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GRAIN PRESSURES IN DEEP BINS.

By J. A. Jamieson, C. E., Mem. Can. Soc. C. E.

The comparatively recent change in the materials of construction of grain storage bins or silos, has made the question of Grain Pressures one of great importance at the present time. Until within a comparatively recent date practically all grain elevators on this Continent were built of wood, the storage bins being of laminated or cribbed construction, formed by building a number of walls both longitudinally and transversely of the building. The walls were constructed of plank 2″ thick, laid flat and spiked one to the other, and from 6 to 8″ wide according to the quality of the material used and the size of bin required. The width of plank or thickness of wall decreased towards the top, and the walls were spaced 12 to 14 feet apart in both directions, thus sub-dividing the storage space into deep bins 12 to 14 feet square and 60 to 70 feet deep.

So long as this construction and size of bin was maintained, there was no great urgency for knowing accurately the lateral pressures produced by grain, as the thickness or necessary strength of the walls to safely resist the lateral pressure, and the strength of the hopper bottoms of the bins to carry the vertical load, had been well established by practice.

With a wooden bin wall of sufficient strength to resist the lateral pressure, the wall had ample area as a column to carry the vertical

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Note.—On page 28, read :—

$$\frac{5{,}000 \text{ lbs. x } 40 \text{ sq. ft.}}{100 \text{ sq. ft.}} \text{ x } 0.6 \text{ x } 0.41667 = 500 \text{ lbs. carried by the walls.}$$

grain load transmitted to it by friction. This form of bin construction has been in use practically from the inception of the grain elevator system on this continent, and in many respects is admirably adapted for the purpose.

The defect from a structural point of view was its lack of vertical rigidity, by reason of the shrinkage of the wood and the compressing of the many horizontal joints during the first loading of the bins, which usually amounts to a settlement of 12 to 18 inches in 70 feet, thus necessitating very great care being taken to distribute the grain load when first filling the bins in order to prevent undue strain of the structure. When, however, the initial settlement has taken place, no further precautions are necessary .

The chief defect, however, of the wooden elevator is its liability to destruction by fire, involving heavy loss on the building and contents, and therefore high insurance premiums.

The increasing cost of Insurance and timber, combined with the great inconvenience and loss of business to transportation companies by the destruction of an important terminal elevator, created a sudden demand for fire-proof buildings ; and the consequent change in the materials of construction made it necessary that a more accurate knowledge of Grain Pressures under all working conditions should be obtained to permit of the intelligent design of bins of different materials or increased diameter and depth.

Notwithstanding that the modern elevator system had its inception, and has reached its highest development in America, there is no record of any systematic series of tests having been made on this Continent, with a view of obtaining a definite knowledge of the pressures produced by grain in deep bins. In fact, there is ample evidence that some who have undertaken the design and construction of bins for the storage of grain, coal, or other granular substances have been entirely lacking in knowledge of this subject ; and there have been very few of even those engineers making a specialty of grain elevator or coal bin construction who could calculate with any degree of confidence the pressures produced by granular materials in bins having a breadth and depth varying to any considerable extent from standard size or constructed of different materials.

The Author does not, however, wish to convey the impression that all grain elevator designers have been entirely groping in the dark on this subject, nor does he claim to have had a superior knowledge of grain pressures over other experienced elevator engineers, before undertaking the extensive and systematic series of tests which form the chief subject of this paper.

It has been well understood by experienced grain elevator engineers that grain stored in bins of standard dimensions (12 to 14 ft. square and 60 to 70 ft. deep) produced comparatively small vertical and lateral pressures, and that much the greater part of the grain load in the bin is carried by the walls, and only a small part on the bin bottom, and that this is due to the friction between the grain and the bin walls.

Very few, if any, have, however, realized to what extent this was governed by ratio of breadth to depth of bin, and the ratio of the horizontal area of the grain column to the area of the bin walls; and therefore to what extent the vertical and lateral pressures are increased, due to increase of horizontal dimensions of the bin.

This lack of data by which to calculate the pressures and strength of grain storage bins of varying dimensions and materials of construction, has been greatly felt by experienced grain elevator designers who have fully realized the importance of an ample factor of safety combined with economy of construction. It has therefore been rather surprising to find that some designers instead of conducting a series of tests to obtain the pressures produced by grain, which would enable them to intelligently proceed with their designs for bins of any dimensions, have built experimental tanks or bins at large expense, from which they gain very little practical information, since some parts of the construction when loaded may be strained far beyond its safe strength, and the weaknesses only be developed by time, while other parts may be of unnecessary strength. This may be called the "fit and try process," on which the wooden grain bin was originally developed and which was no doubt necessary in ancient times, but should now give place to modern engineering methods.

With an accurate knowledge of the pressures produced by grain and the necessary experience to enable the data to be intelligently used, and with the present knowledge of the strength of different materials of construction, there is no reason why a grain elevator may not be designed and built with the same regard to safety and economy as any other engineering work. It must however be borne in mind that while engineers may keep up with the times, their clients do not always do so, and that a structure actually built and in use, even if it has many weaknesses of which he is not aware, will often be selected by the prospective owner in preference to the most carefully prepared designs based on accurate data.

Most of the experienced elevator designers, knowing the very heavy loads that have to be carried in grain elevator or storage structures, have hesitated to depart from the standard sizes of bins, Unfortunately the demand for cheap storage and low insurance rates, has brought men into the field without either engineering knowledge or grain elevator experience, who have undertaken the design and construction of storage tanks apparently built by pure guess work, or at best, on some indefinite percentage of water pressure, with the result that in most cases serious weaknesses have developed and in others total failure and serious losses have occurred. This has frequently been the fault of the prospective elevator owner to whom low first cost of construction is often the chief and sometimes apparently the only consideration.

If the experienced elevator builder declines to undertake this class of construction, inexperienced men may readily be found who are willing to do so. The fact, however, must not be lost sight of that a grain elevator or storage bin structure, due to uneconomical design may be both high in first cost and structurally weak, while another design may be much lower in first cost and of ample strength.

Most engineers recognize that the field of engineering is too vast for any one man to be an expert in all branches, and certain engineers, by making a specialty of a particular line of design and construction, become specialists in that branch, and therefore if requested by a client or employer to design or report on some special problems with which they are not conversant, will admit their lack of previous experience and recognize the fact that they may without loss of prestige recommend the employment of a specialist; or that they be given the necessary time and opportunity to gain full information, and failing this, decline to accept the appointment except on the clear understanding that they will simply use their best efforts.

There have, however, been exceptions where certain gentlemen without sufficient experience or previous study of the subject, accepted a brief to act in the capacity of experts on grain elevator problems and without making tests and ignoring information and records of special tests supplied to them, arbitrarily assumed hydraulic pressures and made an unfavourable report based on the assumption that a grain elevator was intended for the handling and storage of fluids, instead of a granular material, and at a later date apparently assumed the pressures produced by chaff as a basis for their further calculations, and reported favourably on a tank design that will neither safely withstand grain pressures nor 10 per cent. of fluid pressure.

It is quite safe to state that very few Engineers would make the mistake of applying the fluid pressure theory to grain or other granular substances stored in deep bins. To do this it is necessary to ignore the well-known fact that strictly granular materials when placed on a level floor, will form a pyramid or cone with sloping sides, at a considerable angle from the horizontal, clearly indicating considerable friction within the mass. It would be also necessary to ignore all the known published data in regard to friction between different solids and granular substances, and also the many structures throughout the country which have been safely used for years for the storage of grain, coal, etc., but which would not stand the tests of fluid pressures.

With a view to showing the difference between designing a bin or series of bins for the storage of grain or for the storage of a fluid, if we take a bin say 12 feet square and 72 feet deep, with a co-efficient of friction between grain and the bin walls of .468 when filled with grain, the vertical pressure will be only 15% and the horizontal pressure only 9% of the pressure that would be produced by a fluid of the same specific gravity as grain. Therefore the bin bottom will only require to be 15% of the strength to carry the vertical load and the walls to resist the horizontal pressure only 9% of the strength. The walls, however, require to have sufficient strength acting as a column to support over 86% of the total weight of grain in the bin, while if used for the storage of a fluid, the walls would have no load to carry beyond their own weight. On the other hand it is quite practicable to design and build a tank or standpipe that will have an ample margin of safety when filled with water, and that would undoubtedly fail when used for the storage of grain.

In order to show the importance of the question from a financial standpoint, it may be stated that if the bin structure of the Montreal Harbour Commissioners elevator was designed and built to safely withstand fluid pressure and at the same time safely carry the grain loads, the cost would be at least $200,000 greater than if designed for the storage of grain with a factor of safety of 4. It would therefore seem that in cases where so much money was involved, and when the question of the proper design to meet the requirement of an important link in the transportation problem was at stake, the question would have been worthy of careful investigation.

We therefore have as the two extremes, tanks apparently designed to hold chaff, and those of the expert fluid pressure theorist, who would have grain storage bins designed to hold water.

In view of the wide divergence of opinion and the lack of accurate published data on which to base calculations for the strength of grain storage bins, the serious losses that have occurred and the consequent lack of confidence caused thereby, the Author believes that all engineers and owners interested in grain elevators and the storage and handling of grain, will agree that a full investigation and systematic series of tests to ascertain the manner in which grain loads are carried and the pressures produced by grain, are very urgently required.

The Author therefore proposes to present as clearly and briefly as possible the information gained by conducting a systematic series of tests, calculations, and investigations, to ascertain all possible information on this subject and in order to confirm the tests and deductions therefrom, and will illustrate some of the weaknesses that have developed in different forms of construction. He will also endeavor to show the cause for certain failures, and describe the problems to be met in the safe and conomical design of grain bins, and will in connection therewith, illustrate and describe a number of designs of grain bin constructions.

Before proceeding to describe these tests the Author will briefly outline such different tests, calculations and discussions on this subject as it has been possible to obtain from any hitherto published records.

In Great Britain in the year 1882, Isaac Roberts made a series of tests on both model and full-sized bins, which demonstrated that in a grain bin having a depth equal to 4½ times the diameter, the proportion of the grain weight resting on the bin bottom was very small, as also the lateral pressure. Mr. Roberts read a paper describing his tests before "The British Association for the Advancement of Science." The Author, however, regrets that he has been unable to obtain a full copy of this paper.

In 1895 H. A. Janssen, C.E., Bremen, Germany, made a number of experiments on small rectangular bins with a view to obtaining the proportion of weight of the grain contained in a bin that would rest on the bottom, and that would be carried by the bin walls.

His bins were all of approximately the same depth but of varying horizontal areas. Briefly, his system of tests consisted in supporting bin walls on 4 jackscrews while in the bottom of the bin was placed a loosely-fitting board resting on a platform scale. By filling the bin with grain the proportion of weight resting on the bottom was recorded on the scale. When the weights previously placed on the beam balanced the weight of grain resting on the bottom, a record was taken of both the weight of grain in the bin and the proportion of said weight that was resting on the bottom.

The bin was then slightly raised by means of the jackscrews, and owing to the friction of the grain on the bin sides this also relieved part of the bottom pressure and allowed the beam to drop; added weights were then placed on the beam and the filling of the bin proceeded with, the same procedure being folowed until the bin was filled.

Janssen's tests were thus carried out in four different sizes of bins, but were to obtain the bottom pressure only, as he found that having obtained the bottom pressures, it was quite simple to calculate the lateral pressure. By conducting a series of tests to obtain the co-efficient of friction between grain and the bin wall materials, he was enabled with the information thus gained to calculate pressures in different sized bins.

His experiments seem to have been very carefully and scientifically carried out, and his apparatus well adapted for the purpose. The results which he obtained are almost identically the same as those obtained by the Author. Some of his tables and diagrams which we have had translated, will be given in this paper for comparison with the Author's results.

The full description of Janssen's tests are published in "The Zeitschrift Des Vereins Deutscher Ingenieure" 1895, Vol. XXXIX. Page 1045. The Author has a full translation of this paper and also drawings of the bins and apparatus used.

In 1896 there was published in "Zeitschrift Des Vereins Deutscher Ingenieure," Page 1122, a description of certain tests made by one Prante at Bernberg. Prante's tests were conducted with a view to obtaining the lateral pressure of the grain in a cylindrical bin, and appear to have been very unsatisfactory. In fact, from the Author's experience, it would be very difficult, if not impossible, to obtain results of any value with the apparatus used. The chief interest in Prante's tests consists in the greatly increased pressure which he states he obtained with grain in motion, or while the grain was being drawn out of the bin. This was undoubtedly due to the weakness and unsuitability of his appliances, because, from the many observations and tests made by the Author, no such increase of pressure could take place.

The curves of pressure apparently obtained by him do not agree in any particular with any records of tests made by others. Prante himself states that his apparatus was found to be weak, and concludes as follows:—"For the present I must leave the reader to consider the preceding tests, insufficient as they are, as a first contribution, which is to furnish an incenti.e to further and more accurate tests."

It may be remarked here, that while full credit is due to Mr. Prante for his honest efforts to contribute to the very meagre knowledge on this subject, and for his frankness in admitting the imperfections of both his testing apparatus and records, the publishing of admittedly unreliable engineering data obtained from tests, is of doubtful expediency. While this unreliable data may not mislead the experienced, yet we have ample evidence to show that unscrupulous persons, to serve their own purposes, will make quotations from these records, while suppressing the full facts, which may be both unfair to the author of the said tests, and cause serious damage and loss to others.

In 1897, Wilfred Airy, B.A., Mem. Inst. C.E., prepared and read a paper on "The pressures of Grain" before the Institute of Civil Engineers, London, a full report of which is published in the Proceedings, Vol. CXXXI, 1897-98.

While this paper is a valuable contribution on the subject of Grain Pressures, the question is treated from a theoretical point only. Mr. Airy appears to have been lacking in the necessary practical experience to enable him to take into consideration all the conditions which apply in actual practice.

Mr. Airy first made tests with a view to obtaining the co-efficient of friction between grain and grain (or the angle of repose) and the different materials of which bins are usually constructed. From this data and the weight of the grain, he produced a formula for calculating the pressures in a bin of any given depth or breadth. This formula gives the maximum load on the bin bottom when the depth of grain in the bin is equal to 3-5 times the breadth. As, however, a further depth of grain is added to the quantity already in the bin, the load on the bottom decreases until the grain ultimately reaches a depth when the only remaining weight on the bin bottom would be that of a pyramid or cone of grain whose sides were at the greatest angle of repose and the base equal to the horizontal area of the bin and all the balance of the weight of the column would be carried by the bin walls, thus entirely neglecting the important fact that the weight on the bottom having once obtained the maximum, cannot be decreased by any increase of lateral pressure, unless by slightly lowering the bottom.

