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Design Data For Above-Ground Horizontal Silos

I. Grass, Legume and Wheat Silage

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I. Grass, Legume and Wheat Silage

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Tests have been conducted at the Missouri Agricultural Experiment Station for three years to determine the strength requirements of the walls in horizontal silos. Information was obtained on overturning moments developed by the lateral stresses of grass, legume and wheat silage as packed in the silo. Pilasters, poles, posts and other lateral supports can be designed from the data obtained. Lateral unit pressures have been established for the design of the planks or panels between the supporting members.

TESTING PROCEDURE AND CONDITIONS

Tests with Grass and Legume Silage

Fig. 1 shows the test wall panel used the first two years. It consisted of the center portion of one wall of an above-ground horizontal silo. The panel was 20 feet long and 6 feet high, constructed of bridge planks 20 feet long. The planks were spiked to four upright posts which were hinged at the bottom and supported at the top by lateral braces. Hydraulic cylinders were set under the lower ends of the braces, and gauges were used to measure the pressure exerted on the cylinders. The entire test wall panel was free to rotate about the bottom hinges against the lateral supports as stresses were exerted by the silage and packing operations.

Pressure readings were taken on each of the four gauges after each load of forage was added during two successive seasonal filling operations. Silage-depth readings were taken each time the gauges were read. One series of readings was taken as the tractor that was used to pack the silage passed by the test section. The tractor operator attempted to keep the rear tire within one inch of the wall for these readings. The tractor was removed after each load of silage was packed and a second series of pressure readings was taken. Final gauge readings were taken at the end of each day of filling. Readings were taken again the following morning before the tractor was run on the silo, thus measuring the amount of pressure change during the first 12 hours after packing.

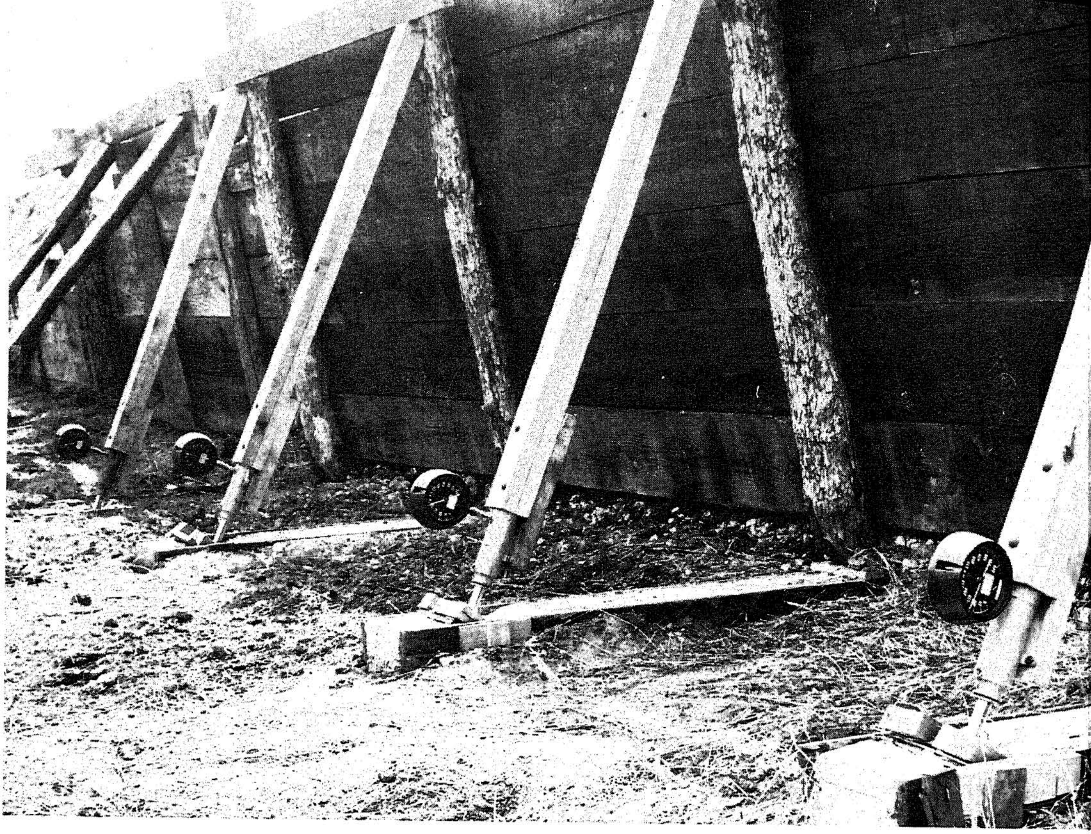

Fig. 1—The test wall panel used in the tests with grass and legume silage. The hydraulic cylinders and gauges are shown in place at the lower ends of the wall braces.

