THE DESIGN OF A CAST-IN-PLACE REINFORCED CONCRETE SILO

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

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1948

The Design of a Cast-In-Place Reinforced Concrete Silo

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

by

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Candidate for the Degree of

Bachelor of Science

June 1948

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INTRODUCTION

The value of silage and chopped grass as a principle source of vitamins, minerals, proteins, and bulk for livestock, proves conclusively that silos are a "must" in the future of modern farming. This food value and the resulting demand for same, has encouraged our agricultural implement manufacturers to design and perfect up-to-date ensiling machinery. Many of the countries leading manufacturers such as John Deere, International Harvester, Case, Allis-Chalmers, and Fox now display and sell a complete line of cutting, loading, hauling, and filling equipment.

The results of increased silage production has developed the trend to construct larger and more modern silos. A modern silo has as its primary function; the economical preservation of silage. It must be durable, as well as, be rot, rust, fire, and storm resisting. Moreover, it must furnish many years of low-cost storage.

After carefully considering the governing factors listed in the preceding paragraph, the Author has chosen twin cast-in-place concrete silos with steel reinforcement, and to make this problem more realistic the Author will design the twin silos to eventually replace two tile silos badly damaged by fire several years ago. The farm is known as the Twin Brooke Farm located in Washington Township, Macomb County, Michigan.

ACKNOWLEDGMENT

I wish to express my gratitude to Professor C. M. Cade of the Civil Engineering Department Michigan State College for his valuable assistance and helpful advice.

The Author.

DIAMETER

The usual practice is to select a silo of such diameter that 2 or 3 inches can be removed daily to avoid spoilage. Two silos are desirable in this case; one for grass and one for corn silage. The feeding ratio is to be approximately 40# of grass and 40# of silage daily to each of 30 dairy cows. This makes a total of 1200# to be removed from each silo daily.

Design:

Try 16' with 2" removal daily

$$\frac{16 \cdot 16 \cdot 3.1416}{4} = 210 \text{ Ft.}^3$$

$$210 \cdot .1666' = 33.55 \text{ Ft.}^3$$

$$33.55 \cdot 40\# \text{ per Ft.}^3 = 1340\#$$

Based on an average weight of 40# per Ft.^{3} this diameter is too large since we are removing only 1200# daily and not 1340#

Try 14' with 2" removal daily

$$\frac{14 \cdot 14 \cdot 3.1416}{4} \; \frac{1}{6} = 25.7 \text{ Ft.}^3$$

$$25.7 \cdot 40\# \text{ per Ft.}^3 = 1028\#$$

This diameter will suffice since a 1200# daily removal will more than insure the minimum 2" spoilage limit (1028#)

HEIGHT

It is practical, in Michigan, to design silos for at least a minimum 200 day feeding season.

Design:

40# per day per cow @ 40# per $Ft.^3$ for 30 head is a 30 $Ft.^3$ per day removal. A 14' silo would have a volume of 154 $Ft.^3$ per foot of height.

$$\text{Height required} = \frac{30 \cdot 200}{154} = 40'$$

SPECIFICATIONS

1. The allowable stress in steel is to be 20000# per $In.^2$ for intermediate grade steel bars conforming with the 1940 Report of the Joint Committee of Standard Specifications for plain and reinforced concrete.

2. The cement for use must conform to the current specifications of the American Society for Testing Materials (ASTM).

3. The concrete must have a high degree of imperviousness and durability to slow the action of silage acids. The minimum compressive strength at 28 days should be: footings 3000 psi., for silo walls, roof, door frames, and chute 4500 psi.

To attain this strength the water-cement ratio of the footings should be less than .734 and for all other parts .677.

4. The weight of silage varies as the depth and in direct proportion to the water content. For a 40' silo the weight varies, on the average, from 20# per $Ft.^3$ at the top to 65# per $Ft.^3$ at the bottom.

5. Data for the lateral pressure and vertical friction pressure computations which follow was obtained from a research study in which the United States Department of Agriculture, The New Jersey Agriculture Experiment Station, The National Association of Silo Manufactures, and The Portland Cement Association cooperated. The work was done at the Dairy Research Farm at Sussex, New Jersey.

