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THE DESIGN, CONSTRUCTION AND TESTING OF A WOODEN SILO FOR GRAIN STORAGE

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ABSTRACT

A hexagonal, double-walled, wooden siloof sides 1.2m, height 1.8m and of 7m3 capacity was designed. The walls and floor were taken as stressed skin panels. These were fabricated using Mansonia altissima for the ribs, while exterior grade structural plywood was used as sheathing. The silo was subjected to non-destructive testing in accordance with the British Standard Code of Practice CP:112 and joints separation, consolidation movement of the foundation and floor deflection were periodically measured over a period of two weeks during which the structure was under load. At the end of the test period there was no measurable consolidation movement and the joints remained intact while the floor deflection was within permissible limit of $\Delta \leqslant L/180$. Further testing and evaluation including subjecting the silo to loading for longer duration and taking measurements of stresses induced on the silo components are to be undertaken.

KEY WORDS:
Hexagonal, plywood, silo, non-destructive, prototype.

1.0 INTRODUCTION

1.1 The Nigerian agriculture is dominated by peasant farmers whose individual farmholdings are between 1 and 10 ha, while annual grain outputs vary between 1 and 5 tonnes (1). This class of farmers can contribute much more to food production in the country of some constraints are removed. One of these is to make available to them improved storage facilities for their crops. The crop storage structures now being used by these farmers are inefficient and result in severe postharvest losses reaching as much as 20 - 30% for grains and 30 - 50% for roots and tubers (2).

It has been suggested that the nation's efforts to achieving self-sufficiency in food supply could be more easily accomplished through adequate preservation and storage of what is presently produced rather than increasing the current production level. It has also been suggested that any effort aimed at increasing food production should be matched with an equal effort at preserving what will be harvested (1).

In designing crop storage structures for peasant farmers, due account has to be taken of their present income level, technical skills and their requirements for storage capacities. A wooden silo, which could be fabricated using local materials was considered of potential. This work was therefore undertaken to evolve a design methodology for a wooden silo and to fabricate and test a prototype of the silo.

2.0 DESIGN CONSIDERATION

2.1 Silo Capacity and Dimensions

The annual production of shelled corn by each of the peasant farmers who produce maize in the country is said to be under 5 tonnes (1). Five tonnes of shelled corn will occupy about 6.7 cubic metres. A silo capacity of 7 cubic metres is chosen, to take account of present level of production and projected increases during the coming year.

A hexagonal shape is preferred to the rectangular shape for the silo. This is to reduce the incidence of stress concentration at the joints (3,4). The regular hexagonal section is to have its six corners lying on the circumference of a circle of radius 1.2 metres. Each side of 1.2 metres in length while the height of the silo is to be 1.8 metres. The internal volume of the silo is to be about 6.73 cubic metres.

2.2 Silo Classification

Silo are categorised as being either 'deep' of 'shallow'. The walls of deep silos are said to experience friction when loaded, while in shallow silos, the walls experience no frictional resistance. It has however been reported that even where wall friction is initially present, this tends to disappear with usage as a result of the deposition of wax-like material on the walls from the grain (5). It is therefore appropriate to design silos as shallow type especially since silos are not normally loaded to full capacities during the earlier stages of usage. Silos are usually overdesigned for capacity to take account of projected increases in later years.

2.3 Silo Wall and Floor Thicknesses

There are no standard equations for estimating these for silos fabricated of wood-based products. The walls and floors however approximate to stressed skin panels, for which there are established design methodologies. The walls and floor thicknesses have therefore been estimated on the basis of their being stressed skin panels.

2.4 Construction Materials

Mansonia wood (Mansona altissima) was used for constructing the ribs of the silo while structural grade plywood (with core and face veneers of redwoods) is used as sheathing material. The properties of these construction materials which were obtained from Codes of Practice (6) were duly modified to take account of expected service conditions. Corrosion-resistant common wire nails were used as connectors while in cases where applicable, cascamite adhesive was used in securing members together, in addition to nailing.

3.0 DESIGN METHODOLOGY

3.1 Stresses on Silo Components

The static lateral pressure (L) imposed on the walls of the silo and the pressure on the floor Fv are calculated, using Ranking equation for shallow silos.

$$L = W + Y \left[\frac{1-\sin\theta}{1+\sin\theta} \right] \quad \text{----} \quad (1)$$

where

W = Bulk density of grain

Y = Depth of grain

θ = Angle of repose of grain

The density for shelled corn W = 720kg/m^3 ; 0 = 27^0 ;y = 1.8m, L , maximum lateral pressure is calculated to be 4774 N/m^2. Although the lateral pressure on the wall of the silo will vary from zero at the top surface of grain to a maximum value at the bottom of the silo, a uniform thickness of silo wall is used in order to facilitate workmanship.