A mixture of grasses and legumes taken from various experimental plots on the Soil Conservation Experimental Farm at McCredie, Mo., was put in the silo both years. The first year the forages were harvested with a direct-cut experimental English-made machine which did not chop the material into short pieces as do conventional choppers. The forages as cut by this machine might be termed long-grass or uncut, although the stems were crushed and broken to some extent. This type of forage provided some interesting experiences in handling, storing and feeding unchopped material, but did not develop lateral pressures that might be representative of most silage made in this country.

During the second filling operation (the second year) forages from approximately the same fields were harvested with a conventional field chopper and placed in the silo. This filling not only provided more representative pressure data for grass and legume forages but made it possible to compare the data obtained with chopped material to that obtained with the long or unchopped material.

Although the forages put in the silo both years were quite similar with respect to variety of grasses and legumes, there was the difference of length of cut and a difference in moisture content. The moisture content of the unchopped forage as placed in the silo the first year averaged about 70 percent. Adequate packing was not obtained with this material. The second year water was added to the forage at the silo to assure good packing and maximum pressures. Moisture samples were taken from each load. The original moisture content of the forage as harvested and brought to the silo the second year was 72.1 percent and enough water was added at the silo to bring the total moisture content to 77.5 percent on a wet basis. The difference in moisture content and the length of cut undoubtedly contributed to the differences in pressures for the two years.

The same packing tractor and the same pressure measuring equipment were used both years. The rate of filling during the second year was somewhat faster than that for the previous season.

Pressure Panel Design for Tests with Wheat Silage

Data from the first two years were used to design a new horizontal silo. This silo was constructed on the University of Missouri Agricultural Engineering Research Farm ten miles west of Columbia.

Design of the Pressure Panel

In place of one of the concrete wall panels, a pressure panel was constructed as shown in Figs. 2 and 3. The pressure panel was constructed of independent horizontal planks so unit pressures could be measured at each foot of height

Fig. 2—The improved pressure test panel used in the test with wheat silage as seen from inside the silo.

