Manson

U.S. Engineer dept

CIRCULAR

OF THE

OFFICE OF THE CHIEF OF ENGINEERS,

NOVEMBER 28, 1881.

PILE FOUNDATIONS

AND

PILE-DRIVING FORMULÆ.

OFFICE OF THE CHIEF OF ENGINEERS,
UNITED STATES ARMY,
Washington, D. C., November 28, 1881.

CIRCULAR }
No. 17. }

The following correspondence respecting pile foundations and pile-driving formulæ is communicated to the Corps of Engineers.

The Chief of Engineers approves the suggestions contained in Major Weitzel's letter of the 4th of October, and desires that the officers of the Corps will, at their leisure, communicate to this Office any views they may have on the subject of this correspondence, which he deems of great practical importance, and also the results of their experiences with pile foundations.

He also desires that whenever an officer of the Corps has occasion to construct a pile foundation, he will cause to be kept an accurate record of the driving of the piles, embracing the kind, and average size and weight of the piles, the weight and fall of the ram, and the penetration at each blow, or at least at each of the last (say five) blows, a copy of which record he will send to this Office with a plan of the foundation on which is marked the estimated weight each pile is to carry, and also a description of the soil.

By command of Brig. Gen. WRIGHT:

Geo. H. Elliot.

Major of Engineers.

UNITED STATES ENGINEER OFFICE,
Detroit, Mich., August 4, 1881.

Brig. Gen. H. G. WRIGHT,
Chief of Engineers, U. S. A.,
Washington, D. C.

GENERAL:

I have the honor to acknowledge the receipt of a reprint of Paper No. 5, on Practical Engineering, being an analytical investigation of the resistance of piles to superincumbent pressure, deduced from the force of driving, &c., by Brevet Lieutenant Colonel James L. Mason, Captain of Engineers.

This reminds me that it must be my duty to inform the officers of the Corps, through you, of my experience on the pile and grillage foundation for the Martello tower at Proctorsville, La., although this information has not been called for by you. I believe, however, that all the official records of this work were lost by a fire in the New Orleans Custom House or through the civil war, and having fortunately preserved a few private notes I deem this communication of some interest at least.

The foundation was constructed in 1856 and 1857.

The site of the tower at Proctorsville, as determined by actual borings, was found to have the following character, viz.: For a depth of nine feet there was mud mixed with sand, then followed a layer of sand about five feet thick, then a layer of sand mixed with clay from four to six feet thick, and then followed fine clay. Sometimes clay was met in small quantities at the depth of six feet, as well as small layers of shells. By draining the site the surface was lowered about six inches.

The foundation piles were driven in a square of twenty piles on a side, four feet from centre to centre. Twenty-four were omitted to leave room for fresh water cisterns, and two extra ones were driven to strengthen supposed weak ones. The total number at first driven was therefore 378. The piles were driven to distances varying from 30 to 35 feet below the surface, or from 10 to 15 feet into the clay stratum. The average number of blows to a pile was 55, and mainly hard driving. After all these piles were driven, ten additional ones were driven at different points to strengthen supposed weak points. Each one of them required over 100 blows to drive it.

Before beginning the foundation I drove an experimental pile exactly in the centre of the site. It was 30 feet long, $12\frac{1}{2}'' \times 12''$

at top and 11½″×11″ at butt. It was sharpened to a bottom surface about 4 inches square. Its head was capped with a round iron ring. Its weight was 1,611 pounds and the weight of the hammer was 910 pounds. Its own weight sank it 5′ 4″, and it required 64 blows to drive it 29′ 6″ deeper. The fall of the hammer at the first blow was 6 feet, increasing each successive blow by the amount of penetration, excepting the last ten blows when the fall was regulated to exactly 5 feet at each blow.

The penetrations in inches were as follows:

12–12–16–11½–10½–10½–8–6–6⅛–6⅛–7¼–7½–7½–6¾–6⅜–6½–6–6–6–6⅛–6¼–6⅜–6–6–6⅜–6⅜–6–5¾–4⅜–4⅛–3⅛–3–2⅞–2½–2¾–2⅝–2⅝–3⅛–2⅞–2⅞–3–3–2–2⅛–2½–2¼–2⅜–2⅜–2½–2⅝–2⅝–2⅝–2¾–3–⅜–⅜–¼–¼–½–⅜–¼–⅜–⅜–⅜.

This pile, according to Colonel Mason's formula, should have borne 52,556 pounds. I loaded it with 59,618 pounds and it did not settle. I afterwards increased the load to 62,500 pounds, when it settled slowly. The greatest weight to be carried by any one pile was between 30,000 and 35,000 pounds.

