



An investigation of some factors affecting pressures in bins
by Wesley P Boulanger

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree
of Master of Science in Civil Engineering at Montana State College
Montana State University
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Abstract:

Model deep bins were used to determine the effect of several fundamental variables on the vertical pressure in bins. These variables were (1) the effect of relative movement between the walls and the base on vertical pressure; (2) the effect of particle size on vertical pressure; (3) the effect of shape of bin cross-section on vertical pressure; and (4) the effect of changing wall roughness on vertical pressure. Observed values of K are compared with values predicted by the method suggested by Professor Alfred C. Scheer in his paper, "Bin Theory and Soil Mechanics." Base pressure of wheat was plotted against relative movement to illustrate the effect of base movement on vertical pressure. The variation in base pressure was small over a large range of base movement. The data obtained were inconclusive as to the effect of particle size on base pressure. The results on the effect of bin shape verified Janssen's theoretical approach where the only reference to bin shape is the hydraulic radius. An increase in wall roughness caused an increase in the value of K for wheat.

Very little work has been done where these variables have been controlled in order to determine their individual effects upon bin pressures, it is believed that a knowledge of their effects will add greatly to the overall understanding of the problem of vertical pressure in deep bins, and will assist in the interpretation of results of future experiments.

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AFFECTING PRESSURES IN BINS

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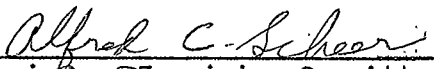
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ABSTRACT

Model deep bins were used to determine the effect of several fundamental variables on the vertical pressure in bins. These variables were (1) the effect of relative movement between the walls and the base on vertical pressure; (2) the effect of particle size on vertical pressure; (3) the effect of shape of bin cross-section on vertical pressure; and (4) the effect of changing wall roughness on vertical pressure. Observed values of K are compared with values predicted by the method suggested by Professor Alfred C. Scheer in his paper, "Bin Theory and Soil Mechanics."

Base pressure of wheat was plotted against relative movement to illustrate the effect of base movement on vertical pressure. The variation in base pressure was small over a large range of base movement. The data obtained were inconclusive as to the effect of particle size on base pressure. The results on the effect of bin shape verified Janssen's theoretical approach where the only reference to bin shape is the hydraulic radius. An increase in wall roughness caused an increase in the value of K for wheat.

Very little work has been done where these variables have been controlled in order to determine their individual effects upon bin pressures. It is believed that a knowledge of their effects will add greatly to the overall understanding of the problem of vertical pressure in deep bins, and will assist in the interpretation of results of future experiments.

INTRODUCTION

Little, if any, research has been performed to determine the separate effects of basic factors which affect the base pressure in deep bins. Most of the investigations in the field of bin pressures have been to gather data for specific materials in specific bins, without attempts to generalize. A major purpose of this thesis is to investigate the effects of base movement, particle size, bin shape, and wall roughness. It is believed that a knowledge of these factors will enhance the understanding of bin pressures.

It was decided to weigh base loads directly on a platform scale. Several prior investigations have used this method, but without considering the effect which base movement may have had on the measured base loads.

It was also decided to use wood model bins because of their low cost and the time which could be saved in the numerous loading and unloading operations. Furthermore, the literature cites cases where the results from model bins checked well with results from full size bins.

REVIEW OF LITERATURE

Isaac Roberts,*(25) in 1882, performed the first recorded experiments on the pressure of wheat in bins. His tests were performed on model cylindrical bins 7 to 20-3/4 inches in diameter. The results of these tests led him to the observation that "all increase of pressure on the bottom ceases before the cells are filled two diameters." In 1884, Roberts performed a second series of experiments using a rectangular bin 6' 9" by 6' 0" in cross section and 52' 2" high. Levers arranged like a weighing machine were used to determine the pressure. Realizing that any movement of the levers would affect his measurement, Roberts added an excess of weight to the scale's beam prior to loading to eliminate this movement. After filling the bin, he gradually reduced the weight and made his readings at the initial movement of the beam. These experiments verified the results he obtained from his first series of tests.

Janssen, (18) in 1895, performed experiments to determine the pressure of grain on bin walls. His tests were performed on square model bins using wheat, corn, and other grains. The bases of his bins were placed directly on the scale's platform and the sides were supported above the base by jacks. These experiments led to the development of his formulas which are still in use today. The development of these formulas are presented in the appendix of this report.

In 1896, the results of a series of tests performed in Germany by Prante(24) were published. Two cylindrical iron bins were used in these

*Number in parentheses refers to Bibliography item, Page 76 .

experiments. They were 1.5 and 2.8 meters in diameter, and were 19 meters high. Side pressures were recorded for the conditions of wheat at rest and moving. The results of his test are not considered reliable because of the inadequacies of his measuring apparatus. However, his experiment did reveal the increase in lateral pressure during the discharge of grain from a bin.

Wilfred Airy⁽³⁾, in 1897, made the next major contribution to this field in a paper to the Institute of Civil Engineers. His paper contained the development of equations for grain pressure on walls due to a wedge of grain between the wall and the plane of rupture. He also reported on a series of tests performed in England to determine the values for angle of repose of grains and the coefficients of friction of grains on bin walls.

A series of tests on a full-sized bin were performed by J.A. Jamieson⁽¹⁷⁾ in 1900. The bin, owned by the Canadian Pacific Railway Elevator, West St. John, N.B., was of timber crib construction 12' 0" by 13' 6" in cross section, and 67' 6" high. Manitoba wheat was used for these tests. Hydraulic diaphragms with water column gages were used to measure both vertical and lateral pressure. This method of measuring pressure was found to be both sensitive and accurate, and was used on a later series of tests Jamieson performed on model bins. Pressure readings were made with the grain at rest and during emptying. The results showed close agreement with those obtained from Janssen's formulas using a value for K of approximately 0.6. The maximum increase in pressure during emptying over the static condition was four percent, a number considerably less than that reported by Prante.

Jamieson⁽¹⁷⁾ later made experiments on 12 inch and 6 inch square model bins 6' 6" high, and on cylindrical model bins 12 inches and 6 inches in

diameter and 6' 6" high. Tests were made using wheat, peas, corn, and flax seed. When the grain was being emptied from the center of the bottom, a maximum increase in pressure of 7.3 percent was observed. Tests were also made with tie bars in the bin. It was observed that they would decrease the flow of grain, but did not affect the pressure due to grain.

About this same time, a series of tests on grain pressures were performed at the University of Illinois by Albert G. Varnes and M.S. Ketchum.⁽¹⁹⁾ The tests were performed on a square model bin 1' 0" by 1' 0" and 8' 6" high. The bottom of the bin was free from the sides and was placed directly on a platform scale to record vertical pressure. Side pressures on a one foot square diaphragm were transmitted by levers to a platform scale for observation. Measurements of the side and vertical pressures were made when the grain was at rest and being emptied. No difference in the pressures with the grain at rest or in motion was observed. The ratio of lateral to vertical pressure was approximately 0.4 for this series of tests.

To check the results of Jamieson, Professor Henry T. Bovey⁽⁸⁾, McGill University, Montreal, performed five series of tests on full-sized bins. Four series of tests were performed on a bin 12' by 14' in cross section and 44' 10" high, at the Canadian Pacific Railway Elevator at Montreal. The maximum lateral pressure for bin emptying, compared to that when the bin was filling, showed an increase of 9.7 percent. The bin for the fifth series was a timber crib bin 13.4' by 12.35' in cross section at the Great Northern Railroad Elevator, Quebec. His readings agreed very closely with those reported by Jamieson.

In 1904, Eckhardt Lufft⁽²⁰⁾ reported on a series of tests made on

full-sized bins at Buenos Aires, Argentina. These tests were made on two circular bins 54.8 feet deep, one 23' 10" and the other 11' 3" in diameter. The inner surfaces of these bins were coated with a cement mortar. Pressures were measured by a rubber diaphragm with a mercury column. In agreement with most tests performed about this time, very little increase in pressures was observed when the grain was moving, compared to the pressures when the grain was at rest.

In 1906, Mr. J. Pleissner⁽²³⁾ reported on a series of tests performed in Germany. The tests were performed on model bins of timber and concrete. The pressures were determined by measuring the deflections from a series of water tests. Values of K for wheat of from 0.3 for concrete bins to 0.5 for timber bins were obtained.

Milo S. Ketchum⁽¹⁹⁾, in 1919, published a book, "The Design of Walls, Bins and Grain Elevators." His publication reported on the work done to that date on the pressures in grain bins, and contained a discussion of some experiments he had performed at the University of Colorado with Professor C. C. Williams. These experiments were on model bins 15" square and 8' high. The base pressures were recorded by placing the bottom of the bin on a knife edge carried at the middle of a lever. One end of the lever was resting on a platform scale where measurements were made. Lateral pressures were determined by measuring the variation in an electric current passing through carbon plates. For grain at rest, it was observed that the value K was not a constant, but increased with the depth of grain. The lateral pressure increased from two to four percent when the grain was being emptied.

L. R. Amundson⁽⁵⁾ published in 1945 the results of tests run on a

cylindrical grain bin at the U. S. Department of Agriculture's bin site at Jamestown, North Dakota. The bin was built of Insulite Graylite Board, and was 10' high and 9' 6-1/2" in diameter. The material used in these tests was wheat. Several bands were placed around the bin to determine the lateral pressure. The strains in these bands were measured by Whittemore strain gages. The readings from these mechanical strain gages were then converted to stress, and the lateral pressures were then obtained. Mr. Amundson concluded from his results that Janssen's equations are adequate for safe design. A value for K of approximately 0.458 was obtained.

Most of the previous experiments prior to 1950 were performed on wheat. To supplement the lack of information on other materials, a series of tests were run on six granular materials at Iowa State College by Alfred C. Scheer and Calvin W. Tooles⁽⁹⁾. Lateral and vertical pressures were measured for wheat, shelled corn, soybeans, cement, sand, and pea gravel. A concrete bin five feet high and eighteen inches in diameter was used. The movable bottom of the bin was supported directly on a platform scale, making it possible to measure vertical load directly. Six steel pressure plates used to measure lateral pressure were supported by cantilever bars and steel bands wrapped around the bin. The additional strain in the bands caused by the lateral pressure was measured by SR-4 Type A-12 electrical-resistance strain gages. Values of K were obtained for all materials in the concrete bin.

R. A. Saul⁽²⁾ reported on additional work done on grain pressures at Iowa State College in 1953. Tests were run on a rectangular bin 12' by 32' in cross section, and 10' high. Panels which were small areas of the

floor or walls were used to measure pressures. These panels were supported by weighing devices which could weigh both the normal and parallel load on the panel face. The weighing devices were steel rods supported as simple beams. The strains in these rods were obtained by SR-4 Type A-7 electrical-resistance strain gages. Three methods of filling the bin were used. In one case, the grain was kept approximately level during filling by moving the spout around within the bin. This method gave a more uniform pressure distribution on the base, and also gave smaller values of lateral pressure. The results showed a rapid decrease in the lateral pressure just above the base.

In 1943, M. Marcel Reimbert⁽¹⁰⁾ presented a formula for calculating horizontal pressure on the walls of silos. Results obtained from tests performed in 1954 showed close agreement with his calculated values.

Reimbert stated that the lateral pressure at a depth y equals:

$$L = \frac{w R}{\tan \phi'} \left[1 - \left(\frac{y}{C} + 1 \right)^{-2} \right]$$

where C is a constant depending on the shape of the silo and the properties of the contained material.

$$C = \frac{R}{\tan \phi' \tan^2 \left(\frac{\pi}{4} - \frac{\phi}{2} \right)} - \frac{R \tan \phi}{3}$$

R = Hydraulic Radius

An interesting point which he discusses is the variation of lateral pressures on the long and short sides of a rectangular bin. He stated that the lateral pressure on the short side would be the same as that on the wall of a square bin with like dimensions, while the lateral pressure on the long

side may be assumed to be that on the walls of a square silo with length of $\frac{2ab-a}{b}$, where a is the length of the short side, and b is the length of the long side.

Professor Alfred C. Scheer⁽²⁶⁾, in 1960, presented a method of predicting values for the ratio of lateral to vertical pressure. His paper also discussed the application of Janssen's equations to problems in pressures on retaining walls, trench sheeting, cellular cofferdams, underground conduits, consolidometer friction and frictional drag on piles. The prediction of K values (the ratio of lateral to vertical pressure) is divided into two cases, rough bins and smooth bins.

Rough bins are bins where ϕ'_B is greater than ϕ , and therefore $\phi' = \phi$.

To predict K :

$$K = a K'$$

$$K' = \frac{1 - \sin^2 \phi}{1 + \sin^2 \phi}$$

ϕ = Angle of internal friction of fill material.

ϕ'_B = Angle of friction of fill material, glued to a block, on bin wall.

ϕ' = Effective angle of friction of fill material on bin wall.