SPECIFICATIONS Cont.

This committee's work showed, (1) that the relation between lateral pressure and head of silage is expressed as a curved line, and (2) that there is no justification for assigning different pressures to different ensiled materials. The data indicates clearly that lateral pressures increase with moisture content and with the diameter of the silo.

6. The allowable soil pressure on a sandy soil is 8000 # per $Ft.^2$*

7. Since juices of legume and grass silages are more strongly acid than normal corn silage, it is advisable to apply a frequent protective coating to the inside surface of silo walls. There are several good treatments available, one of which--Linseed Oil-- will be described here.*

Linseed Oil Treatment. Concrete silo walls should be thoroughly cleaned and dry before application of the linseed oil. Boiled linseed oil is generally used because of its quicker drying properties. For the first coat the oil should be thinned with equal parts of turpentine to give increased penetration. Allow this coat to dry thoroughly before applying the second coat. The second coat is applied without thinning. Spots where the oil has been absorbed should be given additional coats. The last coat should be allowed to dry for at least 2 weeks before the silo is filled. One gallon of linseed oil will cover about 200 $Ft.^2$ -- 2 coats.

* Concrete Information No. CP44 Portland Cement Associati

FOOTING Design

Loads

1. Weight of 1 foot on mean circumference for entire height of 40'.

Area of 15' circle = 177.1 $Ft.^2$

Area of 14' circle = 154.05 $Ft.^2$

Area of hoop = 23.05 $Ft.^2$

Volume of hoop 40' high--23.05 • 40 = 922 $Ft.^3$

$$\frac{922}{3.1416 \cdot 14.5} = 20.2 \text{ Ft.}^3 \text{ per ft. of mean circumference}$$

20.2 • 150 = 3030# per ft. of mean circumference

2. Vertical friction load of silage is based on experimental work (see above) where various samples under different moisture contents are used and the relation between depth and vertical pressure measured. This data is plotted graphically and a curve is found by least squares to fit these values. The equation $f = 5.5\,h^{1.08}$ where f = vertical wall load inpsf and h = depth below top of silo in feet, is the best fit under these conditions. Since the maximum pressure is needed at the base of the footing it is found by intergrating from 0 to h the equation above;

$$F = \int_0^h 5.5\,h^{1.08} = 2.64\,h^{2.08} \quad \text{where } h = 40 \text{ and } h^{2.08} = 2149$$

$F = 2.64\,h^{2.08} = 5673.4\#$ per ft. of circumference

P = allowable soil pressure and W = width of footing in inches.

FOOTING Cont.

Width Design

$$W = \frac{12\ (5673.4 + 3030)}{P} = 13"$$

Depth Design

Shear is not a limiting factor in the design of silo footings hence the depth of plain footings should be calculated by the following formula;

$$d = \frac{\sqrt{P}}{131}\ W$$ where d = required depth, W = width of footing in inches, and P = allowable soil pressure in # per $Ft.^2$

$$d = \frac{\sqrt{8000}}{131} \cdot 13 = 8.89 \text{ use } 9"$$

The weights of the roof, chute, reinforcing steel, footing, and foundation wall were omitted in computing the footing dimensions. The increase in width of the footing due to the above mentioned would amount to about 6½%. Considering the uncertainty as to the allowable soil pressure, the author feels that sufficient accuracy is obtained by use of the vertical friction pressure and the weight of the wall.

