THESIS

PRESSURE OF GRANULAR SUBSTANCES IN LONG TUBES

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on

"PRESSURE OF GRANULAR SUBSTANCES IN LONG TUBES."

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The question of the pressures exerted by granular substances, especially grain and coal, is one of great importance to the engineer, as it should be the basis of computation in designing grain elevators, and the coal bins which must necessarily form a part of every large steam plant. The frequent failure of these structures has led to a great deal of speculation as to the probable pressures, but to very little of actual experiment. Consequently, there is very little engineering literature upon the strains in such structures that is of practical value to the engineer.

The failure of a large coal bin at Paterson, N. J., in the year of 1897 led to numerous discussions in the Engineering News by engineers all over the country, and it was with a view to try to discover something in regard to some of the theories suggested by them that these experiments were conducted. The results obtained related particularly to the pressures exerted on the bottom and on the sides.

If grain, or any granular substance, be poured in a stream in one place it will form a cone. Suppose this process be continued in a grain bin until the base of the cone just reaches the lower edge of the vertical walls. The entire weight of the substance is held by the bottom, and no pressure whatever is exerted on the sides. Suppose the process to be continued; the substance will continue to form in the shape of a cone

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and a pressure must necessarily be exerted on the sides. Consequently, a portion of the weight will be taken off the bottom. The experiments tried were to determine, if possible, how much of this weight was held by friction on the sides, and if there was any heighth at which the addition of matter on the top brought no additional weight on the bottom.

The experiments were tried with the following apparatus: A tube sixteen feet long, square in section and six inches on each side, was constructed of pine lumber. This was rigidly supported in a vertical position, with the lower end about eight inches from the floor. The tube was supported by a frame, to which were bolted several pulleys running a drill; consequently, it was subjected to a slight jar, giving nearly the same conditions as are usually found in an elevator. Over the lower end of the tube was placed a box about 10 by 12 inches, resting on a pair of scales, and the scales elevated so that the inside of the bottom of the box was about two inches from the lower end of the tube.

Under these conditions, enough of the material to be tested was poured in to seal the bottom of the tube, and the weight on the scales noted. Known amounts of grain were then poured in at the top, and the reading noted each time on the scales below. Had there been no friction on sides, or if the entire weight had been held by the bottom, since there was no connection between the scales and the vertical tube, the weight on the scales below would have been equal to the weight of grain put in at the top. The difference between the two is the amount held by the sides, and it was found in every case that after a certain proportionate height the addition of more material at the top brought no additional

weight on the bottom.

The first substance tried was oats, and the result was not very satisfactory, because the size of the tube was evidently too small for a grain having so great a friction. The weight of the box and the grain necessary to seal the end of the tube was 7.6 pounds, and following was the experiment. The experiment was verified, giving same results on second and third trials.

Grain put in at the top.	Total weight on bottom, including the 7.6 #
9.25 #	8.6 #
9.25	9.6
10	9.7
10	9.7
Total 38.50	9.7 Final

The experiments with wheat were as follows, and perhaps are more satisfactory than those with oats, because of the less friction.

Amount necessary to seal the bottom of the tube 11.5 lbs.

Grain at Top	Total weight on bottom.
0	11.5
12	16
10	17
10	18
The tube was raised slightly and it was	14
10	15.5
10	16.5
10	16.5
10	16.5
Total 72	Final 16.5

Experiment 2 with wheat.

Grain at Top		Weight at bottom.	
	0		10 necessary to seal bottom of tube
	13		15
	13		16
	13		16.5
	13		17
	13		17
Total	65	Final	17

In the next experiment with wheat the amount put in each time was made much smaller. This would tend to produce more of a layer effect; reduce the cone formed and more weight would come on the bottom. The experiment verified this fact.

Wt. of Grain at Top		Total weight on bottom.	
	0		10 necessary to seal bottom of tube
	4.5		12.5
	4.5		14
	4.5		15.
	4.5		15.5
	4.5		16.5
	4.5		17
	4.5		17.25
	4.5		17.5
	4.5		18
	4.5		18
	4.5		19
	4.5		20
	4.5		20.5
	4.5		20.5
Total	68	Final	20.5

Additional weight brought no increase on bottom.

Experiment 4 with wheat.

Weight of grain at top		Weight on bottom	
	0		10
	4.5		12.5
	4.5		14.5
	4.5		14.5
	4.5		16.5
	4.5		16.5
	4.5		17.5
	4.5		18.5
	4.5		19
	4.5		19
	4.5		19
	4.5		19.5
	4.5		20
	4.5		20.5
	4.5		20.5
	4.5		20.5
	4.5		20.5
	4.5		20.5
Total	86	Final	20.5

After the experiments with wheat similar ones were tried with beans.

Weight at top		Total on bottom	
	9.25		8.6
	9.25		9.6
	10		9.7
	10		9.7
Total	38.5	Final	9.7

In each case the pressure on the bottom, at the time when additional weight at the top brought no increase of pressure on the bottom, was about one-third of the weight of the material already in the tube. It would seem that, after the tube was filled, a jar would settle the grain and bring increased weight on the bottom, but experiment did not bear out this supposition, as a jar of the tube made no difference, seeming to indicate that the grain acted like a continuously drive wedge, and the increase from the jar probably being borne by the sides. As an incidence of the pressure on the walls, a description in the Engineering News for Jan. 27th., 1898, tells of an elevator in which the bins 80 ft. high having its sides so compressed that the walls were one foot lower when filled with grain than when empty. The same issue contains some interesting discussions of experiments in regard to pressure of stored grain. In those experiments in no case did the pressure on the bottom exceed seven and one-half pounds. The fact that in our experiments the pressure went as high as 20 1/2 is probably accounted for by the fact that in their experiments the tube used was 4 in. square, and in ours 6 in. square.

Another very interesting feature of the experiments described in Engineering News is the following formula:

$$P = A\ C\ D\ W = 1.03\ A.\ D.\ W.$$

$$\frac{P}{A} = C\ D\ W = 1.03\ D\ W$$ in which P is the pressure in pounds on the bottom, A is area of bottom in square feet, D. the diameter of inscribed circle, C a constant found to be 1.03 and W the weight of a cubic foot of wheat. Or, expressed in words, the maximum pressure that can come upon the bottom of a bin of wheat is equal to the

weight of a prism of wheat with a base equal to the bottom of the bin, and altitude equal to the diameter of the inscribed circle.

We think the pressure on the sides, and the angle at which it is exerted, will depend largely on the angle of repose of the substance. It would be interesting to discover the point of maximum pressure on the side, and a few observations indicate that it is 1/3 of the distance from the bottom, but observations are too few to lead to a definite conclusion.

Interesting articles relating to this problem may be found in Engineering News of Jan. 27th., 1898, Nov. 4th., 1897, March 3rd., 1898, Sept. 23rd., 1897, June 19th. and 29th., 1886, Van Nostrand Science Series No. 3, Benjamin Baker's book on Actual Lateral Pressure of Earthworks, Annals des Ponts et Chaussees April, 1887, Report of British Association for the Advancement of Science 1882 and from the experiments of an Englishman by the name of Roberts.