Airy's formula therefore shows the paradox of the greater the weight and depth of grain in the bin, the less the load on the bin bottom. Considering the bin to be filled with grain, and taking the total horizontal pressure against the bin sides multiplied by the coefficient of friction, this would be theoretically correct. but this calculation totally ignores the fact that this total side pressure is not produced until the bin is filled. Practically this decrease of pressure or load on the bottom could be produced by slightly lowering the bin bottom away from the bin sides after the bin was filled, since by this time sufficient side pressure would have been produced to support the full contents of the bin. It would, however, be quite safe to use Airy's formula since in designing a bin the bin bottom would require to be of sufficient strength to carry the maximum load for the lower depth of grain, and the walls for the maximum horizontal pressure and the vertical load.

In 1897 the failure of a Coal Bin in Patterson, N.J., started a discussion in "Engineering News" on the pressures produced by coal and other granular materials stored in shallow bins. This discussion was started by the Editor of "Engineering News," and a number of engineers throughout the country contributed more or less valuable letters on the subject, but no records of actual tests were given, and since the discussion was confined almost entirely to shallow bins there is very little of it applicable to the deep bin problem.

The Editor of "Engineering News," in his original article, says as follows:—

"The fact is that there is comparatively little matter in Engin-"eering Literature upon the strains in such structures as Grain Ele-"vators and Coal Bins which appeal to the practical engineer as "thoroughly safe and reliable."

"We have therefore thought that a general discussion upon the "subject of bin pressures might be of interest to our readers. Let "us preface it, however, by remarking that we lay no claim to in-"fallibility and shall be glad to have errors in the discussion pointed "out to us."

Commenting upon the lack of available data on the subject of the pressure produced by granular material the Editor remarks as follows:—

"We fully agree, however, that the matter of the relation between "the downward and lateral pressure in granular masses is one "which ought to be experimentally investigated. Perhaps some of "the engineering students who are looking about for subjects for "their engineering theses that have not been threshed over by prev-"ious generations, will take the matter up.

It is understood that Mr. Max Toltz, Mem. Am. Soc. C. E., made certain tests for grain pressures in connection with The Great Northern Railway Company's 3,000,000 bushel steel elevator, which he designed and built at West Superior, Wis. The Author has not secured any records of said tests, but it is hoped that Mr. Toltz will be able to give them on the discussion of this paper.

About two years ago, or at the time of the controversy regarding the Montreal Harbour Commissioners' Elevator, Dr. H. T. Bovey, C.E., Dean of Applied Science, McGill University, and John Kennedy, C.E., Chief Engineer, Montreal Harbour Commissioners, made a series of tests in the bins of the Canadian Pacific Elevator, Montreal, and the Great Northern, Quebec. It is hoped that both gentlemen will be able to take part in the discussion of this paper and give the results which they obtained.

At the beginning of the year 1900, it became apparent that wooden elevator construction must soon be replaced by buildings less liable to destruction by fire, and since this would involve entirely different materials of construction, the Author realized that more accurate data was required to permit of intelligent and economical design of new construction. He therefore determined to conduct a series of tests with a view to gaining such information.

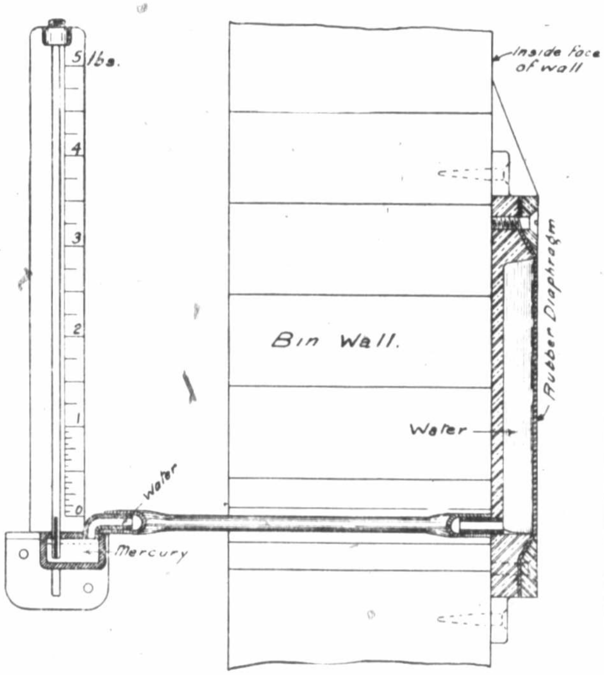
On first consideration, the problem seemed almost too difficult to undertake on account of there being no known appliance suitable for the purpose of making the tests and the time and expense involved.. The first and most difficult problem to be met was the design of the testing appliance to make the tests in a full-sized bin which would meet all requirements as to accuracy, decrease as well as increase of pressure due to the movement of the grain, and would record the pressures in different parts of a bin under all working conditions.

Several styles of weight scale-levers and beams were first designed all of which were open to serious objection and the difficulty seemed unsurmountable until the Author conceived the idea of using a hydraulic diaphragm and a mercury or water column gauge, the first of which could be placed inside the bin at any given point either on the sides or bottom, with a tube leading through a small hole in the wall to the gauge, and therefore ascertain the pressure per square inch either vertically or laterally at any point of the bin. This appliance was immediately designed, care being taken to get the pressure face of the diaphragm, which was made of pure sheet rubber as large as practical, so that there would be no receding of the face by displacement of the water, owing to the pressure raising the mercury in the small gauge glass. When this appliance was manufactured and tested, it was found to be an accurate and sensitive weighing machine, and it is believed that no more suitable or accurate testing gauge can be found for the purpose. (See illustration.)

On the 10th of April, 1900, and following days the tests were carried out in the full-sized bins of the Canadian Pacific Elevator at West St. John, N.B., the inside dimensions of the bin being 12′ 0″ x 13′ 0″ and depth above the hopper bottom 67′ 6″; the grain being used was Manitoba Wheat, weighing 49.4 pounds per cubic foot.

The hopper bottom of the bin was first filled with grain and leveled off. To obtain the lateral pressure the diaphragms were then placed in position against the walls a short distance above the hopper bottom, with the face vertical, and on top of a small platform attached to the hopper bottom with face horizontal, to obtain the vertical pressure.

The gauges were set up in an adjoining bin, a small rubber tube forming the connection between the diaphragm and the mercury cup of the gauge, the diaphragm and tube being completely filled with water. The grain was then weighed and run into the bin in the usual manner, the first draft having a clear drop of 70 feet. Each draft weighed 30,000 pounds and gave a depth of 3′ 9″ in the bin. The gauge was closely observed as the grain was running in, and the maximum readings taken and recorded as each draft was complete, until the bin was filled. The gauges and the grain were then al-



— GRAIN PRESSURE TESTS —

— HYDRAULIC PRESSURE DIAPHRAGM —

— AND —

— MERCURY PRESSURE GUAGE —

- SHEET No 20.-

— J A JAMIESON ENG.-

— MONTREAL JULY 1903

lowed to remain for about 18 hours, at the expiration of which time there was practically no change in the reading of the gauge. The grain was then drawn out of the bin and the gauge closely observed and the readings recorded as each 30,000 pounds were weighed out, the maximum readings during the draft being taken. The grain was drawn off at the rate of 9,000 bushels per hour. The pressures fluctuated considerably as the grain was being drawn out with a maximum increase of 4% over that obtained when filling the bin or when the grain was at rest. The position of the diaphragm was then changed to near the corner of the bin and the above procedure repeated with practically the same readings as in the first test. During the running out test, the valve was suddenly closed several times, stopping the downward movement of the grain; this gave a slight increase of pressure, and when the valve was again opened a corresponding decrease of pressure.

The pressures obtained both vertical and lateral were then plotted, the maximum readings of the different tests being used. The plottings and curves obtained are shown in the accompanying diagram, plate No. 5, and the pressure per square inch both on the bin bottom and against the walls are given in the accompanying Tables, which also show the total side pressure, the relative vertical and lateral pressures and the co-efficient of friction between grain and walls. The column of "Equivalent Fluid Pressure" shows the pressure that would be produced by a fluid of the same specific gravity as the grain due to the different heads, or in other words, the pressures which would exist if there was no friction between the grain and the bin walls.

GRAIN PRESSURE TESTS.

Wheat.—Cribbed Wooden Bin.—Bottom Pressure Tests.
Canadian Pacific Ry. Elevator, St. John, N.B.

Inside dimensions of Bin 12′ x 13′ 6″=23,328 sq. inches. Depth of Bin 67′ 6″. Each draft weighed into Bin=30,000 lbs.=3′ 9″ high. Wheat used for Test, No. 1 Hard Manitoba, weighing 49.4 lbs. per cu. ft. Total grain above diaphragm, 540,000 lbs. To fill hopper bottom, 16,500 lbs.=556,500 lbs.=Total weight of grain weighed into bin.

Grain weighed into bin.	Height of grain column.	Pressure of grain on diaphragm.	Grain carried on bottom.		Grain carried on bin-sides.	
			Weight.	°/o total weight grain.	Weight.	°/o total weight grain.
lbs.	ft. in.	lbs.	lbs.		lbs.	
30,000	3 9	1.118	26,081	86.9	3.919	13.1
60,000	7 6	1.948	45,443	75.7	14,557	24.3
90 000	11 3	2.499	58,297	64.7	31.704	35.3
120,000	15 0	2.927	68 291	56.9	51.719	43.1
150,000	18 9	3.247	75,746	50.4	74 254	49.6
180.000	22 6	3.482	81,228	45.1	98 772	54.9
210 000	26 3	3.635	84,797	40.3	125 203	59.7
240 000	30 0	3.752	87.527	36 4	152,473	63 6
270,000	33 9	3.843	89,650	33.2	180,350	66.8
300.000	37 6	3 924	91,539	30.5	208 461	69.5
330,000	41 3	3.987	93,009	28.1	236 991	71.9
360,000	45 0	4.041	94,268	26 1	265,732	73.9
390,000	48 9	4.077	95,108	24.3	294,892	75.7
420.000	52 6	4.095	05,528	22.7	324.472	77.3
450,000	56 3	4.113	95,948	21.3	354 052	78.7
480,000	60 0	4.129	96 321	20.1	383 679	79.9
510,000	63 9	4.129	96,321	18 8	413.679	81.2
540 000	67 6	4.129	96,321	17.8	443,679	82.2

Carried on bottom 96,321 on sides 443,679 lbs.
In hopper 16,500

Total carried by bottom : = 112,821 lbs.
Total carried by sides : = 443 679 "

Total grain in bin : = 556,500 lbs.

GRAIN PRESSURE TESTS.

Wheat.—Cribbed Wooden Bin.—Side Pressure Tests.

Inside dimensions of Bin 12′ 0″ x 13′ 6″=23,328 sq. inches, Depth of Bin 67′ 6″.=18 sections=3′ 9″ high. Wheat weighing 49.4 lbs. per bushel. Each section of grain column in Bin=3′ 9″ high, weighing 30,000 lbs. Combined area of four sides of bin=27,540 sq. inches.

Grain weighed into bin.	Height of grain column.		Equivalent fluid pressure.	Side pressure of grain on diaphragm.	Side pressure per section.
lbs.	ft.	in.	lbs.	lbs. per sq. inch.	lbs.
30,000	3	9	1.286	0.343	9.446.220
60.000	7	6	2.573	0.938	25,832.520
90,000	11	3	3.859	1.317	36 270.180
120.000	15	0	5.145	1.615	44.477.100
150.000	18	9	6.431	1.804	48.682.160
180,00o	22	6	7.718	2.011	55,382.940
210.000	26	3	9.004	2.111	58.136.940
240,000	30	0	10.290	2.201	60.615.540
270,000	33	9	11.576	2.278	62,736.120
300.000	37	6	12.863	2.345	63,581 300
330.000	41	3	14.149	2.381	65,672.740
360,000	45	0	15.435	2.417	66,564 180
390,000	48	9	16.721	2.435	67 059.900
420,000	52	6	18.008	2.453	67.555.620
450.000	56	3	19.294	2.453	67.555.620
480,000	60	0	20.580	2.453	67,555.620
510,000	63	9	21.866	2.462	67 803.480
540,000	67	6	23.153	2.462	67,803.480

Total side pressure. . 1,004.631.660

RELATIVE VERTICAL AND LATERAL PRESSURE.

(See bottom Pressure Table.) Pressure on bottom due to 67′ 6″ grain = 4.129 lbs. per sq. inch × area of bottom, 23,328 sq. ins. = 96.321 lbs.

Maximum pressure on side of bin due to 67′ 6″ grain = 2.462 lbs. per sq. in.

$$\frac{\text{Vertical pressure} = 4.129}{\text{Lateral pressure} = 2.362} = 59.6\ \%\ \text{of vertical pressure, or vertical pressure} = 1.66\ \%\ \text{of lateral pressure.}$$

Co-efficient of friction between Grain and sides of bin $= \dfrac{\text{Weight oarried by sides} = 443{,}679 \text{ lbs.}}{\text{Total side pressure} = 1004{,}632 \text{ lbs.}} = .441$

TESTS IN MODEL BINS.

The preceeding described tests in the full-sized bins of the Canadian Pacific Elevator at St. John, N.B., gave all the data necessary to proceed with confidence with the designing of bins of approximately the same dimensions as the ones in which the tests were conducted. There still remained, however, considerable data to be obtained in order to devise a formula or system of calculating the pressures, and the proportion of grain weight that would be carried by the sides and on the bottom of bins of any ratio of breadth to depth or constructed of different materials.

After fully considering the question, the Author believed that all the necessary data could be obtained by conducting a series of tests in model bins. This was undertaken in the winter of 1902-03 and the following testing apparatus was designed and manufactured:

One Bin 12″ square, 6′ 6″ deep, the sides being made of corrugated or trough plate steel, the corrugations running horizontally and attached to corner columns.

One Bin 12″ square, 6′ 6″ deep, made of smooth wood boards.

One of the same dimensions as the last with the boards roughened on the inside of the bin, to imitate a bin of ordinary wooden cribbed construction.

One of the latter bins was also lined with flat steel plates to imitate a square steel bin.

One bin 6″ square, 6′ 6″ deep.

One round steel bin 6″ diameter and 6′ 6″ deep.

One round steel bin 12″ diameter, and 6′ 6″ deep.

Six Hydraulic diaphragms: One being 12″ square, one 12″ in diameter, one 6″ square, one 6″ in diameter, one rectangular 3 x 12″ and one 2″ square.

In testing for bottom pressure the diaphragms were the full size of the different bins, forming a complete bottom for them. The total weight of grain coming on the bottom therefore rested directly upon a thin sheet of pure rubber, which in turn rested on the water contained in the diaphragm, while the bin itself rested upon the frame of the diaphragm. Connection was made between the diaphragm and the glass gauge column by a rubber tube, which was set vertically alongside of a measuring scale. To obtain the lateral pressure the diaphragm was made to form part of the bin wall, the face being set vertical and in line with the inside face of the bin. (See Diagram of Test Bins.)

The whole apparatus was set on a platform scale so that the weight of grain could be accurately taken as the bin was filled. The measuring scale was then adjusted accurately to the height of water in the gauge glass. Grain was then poured into the top of the bin in drafts varying from 25 to 6¼ pounds each, according to the size of bin used, and readings of the height of water column in the gauges taken and recorded at each draft as the bin was filled.

