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Design Data For Above-Ground Horizontal Silos

II. Chopped Corn

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This bulletin reports on Missouri
Agricultural Experiment Station
research project 138,
Forage Harvesting

Design Data For Above-Ground Horizontal Silos

II. Chopped Corn

D. B. Brooker and J. S. McKibben

Tests have been conducted at the Missouri Agricultural Experiment Station over a period of five years to determine the loads imposed on the walls of horizontal silos when such silos are filled with various types of silage materials. Research Bulletin 660, Design Data for Above-Ground Horizontal Silos, I. Grass, Legume and Wheat Silage, March 1958, reports results of the first three years of this research. Information was obtained during the last two years concerning the forces developed when chopped corn silage was placed in horizontal silos.

TESTING EQUIPMENT, CONDITIONS, AND PROCEDURE

Design of the Pressure Panel

The tests were conducted in a 60 ft. by 20 ft. horizontal silo. The wall construction was of tilt-up concrete panels supported by concrete pilasters. The wall was six feet in height and sloped outward one inch per foot of side height. In place of one of the center concrete panels a special panel (Figures 1 and 2) was constructed that made it possible to measure the forces exerted against the wall of the silo. Horizontal planks were suspended individually by straps from a rigid pipe above the panel.

Had the planks been without further restraint, the pressure of the silage would have caused them to swing outward, rotating about the upper end of the supporting straps. The planks were restrained from moving in this direction,

