# EVALUATION OF MUD AS A CONSTRUCTION MATERIAL FOR GRAIN STORAGE STRUCTURES

**BY**

**ABDULLAHI MUHAMMAD IBRAHIM EL-OKENE**

**DEPARTMENT OF AGRICULTURAL ENGINEERING**

**FACULTY OF ENGINEERING,**

**AHMADU BELLO UNIVERSITY,**

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## DECLARATION

I hereby declare that the whole of this work now being submitted as a thesis for the degree of Doctor of Philosophy (Ph.D.) of Ahmadu Bello University is the result of my own investigation. The work embodied in this thesis has not been submitted already 'in substance in candidature for any other degree.

Candidate:.....

Date: .....

The above declaration is confirmed by:-

.....

Dr O.J. Mudiare

(Head of Dept and Chairman -Supervisory Committee)

## CERTIFICATION

This project thesis entitled "EVALUTION OF MUD AS A CONSTRUCTION MATERIAL FOR GRAIN STORAGE STRUCTURES by Abdullahi Muhammad Ibrahim El-Okene meets the regulations governing the award of the degree of Doctor of Philosophy of Ahmadu Bello Univesity, Zaria, and is approved for its contribution to knowledge and literary presentation.

.....  .....

Dr O.J. Mudiare — Date

(Head of Agric. Engineering and Chairman, Supervisory Committee)

.....  .....

Dr S. P. Ejeh — Date

(Dean of Engineering and Member, Supervisory Committee)

.....  .....

(Dean, Post Graduate School) — Date

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# ABSTRACT

The technology of grain storage structure is yet to reach a deyelopement stage that can be considered as acceptable in Nigeria, and yet, modern construction materials normally used are becoming more difficult to acquire with each passing day as a result of continuos devaluation of the Naira. Mud an alternative material presently used in the construction of domestic buildings and other special structures was evaluated for its suitability as a construction material for grain storage structure.

In carrying out the above task, "Rumbu", a grain storage bin widely used in Northern Nigeria and principally constructed using mud was investigated for spread, shape, size and usage. State of art of mud preparations and rumbu construction were studied in two selected villages that fairly represents Northern Nigeria in this respect Data collected were then used to assess the status of existing rumbu bins. Various mud mixes were also constituted and evaluated for strength and durability in the laboratory using where possible standard procedures of testing concrete and soilcrete and modifying or adopting other procedures where necessary. Small size mud bin was then constructed and comparatively evaluated with sandcrete and steel bins for resistance to ambient changes like temperature and relative humidity.

Results show that presently, the existing rumbu bins are of three shapes (cylinderical, spherical and pyramidal), with volumes ranging from 1.6m to 197.4m . Laboratory evaluation ofthe various mud mix showed that mud has a compressive strength of between 1.38 to 4.2N/$m^2$ and a tensile strength that ranges between 0.31 to 1.23N/m depending on paste consistency, stabilizer type and whether the mud was settled or not The comparative evaluation of mud structure under varying ambient condition showed that mud can resist heat transfer better and compares with steel in offering resistance to humidity transfer.

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# CHAPTER ONE

# INTRODUCTION

## 1.1 Background Information

A grain storage structure can be described as that physical container within which a quantity of grain is stored for preservation against spoilage. The purpose of storage as stated by Oxley (1949) has always been that of a stock reserve against famine and uneven seasonal or inter-seasonal supply. The length of period over which a container can hold grains in a "good state" is normally used in qualifying the efficiency of that container. However the choice of a suitable storage structure depends on other factors like cost, availability of construction material, construction skill, traditional practices etc.

The practice of crop storage is known to have dated to the megalithic age (10,000 - 7,000 BC) as noted by Igbeka et al (1989). The use of storage structures to store large quantities of grain was first recorded in 188 BC when the Prophet of Allah, Yusuf (Joseph), the son of the Biblical Isaac stored large quantities of unthreshed grains for over seven years, Maududi (1970).

Grains are normally stored either in natural structures like gourd, trees, or in artificially constructed structures like baskets, sacks, underground pits, clay pots, cribs, sandcrete wharehouses, mud walled silos ("rumbu"), steel tins, concrete and steel silos. In actual practice of large storage of grains (above 2 tons) rumbu, sandcrete wharehouses, concrete and steel silos are employed as documented by Lasisi (1988), Bengtsson and Whitaker (1986).

Major areas of research on storage structures have been with respect to methods of structural analysis that will bring about accurate assessment of existing static and dynamic stresses of the silo bin. A number of proposed methods were reviewed by Gumbe (1988). The reason for interest in this area was the need to optimize sectional sizes of materials used and thus reduce material cost. Research work were also carried out on the improvement of constructional details to check rodents, birds, moisture transfer through walls and rain effects in warehouses, and loading/off loading of grains. Ways of improving the ambient condition of the structure by mechanical devices that increase aeration, vary temperature and relative humidity has been other area of research in storage structures. Recommendations by researchers in these areas have been documented among others by Giles (1965) and Igbeka et al., (1989).

Studies carried out by Giles (1965) show that grain is stored more in the Northern part of Nigeria by the local farmers using the traditional mud storage bins known as "Rumbu". He noticed that variation existed in sizes, performance and duration of these rumbu structures. Wheatley (1972) identified the economy of grain storage using the rumbu, but stressed the importance of the need to find ways of simple improvements on the structure. Suggestions have been put forward at ways of improving this structure by international agencies such as the German Agency for Technical Cooperation, Food and Agricultural Organisation (FAO) and Volunteers in Technical Agency (VITA). Most of their suggestions centred on using mud bricks with raised concrete platforms. These suggestions were meant to help check rodents, ground moisture migration and to aid grain discharge during off loading.

In recent times, emphasis on the need to use local materials for construction purposes has been stressed by government and Engineers. Lasisi (1988) pointed out that the use of local material will save the country a lot of money both in the short and long term. This will according to him, encourage the development of local expertise for continuous improvement through research and development. Much work has been done by the Nigerian Building and Road Research Institute (NBRI) and some Nigerian Universities on lateritic soils as a local material for building,. Most of the works were aimed at improving lateritic soil by using better compacting methods and stabilizing agents.

Because of the importance of grain storage in the world, FAO regularly coordinates the national grain policies of various governments with a view of achieving better global policy. FAO report in 1975 showed that the Nigerian government had as its policy plan on strategic grain reserve, the construction of grain storage structures with a total capacity of 250,000 tons. Some of these structures were actually completed only in 1991 and commissioned in 1992.

**1.2 Statement of Problem**

Grain production in Nigeria is constantly increasing. Ashafa (1986) noted that millet production alone increased from an estimated 4.8 million tons in 1980 to 5.2 million tons in 1984. Lasisi (1975) observed that unless solution to the problem of storage of grains and produce is pursued, the increase of agricultural production will have little or no effects in increasing the quantity and quality of food available for human consumption and livestock feeding. He suggested therefore the need for a continuous development of appropriate storage technologies to cope with these increases.

Cost of building materials has increased astronomically as a result of the devaluation of the Nigerian currency. Lasisi (1988) observed that the difficult economic situation has forced a change in orientation and local materials are looked at more closely in the hope of solving our technology related problems. Earlier researchers on local building materials have focused attention on soils. However, solutions offered like use of compaction machines and chemical stabilizing agents often call for a serious departure from the traditional practices thus creating sociological problems in terms of acceptance, cost and availability of skill. Wheatley (1972) showed that any new improvement on storage structures must be simple and cheap to economically justify its application.

Traditional methods of rumbu construction, as presently practised differ widely from village to village and sometimes from one builder to another. Notable differences arewith regards to the following:

(i) mix ratio of constituents used in mud preparation

(ii) type and amount of stabilizer

(iii) constructional details.

The consequences of these differences include variation of sizes, performances and durability of structures, as documented by Giles (1964), Agboola (1985), Bengtsson and Whitaker (1986). Though 'rumbu' bins are used extensively in Northern Nigeria and have been studied, no work has yet been done in determining the properties of mud utilized in their construction. This therefore makes it difficult to know the limiting strength and load capacity of these structures and consequently, level of safety of these structures are not known.

### 1.3 Objectives of the study

Objective of this study are:

(a) To undertake a general study and assesment of existing grain storage structures constructed with mud.

(b) To study the present state of art in mud preparation, rumbu construction and usage in some selected villages within the Northern states of Nigeria.

(c) To evaluate the effect of various mix-ratios of mud constituent (water, soil, grass stabilizers) on workability, strength (compressive and tensile), and durability of the finished material. (dried mud)

(d) To investigate the effect of environmental changes (temperature and relative humidity) on dried mud as compared with steel and sandcrete block which are the two other major materials used for construction of grain storage structures.

# CHAPTER TWO

## 2. LITERATURE REVIEW

Previous research works on grain storage structures using mud as a construction material can conveniently be discussed under the following four areas:

(i) Factors affecting grain storage

(ii) Types of grain storage structure

(iii) Mud as a construction material

(iv) Performance evaluation of grain storage structures.

The above factors are reviewed below followed by a justification of the set objectives.

### 2.1 Factors Affecting Grain Storage

A stored grain bulk has been described by Sinha (1973) as an ecological system in which deterioration results from interactions among physical, chemical and biological variables. He listed the variables as temperature, moisture, oxygen, geographical location, insects, mites, microorganisms, rodents and birds. The proper control of these agents is therefore a basic necessity for successful grain storage. According to Lasisi (1975), these agents can be grouped into three as follows:

(a) Weather

(b) Pests

(c) Micro-organisms and enzymes.

### 2.1.1 Weather

Weather acts on the external surfaces of walls of structures to change the internal conditions of the storage. Therefore weather variations result in changes of the internal parameters associated with storage. It is important to understand the effect of weather in order to control such variations likely to give rise to favourable conditions that allow for deterioration.

Weather acts in form of heat from the sun, direct moisture from rain, and vapour from high ambient relative humidity. The presence of wind often aggravate magnitudes of heat and moisture transfer to and through the structure.

In understanding effects of weather two subject areas were reviewed :

(a) Heat transfer

(b) Mass transfer

**(a) Heat Transfer**

When the atmospheric temperature becomes higher or lower than the internal temperature of a storage structure, temperature gradient across the wall of such structure will be prevalent resulting in heat transfer. If the diurnal temperature variation is high, it could lead to condensation within the structure giving rise to increased grain moisture content. Increased grain moisture content could result in mouldiness and fungi growth. Igbeka et al (1989), Muir (1978), Sinha (1973). It could also result in grain volume increase that could lead to the damage of the structure. Hall (1963) Heat transfer from the environment to within the structure takes place in three stages. The first stage is the heat transfer by radiation and convection to the external surface of the wall, the second stage is

the transfer of the heat by conduction through the wall and the third stage is the transfer of heat from the internal surface of the wall by convection to within the structure.

**(i) Heat Transfer by Radiation:** Thermal heat transfer by radiation takes place by electromagnetic waves between a heat source, other objects around the surrounding and the external wall of structure. The net amount of heat transferred is dependent on the absolute temperature differences between such separate bodies involved.

The net heat radiated between two bodies $q_r$ and $q_2$ is:

$$q_r = F_E F_A A \sigma(T_1^4 - T_2^4) \quad \text{.....(2.1)}$$

where $F_E$ = the radiation factor depending on emissivity (E)

$F_A$ = geometric or view factor

A = surface area ($m^2$)

$T_1$, $T_2$ = temperatures of body 1 and 2 in degree Kelvin.

$\sigma$ = Stefan-Boltzman constant.

The rate of heat flow to the wall per unit area ($Q_R/A$) is given as:

$$Q_R / A = Ehr\ (t_r - t_s) \quad \text{.....(2.2)}$$

(Markus and Morris, 1980)

where

$Q_R$ = rate of heat flow $W/m^2$

E = Emissivity

$t_r$ = mean radiant heat as seen by the wall in degree Kelvin.

$t_s$ = wall surface temperature in degree Kelvin

Markus and Morris (1980) gave the approximate value of (Ehr) as 4.14 $Wm^{-2}k^{-1}$ and noted that emissivity for most opaque building materials can be assumed as 0.9. Effect of radiant

heat transfer on walls can be reduced by decreasing the absorptivity of the wall material, increasing the reflectance of the wall material or shading the wall from hot radiant objects like the sun.

**(ii) Heat Transfer by Convection :** Convective heat transfer is normally as a result of fluid motion created externally by either instruments such as fan or pump or created by a difference of density and the action of gravity. On this basis, convective heat transfer is either termed forced or natural. In normal weather conditions, natural convection is the prevalent form of convection.

The magnitude of heat transferred by natural convection is dependent on several factors like gravitational force (g), thermal expansion ($\beta$), viscous drag ($\mu$) thermal diffusion, the air property, temperature difference between the air and wall surface ($\Delta T$) and the characteristic length of the surface (L). These variables are related in dimensionless quantities called Nusselt number (Nu), Grashoff number (Gr), and Prandtl number (Pr) as shown below:

$$Nu = c\,(Gr.\,Pr)^{n} \quad \text{.....(2.3)}$$

$$Gr = (k/l).\,[(L^3\rho^2\,\beta\;\; g\,\Delta t) / \mu^2\,] \text{.....(2.4)}$$

$$Pr = (\mu c_p) / k \quad \text{.....(2.5)}$$

$c_p$ = constant depending on the physical configuration of the structure

n = constant depending on the nature of flow of the air- whether laminar or turbulent.

The heat transfer coefficient (h) is used to approximate the quantity of heat transfer.

If $Q_c / A$ = Heat flow per unit area due to convection

Then $Q_c / A = h_c (t_a - t_s)$ .....(2.6)

where $t_a$ = temperature of air close to the wall

$t_s$ = wall surface temperature.

The combined effect of radiation and convection will provide a total heat flow which according to Markus and Morris (1980) will be the addition of each of the effects of radiation and convection. i.e.,

$$(Q_r / A) + (Q_c / A) = Eh_r (t_r - t_s) + h_c (t_a - t_s) \quad \text{.....(2.7)}$$

For most of the situation it is sufficient to assume that $t_r = t_a$

Therefore

$$(Q_r / A) + (Q_c / A) = (Eh_r + h_c) (t_a - t_s) \quad \text{.....(2.8)}$$

$$= (1/ R_s)(t_a - t_s)$$

Where $R_s = [1 / (Eh_r + h_c)]$

Markus and Morris (1980) recommended that the value of Rs for convective and radiative surface resistance can be reduced by providing shelters, and wind breakers which will have substantial effect on degree of exposure of the strucure. The British practice, according to him, categorise the degree of exposure of a building structure into three namely, sheltered, normal and severe. In using the above equation, Ehr is taken as 4.14 $Wm^{-2}k^{-1}$ and hc is calculated based on the degree of exposure.

$$hc = 5.8 + 4.1V \quad \text{.....(2.9)}$$

where V = wind speed in (m/sec)

Suggested wind speed for different degrees of exposure are shown below in Table 1.1.

**Table 2.1 Wind Speed for Different Degrees of Exposure**

| Surface | Wind speed (m/sec) | Exposure |
|---|---|---|
| Roof | 1.0 | Sheltered |
| | 3.0 | Normal |
| | 9.0 | Severe |
| Wall | 0.7 | Sheltered |
| | 2.0 | Normal |
| | 6.0 | Severe |

Source : Markus and Morris (1980)

**(iii) Heat Transfer by Conduction:** The actual transfer of heat from the external surface of the wall to the internal surface takes place by conduction. Markus and Morris (1980) described walls of structure as fabrics that function as a filter paper between the external and internal environment. High change in external wall temperature as a result of diurnal variation of temperature can give rise to condensation of moisture on the internal surface of the wall. Conductive heat transfer can be of steady state or transient type depending on the constancy of the external and internal temperatures, but in buildings, steady state heat transfer is normally assumed Mid West Plan Service (MWPS) (1970), Bengtsson andWhitaker (1986) and Markus and Morris (1980).

The major property of the wall material which affects the rate of heat transfer is conductivity (k). Conductivity is the ability of a material to conduct heat and its value depends on other properties like density, size of particles, degree of bond between particles and their arrangement, moisture content and temperature. The relationship between bulk density and thermal conductivity of a brickwork is shown in Figure 2.1. For various building materials, the value of k, or its reciprocal (i.e resistivity) are given in standard text.

Steady state heat transfer through flat walls is given by the equation

$$Q = - Ak (t_1-t_2) / L \quad \text{.....(2.10)}$$

where $Q$ = heat conduction rate

$A$ = cross-section area normal to the direction of heat flow, $m^2$

$k$ = thermal conductivity of material

$t_1$ = internal wall surface temperature

$t_2$ = external wall surface temperature

$L$ = wall thickness

One dangerous consequence of heat conduction is condensation. Gray (1955) relates that whenever the outside wall of a structure is exposed to a lower outside temperature ($t_o$), the inside wall surface temperature ($t_s$) will reduce to that lower than the inside air temperature ($t_i$). If $t_2$ is less than the dew point of the inside air, condensation will occur. He stated that for a wall with an overall heat transfer coefficient U, condensation will occur if,

$$t_s < t_1 - [ U / (f_i (t_1 - t_o ))] \quad \text{.....(2.11)}$$

where $f_i$ = surface conductance of still air close to the inside wall.

The implication is that the higher the U value, the higher the possibility of condensation. Condensation sometimes occur within walls or wall surfaces but the surface type is most disturbing as it is the one that is readily absorbed by grains giving rise to mouldiness and spoilage.

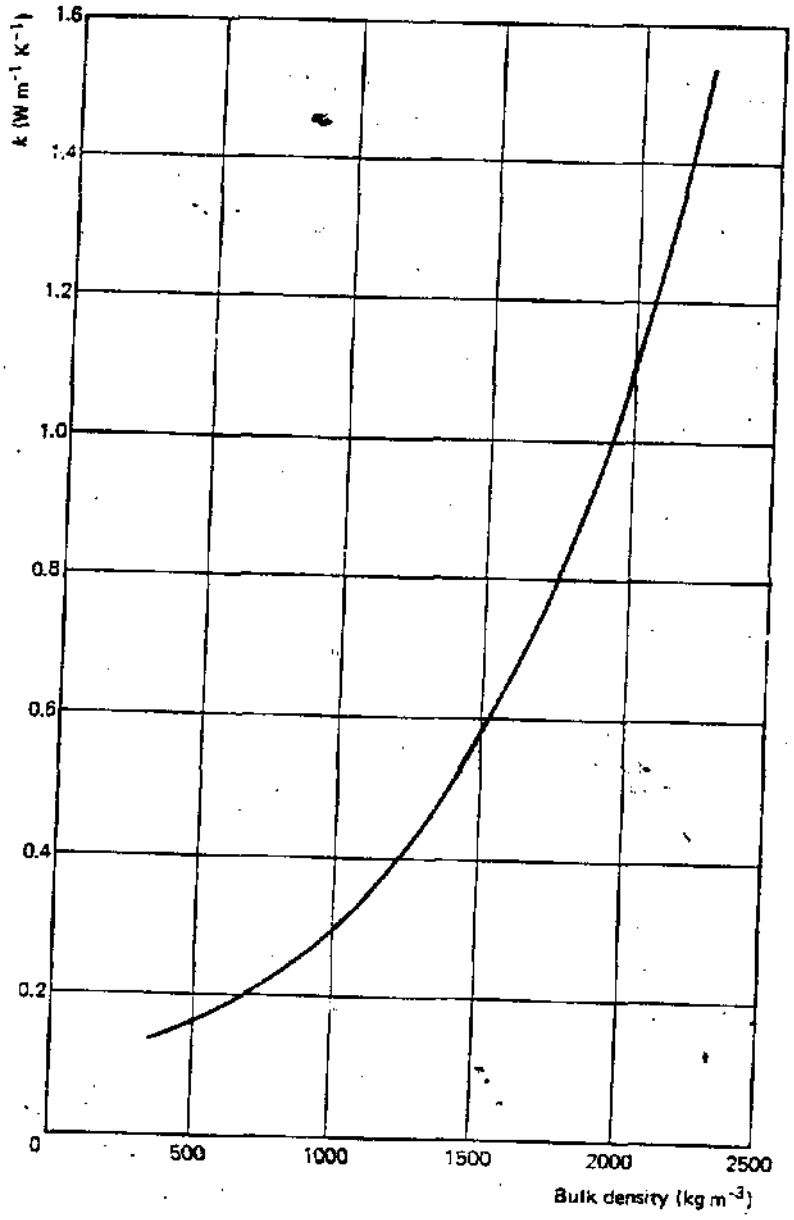



Figure 2.1 Relationship Between Bulk Density and Conductivity of Brickwork. Source: Markus and Morris (1980)

**(b) Mass Transfer**

As a result of rain or high ambient relative humidity, moisture or vapour is transferred across wall of structures giving rise to excess moisture or increased relative humidity within the structure. When grains are stored in such a structure, the moisture content normalises with the internal environment of the structure resulting in an equilibrium moisture content (EMC) for the grains, and an equilibrium relative humidity (ERH) for the environment. Any excess moisture or vapour transferred from external sources into the structure give rise to increase in grain moisture content. Hukill (1963) identified exchange of moisture with atmosphere through the structural wall as one of the reasons that lead to change of moisture content of grains during storage. Giles (1962) noted that the moisture content of stored unthreshed sorghum increased from 6.75% in February when the ambient relative humidity was 11.0% to a moisture content of 11.9% in August when the ambient relative humidity rose to 84.9%. The rate of moisture increase, according to him, is dependant on the vapour barrier presented by the structure. Moisture increase in the structure result in mould and fungi growth. The minimum moisture content required to start fungi growth is put at about 13.5% by Bailey (1954). This he noted results in a further increase of temperature and moisture leading to ordourisation and brownish colourisation of the grain. Pixton (1982) stated that such initial increase of moisture result in a self generating process of heat and moisture due to increased respiratory processes.

Like heat transfer, moisture transfer across the wall of a storage structure takes place in three stages. The first stage is the process of convective "mass" transfer of moisture from the ambient to the external wall of the structure, the second stage is diffusive "mass" transfer of the moisture through the solid wall and the third stage is the convective "mass" transfer of the moisture from the internal surface of the wall.

**(i) Convective Mass Transfer**

Mass transfer as a result of a moving fluid over a solid surface or an immiscible fluid is known as convective mass transfer. If this movement is caused by a pump or similar device, it is referred to as forced convection. If however the movement is caused by difference in density resulting from species concentration or temperature gradient, it is called free or natural convection.

The rate equation for convective mass transfer as presented by Welty et al (1969) is given as:

$$N_A = K_c . \Delta C_A \quad \text{.....(2.12)}$$

where

$N_A$ = molar mass transfer of species A measured relative to fixed spatial coordinates

$\Delta C_A$ = concentration difference between the boundary surface concentration and the average concentration of the fluid stream of the diffusing species

$K_c$ = convective mass-transfer coefficient which in general is a function of system geometry, fluid and flow properties, and concentration difference $C_A$

Since mass transfer is analogous to convective heat transfer, dimensionless numbers are used in relating the variables of natural convection mass transfer, this is done by replacing the prandtl number in convective heat transfer with Schmidt number (Sc). The correlating relationship will then be of the form:

$$Nu_{AB} = f(Gr_{AB}, Sc) \quad \text{.....(2.13)}$$

where $Sc = \mu / PD_{AB}$ (Schmidt Number)

$Gr_{AB} = L^3 g \Delta_{pA} / \rho v^2$ (Grashoff Number)

$Nu_{AB} = K_c L / D_{AB}$ (Nusselt number)

Where

$D_{AB}$ = fluid diffusivity, $m^2$/sec

K = mass-transfer coefficient, m/sec

p = fluid viscosity, $kg/m^2$

$\mu$ = fluid viscosity, kg/m.sec

L = characteristic length, m

$g\Delta_{PA}$ = buoyant force, $kg/m^2sec^2$

**(ii) Diffusive Mass Transfer:** The actual transfer of water vapour or fluid through the structural wall as a result of species concentration gradient is referred to as diffusive mass transfer rate and is based on Fick's law of diffusion - MWPS (1976)

Fick's law is written as:

$$M = - DA (d\rho/dx) \quad \text{.....(2.14)}$$

where M = mass (vapour) transfer rate, kg/sec

A = surface area, $m^2$

D = ordinary coefficient of diffusion, m/sec or permeability

$d\rho/dx$ = vapour pressure density gradient in the direction of flow, $kg/m^2$

The transfer of water vapour according to MWPS (1976) through materials is complex and not well understood. This is because the ordinary coefficient of diffusion, (D) which is primarily dependent on relative humidity (RH) and to some extent on temperature, changes. For walls of homogenous material subjected to constant vapour pressure, the simple case of steady-state vapour transfer is assumed, thus making it easy to determine the vapour

transfer rate by separating variables and integrating. Fick's Law then becomes

$$m = DA\ (p_1-p_2)L \quad \text{.....(2.15)}$$

Where $p_1$ and $p_2$ are the vapour pressures at each end of the flow path and L the length of flow path (material thickness). The mean value of permeability (D), then becomes

$$D = 1/(p_2-p_1) \int dp \quad \text{.....(2.16)}$$

The amount of moisture (m) transmitted through a wall can be estimated from the following equation given by Bengtsson and Whitaker (1986)

$$m = d \times A \times T \times \Delta p \quad \text{.....(2.17)}$$

where m = total moisture transmitted, g

d = permeance, g/24hr.m$^2$.pa

A = unit area, m$^2$

T = time unit, 24hr

$\Delta p$ = pressure difference, pa

Permeance is the ratio of water vapour flow to the vapour pressure difference of a material between the surfaces. It is normally derived from permeability which is the property of the material that allows the migration of water vapour and measured for one meter thickness in g/24hr.m$^2$.pa. Permeability of a material can be measured using the wet or dry cup method. Joy (1972) described the dish or cup method as the simplest and widely used method of measuring water vapour transmission. The procedure is to place the specimen on top of an impermeable test dish containing water so as to maintain a 100% RH for the wet cup method or to place desiccant in the test dish so as to maintain a 0% RH for the dry cup method. In both cases, the mouth of the dish is properly sealed and a 50% constant relative

humidity is maintained outside the dish. The amount of moisture gained by the specimen in 24 hours is measured as the water vapour transmitted. The wet cup method normally gives a higher value as permeability generally increases with relative humidity.

The implications of the moisture transmission equations are that, using a material of low permeability, or minimising pressure or temperature differences will result in less water vapour transmission. Most often particularly in the humid tropics, there is a simultaneous heat and mass transfer. This could result in heating and humidification or cooling and dehumidification. The thermodynamic properties of the ambient and internal can be derived using the psychometric chart. The rate of heat transfer in this case will then be a function of both the humidity ratio and temperature gradients.

## 2.2 Types of Grain Storage Structures

Several types of grain storage structures are in existence and there is no agreed standard form of classification. Bailey (1954) classified storage facilities into seven based on quantity and level of protection given to the grain. These are:

(i) on the ground storage;
(ii) bagged storage;
(iii) bin site storage;
(iv) terminal elevator storage.
(v) underground storage;
(vi) farm bin storage;
(vii) country elevator storage;

Hall (1963) classified grain storage systems into three; traditional, modern and central storage. Giles (1965) used structural shape as a basis and classified the storage structure used in the then Northern Nigeria into six namely:

(i) dried earth granaries;
(ii) grass granary;
(iii) pot storage
(iv) underground pit;
(v) in-hut storage;
(vi) modern silos.

Based on the principles employed in the preservation of the grain, storage systems have also been classified as natural, aerated, cooled, airtight, chilled or refrigerated. However for this review, a classification close to that of Hall(1963) has been chosen as follows:

(i) traditional storage structures;
(ii) improved traditional storage structures and
(iii) modern storage structures.

### 2.2.1 Traditional storage structures

By traditional method, it is meant those methods originally used to store grains in parts of Africa by African themselves and which according to Hall (1963) are still employed today with little or no modification. Traditional storage structures vary widely with respect to construction material, size, principles of preservation, purpose and size of storage. Various traditional methods of storage are discussed below, with supporting sketches as presented by Lasis(1988) shown in Figure2.2

**(a) On the ground storage**: This is a storage system in which according to Bailey (1954), grain is piled on the ground unprotected for a period of between harvest and transportation to a safe place. Unthreshed grains are sometimes gathered into heaps which remain unprotected for a period of one/two days or a long period of over six months in countries of long dry season (Hall, 1963).

**(b) Bunch and Pole storage**: In this method, bundles of unshucked maize cobs are suspended from a tree or tied to poles and driven into the ground tofix vertically in place. This enables drying to continue until the maize is used up (Hall, 1963). See Figure 2.3.

**(c) Rack storage**: This is also a form of storage where unthreshed crops are kept on raised racks such that drying continuously takes place during the storage period. In Ivory Coast, unshucked maize panicles of paddy and millet are stored on vertical racks 2 to 3 metres high and 5 to 20 metres long. See Figure 2.4

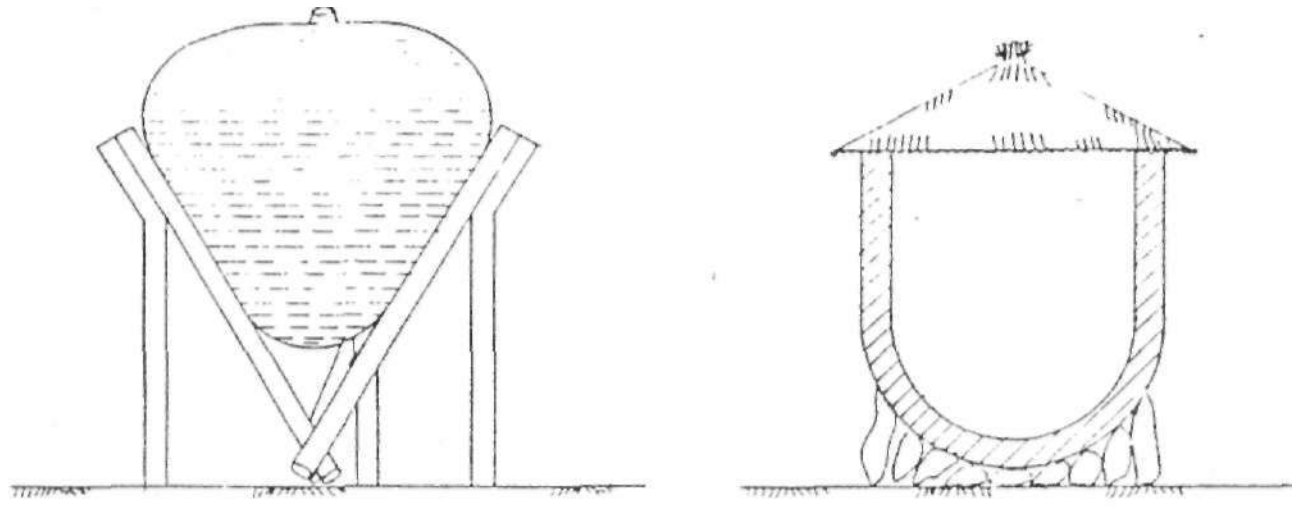
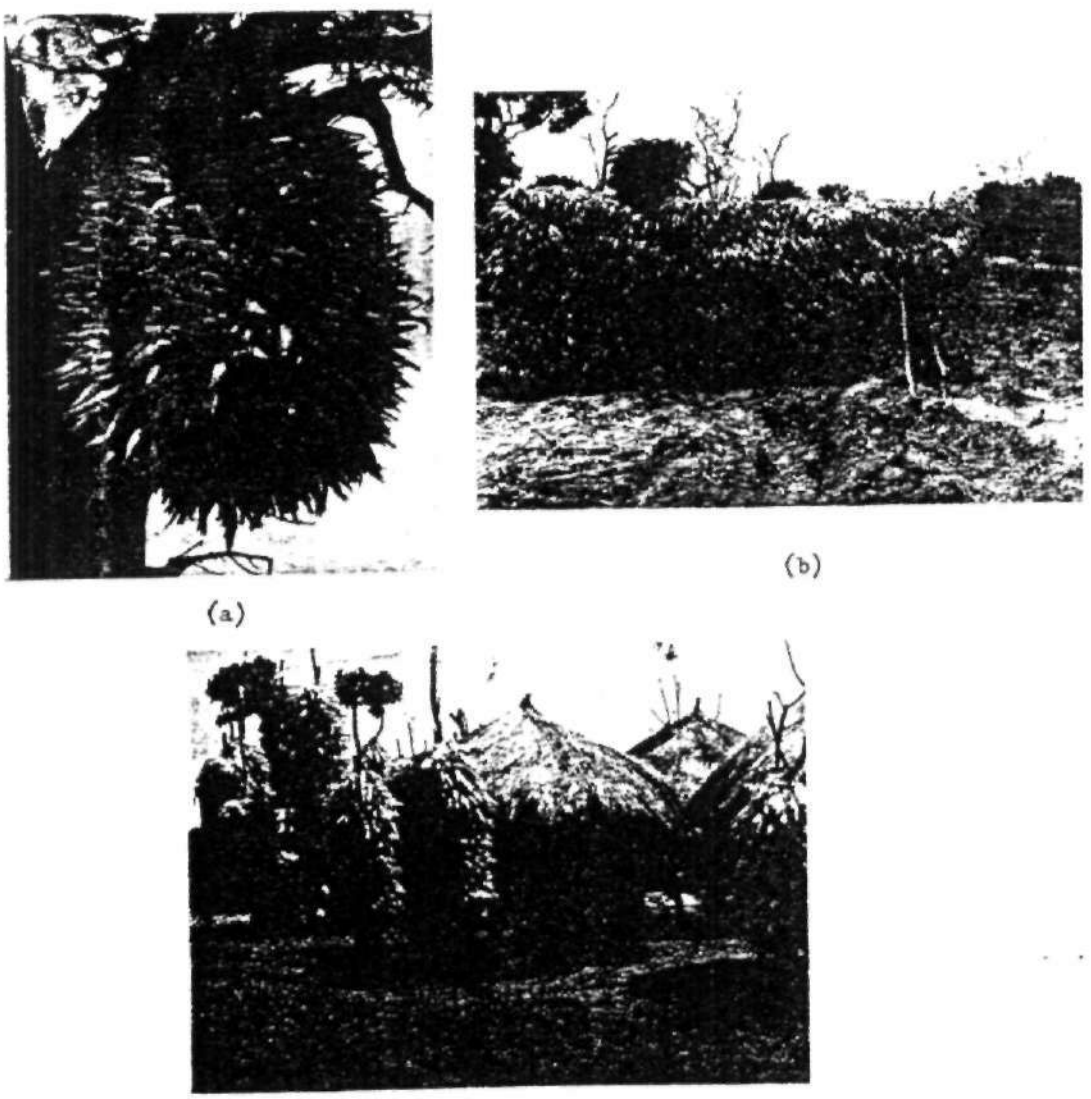



Figure 2.2 Sketches of Traditional Storage Structures

Source: Lasisi (1988)



(a)

(b)

(c)

Figure 2.3 Traditional Methods of Drying/storage of Unsheated Maize Cobs.

(a) Bunch suspended from tree
(b) Rack drying/storage
(c) Pole drying

Source: Hall (1963).



(a)



Figure 2.4 Local Platform Method of Storing Maize Cobs

Source: Hall (1963)

**(d) Platform storage:** In some parts of Northern Nigeria, unthreshed grains are placed on horizontal timber or pole grid of about 2 metre square and between 1 to about 2 metres above ground. A removable thatch roof may be used to cover the platform, and occasionally the fire for cooking (which is normally done outside the living house in the traditional African setting) is set close to the platform in order to aid drying and prevent insect and fungal attack (Hall, 1963).

**(e) Basket storage:** In this storage system, portable or non portable baskets of woven grass or wicker work is held off the ground on poles and used for storing grains. It is used in Nigeria as reported by Lasisi (1986) and in Uganda, Senegal and Kenya as reported by Hall (1963).

**(f) Gourds and Clay Jars:** Calabashes, gourds, and earthen ware jars are used in several countries including Nigeria to store small quantities of threshed grains and seeds. Prior to storing, such grains are dried thoroughly and the mouth of the container, normally narrow, is sealed using mud or a wooden stopper. The container is then stored in the dwelling huts or on top of products in granary (Hall 1963).

**(g) Grass Granary:** The most frequently used grain storage structure in Africa is the container constructed entirely of plant materials, which has clearly defined walls in addition to a floor and roof (Hall, 1963). The container may be circular or rectangular in plan and usually elevated above ground level. The dimensions range from 0.5 to 3.0 metres diameter with walls 1.0 to 2.5 metres high and raised 0.1 to 2.0 metres above ground level.

Giles (1964) noted that Guinea-corn stalks are normally used in constructing these granaries and that storage is often temporary. Plant material granaries are considered easy to build, economic for short-term storage while allowing drying of the contents. The average life of the plant granary is put at five years with a range from two to ten years.