Tests for bottom or vertical pressure were made in all the different bins, and for lateral pressure in a majority of the bins.

In the square trough plate, or corrugated steel, bin, tests were made with the following varieties of grain, viz:—Wheat, peas, corn or maize, and flax-seed; and in the cylindrical bin, tests were made with thoroughly dry, clean river sand. The grain used was the highest grade that could be procured and was thoroughly clean and commercially dry. The wheat was No. 1 Manitoba Hard, weighing 50 lbs. per cubic foot; peas weighed 50 lbs.; corn 45 lbs., and flax-seed 41.5 lbs. The sand weighed 100 lbs. per cubic foot. The weights as above were all carefully ascertained by means of the Grain Testers' Balance. Wheat was used to conduct the full series of tests, while the other grains were only tested in two of the bins, with a view to establishing the comparative pressures with wheat, over 50 separate tests being made in all.

The tests were all carried out in duplicate. After the first series were completed, the readings plotted and calculations extended, the second series were undertaken with a view to checking the first, and to gain such additional information as was found to be desirable. In the first series the grain was poured into the bin from a pail, while in the second series of tests a funnel with a large opening was used. This did not make any difference in the maximum pressures obtained, but the latter mode of filling the bin gave very accurate curves when plotting the diagrams, while the plottings from the first series were in some instances somewhat erratic.

With a view to ascertaining the effect of vibrations or shocks on the pressures, the sides of the bin were sharply tapped with a hammer. It was found that by tapping the bin near the bottom only, the pressure or load on the bottom could be decreased. This was found to be due to a slight deflection in the bin sides, which, however, was not sufficient to allow the grain in the upper part of the bin to settle down. When, however, the tapping was continued from the bottom to the top of the bin on all sides, the grain in the bin could be settled from 2 to 3 inches, giving a slightly increased pressure on the bottom.

In test No. 1A, the full records of which are here given, it will be noted that the settling of the grain amounted to 2¼ inches, giving a maximum reading of 10½ inches of water, or an increase due to the shock of 1¾ inches of water, equal to total increased weight on bottom of approximately 9 lbs. or less than 3%. It may be stated that this shock was proportionately very much greater than could be produced under ordinary conditions in large elevator bins.

The Author may state here that while vibration or shock will slightly increase both the vertical and lateral pressure, as the lateral pressure increases the total friction on the wall will correspondingly increase and therefore there cannot be found any good reason for assuming any material increase of pressure due to shocks.

Again, by slightly raising the bin with screws inserted between the frame of the diaphragm and the bottom of the bin walls, the pressure on the bottom could be very materially decreased. This decrease allowing the water in the gauge to recede from the maximum of 10½ inches to 7 inches, clearly shows that the greater the pressure on the sides the greater the load carried by the walls.

Again by placing Standard weights of 50 lbs. each on top of the grain, the pressure on the bottom could be only slightly increased by each weight applied, while the pressure on the bottom again decreased as the weights were removed.

This experiment was repeated a number of times, in one case 400 lbs. of weights being applied, with practically the same results in every case; indicating clearly that the increased pressure on the bottom by the application of weights on the top of the grain, was due to a slight vertical compression of the bin walls, or the elasticity of the grain.

On the bin being again lowered to its original position, while no increase of lateral pressure was shown by the side diaphragm, there was a very large increase of pressure on the bottom diaphragm, or sufficient to cause the water to flow out of the top of the 4 ft. gauge glass tube, which was not therefore long enough to record the pressure ; in fact, the total weight of the grain was then resting on the bottom diaphragm, and in addition the grain was acting as a column to support the weight of the bin itself.

Very careful tests were also made to ascertain the pressure due to grain in motion, or when the grain was being drawn out of the bin. To obtain the bottom pressure, the grain was drawn from an opening in the side of the bin close to the bottom. There was found to be a decrease of pressure on the bottom when the gate was opened and this decrease was maintained until the bin was about half emptied, then it became approximately the same as when the bin was being filled. Near the bottom the pressures showed an increase over the curve obtained when filling the bin; this, however, was entirely due to the necessity of drawing the grain from the one side of the bin, as when nearly emptied, the remaining grain was all on one side of the bin and therefore nearly all resting on the bottom.

When the grain was being drawn from the opening at the side of the bin, it was found that there was considerable difference in lateral pressure on the different sides. On the side directly opposite to the opening there was a large increase of pressure, and on the same side as the opening the pressure decreased to less than half, when the 3″ x 12″ rectangular diaphragm was being used, and when the 2″ square diaphragm was placed directly over and a short distance above the opening, there proved to be practically no lateral pressure at this point.

When the bin is being filled or when the grain is being drawn from the opening of a square or cylindrical bin through an opening exactly in the centre, a line drawn vertically through the centre of the bin is the centre of pressure, and the lateral pressure per square inch is equal on all sides of the bin. If, however, the grain should be drawn from an opening in the side of the bin, or in the bottom close to the side, then, owing to the moving column of grain being over the opening, the centre of pressure is changed, and the lateral pressure is considerably increased on the side opposite to the opening and decreased on the side over the opening, thus throwing very uneven strains into the bin walls. In a square bin, this will simply throw the increased pressure on the far wall, but in a cylindrical bin this must have a very injurious effect, unless the walls should be of very rigid construction. In a steel tank, the walls of which are very thin and have practically no rigidity, this uneven pressure tends to throw the tank considerably out of round, while the decreased pressure on the side over the opening makes this part of the tank shell very unstaple as a column to carry the vertical load, with the result that steel tanks often buckle inward at varying distances above the opening.

This conclusively shows that in all bins and especially those of cylindrical shape, to avoid these excessive strains, the grain should always be drawn from an opening in the centre of the bin.

This fact has an important bearing on the weaknesses developed by different tank constructions and will be referred to in connection with the "Problem of Grain Bin Design."

To properly ascertain the lateral pressure when the grain was being drawn from an opening in the centre (which is the usual manner in small bins) the bin was provided with a hopper bottom, with the gate opening directly in the centre, the diaphragm being placed on the side as before. The grain was then drawn out and weighed, the gauge carefully observed, readings recorded at the end of each draft, or when the gate was closed, and to ensure getting all fluctuations of pressure, two or three intermediate readings were taken while the grain was in motion.

Several similar tests were made with varying sizes of gate openings and grain running out at speeds varying from 50 lbs. to 120 lbs. per minute, and the increase of lateral pressure due to grain in motion over grain at rest, or when the bin was being filled was found to vary from 5% to 9.3%, the latter being for the highest speed, which is, however, relatively much greater than would be attained in practice in full-sized bins.

Tests were also made by pouring grain in at the top at varying speeds, while it was being drawn out at the bottom, but this was found to have no appreciable effect until the bin was nearly emptied, and the pressure had considerably decreased. By pouring grain in at a higher speed than it was being drawn out, we could again raise the pressure, but in no case did this raise the pressure beyond the maximum of 9.3% over that obtained while filling the bin.

If the grain is drawn from the centre of the bin, it may be safely stated that the increase of pressure due to the grain in motion, over grain at rest, or when the bin is being filled, will not exceed 10% and the increase will be considerably less than this when the ratio of the area of the gate opening to the area of the bin is 1.150, which is approximately the usual practice in standard sized bins.

That no large increase of pressure actually takes place due to grain in motion, when the grain is being drawn from the centre of the bin bottom is, I believe, fully demonstrated by the above tests, and also by the tests in the full-sized bins at St. John, N.B. In addition, the Author has on three different occasions made careful measurements of the deflection of the walls of different elevator bins both when they were being filled; after the grain had been at rest for several days and when the grain was being drawn out. One of the records is as follows:

Bin filled with wheat. Cribbed spruce walls.

Thickness of wall 6¾″. Clear Span 13′ 5¼″.

Depth of Grain in Prism of bin, 65 feet.

Height of grain above point of measurement for deflection 60 ft.

Deflection when first loaded, ⅝″.

Deflection when four days under load, 11-16″.

When grain was being drawn out, the deflection varied from ⅝″ to a maximum of slightly under ¾″, the latter deflection being when the gate was suddenly closed.

Careful calculations were made for the fibre stress in the walls, and it was found that this deflection would be approximately equal to a distributed load of 325 lbs. per square foot of wall.

The Author has an experience extending over twenty years in the designing, superintending construction and the operation of grain elevators, during which time he has always given close attention to the details of the construction and in most cases to the working of the elevator after completion, and with one exception, when a shipping bin bottom failed, has never had any weakness developed in any part of a bin or other construction, and this instance was entirely due to the operating staff disregarding instructions in filling the bin for the first time, causing the full settlement to take place at once. If there was any material increase of pressure due to grain in motion, it would most probably have been discovered during the years of his experience.

Tests were also conducted with a view to ascertaining the complete movement of the grain when it was being drawn out and to find the relative speed of the downward movement of the grain at different points in the bin. To facilitate this, the bin was provided with a glass side, and different coloured grains placed at equal distances apart vertically. The gate was then opened and the movement of the grain down the glass side observed and the time taken when each of the coloured grains came out of the bottom. It was found that a column of grain directly over the opening in the centre of the bin moved at the highest rate of speed, the vertical movement decreasing towards the sides, the whole column of the grain in the bin, however, moving downward. There was a small triangular section of grain at the bottom of the bin, which did not move out until the last. Thus, a part of the first grain put in the bin was the last to run out. (See drawing of Test Bins.)

Tests were also made by placing small ½ x 24 gauge steel bars across the centre of the bin and in both directions, spaced 6″ apart vertically. Tie bars being set on edge with a view to presenting the least resistance to the moving grain column. It was found that tie bars had a very decided effect on the vertical movement of the grain; in fact, ⅓ less grain would run through the opening at the bottom in a given time, as in the same bin with the same opening, without tie bars. This shows that when the grain is moving down a very heavy strain must be thrown into the tie bars, and through the tie bars into the walls, and that the vertical grain load carried by the walls will be considerably increased, and tie bars, if used at all, should not run across the centre of a bin. All tie bars or other obstructions, however, in a bin will be subjected to considerable strain and should be avoided if at all possible. The movement of the grain in a bin both with and without tie bars and also when the grain is being drawn from an opening in the side of the bin is fully shown in Fig. No. 17.

All the above tests were made in bins 12″ square and 12″ diameter x 6′ 6″ deep, and it was found that with walls giving the same co-efficient of friction and having the same ratio of wall area to horizontal area of the bin, there was practically no difference in pressure between the square and cylindrical bins.

The pressure varied, however, directly as the co-efficient of friction, taking as an example Test No. 1A, Bin 12″ square, horizontally corrugated steel sides. Wheat in bin 325 lbs., weight on bottom 45,460 lbs. co-efficient of friction 0.468.

Test No. 5A, bin 12″ square Flat steel plate sides. Wheat in bin 325 lbs. weight on bottom 60.397 lbs., co-efficient of friction 0.355. The latter gave vertical and lateral pressures 32.9% greater than the former, and the walls of the former bin carried 4.88% more of the total weight of the grain in the bin than the latter.

Tests were made in the bins 6″ square and 6″ diameter and 6′ 6″ deep, with a view to determining the difference in pressure due to difference in breadth or diameter and it was found that in each case the pressure per square inch was approximately twice as great in the 12″ bin as in the 6″. Thus, if four 6″ bins were filled with 325 lbs. of grain, the combined load resting on the bottom of the four 6″ bins would only be one half as much as in one 12″ bin.

A test was also made by using a stout canvas bag or cylinder 12″ diameter, 6′ 6″ deep, provided with metal rings at both ends, one ring attached to the metal frame of the 12″ circular diaphragm and a 6″ gauge glass was used.

It will be noted that this formed a cylindrical bin with wall incapable of supporting any vertical load. The bag was extended to full height and the wheat poured in at the top. When the bag was full, it was found that the height of water in the gauge glass multiplied by the area of the diaphragm gave 1½ lbs. more than the total weight of grain, showing that the grain column was supporting a part of the weight of the bag, which weighed 3¼ lbs. and incidentally proving the correctness of the hydraulic diaphragm and water column as an accurate weighing machine.

A test was also made in the 12″ diameter cylindrical bin, using sand instead of grain. The sand was thoroughly dry, clean and of good building quality. Angle of repose 34°, weight 100 lbs. per cu. ft. 537½ lbs. were put into the bin, and it was found that 99.211 lbs. or 19.45% was resting on the bottom and 438.289 lbs. or 81.55% carried by the sides. (It is interesting to note that both sand and wheat gave approximately the same percentage of total weight resting on the bin bottom or diaphragm. The wheat weighed 50 lbs. per cubic foot and gave 18.29% on the bottom and 81.71% carried on the sides.)

By sharply tapping the cylinder on both sides with the hands, we settled the sand 3 inches, increasing the load on the bottom to 120.272 lbs. or 22.37% of the total weight of sand in the bin.

In conducting the tests, the co-efficient of friction between the grain and the bin walls was readily obtained in the following manner: Having found the total grain weight resting on the bottom of the bin, we deduct this bottom weight from the total weight of the grain in the bin. This gives the weight supported by the walls, and by dividing this weight into the total side pressure, we get the co-efficient of friction. The total side pressure was obtained by multiplying the pressure per square inch for each section of the bin, by the area of the walls, and the sum of the pressures per section give the total pressure on the bin walls.

The co-efficient of friction obtained in the above manner agreed very closely in every case with the co-efficients obtained by means of the apparatus shown in Fig. No. 16.

To obtain the relative vertical and lateral pressure produced by the grain, we divide the pressure per square inch on the bottom of the bin, by the pressure per square inch on the side of the bin, both having been obtained by means of the hydraulic diaphragm and gauge.

In every case when wheat was being used for testing, we found the lateral pressure to be approximately equal to 60% of the vertical pressure, or the vertical pressure to be equal to 1.67% of the lateral pressure. This agrees exactly with the angle of repose of 28° for wheat which was obtained by means of the apparatus shown in Fig. No. 16.

To obtain the relative pressures due to the increased depth or diameter of bin, tests were made in bins 6″ square, with a depth equal to 13 times the breadth; and in 12″ square. and a depth equal to 6.5 times the breadth; also in round bins 6″ diameter, and a depth equal to 13 times the diameter; and one 12″ diameter, depth 6.5 times the diameter. It was found in each case that the pressures per square inch both vertical and lateral in the larger bins were approximately twice as great as in the smaller bins, and that the weight resting on the bottom of the larger bins was approximately 8 times as great as in the smaller bins, or twice as great as the sum of the weight for four 6″ bins. This greater load on the bottoms of the larger bins was due to the pressure per square inch being double, while the area was four times as great as in the smaller bins. It was the Author's original intention to have made tests in bins 18 and 24″ square, to ascertain if the relative increase in pressure would increase with the breadth of bin. This, however, was found to be unnecessary as it was readily seen that since the proportion of the grain weight carried by the sides was dependent upon the ratio of horizontal area or the weight of the grain column, to the area of the bin walls and if we increase the breadth and maintain the same ratio of breadth to depth, the pressure will increase directly as the breadth. As, however, the maximum pressures are reached at a depth of 3.5 times to 4 times the breadth, it may be stated that approximately both the vertical and lateral pressure will increase directly as the breadth.

