1941

Utilization of lumber in grain storage structures

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UTILIZATION OF LUMBER IN GRAIN STORAGE STRUCTURES

by

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A Thesis Submitted to the Graduate Faculty for the Degree of

MASTER OF SCIENCE

Major Subject Farm Structures

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1941
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INTRODUCTION

Justification for the Study

Wood as a building material.

Until recently basic information for the use in designing and specifying wood construction has not been extensively available but, nevertheless, wood has been able to hold first place as a building material.

Holtman (13) states, "The availability of wood as compared with other structural materials, its low cost, its exceptionally high strength for its weight, and its ease of working both at the mill and in construction have maintained its prestige in the building and construction field for many generations, and late studies, which make it possible to determine by visual inspection the strength of wood within very narrow limits of range, will continue to maintain and to expand its utility and use.

"In the past, the characteristic variations of wood were not so important as they are today because lumber was cheaper and was easily obtained in large sizes and in almost clear grades. The use of clear grades practically eliminated defects and avoided many of the problems caused by variability in lumber. Plentiful supply, moreover, resulted in the use of
larger sizes than economical design would indicate. But conditions have changed rapidly in the past twenty-five years. By experiment we have learned the structural value of the lower grades of lumber."

The ever-increasing requirements for strict economy that must be met in design are being met by the advancing knowledge of wood technology. The Forest Products Laboratory at Madison, Wisconsin has made tests and studies of the properties of wood, and it is from this source that a large part of the design information has been taken.

Douglas Fir, a wood that has exceptionally good structural properties, is used extensively in sections where it is available, and especially in places where strength is required. The structural properties—those that enable the wood to resist deformations, loads, shocks, and forces—of Douglas Fir and other woods have been determined by experiment and certain recommendations have been made for designing in wood. Due to the structural superiority of Douglas Fir and its availability in the corn belt, it is used very extensively in the construction of buildings in this section of the United States.
The value of corn and grain to Iowa.

Buildings for storing grain on the farm are as important to the average Iowa farmer as are bank vaults to a banker.

Annual monetary value. "Corn is the basis of Iowa's farm wealth, and yet surveys show that the corn cribs and bins are wholly inadequate for the "Ever-Normal Granary" program." (14) The annual production of corn in the United States is approximately 2 1/2 billion bushels. Iowa, with approximately 1/2 billion bushels, or roughly 20% of the nation's production, ranks first among the states in corn production. Using fifty cents per bushel for the value of this corn, a figure below which the price of corn seldom goes, the annual monetary value of Iowa's corn is 250 million dollars. From this it can readily be seen why the proper storage of corn is important to the Iowa farmer. Although the other states in the corn belt have somewhat smaller productions, they still have a sizable yearly investment in corn and the proper storage is important to them as well.

The aim of the study is to develop a corn storage building that will give the growers in the corn belt a building that will best protect their investment in corn for the least money.

Amounts stored on farm. Only a small percentage of the corn crop is sold as cash grain, about 85% of the corn produced in Iowa being fed to livestock in the county where it was grown. The percentage for the Corn Belt as a whole is not
far from this same figure.

In the past, the bulk of the corn was stored right on the farm where it was grown. There are two or three reasons why this will continue to be true. The first reason is that at the time of harvest, Iowa corn is usually too high in moisture content to be shelled and put into terminal storage. The second reason is that even if the corn were dry enough to store at the terminal, the storage charges there are generally higher than they are on the farm. The third reason is that the most strategic location for Iowa corn is the farm where it was grown. According to an unofficial report given at a meeting on grain storage, held at Ames, Iowa, April 4, 1941, there is at present over 160 million bushels of corn in storage on farms and in C.C.C. steel bins. This corn is under government seal and does not include the corn that is stored by the private individuals or that under loans from local banks and other lending agencies. From this it can readily be seen that there is a need for proper corn storage.

The federal government has advanced its "Ever-Normal Granary" plan and it is interested, leaders say, in providing the means to enable the individual farmer to store his grain on the farm, and by so doing to establish orderly marketing to support the price and carry over a reserve from years of good crop production to years of less favorable yields. In the past, the federal department of agriculture points out,
only about seven percent of the corn crop has been carried over from one year to the next. The carry-over of corn in the United States from one year to another ordinarily amounts to about 170,000,000 bushels.

**Losses due to improper storage.** Although it is comparatively easy to realize that corn is a very important crop and that the proper storage of the crop is important, there have been in the past untold losses due to improper storage after the crop has been harvested. Some of the causes of these losses have been faulty ventilation, rat damage, insect damage, structural failure of the crib and several others.

The most important dimension of a crib is its width since that has most to do with the drying out of the stored corn. Since the movement of air through the crib varies inversely with the width, there are certain maximum widths to which cribs can be built. These maximum widths for storing corn have been violated in many cases and, consequently, there has been a sizable loss in stored corn due to improper ventilation. The practice of storing corn in the driveway of a combined corn crib and granary has at certain times turned out to be a rather expensive practice due to the spoilage of corn from inadequate ventilation.

Losses by rats and mice vary from farm to farm and are difficult to estimate in a single figure. There is, however, a definite loss from rodent damage. Figure 1 shows a bad rat infestation of a crib. In a number of cases the rats have also
Figure 1 Side view of crib showing rat damage to cribbing
eaten holes in the roof. Although it is somewhat difficult to do away entirely with this damage, it can be materially reduced.

Losses by insect damage are also difficult to estimate and are not considered as a major problem. This loss is becoming more evident since the installation of the "Ever-Normal Granary" program. With the long time storage of corn, the insects have time to colonize and inflict a loss of considerable size.

The improper planning of the foundation, walls, floors, bracing, and roofing has in the past contributed to short life in the grain storage building. Structural failures such as those shown in Figure 2 have caused untold crib and corn damage. One of the principal causes of these damages has been the inability of the builder or designer to realize the enormous pressures that are developed in the crib.

**Inadequacy of the present type corn storage.**

**General inadequacy.** Many of the cribs that are in use today are very inadequate for the proper storage of corn. They do not meet the requirements that a crib must meet to be of service to the owner. Since the incoming of the "Ever-Normal Granary" program, the amount of corn stored on the farm has been increased and many of the cribs are of insufficient size to carry this extra amount of corn. This has caused many of
Figure 2 Structural failures of crib
the farmers to store corn in the driveway of the crib and in temporary cribs. The practice of storing corn in the driveway impairs the ventilation features of the crib, not only causing poor conditioning of the corn in the driveway, but the corn in the cribs as well. Many of the temporary cribs that are used offer no protection to the corn and a much lower grade of corn is the result. Also in some cribs the relative storage capacity of the grain bins and corn cribs is such that the most economical use of the space cannot be secured. Although there is a great deal of corn and small grains stored in overhead bins, the bins in a great many cases are larger than are needed. This causes an incomplete use of the space in the building.

In many cribs there is an inefficient use of the space enclosed by the boundaries of the crib. Figure 3 (4) compares the arrangement and utilization of space in three buildings that were designed to meet essentially the same conditions leaving the choice of roof shape to the prospective owner. The single-hatched portion is available for the storage of ear corn and the double-hatched portion is available for the storage of shelled corn or small grains. It can readily be seen that in the gable and gambrel roofed cribs as shown with the vertical grain bin walls, there is considerable waste space in the upper portion of the building. However, in the Gothic roofed crib where the bin walls have been sloped,
PLANS AT LEVELS INDICATED

GABLE  GAMBREL  GOTHIC

COMPARISON OF CRIB & GRANARY SECTIONS

Figure 3
Figure 4  Temporary and semi-permanent corn storage
a greater percentage of the roof coverage is available for storage.