Bungudu (1970) in his investigation found that the plant-material granary (rumbu) is mainly used by the Fulani and other people living in the outskirts of main villages and noted that both the plant-material rumbu and rudu (another type of grass granary) are of lesser importance to villagers. The major limitation of this type of granary he noted is that it does not protect the grain from insect infestations.

**(h) Mud Granaries or "Rumbu":**

Mud granaries (also referred to as 'Rumbu') as used in Northern Nigeria have been studied and described by Giles (1964), O,Dowd (1970),Bungudu (1970), Caswell (1975), among others. According to Giles (1964), this structure is used for long storage of large quantities of unthreshed grains. The structure has the advantage of being larger, more permanent, and able to resist termite, rodent, thieves, and fire.

Giles (1964) carried out investigations on some existing "rumbu" structures of this type in Northern Nigeria to determine their size range and durability. His findings are shown in table 2.2

**Table 2.2 Approximate Dimensions, Capacities and Durability of Granaries in Northern Nigeria.**

| Type of Material | | PARAMETER | | | |
|---|---|---|---|---|---|
| | | Diameter (m) | Height (m) | Capacity* (tons) | Durability (yrs) |
| 1. Dried Earth | -most common | 1.7 | 2.7 | 12 | 20 |
| | -range | (1 - 5) | (1 - 6) | (1 - 19) | (10 - 50) |
| 2. Plant Material | -most common | 1.0 | 2.6 | 1 | 1 |
| | -range | (5 - 3) | (1 - 4) | (1 - 7) | (1 - 4) |

Source: Giles (1965)

*Capacity refers to calculated capacity of unthreshed sorghum (in bundles) when the granary is full at 10.2% moisture content (m.c) and density of 243.2K.g/m$^3$ (15.2lb/ft$^3$); 50 bundles of unthreshed sorghum is considered to weights approximately 1 ton.

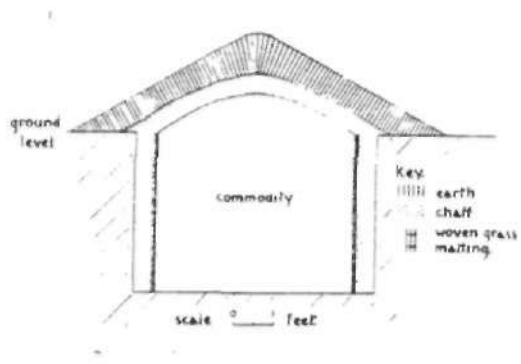
The major problems of these granaries as noted by Giles (1964) and later Bungudu (1970) is the high level of insect infestations. Giles (1964), further noted that depending on the geographical location, this could give rise to a storage loss of between 4% in earth rumbu and 78% in plant material rumbu.

In Nigeria and other African countries like Mali, the use of mud bricks rather that in-sits mud have been reported. Weblay and Harris (1979) described these type of structures where the walls are constructed with mud blocks of approximately 40x20x10cm and internally plastered 2.5cm layer thick. By this method, Weblay and Harris (1979) observed that it was possible to build stores as large as 24x18.4x4.1m and yet maintain a concentration level of fumigant adequate to kill all storage insects in four days, provided doors are well sealed.

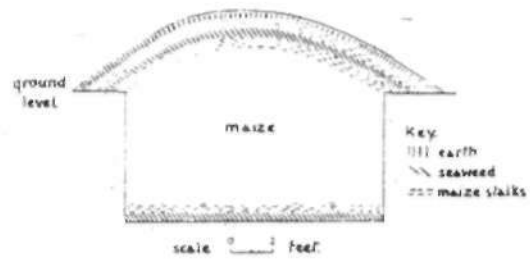
**(I) Underground or pit storage:** Hyde and Burrell (1973) reported that underground pits were used in the ancient times in the Middle East Asia and Southern European Countries. They were normally excavated in soil or rock and usually lined with straw or chaff to absorb moisture entering from the soil. Giles (1964) stated in his report that this method is carried out in the dry areas of the North-eastern Nigeria. Two types of pit according to Giles (1964) are traditionally in use. The first type called 'Bame' pits are used in Lake Chad area of Nigeria and can store threshed grain for a period of over five years. The pits which are flask shaped are often as deep as 6 metres and covered with dried earth cap. In the 'Bame' pits, the grains can be stored for as long as five years. The second type used around Maiduguri is of cylindrical shape and about 2 metres deep. It is lined with grass matting, and the gap between the matting and the earth wall is filled with millet chaff, and the opening covered with taches and thorns.

The principle of air tightness has been said to be the basis on which the pit storage works. As explained by Hyde (1954), the straw or chaff lining absorbs moisture entering from the soil or through leaks in the cover. The dampened straw becomes mouldy and in so doing uses up the oxygen in the pit. Major advantages of pit storage according to Hall (1963) are air tightness, cheapness, evenness of temperature and checking of pilferage.

Shortcomings of this method according to Hall (1963) is deterioration that could result from dampness from the surrounding soils (i.e development of mould) or from attack by insects. The susceptibility of this system to rodent and termite attack has also been pointed out by Igbeka et al (1989). Diagrams of some types of pit storage presented by Hall (1963), courtesy of Pest Infestation Laboratory, England is shown in Figure 2.5.




(a) Diagram of a cross section of a Somaliland native square pit




(b) Diagram of vertical section of a Nigerian (Bornu) native circular pit

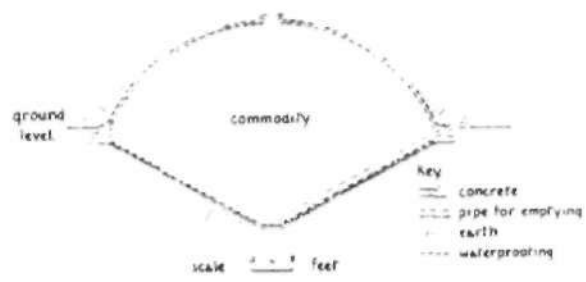



Diagram of vertical section of a circular pit silo in Cyprus to hold 900 tons of grain.

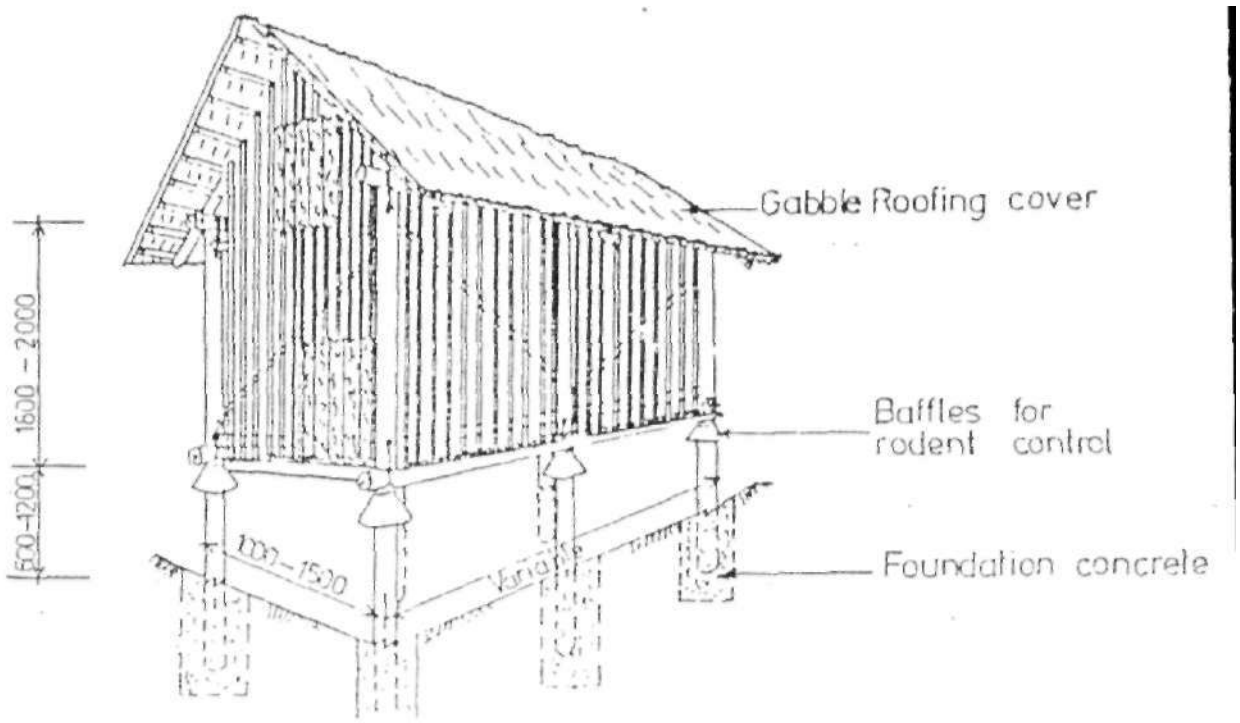
(c) Diagram of vertical section of a circular pit silo in Cyprus to hold 900tons of grains

Figure 2.5 Diagrams of Some Types of Pit Storage
(a) and (b), Traditional type pits;
(c) Modern concrete lined pit Source: Hall (1963).

### 2.2.2 Improved Traditional storage structures

Attempts have been made by organisations and researchers to improve on the traditional storage methods. Most of the improvements have been on the three basic traditional methods of bulk storage namely: the grass granary (that combines drying and storage), the mud granary and the pit storage.

(a) **Improved platform and grass granary:** Major problems associated with the traditional types of these structures include lack of durability, rodent and insect attack, and possible mould growth at the centre for large diameter structure due to non-effective drying. Improvement therefore centred on geometry modification for effective drying, using more durable material and checking rodents by some physical means. The Nigerian Stored Product Research Institute (NSPRI) in 1963 started an experimental maize crib. The experiment was based on the principles of reducing the crib width (in relation to its depth) to say two metres maximum, and reorientating the structure to ensure that the long axis is facing the prevailing wind. The result of this experiment has since resulted in a standard maize crib recommended by NSPRI. The structure as described by Agboola (1985) consist a platform of 1.22m breadth and of variable length, raised 1.22m above the ground level and supported on strong pillars made of either bamboo poles or other wood, and fixed firmly in the ground. The structure is provided with a roof structure while slatted bamboo or wire nets are used as side walls to hold the cobs or panicles. Rodent guards are provided on the pillars to ward off the entry of rodents while insect control is effected by treating the grains with persistent insecticides. Lasisi (1986) also described this crib and rated it as very effective for the humid tropics. Diagram of this structure as presented by Lasis (1988) is shown in Figure 2.6(a).




**(a) Improved Ventillated Crib**

(b)

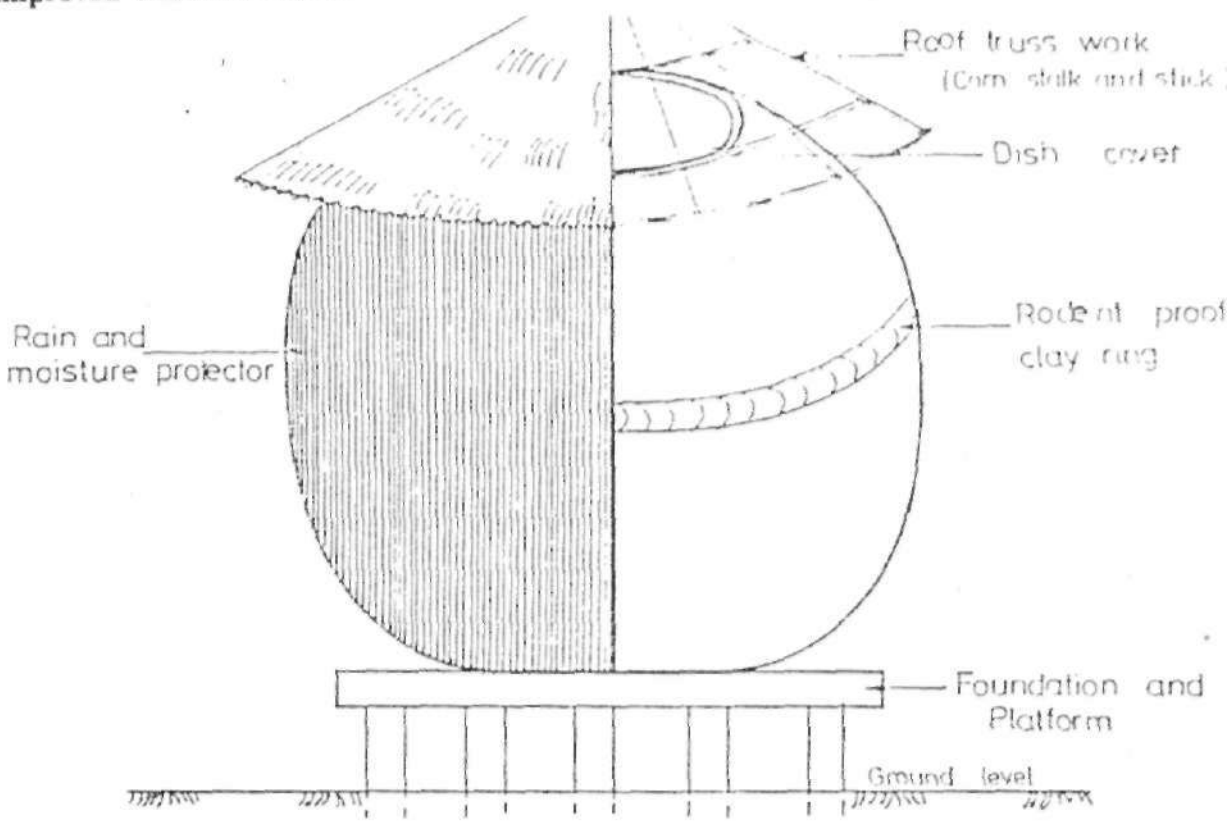



Figure 2.6 Improved Traditonal Storage Structures

(a) Improved Rumbu,

(b) Improved Ventillated Crib. Source: Lasisi (1988)

**(b) Improved Mud Granary:** The major short-comings of traditional mud granary as earlier reviewed included, lack of durability, insect and rodent attack, as well as moisture transfer from ground surface. Lasisi (1986) recommended such improvements as providing raised concrete foundation and platform, this suggested improvements as presented in his sketches is shown above in Figure 2.6. O'Dowd (1971) found that painting external walls of the rumbu with bitumen, increases the resistance to water/moisture intake as well as providing some hermitizing effect.

In Ghana, attempts have been made in improving mud granaries by using precast mud blocks rather than in-situ casting of mud. Dichter (1978) described these improvements in the so called 'Northern Ghana Mud Silo". The construction of the silo according to Dichter (1978) involves:

(i) Constructing the silo on pillars and insulating it from ground moisture by putting tar paper between the pillars and bottom slab.

(ii) Making the bottom and top slabs out of reinforced concrete to give added strength to the structure.

(iii) Providing wooden unloading chute with an airtight plastic cap.

(iv) Painting the silo with a coat of coal tar to inhibit moisture absorption.

FAO reported that in China, the traditional clay/straw silos were improved upon by developing testing methods for mud. This aided in the selection of stronger and more durable clay/straw mix resulting in increased silo sizes. According to the report, present sizes are in the range of 6 to 10 metre diameter with 4 to 7 metres height as against the previous 4 to 8 metres diameter and 2 to 4 metres height. Storage volumes also increased from

201m³ to 550m³. To achieve these improvements, FAO (1982) recommended a minimum clay/straw density wall of 966g/cm³ and wall thickness in centimetres of 12 plus internal diameter of the silo in meters.

(c) **Improved pit:** The problems of traditional underground pit are structural, it could be wall failure resulting from pressures of the surrounding earth or improper vapour control. Hall (1963) recommended as a way of improvement, the use of concrete for the construction of pit walls. Ransom (1960) on the other hand gave recommendations essential to effective pit storage. These are:

(i) The walls of underground stores must be designed to resist both the pressure of the surrounding earth when the store is empty, full or partly full.

(ii) Vapour barriers must be incorporated to prevent entry of air and moisture and the escape of $co_2$.

(iii) The roof may be flexible (a temporary roof of bitumen felt laid directly on the heaped grain, bonded with bitumen to the walls of the pit) or solid (a permanent roof).

(iv) Stores of great length should be avoided, otherwise cracking may occur.

### 2.2.3 Modern Grain Storage Structures

Mordern grain storage strucures have been described by Hall (1963) as basically an elaboration of the traditional method in terms of both construction and usage. While modern construction methods involves use of modern materials, mordern storing system involve storing producein bags in whare houses or in bulk grains in silos. Other modern methods would be said to exist depending on the preservation method, these include, air tight or

hermitic storage, cool storage of grains, chemical method of storage. The two basic types of modern grain structures and associated techniques of preservation are discussed below.

(a) **Warehouse**: These are sheds with walls used for storing grains in bagged form. According to Hall (1963), storage in jute bags within sheds of various types of construction is a more widely used method of grain storage than bulk storage in silo bins. Concrete bricks, timber and steel have been listed by Hall (1963) as the common construction materials utilized in building these sheds, stone he noticed is sometimes in Northern Nigeria for their construction. Agboola (1985) gave the recommended features adopted by NSPRI to be used for standard stores and warehouses. These include:

**(i) Site Location**: The site must be in an area that is never likely to be flooded.

**(ii) Moisture-proof floor**: The floor should be made moisture-proof by putting a moisture barrier in the foundation layers before the final concrete layer.

**(iii) Smooth Walls**: The walls should be plastered smooth and without cracks which can be used by insects as hiding places.

**(iv) Tight-fitting doors and Windows**: Doors and windows should be made tight-fitting to enable the achievement of partially airtight condition if in-situ fumigation shall be required.

**(v) Roof**: Leak-proof roof should be provided.

**(v) Eaves**: The eaves should be completely sealed. Use of dunnage or pallets and bag stacking techniques that allow for stability, good ventilation and inspection has also been recommended Bengtsson and Whitaker (1986).



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Warehouses have been recommended by Gracey and Calverley (1972 ), as suitable for the tropical countries and listed the important design parameters as capacity, shape, store sitting, specifications and construction of foundation, floors and walls. Recommended sizes of building with respect to required storage capacities are shown in Table 2.3.

**Table 2.3: Recommended Building Dimensions For Warehouses.**

| Capacity (tonnes) | Floor Area ($m^2$) | Perimeter (m) | Building Size (m x m) |
|---|---|---|---|
| 1000 | 523 | 94 | 19 x 28 |
| 3000 | 1596 | 170 | 28 x 57 |
| 5000 | 2660 | 244 | 28 x 95 |

Source: Gray and Calverly (1972)

The basic method of preservation in the warehouse is the provision of sufficient aeration although fumigation at initial storage period is often a practice. Agboola (1985), Hall (1963), Gray and Calverley (1972) and others explained the techniques which can be summarised as follows:- Good stacking methods and dunnage are used in such a way as to allow for stability, aeration, inspection and to avoid moisture from walls and floor. Good sealing should be ensured when carrying out fumigation to control insect infestation. Loading and off-loading is best done by mechanical grain handling machines.

**(b) Silo bins**: Silo bins are bulk storage structures fabricated of metal, aluminium or concrete, installed on reinforced concrete platforms. they are usually cylindrical in shape but a few rectangular ones of concrete type are known. The rubber type has also been tested in the past. These silos are of various storage capacities ranging from 10 to over 200 tons each. Agboola (1985).

According to Bailey (1954), silo bins are used as farm bins, bin sites, country elevators and terminal elevators. Farm bins, are silos used singularly in the farm in form of small round steel bins with capacities from 25 to 80 metric tons. Bin sites are batteries of farm bins in large numbers with bin capacities ranging from 50 to 83 metric tons. Bins are in this case constructed mostly of steel or aluminium. Country elevators on the other hand are batteries of silos designed to receive grain directly from producers with a principal function of accumulating the grains for reloading into transportation facilities such as trucks, railroad cars, or barges, and sent it to market. Terminal elevators are batteries of silos located in transportation terminals and larger markets with storage space range of 5,000 to 500,000 metric tons.

In practice silos are usually accompanied with high-capacity equipment for cleaning, drying, and conditioning of grain. They are either of hoppered or flat bottoms. Hoppers with sloping floors are convenient, since all grains flow out by gravity and they are self cleaning. Flat bottoms are cheaper to construct and give slightly more storage space, but cause some delay in loading out, Bailey (1954).

The design and construction of silo according to Stewart and Britton (1973) would need to put into consideration, system capacity, location and orientation, construction materials, techniques of storage and conditioning method.

The major set back of silos in Nigeria as pointed out by Agboola (1985) is condensation and moisture migration as a result of fluctuation in temperature between day and night. This factor alone caused a loss of about 5% (Adesuyi 1976) from rotting and caking of stored grains. High cost of construction material is another set back and according to Halter (1973), an extensive research is needed to attian a more accurate design techniques which may result in some savings in structural cost. The different preservation methods used in silo bin storage are discussed below.

**(i) Aeration:** The major method of grain preservation in silos is by aeration. Burrell (1953) describes the aeration process as consisting of blowing or drawing air through the grain mass usually by means of fans attached to perforated ducts. Ene (1987) recommended that use of convectional metal or plastic silos must be supported by an effective aeration system so as to reduces the risk of damage from insects, mites, and fungi by establishing and maintaining low temperature throughout the bulk. In using the aeration method of preservation, essential factors of consideration have been listed by Burrell (1953) as: biological, with respect to insects, mites, mould growth and germination; physical, with respect to resistance of grain to air flow, air distribution system within the bin, and duct position and spacing; and practical, with respect to sucking or blowing, effect of loading schedule, or duct arrangement, temperature achieved by aeration, moisture changes and frictional loss in air ducts.

**(ii) Air tightness:** Air tightness or hermitic storage is a method often used with the convectional silos for preservation of damp and dry grains. In tropical climates however, Hyde (1969) pointed out that grain should not be more than 13% moisture content (m.c) as there are various hazards in storing damp grains in warm conditions. The principle of preservation in the air-tight storage as explained by Hyde (1973) is that there is depletion of oxygen in the airtight structure to a level which kills or inactivates the harmful organisms like insects or molds, before they become numerous enough to cause serious damage to grain.

Airtight storage in silos are either natural or artificial. In natural airtight storage, removal of oxygen usually results from respiration of the pests themselves. In the artificial airtight storage, an artificial environment is created to produce oxygen-free atmosphere. A typical example of the artificial airtight storage used in Nigeria has been described by Agboola (1985). According to him, the silo is made airtight, filled with crops and the air is purged out from the silo by replacing it with nitrogen - an inert gas. The top of the silo is provided with a thatch roof of palm fronds to reduce the effect of temperature fluctuation, while the silo wall is painted white to reflect sunlight and reduce absorption of the radiant heat. With this kind of grain preservation in silo storage, all insects are killed with 3 - 5 days and grain quality of 100% is obtained after 2 years of storage, Agboola (1985).

**(iii) Chilling:** In this method, grain preservation in the silo is based on the basic principle that at low temperature, insect hazard is seriously reduced. Mites and fungi could also be reduced if chilling is accompanied with low relative humidity. Burrell

(1953) has reported the successful use of grain chillers in warm climate as a means of cooling dry grain to a temperature low enough to prevent grain insects from producing an infestation. The term 'Chilling' as used in grain storage has been defined by Burrell (1953) as being synonymous with 'Refrigeration', which involves the passage of air over refrigerated coil to condition a passing bulk of air to a temperature usually well below ambient before blowing it into a grain bulk. Usually the relative humidity is adjusted to a low level by reheating the cool air slightly with a second warm coil, Burrell (1953). He listed other considerations important for successful storage by chilling as: Moisture content-relative humidity equilibria, mechanics of refrigeration, grain cooling load, and lagging material.

### 2.2.4 Tarpaulin covered stacks

This method of storage is neither traditional nor has it been classified as modern. Its use has been reported by the former West African Stored Product Research Unit (W.A.S.P.R.U), (1961), Hall (1963). The systems were reportedly used in Northern Nigeria, the then Southern Rhodesia and Kenya. The type in each country differed slightly. The type used in Northern Nigeria is popularly referred to as groundnut pyramid with groundnut the major product stored. According to Hall (1963), groundnuts largely for export were stored in pyramid shaped stacks of 11,000 bags, built upon square plinths with concrete block retaining walls filled with rubles and surfaced with sand. Dunnage of bitumen roofing felt are used and the stacks are covered with tarpaulins in the rainy seasons. In Kenya, the use of inflatable plastic known as air warehouse were reportedly used instead of tarpaulin as the covering.

## 2.3 Mud as a Construction Material

Mud has been described as simply a mixture of one or several types of soil with water, Bengtsson and Whitaker (1986). Fletcher and Smoots (1974) described mud as either silt or clay and sand with or without organic material or a mixture of any two of them or more which contains a large amount of water. But as a construction material, its components, method of preparation and use have been described by several researchers and organisations notably Ola (1985), Florek (1985), Jackson (1976), Bengtsson and Whitaker (1986) UNCHS (1986) and others. Based on the summary of their presentation, mud can be defined as a paste derived from a mixture of soil and water in a certain proportion with or without a stabilizing agent. The paste could be casted into a block and sundried giving rise to adobe, or fired in a kiln giving rise to burnt brick. Depending on the type of stabilizer used, the dried casted paste could be referred to as soilcrete, swishcrete, or simply stabilized soil block. In some circumstances, the paste is casted in-situ, like in the construction of rammed earth walls, "pise de terre" walls, and "rumbu walls". The paste is sometimes also used for external rendering like ordinary plasters or dagga plasters.

According to Ola (1985), clay is used extensively as a raw material for the production of building bricks, paving bricks, and structural tiles in manufacturing industries, he also noted that it is good engineering practice to ascertain the suitability of a clay for an intended use by experimentation. It is therefore necessary to know the soil properties, methods of improvement and utilization as they affect the required structural properties of the finally dried mud.

### 2.3.1 Basic Properties of soil

The basic soil properties that are of importance to an Engineer are those that give indications as to the silt/clay fractions, its mouldability and other essential characters needed in the preparation of stabilized soil mud. UNCHS (1986) listed these basic properties as texture, plasticity, compactibility and cohesion. Chemical tests of the soil according to ILO (1987) may also be of importance to determine the amount of organic matter content or to reveal the presence of an unsuspected mineral which might affect the stabilization process.

**(a) Texture:** The grain size distribution of a soil is referred to as its texture. It represents the percentage content of the different grain sizes. The general description or classification of soils according to Jackson (1976) is based mainly on particle size distribution and Atterberg limit tests. In soils of silt sizes and coarser, particle size distribution is the main information required. But for clays, where particle size distribution is both difficult to determine and less informative, the plasticity properties give better information (Jackson,1976). The texture of a soil is determined by particle size analysis which is simply a sieving process to determine the proportion of the rougher grains (Pebbles, gravels, sands and silt) and by sedimentation for the fine clayey materials.

The particle size analysis require the use of four or more sieves. The standard procedure has been described by authors in texts and by organisations in standards and technical memoranda like Smith (1968), Fletcher and Smoots (1974), Jackson (1976), ILO (1987), UNCHS (1986). The simplest method is that described by ILO (1987) and it requires the use of four sieves of different wire mesh sizes (6mm, 2mm, 0.2mm and 0.06mm). A 2Kg sample of sun dried material is weighed out and placed inside the 6mm

sieve located at on top of the nest of sieves. By hand shaking the nest of sieves simultaneously, all the fine particle pass through the respective sieves depending on their fineness. Those finer than the 0.06mm sieve will fall into the catchment tray. The fractions of soil retained on the sieve by weight is classified as shown in Table 2.4.

**Table 2.4 Classification of Soil with respect to Grain Sizes**

| Seize of Sieve Mesh (mm) | Designation of the fraction retained on the sieve (by weight) |
|---|---|
| 6 | Coarse and Medium Gravel |
| 2 | Fine Gravel |
| 0.2 | Coarse and Medium Sand |
| Catchment Tray | Combined Silt and Clay |

Source: ILO (1987)

Sedimentation analysis is required to obtain more information of the soil retained on the catchment tray. Two methods of sedimentation analysis are widely used, the first is the simple sedimentation test described by ILO (1987) and UNCHS (1986) where a wide-necked, straight sided and flat-bottom bottle or jar is filled to one-third height with the soil sample, water is then added until the bottle is two-third full. Two teaspoons of salt are added to aid soil dissolution. The bottle or jar is closed, shaken vigorously for about 3 minutes and allowed to settle for one hour. It is re-shaken again for a further two minutes and allowed to settle for at least 8 hours. Two to three distinct layers should be observed, a lower layer of fine gravel, a middle layer of sand fraction and a top layer of combined silt and clay fractions. The thickness of each layer as a percentage of the total height of the soil sample is recorded as result. This test gives a lower figure according to Bengtsson and Whitaker (1986) than the second or laboratory method because of some silt and clay trapped in the sand. The main disadvantage of this method is that silt and clay fractions cannot be

determined separately, and since silt behaves differently from clay, the result obtained could be misleading, Bengtsson and Whitaker (1986).

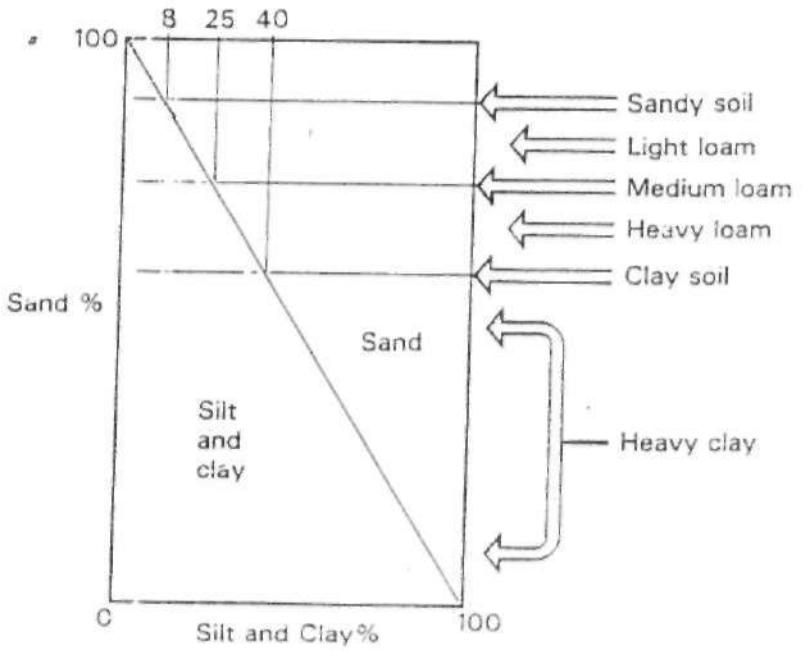
The procedure for the laboratory hydrometer analysis is described in standard texts, Smith (1968), Fletcher and Smoots (1974). It consists of using 50g of soil sample passing 2mm sieve. The sample is placed in a 250 ml beaker and 125 ml of deflocculant added to it. The beaker is then covered and allowed to stand for 2 hours. The classification of the soil grains in this method is more detailed and normally based on American Standards for testing Materials (ASTM) or the British Standards (BS) as shown in Table 2.5.

**Table 2.5 Soil Classification with respect to Grain Size.**

| Class | Designation | Size Range (mm) |
|---|---|---|
| V | Pebble | 200 - 20 |
| V | Gravel | 20 - 2 |
| IV | Coarse Sand | 2 - 0.2 |
| III | Fine Sand | 0.2 - 0.06 |
| II | Silts | 0.06 - 0.02 |
| II^A | Fine Silts | 0.02 - 0.002 |
| I | Clays | 0.002 - 0.00 |

Source: ILO (1987)

The importance of soil classification is that an indication as to the type of stabilization suitable for the soil could be known. Makoju and Srivastava (1985) recommended that in a particle size classification triangle, soils most suitable for lime and cement stabilization are those in the shaded portion shown in Figure 2.8. ILO (1987) recommended that for soils of low silt/clay content (less than 20%), four to six percent of cement stabilization is needed, while for those with high silt/clay content (above 30%), six to eight percent lime stabilization is more suitable.



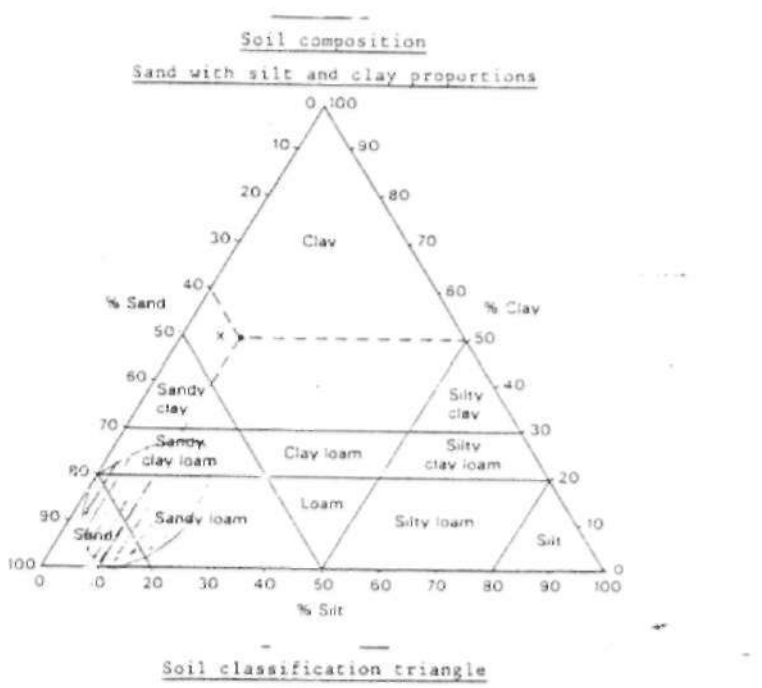




Figure 2.8 Soil Classification Triangle

(Shaded Area represents soil most suitable for lime, or cement stabilization). Source: Makoju (1985)

**(b) Plasticity:** Plasticity refers to the property of a soil that makes it submit to deformation without elastic failure characterised by cracking or disintegration. The plasticity of soil as well as the Atterberg limits of consistency according to Smith (1958) are determined using the "fine mortar" size of the soil (diameter of soil grains less than 0.4mm). The procedure for determining these limits as described in standard texts, Smith (1968), Fletcher and Smoots (1974) etc. is to use sample of soil with particles passing the BS 36 sieve equivalent to the US 40 sieve (0.46mm). Liquid limit (LL) which is the soil moisture content that corresponds to the limit of transition between the state of fluid consistency and plastic consistency is determined by mixing the sieved soil into a paste using a little amount of water. The paste is then placed in a standard brass dish and levelled off to get about 10mm thick paste at the centre of the bowl. The paste is then divided into two halves using a grooving tool 11mm wide at the face and 22mm wide at the bottom. The dish with the paste is then subjected to blows by allowing it to repeatedly drop on a flat surface from a height of 5mm. The number of blows needed to bring the 2mm created groove to close is recorded, the corresponding moisture content is also determined. This process is repeated by mixing the paste with a little more water at each time, recording the number of blows and moisture content. A graph of moisture content versus number of blows is drawn and the moisture content corresponding to 25 blows is taken as the liquid limit.

The plastic limit (PL) which is the moisture content of the transition between the plastic and solid state is determined by rolling the soil paste used above into a thread of approximately 3.2mm diameter. The moisture content at which the thread crumbles when rolled to this thickness is measured and termed plastic limit.

At liquid limit, the soil starts to manifest a certain resistance to shearing until it stops being plastic at PL when it becomes brittle. The range of this plastic behaviour (LL - PL) is known as the plasticity index (PI). The combination of LL and PL according to UNCHS (1986) specifies the sensitivity of the soil to variations in humidity and gives an indication of a moisture range over which mud paste could be prepared.

**(c) Compactibility:** The ability of a soil to be compacted to a higher density is known as compactibility. For a given compacting energy, the moisture content for which the compacted soil will give a maximum dry density is referred to as optimum moisture content (O.M.C). Therefore too low or high soil moisture content will result in poor compaction which is synonymous with low density, and as explained by ILO (1986), this is because the individual soil particle cannot come into close contact with one another, thus allowing the presence of some air spaces between them. ILO (1986) also explained that high moisture content results in greater flow of particles when pressure is applied, with particles being separated by a film of moisture.

The value of O.M.C and density according to Lunt (1980) is a function of the soil type, quantity and type of stabilizing agent used and method of compaction utilized. Compaction methods as explained by Fletcher and Smoots (1974) are based on either dynamic or static compaction. The three basic methods of determining O.M.C are based on dynamic compactions, these are: the drop tests, the standard proctor and the modified proctor.

The drop test method of determining O.M.C is on approximate method used at site. The procedure as described by ILO (1986) is to take a handful of the soil mix, hand-squeeze into a ball and then dropped onto a hard surface from a height of about one metre. Shattering of the sample indicates a value of M.C below O.M.C, squashing of the sample into a flattened mass indicates a value of M.C above O.M.C, while breakage of the sample into four or five lumps is an indication of approximate optimum moisture content (O.M.C).

