THE BEARING POWER OF SOILS

BY

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THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1910

UNIVERSITY OF ILLINOIS

COLLEGE OF ENGINEERING.

June 1, 1910

This is to certify that the thesis of HARRY ERLE SHINN and DANIEL MANNING AVEY entitled The Bearing Power of Soils is approved by me as meeting this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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O U T L I N E .

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INTRODUCTION.

The purpose of this experiment is:

First-

To provide a method of determining the bearing power of soils relative to the foundation bearing area necessary for the support of structures.

Second-

To offer experimental data for shallow clay deposits found in Champaign and Urbana.

The necessity for such experiments is best voiced by a lecture given be F. Collingswood, C. E., delivered before the Rensellaer Polytecnic Institute, in which he quotes John B. Jervis as having said:

" In some works it is a question to what extent expenses shall go. In some, absolute stability and permanence are of high importance. The foundations, however, of any work should be stable, and well adopted to support the superstructure. The engineer will be justified in doing something more than will be necessary rather than fall below safety. Many small structures may fall and be rebuilt without any seriour damage, but large works that provide for the current and especially the the daily wants of society should have every reasonable protection against failure. The reason for this is obvious. Therefore look well to your foundations."

P A R T I.

DISCUSSION OF FORMER METHODS OF EXPERIMENT.

There have been several different methods of determining the bearing power of soils, some of which are somewhat similar to the one used in these experiments . As early as 1885, engineers realized that the soil should be tested before a large sum of money had been expended upon a building. This is shown by the experiments which were carried on at this date to determine the amount of pressure that the soft alluvial soil of the valleys of Vilare and l'Oust in France were capable of supporting.

Previous to this time, all attention had been given to preparing the subsoil for the foundation, without any regard to the amount of pressure it was capable of supporting. The earliest known record which we have of this preparation of the foundation is found in some of the excavated ruins of the ancient Egyptians. In most cases, it was found that the subsoil had been reinforced by excavation, filled with closely rammed sand. Recent excavations show the arch action of the sand upon the surrounding soil.

Recently, more attention is being paid to the datail of experimenting upon the bearing power of subsoil. In a paper by Randel Hunt in the Engineering News of June 16, 1888, the following statement is made, based upon experimental data:

" The supporting power of soft soils is greater in proportion as the land area is limited, or conversely large areas of soft soil will not support as much weight per unit of surface as more limited areas of the same soil."

In a paper by Mr. Braenard upon "Tall Building Foundations upon Soft Clay", the following methods are noted. His first experiment was conducted in a manner similar to the one used in this thesis, the only difference being in the detail of detecting the amount of sinking and in the weight employed, which in his experiments was pig iron instead of water. His second experiments were made under conditions intended to approximate more closely to those realized in a finished structure. A six inch pipe, with the lower edge beveled on the outside at an angle of forty-five degrees to a sharp edge, was driven about eight inches into the bottom of the pit, twenty feet below the curb and caused, as was expected, a slight upheaval around the outer edge. Inside the clay remained apparently undisturbed with the upper surface at the original level. It was assumed that the inside clay thus isolated and confined would correspond more closely with that under the center of a large footing, where the lateral forces might be considered tobe balanced. In the pipe there was inserted an oak piston or mast, which had a carefully squared lower end and fitted to the interior of the pipe for a length of two inches, above shich the diameter was finished sufficiently to insure absolute clearance. The piston projected above the top of the pipe and carried a horizontal platform, properly guided between horizontal struts, loaded with pig iron, giving a pressure of four tons per square footon the lower end of the piston. No settlement whatever was detected from this load. It was increased to five tons per square foot without causing any settlement, and it was decided to be safe to load the footings uniformly to four tons per square foot, and the foundations were accordingly designed upon this basis. They have been subjected to their full load for one year and no settlement has been preceptible by the most careful instrumental observations.

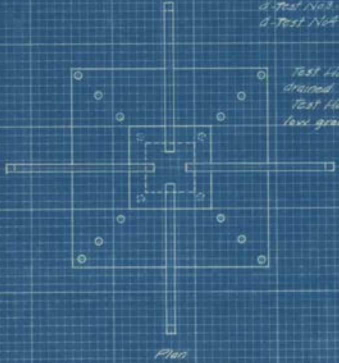
Experiments for the foundations of the St. Paul Building New York City, were made after the excavation had been completed, and the concrete had been placed for grillage. Holes were bored about four feet apart and in one of these holes a mast supporting a platform for pig iron was placed. The loading of this platform up to six and one half tons per square foot, showed no evidence of the soil being displaced, and instrumental observations failed to disclose the rising of the soil in the neighboring bore holes. The soil was a soft wet sand, overlying solid bed rock.

In connection with the capitol building in Albany, New York, Mr. W. J. McAlpine made some experiments on the bearing power. His method was follows: A pit from three to six feet deep, was prepared and carefully leveled. Upon this base, a mast supporting a mast for the pig iron weight was placed. Stakes or pegs were driven on lines radiating from the mast. These pegs were carefully leveled with a spirit level, and the amount of settlement of the mast under load was noted by the forcing up of the pegs, due to the displacement of the surrounding soil. Loads up to and slightly above two tons per square foot showed no distrubance of the soil; but a load of five tons per square foot caused the pegs to rise so that their top surfaces assumed a curve, highest nearest the mast. In making these tests, every care was taken to exclude any surface moisture.