The temporary and semi-permanent cribs in which a great deal of the corn is stored in the corn belt are not adapted to the use of modern elevating machinery. Figure 4 shows some of the temporary and semi-permanent cribs that are in use today.

**Structural inadequacy.** A number of the cribs that are in use today are inadequate structurally to carry the loads that are imposed upon them. These cribs have not only been ineffectively braced but have an inconvenient and inefficient arrangement of the members. Due to this structural inferiority, these cribs do not possess the rigidity, stability, and durability that are essential to the long life of the building. Especially lacking in durability are such cribs as are shown in Figure 4.

In some of the more permanent type buildings, the structural members have been made large enough to carry the loads placed on them but these members have not been joined together in a way that their strength could be realized. This factor, too, contributes to short life in the grain storage building.

**Failures.** The structural inadequacy of cribs has in many cases resulted in structural failures which has proven to be rather expensive to the owner. Some of these failures have not been so expensive at the time but have increased the depreciation rate on the building. This, however, proves to be
expensive when considered over a period of years.

Figure 5 shows a crib with bulging side walls and end walls. This is a result of insufficient strength of members. Another place where strength has been neglected is in the cross braces of the cribs. In a great many cases, these braces are not made strong enough to carry the vertical load that is placed upon them. The crib shown in Figure 6 has failed at the sill joint of the studding. This is an example of the joint failing to develop the strength of the member. Figure 7 shows a crib that has been pushed out of shape by the wind because it lacked the proper bracing to resist the wind loads.
Figure 6  Sill joint failure

Figure 7  Wind damaged crib
Object of the Study

The specific objectives of this study are:

1. To combine and correlate the work of previous investigators.
2. To correct the weaknesses of the conventional designs now in use.
3. To develop a set of plans that is of value to the rural builder.

The general objective of this study is to increase the serviceability of grain storage structures by the proper utilization of the properties of wood.
HISTORICAL

Project

Project setup.

"The Utilization of Lumber in Farm Building Construction", an Iowa Agricultural Experiment Station project of which this study is a part, was initiated in 1937. This project is sponsored by the Weyerhaeuser Sales Company and has as its general objective the improvement in construction of farm buildings through the better use of wood.

Previous investigations.

The improvement of the corn crib and granary was selected as the first specific task under this project. After considerable study of the various requirements of grain storage buildings, J. B. Richardson, (11) began the study of the structural improvement of the corn crib and granary. With a more efficient use of materials in mind, Richardson developed a self-supporting grain bin partition over the central driveway of the building. Several tables on wall and floor design are included in his study.

A. Kirk Crawford (2) the second man to work on this project continued the work on the structural improvement of the corn crib and granary. He attacked the problem by designing with
reference to the arrangement and function of the various
parts of the structure. Crawford also tested several types
of bracing and joints.

C. E. Rice (9), the third man to work on the project,
developed during his year's work, a modification of the gambrel
barn roof. Although Rice's work did not deal directly with the
corn storage building, he determined the value of some joints
and connections that may be applied to the corn storage building.

Review of Literature

Grain pressures.

Loose grain pressures. The characteristics of stored grain
have occupied the interests of various investigators during the
past fifty years. The results of their findings will be only
briefly summarised here. The lateral pressure of grain tending
to burst the bin walls is one of the first structural phases
that must be considered. It does not follow the law of pressure
of fluids but varies with different grains from 0.3 to 0.6 of
the vertical pressure and increases very little after reaching
a depth of 2 1/2 to 3 times the width or diameter of the bin.

Two solutions of the problem of calculating pressures in
grain bins have been proposed: Janssen's Solution and Airy's
Solution. The results of these two methods agree very closely
with experiments. Janssen's solution is most widely used in
determining these quantities and it is used in this study.
His formula is:

\[ L = \frac{wR}{u} \left(1 - e^{-kuh} \right) \]

\[ V = \frac{L}{k} \]

in which,

- \( A \) = Area of bin in square feet
- \( P \) = Perimeter of bin in feet
- \( R \) = Hydraulic radius of bin = \( \frac{A}{P} \)
- \( D \) = Diameter of bin or diameter of inscribed circle in feet
- \( h \) = Height of grain in feet above point in question
- \( u \) = Coefficient of friction of grain on bin walls
- \( w \) = Weight of grain in pounds per cubic foot
- \( V \) = Vertical pressure of grain at depth \( h \) in pounds per square foot
- \( L \) = Lateral pressure of grain at depth \( h \) in pounds per square foot
- \( k = \frac{L}{V} \) = ratio of lateral to vertical pressure
- \( e \) = Base of Naperian Logarithm (2.718)

Both \( u \) and \( k \) can only be determined by experiment on a particular grain and kind of bin, but for practical design purposes, the following coefficient values are frequently assumed: \( u = 0.417; k = 0.6; \) and \( w = 50 \). These assumptions are safe for wheat which constitutes the heaviest loading commonly encountered. Many experiments have been run by various investigators and a description of these is given by Milo S. Ketchum (6).

H. J. Barre (1) has, in connection with his research in
corn storage, made some pressure measurements on cribbed shelled corn. Pressure panels were installed in the doors of two 2000 bushel steel bins at Webster City, Iowa, and the cribs were filled with corn of a moisture content of about 11 percent. (This is a moisture content below the maximum for safe storage of shelled corn.) One bin was filled to a depth of about 11 feet and the other 10 feet, containing about 2300 and 2000 bushels respectively.

The preliminary observations showed that at a depth of 10 feet the outward pressure is about 210 lb. per square foot while the downward pressure at this depth is about 80 pounds per square foot. In other words, the outward pressure at 10 ft. would produce a tension of about 1900 lb. in a one foot strip of wall of the bin 18 ft. in diameter.

From an average value of the downward pressure of about 40 lb. per sq. ft., the bin wall 10 ft. 8 inches high carries a total head of about 24,100 lb., or almost 19 percent of the total weight of the corn. By comparing these outward pressures with those of ear corn it will be noted that the pressure of shelled corn is about three times that of ear corn.

**Ear corn pressures.** Reports of failures in large corn cribs when filled rapidly and the need of experimental data on which to base satisfactory crib design caused the Division
of Structures of the Bureau of Agricultural Engineering, U. S. Department of Agriculture, to make a study of the pressures exerted by ear corn on corn crib floors, walls, and cross bracing (6).

An experimental crib was erected at Toledo Experiment Farm in 1931 for this study. The crib walls and floors were set up so that the pressures on them could be calculated from strain gauge readings. The crib was first set up at the eight foot width and a complete set of readings was taken before any loading was started. The crib was filled four times in the fall of 1931 with corn weighing about 28 lb. per cu. ft.