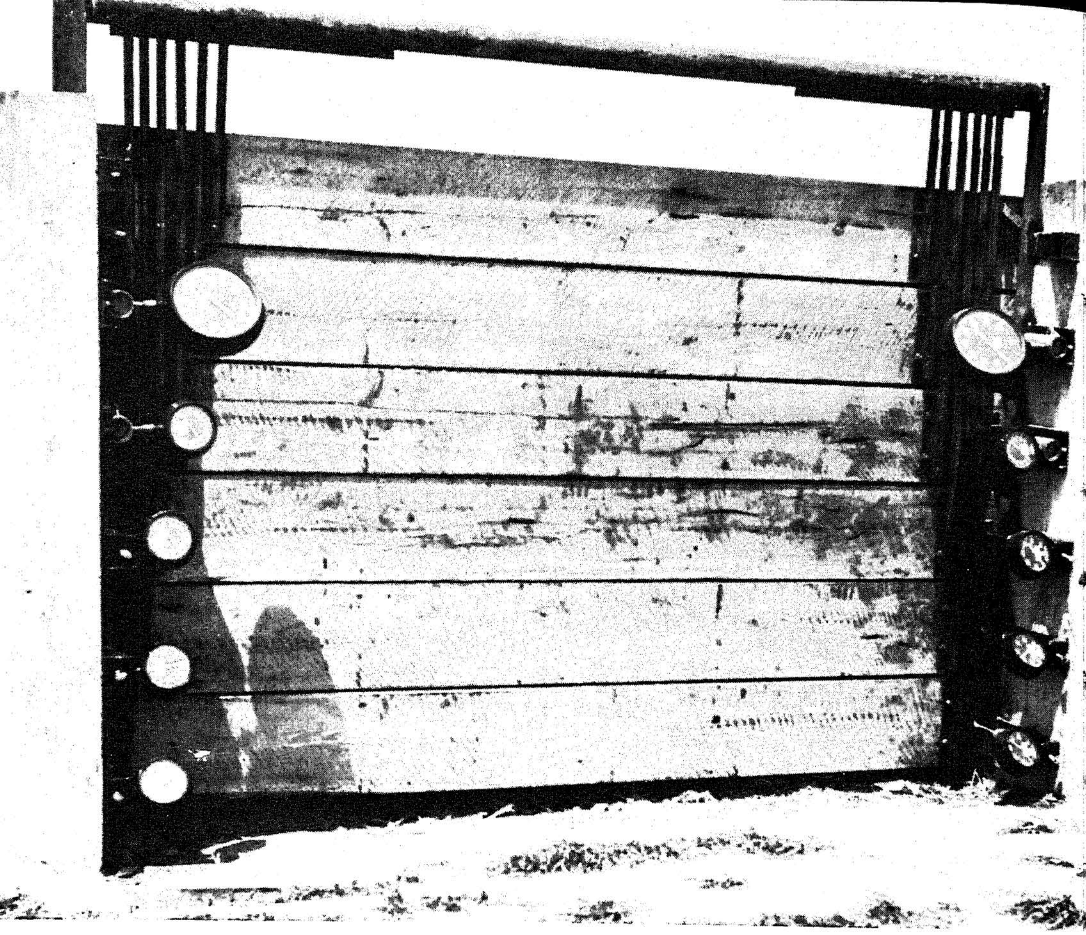

Fig. 3—The improved pressure test panel as seen from outside of silo. Panel consists of 12-inch planks hung individually from an overhead pipe. Outward forces on the planks are measured by hydraulic cylinders and pressure gauges.

during the filling operation. Each plank was 11½ inches wide and was suspended from above on flexible straps. Both ends of the planks were supported horizontally with hydraulic cylinders and pressure gauges as shown in Fig. 3. One-half inch of clearance was provided between all planks, and roll roofing was placed on the inside surface of the planks as shown in Fig. 2.

Each plank had a pressure area of 10 square feet and the total load was supported by the two cylinders. To determine unit pressure (pounds per square foot) at each foot of silo height, the total pressure on the two cylinders supporting each plank was divided by 10. Readings from each gauge were recorded after each load of forage was added to the silo.

The purposes of the additional lateral pressure measurements were (a) to obtain the unit lateral stresses of the silage during and after the silo filling operation, (b) to obtain more extensive pressure information with different forages and harvesting conditions, and (c) to check previous findings with a different type of testing equipment.

Test Conditions

The new silo was filled with field-chopped wheat silage. The wheat was cut with a direct-cut, flail-type forage harvester and was unloaded and spread in the silo with rear-end unloading wagons. It was packed in the usual manner with a farm tractor. The wheat had headed and the kernels were developing from the milk into the dough stage. The forage was not chopped in uniform lengths as it might come from a conventional chopper, but was well broken up and had a moisture content of about 70 percent.

FINDINGS AND ANALYSIS

Tests with Grass and Legume Silage

Overturning Moment: The overturning moment caused by silage pressures (tractor not on silo) was determined from test data. The gauge-pressure readings were first converted from pounds per square inch to total thrust on each lateral support. The total thrusts on each lateral support were then reduced to thrust per linear foot of silo wall, assuming each support was affected by the area of wall extending half way to the adjacent support on each side. The resulting thrusts per foot of silo wall were used to compute moments by multiplying thrust by the perpendicular distance between the lateral support and the bottom hinge.

In order to evolve one moment curve representative of all data, average moments for the four sections were tabulated for each depth of silage during the filling operation. The average moment values per foot of silo wall plotted against silage depth formed a straight line on log-log paper. To obtain a curve of best fit for the data, a regression equation was calculated using the logarithms of the moments as the dependent variable and the logarithms of the silage depths as the independent variable.

Fig. 4 illustrates the curves of best fit for the overturning moment data for field chopped grass and legume silage tested in the first year and the unchopped material tested the following year. The moment equation for the field chopped material is $Y = 61.019\ X^{1.774}$ and for the unchopped material it is $Y = 51.261\ X^{1.823}$, where Y is moment in foot-pounds and X is silage depth in feet. The shapes of the two curves are quite similar. The overturning moments for the unchopped material, however, were about 10 percent less than for the chopped material. The somewhat lower moisture content of the unchopped forage and the springy nature of the long fibers apparently accounted for this. If a moment curve for water were plotted on the same graph it would have lower moment values than the forages up to a depth of approximately 4 feet. Above a depth of 4 feet the moment curve for water would become steeper and the moment values would become increasingly larger than those for the silage material as depth is increased.