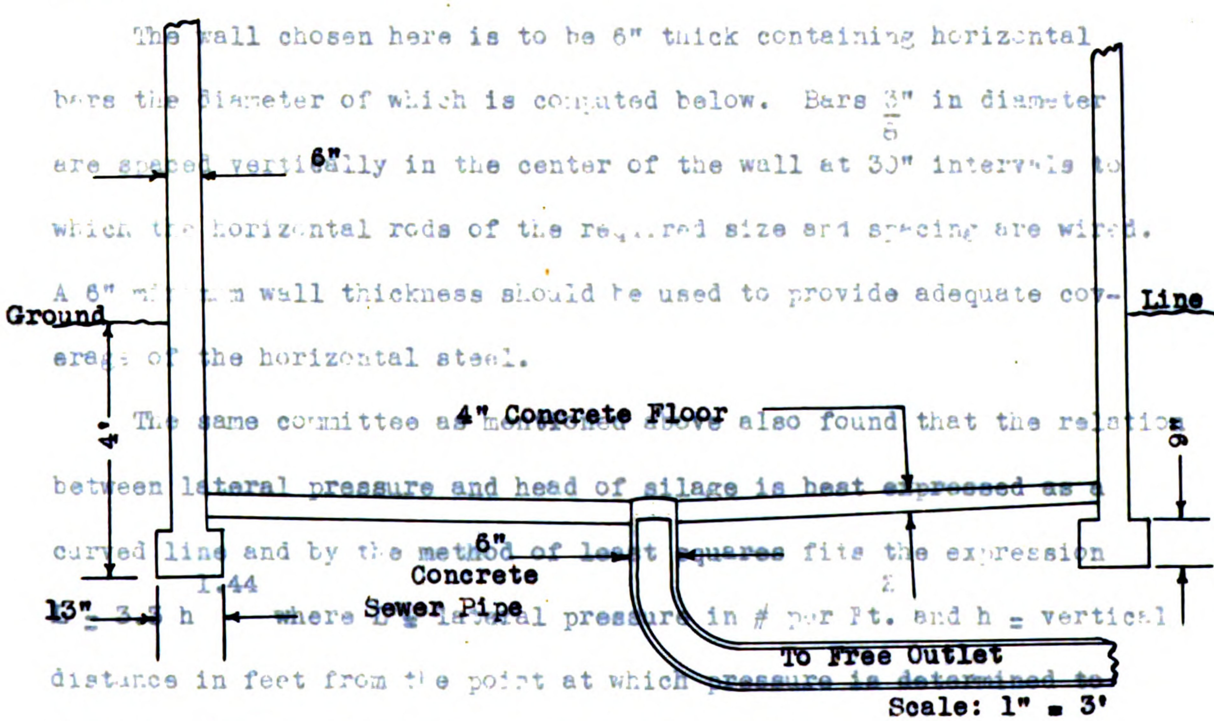
FLOOR and DRAIN

Concrete floors may or may not be provided to facilitate drainage and permit easier cleaning. In this design a 4" concrete floor will be used with a slight slope towards a central drain. The drain is located in the center of the floor and has a 4" sewer tile leading to a free outlet. The floor should be constructed to permit free movement relative to the walls which allows silage settlement without throwing the silo out of plumb.

