	64.0	63.6	31.4	10.41	686.5	41.0	38.0	14.30	870.39	0.38	56.5	82.31	End bearing

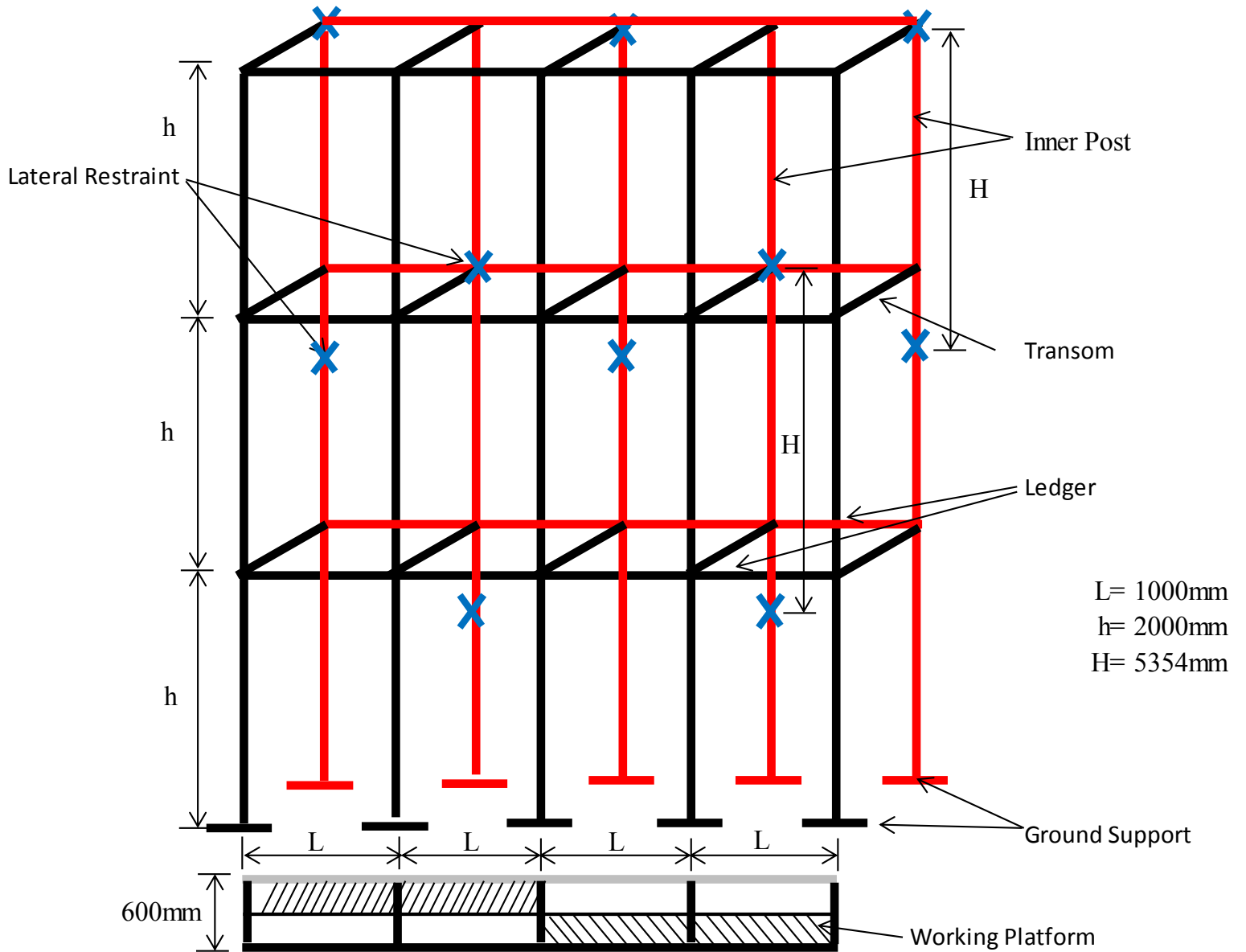
Assessment of Assosa bamboo (*Oxytenanthera abyssinica*) as an alternative scaffolding material