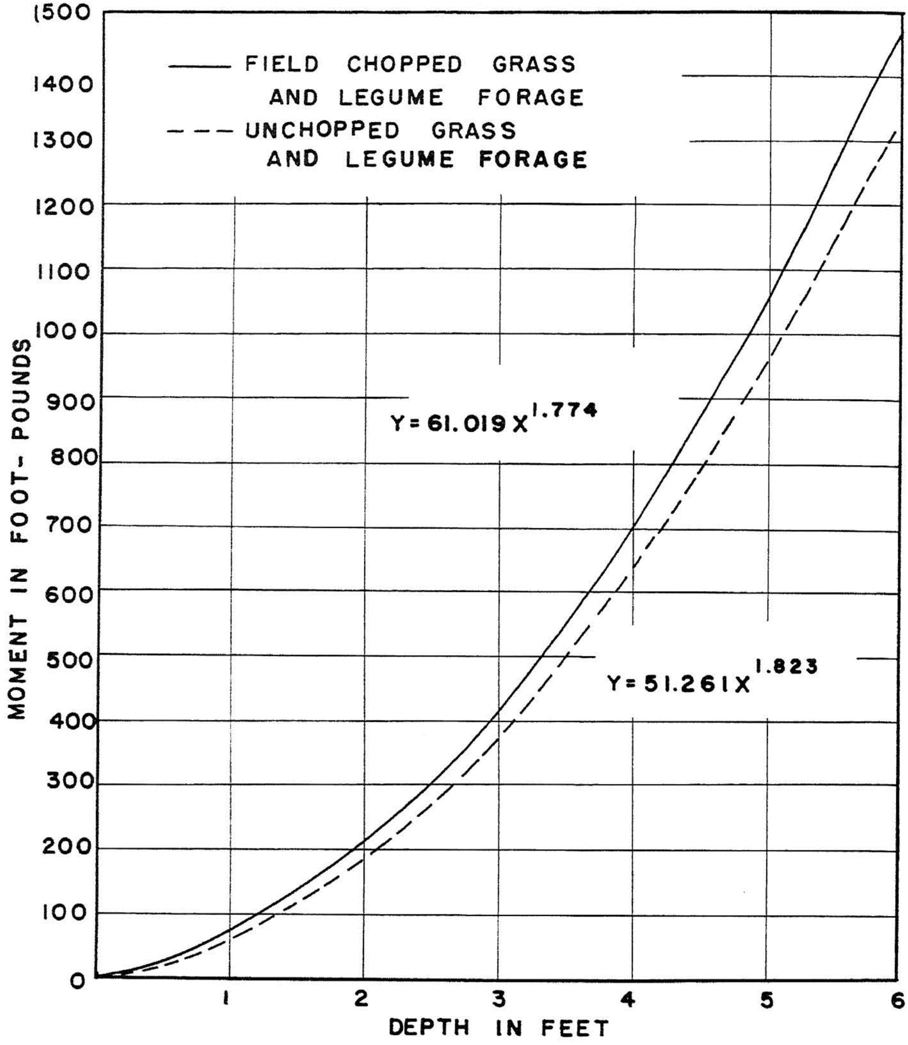

Fig. 4—Overturning moment (per foot of silo wall length) caused by pressure from grass and legume silage.

