STRENGTH AND WATER DURABILITY OF STABILIZED CLAY CONTAINING LIME, RICE-HULL ASH, SODIUM CHLORIDE, AND/OR STRAW, POTENTIAL CONSTRUCTION MATERIAL FOR ON-FARM STORAGE IN DEVELOPING COUNTRIES

by

DAYN LARZ CEDERSTROM

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Approved by:

P A Seib
Do Sup Chung

Co-Major Professors

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Con't.)

LIST OF FIGURES

LIST OF FIGURES (Con't.)

INTRODUCTION

It is a well known fact that considerable amounts of food grain produced in developing countries are lost due to inadequate storage facilities and improper storage methods. The problem of grain loss during storage is more acute in tropical and subtropical countries of the world. Estimates (1) by FAO put the annual losses of food grains in storage at 10% world wide. However, losses in the tropics and subtropics are higher. It is estimated that annually in Latin America stored grain losses are 25 to 50%, in certain African countries 30%, and in Southeast Asia as high as 50%.

Grain is usually stored at the farm or village level by traditional methods in developing countries. Often these traditional methods expose the grain to moisture, insects, rodents, birds and weather. Thus grain losses are incurred. Generally a farmer and his family will eat well immediately after harvest. From this harvest he will select the best grain to be used for seed for next year's planting. However, due to inadequate and improper storage, the grain will become nutritionally deficient and contaminated by rodents, birds, insects, and mold as time goes on. Portions become smaller due to losses, and malnutrition and hunger may be experienced. If worse comes to worse, such as prolonged dry season, the farmer may be obliged to eat the grain he has set aside for seed and famine will ensue.

Economics is another problem faced by the farmer. Due to lack of storage facilities, and repayment of loans, the farmer is forced to sell his grain at the time of harvest, at the same time the market is being flooded with grain from other farmers. Due to the law of supply and demand the market price is at its lowest. In the ensueing months the farmer will have to buy back grain for his own use at a higher market price, thus rapidly depleting his meager income. When his income is depleted he will then have to buy grain on credit, assuming a debt. His situation is not improved much should he decide to store the grain and not have proper storage.

Grain silos constructed of metal or cement can provide safe storage for grain. Silos of these materials can be sealed rather easily, barring the grain from moisture, insects, rodents, and birds. Metal silos (2) are lightweight and can be moved easily, and may pay for themselves from the farmers increased profits. On the other hand, metal is more expensive than most locally available materials, construction requires special equipment and metal rusts quickly in hot, humid areas. Silos made with cement (2) can be constructed with materials that are available worldwide, and can be made into almost any shape. In some areas, cement is cheaper than metal. Ferrocement is most widely used in construction of these silos. Ferrocement has a high cement content and is therefore rather expensive. Knowledge of the technique in using it is not widely available, and still presents a relative great expense for the farmer, compounded also with the expense of steel reinforcement.

Clearly there is a need to concentrate research on traditional storage facilities, methods and materials. Farmers are reluctant to try new ideas, especially if the benefits have not been proven. For them it is a matter of survival. Thus improvement in traditional ways, for which the farmer has a feel, will be much more readily accepted than those that are completely new to him, (3).

Traditional methods of storage vary from country to country and according to the culture of the people and to the grain being stored. Open storage of unhusked maize is quite common in countries of Africa. This varies from maize being tied in a bundle and hung in a tree to being stacked in layers in a circle on a platform. Threshed grain may be placed in weaved baskets or huts. These methods of storage allow the grain to dry further, if there is wind, and are usually protected from rain by a thatched roof. However, grain stored by these methods are easily subject to infestation by insects. In tropical areas where humidity is high, because the grain is open to the air, the grain stored may never reach a moisture content safe for storage. Also, unless precautionary measures are taken, these methods are easily accessable to attack by birds and rodents.

Clay is a basic indigenous material in traditional earther structures used in storage of grain. It also has excellent insulating characteristics and thus heat transfer to the grain is reduced, reducing also the translocation of moisture within the grain. The clay structures prevent infestation of birds, but depending upon the design and construction of the structure they provide little protection against insects and rodents (3). The pusa bin (4) used in India incorporates in its design sheets of plastic sandwiched between two layers of clay bricks. This offers protection against insects and moisture, but rodents are still a problem. Clay by itself can crack and shrink upon drying, causing openings in the structure and exposing the grain. Therefore indigenous additives, such as ant hills, straw and cowdung are often added to the clay. These make the clay more workable, but do little to improve its strength and durability. During the rainy season, the take up of moisture by the clay, combined with the pressure exerted by the grain on the structure, serves to weaken the structure which eventually will have to be replaced. However, storage in clay structures seems favorable and research in the improvement of this indigenous material seems worthwhile.

In 1977 the total worldwide production of grain was estimated at 1,459,012,000 metric tons. Based upon the FAO estimate of a 10% annual post harvest loss, 145,901,200 metric tons of grain were lost during storage. Figuring that a person eats on the average 200 kilograms of grain a year, the grain lost in 1977 would have fed 729,506,000 people. If the 10% annual loss could be reduced by 1%, enough grain would have been saved to feed 72,950,600 people, (5). Thus improvement upon the storage of grain is worthwhile attention and research.

D. W. Hall (1) states six results that would occur in preventing post-harvest losses: 1.) more food for consumption by the farmers, 2.) more food available for the farmers to sell, 3.) a higher living standard for farmers, 4.) more food available for non-farming populations, 5.) higher quality and competitiveness of export commodities in world trade and, 6.) a sounder economy for the country and improvement of its international standing.

LITERATURE REVIEW

Clay and Soil Characteristics

Clay is a cohesive and plastic soil, and in a pure state is free of organic matter. Clay particles are microscopic, flake-shaped crystalline minerals. Clays contain various amounts of silica, alumina, silicates, aluminates, and alumino silicates.

As the water content of a soil decreases the soil-water system passes through a series of states. Starting with a thick soil-water mixture the system passes from a liquid state through a plastic state and then into a solid state. The moisture content of the soil at which it passes from a suspension to a plastic state is known as the liquid limit of the soil. The plastic limit of a soil is the water content at which the soil passes from the plastic state to the solid state. The range of water content in which the soil is in a plastic state is the plastic range. Numerically it is the difference between the liquid limit and the plastic limit, and is referred to as the plastic index. As the water content is decreased the soil shrinks, or the volume decreases; this is known as volume change. When there is no more change in volume, the shrinkage limit or the soil has been reached. These characteristics are more evident in clays and soils containing clay than silts and loesses.

The optimum moisture content of a soil is the moisture content of the soil at which the soil can be compacted to a maximum density. Moisture contents below and above this point will give lower compacted densities for the soil.

Lime-Soil Mixtures and Characteristics

Lime-soil reactions

Modification of soil by the addition of lime causes changes in the physical characteristics of the soil. Notable among these changes are strength, plasticity and volume change. Lime added to modify the soil reacts with the uncombined silicates and aluminates of the soil to form pozzolanic minerals, (6,7). These pozzolanic reactions increase with increase in curing time and temperature.

Lime reactivity with soil can be defined as the increase in the compressive strength of the lime-soil mixture compared to the untreated soil, (8). Lime dissolves in the water and reacts with silicates and aluminates of the clay to form poorly crystallized, colloidal material that cements the clay particles together, (7, 10, 12). The major group of these reaction products are tobermonite material or calcium silicate hydrates. Strength characteristics of calcium silicate hydrates are characterized as cementitious, and are a major part of the strength production in portland cement concrete, (7). The major reaction products of lime-soil mixtures are calcium silicate hydrate (CSH gel) or tobermonite gel, calcium silicate hydrate I (CSH I) and calcium silicate hydrate II (CSH II), (7, 11). CSH gel is a high calcium compound and is formed readily at normal temperatures. CSH I has a much lower calcium content and is also formed at normal temperatures. CSH II has a high calcium content but is formed at high hydrothermal conditions. Calcium aluminate hydrates are formed at normal temperatures and occur in several forms (11), however their role is less significant than the silicate compounds for strength development, (1). Ormsby and Kinter (13) in their investigation of lime-montmorillonite detected no calcium aluminates in cured specimens.

Reactivity of a soil depends upon the amount of pozzolans in the soil. Pozzolans are primarily silicious materials that react with lime and water to form cementitious compounds, (10, 13). For pozzolanic reactions to occur, lime content must exceed the amount needed to modify the soil, (6, 7).

Plasticity

Generally upon the addition of lime to soil, the plasticity index is sharply reduced, (6, 10, 11, 12). The increase of the liquid limit is not as great as the plastic limit, and the combination of both yields a decrease in the plastic index of the lime-soil mixture, (11). Additional amounts of lime beyond an optimum level may increase the plasticity index, (11). In some cases, the addition of lime may initially increase the plastic index, but as the curing period is extended the process is reversed, with the plastic index decreasing to a non-plastic state, (11).

Elasticity

When pressure is applied to a material which returns to its former shape or volume when the pressure is removed, the material is elastic. In general, lime-soil mixtures behave elastically. The modulus of elasticity of lime-soil mixtures is greater than the modulus of elasticity for untreated soils, (9, 13). Thompson reports modular ratios, $E_{lime\text{-}soil}/E_{soil}$, of 3 to 25, (9). As intensity of curing is increased (increased temperature and time) there is a tendency towards a more elastic behavior of the mixture, (9, 13).

Volume Change

The tendency of lime added to soils is to reduce the volume change that occurs in the soil as it dries, (10, 11). As the lime content is increased, the shrinkage limit increases and the shrinkage ratio decreases. Swelling of soils is also decreased. Volume change will decrease up to an optimum lime content.

Strength Development

The main factors affecting the strength development of lime-soil mixtures are lime content, lime type, soil type, density of mixture, time of curing, and type of curing, (10). All are interrelated and no one is more important than another

Generally as the lime content increases in a lime-soil mixture the strength increases, (10, 13, 14). Depending upon the type of soil, there may or may not be an optimum lime content, depending primarily on curing time, (10).

Strength gain for lime-soil mixtures will vary with type of soil, (10, 14, 16, 22). As stated previously, reactivity of a soil depends upon the amount of pozzolans in the soil. The development of pozzolanic reactions are related to the systems gain in strength.

The maximum density of a soil is reduced upon the addition of lime, (10, 11, 22). Strength of the lime-soil mixture is increased when the mixture is compacted to a higher unit weight with greater compactive effort, (10, 11, 21). Optimum moisture content needed to achieve maximum density in the soil alone usually increases in the lime-soil mixture, (10). Further additions of lime, once the optimum moisture content has increased substantially, produces little additional increase in the optimum moisture content.

Lime-soil mixtures increase in strength with age, (10, 21). There is a rapid increase in strength, then the system levels off.

The rate of gain in strength is directly related to the temperature at which the lime-soil mixture is cured, (10, 11, 21). At low temperatures, gain in strength is very low. At normal temperatures, gain in strength is greater and at high temperatures, increases in strength are rapid.

Ormby and Kinter (14) investigated the strength development for two clay minerals, kaolinite and montmorillonite, using two types of lime, calcitic and dolomitic. Results followed the general discussion on strength development and are shown below.

Concentration of lime in lime-soil mixtures	Unconfined Compressive Strength (psi)[1]			
	Calcitic Lime		Dolomitic Lime	
%	Moist cured 28 days/RT	Moist cured 2 days/120°F	Moist cured 28 days/RT	Moist cured 2 days/120°F
Kaolinite				
0	252	235	252	233
2.5	354	396	297	306
5.0	418	639	405	457
7.5	529	946	426	555
10.0	615	1002	442	597
Montmorillonite				
0	182	224	182	224
2.5	143	182	190	169
5.0	170	202	206	230
7.5	203	256	242	271
10.0	284	334	327	306

1. Each strength value is the average of 8 replicates.
RT - room temperature.

As can be seen with the kaolinite clay using both types of lime, as the lime percentages increase, the strength gain increases. Calcitic lime gives superior strength gain than does the dolomitic lime for kaolinite. There is a decrease in strength in the montmorillonite with 2.5% calcitic lime, but with further increases of lime strength increases over the untreated sample. Montmorillonite with dolomitic lime shows increments of strength with each increase in lime content for the 28 day curing. With the 2 day cure there is a decrease in strength with the first addition of lime but an increase over the untreated specimen there after. With the montmorillonite, the dolomitic lime gave the superior strengths.

Addition of Salt (Sodium Chloride)

The formation of tobernonite materials by pozzolanic reactions is increased when sodium chloride is added to the lime-soil system, and thus increasing the strength of the soil. (15, 16, 17) A pH of 10 or greater increases the solubility of silica (18), making it more available to enter into pozzolanic reactions. (16) Only small percentages of sodium chloride are needed to increase the strength of lime-soil mixtures (1, 2 or 3% of dry weight of soil) and this depends upon the type of soil. (16, 17) Addition of sodium chloride also produces an increase in compacted unit weight. Marks and Haliburton (15) showed that a clay treated with 5% lime compacted to a maximum dry density at 0% salt, to 94 pcf. At 0.5% and 1.0% salt contents, the maximum compacted dry densities were 98 pcf and 100 pcf. At 1.5% salt content maximum density was 96 pcf, showing that an optimum salt content was reached to produce a maximum compacted dry density. Corresponding to the increase in compacted densities, there was a decrease in the optimum moisture content. Marks and Haliburton (16) in a later experiment showed that the addition of salt increased the compressive strength of clay. Compressive strength for a clay at 8% lime content, 0% salt content, was 100 psi, while that for the same clay containing 1% salt content was 120 psi.

Addition of Silicious Materials

Pozzolans can be added to soils to increase and to achieve the desired reactions in soils. (10) As has been stated pozzolans are primarily silicious materials and these react with lime in pozzolanic reactions. Fly ash, a by-product of burnt coal and a pozzolanic material, has been added to lime-soil mixtures and increased the compressive strength as much as 290% over that containing no fly ash, (19). Mohan and Rai (20) report that pozzolanic reactions have been obtained using rice hull ash (which contains silica) in lime-clay mixtures, although no results or evidence were given.

Tropical Soils

Lateritic soils cover much of the tropics and subtropical regions of the world, (21, 22). Harty and Thompson (22) investigated the reactivity of tropical soils with lime. Conclusions were generally the same as other experiments. They concluded, however, that lime requirements to maximize strength of tropical and subtropical soils are generally higher than those temperate zone soils. Twenty-six tropical soils from various parts of the world were tested. Of interest are two soils from Panama, Panama Howard and Panama Albrook. Compressive strength for untreated Panama Howard was 106 psi; 7, 28, and 56 day cures gave compressive strengths of 245, 712 and 800 psi, respectively. Untreated Panama Albrook compressive strength was 111 psi; 7, 28 and 56 day cure, compressive strengths were 147, 325 and 365 psi, respectively.

Conclusions From Literature Review

From the previous discussion the following conclusions are drawn.

1. Soil reactivity depends upon the amount and availability of pozzolans in the soil. Lime reactivity is related to the increase of strength of the lime-soil mixture over that of the untreated soil.
2. As the lime content is increased there is a decrease in the plasticity of the soil up to a certain lime content. The soil becomes elastic and elasticity is increased as the intensity of the curing condition (time and temperature) are increased.
3. Volume change (shrinkage) is decreased upon the addition of lime. Shrinkage limit of the soil is increased.
4. In general, as lime content is increased in lime-soil mixtures, compressive strength is increased. Factors affecting this are 1) lime content, 2) lime type, 3) soil type, 4) density, 5) curing time, and 6) type of curing. All factors are interrelated for most types of soils.

   i. Lime content -generally as lime content increases there is an increase in strength.

   ii. Lime type -strength gains will be different for different lime types and how they react with the soil.

   iii. Soil type -strength gain depends upon the reactivity of the soil with the lime being used.

   iv. Density -density of lime-soil is less than that of untreated soils. For maximum strength, lime-soil mixture must be compacted to maximum density.

Also as lime is added, the optimum moisture content is increased.

v. Curing time -as time of cure is increased, strength is increased.

vi. Type of curing -as temperature is increased, strength is increased.

5. Addition of salt increases the strength gain and density of lime-soil mixtures.

6. Additional pozzolanic material can be added to the lime-soil mixture to increase strength.

7. Lime requirements to produce strength gains in tropical soils are generally higher than those of temperate zone soils.

OBJECTIVE

The broad objective of this study was to develop an indigenous construction material for on-farm grain storage in developing countries. The specific objective was to test the strength and durability of clay cylinders with the addition of lime, rice hull ash, salt, and straw. The durability of coatec versus non-coated clay cylinders was also tested. Finally recommendations on the design of a one-ton grain silo were made using the clay mixture developed in this study.

MATERIALS AND METHODS

Materials

The clay used was obtained from the Cloud County Ceramic Company in Concordia, Kansas. The clay was tested by the Kansas Department of Transportation Testing Services to determine its physical characteristics and clay mineral content. The tests conducted were standard proctor density test, grain size analysis, determination of Atterberg limits, and determination of specific gravity according to the specifications of the Kansas Department of Transportation. To determine clay mineral content x-ray diffraction tests were preformed on i) a powder sample with a 60° scan, and 3 oriented slides prepared from a slurry of clay passing a No. 200 sieve, ii) an untreated slide with a 45° scan, iii) a glycolated treated slide with a 15° scan and a heat treated slide (600°C) with a 45° scan.

Clay was oven dried at 110°C for 24 hours. For moisture-density tests the dry clay was ground so that 100% passed through a U.S. Standard No. 4 sieve. For preparation of clay cylinders to test compression, tension and durability, the clay was ground so that 100% passed through a No. 20 sieve. Additives were hydrated lime, rice hull ash, table salt, and straw. Percentages of additions were based upon the dry weight of the clay.

Lime (CaO) is the active chemical of hydrated lime in combination with water in the formation of pozzolanic reactions. Therefore, the percentages of lime added to the clay is based upon the ratios of the atomic weight of lime (CaO), 56 to the atomic weight of hydrated lime ($Ca(OH)_2$), 74. Additions of calcium oxide were 2.0, 4.0, 6.0 and 8.0%.

When burned, rice hulls produce two types of ash, a white ash and a black ash. The black ash is the carbon element of the hulls and is formed at the bottom due to incomplete ashing White ash is formed on top and is the mineral content of the hulls. White ash was added to the clay in amounts of 2.5, 5.0, 7.5 and 10.0%.

Additions of salt were 0.5, 1.0 and 1.5%. Straw added was 2.0% only.

Testing Methods

Moisture-Density Test

The moisture-density test of the Standard Proctor Compaction Test was performed to determine the maximum densities of the clay mixtures at their optimum moisture content. Water was added to 2000 grams at a selected moisture content and thoroughly mixed for 2 minutes using a soil-test mixer. The mixture was compacted in three layers into a mold, 4.6 inches by 4 inches in diameter, with each layer receiving 25 evenly distributed blows. The blows were delivered by a 5.5 lb. hammer free-falling one foot above each layer. After compaction, the mixture was trimmed, and removed from the mold, weighed and dried for 24 hours at 110°C. After drying, the dry weight was recorded to calculate the dry density and actual moisture content. This procedure was repeated 5 or 6 times for each mixture.

Making of Cylinders

For each mixture, the amount of dry ingredients needed was weighed and mixed thoroughly for 2 minutes with an soil-test mixer. The amount of mix needed for each cylinder was placed in an evaporating dish with the required amount of wate which was previously determined by the moisture-density test. The mixture was hand mixed until ingredients were thoroughly moistened, and then transferred to a cylindrical mold and compressed into a cylinder (2-inch diameter by 4-inch long) shown in Figure 1. The clay cylinders were compressed by a compression machine with compression plug and then extruded from the mold. The wet cylinders were individually wrapped in plastic wrap and aluminum foil, placed in an oven and cured for 30 hours at 49°C. After curing, the cylinders were unwrapped and dried for 72 hours at 49°C.

Procedure of Adding Additives and Testing Strength

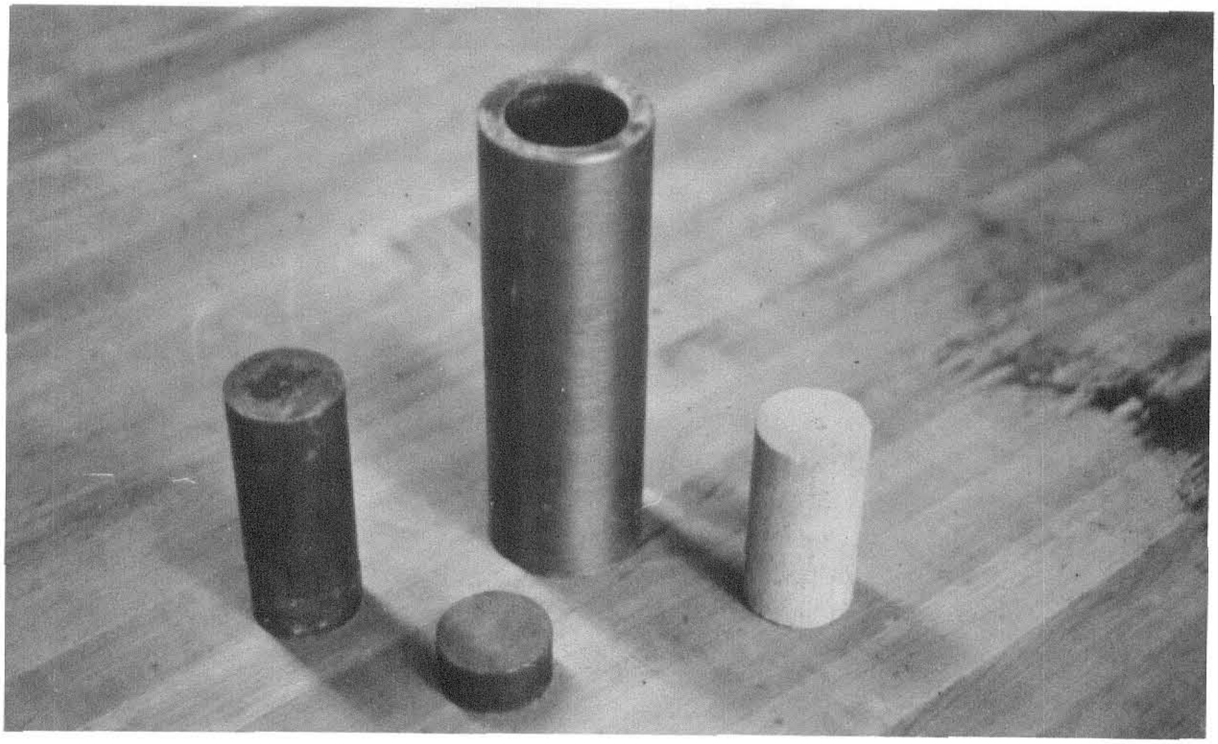
Limed clay cylinders were tested for strength first. The other additives were tested with lime at the level where it produced maximum strength, noting the effect they had upon the strength of the lime-optimum.