Floor loads were calculated from the strain-gauge readings taken at 2-foot intervals along the floor beams. Since the approximate moment at any point in a beam was a function of the strain recorded by the strain gauge, it was found by the formula

\[ M = \frac{dei}{10c} \]

where,

- \( d \) = recorded deformation of 10 inch length of member
- \( e \) = Modulus of elasticity \(- 30,500,000 \) lb. per square inch (by test)
- \( i \) = Moment of inertia of section
- \( c \) = distance from neutral axis to outer fiber of beam

The curves in Figure 8 show average floor loads on the beams.
Calculation of pressures on the walls from the strain gauge readings proved to be more difficult than had been expected. In the fall of 1932 the wall pressures were measured by a simpler method. Pressure panels were installed in the side of the crib so that the readings could be taken directly. After these modifications the crib was filled and readings were taken as each 4 foot depth of corn was added. The outward and downward average pressures on the crib walls are shown in Figure 9.

The ratio between the outward and downward pressures on the walls of the crib is the coefficient of friction. The average results of this test give 0.62 as the value of this coefficient.

Wood fastenings for farm buildings.

Nails. For many years the most common fastening used in farm buildings has been the nail. Nails are relatively cheap and joints are easily fabricated with them due to the fact that nails are easily placed with very little labor. This fastening is satisfactory for many purposes and possibly will never be completely replaced. However, where an attempt is made to design a joint comparable in strength to the structural member, the nail presents its disadvantages. When a nailed joint is placed in shear it begins to yield under a small load. Due to the inadequate bearing surface, a few fibers are crushed in the adjoining surfaces and the nail bends. Even if a sufficient
Figure 8  Floor load exerted by ear corn

Figure 9  Average pressures of ear corn on crib walls
number of nails could be applied to the joints to get the strength, a vibrating load would loosen them and reduce the strength of the joint. Changes in moisture content of wood also seem to have some loosening effect on nailed joints.

New methods of storing crops have presented many problems in the design of structures. One of these problems is that of increasing the holding power of nailed joints. Wooley (15) writes that McNeal, a graduate student at the University of Missouri, made up and tested 200 nailed joints using different varieties of wood and different sizes of common nails. The results of these tests prompted the establishment of some rather definite rules for clinching nailed joints.

"Nails should be bent in the direction of the force on the piece on which they are being clinched. If a joint is to be subjected to alternate tension and compression, the nails should be clinched at right angles to the direction of pull, or across the grain in most cases. Slightly better results were obtained when the nails were clinched away from the end of the stock. (15)

The Forest Products Laboratory at Madison, Wisconsin has made many tests on the holding power of nails. These tests have enabled them to establish some rather definite values for the withdrawal resistance and lateral resistance of nails.

"Tests made at the Forest Products Laboratory indicate that the load required to withdraw common wire nails soon after driving into the side grain of seasoned wood is
\[ P = 6900 \, G \, D^{1/2} \]

in which \( P \) represents the ultimate load per lineal inch of penetration, \( G \), the specific gravity based on oven-dry weight and volume when oven dry; and \( D \), the diameter of the nail in inches.

"If a factor of safety of 6 is applied to this equation, the safe load \( (P_1) \) becomes

\[ P_1 = 1150 \, G^2 \, D \]

"The relationships expressed in these equations are general, and certain species are known to give somewhat higher values whereas others fall below the equation values." (10)

"The Forest Products Laboratory recommends the following equation for expressing the safe lateral load for wire nails:

\[ P = K \, D^{3/2} \]

in which \( P \) represents the lateral load in pounds per nail; \( K \), a constant (varying for various groups of species); and \( D \), diameter of nail in inches." (10)

**Bolts.** Bolts overcome some of the disadvantages of nails but they necessitate bored holes, and are more expensive and in addition require so much labor for installation that they haven't been used extensively.

**Modern timber connectors.** Modern timber connectors have recently been introduced from Europe and are finding many applications in farm structures. Although this type of connection retains the disadvantages of the bolted joint, the area of
contact in a shear joint is materially increased, and test information facilitates accurate joint design.

Glue. In recent years the use of glue in farm buildings has been increasing. The early attempts to use glue were handicapped by the high pressures that were required to secure a successful joint and by the difficulty with which the glue was mixed and applied. However, glues are now available which have overcome some of these handicaps.

"Casein glues are low in cost and, being mixed with cold water, are easily applied. Some now available are self bonding and require little pressure for a successful joint." (3)

In the construction of laminated Gothic rafters, glue has found extensive use and has been proven eminently successful.

"If Gothic rafters are nailed also, or perhaps fastened with a few bolts, the use of glue cannot be questioned, because even if serious deterioration of the glue line occurred, it would be amply strong to carry the small amount of horizontal shear placed upon it." (3)

Although the value of glue as a wood fastening has been proven, its possibilities have not been generally known. It seems fairly certain that we shall see a growing use of glue as a fastening in farm buildings as its possibilities become better known and rural carpenters learn to use it.

Value of Farm buildings.

According to a preliminary news release of the sixteenth
census (11), farm buildings in the United States represent an investment of nearly 10.5 billion dollars. Iowa, which ranks first among the states in total investment, has a farm buildings value of slightly less than 800 million dollars, and, at the annual charge of 6 per cent, an annual outlay of approximately 47.6 million dollars.

On a great many Iowa farms and other farms in the corn belt the grain storage building ranks next to the dwelling and barn in value. Although it is difficult to arrive at a single figure for the value and annual cost of the grain storage building, it can readily be seen that it represents enough investment to command attention. In the past, the individual farmer has not had the services of competent engineers and the buildings have had to suffer.

Joint tests.

Martin (7) made tests on seven different types of sill joints. Three of the joints were the conventional toenailed joints and the remaining four contained wedge strips. These wedge strips were triangular in shape and were made by ripping an S4S 2" x 2" in half on a diagonal. Glue was used in some of the joints and in others it was omitted. The results of these tests justified, among others, the following statements:

"The use of a small quantity of glue increases the strength of the joint many times."
"The use of triangular bearing members (kick plates) increases the strength of the joint over that of the ordinary method of fastening.

"Six 16d nails did not add materially to the strength of the joint over that provided by four 16d nails." (7)

Rice (9) made a series of joint tests, the purpose of which was to determine the comparative strengths of a spliced, glued, nailed joint and a straight unspliced member of the same size and grade. No. 2 common Douglas Fir was used for the main members and No. 1 common white pine was used for splice plates. Rice concluded that, "The results of these tests indicate that joints with angles from 118° to 159° constructed similar to the ones tested approach the strength of a straight, unspliced member of equivalent size and grade."

Although these tests did not deal directly with the corn storage building, they may find application in improvement in the utilization of lumber in grain storage structures.
INVESTIGATION

Analysis of Problem

Requirements for service.

To design any building properly, the service that is expected from the building and the requirements that must be met for the building to be of this service must be determined. Determination of the requirements of a building for the farm storage of grain involves many factors because of the wide variety of conditions encountered. However, due to the special functions of the corn storage building, there are certain requirements that it must meet. These requirements may be divided into four groups, as follows:

(1) Functional soundness
(2) Structural soundness
(3) Simplicity
(4) Economical and aesthetical soundness.

Functional soundness. The basic functions of a crib are:

(1) To provide protection for the corn while it is in storage.
(2) To permit conditioning of the corn for subsequent storage.