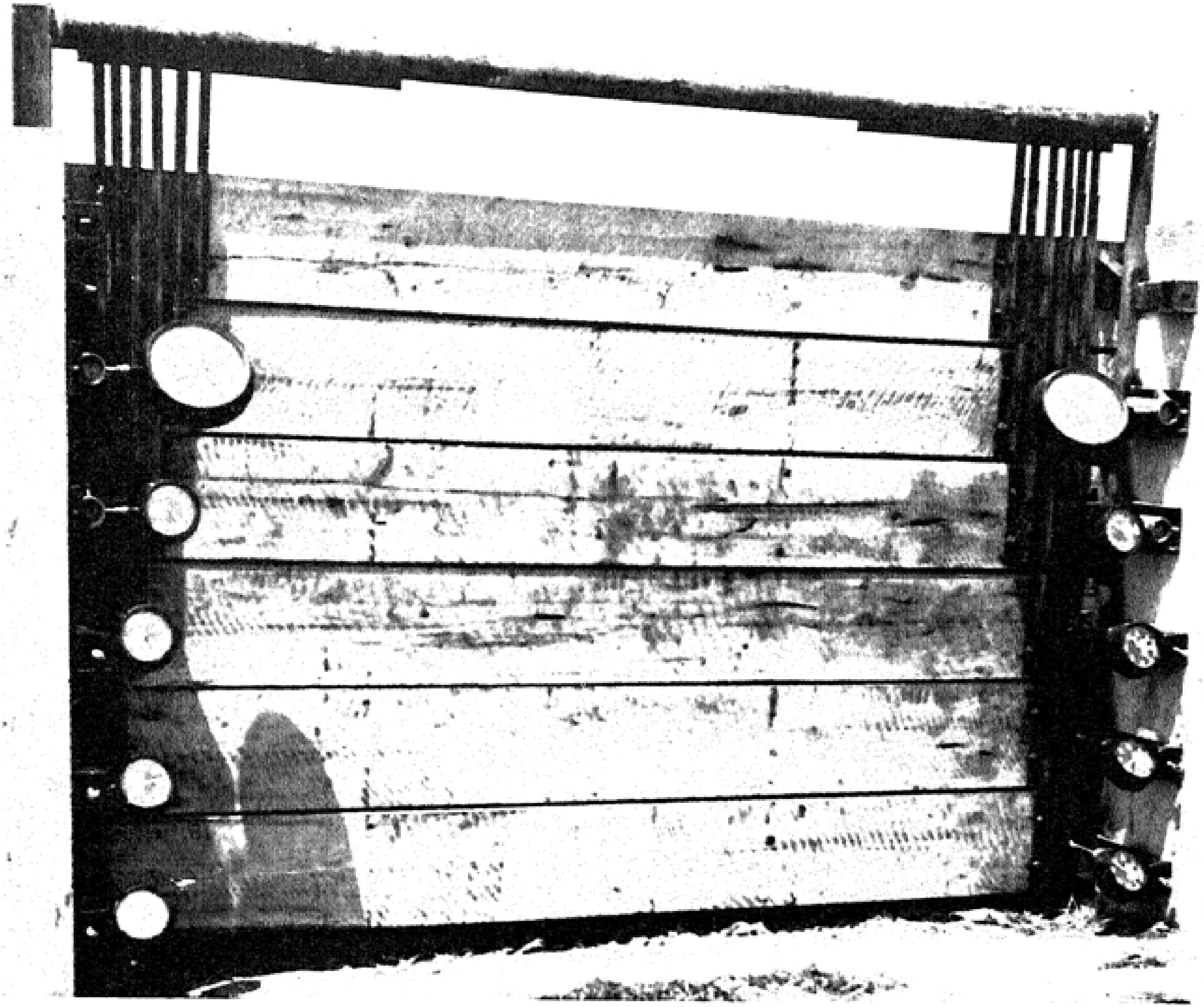

Fig. 1—The special panel used to obtain data concerning the forces against the side of the silo. Each plank pressed against the piston ends of two hydraulic cylinders. Pressures in the cylinders were measured by Bourdon gauges.

Fig. 2—Roll roofing was used to cover the inside surface of the test panel to prevent silage from wedging into spaces around each plank.

however, by the piston end of hydraulic cylinders located at the ends of each plank. Bourdon gauges were used in connection with the hydraulic cylinders to measure the horizontal force of the silage against each plank.

Each plank carried the horizontal force exerted by 10 square feet of the side wall surface of silage. Roll roofing was placed on the inside surface of the panel to help maintain a smooth silage surface against the panel.

Test Conditions

The silo was filled both years with corn, field chopped with a flail type forage harvester equipped with a row crop attachment. The average length of cut of this type of machine is somewhat longer than that usually obtained from cutter-head machines. This statement is based on visual observation. Some lengths of 6 to 7 inches are included. The average length of cut was near enough to that usually placed in a silo, however, to warrant using the pressure data as typical figures.

The corn silage placed in the silo the first of the two test years had an average moisture content of approximately 60 percent. This is a rather low moisture content for corn silage. The second year the average moisture content was approximately 71 percent.

The silage was placed in the silo with self-unloading wagons which spread a relatively thin layer of material as the wagons were pulled through the silo. Packing was accomplished with a row crop tractor.

Testing Procedure

Readings were taken from the gauges on the cylinders for the bottom plank as soon as enough silage was in the silo to give a measurable pressure. Readings were taken from the gauges at each successive plank as the level of the silage reached the plank. All gauges below the level of the silage were read throughout the filling operation.