Smooth bins are bins where ϕ is greater than ϕ'_B . To predict K :

$$K = a K' \quad \phi' = \phi'_B$$

$$K'_{\min} = \frac{1}{1 + 2 \tan \alpha \tan \phi'}$$

$$\cos \alpha + \tan \phi' \sin \alpha = \frac{\tan \phi'}{\sin \phi}$$

$$K'_{\max} = \frac{1 - \sin^2 \phi'}{1 + \sin^2 \phi'}$$

$$K' = \frac{1}{2} (K'_{\min} + K'_{\max})$$

Professor Scheer states that a value of 0.7 for "a" will yield a value of K, which will approximate experimental values of K. However, he points out that experimental values of K should be used whenever appropriate values are obtainable.

The literature search did not reveal any records of experiments in which systematic efforts were made to isolate the individual effects of base movement, particle size, bin shape, and wall roughness on base pressure. In this thesis project, model wood bins were used to study each of these variables.

EXPERIMENTAL EQUIPMENT

Selected fir was used in the construction of all bins. All boards chosen were free of knots, had the grain running longitudinal, and had approximately the same roughness. Since in Janssen's equations, the only reference to the bin's cross section is the hydraulic radius, all bins were constructed so that they would have equal hydraulic radii.

Three rectangular bins were built having hydraulic radii equal to that of a six-inch circle. Their dimensions were 11.48 by 4.07 inches, 7.57 by 4.98 inches, and 6.00 by 6.00 inches. The hydraulic radius for each bin was 0.125 feet. The height of each bin was approximately two feet, which gave a depth of from two to four times the largest dimension.

To approximate a circular bin, using material of the same roughness, a bin was built having fifteen sides, with a minimum inside dimension of six inches. The joints of this bin were quite irregular, a factor which must not be overlooked in the consideration of any results obtained from tests performed on this bin.

In performing the various tests to determine the effect of base movement, particle size, and wall roughness, the rectangular bins were used. The circular bin was used only in the experimental determination of the effect of bin shape.

A Fairbanks-Morse platform scale, which could be read to 0.01 lbs., was used during this investigation. The capacity of this scale was approximately three hundred pounds.

MATERIAL USED

In this investigation, wheat and four sizes of glass spheres were used.

Size and Shape Characteristics

The wheat used was of an undetermined variety. No attempt at determining grain size or shape characteristics was made.

The largest size of glass spheres used was 1/2 inch in diameter. The next largest size, referred to as size AP, had 95 to 100 percent passing the number 20 sieve, and 0 to 15 percent passing the number 50 sieve. Size PM had 100 percent passing the number 70 sieve, and 0 to 10 percent passing the number 230 sieve. The smallest size, MS-ML, had 90 to 100 percent passing the number 140 sieve, and 0 to 10 percent passing the number 270 sieve. A more detailed classification is diagrammed in the appendix.

Frictional Characteristics

Since both the coefficient of internal friction of the fill material and the coefficient of friction between the fill material and the bin walls were important factors, considerable effort was made to determine these values.

To determine the coefficient of internal friction of the material, the emptying angle of repose method was used, since previous investigations report this as being a consistent method. An 8-3/4" x 9-1/2" x 23" box was filled with the material; then one end of the box was removed and the material was allowed to flow out. The angle of repose (θ) was then measured. There were no projections on the open end of the box to

prevent the flow of the material near the base. This method of measuring the angle of repose was followed for all materials. However, in the case of the 1/2 inch diameter marbles, the surface of the material was concave, and the angle recorded was the slope of the center line from the base of the surface to the top of the surface. The tangent of the angle obtained is assumed equal to the coefficient of internal friction (μ) within the material.

Several methods were tried to determine the coefficient of friction between the material and the bin. A block of wood, 2 x 4 x 7 inches, was prepared by gluing the material on one surface. The block was then dragged over the surface of the bin by a spring balance. This method was found to be inadequate, since the readings were quite inconsistent. The coefficient of friction was then obtained from the angle of friction. The bin was placed at a given slope and the block was placed on the inner surface. The angle of friction was that angle at which the block, if pushed up the plane, more often than not, would slide back when released. The tangent of this angle was assumed equal to μ'_B , the coefficient of friction of the material on the bin.

For the rough bin case, whenever θ'_B was greater than θ , the effective coefficient of friction (μ') was assumed equal to the tangent of θ .

In the case of the smooth bin, whenever θ was greater than θ'_B , the effective coefficient of friction (μ') was assumed equal to the tangent of θ'_B .

The frictional characteristics of the materials are quite variable, depending upon the method used to determine them. This factor must not

be overlooked in the consideration of the experimental results.

Friction values used in this thesis are shown in Table II. These values were taken from unpublished data in Professor Scheer's files gathered as part of an M.S.C. Engineering Experiment Station research project.

TABLE II

Friction Angles for Materials Used

	<u>Wheat</u>	<u>1/2 Dia. Marbles</u>	<u>AP</u>	<u>PM</u>	<u>MS-ML</u>
\emptyset	28.0°	12.5°	25.0°	25.9°	27.0°
\emptyset'_B *	21.7°	19.25°	25.9°	25.2°	24.8°
\emptyset'_B **	All values greater than \emptyset .				

* For wood bin.

** For sandpaper bin.

EXPERIMENTAL PROCEDURE

Investigation into the effects of four factors on the base pressure in bins was performed. These factors were relative movement between the walls and the base, particle size, bin shape, and wall roughness.

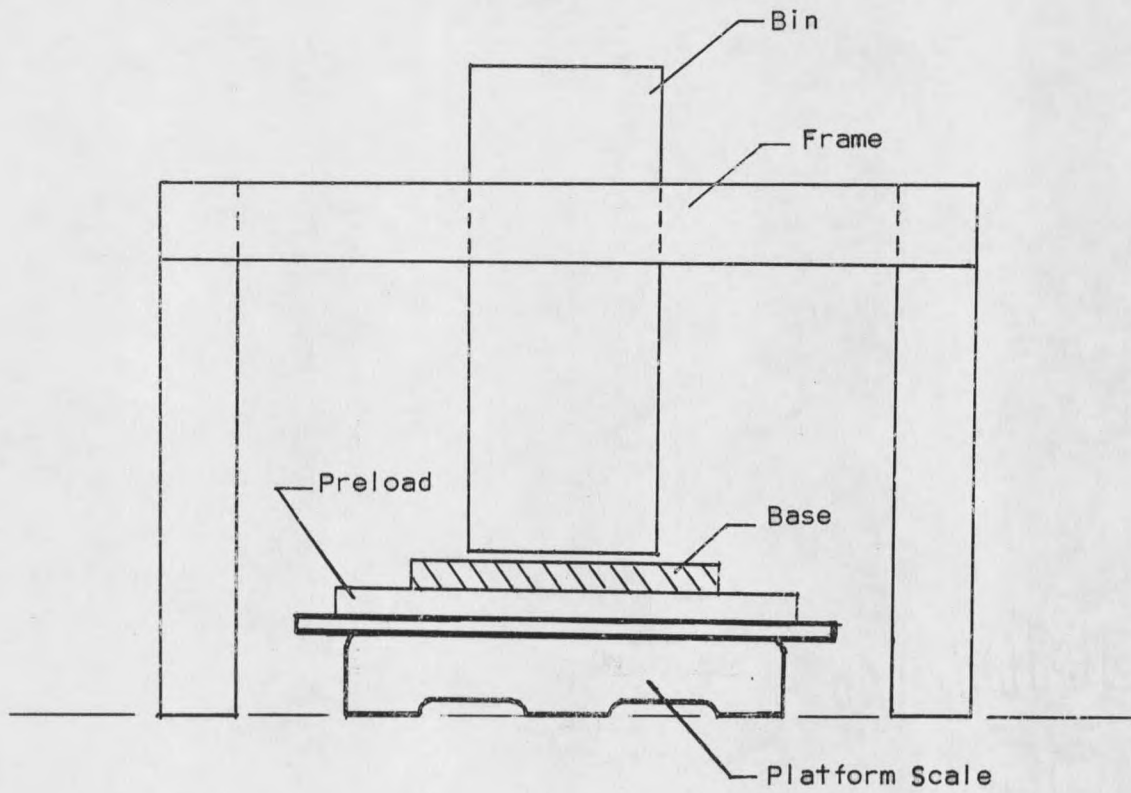
A total of 17 tests was made. Each test consisted of from four to eight runs. Each run represented one filling of the bin. All 17 tests are summarized in the appendix.

The first nine tests were conducted primarily to determine the effect of relative movement between the walls and the base. Tests 10 through 13 were made to investigate the effect of particle size. Tests 2, 14, 15, and 16 furnished the data to determine the effect of bin shape. Data from test 2 and test 17 show the effect of changing wall roughness.

Effect of Relative Movement

The first investigation was to determine the effect of relative movement between the walls and the base on the vertical pressure in bins. All tests were performed on the 4.98 x 7.57 inch bin, using wheat. Dial indicators were placed at three of the lower corners. They were attached to the sides of the bin and recorded the relative deflection between the walls and the base. Two of the dial indicators were capable of obtaining measurements to 0.0001 inches. These two indicators were placed on opposite corners. The third dial indicator, which could be read to 0.001 inches, was placed at one of the two remaining corners. Therefore, any irregular deflection of the base or sides could be observed. The base of the bin was placed on the platform of the scale along with a preload, and the sides were rigidly suspended above it by a rectangular frame, as

shown in Figure 1. A conical metallic funnel was used to load the material into the bin. So that all material would be placed into the bin in approximately the same fashion, the funnel, supported by hand, was set lightly on the material in the bin (or on the base of the bin) and was then filled with the material. The funnel was then slowly raised, allowing the material to flow out. As the material was flowing out, the funnel was moved about within the bin, thereby keeping the surface of the material approximately level. Two types of runs were made. In one set of runs, the bin was completely filled before any readings were made. In the other runs, the bin was filled in five increments. Four equal increments of five inches of material were placed in the bin, and the fifth increment then filled the bin to the same level as it was in the first set of runs. Readings of the dial indicators were made after each increment was added. After running the first three tests, the inner surface of the bin appeared to have become smoother than it had been at the beginning of these tests. To verify this, wheat was glued on one surface of a piece of wood and dragged over the inner and outer surface of the bin. Readings were made by a spring balance. Although the method of measurement did not give accurate friction values, they did show that inner surface was smoother than outer surface. Table I shows the spring balance readings obtained by dragging the block of wood over the inner and outer surfaces. The averages are shown for comparison.



SET-UP FOR BASE ON SCALES

Figure 1

TABLE I

Force Required to Drag Block Over Surfaces	
Inner Surface (Oz)	Outer Surface (Oz)
12.4	11.6
13.4	13.6
9.9	12.7
<u>12.0</u>	<u>14.1</u>
Ave = 11.9	Ave = 13.0

To obtain results under the same frictional resistance, three more tests were conducted.

In reading the platform scale load, when investigating relative movement, two different methods were used. Readings were taken with the scale's beam in its extreme upper and its extreme lower position. When readings were taken with the beam in its lower position, the beam was loaded with an excess weight prior to filling the bin. After the bin had been filled with the material, the weights on the scale's beam were gradually reduced. The reading was recorded when it was just possible to see light between the scale's beam and its rest. The maximum movement of the scale's platform during weighing never exceeded 0.0002 inches. When weighing was done with the beam in its upper position, no weight was added to the scale's beam prior to loading. After filling the bin, weights were gradually added to the beam of the scale. The reading was recorded under the same condition as when the beam was in its lower position.