In some localities and during some seasons, corn cannot be left in the field until it has dried out sufficiently for safe
storage. To avoid spoilage the excess moisture must be removed as soon as possible after the corn has been stored. Removal of moisture depends on the air movement through the corn and therefore, it is essential to have maximum ventilation to permit drying at every opportunity when the weather is favorable. Barre (1) states, "In colder areas of the corn belt, most of the drying takes place in the spring months. Some drying will take place in the fall if the weather is warm and otherwise favorable. Very little drying will take place, if any, during the winter months. In fact the corn will take up moisture during these months if the fall is drier than usual."

The most important dimension of a crib in promoting ventilation is its width. Certain maximum widths for cribs are recommended for different localities. To permit the passage of air through the side walls of the crib, openings must be provided. This is generally accomplished by spacing the siding boards apart, leaving an open space between the boards. Light sheds built against the side of a crib and adjacent building interfere with air circulation and decrease the rate of drying. Placing the building broadside to the prevailing winds and leaving the doors open speeds up drying.

Although it is desirable to expose the corn to the prevailing wind as much as possible, protection against the weather and vermin must be maintained. Temporary cribs such as those shown
Figure 10  Temporary corn storage
in Figure 10 offer storage of a very low initial cost but the corn is exposed to the weather and has practically no protection against rats and mice. This exposure to the weather and rodents undoubtedly causes much damage to the stored corn and a loss in sale or feeding value. This type of structure may prove to be a very expensive investment. To be of the most service, a permanent corn storage building must furnish protection against loss or damage to its contents.

The builder of a permanent corn storage structure usually has a fairly definite amount of corn to be stored and consequently the crib should have storage capacities to accommodate his needs. Whether the corn is grown for sale or for consumption on the farm has a bearing on the size. Kelley (5) states, "Permanent cribs with a capacity about 5 percent greater than the average crop are usually more than sufficient to take care of the corn."

In some cases, the combined crib and granary has furnished more grain storage than necessary and an insufficient amount of ear corn storage space. It is common practice to provide 2.5 cubic feet of storage space for each bushel of cleanly husked ear corn and 1.25 cubic feet for each bushel of small grain or shelled corn to be stored.

To be of the greatest service to the owner, the grain storage structure should be free of low and inconvenient
structural members and adapted to the use of modern elevating equipment. Braces and other structural members that are low hanging are obstructing to the convenient use of the space in the crib and cause an increase in the labor used in the loading and unloading of the building. Most cribs with a capacity of 1,000 bushels or more should be adapted to the use of elevators that will handle ear or shelled corn and small grain. Two types of elevators are in general use. The portable elevator fills the crib through the roof, elevating the grain by drags or scraping bars on an endless chain. Stationary elevators require space and clearance inside the building and may be equipped with receiving hoppers like those used on portable elevators or may have a pit and a dump log. The type of elevating machinery to be installed should be selected before the crib is built and space should be provided according to manufacturer's specifications.

**Structural soundness.** Structural soundness is possibly the most important factor to be considered in the design of a corn storage building that will give satisfactory service for a period of years. The corn crib is subjected to many complex loadings resulting in some very complex stresses. Due to the necessary complex arrangement of the structural members, it becomes difficult to design for these loads and pressures. Field observations and experience have shown that unless cribs are designed to withstand these rather large loads and pressures with a reasonable degree of safety,
failures are sure to occur, with the result that the life of the building as well as the period of usefulness is considerably impaired. To obtain structural soundness the various members of the structure must have strength to resist the loads that are placed on them. These members must then be effectively joined together. No matter how large and strong the structural members may be, the joints, in a good many cases, determine the effectiveness of the member. Although wind pressures are secondary to the pressures and loads exerted on the crib by the cribbed corn, they should be considered and rigidity enough to resist average winds should be provided in the structure. When the cribs and grain bins are loaded, the unyielding mass of corn offers sufficient resistance to wind pressures. Also in the interest of long time service, the building should be built of a durable material.

Simplicity. No matter how well a crib meets its structural requirements, if it is not simple enough to be within the knowledge and experience of the prospective builder, the design is of very little value to him and consequently will not be of service. First, the design must be of simple unit construction. This not only helps the prospective builder by contributing to easier construction but makes repairs and replacements easier to make and possibly less expensive than in the more complex building. Many of the lumber manufacturers
are now cutting lumber to exact lengths. The ends of this lumber are squared so that full bearing may be secured and no further cutting is necessary. Lumber is manufactured in many different sizes but not always can all these sizes be found in the local lumber yard. However, there are certain sizes of lumber that are found in most all lumber yards, and these sizes are usually priced lower than sizes that are not carried in stock and would have to be secured on special order.

By designing the building so that these sizes and lengths of lumber may be used, a contribution is made to the general simplicity and to the simplicity of construction of the structure. Reduced labor costs and reduced waste lumber are also benefits realized from this practice.

Another requirement for simplicity is that the design makes use of connections that are easily made and do not require the use of special tools. Ordinarily the rural builder does not have access to the special tools that are required to make some joints. This causes him to resort to make-shift means of fabricating the joint and the result is a weak joint. However, there are certain types of joints that do not require special tools and are simple and easy to make. The challenge is to make use of this type joint in design.

For a well designed building to be of value to the prospective builder, it must be presented in simple, complete, easy to read plans that are easily understood so that erection will be carried out as it was intended by the designer. No
matter how well the building may be designed, if it is not properly presented, the purpose of the design may be lost in the confused plans. Too many times the structure is only presented in a general way leaving the details for the builder to work out for himself. In some buildings where only small loads are encountered, this practice works all right, but not so in the corn storage building. To keep within the limits of economical design the members of the corn storage building must be loaded more than in most buildings. This necessitates very close design and if the builder, who possibly does not realize the magnitude of the loads on the building, is left too much on his own for the erection his economical mind will cause him to put less lumber in than is necessary. But with a properly designed building, presented so that erection can be done only one way, there is little chance for the incorporation of different ideas than those in the mind of the designer.

Economical and aesthetical soundness. Harmonious appearance of the grain storage building and the lowest possible lifetime cost consistent with the attainment of the requirements already stated should be embodied in the design of the building. The progressive farmer is interested in the upbuilding of the looks of his farmstead and to do this he must secure a harmonious appearance of the buildings which make up the farmstead. To meet this requirement the corn storage building must blend pleasingly with the appearance of the buildings which are around
For economy the building must have a low initial cost and minimum maintenance cost. There is, however, a certain limit below which the initial cost no longer contributes to economy but increases the maintenance cost so that the lifetime cost of the building is increased. In attaining low-cost construction, it becomes necessary to stress the materials used in construction closer to their ultimate strength than is the practice in building or bridge construction. The working stresses that are generally used are for long continued load and are considered safe under circumstances such that failure would cause personal injury or large property damage. When these values are used, no failure would be expected from loads 50 per cent in excess of those computed and decrease in the strength of the timber to two-thirds its original value. Due to the type of construction and the manner of loading the grain storage building, it seems entirely justifiable to stress the lumber nearer to its ultimate strength.
Types of storage buildings.

**Single crib.** Early corn cribs were of the single crib type with a shed roof. The height of these cribs was limited to the height to which corn could be lifted with a scoop. Large capacity was obtained by building long cribs or a number of short ones. This type crib is still used in places but due to its extremely narrow width it is hard to erect so that it will resist the wind pressures.