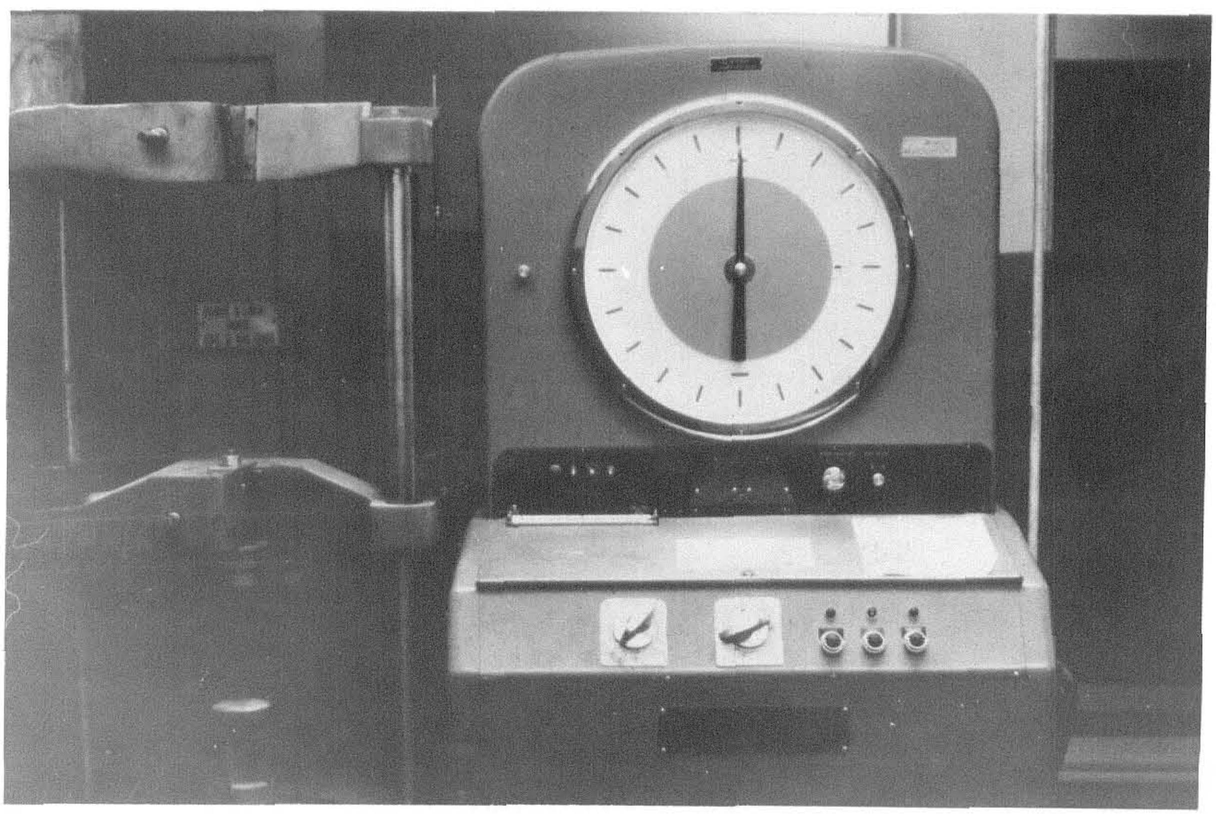
Testing of Compression Strength

Compression strength of mixtures was tested by axially compressing the cylinders to failure, using a Reighle machine, (Figures 2 and 3). Compression computed by the formula $f'_c = P/A$, pounds per square inch, where P is the load causing failure and A is the cross sectional area of the cylinder.

Figure 1. Apparatus for making cylinders. From left to right, compressing plug, bottom plug, collar, and resulting cylinder.

Figure 2. The Reighle testing machine.





Testing of Tensile Strength

Tensile strength was tested by using the split cylinder tensile test. The cylinders were placed horizontally in the Reighle testing machine, and compressively loaded until failure of the cylinder occurred, (Figure 4). Tension was computed by the formula, $f'_{sp} = 2P/\pi dL$, pound per square inch, where P is the load causing failure, d is the diameter of the cylinder and L is the length of the cylinder.

Testing of Durability

Durability of mixtures were tested by immersing the cylinders in water at room temperature. After an alotted time period, the cylinders were removed and weighed, noting either gain or loss in weight caused by the water. The cylinders were again immersed and the procedure repeated until there was no notable weight gain in the cylinders, or until obvious deterioration was observed. Clay cylinders that had been coated with a water vinyl sealer were also tested for durability over a 5-minute period.

Atterberg Limits

The Atterberg limits were determined for the 4.0% limed clay with 2.5% ash using a standard procedure in <u>Soil Testing For Engineers</u> by T. Williams Lambre, John Wiley & Son's, Inc., pages 22-28. The Atterberg limits are the liquid limit and plastic limit. The liquid limit is the water content at which the clay has such a small shear strength that it flows to close a groove of standard width when jarred in a specfic man-

Figure 3. Arrangement of cylinder for testing compression.

Figure 4. Arrangement of cylinder for testing tension.

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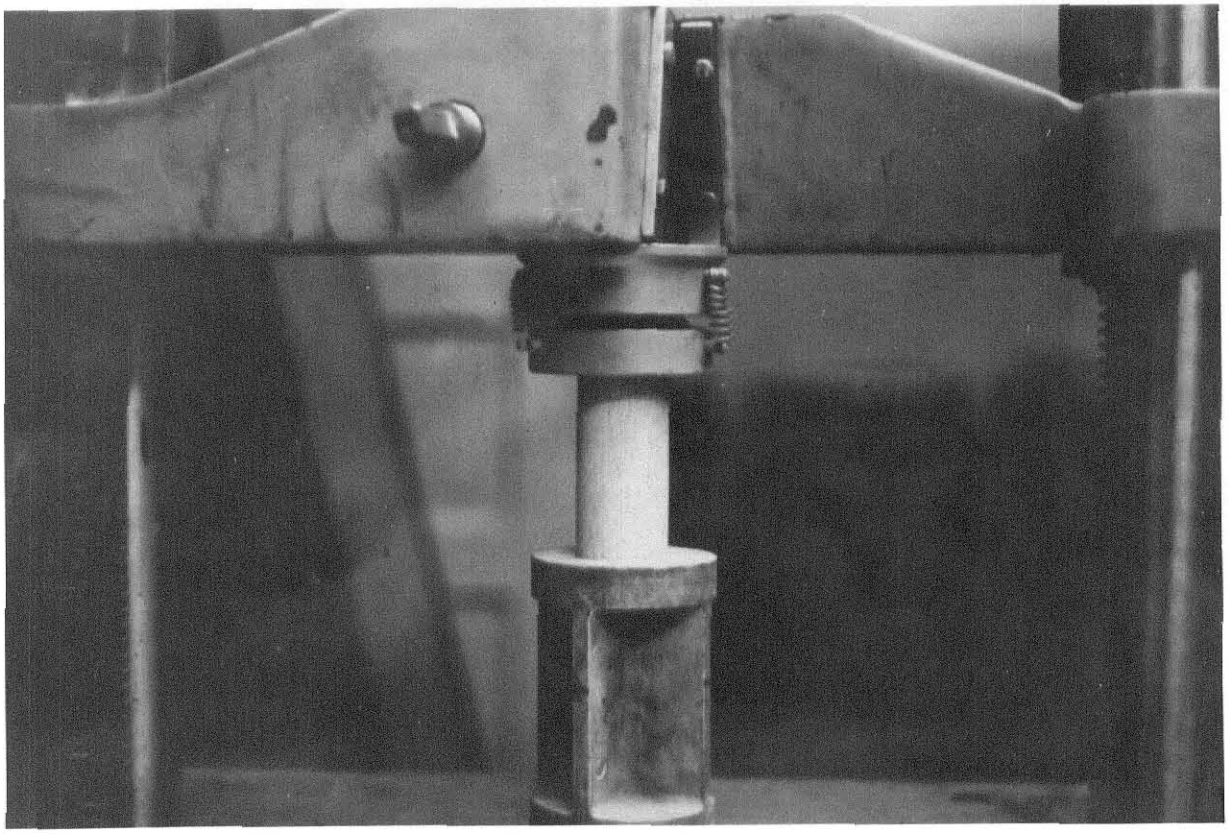

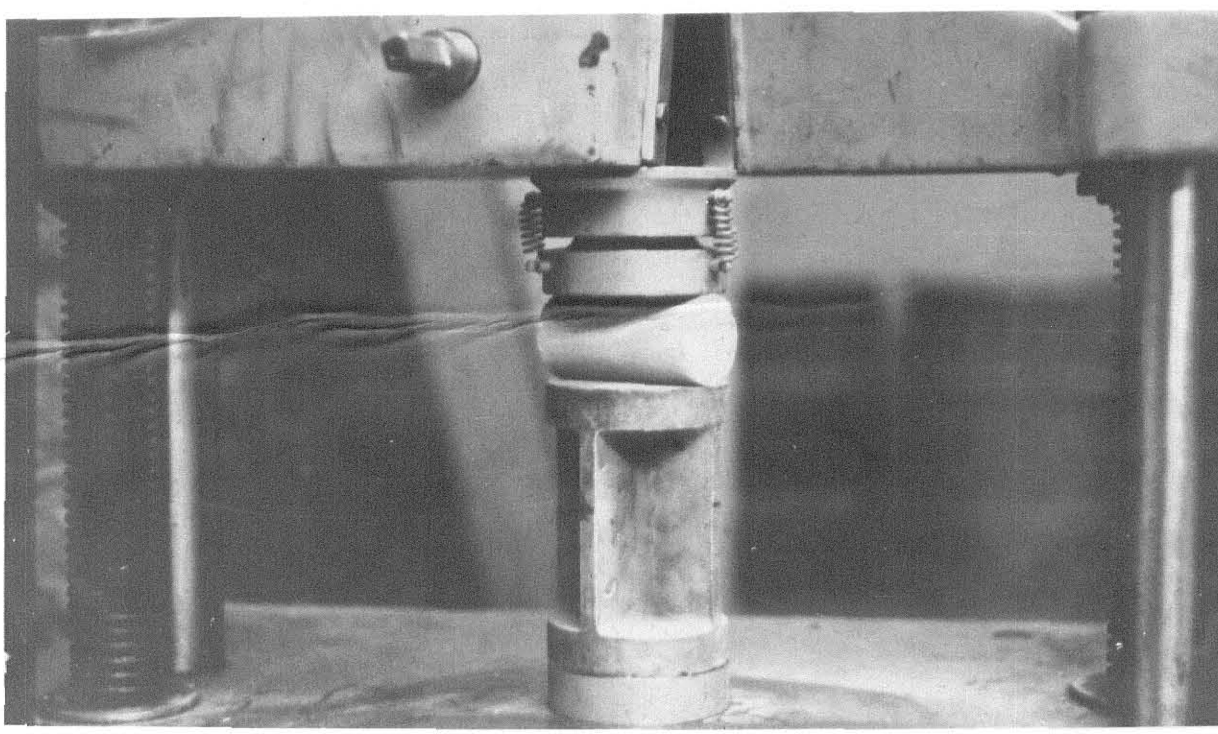

ner. The liquid limit is determined by a device in which a cup containing a paste of water and clay is dropped 0.394 inches a number of times, to close a groove that has been drawn through the clay. The water content generally accepted as the liquid limit of the clay is when the groove closes at 25 drops or blows. The plastic limit is the water content at which the clay begins to crumble when rolled into threads of specified size. Clay is rolled by hand on a glass plate into a thread. The water content of a clay accepted as the plastic limit is when a 1/8 diameter thread of clay shows signs of crumbling.

RESULTS AND DISCUSSION

Clay Characteristic and Clay Mineral Content

Physical characteristics of the clay are shown in Table 1 and Figure 5. Results of x-ray diffraction test are shown in Figures 6, 7, 8 and 9. The powder slide and the untreated oriented slide showed the clay to be comprised of kaolinite, illite and quartz minerals. The glycolated slide showed the clay contained no expansive clays and in the heat treated slide, the kaolinite peaks were destroyed.

Moisture-Density Test

Results of the moisture-density test are shown in Table 2. Difficulty was experienced in making a uniform, smooth cylinder at the moisture content that gave maximum density. Satisfactory cylinders were obtained at a moisture content about 2% higher than the optimum moisture content. The dry weights and nominal moisture contents used in making the cylinders are shown in Table 3. No moisture-density test was performed on mixtures with straw. The moisture content used for clay with straw was that used in the corresponding mixture without straw and the weight of the straw clay cylinders determined by trial and error.

Compression and Tension Test

The results of compression and tension tests of the control and lime-clay mixtures are shown in Tables 4a and 4b. The addition of lime increases the compression strength of the clay, with maximum strength obtained at 4.0% lime, at which

Table 1. Physical Characteristics of Clay.

STANDARD-PROCTOR DENSITY TEST

Moisture Content, %	Dry Density (Pounds per cubic foot)
9.9	107.6
12.2	106.6
13.9	109.9
16.2	111.3 (maximum density)
17.6	109.6
20.1	106.2

GRAIN SIZE ANALYSIS

Sieve Analysis

Sieve Number	Opening (milimeters)	Percent Passing
10	2.00	100.0
20	0.84	98.6
40	0.42	97.0
60	0.250	95.6
100	0.149	94.2
200	0.074	90.4

Hydrometer Analysis

Maximum Grain Size (milimeters)	Actual Grain Size (milimeters)	Percent in Suspension
0.112	0.049	84
0.078	0.036	80
0.055	0.025	78
0.035	0.016	76
0.020	0.010	71
0.014	0.0067	69
0.010	0.0047	65
0.005	0.0024	57
0.002	0.0010	47

ATTERBERG LIMITS

Liquid Limit (L.L.)	40.0%
Plastic Limit (P.L.)	17.5%
Plastic Index (P.I.)	22.5%

SPECIFIC GRAVITY

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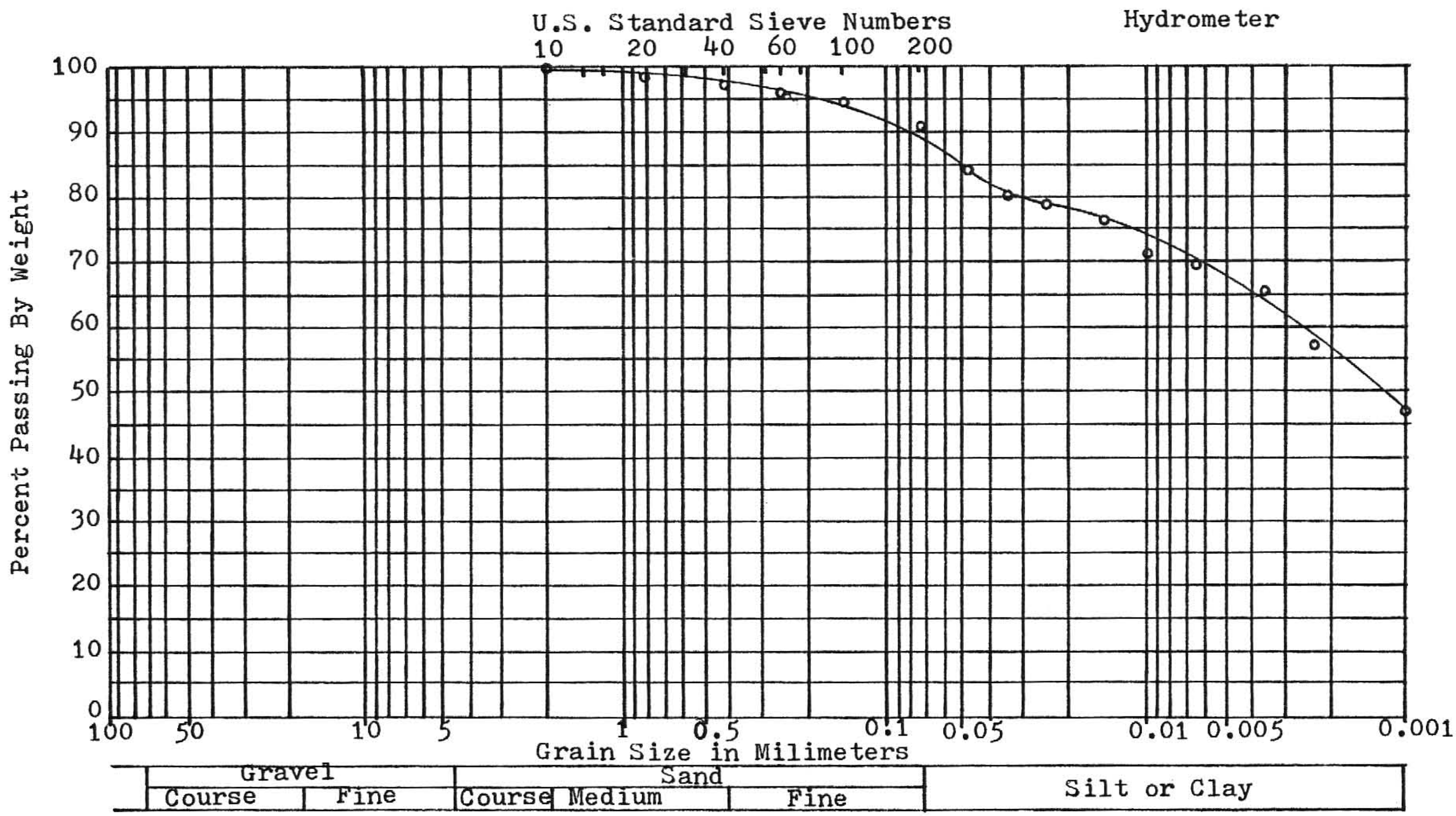


Figure 5. Sieve and Hydrometer Analysis of Clay.

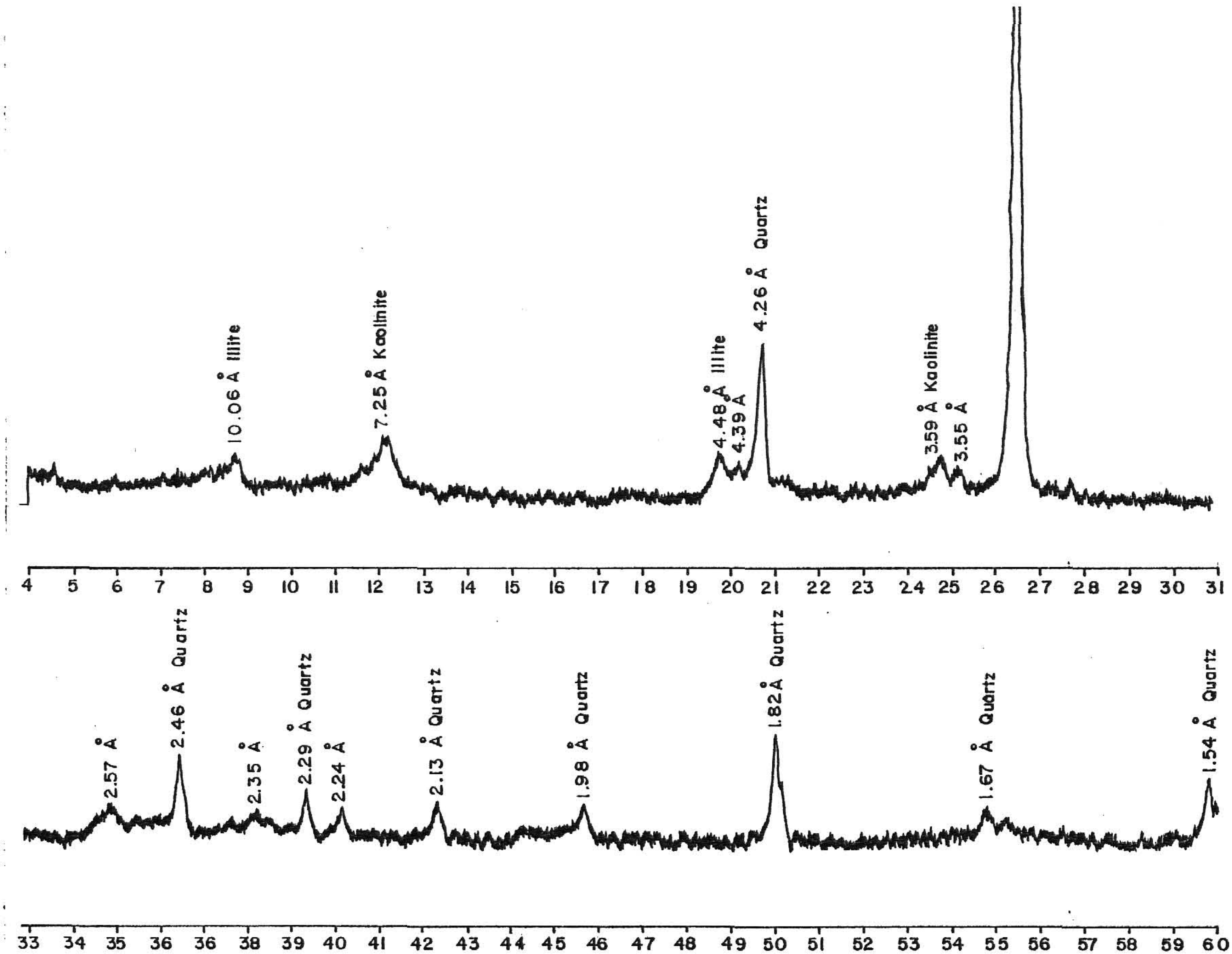


Figure 6. X-ray diffraction of powder sample, 60°scan.