The pressure on the silo floor (Fv) equals weight of grain stored divided by the floor area.

$$Fv = \frac{\text{Silo Floor Area x Height of Grain in Silo (h) x Bulk density of Grain}}{\text{Silo Floor Area}}$$

$= W h$

$= 720 \times 9{,}81 \times 1.8 \text{ N/m}^2$

$= 12{,}714 \text{ N/m}^2$

Although static pressures induced by stored grain are often modified by an over-pressure factor to take account of the dynamic loads which are developed during unloading, such dynamic loads are neglected for this work in view of the small capacity of the silo. The calculated static loads are therefore used in the design.

3.2 The Silo Wall and Floor

These are to be designed as double skin panels using the procedures presented by Booth and Reece (1967) (8), Ozelton and Baird (1976) (4) and Gurfinkel (1979) (3). The procedures involve the selection of appropriate dimensions for the webs, web spacing and flanges to be tested for strength and serviceability.

3.2.1 Proportioning of the Panel

This is governed by the ratio of the span to the overall depth of the panel which should not exceed 30. The width of the webs should provide adequate area of contact between the webs and the flanges in order to keep the rolling shear stress induced within permissible limit. The web spacings are chosen so as to prevent excessive transverse deflection of the topskin between adjacent webs.

For the purpose of this design, a typical wall panel is taken as being 1800mm x 1200mm, while a 2080mm x 1200mm section is chosen for the floor. The panels' proportions and other relevant data are presented in Table 1 while a typical double stressed skin panel is shown in Fig. 1.

3.2.2. Strength and Serviceability

In the design of stressed skin panels, it is assumed that the plywood flanges bear the bending stresses while the stringers or webs bear the shear stresses. The strength and serviceability of the panel are determined through checks on the following:

a) Buckling of the topskin.
b) Bending stresses on the top and bottom flanges.
c) Horizontal shear stress at the Neutral Axis of the entire panel.
d) Rolling shear stresses at the flange/web joints.
e) Overall panel deflection.

To effectively carry out these checks, the Neutral Axis of the panel is located, the sectional rigidity, and the first moment of elements above and below the Neutral Axis are determined. The same design procedure was done for the wall and floor panels, taking into account appropriate dimensions and structural properties.

The stress to cause buckling at the topskin is compared with the bending stress σ induced on the topskin by the external load and the self weight of the floor:

$$\sigma = \frac{M}{Z} = \frac{wL^2}{8Z}$$

Where M = Bending Moment
Z = Section Modulus
W = Intensity of the Uniformly distributed load
and L = Span

For the wall, the stress σ was evaluated as being 3.84 N/mm2 while for the floor panel it was 1.59 N/mm2. Since these stresses are less than the permissible values, buckling would not occur.

Bending stress (Fb) at the extreme edge of he flanges was calculalted using the equation:

$$F_b = \frac{My^E}{EI} = \frac{wL^2y^E}{8\ EI} \quad \text{——— (4)}$$

where EI = Sectional rigidity
y = Distance from edge of flange to the Neutral Axis.

For the wall panel, the stress values at the op and bottom skins were evaluated as being 1.9 N/mm^2 and 2.4 N/mm^2 respectively, while for the floor anel, the values were 4.1 N/mm^2 and 4.7 N/mm^2 repectively. These are all below the permissible stresses.

The horizontal Shear stress in each panel (Fh) maximum at its Neutral axis. This was evaluated sing the equation:

$$F_h = \frac{v\,(E_fQ_F + E_wQ_w)}{t\ \Sigma\ EI} \quad \text{——— (5)}$$

where V = Shear force
t = total thickness of webs
Q = 1st moment of area of element.

For the wall panel, F_h was evaluated as being 0.34 N/mm^2 while for the floor panel, F_h equals 0.37 N/mm^2, both being below the permissible values.

Rolling shear (Fr) at the interface of the flange and web of each panel is evaluated from the relationship.

$$Fr = \frac{v\ \Sigma E_fQ_f}{t\ \Sigma\ (EI)} \quad \text{——— (6)}$$

Values of rolling shear at the wall and floor panels were 0.29 N/mm^2 and 0.31 N/mm^2 respectively. These are lower than the 0.47 N/mm^2, the permissible value of rolling shear for the plywood.