The standard proctor as described by Fletcher and Smoots (1974) is carried out by compacting soil sample mix in a 105mm diameter cylindrical mould with a 2.5kg rammer having a 50mm diameter head falling freely from a height 300mm above the top of the soil. Compaction is effected in 3 layers, each layer being given 27 blows. After the 3 layers of compaction, excess soil is removed using a sharp knife and both the compacted weight of soil and corresponding moisture content are measured. The soil sample is then removed from the mould remixed with a further quantity of water (about 2%) and the procedure of compaction, weighing and moisture content determination repeated. This process of increasing moisture content and weighing is continued until weight of the compacted soil starts to drop. A graph of moisture content versus density is then plotted to obtain the O.M.C.

The modified proctor method is similar to the standard proctor method except that compaction is by a rammer of 4.5kg mass falling freely from a height of 450mm with compaction done in five layers, Smith (1968). Fletcher and Smoots (1974) pointed out that while the standard proctor simulates the compacting process of small compaction rollers, the modified proctor simulates the compaction process common with heavy vibrated rollers.

**(d) Cohesion:** The cohesion of a soil is an expression of the capacity of its grains to remain together when a tensile stress is imposed. According to UNCHS (1986), this property of cohesion is as a result of the adhesive or cementatious nature of its coarse mortar which binds the inert grains together and that this coarse mortar may be grouped into five as follows:

A : Sandy mortar
B : Lean mortar
C : Average mortar
D : Fat mortar
E : Clays

### 2.3.2 Improvement Methods on Mud Materials

Mud is improved basically by process of stabilization which according to UNCHS (1986) is the modification of the properties of a soil-water-air system in order to obtain lasting properties which are compatible with a particular use or application. Stabilization, therefore, is directed at the texture and structure of the soil with the following objects:

(a) Reducing porosity by reducing the volume of interstitial voids.

(b) Reducing permeability by filling voids which can not be eliminated.

(c) Increasing the mechanical strength (compressive and shearing) by improving bonding between the grains.

According to Ola (1980), UNCHS (1986) and others, there are three basic forms of stabilization. These are:

(a) Physical stabilization

(b) Mechanical stabilization

(c) Chemical stabilization

Each of these method can be applied singularly or in combinations as explained by UNCHS (1986). Stabilization can complicate both production process and increase cost by about 30 to 50%, therefore it should only be considered when material is severely exposed or when there is a strong need to increase soil compressive strength and bulk density, UNCHS (1986).

**(a) Physical Stabilization:** In physical stabilization, a stabilizing agent in form of a foreign material is introduced into the soil to give it new structural qualities. Example of physical stabilizers of practical importance are fibres and bitumen. Other stabilizers that are not of practical importance either because of cost or unavailability in desirable quantity are vegetable oil, fats, ashes, and termite hills.

**(i) Fibre:** According to Ejeh (1989), fibres used as soil stabilizers are of three types, namely: plant fibre in form of grasses and straw, animal fibre in form of livestock fur or hair, and synthetic fibres in form of cellophane, steel and glass wool threads. Akinmusuru and Adebayo (1981) explained that fibres by their nature when introduced in a mud result in a fibre-reinforced matrix which possesses high degree of resistance to cracking and crack propagation. They explained that when a cylindrical earth mass is sheared under triaxial system of stresses, failure takes place along a plane inclined at an angle of $(45 + \phi/2))$, where $\phi$ is the angle of internal friction of the soil. The placement of fibre across this potential failure plane therefore prevents shear at the stress level with a degree of resistance proportional to the tensile strength of the fibre. According to UNCHS (1986), fibres hinder cracking upon drying by taking upon itself the tension arising from the shrinkage of

the clay, thus increasing the tensile strength which is the most important property. Fibre also lighten the material reducing the bulk density thereby improving the insulating properties. UNCHS (1986) puts densities of fibre to vary between 20 and 30kg /$m^3$ and recommends a minimum amount of 4% by volume (which is equivalent to 0.6% to 0.9% by weight for a soil of 1400kg/$m^3$ bulk density) for satisfactory result. For rice straw fibres FAO (1982) puts the mean breaking strength at 7.6kg for a single straw of rice and 17.0kg for a single straw of wheat. Akinmusuru and Adebayo (1981) put the tensile strength of "Okun gambari" fibre (a plant fibre found in Western Nigeria having an approximate cross sectional area of (0.5mm x 3mm) as 50N/$mm^2$ (this is equivalent to a breaking strength of 33.16kg). The advantage of fibre reinforced matrix is most noted according to Ibrahim (1989) beyond failure when the matrix has cracked, but still stay together because of the fibres yet to break. In practice UNCHS (1986) noted that fibre reinforced bricks stay in one piece beyond failure point as compared to the non-reinforced which crack and fall into scatter.

Not much has been done in determining strength properties of physically stabilized soil. Akinmusuru and Adebayo (1981) have established that 20% fibre (okun gambari) stabilization result in an optimum compressive strength of 1.0N/$mm^2$ after air curing at 25% for 2 days. It has also been generally established that fibre stabilization can increase compressive strength by about 15% ( UNCHS, 1986).

**(ii) Bitumen:** Bitumen is usually dark brown or black and in general durable, resistive to water vapour and many chemicals. Bitumen is used either in heated

form, or mixed with solvents resulting in "cut-back" or dispersed in water as an emulsion. Cut-backs" are bitumen to which a volatile solvent has been added, making them less viscous. The solvents can be gasoline, kerosine, and naphtha. Some of the `cut backs' dry slowly, some moderately quickly, while others dry rapidly. They cannot be used in the rain and are flammable UNHS (1986). Emulsion on the other hand is bitumen (55 to 60%) dispersed in water with the help of emulsifying agent (1 to 2%). This agent also keeps the bitumen in suspension. Emulsion is always very fluid and mix easily with soil which is already moist. They are less stable than cutbacks and there is a danger of the water and bitumen bond breaking down (separation).

Bitumen when used in stabilizing soil improves its weather-resisting properties. It has also been established that there is improvement in the cohesive properties ofnon cohesive soils stabilized with bitumen ILO (1987). However, for cohesive soils or high clay soils, uneconomically large amount of bitumen is needed to obtain satisfactory result. Another disadvantage of bitumen as noted by ILO (1987) is its susceptibility to break down when subjected to high temperature like those present in the tropics. ILO (1987) recommends 2 to 3% bitumen stabilization for sandy or silty soils.

**(b) Mechanical Stabilization:** Mechanical stabilization is achieved basically by soil compaction resulting in changes in soil density, mechanical strength, compressibility, permeability and porosity UNCHS (1986). ILO (1987) explains that in mechanical stabilization, the soil is mechanically manipulated, so that maximum air is eliminated by

kneading and compressing the soil. This means that soil grains are only redistributed without any change in grain size distribution.

Methods of achieving soil compaction include the use of foot for treading and hand tamping equipments with compacting pressures varying between 0.05 to 4 N/mm$^2$. For effective compaction, UNHS (1986) recommends that the soil should be semi-solid or solid paste. The procedures and processes are discussed in section 2.3.3.

Effects of mechanical stabilization on level of improvement of soil have been studied and findings have been made available. Fritzmaurice (1958) shows that dry compressive strength increase with dry density. He also noted that dry density increases with compaction pressure and that the rate of increase is highest for an optimum moisture content. Ola (1985) showed that there is a consistent increase in strength with increase in compaction pressure from 1 to 6 N/mm$^2$ and that this result in strength improvement depending on soil type, but always higher than 300% for compaction pressure of about 6 N/mm$^2$.

The findings of Florek and Ezetah (1985) also show that compressive strength increases with both curing age and compaction pressure. Ola (1985) noted that tensile strength obtained for compaction pressures lower than 0.4 N/mm$^2$ were insignificant and recommended compaction pressures of between 6 to 8 N/mm$^2$ for most economic benefits.

**(c) Chemical Stabilization:** In chemical stabilization, materials used have a physio-chemical effect on the soil, resulting in a matrix of binded grains. Examples of chemical stabilizers are Portland cement, lime and electrolyte solutions of sodium silicate salts. In practice however, only cement and lime are used as explained by UNCHS (1986).

**(i) Cement:** Portland cement has always been preferred for soil stabilization, but due to its scarcity in some countries (and its cost in others), and the fact that Portland cement cannot be used to stabilize certain categories of soils combined with the possibility of local and small manufacture of hydrated lime, has madelime more acceptable and enhanced in Africa (Ola, 1977).

The *quantity of cement needed for stabilization to obtain a good result has* been put at between 6 to 12% (by weight) by UNCHS (1986). Exact quantity depends on grain size distribution, soil structure and method of application. Ola (1985) noted that strength and durability are increased with increase of both cement and compaction pressure. Ola (1985), UNCHS (1986) recommended a minimum curing period of 14 days in a moist environment.

**(ii) Lime:** Lime according to UNCHS (1986), are of three types: non-hydraulic lime, hydraulic lime and agricultural lime. Non hydraulic limes are produced by burning very pure limestones in kilns. This results in quicklime (ca O) which is a caustic material that must be handled with great care as it becomes hot during hydration (150°C). To avoid this draw back, quick lime is normally hydrated to obtain slaked lime (caOH), which is much safer to use. Hydraulic lime on the other

hand is either artificially produced or found naturally. While artificial lime is similar and as costly as cement, natural hydraulic limes (XHN) are cheaper and more efficient than artificial stabilizers ( UNCHS, 1986). Five basic mechanisms according to ILO(1987) are involved in lime stabilization process, and these are:

(i) Water absorption in which quicklime undergoes hydration.

(ii) Cation exchange which gives the clay a lower affinity for water.

(iii) Flocculation and agglomeration due to the cation exchange above resulting in the formation of clusters of macroscopically small particles which makes the mix more viscous.

(iv) Carbonation of the lime itself as it reacts with carbon dioxide ($co_2$) from air giving rise to a hardening effect.

(v) A pozzolanic reaction. This is a chemical reaction of lime and clay yielding hydrated calcium silicate aluminate compound similar to those of Portland cement.

The first three reaction mechanisms are immediate while the last two are slower, causing strength development of lime stabilized soils to take weeks, or months and sometimes years afterwards ILO (1987).

Suitability of soils for lime stabilization depends on some factors. ILO (1987) points out that for a given shrinkage, cement to soil ratio is a function of compacting pressure and that for shrinkage of 25mm or more, lime stabilization is better. Thompson (1966) listed organic matter, clay content, clay mineralogy and chemical properties as factors that affect lime stabilization. UNCHS (1986) presents

that lime has only very limited effect on soils with high organic matter content (above 20%) and soils short of clay and that lime is more effective than cement for clay-sand and very clayey soils.

Researches carried out showed that lime has a positive effect on soil strength. Osman and Muhammed (1987) found that local laterite of sudan origin stabilized with 6 to 8% lime and compacted with locally produced mechanical press attained a dry compressive strength of 3.4 to 4.8 N/mm$^2$ at 10 to 20% m.c. Hashim (1992) found that 9% lime stabilization of a soil with 40% clay content resulted in a compressive strength of 4.6 N/mm$^2$ representing a 71.8% increase over a non stabilized clay soil. Durability he noticed is also considerably improved.

### 2.3.3 Mud Preparation, Usage and Constructional Practices

The knowledge of soil properties, methods of improving their quality are important to achieve a stronger and more durable material. The trouble taken in careful soil study and stabilization selection will not be worth while if the material in the final end is not well prepared and utilized functionally with good constructional practice. This section reviews reported methods of mud preparation, utilization and constructional practices.

**(a) Mud preparation:** In summary of various reports, UNCHS (1986), ILO (1987), Singh and Dirisu (1985) etc, mud preparation procedure can be outlined in five steps:

(i) Excavation of the earth

(ii) Selection of suitable stabilizer and proportion

(iii) Pugging and mixing of the soil, stabilizer and water

(iv) Casting (precast or insitu)

(v) Curing.

(i) **Excavation of the earth**: For small scale production, Singh and Dirisu (1985) have reported that soil is dug manually from places close to water ponds. UNCHS (1986) reported that excavation is normally done dry and sometimes wet, but that excavation sites are often water logged. Bengtsson and Whitaker (1986) advice that excavated soils should be rid of large particles and lumps by sieving with 10mm screen. For small-scale, on-site manufacture of stabilized soil building blocks, a minimum of 700 tonnes of soil is needed per year and trial holes must be dug prior to excavation to estimate quantity and suitability of soil ILO(1987). Soil profile of the area is normally obtained by digging test holes of about 15cm diameter at a depth of 2 to 3 meters.

**(ii) Stabilizer selection and proportion:** In local preparation of mud, Singh and Dirisu (1985) stated that grasses are used as the main stabilizer with quality depending on experience. FAO (1983) reports that in China, rice straw with an average mean breaking strength of 1kg per straw is used as one of the main local stabilizers. For modern stabilized soils, lime is selected for clayey soils, and cement for sandy and lateritic soils.

(iii) **Pugging**: Method of mixing depends on the size of mix and level of available technology. Local practice as reported by Singh and Dirisu (1985) involve the use of foots to trample the mud paste until the grass stabilizer is well incorporated. In

modern practice, UNCHS (1986) reported that mixing is done mechanically using such machines as the vertical mixer, rendering mixer, linear mixer, screw mixer and planet wheel mixers. Concrete mixer is poorly rated but sometimes used. FAO (1983) reported that in China, mud is pugged by first pruning the straw, levelling it at the root ends and dividing into two halves. The two halves are then turned in opposite direction and placed together to maintain a uniform size from the root section of the first half to that of the second. The straw bundle is finally spread flat out and soaked in the clay mud. This kind of mud is referred to as clay/straw bundle. It has a length of about 80 to 100cm tapered at both ends. The ideal proportion for this kind of clay/straw has been put at 1:7 straw/clay on dry weight basis. FAO (1983), Bengtsson and Whitaker (1986).

**(iv) Casting:** According to Singh and Dirisu (1985) mud in most cases is precasted in block form, dried and used as bricks with mud mortar. Giles (1964) reported the use of mud as in-situ casting in the construction of special structures like "rumbu" ILO (1987) has also reported the use of mud as in-situ casting in the construction of rammed earth wall and the mud is casted in-situ by ramming it in the formwork with heavy rammers.

**(v) Curing:** Depending on type of stabilizer utilized, curing could be by hydration or dry air. For cement stabilized soils, UNCHS (1986) recommended a 14 days curing under a temperature of about $32^{0}$ C and a high relative humidity by using plastic sheet as a cover under the sun. Ola and Awoleye (1985) cured cement stabilized mud by sprinkling water on the blocks for seven days. Florek and Ejeh

(1985) recommended that for cement stabilized soil, there should be an initial curing, for seven days during which time, water is sprayed every morning and evening on the casted blocks and then covered with a cellophane sheet. This should then be followed by a second curing for about 21 days during which the blocks are allowed to dry under a room condition. Akinmusuru and Adebayo (1981) noted that for straw stabilized blocks, curing by sprinkling or soaking in water will result in crumbling of the blocks. They further noted that curing by covering with cellophane sheet will be unsatisfactory as it will result in increased block moisture content, they therefore recommend air drying at ambient temperature of about 25°C for at least 8 days. Sun drying of adobe for 2 days as a means of curing during the hot dry season has been reported as the local practice Singh and Dirisu (1985).

**(b) Usage and Constructional Practices:** Apart from road construction, major utilization of mud has been with respect to domestic building walls and in some cases, roofs and grain storage buildings. Domestic building walls are in most cases not load bearing, and when they are, they basically carry compressive load. This has therefore made researchers to focus attention on dry compressive strength most of the time. Florek and Ejeh (1985). When mud is used for domestic walls, it is most of the time in form of precast blocks or balls, Mele (1989). However when mud is used for roof or storage walls, it is most of the time in form of in-situ casting.

### 2.3.4 Structural Properties of Mud

Like concrete, mud has a fresh and dry state and as a material mixed from different constituents, mud can be likened to concrete , therefore most of the testing methods for

concrete have been adopted for stabilized soils as evident in the work of Florek and Ejeh (1985), Ola (1985), Akinmusuru and Adebayo (1981); Hashim (1992) and others. The important properties of mud in its fresh state is consistency, and during its drying state it is shrinkage, when it becomes dry hardened, the important properties are hardiness, strength and durability .

**(a) Consistency:** This is an indication of pastiness and paste uniformity with regards to aggregates, stabilizer and water. For cement stabilized soils, mixture of the soil and cement into paste is carried out at optimum moisture content with emphasis normally placed on thorough mixing, but so far no standard method has been described or presented for determining constitency. For cement concrete however, standard methods like the slump test, the Vee Bee consistometer test and the compactor factor test are used to determine the workability which is a reflection of consistency.

For grass stabilized soil, a lot of factors affect the required amount of water to be used in mixing the constituents into paste. This factors include, stabilizer type, mixing method and use of the mud. There is therefore the necessity to control the consistency of mix from one batch to another as in concrete. The only method available is that developed and described by FAO (1983 ) for China clay/straw mud. The method uses an apparatus known as a consistometer. The consistometer consists of a 15cm cube container for holding the fresh mud on to which a graduated scale is attached from where a penetrating cone (7.5cm diameter, 15cm side length) hangs. By releasing the penetrating cone, after being brought to rest at the top of the paste, penetration due to the cone is measured and termed consistency.

**(b)Shrinkage**: Apart from shrinkage tests reviewed in section 2.3.1 which are applicable to soils, no other methods are known to be used for constituted mud.

**(c) Dry compressive strength**: This is important as it gives an indication on the amount of load the material can withstand when subjected to compression load such as lintels, roof, and roof beams.

Field and laboratoty methods used in determining dry compressive strength of mud are similar to those specified for concrete and sandcrete blocks as evident in the work of Florek and Ejeh (1985), ILO (1987), Hashim (1992). The popular laboratory method is to cast the material in a cube form at a specified compaction, have it cured and dried for a specified period. Compression load is then applied on the cube surface covered with platens using a hydraulic machine that has a controllable rate of loading. The crushing or failure load is determined and used to calculate the compressive strength, which is the failure load per unit area of the loaded surface. The type of platen used has effect on the evenness of load distribution during the compressive test as shown by Ejeh (1983) who recommended a cellotex platen for soilcrete samples instead of the normal steel platens.The compression pressure also affect the compressive strength as shown in Figure 2.9. Sometimes precast blocks of the material are used instead of cast cubes. ILO (1987) recommend that in using hydraulic compression testing machine for crushing, load must be applied without shock and at a rate that will result in the crushing of the cube within 0-5 to 1.5 minutes which approximates to about 0.5 to 5.0 $N/mm^2$ for stabilized soil blocks with expected crushing strength less than $7N/mm^2$ and between 1.0 to $10.0N/mm^2$ for cubes with expected crushing strength above $7N/mm^2$.

Only ILO (1987) suggested a method for testing compressive strength of stabilized soil blocks at site. The method suggested involve crushing 50mm cube casts with a special site compression machined constructed of wood as shown in Figure 2.9. The basic portion of the machine is a timber lever with a leverage length of 1676mm. The 50mm cube cast is placed 85mm away from the hinge and a load consisting of soil in a bucket is applied at the end of the lever and increased with additional soil until the cube fails. The crushing force is determine from the following equation and used to calculate the compressive strength.

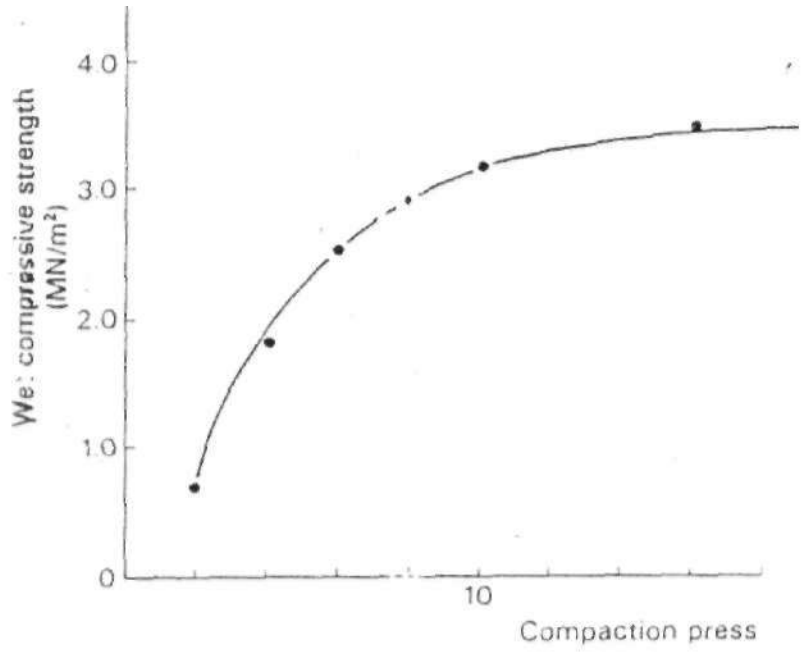
$$W = [\text{Crushing force (kg)} \times 85 - (5 \times 838)] / [1{,}676]$$

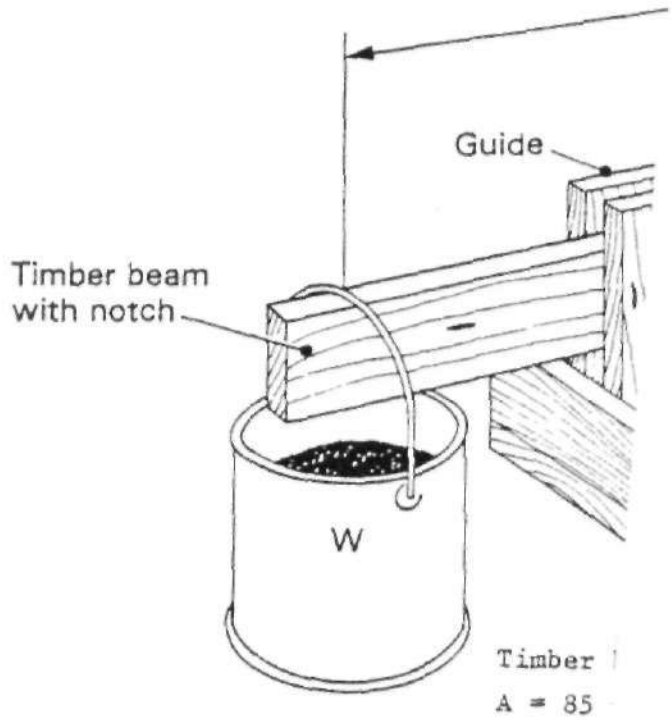
where

W = Weight of bucket or hanger and its content (i.e. crushing weight)

The federal ministry of works specifies a minimum compressive strength of 2.8N/mm$^2$ for precast concrete. For most countries blocks with a dry compressive strength of 2.1N/mm$^2$ or greater are acceptable for domestic building purposes. ILO (1987).

**(d) Dry tensile strength**: Tensile strength of a material is most important when the material is supporting pressure load in a plate or shell form. Very few work has been carried out with respect to determining tensile strength of either concrete or stabilized soils. This is because they are more often used as compression and flexural members in forms of columns, beams and slabs rather than tensile members in form of shells and plates. MWPS (1976) stated that concrete is best used where it is in compression but its tension strength is also significant in some situations. BS 1881, part 4 recommends the split-cylinder test as an indirect method for determining the tensile strength of a concrete material. MWPS (1976) has discussed that true tensile strengths are hard to determine and that flexural




Timber
A = 85
L = 1,67
W = Wei

Figure 2.9 Effect of Compaction Press
and site Compression Testing M

tension properties have been measured in terms of modulus of rupture by breaking unreinforced beams in flexure and according to them a better method for determining axial tension is the split-cylinder test. In this method a cylinder is casted, cured and placed axially in between platens (packing strips) on a hydraulic compression testing machine. Load is then applied at a rate of 1.5N/mm$^2$ per minute until the cylinder splits. The failure load (p) is then used to calculate the tensile strength ($\sigma_t$) as follows:

$$\sigma_t = [2p] / [\pi dL]$$

where

d = diameter of cylinder cast (mm)

L = length of cylinder cast (mm)

P = splitting or failure load (N)

Ibrahim (1989) simulated a direct method that employs a hollow cylinder cast loaded with flowable non-compactible soil grains in form of gravels or sand. Load is then applied simultaneously from top and bottom on the soil grains with the aid of disc plugs. This is expected to be transformed into pressure acting internally on the walls of the hollow cylinder. To allow approximate pressure distribution, the inside surface of the hollow cylinder is made very smooth to reduce surface friction, while the disc plugs are allowed to have free vertical displacement. The failure load is then converted into appropriate pressure enabling the calculation of the tensile strength. Ibrahim's method attempt to simulate the real case of loading grains or fluid in a cylindrical tank. The result obtained from this method has been shown by Ibrahim (1989) to be closest to exact than other methods. For design purposes, the tensile strength of concrete is normally assumed to be 0.5 to 0.7 of the measured tensile strength, as reported by Raynolds and Steedmen (1989).

**(e) Durability**: Long term durability of stabilized soil with respect to its resistance to weather like rain and abrasive action of wind borne sand is important. Methods recommended for determining durability of stabilized soils, assume that stabilization is by lime or cement. ILO (1987) described two such methods, the water-spray test and the abrasive wear test. In the water spray test, water is sprayed continously for 2 hours from a 100mm diameter spray head under a pressure of 1.5 kg/cm$^2$ onto a cured stabilized block placed 200mm from and parallel to the face of the spray head. The block is then examined for erosion and pitting and classified as durable if the pitting or erosion is slight, otherwise it is regarded as non durable.

The abrasive wear test is designed to simulate the abrasive effect of wind-borne sand. This involve brushing a casted block with a specified brush (wire brush, or nylon brush heads) for a number of strokes and studying the destruction caused. Hashimu (1992) described this method in detail.

**(f) Water Absorption**: For buildings constructed with stabilized soil , the amount of water absorbed per unit time is important, as water absorption lead to weight increase and material weakening. Two methods used are the 3mm immersion and the complete immersion test. Ola (1985) described both methods.

In the 3mm immersion test, specimens are placed on suitable carriers, weighed and put on a perforated plate in a second metal tank in which water is maintained at a level of 3mm above the bottom of the specimen. The weight of water absorbed in gramme by the brick in 1 minute is determined by weighing. Since bricks are of varying dimensions, the

value thus obtained is corrected mathematically to give IRA (Initial Rate of Absorption) in terms of a standard bedding surface area of contact, taken as 193.55sq.cm (30 sq in). Therefore, the IRA of a brick is expressed as the number of grams of water absorbed in 1 minute on 193.55sq.cm. area. Similarly, the weight of water absorbed in gramme is then determined at intervals of 1,3,7,14 and 28 days by finding the increase in weight of specimens.

In the complete immersion test, specimens are first dried to a constant weight at 100°C, cooled to room temperature and then immersed completely in water at room temperature for 24 hours. The bricks are then removed from the water, the surface water wiped off with a damp cloth and weighed to find the quantity of water absorbed.

## 2.4 Types of Grain Storage Systems

According to Eaton (1980), while grain storage structures are normally classified into types with respect to the technological method of preservation, they are sometimes classified into different types of grain storage system with regards duration and purpose of storage. The type of system required will normally determine type of grain storage structure appropriate. There has been however no standard form of classification of different systems of grain storage but from the presentation of several authors' on this subjects, the following classification can be derived.

(a) Temporary storage systems

(b) Seed storage systems and

(c) Reserve stock storage system

**2.4.1 Temporary Storage Systems**: These are systems where grains are held for temporary purposes, examples of these as mentioned by Bailey (1974), Halter (1973) and Agboola (1986) are : on-farm storage, drying storage, elevators of different types for transportation, collection point storage and consumer storage. In temporary storage systems, the structures required could be sophisticated like elevators used for transportation and collection point storage. They could also be simple like the on-farm, drying and consumer storage.

**2.4.2 Seed Storage System**: Seed storage is more complicated than other grain storages as not only the safety of the grain is required, but more important is its viability. Seed storages like the temporary storage is in most cases for a duration of one year or less.

**2.4.3 Reserve Stock Storage**: Most of the grain storages normally embarked on, is the grain reserve storage. According to Eaton (1980), there are four basic types namely:

(a) The working stock,

(b) The Buffer stock,

(c) The food aid reserve and

(d) The Emergency reserve.

**(a) Working stock reserve**: This represents a market reserve in which grain is stored for gradual use over the remainder of the growing cycle.

**(b) Buffer stock reserve**: This represents a system whereby a stock of grain is held from years of excellent harvest for use in other years plagued by poor production. This is the typed of reserve deviced by Prophet of Allah Yusuf (the bibilical Joseph)-[May the peace

of Allah the most High be upon him], as a result of his interpretation to Pharaoh's dream. According Allah in the Qur'an Prophet Yusuf reserved a portion of seven years of excellent harvest and later used it during the seven years of famine that followed. According to Eaton (1980) the actual amount reserved by Prophet Joseph was one-fifth of each years harvest. But Li k'o a Minister Wei (who lived in China in the 12th century BC), created a reserve that combined the idea of working stock and the buffer stock reserve. As presented by Eaton (1980), Li k'o's policy was to keep price of grain low enough so it would not hurt consumers and high enough not to impoverish farmers. This means that he had to create a working stock reserve to stabilize prices within the year and to further create a buffer stock reserve to stabilize prices from year to year.

**(c) Food aid reserve :** This is a type of reserve where stock grain is set aside at anytime (even during a year of productive shortfall) for distribution to domestic or foreign persons defined as needy. Examples of such needy persons could be rehabilitation centres, poor countries etc.

**(d) Emergency reserve:** This is a system that creates a stock to be used in despatch to a site of natural disaster or civil disorder.

As pointed out by Eaton (1980), these four reserve varieties can be distinguished by the certainty of demand, rate of stock turnover, and their function, as shown in the table 2.

**Table 2. Types of Reserve Stock Storage System**

| S/No | Reserve Type | Demand Certainty | Rate of Reseve Turnover | Social Stabilization |
|---|---|---|---|---|
| 1 | Working Stock | Relatively certain | Disposed off within one year | Intra-year Stabililization. |
| 2 | Buffer Stock | Uncertain | Build-up and, release rules set time of storage | Intra-year Stabilization |
| 3 | Food Aid Reserve | Relativerly Uncertain | Determined by need of target group | Political leverage or humanitarian use. |
| 4 | Emergency Reserve | Uncertain | Depends upon what is defined as emergency | „ |

Source: Eaton (1980)

**2.4.4 Effect of Storage Systems on Storage Structures:** As can be observed from sections 2.4.1 and 2.4.2, both seed storage and drying storage require very special structures and continuous attention . Reserve storage however require simpler structures that would need little attention during its probable long duration of storage.

Grain reserve can be at domestic level, on-farm, collection point, processing plant, local government state and federal government level. Each of this level will necessitate an appropriate structure that may not be suitable for other levels. Depending on the type of reserve, storage structures may also have to differ. The working stock reserve dictates that storage structures must be of the type that allows for easy off loading of the contents. Since the major aim of this type of grain reserve is that of price stabilization, the state and local

government are more likely to be involved implying that structures could be gigantic. Since duration of this type of reserve is normally for one year or less, aerated silos or partially fumigated warehouses would be more appropriate than hermitic, inert atmosphere or chilled storage structures.

The buffer stock reserve is normally for a long duration (between two to sometimes over seven years). All levels from domestic to federal government (except collection points and processing plants) are involved in this type of reserve. Therefore while a very large inert atmosphere structure could be appropriate for a federal government, it would be economically and technically unsound as an on-farm, village, or domestic level. It is also a known fact that total cumulative domestic and village storage could far out weigh gigantic but few government storages. The need to develop appropriate structures for each type of storers is therefore important.

## 2.5 Performance Evaluation of Grain storage Structures

Stewart and Briton (1973) have classified performance evaluation of storage structures into structural evaluation and function evaluation and we shall follow this classification in reviewing existing methods of evaluating perfomance of storage structure.

### 2.5.1 Structural Assesment and Evaluation

Structural evaluation is directed at assessing level of stability of the physical structure when subjected to maximum designed load capacity. The aim of any structural evaluation is therefore to assess the efficiency of the structural design. Codes of structural practices like the British standards on structural steel (BS449) and the code of practice on reinforced

concrete structures (BS8110) have presented objects of structural design which can be summarised as follows:

That the basis of design is to achieve a structure using a proper design method that puts into consideration, durability, workmanship and materials with an aim that such structure shall have an acceptable degree of probability of performing satisfactorily during the intended life.

The process of structural design is normally in five stages:

(i) Load determination which include, self, imposed and sometimes wind load.

(ii) Material selection for the structural members.

(iii) Structural analysis to determine forces and moments in the structural members as a result of loads exerted on the structures.

(iv) Proportioning and sizing process to achieve a structure capable of withstanding the existing internal forces and moments.

(v) Checking to ensure that deflection as a result of the sizing is acceptable.

**(a) Structural Analysis of Grain Storage Bin:** The major problem in structural design of silos is to predict, with reasonable accuracy, loads (pressures, internal forces), that structures will be required to withstand during their service life (Gumbe1988). Several methods have been proposed for predicting the pressures in storage bins as documented by Gumbe (1988), but the appropriate method to be used will depend on factors like :

(i) - Bin configuration

(ii) - Type of product to be stored

(iii) - Type of pressure expected.

**(i) Bin configuration** : Based on configuration storage, bins can be classified as either shallow or deep. According to Stewart and Britton (1973), a shallow bin is one which has a depth less than the least lateral dimension of the bin, other wise it is considered a deep bin. Large percentage of farm storage bins according to Stewart and Briton (1973) are shallow while country elevators and terminal storage bins are of deep configurations. Stewart and Britton (1973) noticed that even though several theories have been developed to predict pressures in shallow bins, the Rankine theory is the most widely accepted in bin design. Reynolds and Steedman (1989) presents that shallow bins behave like a retaining wall and recommended the Rankine formula for analysing them.

**Rankine Equation for Shallow Bins:**

$$q_n = K_2 D h \quad \text{.....(2.20)}$$

Where

$q_n$ = pressure per unit area at depth h ($KN/m^3$)

$K_2 = (1 - \sin\theta)/(1 + \sin\theta)$

$\theta$ = angle of internal friction (or angle of repose)

D = unit weight of stored product ($KN/m^3$)

The Rankine equation is based on the assumptions that:

(1) - Pressure is caused by a sliding wedge of grain,

(2) - There is no surcharge

(3) - Their is no active frictional force between the stored grain and bin wall.

For deep configuration, Reynolds and Steedman (1989), Stewart and Britton (1973) recommends the use of Janssen's equation for computing bin static pressures.

**Janssen's Equation for Deep Bins:**

$$q_h = Dr/\tan\mu\,(1 - e^{-hK\tan\mu/r}) \quad \text{.....(2.21)}$$

Where

q = intensity of lateral (horizontal) pressure at depth h = Kq (KN/m2)

D = unit weight of stored product (KN/m2)

r = hydraulic radius = (plan area of container)/(plan perimeter on container)

$\mu$ = angle of friction between contained material and bin wall.

h = depth of grain to point under consideration (m)

K = $q_h/qr$

$q_v$ = intensity of vertical pressure at depth h = $q_h/K$.

Reynolds and Steedman (1989) recommended that maximum lateral pressure ($q_{hmax}$) should be used for design.

$$q_{hmax} = Dr / \tan\mu \quad \text{.....(2.22)}$$

Janssen's method according to Gumbe (1988) is based on static equilibrium of a thin horizontal layer of stored material assuming the following:

(1) - Vertical pressures are uniform throughout horizonal plane θ

(2) - Horizonal pressures are uniform over the perimeter of a cross section.

(3) - The ratio of the horizontal to vertical pressure (K) is constant at all locations

.

For most storage bins, the walls are vertical, however situations exist where walls are inclined as in hopper bottoms. Reynolds and Steedman (1989) treated this case and gave the lateral pressure normal to slope of inclined surface, such as hopper bottom ($q_h$) as

$$q_h = Dh(K_2 \sin^2\theta_1 + \cos^2\theta_1) \quad \text{.....(2.23)}$$

where

D = unit weight of material ( $KN/m^3$)

h = depth of hopper below the level surface of filling

$K_2 = (1 - \sin\theta) / (1 + \cos\theta)$

$\theta_1$ = angle between the horizontal and the sloping surface.

$\theta$ = angle of internal friction

If the slopping wall has a weight per unit area of $g_s$ then the total pressure on the slopping wall ($q_n$) is giving by:

$$q_n = K_4 D_h + g \cos\theta \quad \text{.....(2.24)}$$

where

$K_4 = K_2 \sin^2\theta_1 + \cos^2\theta_1$

**(ii) Type of product stored**: The type of product stored influences to a large extent the lateral pressure exerted on bin walls. Where stored grains are dry and tend to be cohesionless, the Rankine equation and Janssen equation will serve well. However when the stored grain has high internal friction and tend to be cohesive, a lateral pressure computed using the above formulae will be far in excess of the existing pressure. Britton and Stewart(1973) recommend the use of coulomb's equation in computing active pressures for grain with high internal friction.