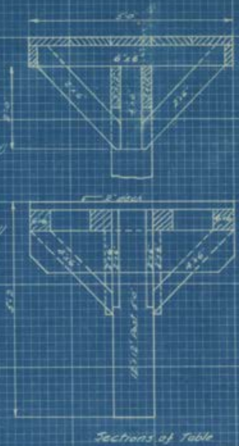
Tests similar to those of Mr. McAlpine were made upon the foundation surface of the Congressional Library Building at Washington, D. C. The latter tests differed in that four one foot square foot plates were used to sustain the weight. The load used was pig iron.

The attached blue print shows the results of tests by the Memphis Terminal Railroad Co. A diagram of the apparatus used is also included. The experiments were on the foundations of the new express and baggage house at Memphis.

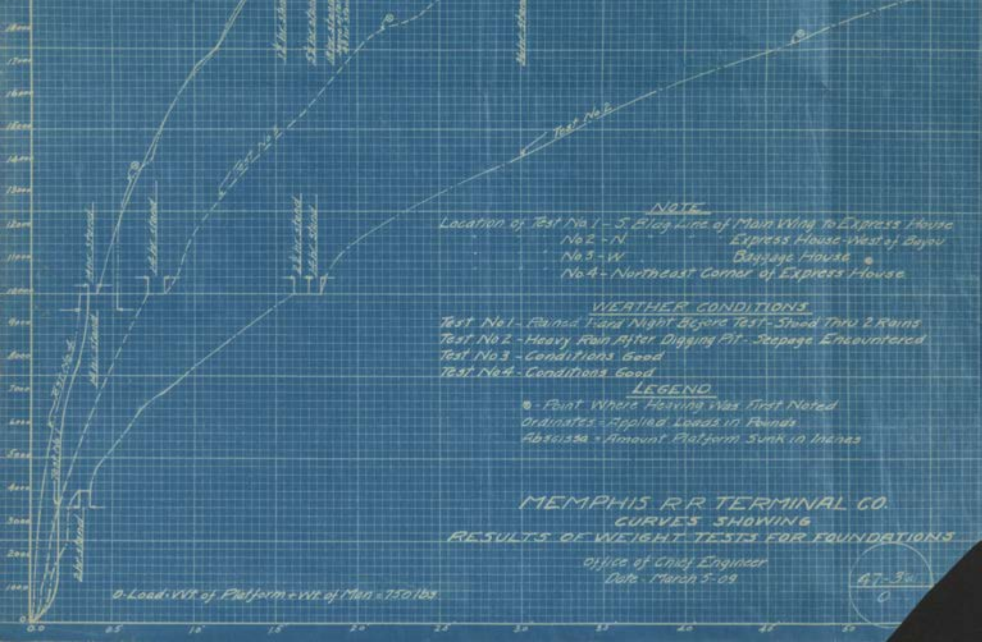
a = dist. from surface soil
a - Test No 1 = 1 ft
a - Test No 2 = 5½ ft (made ground)
a - Test No 3 = 1½ ft
a - Test No 4 = 1½ ft



Test Holes No 1 & 4 well drained
Test Holes No 2 & 3 in low ground



MEMPHIS R.R. TERMINAL CO.
SKETCH OF
TEST PIT & TABLE
Office of Chief Engineer
March 6-09


Test No 1
Test No 2
NOTE
Location of Test No 1 - S. Bldg. Line of Main Wing to Express House
No 2 - N Express House - West of Bayou
No 3 - W Baggage House
No 4 - Northeast Corner of Express House
WEATHER CONDITIONS
Test No 1 - Rained Hard Night Before Test - Stood Thru 2 Rains
Test No 2 - Heavy Rain After Digging Pit - Seepage Encountered
Test No 3 - Conditions Good
Test No 4 - Conditions Good
LEGEND
● - Point Where Heaving Was First Noted
Ordinates = Applied Loads in Pounds
Abscissa = Amount Platform Sunk in Inches
MEMPHIS R.R. TERMINAL CO.
CURVES SHOWING
RESULTS OF WEIGHT TESTS FOR FOUNDATIONS
Office of Chief Engineer
Date - March 5-09
0-Load: Wt. of Platform + Wt. of Man = 750 lbs.
67-3
0

P A R T 2.

DISCUSSION OF METHOD USED IN THESE EXPERIMENTS.

The method adopted in this experiment was similar, as to general ideas involved, to the experiments of Mr. W. J. McAlpine and also those of Mr. Braenard. The unique features of this experiment were ;

(1) The weight employed to secure settlement of the apparatus , together with means of measureing the weight.

(2) The manner of noting the settlement.

The weight used was a known quantity of water contained in a tank six feet in diameter and six feet in depth, resting upon a platform which in turn transfered the load to an eight inch by eight inch square mast resting upon the soil under investigation. The weight of the water was taken as sixty-two and one half pounds per cubic foot; and the tank was calibrated for accurate measurements, and a glass guage was attached to a stop-cock between the tank and the escape valve so as furnish the means of reading the quantity of water directly. (See the accompanying diagram).