Culm Number Three Test Result																	
Item No.	Sample Code No	Specimen position along the culm	Sample Position	Cumulative Height from Bottom(mm)		Specimen dimension			Cross Sectional Area(mm ²)	Air Dry Weight (g)	Oven Dry Weight (g)	Moisture Content	Dry Density (Kg/m ³)	Radial Shrinkage(%)	Compressive Force (KN)	Compressive Strength (N/mm ²)	Type of Failure
						Sample Length (mm)	Average Dia (mm)	Average Thickness (mm)									
26	AST3023	T	Internode	2838.1	179.0	61.3	30.75	10.825	677.6	39.0	35.0	11.43	842.62	0.34	50.5	74.53	End bearing
27	AST3024	T	Internode	2898.1	60.0	58.5	30	10.0625	630.3	36.0	32.0	10.00	867.90	0.31	50	79.33	Splitting
28	AST3025	T	Internode	2958.1	60.0	58.8	30.0	10.2	634.5	36.0	32.0	12.50	857.74	0.31	51.4	81.01	End bearing
29	AST3026	T	Internode	3028.1	70.0	58.7	30	10.18	633.9	35.0	29.0	12.10	779.40	0.26	51.1	80.62	End bearing
30	AST3027	T	Internode	3097.1	69.0	58.6	30.5	10.8	668.4	34.0	28.0	12.50	714.86	0.25	49.6	74.21	End bearing
31	AST3028	T	Internode	3375.1	278.0	58.7	29.5	9.815	607.0	33.0	29.0	13.79	813.92	0.19	49.1	80.89	End bearing
32	AST3029	T	Internode	3433.1	58.0	58.2	29	9.77	590.2	31.0	27.0	12.70	785.99	0.17	45.9	77.77	End bearing
33	AST3030	T	Internode	3489.1	56.0	55.8	28.6	9.5125	570.4	30.0	27.0	11.11	848.27	0.14	45.1	79.06	End bearing
34	AST3031	T	Internode	3545.1	56.0	55.7	28.45	9.4925	565.3	30.0	27.0	11.11	857.43	0.12	46.2	81.72	End bearing
35	AST3032	T	Internode	3601.1	56.0	55.3	28.5	9.2	557.8	31.0	28.0	10.71	907.69	0.21	45.1	80.85	End bearing
36	AST3033	T	Internode	3657.1	56.0	55.4	28.45	9.2025	556.5	31.0	28.0	10.71	908.28	0.19	46.1	82.85	End bearing

Note: T- Top, M-Middle, B-Bottom

Appendix B: Statical Calculations for 6m High Double Layered Bamboo Scaffolds

Design of Primary Members for 6m Height Double Layered Bamboo Scaffold



Transon Design

Design Parameters:	Bending Modulus of Elasticity	$E_b =$	11.14 KN/mm ²
	Compressive Strength	$P_c =$	31.25 N/mm ²
	Bottom Diameter	$f_b =$	37.90 N/mm ²
	$D_e =$	40 mm	
	$D_i =$	7 mm	
		$A_t = \frac{\pi}{4} (D_e^2 - D_i^2)$	
		$A_t =$	1,218.15 mm ²
	W_{pl} section modulus =	$\frac{\pi \times (D_e^4 - D_i^4)}{32 \times D_e}$	= 6277.2924 mm ³

M_{cRd} is the design moment resistance of the cross section of bamboo

$$M_{cRd} = \frac{W_{pl} \times f_b}{\gamma_{mo}}$$

$$= 0.12 \text{ KNm}$$

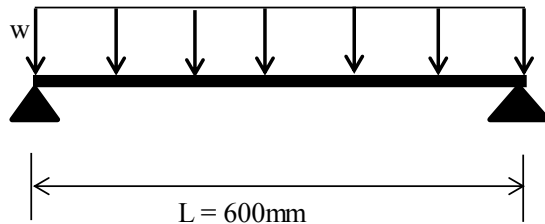
V_{Rd} is the design shear resistance of the cross section of bamboo

$$V_{Rd} = \frac{2A/\pi \times (\frac{f_{cd}}{\sqrt{3}})}{\gamma_{mo}}$$

$$= 7.00 \text{ KN}$$

Design Check: Transon is a simply supported beam under uniform load from platforms

Hence, it shall satisfy the design criteria, $M_{sd} \leq M_{cRd}$ and $V_{sd} \leq V_{Rd}$