The overall panel deflection (Δ) is calculated as suggested by Ozelton and Baird (4):

$$\Delta = \frac{5wL^4}{0.9 \times 384\ EI} \quad \text{——— (7)}$$

This worked out as Δ = 4.25mm for the wall panels and 10.7mm for the floor panels. For storage structures, the permissible deflection should be limited to the span divided by 180 (4). Permissible deflection thus works out to 10.0mm and 11.5mm for the wall and floor panels respectively. These are greater than the maximum deflections as calculated.

3.3 SUPPORTING COLUMNS

In order to prevent rise-in dampness and rodent infestation, and to provide adequate space for the positioning of a container onto which the stored grain can be emptied, the silo superstructure is to be supported by nine identical wooden columns at a height of 1 metre above ground level. The grain load to be supported is 5 tonnes while the self weight of the superstructure is 0.5 tonnes.

A total load of 55 KN is therefore to be sustained by the nine columns. Nine, 75mm x 75mm x 1000mm columns are selected and these were evaluated for their strength and stability. Using basic column equations, (3,4) for 'intermediate' wooden columns, the minimum size of leach Column is calculated as 9.14mm x 9.14mm x 1000mm. The choice of 75mm x 75mm x 1000mm columns of Mansonia is therefore quite adequate.

4.0 CONSTRUCTION

There are three major parts to the silo. These were the foundation, the hopper made up of the floor and wall and the finishes/miscellaneous items.

Six lumber pieces each 50mm x 50mm and

length 120mm are required for the floor. These are to form the circumferential webs. Each was bevelled at 120" on both ends and nailed together, using head-to-tail arrangement. The inner webs were cut to appropriate lengths, bevelled and attached to the circumferential webs. The top and bottom skins were then attached. Six vertical studs of 50mm x 50mm x 1800mm being part of the wall panels, were positioned at the corners of the hexagonal floor. Horizontal bracings were secured to the studs at intervals, equal to the calculated web spacing for the wall panel. The inner and outer skins were then attached.

The foundation consisted of nine wooden piles, eight of which were positioned along the circumference. The wooden piles were prepared and the positions of the piles were marked on the ground. The holes for the piles were dug to a depths of 30cm and the piles installed and concrete poured to secure them. Eight days were allowed for the concrete to set after which the floor joists were nailed onto the piles. The semi-finished superstructure was then positioned on the foundation.

The finishing aspect of the fabrication consisted of the roof construction, a door on one of the panels, a window on the roof and a discharge chute on a panel opposite that on which the door was located. The completed structure was painted, using aluminium paint. Fig. 2 and plate 1 show the competed structure.

5.0 PROTOTYPE TESTING

According to the British Standard Code of Practice CP: 112 (9), where the design methodology adopted for a structure is other than those in the Code of Practice, prototypes of the structure should be built and subjected to testing to ascertain its structural adequacy. This silo design is in this category. Non-destructive prototype testing was therefore carried out, to determine the deflection characteristics of the structure and the ultimate load it can sustain in service. The structure is subjected to a load equivalent to its design capacity and the deflection and behaviour of joints are observed over a period of time.

Three test parameters were used in evaluating the silo. These were failure at the joints, consolidation movement of the foundation and the deflection of the silo floor. To effectively carry these out, the following pre-loading activities were done:

i) **Marking of foundation piles:**

In order to establish the degree of foundation penetration into the ground due to the load, the surroundings of the piles were thoroughly cleaned and levelled. Scales were made on all the wooden piles at an interval of 5mm starting from the ground surface upward.

ii) **Photograph of joints:**

Adequate nailing and the use of glue resulted in close fitting joints. This notwithstanding, joint failure under load was considered a possibility. The method adopted to monitor joint condition was taking the photographs of the joint before and after loading and comparing these.

iii) Installation of Dial Indicator

Theoretically the maximum deflection should occur at the centre of the silo floor. However, since the centre of the silo floor rested on a pile, the maximum deflection should occur at a point between the centre and circumference of the floor. A dial guage was installed on the silo floor at a point where the maximum floor deflection was expected.

Using fine aggregate of density 1400kg/m3 as the test material in place of shelled corn of density 720kg/m3, the silo was filled to a height of 0.95m. The material was loaded in bulk to ensure even distribution of loads on the silo components. The load was left in place for two weeks and observations were made periodically and further observation were made after unloading.