**Coulombs Equation**

$$q_h = Dh\cos\acute{\theta}\left[\frac{\operatorname{cosec}\beta\sin(\beta-\theta)}{\sqrt{\sin(\beta+\acute{\theta})}\sqrt{\frac{\sin(\theta+\acute{\theta})\sin(\theta-i)}{\sin(\beta-i)}}}\right]^2 \qquad 2.25$$

where

$q_h$ = lateral pressure at height h.(KN/m$^2$)

h = height (m)

$\theta$ = internal angle of friction (= angle of repose)

$\theta'$ = angle of wall friction

$\beta$ = angle between bin wall and horizontal

But in most cases, $\beta = 90$ and i = 0 for no surcharge, reducing the equation to :

$$q_h = Dh\cos\acute{\theta}\left[\frac{\cos\theta}{\sqrt{\cos\acute{\theta}}\sqrt{\sin(\theta+\acute{\theta})\sin\theta}}\right]^2 \qquad 2.26$$

Coulomb unlike Rankine, assumed that wall friction did exist. Therefore from the above relation, the vertical component of the wall force is:

$q_v = q_h \tan\theta'$ .....(2.27)

Reynolds and Steedman (1989) state that the active pressure exerted by cohesive soils vary greatly due to cohesion. Pressure is generally less that those due to granular soil except in cases of saturation where it is much greater. They recommended the use of the formula derived by A.L. Bell.

**Active pressure for cohesive soils.**

$$q_2 = K_2 Dh - 2c\sqrt{K2} \qquad (2.28)$$

Where

$K_2 = (1 - \sin\theta) / (1 + \sin\theta)$

$q_2$ = Intensity of lateral pressure at depth h on vertical wall (with no surcharge)

D = Unit weight of soil ($KN/m^3$)

C = cohesion factor (shearing strength of unloaded soil) - $KN/m^2$

h = height under consideration (m)

According to this formula, there is no pressure against the wall down to a depth of $2c/(D/K_2)$. The value of C varies from less than $35KN/m^2$ for sandy clay to over $140KN/m^2$ for stiff and hard clay.

**(iii) Type of pressure expected**: Storage may be subjected to either a static or dynamic pressure depending on the method of off loading stored material. Where a hopper is used to off load material from the bin, excess or over pressure results. It is generally accepted that the maximum lateral pressure occur in silos during emptying, but there is disagreement as to the location and magnitude of these maximum pressures (Gumbe, 1988). There are two approaches of determining total pressures (i.e static pressure plus over pressures) wherever dynamic pressure exist: One is to modify the computed static pressure using over pressure factors; the second is to compute total pressure directly.

(i) Computing Dynamic Pressure By Modifying Static Pressure: Gumbe (1988) reported that a design over pressure factors are suggested by various codes such as the American Concrete Standard AC1 313-77 (1977), the German Code DIN 1055 (1964) and the Soviet Code CH-302-65 (1965) for modifying the static pressures. These factors range between 1.3 to 4.0.

(ii) Computing Total Pressure Directly: For practical design purposes the over pressure factors suggested by the various codes are used, but various theories and equations have been developed for predicting dynamic pressures which are yet to be adequately designed. Gumbe (1988) discussed some of these method which include:

- Jenike's method
- Reimbert method for operational pressures in silos
- Theirmers approach.

There are situation where the stored product is not in granular form, like the storage of silage in silo bin. This situation also corresponds to storing unthreshed heads of millet or sorghum in bins. In this situation, the use of the equation for freely flowing grains may not be appropriate, for example, lateral pressure computed using Janssen's equation was much higher than experimentally observed values for bins of same sizes. A typical example computed from graphs of lateral pressures in grain bin and silos reported in Barre and Sammet (1958), Gray (1955) is shown in figure 2.10. For purpose of clarity, the graphs were combined and their units converted to metric.

It is recommended that silos for storing corn silage should be designed with pressure computed from that due to grass silage which exert a higher pressure at same moisture content. In a study by Bishara (1985) reported by Gumbe (1988), the lateral pressure distribution of silo storing silage computed using 15 different methods varied by as much as 500%. Bishara (1985) then presented 3 equations based on studies using Finite Element Method for computing pressures due to silage, fine and coarse granular material stored in silos. These equations are presented below:

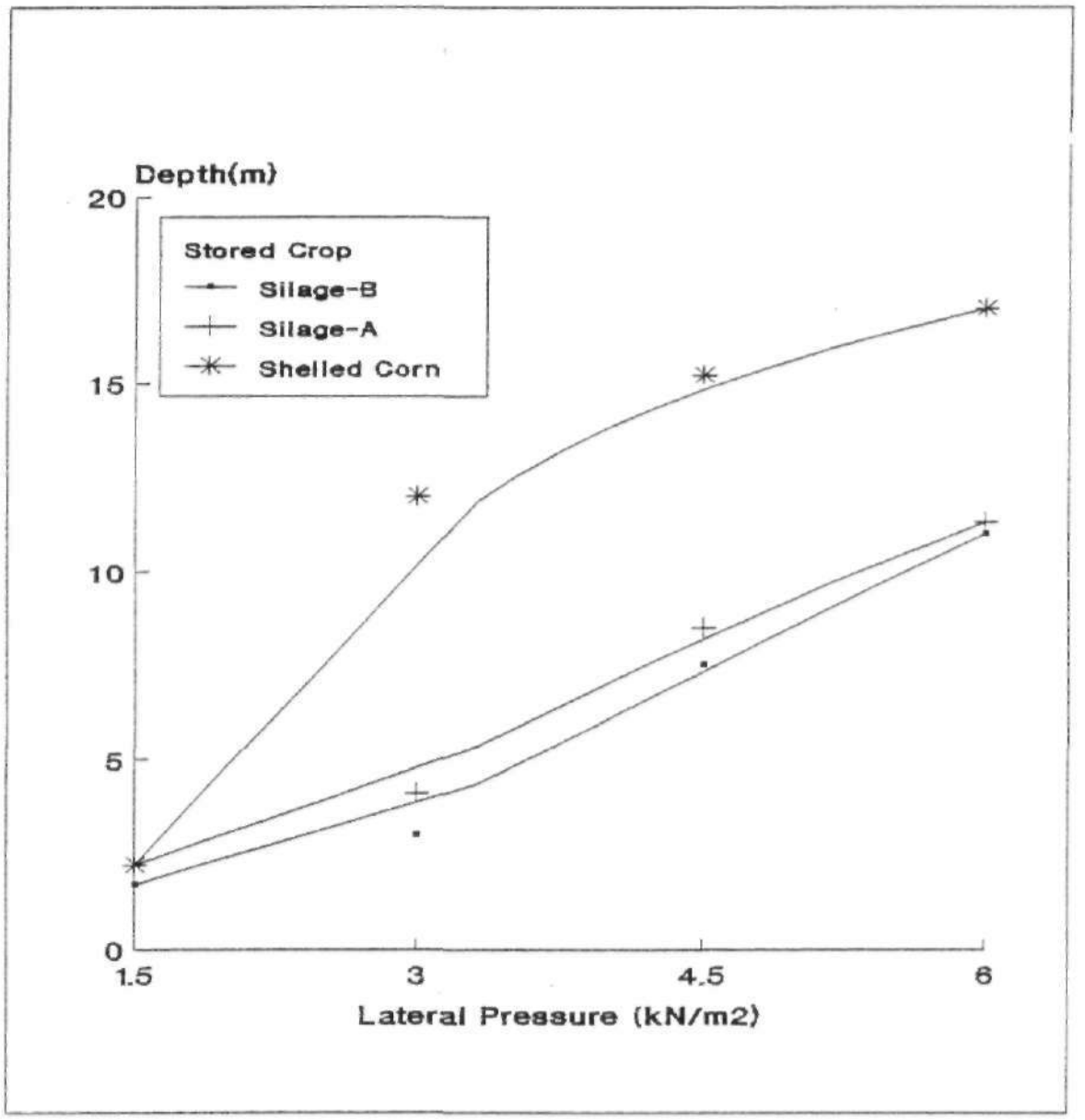



Figure 2.10 Computed and Experimentally Observed Lateral Pressures of Shelled Corn and Silage in a Galvanised Iron Bin.

Source: Gray (1955), [with some modifications]

**(i) Silage stored in silo**

$$q_{hmax} = \frac{0.46d^{0.75}h}{(D\dot{\theta})^{0.25}} \tag{2.29}$$

$$q_{vmax} = 1.82d^{0.55}h^{0.62}\left(\frac{D}{\dot{\theta}}\right)^{\frac{1}{9}} \tag{2.30}$$

Where

$q_{hmax}$ = maximum lateral pressure (KN/m$^2$)

$q_{vmax}$ = maximum average vertical pressure (KN/m$^2$)

d = silo diameter (m)

h = average settled height (m)

D = unit weight of material (KN/m$^3$)

$\theta$ = silo / silage coefficient of friction

**(i)Fine Granular Material** (with average particle diameter less than 2.5mm)

$$q_h = \frac{0.329\cos^2\theta D^{1.12} d^{0.83}}{(\acute{\theta})^{1.08}}\left(1 - e^{-2k\frac{\acute{\theta}}{d}}\right) \qquad (2.31)$$

$$q_v = 2.06\sin^2\theta D^{1.03} \frac{d}{\acute{\theta}^{1.08}}\left(1 - e^{-\frac{2k\acute{\theta}}{d}}\right) \qquad (2.32)$$

Where

θ = angle of internal friction of material

h = depth at which qh, qv is being considered

**(iii)Coarse Granular Material**(with avg particle diameter greater than 2.5mm)

$$q_h = \frac{0.526\cos^2\theta D^{1.08} d^{0.80}}{(\acute{\theta})^{0.96}}\left(1 - e^{\frac{-2k\acute{\theta}}{d}}\right) \qquad (2.33)$$

$$q_v = \frac{0.746\sqrt{\sin\theta}\, D^{1.12} d^{0.91}}{(\acute{\theta})^{0.91}}\left(1 - e^{\frac{-2k\acute{b}}{d}}\right) \qquad (2.34)$$

According to Reynolds and Steedman (1989),the wall of a cylindrical tank carrying liquid or non cohesive following granular material is primarily designed to resist direct tension due to the horizontal (lateral) pressures of the contained materials. The direct tension (N) in a horizontal ring of unit depth is $1/2q_h d$. Where d is the internal diameter of the tank.

**2.4.2 Functional Evaluation :** This evaluation otherwise referred to as functionality has to do with evaluating the storage structure with regards to functions for which it was designed.

A grain bulk according to Sinha (1973) is a man made ecological system in which living organisms and there nonliving environment interact on each other. He further stated that a granary structure must maintain and improved storage stability of stored grain and that the choice of a construction material is important in controlling temperature and moisture or rodents and birds depending on the biological and geographical stability .

The moisture content of stored grain bulk is dependent on the temperature and relative humidity existing in the structure. Therefore an equilibrium is always maintained between the relative humidity temperature and the grain moisture content. The stable moisture content at a particular relative humidity is referred to as equilibrium moisture content (EMC) and equilibrium relative humidity (ERH). According to Hunt and Dixton (1974), deterioration may occur in stored grain (even if the grain is at safe and uniform moisture content), if there is marked difference in temperature in different parts of the bulk. He noticed that the intergranular air is not static but in constant motion through convective currents leading to movement of moisture from warm to cooler region.This may cause the ERH to exceed the safe level and in extreme cases, the air on striking a cold surface may be cooled to below the dew point resulting in water condensation. This moisture may either fall on walls of storage structure or on surfaces of the grain bulk, thereby increasing the risk of deterioration in that region.

It is also stated by Reynolds and Steedman (1989) that a rise in temperature produces an increase in pressure of about 2% per 10°c. According to Muir (1973) changes in diurnal variation affect grain temperatures in bins up to 15cm. He further noticed that in an unaerated grain bulk of relatively uniform moisture content, moisture is transferred mainly by convective air currents caused by temperature gradients in the bin. Based on the above reasons, Muir (1973) suggested that materials for walls and roofs of granaries should be able to resist heat flow into the granary from high outside air temperature or solar radiation so as to keep the grain cool.

It can be understood from the above review that functional evaluatation of a storage bin would necessitate evaluating it's ability to resist heat transfer from varying outside temperature and relative humidity.

## 2.5 Justification For Study

Northern Nigeria is relatively dryer when climatically compared to the southern part of Nigeria. This has contributed to the successful usage of mud structures which is not only economically viable but very durable in this region if well constructed and protected. Rumbu, a grain reserve storage structure is constructed principally of mud. The popularity of this structure as it is used in Northern Nigeria has been established by researchers like Lasisi (1989), O'Dowd (1970), Bungudu (1970), Igbeka (1989) etc.

Some of these researchers have even gone to suggest some changes necessary to improve the rumbu. However, grain reserve structures need to be voluminous and strong. Sizing and detailing of this structure has up to now been done on estimates and experience.

No data or knowledge exist as to the structural reliability of this structure. Although researchers have also attributed some qualities to the rumbu in terms of its high thermal capacity, no attempt has been made to show the behaviour of this structure as it compares with its steel and sandcrete counterparts.

If any serious improvement has to be achieved in a rumbu construction and usage there is a need to determine the range of structural reliability of this structure so as to use the mud optimally. There is also the need to compare the behaviour of this structure with its counterparts when subjected to environmental hazards to access correctly the extent of performance of this structures.

# CHAPTER THREE

## 3.0 METHODOLOGY

Most of the earlier studies carried out in Nigeria on grain storage structures show that usage of mud as a construction material for grain storage structures is more prevelant in Northern Nigeria.This is evident from the works of Giles (1964), Hall (1963), and others previously reviewed in chapter two. To correctly asses the suitability of mud would therefore necessitate undertaking a complete study of existing structures and construction practices in Northern Nigeria. Because of the size of Northern Nigeria and limits of both staff and time, this would be an impossible task. A preliminary ivestiagtion was therefore carried out first to study the configuration and spread of existing structures along easily acssesible areas so as to have an anlaytical assesment of existing structures with regards structural stability. The investigation will also help in the selection of three representative villages where detailed study of mud preparation, construction processes and storage methods can be carried out. After this detailed study, a laboratory investigation was then carried out to asses the properties of different mud constituents so as to come out with optimal of mix ratios. A functional evaluation was finally carried out to asses the performance of mud structure under varying ambient conditions and as it compare with steel and sandcrete structures.

**3.1 Preliminary Investigation :** A general survey of the rumbu structures along the Lokoja - Abuja - Kaduna - Sokoto - Wurno and Kaura-Namoda highway was carried out. In doing this a questionnaire (sample in Appendix A) was designed to collate needed information with regards structural configuration, stored product and history of both structure and stored product. A journey was undertaken from Lokoja to Abuja through

Kaduna, Zaria ,Gusau, to Sokoto, Wurno, and Kaura-Namoda. During the journey, wherever a rumbu or batteries of rumbu were observed in a village, a stoppage was made to collect needed information. This process was repeated whenever there is a change in shape, size, and frequency of occurrence.

A 30 meter Stanley steel tape was used for measuring dimensions where structures were of regular geometrical shapes, but where structures were geometrically irregular, perimeters were measure by using the tape with some estimation. At each stoppage, attention was paid to the following:

(a) availability of organised construction practice

(b) availability of existing structures still in use

(c) availability of stored product in the structures

(d) quantity of structures available

**3.2 Detailed Investigation :** From the result of the general survey of section 3.1.1, it was found that the rumbu structures along Gusau-Sokoto-Wurno-Kaura were more in quantity, larger in size and more utilized when compared to others. Specialised builders were also more in number and easily available along this route. Lamba Tureta in Tureta local government of Sokoto State was found to be a village with peculiar history of storage in terms of purpose of storage, while Lugu a village in Wurno local government was found to have pyramidically shaped rumbu structures in addition to the other shapes available in other areas along this route. Wurno was also found to be about the oldest town in existence along this route. These three villages (Lamba Tureta, Wurno and Lugu) were therefore selected for carrying out the detailed survey of the rumbu structure vis a vis its construction

and use. Lamba Tureta is located about 61 kilometres to Sokoto along Gusau - Sokoto highway, Wurno on the other hand is located about 40 kilometres from Sokoto off Sokoto-Kaura-Namoda highway while Lugu is located at about 5kilometer into Wurno hinterland. It was also discovered from the preliminary investigations that construction of rumbu were carried out during the period of december through march. The period of february was considered best and chosen for carrying out the detailed survey as several structures are at various stages of construction.

By Rapid Research Appraises (RRA), procedures for procuring construction material were asked, and visual observations carried out with regards to methods of mud preparation and proportions used. Inquiries were made as to reasons behind some of the decisions taken. Also by visual observation, construction steps at various stages of construction were studied. This stages include land clearing, foundation, floor and wall construction, roofing structure and protective cover of the structure against rain. During this investigation, unprepared dry samples were obtained for identification and laboratory analysis. Structural properties like consistency, dry compressive and tensile strength were determined as outlined in section 2.3.2, while properties like textures, plasticity and compactibility were determined using the procedures outlined in section 2.3.1. Results are presented in table 4.6.

Procedural practices involved in storage of crops using the rumbu were also studied and questions asked as to reasons for usage of such practices. Particular attention was paid to finding out chemical treatment if any of the crops before, during and after storage. The state of the grains presently in storage were also observed for any physical damage and colour change, where possible samples were collected for viability test.

### 3.3 Assessment of Existing Structures

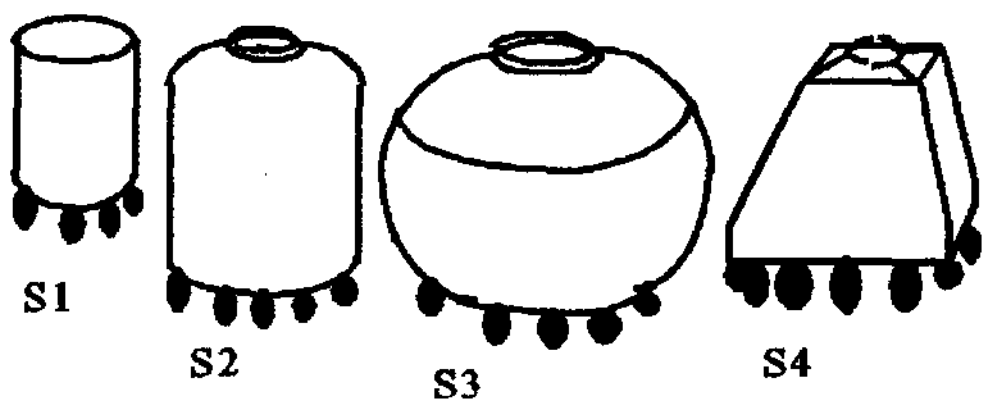
To evaluate the structural stability of any structure, it is important to know the possible or likely envisaged maximum stresses and moments expected within the structure. Such stresses can then be checked against material resisting strength. This section explains the procedure used in estimating possible maximum stresses of documented rumbu bins. First, the volumes and possible maximum capacities were estimated, then lateral pressures due to these capacities were determined. Finally, using bin diameters and wall thicknesses, direct wall tensions and stresses were computed.

**3.3.1 Volumes and Capacities :** Volumes and capacities of the documented rumbu bins were calculated by approximating the bin shapes to standard known configuration, making assumptions with respect to type of crop stored and whether threshed or unthreshed.

**(a) Volumes :** From the results of the initial investigation, the shapes of the rumbu bins in use were found to be of four types namely :

geometrically shaped cylinder (S1)
geometrically domed cylinder (S2)
geometrically imperfect sphere (S3)
geometrically bi-sected pyramid (S4)

To estimate the volumes, the configurations S1 and S2 were treated as cylindrical shells, while S3 and S4 were treated as a perfect sphere and a cuboid respectively. See Figure 3.1.




S1 = Cylinderically Shaped Bin S3 = Spherically Shaped Bin

S2 = Cylinderically-Domed Bin S4 = Incomplete Pyramidal Bin

Figure 3.1 Sketch Diagram of Existing Configurations of Rumbu Bins

**(b) Capacities** : Three different capacities were used to compute the different possible lateral pressures. The first capacity was based on results of the preliminary investigations shown in tables 4.1 to 4.5 where capacities (in bundles) based on estimates given by owners of the rumbu bins were documented. The second capacity was based on computed volumes and bulk density of unthreshed millet head, while the third capacity was based on computed volumes and bulk density of threshed millet grains. In determining the bulk density of unthreshed millet head, a wooden crate having a dimension 1.0m x 0.5m x 0.2m was used.

**3.3.2 Lateral Pressures** : Lateral pressures were determined using the Rankine method suggested by Reynolds and Steedman (1989) and reviewed in section 2.4.1. In carrying out the analysis the rumbu bins were classified into three categories :

(a) bins of vertical wall
(b) bins of positively inclined wall
(c) bins of positively inclined wall

**(a) Vertically Walled Bins** : Both shapes S1 and S2 were treated as cylindrical bins and therefore vertically walled. The three different lateral pressures due to each case of the capacities were then calculated.

(i) Case-1: Lateral pressure ($q'_1$) due to unthreshed millet, based on owner estimated capacity. Recall Rankine equation (2.20),

$$q'_1 = K_2 (D_1) h \quad (N/m^2)$$

Where $K_2 = (1 - \sin\theta) / (1 + \sin\theta)$

$\theta$ = angle of internal friction

h = height of wall (m)

$D_1$ = unit weight of unthreshed millet based on capacity given by rumbu owner.

(ii) Case-2 : Lateral pressure ($ql_2$) due to unthreshed millet, based on determined volume and bulk density.

$$ql_2 = K_2(D_2)h \quad (N/m^2)$$

Where

$D_2$ = Unit weight of unthreshed millet (= 2.3 $kN/m^3$)

(iii) Case-3 : Lateral pressure ($ql_3$) due to threshed millet, based on determined volume and bulk density.

$$ql_3 = K_2(D_3)h \quad (N/m^2)$$

Where

$D_3$ = Unit weight of threshed millet ( = 6.3 $kN/m^3$)

**(b) Positively Inclined Walled bins :** The S3 shaped rumbu bins were treated as bins with positively inclined walls carrying load both by friction and directly, and in the same manner as above, the different lateral pressures ($ql_{11}$, $ql_{21}$, and $ql_{31}$) were calculated for unit weights of D1, D2, and D3. Recalling equation (2.24), the corresponding equations therefore becomes:

$$ql_{11} = K_4 ( D_1 )h$$
$$ql_{21} = K_4 ( D_2 )h$$
$$ql_{31} = K_4 ( D_3 )h$$

Where $K_4 = K_2 \sin^2\theta + \cos^2\theta$

$\theta$ = angle of inclination

**(c) Negatively Inclined Wall Bins :** The S4 rumbu bins were treated as negatively inclined walls. No lateral pressures were calculated for this situation as no load from the grain or unthreshed millet act on the wall.

Values of ($\theta$) : The values of angle of internal friction (approximately equal to angle of repose) is a function of material dryness and flowability. For unthreshed millet,

storage is reported to be carried out (as described in section 4.1) by arranging the unthreshed heads inside the rumbu and compacting it by human weight indicating that flowability of the material is close to nil. The angle of repose or internal friction will therefore play an insignificant role and can be safely assumed as 70 degrees. For the threshed millet, the value of ($\theta$) was determined to be 27 degrees.

**3.3.3 Direct Stresses :** The direct tensions and stresses of the bin were calculated in the manner recommended by Reynolds and Steedman (1989) as earlier reviewed in section 2.4.1

**(a) Direct Tension (N)**

(i) For vertically walled bins, the direct tension (N) is given as :

$$N = (q_h.d) / 2 \text{ (N/meter height)} \quad \text{.....(3.1)}$$

(Reynolds and Steedman, 1989)

(ii) For bin walls with inclination, the direct tension (N) is given as :

$$N = V\text{cosec}\theta \quad \text{.....(3.2)}$$

(Reynolds and Steedman, 1989)

Where

$V = F_1 / (\pi\, d_1)$

$F_1$ = weight of the material above the slanted portion

$d_1$ = effective diameter of the slanted portion

It is safe to assume that the slanting surfaces practically supports half of the load, while the remaining is supported by the floor, therefore:

$$F = D(3/16)\, d.h \quad \text{.....(3.3)}$$

$$N = (3/16) d.h.\text{cosec}\theta \quad \text{.....(3.4)}$$

**(b) Tensile Stresses :**

The tensile stresses ($\sigma$) were calculated using the wall thicknesses.

$$\sigma = N / (t \times 1) \quad (N/m) \text{.....(3.5)}$$

Where

N = direct tension in Newton per meter length

t = thickness (m)

1 = one meter as a unit length

## 3.4 Material Investigation

**3.4.1 Mud :** From the preliminary investigation, it was found that major varying factors in mud preparation were type of stabilizer, water- soil ratio, and period of settlement. Even though grass was the major and most relied stabilizer normally used it was clear that type used was mainly dependent on level of availability, but thiner straw grasses were generally favoured. An experiment was therefore designed where to study effect of stabilizer type, stabilizer-soil ratio water-soil ratio and settlement.

**3.4.2 Stabilizer Selection :** From the commercially available grass stabilizers in Zaria, one each of thin and thick-stalked similar to those being used at the studied sites were selected. The thin-stalked being summer grass while the thick-stalked chosen was rice straw. Summer grass is physically a thin grass that stretches on the ground with each node forming a root.

It is not uncommon to find it growing in stretches of over one meter. it has an average diameter range of 4.0mm when wet and 1.0mm when dry. It is not easily cut or broken manually when dry except at the nodes. Rice straw is physically of a thick stem when compared to the summer grass, growing upright into the air. It has an average diameter of about 7 mm when wet and 2.5mm when dry. It takes less effort to break or cut the rice straw when compared to the summer grass.

**3.4.2 Soil selection :** Four types of soil were found to be commercially available in Samaru area , these are the potters clay soil, sand, the builders lateritic red soil and the builders lateritic dark brown soil. The builders lateritic red soil found at a popular excavation site in Giwa (about 15 km from Samaru along Zaria - Sokoto road) was selected. Basic soil properties like texture, liquid and plastic limits, optimum moisture content and max dry density were determined in the Civil Engineering laboratory of Ahmadu Bello University. The standard procedures earlier outlined in literature were used.

**3.4.3 Designed Experiment :** The purpose of this experiment was to quantify the effect of water-soil ratio and grass-soil ratio on the quality of mud. These ratios were therefore varied at four levels within a domain that covered the present practice. The water- soil ratio was varied from 20.0 to 35.0% at 5% increment, while the grass- soil ratio was varied from 0.0 to 1.5% at 0.5% increment. This resulted in a sixteen point test conditions as shown in Table 3.1

**Table 3.1: Levels of Variables in the Experiment**

| Sample No | (a) Original Units of Variable | | (b) Coded Units of Variables | |
|---|---|---|---|---|
| Test Condition | Grass Stabilizer(%) | Water (%) | Grass Stabilizer | Water |
| 1 | 0 | 20 | 0 | 0 |
| 2 | 0 | 25 | 0 | 1 |
| 3 | 0 | 30 | 0 | 2 |
| 4 | 0 | 35 | 0 | 3 |
| 5 | 0.5 | 20 | 1 | 0 |
| 6 | 0.5 | 25 | 1 | 1 |
| 7 | 0.5 | 30 | 1 | 2 |
| 8 | 0.5 | 35 | 1 | 3 |
| 9 | 1.0 | 20 | 2 | 0 |
| 10 | 1.0 | 25 | 2 | 1 |
| 11 | 1.0 | 30 | 2 | 2 |
| 12 | 1.0 | 35 | 2 | 3 |
| 13 | 1.5 | 20 | 3 | 0 |
| 14 | 1.5 | 25 | 3 | 1 |
| 15 | 1.5 | 30 | 3 | 2 |
| 16 | 1.5 | 35 | 3 | 3 |

**3.4.4 Sample Preparation :** For each of the test run, a fresh mud sample was prepared. The preparation was carried out in five stages. First, a 10Kg of the soil was weighed out, with the corresponding amounts of grass stabilizers and water .The soil clods was then broken and the grass straws chopped into short lengths of between 2 to 3 cm. The soil, water, and grass stabilizer were then mixed properly into a smooth paste. The paste consistency (PC) of the mixed mud was measured after which the first set of cubes and cylinders were casted as samples of unsettled mud. The remaining mud paste was left in a

sealed plastic bag for three days to allow for settlement, after which the second sets of cubes and cylinders were casted as samples of settled mud.

### 3.4.5 Determination of Mud properties

**(a) Consistency:** The method of consistency determination using mud consistometer suggested by FAO (1982) described earlier in section 2.3.4 was adopted for utilization in this experiment. The mud consistometer was constructed and preliminarily tested for mud pastes over a range of water- soil ratio. Results obtained shows that there was hardly any measurable change for water- soil ratio variation between 30% and lower. The consistometer was therefore modified by reducing its cone diameter but maintaining the same weight to allowed for higher penetration and hence easily measurable values.

In using this instrument (see Figure 3.2), the cone was first raised and held in position with the aid of a wing screw, the mud paste to be tested was then poured into the cubical container until full and compacted with hand. The cone was then released gently until the cone tip touches the top of the paste, the position of the needle indicator on the centimetre graduated rule was noted. The cone is then fully released and the final position of the needle indicator was also noted after one minute. The difference in the two readings (i.e the cone depression) is recorded as the paste consistency (PC). This procedure was repeated for every batch of mud and detailed results are presented section 4.3.

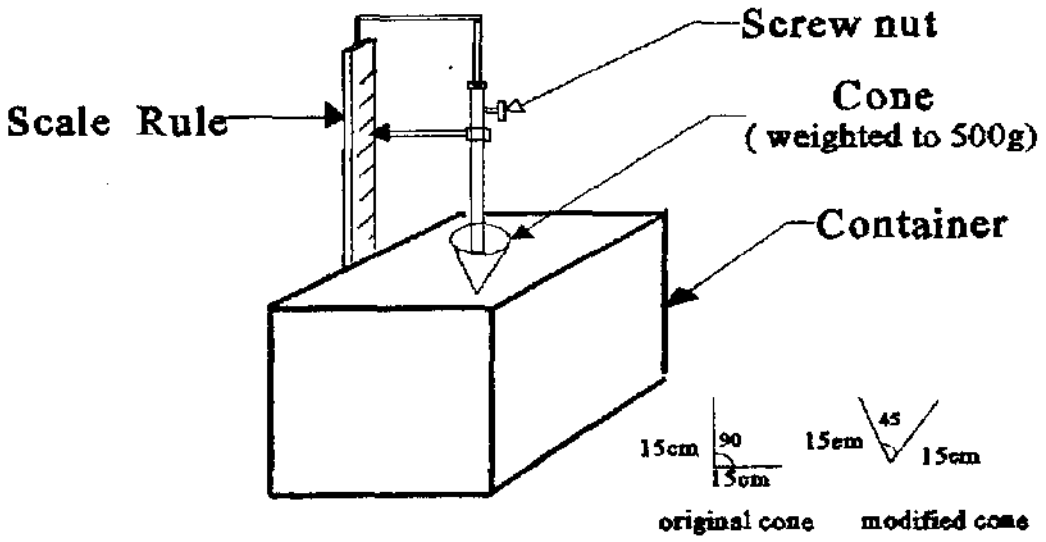



Figure 3.2 Sketch of The Mud Consistometer

**(b) Shrinkage Test :** The knowledge of mud shrinkage as it varies with type of stabilizer and moisture content is very important. No method has however been proposed for determining the shrinkage ratio of grass stabilized mud. The standard method using a 10cm long bi-sected cylinder to determine linear shrinkage (LS) of unstabilized mud described in section 2.3.1 of the literature review was modified by increasing both the length and diameter of the instrument. The length and diameter were increased from 10cm to 20cm and 10mm to 20mm respectively. In using the modified instrument, the container was filled with fresh mix from each batch, hand compacted and levelled with a knife. The container with the mud was then dried in the oven for 24 hours. The reduction in length divided by the original length was recorded as shrinkage ratio (SR). The results are presented in section 4.3.

**(c) Dry compressive strength :** The popular method of cube casting and crushing normaly used for concrete mix was used for this test. To ensure uniformity of mix and compaction pressure, the smallest cube size (50mm cube) suggested by ILO (1987) was used.

Mould used in casting the cubes was constructed from galvanized mild steel to an internal dimensions 50x50mm, while plates measuring 48mm x 48mm and were also cut to serve as a plungers. In casting the mud cubes, freshly remixed sample prepared as explained in section 3.2.4 was used. The mould was lubricated with used engine oil and placed on the base plate which itself is also placed on a flat bathroom weighing balance (0.5 kg sensitivity), the mud is then poured on to the mould until full, using the plunger, the mud was compressed until the weighing balance reads 20kg this compression was maintained for

one minute after which the plunger was then pushed against the handle of the mould to have the mould removed leaving the freshly casted mud cube on the base plate. The assembly of the mud cube and base plate was then weighed and cured by drying in the laboratory under a fan for at least 3 weeks. Curing was assumed completed when no change in weight was observed for three to four days. It is worth mentioning that all cubes were casted during the months of December, January and February when the ambient relative humidity was always lower than 30%. Finally the cured samples were weighed and measured. The pictuers of some of the cured samples are shown in Figure 3.3.

Using the MFL automatic universal hydraulic testing machine available in the Civil Engineering laboratory of Ahmadu Bello University, the cubes were loaded in compression at the rate of 0.2 N/mm$^2$/min until it fails. Cellotex packings as suggested by Ejeh (1984) were used as platens. The crushing loads (P) were recorded and later used in calculating the dry compressive strength ($\sigma_c$)

Where $\sigma_c$ = [crushing load (P)] / [loaded surface area (A)] (N/mm$^2$)

Results are presented in section 4.3.2.

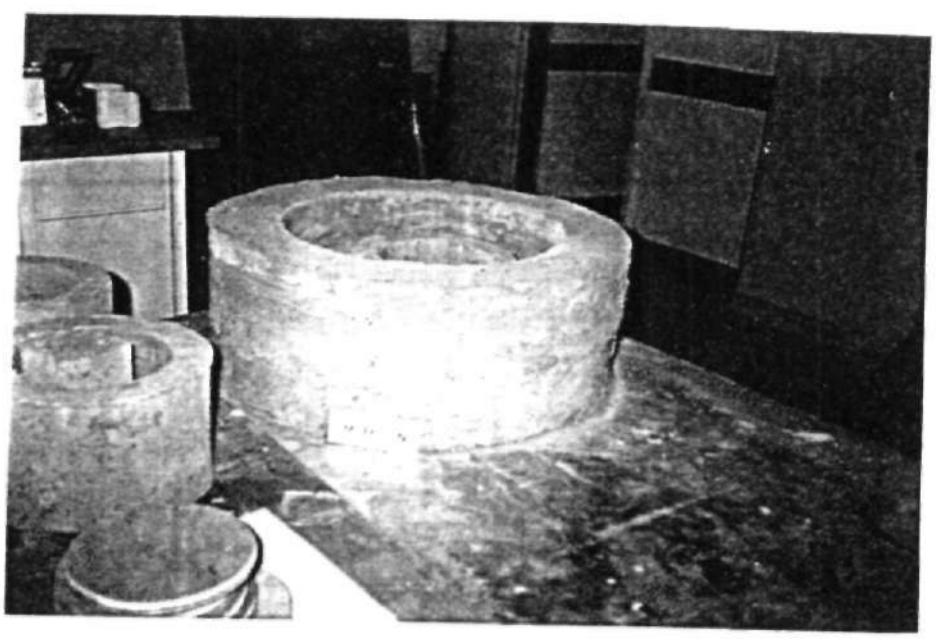


Figure 3.3 Picture of some of the casted and cured samples

**(d) Dry Tensile strength** : The indirect method of tensile strength determination using casted solid cylindrical specimen as recommended by BS 1881 part 4 of 1970 was used in conjunction with the direct cylindrical ring method used by Ibrahim (1989) to test the tensile strength of fibre reinforced concrete.

(i) The indirect method : Using each of the re-mixed batches of mud, solid cylindrical muds were casted alongside the casting of the mud cubes. Galvanised iron pipe of length and diameter served as the mould while a diameter disc served as the plunger. The solid mud cylinders were casted and cured in the same manner as for the mud cubes.

