DESIGN AND CONSTRUCTION OF A WOODEN GRAIN SILO

BY

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FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA
NIGER STATE.

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A PROJECT SUBMITTED TO
THE DEPARTMENT OF AGRICULTURAL ENGINEERING
SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY
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IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF
BACHELOR OF ENGINEERING (B. ENG.) DEGREE IN AGRICULTURAL ENGINEERING

CERTIFICATION

The undersigned certify that they have read and recommended to the School of Engineering and Engineering Technology for acceptance, a Project titled "DESIGN AND CONSTRUCTION OF A WOODEN GRAIN SILO" submitted by TOLUFASE JOSEPH STEPHEN in partial fulfilment of the requirements for the award of the Bachelor of Engineering Degree.

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DECLARATION

I hereby declare that this project is an original work of mine and has never been presented elsewhere for the award of any degree. Information derived from published or unpublished work of others have been acknowledged in the text.

....

SIGNATURE OF STUDENT

Date..13/3/98.

DEDICATION

This project is dedicated to God who gives wisdom and to my beloved parents:

My father, **LATE J. A. TOLUFASE** and

My mother, **S. M. TOLUFASE.**

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I thank my God for his love and faithfulness; And especially for the grace to study up to this level.

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LIST OF SYMBOLS

A	=	Area
C	=	Force Coefficient
D	=	Internal Diameter of Silo
d	=	Depth of column
DL	=	Dead load
E	=	Modules of Elasticity of Iroko
Fcu	=	Grade of Cement
Fv	=	Vertical floor pressure due to grain
H	=	Height of silo or grainfill
I	=	Moment of Inertial of a section
L	=	Lateral pressure per unit wall area
LL	=	Live load
LR	=	Lateral pressure considered as a resultant load
LT	=	Total lateral pressure per unit wall perimeter
mm	=	Millimeters
n	=	Number of sides of a hexagon
Pcr	=	Critical load
Pu	=	Ultimate Soil Pressure
Px	=	Punching Shear
q	=	Wind load
qf	=	Footing Dimension
R	=	Circumscribed radius
r	=	Inscribed radius
S	=	Width of panel
t	=	Thickness of plate
V	=	Volume
Vw	=	Wind Velocity
w	=	Bulk density of grain
W	=	Load on plate
Y	=	Slant edge of roof
Z	=	Sectional modulus
S	=	Deflection
σd	=	Allowable stress
σA	=	Actual stress
θ	=	Angle
ϕ_1	=	Angle of internal friction of grain

ABSTRACT

The search for alternative materials to steel for the construction of grain silos in Nigeria has become necessary in view of the problem of moisture condensation within the walls of a steel silo under the Nigeria climate which leads to the deterioration of the stored grain. Various constructional materials have been tested but no one has proven satisfactory over the other. Wood products from tests are found to be of potential from the point of view of elimination of moisture condensation and reduced temperature fluctuations within the silo.

The silo designed was 1 ton capacity for use by rural farmers in the Nigeria local condition making use of plywood extensively as constructional material. The silo is hexagonal in shape with a conical roof. Loading is done through a door on one side and a window located on the roof while discharge is by gravity through a chute located on the side.

From tests carried out, it was deiscovered that the wooden silo can maintain a relatively uniform temperature within for the stored grain. This is due to the low thermal conductivity of the plywood material. There was not much temperature fluctuation in the silo compared to the ambient temperature.

It is therefore recommended that a longer period of testing should be carried out to determine the suitability of plywood as a constructional material.

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CHAPTER ONE

INTRODUCTION

1.1 GENERAL

A silo is a structure designed and erected to store free-flowing solid materials. Agricultural materials such as shelled corn, guinea corn, millet and threshed rice are stored inside a silo. It is also used in storing cement. The production of food grains traditionally occupies a major portion of the world agricultural inductry. In Nigeria for example, these crops form a major part of food for human consumption and aalso as feed to livestock. Because of the role these grains play in the life of the people, the demand for them is continous but they can only be produced at certain periods of the year hence the need to store some of these grains so as to provide supply consistent with demand all year round.

Farmers all over the world lose much of their grains after it is harvested to insects, rats, birds, micro-organisms etc. In Nigeria, this losses are up to 50% (Igbeka, 1992) in storage because farming families store their produce in traditional out-door structures like mud rhumbu, local crib and other indoor storage facilities like bags and earthen pots. These structures are prone to different risks like fire, theft and insect infestation, hence farmers income is reduced and losses increased. Increased productivity cannot be translated into a proportionate increase in the level of real income if storage system is inefficient because the farmer lose motivation to grow more due to the fact that there is no adequate storage facility for his produce and also the length losses and maintain quality of food grains making use of locally available material is necessary.

Most of the large scale storage structures in Nigeria todaay are being purchased from foreign countries with little emphasis placed on the climatic difference between the temperate conditions of the exporting countries as against the hot, humid tropical environment of this country. The use of steel or aluminium silos has proven ineffective due to temperature variation within the grains, causing deterioration. The cost of purchasing one by a peasant farmer is expensive.

The design of farm grain storage must suit the purpose which it is to serve. The choice of any material for construction in any environment will depend on the availability of the material, the technology to install the silo, subsequent maintenance and the relative cost of the material compared to all other possible material of construction. Steel, Aluminium, Concrete and wood are the most common materials that have been used in silo construction.

There is the need to design and construct a silo using locally available materials to meet the need of the local farmers.

1.2 AIMS AND OBJECTIVES

1. To design and construct a wooden silo.
2. To investigate the potentials of wood products i.e Plywood as an alternative material for grain silo construction.
3. To construct a silo that is easily erected with locally available labour and suitable to the environment.

1.3 JUSTIFICATION

The warm humid type of climaate in Nigeria is characterised by wide daily temperature fluctuation and high relative humidity due to high day and low night temperarures over the years. These temperatures results in condensation of moisture and excessive heating on the walls and roofs of silos (metallic) and its redistribution within the bulk of graain. This leads to grain caking, development of hot spots, mould growth, seed germination and rapid development of insects in the event of infestation. Igbeka (1992) recorded that about 50% of the total losses occur during storage.

There is need to look for an alternative material suitable to this environment apart from steel or aluminium for silo construction in view of the depreciating value of the Naira which has made imported silos very expensive and unaffordable for farmers and also because of the storage associated problems of a metallic silo coupled with the volume of the gigantic metal silos not fully etilised. It is necessary therefore to utilise locally available resources to build a silo that is of low cost, easy to erect and maintain as well as suitable to this environment. This work was initiated to investigate the potentials of a local material (Plywood) as a silo construction material.

1.4 SCOPE OF THE STUDY

The project work would involve the following

1. Design and construction of a wooden silo.
2. Determination of the effects of variables such as initial temperature of the grains, the ambient temperature, relative humidity, wind, and the material of the bin wall of the grain storability.

CHAPTER TWO

LITERATURE REVIEW

2.1 EVALUATION OF STORAGE STRUCTURES AND METHODS IN NIGERIA

The primary aims of storage, regardless of place, time or length of period and methods is to provide supply consistent with demand, to provide surplus storage with which to carry over supplies into years of low production, to adjust and maintain quality consistent with the intended use of the grain and to prevent monetary lose resulting from various destructive agents such as weather, insects, micro-organisms and rodents. Basically, the principle of crop storage involves the elimination, inactivation or effective control of these destructive agents. This is carried out by manipuplating the environment in and around the store product so as to impose unfavourable conditions necessary to prevent the activities of the destructive agents.

Storage of grain and its quality control can take place at different locations. It could be on the farm, at collection points or in transit and at terminal points where the grain is processed or moved forward in large bulks. A number of grain preservation and storage methods are in existence. New ones are coming up while work is still progressing on the improvement of the existing ones.

Nigeria can be divided into three climatic zones: The tropical rain forest zone (over 300mm precipitation) of the south, the guinea savannah of the middle belt (500-2000mm) and the semi sudan savannah region of the north (500mm or less rainfall) (J.C. Igbeka and D.O. Olumeko, 1996). It has a comparatively year round high temperature (average 28 C) that poses no serious limitations to the growth of tropical agricultural crops. It is therefore pertinent to note that because of these climatic division, storage systems differ from zone to zone. According to (Ajisegiri and Osunde, 1991), methods of grain preservation and storage can be grouped into subsistence or traditional, middle level and commercial level storage.

2.1.1 Subsistence level grain storage

This vary from crib, rhumbu and bags in the north to suspension over fire place, use of baskets, gourds, storage on decking of building, hanging from roof and stacking on pole. Some of these methods are discussed below.

(i) Gourd and Calabash Storage:

The gourds are the dried fruit cases of cucaribitacae. They are small and mainly used to store seed grains. This is because of the cool interior of such containers. However, it is breakable, the content could be attacked by insects, rodents and microbiological agents and it has very limited capacity.

(ii) Pot Storage:

These are clay pots used usually to store threshed grains. They are either placed on top of the ground or buried up to its neck in the shed or hut. It has higher capacity than gourd and it facilitates easy loading and unloading. It absorbs moisture readily and this causes moulding. Also it can easily be broken hence needs to be handled carefully. When buried, this problem is greatly reduced but it increases its absorptivity problem.

(iii) Drum and Kerosine Tins:

Shelled grains could be stored at home or even by some small scale traders using these containers. They are relatively air tight and fumigants are usually required to reduce the incidence of insect infestation. The containers can become rust and heating up of the grains inside is another major problem if grain is not properly dried.

2.1.2 Middle Level

These are for medium scale farmers. It includes

(i) Sacks:

Types known include the sisal, jute and plastic bags. Shelled produce are stored in these bags which are stacked mostly on raised planks in stores, barns, houses or even ware houses. The major disadvantage of this method is that it encourages insect infestation. Except the plastic bags are thick, they can break easily when old and allow free passage of moisture.

(ii) Rhumbu:

It is roughly cylindrical in shape or flask shaped tapering at one end. Rhumbu's floor is usually raised slightly from the ground to avoid damages by rain torrents to reduce rodent accessibility and to facilitate the process of unloading the structure which is normally done by gravity at the centre underneath the storage structure. It is very common in all parts of the country and is used to store shelled groundnut, maize and other grains. It has low capacity and it is difficult to make the bin air tight coupled with incidence of heating up of the inside. Inspite of these problems, the rhumbu still remains a

(iii) Crib:

It is gaining wide spread use in the country because it is used both as dryer and store. It is used for the storage of maize cobs, unshelled groundnut and other grains. It consists of a platform raised between 0.8m and 1.5m above ground level. A box like structure is constructed on the platform usually of wood, bamboo or wire mesh while the roof could be corrugated iron sheet or thatch grass. Rodents gourds are usually provided to prevent climbing of the structure by rodents. This method affords farmers to harvest their crop before it is completely dry on the farm. As aeration continues, the crop is dried during storage.

(iv) In-bin Drier/Store:

It is a recent method of grain storage. In this case, the grains are harvested when matured. They are put in this specially designed store that has a fan installed. The fan draws air through the grain to facilitate fast drying and it can also be used to store for the dried produce. It can reduce the moisture content of a farm produce from over 36% to less than 14% in only 18 hours (Ajisegiri and Osunde, 1991). Insect control is by treating the grain with persistent insecticides, for example actellic dust.

2.1.3 Commercial Storage

Storage of grains in commercial quantities is carried out by large scale traders, exporters, agro-based and allied companies, government agencies and some of the few existing large scale farmers. The structure for this method of storage are long lasting and permanent. They

(i) Ware House Storage:

Produce are already bagged and are stacked on wooden pallets away from the wall. The building must be located in a flood free area with smooth walls, leak proof and sealed eaved roofs and moisture proof floors. The doors and windows must be air tight to facilitate fumigation and to prevent rain and rodents from entering. This method has proven to be highly successful in both developing and developed countries.

(ii) Silos:

These are basically bins which are used as large scale grain storage of materials that are capable of flowing. These are of three types. They are the mart gas silos, the conventional silo and the butyl rubber silo. Apart from butyl rubber type, other forms of silos are fabricated from metals (aluminium, zinc etc), concrete, bricks, mud and wood. It can be classified based on the material of construction and capacity.

2.2 TYPES OF SILOS BREAKDOWN

2.2.1 Bunker Silo

Which is also known as Shallow Silo (Gurfinkel, 1979) can be traced back to the early 1950s. Experiments were conducted on wooden and concrete silos (Esmay and Brooker 1955, Esmay et al, 1956). The results of these early investigations and others were summarized and they formed the basis for the design loads that have been used in Canada and United States for bunker silo for the past 20 years. Bunker silos are prone to cracks initiated by a combination of high negative moment and shear.