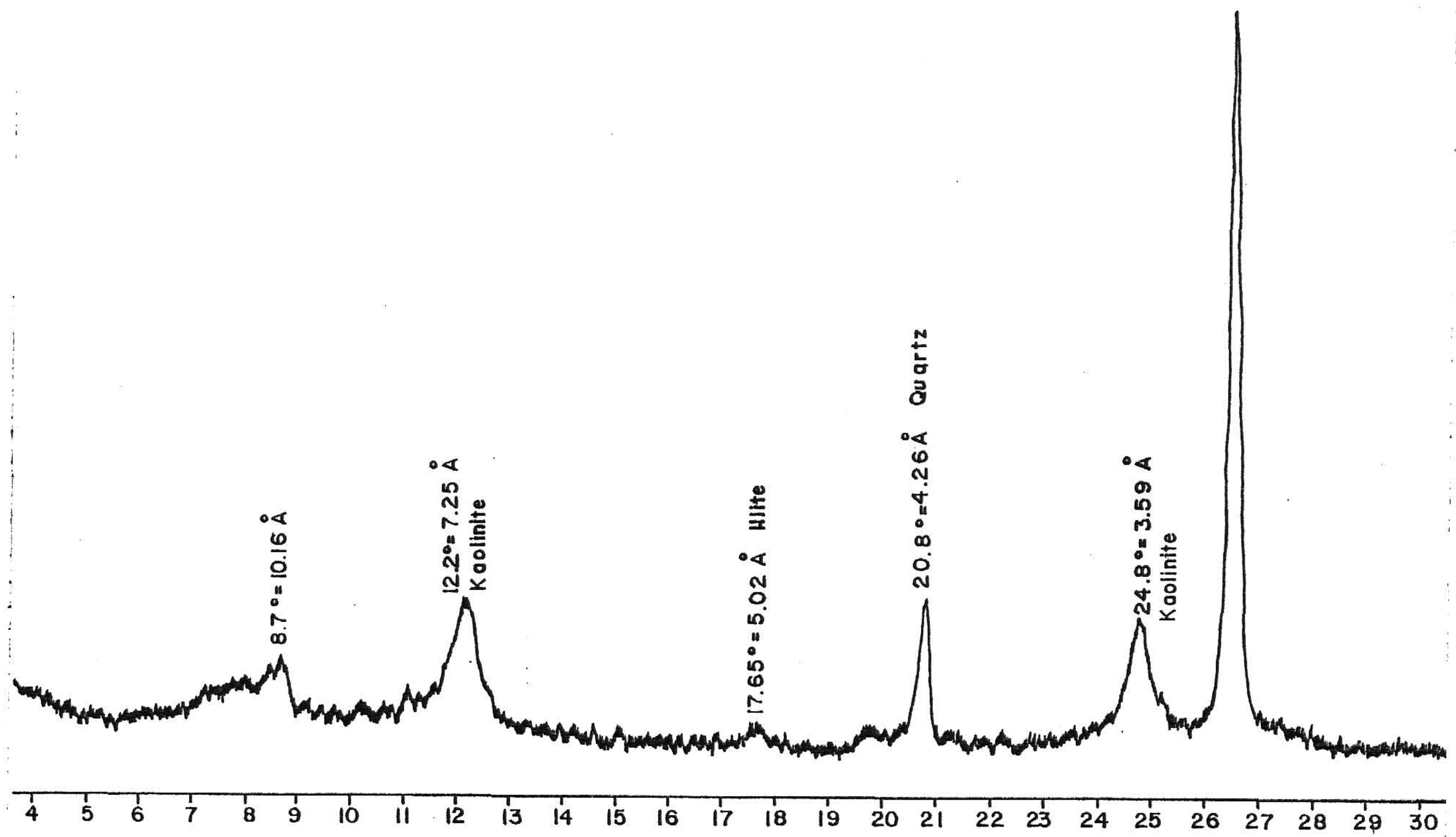


Figure 7. X-ray diffraction of slurry slide, 45° scan.

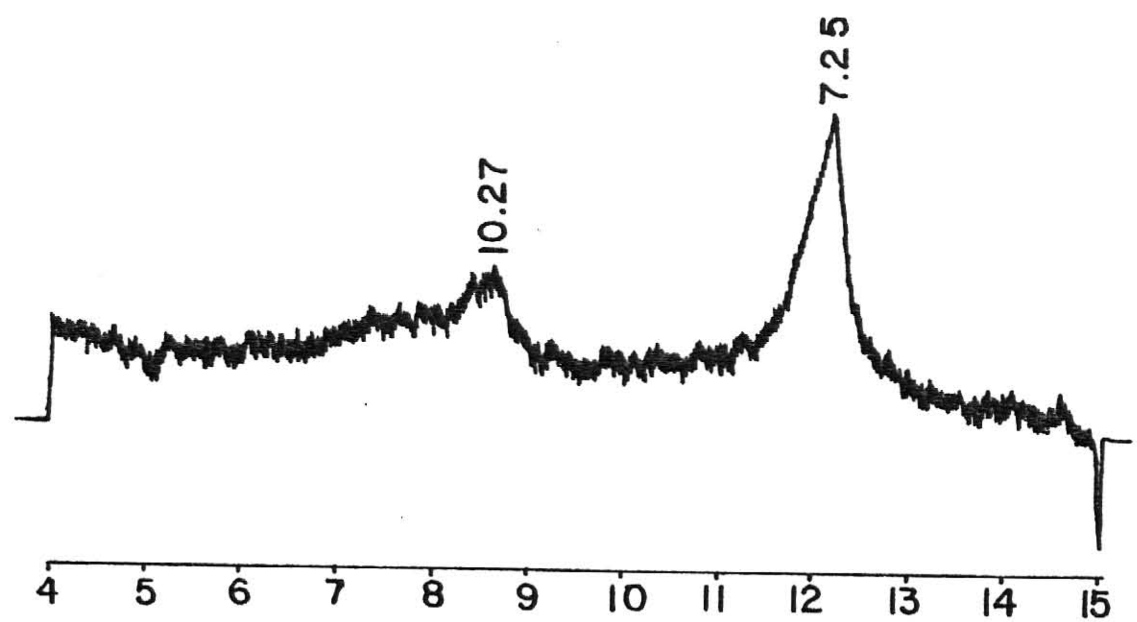


Figure 8. X-ray diffraction of glycolated treated slide, 15° scn.

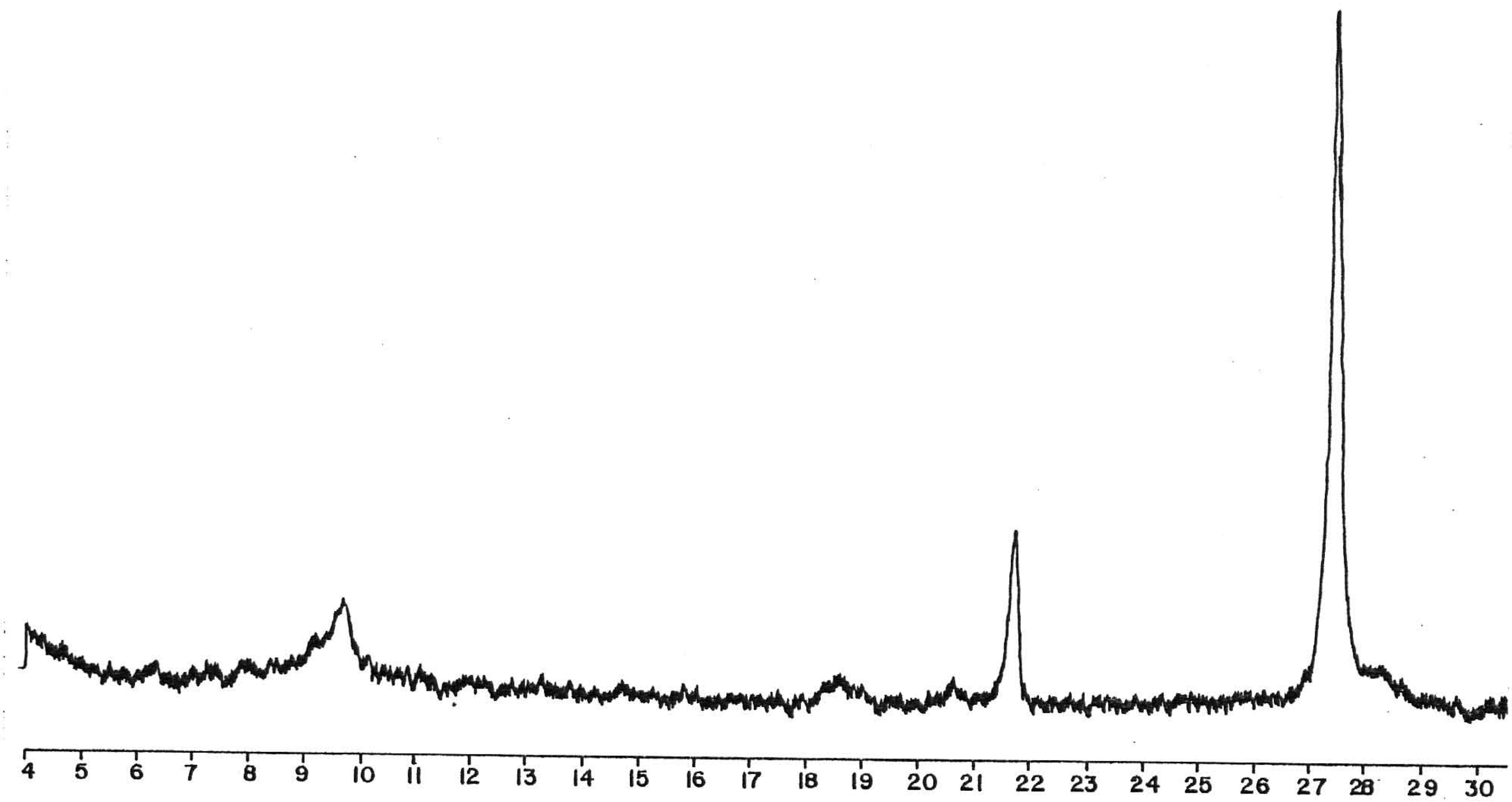


Figure 9. X-ray diffraction of heat treated slide, 45° scan.

Table 2. Moisture-density tests of clay mixtures.

2.0% lime

M.C. %	Density, pcf
15.4	101.4
18.1	101.1
20.1	101.7
22.0	101.1
24.0	99.3
25.3	96.3

4.0% lime

M.C. %	Density, pcf
16.1	98.4
18.4	100.8
19.7	101.7
21.7	100.8
23.1	99.9
25.2	96.3

6.0% lime

M.C. %	Density, pcf
16.9	99.8
18.4	100.5
20.8	100.8
22.2	100.2
25.2	97.5

8.0% lime

M.C. %	Density, pcf
17.9	98.1
20.0	98.1
22.3	99.0
24.4	98.2
27.2	94.4

2.5% ash-4.0% lime

M.C. %	Density, pcf
16.4	100.2
18.8	101.8
20.6	102.0
22.4	101.3
24.8	99.0

5.0% ash-4.0% lime

M.C. %	Density, pcf
20.3	98.3
21.8	99.0
22.8	98.2
25.4	95.1
27.2	94.4

7.5% ash-4.0% lime

M.C. %	Density, pcf
19.5	92.1
20.6	95.5
23.0	96.0
25.3	95.5
27.0	93.9

10.0% ash-4.0% lime

M.C. %	Density, pcf
20.0	91.0
22.9	93.1
25.1	94.3
26.3	93.5
27.5	92.3

0.5% salt-4.0% lime

M.C. %	Density, pcf
16.2	101.8
18.3	102.5
20.2	101.4
22.2	101.2
24.0	99.0

1.0% salt-4.0% lime

M.C. %	Density, pcf
16.1	102.0
17.9	102.4
20.3	102.5
22.0	101.8
23.7	99.4

1.5% salt-4.0% lime

M.C. %	Density, pcf
15.7	105.5
17.3	106.5
18.2	106.3
20.2	104.9
21.9	102.9

Table 3. Dry weights and moistre content of cylinders.

Mixture	Dry Weight, grams	Moisture Content, %
Control	369	18.0
2.0% lime	335	22.0
4.0% lime	335	22.0
6.0% lime	330	22.0
8.0% lime	324	24.0
2.5% ash-4.0% lime	335	22.0
5.0% ash-4.0% lime	324	22.0
7.5% ash-4.0% lime	315	25.0
10.0% ash-4.0% lime	309	26.0
0.5% salt-4.0% lime	335	20.0
1.0% salt-4.0% lime	335	22.0
1.5% salt-4.0% lime	350	20.0
2.0% straw-4.0% lime	329	22.0
2.0% straw-1.0% salt-4.0% lime	329	22.0

Moisture content based upon dry weight of mixture.

Table 4a. Compression strength of control and limed clay cylinders.

Mixture	Control		2.0% lime		4.0% lime		6.0% lime		8.0% lime	
Replicate	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2
1	376	26.44	554	38.96	624	43.88	608	42.76	520	36.57
2	401	28.20	522	36.71	665	46.77	598	42.06	500	35.16
3	455	32.00	579	40.72	656	46.13	598	42.06	499	35.09
4	439	30.87	528	37.13	639	44.94	563	39.59	522	36.71
5	414	29.11	547	38.47	618	43.46	594	40.37	506	35.59
Average	417.0	29.32	546.0	38.39	640.4	45.04	592.2	41.65	509.4	35.82
S.D.*	±31.1	±2.18	±22.7	±1.62	±20.1	±1.41	±17.1	±1.20	±10.9	±0.77

* Standard Deviation

Table 4b. Tension strength of control and limed clay cylinders.

Mixture	Control		2.0% lime		4.0% lime		6.0% lime		8.0% lime	
Replicate	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2
1	46	3.24	47	3.31	49	3.45	42	2.95	37	2.60
2	47	3.31	46	3.24	50	3.52	40	2.81	37	2.60
3	47	3.31	47	3.31	54	3.80	40	2.81	38	2.67
4	53	3.72	47	3.31	51	3.59	41	2.88	36	2.53
5	56	3.93	47	3.31	50	3.52	44	3.09	34	2.39
Average	49.8	3.50	46.8	3.29	50.8	3.57	41.4	2.91	36.2	2.55
S.D.*	±4.4	±0.31	±0.4	±0.03	±1.9	±0.14	±1.7	±0.12	±1.9	±0.11

* Standard Deviation

level the compression strength was 53.5% higher than the control. Tension strength generally decreased with the additions of lime compared to the control but when 4.0% lime was added tension strength was about the same as that of the control, (Table 4b).

Rice-hull ash was added to the 4.0% limed clay. Results are shown in Tables 5a and 5b. Maximum strength, in both compression and tension was obtained by the initial and smallest addition of rice hull ash, 2.5%, to the 4.0% limed clay. With 2.5% rice-hull ash compressive strength was increased 38.6%, while tensile strength gained 91.5%. Strengths for higher levels of rich-hull ash were significantly lower.

Salt was added at levels of 0.5, 1.0 and 1.5% to the 4.0% limed clay. Results are given in Tables 6a and 6b. The level of salt needed for maximal strength is not easily derived because of the considerable deviation of the data. However, the 4.0% limed clay with 1.0% salt added was the most consistent, and gave a 53.4% gain in compression and a 92.2% gain in tension strength 4.0% limed clay control.

Tables 7a and 7b show the results of 2.0% straw added to the 4.0% limed clay and 4.0% limed clay with 1.0% salt added. The addition of straw to the 4.0% limed clay decreased compression strength but greatly increased tension strength by 58.0%. Addition of straw to the 1.0% salt - 4.0% limed clay produced an adverse effect in both compression and tension. Compression decreased by 42.0% and tension by 8.8%. The straw may compete with the clay for the sodium ions and therefore the desirable reactions in 4.0% limed clay with 1.0% salt added do not occur to the same extent when straw is added.

Table 5a. Compression strength of cylinders made from 4.0% limed clay with varying amounts of ash.

% of Ash	2.5		5.0		7.5		10.0	
Replicate	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2
1	914	64.28	614	43.18	707	49.72	850	59.78
2	847	59.57	618	43.46	742	52.18	694	48.81
3	901	63.36	656	46.13	713	50.14	710	49.93
Average	887.0	62.40	629.3	44.26	720.7	50.68	751.3	52.84
S.D.*	±35.5	±2.50	±23.2	±1.63	±18.7	±1.32	±85.8	±6.03

Average of 4.0% CaO

640.4 45.04

* Standard Deviation

Table 5b. Tension strength of cylinders made from 4.0% limed clay with varying amounts of ash.

% of Ash	2.5		5.0		7.5		10.0	
Replicate	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2
1	94	6.61	69	4.85	77	5.42	63	4.43
2	101	7.10	73	5.13	79	5.56	70	4.92
3	97	6.82	70	4.92	75	5.27	82	5.77
Average	97.3	6.84	70.7	4.97	77.0	5.41	71.7	5.04
S.D.*	±3.5	±0.25	±2.1	±0.15	±2.0	±0.14	±9.6	±0.68

Average of 4.0% CaO
50.8 3.57

* Standard Deviation

Table 6a. Compression strength of cylinders made from 4.0% limed clay with varying amounts of salt.

% of Salt	0.5		1.0		1.5	
Replicate	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2
1	987	69.41	974	68.50	935	65.76
2	952	66.95	970	68.22	871	61.25
3	844	59.36	989	69.55	948	66.67
4	1028	72.30	977	68.71	1003	70.54
5	974	68.50	1003	70.58	1006	70.75
Average	957.0	67.29	982.6	69.10	952.6	66.99
S.D.*	±69.0	±4.85	±13.4	±0.94	±55.6	±3.91

Average of 4.0% CaO

640.4 45.04

* Standard Deviation

Table 6b. Tension strength of cylinders made from 4.0% limed clay with varying amounts of salt.

% of Salt	0.5		1.0		1.5	
Replicate	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2
1	82	5.77	91	6.40	98	6.89
2	92	6.47	99	6.96	91	6.40
3	90	6.33	103	7.24	101	7.10
4	75	5.27	99	6.96	101	7.10
5	96	6.75	98	6.89	105	7.38
Average	87.0	6.12	98.0	6.89	99.2	6.98
S.D.*	±8.4	±0.59	±4.4	±0.31	±5.2	±0.37

Average of 4.0% CaO

50.8 3.57

* Standard Deviation

Table 7a. Compression strength of cylinders made from either 4.0% limed clay with 2.0% straw or 4.0% limed clay with 1.0% salt and 2.0% straw.

Mixture	4.0% lime with straw				1.0% salt-4.0% lime with straw			
Replicate	psi	kg_f/cm^2			psi	kg_f/cm^2		
1	541	38.05			592	41.63		
2	516	36.29			646	45.43		
3	691	48.59			490	34.46		
4	621	43.67			554	38.96		
5	646	45.64	Average of		567	39.88	Average of	
	———	———	4.0% lime		———	———	1.0% salt-4.0% lime	
Average	603.0	42.40	640.4	45.04	569.8	40.07	982.6	66.99
S.D.*	$\pm$73.0	$\pm$5.13			$\pm$56.8	$\pm$3.99		

* Standard Deviation

Table 7b. Tension strength of cylinders made from either 4.0% limed clay with 2.0% straw or 4.0% limed clay with 1.0% salt and 2.0% straw.

Mixture	4.0% straw				1.0% salt-4.0% with straw			
Replicate	psi	kg_f/cm^2			psi	kg_f/cm^2		
1	89	6.26			88	6.19		
2	80	5.63			93	6.54		
3	78	5.49			87	6.12		
4	77	5.42			91	6.40		
5	79	5.56	Average of 4.0% lime		88	6.19	Average of 1.0% salt-4.0% lime	
	—	—			—	—		
Average	80.6	5.69	50.8	3.57	89.4	6.26	98.0	6.89
S.D.*	±4.8	±0.34			±1.9	±0.13		

* Standard Deviation

Durability Test

Cured test cylinders made from untreated clay (control), limed (4.0%) clay, limed clay with ash (2.5%) and limed clay with salt (1.0%) were tested for durability. Results are shown in Tables 8a, 8b and 8c and in Figure 10. Figure 10 shows the control gained in weight by water absorption up to six minutes, then began to slowly deteriorate and lose weight. The cylinder made from limed clay gained water rapidly up to 3 minutes, but rapidly deteriorated. The cylinder made from limed clay with 1.0% salt began to deteriorate rapidly immediately upon immersion. The cylinders made from the 4.0% limed clay with 2.5% ash showed a continual weight gain from 0-20 minutes, (Figure 10). Figure 11 shows clay cylinders before and after immersion in water. In another experiment the cylinders from the mixtures of lime, ash and salt mixtures were sealed with a vinyl water sealer (Product #34, Ferlemann & Associates, 2924 Sherwood Road, Columbus, Ohio 43209) and tested for durability, (Figure 10). There were only very slight gains in weight of the coated cylinders during five minute period of submersion.

The durability test period was extended to find the time at which the cylinders made from 4.0% limed clay with 2.5% ash might deteriorate. Results are shown in Table 8c and Figure 13. The peak gain in weight was reached at about 80 minutes. Only slight gains in weight were measured after the peak. Visual examination of the cylinders showed only slight deterioration on the ends, (Figure 12).

Table 8a. Durability test of control (untreated clay) cylinders.

Replicate	Weight, grams			
	1	2	3	Average
<u>Minutes</u>				
0	356.88	353.56	356.80	355.68
1	361.46	356.86	361.11	359.81
2	363.85	359.05	363.12	362.02
3	365.80	361.31	365.18	364.10
4	366.42	362.66	366.86	365.32
5	368.44	362.92	367.86	366.41
6	368.43	363.25	367.35	366.34
9	369.69	358.82	367.84	365.45
12	367.41	353.98	366.07	362.49
15	362.00	351.00	366.00	359.67
20	359.12	349.22	354.80	354.38

Table 8b. Durability test of 4.0% limed clay and 1.0% salt-4.0% limed clay cylinders.

	Non-sealed Weight, grams				Sealed Weight, grams			
Replicate	1	2	3	Average	1	2	3	Average
Minutes								
Lime 0	332.26	335.28	335.16	334.23	334.70	339.50	338.2.	337.47
1	341.00	347.00	349.58	345.86	335.15	339.80	338.42	337.79
2	345.54	352.16	352.92	350.21	335.31	339.94	338.44	337.90
3	349.37	353.54	356.72	353.21	335.41	340.02	338.48	337.97
4	341.38	349.53	348.73	346.55	345.42	340.16	338.50	338.03
5	339.28	341.00	341.80	340.69	335.54	340.28	338.50	338.11
Salt 0	334.23	334.48	334.28	334.33	338.02	340.00	340.70	339.57
1	333.81	332.54	334.28	333.54	338.46	340.48	341.10	340.01
2	329.18	330.06	328.72	329.32	338.55	340.58	341.28	340.14
3	320.00	321.20	319.60	320.38	338.75	340.74	341.26	340.25
4	309.00	312.14	310.68	310.61	338.84	340.84	341.32	340.33
5	297.84	300.82	299.10	299.25	338.96	340.96	341.42	340.45

Table 8c. Durability test of 2.5% ash-4.0% limed clay cylinders.