**Double crib.** Later in the development of storage structures two shed roofed cribs were joined together, separated by a driveway through the center of the structure. This driveway furnished shelter for the loading and unloading of the crib and could be used for the storage of light machinery and vehicles.

**Commercial buildings.** Several all-steel prefabricated cribs for the storage of ear corn are now on the market. Just how practicable these cribs are for the long time storage of corn is not definitely known. Several of these cribs are now under observation at the Agricultural Engineering research farm.

**Temporary storage.** The demand for increased storage space by the "Ever-Normal Granary" program has caused corn to be stored in many different types of temporary structures. Temporary structures built from snow fence and from slats are quite often seen. On an inspection trip north of Nevada, Iowa, several buildings, prefabricated for other purposes were found filled with shelled corn. Among these buildings being used for the storage
of shelled corn were small brooder houses, hog houses, and one building that had been built for a small cattle barn.

**Combined crib and granary.** Introduction of the farm elevator led to the development of high cribs with the storage of small grain over the driveway. The combined crib and granary with storage space for grain over the driveway is a typical corn belt structure and it offers several advantages which make it attractive to the farm operator. Besides retaining the sheltering feature of the double crib, spouts from the overhead bins facilitate the removal of the major portion of the grain by gravity. Corn can be shelled and elevated directly into the bins or the grain may be aerated by moving it from one bin to another. However, as this type of structure has been built, a number of problems have been overlooked and not adequately solved.

**Cribs for the storage of only ear corn.** The increased demand for ear corn storage space has caused farm operators to store corn in the driveway of the combined crib and granary. This practice causes inadequate ventilation for the corn in the side cribs as well as that in the driveway. Some farm operators have very little need for small grain or shelled corn storage space in the same building with ear corn storage. This situation has been coped with in several different ways. In some instances two cribs have been built under the same roof
separated only be a ventilating space. Other buildings for this same purpose have been wide cribs with a triangular shaped ventilator through the lower portion of the crib. In a building of the same general shape and size of the combined crib and granary, three crib sections, side by side, with ventilating spaces between can be used instead of the driveway and overhead bins.
Method of Procedure

From the foregoing discussion, it is evident that the corn storage problem may be attacked from one of many sides. It is very definitely a structural problem and the principal part of this work is devoted to that, not losing sight of the other factors that must be considered. In attempting to find a solution to the problem, there appear to be two rather general alternatives, namely:

To improve the present design,

To study other designs.

For the combined crib and granary the first of these alternatives was followed. The general method and order of procedure was as follows:

1. Studying of corn crib plans that are now presented to the builder.
2. Inspecting cribs erected according to these plans.
3. Working details out for improved design.
4. Drawing plans.

The first step, the study of plans, was to determine in what ways and for what reasons some of these plans had not proven entirely satisfactory. Such plans as Mid-West plan No. 73221 and 73222 were studied and discussed and found to be lacking in several respects. All too often the details of
construction are left entirely to the builder.

Secondly, the crib inspection was for the observation of failures and unsatisfactory service that buildings erected according to these plans had been giving. Unsatisfactory service was observed in many cases and in some cases failures had occurred.

The next step, then, was to work out the details of an improved design. The scale model was found to be very useful in this part of the study. By the use of this method the arrangement of materials and the joints of the structure were worked out, maintaining as much as possible of the desirable features of the plans now in use.

In drawing the plans of the building, an attempt was made to show as much in as simple a way as possible. The isometric and oblique drawings were found very useful in showing the details of construction.

Results

Combined crib and granary.

General design. From the foregoing discussion of the combined crib and granary, it can be seen that it is a building of great importance to the mid-western farmer. Although this type of building has in some cases given unsatisfactory service, this has not been due to the type of building but rather to poor engineering practices. In this study the building has been broken down into its integral parts and studied, then reassembled
to make the best use of the properties of wood. In studying the various available plans and observing erected structures, there was a noticeable variation in roof types used. Two principal factors govern the type of roof that should be used. They are, (1) the type of roof used on surrounding buildings, and (2) the volume required for a given floor area.

The so-called Gothic type roof has become increasingly popular in recent years. Many new barns have been erected using the bent laminated rafter. Also in smaller farm buildings, this type roof has been used. On March 1, 1941, observations were made on several cribs that had been built by the same contractor. The Gothic type roof was used on practically all these building and the builder stated that he had very little call for any other type roof on corn storage buildings as well as on barns and the smaller farm buildings such as hog houses, brooder houses, etc. This type roof lends itself very desirably to the use of standard sizes and lengths of lumber. By using the Gothic type roof in the corn storage building, the outside walls may be reduced to a minimum height. Since the studs in the side walls of the crib act much as a beam, it becomes desirable to reduce this span as much as possible. A pleasing unit construction and a pleasing appearance is presented by this roof type. The final selection of roof type has been left to the prospective builder, but due to its many advantages, the Gothic type roof has been used in this study.
In the past the gable type roof has been the most popular in farm buildings. Its popularity can be explained by its simple design and the ease with which it can be erected. Although it is simple and the method of its construction is widely known, it possesses some definite disadvantages. The most outstanding is the required purlin supports. These supports cause the storage space not to be clear and consequently the most efficient use of space is not realized. Crawford (3) showed that the largest reactions in the gabled sections fall on the sill joint of the studding. This joint, when at its best, is a very difficult joint to make hold and the use of the gabled roof does not reduce the load on this joint. A large part of the load on the roof tends to thrust outward at the plate and ties are necessary to prevent sagging or bulging. In a number of cases, the rafters are excessive in length and do not lend themselves well to the use of standard lengths of lumber. Due to the extra length, the price of this lumber is higher and the initial cost of the building is increased.

The gambrel roof is a very popular type and is practical for all average conditions. In comparison with the gable roof, the gambrel shows a greater storage capacity. No internal supports are required but the rafter must be braced. This gives a space that is somewhat more clear but still has some obstructions. This type roof offers considerable resistance to wind, dead and live loads, and when properly constructed, has no tendency to sag.
The shed type roof has found many uses on smaller corn cribs; for the larger combined crib and granary it is considered unsatisfactory.

Figure 11 shows how the proposed design may be adopted to any one of the three major roof types that are in use.

The same general arrangement of the building that has been used in the past has been maintained. This arrangement of two cribs on either side of a central driveway, with bins for the storage of small grain or shelled corn over the driveway has several advantages. One particular feature is the covered driveway with inside elevator sheltering both the operator and the crop while unloading. Spouts from the overhead bins make possible the removal of most of the grain without hand shoveling. Corn can be shelled and elevated directly into the bins or grain moved from one bin to another to aerate and cool it. Although it is not recommended that the driveway be used for a machinery shed, it does offer temporary storage space when not in use.

From the study of crib plans and observation of cribs in use, it was found that a great number of the buildings had more small grain storage than was needed and an insufficient amount of ear corn storage. In other words, the ratio of small grain to ear corn storage space did not suit the ratios of small grain and ear corn to be stored. To get a ratio of storage areas that would more nearly suit the amounts and ratios of grain to be stored, the side walls of the grain bins were
Figure 11. Major roof types used on combined crib and granary.
pulled in at the top to a width of 24 inches. The proposed design has storage capacities as follows: 59.0 bushels of small grain or shelled corn per foot length of crib and 146.5 bushels of ear corn per foot length of crib. According to these figures, the approximate capacity of a 32 foot crib erected according to this design would be 1900 bushels of small grain and 4700 bushels of ear corn or a ratio of about 1 to 2.5. It is believed that this ratio more nearly suits the ratios of small grains and ear corn that are to be stored.