For determining the amount of settlement under a given load a fine piano wire was stretched between two carefully leveled stakes having their tops considerably below the platform. These stakes were set at a distance of four feet from the mast so as not to be affected by the upheaval of the ground around the mast ; and attached to the mast was a strip of zinc so arranged that the piano wire just touched it, but was not drawn out of line. A scratch on this zinc marked the zero point, that is, the point of minimum settlement; then as the load was applied the amount of settlement was measured directly with asteel scale. The readings were taken to the hundredth of an inch. (See accompanying diagram).

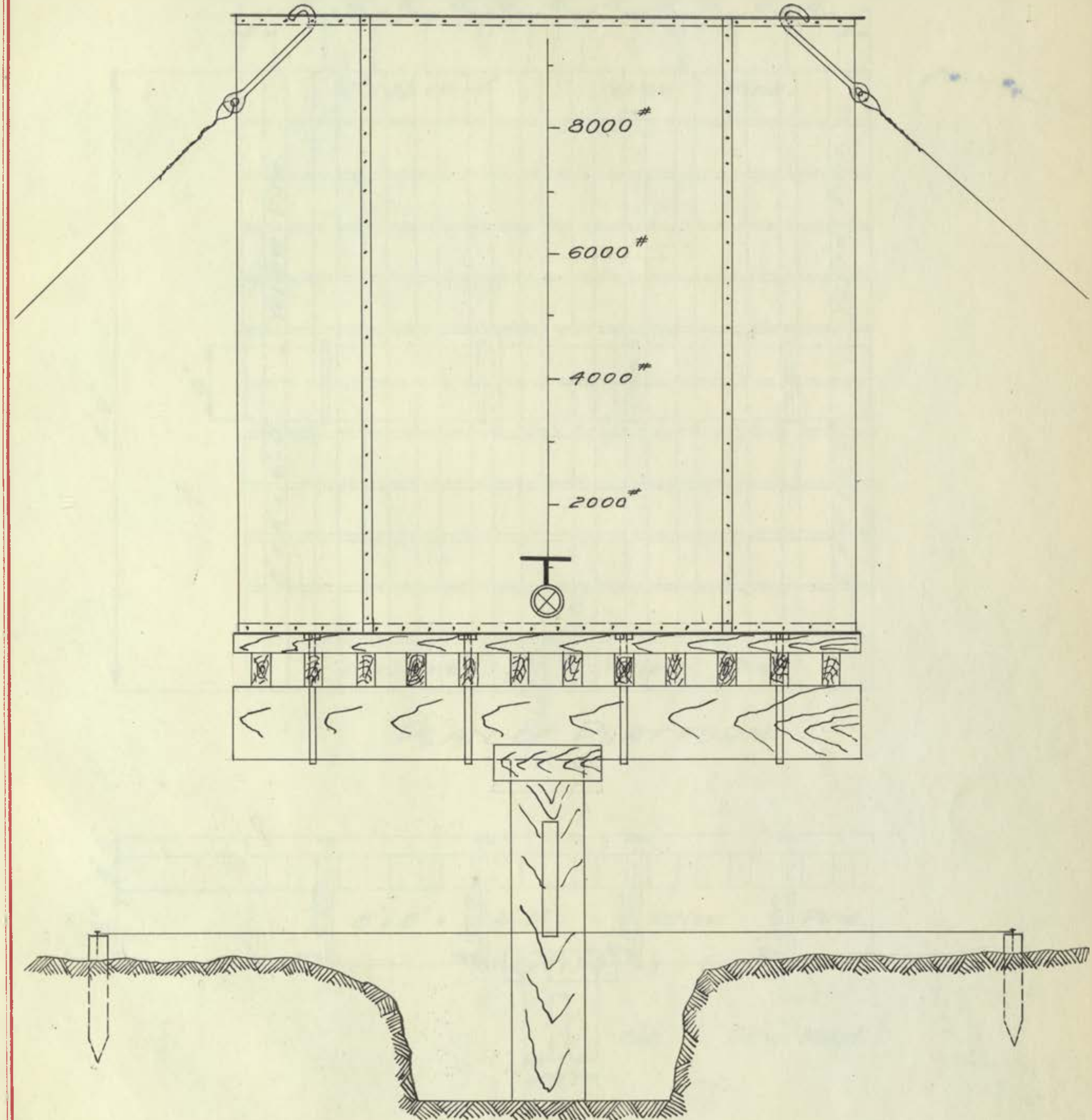
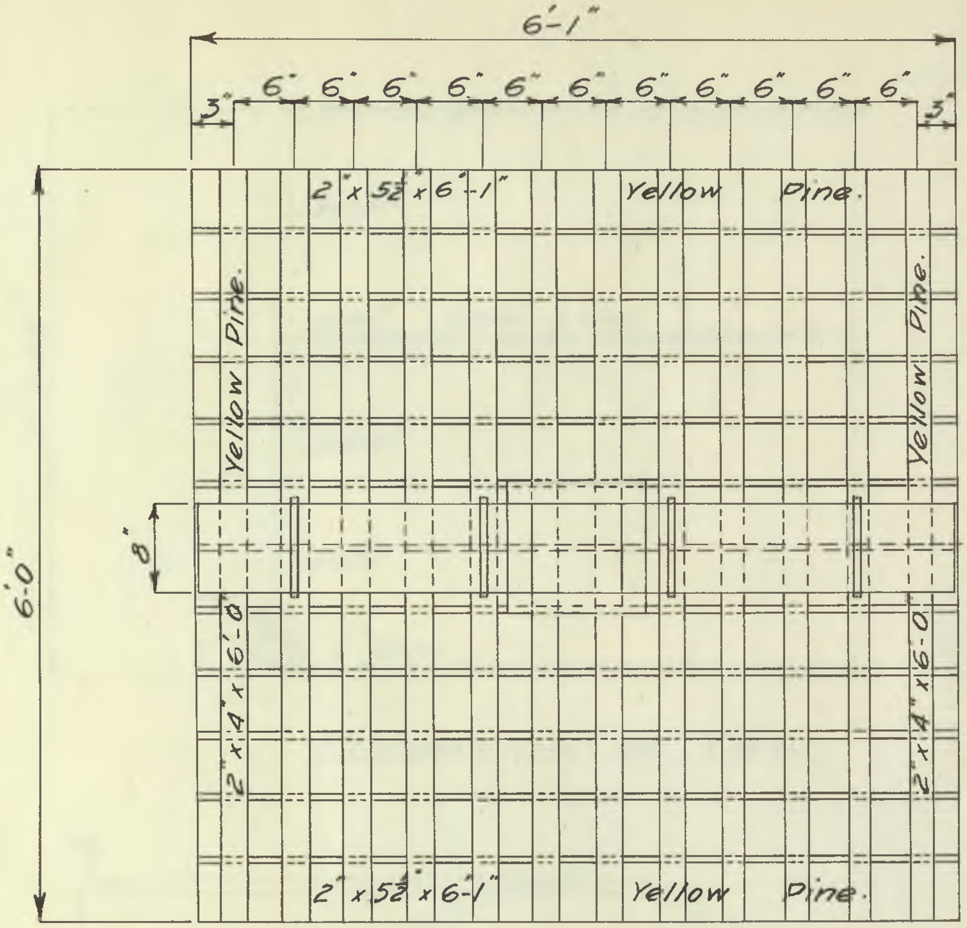
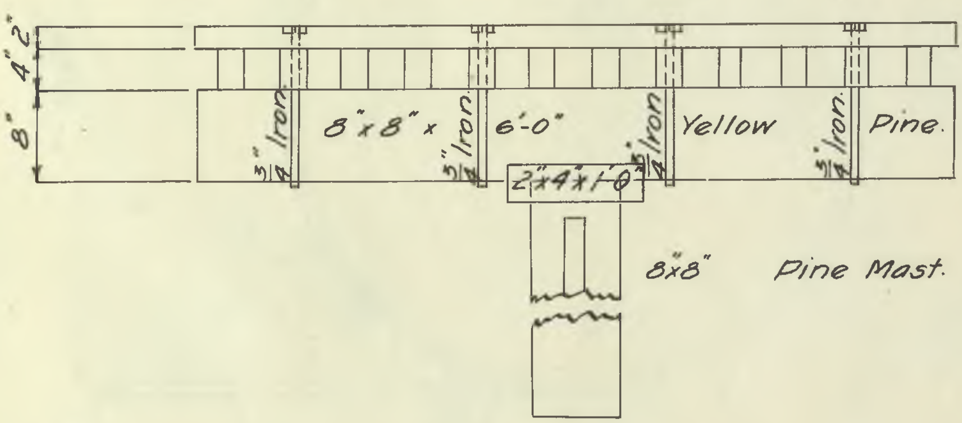