Pressure Relaxation

The procedure of taking final pressure readings at the end of each day during the silo-filling operations and subsequent readings the following morning prior to the time the packing tractor was put on the silo, made it possible to evaluate the pressure change during the first 12 hours after the silo was filled. In each case the pressures were reduced or "relaxed". Fig. 5 illustrates the amount

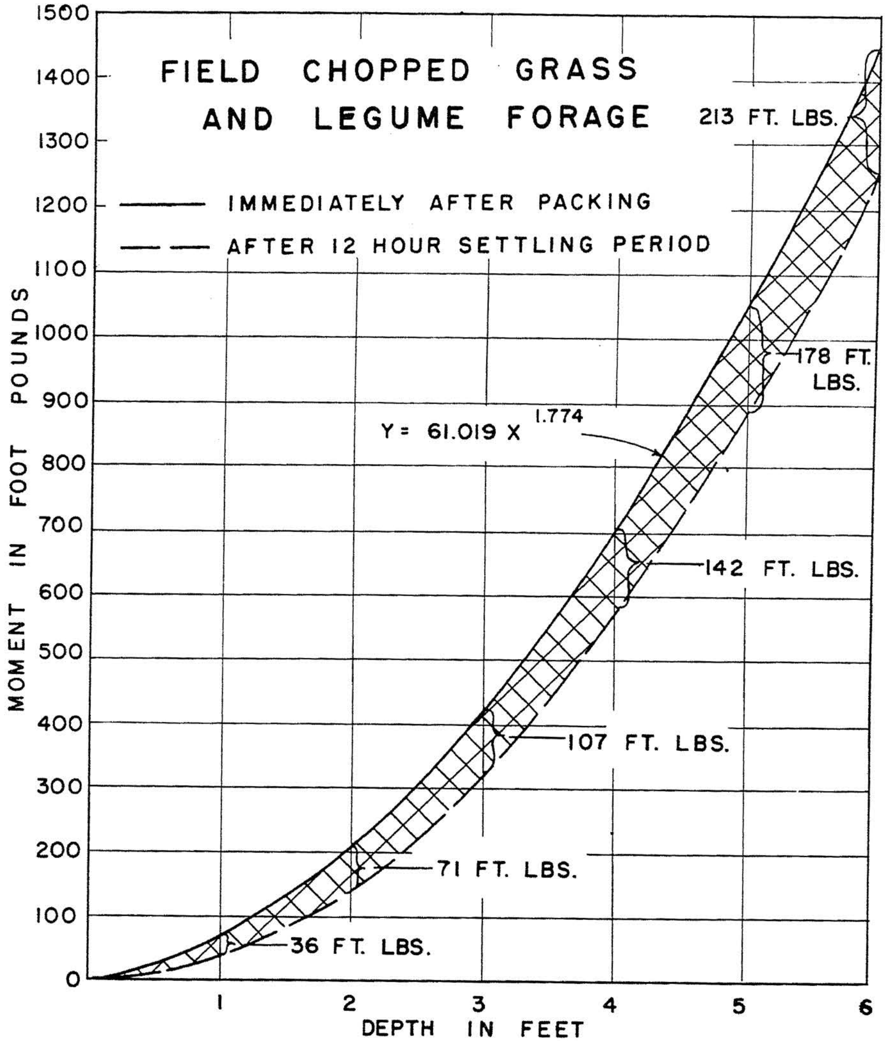

Fig. 5—These curves show the decrease in overturning moment (per foot of silo wall length) after a 12-hour period of settling.

of this relaxation for the chopped grass and legume silage. A comparable amount of relaxation was observed for the unchopped forage. The amount of relaxation for the chopped forage increased from 15 percent of the original overturning moment at a depth of 6 feet to 50 percent of the original moment at the 1-foot depth. Although maximum stresses were the chief concern of the study, this relaxation is of interest in a study of pressure characteristics of packed forage.