WALL

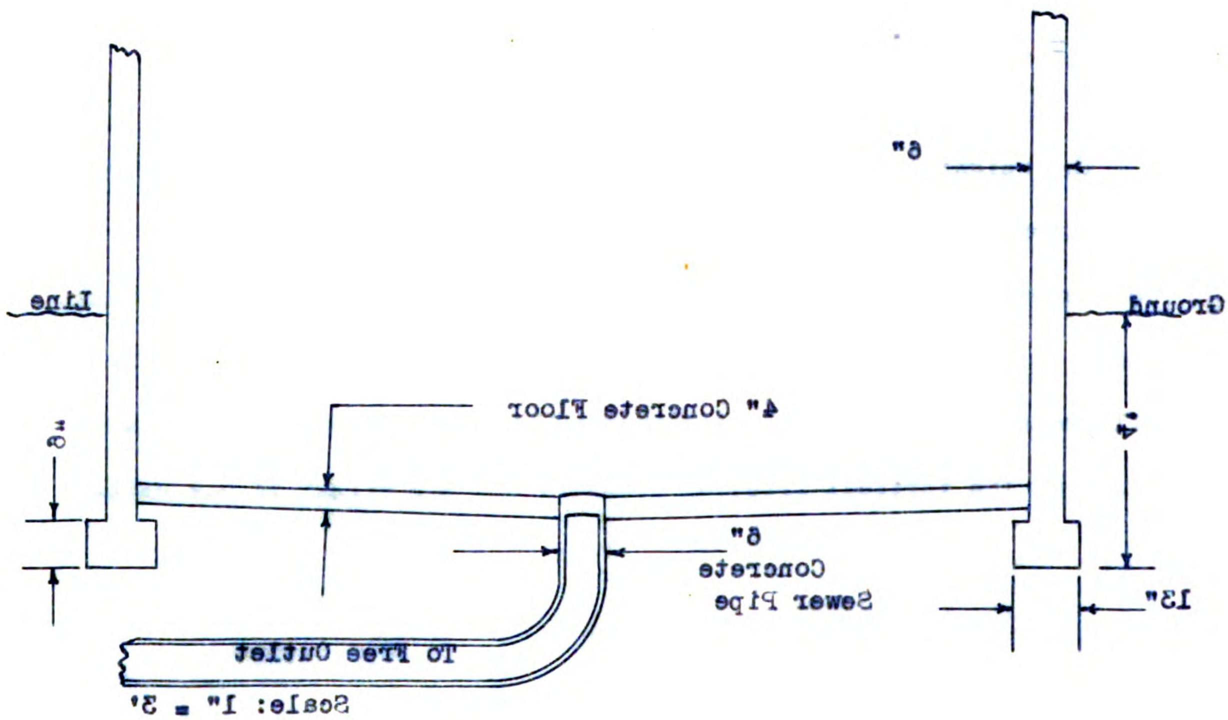
The wall chosen here is to be 6" thick containing horizontal bars the diameter of which is computed below. Bars $\frac{3}{8}$" in diameter are spaced vertically in the center of the wall at 30" intervals to which the horizontal rods of the required size and spacing are wired. A 6" minimum wall thickness should be used to provide adequate coverage of the horizontal steel.

The same committee as mentioned above also found that the relation between lateral pressure and head of silage is best expressed as a curved line and by the method of least squares fits the expression $L = 3.5\, h^{1.44}$ where L = lateral pressure in # per Ft.^{2} and h = vertical distance in feet from the point at which pressure is determined to the top of silo. The lateral pressure of either grass or corn silage of moisture content not exceeding 75% should be calculated by



FLOOR PLAN

(6A)