2.2.2 Underground Storage Silo

Underground storage of grain and dry edible beans is a management technology that has evolved independently on even continent in the world. As long as 1000B.C., some cultures used underground storage as their principal means of strategic national storage (Dunkel, 1985; Sterling, et al, 1983). Experiment conducted showed that underground storage constructed of modified flexible polyolefin being monitored over nine month period and taking two layer by layer autopsies remained free of detestable live insects and exhibited fungal growth associated with only flaws. Both modern and ancient reports have claimed that insect infestation, fungal growth and taste acceptability are well controlled in underground structures.

2.2.3 Concrete Silo:

These include Masonry silos, Brick silos, Hollow-tile Cement stave and Monolithic concrete silo. The use of clay blocks for silos was developed by the Iowa experimental station (Iowa silo).

Concrete in various forms have also been tested as a possible material for grain silo construction in Nigeria.

While it was possible to eliminate caking and the development of hot spots, moisture condensation was still present even though it took a longer time to occur in the concrete silos than in steel and rubber ones. There was also the problem of water seepage in carelessly constructed silo (Osobu, 1971; Lasisi, 1989). Concrete has been used widely in the construction of silos because it is a durable and economical material for construction is used in this form, it requires considerable forming and labour. Concrete has the following advantages as a constructional material for silo.

(i) It is a poor conductor of heat and grain inside the silo is insulated from the external varying temperature.

(ii) The wall of a concrete silo is water proof and the stored grain is protected against increase in moisture content.

(iii) It is fire proof, rodent proof and can easily be constructed to any desired shape.

(iv) Raw materials for concrete silos are locally available and likewise the labour which is adequate for the construction and its subsequent maintenance.

Concrete as a constructional material has the following disadvantages:

(i) If surface is not given a smooth finish, rough surface harbours insects which feed on the stored grains leading to deterioration in grain quality.

(ii) Concrete is heavy and handling is difficult hence there is the danger of cracking and breakage of pre-cast concrete in transit.

(iii) Concrete structures are permanent and are not easy for remodelling.

(iv) Concrete is very poor in tension and the walls must be reinforced to be able to resist the lateral pressure of the stored grains. The reinforcement increases the cost of manufacture.

2.2.4 <u>Wooden Silo</u>:

Wood as a constructional material for silos is not generally as common as steel, aluminium and concrete in Nigeria. Wood has however been successfully used in silo construction in Washington United States as far back as 1948 (Aldrich 1948; Warner 1956). It has been used primarily in Nigeria for the construction of cribs. A major problem is that many farm storages have been installed on very short notice owing to excessively large yields or overfilled commercial storages. Such installations have given increased advantage to the pre-fabricated bin market. Types of wooden silo include wood-stave silo, panel silo, wood-hoop silo and creasoted-stave silo. Some of the advantages of wood are:

(i) It has low thermal expansion coefficient and low thermal conductivity (timber) in the range of 0.094-0.42W/M°C (Society of American Foresters, 1955) which is quite small compared to 0.8-0.14W/M°C for concrete; 12-62W/M°C for steel depending on the composition and 204W/M°C for aluminium all measured at 20°C (Parrish, 1973). Hence the stored grain is adequately protected from the direct heat from the surrounding.

(ii) The raw material is locally available and inexhaustible if properly planned by tree planting.

(iii) The labour requirement to work the wooden material and erect the silo can be met locally.

(iv) It has good ease of workability.

(v) The problems of durability and stability in service are surmountable if correct species are chosen and correctly treated.

Some of the disadvantages of wood as a constructional material include:

(i) Several wood species can rot leading to mould growth which may lead to deterioration of the store grains.

(ii) Difficulty in making the surface of many wood species smooth, cracks and splits may develop hence insect herbinate and fumigation is difficult.

(iii) Panel joints are difficult to be made water-proof.

The problems associated with wood as enumerated above are not sufficient to consider wood as an unsuitable material for silo construction. Plywood has overcome many of the disadvantages of wood with respect to strength characteristics and gives the possibility of pre-fabrication in large sections. In advanced countries such as the United States, wood products have been extensively used for silo construction and are known to compete favourably well with those of steel, aluminium and concrete (Aldrich, 1948; Warner 1956; Warner 1962). Plywood boxes have been successfully used for the storage of grains in Nigeria for up to twelve months (Lasisi, 1975).

2.2.5 Plastic/Rubber Silo:

Silos made from rubber of various types have been tested but found to be unsuitable. Rigid plastics and fiber glass have not been competitive with wood or steel.

There was the problem of moisture condensation as a result of the high tendency of the material to absorb heat and its high degree of susceptibility to rodent attack. Weathering under the intense heat of this country leaves a lot of cracks graduating into cuts and holes on the silo rubber after a period of use. Losses as much as 60% or more were common in the rubber silo (Agboola, 1985).

2.2.6 Steel/Aluminium Silo:

Perhaps the most common material used for the construction. It can be easily adapted to high volume pre-fabricated manufacture. Steel, used in thin sections, is relatively light in weight. Generally it must be galvanized or otherwise coated to minimize deterioration from moisture and oxidation. One of the main problems with steel is its extreme low resistance to heat transfer. Steel and aluminium however also have the following disadvantages especially in tropical countries.

(i) They are predominantly imported material hence attracting higher cost for silo construction.

(ii) Both materials are good conductor of heat and a silo constructed of this material is subjected to cycles of low and high temperature. This lead to moisture condensation on the inner side of the silo wall and mould development may occur. The stored grains are also subjected to excessive heating which may result in the deterioration of the quality of grains.

2.2.7 Shallow and Deep Silo:

Silos can be divided into deep and shallow types and various methods have been used in the classification. One of the methods is based on the plane of rupture which is determined by the angle of repose of the stored grain. When plane of rupture intersects the silo wall within the grain mass, the silo is said to be deep while in the shallow silo, the plane of rupture does not intersects the silo wall within the grain mass but the roof (fig 1).

A second distinction is based on the ratio of height to least lateral dimension of the silo. A shallow silo is one in which the depth is less than the least lateral dimension while a deep silo has a depth greater than the least lateral dimension (fig 2).

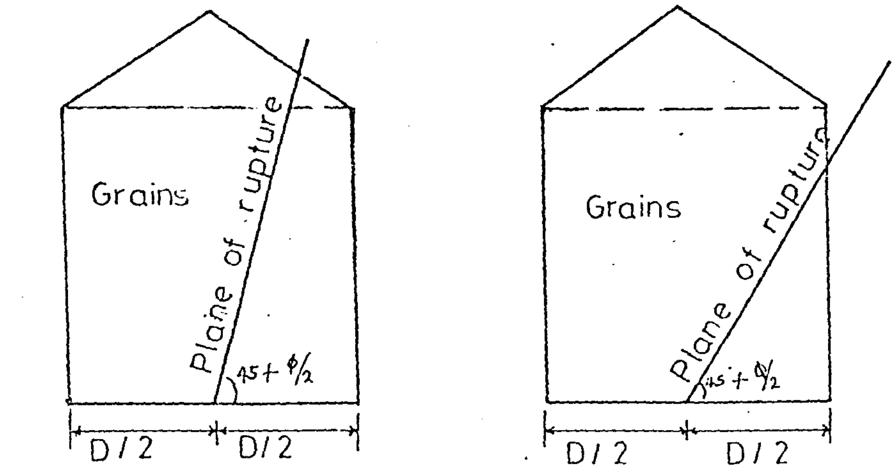
The most recent distinction is based on the depth of the silo (H), the diameter of the silo (D), and the coefficient of friction of grain on wall (H) (Mohsenin, 1975). By this distinction, for a deep circular silo

$$\frac{H}{D} \geq 0.75 \frac{1}{\mu , K} \quad ...... \quad 2.0$$

Where K = the pressure ratio.

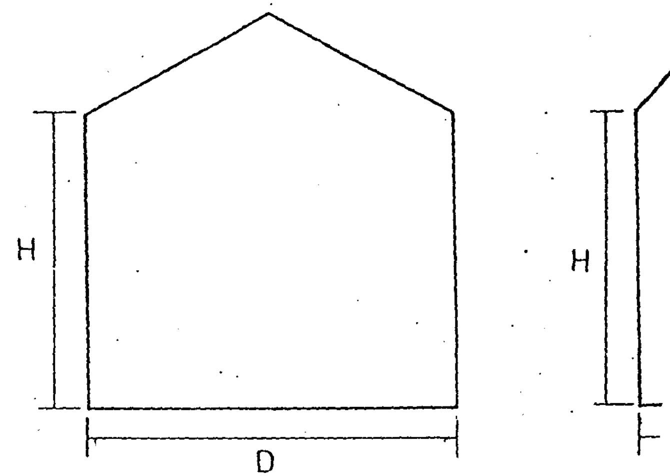
In this distinction, the properties of the grain will to a large extent determine whether the silo is deep or shallow.

The above distinctions are some of the many already presented and the search for a universally accepted distinction is still a matter for research.



(I) Shallow Silo   (II) Deep Silo

Fig 1 Shallow and Deep Silos



(I) Shallow Silo   (II) De

$\frac{H}{D} \nless 1$

Fig 2 Shallow and Deep Silos

2.3 DEVELOPMENT OF SILOS IN NIGERIA

The use of silos as grain storage structures in nigeria dates back to the mid-1950s. The first silo in Nigeria was a twenty ton aluminium type erected at Ilero in Oyo State in 1957 and 1958, a similar one was erected at Ilaro in Ogun State. (Williams, 1971).

These silos were wholly for the storage of maize, made of metal and supplied in pre-fabricated forms by the United States Department of Agriculture (USDA). These imported silos were initially excellent grain storage structures since they had the advantages of large storage capacities but were associated with the problem of tropical climate generally characterized by high temperatures, wide daily temperature fluctuations and relative humidity; the capacities of the silo structure, the cost of acquisition and maintenance.

The first indigenous silo was a ventilated out-door concrete type designed and erected by the Institute of Agricultural Research and Training, Moor Plantation, Ibadan in 1965 (Osobu, 1985). This silo was constructed to reduce the cost of silos making use of locally available materials. The number of silo increases to sixteen by 1971 (Williams, 1971) erected mainly in the Western States of Nigeria. By 1989, the Federal Government planned to erect twenty new metallic silos. These silos were located all over the country and by 1990 they are at different stages of completion. In addition to these, the government purchased some privately owned silo complexes and had concluded arrangement to ensure that every state of the country had a silo complex.

Due to the important nature of silos to the economy and in attempt to reduce stored grain losses due to problems associated with metallic silos, research efforts are being directed towards the use of local materials such as wood products (Mijinyawa, 1989) and Laterite (Osunade, 1977).

2.4 PROBLEMS OF BULK GRAIN STORAGE

Many factors are responsible for the deterioration of produce after harvest. The composition and behaviour characteristics of food grains vary, and grains are constantly being exposed to external forces including physical and biological agencies.

2.4.1 Physical factors Include:

(i) **Temperature:**

It is a determining factor in the development of all organisms and its effect is correlated with the amount of moisture present; the relative amount of moisture in the atmosphere decreases when temperature is raised. Under very damp condition, grain respiration increases to the point where germination occurs. The lower the temperature, the greater the retarding influences on respiration rate. When grain temperature rises above 66°C, not only is germination damaged, it also damage the quality of the grain.

Increase in temperature above the level at which food grains are initially stored in an indication of **deterioration**. It has been shown that because of the low thermal **conductivity of grain, increase in temperature** within a parcel of food grains is due either to the respiration of the grain itself or to the development within the grain of insects, fungi or bacteria.

Temperature variation inside stored products should be avoided. Locally higher temperatures may occur in the centre of grain stored in bulk in a silo, or be caused by big **differences in day and night time** temperatures, especially in metal silos. These situation results in the development of hot spots and it can also be caused by insects.

(ii) **Moisture Content and Relative Humidity:**

Biological activities occur when moisture is present. Therefore the moisture content of the product itself and that of the surrounding air, it important for safe storage. Each grain has its own characteristics balance or equilibrium between the moisture it contains and the water vapour in the air surrounding it. Warm air contains more moisture, therefore if the amount of moisture in air is constant, and the temperature increases, the relative humidity will decrease.

The maximum allowable moisture content for safe storage a stored product is usually considered as the moisture content at 27oC in equilibrium with relative humidity of 70% for the tropics (Hall, 1970). Maximum acceptable equilibrium moisture contents for safe storage of maize and cowpea at 27oC and 70% relative humidity are:

Maize = 13.5% (w.b)

Cowpea = 15% (w.b).