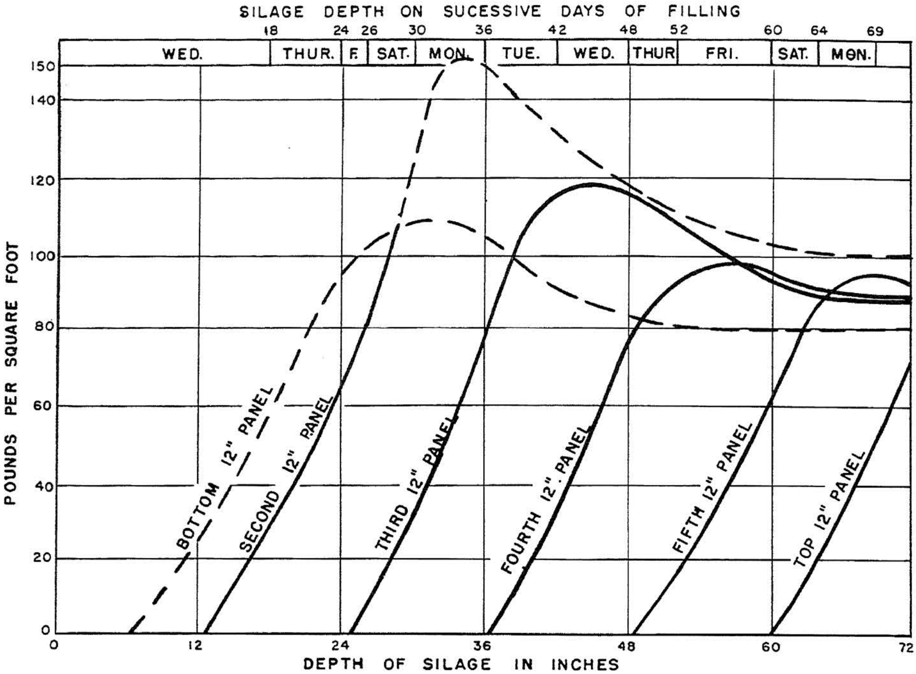

Fig. 6—Lateral unit pressure on each 12-inch panel throughout the silo filling operation. The silo was filled with wheat silage.

Tests with Wheat Silage

When the first foot of silage was placed in the new silo for the third test, the bottom plank was put under stress. As the depth of silage increased to 2 feet the bottom two planks were under stress continuing up to 6 feet when all six planks were under stress.

The pressure readings taken during the silo-filling operation provide a complete picture of the unit pressures at each depth. These pressures are illustrated graphically in Fig. 6. The graph shows that the unit pressure of each plank, except the bottom one, increased quite uniformly as the level of silage went up from the bottom to the top edge of each plank. Although the pressure on each plank actually is not expressed correctly as pounds per square foot until the entire plank is covered, it has been recorded as such.

A firm pack of forage was not obtained in the silo during the first day of filling. The depth at the end of the day was recorded as 18 inches but compared to the compacted depths recorded during the rest of the filling operation, the amount of silage placed in the silo that day should have packed to about 12 inches. This discrepancy moves the curve for the bottom panel to the right in Fig. 6 and for that reason it is shown as a broken line.

The unit pressure on each plank reached a maximum as the silage level increased up to 1 foot above the plank. These data indicate that as the silo is filled, the silage in the top 2 feet is packed in excess of what the internal friction of the material will retain. Therefore, as the silage level increases beyond a foot above each plank, the unit pressure is relaxed. As indicated by the curves of Fig. 6, the unit pressures relaxed down to 100 pounds per square foot or less.

The pressure on the second plank from the bottom reached a maximum at a considerable higher pressure than any of the others. As indicated by the filling schedule shown on the top part of Fig. 6 the rate of filling was quite slow from the 2- to the 3-foot level. The filling operation was halted both Friday and Saturday afternoons because of rain. Even though little forage was added, considerable packing was done and the rain helped make the packing tractor more effective. No packing or filling was done over Sunday, although an additional inch of rain fell to further help settle the silage. It is believed that these conditions caused the abnormally high peak of 155 pounds per square foot for the unit pressure of the second plank from the bottom and for these reasons the upper portion of the curve is shown as dotted.

The curves of Fig. 6 show that a unit pressure versus depth curve for the silage would change throughout the silo filling operation. In general the unit pressure is at a maximum approximately 2 feet below the silage surface. At depths below this peak the pressure levels off at approximately 100 pounds per square foot.

Fig. 7 shows the shape and magnitude of a unit-pressure versus depth curve for silage soon after the silo is filled. After a period of several hours the excess pressure at the 2-foot level relaxes until the pressure curve is practically vertical.

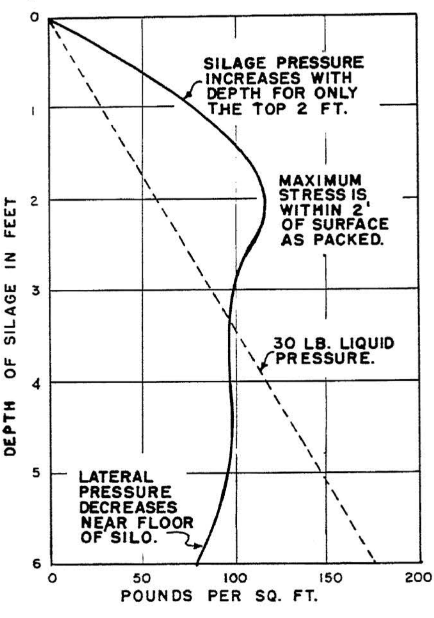

Fig. 7—Lateral unit pressure on silo walls soon after silo has been filled to a depth of 6 feet.