Positive values of deflection designate a movement of the base away from the sides, and negative values designate movement of the base towards

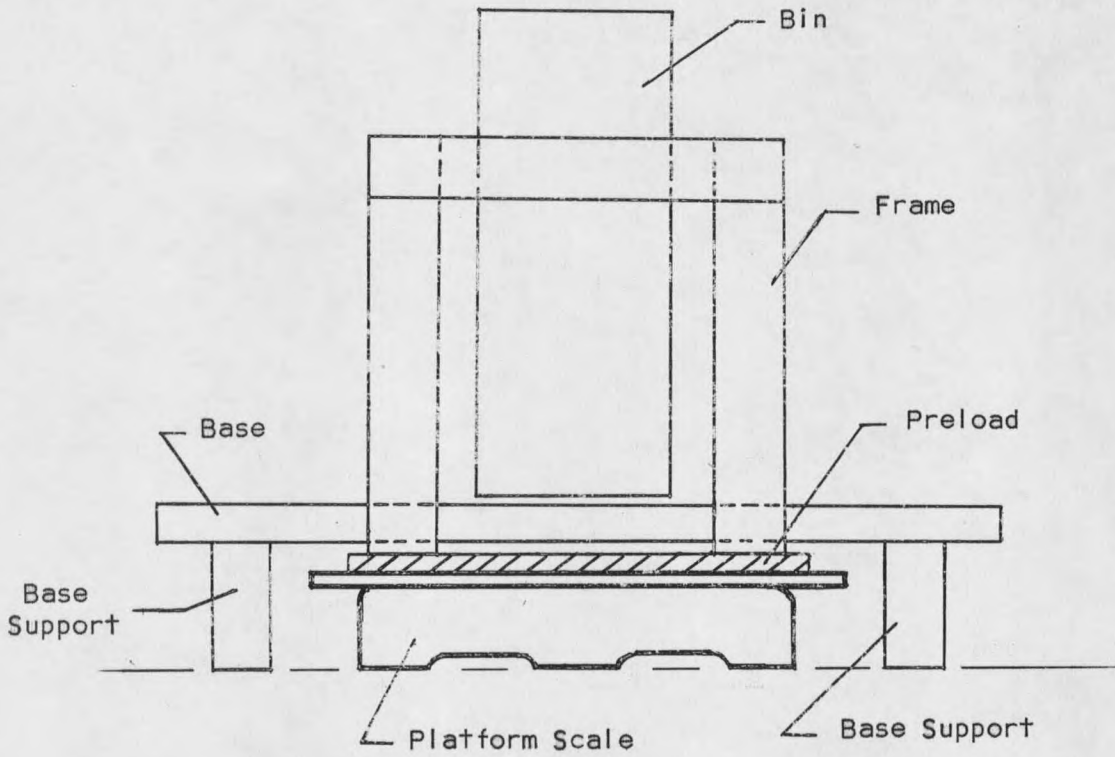
the sides.

Movements of the base away from the sides of approximately 0.0035 inches were obtained. By increasing the preload on the platform of the scale, the movement was reduced to approximately 0.0008 inches. To obtain a relative deflection of the base towards the sides, the frame supporting the sides was placed on the platform of the scale. The base was then supported on two blocks on opposite sides of the scale, as shown in Figure 2. Thus, the base was now free of both the sides of the bin and the platform of the scale. Readings were taken with the scale's beam in its lower position. In the first test run with this arrangement (Test #6), the blocks supporting the base were placed at the ends of the base, and positive movements of approximately 0.0008 inches were recorded. When the blocks were moved in along the base until they were next to the scale, deflection of the base toward the sides was obtained.

Effect of Particle Size

The second factor tested was the effect of particle size on base load. All tests were performed on the 4.98 by 7.57 inch bin. All four sizes of glass spheres were used.

The base of the bin was placed on the platform of the scale, along with a preload of approximately 130 pounds. The sides of the bin were suspended above the base by rectangular frames. The loading procedure was the same as for the first series of tests. The dial indicators were removed, since their readings were no longer desired. The end opening in the funnel was readjusted for each of the particle sizes so as to keep a more uniform flow. However, in the case of the 1/2 inch diameter marbles, it was



SET-UP FOR BIN ON SCALES

Figure 2

necessary at times to slightly shake the funnel to keep them flowing.

Effect of Bin Shape

The next factor tested was the effect of bin shape on the vertical pressure in bins. Three rectangular bins and the circular bin were used for this series of tests. Their dimensions were 6.00 by 6.00 inches, 4.98 by 7.57 inches, 11.48 by 4.07 inches, and 6.00 inches in diameter. The loading procedure and setup for these tests were similar to those used for the investigation of particle size. Wheat was used for this series of tests.

Effect of Wall Roughness

The final factor tested was the effect of varying roughness of the bin sides on the vertical pressure. The 4.98 by 7.57 inch bin was used for these tests. It was taken apart, size 2/0 emery paper was glued to the inner surface to obtain a rough texture, and then the bin was reassembled. The dimensions were slightly changed, giving a final cross section of 7.54 by 4.93 inches. Wheat was used for this series of tests. The setup and loading procedure was the same as that used for the preceding tests.

The coefficient of friction of the material on the bin wall, and the angle of repose of the material were determined by the Montana State College Engineering Experiment Station.

EXPERIMENTAL RESULTS

Effect of Relative Movement

The effect of movement between base and sides, on the base load of wheat, is illustrated by Figure 3.

When the base of the bin was supported on the scale's platform, and the beam in the upper position, the platform had a slight movement toward the grain during weighing. This movement caused a compaction of the grains, thus giving a higher value of base load. With the beam in the lower position, the movement was down away from the grain, giving the opposite effect. When the bin walls are supported on the scale's platform, the movements will be just reversed in each case, giving the opposite effect on base load. These movements of the base and sides, during weighing, never exceeded 0.0002 inch, and therefore had a minor effect on vertical pressure according to Figure 3.

The inner surface of the bin became smoother during the first few tests, which may account for the base loads from the first three tests being less than values from subsequent tests with like deflections.

The deflections that were obtained for later tests were between 0 and approximately 0.0025 of an inch. Observation from Figure 3 would indicate that the base loads obtained from these later tests were slightly less than would have been obtained if there had been no base movement, with a maximum error of perhaps 10%, unless the other materials behave drastically different from wheat. This is a factor worthy of further investigation. The other materials were not similarly tested, because the tests were very time-consuming, and it was desired to investigate other factors besides

base movement.

In all subsequent tests to determine the effect of particle size, bin shape, and wall roughness on base pressure, the base was supported on the scale's platform, and readings of load were taken with the beam in its lower position.

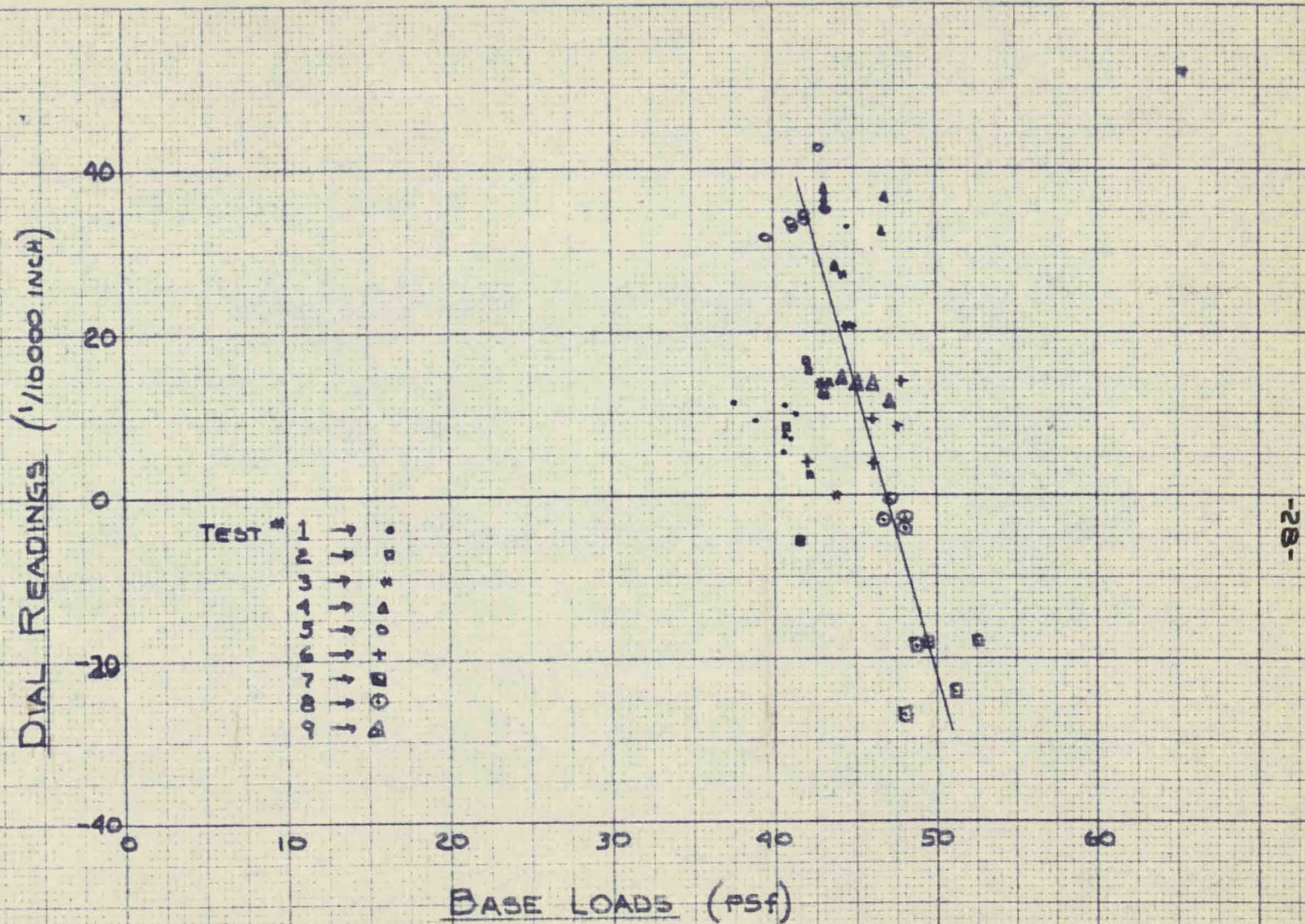


FIGURE 3
EFFECT OF BASE MOVEMENT ON BASE LOADS

Effect of Particle Size

Figures 4 to 7 are plots of the pressure distributions in the 7.57 x 4.98 inch bin for the different materials tested to determine the effect of particle size.

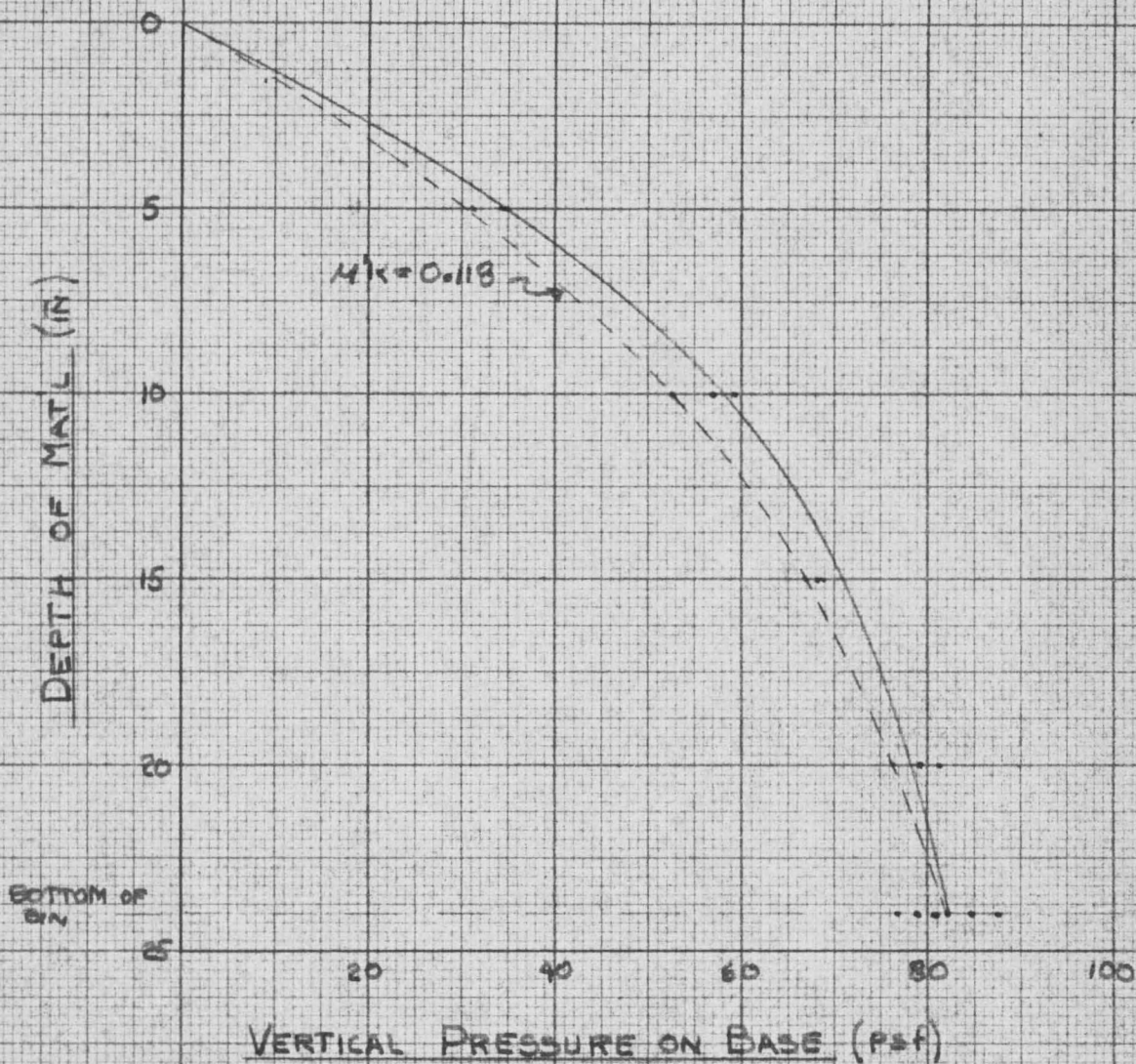
Values of M^*K were selected that would give curves using Janssen's equation, which would approximate the experimental curves.