6.0 RESULTS AND DISCUSSIONS

6.1 The Joint

Throughout the experimentation period, the joints did not show any sign of failure such as nail pulling or opening of interpanel spaces. After the silo had been unloaded, the various components showed no sign of failure.

6.2 Consolidation movement of the foundation

The foundation piles showed no sign of consolidation movement of the foundation.

6.3 Deflection of the silo floor

The results of the deflection tests on the floor as contained in figures 3 and 4, show substantial deflection with the placement of the first few centimetre-layer of load into the silo. This was as a result of the gaps (slacks) that existed between the silo floor and foundation network which had to close up upon putting load into the silo. The total reading of the dial guage thereafter gradually increased but at a decreasing rate. The total dial guage reading is made up of the consolidation movement of the floor onto the foundation network and local deflection of the floor relative to the foundation joints

This second component of the deflection is recovered when the load is removed. The recoverable deflec-

tion was determined by undertaking further reading of the dial guage after the silo has been unloaded. The dial guage reading, which at the end of loading was 4.5 mm rose to 8.75 mm at maximum deflection. The final guage reading after the silo has been unloaded was 5.3mm. This gives a deflection of 3.45mm while 5.3mm was due to consolidation of the floor onto the foundation.
This deflection of 3.45mm is within the 10.7mm limit calculated as permissible deflection for the floor.

CONCLUSIONS AND RECOMMENDATIONS

A methodology for designing wooden silos has been evolved. This is by taking the wall and floor panels as being stressed skin panel made up of solid wood ribs and plywood sheathings. Prototype testing of the designed and fabricated wooden silo confirmed its adequacy in strength and stability. The joints of common wire nails maintained structural adequacy during the test.

Longer term tests are required especially to determine the effects of years of exposure of the silo to weather on its durability.

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Table 1: Dimensions and Some Other Details of Panels

Parameters	Wall panel	Floor panel
Span of panel L (mm)	1800	2080
Width of panel (mm)	1200	1200
Thickness of topskin (mm)	12	18
Depth of web (mm)	50	50
Width of web (mm)	50	100
Thickness of bottom skin (mm)	6	12
Overall depth of panel D (mm)	68	74
Ratio of L/D	26.5	28
No. of webs	5	7
Web spacing (mm)	390	230
Total thickness of webs (mm)	250	700
External load on panel (KN/m^2)	4.774	12.714
Self-weight of topskin (KN/m^2)	0.06	0.09
Total load on topskin (KN/m^2)	4.834	12.804
Self-weight of entire panel (KN/m^2)	4.914	12.944
Shear force V (KN)	4.423	13.46