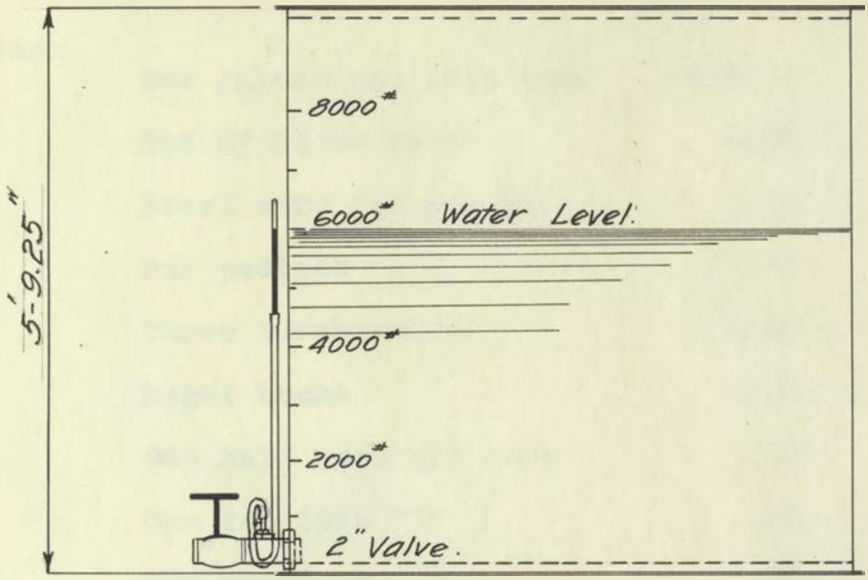
DIAGRAM OF APPARATUS.