Replicate	Weight, grams			
	1	2	3	Average
Minutes				
0	336.12	336.12	335.90	336.11
3	350.36	351.10	350.56	350.67
6	356.60	356.75	357.72	357.02
9	361.69	360.75	363.31	361.92
12	366.18	365.04	368.00	366.41
15	369.91	368.74	371.92	370.19
20	374.71	373.66	376.95	375.11
25	378.92	378.00	381.55	379.49
30	381.91	381.00	384.63	382.51
40	386.42	386.15	389.38	387.42
50	389.69	389.58	392.84	390.70
60	391.96	391.76	394.98	392.90
80	393.43	392.86	396.52	394.27
140	393.73	392.96	396.76	394.48
200	393.81	393.09	397.00	394.63
560	394.34	393.61	397.51	395.15
Sealed				
0	336.38	337.58	336.44	336.80
1	336.42	337.82	336.50	336.94
2	336.46	338.10	336.58	337.05
3	336.52	338.14	336.52	337.06
4	336.58	338.24	336.52	337.11
5	336.64	338.32	336.54	337.17

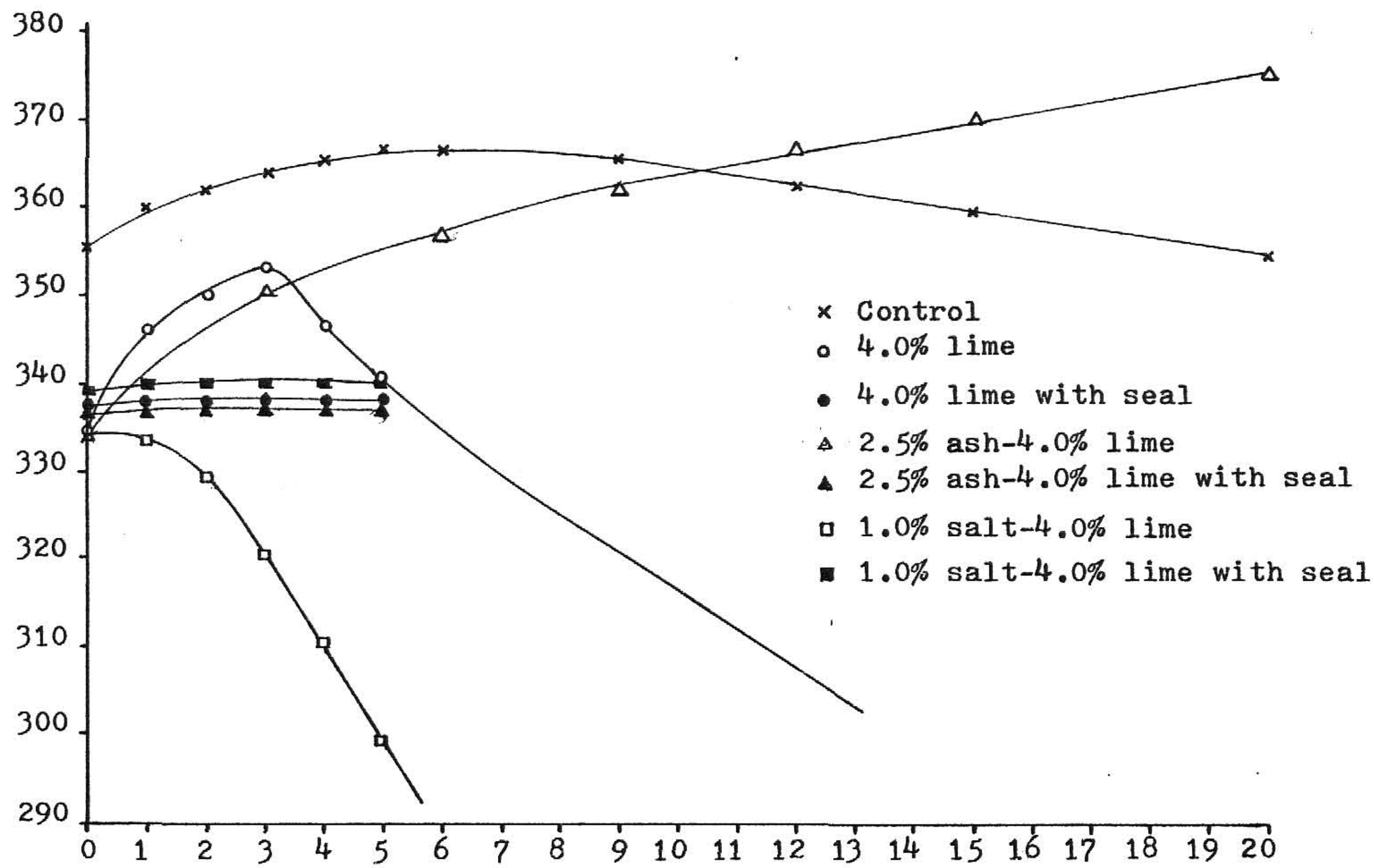


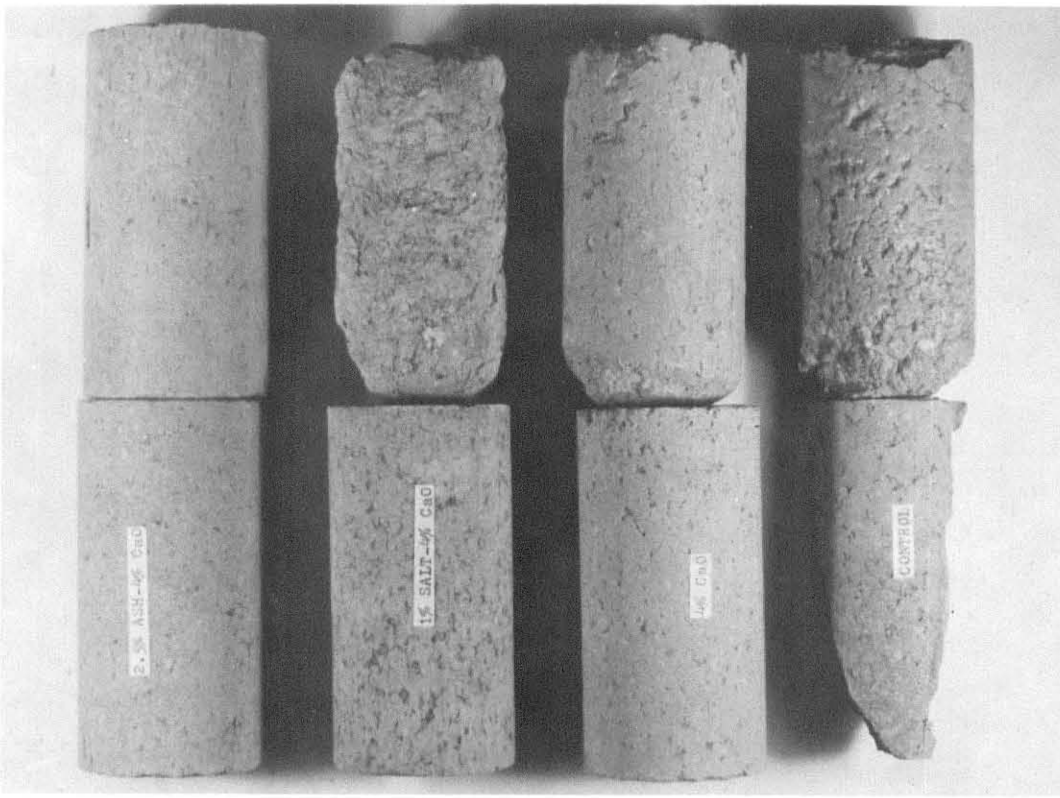
Figure 10. Durability of clay cylinders.

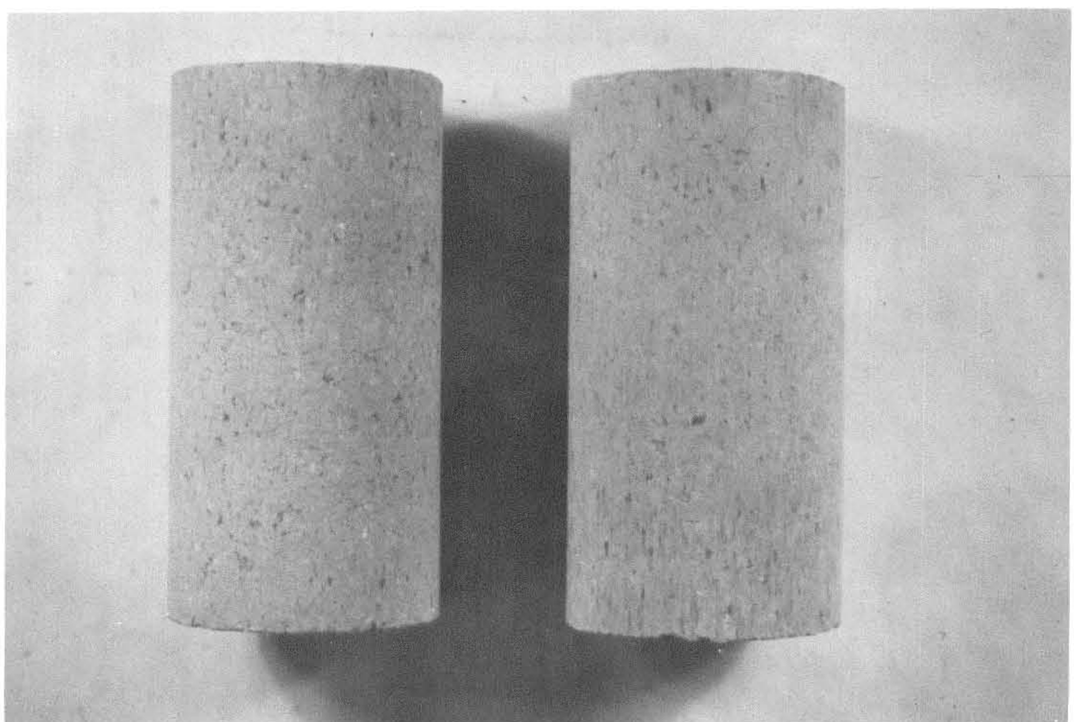
Figure 11. Effect of durability test on clay cylinders. From left to right, 2.5% ash-4.0% limed clay, 1.0% salt-4.0% limed clay, 4.0% limed clay, and control (untreated clay).

Figure 12. Effect of extended durability test on 2.5% ash-4.0% limed clay cylinders. Cylinder on the right has not been immersed in water, while cylinder on the left was immersed in water for 560 minutes.

THIS BOOK CONTAINS NUMEROUS PICTURES THAT ARE ATTACHED TO DOCUMENTS CROOKED.

THIS IS AS RECEIVED FROM CUSTOMER.


2.5% ASH-4% CaO
1% SALT-4% CaO
4% CaO
CONTROL



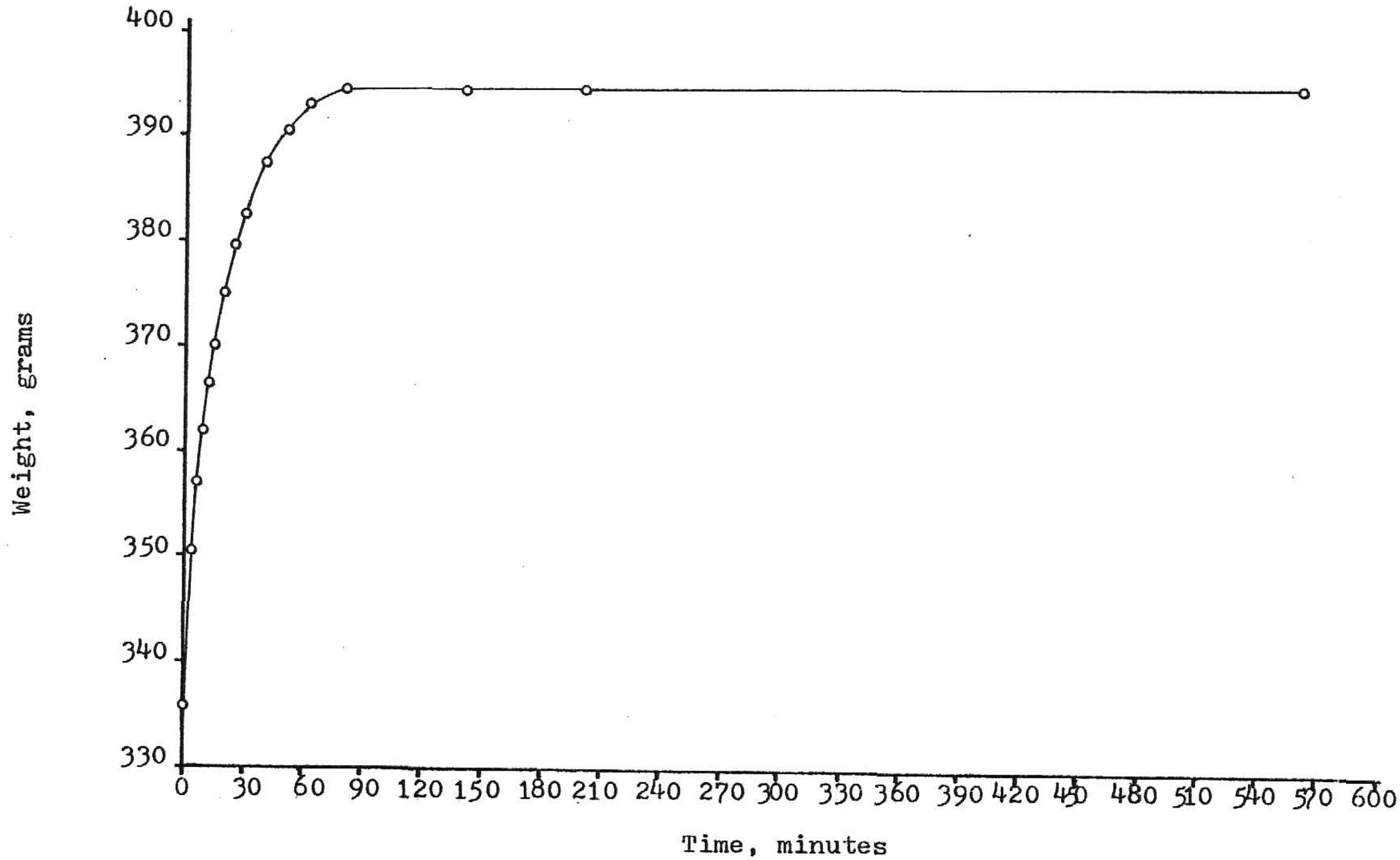


Figure 13. Durability of 2.5% Ash-4.0% limed clay cylinders.

Table 5a and 5b show that the smallest addition (2.5%) of ash to the limed clay produced the greatest compression strength. The higher levels of ash (5.0, 7.5 and 10.0%) gave much lower compressive strength than the 2.5% level, but at levels higher than 5.0% added ash, the strength did continue to gradually increase, but never did reach the strength at the 2.5% level. The cylinders made at the four levels of ashes were tested for durability to determine whether the increase of rice-hull ash affected durability. Results are shown in Tables 9a, 9b, and Figure 14.

The results followed closely those observed for the 4.0% limed clay with 2.5% ash. The peak in weight gain in water absorption occurred at about 80 minutes for the 5.0% ash mixture, which is the same as observed for the 2.5% ash mixture. At the 7.5% and 10.0% addition of ash, peak weight gain occurred in the cylinders at about 150 minutes.

It should be mentioned that cracks developed during testing of the cylinders with 5.0% and 7.5% ash. In the 5.0% ash mixture there were horizontal and vertical cracks forming an I-shape. In the 7.5% ash mixture only horizontal cracks developed. Deterioration, other than cracking, was limited to only the surface of the ends of the cylinders, as in the 2.5% ash mixture. In the 10.0% ash mixture, no cracking or deterioration other than that on the ends of the cylinders was noted, (Figure 15).

Retention of Tension Strength

The cylinders made from 4.0% limed clay with 2.5% ash were tested for retention of tensile strength after being wetted to its highest level of water absorption and dried. Results are shown in Table 10. For cycles 1 and 2, tension strength declined from the initial tension strength by an average of 39.7%. Cycle 3 showed a decline of 45.0%. The cylinders in cycle 1 showed only slight deterioration on the ends. Horizontal cracking and deterioration of the surface on the sides appeared in cycle 2. In cycles 3, horizontal cracks in some cylinders deepened enough to break the cylinders apart. Deterioration did not progress much further than that which occurred in cycle 2, since cylinders in cycle 3 were still recognizable, (Figure 16).

Workability

The ability to add moisture to clay was greatly improved in the presence of lime and/or ash.

The clay itself when mixed at its optimum moisture content, formed several large clumps of wetted clay, with a small amount of dry clay which had to be vigorously worked into of the wetted clay. This characteristic of clay, known as coagulation, did not occur in the presence of lime and/or ash, which allowed a more even absorption of the water to the mixture. The lime and ash changes the Atterberg limits of the clay. The clay itself has a plastic index (P.I.) of 22.5%, which is the difference between its liquid limit (L.L.) of 40.0% its plastic limit of 17.5%. For the 4.0% limed clay with 2.5% ash there is an increase in both the liquid limit and plastic limit. However the plastic index is about 50% less than that of clay, (Table 11 and Figure 17).

Table 9a. Durability test of 2.5% ash- 4.0% limed clay and 5.0% ash-4.0% limed clay cylinders.

Mixture	2.5% ash-4.0% lime				5.0% ash-4.0% lime			
	Weight, grams				Weight, grams			
Replicate	1	2	3	Average	1	2	3	Average
Minutes								
0	332.00	332.68	331.90	332.12	317.57	318.22	318.50	318.10
3	346.65	343.27	343.00	342.87	329.67	330.39	330.93	330.33
6	351.35	351,92	352,21	351,83	339.46	340.39	340.64	340.16
9	356.57	357.10	357.15	356.94	344.90	345.98	346.27	345.72
12	360.48	361.27	361.38	361.04	349.06	350.04	350.55	349.88
15	364.24	364.96	365.20	364.80	352.97	353.80	354.34	353.70
20	368.86	369.72	369.85	369.48	357.25	358.39	359.03	358.22
30	375.47	376.40	376.37	376.08	363.25	364.84	365.52	364.54
60	387.34	388.18	387.79	387.77	375.45	377.65	379.47	377.52
90	392.66	392.54	392.54	392.58	383.50	385.14	385.44	384.69
120	392.96	393.20	393.04	393.07	384.36	385.54	385.46	385.12

Table 9b. Durability test of 7.5% ash-4.0% limed clay and 10.0% ash-4.0% limed clay cylinders.

Mixture	7.5% ash-4.0% lime				10.0% ash-4.0% lime			
	Weight, grams				Weight, grams			
Replicate	1	2	3	Average	1	2	3	Average
Minutes								
0	316.72	316.37	316.30	316.46	307.80	308.12	307.63	307.85
3	334.26	333.76	333.98	334.00	325.62	325.56	325.35	325.51
6	342.46	341.44	431.80	341.70	333.60	333.58	333.42	333.53
9	348.07	347.15	347.53	347.58	336.27	339.41	339.22	339.30
12	352.67	351.62	352.03	352.11	343.85	344.06	343.74	343.88
15	356.60	355.92	356.17	356.23	347.86	348.04	347.70	347.87
20	361.19	360.21	360.71	360.70	352.47	352.54	352.38	352.46
30	367.28	366.23	366.40	366.64	358.15	358.62	358.26	358.33
60	378.58	378.16	378.13	378.29	369.54	370.08	369.37	369.66
90	386.43	386.71	386.04	386.89	377.80	378.16	377.19	377.72
120	390.91	390.30	389.71	390.31	382.71	383.04	381.42	382.39
150	392.36	390.75	390.62	391.24	385.20	385.51	383.37	384.69
180	392.77	390.39	390.37	391.17	385.25	385.94	383.50	384.90

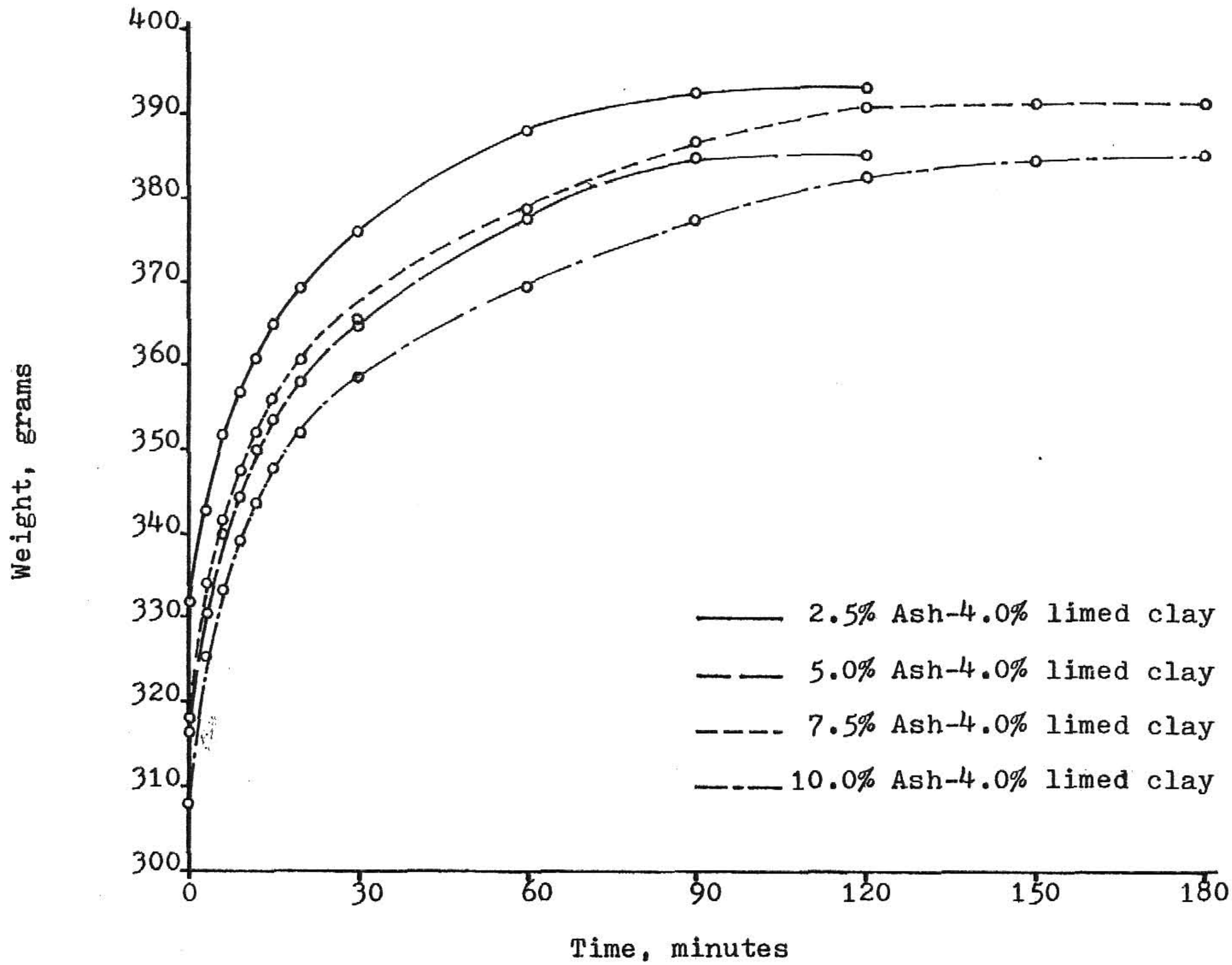
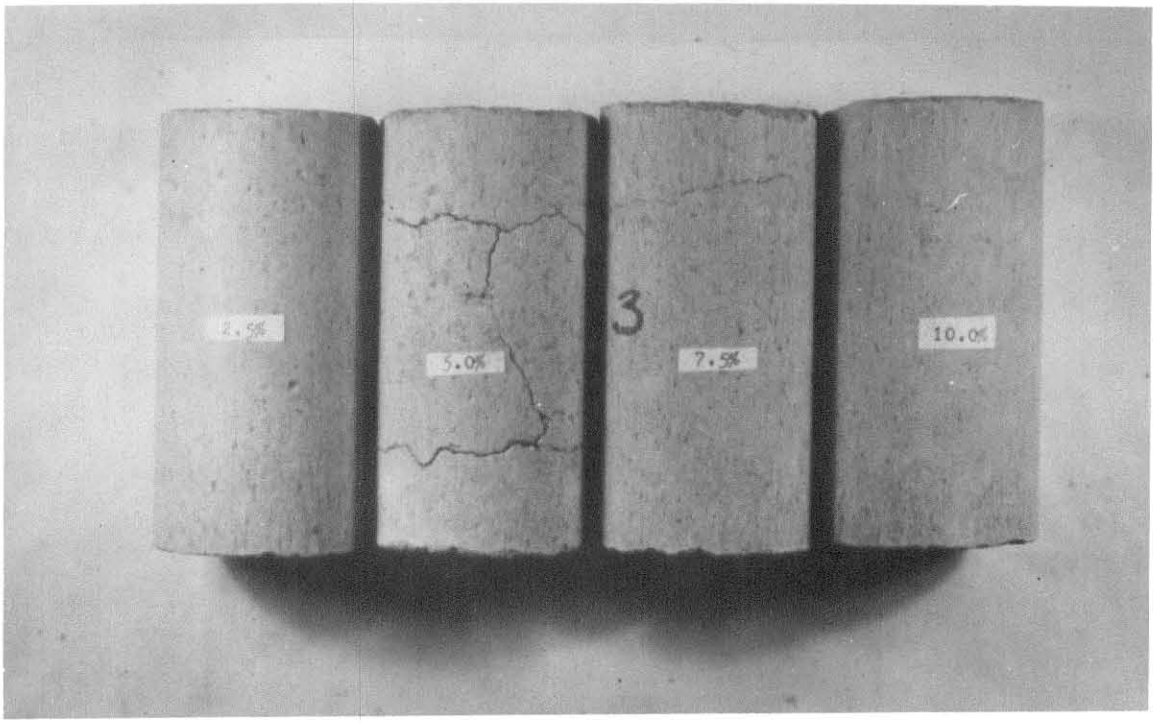


Figure 14. Durability of Ash-Lime-Clay cylinders.