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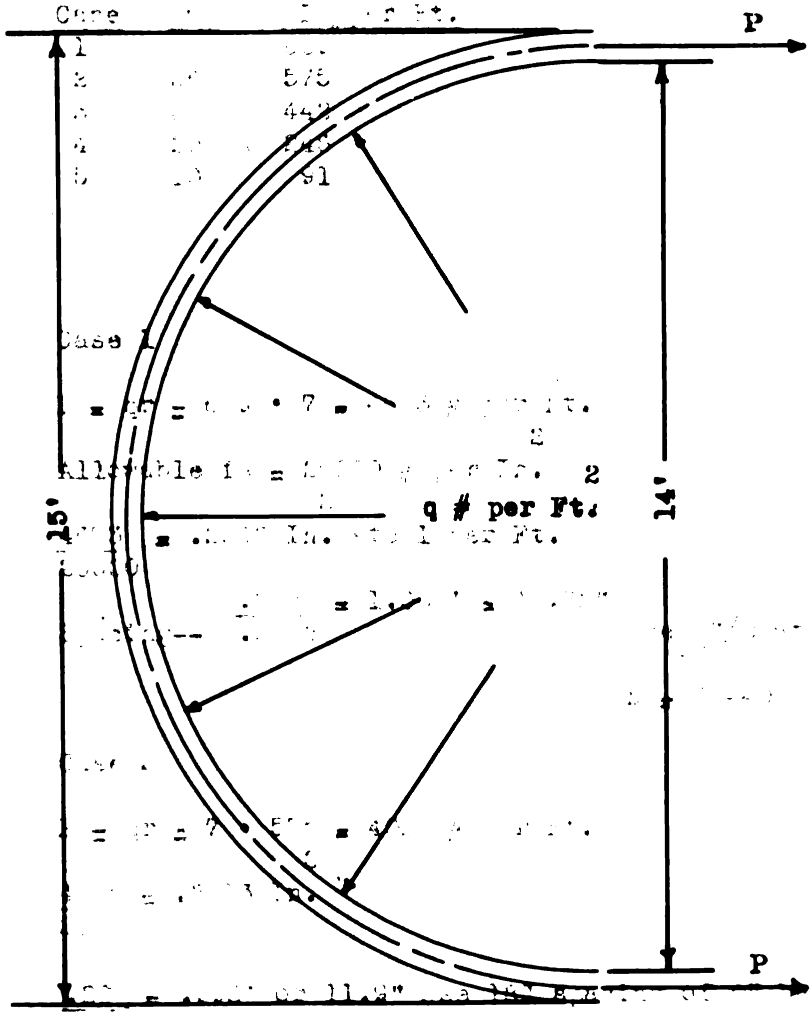
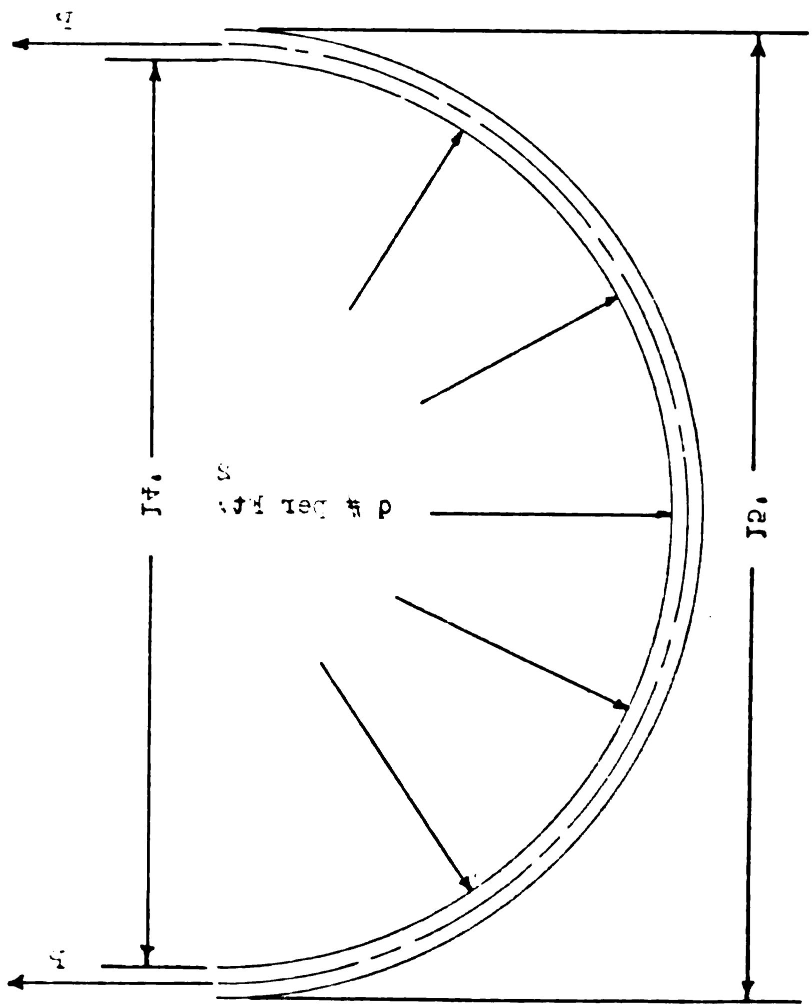


P = qr

Scale: 1" = 3'



P = dr

Scale: 1" = 3'

WALL Cont.

the above formula.

$$L = 3.3\,h^{1.44}$$

Case	h	L # per $Ft.^2$
1	40	669
2	36	575
3	30	442
4	20	246
5	10	91

Case 1

$P = qr = 669 \cdot 7 = 4683$ # per Ft.

Allowable $fs = 20000$ # per $In.^2$

$\frac{4683}{20000} = .2342$ $In.^2$ steel per Ft.