Wheat and corn are the two varieties of grain which are most largely stored and handled; we have therefore taken wheat as a basis of all our tests and calculations. Taking wheat weighing 50 pounds per cubic ft. as a standard, we find that corn weighing 45 pounds per cu. ft. will give approximately the same pressure per square inch as wheat; this being due to the slightly lower co-efficient of friction between the corn and the bin walls.

Peas, weighing 50 lbs. per cu. ft. give a vertical and lateral pressure of approximately 20% greater than wheat; while flax-seed, weighing 45 lbs. per cu. ft. will give a lateral pressure 10% greater, and a vertical pressure 12% greater than wheat, this being due to its lower angle of repose, and lower co-efficient of friction. A bin designed with a proper factor of safety for wheat, will, however, be quite safe for the storage of peas or flax-seed.

Taking a trough plate bin filled with wheat as a standard, and with a depth of bin equal to the breadth, we find that 57.1% of the grain load is carried on the bottom and 42.9% carried by the walls. At a depth equal to twice the breadth, 38.9% is carried on the bottom, and 61.1% by the sides. Depth equal to 4 times the breadth 21.9% on the bottom and 78.1% by the sides. Depth equal to 5 times the breadth 17.6% carried on the bottom and 84.9% on the sides. Depth equal to 6 times breadth 15.1% carried on the bottom and 84.9% on the sides. Depth equal to 6.5 times the breadth 13.9% carried on the bottom, and 86.1% by the sides.

The above is for the weight of grain in the prism of the bin only, and if the bin is provided with a hopper bottom the full weight of the contents of the hopper bottom must be added to the bottom load, since the walls cannot carry any part of this weight.

THEORETICAL CALCULATIONS FOR GRAIN PRESSURES.

Dealing with the question theoretically, it is well-known that if we pour grain upon a level floor that it will assume the form of a cone with sloping sides at a considerable angle from the horizontal, and if we endeavour to run grain through a spout, the spout must have a considerable angle before the grain will run, thus clearly indicating a considerable friction, both of grain on grain and between grain and any material of which the spout or a bin wall may be constructed. It will be readily understood that if there was no friction between the grain and the bin walls, the total grain weight would rest on the bottom, and if there was no friction within the mass of grain, the horizontal pressure would be equal to that produced by a fluid of the same specific gravity as grain; it is this friction on the one hand and the lack of cohesion between the particles on the other, that distinguishes a granular mass from either a fluid or a solid. If the sides or walls of the bin are constructed of very smooth material or without any projections, the co-efficient of friction between the grain and the walls will be considerably lower than if the walls were built of rough material, and the rougher the wall, the higher will be the co-efficient of friction until it may reach a maximum of grain on grain. As the form of the walls and the materials of construction have a great influence on pressures, it is necessary to establish both the coefficient of friction of grain on grain, and of grain on the sides of bins of different forms or constructed of different materials.

To enable the co-efficients to be readily and accurately obtained the Author designed the simple apparatus shown in Diagram Sheet No. 16. To obtain the angle of repose of grain, the tray which is attached to the pivoted frame is filled and carefully levelled off and the frame balanced, the end holding the tray is then carefully raised until the first movement of the grain takes place and the angle carefully noted and taken as the angle of repose. By attaching to the pivoted frame a piece of any material of which bin walls may be constructed, and again filling a special tray with grain, with the tray inverted with the grain against the face of the bin material, and tilting the frame as before, we find that if the material is rough or has projections placed upon its face, that we can tilt the platform to a considerably higher angle than if the material is smooth. By carefully noting the angle of the first movement of the tray and the grain, and finding the tangent of the angle we obtain the co-efficient of friction between grain and any material of which Bin walls may be constructed by, placing weights on top of the tray, we have ascertained that the co-efficient of friction remains approximately constant for pressures up to five pounds per square inch, which was about the limit of strength of our apparatus.

By careful tests in the manner above described, it has been found that different varieties of grain have angles of repose varying from 24° to 36° and that different samples of wheat will vary from 26° to 34°. The amount of moisture contained in the grain, and even a damp or dry day having considerable influence, the Author therefore decided to adopt a No. 1 Hard Wheat, weighing 50 lbs. per cubic foot and an angle of repose of 28° as a standard, and which will be safe to use for all varieties of grain.

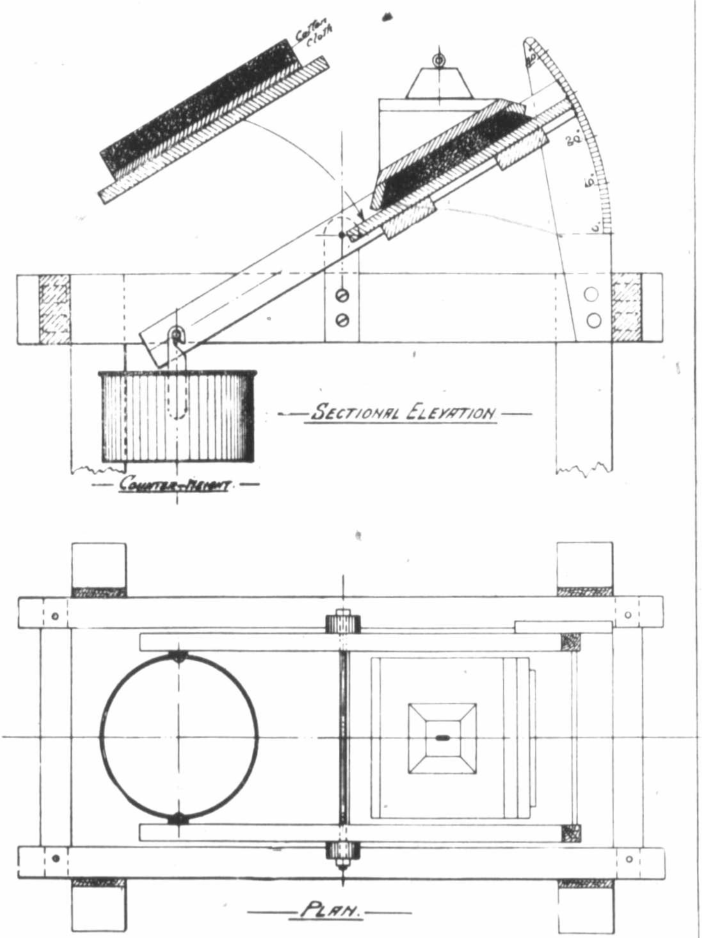
The co-efficient of friction between standard wheat and different forms of walls built of different materials of construction, will vary considerably, but may be safely taken at the values as given in the following table:

TABLE OF CO-EFFICIENT OF FRICTION

Between Wheat and Various Materials of Construction of Bin Walls.

Wheat used for all Pressure Tests No. 1, Manitoba Hard, weighing 50 lbs. per Cubic Foot. Angle of Repose 28°=0.532 Co-efficient of Friction.

	Co-efficient of Friction.
Wheat on Wheat	0.532
" " Steel Trough Plate Bin	0.468
" " Steel Flat Plate, riveted and tie bars	0.375 to 0.400
" " Steel Cylinders, riveted	0.365 to 0.375
" " Cement-Concrete, smooth and rough	0.400 to 0.425
" " Tile or Brick, smooth or rough	0.400 to 0.425
" " Cribbed Wooden Bin	0.420 to 0.450



Grain Pressure Tests

Apparatus for Ascertaining Angle of Repose of Grain and Coefficient of Friction between Grain and Material of Bin Walls.

Sheet No 16.

J.A. Jamieson Eng

It will now be clear that since there is no cohesion between the grains forming the mass, that we will have considerable horizontal pressure, but as there is considerable friction within the mass, it will not be so great as that produced by a fluid of the same specific gravity and since there will be considerable friction between the grain and the confining walls, the pressure and the friction must cause the walls to carry a part of the load, and that the proportion of the weight which the walls will carry must increase as the pressure, and therefore when the total pressure against the circumference of the bin walls, (say for one foot in depth) divided by the co-efficient of friction, becomes equal to the total weight of the grain in that section, then there cannot be any further material increase of either vertical or lateral pressure. It is therefore evident that as the proportion of the weight of each layer carried by the wall is increased with the depth of grain, and particularly when the limiting pressure is reached before the bin is completely filled, the ratio of depth to breadth is an important factor in determining the proportion of the total weight of grain in a bin, that will be carried by the walls and on the bin bottom; and again, since to support a given weight will require a given area of wall, with a given pressure per unit of area, and co-efficient of friction, it is evident that the area of the walls must bear some definite relation to the horizontal area of the bin.

We now find that the proportion of the total weight of grain in a bin that would be carried by the walls and on the bottom of the bin, and therefore the intensity of both the vertical and lateral pressures produced by grain is entirely dependent upon the following factors:—

(1) The co-efficient of friction between grain and the bin walls.

(2) The ratio of the breadth or diameter of the bin to the depth.

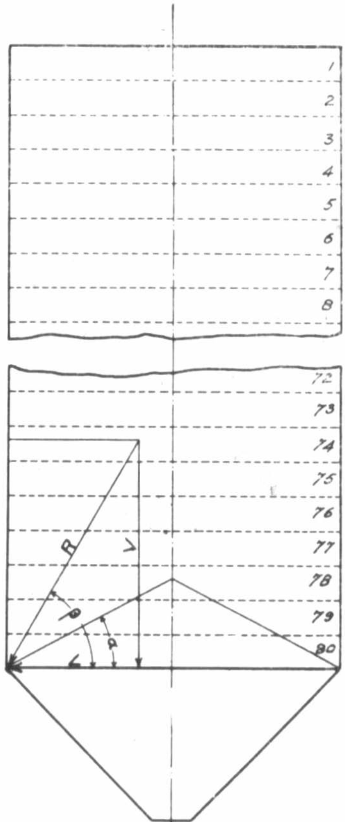
(3) The ratio of the horizontal area or weight of the grain column to the area of bin walls.

(4) The angle of repose of grain, or the ratio of the lateral to the vertical pressure.

The latter is fully shown by Diagram Sheet No. 11.

As the co-efficients of friction will vary with the form and material of the bin wall, we wil select 0.41667 in order to simplify calculations

Having now established the factors and their values which govern the pressures produced by grain, it becomes a comparatively easy problem in simple arithmetic to determine the vertical and



V = Intensity and Direction of Vertical Grain Pressure

L = " " " Lateral " "

R = " " " Resultant " "

α = Angle of Repose or Natural Slope of Grain

β = " " Shear = $45° + \frac{\alpha}{2}$ $V = L \tan \beta = \sqrt{R^2 - L^2}$ $L = V \tan 90° - \beta = \sqrt{R^2 - V^2}$

$R = L \operatorname{secant} \beta = V \operatorname{secant} 90° - \beta = \sqrt{V^2 + L^2}$

For Wheat $\alpha = 28°$ $\beta = 59°$ $V = 1{\cdot}665L$ $L = 0\,6V$ $R = 1{\cdot}167V = 1{\cdot}94L$

Sheet No. 11.

J. A. Jamieson Eng.

Montreal July 1903.

lateral pressures and the proportion of the weight of the contents of a bin of any given breadth and depth, or construction of walls, that will be carried by the walls and on the bin bottom.

For the purpose of illustrating this method, we wil assume a bin 10 ft. square, 100 sq. ft. horizontal area, filled with wheat weighing 50 pounds per cubic foot, each layer one foot thick will contain 100 cubic feet weighing 5,000 lbs. and the area of the four walls for one foot in depth of bin, will be 40 square feet.

Starting with the top layer, we find that the lateral pressure, and therefore the friction between the grain and the walls, is very slight and may be neglected, and assume that the full weight of the first layer is resting on top of the second layer.

We therefore have:

$$\frac{5\,000 \times 40}{400} \times 0\,6$$

This 500 lbs. deducted from the weight of the second layer will leave 4,500 lbs. (which we will call the remaining weight) plus the full weight of the first layer, making 9.500 lbs. which will rest on top of the 3rd layer, and will produce lateral pressure in the third layer sufficient to support 950 lbs., which, deducted from the weight of the 3rd layer, will give a remaining weight of 4,050 lbs. This remaining weight of the 3rd layer plus the remaining weight of the 2nd layer, and the full weight of the 1st layer, will produce pressure on top of the 4th layer, and so on for all succeeding layers. As the weight on top of each layer increases, the lateral pressure will be correspondingly increased, and the greater the pressure against the walls, the greater proportion of each layer that will be supported by the walls. While the weight being added to the bottom pressure by each succeeding layer, will correspondingly decrease, until a depth has been reached where the pressure against the sides becomes sufficient to cause the full weight of the layer to be supported by the walls, then the maximum lateral pressure has been reached, and no further weight will be added to the bottom.

The total weight on the bottom of a bin containing any number of layers of grain will therefore be equal to the sum of the weight of the top layer plus the remaining weights of all succeeding layers, and the weight carried by friction on the bin walls will be the difference between the weight on the bottom and the weight of the total amount of grain in the prism of the bin.

This may be called the "step process," and calculations may be made in this manner to obtain the pressures in any given size, or construction of bin filled with grain or any other strictly granular material.

The two following tables giving the pressures for bins 10 ft. and 20 ft. square and 80 ft. deep, are calculated by the above process.

The two columns at right of the tables give the pressures calculated by "Pressure Factors" obtained by the tests.

VERTICAL AND LATERAL PRESSURE;

Also Proportion of Grain Load Carried by Bin Walls and on Bin Bottom.—Calculated by Step Process.