The same hydraulic machine used for the mud cubes was employed except that the cylinders were loaded laterally by placing it horizontally in between the cellotex packing strips. Load was then applied at the rate of 0.2 $N/mm^2$/min until the cylinder splits. The splitting loads (P) were recorded and used to calculate the corresponding tensile strength ($\sigma t$).

$$\sigma_t = [P/(\pi.d.l/2)] \quad (N/mm^2)$$

Where

P = splitting load (N)

$\pi.d.l/2$ = approximate effective area ($mm^2$)

d = cylinder diameter (mm)

l = cylinder length (mm)

(ii) The Direct Method : As for the cylindrical ring method, special moulds were constructed and the same mud mix used to cast the cylindrical ring. One cylindrical ring was casted for each batch of mud mix and cured like the other samples. The

same hydraulic testing machine used above was employed. Sand grains were however used as the ring pressure distribution material instead of gravel used by Ibrahim (1989), while plywood plugs were used as platen instead of the concrete plugs used by Ibrahim (1989). These changes were necessary as mud weaker than concrete and could therefore fail prematurely if gravel grains and concrete plugs were used. The loading arrangement is shown in picture of Figure 3.4). To obtain an approximately uniform pressure distribution through the cylindrical ring height, it was necessary to equalise the load from the two ends of the cylindrical ring. This was achieved by allowing free vertical displacement of the two plywood plugs placed at the top and bottom of the ring. Ibrahim (1989) has presented that for smooth internal ring surface, friction between the surfaces and the aggregates are small when compared to the lateral forces and can be neglected. The two disc plugs were averagely 10mm less than the internal diameter of the ring to allow for free movement of the plugs. Paper packings were also provided for the gap between the plywood plug and internal wall of the cylindrical ring. This is to disallow the gap been filled up by the sand grains. The vertical load was applied at an incremental load of 0.5 KW until failure and circumferential strain readings were monitored at mid height of the specimen to ensure balanced loading. The loading patterns of both the direct and indirect method are sketched in Figure 3.5.

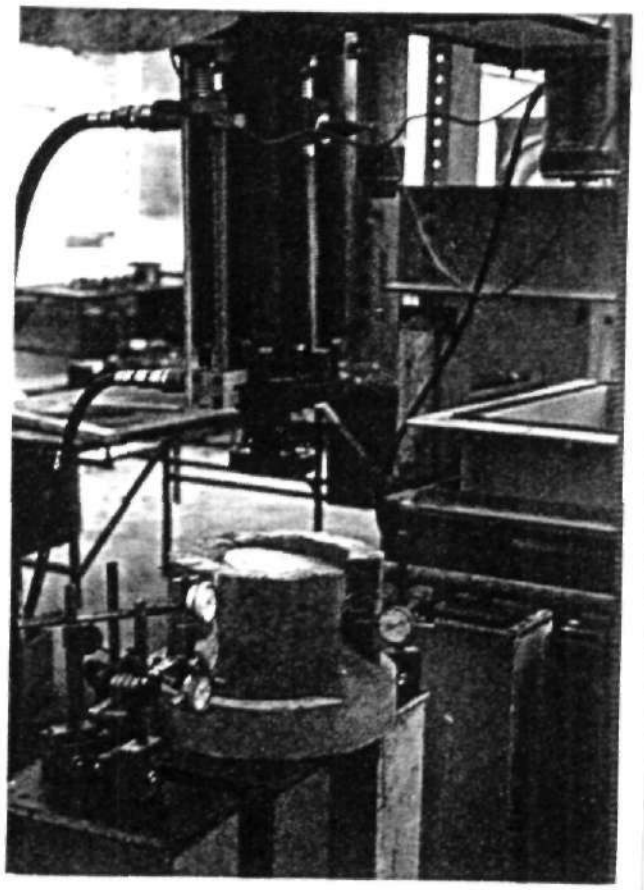
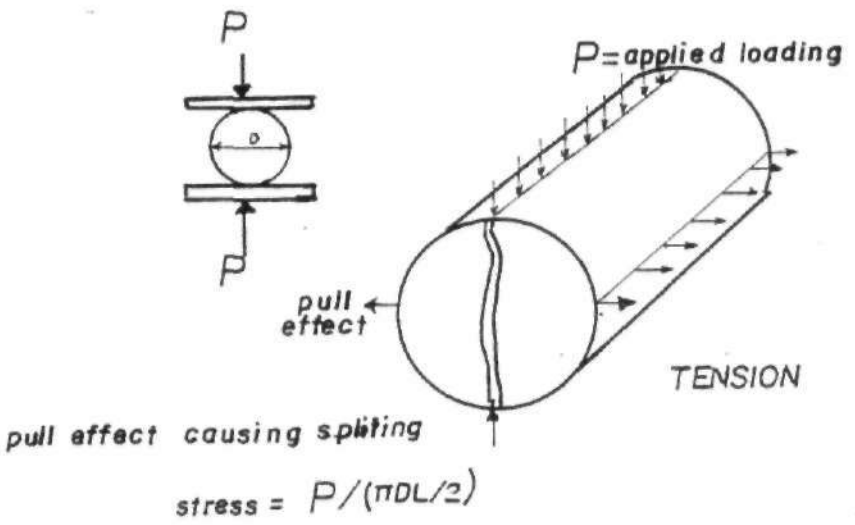
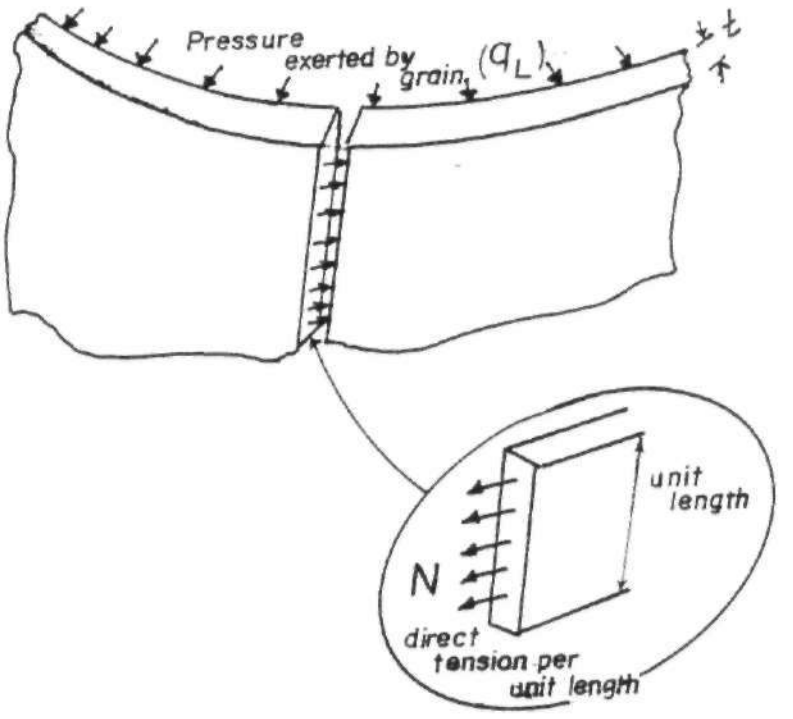


Figure 3.4 Picture of the Loading Arrangement During Direct Testing of Tension using Cylinderical Shell.




(a) Loading Pattern for the Indirect Method




(b) Loading Pattern for the Direct Method

Figure 3.5 Loading Pattern of the Direct and Indirect Method of Testing for Tension.

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**(e) Durability Test :** Two methods were used to assess the relative durabilities of the mud samples. These were :

(i) The water absorbtion method

(ii) The modified brush method

(i) The water absorbtion method : For this test, one cube from each batch of mud sample similar to those used for the compressive test was selected and oven dried for 24 hours at a temperature of 130$^0$C then weighed. The cubes were then placed in a 2mm thick carriage assembly and inserted in a 5mm deep tray full of water. The tray was continuously kept overflowing giving an effect of 3mm immersion on the mud cubes. Using a stop watch, one minute immersion was monitored after which the carriage assembly was removed and allowed to drip for 5 minutes. Each of the sample was then weighed to determine the weight of the water absorbed in grammes. The weight of the absorbed water was then expressed in relation to a standard bed surface of 30 sq.in (19355mm$^2$) to get the value of Initial Rate of Absorbtion (I RA). That is :

$$IRA = (A \times W_a) / 19355$$

Where

A = actual bed surface of cube having contact with water (mm$^2$)

$W_a$ = weight of absorbed water (gm)

19355 = standard bed surface area (mm$^2$)

Each of the sample was then placed in a standard filter paper jacket, and replaced in the carriage assembly. The carriage assembly was immersed as before and removed at 10, 20, and 30 minutes to determine amount of water absorbed by the samples. The use of the filter paper was necessary to avoid loss of the disintegrating portion of the sample due to

long duration of immersion. The weight of a soaked filter paper was determined and always subtracted.

(ii) The Brushing Method: The brushing method was modified to suit the fragile and easily erodible nature of the mud samples. A 200mm x 100mm x 50mm polystyrene block was employed instead of a steel wire brush. Five strokes and one cycle of immersion was used instead of the normal twelve cycles. The blocks were also immersed at 3mm depth and for only thirty minutes as against the normal 24 hour complete immersion before brushing. The brushed samples were dried in the oven for 24 hours, and weighed to determine the percentage loss.

The results of both methods are presented in section 4.2

### 3.5 Comparative Evaluation

This section of the research was necessary as a means of objectively evaluating the performance of grass stabilized mud as a storage material. There is for example the need to discuss the obtained result with regards to structural strength and durability in the light of other similar materials like lime and bitumen stabilized mud. There is also the need to compare the functional behaviour under environmental changes with other commonly used storage construction materials.

**3.4.1 Structural properties** : Present recommendations on other stabilized materials like lime and bitumen stabilized lateritic soils are based on conditions that soil used shall be sieved and blocks are casted using compression machines that aids the compaction effort. To compare obtained results with such other materials will therefore require that samples be prepared locally under the same condition. Based on these facts, experiments were

therefore designed to compare structural properties of grass stabilized mud against lime and bitumen stabilized mud prepared under similar conditions as earlier outlined in section 3.3.

Structural properties evaluated were consistency of fresh mix, linear shrinkage, compressive strength, tensile strength and durability. The proportional mix ratios used for the samples were based on the result obtained for grass stabilized mud presented in section 4.3, while for lime and bitumen stabilized samples, the ratios were based on the recommendations of ILO (1987). These ratios are shown below in table 3.2

**Table 3.2 Mix Ratios of the Comparative Mud Samples**

| Sample No | Stabilizer Type | Water-Soil Ratio (%) | Stabilizer-Soil Ratio (%) |
|---|---|---|---|
| 1 | Summer Grass | 25 | 1.5 |
| 2 | Lime | 19 | 7 |
| 3 | Bitumen | 3 | 14 |

In preparing the mud samples for the above test, it was not possible to obtain soil from the original sight as excavation at that site had been officially stopped. Soil was therefore obtained from the new excavation site of the same village. However since this is a comparative test, the effect of this change will have no overall effect on the results. The mechanical and structural properties of the soil and mud were determined as earlier described in section 3.2.

**3.4.2 Functional Evaluation :** In carrying out a functional evaluation, simulated environments was employed to determine the comparative resistance offered to heat and moisture transfer by mud, galvanised steel sheet and sandcrete hollow blocks.

**Simulated Environment** : Three small bins of approximately 0.05m3 were constructed using mud, steel and sandcrete hollow blocks. They were then individually subjected to externally varying temperatures and humidity by application of heat and moisturised air. Relative humidities and temperatures for both the internal and external of the bin were monitored against time. To maintain an externally uniform condition, a collapsible environmental chamber was constructed to house the bin under test with both the heater and humidifier. The environmental chamber walls were constructed with a 12mm thick plywood and lined with a 25mm thick polystyrene sheet insulator. The base of the chamber which is separate was made up of a 5mm mild steel sheet layed on a 75mm thick wooden table. The top cover was also made up of a 12mm thick plywood lined with a 25mm plysterene sheet. See Figure 3.6.

A "Kaloric" electric heater and a "Super Cool" humdifer were used to apply the heat and the moisturised air respectively, while the temperatures and humidity were measured with thermohydrographs. The picture of the setup is as shown in Figure 3.6, while the sketch showing the dimensions of the chamber is shown in figure 3.7.

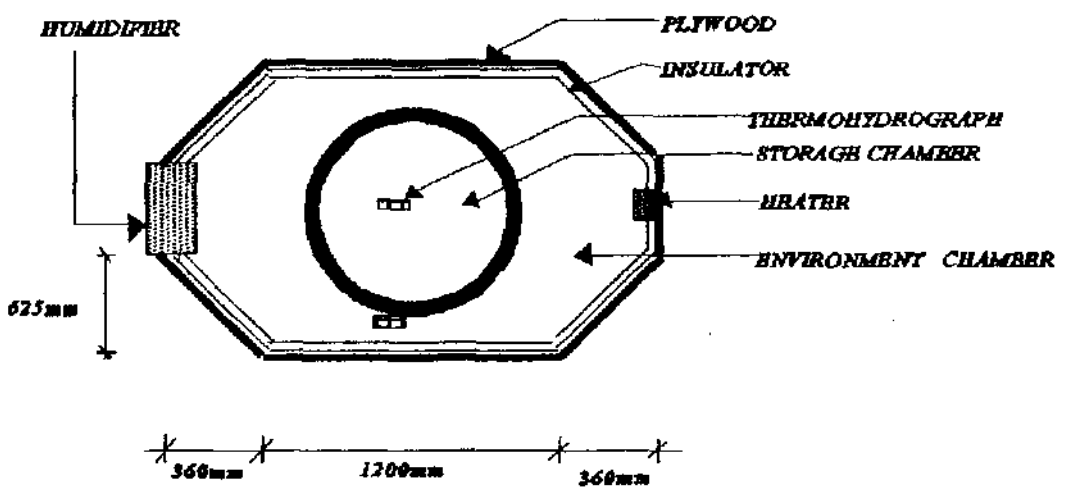



Figure 3.7 Diagramatic Sketch of the Environmental Chamber

# CHAPTER FOUR

# RESULTS AND DISCUSSION

This chapter present the results of the work done, its analyses and discussion. The presentation is in four sections. The first section present the results obtained from the preliminary investigation with regards the present state of art in usage, construction practice and spread of the rumbu bin. The second section present results of assesment carried out on existing structures with regards to capacities, bin lateral pressures and bin-wall stresses of existing rumbu bins. The third section concentrates on the results, analysis and discussion of the laboratory experiment carried out to investigate some aspects of mud as a construction material with regards to strength and durability. The last section present results and discussion the comparative evaluation carried out between grass stabilized mud and bitumen or lime stabilized mud with regards strength, and between mud and steel or sandcrete with regards resistance to ambient changes.

## 4.1 Preliminary Investigations

From both the questionnaires administered and the rapid rural appraisal (RRA) carried out, four factors were found to vary significantly. These are:

(i) shape and size of structure,
(ii) number of structures per family,
(iii) expected life of structure,
(iv) stored commodity and duration.

The above factors were found to change from one location to another with minimal differences within a zone of about 50 to 80km distance. These changes were fuither found

to follow some trend as one moves from Lokoja towards Sokoto. The results are therefore presented with regards to five artificially created zones, namely:

(a) Lokoja-Abuja route zone (LA)

(b) Abuja-Kaduna route zone (AK)

(c) Zaria-Gusau route zone (ZG)

(d) Gusau-Sokoto route zone (GS)

(e) Sokoto-Wurno-Kaura zone (SWK)

**(a) Lokoja-Abuja Route**: Along this route most of the rumbu bins were observed to be of cylindrical shapes with diameters ranging between 0.6m to1.0m and vertical heights that ranged between 1.8m to 2.0m. The shell thicknesses were found to be about 12cm. The rumbu bins in this zone were generally raised about 20cm above the ground with the aid of large stones. The openings are at the top of the bin and were as wide as the mid section diameter, while the roofs are made of tathces that were fastened to a conical truss. The configuration details are presented in Table 4.1.

It was learnt in places like Orehi, Gegu-Beki, and Abaji that most of the rumbu bins were owner constructed and that the procedure of construction is as for domestic buildings. On the average, about 25% of farmers in this zone own a unit of rumbu, and it was rear to find farmers owning more than one unit. The bins were normally located at the frontage of the house and owners have put their life span at a maximum of about five years, with some failing prematurely after one year. Farmers in this zone were basically involved in commercial cultivation of tuber crops like yam and cassava, while maize, guinea corn, are usually grown for consumption. Different crops were found to be stored together in the bins.

**Table 4.1 Configurations of Typical Rumbu Bins Along Lokoja-Abuja (LA) Route***

| S/No | Label | Shape | P (m) | VL (m) | TH (cm) | Capacity (bundles) | Crop stored |
|---|---|---|---|---|---|---|---|
| 1 | LA1 | S1 | 3.3 | 2.1 | 12.1 | - | mixed |
| 2 | LA2 | S1 | 3.9 | 2.3 | 13.2 | - | „ |
| 3 | LA3 | S1 | 3.7 | 2.4 | 10.8 | - | „ |
| 4 | LA4 | S1 | 3.8 | 2.5 | 12.3 | - | „ |
| 5 | LA5 | S1 | 3.5 | 2.3 | 12.5 | - | „ |
| 6 | LA6 | S1 | 3.8 | 2.4 | 12.0 | - | „ |

S1 = geometrically perfect cylinder P = Perimeter of Mid Section

VL= Vertical Length of wall TH = Thickness of wall

This zone belongs to the guinea savannah and it is the most rainy of the areas investigated, this probably explains why more tubers are grown. The heavy rain combined with owner construction normally of low skill and devoid of expertise could be the reason for the small life span and the sometimes premature failure that results.

**(b) Abuja-Kaduna Route:** *Along this route, rumbu bins were observed to be of two* shapes. There is the cylindrical shape like in the previous zone and a spherical shape that is not geometrically perfect which were common around Tafa village. The cylindrical shapes were however more common in this zone and had diameters ranging from 1.0m to 1.7m with vertical heights between 1.9m to 2.8m. The shell thicknesses ranged between 4cm to 12cm while the roofing patterns were like those of the previous zone. At the time of investigation, most of the bins were empty except for few that had different crops mixed in the bins. Configuration details of typical representative bins are presented in Table 4.2.

**Table 4.2. Configuration of Typical Rumbu Bins along Abuja-Kaduna (AK) Route.***

| S/No | Label | Shape | P (m) | VL (m) | TH (cm) | Capacity (bundles) | Crop Stored |
|---|---|---|---|---|---|---|---|
| 7 | AK1 | S2 | 5.1 | 2.7 | 14.1 | - | mixed |
| 8 | AK2 | S1 | 5.6 | 2.9 | 12.1 | - | „ |
| 9 | AK3 | S2 | 6.2 | 2.0 | 9.3 | - | „ |
| 10 | AK4 | S1 | 5.5 | 2.8 | 11.4 | - | „ |
| 11 | AK5 | S1 | 5.4 | 2.2 | 12.0 | - | „ |
| 12 | AK6 | S1 | 5.2 | 2.6 | 13.1 | - | „ |
| 13 | AK7 | S2 | 5.4 | 2.6 | 10.1 | - | „ |

S1 = Geometrically Perfect Cylinder
S2 = Geometrically Domed Cylinder
S3 = Geometrically Imperfect Sphere

P = Perimeter of the widest cross section (m)
VL = Vertical Length of the wall (m)
TH = Shell or Wall Thickness (cm)

**(c) Zaria-Gusau Route:** The rumbu bins along this route were much bigger than the previous ones. Most of the rumbu were either cylindrical or spherical in shape, but like in the previous situation, the spheres were not geometrically perfect. The diameter for the shapes ranged from 2.1m to 3.2m, while their vertical lengths varied between 2.9m to 3.2m. Dimensional configurations of the typical cases are presented in Table 4.3.

**Table 4.3 Configuration of Typical Rumbu Bins along Zaria-Gusau (ZG) Route.***

| S/No | Label | Shape | P (m) | VL (m) | TH (cm) | Capacity (bundles) | Crop Stored |
|---|---|---|---|---|---|---|---|
| 14 | ZG1 | S1 | 7.8 | 2.4 | 4.7 | 60 | Sorghum |
| 15 | ZG2 | S3 | 8.7 | 2.6 | 4.7 | 50 | Maize |
| 16 | ZG3 | S1 | 10.0 | 3.2 | 4.8 | 70 | „ |
| 17 | ZG4 | S3 | 12.0 | 3.9 | 4.1 | 120 | Millet |
| 18 | ZG5 | S2 | 11.4 | 3.2 | 4.2 | 100 | „ |
| 19 | ZG6 | S2 | 12.3 | 3.8 | 4.4 | 100 | Maize |
| 20 | ZG7 | S2 | 12.0 | 3.8 | 4.0 | 100 | Millet |

S1 = Geometrically Perfect Cylinder
S2 = Geometrically Domed Cylinder
S3 = Geometrically Imperfect Sphere

P = Perimeter of the widest cross section (m)
VL = Vertical Length of the wall (m)
TH = Shell or Wall Thickness (cm)

The rumbu bins in this zone were found to be classified by the natives as among "special structures" that are generally contracted out to special builders known as expert builders within a building clan. Other structures considered to be special are Mosques and King's palaces. Farmers in this area grow maize, sorghum and millet on commercial bases, but mainly store sorghum and millet. Most of the rumbu bins are located in family compounds making them not easily seen along the highway. Unlike in the previous zones, most of the bins were found to contain single crop at full capacity, most farmers in this zone also had between one to four units of bins in the family compound. Duration of storage is said to be between six months to one year for maize and about a maximum of three years for sorghum (major crop of storage). Most owners interviewed put the life span of the bins at between ten to twenty years.

**(d) Gusau-Sokoto Route:** Along this route a rumbu bin or battery of rumbu bins were found every ten to fifteen kilometre distance along the highway. Rumbu bins in this zone were of two shapes, domed-cylindrical and spherical with the spherical configuration dominating.

The spherical shaped bins had mid section diameters varying from 3.5m to 5.1m, wall lengths of between 3.2cm to 5.3cm, shell thicknesses of 4.2cm to 7.8 cm and well defined mud floors raised 20 to 30cm above ground level with big stones.

The domed-cylindrical shaped bin had mid section diameters ranging between 5.0m to 6.0m, wall lengths of between 3.4m to 6.0m and shell thickness of 7.5cm to sometimes 20cm. While some of the domed cylindrical shapes ware raised above the ground floor with stones, some were built on raised concrete floors having convectional strip foundations. There were however some that were built directly of the floor. The dimensions of some of the rumbu bins documented are in Table 4.4.

The roofing of the bins in this zone were of two tiers, a lower tier in form of a skirt-covering made from grass tatches and a top tier in form of a normal thatched roof made up of grass tatches tied to a conical corn stalk truss system. Like in the Zaria-Gusau zone, rumbu bins are classified as special structures contracted to expert builders.

**Table 4.4 Configuration of Typical Rumbu Bins along Gusau-Sokoto Route.***

| S/No | Label | Shape | P (m) | VL (m) | TH (cm) | Capacity (bundles) | Crop Stored |
|---|---|---|---|---|---|---|---|
| 21 | GS1 | S3 | 19.8 | 5.7 | 8.0 | 300 | Millet |
| 22 | GS2 | S2 | 20.2 | 5.7 | 7.5 | 350 | „ |
| 23 | GS3 | S2 | 21.0 | 6.0 | 20.0 | 350 | „ |
| 24 | GS4 | S2 | 20.1 | 6.1 | 20.0 | 350 | Beans |
| 25 | GS5 | S1 | 10.7 | 3.4 | 17.0 | 100 | Sorghum |
| 26 | GS6 | S3 | 18.2 | 5.1 | 6.0 | 300 | Millet |
| 27 | GS7 | S3 | 16.7 | 5.4 | 8.5 | 300 | „ |
| 28 | GS8 | S2 | 16.5 | 5.6 | 6.2 | 250 | „ |
| 29 | GS9 | S2 | 18.7 | 5.2 | 7.3 | 300 | „ |
| 30 | GS10 | S2 | 15.1 | 5.1 | 5.1 | 200 | „ |
| 31 | GS11 | S2 | 12.4 | 3.7 | 3.7 | 200 | „ |
| 32 | GS12 | S3 | 10.5 | 3.2 | 3.2 | 100 | „ |

S1 = Geometrically Perfect Cylinder
S2 = Geometrically Domed Cylinder
S3 = Geometrically Imperfect Sphere

P = Perimeter of the widest cross section (m)
VL = Vertical Length of the wall (m)
TH = Shell or Wall Thickness (cm)

Most family compounds in this zone own rumbu batteries of three to nine units normally located conspicuously in front of the family house. It was learnt that apart from its basic use as a storage structure, the rumbu bin in this area serve other purposes. These purposes include wealthiness, level of resistance of a family in case of famine, marriageability and aesthetics. Farmers in this zone were found to grow mainly millet, some sorghum, groundnut and beans, but millet is said to be favoured both for cultivation and storage because of its resistance to draught and insect infestation during storage. Duration of storage for millet was put at seven to nine years, while life span of the rumbu was put at between twenty to fifty years depending on maintenance of structure, thatched roof and skirt.

**(e) Sokoto-Wurno-Kaura Route:** The rumbu bins in this zone is much the same as the Gusau-Sokoto zone except in three respects only. The first is that, a fourth structural shape of incomplete rumbu bins were found in limited quantity within this zone. The second is the higher quantities of rumbu unit per family, and the third is that only millet was found to be stored in most cases within this zone. The configuration of the typical rumbu bins as documented are shown in Table 4.5.

**Table 4.5 Configuration of Typical Rumbu Bins along Sokoto-Wurno-Kaura Route***

| S/No | Label | Shape | P (m) | VL (m) | TH (cm) | Capacity (bundles) | Crop Stored |
|---|---|---|---|---|---|---|---|
| 33 | SWK1 | S4 | 20.8 | 5.6 | 10.1 | 300 | Millet |
| 34 | SWK2 | S4 | 21.6 | 5.7 | 10.0 | 300 | „ |
| 35 | SWK3 | S2 | 15.4 | 3.8 | 7.5 | 150 | „ |
| 36 | SWK4 | S2 | 16.2 | 3.7 | 4.2 | 150 | „ |
| 37 | SWK5 | S2 | 18.4 | 5.2 | 6.5 | 250 | „ |
| 38 | SWK6 | S2 | 18.2 | 5.4 | 6.6 | 250 | „ |
| 39 | SWK7 | S3 | 15.7 | 3.7 | 10.4 | 200 | „ |
| 40 | SWK8 | S3 | 16.8 | 3.7 | 10.2 | 200 | „ |

S4 = Geometrically incomplete Pyramid
S2 = Geometrically Domed Cylinder
S3 = Geometrically Imperfect Sphere

P = Perimeter of the widest cross section (m)
VL = Vertical Length of the wall (m)
TH = Shell or Wall Thickness (cm)

**4.2. Detailed Investigation:** The study undertaken in Lamba Tureta, Lugu and Wurno of Sokoto state showed that construction and storage practices are the two major areas that cover the art of storage using mud structures.

**4.2.1 Construction Practice:** The construction of a rumbu bin was found to involve six stages as follows:

(a) Site selection and preparation,
(b) Material selection and estimation,
(c) Mud preparation,
(d) Construction of foundation-floor assembly,
(e) Shell construction,
(f) Finishing and roofing.

**(a) Site Selection and Preparation** : The duty of selecting site for the construction of a new rumbu bin is normally left to expert the builder who has been contracted to build the structure. Factors used by the expert builder in selecting a site include the following:

(i) Good drainage,
(ii) Visibility of the structure (frontage of family compound is preferred) ,
(iii) Nearness to an existing rumbu so as to form a battery,
(iv) Freedom of site from termite infestation,
(v) Visible hardness of the ground surface.

In this particular study, the site was close to an existing bin belonging to the owner. The site was cleared of top vegetation and some of the organic soil. It was learnt that for termite infested sites, used engine oil or a poisonous chemical is first sprayed at such a site.

**(b) Material Selection and Estimation** : All the materials to be used were carefully listed by the builder, and the quantity likely to be needed estimated. In estimating the quantities, the builder based his judgement on a so called standard unit of rumbu, which should hold about 200 bundles of millet. The builder explained that bins normally constructed were designed to hold either 100, 200,250 or 300 bundles at maximum, but that there are however special instances when 350 bundle size rumbu units are demanded and constructed. The construction materials listed were :

(i) Clayey soil for mud preparation,
(ii) Stabilizers ( grasses, cowdung, and ashes),
(iii) Poles for construction of the floor grillage,
(iv) Grass thatching for making lower tier protective skirt and roof,
(v) Water.

The corresponding estimate and cost of materials conveyed to the site for the construction of a single unit of a 200 bundle rumbu bin is shown in Table 4.6.

The clay soils were purchased from an excavation site outskirt of the village at both Lugu and Wurno and conveyed to site with donkeys. But in Lamba Tureta, soil was purchased and used in combination with soil derived from old structures around the site.

In Lamba Tureta bundles of summer grass 'Harkiya' were purchased while in Lugu, the rumbu owners had rice straw bundles from his farm. At both sites, other stabilizing agents like cowdungs, ashes and other grasses nearby were collected to the site. Grasses found to be available in commercial quantities include summer grass, rice straw, and gamba.

**Table 4.6 Quantity and cost of Material Required for one Unit of 200- Bundle Rumbu Bin. ***

| S/No | Material | Location | Quantity | Unit Cost* (Naira) |
|---|---|---|---|---|
| 1 | Soil | Lamba Tureta | 10m3 | 20.00 |
| | | Wurno | ,, | 25.00 |
| | | Lugu(Wurno) | ,, | 25.00 |
| 2 | Stones | Lamba Tureta | 20 to 50 | 0 .20 |
| | | Wurno | 20 to 70 | 0.10 |
| | | Lugu | 20 to 100 | - |
| 3 | Big Poles | Lamba Tureta | 25 | 1.00 |
| | (4.0 to 8.3cm) | Wurno | 20 | 2.00 |
| | | Lugu | 20 | 2.00 |
| 4 | Small Poles | Lamba Tureta | 100 | 0.50 |
| | (2.2 to 4.0cm) | Wurno | 100 | 0.50 |
| | | Lugu | 100 | 0.50 |
| 5 | Corn Stalks | Lamba Tureta | 4 bundles | - |
| | | Wurno | 5 bundles | - |
| | | Lugu | 5 bundles | - |
| 6 | Grass Straws | Lamba Tureta | 20 bundles | 5.00 |
| | (for stabilization) | Wurno | 15 bundles | 7.00 |
| | | Lugu | 10 bundles | 7.00 |
| 7 | Grass Taches | Lamba Tureta | 10 bundles | 5.00 |
| | for | Wurno | 10 bundles | 10.00 |
| | (skirt and roof) | Lugu | 10 bundles | 10.00 |
| 8 | Total Estimated | Lamba Tureta | | 600.00 |
| | Cost for Materials | Wurno | | 700.00 |
| | and Labour. | Lugu | | 700.00 |

* *Cost of Material in Naira as at February 1988.*

Wooden poles recognised by the villagers as termite resistant were purchased from a timber seller in the village. It was learnt that some farmers sometimes source the poles themselves from nearby bushes. Local names of some of the poles known to be termite resistant are 'guavan-daji', 'sabara','borogi' and 'geza'. Common lengths of these poles range between 1.4 to 2.6m with thicknesses between 2.2 to 8.3cm.

It was also found out that sometimes the builders charge for both the cost of the materials and labour so that materials already in their possession are used for the owner. Example of such estimated cost of material and labour were shown in Table 4.6 above.

**(c) Mud Preparation :** In preparing the mud about 95% of the soil brought to the site was first spread, the big clods were then broken up. 80% of the grass stabilizer purchased was then broken in to pieces over the soil, in breaking the grasses, they were held with two hands, squeezed and pulled resulting in pieces of 2 to 15cm lengths. Water was then continuously poured over the soil-grass assembly, while between five to eight men enter the mud pool to mix it by marching and trampling on and in the mud with bare feet. The mud covered their legs to sometimes upto the knee cap. After the grass has been properly incorporated in the mud, the mixture was covered with the cow dungs, and ashes, the remaining grass stabilizers were then used to cover the freshly mixed mud and allow to settle for three days. After the three days, the mud was uncovered and remixed, while adding more water and incorporating more broken grasses, the mixture was then heaped up and covered again with grasses and left to settle for three more days after which the mud was ready to be used. It was also learnt that some builders sometimes remix and allow for another three more days of settlement.

Whenever the mud is to be used, quantity to be used immediately is separated and remixed to a desired smoothness and consistency and where necessary more soil, water or grass stabilizer where incorporated. Quantity of grass stabilizer used varied between 0.8 to 1.3% of the dry soil by weight at the different sites visited. The mud moisture content were found to vary between 20.6 to 25.6%. Details of these are shown in Table 4.7. The compressive strength of the mud used at the various sites were found to range between 0.6 to 1.45N/mm$^2$, while the tensile strength were found to vary between 0.34 to 1.0N/mm$^2$. Details of these results are shown in Table 4.8

**Table 4.7 Ratio of Mud Constituents used at different sites.**

| S/No | Site* | Builder | Grass Type | Grass :Soil** | M.C |
|---|---|---|---|---|---|
| 1 | LT1 | A | Summer grass | 1.2 | 25.2 |
| 2 | LT2 | A | „ | 1.1 | 25.6 |
| 3 | LT3 | A | „ | 0.9 | 24.8 |
| 4 | LT4 | B | „ | 1.3 | 24.3 |
| 5 | LT5 | C | Mixed | 1.0 | 20.6 |
| 6 | WR1 | D | Gamba grass | 0.8 | 24.8 |
| 7 | WR2 | D | Rice Straw | 1.2 | 24.6 |
| 8 | WR3 | D | „ | 1.2 | 25.1 |
| 9 | LG1 | E | Mixed | 1.3 | 20.4 |
| 10 | LG2 | F | „ | 1.1 | 21.5 |
| 11 | LG3 | F | „ | 1.2 | 22.7 |

* LT = Lamba Tureta, LG = Lugu, WR = Wurno, ** Ratio is percentage weight of soil

**Table 4.8 Properties and Strength of Mud Used at the Different Sites.**

| S/No | Site | Mechanical Properties* | L.L | P.L | P.I | L.S | Compr Strength | Tensile Strength |
|---|---|---|---|---|---|---|---|---|
| 1 | LT1 | 25:34:41 | 26.0 | 11.9 | 13.1 | 7.1 | 1.02 | 0.49 |
| 2 | LT2 | ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 3 | LT3 | ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 4 | LT4 | 28:32:40 | 30.0 | 12.9 | 17.1 | 9.3 | 0.68 | 0.34 |
| 5 | LT5 | ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 6 | WR1 | 29:30:41 | 19.0 | 16.6 | 2.4 | 5.4 | 1.45 | 0.58 |
| 7 | WR2 | ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 8 | WR3 | 22:23:52 | 28.0 | 16.7 | 11.3 | 7.9 | 1.32 | 1.00 |
| 9 | WR4 | 16:20:64 | 22.5 | 10.7 | 11.8 | 2.9 | 0.82 | 0.73 |
| 10 | WR5 | ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 11 | WR6 | ,, | ,, | ,, | ,, | ,, | ,, | ,, |

* Mechanical Properties refer to ratios of Gravel : Sand : Clay (Strengths are in N/mm2)

L.L = Liquid Limit (%) P.I = Plasticity Index

P.L = Plastic Limit (%) L.S = Linear Shrinkage (%)

**(d) Foundation-Floor Assembly** : Three types of foundation-floor assembly obtain in the areas investigated. These are:

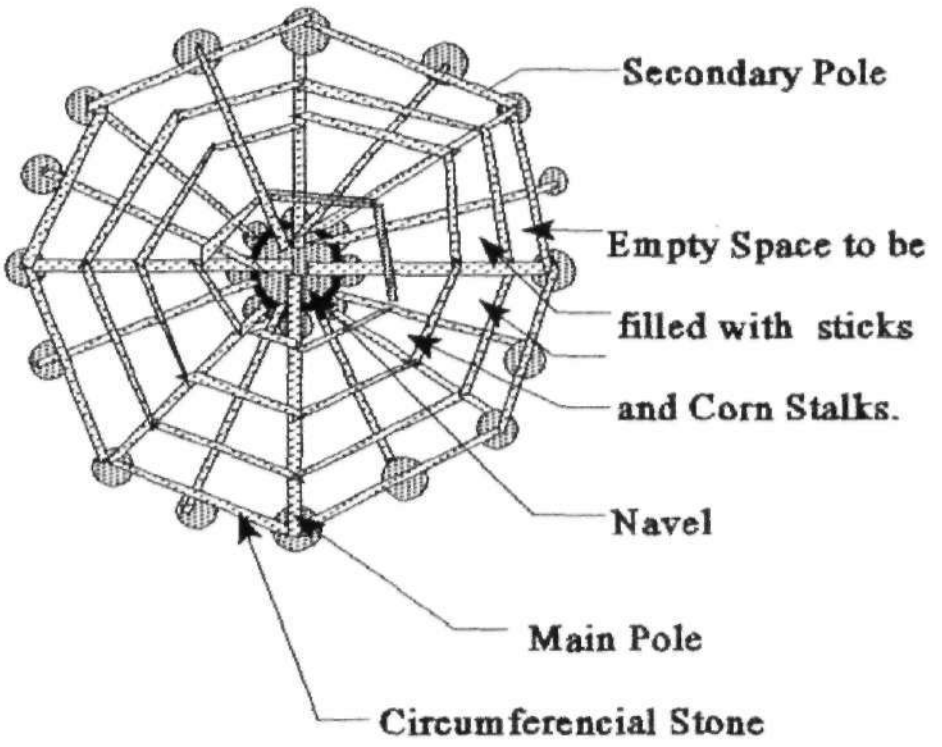
(i) Stone foundation with pole grillaged mud floor,

(ii) Stone foundation with mud floor,

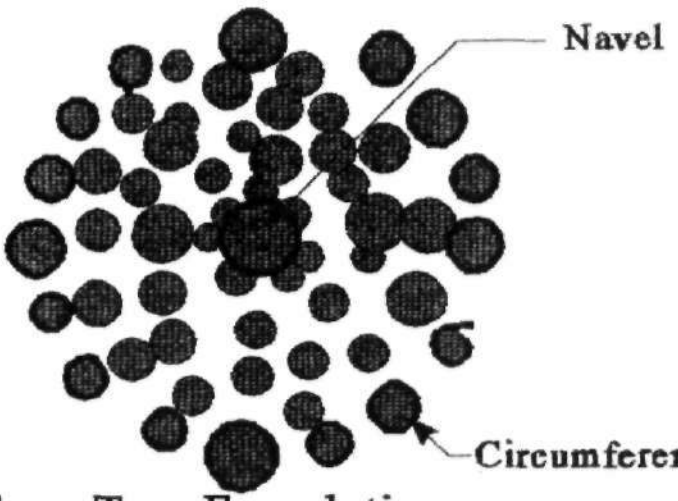
(iii) Strip foundation with raised compacted concrete floor.