The materials used in order of diminishing particle sizes are 1/2" diameter marbles, AP microbeads, PM microbeads, and MS-ML microbeads.

BIN : 4.98 x 7.57 INCH

— EXPERIMENTAL CURVE

- - - JANSSEN'S EQUATION



PRESSURE DISTRIBUTION CURVE FOR
1/2 INCH DIAMETER MARBLES

FIGURE 4

BIN : 4.98 x 7.57 INCHES

— EXPERIMENTAL CURVE

- - - JANSEN'S EQUATION

DEPTH OF MATERIAL (IN)

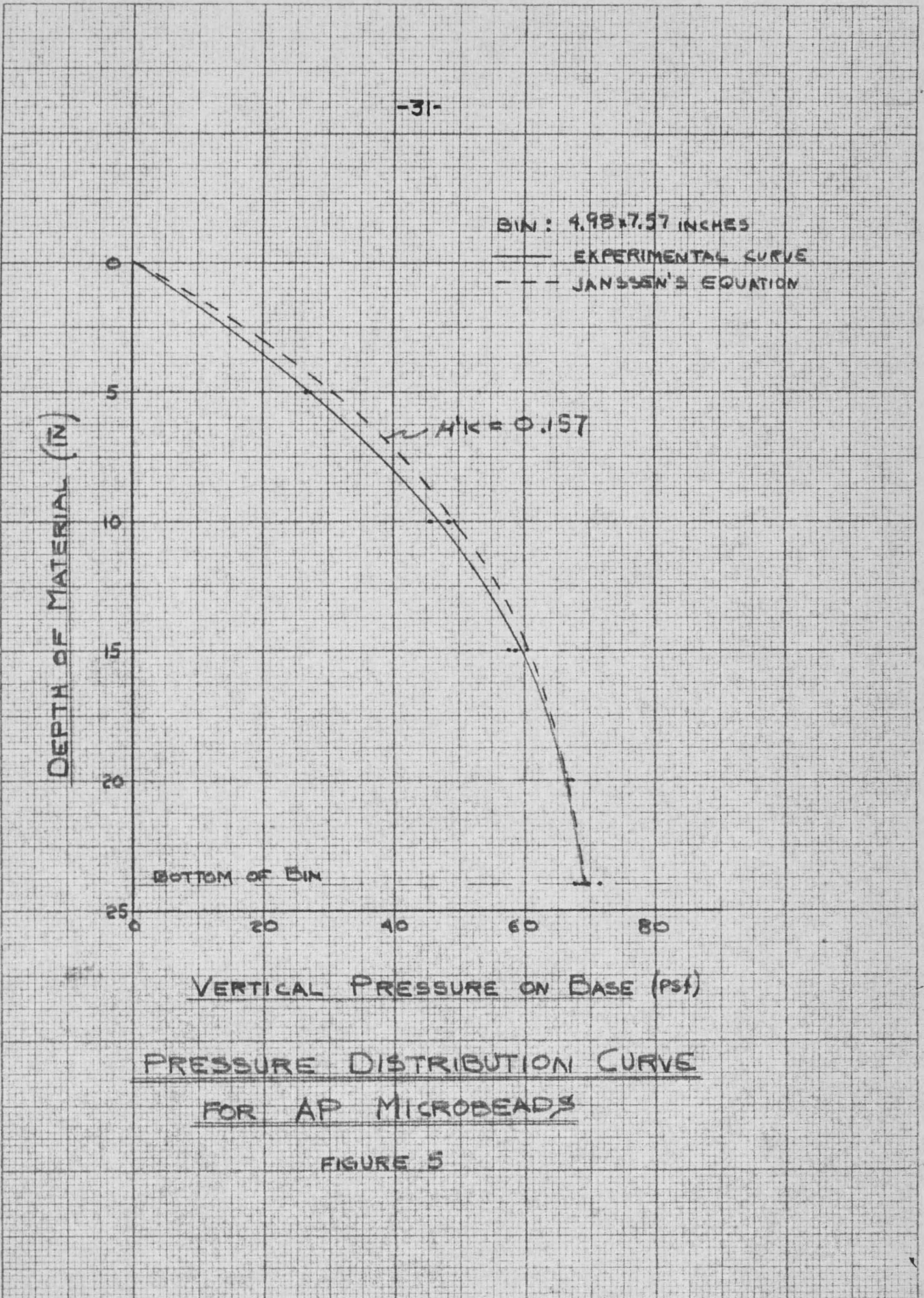
$H/K = 0.157$

BOTTOM OF BIN

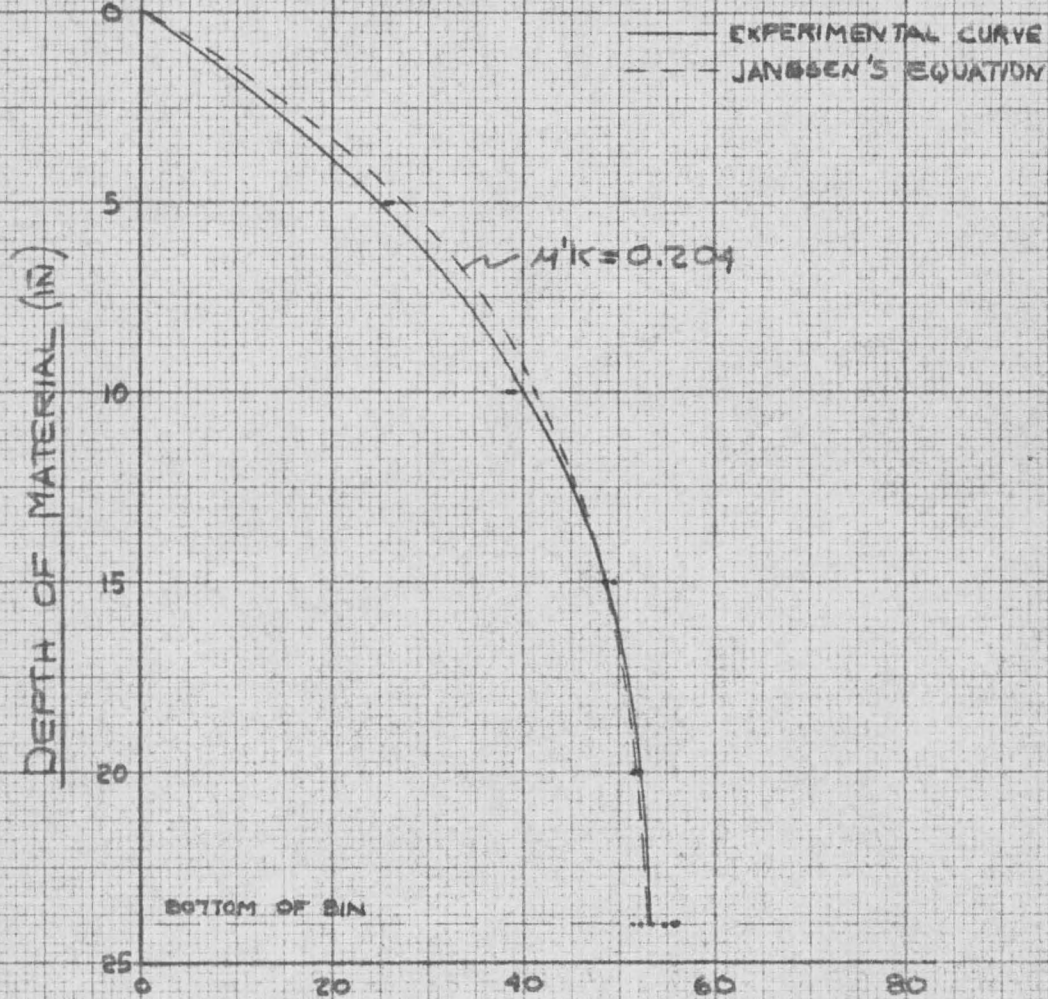
VERTICAL PRESSURE ON BASE (PSI)

PRESSURE DISTRIBUTION CURVE
FOR AP MICROBEADS

FIGURE 5



BIN: 4.98 x 7.57



VERTICAL PRESSURE ON BASE (psf)

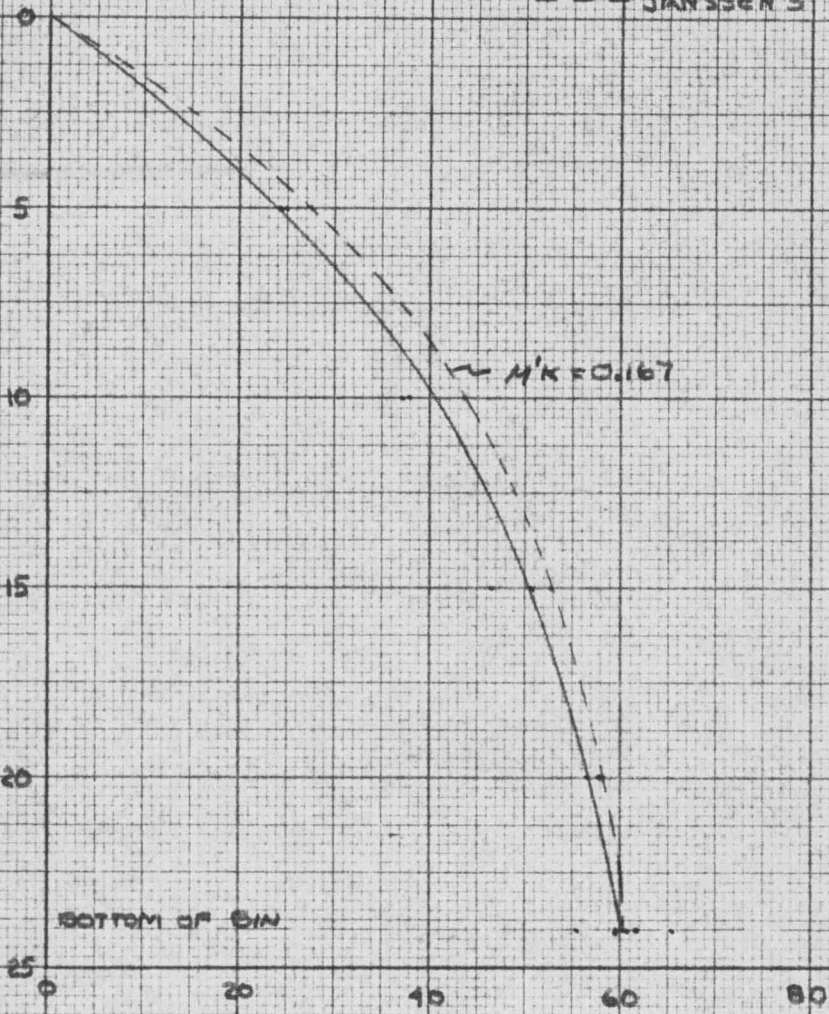
PRESSURE DISTRIBUTION CURVE
FOR PM MICROBEADS

FIGURE 6

BIN: 4.98 x 7.57 (IN)

— EXPERIMENTAL CURVES
- - - JANSEN'S EQUATION

DEPTH OF MAT'L (IN)



VERTICAL PRESSURE ON BASE (PSF)