The design load is

$$w = (1.6 \times 1.5 + 1.3 \times 0.144)$$

$$= 2.59 \text{ KN/m}$$

Check for Maximum Shear

$$V_{sd} = (W \times L)/2$$

$$= 0.78 \text{ KN} \leq V_{Rd} = 7.0 \text{ KN} \quad \text{OK!}$$

Check for Maximum Bending Moment

$$M_{sd} = (W \times L)/8$$

$$= 0.19 \text{ KNm} < 2 \times M_{cRd} = 0.12 \text{ kNm} \quad \text{OK!}$$

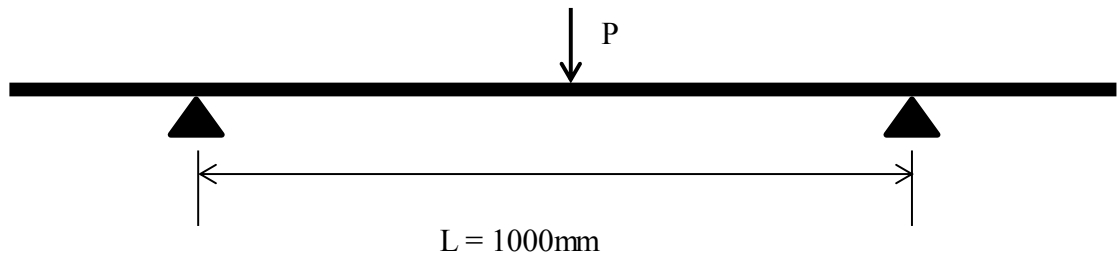
Therefore, use two Assosa bamboo for use as a transon $2 \times 0.12 = 0.24 \text{ kNm}$

Ledger Design

Design Parameters:	Bending Modulus of Elasticity	$E_b =$	11.14	KN/mm ²
	Compressive Strength	$P_c =$	31.25	N/mm ²
	Bottom Diameter	$f_b =$	37.9	N/mm ²
	$D_e =$	40 mm		
	$D_i =$	7 mm		
			$A_l = \frac{\pi}{4}(D_s^2 - D_i^2)$	
			$A_l =$	1,218.15 mm ²

Design Check: Ledger is a simply supported and continuous beam under a point load from transoms

Hence, it shall satisfy the design criteria, $M_{sd} \leq M_{cRd}$ and $V_{sd} \leq V_{Rd}$



The point load is

$$P = 0.78 \text{ KN}$$

Check for Shear

$$V_{sd} = 1.062 \times P$$

$$= 0.82 \text{ KN}$$

1.062 = max shear coefficient for different load combination

$$\leq V_{Rd} = 7.0 \text{ KN} \quad \text{OK!}$$

Check for bending moment

$$M_{sd} = 0.213 \times P \times 1.2$$

$$= 0.20 \text{ KNm}$$

0.213 = max bending moment coefficient for different load combination

$$< 2 \times M_{cRd} = 0.12 \text{ kNm} \quad \text{OK!}$$

$$3 \times 0.12 = 0.36 \text{ kNm}$$

Therefore, use three Assosa bamboo as a Ledger to support the load coming from the transom

Post Design

Design
Parameters:

Bending Modulus of Elasticity	$E_b =$	11,140.00 MPa
Compressive Strength	$P_{ck} =$	62.50 MPa
Bottom Diameter	Top Diameter	
$D_e =$ 40 mm	$D_e =$	35.00 mm
$D_i =$ 7 mm	$D_i =$	11.00 mm
Length of vertical member=	2 m	
Support condition is pin ended and staggered so, effective length coefficient $K_e = 1.05$		
Effective length, $h_{eff} = K_e \times L$	2,100.00 mm	

i) Sectional Properties

Cross Sectional area;

$$A_s = \frac{\pi}{4}(D_s^2 - D_i^2) \quad A_s = 867.08 \text{ mm}^2$$

$$A_l = \frac{\pi}{4}(D_s^2 - D_i^2) \quad A_l = 1,218.15 \text{ mm}^2$$

Second moment of area;

$$I_l = \frac{\pi}{64}(D_s^4 - D_i^4) \quad I_l = 125,545.85 \text{ mm}^4$$

$$I_s = \frac{\pi}{64}(D_s^4 - D_i^4) \quad I_s = 72,943.07 \text{ mm}^4$$

Radius of Gyration

$$r_l = \sqrt{\frac{I_l}{A_l}} \quad r_s = \sqrt{\frac{I_s}{A_s}} \quad r_l = 10.15 \text{ mm} \quad r_s = 9.17 \text{ mm}$$