Bin 10 ft. square, 80 ft. deep.—Wheat, 50 lbs. per cu. ft.; weight 1 ft. depth, 5,000.—Horizontal area of bin, 100 sq. ft.=14,400 sq. inches.—Area of 4 walls for 1 ft. depth=40 sq. ft.=5,760 sq. inches.—Co-efficient of friction between grain and bin sides= 0.41667.

$$\frac{5000 \times 100}{0.41667 \times 40 \times 0.6}$$

Angle of Repose of Wheat, 28°
L=0 6 V

Height of Grain. Ft.	Weight in Bin. Lbs	Car. by Sides. Per ft. Lbs.	Car. by Sides, Totals. Lbs.	Car on Bottom Per ft. Lbs.	Car. on Bottom. Totals. Lbs.	Pressure per sq. in. lbs. By Step Process. Lat l.	Pressure per sq. in. lbs. By Step Process. Vrt'l.	Pressure per sq. in. lbs. By Pr'sure Factors. Lat'l.	Pressure per sq. in. lbs. By Pr'sure Factors. Vrtl
1	5000	000	000	5000	5000	0.00	0.35	0.00	0.29
2	10000	500	500	4500	9500	0.21	0.67	0.13	0.67
3	15000	950	1450	4050	13550				
4	20000	1355	2805	3645	17105				
5	25000	1720	4525	3280	20475	0.72	1.43	0.67	1.38
6	30000	2048	6573	2952	23427				
7	35000	2343	8916	2657	26084				
	40000	2608	11525	2392	28475				
9	45000	2848	14373	2152	30627				
10	50000	3063	17436	1937	32564	1.28	2.28	1.26	2.16
15	75000	3856	35296	1144	39704	1.61	2.78	1.61	2.67
20	100000	4325	56080	675	43920	1.80	3.07	1.81	2.96
25	125000	4601	78591	399	46409	1.92	3.25	1.94	3.14
30	150000	4764	102120	236	47880	1.99	3.35	2.01	3.28
35	175000	4861	126252	139	48748	2.03	3.41	2.07	3.38
40	200000	4918	150740	82	49260	2.05	3.45	2.10	3.44
45	225000	4952	175437	48	49563	2.06	3.47	2.11	3.48
50	250000	4971	200258	29	49742	2.07	3.48	2.12	3.51
55	275000	4983	225152	17	49848	2.08	3.49	2.12	3.53
60	300000	4990	250090	10	49910	2.08	3.49	2.13	3.54
65	325000	4994	275053	6	49947	2.08	3.50	2.13	3.55
70	350000	4997	300032	3	59968	2.08	3.50	2.14	3.56
75	375000	4998	325019	2	49981	2.08	3.50	2.14	3.57
80	400000	4999	350012	1	49988	2.08	3.50	2.15	3.58
Maximum		5000		0	50000	2.08	3.50		

The co-efficient of friction of 0.41667 was chosen to reduce the amount of work required in calculating this table, 0.41667 x 0.6 being 0.25.

VERTICAL AND LATERAL PRESSURE;

Also Proportion of Grain Load Carried by Bin Walls and on Bin Bottom.—Colculated by Step Process.

Bin 20 ft. square, 80 ft. deep. Wheat=50 lbs. per cu. ft. Weight, 1 ft. depth=20,000 lbs. Horizontal area of bin 400 sq. ft.=57,600 sq. inches. Area of 4 walls for 1 ft. depth=80 sq. ft.= 11,520 sq. inches. Co-efficient of friction between grain and bin sides=0.41667.

$$\frac{20\ 000 \times 400}{0.41667 \times 80 \times 0.6}$$

Angle of Repose of Wheat 28*
L=0.6 V.

Height of Grain Ft.	Weight in Bin. Lbs.	Car. by Sides per ft. Lbs.	Car. by Sides Totals. Lbs.	Car. on Bottom per ft. Lbs.	Car. on Bottom Totals. Lbs.	Pressure per sq. in. lbs — By Step Process — Lat.	Pressure per sq. in. lbs — By Step Process — Vrt'l	Pressure per sq. in. lbs — By Pressure Factors. — Lat.	Pressure per sq. in. lbs — By Pressure Factors. — Vrt'l
1	20000	000	000	20000	20000	0.00	0.34	0.00	0.00
2	40000	1000	1000	19000	39000	0.21	0.66	0.00	0.62
3	60000	1950	2950	18050	57050				
4	80000	2853	5803	17147	74197				
5	100000	3710	9513	16290	90487	0.77	1.54	0.56	1.59
6	120000	4524	14037	15476	105963				
7	140000	5298	19335	14702	120665				
8	160000	6033	25368	13967	134632				
9	180000	6732	32100	18268	147900				
10	200000	7395	39495	12605	160505	1.54	2.73	1.34	2.76
15	300000	10247	85317	9753	214683	2.14	3.65	2.02	3.67
20	400000	12453	143395	7547	256605	2.59	4.36	2.51	4.33
25	500000	14160	210955	5840	289045	2.95	4.91	2.91	4.90
30	600000	15481	285955	4519	314145	3.23	5.34	3.21	5.34
35	700000	16504	366434	3496	333566	3.44	5.67	3.46	5.64
40	800000	17295	451405	2705	348595	3.60	5.93	3.63	5.89
45	900000	17907	539779	2033	360221	3.73	6.12	3.75	6.10
50	1000000	18380	630780	1620	369220	3.83	6.28	3.87	6.28
55	1100000	18747	723818	1253	376182	3.91	6.40	3.96	6.43
60	1200000	19030	818430	970	381570	3.97	6.49	4.02	6.55
65	1300000	19250	914262	750	385738	4.01	6.56	4.08	6.67
70	1400000	19319	1011041	581	388959	4.05	6.67	4.14	6.76
75	1500000	19551	1108544	449	391456	4.07	6.66	4.18	6.82
80	1600000	19652	1206612	348	393388	4.09	6.69	4.20	6.88
	Maximum	20000		0	400000	4.17	6.94		

The co-efficient of friction of 0.41667 was chosen to reduce the amount of work required in calculating this table, 0.41667 x 0.6 being 0.25.

While this process is very simple, it is a somewhat long and tedious one, by which to make the calculations for deep bins; but is undoubtedly correct and agrees in every particular with the results obtained from the Author's tests, both in the model and full-sized bins, and also with Janssens' tests. This process may, however, be reduced to a very simple formula since we find that no matter how deep the bin may be, if the walls be not compressed vertically due to the load, we can readily find the maximum vertical and lateral pressure in a bin of any given dimensions, filled with any granular material.

Assuming as above, a bin 10 ft. square, filled with wheat weighing 50 lbs. per cubic foot, the co-efficient of friction between grain and the bin walls as 0.41667 and the angle of repose of the gran as 28° and therefore the ratio of bottom to side pressure as 1 : 0.6. We have the total side pressure resuired in a layer 1 ft. deep to support the total weight of that layer by friction on the wall, as follows:

$$L = \frac{5.000}{0.41667} = 12,000 \text{ lbs. pressure to support } 5,000 \text{ lbs.}$$

and the side pressure per square foot.

$$l = \frac{5,000}{0.41667 \times 40} = 300 \text{ lbs. or } 2.08 \text{ lbs. per square inch.}$$

The bottom pressure per square foot will therefore be

$$V = \frac{5,000}{0.41667 \times 40 \times 0.6} = 500 \text{ lbs. or } 3.47 \text{ lbs. per square inch}$$

and the total bottom pressure

$$V = \frac{5,000 \times 100}{0.41667 \times 40 \times 0.6} = 50,000 \text{ lbs. on horizontal bottom.}$$

It happens that this 50,000 lbs. total weight on the horizontal bottom of the bin is exactly equal to the weight of a column of grain having a height equal to the horizontal dimensions of the bin, and this would hold true for any square or cylindrical bin having the same co-efficient of friction, filled with material having the same weight and angle of repose. If, however, the co-efficient of friction should be lower, the weight on the bottom will be correspondingly higher, or vice versa. If the angle of repose should be lower and the co-efficient of friction between the grain and the bin walls remain the same, then the lateral pressure would be greater, and the weight on the bottom lower, but since a lower angle of repose of the grain will usually give a lower co-efficient of friction, between the grain and the bin walls, the angle of repose of the grain will always have considerable bearing on the latter, in addition governing the relative vertical and lateral pressure.

We will therefore assume a bin of the same size as before, filled with grain weighing 50 pounds per cubic foot with the co-efficient of friction as 0.35, angle of repose of grain 24° and therefore a ratio of bottom to side pressure of 1 : 0.65.

We have the side pressure per square foot:

$$1 = \frac{5{,}000}{0\ 35 \times 40} = 357 \text{ lbs. or } 2\ 48 \text{ lbs. per square inch.}$$

Bottom pressure per square foot

$$V = \frac{5{,}000}{0\ 35 \times 40 \times 0.65} = 549 \text{ lbs. or } 3.82 \text{ lbs per square inch}$$

and the total bottom pressure

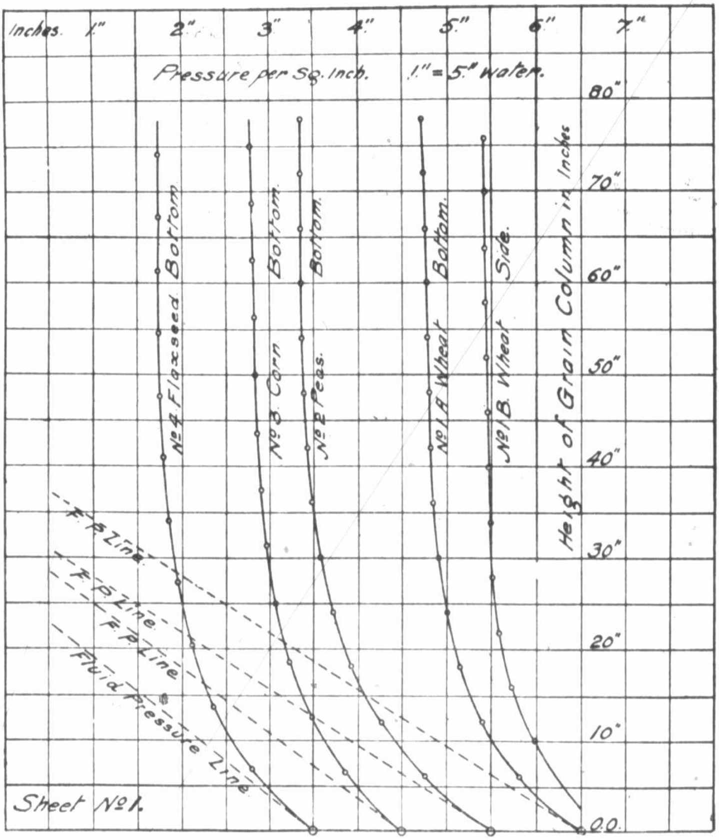
$$V = \frac{5{,}000 \times 100}{0.35 \times 40 \times 0.65} = 54{,}946 \text{ lbs- on horizontal bottom.}$$

It must be borne in mind that the preceeding formula gives only the maximum vertical and lateral pressures and grain load on the horizontal bottom of the bins when the bins are being filled, or the grain at rest, and no matter how deep the bin may be if the bin walls be not compressed vertically due to the load, those maximums will not be materially exceeded. For bins having a depth equal to twice the breadth or less, the pressures by formula are too high and will require to be obtained by the "step process."

In a bin having a hopper bottom, the weight of grain in hopper must be added to total weight on horizontal bottom.

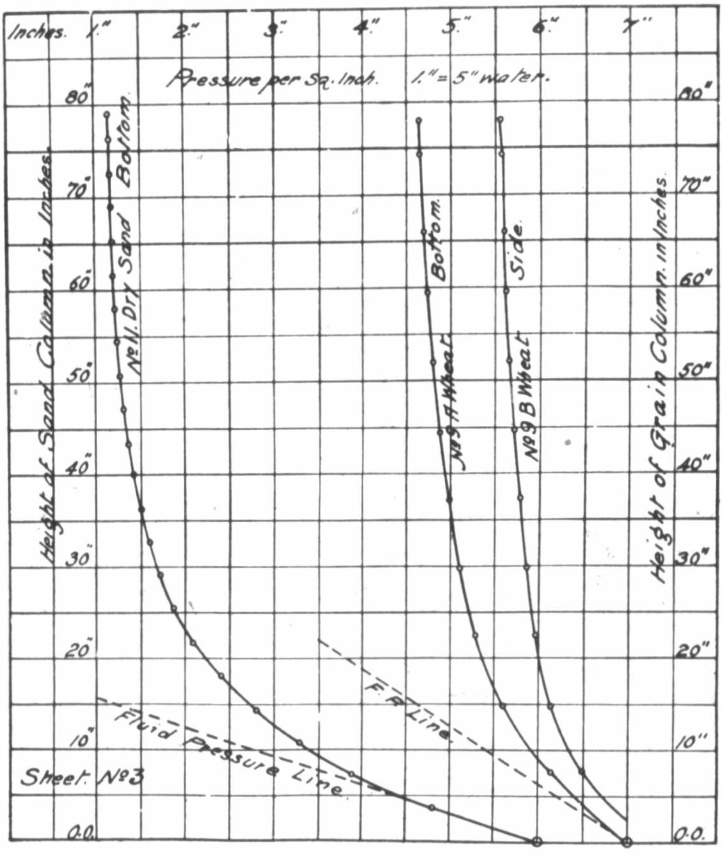
The pressures obtained by the foregoing system of calculation agree acurately with the tests made in the model bins, and the pressures obtained in the latter, multiplied by the increased breadth or diameter agree most closely with the tests made in the full-sized grain bins of the same ratio of breadth to depth.

The Author believes that he has now fully demonstrated that the pressures produced by grain stored in deep bins is only a small percentage of the pressure that would be produced by fluids of the same specific gravity, and that the pressures produced by grain or any other dry granular material stored in bins of any dimensions may be accurately calculated.



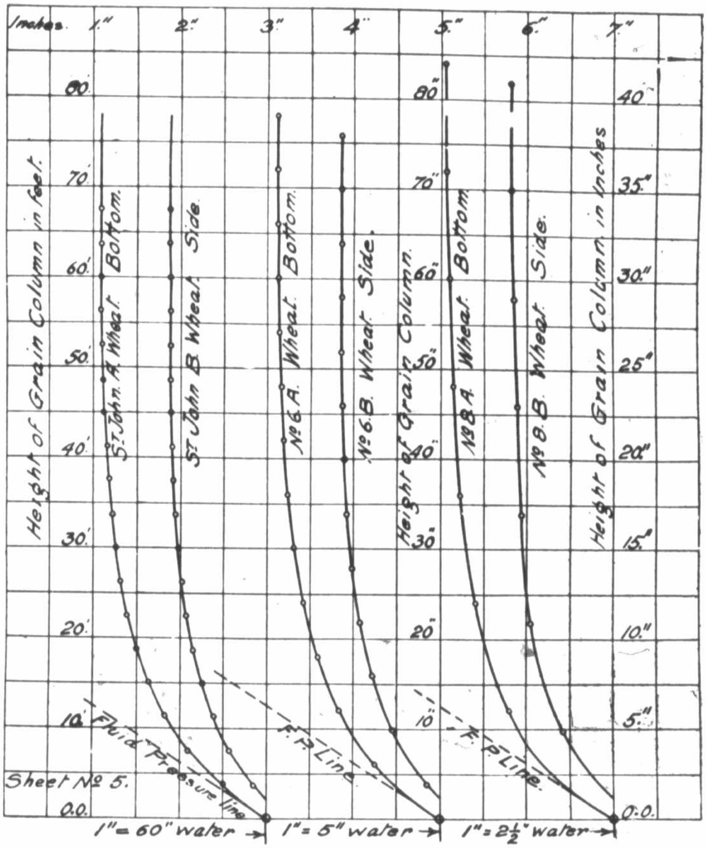
SHEET No. 1.