— PRESSURE DISTRIBUTION CURVE —
FOR MS-ML MICROBEADS

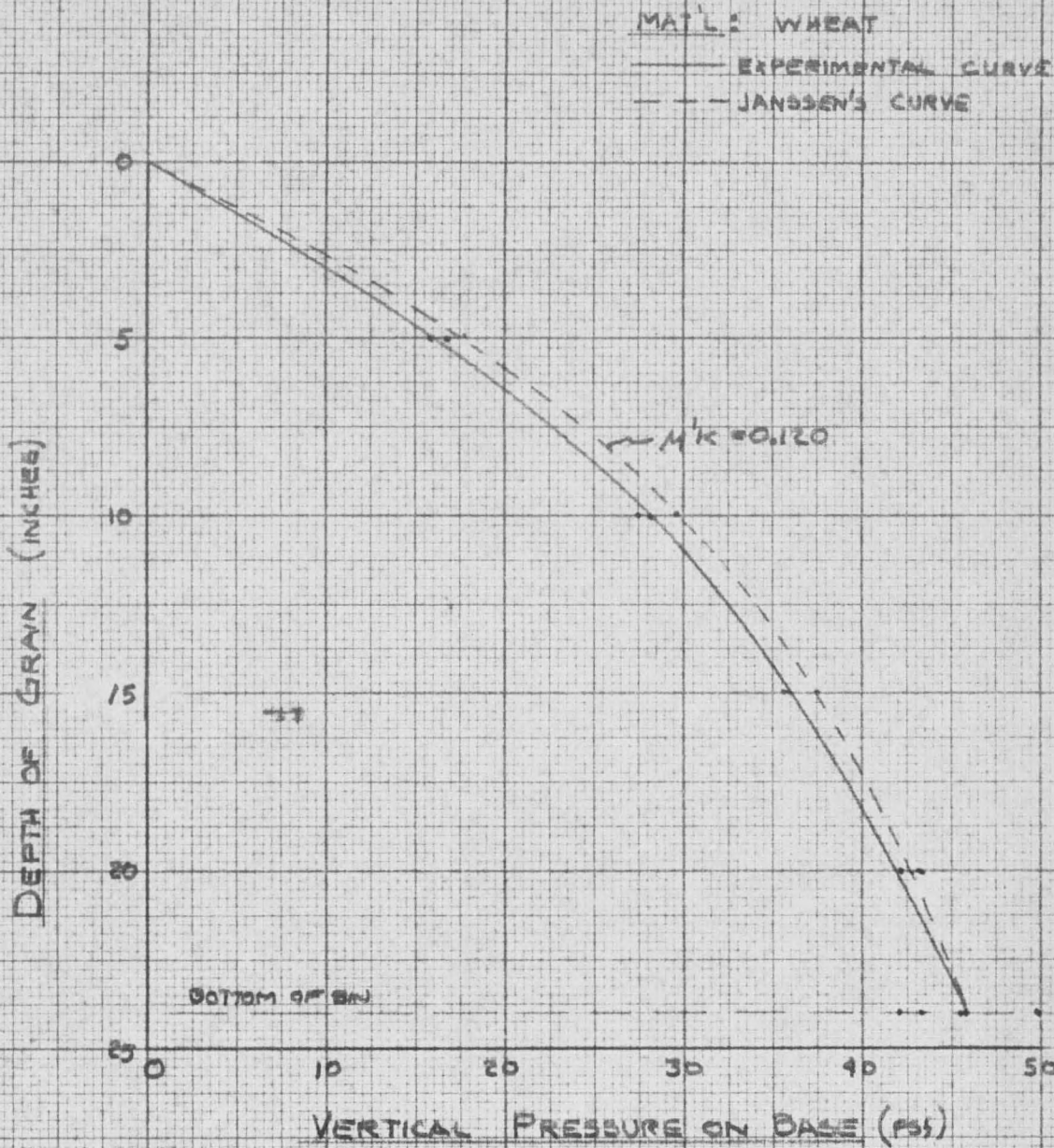
FIGURE 7

Effect of Bin Shape

Four bins were tested to determine the effect of bin cross section on base pressure. Their pressure distribution curves are shown in Figures 8 to 11. Wheat was used as the fill material.

As discussed under the section on Design of Bins, due to its construction, the results from the circular bin may not be very reliable.

Values of $\mu'K$ were selected such that Janssen's equation would give a theoretical curve that would approximate the experimental curves. These theoretical curves are superimposed upon the experimental curves.



WHEAT IN 6.00 INCH DIA. CIRCULAR BIN

FIGURE B

— EXPERIMENTAL CURVE
- - - JANSSEN'S EQUATION

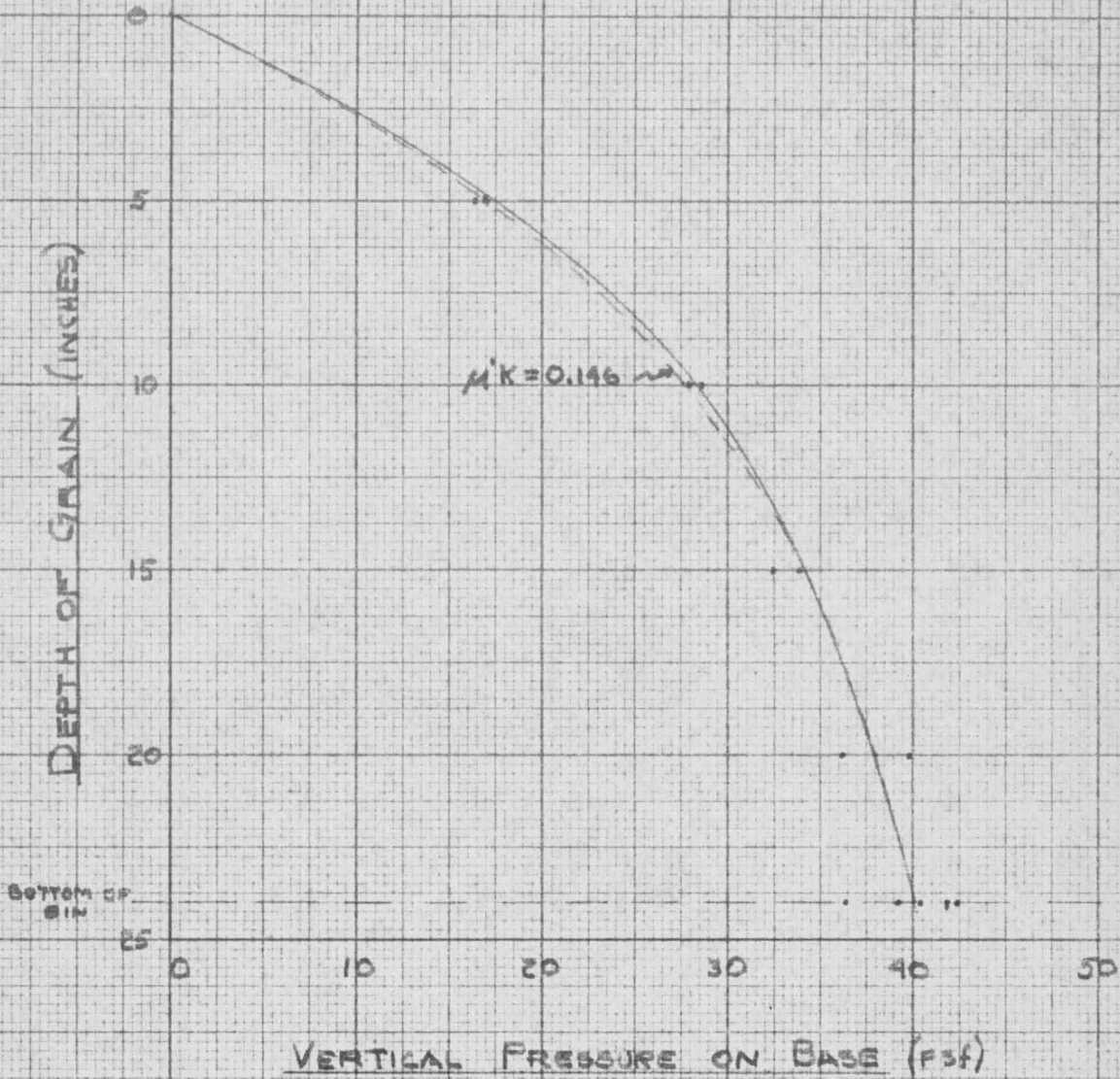
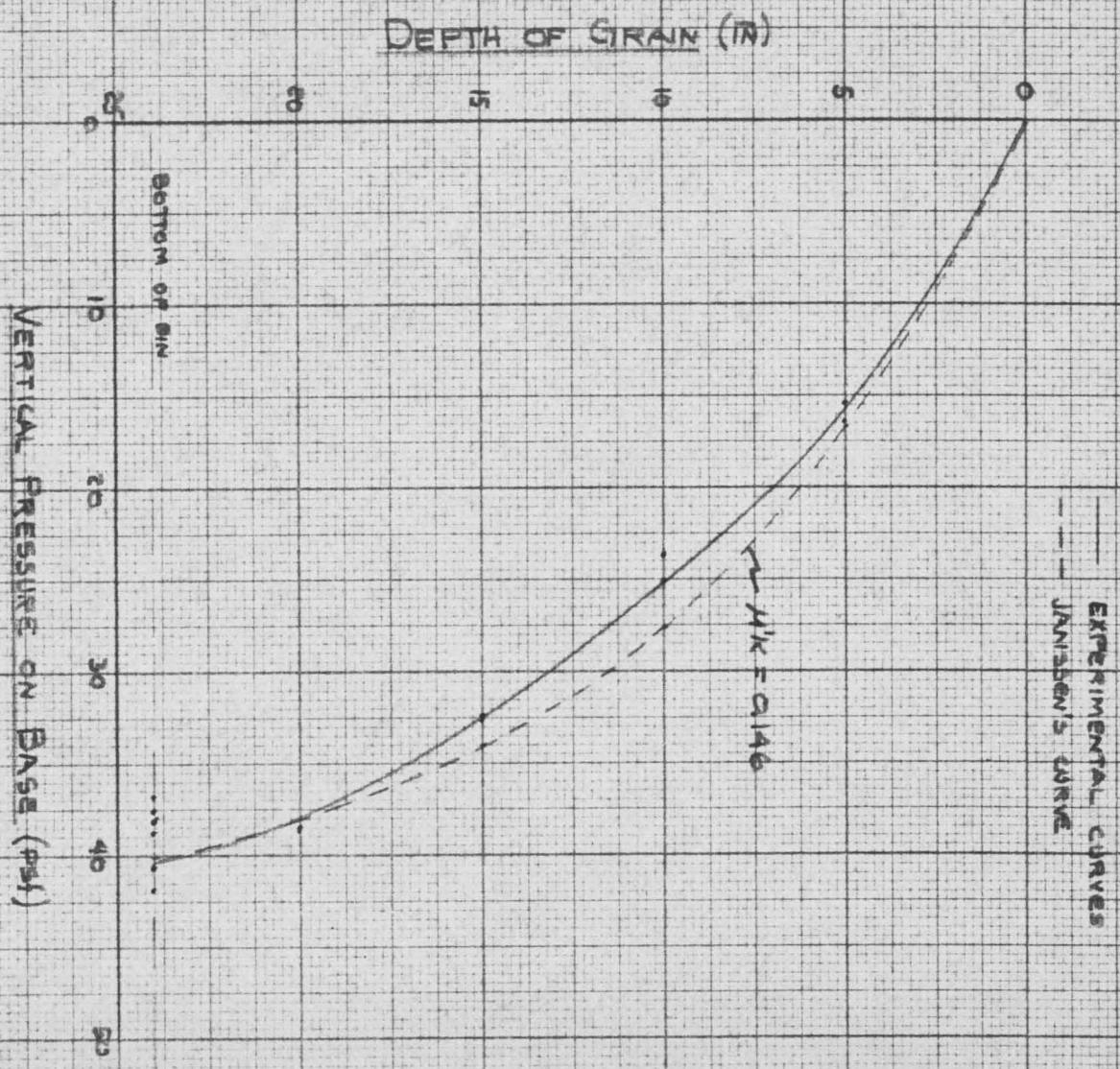