Figure 15. Effect of durability test on ash-limed clay cylinders. From left to right, 2.5% ash-4.0% limed clay, 5.0% ash-4.0% limed clay, 7.5% ash-4.0% limed clay, and 10.0% ash-4.0% limed clay.

Figure 16. 2.5% ash-4.0% limed clay cylinder after 3rd cycle of being weetted and dried.


2.5%
5.0%
3
7.5%
10.0%

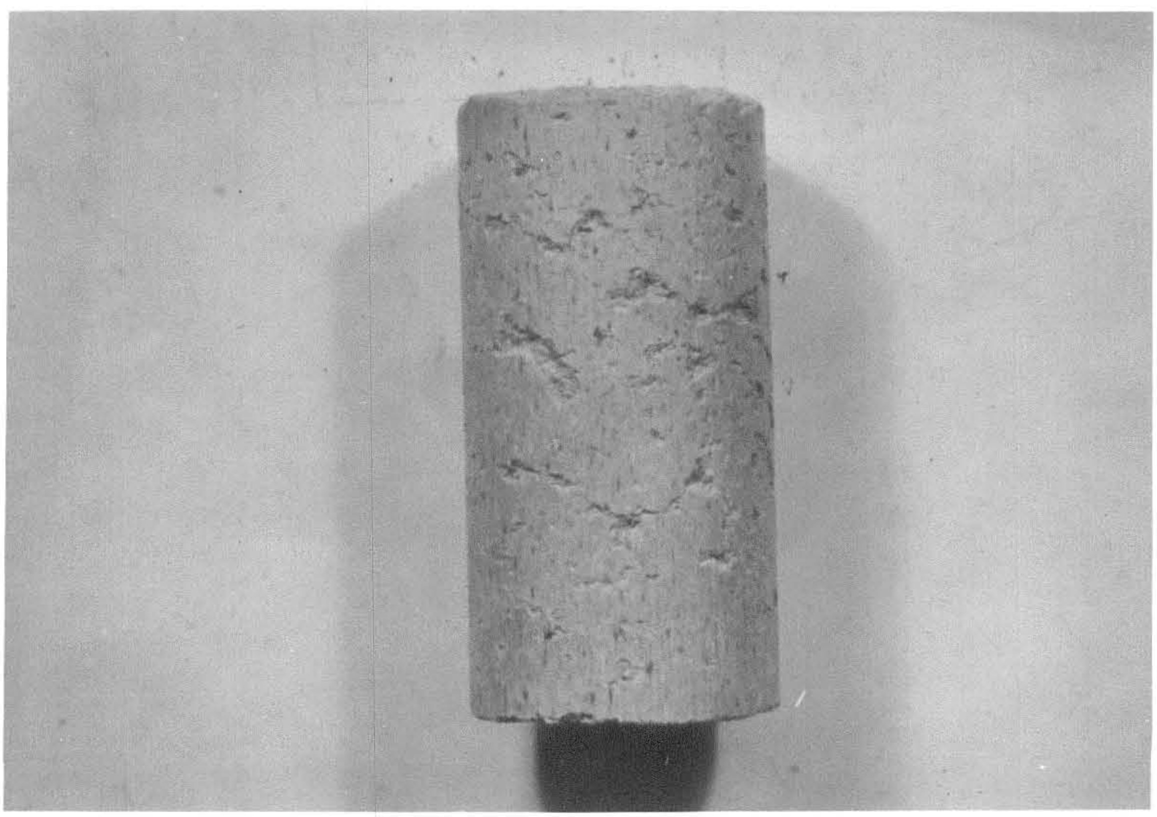


Table 10. Tension strength of 2.5%-4.0 limed clay cylinders given several wet and dry cycles.

Replicate	Initial		1st cycle		2nd cycle		3rd cycle	
	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2	psi	kg_f/cm^2
1	94	6.61	60	4.22	60	4.22	53	3.73
2	101	7.10	54	3.80	65	4.57	54	3.80
3	97	6.82	56	3.94	57	4.01	53	3.73
Average	97.3	6.82	56.7	3.99	60.7	4.27	53.3	3.75
S.D.*	±3.5	±0.25	±3.1	±0.22	±4.0	±0.28	±0.6	±0.04

* Standard Deviation

Table 11. Atterberg limits of 2.5% ash-4.0% limed clay.

LIQUID LIMIT

No. of Blows	Moisture Content, %
28	48.6
16	52.0
12	54.6

Liquid Limit** (from Figure 14) 49.0%

PLASTIC LIMIT

Sample	Moisture Content, %
1	37.2
2	37.3
3	37.2
Average	37.2
S.D.*	$\pm$0.2

Plastic Index (P.I.)= L.L.-P.L.
= 49.0-37.2 = 11.8 %

**Liquid limit is moisture content for 25 blows (see Materials and Methods)

*Standard Deviation

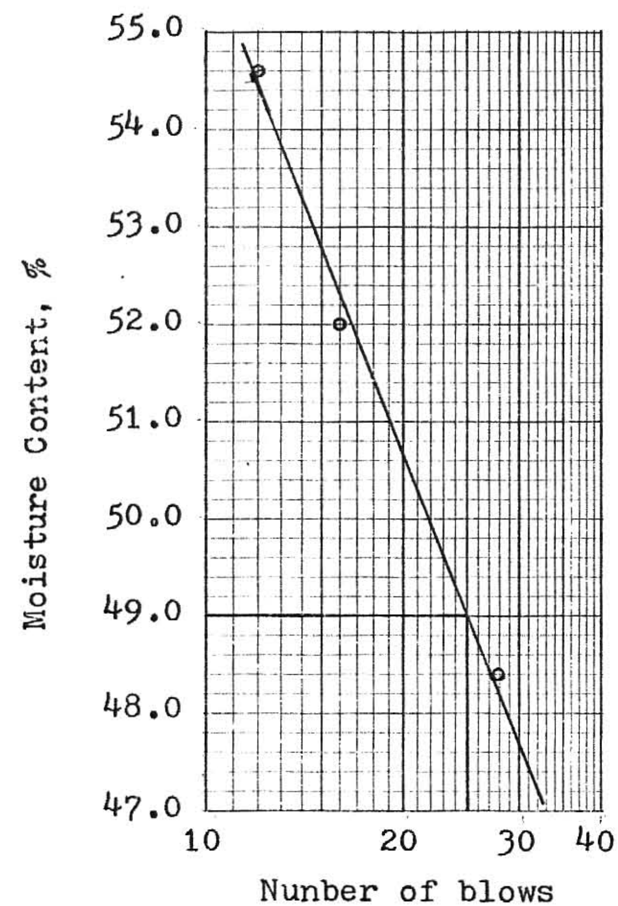


Figure 17. Flow curve for 2.5%-4.0% limed clay.

Comparison of Adobe Brick and Clay Cylinders made from 4.0% Limed Clay with 2.5% Ash

A grain storage system constructed of adobe material being used in Chad was evaluated by Kansas State University in the spring of 1977, (23). The adobe material used consisted of the following locally available ingredients: clay, straw, ant hill (as a binding agent), and water. Samples of this adobe were tested for compression and tensile strength. The comparison of results is shown in Table 12a and 12b. The cylinders made from the 4.0% limed clay with 2.5% ash were considerably superior in strength, especially compression strength. The durability of the adobe material is unknown, as no test was conducted by the original investigators. No adobe material was available to conduct a test in this investigation. The only ingredient of the adobe material that may enhance the durability of the adobe mixture, would possibly be the ant hill.

Table 12a. Comparison of compression strength between adobe brick and 2.5% ash-4.0% limed clay.

Replicate	Adobe		2.5% ash-4.0% lime	
	psi	kg_f/cm^2	psi	kg_f/cm^2
1	178	12.52	914	64.28
2	198	13.92	847	59.51
3	175	12.31	901	63.36
Average	183.7	12.92	887.3	62.36
S.D.*	±2.5	±0.88	±35.5	±2.53

* Standard Deviation

Table 12b. Comparison of tension strength between adobe brick and 2.5% ash-4.0% limed clay.

Replicate	Adobe		2.5% ash-4.0% lime	
	psi	kg_f/cm^2	psi	kg_f/cm^2
1	88	6.19	94	6.61
2	79	5.56	101	7.10
3	45	3.16	97	6.82
Average	70.7	4.97	97.3	6.84
S.D.*	±22.7	±1.60	±3.5	±0.25

* Standard Deviation

CONCLUSIONS

Conclusions drawn from this investigation are summarized below:

1. When test clay cylinders are made, the addition of lime to clay, when properly cured, increased the compression strength. Maximum strength was produced by addition of 4.0% lime; further additions of lime, while producing greater compression strength than the control clay, produced lower strength than the grains in tensile strength upon addition of lime were negligible.
2. The addition (2.5%-10.0%) of rice hull ash at the optimum level of lime produced additional increases in compression and tension strength. The maximum increase in strength was obtained with the initial and smallest addition of ash (2.5%).
3. The strength of the cylinders also increased with the addition of salt to the 4.0% limed clay.
4. Straw added to the optimum mixture of lime and clay further increased the tensile strength of cylinders while decreasing their compression strength. Straw added to the optimum mixture of limed clay with 1.0% salt decreased both compression and tensile strengths.
5. Cylinders prepared from the ash-lime optimum were the most durable when submerged in water at 25°C. Durability of all cylinders was increased when coated with a water sealer.
6. The tensile strength of cylinders made from a clay mixture containing 2.5% ash and 4.0% lime, decreased when subjected to wet and dry cycles.

7. Clay containing added lime and/or ash was more workable than clay alone.

8. Clay containing 2.5% ash and 4.0% lime is considered most suitable for bricks to construct a silo. It is proposed that bricks prepared from this mixture would be strong and the most durable, compared to other mixtures tested.

RECOMMENDATIONS FOR SILO DESIGN

Four different types of 1-ton silos were analyzed in Appendix A. The grain used in these analyses was maize. Lateral and vertical pressures imposed by the maize on the silos were calculated using Janssen's formulas. These pressures were used to compute flexural and bearing stresses that occur in the silos. The stresses for the first silo analyzed were 2.18 psi, compression flexure, 2.26 psi, tension flexure and 11.4 psi, compression bearing pressure. For the second silo, the stresses were 2.82 psi, compression flexure, 2.89 psi tension flexure and 6.40 psi, compression bearing pressure. The third and fourth silo have the same stresses; 2.85 psi, axial tension and 6.40 psi, compression bearing pressure. The limits of compression (887 psi) and tension (97 psi) strength of the 4.0% limed clay with 2.5% ash are more than adequate in compensating for these imposed stresses in the one ton silos. Therefore, based upon these analyses, the silos shown in Figures 18, 19 and 20 are recommended as four types of silos that may be constructed using the ash-limed clay. The Cinva-Ram silo (Figure 18) and the Platform-Block silo (Figure 19) are stave type silos, constructed of individual bricks, placed side by side to form a circle. The bricks for the Cinva-Ram silo are manufacted by using a Cinva-Ram (Figure 21) and the bricks for the Platform-Block silo are made by using a brick mold. The Rammed-Earth Platform silo (Figure 19) and the Rammed-Earth silo (Figure 20) are constructed by tamping the ash-limed clay between an inner and outer form. The resulting structure, once the forms have been removed, is a seamless, con-

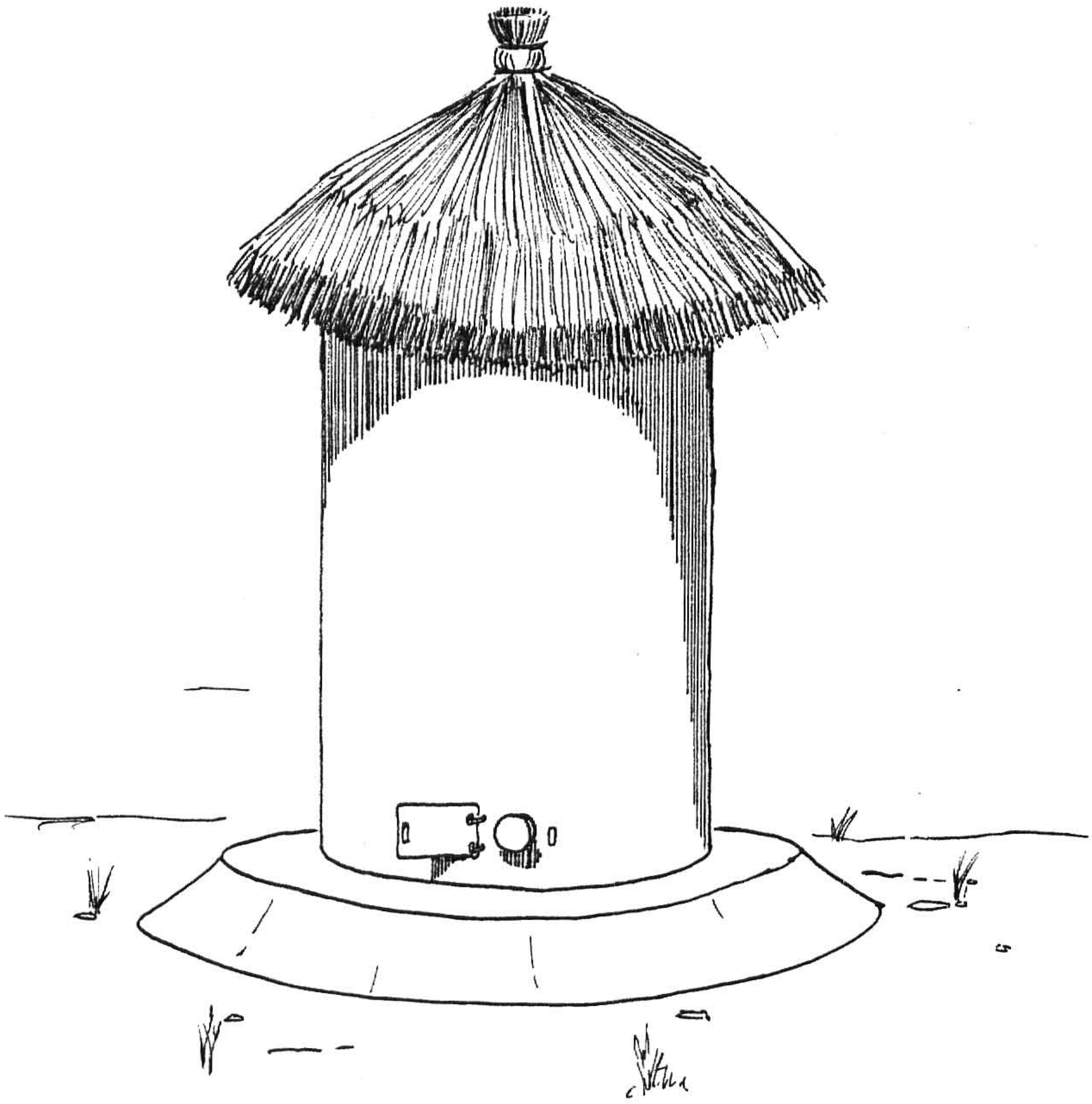


Figure 18. Cinva-Ram silo.

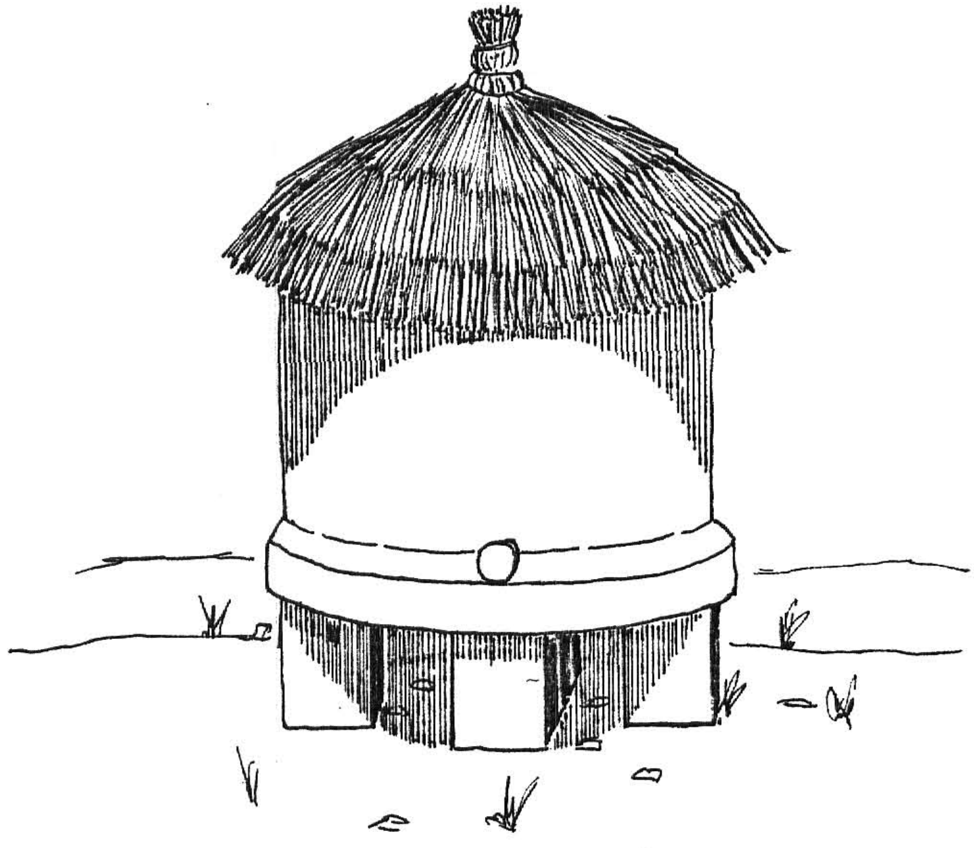


Figure 19. Platform-block silo or Rammed-Earth Platform silo.

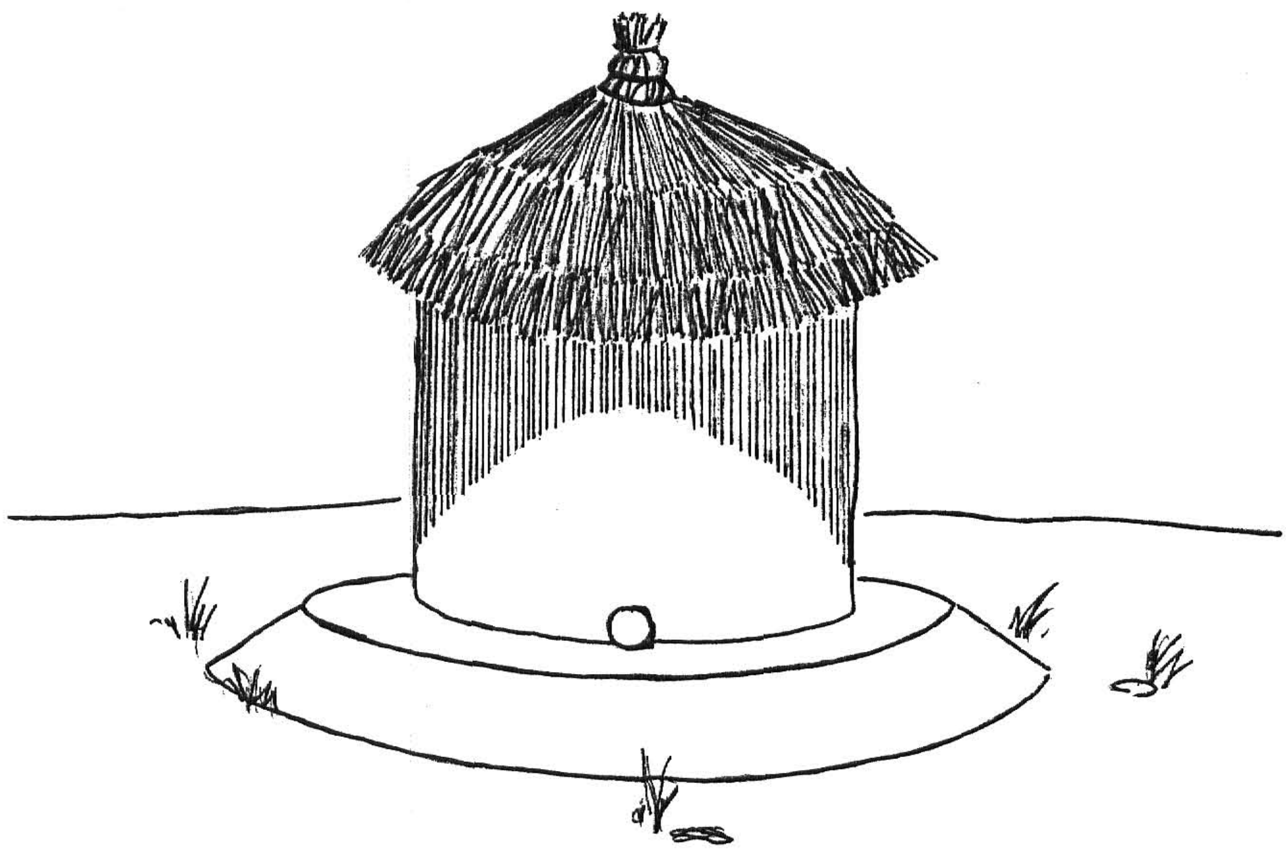


Figure 20. Rammed-Earth silo.