(iii) **Flow:**

Grains have a characteristic flow property which is unlike that of liquids. Each type of produce has a natural angle of repose of about 30o (Hall, 1970) but this varies somewhat according to the size, shape, moisture content and cleanliness of the grains.

(iv) **Pressure Distribution:**

Grains stored in a silo exert pressure, both vertical and lateral, on the sides of the container. For very small storages, the lateral pressure varies with the depth of grain. Vertical pressure rises rapidly in the depth of the grain up to 6 metres, thereafter the rate of increase becomes less rapid. Pressure also vary with the moisture content of the grain because of changes in the coefficient of friction which is greater at lower moisture content.

2.4.2 Biological Factors

(i) **Insects and Mites:**

Generally, insects have short life span but since they reproduce in storage, they continuously increase in number. Insect bite off, scrape or chew food using their mandible. Female insects make holes in grains and lay their eggs there.

Insects consume the stored products and contaminate them with faeces, ill smelling, fragments and metabolic products. Their infestation results into weight loss; loss of quality and market value; promote mould infestation; reduce germination and reduces the nutritional values of the food.

Sources of insect infestation include residues from the previous year(s); the infested store; rodent also carry insects; crops can also be infested from the field.

(ii) Fungi:

These are very small plants and are not visible to human eye. In a warm and moist environment the spores germinate and produce threads called hyphae. The hyphae penetrates the grain and convert part of it into other substances needed for their growth.

Fungi causes harm to the stored product by producing chemicals (enzymes) which may stop seeds from germinating; decreases quality of products; change in taste and production of poisonous substances to people and animals.

(iii) Bacteria:

These also cannot be seen by the naked eye, but occur almost everywhere, especially in moist environments. Under moist conditions they cause further deterioration of already affected grains and cause chemical changes and sometimes produce toxic substances.

(iv) Rodents:

Rats and mice may cause considerable damage to crops in the field and products in storage. This can occur in various ways by consuming part of the product; contamination of the product with their excrement; damage to buildings/storage containers and carriers of diseases which are harmful to people.

A bulk of grain storage as exists in silos is a man-made eco-system in which biological, physical and chemical factors are in continuous interactions with each others. These factors are important to the management of grain silos.

2.5 FUNCTIONAL REQUIREMENTS OF SILO

The functional requirement of a silo can broadly be grouped into two and these are the containment of the material (structural adequacy) and conditioning of the stored materials (environmental requirement).

A silo structure must be adequately strong and stable to confine and support the stored grain in both the vertical and lateral directions; and to resist the external loads that may be imposed on it by wind.

The functions of the roof are to protect the direct pour of rain unto the stored grains; to reduce the direct heat from solar radiation reaching the stored grains; and to resist loads which may be imposed on it by wind and rain. The silo roof should be of adequate strength and right material of construction to fulfil these requirements.

The major load sustained by the wall of a silo is the lateral pressure imposed on it by the stored grains. This pressure is assumed to have an intensity which is constant at any horizontal section but varies in the vertical direction, decreasing from a maximum value at the bottom to zero at the top surface of the stored grains. The silo wall must therefore be strong enough to be self supporting and to be able to resist imposed loads. It should be vertical to permit free settling of grains. Both the interior and exterior surfaces of the wall should be protected, metal from corrosion and wood from excessive drying and decay. The wall should prevent the penetration of water into the stored grains. The surfaces of the wall material should be as smooth as possible so as not to harbour insect, in cracks and crevices.

The silo floor provides vertical support for the grains and the super structure if the wall rests on the floor. For shallow silos, it is normally assumed that the entire vertical load due to grain is transmitted onto the floor but for deep ones, the wall sustain part of the vertical load due to grain thus reducing the amount of vertical pressure borne by the floor. The floor must be structurally strong enough to resist the load to be borne. Weakness in silo floor promotes structural damage or failure of the silo super structure. A suspended floor if not properly designed and erected, may sag under heavy loads of grain and this may weaken the entire silo.

The floor must be capable of excluding rodent and insects from the stored materials and also protect it from ground moisture. A common source of insect infestation in silos is from those harboured in grain and dust accumulated in floor cracks. An ideal silo floor should be impenetrable by insect, smooth and free of crevices and cracks so that it can be easily cleaned.

2.6 PROPERTIES OF WOOD PRODUCTS

Wood is naturally formed organic material consisting essentially of elongated tabular elements called cells and arranged in a parallel manner. Wood products in general include any item that is obtained from the conversion and processing of timber but here the term is limited to plywood and sawn solid wood (planks). Degroot and Esenther (1978) reported the use of various untreated timber species as fence posts in the United States which lasted for between 15-43 years. There are a number of Nigeria timber species that can compare favourably with the range reported. Some of such Nigerian timber species include Aformosia, Apa, Ayan, Belina, Erun, Iroko, Mansonia, Okan, Mahogany, and Opepe (NCP:2). Some of the properties include:

(i) **Colour:**

Colour and figure give wood its aesthetic value for furniture, panelling, flooring and many other uses. Both are variable within and between species. Figure will be different according to rate of growth, type of growth character (soft wood, hard wood) and direction of cut of the piece involved. Sap wood is usually white while heart wood is coloured as a result of infiltration products present.

(ii) **Luster:**

It is the property of wood that enables it to reflect light. It helps in identification.

(iii) **Odour:**

This property is the result of the infiltration products in wood since the basic cell wall materials are odourless and tasteless.

DENSITY AND SPECIFIC GRAVITY

The density of wood is the amount of wood substances, the amount of extractives and the amount of water in a certain piece of wood. It is expressed as weight per unit volume while specific gravity (GM) of wood at a given moisture condition (M) is the ratio of the weight of oven dry wood (W_o) to the weight of water displaced by the sample at the given moisture condition (W_m)

$G_m = W_o/W_m$ - Volume and weight constant under special condition.

(iv) **Thermal properties**

Dry wood expands when heated and contracts when cooled like most other solids. In wood the amount of this movement vary in the tangential, radial and longitudinal directions, but all are only from one-tenth to one-third that of concrete and glass.

Thermal conductivity of wood is very low and thus makes a good insulator (see 2.1.3iid). The lightest wood makes the best insulators. It varies with the direction of heat flow with respect to the grain.

(v) **Electrical Properties:**

Wood is resistant to the passage of electric current to such an extent that it has special value in high voltage power line cross arms and the handles on line men's tools. Resistance vary inversely with the density of the wood. Where electrical resistance is required, it is important to keep the wood dry.

(vi) **Chemical Properties:**

Wood is highly resistant to mild acids and solutions of acidic salts and is widely used in vats, containers and structures where these chemicals abound. But it is not resistant to alkalies.

(vii) **Sound Properties:**

Wood is an exceptionally good material that absorb sound energy in large amounts before they are activated to transmit the wares or to

2.7 THEORETICAL CONSIDERATIONS

2.7.1 PRESSURE ANALYSIS EQUATIONS IN BINS:

Grain pressures in bins have been studied for many years and theoretically, grain is considered to be a semi fluid. A large percentage of farm storages consist of shallow storage structures, whereas with country elevators or terminal storages, the bins are usually of deep configuration.

Pressure in deep bins were first studied by Janssen (Taylor, 1962) whose theory of lateral and vertical pressure distribution was first published in 1878. He stated that grain loads were carried by a grain arch within the structure which distributes a portion of the grain weight to the walls in the form of a vertical wall load. This theory resulted in the following equation

$$L = (WR/\mu')\,(1 - e^{-K\mu' h/R}) \quad \ldots\ldots\ 2.1$$

Where

- L = Lateral Pressure (N/m^2)
- W = Grain specific weight (weight/unit volume)
- μ' = Coefficient of friction between grain and bin wall
- R = Area of the bin floor divided by the perimeter (units of length)
- K = Ratio of lateral to vertical pressures in the grain
- h = Depth of grain to point under consideration (units of length).

Janssen assumed that K was constant through out the grain mass.

Vertical wall load, Fv, per unit of perimeter is given by.

$$Fv = \mu'P = \mu'\int_0^h Ldh.$$

For deep bins, the vertical pressure on the floor is determined by the ratio L/k. Thus if L is determined for a maximum depth, h, the floor load V, per unit area will be given as

$$V = L/k \quad \ldots\ldots\ldots \quad 2.1.1$$

Although other have developed theories to predict pressures in deep bins, Janssen's equation is still most widely used in design.

Airy and Rankine according to cain (1916) developed theories for pressures induced by granular materials against retaining walls or in shallow bins before the deep bins. Of these, the Rankine theory is most widely accepted in bin design. Airy equation is given as follows:

$$L = WY\left[\frac{1}{\sqrt{\mu+(\mu+U')}} + \sqrt{(1+U^2)}\right]^2 \quad \ldots\ldots \quad 2.1.2$$

Where

$U = \tan 0$ and $U' = \tan 0'$

Rankine assumed that the wall was smooth and that there was no frictional force between the stored grains and the silo wall. He presented his equation as

$$L = WY\left[\frac{1 - \sin\theta}{1 + \sin\theta}\right] \quad \ldots\ldots \quad 2.1.3$$

and the total horizontal force per metre of wall length; LT for a silo of depth h, was given as

$$LT = \frac{Wh^2}{2}\left[\frac{1 - \sin\theta}{1 + \sin\theta}\right] \quad \ldots\ldots \quad 2.1.4$$

The vertical floor pressure Fv on the silo floor is given as

Coulomb according to Taylor, (1962) developed a general wedge theory in 1773 which predicts active and passive pressures against retaining walls. He took the active pressures as the pressure exerted in a wall by grain when the maximum internal friction of the grain is being used in helping the grain support itself. He presented the following equation

$$L = Wy \cos \phi' \left[\frac{\cos\beta \sin(\beta-\phi)}{\sin(b+\phi')+\sin(\phi+\phi')\sin(\phi-i)/\sin(\beta-1)} \right] \quad \ldots\ldots\ 2.1.6$$

Where

L = Lateral pressure in N/m^2

W = Bulk density in Kg/m^3

Y = Depth of grain to point under consideration (m)

ϕ = Angle of Internal friction (degree)

ϕ' = Angle of wall friction (degree)

B = Angle between bin wall and horizontal (degree)

i = Angle of surcharge of the grain surface (degree).

Coulomb took into account the fact that the wall of vertical silos is very often at right at right angle to the floor and equated B to 90o. This resulted in the following equation

$$L = WY\cos\phi' \left[\frac{\cos \phi}{\sqrt{\cos\phi'} + \sqrt{\sin(\phi+\phi')\ \sin(\phi-i)/\cos i}} \right] \quad \ldots\ldots\ 2.17$$

Friction was assumed to exist between the grain and the wall; and the vertical component of the wall load; fv; was determined from the equation

$$Fv = L \tan \phi' = L\mu'$$

A method known as the Equivalent fluid density (EFD), has also been presented for the analysis of silo pressures (Bokhoven, 1983). The equivalent density of any grain is the product of the bulk density and the pressure ratio. With the knowledge of the EFD for the stored grains, the lateral pressure at any depth Y, below the grain surface is given by

$$L = EFD \times Y \quad \ldots\ldots \; 2.1.9$$

The Janssen's equation of 1895 for the design of deep silos predicts static lateral and vertical pressures but it fails to predict dynamic pressures when the grain is in motion such as during unloading since the pressure developed during movement (dynamic) is often greater than the pressure developed when the grain is at rest (static), it has been suggested that when pressures have been calculated from the Janssen's/Rankine equation; they should be multiplied by over pressure factor before being used for design. This factor varies from 1 to 2 (Thompson et al, 1982).

According to Mohsenin, (1978), the lateral pressure on the wall of a silo can be considered to be a resultant load. He considered also, the wall to be a triangle at which the pressure is acting at two-third of the wall height. The lateral pressure LR was given as

$$LR = \tfrac{1}{2}\, Wh^2 \tan^2 (45 - \frac{\phi}{2}) \quad \ldots\ldots \; 2.2$$

2.8 DESIGN CONSIDERATIONS

Before any design is made, a number of factors relevant to that design must be considered. Such factors provide data and related information on which the design must be based.

The beneficiaries of the work are targeted to be the rural peasant farmers who although produce very little individually but the aggregates of their individual production accounts for well over 80% of the total national production (Igbeka, 1981).

Some of the factors that are relevant to the design of a silo include

(i) **Quantity of material to be stored:**

An idea of the amount of gram to be stored is taking into account, the present level of production and as much as possible, projections into the future is necessary. Such information will help the designer to know the required volume of storage for a typical Nigeria farmer and make relevant allowances in the design. According to Igbeka (1983) and Akintunde (1987), the annual grain output for a small scale farmer in Nigeria is between 1 and 5 Tonnes. Hence a capacity of 1 ton (1000kg) of shelled corn is considered adequate for this work.