FIGURE 9

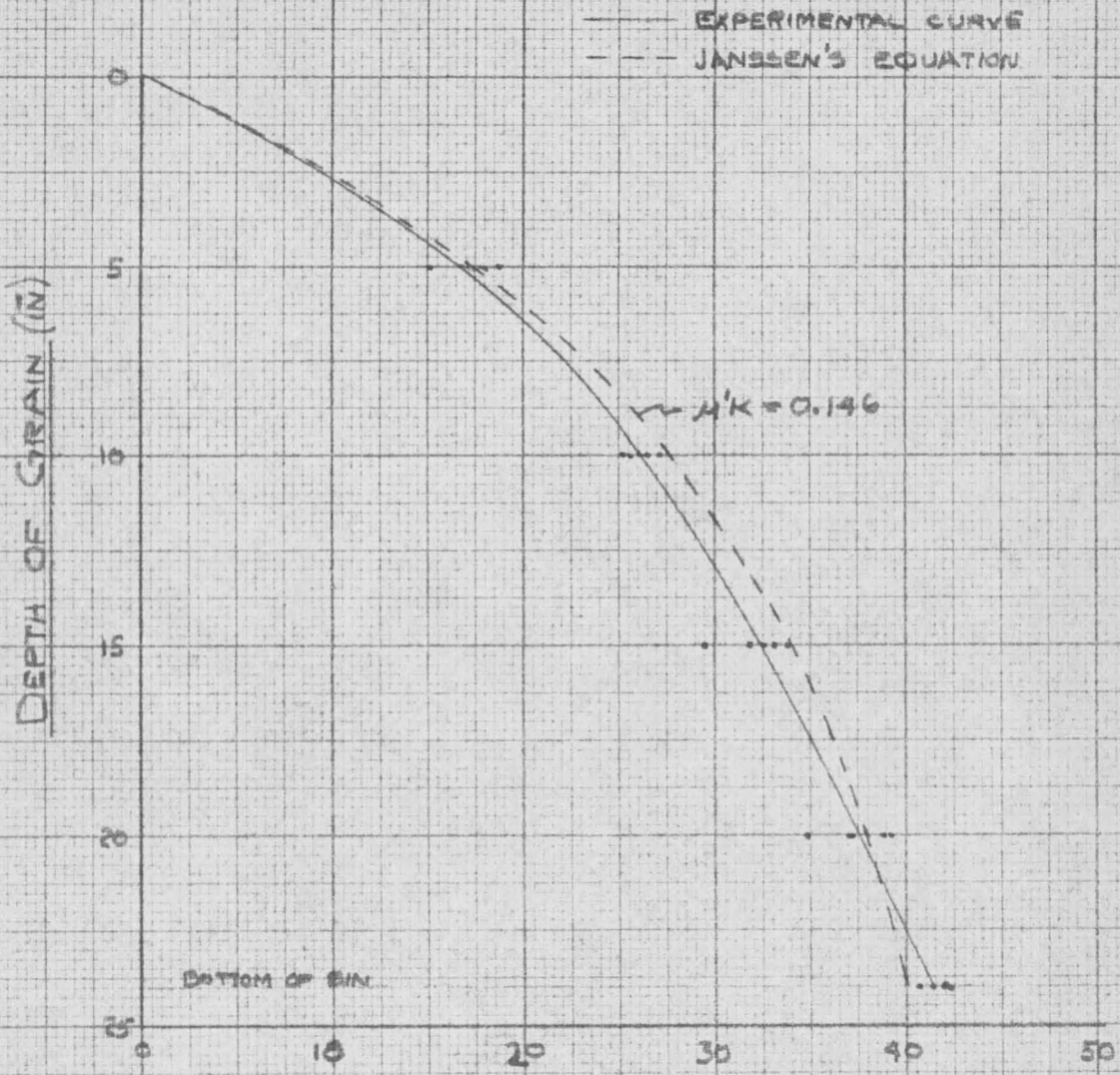
WHEAT IN 6.00 x 6.00 INCH BIN



WHEAT IN 11.48 OR 4.07 INCH BIN
FIGURE 10

EUGENE DIETZGEN CO.
MADE IN U. S. A.

NO. 340 20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH



VERTICAL PRESSURE ON BASE (PSF)

WHEAT IN 4.98 x 7.57 INCH BIN

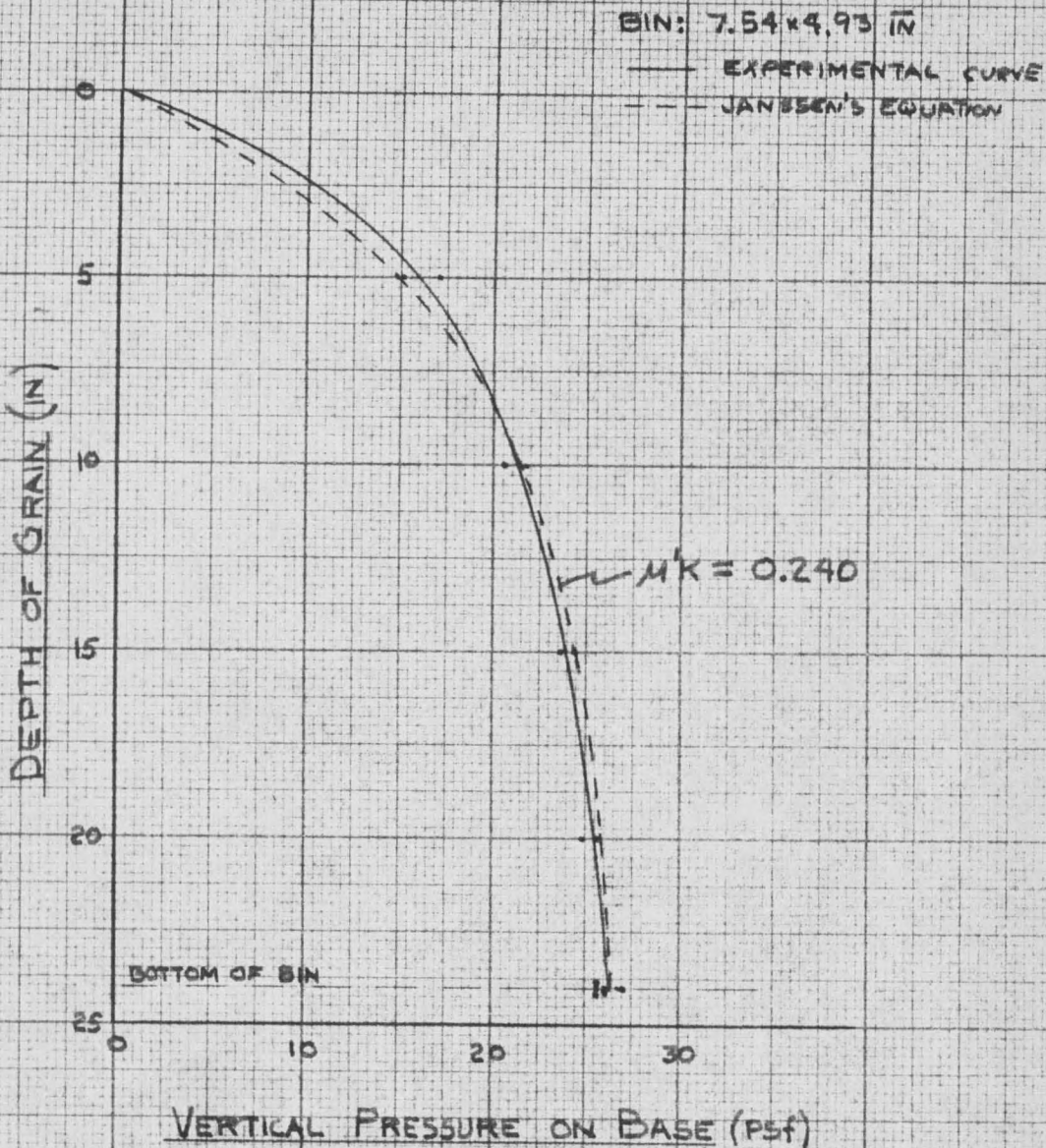
FIGURE 11

Effect of Wall Roughness

Figure 12 shows the pressure distribution curve for the bin which had its inner surface covered with sandpaper to increase the roughness.

The dimensions of this bin were 7.54 x 4.93 inches, which is very similar in cross section to the 4.98 x 7.57 inch bin. Using wheat, a value of $\mu'K$ of approximately 0.240 yields a curve using Janssen's equation, which shows close agreement with the experimental curve. The 4.98 x 7.57 inch bin, which had no covering on its inner surface, required a value of $\mu'K$ of approximately 0.146 in Janssen's equation for the experimental and theoretical curves to be in agreement.

For this bin, $\theta < \theta'_B$; therefore, it would be classified as a rough bin, and the effective μ' value equals $\tan \theta$.



WHEAT IN SAND - PAPER LINED BIN

FIGURE 12

PREDICTION OF K VALUES

Prediction of K values were made by the method suggested by Professor Alfred Scheer in his paper, "Bin Theory and Soil Méchanics." (26)*

Wheat

$$\phi = 28.0^\circ$$

$\phi'_B < \phi$ ∴ Smooth Bin

$$\phi'_B = 21.7^\circ$$

$$\phi' = \phi'_B$$

$$\cos \alpha + \tan \phi' \sin \alpha = \frac{\tan \phi'}{\sin \phi}$$

$$\cos \alpha + 0.398 \sin \alpha = \frac{0.398}{0.469}$$

$$\alpha = 59.5^\circ$$

$$K'_A = \frac{1}{1 + 2 \tan \alpha \tan \phi'}$$

$$K'_A = \frac{1}{1 + 2 \tan 59.5^\circ \tan 21.7^\circ}$$

$$K'_A = 0.425$$

$$K'_B = \frac{1 - \sin^2 \phi'}{1 + \sin^2 \phi'}$$

$$K'_B = \frac{1 - \sin^2 21.7^\circ}{1 + \sin^2 21.7^\circ} = 0.759$$

$$K' = \frac{1}{2} (K'_A + K'_B)$$

$$K' = 0.592$$

*Bibliography Reference Number Page 77.

1/2 Dia. Marbles

$$\emptyset = 12.5^\circ$$

$\emptyset'_B > \emptyset \therefore$ Rough Bin

$$\emptyset'_B = 19.25^\circ$$

$$\emptyset' = \emptyset$$

$$K' = \frac{1 - \sin^2 \emptyset}{1 + \sin^2 \emptyset}$$

$$K' = \frac{1 - \sin^2 12.5^\circ}{1 + \sin^2 12.5^\circ} = 0.910$$

AP Microbeads

$$\emptyset = 25.0^\circ$$

$\emptyset'_B > \emptyset \therefore$ Rough Bin

$$\emptyset'_B = 25.9^\circ$$

$$\emptyset' = \emptyset$$

$$K' = \frac{1 - \sin^2 \emptyset}{1 + \sin^2 \emptyset}$$

$$K' = \frac{1 - \sin^2 25.0^\circ}{1 + \sin^2 25.0^\circ} = 0.699$$

PM Microbeads

$$\emptyset = 25.9^\circ$$

$\emptyset'_B < \emptyset \therefore$ Smooth Bin

$$\emptyset'_B = 25.2^\circ$$

$$\emptyset' = \emptyset'_B$$

$$\cos \alpha + \tan 25.20 \sin \alpha = \frac{\tan 25.2^\circ}{\sin 25.9^\circ}$$

$$\alpha = 38^\circ$$

$$K'_A = \frac{1}{1 + 2 \tan 38^\circ \tan 25.2^\circ}$$

$$K'_A = 0.576$$

$$K'_B = \frac{1 - \sin^2 25.2^\circ}{1 + \sin^2 25.2^\circ}$$

$$K'_B = 0.692$$

$$K' = 1/2 (0.576 + 0.692)$$

$$K' = 0.634$$

MS-ML Microbeads

$$\phi = 27.0^\circ$$

$\phi'_B < \phi$ ∴ Smooth Bin

$$\phi'_B = 24.8^\circ$$

$$\phi' = \phi'_B$$

$$\cos \alpha + \tan 24.8^\circ \sin \alpha = \frac{\tan 24.8^\circ}{\sin 27.0^\circ}$$

$$\alpha = 47^\circ$$

$$K'_A = \frac{1}{1 + 2 \tan 47^\circ \tan 24.8^\circ}$$

$$K'_A = 0.425$$

$$K'_B = \frac{1 - \sin^2 24.8^\circ}{1 + \sin^2 24.8^\circ}$$

$$K'_B = 0.700$$

$$K' = 1/2 (0.425 + 0.700)$$

$$K' = 0.562$$

Sand Paper Lined Bin

Material: Wheat

Bin: 4.93 x 7.54

$\phi'_B > \phi$ ∴ Rough Bin

$\phi' = \phi$

$$K' = \frac{1 - \sin^2 28^\circ}{1 + \sin^2 28^\circ}$$

$$K' = 0.640$$

The calculations are summarized in Table III.

TABLE III

Wheat

<u>Bin</u>	<u>(M'K) Fitted</u>	<u>M'</u>	<u>K_{obs}</u>	<u>K'_{cal}</u>	<u>a = k/K'</u>
6.00 x 6.00	0.146	.398	.366	0.592	.619
11.48 x 4.07	0.146	.398	.366	0.592	.619
4.98 x 7.57	0.146	.398	.366	0.592	.619
4.93 x 7.54 (sandpaper lined)	0.240	.469*	.512	0.640	.800

Bin: 4.98 x 7.57

<u>Material</u>	<u>(M'K) Fitted</u>	<u>M'</u>	<u>K_{obs}</u>	<u>K'_{cal}</u>	<u>a = k/K'</u>
1/2 Marbles	0.105	.222*	.473	.910	.520
AP	0.157	.466*	.337	.699	.482
PM	0.204	.471	.433	.634	.684
MS - ML	0.167	.460	.363	.562	.646

*Rough bin (All others smooth bin).

$\emptyset < \emptyset'_B$; therefore $M' = \tan \emptyset$

Professor Scheer in his paper, "Bin Theory and Soil Mechanics," suggests a value of 0.7 for "a". The predicted values of K for "a" of 0.7 are compared with the observed values of K in Table IV.