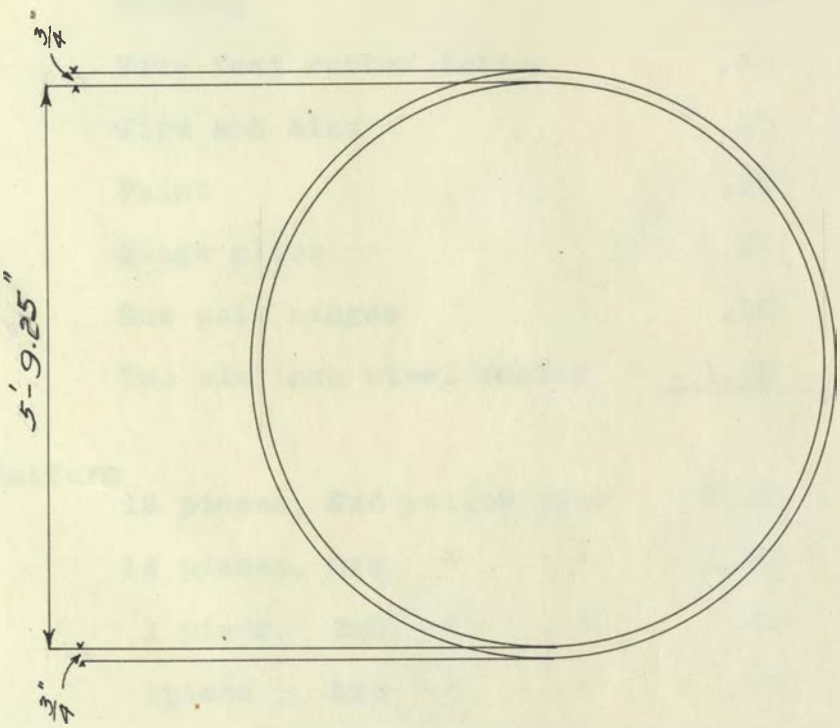
PLAN OF PLATFORM.



ELEVATION OF PLATFORM.



ELEVATION OF TANK.



PLAN OF TANK.

Cost of experiments.

Items	Cost	Total
Tank		
One galvanized iron tank	$35.00	
One 2" Globe valve	3.00	
Steel wire for guying	.85	
One padlock	.75	
Three turnbuckles	1.20	
Eight hooks	2.65	
One half inch air cock	.40	
One two inch "T"	.40	
Two bushings	.30	
One two inch nipple	.50	
Packing	.20	
Five feet rubber tubing	.50	
Wire and zinc	.15	
Paint	.30	
Guage glass	.25	
One pair hinges	.10	
Two six inch steel scales	- 1.30	$47.85
Platform		
12 pieces, 8x6 yellow pine	2.13	
14 pieces, 2x4 " "	1.20	
1 piece, 8x8 " "	.45	
1piece , 8x8 " "	.77	
1 piece, 8x8 " "	1.02	
	5.57	
Total forward		$47.85

Total forward		$47.85
Forward	$5.57	
1 piece 8x8 yellow pine	.97	
Total for platform	$6.54	6.54
Labor		
Moving tank & plumbing	$1.50	
Moving tank	2.00	
Total for labor	3.50	3.50
Grand total		$57.89

EXPERIMENT 1.

Date.	Reading of Tank Gauge.	Weight of Apparatus.	Total Weight.	Pressure Tons per sq. foot.	Reading of Mast Vernier.	Rainfall inches.	Remarks.
May 12, 09.	2350	990	3340	3.72	2.13	0.00	Filling Tank.
" 12, 09.	3100	990	4090	4.57	8.04	0.00	" "

EXPERIMENT 2.

Date.	Reading of Tank Gauge.	Weight of Apparatus.	Total Weight.	Pressure Tons per sq. foot.	Reading of Mast Vernier.	Rainfall inches.	Remarks.
May 24, 09.	3300	990	4290	4.82	0.40	0.02	
" 24, "	4675	990	5665	6.37	0.81		
" 25, "	4750	990	5740	6.45	1.37	1.22	
" 26, "	5050	990	6040	6.80	1.53	1.82	
" 27, "	5050	990	6040	6.80	2.67		
" 28, "	5050	990	6040	6.80	2.78		
" 29, "	5050	990	6040	6.80	2.80		
" 31, "	5050	990	6040	6.80	2.86	0.32	
June 3, "	5100	990	6090	6.85	2.88	0.65	
" 4, "	5050	990	6040	6.80	2.89		
" 4, "	5050	990	6040	6.80	2.89		
" 5, "	7100	990	8090	9.10	3.32		Filled Tank.
" 6, "	7100	990	8090	9.10	3.70		
" 7, "	7100	990	8090	9.10	6.75		

EXPERIMENT 3.