(ii) **Number of different grains to be stored:**

Normally different grains will have to be stored in different silos and hence the different types of grains to be stored will determine the number of silos to be provided for the purposes of turning stored grains. In this case, only one silo is needed to store the shelled corn. Grain properties used in the silo design are presented in table (1).

(iii) **Shape and Available Space:**

Silos could be rectangular, square, circular or polygonal in shape with each shape type having its merits and demerits. Where space is a limiting factor, rectangular and square silos can be erected adjoining one another, separated by party walls but then there is the disadvantage of stress concentration at the corners which become weak points and potential failure zones. The use of circular silos eliminate the problem of stress concentration but has the disadvantage of requiring larger ground area that the rectangular and square ones when installed in groups because circular silos have to be arranged such that they do not touch one another. The use of polygonal silo will appear to combine the advantage of small area ground and reduce stress concentration since there are more corners. For this design, a hexagonal shape will be considered.

(iv) **Silo Classification:**

The class to which a silo belongs determines the load distribution pattern within it. When the silo is of the shallow type, the vertical pressure due to the stored grain is completely borne by the floor which the walls bears only the lateral grain pressure. However, when the

Table 1: GRAIN PROPERTIES RELEVANT TO SILO DESIGN

Product	Unit weight N/m^2	Density Kg/m^3	Angle of repose (0°)	Coefficient of Wall Friction Steel	Smooth Concrete	Smooth Wood	Pressure ratio (k)
Shelled corn	7070	719	27	0.374	0.423	0.308	0.64
Sorghum	7070	720	23	0.374	0.33	0.3	-
Rice	6540	667	36	0.41	0.52	0.44	0.48
Wheat	7545	769	28	0.40	0.42	0.46	0.60
Soya beans	2514	256	29	0.366	0.442	0.322	-
Cowpea	7554	770	29	-	-	-	-

Source FAO, 1970

silo is deep, a portion of the vertical pressure due to the grain is carried by the wall, and beyond a specific height of grain in the silo, an increase in grain height does not result in any increase in floor pressure. The class of the silo to be developed is the shallow type and the pressure analysis equation applicable to this silo is the Rankine's equation.

(v) Loads:

The various loads imposed on the silo, their sources, magnitude and duration must be ascertained. There are three main sources of loads. These are the self weight or dead weight of the silo material, grain load and wind load. With the knowledge of densities of the material used for construction, the self weight of the silo can be deduced. Wind load may cause silo failure by lifting and over-turning. Its intensity depends on the height of that section above the ground level; the wind speed; the form and orientation of the structure and availability of wind breaks. It is a short term load.

Loads due to gram are all live load and could be of short and long term duration depending on the period for which the grain is in storage at any one time. These loads are lateral wall pressure, vertical wall load resulting from the friction between the stored grain and surface of wall material; vertical floor pressure and induced stress with the elements of the wall material. Lateral pressure on the silo floor is not really uniform although it is so assumed in design for lack of a mathematical formulae to take account of the variation. It varies from a minimum value at the side of the wall to a maximum value at the centre of the floor.

(vi) **Material of Construction:**

Different materials have been used for the construction of a silo. The popular ones are Rubber, Metal (Steel and Aluminium), Concrete, Wood, Clay and Straw. The choice of a material of construction depends on factors like availability of the material, technology to erect the silo and its maintenance; the relative cost compared to all other possible materials of construction and the efficiency of the material under similar economic and climatic situations where it has previously been successfully used. For this design, plywood was considered as material for construction of the silo. The choice takes into account the quantity of grains to be stored and the properties of the material.

In the design of grain storage structures, material of which the structure is to be constructed are important. Some of such properties are presented in table 3. Throughout the design to be presented, the compression and tension stresses are to be limited to $6.895 N/mm^2$. This corresponds to S_1

TABLE 2:

Green Grade Stresses for Timber Species (N/mm^2)

(Applicable to timber with a moisture content greater than 18%)

E = Modulus of Elasticity.

Group	Grade	Bending and Tension	Compression Parallel To Grain	Compression Perpendicular To Gran	Sliding Shear	E Mean	E Minimum
SI	Basic	13.8	9.65	1.72	1.52	8960	4480
	75%	10.4	7.24	1.52	1.03	"	"
	65%	8.97	6.21	1.52	0.89	"	"
	50%	6.895	4.83	1.31	0.68	"	"
	40%	5.52	3.79	1.31	0.5	"	"
SII	Basic	11.03	8.28	1.379	1.379	6895	4140
	75%	8.28	6.21	1.17	1.034	"	"
	65%	6.89	5.17	1.172	0.896	"	"
	50%	5.52	4.14	1.03	0.689	"	"
	40%	4.48	3.10	1.03	0.582	"	"
SIII	Basic	7.58	5.52	1.03	1.103	5860	3103
	75%	5.51	4.11	0.896	0.827	"	"
	65%	4.83	3.45	0.896	0.689	"	"
	50%	3.79	2.76	0.758	0.552	"	"
	40%	3.10	2.07	0.758	0.414	"	"

TABLE 3: SELECTED TIMBER SPECIES AND PROPERTIES

	Standard Name	Botanical Name	Density at 18% M.C. (kg/m^3)	Strength Group	Natural Durability	Resistance to Impregnation	Movement	Shrinkage
1.	AFRORMOSIA	*Afrormosia elata*	784	1	very durable	Extremely resistant	small	small
2.	APA	*Afzelia africana bipindensis pachyloba*	864	1	very durable	moderate	small	-
3.	AYAN	*Distemonanthus benthamianus*	704	1	very durable	Resistant	small	-
4.	AYO	*Holoptelea grandis*	752	1	moderate	moderate	-	-
5.	BERLINIA	*Berlinia confusa grandiflora*	720	1	very durable	Resistant	small	-
6.	(CELTIS) OHIA	*Celtis zenkeri mildbraedii*	832	1	perishable	permeable	large	large
7.	DAHOMA	*Piptadeniastrum africanum*	720	1	moderately durable	Extreme	small	medium
8.	EKKI	*Lophira alata*	1136	1	very durable	Extreme	medium	medium

TABLE 3 CONT.

	Standard Name	Botanical Name	Density at 18% M.C. (kg/m^3)	Strength Group	Natural Durability	Resistance to Impregnation	Movement	Shrinkag
9.	ERUN	*Erythrophleum ivorense suavecolens*	832	1	very durable	very resistant	small	small
10.	IROKO	*Chlorophora excelsa*	688	1	very durable	Resistant	small	small
11.	OKAN	*Cylicodiscus gabunensis*	976	1	very durable	Extreme	medium	-
12.	OPEPE	*Nauclea diderrichi*	800	1	very durable	moderate	small	small
13.	ABURA	*Mitragyna ciliata*	576	II	non-durable	moderate	small	small
14.	AGBA	*Gossweilerodendron balsamiferum*	544	II	Durable	Resistant	small	small
15.	DANTA	*Nesogordonia papaverifera*	734	II	Moderate	Resistant	medium	medium
16.	IDIGBO	*Terminalia ivorensis*	576	II	Durable	Extreme	small	small
17.	AFARA	*Terminalia supersba*	464	III	non-durable	permeable	small	small
18.	CANARIUM	*Canarium schweinfurthii*	544	III	perishable	permeable	medium	medium
19.	OBECHE	*Triplochiton scleroxylon*	384	III	non-durable	moderate	small	small

Source:- Nigerian Standard Code of Practice, NCP 2 (1973).

CHAPTER THREE

DESIGN CALCULATIONS

3.1. Capacity of silo

$$\text{Volume (V)} = \frac{\text{Mass of grain}}{\text{Bulk Density of grain}}$$

Where Mass = 1000kg

Bulk density of maize (shelled) = $719 kg/m^3$ from table 1

$$\text{Volume V} = \frac{1000\ kg}{719\ kg} \times \frac{m^3}{1}$$

$$= 1.39m^3.$$

(ii) Area of a regular Polygon is given by (Gurfinkel .G., 1979) as $A = \frac{1}{2} nr^2 \sin \left(\frac{360}{n}\right)$ 3.0

Where A = Area of a hexagon (m^2)

r = radius (m)

n = number of sides of the hexagon = 6 sides

from equation 3.0

$$r = \frac{\text{Diameter}}{2} = \frac{D}{2}$$

Substituting for r in the equation

$$A = \frac{1}{2} n \left(\frac{D}{2}\right)^2 \sin \left(\frac{360}{n}\right)$$

$$= \frac{1}{2} n \frac{D^2}{4} \sin \frac{360}{6}$$

$$= \frac{nD^2}{8} \sin \left(\frac{360}{6}\right)$$

$$= \frac{6D^2}{} \sin 60°$$

$$= \frac{6 \times 0.8660D^2}{8}$$

$$A = \frac{5.1962D^2}{8}$$

$$A = 0.6495D^2$$

Volume = Area X height

hence $1.39 = 0.6495D^2H$

$D^2H = \frac{1.39}{0.6495}$

$D^2H = 2.14$

Assume $H = 1.1m$, hence $D^2 = \frac{2.14}{1.1}$

$D = \frac{2.14}{1.1} = 1.4m$

Where D is the internal diameter of the silo.

From figure 3, to determine the actual capacity using (a,b,c,d,e,f) to advantage and also to determine the width of a side, the formulas below given by (Erik et al, 1979) are used.

$A = 3.464r^2$

$S = R =$ Circumscribed radius.

$= 1.155r.$

where $r =$ inscribed radius

From above, the internal diameter = 1.40m, hence inscribed radius $r = \frac{D}{2} = \frac{1.40}{2} = 0.7m$

Therefore to determine the width of a side of the hexagon is

$S = R = 1.155r$

$= 1.155 \times 0.7$

$= 0.81m$

Actual area $= 3.464r^2$

$= 3.464 \times (0.7)^2$

$= 1.70m^2$

Actual diameter D of the silo $= 2R$

$= 2 \times 0.81$

$= 1.62m$

Actual volume of the silo structure V = area X height

$= 1.70m^2 \times 1.1m$

$= 1.87m^3$

The increase in volume from $1.39m^3$ to $1.87m^3$ is due to area (a,b,c,d,e,f) used to advantage.

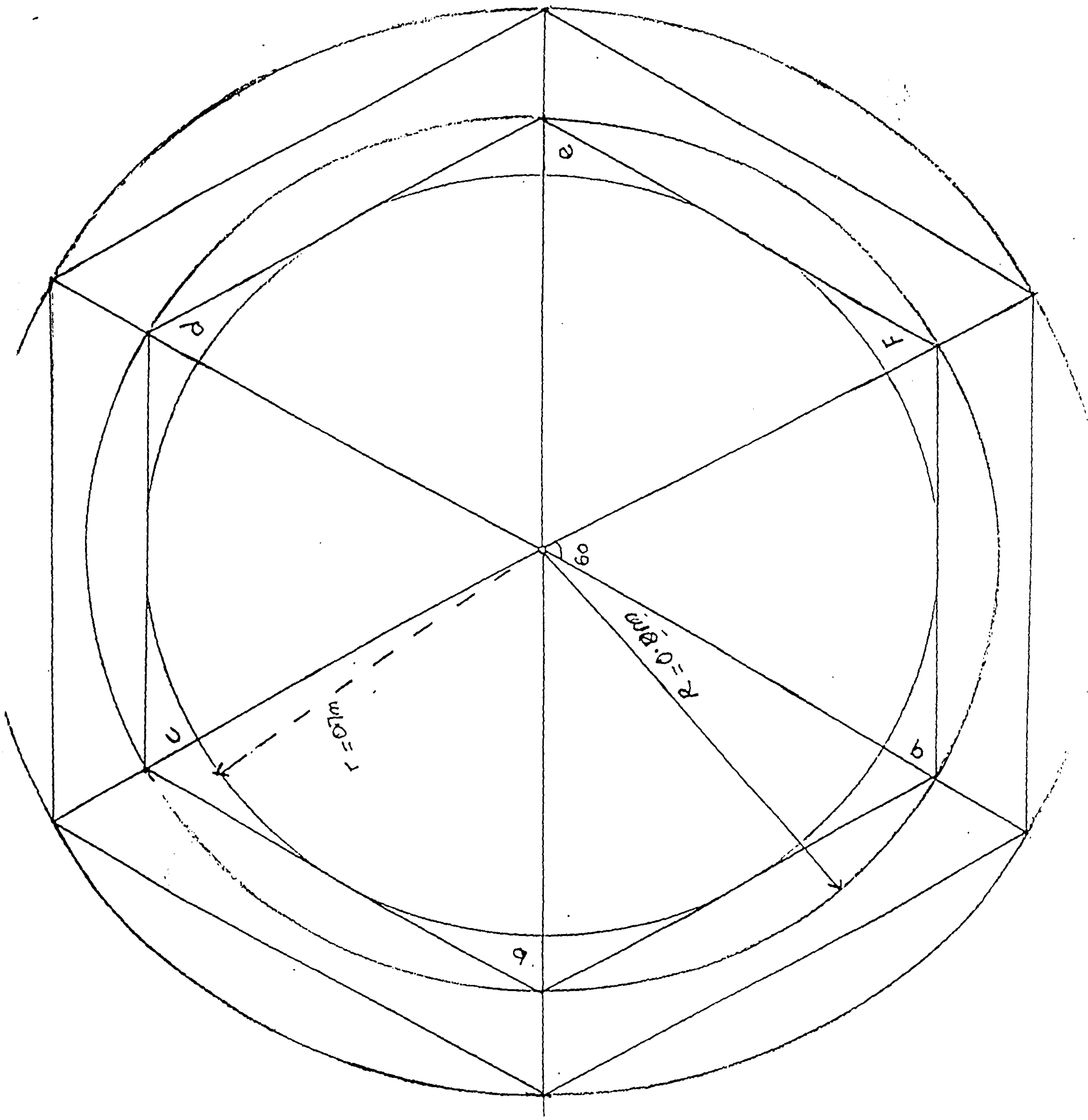


Fig 3: Plan view of the roof and its extension

3.2 Imposed load on the Roof

(i) Wind load:

One of the empirical formulae for predicting wind loads on structure was given by (Barre and Sammet, 1966) as

$q = 0.00256v^2C$ 3.1

where

q = Basic wind pressure on the structure moving at right angle against the bin N/m^2

v = Wind velocity km/hr

c = Force coefficient = 0.8, for cylindrical or polygonal shapes which considers orientation of the surface to the direction of the wind.

Wind velocities which may be used in evaluating wind load in Nigeria are presented in Table.......

For middle belt zone in which Niger State is a part of the zone, a wind velocity of 195km/hr open country is assumed for this Northern region.

Wind pressure $q = 0.00256v^2C$

195km/hr $\Longrightarrow$ 122mph.

$q = 0.00256\ (122)^2$

$= 38.10 \times 47.8803\ N/m^2$

$= 1824.385 N/m^2$

Design wind pressure = Basic wind pressure X force coefficient = 1824.385 x 0.8

$= 1459.51 N/m^2$.

Maximum wind load imposed on the silo structure can be determined using figure 4.

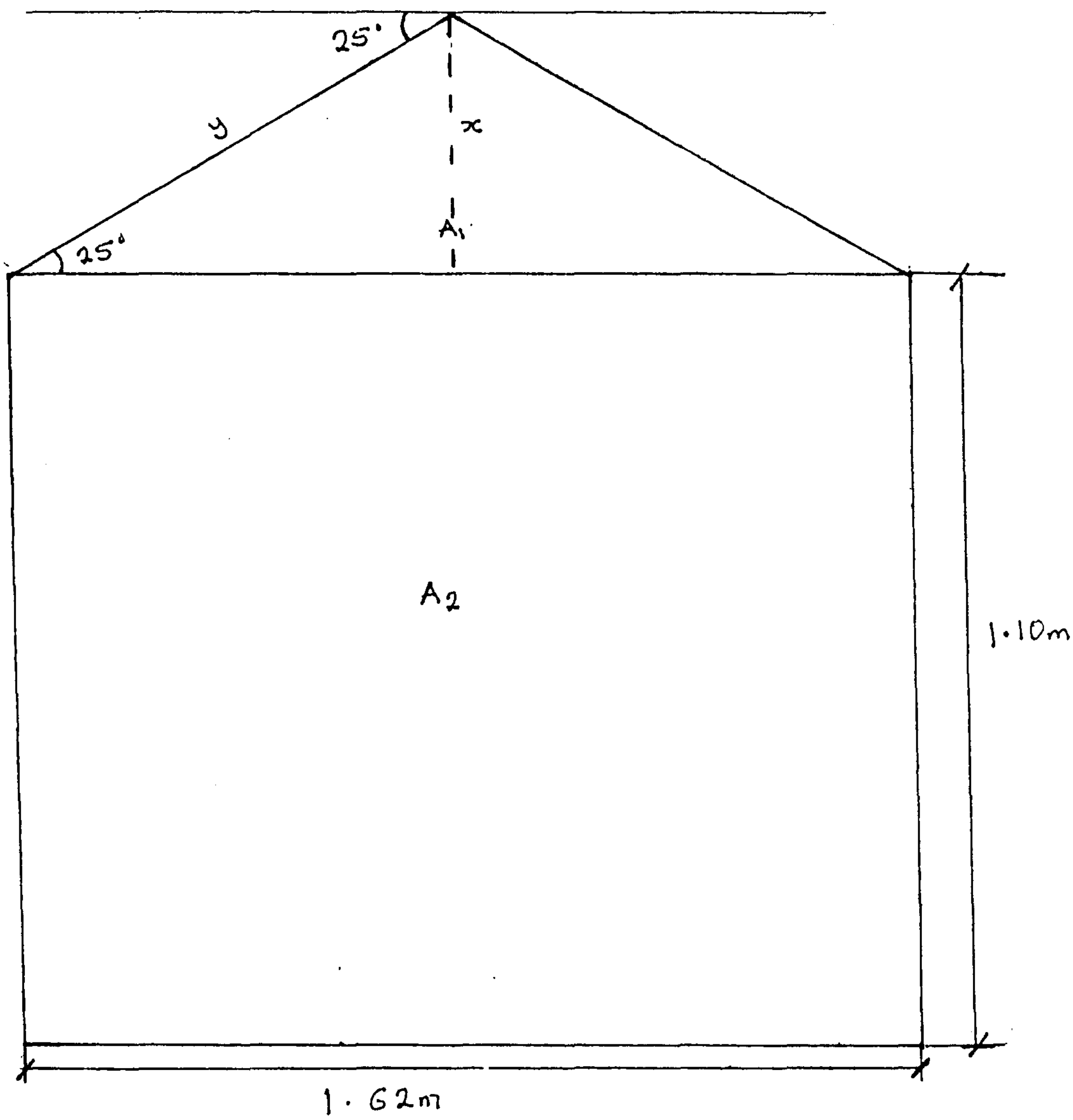


Fig 4: Silo Structure

Table 4: <u>WIND VELOCITY IN NIGERIA</u>

Distance of building location from the coast to the hinter land (km)	Condition of exposure of the environment where the building is located	Design velocity km/hr
0 - 160	Open country	112
0 - 160	Built-up areas	96
160 - 480	Open country	145
160 - 480	Built-up areas	104
Above 480	Open country	195
Above 480	Built-up areas	128
	Source NCP 1: 1973	

From figure 4, a pitch angle of 25 was assumed because of the size of the structure, the ease of draining rain water and for economic reasons.

The height x covered by the roof is given as

$$\text{Tan } 25^\circ = \frac{x}{0.81}$$

$$0.81 \tan 25^\circ = x$$

$$x = 0.38\text{m.}$$

$$\text{Area } A_1 = \tfrac{1}{2} \text{ base X height}$$

$$= \tfrac{1}{2}\ 1.62 \text{ X } 0.38$$

$$= 0.31\text{m}^2$$

Slant edge of the roof rafter y $= 0.81^2 + 0.31^2$

$= 0.87\text{m}$

$$\text{Area } A_2 = \text{Length X Breadth}$$

$$= 1.62 \text{ X } 1.1$$

$$= 1.78\text{m}^2$$

$$\text{Total Area} = A_1 + A_2 = 1.78 + 0.31$$

$$= 2.09\text{m}^2.$$

Maximum wind load imposed on the silo $= 1459.51$ X 2.09

$= 3050.4\text{N}$

3.3 <u>Determination of Lateral wall pressure</u>:

The Lateral pressure induced on the wall of the silo when loaded is given by Rankine in section 2.7.1 as

(i) $L = wy \dfrac{(1 - \sin\theta)}{(1 + \sin\theta)}$ from equation 2.1.3

$$= 719 \text{ X } 1.1 \frac{(1 - \sin 27^\circ)}{(1 + \sin 27^\circ)}$$

$$= 2913.6$$

$$= 2.91\text{kN/m}^2.$$

(ii) $LT = \dfrac{Wh^2}{2} \dfrac{(1 - \sin\theta)}{(1 + \sin\theta)}$ from equation 2.1.4

$$= \frac{719 \times (1.1)^2}{2} \quad \frac{(1 - \sin 27^\circ)}{(1 + \sin 27^\circ)}$$

$$= \frac{719 \times (1.1)^2}{2} \quad \frac{(0.55)}{(1.45} \times 9.81$$

$$= 1602.5 N/m$$

$$= 1.60 KN/m$$

(iii) $LR = \frac{1}{2} Wh^2 + \tan^2 (45 - \frac{\phi}{2})$ from equation 2.2

$$= \frac{1}{2} \times 719 \times (1.1)^2 \times \frac{2}{3} \tan^2 (45 - \frac{22}{2}) \times 9.81$$

$$= 1294.3 N/m$$

$$= 1.29 KN/m$$

The load calculated above in (2.2) is static hence modifying it by an over pressure factor section 2.7, is necessary. For the purpose of this design and considering the size of the silo, an over pressure factor (1.1) was used. This factor takes care of dynamic loading and give a maximum design load.

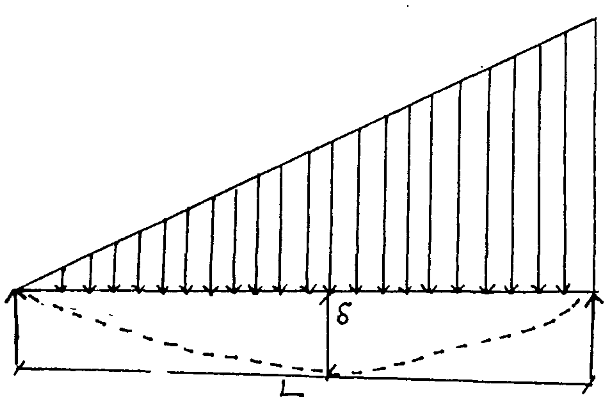
Therefore, for the wall,

$$LR = 1.294 \times 1.1$$

$$= 1.424 KN/m.$$

3.3.1 Determination of wall thickness

The wall was considered to be a triangle for analysis because the lateral pressure at the bottom is higher and it decreases to zero at the top.



Fir 5: Lateral Pressure distribution on the wall

From figure 5, maximum bending moment is given by (Jensen and Chenoweth, 1975) as

$$M_{max} = \frac{WL^2}{9\sqrt{3}} \quad \ldots\ldots\ 3.1.1$$

Where

W = Resultant load in N/m

L = height of the wall (m)

$$M_{max} = \frac{1.424 \times 10^3 \times (1.1)^2}{9\sqrt{3}}$$

$$= 110.53 Nm.$$

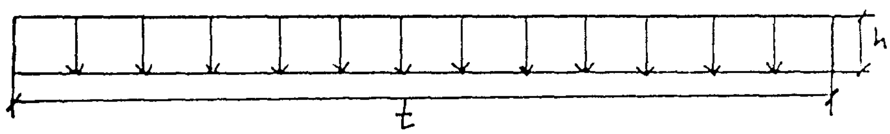


Figure 6: Load distribution on the wall panel

From figure 6, t = width of wall material (m)

and h = thickness (m)

$$\text{Sectional modulus } Z = \frac{th^2}{6} \quad \ldots\ldots\ 3.1.2$$

$$\text{Also } Z = \frac{M_{max}}{\sigma_d} \quad \ldots\ldots\ 3.1.3$$

Where σ_d = Allowable stress for timber.

The allowable stress for Iroko wood was used for this design. See table 3. It is taken as $6.895 \times 10^6 N/m^2$ at 50% grade

Hence

$$Z = \frac{M_{max}}{\sigma_d} = \frac{110.53 Nm}{6.895 \times 10^6 N/m^2}$$

$$= 1.603 \times 10^{-5} m^3.$$

From equation 3.1.2

$$Z = \frac{th^2}{6}$$

$$h = \sqrt{\frac{6Z}{t}} = \left[\frac{6 \times 1.603 \times 110^{-5} m^3}{0.81 m}\right]^{\frac{1}{2}}$$

$$= 0.010897$$

$$= 10.90mm$$

For this design, adopt a 12.7mm thickness plywood for the wall.