Spacing-- $\frac{.249}{.2342} = 1.061' = 12.72"$

Use $\frac{9}{16}$"/Ø at 12" in interval
$h = 36$–40

Case 2

$P = qr = 7 \cdot 575 = 4025$ # per Ft.

$\frac{4025}{20000} = .2013$ $In.^2$

$\frac{.20}{.2013} = .993'$ or 11.9" Use 12" spacing of ½" bars

Case 3

$P = qr = 442 \cdot 7 = 3094$ # per Ft.

$\frac{3094}{20000} = .1547$ $In.^2$ per Ft.

$\frac{.20}{.1547} = 1.295'$ or 15.5" Use 12" spacing of ½" bars

WALL Cont.

Case 4

$P = qr = 246 \cdot \frac{7}{2} = 1722$ # per Ft.

$\frac{1722}{20000} = .0861$ In. per Ft.

$\frac{.20}{.0861} = 2.32'$ or 27.9" with ½" bars

Case 5

$P = qr = 91 \cdot \frac{7}{2} = 637$ # per Ft.

$\frac{637}{20000} = .03135$ In. per Ft.

$\frac{.20}{.03135} = 6.38'$ or 76.6" with ½" bars

Spacing:

From h = 36' to h = 40' use 12" spacing with $\frac{9}{16}$" diameter bars.

From h = 22' to h = 35' use ½" diameter bars with 12" spacing.

From h = 0' to h = 22' use ½" diameter bars with 24" spacing.

DOORWAY

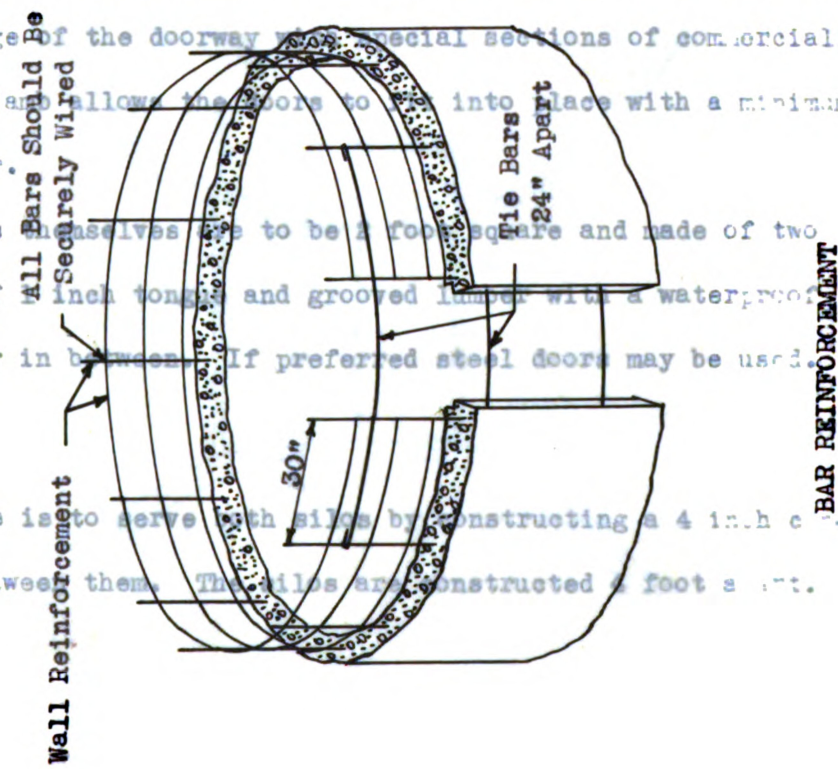
The doorway can be either the intermittent or the continuous opening type. It was convenient in this design to choose the latter. Bars 1 inch in diameter and 8 feet long span the 2 foot continuous doorway at 24 inch intervals. The length allows a loop on each end to anchor on the vertical reinforcement. (See Drawing)

A jamb 2 inches by 2 inches is formed in the concrete wall on the inside edge of the doorway with special sections of commercial forms. This jamb allows the doors to fit into place with a minimum leakage of air.