Date.	Reading of Tank Gauge.	Weight of Apparatus.	Total Weight.	Pressure Tons per sq. foot.	Reading of Mast Vernier.	Rainfall inches.	Remarks.
Nov. 10, 09	0000	990	990	1.11	0.00		
" 10 "	3200	990	4190	4.71	0.47		
" 11 "	3200	990	4190	4.71	0.74	0.09	
" 12 "	3250	990	4240	4.77	0.79	0.41	
" 13 "	3250	990	4240	4.77	0.85		
" 14 "	3250	990	4240	4.77	0.90	0.20	
" 15 "	3250	990	4240	4.77	0.90	0.11	
" 15 "	3300	990	4290	4.83	0.90		Filled Tank.
" 15 "	4000	990	4990	5.60	0.90		" "
" 15 "	4500	990	5490	6.16	1.00		" "
" 15 "	5000	990	5990	6.72	1.17		" "
" 16 "	5200	990	6190	6.95	2.27	1.09	
" 17 "	5200	990	6190	6.95	2.42		
" 18 "	5200	990	6190	6.95	2.50		
" 19 "	5200	990	6190	6.95	2.52		
" 20 "	5200	990	6190	6.95	2.54		
" 21 "	5200	990	6190	6.95	2.55		
" 22 "	5200	990	6190	6.95	2.55	0.55	
" 28 "	5200	990	6190	6.95	2.70		
" 30 "	5200	990	6190	6.95	2.70		

EXPERIMENT 3 CON'T.

Date.	Reading of Tank Gauge.	Weight of Apparatus.	Total Weight.	Pressure Tons per sq. foot.	Reading of Mast Vernier.	Rainfall inches.	Remarks.
Nov. 30, 09	6000	990	6990	7.85	2.77		Filled Tank.
" 30 "	7000	990	7990	8.99	2.97		" "
" 30 "	7500	990	8490	9.55	3.40		" "
" 30 "	8000	990	8990	10.10	3.92		" "
" 30 "	9000	990	9990	11.25	4.83		" "
Dec. 1, 09	9000	990	9990	11.25	6.00		
" 2 "	9000	990	9990	11.25	6.20	0.04	
" 3 "	9000	990	9990	11.25	6.20		
" 4 "	9000	990	9990	11.25	6.21	0.09	
" 5 "	9000	990	9990	11.25	6.21	0.25	
" 6 "	9000	990	9990	11.25	6.22		
" 7 "	9000	990	9990	11.25	6.26	0.65	Snow 7 inches.
" 8 "	9000	990	9990	11.25	6.26		

DISCUSSION OF DATA.

In the consideration of the data and conclusions to be drawn from the experiments, the writers wish to offer an apology for the extreme scope of the title under which it is offered. The data obtained are necessaryily scant owing to the time taken for each experiment , and the amount of time devoted to the preparation of theapparatus, and its subsequent moving and resetting. Such conclusions as may be drawn will without doubt be of value only as hypotheses to be proven, or else disproven by those who succeed the writers in the line of work indicated.

Experiment L. (See table 1).