TABLE IV
Comparison of Observed With Predicted Values of K

Material	Bin	Obs K	Predicted K
Wheat	4.98 x 7.57	0.366	0.414
Wheat	6.00 x 6.00	0.366	0.414
Wheat	4.07 x 11.48	0.366	0.414
Wheat	4.93 x 7.54 (sandpaper lined)	0.512	0.448
Wheat	6.00 in. dia. (circular)	0.302	0.414
1/2 Marbles	4.98 x 7.57	0.473	0.636
AP	4.98 x 7.57	0.337	0.488
PM	4.98 x 7.57	0.433	0.443
MS-ML	4.98 x 7.57	0.363	0.393

DISCUSSION AND RECOMMENDATIONS

Considerable caution must be used in relating model bin results to full size bins. The greater depths in full size bins causes much larger pressures which result in greater consolidation of the fill material. From similitude considerations, possibly a fluffy compressible material like mica chips or rubber chips should be used in model bins to get equivalent consolidation. However, literature reports, though meager, generally furnish evidence that K values for model bins may be applied to full size bins with confidence.

All tests, with all material, except for tests numbered 3, 4, 6, 7, and 8, were conducted with the beam in the lower position and the base of the bin resting on the scale's platform. This method is believed to give results that are more nearly representative of conditions in full-sized bins where consolidation is more pronounced than it is in model bins. In full size bins, consolidation causes considerable downward movement of the fill relative to the bin walls. When the beam is balanced under the above conditions, the base has a slight deflection away from the fill material. This deflection increases the movement of the fill relative to the bin walls.

Excellent correlation, relative to bin shape, was obtained for the three rectangular bins tested. When a value of $M'K$ of 0.146 is used in Janssen's equation, the pressure distribution curve obtained closely approximated the experimental curves for each of the rectangular bins. In Janssen's equation, the sole geometric property of the bin's cross section is the hydraulic radius. The results obtained strongly support Janssen's theory. Even the circular bin, when viewed in the light of its crude work-

manship, which yielded a $\mu'K$ value of 0.120, showed fairly good correlation with the other bins. However, to obtain a more complete understanding of the effect of bin cross section on base pressure, it would be necessary to perform a series of tests on circular bins, rectangular bins, and bins of other shapes, perhaps including an equilateral triangle, all built of the same material.

It was impossible to arrive at a conclusion regarding the effect of particle size on base pressure. It was originally hoped that the use of the glass marbles, and the various sizes of glass microbeads, would effectively isolate particle size as the primary physical variable. However, these materials had different frictional characteristics which were undoubtedly attributable, partly at least, to factors other than particle size. The percentage of true spheres was variable, and the microbeads were not uniform in size. This latter factor could have been partially corrected through selective sieving, but it was not felt to be warranted in view of the uncertainties which would still remain. The large size gap, between the marbles and the largest beads, was also a serious obstacle.

It is suggested that future researchers seriously consider using a single size material in bins of different size, to determine whether the ratio of particle size to bin diameter affects pressure. If different fill materials are used, they should be more carefully controlled, as to size and shape, than was done here.

Except for an outline of Airy's solution in the appendix, very little else has been mentioned of it in this thesis. Of the two mathematical

approaches, Janssen's is the more rational and the more widely used by engineers, and therefore was used to aid in analyzing the data throughout this investigation. Airy, in his solution, takes a one foot wide section out of the bin and fails completely to relate bin shape to pressure. Furthermore, he includes the forces on only one side of this section, where it bears against the wall, and neglects the forces on the opposite side.

In general, the pressure distribution curves did not flatten out as rapidly as the theoretical Janssen's curves do. This trend appears to be definite enough and important enough to warrant further investigation. It is possible that slightly different values of $M'K$ would have been selected to fit the experimental curves if the bins had been deeper. It is recommended that future tests be performed on relatively deeper bins to find the depth at which the base pressure does become essentially constant.

The observed value of K for wheat in the rectangular bins was 0.366. Milo Ketchum reported a value of K for a wood rectangular bin of 0.4, while Pleissner observed values from similar bins of 0.3 to 0.5, using a fill material of wheat. Janssen and Jamieson, using wheat in wood bins, reported higher values for K ; their values were 0.67 and 0.596, respectively. Considerable variation in the reported values of K could be expected because of the variation in the frictional characteristics of wheat and the different frictional characteristics of bins of the same type.

When the bin walls were covered by emery paper, the angle of friction ϕ'_B of the wheat on the wall was increased until it had exceeded the angle of repose, ϕ . The effective coefficient of friction was then equal to the

tangent of θ . This increase in roughness resulted in an increase in K for wheat of from 0.366 to 0.512.

Prediction of K values were then made by the method presented by Professor Alfred C. Scheer. The predicted values shown in Table IV, Page 46, gave a fair estimate of the observed K values. His use of $a = 0.7$ is, of course, nothing more than an estimate, because "a" could not possibly be a universal constant. The results do give hope, however, that K may ultimately be accurately predicted if a refined method of estimating "a" is devised.

CONCLUSIONS

1. From Figure 3, it is concluded that a movement of the base of ± 0.0020 inches will result in a variation in the base load of less than $\pm 10\%$ for wheat in a bin of this size and type. This variation is relatively small, and therefore inspires confidence in the platform scale method of measuring base loads.

2. The near identical nature of Figures 9, 10, and 11, conclusively demonstrates that varying the ratio of the sides of a rectangular bin did not cause any significant variation in the average base pressure of wheat.

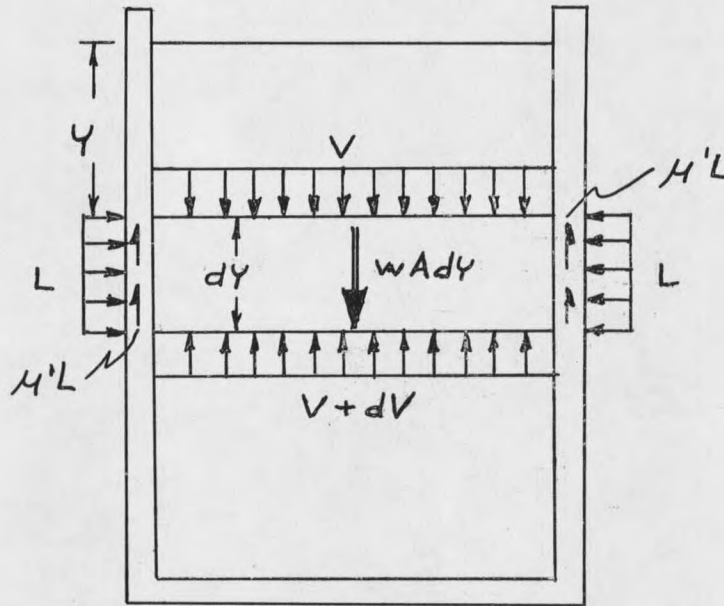
3. In investigating the effect of particle size, extremely close control must be exercised over the size and shape of the particles, if a significant conclusion is to be reached. The control was insufficient in this project.

4. It is concluded that a significant variation in wall roughness, which causes a change from the smooth bin case to the rough bin case, may be expected to cause a significant change in K. When emery paper was glued to the walls of a rectangular wood bin, the observed value of K for wheat in this bin increased from 0.366 to 0.512.

5. To obtain the observed K's, using Scheer's K prediction equations, it would be necessary to use values of "a" that lie between 0.5 and 0.8.

APPENDIX

DERIVATION OF JANSSEN'S EQUATION



NOMENCLATURE

ϕ' = Angle of friction of the grain on the bin walls.

μ' = $\tan \phi'$ = Coefficient of friction of grain on the bin walls.

w = Weight of grain in lbs. per cu. ft.

V = Vertical pressure in lbs. per sq. ft.

L = Lateral pressure in lbs. per sq. ft.

A = Area of bin in sq. ft.

U = Circumference of bin in ft.

$R = \frac{A}{U}$ = Hydraulic radius in ft.

Y = Depth from top of bin to point where pressure is desired in ft.

K = Ratio of lateral to vertical pressure.

$$\Sigma v = 0$$

$$(V + dV) A + M' L U dY - VA - wAdY = 0$$

$$VA + Adv + M' L U dY - VA - wAdY = 0$$

$$dV = w dY - M' L \frac{U}{A} dY$$

$$R = \frac{A}{U} \quad U = \frac{A}{R}$$

Therefore

$$dV = w dY - \frac{M' L}{R} dY$$

Solving for dY

$$dY = \frac{dV}{w - \frac{M' L}{R}}$$

$L = KV$ Lateral pressure is equal to vertical pressure times a constant.

$$dY = \frac{dV}{w - \frac{M' K V}{R}}$$

Integrating we get

$$Y = - \frac{R}{M' K} \log (w - \frac{M' K V}{R}) + \text{constant}$$

$$\text{At } Y = 0 \quad V = 0$$

Solving for C gives

$$C = \frac{R}{M' K} \log w$$

Then:

$$Y = - \frac{R}{M'K} \log \left(w - \frac{M'K V}{R} \right) + \frac{R}{M'K} \log w$$

$$- \frac{M'K}{R} Y \cong \log \left(w - \frac{M'K V}{R} \right) - \log w$$

$$- \frac{M'K}{R} Y = \log \left(\frac{w - \frac{M'K V}{R}}{w} \right)$$

$$e^{-\frac{M'K Y}{R}} = \frac{w - \frac{M'K V}{R}}{w}$$

Solving for V

$$w e^{-\frac{M'K Y}{R}} = w - \frac{M'K V}{R}$$

$$V = \frac{R}{M'K} \left(w - w e^{-\frac{M'K Y}{R}} \right)$$

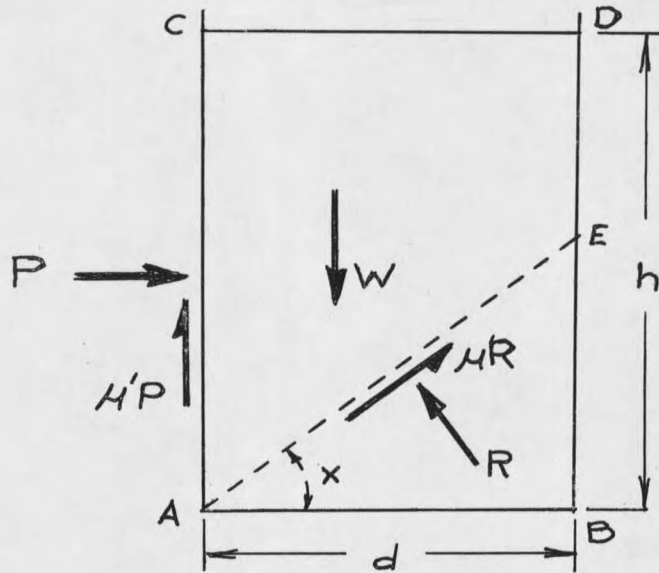
$$V = \frac{R w}{M'K} \left(1 - e^{-\frac{M'K Y}{R}} \right) \text{ Vertical pressure at depth } Y.$$

$$L = KV$$

Therefore

$$L = \frac{Rw}{M'} \left(1 - e^{-\frac{M'K Y}{R}} \right) \text{ Lateral pressure at depth } Y.$$

AIRY'S SOLUTION



W = Weight of AEDCA one foot thick.

P = Pressure against side AC.

μ' = Coefficient of friction between the grain and the wall.

μ = Coefficient of friction of grain on grain.

d = Breadth of the bin.

h = The depth of the grain.

w = Weight of grain lbs. per cu. ft.

Deep Bin One in which the plane of rupture AE meets the opposite side of the bin within the mass of grain.