Two sets of data were obtained. One set included gauge readings during the packing operation. The packing tractor was driven as close to the wall as possible without rubbing the tire against the wall; gauges were read just as the tractor passed by the gauge location. The other set included gauge readings that were taken after the packing tractor completed packing each load of silage and the tractor was driven off the silo. Depth of silage was recorded each time the gauges were read

FINDINGS AND ANALYSIS

Lateral Unit Pressure

One of the criteria needed for design of horizontal silos is the pressure exerted by the silage on a square foot of silo wall surface. The pressure is stated as pounds per square foot and is called lateral unit pressure. The lateral unit pressure is used to design the wall between adjacent vertical supports such as posts or pilasters.

Lateral unit pressures were determined by using gauge readings to calculate the total horizontal force on each plank. Since each plank carried the pressure of 10 square feet of silage, the unit pressure for any particular reading was one-tenth of the total calculated force.

Figure 3 is a plot of lateral unit pressure versus depth of silage as measured at six different depths. The general shapes of the lateral unit pressure curves were essentially the same for the two years when the silo was filled with corn silage and for a previous year when wheat silage was used. Since the silage moisture content was higher the second year corn silage was used, the curves for that year are shown in Figure 3. The pressure at each depth is not correctly shown as lateral unit pressure until the silage covers the entire plank, since calculations for all data include taking one-tenth of the total force on the plank.

In general, the lateral unit pressure is maximum when the silage level is between 1 and 2 feet above the area considered. As the silo is filled above this point the pressure is "relaxed" and becomes constant. The value for this "relaxed" pressure for the corn silage ranges between 90 and 100 pounds per square foot. The same figure for the year when the moisture content was low was approximately 80 pounds per square foot.