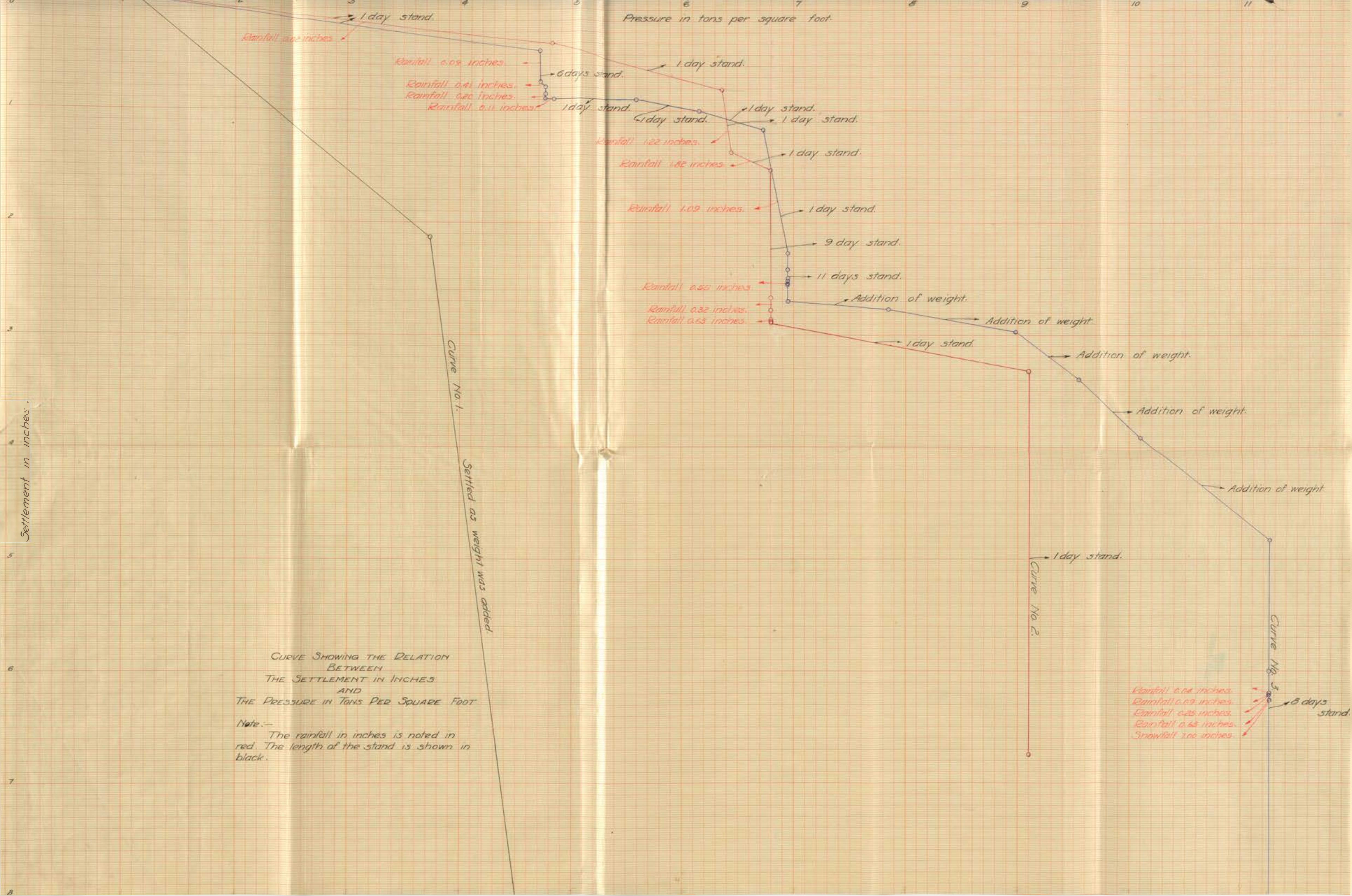
The first experiment, shown graphically on the attached sheet (curve No.1) was obtained upon the black alluvial soil overlying the greater portion of the land in the vicinity of Champaign.The surface sod was removed and the surface of the exposed black dirt was leveled to an even surface without compression. A slight settlement under the weight of the apparatus was noted, but the zero reading was taken the day following after the preliminary equilibrium was reached. Upon the application of the weight a uniform settlement ensued and continued up to two and eight tenths tons per square foot,when a seemingly critical point was reached. From this point the settlement was more rapid and pronounced up to the time when the cross beam support of the platform rested upon the ground at the edges of the pit. This incident taught the writers in future experiments to excavate a shallow trench under the ends of the cross beam so as to allow the maximum settlement. At the time of of the experiment the soil was in a semi-dry state as a result of a period of more than a week without any rainfall. The data obtained would indicate that the bearing power of the black soilis less than two and one half tons per square foot; and that even tho it were compacted, the value used for computation of bearing areas should be less than one and one half tons per square foot.

Experiment 2. (See table 2)

This experiment was conducted on the yellow clay soil underlying the black surface deposit. The depth below the surface of the ground was two feet and eight inches. The soil was damp but not of such consistency that it would hold its form when rolled between the hands. No settlement whatsoever was noted under the weight of the tank alone(a pressure of one and elevn hundredths tons per square foot) ; but upon the addition of weight, a steady settlement followed up to the point where the pressure was four and eight tenths tons per square foot. The sinking was more rapid in the interval between the pressures of four and eight tenths tons and six and thirty-seven hundredths tons per square foot. The addition of weight was suspended at six and thirty seven tons per square foot. On the following night a rainfall of about one and twenty two hundredths inches increased the weight of the apparatus and a sinking was noted, more in proportion to its weight than the preceding settlement had indicated. This sinking was due to the weakening of the structure of the soil due to the moisture. The following day the sinking was approximately proportional to the weight added by a rainfall of one and eighty-two hundredths inches, indicating that the rain had in addition to the increasing of the weight affected the bearing power of the clay. After standing for eight days with no addition of weight,water was added and the sinking began almost immediately, indicating that the compression had reached just the critical point at which a slight increment of weight produced an immediate effect. The total pressure at this time was nine and one tenth tons persquare foot , and as might be expected the settlement proceded until the cross support again touched the ground. The end of this experiment was however slightly anticipated by a pony becoming entangled in one of the guy wires so as to throw the apparatus out of plumb.

Experiment 3. (See table 3).