Table 13. Specifications of silos

Silo	Cinva-Ram Silo	Platform-Block Silo	Rammed-Earth Silo	Rammed-Earth Platform Silo
Capacity	1.00 metric ton of maize	1.02 metric ton of maize	0.97 metric ton of maize	0.97 metric ton of maize
Volume	49.16 cf 1.39 m^3	50.04 cf 1.42 m^3	47.92 cf 1.36 m^3	47.92 cf 1.36 m^3
Height	6.23 ft 190 cm	5.58 ft 170 cm	3.94 ft 120 cm	5.58 ft 170 cm
Diameter	3.50 ft 107 cm	4.35 ft 133 cm	4.27 ft	4.27 ft 130 cm

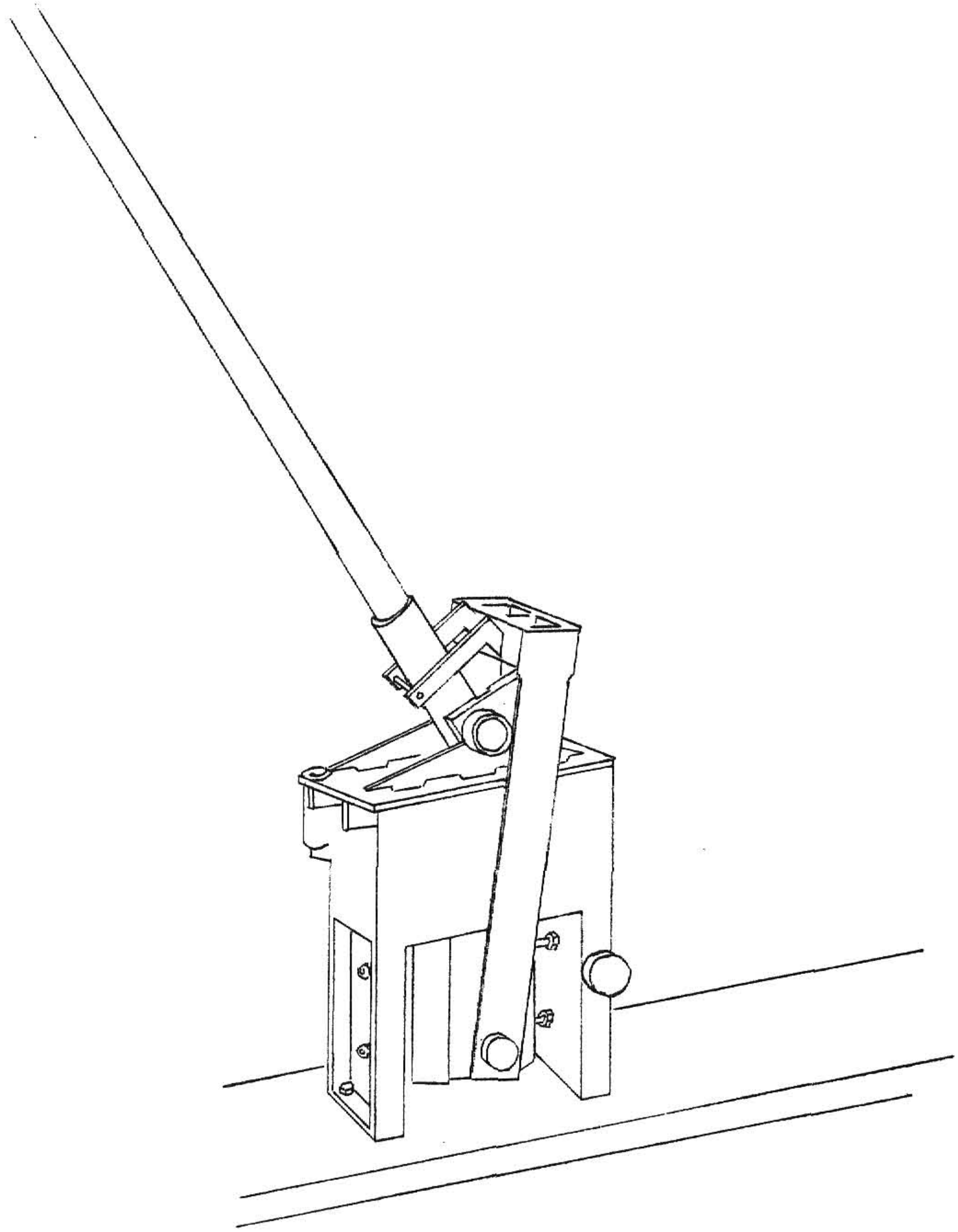
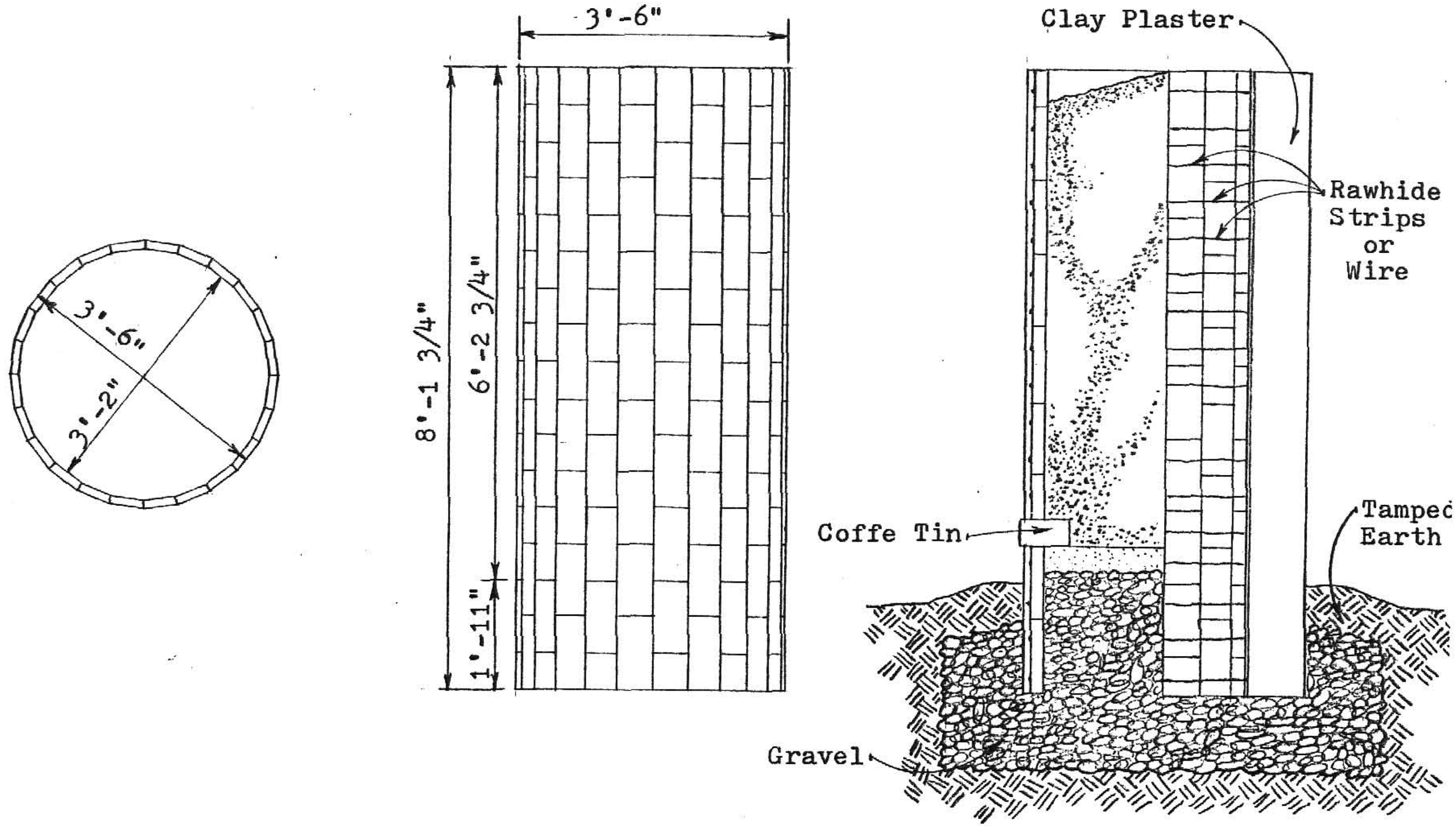


Figure 21. Cinva-Ram press.



Plan view brick arrangement   Side view brick arrangement   Quarter-section side view

Figure 22. Details of Cinva-Ram silo.

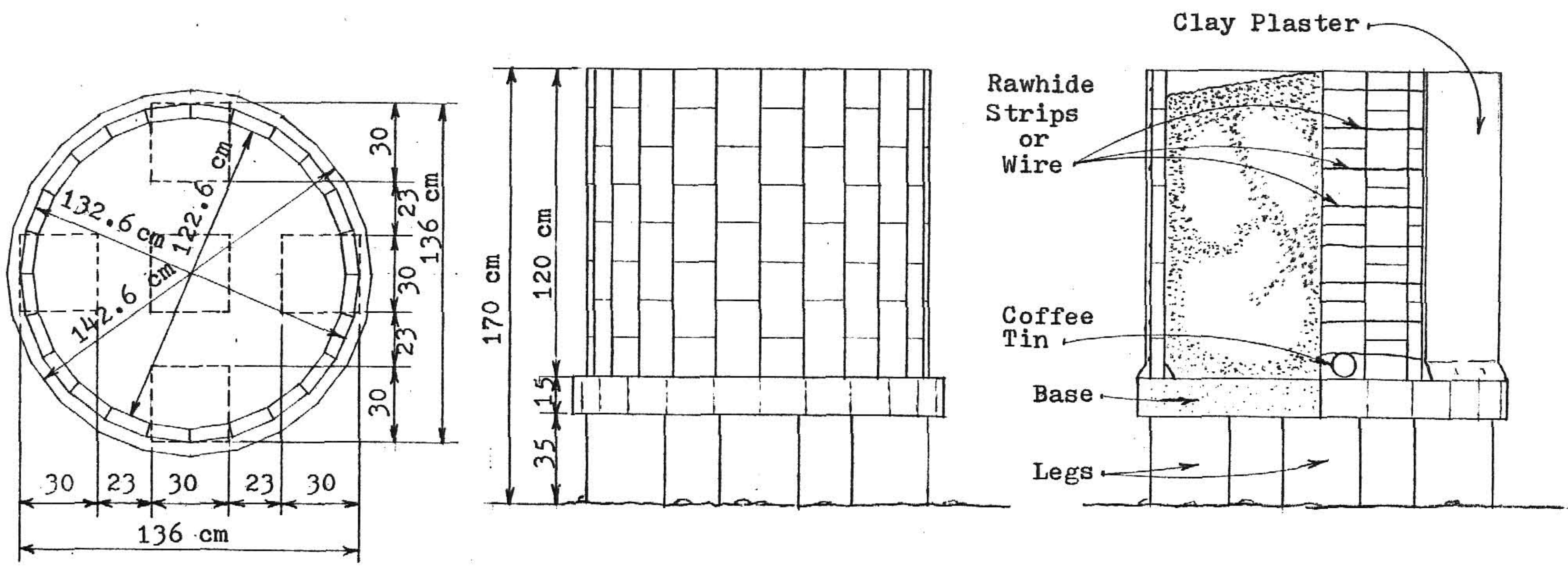


Figure 23. Details of Platform-Block silo.

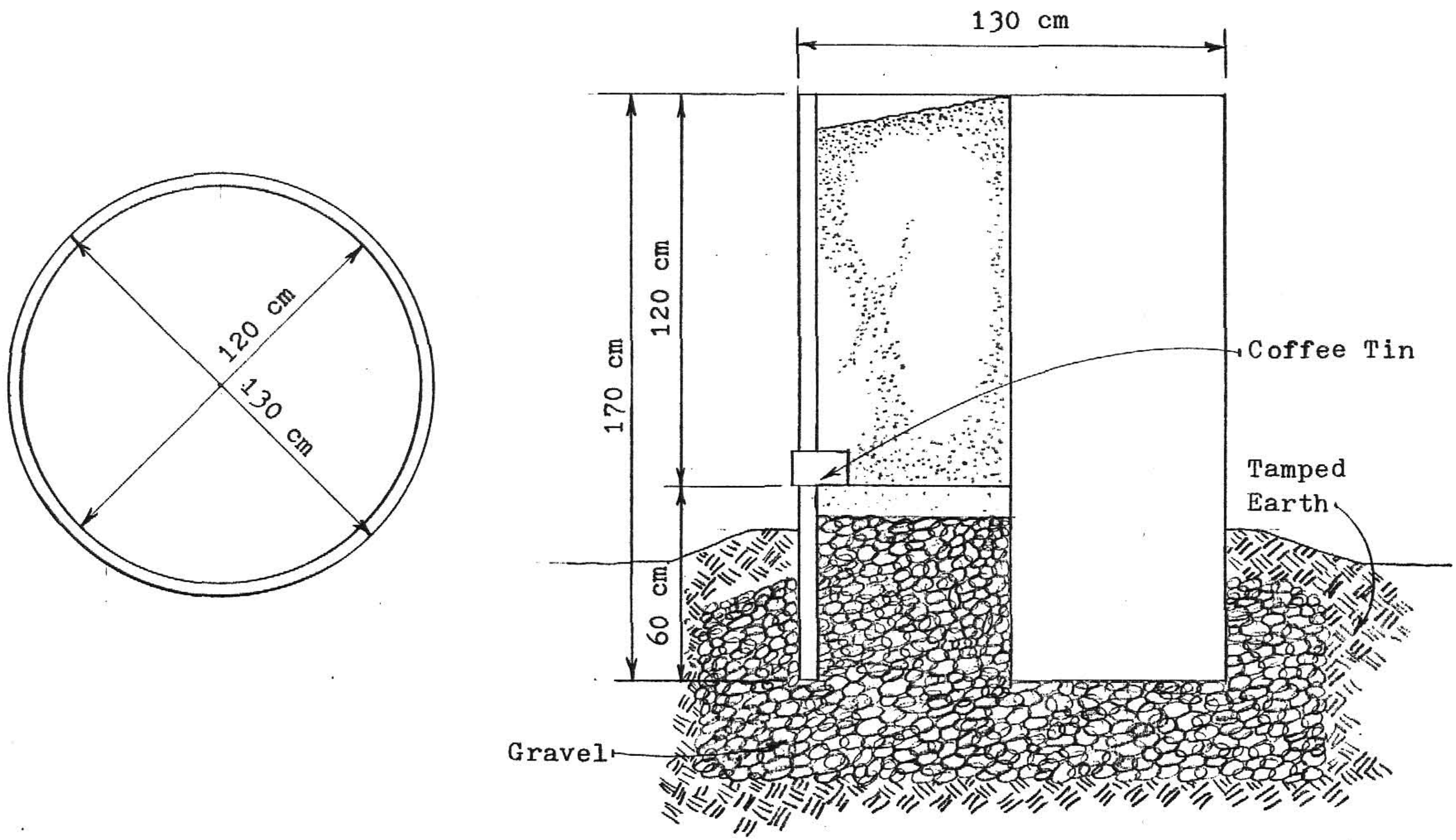


Figure 24. Detail of Rammed-Earth silo.

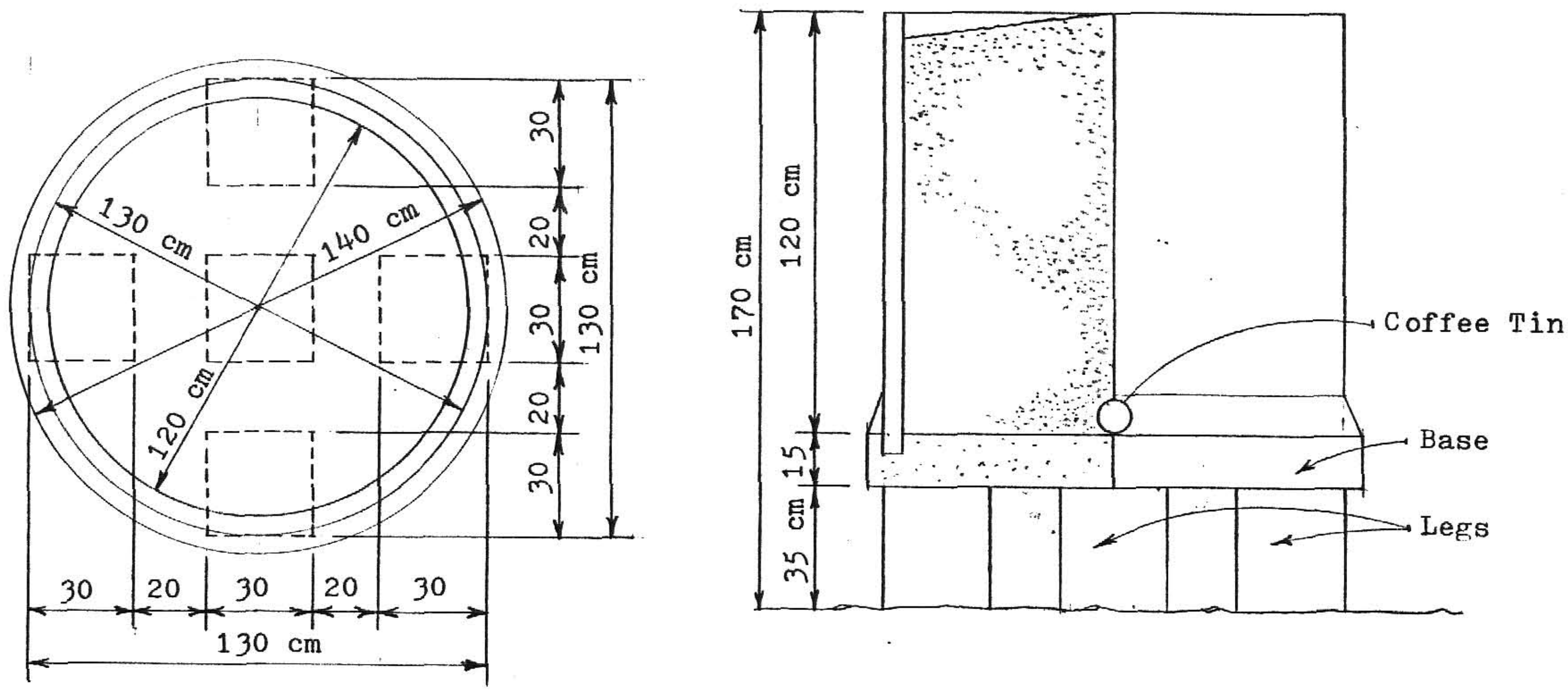


Figure 25. Details of Rammed-Earth Platform silo.

tinuous grain silo. Specifications of the silos are given in Table 13.

Details of the silos are shown in Figures 22, 23, 24 and 25. The Cinva-Ram silo and the Rammed-Earth silo would be used in dry areas or in locations away from flooding. The purpose of the gravel upon which the silos rest is to break up the capillary action of the ground water, keeping it away from the structure. The Platform-Block silo and the Rammed-Earth Platform silo would be used in areas where there is a lot of ground moisture or where flooding occurs. Hoop tension in the Cinva-Ram silo and the Platform-Block silo is provided by either using wire that has been tightened or by using wet rawhide, tieing it tight around a tier of bricks and allowing it to dry. Construction of the brick silos is completed by plastering the outside with a clay-mixture plaster and then painting the inside and out of the silo with a water sealer. No plastering of the Rammed-Earth silos is required, however, they should be coated with a water sealer. The silos are filled at the top. When filled, the top of the silo can be covered with boards, cut to the shape of the silos and the boards covered with clay or mud, sealing the grain in the silo. A thatched roof placed over the silo will shed rain away from them. Grain is removed through a coffee tin (hole in both ends) that has been inserted in one of the bricks or placed in the wall.

Details of the bricks for the silos are shown in Figure 26 for the Cinva-Ram silo and Figure 27 for the Platform-Block silo. Figure 28 shows the details of the mold insert that is placed in the Cinva-Ram press to produce the brick

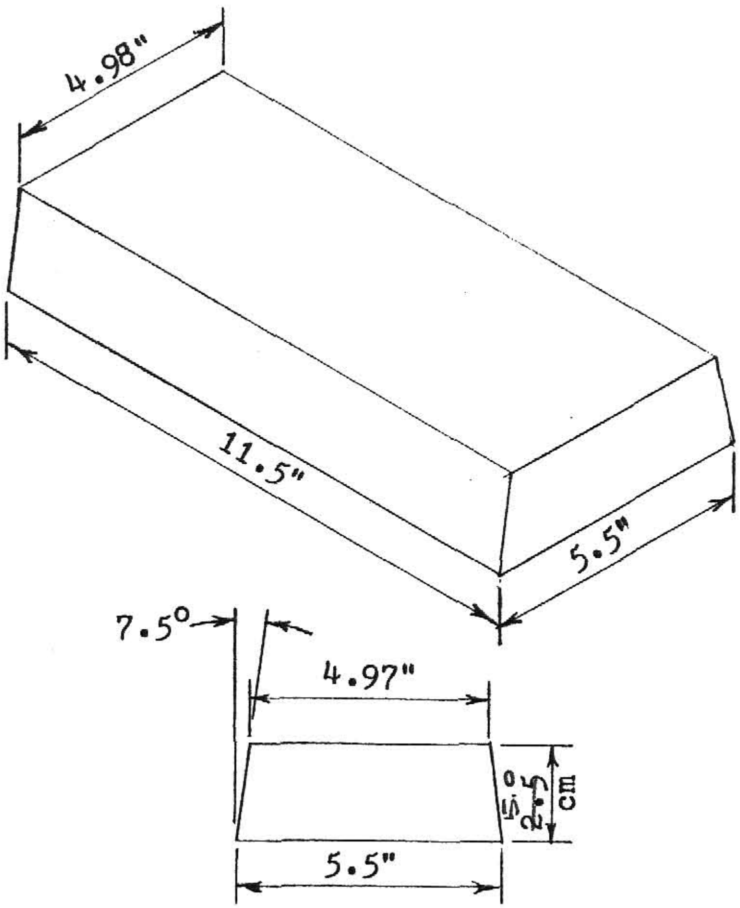


Figure 26. Details of Cinva-Ram brick.