To check for the adequacy of the plywood chosen,

$$Z = \frac{th^2}{6}$$

$$Z = \frac{0.81 \times (0.0127)^2}{6}$$

$$Z = 2.17 \times 10^{-5} m^3$$

σAd ..... Actual Allowable stress is given as

$$\sigma Ad = \frac{m}{Z} = \frac{110.53Nm}{2.18 \times 10^{-5} m^3} \quad N/m^2$$

$$= 5.07 \times 10^6 N/m^2$$

Since σAd is less than allowable stress 6d of the wall material (plywood), design is safe i.e. $\sigma Ad < \sigma d$.

3.3.2 Deflection of Wall Material

From figure 6 deflection was given by (Jensen and CHenoweth, 1975) as

$$\delta = \frac{-0.01304 \, W^{L^3}}{EI} \quad .... \; 3.1.4$$

Where

E = Modulus of elasticity of wood (Iroko) at minimum value = $4480 N/mm^2$ from table 3

I = Moment of inertial of a rectangular section (mm4) = $\frac{bh^3}{12}$ see figure (7)

where b = breadth (m)

h = height of wall (m)

W = Resultant load on the wall (N)

$W = \frac{1}{2} \times 1.424 \times 10^3 \times 1.1$

$= 783.2N$

$I = \frac{bh^3}{12} = \frac{810 \times (1100)^3}{12}$

$= 8.98 \times 10^{10} mm^4$

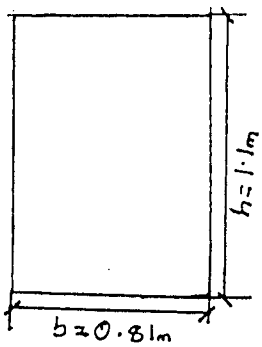


Fig 7: Wall panel

Substituting into equation 3.1.4

$\delta = \frac{-0.01304 \times 783.2N \times (1100)^3 mm^3}{4480 \frac{N}{mm^2} \times 8.98 \times 10^{10} mm^4}$

$= -3.38 \times 10^{-5} mm$ - This shows that deflection is negligible at the walls hence it will withstand the material stored inside it.

3.4 Floor pressure induced by grains

The silo is expected to be filled to capacity hence the pressure on the floor can be calculated from Rankine's using equation 2.1.5.

$Fv = wh$

$Fv = 719 \times 1.1 \times 9.81$

$= 7758.73N/m^2$

$= 7.76KN/m^2$

Considering the over-pressure factor, gives

$7.76 \times 1.1 = 8.5350$

$= 8.54KN/m^2$

3.4.1 Floor Thickness

The floor is a base plate with edge supported around the circumference and a uniformly distributed load over the surface of the plate. The formula for calculating the thickness was given by (Erik et al, 1979) as

$$t^2 = \frac{0.39w}{6d} \quad \text{....... equation 3.1.5}$$

Where

W = Total load on plate (N)

t = Thickness of plate (mm)

6d = Allowable stress for wood N/mm^2

Subsisting into the formula

$$t = \left(\frac{0.39w}{6d}\right)^{\frac{1}{2}}$$

$$t = \left[\frac{0.39 \times 8.54 \times 10^3 \ N/m^2 \times 1.70m^2}{6.895 \ N/mm^2}\right]^{\frac{1}{2}}$$

$$t = 28.66mm$$

Choose a thickness of 31.75mm

Checking the adequacy of the plate.

$$6A = \frac{0.39w}{t^2}$$

$$= \frac{0.39 \times 8.54 \times 10^3 \times 1.7}{(31.75)^2}$$

$$= 5.62N/mm$$

Hence, since $6A < 6d$, the design is safe.

3.5 Determination of the total weight of the structure:

(i) Live loads: These are due to the grain and wind effect.

Load due to grain,

$$= 8.54 \frac{KN}{m^2} \times 1.70m^2$$

$$= 14.52KN$$

Wind load from calculation = 3050.4N

Live load = 14.52KN + 3.05KN

= 17.57KN

(ii) Dead loads: These are due to material of construction of the silo.

(a) Rafters: Adopt 50.8mm by 50.8mm timber

Weight of rafters is given as

$A = B^2L \times 6$

Where b = breath of the rafter = 50.8mm by 50.8mm

L = length of rafter = 0.87m

The total number of rafters = 6

$A = 0.0508 \times 0.0508 \times 0.87 \times 6$

$= 0.0135m^2$

From table 3, density of Iroko wood = 688 kg/m^3 X 9.81

= 91.12N

(b) Roof panel: From figure (8), the panel was considered as an equilateral triangle.

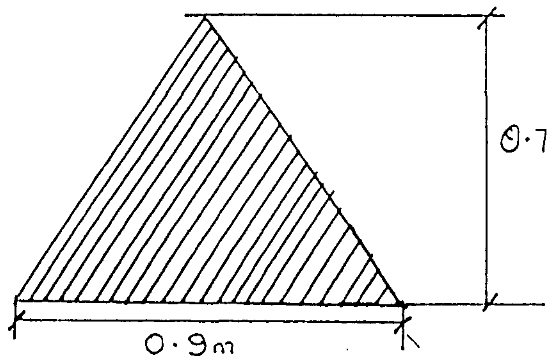


Fig. 8: Roof panel

Weight of roof panel was determined usin,

Area = $\frac{1}{2}$ base X height

$= \frac{1}{2} \times 0.9 \times 0.78$

$= 0.351m^2$

Volume of the material = Area X thickness

$V = 0.351 \times 0.01905$

$= 6.69 \times 10^{-3} m^3$

Total number of roof panels required = 6

Weight of the panel = $6 \times 6.69 \times 10^{-3} \times 688 \times 9.81$

= 270.92N

(c) Wall material: It is rectangular in section.

$A = L \times b$

Volume $= L \times b \times h$

$= 1.1 \times 0.81 \times 0.0127$

$= 0.011176 m^3$

Weight $= 0.011176 \times 688 \times 9.81 \times 6$

= 452.60N

(d) Supporting Beams: Adopt 50.8mm by 50.8mm timber for the beams

Area = Length X Breadth

$= 0.81 \times 0.0508 \times 0.0508$

$= 2.09 \times 10^{-3} m^2$

Weight $= 2.09 \times 10^{-3} \times 9.81 \times 688 \times 6$

= 84.65N

(e) Weight of columns: Adopt 50.8mm by 50.8mm timber for the supporting columns as

$A = L \times B$

$= 1.4 \times 0.0508 \times 0.0508$

$= 3.613 \times 10^{-3} m^2$

Weight $= 3.613 \times 10^{-3} \times 6 \times 9.81 \times 688$

= 146.31N

Total dead load = 1045.60N

Total weight of the silo structure = Live load + Dead load

= 17.57KN + 1.05KN

= 18.62KN

3.6 Roof Panel Thickness

The roof panel was considered to be a plate supported by rafters with a uniformly distributed load.

Using the formula in equation 3.1.5

$$t^2 = \frac{0.39W}{6d}$$

$$t = \left(\frac{0.39 \times 3050.4N}{6.895N/mm^2}\right)^{\frac{1}{2}}$$

$t = 13.14mm.$

Adopt 19.05mm thickness plywood for roofing panels.

Checking the adequacy of the roof panel is given as

$$6A = \frac{0.39W}{t^2}$$

$$= \frac{0.39 \times 3050.4}{(19.05)^2}$$

$$= 3.29N/mm^2$$

Since 6A is less than the allowable stress 6d, design is safe.

3.7 Determination of critical load on the columns

For the columns, adopt 50.8mm by 50.8mm square section. Critical load for the columns is given by (Erik et al, 1979) as

$$Pcr = \frac{\pi^2 E I}{(\mu L)^2} \quad \ldots\ldots\ldots 3.1.6$$

Where π = pI

E = Modulus of Elasticity of Iroko from table 3

= $4480N/mm^2$

I = Moment of inertia (mm^4)

U = End conditions for columns that is fixed at the base and at the other end free and guided = 2.

l = Length of column

I for a square section is given as

$$I = \frac{a^4}{12} = \frac{(50.8)^4}{12} = 554975.23mm^4$$

$$Pcr = \frac{(3.142)^2 \times 4480\frac{N}{mm^2} \times 554975.23mm^4}{(2 \times 1400)^2 mm^2}$$

$$= 3129.94N$$

$$= 3.13KN$$

Total load on silo structure = 18.62KN

Number of columns required = 6

Load to be carried by each column $= \frac{18.62}{6}KN$

$$= 3.10KN$$

The condition against buckling is that the Pcr should be equal or greater than the total load on the column. Hence from the calculation, the columns can withstand the total load against buckling.

3.8 Connectors

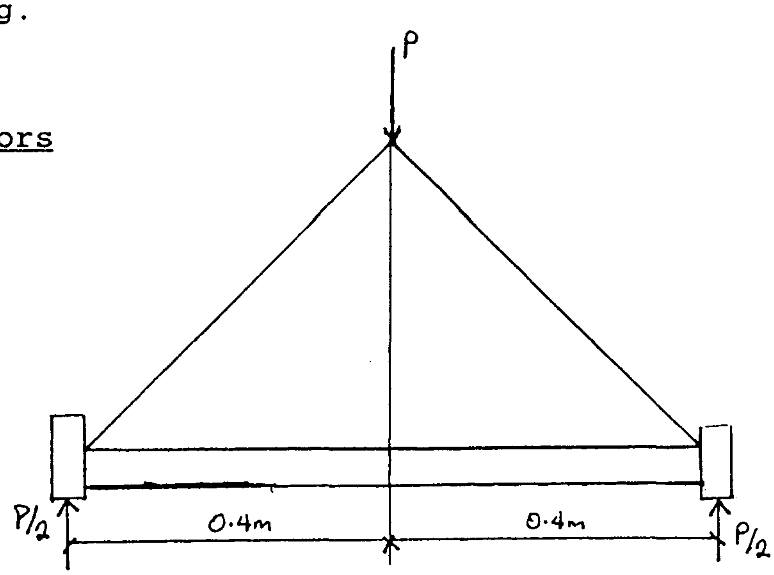


Fig. 9: Connectors

From the diagram above the beams are serving as connectors for the columns. The connectors are in bending hence taking moment about either point,

$$\text{Moment} = p/2 \times 0.405 \times 0.81$$

Where P = Load per unit wall from equation 2.2

$$M = \frac{1.424\frac{KN}{m}}{2} \times 0.405 \times 0.81m$$

$$= 233.57Nm$$

The stress analysis of the connectors is carried out using the relation

$$6 = \frac{MY}{I} = \frac{M}{Z}$$

$$Z = \frac{M}{6d}$$

Using ultimate stress of wood in bending of $54MN/m^2$ and factor of safety of 3 (The Engineer's manual, 1944)

$$Z = \frac{3M}{54 \times 10^6} = \frac{3 \times 233.57}{54 \times 10^6} = 1.2976 \times 10^{-5}m^3$$

Also,

$$Z = \frac{th^2}{6}$$

Assuming a square section, t = h = thickness

$$\text{Hence} \quad Z = \frac{th^2}{6} = \frac{h^3}{6}$$

$$\text{Therefore} \quad h = \sqrt[3]{\frac{Z}{6}}$$

$$= \sqrt[3]{\frac{1.2976 \times 10^{-5}}{6}}$$

$$= 12.9mm$$

Using the nearest standard wood section,

$$h = t = 50.8mm$$

Hence a 50.8mm X 50.8mm timber will serve the purpose.

3.9 FOUNDATION DESIGN

To install the silo at the site, involves using stip foundation.

Dead Load (DL) = 1.21KN

Live Load (LL) = 17.41KN

Size of Column = 50.8mm X 50.8mm.

Bearing capacity of soil = 160kpa (FAO, 1986) for sandy loam soil.