In this experiment, as in the previous, the soil under investigation was yellow clay at the depth of two feet and two inches, and was of the same constituency as in the preceding experiment. In this case provision was made for a greater sinking than before, as the intention was to carry the experiment to the full capacity of the tank. The soil at the base of the pit was dry almost to the point of crumbling between the fingers when compressed. As before, the weight of the tank produced no noticable sinking, but on the addition of water a unifor sinking, apparently directly proportional to the increments of weight, was noted. After standing one day the settlement ceasedand the following day a slight additional amount of added weight (six hundredths of a ton per square foot) produced a slight settlement, whcich continued for two days when a point was reached at which the settlement ceased and did not begin again even under the addition of eighty-three hundredths of a ton per square foot. This would seem to indicate that a critical point was reached at some place four and seventy-seven hundredths, and five and six tenths tons per square foot pressure. After this point a slight additional weight produced a settlement that proceeded for seven days, when it was apparent that the soil became compressed to a degree where it was capable of supporting the weight which was at this time equivalent to six and ninty-five hundredths tons per square foot. Upon the further addition of weight the proportional settlement proceeded, and when allowed to stand for seven days the sinking still continued, decreasing in amount each day. The pressure was eleven and twenty-five hundredths tons per square foot. The reading on the eighth day was identical with the one of the proceeding day so that it may be assumed that the soil had become compressed sufficiently to stand the pressure. The following night a hard freeze resulted in some internal change so that the apparatus sank to its limit (resting upon the ground). The weight still remained the same as given above, namely eleven and twenty-five hundredths tons per square foot. The writers are unalbe to offer any explanation of why the freezing caused the apparatus to sink, other than that the internal stress within the soil introduced by the freezing action, tended to weaken its structure in such a manner that it was unable to resist the compressive force as before. It is reccomended by the writers that a thorough investigation of this apparent action , be made. If the reasons advanced are found to be true,the failure of dams due to ice thrust may be found to be in a degree due to the failure of the weakened subsoil on the down stream side to withstand the thrust of the toe of the dam. The results of this experiment are shown graphically on Curve NO. 3.


Pressure in tons per square foot.
Settlement in inches.
1 day stand.
Rainfall 0.09 inches.
6 days stand.
Rainfall 0.41 inches.
Rainfall 0.20 inches.
Rainfall 0.11 inches.
1 day stand.
1 day stand.
1 day stand.
1 day stand.
1 day stand.
Rainfall 1.22 inches.
1 day stand.
Rainfall 1.82 inches.
Rainfall 1.09 inches.
1 day stand.
9 day stand.
11 days stand.
Rainfall 0.55 inches.
Addition of weight.
Rainfall 0.32 inches.
Rainfall 0.63 inches.
Addition of weight.
1 day stand.
Addition of weight.
Addition of weight.
Addition of weight.
1 day stand.
Curve No. 1.
Settled as weight was added.
Curve No. 2.
Curve No. 3.
Rainfall 0.04 inches.
Rainfall 0.09 inches.
Rainfall 0.25 inches.
Rainfall 0.68 inches.
Snowfall 1.00 inches.
8 days stand.
Curve Showing the Relation
Between
The Settlement in Inches
and
The Pressure in Tons Per Square Foot
Note.—
The rainfall in inches is noted in red. The length of the stand is shown in black.

DATA ON POWER PLANT CHIMINEY.

The weight of the chiminey is two million one hundred and sixty-five thousand one hundred and eighty pounds (2,165,180#) Its foundation area is nine hundred and sixty-one square feet (961). The base is a square block of concrete thirty-one feet by thirty one feet.

The elevation of a bench mark described as follows(this will be inserted below when established), is refered to the U. S. B. M. at the South East corner of Engineering Hall.

CONCLUSIONS.

The following conclusions are offered based upon the writers personal observations and study as well as upon the data herein presented.

(1) The bearing power of the black glacial soil overlying the land in the vicinity of Champaign has a bearing power of less than one and one-half (1½) tons per square foot.

(2) The yellow clay soil underlying the black soil has a bearing power of about five (5) tons per square foot.

(3) The presence of moisture in the soil lessens the bearing powere of both the black and the clay soild.

(4) The freezing of the soil sets up some internal action that tends to lessen its bearing power.

(5) The thawing of the frozen ground tends to lessen the bearing power of the soil.

SUGGESTIONS RELATIVE TO FUTURE EXPERIMENTS.

To those who continue these experiments, the writers wish to enumerate a few points that have been made evident by their experience.

First.

It is advisable to add very small increments of weight up to a load of about four (4) tons per square foot, on all soils of the bearing power or of less resistance.

Second.

Extreme care should be used in adjusting the guy wires so that the pressure is kept constantly perdicular to the surface.

Third.

It is not advisable to attempt experiments during sever winter weather, due to the danger to the tank on account of freezing of the water.

Fourth.

Care should be taken that the stakes holding the guage wire are at a sufficient distance from the tank, so that no heaving of the soil will affect them. And further, that the top of the stakes should be made firm and should be at the same level.

Fifth.

Some method should be devised by means of which the apparatus may be carefully lowered upon the mast and the settlement due to the apparatus alone determined.

As for future investigation the writers wish to suggest some lines of thought, to wit:

(1) A study should be made with a view to determining the effect of different areas of bearing surface.

(2) The effect of differing ratios between the areas and the perimeters should be noted with a view to finding if the cutting edge of the mast tends to lessen the bearing power.

(3) Determine if the heaving of the soil is directly proportional to the sinking (Note Mr. W. J. McAlpine's experiment on the Capitol Building at Albany, New York).

(4) By the use of a pipe driven into the ground and with the mast resting in the center, determine the bearing power when the lateral distribution of pressure is prevented.

(5) Note the sinking of the chimney of the power plant at the corner of Goodwin Avenue and Railroad Street in Urbana. (See next page for data on this chimney)