The pressure curve turns in at the bottom of the silo due to the friction of the silage on the floor. This is indicated in Fig. 6 by the lower pressures on the bottom plank throughout the filling operation. It is interesting to note the contrast in Fig. 7 between the pressure curve for a liquid equivalent of 30 pounds per cubic foot and that for silage soon after it has been packed.

Overturning Moment Caused by Silage Pressures

Fig. 8 illustrates the moment curves obtained from the three successive years of testing. (Same as Fig. 4 except that the curve for wheat silage has been added.) Curves for the tests on grass and legume silage are illustrated by the broken lines in Fig. 8 and the curve for wheat silage is shown as a solid line.

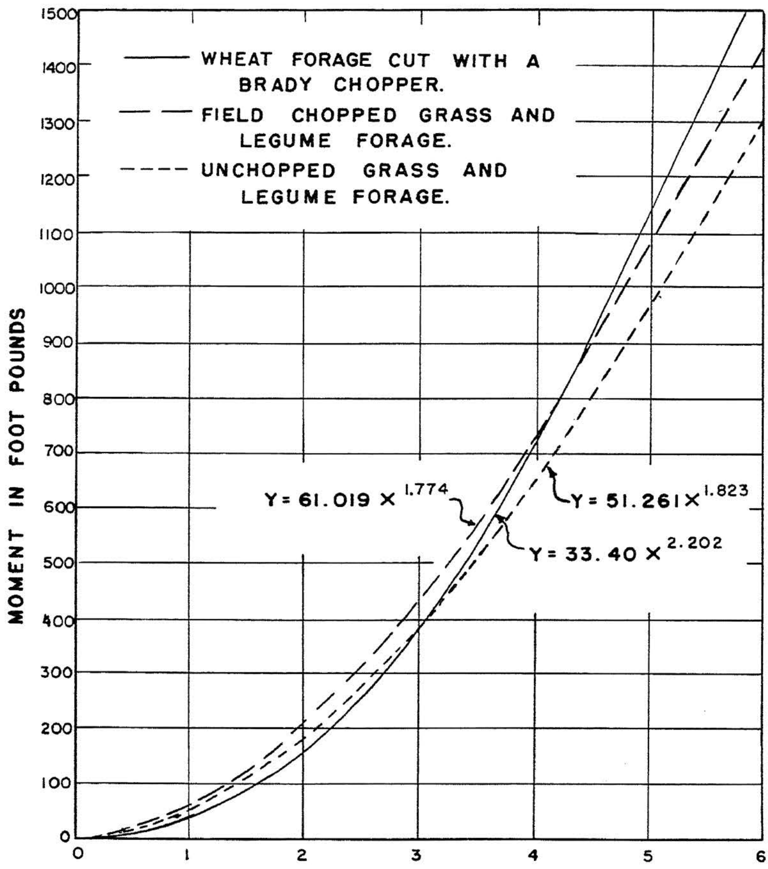

Fig. 8—Overturning moment (per foot of silo wall length) caused by silage pressure. The data for wheat silage is compared to the data for grass and legume silage shown on Fig. 4.

The curves show considerable similarity in shape and magnitude in view of the existing variables of different forages, different types of cuts, and different moisture contents. The best silage pack was obtained the third year with the wheat silage, and this is reflected in the higher moment values shown by the solid line curve in Fig. 8. Data from the moment curve for the wheat tests are therefore considered to be the most reliable for design purposes.

Stresses Caused by Packing Tractor

Note that the unit stresses of Figs. 6 and 7 and the overturning moment of Fig. 8 are for the silage only, without the packing tractor on the silo, and these curves all represent data for conditions soon after the tractor was taken off the silo. Fig. 9 indicates that the tractor accounts for considerable additional stress.

Fig. 9 is plotted similar to Fig. 6 and shows the loads on each plank throughout the filling operation as the tractor was run within 1 inch of the wall. The average concentrated horizontal load on any one plank ranged from about 135 to 195 pounds. Of particular interest with regard to lateral loads caused by the tractor is the fact that they did not extend down to appreciable depths. It will be noted from Fig. 9 that the concentrated load began to drop off on each plank immediately after the silage level rose above that particular plank.