No. 1.—A.	Corrugated	Steel	Bin	12"	sq.	by 6' 6"	high.	Wheat.
No. 1—B.	"	"	"	12"	"	" 6' 6"	"	"
No. 2.	"	"	"	12"	"	" 6' 6"	"	Peas.
No. 3.	"	"	"	12"	"	" 6' 6"	"	Corn.
No. 4.	"	"	"	12"	"	" 6' 6"	"	Flaxseed.



SHEET No. 3.

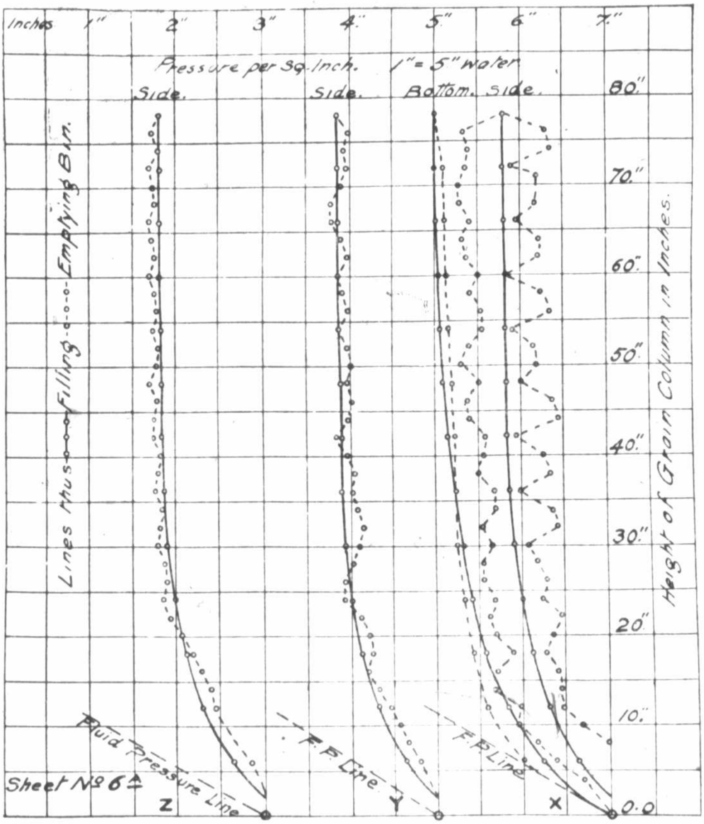
No. 9.—A. Round Steel Bin 12" diam. by 6' 6" high. Wheat.
No. 9.—B. " " " 12" " " 6' 6" " "
No. 11. " " " 12" " " 6' 6" " Sand.



SHEET No. 5.

No. 8.—A. Wooden Bin 6″ sq. by 3′ 3″ high. Wheat.
No. 8.—B " " 6″ " " 3′ 3″ " "
No. 6.—A. Cribbed Wooden Bin 12″ sq. by 6′ 6″ high. Wheat
No. 6.—B. " " " 12″ " " 6′ 6″ " "
St. J.—A. " " " 12′ × 13′ 6″ by 67′ 6″ "
St. J.—B. " " " 12′ × 13′ 6″ by 67′ 6″ "

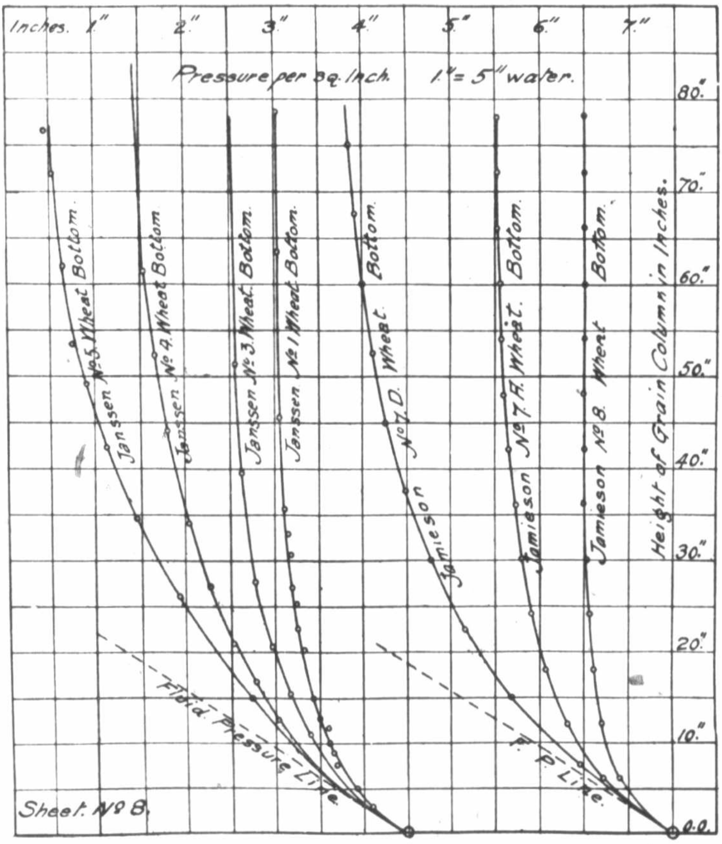
Comparative Curves:—Models and full size bin.



SHEET NO. 6—A.

Comparative Pressure: Filling and emptying bins, with gate opening at side and centre of bottom.

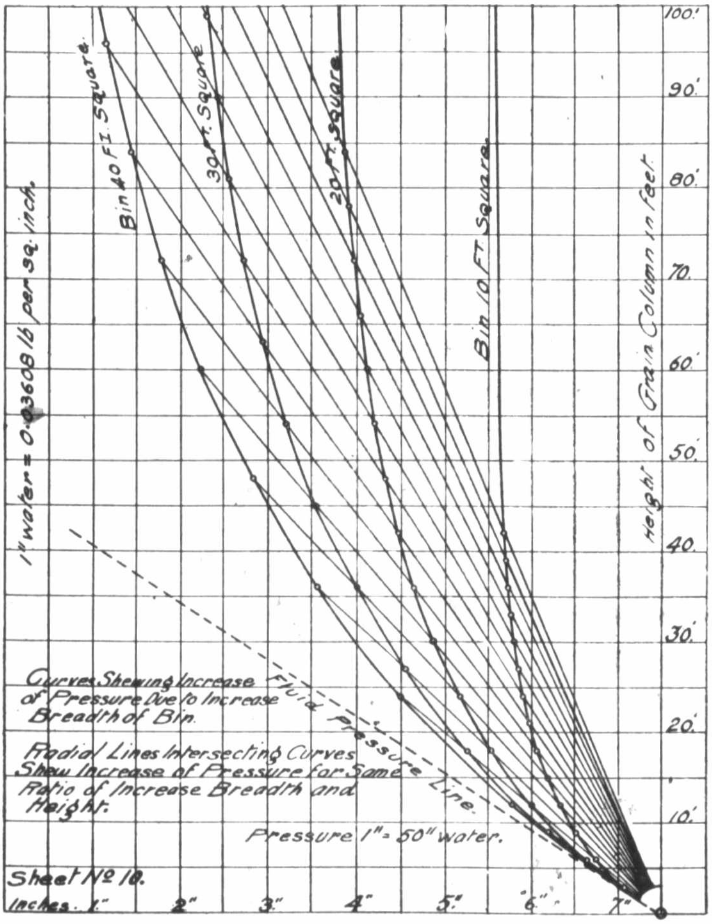
X. Gate opening at Side.
Y. " " " Centre. Tie-bars across bin.
Z. " " " " Without tie bars.



SHEET No. 8.

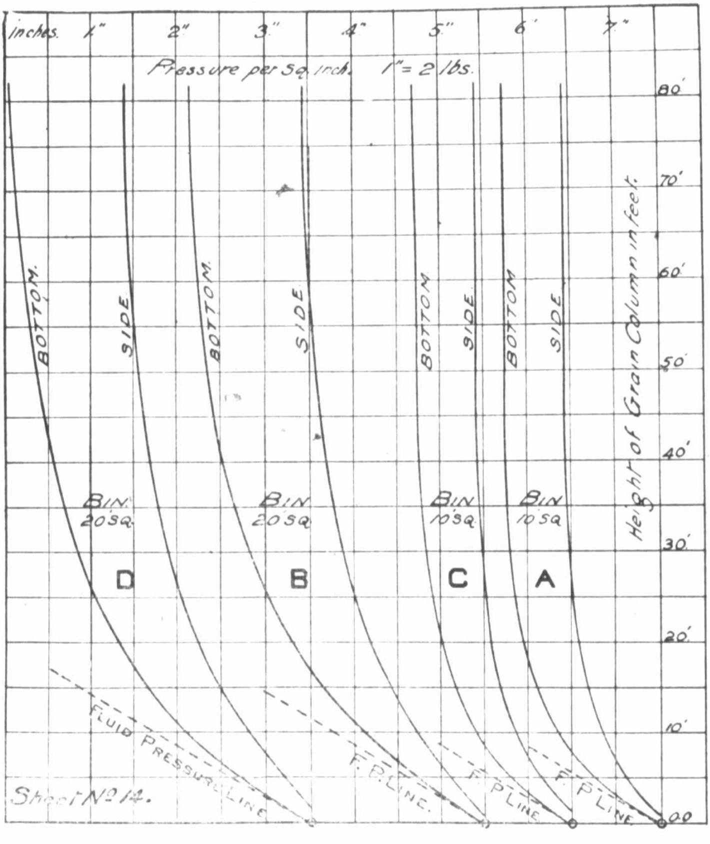
Comparative Curves :—Plotted from pressures obtained by tests made in square wooden bins showing increase of pressure per sq inch due to increase of diameter.

Janssen's Tests.			*Jamieson's Tests.*		
No. 1.	Bin 7.9 inches square.		No. 8.	Bin 6 inches square.	
" 3.	" 11.8 " "		" 7. A.	" 12 " "	
" 4.	" 15.7 " "		" 7. D.	" 24 " "	
" 5.	" 23.0 " "				



SHEET No. 10.

Diagram illustrating the ratio of increase of pressure with increased breadth and depth of bin.



SHEET No. 14.

COMPARATIVE CURVES

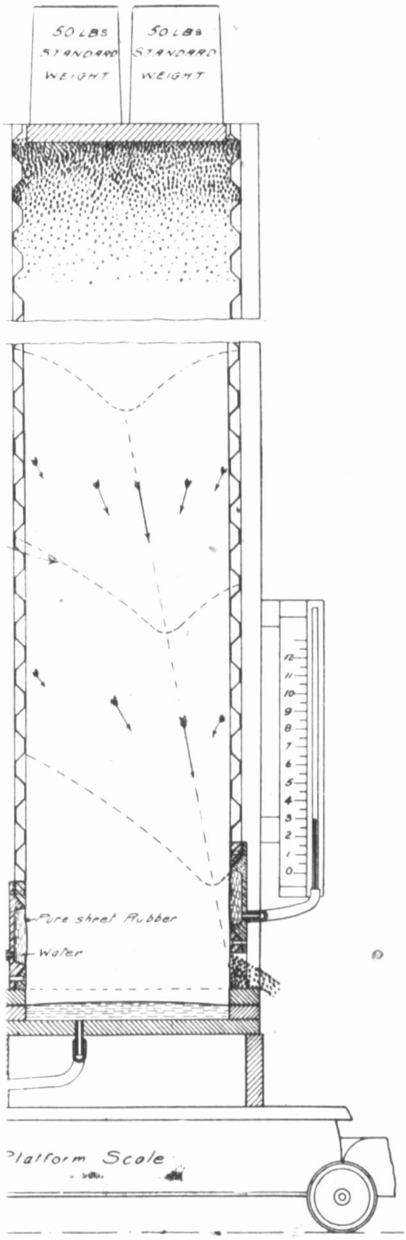
Bins 10 ft. and 20 ft. square, 80 ft. deep.

A. and B. derived from theoretical calculation.

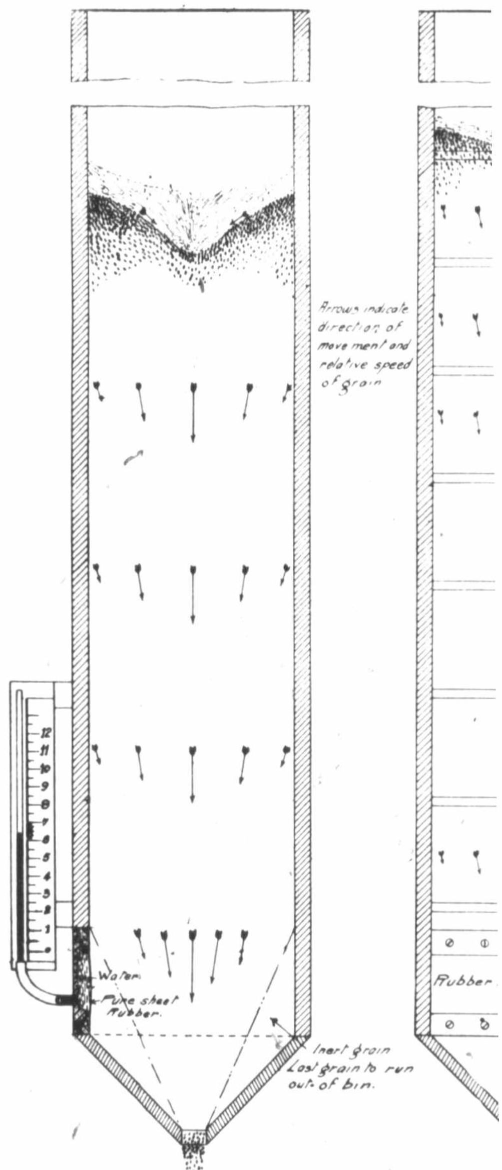
C. and D. derived from tests.

Wheat = 50 lbs. per cub. ft. Angle of repose 28°.