Summation of Forces in Direction of AE

$$\mu R + P \cos x + \mu' P \sin x - W \sin x = 0$$

$$\mu R + P \cos x = (W - \mu' P) \sin x$$

Summation of Forces Perpendicular to AE

$$R + \mu' P \cos x - P \sin x - W \cos x = 0$$

$$R - P \sin x = (W - \mu' P) \cos x$$

Solving for P

$$\mu = \frac{(W - \mu' P) \sin x - P \cos x}{(W - \mu' P) \cos x + P \sin x}$$

$$\mu (W - \mu' P) \cos x + P \sin x = (W - \mu' P) \sin x - P \cos x$$

$$\mu (W - \mu' P) + P \tan x = (W - \mu' P) \tan x - P$$

$$P (\mu \tan x + \mu' \tan x - \mu \mu' + 1) = W (\tan x - \mu)$$

$$P = W \frac{\tan x - \mu}{1 - \mu \mu' + (\mu + \mu') \tan x}$$

However

$$W = w (\text{Area AEDCA}) = w (CD) \left(\frac{AC + DE}{2} \right)$$

$$= w \frac{d}{2} (2h - d \tan x)$$

Therefore

$$P = w \frac{d}{2} (2h - d \tan x) \frac{\tan x - \mu}{1 - \mu\mu' + (\mu + \mu') \tan x}$$

or

$$P = w \frac{d}{2} \left\{ 2h \frac{\tan x - \mu}{1 - \mu\mu' + (\mu + \mu') \tan x} - d \left(\frac{\tan^2 x - \mu \tan x}{1 - \mu\mu' + (\mu + \mu') \tan x} \right) \right\}$$

To find x which makes P_{maximum} set $\frac{dP}{dx} = 0$

$$\begin{aligned} \frac{dP}{dx} &= w \frac{d}{2} \left\{ 2h \left[\frac{1}{\cos^2 x} (1 - \mu\mu') + \frac{1}{\cos^2 x} (\mu + \mu') \tan x \right. \right. \\ &\quad \left. \left. - \frac{1}{\cos^2 x} (\mu + \mu') \tan x + \frac{1}{\cos^2 x} \mu(\mu + \mu') \right] \right. \\ &\quad \left. - d \left[\left(2 \tan x \frac{1}{\cos^2 x} - \mu \frac{1}{\cos^2 x} \right) \left\{ 1 - \mu\mu' + (\mu + \mu') \tan x \right\} \right. \right. \\ &\quad \left. \left. - \frac{1}{\cos^2 x} (\mu + \mu') (\tan^2 x - \mu \tan x) \right] \right\} \end{aligned}$$

All divided by $\left\{ 1 - \mu\mu' + (\mu + \mu') \tan x \right\}^2$

So that

$$2h (1 + \mu^2) - d \left\{ \tan^2 x (\mu + \mu') + 2 \tan x (1 - \mu\mu') - \mu (1 - \mu\mu') \right\} = 0$$

Which gives

$$\tan x = \sqrt{\frac{2h (1 + \mu^2)}{d (\mu + \mu')} + \frac{(1 + \mu^2)}{\mu + \mu'} \left(\frac{1 - \mu\mu'}{\mu + \mu'} \right) - \frac{1 - \mu\mu'}{\mu + \mu'}}$$

Therefore

$$P = \frac{1}{2} wd^2 \left[\frac{\sqrt{\frac{2h}{d}(M+M') + 1 - MM'} - \sqrt{1+M^2}}{M+M'} \right]^2$$

To determine unit pressure L at depth Y

Differentiate P with respect to depth,

$$L = \frac{wd}{M+M'} \left[1 - \frac{\sqrt{1+M^2}}{\sqrt{\frac{2h}{d}(M+M') + 1 - MM'}} \right]$$

Vertical pressure at any point

$$V = \frac{L}{K}$$

EXPERIMENTAL DATA

Test #1

Bin: 4.98 x 7.57

Material: Wheat

Method of Loading: Preload on base, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Grain</u>	<u>Deflection</u>
1	1	40.42 psf	27.26 lbs	5.25/10000
2	1	44.66	27.20	33.0
3	1	40.46	27.42	7.25
4	1	41.03	27.47	7.0
5	1	40.65	27.41	11.0
6	1	38.93	27.02	9.25
7	1	37.41	27.40	11.25
8	1	41.41	27.43	10.0

Test #2

Bin: 4.98 x 7.57

Material: Wheat

Method of Loading: Preload on base, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Grain</u>	<u>Deflection</u>
1	1	17.94 psf	5.73 lbs	8.0/10000
	2	27.10	11.46	5.0
	3	33.78	17.19	0.0
	4	39.32	22.92	- 3.0
	5	41.41	27.47	- 5.25
2	1	17.75	5.73	9.25
	2	25.57	11.46	14.0
	3	31.87	17.19	15.5
	4	37.22	22.92	16.0
	5	41.99	27.30	16.5
3	1	16.79	5.73	6.75
	2	26.53	11.46	7.0
	3	33.01	17.19	5.75
	4	38.93	22.92	4.25
	5	42.18	27.35	2.5
4	1	18.70	5.73	8.0
	2	26.15	11.46	13.0
	3	32.64	17.19	14.25
	4	37.02	22.92	15.0
	5	42.18	27.31	15.5
5	1	15.08	5.73	7.0
	2	25.38	11.46	9.0
	3	29.58	17.19	11.5
	4	34.93	22.92	10.5
	5	40.65	27.41	8.5

Test #3

Bin: 4.98 x 7.57

Material: Wheat

Method of Loading: Preload on base, arm in upper position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Grain</u>	<u>Deflection</u>
1	1	43.90 psf	27.37 lbs	0.0/10000
2	1	42.94	27.44	14.5
3	1	43.32	27.37	14.25
4	1	17.18	5.73	12.5
	2	26.15	11.46	19.0
	3	34.16	17.19	23.0
	4	40.08	22.92	26.0
	5	44.28	27.43	27.0
5	1	17.17	5.73	8.75
	2	26.34	11.46	14.0
	3	34.35	17.19	17.0
	4	40.84	22.92	20.0
	5	44.85	27.42	20.25

Test #4

Bin: 4.98 x 7.57

Material: Wheat

Method of Loading: No preload on base, arm in upper position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Grain</u>	<u>Deflection</u>
1	1	43.70 psf	27.39 lbs	28.0/10000
2	1	46.95	27.36	36.5
3	1	43.32	27.31	36.5
4	1	18.89	5.73	18.0
	2	27.29	11.46	23.75
	3	34.54	17.19	31.75
	4	41.80	22.92	38.0
	5	43.70	27.26	37.0
5	1	17.37	5.73	12.5
	2	27.10	11.46	19.0
	3	36.26	17.19	25.0
	4	42.56	22.92	29.0
	5	46.76	27.34	32.0

Test #5

Bin: 4.98 x 7.57

Material: Wheat

Method of Loading: No preload on base, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Grain</u>	<u>Deflection</u>
1	1	39.51 psf	27.46 lbs	31.5/10000
2	1	41.41	27.53	33.5
3	1	41.80	27.35	34.75
4	1	42.75	27.38	43.5
5	1	41.80	27.40	34.0
6	1	17.94	5.73	15.5
	2	26.34	11.46	23.5
	3	32.25	17.19	27.25
	4	39.51	22.92	32.25
	5	41.03	27.38	33.0
7	1	18.32	5.73	21.25
	2	27.29	11.46	28.25
	3	33.78	17.19	32.0
	4	38.93	22.92	33.0
	5	43.13	27.36	35.25

Test #6

Bin: 4.98 x 7.57

Material: Wheat

Method of Loading: No preload, arm in lower position. Sides supported on platform of scale, blocks supporting base at the extreme ends of base.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Grain</u>	<u>Deflection</u>
1	1	46.07 psf	27.37 lbs	9.75/10000
2	1	42.64	27.37	4.0
3	1	47.64	27.43	8.75
4	1	19.39	5.73	9.75
	2	29.05	11.46	9.5
	3	37.37	17.19	7.5
	4	43.78	22.92	6.5
	1	46.30	27.18	4.0
5	1	18.63	5.73	11.5
	2	29.24	11.46	17.75
	3	36.41	17.19	17.75
	4	41.11	22.92	16.75
	1	47.98	27.27	14.0

Test #7

Bin: 4.98 x 7.57

Material: Wheat

Method of Loading: No preload, arm in lower position. Sides supported on platform of scale, blocks supporting base moved in along base nearer to scale.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Grain</u>	<u>Deflection</u>
1	1	49.70 psf	27.37 lbs	- 18.0/10000
2	1	47.71	27.40	- 27.0
3	1	52.48	27.45	- 18.5
4	1	51.07	27.53	- 24.0
5	1	48.86	27.45	- 18.5

Test #8

Bin: 4.98 x 7.57

Material: Wheat

Method of Loading: Base of bin fixed in position, sides supported on platform of scales, preload on scale, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Grain</u>	<u>Deflection</u>
1	1	46.83 psf	27.42 lbs	- 3.0/10000
2	1	47.03	27.42	- 0.75
3	1	48.06	27.34	- 2.5
4	1	48.17	27.47	- 3.0

Test #9

Bin: 4.98 x 7.57

Material: Wheat

Method of Loading: Preload on base, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Grain</u>	<u>Deflection</u>
1	1	45.23 psf	27.39 lbs	13.5/10000
2	1	43.51	27.38	13.5
3	1	44.09	27.44	14.25
4	1	47.33	27.40	11.5
5	1	46.19	27.31	13.5

Test #10

Bin: 4.98 x 7.57

Material: Glass Marbles (1/2" Dia.)

Method of Loading: Preload on platform, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Marbles</u>
1*	1	84.74 psf	47.37 lbs
2	1	81.87	47.81
3	1	79.01	47.90
4	1	76.91	47.77
5	1	34.75	9.98
	2	59.35	19.96
	3	68.13	29.94
	4	81.11	39.92
	1	87.60	47.54
6	1	34.35	9.98
	2	57.06	9.98
	3	68.71	9.98
	4	79.20	39.92
	1	82.07	37.57

*Funnel was not properly adjusted.

Test #11

Material: No. AP Class II

Bin: 4.98 x 7.57

Method of Loading: Preload on platform, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Material</u>
1	1	67.75 psf	50.01 lbs
2	1	68.71	50.00
3	1	69.85	50.07
4	1	69.66	50.00
5	1	26.72	10.50
	2	48.29	21.00
	3	57.64	31.50
	4	66.61	42.00
	1	71.57	49.62
6	1	27.10	10.50
	2	45.61	21.00
	3	58.97	31.50
	4	67.18	42.00
	1	68.52	49.70

Test #12

Bin: 4.98 x 7.57

Material: No. PM Class II

Method of Loading: Preload on platform, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Material</u>
1	1	53.25 psf	47.44 lbs
2	1	54.58	47.39
3	1	52.10	47.51
4	1	51.34	47.41
5	1	26.15	9.91
	2	38.55	19.82
	3	48.86	29.73
	4	52.10	39.64
	1	55.92	47.29
6	1	25.76	9.91
	2	38.93	19.82
	3	49.43	29.73
	4	51.15	39.64
	1	54.96	47.45

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Test #13

Bin: 4.98 x 7.57

Material: No. MS-ML Class III

Method of Loading: Preload on platform, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Wt. of Material</u>
1	1	61.64 psf	45.54 lbs
2	1	60.88	45.26
3	1	55.35	45.10
4	1	65.27	45.16
5	1	25.00	9.46
	2	37.22	18.92
	3	46.38	28.38
	4	56.49	37.84
	1	59.16	45.76
6	1	24.24	9.46
	2	37.98	18.92
	3	50.96	28.38
	4	57.83	37.84
	1	60.50	45.70

Test #14

Bin: 6.00 x 6.00

Material: Wheat

Method of Loading: Preload on platform, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Weight of Wheat</u>
1	1	36.40 psf	25.65 lbs
2	1	41.80	25.62
3	1	39.40	25.73
4	1	40.40	25.73
5	1	16.40	5.38
	2	28.00	10.76
	3	32.40	16.14
	4	36.20	21.52
	1	41.80	25.75
6	1	16.80	5.38
	2	28.60	10.76
	3	33.80	16.14
	4	39.80	21.52
	1	42.40	25.71

Test #15

Bin: 11.48 x 4.07

Material: Wheat

Method of Loading: Preload on base, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Weight of Wheat</u>
1	1	36.83 psf	33.00 lbs
2	1	37.60	32.96
3	1	38.06	33.02
4	1	38.83	33.11
5	1	16.49	6.85
	2	25.12	13.70
	3	32.42	20.55
	4	38.68	27.40
	1	41.92	33.13
6	1	15.41	6.85
	2	23.73	13.70
	3	32.67	20.55
	4	38.68	27.40
	1	40.68	33.05

Test #16

Bin: Circular, 6 in. Dia.

Material: Wheat

Method of Loading: Preload on platform, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Weight of Wheat</u>
1	1	42.02 psf	20.97 lbs.
2	1	45.84	20.98
3	1	43.29	21.01
4	1	57.55	20.95
5	1	16.81	4.36
	2	27.50	8.72
	3	35.65	13.08
	4	43.29	17.44
	5	49.66	20.55
6	1	15.79	4.36
	2	28.27	8.72
	3	35.91	13.08
	4	42.02	17.44
	1	45.58	20.67

Test Sandpaper-Lined Bin

Bin: 4.93 x 7.54

Material: Wheat

Method of Loading: Preload on base, arm in lower position.

<u>Run</u>	<u>Increment</u>	<u>Base Pressure</u>	<u>Weight of Grain</u>
1	1	26.74 psf	27.17 lbs
2	1	25.58	27.14
3	1	26.16	27.15
4	1	25.58	27.15
5	1	17.05	5.73
	2	21.71	11.46
	3	24.42	17.19
	4	25.58	22.92
	5	27.13	27.29
6	1	15.12	5.73
	2	20.54	11.46
	3	23.64	17.19
	4	24.81	22.92
	5	25.58	27.31

TYPICAL SIZE DISTRIBUTION

Class II

Minimum of 75% true spheres

Percent Passing U. S. Sieves

Catalog Number	20	30	50	70	80	100	140	230	325
AP	95-100		0-15						
PM				100	85-100		15-55	0-10	

TYPICAL SIZE DISTRIBUTION

Class III

Minimum of 85% true spheres

Percent Passing U.S. Sieves

Catalog Number	60	70	100	140	200	270	325	400
MS-ML				90-100		0-10		

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