The data for the bottom plank indicated that the pressure began to "relax" as the depth of silage increased above 30 inches and then began to increase again when silage depth reached 43 inches. This could have been the result of accumulation of silage juices in the bottom of the silo. However, since the silo was filled in a period of two days, and good drainage was provided, this is unlikely, These data, which are contrary to all other data obtained in the tests, are pictured with the dashed line in Figure 3.

A design figure of 120 pounds per square foot would appear to be appropriate. Since the test silo is six feet in depth it is problematical how much deeper the silo would have to be before this figure would need to be increased. Researchers at South Dakota report that the "relaxation" is evident when grass silage is placed in a silo eight feet deep.[1]

The figure of 120 pounds per square foot does not take into account the pressures exerted as the packing tractor tire moves along the wall. The additional load on the wall caused by the packing tractor is discussed in another section.

Overturning Moment Caused by Silage Pressures

The overturning moment is a design criteria for the vertical supports of the silo wall. These may be pilasters or posts. Data obtained from the tests were used to calculate overturning moments versus depth of silage. A plot of the re-

[1]South Dakota Agricultural Experiment Station Circular 477, Storage Structures for Grass Silage by G. C. Zoerb, H. G. Young, H. H. DeLong and D. L. Moe.

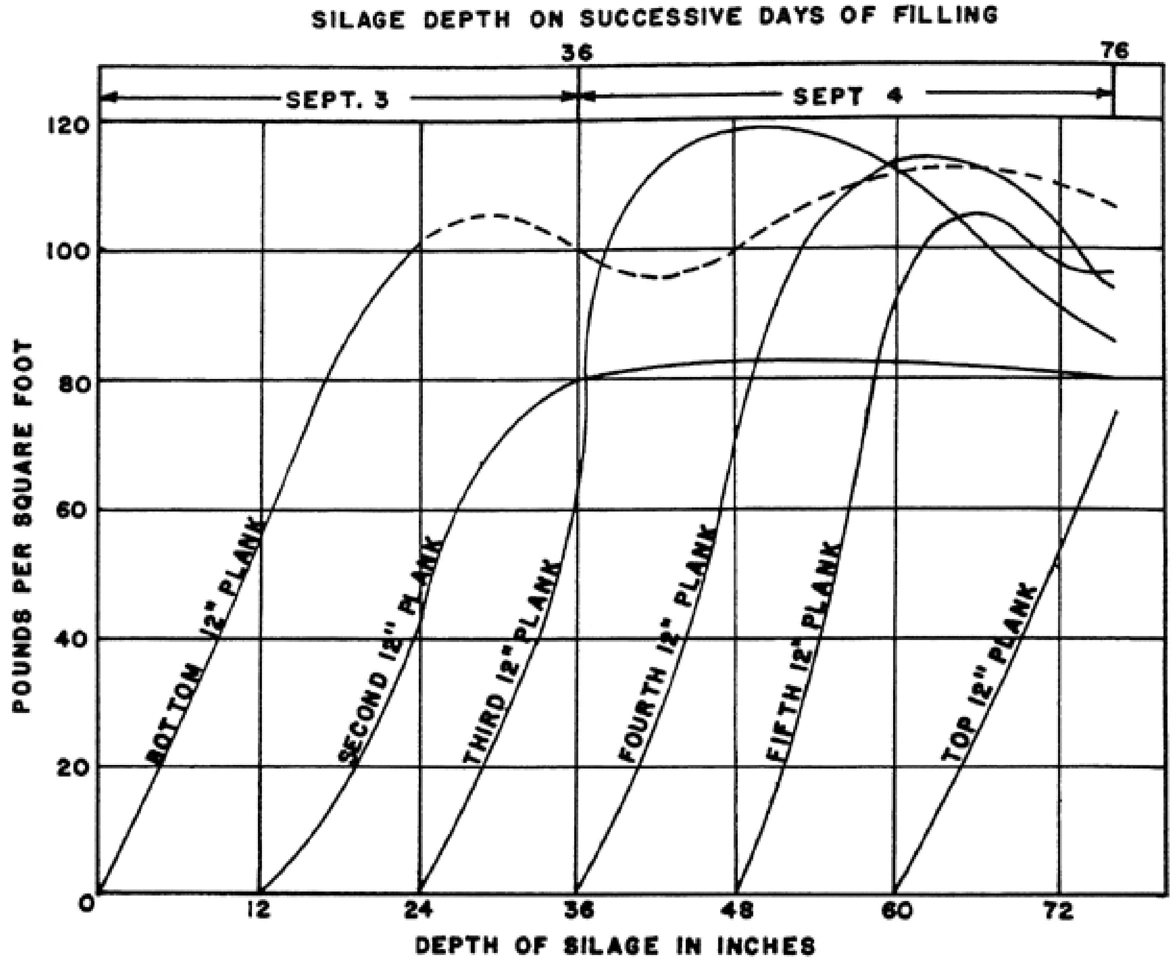

Fig. 3—The pressure against the silo wall as recorded at each foot of silage depth throughout the silo filling operation. These data are for silage pressure alone and do not include the additional load imposed by the packing tractor as it moves along the silo wall.

sulting curves for the two years is shown in Figure 4. These curves represent the overturning moment caused by the silage resting against *one foot* of the wall length. The total overturning moment that should be used for the design of a particular silo should take into account the length of side wall supported by the vertical support being designed.

The curves in Figure 4 are "best fit" curves calculated from the measured data. The equations for the calculated curves are given for each set of data. In the equations, Y is foot-pounds per foot of wall length and X is depth of silage in feet. The curve for the corn with a moisture content of 71 percent is used for design recomendations.

The similar equation for chopped wheat from a previous test is $Y = 33.40\ x^{2.202}$.