Slenderness ratio;

$$\lambda_s = \frac{h_E}{r_s} \quad \lambda_s = 228.96$$

ii) Calculation of Elastic critical bulking strength;

$$\rho = \left(\frac{I_l}{I_s} - 1 \right) = 0.11$$

Where α , non- prismatic parameter and if α lies between 1.0 and 2.35, defined as,

$$\alpha = 1.005 + 0.4751\rho - 0.011\rho^2 = 1.055638$$

$$P_{cr} = \alpha \frac{\pi^2 E_b}{\lambda_s^2} = 2.21 \text{ MPa}$$

iii) compressive strength P_c calculated as;

$$P_c = \frac{P_{ck}}{\gamma_{mo}} \quad \gamma_m = 2$$

$$= 31.25 \text{ MPa}$$

iv) compressive buckling strength calculated by;

$$P_{c,c} = \frac{P_{cr} P_c}{\phi + (\phi^2 - P_{cr} P_c)^{1/2}}$$

$$= 1.63 \text{ Mpa}$$

$$\phi = \frac{P_c + (1 + \eta) P_{cr}}{2}$$

$$= 21.99 \text{ Mpa}$$

Perry factor, $\eta = 0.001 \alpha (\lambda_s - \lambda_o)$

$$= 4.75$$

$$\text{limiting slenderness ratio, } \lambda_o = \sqrt{\frac{\pi^2 E_b}{P_c}}$$

$$= 59.32$$

Modified slenderness ratio

$$\bar{\lambda} = \sqrt{\frac{P_c}{P_{cr}}}$$

$$= 3.76$$

Modified strength

$$\psi_c = P_{c,c} / P_c$$

$$= 0.05$$

Axial Load Resistnace

$$P = P_{c,c} A_1$$

$$= 1.42 \text{ kN}$$

Check Column Capacity

Assuming a single worker on the scaffold weights 80Kg

$$V_{\max} = 1.062 \times 80 \text{ Kg} \times 9.81 / 1000 = 0.83 \text{ kN} < V_{Rd} = 7.0 \text{ KN} \quad \text{OK!}$$

$$M_{\max} = 0.213 \times 1.26 \times 1.0 = 0.27 \text{ kNm} < 3 \times M_{cRd} = 0.12 \text{ kNm} \text{ OK!}$$

$$3 \times 0.12 = 0.36 \text{ kNm}$$

Design of Restraints

Design Condition: The spacing of the posts in the inner and outer layer is the same at 1.2meters

Load coming from the platform is

$$P_{\text{platform}} = 0.82$$

The axial load resistance of Assosa bamboo with an effective height of 2m is 1.42kN

The effective length of the post in DLBS for inner layer, h_{ei} , as follows:

$$h_{ei} = k_e \times h_i$$

$$k_e = k_i \times k_b$$

From Table 4-4

K_i is read as 1.5 for $H=2.667h$ in a staggered manner

K_b is 0.7 for DLBS with staggered lateral restraints

$$K_e = 1.05$$

$$h_{ei} = 2100 \text{ mm}$$

$$P_{\text{axial}} = 1.42 \text{ kN}$$

Design Check: Number of loaded working platforms

$$= P_{\text{axial}} / P_{\text{platform}}$$

$$= 1.73$$

$$= 1$$

Total factored load for loaded platform= 1×0.82

$$= 0.82 \leq 1.42$$

Therefore only one working platforms may be used at any time

Transom-Post Connection check: The transom-post connection resistance of a bamboo strip is 1.0kN and the maximum load from platform is 0.82kN. Therefore, the bamboo strip connection could resist the maximum load from platforms

Column Connection check: The maximum force in the posts of double layer bamboo scaffold is 1.64kN. Bamboo strip connection resistance is 1.0kN. Hence, use at least two fastenings in all column to column connection.

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DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university. All sources of materials used for the thesis have been duly acknowledged.

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Date of submission: _____

Signature: _____

Title of the thesis:

“Assessment Of Assosa Bamboo (Oxytenanthera Abyssinica) as an Alternative Scaffolding Material”

This thesis has been submitted for examination with my approval as a university advisor

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