Certain recommendations have been made for crib widths for different sections of the corn belt. Eight feet has been recommended for the central corn belt and it has been used quite extensively. Due to the fact that this width has been used and found satisfactory, it has been maintained in the proposed design.

Several cribs observed showed sagging of the grain bin floors. The cribs on which this had occurred generally had a driveway width of 13 feet or more and the joists were not strong enough to carry the load on that long span. The proposed design makes use of an eleven foot driveway. This width gives sufficient clearance for implements and vehicles that must pass through the driveway and also permits the use of 12 foot grain bin floor joists to span the driveway.

A clearance of approximately 12 feet vertical is required in the driveway to facilitate dumping. This has been secured by making the foundation wall extend 18 inches above the ground
and using studding 10 feet long. Added to this height is the thickness of four, two inch pieces of lumber which make up the sill and plate. This gives a clearance of 12 feet and 1/2 inch between the driveway floor and the lower side of the grain bin floor joists.

The ridge height of the building is limited to approximately 30 feet. Heights that exceed this usually cause excessive loss of corn from shattering when the crib is filled. Also the angle at which an outside elevator will operate is limited and the corn will roll back down if this angle is too great. For various reasons the inside elevator may not be provided at the time of construction and in some cases not at all, thus making it necessary to consider this limiting factor of design. In the proposed design the ridge height has been limited to a few inches less than 30 feet.

In some of the cribs observed, the outside walls had been made two feet higher than the walls of the driveway and difficulty was encountered in tying and bracing. Also when this is done and the Gothic type roof used, it becomes difficult to maintain the ridge height below its maximum and still maintain the desirable strength features of this roof. Consequently, 10 foot studding has been used in the outside walls, the same as is used in the driveway walls.

As previously mentioned, the side walls of the grain bin have been pulled in at the top to a width of 24 inches.
With a 12 foot depth of bin and a 13 to 4 1/2 slope on the side walls of the bin, the studding can be cut from lumber 14 feet long with very little waste. This arrangement not only contributes to a more desirable ratio of stored grains as has been explained but also has its structural advantages and facilitates a more complete use of the space within the building. The wall, which slopes at approximately 20° with the vertical, approaches the angle of repose of the grain and the pressure perpendicular to the wall studding is reduced. Width at the top of the bin proves sufficient to serve as a cat-walk and there is just enough clearance above the bins for an average man to walk. It is almost impossible to do away with waste space completely in the building, but in this case it has been reduced to a minimum.

**Structural members.** To arrive at a final design of the building, it became necessary to analyze several members of the building. First, the loads to be placed on the members must be found and the members then designed to carry the load. In Janssen's (6) solution of grain pressures, the side walls of grain bins are allowed to carry part of the vertical load by friction. However, in the calculation of the load on the floor joists of the grain bin, the side walls were assumed to carry no vertical load due to their slope. The entire weight of the grain in the bin was considered as an evenly distributed load over an eleven foot span. Figure 12 shows the loading.
shear and moment diagrams for the grain bin floor joists. To carry this load, 2" x 12", S4S members, 12 feet long placed 12 inches on center were selected.

The horizontal loads on the walls of the grain bin were calculated directly according to Janssen's solution, using wheat at 50 pounds per cubic foot. Due to the arrangement of the side wall of the grain bin and the function as a ventilator that is to be expected of it, a 2" x 6" was insufficient to carry the load on the total span. A fiber stress of 3870 lbs. per square inch was produced.

Figure 13 shows the horizontal loads exerted on the side walls of the grain bin and the resulting shear and moment values. The total span was fixed by the dimensions of the bin so there remained two alternatives for the solution. The size of the stud could be increased or the span could be broken and a restraining member placed at an effective point between the extremities of the stud. It was not desirable to increase the size of the member since that would cause more waste space in the building, so the second alternative was resorted to. A 2" x 8" cross tie was placed across the bin between each pair of studs, at the point of maximum moment caused by the load. This tie was extended over to and joined to the rafter to give increased unity to the building. This arrangement of members was placed on two-foot centers thus joining to alternate floor joists.
Space Diagram

Note: Loads are given in pounds per lineal foot. Shear values are given in pounds. Moment

Shear Diagram

Moment Diagram

Figure 12 Grain bin floor load, shear and moment values
Grain Bin Studs

Note: Loads are given in pounds per lined foot. Shear values are given in pounds. Moment values are given in foot pounds.

Figure 13  Grain bin side wall load shear and moment values
The pressures on the side walls of the crib were calculated from the results of the work of McCalmont and Ashby (8). The crib was considered filled with ear corn to a depth of 24 feet and the outward pressures resulting were taken from the results of experiments run on an 8 foot crib. These experiments are discussed previously in this thesis and space will not be taken here to repeat this. Figure 14 shows the outward pressures produced by the ear corn and Figures 15 and 16 show the resulting shear values and bending moment values produced on the side walls of the crib. For the studding in the outside walls and end walls 2" x 6" studding 10 feet long were placed 2 feet on center. The spacing of studding in the driveway walls was reduced to 12 inches so that each grain bin floor joist could rest directly over a stud. At all corners and partitions, double studding was used.

The Gothic arch type roof was used in this study making use of a constant depth bent laminated rafter. A radius of curvature of 24 feet with the center taken 2 feet 6 inches below the plate line was used. This arrangement gives a very pleasing appearance and when used with a 10 foot height of studding stays within the 30 foot limit for ridge height. Five \( \frac{25}{32} \) x 2 5/8" laminae bent to the proper curvature and glued with casein glue make up the rafters. On several of the cribs that were observed during this study, this size rafters had been used and were giving satisfactory service. The rafters are joined at the ridge with a 2" x 6" ridge board and
Ear Corn Pressures Exerted on Side of Crib

Space Diagram

Note: Loads are given in pounds per lineal foot.

Figure 14 Outward pressure exerted by ear corn
Shear Diagram for Crib Sidewall

Note: Shear values are given in pounds.

Figure 15 Shear produced by outward ear corn pressures
Moment Diagram for Crib Sidewall

Hinge

216

264

96

290

483

676

868

1062

1255

1431

1582

1698

1772

M_{\text{max.}} = 1800

1798

1771

1684

1534

1317

1027

661

1203

1332

1364

M_{\text{max.}} = 1370

1299

1134

870

541

Note: Moment values are given in foot pounds.

Figure 16  Bending moment caused by outward ear corn pressures
cross-tied with a collar beam of a 1" x 6" board nailed to each side of the rafter. These rafters are placed on 2 foot centers thus matching each pair of studs in the outside crib walls.