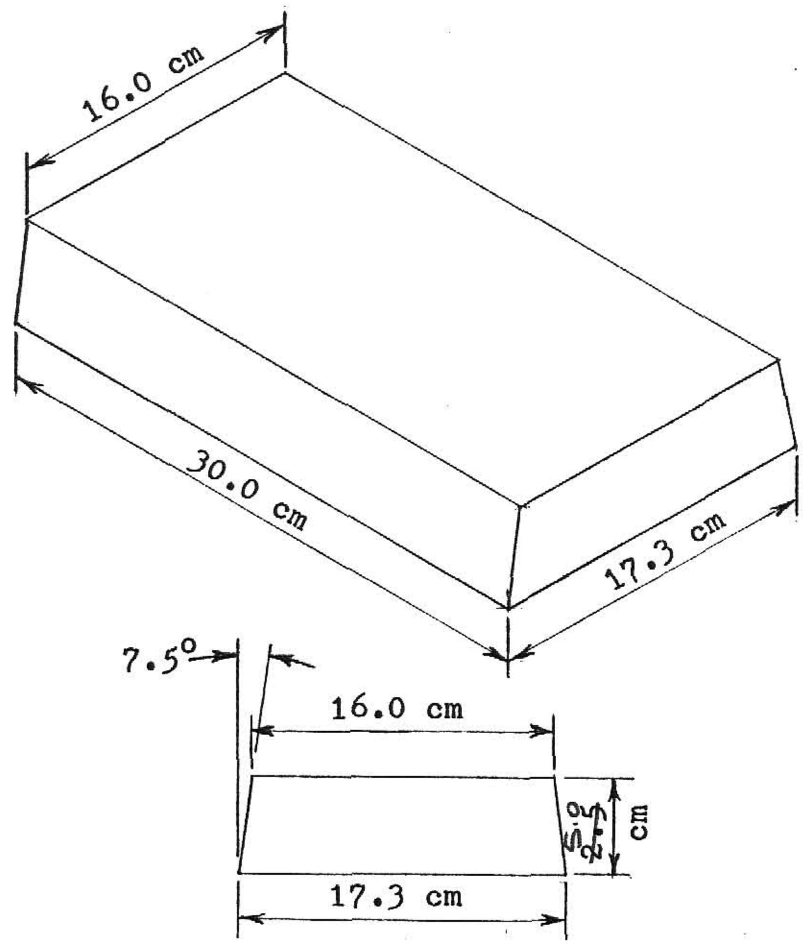


Figure 27. Details of brick for Platform-Block silo.

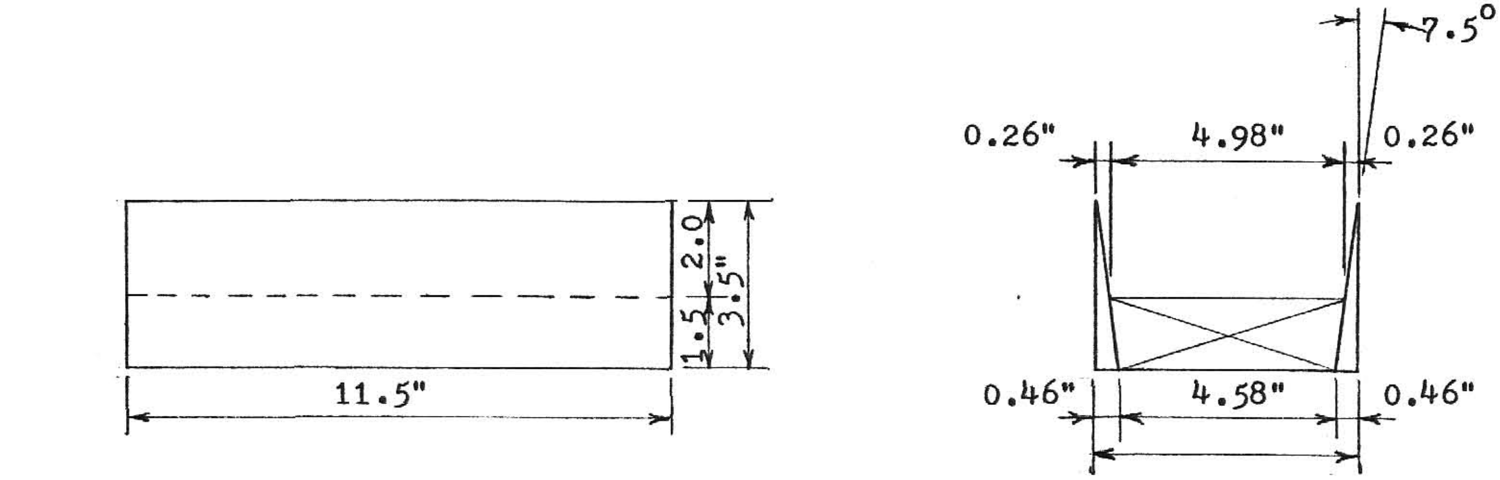


Figure 28. Detail of mold insert for Cinva-Ram press.

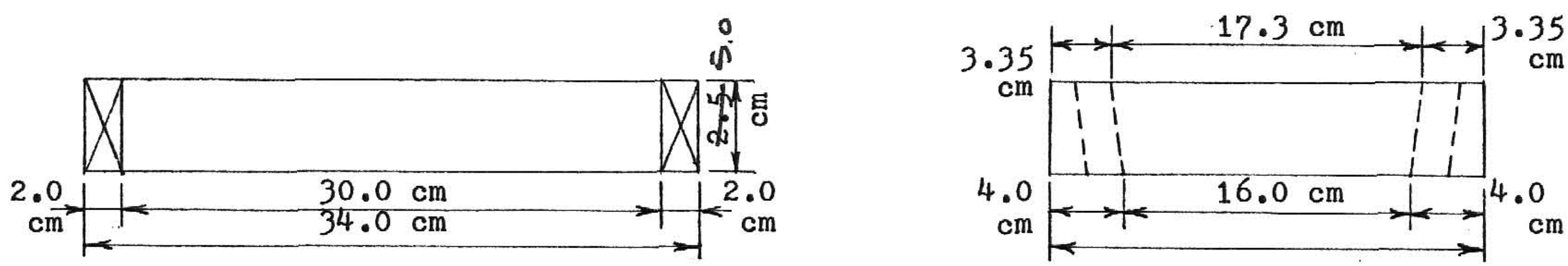


Figure 29. Detail of brick mold for Platform-block silo.

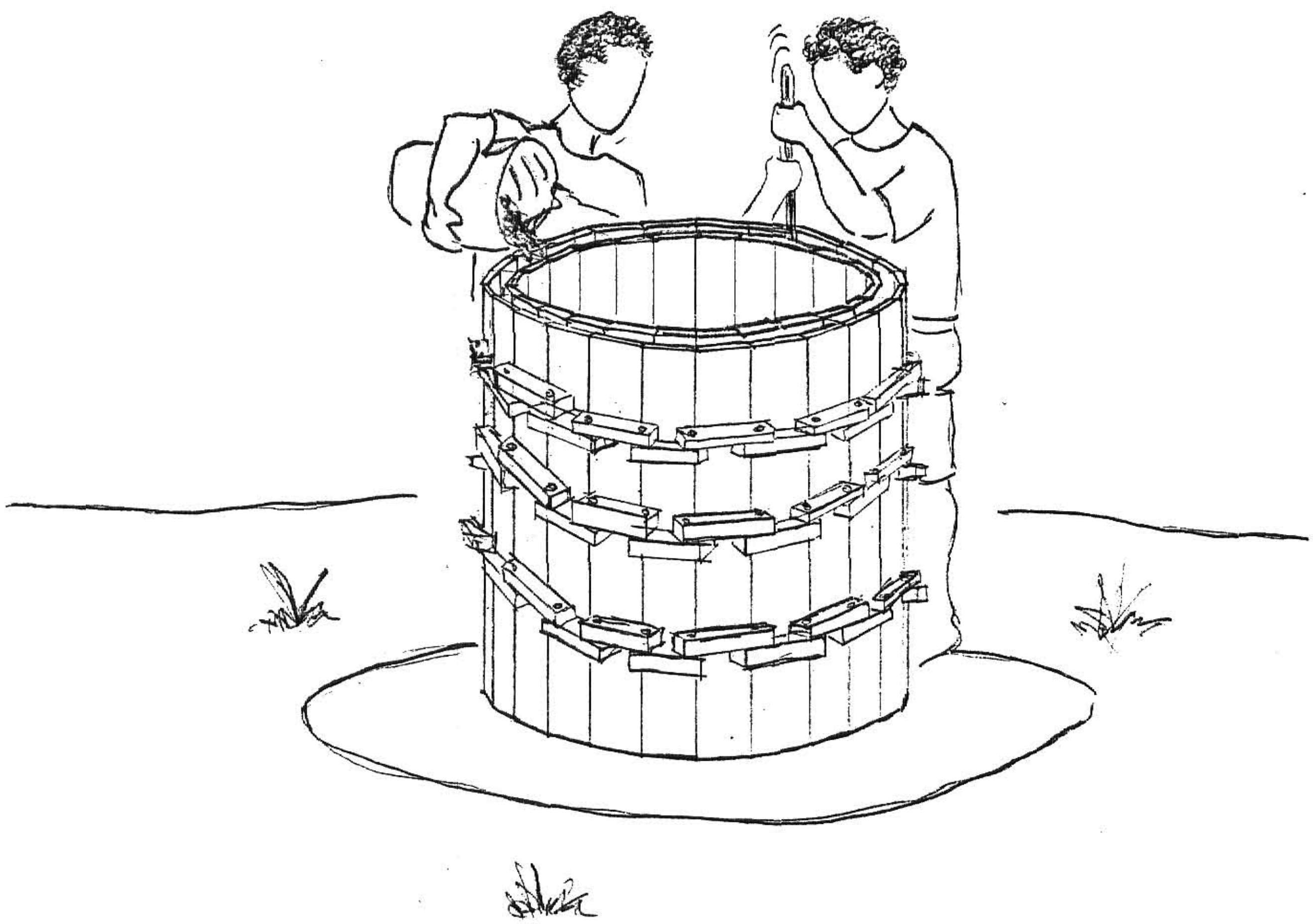


Figure 30. Arrangement and use of a wooden form for a Rammed-Earth silo.

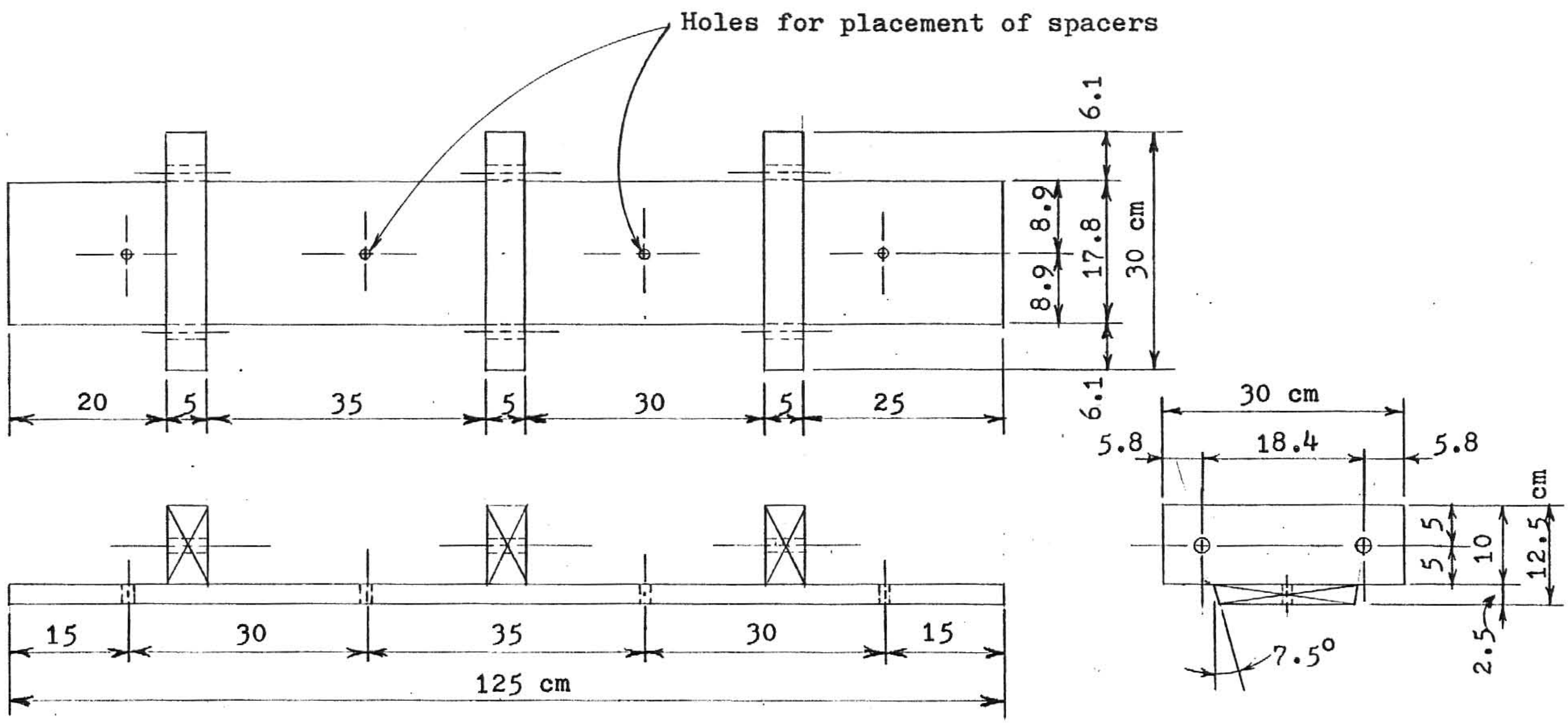


Figure 31. Details of boards for outer form for Rammed-Earth silos.

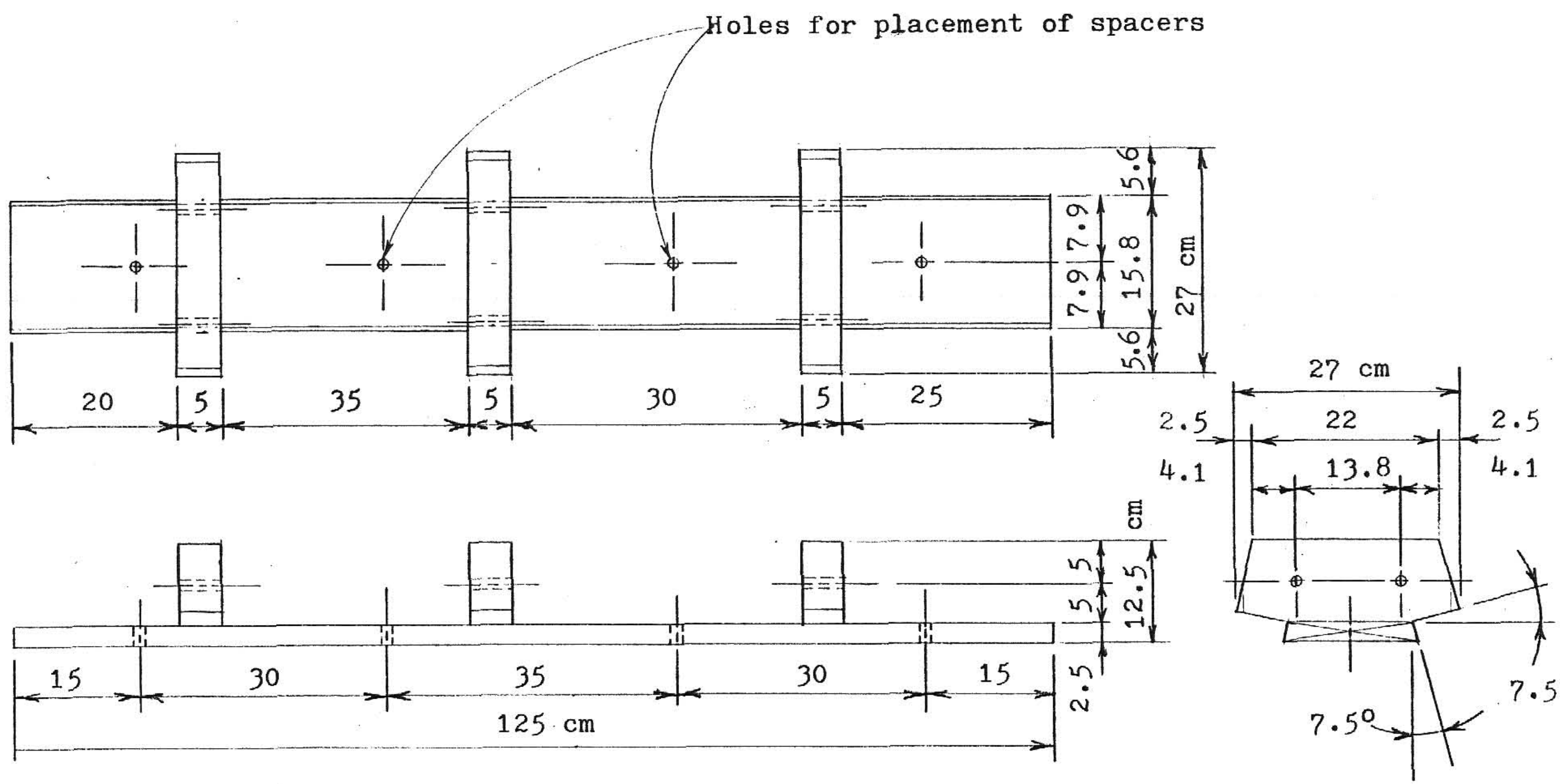


Figure 32. Details of boards for inner form for Rammed-Earth silos.

seen in Figure 26. Figure 29 shows the details of the brick mold for making the bricks for construction of the Platform-Block silo.

An arrangement and use of an outer and inner form made out of wood is shown in Figure 30. The clay mixture is tamped in between the forms. Spacers placed between the forms keep the thickness of the wall (2 inches) even. As the form fills, the spacers are removed. Details of the boards used for the form are shown in Figures 31 and 32. Twenty-four boards are needed for the outer form and twenty-four for the inner form. The forms are put together by inserting bolts in the corners of the cross pieces, putting the inner form together first and then the outer form. The same forms can be used for constructing both the Rammed-Earth silo and the Rammed-Earth Platform silo. Only in construction of the Rammed-Earth silo, the form will have to be moved up to complete construction.

It is important in the manufacting of bricks or the construction of the Rammed-Earth walls of the ash-limed clay that they be moist-cured to attain proper strength and durability. This may be done by covering the bricks or the walls with sheets of plastic, or covering the bricks or the walls with jute sacks and keeping them wet during the curing period. After curing, the bricks or the walls should be dried before using.

The amount of materials needed for construction of these silos is given in Table 14.

Table 14. Amount of materials needed for silos.

Cinva-Ram silo		
Clay	2060 lb	934.7 kg
Lime	108 lb	49.0 kg
Ash	52 lb	23.6 kg
Gravel	2.7 tons	1.2 metric tons
Sealant	0.5 gallons	1.9 liters
Platform-Block silo		
Clay	1971 lb	894.3 kg
Lime	105 lb	47.6 kg
Ash	50 lb	22.7 kg
Sealant	0.5 gallons	1.9 liters
Rammed-Earth silo		
Clay	1750 lb	794.0 kg
Lime	100 lb	45.4 kg
Ash	44 lb	20.0 kg
Gravel	3.6 tons	3.3 metric tons
Sealant	0.5 gallons	1.9 liters
Rammed-Earth Platform silo		
Clay	2080 lb	943.7 kg
Lime	110 lb	50.0 kg
Ash	52 lb	23.6 kg
Sealant	0.5 gallons	1.9 liters

RECOMMENDATIONS FOR FURTHER STUDY

This investigation is by no means complete regarding the improvement of clay as a construction material for on-farm grain storage in developing countries. Listed below are recommendations for further study:

1. In this investigation, clay was optimized by the addition of lime, rice-hull ash, salt, and straw for strength, then tested for durability.. Since strength was sufficient in all clay mixtures for 1-ton silos, a future study should optimize clay for durability, then test for strength.
2. Clay mixtures were tested in this investigation at their standard-proctor density, the maximum density of the clay mixture at an optimum water content. This water content was in the range of 18% to 26% for the various clay mixtures. Because of this low moisture content bricks and walls of the silos recommended must be made with some sort of applied force, either mechanical or tamping with weights to achieve the necessary density of the clay mixture. A future study should investigate the strength and durability of clay mixtures at higher water contents (within the plastic range in the hopes of finding a clay mixture that is strong and durable. Such a clay mixture could be worked by hand, enabling the construction of a grain silo without the use of any specialized equipment (rampress, brick molds, or forms).

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APPENDIX A

Analysis of Silos

The most widely used formula used to determine the forces imposed upon a silo by grain are Janssen's formulas for lateral and vertical pressure, shown below:

Lateral Pressure

$$L = \frac{wD}{4\mu}(1-e^{-4K\mu H/D})$$

Vertical Pressure

$$V = \frac{wD}{4}\left(H+\frac{e^{-4K\mu H/D}}{4\mu/D} - D/4K\mu\right)$$

where: L = lateral pressure, psf
V = vertical load, plf
w = grain bulk density, pcf
D = equivalent diameter, ft.
K = ratio of lateral to vertical internal pressure
K = (1-sin Ø) / (H sin Ø) where Ø = angle of repose of grain
μ = coefficient of friction, material on wall
H = depth of fill

It is recommended that these formulas be used for deep silos only; where the heigth of the silo is greater than its diameter. For a shallow silo the formulas recommended to compute the static loads imposed by grain on the silo are shown below:

Lateral Pressure

$$L = EFD \times H, \text{ psf}$$

Vertical Pressure

$$V = \mu \times EFD \times H^2/2, \text{ plf}$$

where: μ = coefficient of friction, material on wall
H = depth of fill
EFD is the Equivalent Fluid Density
$EFD = w \tan^2 (45^o - \phi/2)$ pcf
where: w = grain bulk density, pcf
ϕ = angle of repose of grain

Maize is the grain used in the analysis of the silos and the bulk density is 45 pcf. The coefficient of friction, is 0.54 and the angle of respose, ϕ, for maize is 27^o. Therefore,

$$K = (1-\sin 27^o) / (1+\sin 27^o) = 0.546 / 1.454 = 0.376$$

Analysis of Cinva-Ram Silo

Lateral Pressure

The lateral pressure exerted by the maize at the bottom of the silo is:

$$L = \frac{45(3.17)}{4(0.54)} (1-e^{-4(0.376)(0.54)6.23/3.17})$$

$$= 52.7 \text{ psf}$$

At one brick higher in the Cinva-Ram silo 11.5 inches, 63.25 inches from the top, the lateral pressure is:

$$L = \frac{45(3.17)}{4(0.54)} (1-e^{-4(0.376)(0.54)5.27/3.17})$$

$$= 48.9 \text{ psf}$$

Changing these loads from pounds per square foot to pounds per lineal foot, so as to compute the moments imposed by the lateral loads on the brick, the forces are multiplied by 4.98 / 12 feet, to obtain 20.3 plf and respective to 48.9 psf and 52.7 psf. To further make it easier to compute moments, the loads per lineal foot are converted to pounds per lineal inch, 1.69pli and 1.83 pli, respectively.