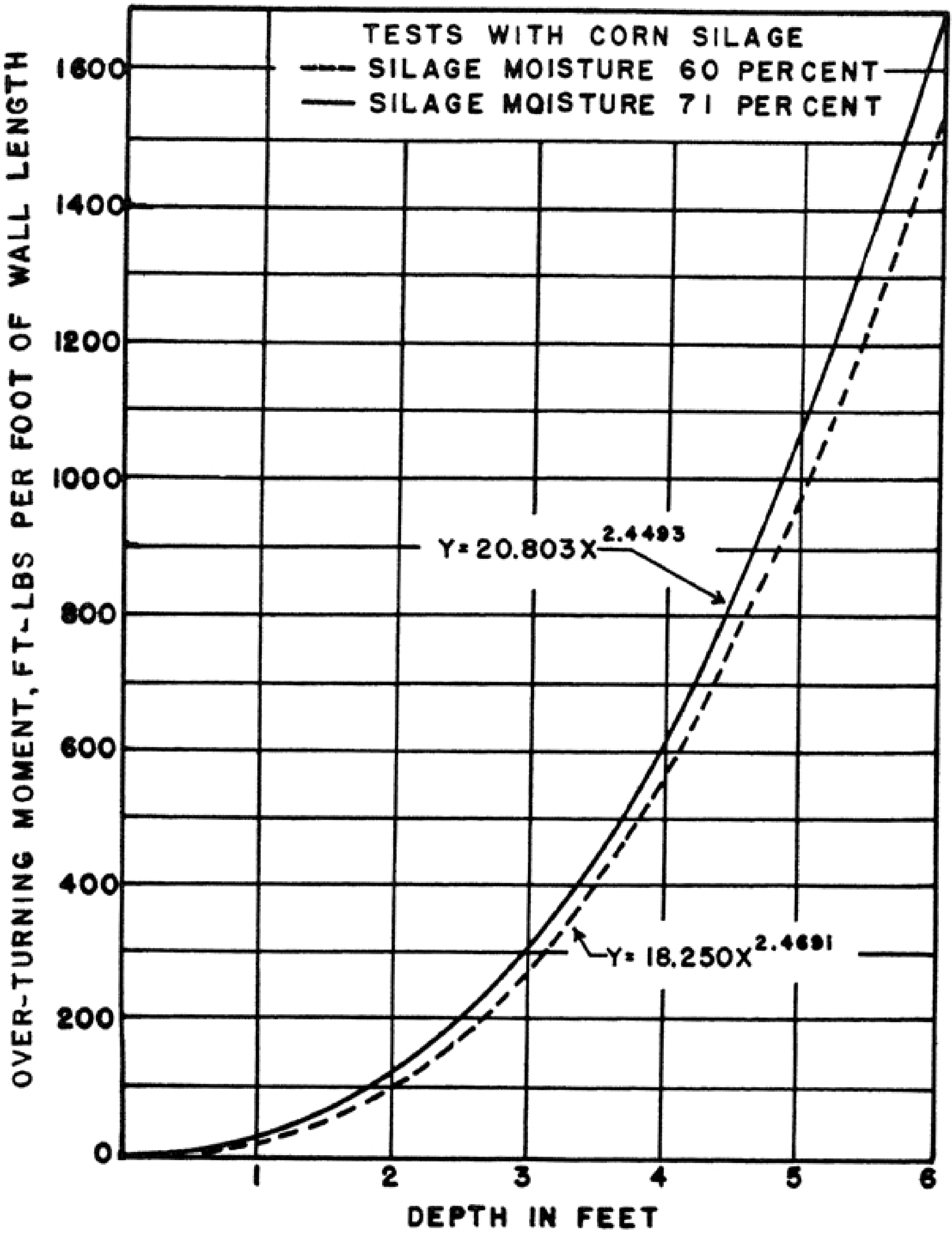

Fig. 4—Pressure on the silo wall causes an overturning moment about the base of the post or pilaster supporting the silo wall. Moments given are those caused by silage pressure against each foot of wall length. The overturning moments do not include the additional load imposed by the packing tractor as it moves along the silo wall.

It is interesting to note that at the 5 and 6-foot depths the equations for wheat and for the higher moisture corn silage give essentially the same overturning moment.

These curves do not reflect the the effect of the packing tractor on the overturning moment.

Forces Due to Packing Tractor

As the packing tractor moved along the silo wall the gauges would momentarily show readings higher than those from the silage alone. Little effect was noticeable on gauge readings until the tractor tire was almost at the gauge location. For design purposes this extra loading might be considered a series of loads concentrated at 1-foot intervals along a vertical line on the silo wall extending from the top surface of the silage to the bottom of the silo. The line extends down from the tractor tire and moves with the tractor as it passes along the wall.

The extra forces due to the packing tractor are depicted in Figure 5. The largest of these forces is located at the top of the silage. As silage level reaches the top of each plank the force on the plank due to the packing tractor has a value of about 200 pounds. Some individual readings indicated forces larger than 200 pounds, but these were isolated readings and possibly resulted from the tractor tire rubbing against the wall of the silo. As silage level increases above any given plank the effect of the packing tractor becomes less pronounced. For example, when the silo was filled to a depth of 6 feet the force due to the tractor on the four bottom planks was less than 50 pounds on each plank.

In the design of wall sections between vertical supports, a load of 200 pounds concentrated on each foot of length of a vertical line located midway between vertical supports should be added to the load imposed by the lateral pressure of the silage.

For purposes of designing the vertical supports the extra overturning moment due to the tractor can be approximated by considering a point load of 300 pounds at the silage surface. The overturning moment so computed exceeds the total overturning moment based on the data for depths of silage up to 6 feet in every instance but one. In this instance it is highly probable that the tractor tire rubbed the wall of the silo.

The total weight on the rear wheels of the tractor used for packing the silage was 2540 pounds.