Details of construction. To work out the details of construction, it was decided to build a model of the proposed structure. A scale of 1 1/2 inches equal to 1 foot was selected. Built to this scale, the building is small enough and light enough that it can be easily moved and due to its light weight, the model will be less likely to tear apart than one built to a larger scale. Although the primary purpose of this model was to work out construction details, it may later be used for exhibition purposes or as an aid in instruction. Lumber of American Standard S4S sizes was cut to scale from white pine. White pine was selected because of its light weight and the ease with which it can be worked. Cold water casein glue was used as the fastening where possible. Except for putting on the siding and sheathing, nails were only used to hold the joints until the glue had time to set. The completed model, shown in Figure 17, was found very useful in working out the construction details.

Most of the cribs observed and the plans studied lacked strength in the end of the grain bin to resist the outward pressure of the grain. To overcome this weakness, a plate was placed across the driveway so that it would act as a beam
resisting the outward pressures. To assist this beam, a 2" x 12" member was let into the face of the end studding so that the flooring of the grain bin could be brought out and nailed to it, thus helping the plate to resist the loads. Figure 18 shows the loads transmitted to the lower edge of the grain bin by the end studding and the shear and moment values caused by these loads. To further strengthen this end construction, a 2" x 6" member was let into the face of the studs on either side of the grain bin in the same plane as the grain bin side wall studding. The siding of the grain bin was then extended out and nailed to these members, which also act as a brace for the end of the crib. Since the 2" x 6" members that were being used in the end of the grain bin were not of sufficient strength to carry the total load on the end of the bin, it became necessary to break the span of these members into two shorter spans. A double plate was placed six feet above the driveway, approximately at the point where the maximum bending moment produced by the loads occurred. Although the plate was not placed at the exact point of maximum bending moment, it was very near and this placing facilitated the use of standard length lumber. Figure 19 shows the loads transmitted to this place by the studding in the end of the grain bin and the shear and bending moment produced by these loads. This same plate arrangement was used in the grain bin partition walls. By joining this plate and the partition wall studding to the side wall studding and floor joist of the grain bin, the partition wall was tied in very effectively to the side walls of the bin.
Figure 17  Front and side views of laboratory model.
Plate Over Doorway

Space Diagram

Note: Loads are given in pounds. Shear values are given in pounds. Moment values are given in foot pounds.

Shear Diagram

Moment Diagram

Figure 18 Load, shear, and moment values for plate at lower edge of grain bin end wall.
To secure additional bracing and continuity across the center of the building, a center partition wall has been provided. The farming of this wall is essentially the same as that used on the end walls. The wall extends the entire height of the crib and consists of 1" x 6" siding laid diagonally on 2" x 6" studding placed 2 feet on centers. Not only does this wall serve as a very effective brace and tie from the top to the bottom of the crib, but also offers possibilities for the division of the stored corn between the landlord and tenant. Although the exact bracing value of the partition was not determined, it is hardly questionable that it makes a definite contribution to lateral stability and it is believed that a more than usually substantial cross brace placed on 8 foot centers will furnish adequate lateral stability in the building. However, due to the lack of test information on this arrangement, the conventional cross brace and tie made up of three 1" x 12" members has been maintained.

The sill joint of the crib wall studding is known to be a very critical joint and in many cases, failure has occurred at this joint. To increase the strength of this joint by providing more bearing surface for the stud, a 2" x 2" kick plate has been glued and nailed to the outer edge of the top side of the sill and the studding knotted out to fit over this. A similar arrangement has been used at the rafter to plate joint. The 2" x 2" kick plate is glued and nailed to the outer edge of the wall plate and the rafters are set behind it. By nailing through the kick plate into the rafter and also toe-nailing the
Figure 19 Load, shear, and moment values for partition wall plate

Note: Loads are given in pounds. Shear values are given in pounds. Moment values are given in foot pounds.
rafter to the plate, the angle iron connection that has been previously used is eliminated.

Beveled crib siding has been laid horizontally on the outside walls of the crib. These 6" siding boards have been placed 7" on centers to allow for the movement of air through the walls. 1" x 6" siding placed 7" on centers has been laid diagonally on the inside walls of the crib. This diagonal placement of the siding gives considerable bracing to the crib and the disadvantage of replacing decayed ends of the siding is not encountered here since it is protected from the weather. The inside walls of the grain bin are of tongue and groove material laid horizontally, and on the outside of the studding is laid diagonally 1" x 6" siding 7" on centers. Also on the inside of the rafters 1" x 6" siding is laid horizontally and 7" on centers. This arrangement provides a ventilation space on either side of the corn from the plate line to the top of the corn column. The diagonal siding on the grain bin also provides additional bracing.

**Plans.** The laboratory model was found to be very helpful in drawing up the final set of plans for the proposed structure. Figures 20, 21, 22, and 23 show the completed plans as they are to be presented to the prospective builder. An attempt has been made to keep these plans as simple and as easily interpreted as possible and yet present the building in a clear and concise manner.
Tripod crib.

For one reason or another, a farm operator may have need for a building for the storage of only ear corn. Some time and study have been devoted to the development of a building to serve this purpose. Figure 24 shows a cross section view of the building and it is readily seen from this that it is merely a modification of the combined crib and granary. The principal changes are:

(1) The grain bins have been removed

(2) A third crib installed in the place formerly occupied by the grain bins and driveway.
Figure 22 Framing elevation and details of corn storage building
Figure 24 Section of triple crib
Ventilation spaces 2 feet wide are provided on either side of the center 7-foot crib and the lower portion of these ventilation spaces are made to serve as shelling trenches. The building will necessarily have to be filled with an outside elevator and the corn removed through doors in the side of the cribs and the shelling trenches.
At the beginning of this study the objective set forth was to increase the serviceability of grain storage buildings, through the proper utilization of the properties of wood by:

1. Combining and correlating the work of previous investigators,
2. Correcting the weaknesses of the conventional designs now in use,
3. Developing a set of plans that are of value to the rural builder.

After a study of the work of previous investigators on this project and the work of several other investigators, a study was made of the building plans for corn storage structures that are now presented to the prospective builder. These plans were found deficient in several respects.

Inspection trips for the observation of corn storage structures that had been erected according to the available plans were made. Buildings of several different types were found being used for the storage of corn. Weaknesses were observed in many of the combined crib and granary buildings and in some cases, failures had occurred.
The service that is to be expected from a building and the requirements necessary to realize this service must be determined before the building can be properly designed. These requirements were determined for the grain storage building and divided into four groups, as follows:

(1) Functional soundness
(2) Structural soundness
(3) Simplicity
(4) Economical and aesthetical soundness

Janssen's solution of grain pressures was used in the calculation of the pressures exerted on the side walls of the grain bin.

The total weight of the grain to be stored in the grain bin was considered as a uniformly distributed load on the floor joists and the floor designed on this basis.

The results of an experiment run by the United States Department of Agriculture were used for the calculation of the ear corn pressures exerted on the side walls of the crib.

All calculated forces, loads, and the shears and bending moments produced were shown in diagrams.

The results of the investigation were incorporated into a crib design.

The Gothic type roof with the bent, glued, laminated rafter was used in this study.

A laboratory model of the proposed design was built and
found very useful in working out the details of construction.

Simple, easy to read plans of the proposed design were prepared making use of isometric and oblique drawings for showing the construction details.

The contact with the problem and with the builders and users of corn storage structures has enabled the writer to realize and appreciate some of the problems confronting the mid-western corn grower.