The procedure involve in designing the foundation goes thus

Footing dimension was determined using

$qf = P/A$

Where

P = Total load (for serviceability state)

A = Area of the footing

P = 1.0DL + 1.0LL (Mosley and Bungey, 1976)

P = 1.0 (1.21) + 1.0 (17.41) = 18.62KN

Load on one column = $\frac{18.62}{6}$ = 3.10KN

Designing for square footing,

$A = B \times B \ (mm^2)$

$A = \frac{P}{q} = \frac{3.10\ KN}{160\ KN/m^2} = 0.019m^2$

$= 19{,}000mm^2$

$A = B^2$

$B = A$

$B = 19{,}000 = 137.8mm = 0.138m$

The ultimate soil pressure qultimate by (Mosley and Bimgey, 1976) is given as

$Pu = 1.4DL + 1.7LL$

$= 1.4(2.1) + 1.7(17.41)$

$= 1.68 + 29.60$

$= 31.29KN$

$\text{qultimate} = \frac{31.29}{0.019} = 1647KN/m^2$

For a unit strip wide as shown below in fig ......, shear force (

... on a 1m wide section = 0

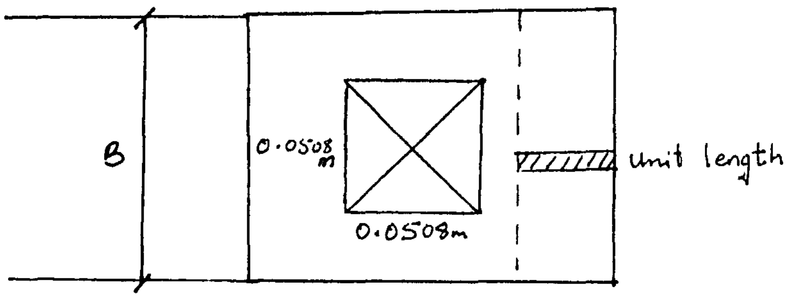


Fig. 10: Force on a unit strip of foundation

Depth of column (d), is given as

d X unit length X c - (length of $\frac{\text{footing - column}}{2}$ size -

d) X quitimate = 0

c = 0.065mpa (Mosly and Bungey, 1976)

$$d \times 1m \times 0.65 - \left(\frac{0.138 - 0.0508}{2} - d\right) 1647 = 0$$

$$d \times 0.65 - \left(\frac{0.138 - 0.0508}{2} - d\right) 1647 = 0$$

$$2 (0.65d) - (0.138 - 0.0508-d) 1647 = 0$$

$$1.3d - (227.3 - 83.67 - 1647d) = 0$$

$$1.3d - 227.3 + 83.67 + 1647d = 0$$

$$1648.3d = 227.3 - 83.67$$

$$1648.3d = 143.63$$

$$d = \frac{143.63}{1648.3}$$

$$= 0.087m$$

From calculations, adopt a depth of 200mm for the footing so that the soil can withstand the imposed load.

Punching shear can be calculated using

$$Px = \frac{P}{\text{column perimeter} \times d}$$

$$= \frac{3.10 \times 10^3}{2(50.8 + 50.8) \times 200mm}$$

$$= 0.076 N/mm^2$$

The condition for punching shear as given by Mosley and Bungey, (1976) is

If $0.076 < 0.8\sqrt{Fcu}$ then design is satisfactory

Where

Fcu = grade of cement to be used

= $35N/mm^2$, (BS 8110, 1985)

= $0.8\sqrt{35}$

= $4.73N/mm^2$

Since $0.076N/mm^2 < 4.73N/mm^2$, by inspection the normal shear on the section at the column face will be less severe. Therefore section is okay and need no reinforcement.

CHAPTER FOUR

TEST EXPERIMENT

4.1 TESTING

The test parameters and procedures carried out include

(i) **Loading Test** -

The loading was done manually through the door (see plate 2). Test observations include

(a) Behaviour of joints

(b) Sinking or consolidation of foundation.

(ii) **Unloading Test** -

This involves discharging the grain out from the silo though the discharge chute

Test observations include

(a) Behaviour of joints

(b) Sinking or consolidation of foundation.

(iii) **Temperature Measurement** -

It was considered necessary to monitor the variation of temperatures within and outside the silo since comparism between the ambient temperature and that within the silo structure provides information on the rate of heat movement into and out of the structure. A thermometer was placed inside the loaded structure and another on the wall of the structure to monitor the daily temperature inside the structure and that of ambient. Temperatures were read from the thermometers thrice daily, morning (7.00 a.m), noon (12.00 p.m) and evening (5.00 p.m) at five hours interval.

4.2 TEST RESULTS AND DISCUSSION

A. Loading Test:

(i) **Joints -**

While loading was in progress, the joints were observed for any nail pulling, opening or failure. After loading, no sign of failure was noticed.

(ii) **Sinking and Consolidation of Foundation -**

The height of the column from the base of the silo to the soil interface was measured before and after loading. No difference was observed in the column length.

B. Unloading Test:

(i) Joints:

During unloading, the joints were observed constantly and no failure noticed.

(ii) Sinking and Consolidation of Foundation -

After the grains has been unloading and the column measured, there was no change in the column length.

C. Temperature Measurement:

Table 5 shows the result of the 7 days testing of the silo. From figures 11-13, it was observed that in the morning, the ambient temperature is lower as compared to the wooden silo while in the noon, the ambient temperature was higher in the wooden silo. Also in the evening, there was an overlap in the ambient and silo temperatures.

Hence, it can further be deduced that from the results, the wooden silo can maintain a uniform temperature within due to the low thermal properties of the wood as compared to the variable ambient temperature.

TABLE 5: RECORDS OF DAILY TEMPERATURE MEASUREMENTS WITHIN AND OUTSIDE THE SILO

DAY	TIME	AMBIENT TEMPERATURES (A) (°C)	TEMPERATURE IN WOODEN SILO (S) (°C)
1	Morning (M)	28.00	29.00
	Afternoon (N)	38.00	31.00
	Evening (E)	36.00	35.00
2	M	29.00	29.00
	N	38.00	31.00
	E	36.00	35.00
3	M	29.00	29.00
	N	38.00	30.80
	E	37.80	37.00
4	M	26.00	29.00
	N	38.00	31.50
	E	36.00	36.50
5	M	25.00	28.00
	N	36.00	29.00
	E	35.00	35.00
6	M	26.00	28.00
	N	36.00	29.00
	E	35.00	34.80
7	M	27.00	28.00
	N	36.00	29.00
	E	35.00	35.00