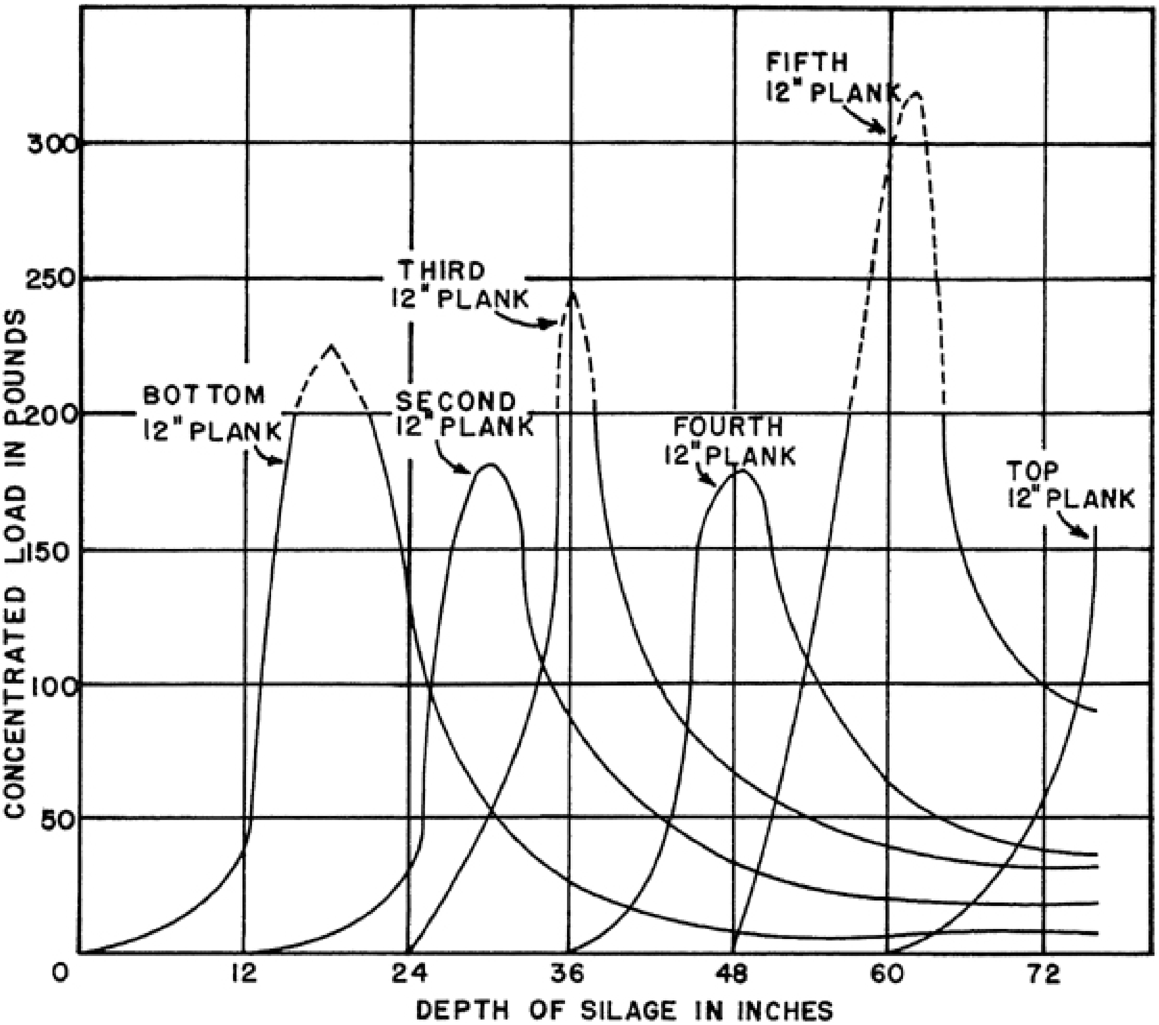

Fig. 5—As the packing tractor moves along the wall it imposes an additional load. This extra load may be considered as concentrated along a vertical line extending from the bottom of the silo to the top. The amount of the load carried by each plank in the test panel was determined as each load of silage was placed on the silo. Values above 200 pounds are single readings and are possibly the result of the tire rubbing against the silo wall.

SUMMARY

Data are presented, based on tests conducted on a horizontal silo filled to a depth of 6 feet with chopped corn silage. On the basis of these tests it has been concluded that a horizontal silo may be designed using the following information. Extrapolation of these data beyond silage depths of 6 feet should be done with the test conditions of this study in mind. One item worth consideration is that good drainage was provided for the test silo.

1. A lateral unit pressure of 120 pounds per square foot will be carried by the silo wall due to silage pressure against the silo wall.
2. In addition to the lateral unit pressures due to the silage, the packing tractor causes a load that has maximum effect midway between the vertical supports and is concentrated along a line extending from the bottom to the top of the silo. The magnitude for this load is 200 pounds per foot length of the line or per foot of silage depth.
3. The overturning moment caused by the pressure exerted by the silage on the silo wall can be expressed by the equation $Y = 20.803\ x^{2.4493}$ where Y is the overturning moment in foot-pounds per foot of length of silo wall and X is depth of silage in feet.
4. In addition to the overturning moment caused by silage pressure, the packing tractor causes a moment that may be calculated by considering a concentrated force of 300 pounds outward at the silage surface.