**(i) Type One** : In this type, stones are used as foundation which then carries a grillage ofpoles on top which the mud floor is constructed. In constructing this type of assembly, a very big stone of about 25 to 45cm in diameter known as the navel is use at the centre while other stones which are smaller but of similar height to the navel are laid concentrically around the navel to support it. Other stones are the

arranged circumferencially at outer edge of the floor area at intervals of between 20 to 35cm. The stones are normally driven a little bit into the ground so as to achieve some form of stability. A grillage of poles is then constructed using the big termite resistance poles as longitudinal members while the smaller poles are used as the lateral members. The remaining spaces are then filled up with corn stalks and other small sticks. See figure 4.1(a). Starting from the centre, the premixed mud is moulded into a ball and laid at the navel or centre of the grillage, the mould is the flattened out to form a small disc of between 4 to 8cm thick. More mud moulds are blended in until the disc has reached a diameter of between 20 to 30cm. This is then left to dry for about ten to twelve hours when another 10 to 15cm layer of freshly premixed mud of the same thickness as before is layed carefully to blend with the drying layer. This process is continued until the floor is completed up to the circumference. This kind of foundation-floor assembly is the most commonly found within Lamba Tureta and Wurno.




**(a) Type One Foundation**




**(b) Type Two Foundation**

**(ii) Type Two:** In this type of foundation, the floor is completely supported on stones without any grillage of poles. The procedure of construction is to start with a big stone of about 30 to 40cm diameter at the centre of the floor area, other equally bigger stones are the arranged concentrically and closely up to the circumferential limit of the floor area. Smaller stones are then used to fill up any other spaces yet to be properly filled.stable. Starting from the centre, freshly premixed mud is used to begin the insitu casting of the mud floor on the bare stones in the same manner like for type-one. See figure 4.1(b). This type of foundation-floor assembly was found to be more common at Lugu in Wurno area. It was explained by the builders that this type of foundation-floor construction is favoured in this zone due to the sandy nature of the area making it difficult to achieve large size rumbu with the previous type of foundation-floor assembly.

**(iii) Type Three** : In this type, convectional concrete strip foundation of about 20cm width and 35cm depth is constructed, lateritic stones are then used to fill the floor such that they are sunken about 10cm deep into the ground and about 30cm above the ground. Cement stabilized lateritic soil is then used as the wall plaster and floor surfacing. This type of foundation was found to be used by the very big farmers and for rumbu bins having domed-cylindrical shapes with diameters above 5.0m.

**(e) Shell Construction**: This is the major part of the rumbu construction, during this period the builder is very carefiul with respect to uniformity of mud consistency, shell thickness and the overall shape of the structure. The casting procedure is exactly the same as for the floor, twice a day, (early in the mornings and in the evenings), the shell is casted with the height of each casting ranging between 8 to 10cm.

**(f) Finishing and Roofing**: The construction of the shell is continued until the structure is completed with an apical opening of between 0.6 to 1.0m diameter then structural finishings put in place. These include a mud ring provided at about the mid section and a thatch skirt worn above the ring. This arrangement serve as a deterrent to rodents, and as a prevention from rain on the wall. In constructing the mud ring, mud paste of about the same consistency as was used for the shell is formed into a ball , plastered on to the wall about the mid-section or a little bit higher then shaped into a small semi-cylindrical solid, more paste balls are then added to blend so as to continue a ring of near semi-circle in cross section. A thatch roof having a conical roof truss is then constructed on the floor and raised to cover the finished structure. Picture of a finished spherically shaped rumbu bin is shown in Figure4.2.

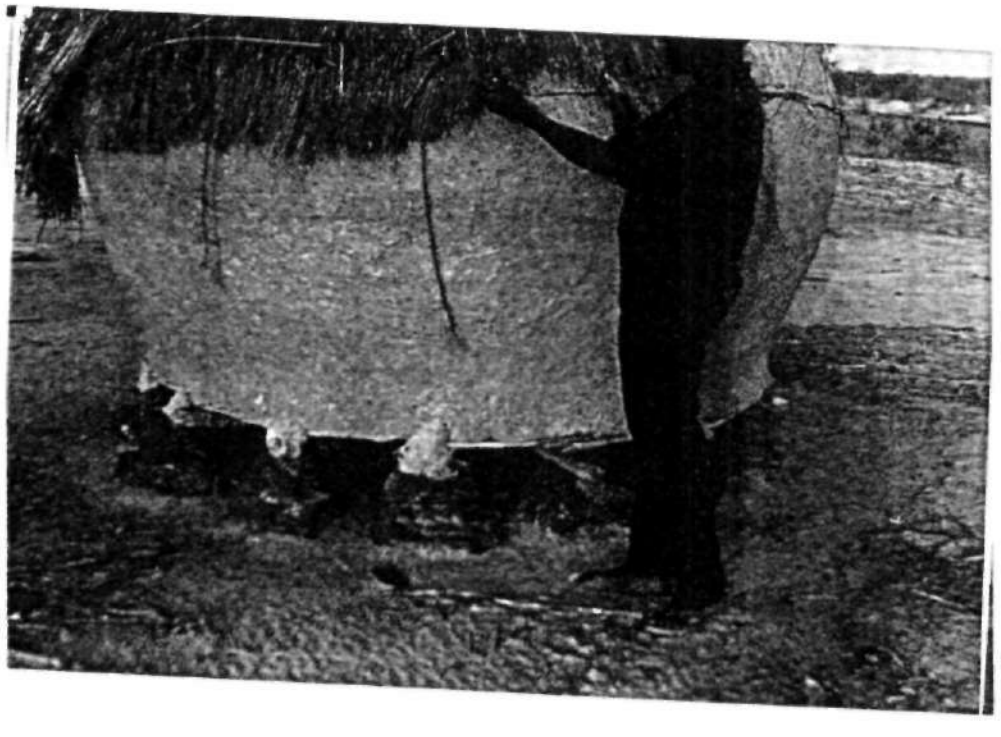


Figure 4.2 Picture of a Finished Spherically Shaped Rumbu

**4.2.2 Storage Practice:** The major crop found to be stored in the areas investigated is unthreshed millet. It was learnt that the crop is normally stored for a minimum of two years and a maximum of between seven to ten years. The unthreshed crops are brought from the farms in bundles tied with rope. The bundles are of same size with four bundles giving approximately 100 Kg of threshed grain. Where the millet is to be stored for a duration of one year or less, the bundles are not loosened, but stacked in the rumbu. Where however, the storage is to be for a long duration, the bundles are loosened, and put into the bin by a special arrangement carried out by four to eight people depending on the size and height of the rumbu. The first person stays on the ground looses the bundles and pass it to the second person who is on top of the bin or on the ladder. The third person who is inside the rumbu or on another ladder inside the rumbu collects the millet heads and together with the fourth person known as the "good hand" arrange the millet heads in the structure. The man referred to as the "good hand" is a person believed to be naturally disposed to storage, such that when he stores a product, minimum deterioration occurs compared to other people. In arranging the millet heads, the "good hand" arrange them in a concentrically overlocking pattern, such that the millet are self supporting in a way. After about 30 to 40cm depth of storage three to five other men climb into the structure and together with the two men already inside, the stored product is compressed. This procedure is continued until the bin is filled to the brim, when the roof is then lifted and put in place. After about three to four weeks, the rumbu bin is inspected for settlement. Settlement is the settling of the stored millet mass by virtue of its self weight resulting in both the reduction of depth of storage height and width. When about 5cm reduction in depth with a corresponding gap of about one to two centimetre between stored millet and rumbu shell is observed, the storage is considered good, the mouth of the bin is then sealed with a mud disc and the roof put in place.

Unloading of the stored crop could sometimes become difficult and cumbersome because of the above loading procedure. In large capacity rumbu bins, part of the shell may have to be broken to create an opening for ease off-loading, the created opening is later sealed after complete evacuation of stored product. Pictures of such situations are shown in Figure 4.3.

### 4.3 Assesment of Existing Rumbu Bins.

In assessing the existing rumbu bins, results obtained from the preliminary studies presented in section 4.1 were analysed as explained in section 3.3. It was found that not only did calculated capacities varied widely, but owner estimated capacities were in much cases much smaller than the calculated capacities. The analysis also showed that lateral pressures for spherically shaped rumbu bins were much higher than for the cylindrically shaped ones. Wall stresses as expected were found to be directly dependent on lateral pressures and wall thickness. Details of these findings are presented .

**4.3.1 Volumes :** The calculated bin volumes (based on approximated configurations, ie., S1 to S4) varied from 1.6m3 to 197.4$m^3$. For Lokoja-Abuja route, the average volume was found to be 2.2$m^3$ as compared to 5.3$m^3$ average obtained for Abuja-Kaduna route. The Gusau-Sokoto zone average is 101.8$m^3$ which is a little bigger than the Sokoto-Wurno-Kaura average of 88.1$m^3$. See Table 4.8 for details.

**4.3.2 Capacities:** The calculated bin capacities (Cap2), based on approximated configurations (S1 to S4) in terms of unthreshed millet were found to be very high varying from 10 to over 1000 bundles when compared with owner-estimated capacities (Cap1) which varied from 60 to 350 bundles for the same unthreshed millet. For the Lokoja-Abuja and Abuja-Kaduna route, there were no owner-estimated capacities, but calculated capacity averages were 13.5 and 33.4 bundles respectively. However for Zaria-Gusau zone, the calculated average capacity calculated to be 170.3 bundles was about 200% of owner-estimates, while for Gusau-Sokoto and Sokoto-Wurno-Kaura zones, the calculated average of 641.5 bundles was about 250% of the owner-estimates. See Table 4.8 for details.

**Table 4.8 Calculated Volumes and Capacities of Documented Rumbu Bins**

**(Based on approximated configurations S1 to S4 and assuming millet as stored crop)***

| S/No | Label | Vol | Cap1 | Cap2 | | S/No | Label | Vol | Cap1 | Cap2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | LA1 | 1.6 | - | 10.1 | | 21 | GS1 | 97.0 | 300 | 611.1 |
| 2 | LA2 | 2.3 | - | 14.5 | | 22 | GS2 | 170.5 | 350 | 1074.2 |
| 3 | LA3 | 2.4 | - | 15.1 | | 23 | GS3 | 197.4 | 350 | 1243.6 |
| 4 | LA4 | 2.5 | - | 15.8 | | 24 | GS4 | 180.2 | 350 | 1135.3 |
| 5 | LA5 | 1.9 | - | 12.0 | | 25 | GS5 | 28.1 | 100 | 177.2 |
| 6 | LA6 | 2.4 | - | 13.2 | | 26 | GS6 | 71.5 | 300 | 450.5 |
| 7 | AK1 | 4.6 | - | 29.0 | | 27 | GS7 | 67.4 | 300 | 424.6 |
| 8 | AK2 | 6.6 | - | 41.6 | | 28 | GS8 | 105.9 | 250 | 667.9 |
| 9 | AK3 | 5.0 | - | 31.5 | | 29 | GS9 | 147.0 | 300 | 927.1 |
| 10 | AK4 | 6.4 | - | 40.3 | | 30 | GS10 | 86.9 | 200 | 548.0 |
| 11 | AK5 | 4.3 | - | 27.1 | | 31 | GS11 | 56.1 | 200 | 353.8 |
| 12 | AK6 | 5.2 | - | 32.8 | | 32 | GS12 | 13.4 | 100 | 84.4 |
| 13 | AK7 | 5.0 | - | 31.5 | | 33 | SWK1 | 135.2 | 300 | 851.7 |
| 14 | ZG1 | 9.5 | 60 | 59.9 | | 34 | SWK2 | 148.7 | 300 | 936.8 |
| 15 | ZG2 | 7.2 | 50 | 77.5 | | 35 | SWK3 | 64.1 | 150 | 403.8 |
| 16 | ZG3 | 23.3 | 70 | 146.8 | | 36 | SWK4 | 21.2 | 100 | 133.6 |
| 17 | ZG4 | 23.4 | 120 | 235.6 | | 37 | SWK5 | 131.2 | 250 | 826.6 |
| 18 | ZG5 | 27.5 | 100 | 173.3 | | 38 | SWK6 | 132.1 | 250 | 832.2 |
| 19 | ZG6 | 40.6 | 100 | 255.8 | | 39 | SWK7 | 34.8 | 200 | 19.24 |
| 20 | ZG7 | 38.6 | 100 | 243.8 | | 40 | SWK8 | 37.4 | 200 | 235.6 |

*Vol = Volume of Bin (m3) Cap1 = Capacity of bin in bundles (Owner-estimate)

One bundle of unthreshed millet = 37.5Kg Cap2 = „ „ „ „ (Calculated estimate)

Bulk Density of unthreshed millet = 2.3KN/m3.

**Table 4.9 Volume and Capacity Averages of The Documented Rumbu Bins For The Different Zones.**

| S/No | Zones | Vol | Cap1 | Cap2 |
|---|---|---|---|---|
| 1 | LA | 2.2 | - | 13.5 |
| 2 | AK | 5.3 | - | 33.4 |
| 3 | ZG | 24.3 | 85.7 | 170.3 |
| 4 | GS | 101.8 | 258.3 | 641.5 |
| 5 | SWK | 88.1 | 218.8 | 554.9 |

LA = Lokoja-Abuja Zone ZG = Zaria -Gusau Zone

Ak = Abuja-Kaduna Zone GS = Gusau-Sokoto Zone

SWK = Sokoto-Wurno-Kaura Zone

Cap1 = Capacity of Rumbu bin in bundles (Owner-estimate)

Cap2 = Capacity of Rumbu Bin in bundles (Calculated)

The values obtained for calculated volumes agree to some extent with those obtained by Giles (1965), who documented the maximum and minimum sizes of rumbu obtainable in Northern Nigeria to be 91.4m3 and 0.94m3 respectively. Since his findings were in 1965, this might indicate that there has been some improvement in bin sizes since then.The values obtainedfor capacities agree with the findings of Bungudu (1970) who gave owner-estimated capacities for the village of Bungudu situated in the Zaria-Gusau zone as between 50 to 200 bundles of unthreshed sorghum. Giles (1965) on the other hand puts the maximum estimated capacity for the biggest rumbu bin in Northern Nigeria as 800 bundles.

A close study of tables 4.8 and 4.9 would shows that a trend of volume and capacity increase exist from Lokoja towards Abuja down to Kaduna. This increasing trend is continued upto Gusau, and Sokoto. The explanation for this is probably rooted in the vegetational and socio-historical changes that also follow this trend. For while the area between Lokoja towards Abuja and close to Kadma is part of Guinea savannah with alot

of rainfall, the area between Zaria and Gusau belongs to the sudan savannah region with less rainfall. As from Gusau towards Sokoto and Wurno belongs to the Sahel savannah with little rain and often draught stricken. This vegetational changes makes it easier to grow only the draught resistant crops like millet in the Sokoto area, and makes it important to have a storage structure, as the probability of famine increases with reduction of rainfall. Socio-historically, the area north of Zaria enjoyed rich architectural and advanced building technology due to the advent of Islam, giving rise to better rumbu structures.

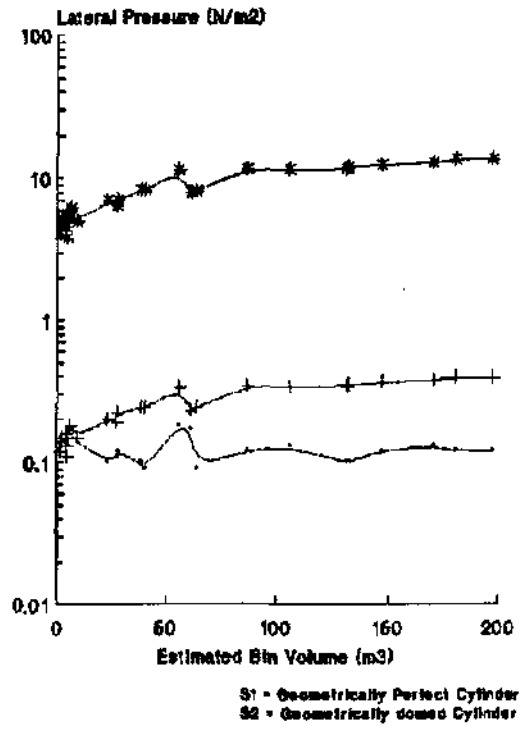
The wide differences between owner-estimates and the calculated values can be attributed to two reasons. The first has to do with low degree of accuracy of the owners, for owners generally estimate capacities in fifties making it possible to have an estimation error of at least 30% for an average size rumbu bin of 150bundles. The general estimate by farmers that four bundles of unthreshed crop should thresh to give 100 Kg of threshed grains is subject to error of sometimes more than 20% depending on the crop variety, management and yield per hectare. The second reason can be attributed to method of calcuation which used bulk density thereby assuming that all available space was utilized.

**4.3.3 Lateral Pressures on Rumbu Bin Walls** : The lateral pressures were generally much higher for spherically shaped rumbu bins than for others. Lateral pressures calculated due to unthreshed millet based on owner-estimate capacities varied between 0.09 to 0.18 N/m2 for the cylindrically shaped bins and between 2.4 to 6.6 N/m2, but based on computed capacities for unthreshed millet, the lateral pressures increased in some cases to more than 350%. The implication of this result is that load inside the bin have been seriously under estimated. This implies that no rational design could have been possible using owner

estimated capacities. Detail results of these values are shown in table of Appendix B and graphically presented in Figures 4.4.

Lateral pressures based on threshed millet were found to be astronomically higher than for unthreshed. These were sometimes 10,000% of what was obtained for the unthreshed grains. The implication of this also, is that rumbu bins presently used will have to be tested for structural stability before they can be satified for use in holding grains to full capacity. Details of computed values are shown in Appendix B and graphically presented in Figure 4.4

(a) S1 and S2 Type Bins




(b) S3 Type Bin

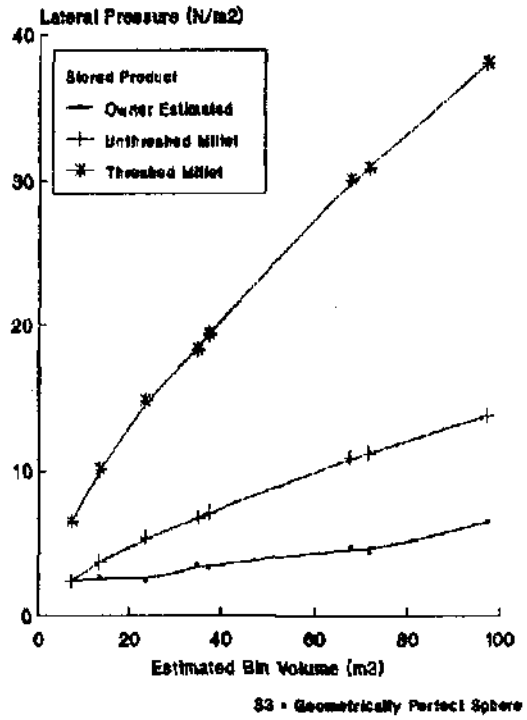
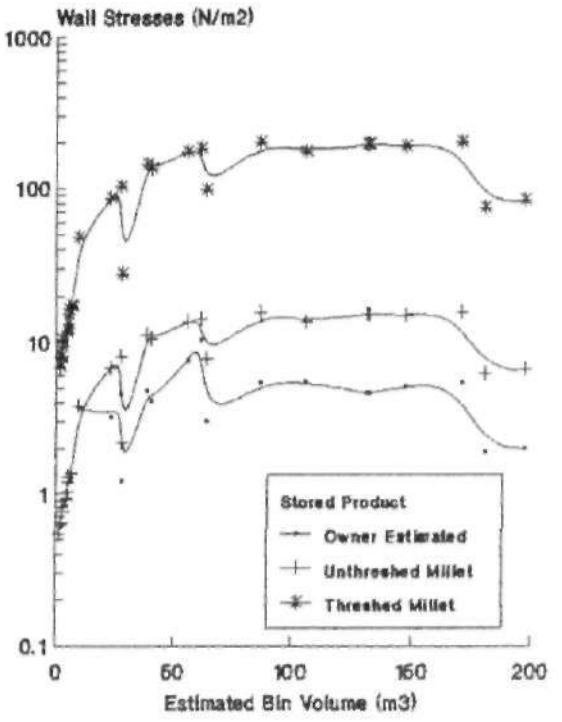



Figure 4.4 Effect of Bin Capacity on Lateral Wall Pressures of Bins

Since lateral pressure is a function of height, while capacity is more a function of diameter, the plot of pressure verses volume did not exactly resulted in a straight line, though it is clear that there is a general trend of increase in lateral pressure with volume. This mean that builders that construct shorter bin of the same capacity, subject the bins to less pressure.

**4.3.4 Bin Wall Stresses** : The stresses created within bin walls as a result of the lateral pressures were found to vary with respect to both wall thickness and bin size, detail results of these stresses are shown in Appendix B, while the plot of the stresses verses the volume is shown in Figure 4.5. Lateral pressures acting on the lower part of the spherically shaped bins was more or less close in magnitude to the vertical pressures acting on the floor, resulting in very high tensile stresses, which was in most cases 300% of what obtained for walls of the cylindrically shaped bins.

(a) S1 and S2 Type Bins




(b) S3 Type Bins

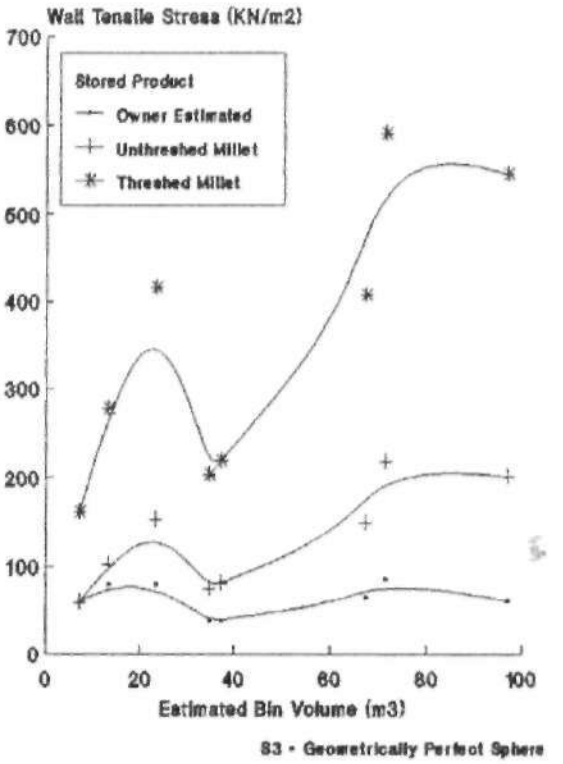



Figure 4.5 Effect of Bin Capacity on Wall Stresses of Rumbu Bins

### 4.4 Structural properties of mud

The mechanical properties of the soil used for the preparation of mud was determined to be as follows:

| | |
|---|---|
| Liquid limit | 34.5% |
| Plastic limit | 24.4% |
| Plasticity index | 10.1 |
| Specific gravity | 2.69 |
| Maximum dry density | 1852.6 kg/m3 |
| Optimum moisture content | 16.2% |

From the results of the sieve and hydometer analysis, the soil grain were found to be in the ratio of 28:30:42 for gravel, silt and clay respectively.

The results of the material investigation carried out showed that both the water : soil and the stabilizer : soil ratios had significant effect on the general behaviour of mud. However the effect of their interactions were only significant with respect to paste consistency, bulk density, compressive and tensile strengths. Detail of the results are shown in Appendix C-1 and C2, while graphical representations, statistical analysis, and interpretations are presented below.

**4.4.1 Paste Consistency (PC) :** The paste consistency of the fresh mud measured using the mud consistometer described in section 3.3 was found to vary between 12 to 94mm with a mean of about 49.8mm for mud stabilized with summer grass (stabilizer-A) and 45mm for mud stabilized with rice straw (stabilizer-Both the water : soil ratio and the stabilizer : ratio were found to have significant effect at 1% level of significance. The effect of the water : soil ratio was however more pronounced as is evident from graphs of Figure

4.6. There is a general trend of increase in PC with increase of water : soil ratio, and a decrease of PC with increase of stabilizer : soil ratio. The Value of PC was found to be minimum at maximum stabilizer : soil ratio (1.5%) and minimum water : soil ratio (20%). Stabilizer-B however seem to be more effective in lowering the paste consistency as the water : soil ratio increases.

Interactive effect of both the water : soil ratio and the stabilizer : soil ratio was found to be significant at 1% level of significance. Regression analysis carried out showed that paste consistency can be predicted for stabilizer-A mud at 91.8% and for stabilizer-B mud at 96.4% level of confidence.

The prediction equations for PC are:

Stabilizer-A

$$PC\ (mm) = -86.2 - 0.27A + 4.96MC\% \quad \text{.....(4.1)}$$

Stabilizer-B

$$PC\ (mm) = -73.4 - 10.4B + 4.57MC\% \quad \text{.....(4.2)}$$

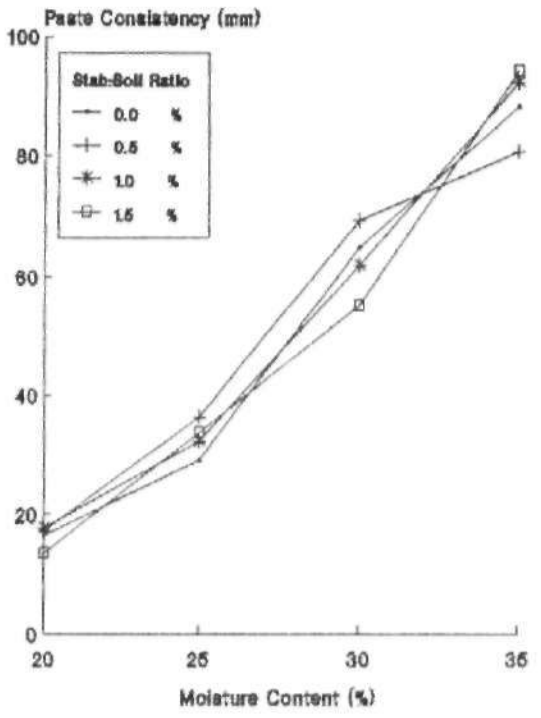
where PC (mm) = Paste consistency (%)

A = Stabilizer : Soil ratio for summer grass stabilizer

B = „ „ „ for rice straw stabilizer

MC = water : Soil ratio (%)

(a) Stabilizer-A




(b) Stabilizer-B

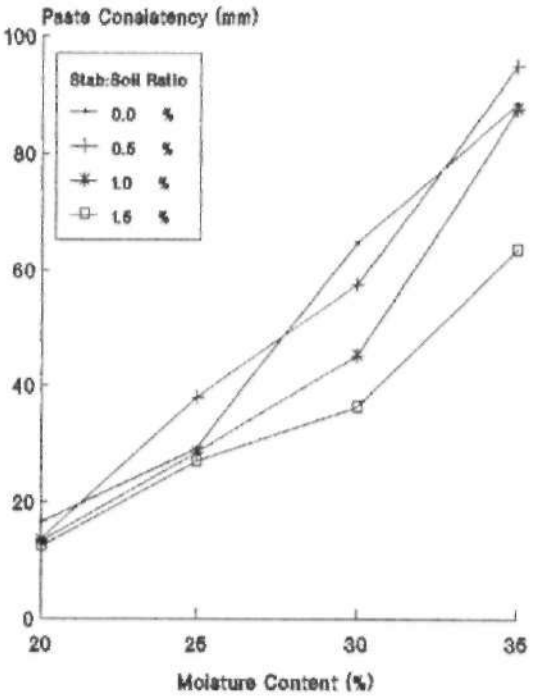



Figure 4.6 Effect of Water-Soil Ratio on Paste Consistency (PC) of Mud for Stabilizers- A and -B at Different Stabilizer-Soil Ratios.

The trend in the above result is because consistency is a measure of paste flowability and viscosity, therefore increase in water : soil ratio is likely to cause more flow and less viscosity, thereby increasing consistency. The incorporation of non fluid material like grass stabilizer no doubt reduced flowability as is indicated also by the result. However the effect of the stabilizers were found to be vary, with the thicker and more coarse rice straw reducing the paste consistency better than the summer grass which is thinner and smoother.

**4.3.2 Shrinkage Ratio (SR):** The shrinkage ratios for the mud samples ranged between 2.0 to 6.7% with a 4.3% mean for stabilizer-A samples and a mean of 4.6% for stabilizer-B samples. The shrinkages were significantly affected by both the water : soil ratio and the stabilizer:soil ratio at 1% level of significance. Shrinkage generally increased with water:soil ratio and decreased with stabilizer:soil ratio. Stabilizer-A was however found to be more effective in decreasing shrinkage ratio as demonstrated by higher F-factors obtained and presented in Appendix E1. The graphs as in Figure 4.7 also confirm this trend.

The interaction effect on the shrinkage ratio was however not found to be significant at 5% level of significance. Regression analysis carried out showed that shrinkage ratios can be predicted for stabilizer-A and stabilizer-B with 96.5% and 91.8 % level of confidence respectively. The prediction equations for SR are:

Stabilizer-A

$$S.R\ (\%) = -0.434 - 1.13A + 0.201MC\ (\%) \quad \text{.....(4.3)}$$

Stabilizer-B

$$S.R\ (\%) = 1.36 - 0.740B + 0.138MC\ (\%) \quad \text{.....(4.4)}$$

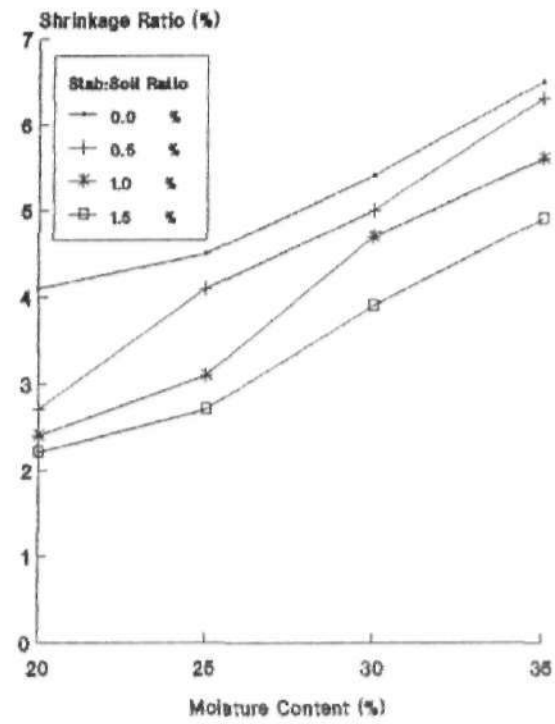
where S.R (%) = Shrinkage ratio (%)

A = Stabilizer:soil ratio for summer grass stabilizer

B = „ „ „ for rice straw stabilizer

MC = water : Soil ratio (%)

(a) Stabilizer-A




(b) Stabilizer-B

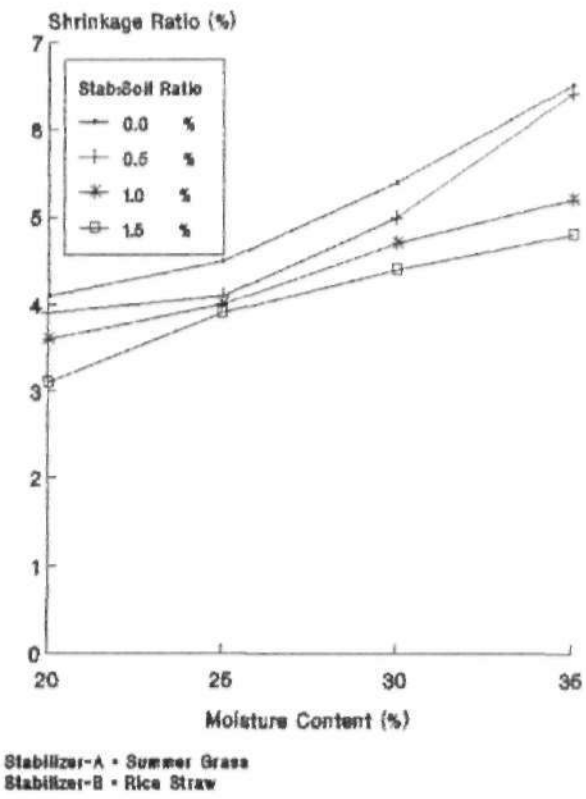



Figure 4.7 Effect of Soil-Water Ratio on Shrinkage of Mud for Stabilizers-A &-B at Different Stabilizer-Soil Ratio.

The shrinkage ratio values obtained can be judged as reasonable when compared with those of stabilized lateritic soils. Singh and Dirisu (1985) obtained a drying shrinkage of 4.3% and 4.0% for fired and stabilized bricks respectively.

The reason for shrinkage being lowest at minimum water : soil ratio is that shrinkage occurs as a result of contraction of wet paste as it dries, therefore less free water would mean less contraction . The tendency for the incorporated grasses to resist this contraction is a probable explanation for the reduction of shrinkage with increased stabilizer soil ratio. The result also show that stabilizer-A reduces shrinkage better, this may be due its higher strength and the existence of nodes, thereby causing it to resist contraction better than stabilizer-B.

**4.3.3 Bulk Density (BD)** : The bulk densities for the mud samples varied between 1529 to 1997Kg/m3, with a mean of 1719.5Kg/m3 for stabilizer-A samples and 1737.6Kg/m3 for stabilizer-B samples. The effect of water : soil and stabilizer:soil ratios were significant at 1% level of significance and there was a general trend of decrease of bulk density with increase of water-soil and stabilizer-soil ratios as can be observed from figure 4.8. The F-factor ratios of the two way analysis ( presented in Appendix E1) shows that stabilizers reduce bulk density more than water for the range of water-soil ratios tested. Interactive effects of both variables was also found to be significant at 1%.