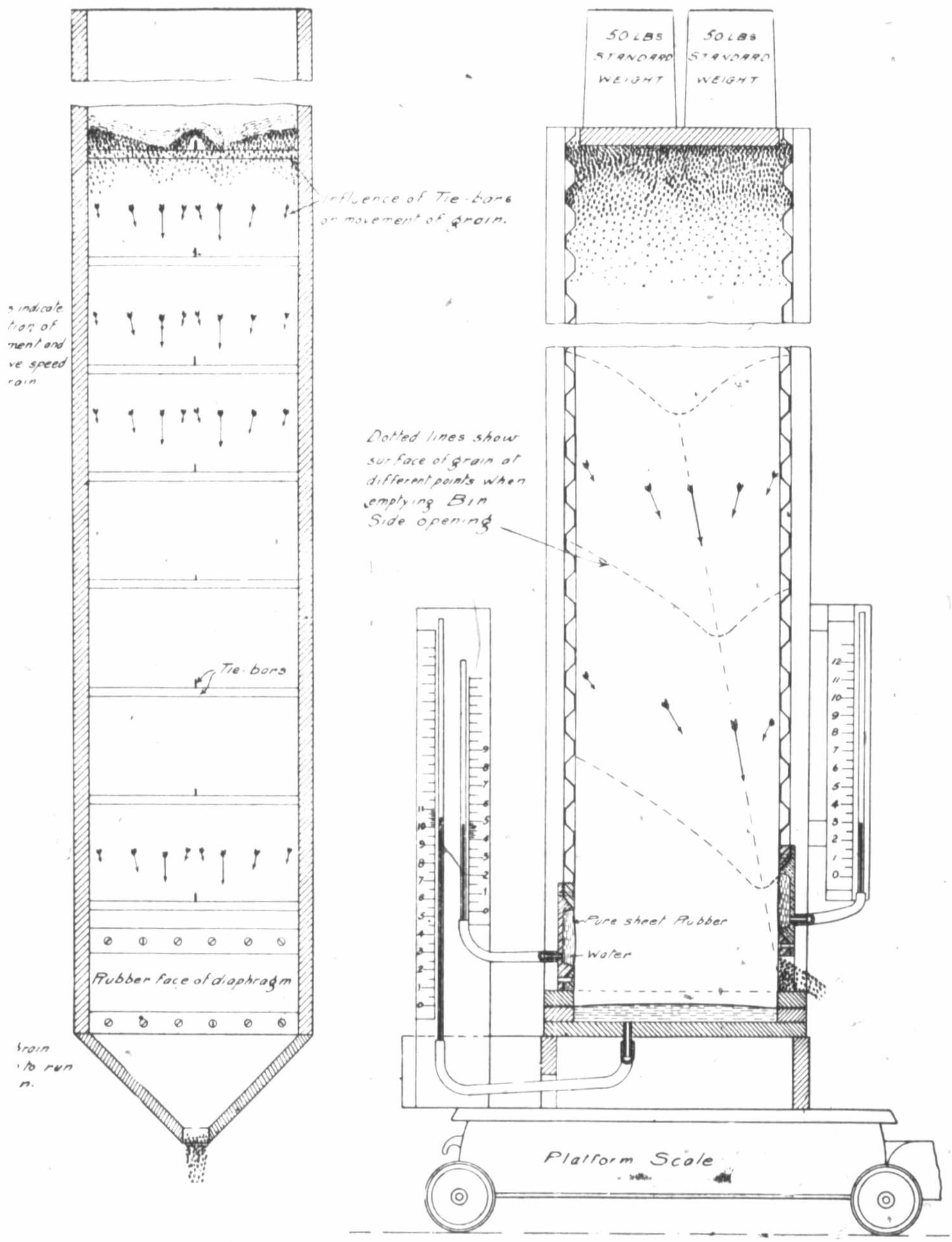
Co-efficient of friction between grain and bin sides = 0.41567,



J A JAMIESON. ENG.



— MODEL
— SHEWING POSITION OF
— GRA



- MODEL BINS —

...SITION OF DIAPHRAGMS —

— GRAIN RUNNING OUT —

J A JAMIESON ENG. -

Tests made by J. A. Jamieson, Elevator Engineer.

GRAIN PRESSURE TESTS. No. 1A.

Wheat.—Corrugated Steel Bin.—Bottom Pressure Test.

Size of Bin 12″ x 12″ x 6′ 6″ high.

Diaphragm on bottom, size 12″ x 12″=144 sq. inches.

Wheat 50 lbs. per cu. ft., equal to 62.2 lbs. per bushel.

Grain weigh'd into bin.	H'ight of grain col'mn.	Equivalent fluid pressure.	Pressure of grain on diaphragm.	Grain carried on bottom. Weight.	Grain carried on bottom. % of total weight of grain.	Grain carried on bin-side. Weight.	Grain carried on bin-side. % of total weight of grain.
lbs.	in.	in. water.	in. water	lbs.		lbs.	
25	6	4.81	$3\frac{1}{2}$	18.184	72.7	6.816	27.3
50	12	9.62	$5\frac{1}{2}$	28.575	57.1	21.425	42.9
75	18	14.43	$6\frac{5}{8}$	34.420	45.9	40.580	54.1
100	24	19.24	$7\frac{1}{2}$	38.966	38.9	61.034	61.1
125	30	24.05	$7\frac{3}{4}$	40.914	32.7	84.086	67.3
150	36	28.86	$8\frac{1}{16}$	41.888	27.8	108.112	72.2
175	42	33.67	$8\frac{1}{4}$	42.863	24.5	132.137	75.5
200	48	38.48	$8\frac{7}{16}$	43.837	21.9	156.163	78.1
225	54	43.29	$8\frac{1}{2}$	44.161	19.6	181.839	80.4
250	60	48.10	$8\frac{1}{2}$	44.161	17.6	205.839	82.4
275	66	52.81	$8\frac{9}{16}$	44.486	16.1	230.514	83.9
300	72	57.62	$8\frac{3}{4}$	45.460	15.1	254.540	84.9
325	78	62.53	$8\frac{3}{4}$	45.460	13.9	279.540	86.1
Effect of 50lbs. of weights placed on top of grain column :—							
682	[1] 163,68	131.27	$9\frac{3}{8}$	48.708	7.1	633,292	92.9

Increase of pressure on bottom by placing weights on top of grain column in bin :—

Weights.	Increases gauge reading From	Increases gauge reading To	Increases in Inches	Increases in lbs
lbs.				
50	$8\frac{3}{4}$	$9\frac{3}{8}$	$\frac{5}{8}$	3,247
100	$9\frac{3}{8}$	10	$\frac{5}{8}$	3,247
150	10	$10\frac{5}{8}$	$\frac{5}{8}$	3,247
	Total increase	with 30 lbs. . .	$1\frac{7}{8}$	9,741

When weights were removed gauge returned to $8\frac{3}{4}$″

NOTE.—By sharply tapping sides of bin, grain settled $2\frac{1}{4}$″ from top, and gave a maximum gauge reading of $10\frac{1}{2}$in. of water, equal to a load on bottom of 54,553lbs., or 16.78 % of total weight of grain in bin.

By raising bin by means of screws at the corners, the gauge receded to 7 inches.

[1] A grain column weighing 325 lbs. exerts a pressure of 45.46 lbs. on the bottom. 50 lbs. therefore are equal to a grain column weighing $\frac{326 \text{ x } 50 \text{ lbs.}}{44.56}$ or 357 lbs. This added to the 325 lbs. already in the bin equals 682lbs.

GRAIN PRESSURE TESTS, No. 1B.

Wheat.—Corrugated Steel Bin,—Side Pressure Tests.

Size of Bin 12″ x 12″ x 6′ 6″ high.

Diaphragm on side, size 6″ x 6″=36 sq. inches.

Wheat 50 lbs. per cu. ft., equal to 62.2 lbs. per bushel.

Each section of the grain column in the Bin=6″ high, weighing 25 lbs. Combined area of the four sides=288 Sq. inches.

Grain weighed into bin.	Height of grain column.	Equivalent fluid pressure.	Pressure of grain on diaphragm.		Side pressure per section.	Grain running out, pressure of grain on diaphragm.	
lbs.	ins.	ins. water	ins. water	lbs. per sq. inch	lbs.	ins. water	lbs. per sq. inch
25	6	4.81	$\frac{5}{8}$	0.02255	6.494	$1\frac{1}{2}$	0.054120
50	12	9.62	$2\frac{1}{2}$	0.09020	25.978	$3\frac{3}{4}$	0.135300
75	18	14.43	$3\frac{7}{8}$	0.13981	40.265	5	0.180400
100	24	19.24	$4\frac{9}{16}$	0.16461	47.409	5	0.180400
125	30	24.05	$4\frac{3}{4}$	0.17138	49.357	$5\frac{1}{4}$	0.189420
150	36	28.86	$4\frac{7}{8}$	0.17589	50.656	$5\frac{1}{8}$	0.184910
175	42	33 67	5	0.18040	51.955	$5\frac{1}{4}$	0.189420
200	48	38.48	$5\frac{1}{8}$	0.18491	53.254	$5\frac{1}{4}$	0.189420
225	54	43.29	$5\frac{1}{8}$	0.18491	53.254	$5\frac{3}{8}$	0.193930
250	60	48.10	$5\frac{3}{16}$	0.18716	53.903	$5\frac{1}{2}$	0.198440
275	66	52 81	$5\frac{1}{4}$	0.18942	54.553	$5\frac{1}{2}$	0.198440
300	72	57 62	$5\frac{1}{4}$	0.18942	54.553	$5\frac{9}{16}$	0.200695
325	78	62.53	$5\frac{1}{4}$	0.18942	54.553	$5\frac{1}{4}$	0.189420

Total Side Pressure..596.184

RELATIVE VERTICAL AND LATERAL PRESSURE.

(See Test No. 1A.) Pressure on bottom of bin $8\frac{3}{4}$″ water = 0.3157 lbs. per sq. inch × by area of diaphragm 144 sq. ins. = 45.46 lbs.

Maximum pressure on side when grain at rest $5\frac{1}{4}$″ water = .18942 lbs sq. in.

Vertical pressure = .31570
——— = 60 °/。 of vertical pressure, or vertical
Lateral pressure = .18942 pressure = 1.67 °/。 of lateral pressure.

Co-efficient of Friction :—

Co-efficient of friction between Wheat and sides of bin = Weight carried by sides 279.54 lbs. / Total side pressure 596.184 lbs. = 0.468

Grain in Motion :—

Grain running out of bin at rate of 50 lbs. per minute through opening in centre of hopper bottom, maximum pressure $5\frac{6}{16}$″ water = D.200695 lbs. per sq. inch = 6 °/。 increase of pressure due to grain in motion.

GRAIN PRESSURE TESTS, No. 5A.

Wheat.—Square Bin, Flat Sheet Steel.—Bottom Pressure Tests.

Size of Bin 12" x 12" x 6' 6" high.

Diaphragm on bottom, size 12" x 12"=144 sq. inches.

Wheat 50 lbs. per cu. ft., equal to 62.2 lbs. per bushel.

Grain weigh'd into bin.	H'ight of grain col'mn	Equivalent fluid pressure.	Pressure of grain on diaphragm.	Grain carried on bottom.		Grain carried on bin sides.	
				Weight.	% of total weight of grain.	Weight.	% of total weight of grain.
lbs.	in.	in. water.	in. water	lbs.		lbs	
25	6	4.81	$3\frac{7}{8}$	20.132	80.52	4.868	19.48
50	12	9.62	$6\frac{3}{16}$	32.147	64.29	17.853	35.71
75	18	14.43	$7\frac{9}{16}$	39.291	52.38	35.709	47.62
100	24	19.24	$8\frac{13}{16}$	45.785	45.78	54.215	54.22
125	30	24.05	$9\frac{1}{4}$	48 058	38.44	76.942	61.56
150	36	28.86	$9\frac{15}{16}$	51 630	34.42	98.370	65.58
175	42	33.67	$10\frac{5}{16}$	53.578	30.61	121 422	69.39
200	48	38.48	$10\frac{3}{4}$	55.851	27.92	144.149	72.08
225	54	43.29	$11\frac{1}{8}$	57.800	25.68	167.200	74.32
250	60	48.10	$11\frac{3}{8}$	59 100	23.64	190.900	76.36
275	66	52.81	$11\frac{1}{2}$	59.740	21.73	215.252	78.27
300	72	57.62	$11\frac{5}{8}$	60.397	20.13	239.603	79.87
325	78	62.53	$11\frac{5}{8}$	60.397	18.58	264.603	81.82
		Carried on bottom		60,397	on sides	264,603	

Tests made at same time as No. 5—B. Both readings taken together. Pressure on bottom of bin = $11\frac{5}{8}$" water = 0.419430 lbs. per sq. inch × area of diaphragm 144 sq. inches = 60,397 lbs.

By sharply tapping bin with hammer grain settled 3", and gave maximum reading of $13\frac{1}{4}$" water = 0,47806 lbs. per sq. in. × 144" area of diaphragm = 68.84 lbs. total pressure on bottom - 11.18 % of total weight of grain in bin.

GRAIN PRESSURE TESTS, No. 5B.

Wheat.—Square Bin, Flat Sheet Steel.—Side Pressure Tests.

Size of Bin 12″ x 12″ x 6′ 6″ high.

Diaphragm on side, size 6″ x 6″=36 sq. inches.

Wheat 50 lbs. per cu. ft., equal to 62.2 lbs. per bushel.

Each section of grain column in the Bin=6″ high, weighing 25 lbs.

Combined area of the four sides=288 sq. inches.

Note.—Test made at same time as No. 5A. Both readings taken together.

Grain weighed into bin.	Height of grain column.	Equivalent fluid pressure.	Pressure of grain on diaphragm.		Side pressure per section.
lbs.	inches.	inches water.	inches water.	lbs. per sq. inch	lbs.
25	6	4.81	$3\frac{6}{8}$	0.03157	9.092
50	12	9.62	$3\frac{1}{8}$	0.11275	32.472
75	18	14.43	$4\frac{1}{4}$	0.15534	44.162
100	24	19.24	5	0.18040	51.955
125	30	24.05	$5\frac{1}{2}$	0.19844	57.150
150	36	28.86	$2\frac{15}{16}$	0.21422	61.695
175	42	33.67	$6\frac{1}{4}$	0.22550	64.944
200	48	38.48	$6\frac{9}{16}$	0.23677	68.191
225	54	43.29	$6\frac{11}{16}$	0.24128	69.490
250	60	48.10	$6\frac{13}{16}$	0.24579	70.788
275	66	52.81	$6\frac{7}{8}$	0.24805	71.438
300	72	57.62	$6\frac{15}{16}$	0.25030	72.087
325	78	62.53	$6\frac{15}{16}$	0.25030	72.087

Total side pressure . . 745.552

RELATIVE VERTICAL AND LATERAL PRESSURE.

(See Test No. 5A.) Pressure on bottom of bin $11\frac{5}{8}$″ water = 0.419430 lbs. per sq. inch × area of diaphragm 144 sq. ins. = 60.397 lbs.

Maximum pressure on sides when grain at rest $6\frac{15}{16}$″ water = .250305 lbs. per sq. inch.

$$\frac{\text{Vertical pressure} = 0.419430}{\text{Lateral pressure} = 0.250305} = 59.69\ \%\ \text{of vertical pressure, or vertical pressure} = 1.66\ \%\ \text{of lateral pressure.}$$

$$\text{Co-efficient of friction between Wheat and sides of bin} = \frac{\text{Weight carried by sides} = 264.603\ \text{lbs.}}{\text{Total side pressure} = 745.552\ \text{lbs.}} = 551.65$$

By sharply tapping bin with hammer grain settled 3″ and gave maximum reading of $7\frac{13}{16}$″ water = 0.281875 lbs. per sq. inch = 12.49 % of fluid pressure.

GRAIN PRESSURE TESTS NO. 7A.