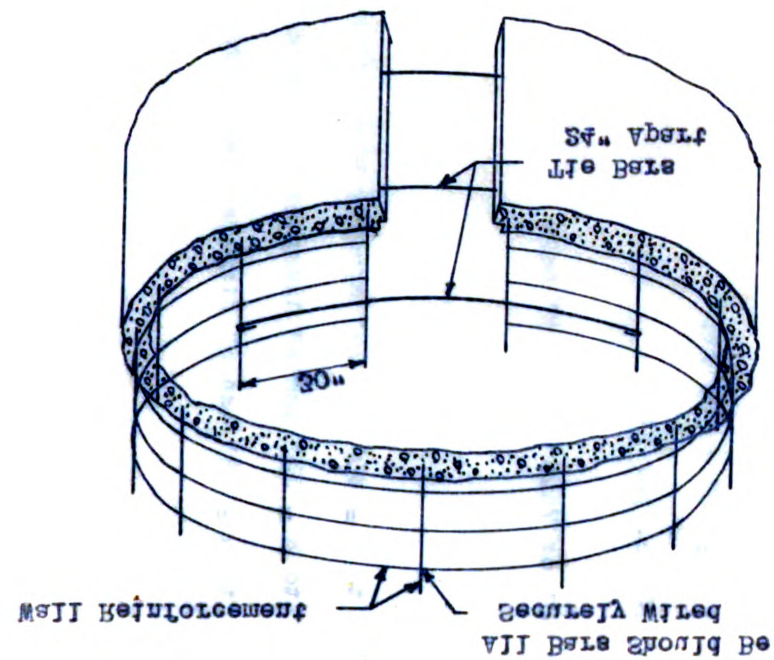
The doors themselves are to be 2 foot square and made of two thicknesses of 1 inch tongue and grooved lumber with a waterproof building paper in between. If preferred steel doors may be used.

CHUTE

One chute is to serve both silos by constructing a 4 inch concrete wall between them. The silos are constructed 4 foot apart.



BAR REINFORCEMENT



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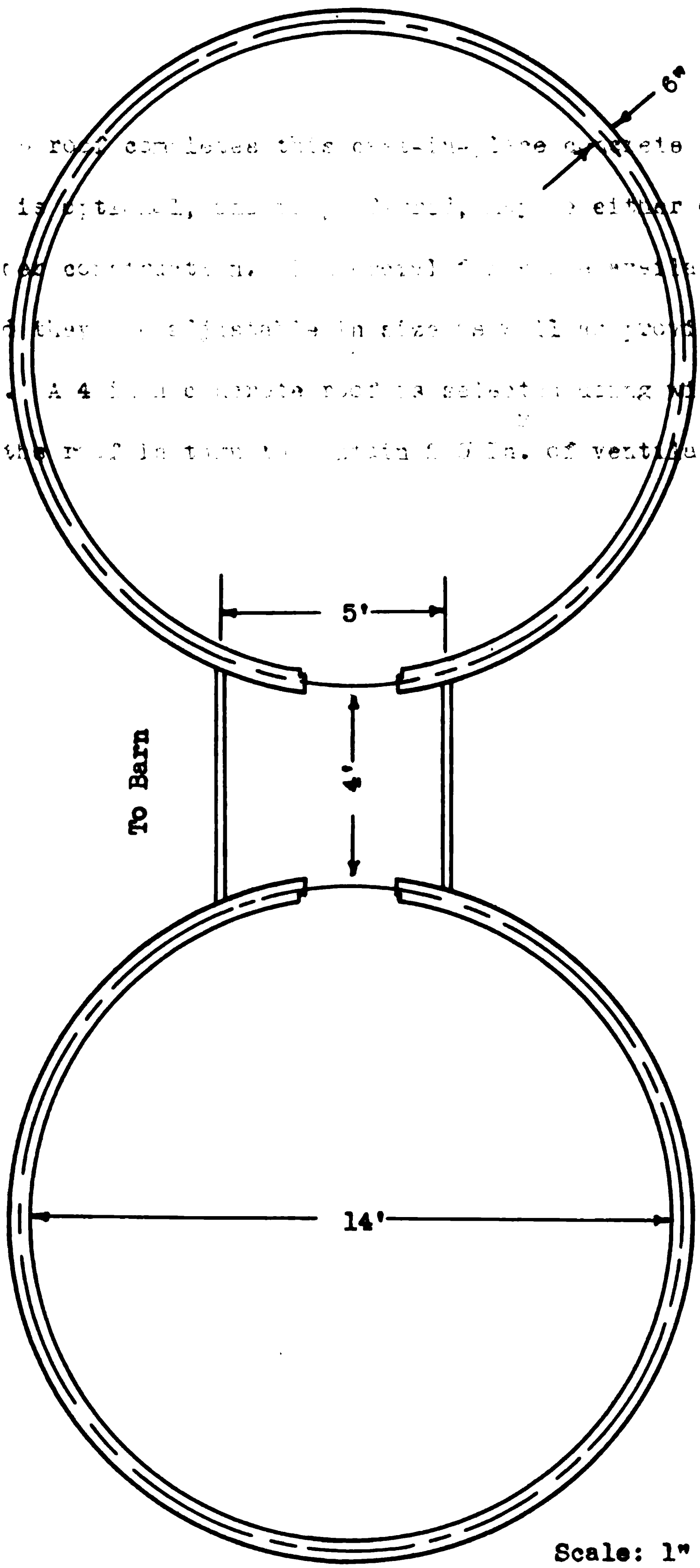