MORNING

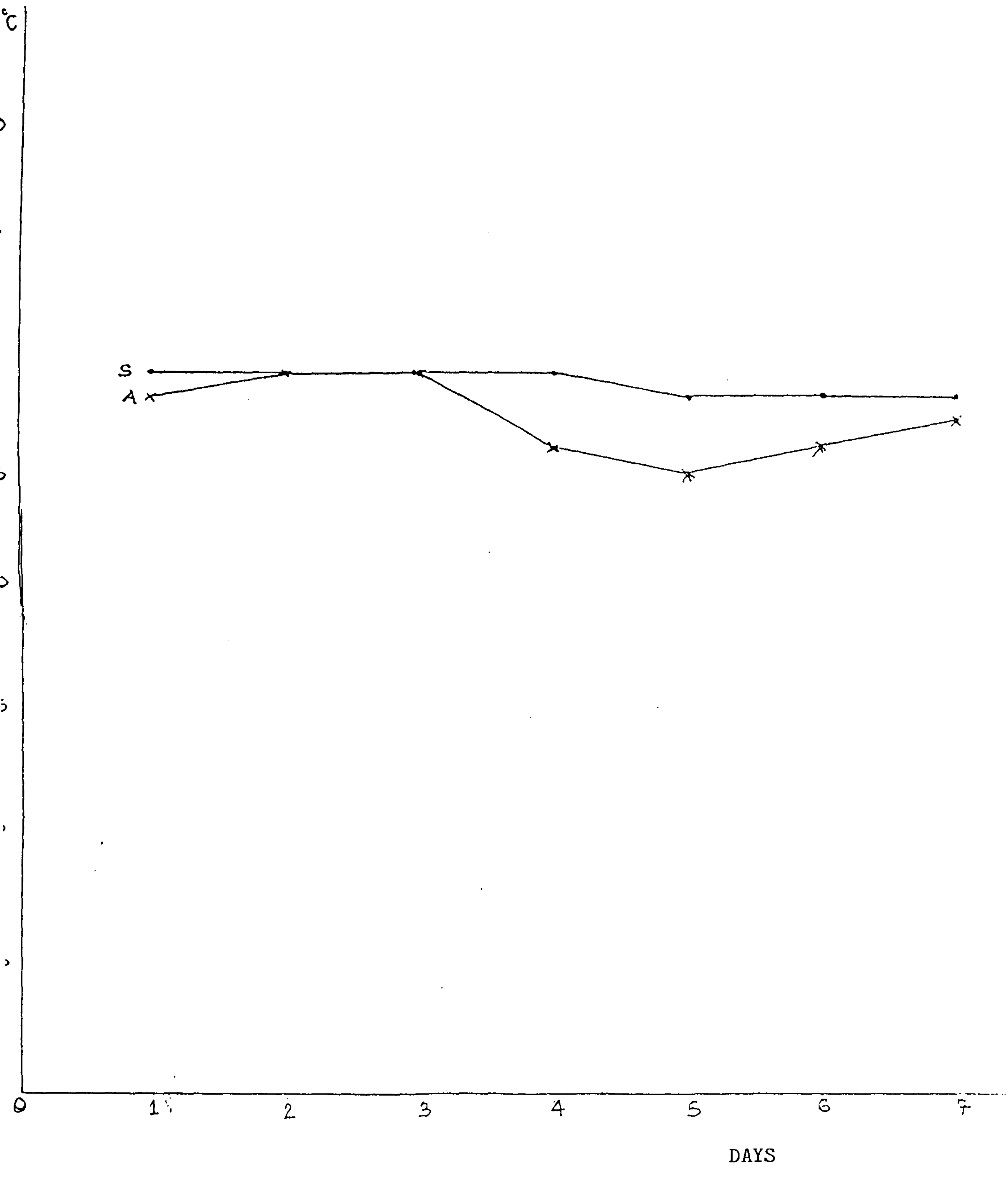


Fig 11: Graph of test results for morning temperature

NOON

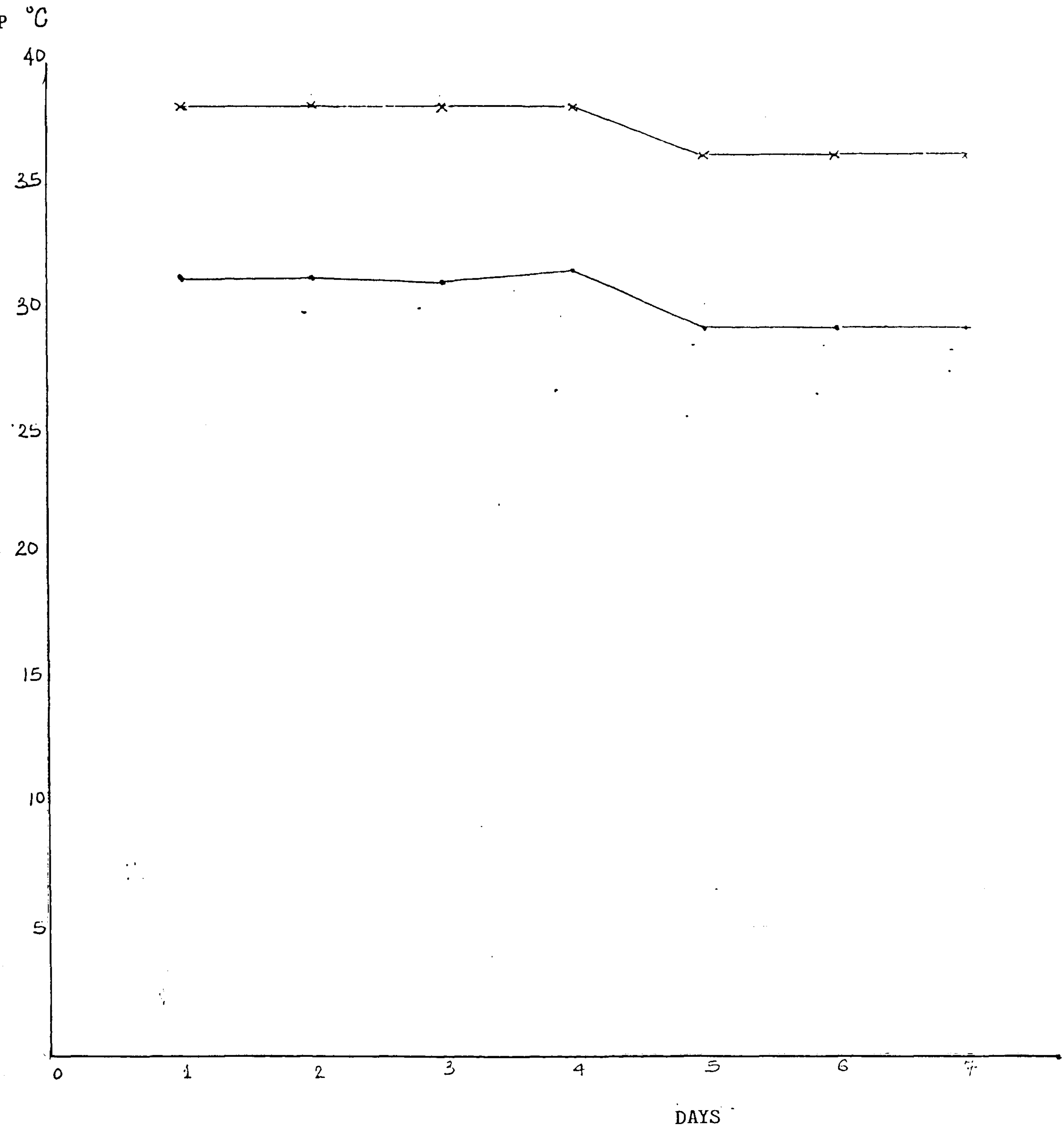


Fig 12: Graph of test results for noon temperature

EVENING

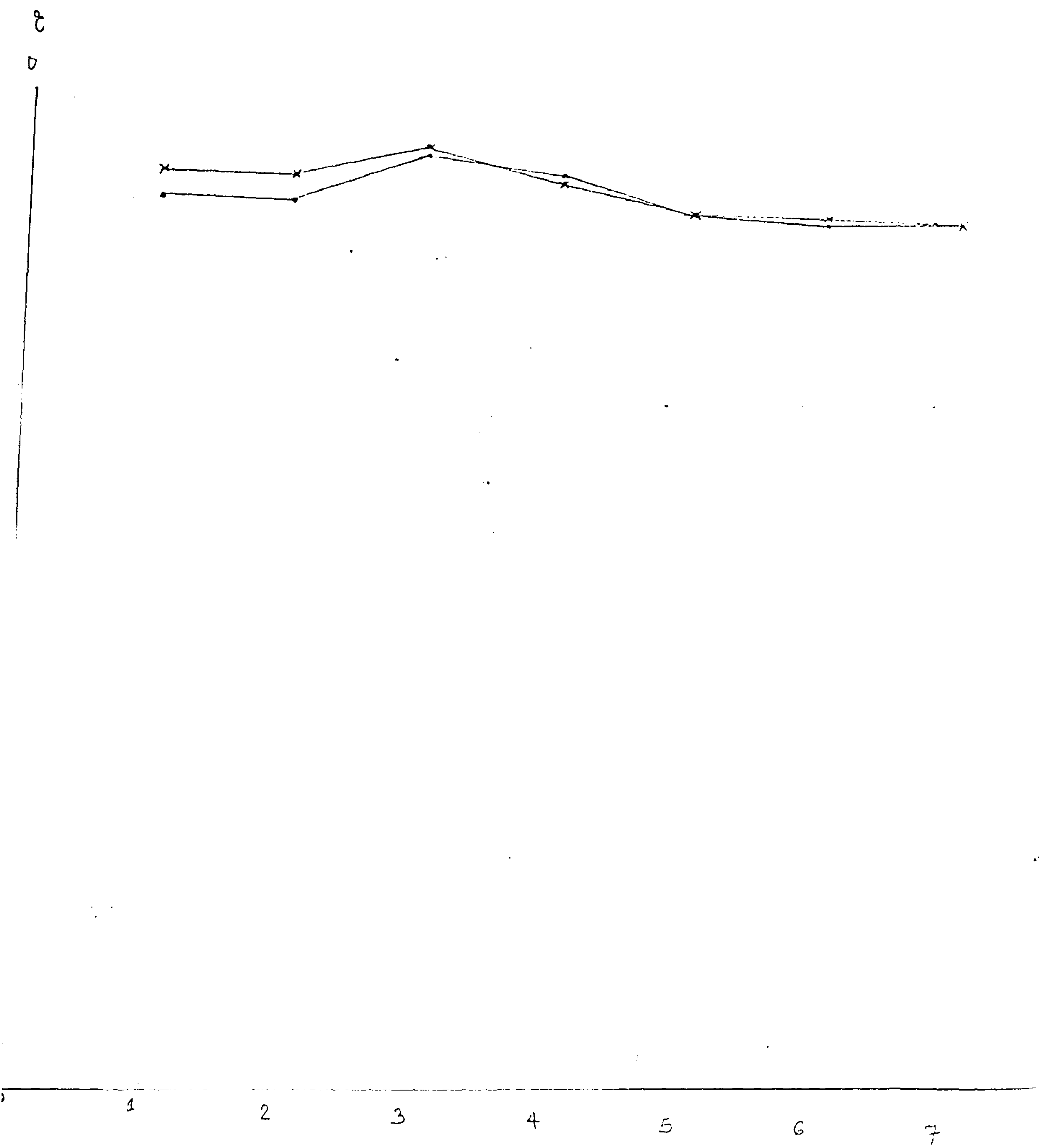


Fig 13: Graph of test results for evening temperature

4.3 SILO DESCRIPTION

The constructed silo is shown in plate 1. It is hexagonal in shape and with an inner diameter of 1.62m; and each side measures 0.81m while the height is 1.10m. The capacity is 1.87m^3; an equivalent of 1 ton for shelled corn. The floor, wall and the roof are made of plywood.

The floor is elevated above the ground level and supported on six wooden beams with reinforcements underneath to support grain load. The elevated floor guides against rise in dampness and rodents; to aid ventilation below the floor and to provide adequate space for the positioning of a container on to which the stored material can be discharged.

Also the roof and the walls are supported by another size beams above which hold the rafters, king post and the wall panels in place. There are also six ccolumns of 1400mm long which helps to transmit the dead and live load into the foundation. These columns holds the wall panels in place.

There are three accessories on the silo and these are the door; discharge chute and the loading chute. These accessories are of the same thickness as the component of the constructed silo.

The door forms part of one of the wall panels and it is hinged onto the wall panel. It measures 600mm in width and height to flush with the wall and it is located 250mm above the floor level. On the panel directly opposite to that on which the door is located is the discharge chute. It is rectangular in shape measuring 500mm by 400mm and located almost at the floor level.

The loading chute forms part of one of the roof panels and it is triangular in shape. It measures 600mm by the sides and 500mm in height.

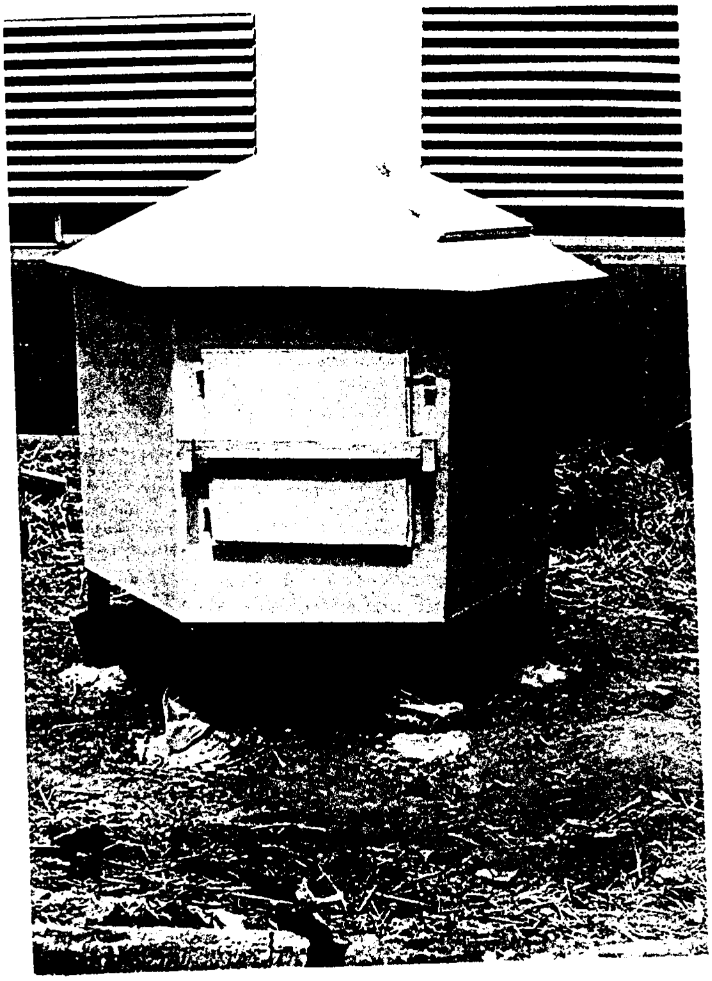


PLATE 1: Picture of the constructed Silo structure

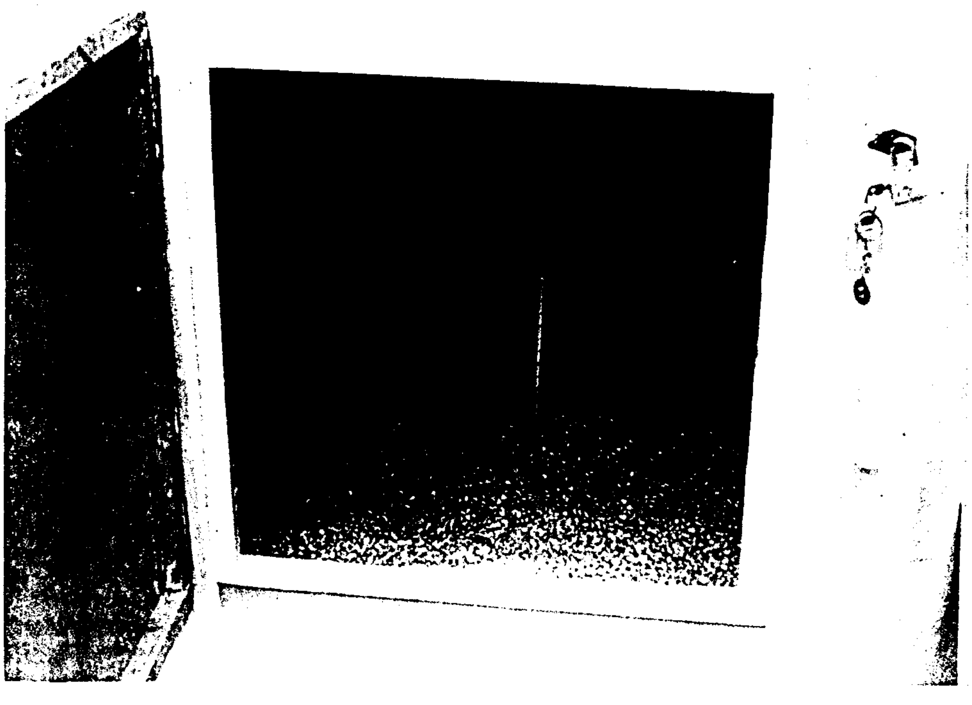


PLATE 2: Picture of the loaded Silo during experiment

4.4 COST ANALYSIS

TABLE 6: ESTIMATE OF CONSTRUCTION MATERIALS AND OTHER COSTS

S/NO	ITEM	QUANTITY	UNIT PRICE (₦)	TOTAL (₦)
1.	½" AT and P'Plywood	5	1,300	6,500
2.	(2" by 2") Timber Plank	-6	60	360
3.	(2" by 4") Timber Plank	1½	120	180
4.	Nails (1½")	2 pounds wt	40	80
5.	Nails (2½)	2 pounds wt	40	80
6.	Body fillers	½ tin	1,000	500
7.	Thinner	½ gallon	500	250
8.	Emulsion paint	2 gallon	300	600
9.	Gloss paint (white)	1 gallon	600	600
10.	Black paint	1 tin	150	150
11.	Hinges	6	25	150
12.	Screw	12	10	120
13.	Glue adhesive	2	250	500
14.	Padlock	3	70	210
15.	Cement	½ bag	500	250
16.	Sand paper	4	50	200
17.	Grains	2 bags	900	1,800
18.	Transportation			1,000
	TOTAL			13,530
19.	LABOUR: 20% of total cost			2,706
	TOTAL ESTIMATES = 13,530 + 2,706 = ₦16,236.00			

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the results of the experiment carried out, it was observed that a wooden silo can maintain a uniform temperature within it hence enhancing better storability of grains stored. Also the results has confirmed the suitability and adaptability of wood as constructional material thereby achieving the overall aims and objectives of the project work.

5.2 RECOMMENDATION

The wooden silo constructed needs to be subjected to some environmental conditions hence further tests of longer duration and of wider area including loading tests are necessary. These are expensive tests and the Government and Research Institutions should take interest and make funds available for such further work on this project.

A co-ordinated production system whereby the silo components are factory produced with proper seasoning and treatment is recommended. This will reduce cost of production and with a little subsidy from the Government, silos can be affordable by the individual small scale farmers.

Grain silo management based on good construction practice, better environmental conditions and hygenic crop conditions are actions that must jointly be conducted to limit storage looses.

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