Wheat.—Square Wooden Bin.—Bottom Pressure Tests.
Smooth Boards.
Size of Bin 12″ x 12″ x 6′ 6″ high.
Diaphragm on bottom, size 12″ x 12″=144 sq. inches.
Wheat 50 lbs. per cu. ft., equal to 62.2 lbs. per bushel.

Grain weigh'd into bin.	H'ight of grain col'mn	Equiva-lent fluid pressure.	Pressure of grain on dia-phragm.	Grain carried on bottom.		Grain carried on bin-side.	
				Weight.	% of total weight of grain	Weight.	% of total weight of grain.
lbs.	in.	in. water.	in. water	lbs.		lbs.	
25	6	4.81	3¾	19.483	77.93	5.517	22.07
50	12	9.62	5⅞	30.524	61.04	19.476	38.96
75	18	14.43	7	36.368	48.49	38.632	51.51
100	24	19.24	7⅞	40.914	40.91	59.086	59.09
125	30	24.05	8¼	42 863	34.29	82 137	65.81
150	36	28.86	8⅝	44.811	29.87	105.189	71 13
175	42	33.67	8⅞	46.110	26.35	128.890	73.65
200	48	38.48	9	46 759	23.37	153 241	76 63
225	54	43.29	9 7/16	49.032	21.79	175.968	78 21
250	60	48.10	9 9/16	49 682	19.87	200.318	80.13
275	66	52.81	9¾	50 656	18.42	224 344	81.58
300	72	57.62	9¾	50 656	16.88	249 344	83.12
325	78	62.53	9¾	50.656	15.58	274 344	84.42

Carried on bottom 50.656 on sides 274.344

By sharply tapping sides of bin, grain settled 2⅞ in. from top, and gave maximum gauge reading of 11⅞ in. water=equals total load on bottom of 61.696 lbs., or 20.56% of total grain in bin.

GRAIN PRESSURE TESTS, No. 7B.

Wheat.—Square Wooden Bin.—Side Pressure Tests.

Size of Bin 12″ x 12″ x 6′ 6″ high.

Smooth Boards.

Diaphragm on bottom, size 12″ x 12″=144 sq. inches.

Wheat 50 lbs. per cu. ft., equal to 62.2 lbs. per bushel.

First section of grain column in Bin 12″ high covering face of diaphragm weight 50 lbs.; combined area of four sides=576 sq. in. all following sections=4.80 inches high, weighing 20 lbs. area of four sides=230.4 square inches.

Grain weighed into bin.	Height of grain column	Equivalent fluid pressure.	Pressure of grain on diaphragm.		Side pressure per section.	Grain running out, pressure of grain on diaphragm.	
lbs.	ins.	ins. water.	ins. water.	lbs per sq. inch.	lbs.	ins. water.	lbs. per sq. inch.
50	12.00	9 62	$2\frac{7}{8}$	0.10373	59.748	2	0.07442
70	16.80	13.47	$4\frac{1}{4}$	0.15334	35.329	$4\frac{1}{4}$	0.15334
90	21.60	17.31	$4\frac{3}{4}$	0 17138	39 496	$5\frac{5}{8}$	0.20295
110	26.40	21.15	$5\frac{1}{8}$	0.18491	42.603	$5\frac{3}{4}$	0.20746
130	31.20	24.99	$5\frac{7}{16}$	0.19619	45.201	$5\frac{3}{4}$	0.20746
150	36.00	28.86	$5\frac{1}{2}$	0.19844	45.720	$5\frac{7}{8}$	0.21197
170	40.80	32.71	$5\frac{9}{16}$	0.20070	46.240	6	0.21648
190	45.60	36.56	$5\frac{5}{8}$	0.20295	46.760	$5\frac{7}{8}$	0.21197
210	50.40	40.41	$5\frac{11}{16}$	0.20521	47.279	$6\frac{1}{8}$	0.22099
230	55.20	44.26	$5\frac{3}{4}$	0.20746	47.799	$6\frac{1}{8}$	0.22099
250	60.00	48.10	$5\frac{3}{4}$	0.20746	47.799	$6\frac{1}{4}$	0.22550
270	64.80	51.95	$5\frac{7}{8}$	0.21197	48.838	$6\frac{5}{16}$	0 22775
290	69.60	55.80	$5\frac{7}{8}$	0.21197	48.838	$6\frac{5}{16}$	0.22775
310	74.40	59.65	$5\frac{7}{8}$	0.21197	48.838	$6\frac{5}{16}$	0.22775
325	78 00	62 53	$5\frac{7}{8}$	0.21197	36.620	$7\frac{7}{8}$	0.21197

Total side pressure. 687.108

RELATIVE VERTICAL AND LATERAL PRESSURE.

(See Test No. 7A.) Pressure on bottom of bin $9\frac{1}{4}$″ water = 0.35178 lbs. per sq. in. × area of diaphragm 144 sq. inches = 50.656 lbs.

Maximum pressure on sides when grain at rest – $5\frac{7}{8}$″ water = .21197 lbs. per sq. inch.

$$\frac{\text{Vertical pressure} = 0.35178}{\text{Lateral pressure} = 0.21197} = 60\ \%\ \text{of vertical pressure, or vertical pressure} = 1.67\ \%\ \text{of lateral pressure.}$$

Co-efficient of friction between Wheat and sides of bin $\dfrac{\text{Weight carried by sides} = 274.344 \text{ lbs.}}{\text{Total side pressure} = 687.108 \text{ lbs.}} = 0.397$

Grain in Motion :—

Grain running out of bin at rate of 120 lbs. per minute through opening in centre of hopper bottom, maximum pressure $6\frac{5}{16}$″ water, equals 0.22775 lbs. per square inch = 9.3 % increase of pressure due to grain in motion.

GRAIN PRESSURE TESTS, No. 9.

Wheat.—Round Steel Bin.—Bottom Pressure Tests.

12″ Diam. x 6′ 6″ deep.

Wheat 50 lbs. per cu. ft., equal to 62.2 lbs. per bushel.

Diaphragm 12″ Diam. (Area 113.10 sq. inches) on bottom.

Grain weigh'd into bin.	Height of grain column.	Equivalent fluid press'r	Pressure of grain on diaphragm.	Grain carried on bottom.		Grain carried on bin-sides.	
				Weight.	°/₀ of grain weighed in.	Weight.	°/₀ of grain weighed in.
lbs	ins.	ins. water.	ins. water.	lbs.		lbs.	
25	7.44	5.96	$4\frac{1}{8}$	16.833	67.33	8.167	32.67
50	14.88	11.92	$6\frac{1}{2}$	26.524	53.48	23.476	46.52
75	22.32	17.88	$8\frac{3}{8}$	34.175	45.43	40.825	54.57
100	29.76	23.84	$9\frac{5}{16}$	38.001	38.00	61.999	62.00
125	37.20	29.80	10	40.806	32.64	84.194	67.36
150	44.64	35.76	$10\frac{1}{2}$	42.847	28.56	107.153	71.44
175	52.08	41.72	$10\frac{15}{16}$	44.632	26.64	130.368	73.36
200	59.52	47.68	$10\frac{1}{4}$	45.907	24.95	154.093	75.05
225	66.96	53.64	$11\frac{1}{2}$	46.927	23.07	178.073	76.93
250	74.40	59.65	$11\frac{11}{16}$	47.692	19.07	202.308	80.93
$262\frac{1}{2}$	78.00	62.54	$11\frac{3}{4}$	47.937	18.29	213.563	81.71
			Carried on bottom	47.937	on sides	214.563	

By sharply tapping sides of bin with hands, grain settled $2\frac{3}{4}$ in. from the top, and gave maximum guage reading of $13\frac{1}{4}$ in. water, equal total load on bottom of 54.063 lbs., or 20.5°/₀ of total grain in bin. Pressure per square inch on bottom $= 11\frac{3}{4}$ in. water $= 0.42394$ lbs. per square inch x area of diaphragm 113.10 sq. inches $= 47.957$ lbs.

GRAIN PRESSURE TESTS No. 11.

Sand.—Round Steel Bin.—Bottom Pressure Tests.

12″ Diam., 6′ 6″ high.

Sand, weighing 100 lbs. cu. ft., each draft represents ¼ cu. ft., or 25

Diaphragm on bottom 12″ Diam. (Area 113.10 sq. in.)

Sand weigh'd into bin.	Height of sand column.	Equivalent fluid pressure.	Pressure of sand on diaphragm.	Sand carried on bottom.		Sand carried on bin-sides.	
				Weight.	°/₀ of total weight of sand.	Weight.	°/₀ of total weight of sand.
lbs.	ins.	in. water	in. water	lbs.		lbs.	
25	3.63	5.82	$5\frac{7}{8}$	24.000	96.00	1.000	4.00
50	7.26	11 64	$10\frac{5}{8}$	43.356	86.71	6.664	13.29
75	10.89	17.46	$13\frac{5}{8}$	65.598	74 13	19.402	25.87
100	14.53	23.28	16	65.290	65.29	34.710	34.71
125	18.15	29.10	18	73.452	58.76	51.548	41.24
150	21.79	34.92	$19\frac{1}{2}$	79.573	53.04	70.427	46.96
175	25.41	40.74	$20\frac{5}{8}$	84.163	48.09	90.837	51.91
200	29.05	46.56	$21\frac{3}{8}$	87.224	43.61	112 776	56.39
225	32.67	52.38	$22\frac{1}{8}$	80 284	40.12	134 716	59 88
250	36.30	58.20	$22\frac{1}{2}$	91.815	36.72	158.185	63.28
275	39.93	64.02	$22\frac{7}{8}$	93.345	33.94	181.655	66.06
300	43.57	69 84	$23\frac{3}{16}$	94.620	31 54	205.380	68.46
325	47.19	75.68	$23\frac{1}{2}$	95.895	29.50	229.105	70.50
350	50 82	81.48	$23\frac{5}{8}$	96.405	27.54	253.595	72.46
375	54.46	87.30	$23\frac{11}{16}$	96.660	25.77	278.340	74.23
400	58.08	93.15	$23\frac{13}{16}$	97 681	24.42	302.319	75.58
425	61.71	98 95	$24\frac{1}{16}$	98.191	23 10	326.809	76.90
450	65.34	104.77	$24\frac{1}{8}$	98.446	21.87	351.554	78.13
475	68.97	110 58	$24\frac{1}{8}$	98.446	20.72	376 554	79.28
500	72 60	116.40	$24\frac{3}{16}$	98.701	19.74	401.299	80.26
525	76.23	122.22	$24\frac{1}{4}$	98.956	18.84	426.044	81.16
$537\frac{1}{2}$	78.00	125.09	$24\frac{5}{16}$	99.211	18.45	438.289	81.55
		Carried on bottom		99 211	on sides	438.290	

By sharply tapping bin, sand settled 3 inches in bin, and gave maximum reading of gauge $29\frac{1}{2}$ inches of water, equals total load on bottom of 120,272 lbs., or 22.37 °/₀ of total sand in bin.

Sharp clean Chateauguay River sand, thoroughly dry :

Angle of Repose 34° from the horizontal.

TESTS OF GRAIN PRESSURES IN BINS.

By H. A. Janssen, Engineer, Bremen, Germany.

(From Zeitschrift Des Vereins Deutscher Ingenieure.)

1895, Vol. 39, Page 1045.)

Table of Grain Pressure calculated from Tests by H. A. Janssen, reduced to English Weights and Measures for comparison with tests made by J. A. Jamieson.

Wheat.—Janssen Test No. 3.—Square Wooden Bin.

Bin No. 2.—Size 11.8″ x 11.8″—139.24 sq. inches.

Grain weighed into bin.	Height of grain column.	Pressure of grain on bottom of bin.		Grain carried on bottom.		Grain carried on sides.	
				Weight	% of total weight of grain.	Weight.	% of total weight of grain.
lbs	inches.	in. wat'r	lbs per sq. inch.	lbs.		lbs	
23.2	6.0	$3\frac{3}{4}$	0.13530	18.84	81.20	4.36	18.80
46.4	12.0	$5\frac{3}{4}$	0.20746	28.89	62.26	17.51	37.74
69.6	18.0	$7\frac{3}{16}$	0.25933	36.11	51.88	33.49	48.62
92.8	24.0	$8\frac{1}{8}$	0.29315	40.82	43.98	51.98	56.02
116.0	30.0	$8\frac{3}{4}$	0.31570	43.96	37.90	72.04	62.10
139.2	36.0	$9\frac{3}{16}$	0.33149	46.16	33.16	93.04	66.84
162.4	42.0	$9\frac{1}{2}$	0.34276	47.73	29.39	114.67	70.61
185.6	48.0	$9\frac{5}{8}$	0.34727	48.35	26.05	137.25	73.95
198.4	51.3	$9\frac{5}{8}$	0.34727	38.35	24.36	150.06	75.64
208.8	54.0	$9\frac{5}{8}$	0.34727	48.35	23.15	160.45	76.85
232.0	60.0	$9\frac{3}{4}$	0.35178	48.98	21.11	183.02	78.89
255.2	66.0	$9\frac{13}{16}$	0.35404	49.30	19.35	205.90	80.65
278.4	72.0	$9\frac{7}{8}$	0.35629	49.61	17.82	228.79	82.18
301.6	78.0	$9\frac{7}{8}$	0.35629	49.61	16.44	251.99	83.56

Carried on bottom 49.61 on sides 251.99

Tests made by J. A. Jamieson, Elevator Engineer.

Montreal, April, 1903.

GRAIN PRESSURE TESTS.

Table giving comparative Grain and Fluid Pressure.

Corrugated Steel Bin.

Size of Bin 12" x 12" x 6' 6" high.

Wheat 50 lbs. per cu. ft. Fluid 50 lbs. per cu. ft.

Total depth equals 6.5 times diameter.

Fluid pressure columns show the pressure that would be produced by grain if there was neither friction within the grain mass nor between the grain and the confining walls.

Height of column	Test No. 1.—A. Vertical Pressure. Lbs. per sq. inch		Grain = % fluid pressure.	Test No. 1.—B. Lateral Pressure. Lbs. per sq. inch.		Grain = % fluid press're
Inches.	Fluid	Grain.	%	Fluid.	Grain.	%
6	0.17364	0.12628	.73	0.17363	0.02255	.13
12	0.34727	0.19844	.57	0.34727	0.09020	.26
18	0.52090	0.23903	.46	0.52090	0.13981	.27
24	0.69679	0.27060	.39	0.69679	0.16461	.24
30	0.87043	0.28413	.33	0.87043	0.17138	.20
36	1.04406	0.29090	.28	1.04406	0.17589	.17
42	1.21770	0.29766	.24	1.21770	0.18040	.15
48	1.39359	0.30442	.22	1.39359	0.18491	.13
54	1.56722	0.30668	.20	1.56722	0.18491	.12
60	1.73635	0.30668	.18	1.73635	0.18716	.11
66	1.91124	0.30893	.16	1.91124	0.18942	.10
72	2.08487	0.31570	.15	2.08487	0.18942	.09
78	2.25700	0.31570	.14	2.25700	0.18942	.08