Therefore, assuming linear distribution over the length of the brick, the loading diagram is shown in Figure 33. The resistive forces, R_A and R_B are generated by the tension hoops located $\frac{1}{4}$ of the brick's length from the ends. Solving for the resistive forces:

$$M_A = (1.69 \text{ pli})(11.5 \text{ in})(2.875 \text{ in}) + (0.14 \text{ pli})(11.5 \text{ in})(4.79 \text{ in})/2 - 5.79 \text{ in } R_B = 0$$

$$5.79 \text{ in } R_B = 59.74 \text{ in-p}$$

$$R_B = 10.39 \text{ p}$$

and

$$M_B = -(1.69 \text{ pli})(11.5 \text{ in})(2.875 \text{ in}) - (0.14 \text{ pli})(11.5 \text{ in})(0.96 \text{ in})/2 + 5.75 \text{ in } R_A = 0$$

$$5.75 \text{ in } R_A = 56.65 \text{ in-p}$$

$$R_A = 9.85 \text{ p}$$

The free body diagram, shear and moment diagram, are shown in figure 26.

The maximum moment is 7.75 in-p. Using the flexuse formula and checking for tension that occurs on the inner face of the brick.

$$f_T = \frac{Mc}{I} = \frac{7.75 \text{ in-p } (1.017 \text{ in})}{3.487 \text{ in}^4} = 2.26 \text{ psi, tension}$$

where, M is moment in inch pounds, c is distance in inches from the neutral axis to the face of the brick, and I is the moment of inertia (see Appendix B for calculations of neutral axis and moment of inertia). Compression occurs at the outer face of the brick and is,

$$f_c = \frac{Mc}{I} = \frac{7.75 \text{ in-p } (0.983)}{3.487} = 2.18 \text{ psi, compression}$$

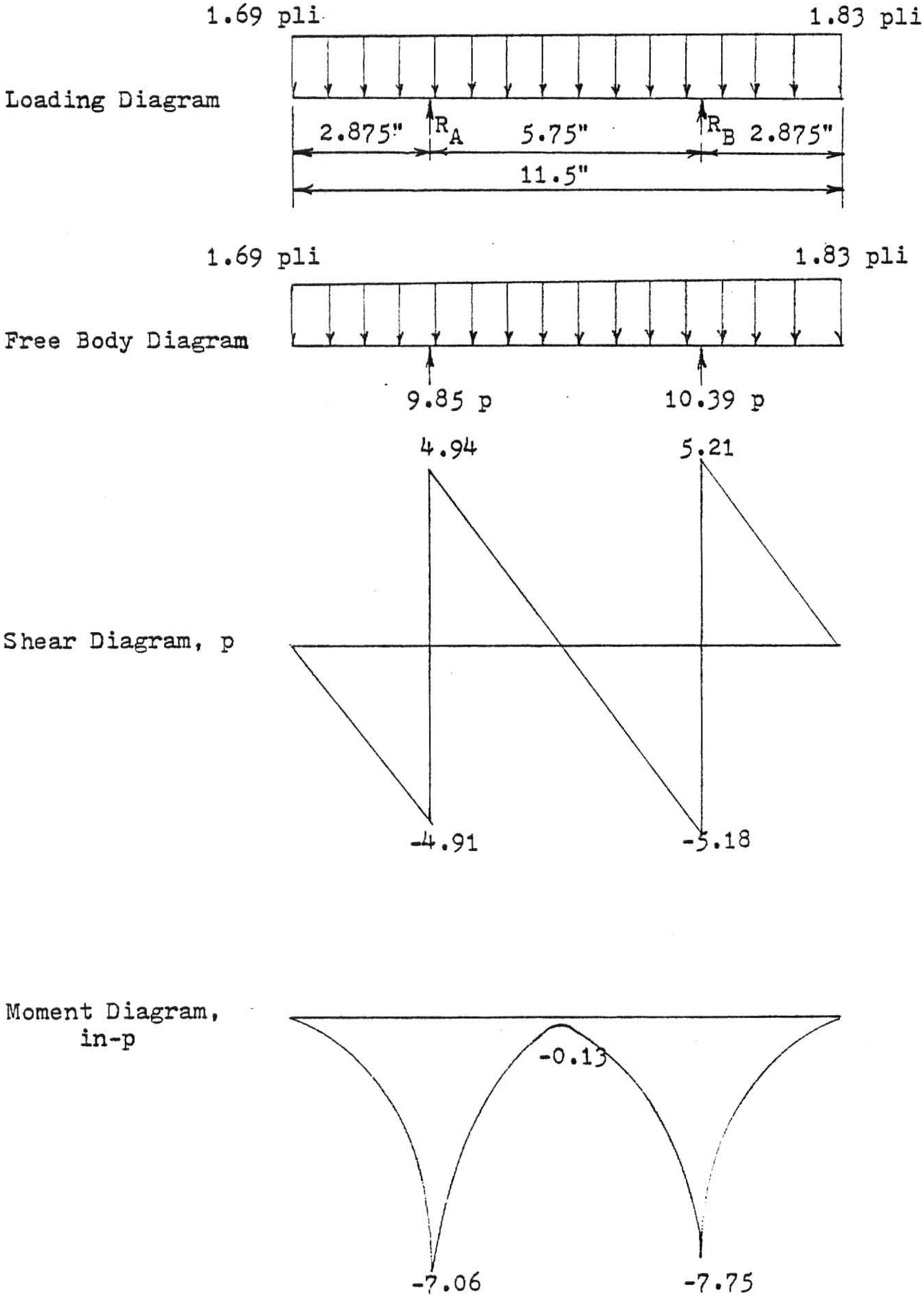


Figure 33. Force Diagram of Cinva-Ram brick.

Vertical Load

The vertical static load, V, imposed on a vertical unit length of the silo wall by the maize is,

$$V = \frac{45(3.17)}{4}(6.23+e^{-4(0.376)(0.54)6.23/3.17}-3.17/(4) \times(0.376)(0.54))$$

$V = 111.26$ plf

The total vertical load imposed by the grain is,

$Vg = 111.26 \text{ plf} \times (3.17f) = 1108p$

To check for bearing pressure that occurs along the bottom of the silo wall all vertical forces must be computed. The weight of the wall is,

$Vw = (3.5ft^2 - 3.17ft^2)/4 \times 9.15ft \times 101.0 \text{ pcf} = 1598p$

Weight of the top, when sealed, is,

$Vt = (3.5ft)^2/4 \times 2/12ft \times 101.0 \text{ pcf} = 162p$

Therefore the total vertical weight is,

$V_T = 1108p + 1598 + 162 = 2868p$

Therefore checking bearing pressure,

$f_b = V_T/A = 2868p/24(10.47 \text{ in}^2) = 11.4$ psi, compression

Comparison of Pressures

The forces exerted by the grain on the silo are compared to the limits of the 2.5% ash - 4.0% limed clay mixture below.

Imposed Pressures		**Limits of 2.5% ash -4.0% Limed Clay**
Compression Flexure	2.18 psi	887 psi
Tension Flexure	2.26 psi	97 psi
Bearing Pressure	11.4 psi	887 psi

As can be seen, the design of the silo is more than adequate to withstand the pressures imposed by the grain.

Hoop Tension

The lateral pressure of the grain imposed on the silo exerts tension in the circumference of the silo. In stave silos, this tension force is transfered to the tension hoops that hold the staves together. In the Cinva-Ram silo the greatest hoop tension occurs at the bottom.

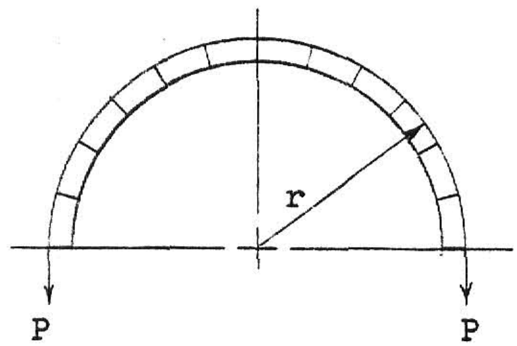


Figure 34.

Splitting the silo in half as in Figure 34, and taking the bottom tier of brick, the resistance force in the tension hoop is 2P, which can be determined by the formula

$$2P = Lt \times r$$

where Lt = lateral pressure per unit length, plf
r = radius, ft

The lateral pressure along the bottom half tier of bricks is 24.8 plf, therefore,

$$2P = 1(24.8 \text{ plf})\ 1.75 \text{ ft}$$
$$P = 43.4 \text{ p}$$

Therefore the material providing hoop tension should be able to provide 50 pounds of tension.

Analysis of Platform-Block Silo

The Platform-Block silo is a shallow silo and therefore the second set of equations must be used in calculations of loads.

Lateral Pressure

The Equivalent Fluid Density for maize is

$$EFD = 45 \tan^2 (45^\circ - 27^\circ/2) = 16.9 \text{ pcf}$$

Therefore, the lateral pressure is,

$$L = EFD \times H = 16.9 \text{ pcf} \times 3.94 \text{ ft} = 66.6 \text{ psf}$$

and at one brick higher the lateral pressure,

$$L = 16.9 \text{ pcf} \times 2.96 \text{ ft} = 50.0 \text{ psf}$$

Changing these loads to pounds per lineal inch, the forces become 2.16 pli and 2.88 pli respective to 50.0 psf and 66.6 psf.

The force diagram is shown in Figure 35. Solving for the resistive forces R_A and R_B:

$$M_A = 2.16\text{pli}(11.8\text{in})(2.95\text{in}) + (0.72\tfrac{1}{2};\text{o})(11.5\text{in})(4/92\text{om})/2 - 5.9\text{in}R_B = 0$$

$$5.9R_B = 95.56 \text{ in-p}$$
$$R_B = 16.20\text{p}$$

and

$$M_B = -2.16\text{pli}(11.8\text{in})(2.95\text{in}) - (0.72\text{pli})(11.8\text{in})(0.98\text{in})/2 + 5.9\text{in}R_A = 0$$

$$5.9\text{in}R_B = 79.35 \text{ in-p}$$
$$R_B = 13.45\text{p}$$

Maximum moment is 12.8 in-p. Checking for flexure

$$f_T = \frac{(12.3 \text{ in-p})(1.013\text{in})}{4.312 \text{ in}^4} = 2.89 \text{ psi, tension}$$

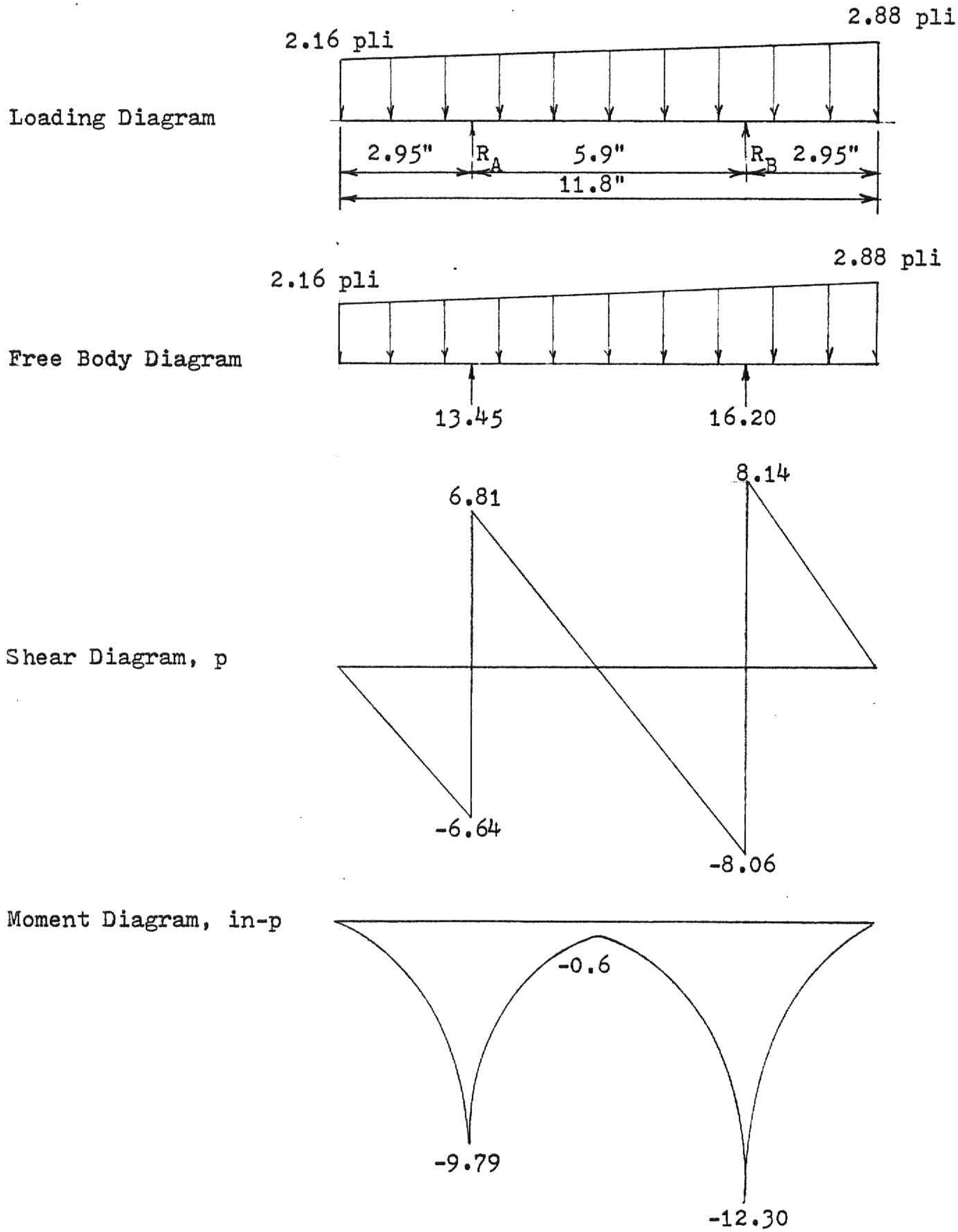


Figure 35. Force Diagram of Platform-Block Silo Brick.

and

$$fc = \frac{(12.3\ in\text{-}p)(0.987in)}{4.312\ in^4} = 2.82\ psi,\ compression$$

Vertical Pressure

The vertical load imposed on the silo is,

$$V = 0.54 \times 16.9pcf\ (3.94ft)^2/2 = 71.0\ plf$$

The total vertical load imposed by the grain is,

$$Vg = 71\ plf \times\ (4.02ft) = 897\ p$$

The weight of the wall is,

$$Vw = (4.35^2 - 4.02^2)/4 \times 3.94ft \times 101.0\ pcf = 863\ p$$

Weight of top when sealed,

$$V_t = (4.35ft^2)/4 \times 2/12ft \times 101.0\ pcf = 250\ p$$

Therefore the total vertical load on the walls is

$$V_T = 897 + 863 + 250 = 2010\ p$$

Checking bearing pressure for the wall,

$$f_b = V_T/A = 2010\ /\ 24(13.13) = 6.4\ psi$$

Now checking the bearing pressure exerted on the foundation legs, the loads are the weight of wall and the top, 1113 p, the weight of the grain, 2204 p and the weight of the base, which is,

$$V_b = (4.60ft)^2/2 \times 0.5ft \times 101.0\ pcf = 837$$

The total weight is,

$$V_T = 1113 + 2204 + 837 = 4154\ p$$

Checking bearing pressure for the legs,

$$f_b = 4154p/5(139.24in^2) = 5.97\ psi$$

Comparison of Pressures of Platform-Block Silo

The forces exerted by the grain on the silo are compared to the limits of the 2.5% ash - 4.0% CaO clay mixture below.

Imposed Pressures		Limits of 2.5% ash -4.0% Limed Clay
Compression Flexure	2.89 psi	887 psi
Tension Flexure	2.82 psi	97 psi
Wall Bearing Pressure	6.40 psi	887 psi
Leg Bearing Pressure	5.97 psi	887 psi

Hoop Tension of Platform-Block Silo

The tension in the bottom tension hoop is,

$$2P = 2(28.7 \text{ plf})(2.01 \text{ ft})$$
$$P = 57.7 \text{ p}$$

Analysis of Rammed-Earth Silos

Lateral Pressure

The rammed-earth silos are shallow silos, therefore lateral pressure is:

$$L = 16.9 \text{ pcf} \times 3.94 \text{ ft} = 66.6 \text{ psf}$$

The critical stress in the rammed-earth silos is tension. The action of the lateral pressure is outward on the silos, and in a sense, trying to split the silo. Figure 36 shows the

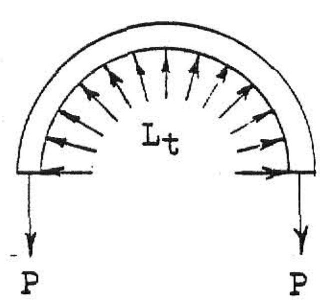


Figure 36. Tension Forces in Half-Section of Silo.

action of the lateral pressure per lineal foot, L_t, upon a half-section of the silo. Tension in the half-section is resisted by the tension forces, 2P. The lateral pressure per lineal foot, L_t, is:

$$L_t = 66.6 \text{ psf} \times 3.94 \text{ ft} \times \tfrac{1}{2} = 131.2 \text{ plf}$$

The tension force may be computed by the formula,

$$2P = 2L_t \times r$$

where r = 2.05 ft, in this case.

Therefore

$$2P = 2(131.2 \text{ plf})(2.05 \text{ ft})$$

$$P = 269 \text{ p}$$

The cross-sectional area of the silo wall is 94.5 in^2, therefore the actual tension stress is,

$$f_t = P/A = 269 \text{ p}/94.5 \text{ in}^2 = 2.85 \text{ psi, tension}$$

The tension limit (97 psi) of the 4.0% limed-clay with 2.5% ash is more than adequate to compensate for the actual tension stress imposed upon the rammed-earth silos.

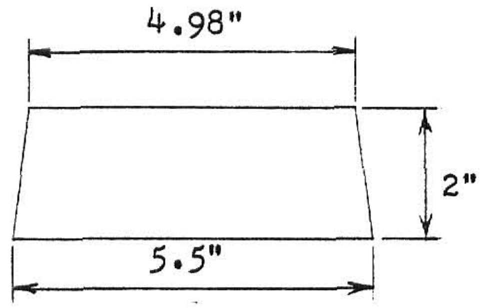
Vertical Loads

The vertical loads and bearing pressures imposed upon the rammed-earth silos are the same as those imposed upon the Platform-Block silo.

APPENDIX B

Neutral Axis and Moment of Inertia of Cinva-Ram Brick

The dimensions of the brick made with the Cinva-Ram press are shown below.



The neutral axis of the brick is,

$$N_A = \frac{(4.98in)(2in)(1in) + (0.52in)(2in)(2/3in)/2}{(4.98in)(2in) + (0.52in)(2in)/2}$$

N_A = 0.983 in, from the bottom

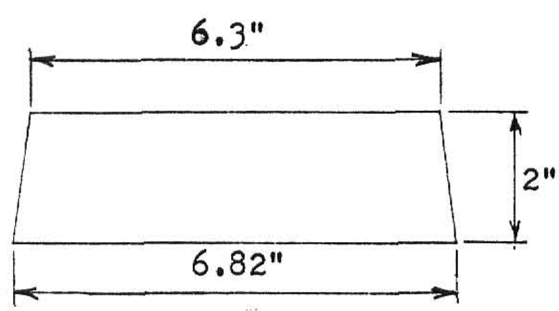
The moment of inertia is therefore,

$$I_o = 1/12(4.98in)(2in)^3+(4.98in)(2in)(0.017in)^2+1/36(0.52in)(2in)^2+(0.52in)(2in)(0.316in)^2/2$$

$$I_o = 3.487\ in^4$$

Neutral Axis and Moment of Inertia of Platform-Block Silo Brick

The dimensions of the Platform-Block silo brick are shown below,



$$N_A = \frac{(6.3in)(2in)(1in) + (0.50in)(2in)(^2/_3in)/2}{(6.3in)(2in) + (0.50in)(2in)/2}$$

N_A = 0.987 in, from the bottom.

Therefore, the moment of inertia is,

$$I_o = 1/12\ (6.3in)(2in)^3+(6.3in)(2in)(0.013in)^2 + 1/36\ (0.52)(2in)^2+(0.52in)(2in)(0.32in)^2/2$$

$$I_o = 4.312\ in^4$$

STRENGTH AND WATER DURABILITY OF STABILIZED CLAY CONTAINING LIME, RICE-HULL ASH, SODIUM CHLORIDE, AND/OR STRAW, POTENTIAL CONSTRUCTION MATERIAL FOR ON-FARM STORAGE IN DEVELOPING COUNTRIES

by

DAYN LARZ CEDERSTROM

B. S. Kansas State University, 1978

AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

Clay cylinders were prepared to test the effects of four additives on the strength and durability of clay. Lime, rice-hull ash, salt (sodium chloride) and straw were added to clay, respectively at four levels (2.0%-8.0%), four levels (2.5%-10.0%), three levels (0.5%-1.5%) and one level (2.0%). Moistened clay samples were compacted into a 2-inch diameter by 4-inch long cylinder, moist cured for 30 hours at 49°C, then dried for 72 hours at 49°C. Compression strength was tested by axially loading the cylinder, where tension strength was tested by using the split-tension test, in which the cylinder is placed horizontally in a compression machine. Durability was tested by immersing the cylinders of clay in water and noting either weight gain or loss after an alotted time period.

. Compression and tension strength of the control clay cylinders were 417 psi and 50 psi, respectively. The optimum of the limed clay cylinders was at 4.0%, 640 psi in compression and 51 psi in tension. Rice-hull ash (2.5%) added to the 4.0% limed clay, produced 887 psi in compression and 97 psi in tension. Strength for the 4.0% limed clay cylinders with 1.0% salt added was 983 psi in compression and 98 psi in tension. Straw (2.0%) added to the 4.0% limed clay increased tensile strength of the cylinders to 81 psi but decreased compression strength to 603 psi. Straw (2.0%) added to 4.0% limed clay with 1.0% salt decreased both compression and tension strength to values of 570 psi and 89 psi, respectively.

Upon immersion in water, control, limed clay and salt-limed clay cylinders deteriorated. Cylinders prepared from the ash-limed clay were immersed for 560 minutes and did not deteriorate. Durability of all clay cylinders were increased when coated with a vinyl water sealer.

Specifications of bricks are given that can be made using clay containing 2.5% rice-hull ash and 4.0% lime. Recommendations of types of silos using these bricks are suggested.