A regression analysis showed that bulk densities of dried samples can be predicted for stabilizer-A with 86.2% and for stabilizer-B with 89.5% levels of confidence. The prediction equations are :

Stabilizer-A

$$BD = 2150 - 201A - 10.1MC \quad \text{.....(4.5)}$$

Stabilizer-B

$$BD = 2229 - 185B - 12.8\% \quad \text{.....(4.6)}$$

where BD = Bulk density (Kg/m3)

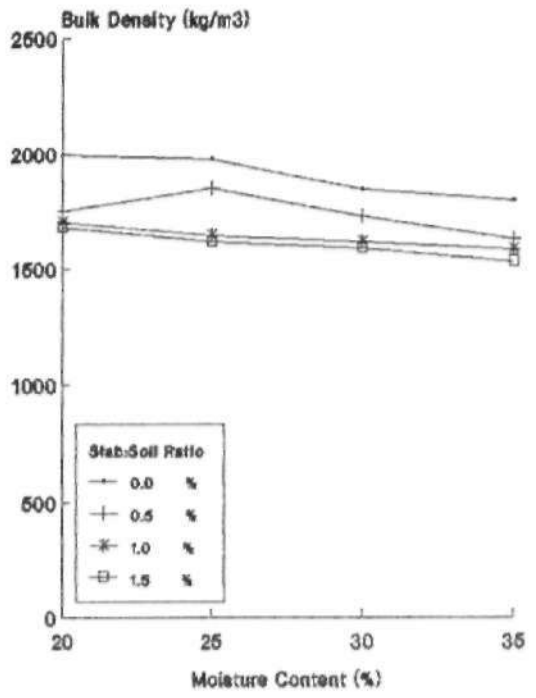
A = Stabilizer:soil ratio for summer grass stabilizer (%)

B = „ „ „ for rice straw stabilizer (%)

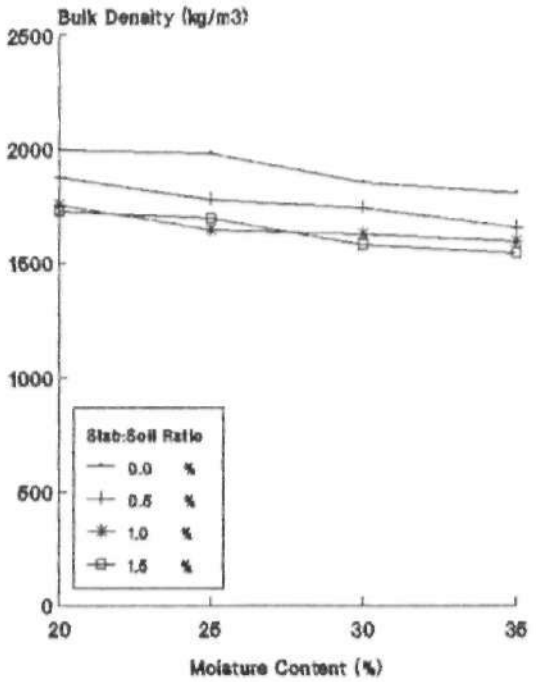
MC = water : Soil ratio (%)

The values of the bulk densities obtained can be said to be high when compared to those of fired or cement and lime stabilized bricks. Singh and Dirisu (1985) obtained the bulk density of fired and cement stabilized bricks to be 1700 and 1800Kg/m3 respectively. Ola (1985) found the maximum dry density of some cement stabilized Kwara soils to vary between 1730 and 1810Kg/m3. Reasons for the high densities obtained with mud may be attributed to both the high level of clay and unsieved gravels present in the mud. The steady decrease of bulk density with water : soil ratio confirms that water : soil ratios used were above the optimum moisture content.

(a) Stabilizer-A




(b) Stabilizer-B



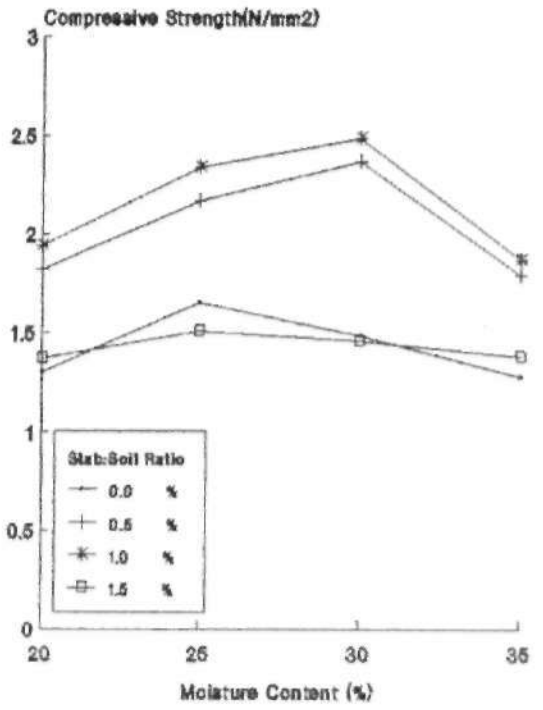

Stabilizer-A : Summer Grass
Stabilizer-B : Rice Straw

Figure 4.8 Effect of Soil-Water Ratio on Bulk Density of Mud for Stabilizers-A &-B at Different Stabilizer-Soil Ratio.

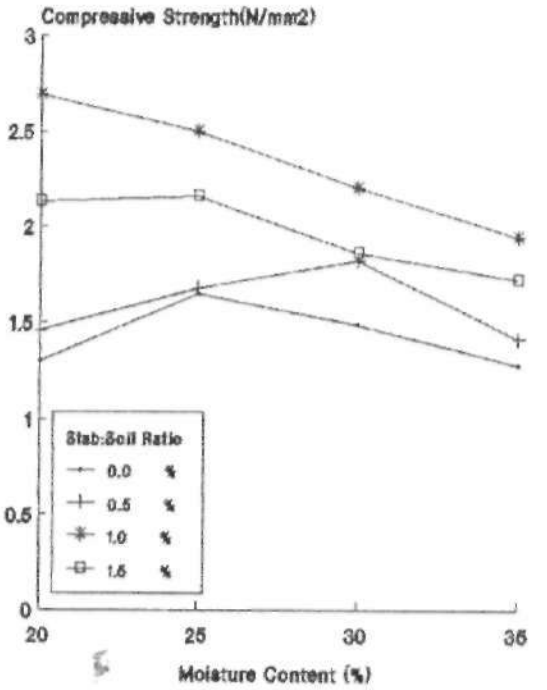
**4.4.4 Compressive Strength (un-settled mud):** The compressed strength of the unsettled mud ranged between 1.24 to a maximum of 2.69N/mm2 and were significantly affected by both the water : soil and the stabilizer:soil ratios at 1% level if significance. The F-factor values are shown in Appendix E1.

The maximum compressive strength occurred at an optimum stabilizer:soil ratio of 1.0% for both stabilizers-A and stabilizer-B. The corresponding optimum for the water:soil ratio is 30% for stabilizer-A, while for stabilizer-B, the optimal water:soil ratio changes for every stabilizer:soil ratio as shown in figure 4.9. Interactive effect of both variables was found to be significant at 1%, but regression analysis shows that compressive strength for unsettled mud can not be predicted with any reasonable leve of confidence.

(a) Stabilizer-A (Unsettled Mud)




(b) Stabilizer-B (Unsettled mud)




Stabilizer-A - Summer Grass
Stabilizer-B - Rice Straw

Figure 4.9 Effect of Soil-Water Ratio on Dry Compressive Strength of Unsettled Mud for Stabilizers-A &-B at Different Stabilizer-Soil Ratio.

**4.4.5 Compressive Strength (settled mud) :** The compressive strength of mud was found to increase by at least 5.% due to settlement. The compressive strengths ranged from 2.0 to 4.2N/mm$^2$ with a mean of 3.38 and 3.23N/mm$^2$ for stabilizers A and B mud samples. However, interactive effect of the two variables was not as pronounced as for unsettled mud samples. The F-factor ratios were in some cases less than 2.5% of those of unsettled mud. The effect of the stabilizer:soil ratio was not significant at 5% for stabilizer-A even though it was significant at 1% for stabilizer-B. There was a trend of decreased compressive strength for increased water:soil ratio for stabilizer-A mud samples as can be observed from Figure 4.10 below. Regression analysis carried out show that compressive strength for settled mud can be predicted for stabilizer-A mud samples with 84.7% level of confidence. Prediction for stabilizer-B samples was only possible with 1% level of confidence. The regression equations are:

Stabilizer-A

$$CS2 = 5.72 - 0.335A - 0.0735MC \quad \text{.....(4.7)}$$

Stabilizer-B

$$CS2 = 4.38 - 0.25B - 0.034MC \quad \text{.....(4.8)}$$

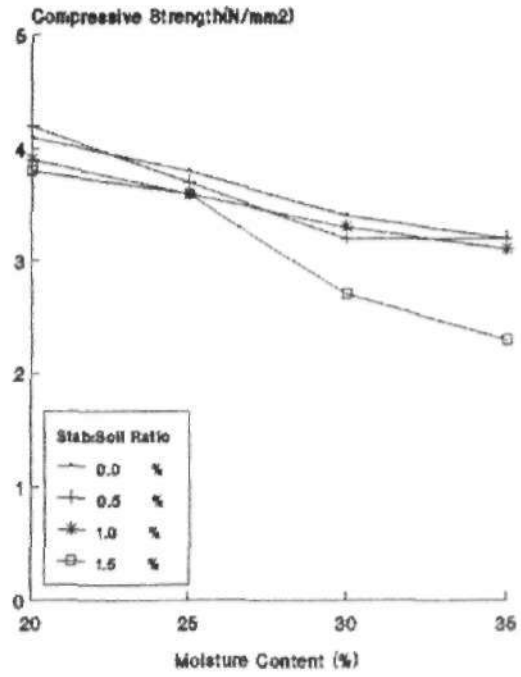
where CS2 = Compressive Strength for settled mud (N/mm$^2$)

A = Stabilizer:Soil ratio for stabilizer-A (%)

B = Stabilizer:Soil ratio for stabilizer-B(%)

MC = Water:Soil ratio (%)

(a) Stabilizer-A (Settled Mud)




(b) Stabilizer-B (Settled Mud)

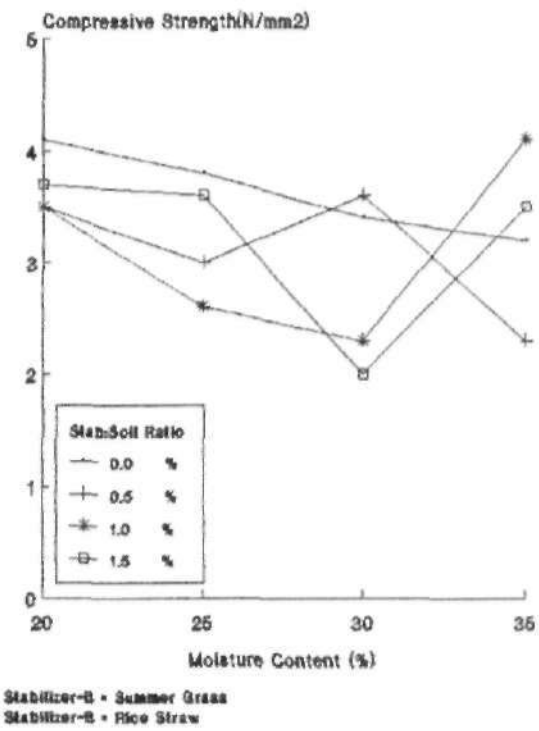



Figure 4.10 Effect of Soil-Water Ratio on Dry Compressive Strength of settled Mud for Stabilizers-A &-B at Different Stabilizer-Soil Ratio.

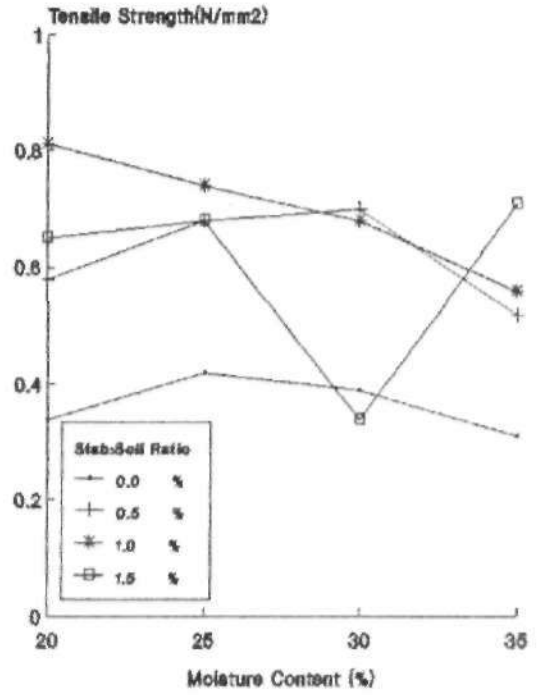
The differences observed between settled and unsettled mud may be attributed to increased cohesion that takes place due to longer soaking period. This also justifies the local belief that period of settlement has effect on mud strength. The influence of settlement may also explain the no explainable trend for varying quantity of stabilizer as was the case for stabilizer-B samples.

The values obtained for both the settled and unsettled mud compares well with lime and cement stabilized lateritic soils. Akinmusuru and Adebayo (1981) obtained a maximum compressive strength of 1.74N/mm$^2$ for plant fibre reinforced mud block. Singh and Dirisu (1985) quoted 1.4N/mm$^2$ as the minimum compressive strength considered adequate for single story buildings, and that Fitzmaurice has suggested that values could be reduced to 0.69N/mm$^2$ for low cost housing containing up to 70% gravel. They also quoted 1.76N/mm$^2$, 1.39N/mm$^2$ and 2.5N/mm$^2$ as the minimum requirements for stabilized blocks in India, Ghana and Nigeria respectively.

**4.4.6 Tensile Strength (un-settled mud)** : The tensile strengths measured using the approximate method of split test gave values of between 0.27N/mm$^2$ to 0.81N/mm$^2$ with a mean of 0.56N/mm$^2$ and 0.46N/mm$^2$ for stabilizers A and B samples respectively. The results obtained using the direct method of Ibrahim (1980), gave values that were 2 to 11% higher than those of the split cylinder. The trend were however the same and for this reason, the split cylinder values were used in the discussions that follow. Detail results are presented in Appendix C-1 and C2. There is a trend of strength increase with stabilizer-soil ratio (see graph of Figure 4.11 ). Effects of both variables were significant at 1%. For stabilizer-B mud, maximum strength (0.7N/mm$^2$) was obtained at an optimum water:soil ratio of 30%

and maximum stabilizer:soil ratio. For stabilizer-A, the maximum tensile strength (0.81N/mm$^2$) was obtained at the lowest water:soil ratios and 1% of stabilizer:soil ratio.This evidently suggests that grass stabilizer improve the tensile strength of mud but upto a certain optimum. The possible explanation is that during tension, there has to be a split of the stabilizing fibres that lie across the split boundary in addition to the cohesive forces binding the clay particles. However increasing the quantity of grass fibre leads to a gradual reduction of the cohesive forces binding the clay particles up to a point where additional grass fibre result in overall reduction of strength.

(a) Stabilizer-A (Unsettled Mud)




(b) Stabilizer-B (Unsettled Mud)

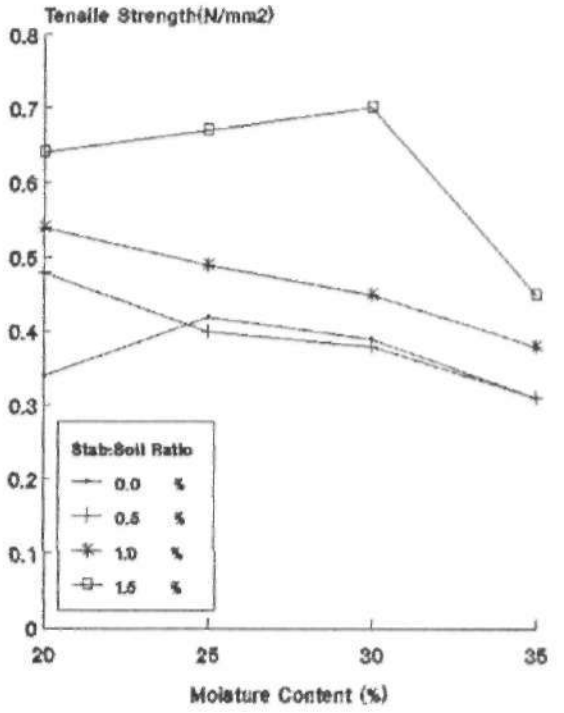



Figure 4.11 Effect of Soil-Water Ratio on Dry Tensile Strength of Unsettled Mud for Stabilizers-A &-B at Different Stabilizer-Soil Ratio.

**4.4.7 Tensile Strength ( settled mud ):** As was the case for compressive strength, settled mud had tensile strengths that were at least 50% higher than for unsettled mud. The approximate tensile strengths ranged from 0.34N/mm$^2$ to 1.33Nmm$^2$. Stabilizer-A had higher tensile strengths than stabilizer-B mud. For stabilizer-A mud, there is a trend of strength increase with stabilizer:soil ratio upto an optimum of 1.0%. For stabilizer-B mud, maximum strength occurred at minimum water:soil and stablilizer:soil ratios with a continuous decrease of strength as the ratios of the variables increases, see Figure 4.12 for the graphical presentation. Statistical analysis show that the effect of the two variables were individually and interactively significant at 1% test of significance. Reasons for increase in strength with respect to settlement of the mud is the same as earlier explained for compressive strength of settled mud. Regression analysis carried out showed that tensile strength for settled mud can be predicted for stabilizer-B mud with some reasonable level of confidence (71.4%). But for stabilizer-B mud level of confidence is too low(30.2%). The regression equations are:

Stabilizer-A

$$TS2 = 1.40 + 0.148A - 0.0179MC \quad \text{.....(4.9)}$$

Stabilizer-B

$$TS2 = 1.95 - 0.136B - 0.0395MC \quad \text{.....(4.10)}$$

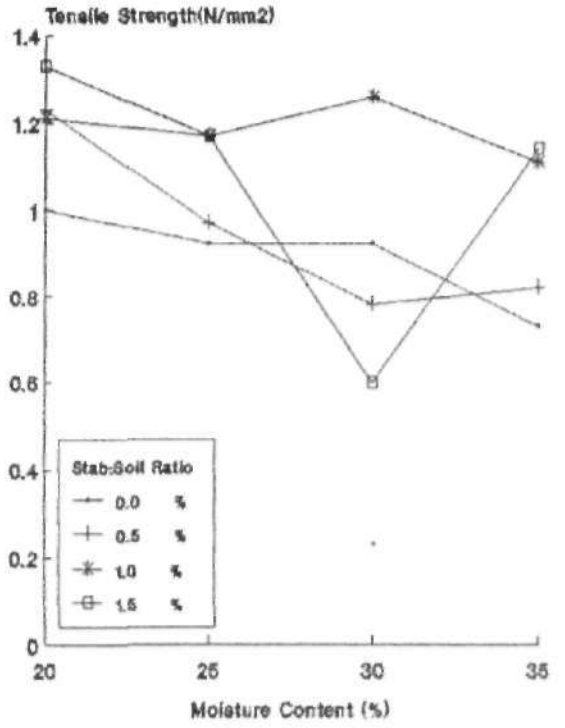
where TS2 = Tensile strength of mud (N/mm$^2$)

A = Stabilizer:Soil ratio for stabilizer-A (%)

B = Stabilizer:Soil ratio for stabilizer-B(%)

MC = Water:Soil ratio (%)

(a) Stabilizer-A (Settled Mud)




(b) Stabilizer-B (Settled Mud)

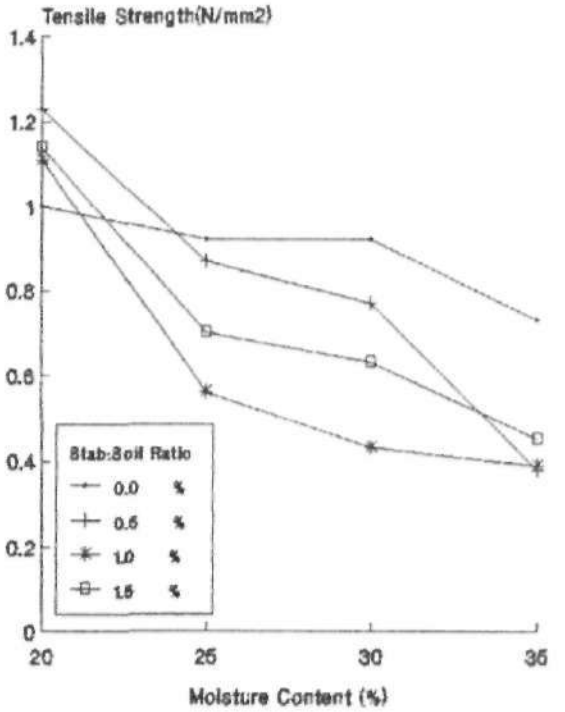


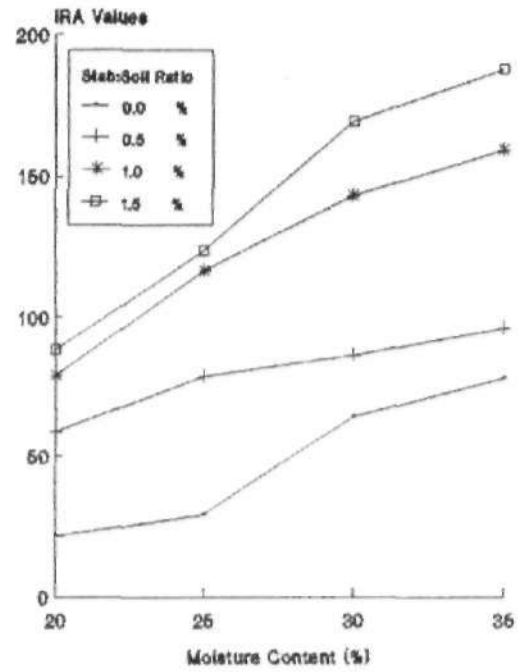

Figure 4.12 Effect of Soil-Water Ratio on Dry Tensile Strength of settled Mud for Stabilizers-A &-B at Different Stabilizer-Soil Ratio.

### 4.4.8 Durability

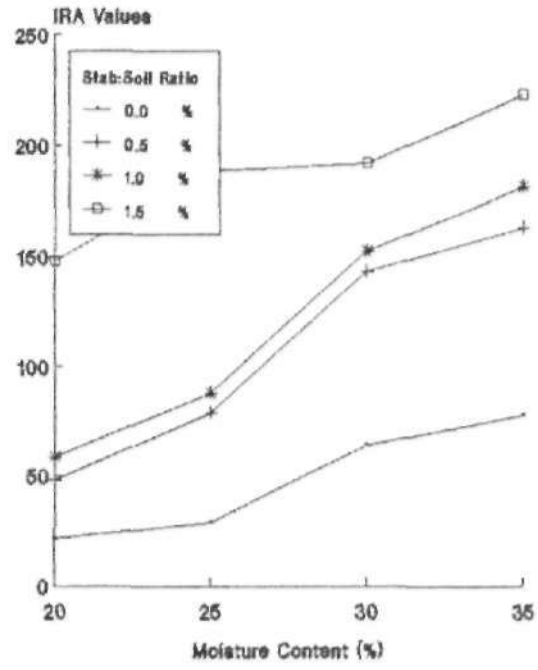
The water absorbtion tests gave Initial Absorbtion Rate (IRA) values of between 22 to 222 as compared to values of lower than 30 normally observed for soilcrete samples. The percentage soil loss arising from the modified brushing test were in the range of 13% to over 30% as compared to the less than 10% normally observed for soilcrete samples. However the results show a comparative trend between the different samples as explained below.

**(a) Water Absorbtion :** The IRA values increased with increased in both water-soil ratio and stabilizer-soil ratio as shown in graphs of Fig 4.13. Detailed IRA values are presented in Appendix C1 and C2. The values were generally lower for stabilizer-A samples than for stabilizer-B samples. The lowest value of 21.5 occurred for 0% stabilizer-soil ratio and 20% water-soil ratio mud samples, while the maximum value of 222.2 was obtained for 1.5% stabilizer-soil ratio and 35% water-soil ratio mud samples. Statistical analysis showed that effect of both the stabilizer-soil ratio and the water-soil ratio on the IRA values were individually significant at 1% level of statistical significance.

(a) Stbilizer-A




(b) Stabilizer-B




Stabilizer-A - Summer Grass
Stabilizer-B - Rice Straw
IRA - Initial Rate of Absorbtion

Figure 4.13 IRA Values Based on 3mm-One Minute Immersion Tests of Stabilizer -A & -B Mud Samples

The interactive effect of the two variables were not significant at 5% level of statistical significance. The F-ratio values of the two-way ANOVA tests are shown in Appendix E1. The lower values of IRA for the stabilizer-A samples could be attributed to the thin nature of the stabilizer-A fibre, resulting in a lower porosity when compared to stabilizer-B with thicker fibres.

**(b) Brushing Test** : The percentage soil weight loss resulting from the modified brushing test followed the same trend as for the water absorbtion test reported above. However the effect of the two variables were found to be statistically insignificant at 5% level of statistical significance. Detailed result is presented in Appedix C1and C2, while the trends are shown in Figure 4.14. The F-ratios for the ANOVA test is shown Appendix E1. The reason of fibre size advanced above could also be said to be responsible for the trend obtained here. The statistical insignificance can be attributed to the presence of other factors that affect soil loss. Soil loss during brushing is both a factor of soil-grass, soil-soil bond strength and resistance of the bond as it absorbs water. Since both factors cannot easily be separated with respect to procedure used, it is difficult for fibre size to individually play a significant role.

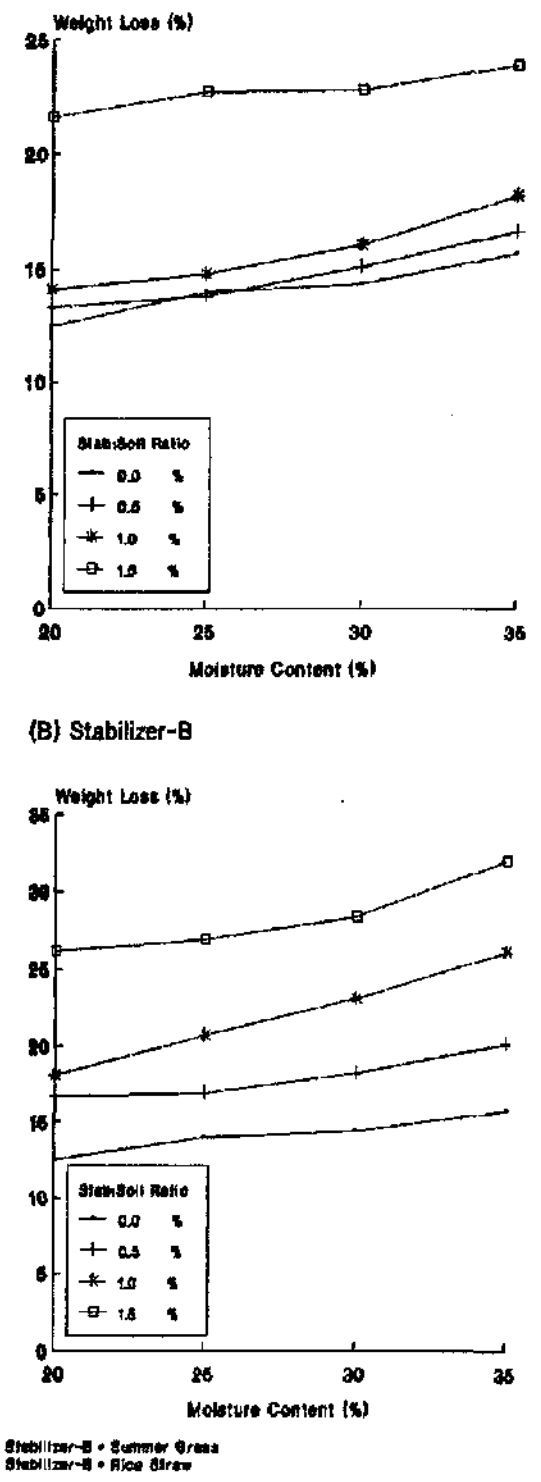



Figure 4.14 Percentage Weight Soil Loss From the Modified Brushing Method of Testing Durability.

## 4.4 Comparative Evaluation

The results of the comparative evaluation of structural properties showed that grass stabilized mud samples compared favourably with both bitumen and lime stabilized mud samples. It also showed that bitumen stabilized mud samples were most durable, while grass stabilized samples were least durable. Comparative evaluation of functional properties showed that mud as a material was more functional in resisting changes due to rise and fall of ambient temperatures, while sandcrete and steel materials were more functional in coping with varying ambient relative humidity.

**4.4.1 Structural Properties** : The mechanical properties of the new soil used was found to be as follows:

| | |
|---|---|
| Liquid limit | 30.2 |
| Plastic limit | 17% |
| Plasticity index | 12.3% |
| Specific gravity | 2.68 |
| Maximum dry density | 1819.2 |
| Optimum moisture content | 10.8 |

The result of the sieve analysis showed that the soil grains were in the ratio of 55:32.5:12.5 for gravel, silt, and clay respectively.

The results of the structural properties measured are shown in Table 4.10.

**Table 4. Structural Properties of Mud Stabilized with Grass, Lime, and Bitumen.**

| S/No | Stabilizer | m.c | BD | PC | SR | CS | TS | IRA | WL |
|---|---|---|---|---|---|---|---|---|---|
| 1 | grass | 24.4 | 1853 | 6.0 | 1.9 | 1.59 | 0.24 | 24.2 | 12.1 |
| 2 | lime | 18.0 | 1890 | 4.5 | 2.1 | 1.88 | 0.07 | 14.4 | 2.3 |
| 3 | bitumen | 16.9 | 2166 | 4.5 | 3.8 | 1.77 | 0.12 | 2.1 | 1.0 |

m.c = Moisture content (%)
BD = Bulk Density (Kg/m$^3$)
PC = Paste Consistency (mm)
IRA= Initial Rate of Absorbtion
SR = Shrinkage Ratio (%)
CS = Compressive Strength (N/mm$^2$)
TS = Tensile Strength (N/mm$^2$ )
WL = Soil Weight Loss (%)

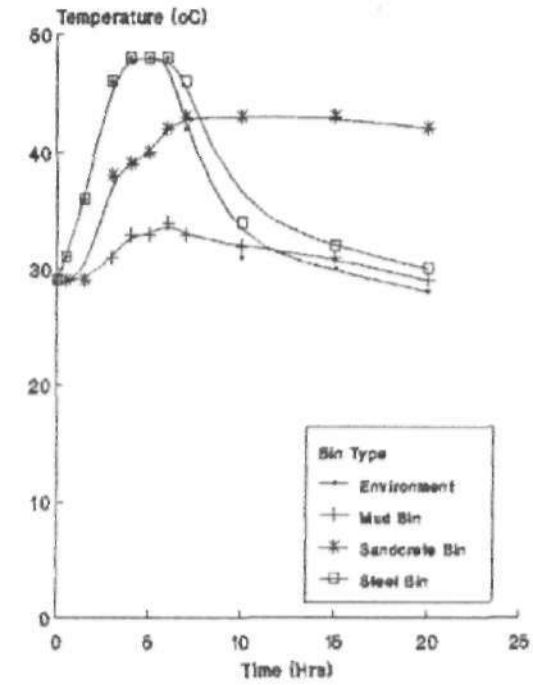
From the above result, grass stabilized samples rated least, except with regards tensile strength and shrinkage ratio. The tensile strength of 0.24 N/mm$^2$ obtained for grass-stabilized samples was at least 100% higher than was obtained for the rest samples, even though this value is much smaller than the 1.23 N/mm$^2$ maximum tensile strength earlier obtained for samples reported in section 4.3.6. The reason for this wide difference could be attributed to the low clay content of the soil and non settlement of the mud samples used for this phase of experiment in conformation with preparation methods adopted for the comparative evaluation.

The results further show that bitumen stabilized mud samples exhibited better durable properties and are more resistant to water absorbtion and soil loss from abrasions. The IRA and percentage weight loss obtained here for stabilizer-A and stabilizer-B samples compare to values earlier obtained in section 4.3.7 implying that effect of settlement is not visibly significant with respect to durability.

**4.4.2 Effect of Ambient Changes** : Results of ambient and bin temperatures and relative humidities for the three different treatments carried out are presented graphically in Figures 4.15 to 4.17, while detailed results are presented in Appendix D. Each of the treatments are discussed below.

**(a) Effect of Environmental Heating Alone** : In real situations, heating of environment alone occurs during the months of March and April prior to beginning of the rainy season in Northern Nigeria. In simulating this situation, a 5-hour continuous heat was applied on the environment as earlier explained in section 3.4.3. This resulted in a 15$^{0}$C temperature rise for both the ambient and steel bin as compared to sandcrete and mud bins where rise in bin temperatures were 8$^{0}$C and 5$^{0}$ C respectively. This treatment also resulted in a decrease of 35% and 18% relative humidity for the ambient and the steel bin respectively, while there was an increase of 27% and 7% relative humidity for the sandcrete and mud bins respectively. Looking closely at Figure 4.15, it would also be observed that discontinuing the heating process results in a continuous rise of relative humidity in the sandcrete bin, while the ambient and the other bins tend to return to the initial conditions.

(a) Bin Internal Temperature




(b) Bin Internal Relative Humidity

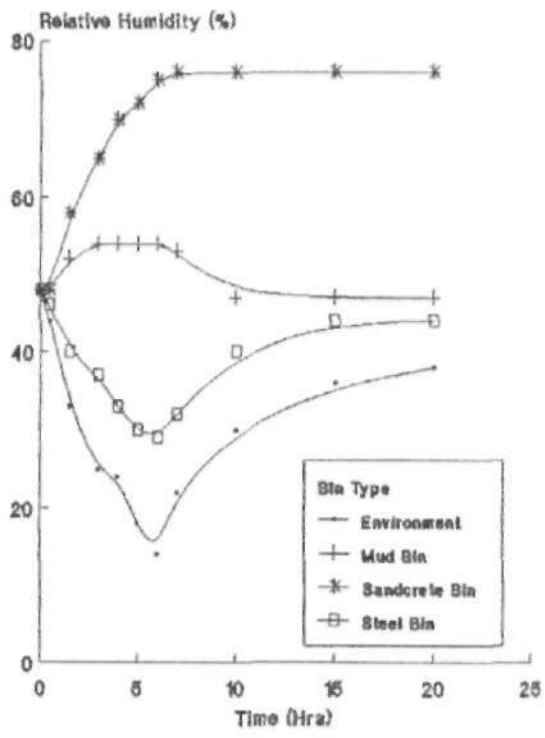



Figure 4.15 Effect of Environmental Heating Alone on Temperatures and Relative Humidity of Bins

As stated at the beginning of this section, this treatment was most pronounced than the remaining treatments that followed, discussion af result are presented below.

**(i) Steel Bin** : The behaviour displayed by steel bin showed that every little change in ambient heating is immediately accompanied with a rise in bin temperature, and that discontinuation of the heat results in a decrease in bin temperature with a corresponding rise in relative humidity. This phenomena is easily prone to condensation, and since steel is a non absorbent material, free water will be available along the wall of the bin.

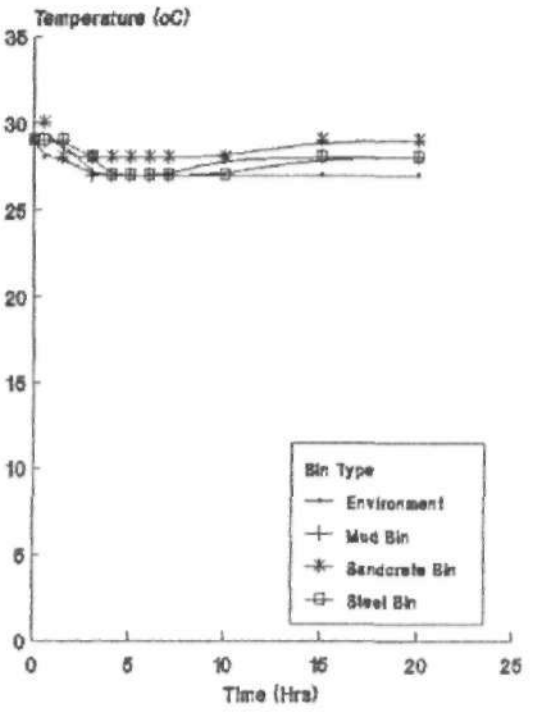
**(ii) Sandcrete Bin** : As for the sandcrete bin, the effect of ambient heating gave rise to both increase of temperature and relative humidity, implying that moisture is available within the sandcrete material prior to heating which is continuously released to the bin. After ambient heating is discontinued, the level of bin relative humidity is maintained, meaning that condensation will easily occur when the temperature of the wall further reduces by night.

**(iii) Mud Bin** : Increase of temperature and relative humidity in mud bin due to ambient heating was less than 10% of the magnitude observed for both steel and sandcrete bins. Discontinuing ambient heating also brought about normal situation in the bin within 5 to 6 hours. This imply that only little moisture increase is experienced as a result of the ambient heating and therefore condensation would be small. Since, mud is an absorbent material, it also imply that the little condensation would be absorbed.

**(b) Effect of Humidification Alone** : In reality, environmental humidification occurs singularly in most part of Northern Nigeria the months of July and August when the rains is at its peak with the cloud constantly covering and little or no insolation occurring. The effect of humidification alone on the environment, mud, steel and sandcrete bin conditions are shown in Figure 4.16.