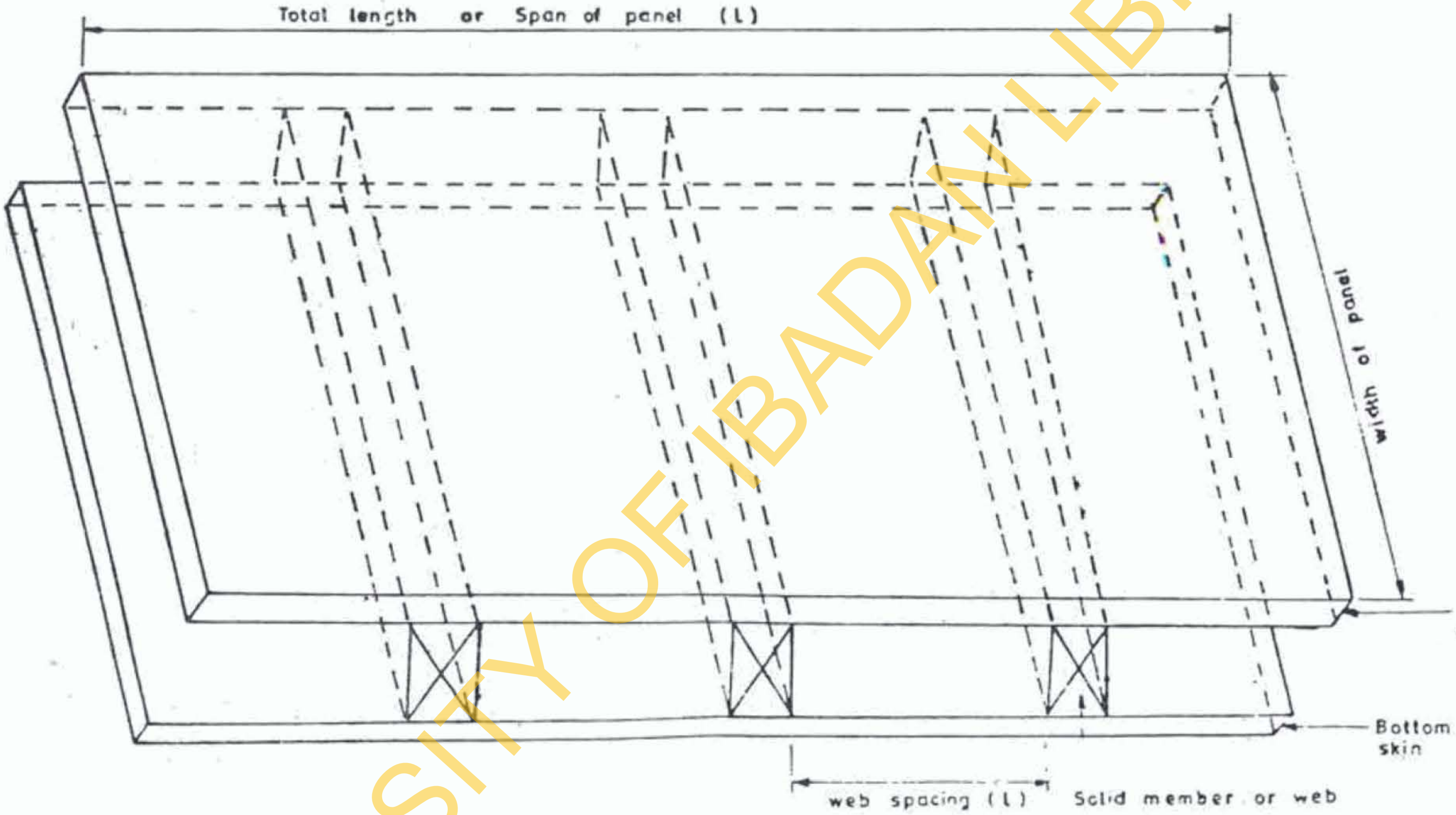

FIG. 1: A TYPICAL DOUBLE STRESSED SKIN PANEL

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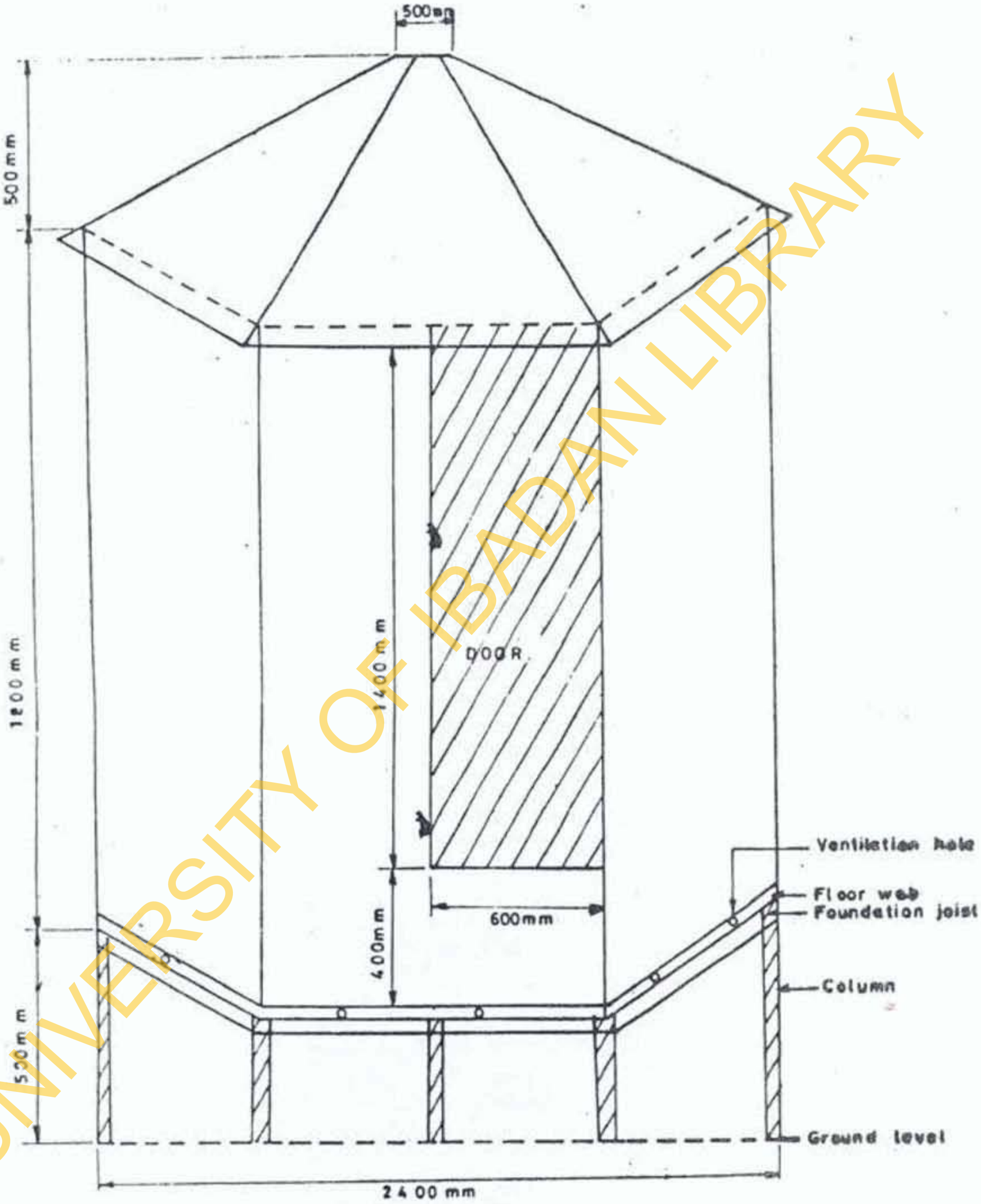
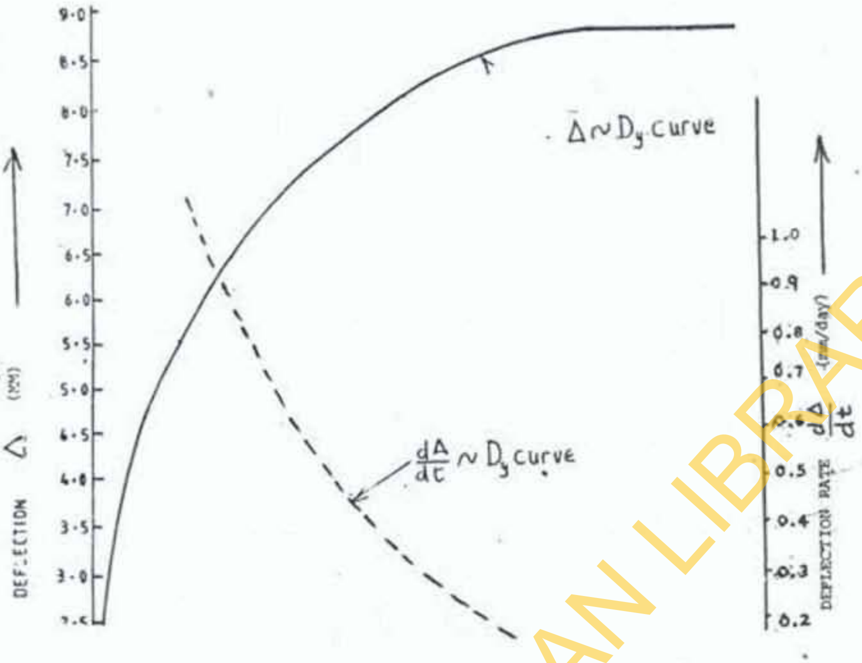


FIG. 2 : FRONT VIEW OF THE COMPLETE SILO ASSEMBLY



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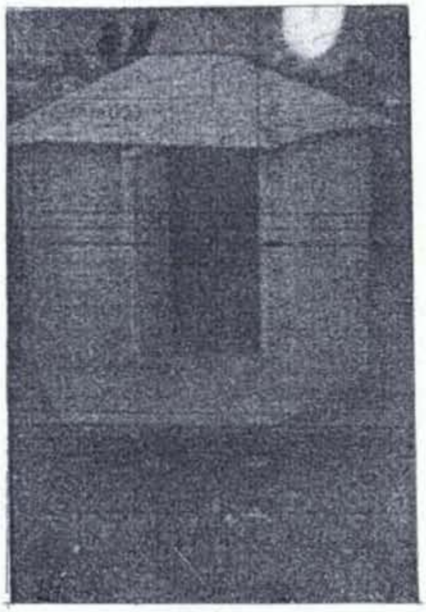

PLATE 1

The completed Wooden Silo.