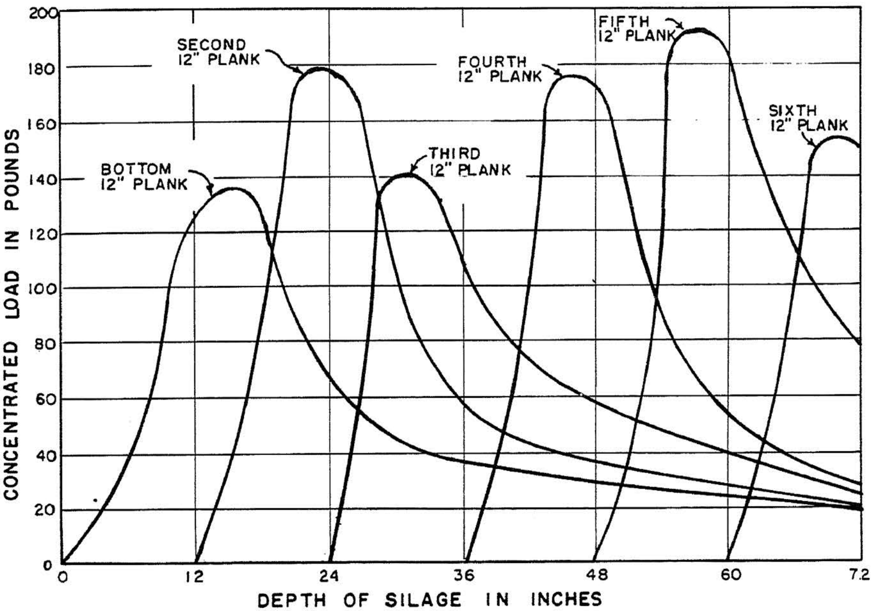

Fig. 9—Lateral concentrated load caused by the packing tractor throughout the silo filling operation.

A concentrated load for the packing tractor of 200 pounds at the surface of the silage seems justifiable for design purposes. Higher stresses, and particularly those occurring when the tractor wheel rubs against the wall, must be taken care of by the safety factors in design.

SUMMARY OF FINDINGS

1. Maximum unit lateral pressures of 125 to 150 pounds per square foot will occur temporarily at a depth of from 1 to 2 feet below the silage surface during the filling operation when grass, legume, or wheat silage is placed in an above-ground horizontal silo.

2. At depths below 2 feet (from the silage surface) the unit lateral pressures relax to approximately 100 pounds per square foot.

3. A unit pressure versus depth curve for the silage changes constantly during the silo filling operation but soon after the silo is filled becomes practically a vertical line of about 100 pounds per square foot from the 2-foot depth (measured from the top) down to the 6-foot depth.

4. When grass and legume silage is packed with a tractor in a horizontal silo the lateral forces on the sidewall cause an overturning moment expressed by an equation of the type $Y = AX^b$ where Y is the overturning moment in foot-pounds (measured immediately after packing) per foot of length of silo wall and X is the depth of silage in feet. The constants A and b, as determined from these tests, are 61.019 and 1.774 respectively for field chopped and 51.261 and 1.823 for unchopped forages.

5. Under the conditions of these tests, the overturning moments caused by unchopped grass and legume silage, as measured immediately after packing, were approximately 10 percent less than those caused by chopped grass and legume silage.

6. The overturning moment caused by the lateral stresses in wheat silage harvested with a flail-type chopper is expressed by the equation $Y = 33.40 X^{2.202}$ These moments are slightly lower at shallow depths and somewhat higher at greater depths than the moments found for the grass and legume silage.

7. An appreciable portion (15 percent when the silage is 6 feet deep and 50 percent when the depth is 1 foot) of the initial overturning moment caused by packing grass and legume silage in a horizontal silo is relieved during the first 12 hours following packing.

8. The average concentrated lateral loads caused by the packing tractor ranged from 135 to 190 pounds at the silage surface. The horizontal load on the silo wall 2 feet below the surface is not affected appreciably by the tractor.

9. The packing tractor causes a concentrated load at the silage surface that for design purposes may be considered to be 200 pounds.