**(c) Effect of Heating and Humidification** : In reality, the combined effect of heating and humidification occur in Northern Nigeria during the months of May and June, when the rains have been established but clear days are still prevelant. In this simulation, an ambient rise of 14$^0$C and 34% relative humidity, gave rise to corresponding rises of 9$^0$C:19%, 7$^0$C : 4%, and 12$^0$ C : 16%, temperature : relative humidity for mud, sandcrete and steel bin respectively. Like in the case of humidification alone, all the bins maintained the increased level of humidity long after ambient heating and humidification has been discontinued, as can be observed from Figure 4.17

(a) Bin Internal Temperature




(b) Bin Internal Relative Humidity

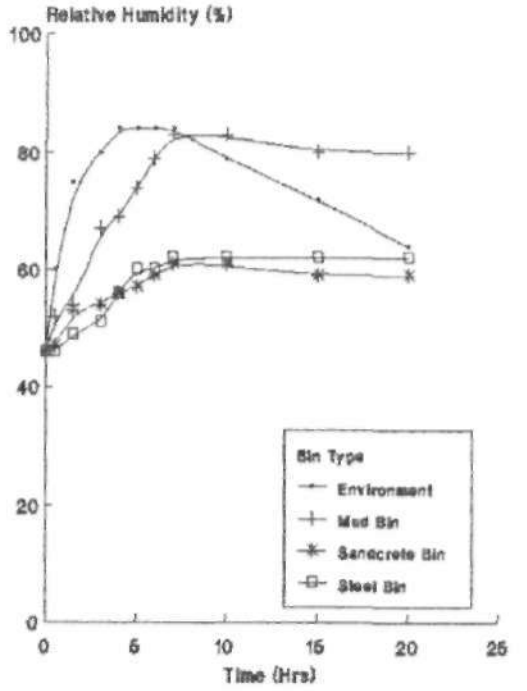
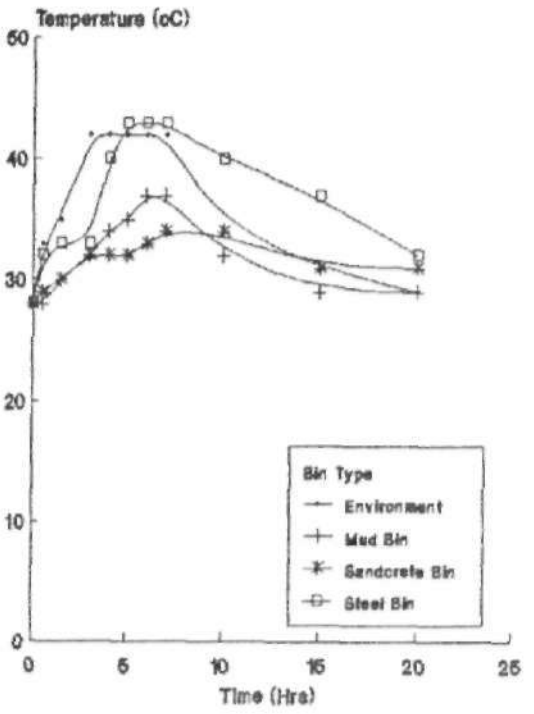



Figure 4.16 Effect of Environmental Humidification Alone on Temperatures and Relative Humidity of Bins

(a) Bin Internal Temperature




(b) Bin Internal Relative Humidity

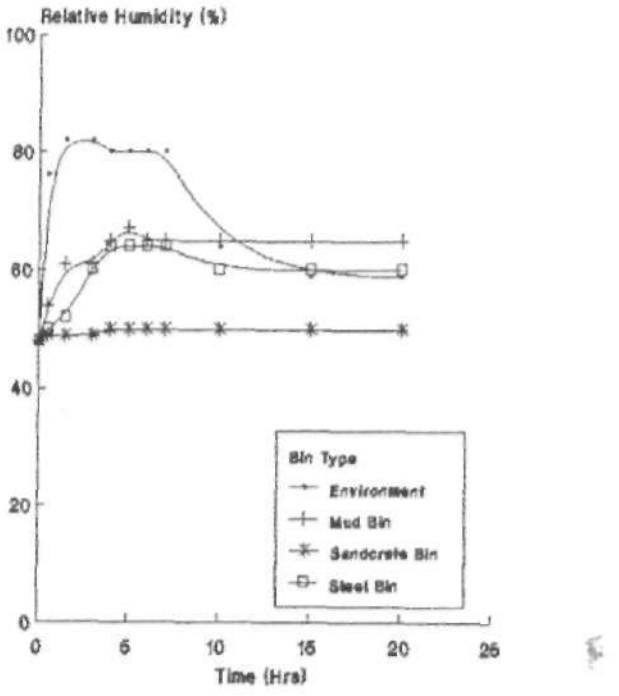



Figure 4.17 Effect of Environmental Heating and Humidification on Temperatures and Relative Humidity of Bins

**(d) Relative Significance of Temperature and Relative Humidity:** A two-way ANOVA carried out showed that, all the treatments had more significant effect on the relative humidity of the bins than the temperatures and that this effects were significant at 1% level of statistical test of significance. With regards to bin temperature, this is more pronounced for steel bin and minimum for the mud bin, while with regards to relative humidity, the effect is more pronounced for sandcrete bin and minimum for steel bin. The computed F-ratios of the two-way ANOVA for the measured temperatures and relative humidity are shown in Table of Appendix E2.

# CHAPTER FIVE

## 5. CONCLUSIONS AND RECOMMENDATIONS

The evaluation of mud as a construction material for grain storage structures has been undertaken by assessing the existing mud storage structures "Rumbu", and studying the construction and storage practices involved. Laboratory investigation of the mud was then undertaken to assess the effect of mud constituents on the structural properties of mud. Finally, mud was evaluated for functionality by subjecting it to different ambient conditions and comparing its behaviour with sandcrete and steel bins. Important conclusions and recommendation arising from this study is presented in this chapter.

### 5.1 CONCLUSIONS

Conclusions with respect to status of presently used rumbu bin, structural properties of mud, optimal mix ratios, comparative performance of mud and its suitability as a construction material for storage structure is presented below.

**5.1.1 Assessment of Existing Mud Rumbu Bins and Present State of Arts:** The following conclusions can be made with regards existing rumbu bins and present state of art of mudd construction.

**(a) Shapes and Sizes** : Three major types of shapes are in existence, namely cylindrical, spherical, and pyramidal. The cylindrical shaped bins combine advantages of big volume and lower wall stresses when compared with spherically shaped bins which are liable to high wall stresses or when compared with pyramidally shaped bins which are liable to small volumes. The volume sizes of the bins range from 1.6 $m^3$ to

197.4 $m^3$. Unthreshed millet is the major crop stored, and owner estimated capacities were found to be generally less than 50% of actual bin capacities.

**(b) Safety Levels** : Shell thicknesses were found to be more a function of the builder than bin size with thicknesses remaining the same for large volume variation. However shell tensile stresses due to unthreshed crops at full capacity in the cylindrically shaped bins are in the neighbourhood of 0.1% to 1% of material resisting tensile stress while for the spherically shaped bins, this values goes up to between 1% and 25% . Presently rumbu bins are used to store only unthreshed grains, but if the bins were to store threshed grains, the shell stresses will rise to between 1% and 25% of material resisting stress for cylindrically shaped bins and between 20% to 125% for spherically shaped bins.

**5.1.2 Effect of Various Mix-Ratios on Structural Properties of Mud** : The following conclusions can be made with regards effect of various mix-ratios on such structural properties of mud like strength, workability and durability.

**(a) Factors Affecting Structural Properties of Mud:** Settlement, clay content, water-soil ratio, stabilizer-soil ratio and stabilizer type are the major factors found to affect the structural properties of mud.

**(b) Paste Consistency**: Paste consistency determined using the modified consistometer gave a good indication of water-soil ratio and varied between 13.4mm to 94.3mm.

**(c) Compressive Strength**: Compressive strength for rice-straw stabilized mud is higher for unsettled mud (1.38 to 2.69N/$mm^2$) than for settled mud (2.3 to 4.2N/$mm^2$).

**(d) Tensile Strength** : Tensile strength for smmer-grass stabilized mud is higher for unsettled mud (0.31 to 0.70 N/$mm^2$) than for settled mud (0.38 to 1.23N/$mm^2$).

**(d) Durability** : Increase of both water-soil and stabilizer-soil ratios reduces durability of mud. Summer-grass stabilized mud samples were generally more durable than rice-straw stabilized mud samples.

### 5.1.3 Comparative Behaviour of Mud :

**(a) Structural Properties**: Grass stabilized mud had an average compressive strength of 1.6 which compared well with both bitumen and lime stabilized mud that had values of 1.8 and 1.9 respectively. However grass stabilized mud had a better tensile strength with an average value of 0.24 when compared with bitumen and lime stabilized mud that had tensile strength of 0.12 and 0.07 respectively.

**(b) Durability**: Grass stabilized mud performed poorly with respect durability when compared with both bitumen and lime stabilized mud. Bitumen stabilized mud displayed the highest durability with an average IRA value of 2.1 when compared with lime and grass stabilized mud that had values of 14.4 and 24.2 respectively. The average percentage soil weight loss of 1.0 for bitumen stabilized mud is least when compared with 2.3 and 12.1 for lime and grass stabilized mud respectively.

**(c) Resistance to ambient changes**: When there is an ambient change due to heat alone, mud offers better resistance to temperature change when compared to steel and sandcrete. When the ambient change is due to relative humidity alone, mud does not offer as much resistance as steel and sandcrete. If however the ambient changeis a combined effect of environmental heating and humidification, mud resist rise in temperature better while it compares with steel in resisting humidity change.

## 5.2 RECOMMENDATIONS

### 5.2.1 Recommendations from the Study:

(a) The construction of cylindrically shaped rumbu bin should be encouraged over other shapes and for larger volumes than presently used.

(b) The storage of threshed grains in presently existing cylindrically shaped rumbu bins should be encouraged as they are safe in carrying the pressures resulting from this load.

(c) It is recommended that mud should be properly settled before usage.

(d) For maximum compressive strength, summer grass is recommended as the stabilizer, at a stabilizer-soil ratio of 1.5% along with water-soil ratio of 20%.

(e) For maximum compressive strength, rice straw is recommended as the stabilizer, at a water-soil ratio of 20%, stabilizer-soil ratio of 0.5%.

(f) For maintaining maximum strength, it is recommended that the consistometer be used to determine the paste that give maximum strength, this should then followed during the course of construction.

(g) The present practice of covering mud bins with thatches of woven grass should be encourage to enhance the durability and life of the structure.

### 5.2.2 Recommendations for Further Study:

(h) A study should be undertaken on the possibility of evolving a special precast block with interlocking ends, so as to come up with ways of building mud storage structure using precast blocks rather than the present method of insitu casting which takes long period to complete.

(i) A study should be undertaken on efficiency of fumigation inmud bin, and the possibility of mechanically improving the present method of loading and off-loading.

(j) The use of butyl rubber or other plastics sheets as earlier studied by O'Dowd, should be revisited, but with mud bin as the supporting frame instead of wiremesh. This would make it possible to undertake airtight storage of grains using mud bin structures.

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# 7. APPENDICES

# APPENDIX A

## Sample of the Questionnaire Utilized for Preliminary Investigation

APPENDIX B

Effect of Bin Capacity on Wall Lateral Pressures and Tensile Stresses for Cylinderically Shaped Rumbu

| S/No | Label | VOL | ql1 | ql2 | ql3 | σ1 | σ2 | σ3 |
|---|---|---|---|---|---|---|---|---|
| 1 | LA1 | 1.6 | - | 0.12 | 4.1 | - | 0.54 | 6.9 |
| 2 | LA5 | 1.9 | - | 0.14 | 4.8 | - | 0.62 | 7.9 |
| 3 | LA2 | 2.3 | - | 0.14 | 4.8 | - | 0.64 | 8.1 |
| 4 | LA3 | 2.4 | - | 0.15 | 5.0 | - | 0.82 | 10.4 |
| 5 | LA4 | 2.5 | - | 0.15 | 5.3 | - | 0.75 | 9.5 |
| 6 | AK5 | 4.3 | - | 0.13 | 4.6 | - | 0.94 | 11.9 |
| 7 | AK1 | 4.6 | - | 0.16 | 5.5 | - | 0.91 | 11.6 |
| 8 | AK3 | 4.9 | - | 0.11 | 3.8 | - | 1.20 | 15.2 |
| 9 | AK7 | 5.0 | - | 0.15 | 5.3 | - | 1.30 | 16.5 |
| 10 | AK6 | 5.2 | - | 0.16 | 5.5 | - | 1.04 | 13.2 |
| 11 | AK4 | 6.4 | - | 0.18 | 6.0 | - | 1.38 | 17.5 |
| 12 | AK2 | 6.6 | - | 0.18 | 6.2 | - | 1.35 | 17.1 |
| 13 | ZG1 | 9.5 | 0.14 | 0.15 | 5.0 | 3.7 | 3.8 | 47.6 |
| 14 | ZG3 | 23.3 | 0.10 | 0.20 | 7.0 | 3.2 | 6.8 | 86.0 |
| 15 | ZG5 | 27.5 | 0.11 | 0.19 | 6.5 | 4.5 | 8.1 | 102.9 |
| 16 | GS5 | 28.1 | 0.12 | 0.22 | 7.1 | 1.2 | 2.2 | 27.7 |
| 17 | ZG7 | 38.6 | 0.10 | 0.24 | 8.2 | 4.8 | 11.3 | 143.6 |
| 18 | ZG6 | 40.6 | 0.09 | 0.24 | 8.2 | 4.1 | 10.6 | 134.0 |
| 19 | GS11 | 56.1 | 0.18 | 0.33 | 11.3 | 7.6 | 13.7 | 173.6 |
| 20 | SWK4 | 61.6 | 0.17 | 0.23 | 7.9 | 10.4 | 14.3 | 181.6 |
| 21 | SWK3 | 64.1 | 0.09 | 0.24 | 8.1 | 3.0 | 7.8 | 98.7 |
| 22 | GS10 | 86.9 | 0.12 | 0.34 | 11.6 | 5.4 | 15.8 | 200.8 |
| 23 | GS8 | 105.9 | 0.13 | 0.34 | 11.6 | 5.5 | 13.7 | 173.6 |
| 24 | SWK5 | 131.2 | 0.10 | 0.34 | 11.6 | 4.6 | 15.3 | 193.7 |
| 25 | SWK6 | 132.1 | 0.10 | 0.35 | 12.0 | 4.6 | 15.3 | 195.3 |
| 26 | GS9 | 147.0 | 0.12 | 0.36 | 12.4 | 5.1 | 14.9 | 189.4 |
| 27 | GS2 | 170.5 | 0.13 | 0.37 | 12.7 | 5.4 | 15.8 | 200.9 |
| 28 | GS4 | 180.2 | 0.12 | 0.39 | 13.5 | 1.9 | 6.2 | 74.8 |
| 29 | GS3 | 197.4 | 0.12 | 0.39 | 13.5 | 2.0 | 6.6 | 83.4 |

VOL = Volume of Rumbu Bin (m3)
ql1 = Lateral Pressures due to Unthreshed Millet at Owner Estimated Capacity ($N/m^2$)
ql2 = „ „ „ „ „ for Calculated Capacity ($N/m^2$)
ql3 = „ „ due to Threshed Millet for Calculated Capacity ($N/m^2$)
σ1 = Tensile Stress due to ql1 ($KN/m^2$)
σ2 = „ „ „ „ ql2 ($KN/m^2$)
σ3 = „ „ „ „ ql3 ($KN/m^2$)

APPENDIX C-1

Structural Properties of Mud Samples Stabilized with Summer Grass (Stabilizer-A) at Different Water-Soil Ratio (Moisture Content)

| S/No | S.S | M.C | P.C | S.R | B.D | CS1 | CS2 | TS1 | TS2 | IRA | WL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0 | 20.1 | 16.4 | 4.1 | 1995 | 1.30 | 4.1 | 0.34 | 1.0 | 21.5 | 12.5 |
| 2 | 0.0 | 25.4 | 29.0 | 4.5 | 1980 | 1.65 | 3.8 | 0.42 | 0.92 | 28.9 | 14.0 |
| 3 | 0.0 | 29.5 | 64.7 | 5.4 | 1849 | 1.49 | 3.4 | 0.39 | 0.92 | 63.9 | 14.4 |
| 4 | 0.0 | 34.8 | 88.3 | 6.5 | 1802 | 1.28 | 3.2 | 0.31 | 0.73 | 77.6 | 15.7 |
| 5 | 0.5 | 20.4 | 17.1 | 2.7 | 1752 | 1.82 | 4.2 | 0.58 | 1.23 | 58.7 | 13.3 |
| 6 | 0.5 | 24.9 | 36.3 | 4.1 | 1825 | 2.17 | 3.7 | 0.68 | 0.97 | 78.5 | 13.8 |
| 7 | 0.5 | 30.3 | 69.3 | 5.0 | 1729 | 2.37 | 3.2 | 0.70 | 0.78 | 85.8 | 15.1 |
| 8 | 0.5 | 35.9 | 80.7 | 6.3 | 1631 | 1.79 | 3.2 | 0.52 | 0.82 | 95.8 | 16.7 |
| 9 | 1.0 | 19.7 | 17.6 | 2.4 | 1701 | 1.94 | 3.9 | 0.81 | 1.21 | 78.8 | 14.1 |
| 10 | 1.0 | 26.8 | 32.3 | 3.1 | 1645 | 2.34 | 3.6 | 0.74 | 1.17 | 116.5 | 14.8 |
| 11 | 1.0 | 29.8 | 61.7 | 4.7 | 1614 | 2.49 | 3.3 | 0.68 | 1.26 | 143.3 | 16.1 |
| 12 | 1.0 | 35.1 | 92.3 | 5.6 | 1583 | 1.87 | 3.1 | 0.56 | 1.11 | 159.2 | 18.2 |
| 13 | 1.5 | 19.8 | 13.4 | 2.2 | 1681 | 1.37 | 3.8 | 0.65 | 1.33 | 88.0 | 21.6 |
| 14 | 1.5 | 26.8 | 33.7 | 2.7 | 1617 | 1.51 | 3.6 | 0.68 | 1.17 | 123.7 | 22.7 |
| 15 | 1.5 | 30.2 | 55.0 | 3.9 | 1590 | 1.46 | 2.7 | 0.34 | 0.60 | 169.2 | 22.8 |
| 16 | 1.5 | 34.7 | 94.3 | 4.9 | 1532 | 1.38 | 2.3 | 0.71 | 1.14 | 187.8 | 23.9 |

S/No = Sample Number
S.S = Stabilizer-Soil Ratio (%)
M.C = Moisture Content (%)
P.C = Paste Consistency (mm)
S.R = Shrinkage Ratio (%)
B.D = Bulk Density (kg/m$^3$)

CS1 = Compressive Strength of Unsettled mud(N/mm$^2$)
CS2 = „ „ settled mud „
TS1 = Tensile Strength of Unsettled mud (N/mm$^2$)
TS2 = „ „ settled mud „
IRA= Initial Rate of Absorbtion
WL = Weight Loss (%)

## APPENDIX C-2

### Structural Properties of Mud Samples Stabilized with Rice Straw (Stabilizer-B) at Different Water-Soil Ratio (Moisture Content)

| S/No | S.S | M.C | P.C | S.R | B.D | CS1 | CS2 | TS1 | TS2 | IRA | WL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | 0.0 | 20.1 | 16.4 | 4.1 | 1995 | 1.30 | 4.1 | 0.34 | 1.0 | 21.5 | 12.5 |
| 18 | 0.0 | 25.4 | 29.0 | 4.5 | 1980 | 1.65 | 3.8 | 0.42 | 0.92 | 28.9 | 14.0 |
| 19 | 0.0 | 29.4 | 64.7 | 5.4 | 1849 | 1.49 | 3.4 | 0.39 | 0.92 | 63.9 | 14.4 |
| 20 | 0.0 | 34.8 | 88.3 | 6.5 | 1802 | 1.28 | 3.2 | 0.31 | 0.73 | 77.6 | 15.7 |
| 21 | 0.5 | 20.2 | 13.6 | 3.9 | 1872 | 1.46 | 3.5 | 0.48 | 1.23 | 48.0 | 16.7 |
| 22 | 0.5 | 26.5 | 37.7 | 4.1 | 1774 | 1.68 | 3.0 | 0.40 | 0.87 | 78.5 | 16.9 |
| 23 | 0.5 | 29.4 | 57.5 | 5.0 | 1741 | 1.82 | 3.6 | 0.38 | 0.77 | 143.3 | 18.2 |
| 24 | 0.5 | 34.1 | 94.0 | 6.4 | 1652 | 1.42 | 2.3 | 0.31 | 0.38 | 163.2 | 20.1 |
| 25 | 1.0 | 20.1 | 13.2 | 3.6 | 1751 | 2.69 | 3.5 | 0.54 | 1.11 | 58.7 | 18.1 |
| 26 | 1.0 | 25.1 | 28.3 | 4.0 | 1640 | 2.50 | 2.6 | 0.49 | 0.56 | 87.6 | 20.7 |
| 27 | 1.0 | 29.7 | 45.0 | 4.7 | 1623 | 2.20 | 2.3 | 0.45 | 0.43 | 152.5 | 23.1 |
| 28 | 1.0 | 36.6 | 87.5 | 5.2 | 1592 | 1.94 | 4.1 | 0.38 | 0.39 | 181.2 | 26.1 |
| 29 | 1.5 | 19.6 | 12.3 | 3.1 | 1725 | 2.13 | 3.7 | 0.64 | 1.14 | 148.1 | 26.2 |
| 30 | 1.5 | 26.0 | 26.8 | 3.9 | 1693 | 2.16 | 3.6 | 0.67 | 0.70 | 188.2 | 26.9 |
| 31 | 1.5 | 30.7 | 36.2 | 4.4 | 1577 | 1.86 | 2.0 | 0.70 | 0.63 | 191.7 | 28.4 |
| 32 | 1.5 | 35.7 | 63.5 | 4.8 | 1541 | 1.72 | 3.5 | 0.45 | 0.45 | 222.2 | 32 |

S/No = Sample Number
S.S = Stabilizer-Soil Ratio (%)
M.C = Moisture Content (%)
P.C = Paste Consistency (mm)
S.R = Shrinkage Ratio (%)
B.D = Bulk Density (kg/m$^3$)

CS1 = Compressive Strength of Unsettled mud(N/mm$^2$)
CS2 = „ „ settled mud „
TS1 = Tensile Strength of Unsettled mud (N/mm$^2$)
TS2 = „ „ settled mud „
IRA= Initial Rate of Absorbtion
WL = Weight Loss (%)

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## APPENDIX D-1

### Average Values of Measured Temperatures and Relative Humidity of Bins due to External Effect of Environmental Heating

| Time | T0 | RH0 | T1 | RH1 | T2 | RH2 | T3 | RH3 |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 29 | 48 | 29 | 48 | 29 | 48 | 29 | 48 |
| 0.5 | 31 | 44 | 29 | 48 | 29 | 48 | 31 | 46 |
| 1.5 | 36 | 33 | 29 | 52 | 29 | 58 | 36 | 40 |
| 3.0 | 46 | 25 | 31 | 54 | 38 | 65 | 46 | 37 |
| 4.0 | 48 | 25 | 33 | 54 | 39 | 70 | 48 | 33 |
| 5.0 | 48 | 18 | 33 | 54 | 40 | 72 | 48 | 30 |
| 6.0 | 48 | 14 | 34 | 54 | 42 | 75 | 48 | 29 |
| 7.0 | 42 | 22 | 33 | 53 | 43 | 76 | 46 | 32 |
| 10.0 | 31 | 30 | 32 | 47 | 43 | 76 | 34 | 40 |
| 15.0 | 30 | 36 | 31 | 47 | 43 | 76 | 32 | 44 |
| 20.0 | 28 | 38 | 29 | 47 | 42 | 76 | 30 | 44 |

T0, R0 = Temperature and Relative Humidity of External Environment
T1, R1 = „ „ „ Mud Bin
T2, R2 = „ „ „ Sanderete Bin
T3, R3 = „ „ „ Steel Bin

## APPENDIX D-2

### Average Values of Measured Temperatures and Relative Humidity of Bins due to External Effect of Humidification.

| Time | T0 | RH0 | T1 | RH1 | T2 | RH2 | T3 | RH3 |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 29 | 46 | 29 | 46 | 29 | 46 | 29 | 46 |
| 0.5 | 28 | 60 | 29 | 52 | 30 | 47 | 29 | 46 |
| 1.5 | 28 | 75 | 29 | 54 | 28 | 53 | 29 | 49 |
| 3.0 | 27 | 80 | 27 | 67 | 28 | 54 | 28 | 51 |
| 4.0 | 27 | 84 | 27 | 69 | 28 | 56 | 27 | 56 |
| 5.0 | 27 | 84 | 27 | 74 | 28 | 57 | 27 | 60 |
| 6.0 | 27 | 84 | 27 | 79 | 28 | 59 | 27 | 60 |
| 7.0 | 27 | 84 | 27 | 83 | 28 | 61 | 27 | 62 |
| 10.0 | 27 | 79 | 28 | 83 | 28 | 61 | 27 | 62 |
| 15.0 | 27 | 72 | 28 | 80 | 29 | 59 | 28 | 62 |
| 20.0 | 27 | 64 | 28 | 80 | 29 | 59 | 28 | 62 |

T0, R0 = Temperature and Relative Humidity of External Environment
T1, R1 = " " " Mud Bin
T2, R2 = " " " Sandcrete Bin
T3, R3 = " " " Steel Bin

## APPENDIX D-3

### Average Values of Measured Temperatures and Relative Humidity of Bins due to External Effect of Heating and Humidification.

| Time | T0 | RH0 | T1 | RH1 | T2 | RH2 | T3 | RH3 |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 28 | 48 | 28 | 48 | 28 | 48 | 28 | 48 |
| 0.5 | 33 | 76 | 28 | 54 | 29 | 49 | 32 | 50 |
| 1.5 | 35 | 82 | 30 | 61 | 30 | 49 | 33 | 52 |
| 3.0 | 42 | 82 | 32 | 61 | 32 | 49 | 40 | 60 |
| 4.0 | 42 | 80 | 34 | 65 | 32 | 50 | 43 | 64 |
| 5.0 | 42 | 80 | 35 | 67 | 32 | 50 | 43 | 64 |
| 6.0 | 42 | 80 | 37 | 65 | 33 | 50 | 43 | 64 |
| 7.0 | 42 | 80 | 37 | 65 | 34 | 52 | 40 | 64 |
| 10.0 | 34 | 64 | 32 | 65 | 34 | 50 | 37 | 60 |
| 15.0 | 31 | 59 | 29 | 65 | 31 | 50 | 32 | 60 |
| 20.0 | 29 | 59 | 29 | 65 | 31 | 50 | 30 | 60 |

T0, RH0 = Temperature and Relative Humidity of External Environment
T1, R1 = „ „ „ Mud Bin
T2, R2 = „ „ „ Sandcrete Bin
T3, R3 = „ „ „ Steel Bin

## APPENDIX E-1

### Table of F-Ratios from the Two-Way Analysis of Variance(ANOVA) of the Different Mud Properties

| Type of Property | Source of Variation | DF | SS | | MS | | Observed | | Required-F (5%) | (1%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | St. type | A,B | A | B | A | B | A | B | A,B | A,B |
| 1. Paste Consistens y | St. ratio | | 25.8 | 1299.3 | 8.6 | 433.1 | 10.2 | | 3.24 | 5.29 |
| | m.c(%) | 3 | 24995 | | 8331.8 | | 383.3 | 11571 | 3.24 | 5.29 |
| | Interaction | 3 | 21246.3 | | 7082.1 | | 6267 | | 2.54 | 3.78 |
| | Error | 9 | 422.8 | 920.5 | 47.0 | 102.3 | 65.3 | | | |
| | Total | 16 | 11.5 | 18.0 | 0.7 | 1.1 | 90.5 | | | |
| | | 31 | 25455.6 | 23484 | | | | | | |
| 2. Shrikage Ratio | St. type | A,B | A | B | A | B | A | B | A,B | A,B |
| | St. ratio | 3 | 13.9 | 6.5 | 4.6 | 2.2 | 33.5 | 20.0 | 3.24 | 5.29 |
| | mc(%) | 3 | 38.5 | 19.0 | 12.8 | 6.3 | 93.0 | 58.0 | 3.24 | 5.29 |
| | Interaction | 9 | 0.9 | 1.9 | 0.1 | 0.2 | 0.7 | 1.9 | 2.54 | 3.78 |
| | Error | 16 | 2.2 | 1.7 | 0.1 | 0.1 | | | | |
| | Total | 31 | 55.4 | 29.1 | | | | | | |
| 3. Bulk Density | St. type | A,B | A | B | A | B | A | B | A,B | A,B |
| | St. ratio | 3 | 431291 | | 143764 | | 826.2 | | 3.24 | 5.29 |
| | mc(%) | 3 | 367074 | | 122358 | | 1246 | | 3.24 | 5.29 |
| | Interaction | 9 | 114987 | | 38329 | 56886 | 220.3 | 579 | 2.54 | 3.78 |
| | Error | 16 | 170656 | | 2858 | 1695 | 16.4 | 17 | | |
| | Total | 31 | 25722 | 15260 | 174 | 98 | | | | |
| | | | 2784 | 1571 | | | | | | |
| | | | 574784 | | | | | | | |
| | | | 554562 | | | | | | | |
| 4.Compre-ssive Strength-1 (unsettled mud) | St. type | A,B | A | B | A | B | A | B | A,B | A,B |
| | St. ratio | 3 | 3.7 | 3.9 | 1.2 | 1.3 | 163.1 | | 3.24 | 5.29 |
| | mc(%) | 3 | 0.8 | 0.8 | 0.3 | 0.3 | 423.4 | 34.5 | 3.24 | 5.29 |
| | Interaction | 9 | 0.3 | 0.6 | 0.03 | 0.06 | 81.0 | | 2.54 | 3.78 |
| | Error | 16 | 0.1 | 0.05 | 0.01 | 0.003 | 4.5 | 20.1 | | |
| | Total | 31 | 4.9 | 5.35 | | | | | | |
| 5. Compre-ssive Strength-2 (Settled mud) | St. type | A,B | A | B | A | B | A | B | A,B | A,B |
| | St. ratio | 3 | 1.0 | 1.4 | 0.3 | 0.5 | 3.2 | | 3.24 | 5.29 |
| | mc(%) | 3 | 6.1 | 2.8 | 2.0 | 0.9 | 10.4 | | 3.24 | 5.29 |
| | Interaction | 9 | 0.7 | 7.8 | 0.1 | 0.9 | 19.1 | | 2.54 | 3.78 |
| | Error | 16 | 1.7 | 0.7 | 0.1 | 0.04 | 21.4 | | | |
| | Total | 31 | 9.5 | 12.7 | | | 0.7 | 19.7 | | |
| 6. Tensile Strength-1 | St. type | A,B | A | B | A | B | A | B | A,B | A,B |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (Unsettled | St. ratio | 3 | 0.48 | 0.32 | 0.16 | 0.11 | 140.1 | | 3.24 | 5.29 |
| | *mc(%)* | 3 | *0.06* | *0.11* | *0.02* | *0.04* | 128.6 | | 3.24 | 5.29 |
| mud) | Interaction | 9 | 0.24 | 0.05 | 0.03 | 0.005 | 18.0 | 44.3 | 2.54 | 3.78 |
| | Error | 16 | 0.02 | 0.01 | 0.001 | 0.001 | 23.7 | 6.3 | | |
| | Total | 31 | 0.81 | 0.49 | | | | | | |
| 7. Tensile Strength-2 | St. type | A,B | A | B | A | B | A | B | A,B | A,B |
| (Settled | St. ratio | 3 | 0.49 | 0.34 | 0.16 | 0.11 | 76.7 | 85.4 | 3.24 | 5.29 |
| | mc(%) | 3 | 0.35 | 1.82 | 0.12 | 0.61 | 53.5 | 459.6 | 3.24 | 5.29 |
| mud) | Interaction | 9 | 0.18 | 0.25 | 0.02 | 0.03 | 9.2 | 20.8 | 2.54 | 3.78 |
| | Error | 16 | 0.03 | 0.02 | 0.002 | 0.001 | | | | |
| | Total | 31 | 1.05 | 2.43 | | | | | | |
| 8. Inital Rate of | St. type | A,B | A | B | A | B | A | B | A,B | A,B |
| Absorbtion | St. ratio | 3 | 38465 | 76956 | 12822 | | 72.4 | | 3.24 | 5.29 |
| (IRA) | mc(%) | 3 | 21806 | 40465 | 25652 | | 94.3 | | 3.24 | 5.29 |
| | Interaction | 9 | 3583 | 9544 | 7269 | | 41.1 | | 2.54 | 3.78 |
| | Error | 16 | 2832 | 4355 | 13488 | | 49.6 | | | |
| | Total | 31 | 66686 | | 398 | 660 | 2.2 | 2.4 | | |
| | | | 1277720 | | 177 | 272 | | | | |
| 9. Weight Loss(WL) | St. type | A,B | A | B | A | B | A | B | A,B | A,B |
| | St. ratio | 3 | 329.8 | 1167.9 | 109.9 | 389.3 | 2.8 | 5.1 | 3.24 | 5.29 |
| | mc(%) | 3 | 51.6 | 170.3 | 17.2 | 56.8 | 0.4 | 0.7 | 3.24 | 5.29 |
| | *Interaction* | 9 | 5.5 | 29.8 | 0.6 | 3.3 | 0.02 | | 2.54 | 3.78 |
| | Error | 16 | 626.3 | 1228.1 | 39.1 | 76.8 | 0.04 | | | |
| | Total | 31 | 1013.2 | 2596.2 | | | | | | |

St. type = Stabilizer Tupe
*St. ratio = Stabilizer Ratio*

APPENDIX E-2

Table of F-Ratios from the Two-Way Analysis of Variance(ANOVA) for Measured Temperatures of Mud, Sandcrete and Steel Bins *under Varying Ambient Condition*

| Bin Type | Source of Variation | DF | SS | MS | Observed-F | Required-F 5(%) | 1(%) |
|---|---|---|---|---|---|---|---|
| 1. Mud Bin | Environment | 2 | 188.8 | 94.4 | 236 | 3.3 | 5.3 |
| | Time | 10 | 112.0 | 11.2 | 28 | 2.14 | 2.95 |
| | Interaction | 20 | 196.5 | 9.8 | 24.5 | 1.9 | 2.50 |
| | Error | 33 | 13.0 | 0.4 | | | |
| | Total | 65 | 510.3 | | | | |
| 2.Sandcrete Bin | Environment | 2 | 1087 | 543.3 | 1358.3 | 3.3 | 5.3 |
| | Time | 10 | 333 | 33.3 | 83.3 | 2.14 | 2.95 |
| | Interaction | 20 | 439 | 22.0 | 55 | 1.9 | 2.50 |
| | Error | 33 | 12.5 | 0.4 | | | |
| | Total | 65 | 1872 | | | | |
| 3.Steel Bin | Environment | 2 | 1420 | 710.2 | 1775.0 | 3.3 | 5.3 |
| | Time | 10 | 1133 | 113.2 | 283.0 | 2.14 | 2.95 |
| | Interaction | 20 | 816 | 40.8 | 102.0 | 1.9 | 2.50 |
| | Error | 33 | 14.0 | 0.4 | | | |
| | Total | 65 | 3383 | | | | |

## APPENDIX E-3

### Table of F-Ratios from the Two-Way Analysis of Variance(ANOVA) for Measured Relative Humidity of Mud, Sandcrete and Steel Bins under Varying Ambient Condition

| Bin Type | Source of Variation | DF | SS | MS | Observed-F | Required-F 5(%) 1(%) | |
|---|---|---|---|---|---|---|---|
| 1. Mud Bin | Environment | 2 | 3593 | 1796 | 2245.8 | 3.3 | 5.3 |
| | Time | 10 | | 247 | 309.1 | 2.14 | 2.95 |
| | Interaction | 20 | 2473 | 92.4 | 115.5 | 1.9 | 2.50 |
| | Error | 33 | 1849 | 0.8 | | | |
| | Total | 65 | 27.5 | | | | |
| | | | 7943 | | | | |
| 2.Sandcrete Bin | Environment | 2 | 3588 | 1794 | 3588 | 3.3 | 5.3 |
| | Time | 10 | 1809 | 181 | 361.8 | 2.14 | 2.95 |
| | Interaction | 20 | 1019 | 51 | 101.8 | 1.9 | 2.50 |
| | Error | 33 | 16.0 | 0.5 | | | |
| | Total | 65 | 6433 | | | | |
| 3.Steel Bin | Environment | 2 | 4986 | 2493 | 1558.1 | 3.3 | 5.3 |
| | Time | 10 | 577 | 57.8 | 36.1 | 2.14 | 2.95 |
| | Interaction | 20 | 2046 | 102.3 | 63.9 | 1.9 | 2.50 |
| | Error | 33 | 51.5 | 1.6 | | | |
| | Total | 65 | 7661 | | | | |