Unfortunately the experimental work that was originally planned had to be given up. The writer feels that tests should be run on scale model sections of the combined crib and granary to determine the exact bracing effect of the center partition wall that has been added and the amount of the conventional cross-bracing and tieing that can be replaced by this wall. Also the possibility of using fixed joints and rigid frame construction should be investigated.

The further development of a triple crib seems to offer an excellent opportunity for future study. This particular type structure was not given enough study to make any detailed recommendations for its construction, but it is believed that it will find a definite place in the storage of corn.
CONCLUSIONS

1. In general, the combined crib and granary building plans that have previously been available to the prospective builder have not shown the details of construction sufficiently.

2. The end walls of the grain bin in a combined crib and granary have in the past been points of weakness and the resistance they offer to the outward pressure of the grain may be increased by properly tying the siding of the grain bin side-walls and the grain bin flooring to the end walls.

3. The sloping side-wall arrangement of grain bins may be used in a combined crib and granary with either the gable, gambrel or Gothic roof type.

4. A grain bin 12 feet deep having side walls with a slope of 13 to 4 1/2 is desirable for use in a combined crib and granary having an eleven foot driveway.

5. A double plate placed in the end and partition walls of the grain bin, at or near the point of maximum moment caused by the loads, increases their strength to resist the lateral grain loads.

6. When the Gothic type roof is used on the combined crib and granary, a 2" x 2" kick plate glued and nailed to the outer edge of the top outside wall plate will furnish horizontal support to the lower end of rafters against the outward pressure of the ear corn.
7. A 2" x 2" kick plate glued and nailed to the outer edge of the wall sill will furnish horizontal support to the lower end of the wall studding against the outward pressure of the ear corn.

8. A partition wall of 1" x 6" siding laid diagonally on 2" x 6" studding through the center of the combined crib and granary provides lateral bracing to the center of the structure an an effective means for the division of the contents of the building.

9. By properly arranging the siding of the grain bin, the grain bin walls may be made to serve as ventilators from the top of the driveway to the top of the stored corn.

10. A triple crib, for the storage of only ear corn, can be designed so that it will make use of the same arrangement of most of the main members that has been used in the proposed crib and granary design.
LITERATURE CITED


11. U. S. Census, 16th, 1940 Federal census announces farms, acreage, and values. Agriculture; U. S. Summary; Preliminary news release, February 5, 1941.


ACKNOWLEDGEMENTS

The author desires to express his gratitude to all
the members of the Agricultural Engineering Department and
especially to Dr. J. B. Davidson and Professor Henry Giese
whose encouragement, suggestions, and aid have played a large
part in this study.

He desires further to express his appreciation to Mr. Glenn
R. Newton of Nevada, Iowa for his cooperation and assistance
in this study of corn storage structures.

To the Architectural Engineering and Mechanical Engineering
Departments the author is truly thankful for the temporary office
and laboratory space furnished by them.

To the Weyerhauser Sales Company the author is indebted
for their part in making this study possible.
APPENDIX I

The Triple Corn Crib

Observations made during the study of the combined-crib and granary show that there is a definite need for a building for the storage of ear corn only and for one that would more completely utilize the space in the building. On several occasions ear corn was seen stored in the driveway of the combined crib and granary and shelled corn was found stored in other buildings. Some of this, of course, was only a temporary measure, but it did indicate that there was a need for more ear corn storage and that the shelled corn and small grain storage could be taken care of in building separate from the corn crib.

A triple-corn crib, which is essentially an adaptation of the proposed crib and granary design, has been designed. Its purpose is to furnish ear corn storage to the farm operator who, for one reason or another, does not desire to store shelled corn or small grain in the same building with the ear corn and yet desired to get a maximum utilization of the space in the crib. Most of the main structural members are arranged as they are in the proposed corn crib and granary design.
The requirements of a building of this kind may be reviewed briefly here. They are divided into groups as follows: (1) Simplicity, (2) Functional Soundness, (3) Structural soundness, (4) Economical and Aesthetical soundness. The building must be within the range of the builder's knowledge and experience. It must be capable of doing the job that is expected of it. Strength to resist the loads placed on the structure is required and the building present a harmonious appearance. These requirements are covered rather fully in the main body of the thesis.

The triple crib is made up of two eight-foot cribs, placed as they were in the combined crib and granary, and a seven-foot crib separated by a two-foot ventilation space and alley way on either side of the center crib. The center seven-foot crib and the 2 two-foot alley ways occupy the space that is used in the eleven foot driveway and the grain bins of the combined crib and granary. Since there is no driveway provided in the building it becomes necessary to fill the crib through the top with an outside elevator. By using 10 foot studding in the outside walls and a rafter with a radius of curvature of 24 feet with the center of curvature taken 2 feet 6 inches below the plate line the ridge height of the building has been maintained at about 30 feet. If this height is exceeded very much the outside elevator cannot be
used satisfactorily.

In accordance with the recommended crib widths for Iowa the outside cribs have been made 8 feet wide. However, since the center crib is somewhat protected it has been made only 7 feet wide. The floor of the opening on either side of the center crib has been set at the ground line and the crib floors raised 16" above the ground line thus forming two shelling trenches at the third points of the width of the crib. The three cribs may be emptied through these two shelling trenches thus making it unnecessary to provide a shelling trench in the center of each crib. Above the plate line the inside walls of the outer cribs are tilted toward the center at a slope of 13 to 4 1/2. The side walls of the center crib join these walls approximately 18 feet above the floor line. Above this point siding is placed on either side of the studding thus leaving a space for the passage of air through the building. 1" x 6" siding is placed 7" O.C. and diagonally on these sloping walls. The inside walls of the outer cribs, below the plate line, are also sided with diagonal siding laid 7" on centers. 1" x 6" siding placed 7" on centers is laid horizontally on the walls of the center crib and the inside of the rafters. The outside walls are of 1" x 6" horizontal crib siding laid 7" on centers. For wind bracing in the outer walls 1" x 6" boards are let
into the face of the studs.

A center partition wall made up of 1" x 6" siding laid diagonally on 2" x 6" studding has been placed in the center of each crib. This wall furnishes additional lateral bracing and tying, and a division line through the center of the crib. The features of this wall are covered in the main body of the thesis and will not be repeated here. 1" x 12" X - braces with center ties are placed 4' on centers in all the cribs. To increase the resistance to the outward pressure of the corn 2" x 2" kick plates are placed at the lower end of the studding of the side walls and at the lower end of the rafters.

To study the construction of this building, a model to the scale of 1 1/2 inches equal 1 foot was built. Among other things this model provided a means for working out the construction details and gave some idea of how the building will look in actual size. Figure 25 shows an end and a side view of the completed model.

The total capacity of the triple corn crib is approximately 6050 bushels of ear corn making use of 76% of the space in the building. The center crib holds approximately 1874 bushels and each of the outer cribs 2088 bushels. Since in the proposed crib and granary design only 66% of the space in the building was available for the storage of grain a contribution has been made to better utilization of the space in the building. The driveway along occupies about 18% of the space in the crib and granary.
Figures 26, 27, and 28 show the elevations, cross-sections, floor plan and details of construction for the proposed triple corn crib.
Figure 24 - Scale model of Triple Corn Crib
Figure 25 - Plans for Triple Corn Crib I
Figure 26 - Plans for Triple Corn Crib II
Figure 27 - Plans for Triple Corn Crib III