Scale: 1" = 4'

Chute Detail
(10A)

ROOF

A concrete roof completes this cast-in-place concrete silo, although a roof is optional, and if preferred, may be either of concrete, steel, or lumber construction. Commercial forms are available for this step, and they are adjustable in size as well as provide for a dormer window. A 4 inch concrete roof is selected using wire mesh reinforcing, the roof in turn to contain 250 In.^{2} of ventilation opening.

MATERIAL REQUIREMENTS--EACH SILO

Steel--Horizontal

4-- $\frac{9}{16}$" diameter bars 43 Ft. 8 In. long

25-- $\frac{1}{2}$" diameter bars 43 Ft. 8 In. long

21-- 1" diameter bars 8 Ft. long

Steel--Vertical

54-- $\frac{3}{8}$" diameter bars 14 Ft. 8 In. long

Roof

$\frac{1}{4}$" wire mesh spaced 4"

No. of Bars	Diameter	Length	Wt. in # per Ft.	Total Weight
4	$\frac{9}{16}$"	43' 8"	.830	145#
25	$\frac{1}{2}$"	43' 8"	.668	728#
21	1"	8'	2.67	448#
54	$\frac{3}{8}$"	14' 8"	.376	298#
				1619#

Concrete--Footing

A $1:2\frac{3}{4}:4$ mix is used here to secure the required strength. 1 $Yd.^3$ of this proportion requires: 5 sacks of cement, 14 $Ft.^3$ of sand, 20 $Ft.^3$ of gravel, and $27\frac{1}{2}$ gallons of water.

Cubic yards required $= \dfrac{13 \cdot 9 \cdot 14}{1200} = 1.36$

$1.36 \cdot 5 = 6.8$ sacks of cement

$1.36 \cdot 14 = 19$ $Ft.^3$ of sand

$1.36 \cdot 20 = 27.2$ $Ft.^3$ of gravel

$1.36 \cdot 27\frac{1}{2} = 37.4$ gallons of water

Concrete--Walls, Floors, Chute, and Roof

Here a $1:2\frac{1}{4}:3$ mix is used,needed is $6\frac{1}{4}$ sacks of cement, 14 $Ft.^3$ of sand, 19 $Ft.^3$ of gravel, and $31\frac{1}{2}$ gallons of water per $Yd.^3$

Reasoning as above the requirements are 238 sacks of cement, 20.5 $Yd.^3$ sand, 27 $Yd.^3$ gravel, and 1200 gallons of water.

Bill of Materials

Steel -- 1619 # plus roof mesh

Cement -- 245 sacks

Gravel -- 28 $Yd.^3$

Sand -- 27.6 $Yd.^3$

Water -- 1240 gallons