The tops of the piles were sawed off on a level, and the whole surface between them covered with a flooring of three-inch planks tightly fitted in, the upper surface of this floor being flush with the tops of the piles. They were then capped in one direction by stringers 18″×18″ and 85′ long. Each of these stringers was constructed by splicing two shorter ones of equal length by means of the regular scarf joint. These were bound together by 12″×12″ stringers 85′ long (formed by splicing two shorter ones) running over the line of piles in the perpendicular direction. These 12″×12″ stringers were let into the 18″×18″ so that their top surfaces were flush. In the little squares thus formed and next to the 18″×18″ timbers, were laid short pieces 12″×12″ timbers, and the intervals filled in up to the level of the latter with concrete. The whole grillage was then levelled off with short pieces of 6″×12″ planks. This grillage was, therefore, 18 inches thick. Long sheet piling was driven for the scarp of the wet ditch, the upper ends resting on the inside of the stringers on the outer row of piles.

In order to distribute the weight of the tower uniformly over this foundation, strong reversed groined arches were turned, the space between their backs and the grillage being filled in with solid concrete masonry.

When the brick work of this tower, which was carried up even on all sides, was about half completed and the foundation had on it less than half the load it was designed to carry, the appropriation became exhausted and the work was stopped. This was in the spring of 1858. When I visited the work about six months thereafter I found a marked settlement. The four salients apparently remained intact, but on every side the settlement was about the same, and largest about the middle, so that the courses of brick which were laid perfectly level had the form of a regular curve.

I was serving at that time as assistant to Brevet Major G. T. Beauregard, Captain of Engineers. In addition to his military works, he was in charge of the construction of the new Custom House in New Orleans, La.

In order to ascertain the cause of this settlement he directed some experiments to be made by the architect of that building, Mr. Roy.

I do not remember the details of these experiments. I was on duty at forts St. Philip and Jackson, and afterwards stationed at West Point while they were made. The civil war also intervened. Subsequently, however, to the latter, I met Mr. Roy and he told me briefly that the experiments proved that piles of different cross-sections driven in the same Louisiana soil and under exactly the same conditions, do not have a power of resistance proportional to the area of their cross-section, and that the capacity of resistance per square inch in cross-section of pile diminishes as the area of this cross-section becomes greater. That is to say, a pile 4″ square in cross-section does not have four times the resistance to pressure of one 2″ square. This decrease, he said, became quite marked as the cross-section of the piles increased. He believed that the piling for the foundation at Proctorsville was driven so closely that the whole system assumed the character of a single pile about 81 feet square in cross-section and that therefore its capacity of resistance per square foot was very much reduced as compared with the capacity of resistance per square foot of my experimental pile.

I have never since had an opportunity to test the accuracy of this conclusion, but I believe that some of the officers of our Corps are so situated that they can do it, hence this communication.

Very respectfully, your obedient servant,

G. Weitzel,
Major of Engineers.

UNITED STATES ENGINEER OFFICE,
Detroit, Mich., October 4, 1881.

Brig. Gen. H. G. WRIGHT,
Chief of Engineers, U. S. A.,
Washington, D. C.

GENERAL:

I have the honor to state that by letter to you dated August 4, 1881, I acknowledged the receipt of a reprint of Paper No. 5 on Practical Engineering, being an analytical investigation of the resistance of piles to superincumbent pressure deduced from the force of driving, &c., by Brevet Lieutenant Colonel James L. Mason, Captain of Engineers.

In my letter I informed you of my experience on the pile and grillage foundation for the Martello tower at Proctorsville, La.

I was serving at the time this foundation was constructed as assistant to Brevet Major G. T. Beauregard, Captain of Engineers. In my letter I referred to some experiments made upon the resistance of piles in that soil to pressure, made by Mr. John Roy, architect of the New Orleans Custom House, the erection of which was also in charge of General Beauregard.

A copy of my letter was sent from your office to General Beauregard inquiring if any records of these experiments were in his possession, and he referred it to Mr. John Roy. In reply the latter on August 31, 1881, enclosed to you a printed table of the results of these experiments. On September 1, 1881, he also enclosed a newspaper article bearing upon this subject, which he had contributed to the New Orleans Times of July 10, 1879. Both of these letters were referred to me for my information, and are herewith respectfully returned.

The table of experiments sent by Mr. Roy with his letter of August 31, and the result of the experience gained at Proctorsville, La., show conclusively, it seems to me, that although Mason's rule may hold good for an isolated pile, it cannot be depended upon for a system of piles such as are driven for foundations. In order, therefore, to determine the factor of safety for such foundations, the views and experiences of the officers of corps, it seems to me, would be valuable, and then if a proper system of experiments could be made by such of the officers as have facilities for doing so, it might lead to practical results in solving this very important question.

On September 21, 1881, Major George H. Elliot wrote me a private letter on this subject. He can undoubtedly furnish you a copy of it. It is very interesting, and the conclusions which he arrives at, seem to me very practical.

I also asked a brief opinion of Lieutenant Colonel C. B. Comstock on the general subject of pile driving, without mentioning to him the special case which produced my original letter. He has authorized me to use his reply. It is as follows:

"The energy with which a ram strikes the head of a pile is spent in changing the form of the pile, of the ram, in heating them and making them vibrate, and in most cases mainly in overcoming the friction of the earth against the pile and in moving the particles of the earth among themselves, thus causing further friction.

"The formulæ only consider the resistance during the very short period of the blow. It would be strange if such resistance were always, for all soils, the same as when, sometime after the pile had been driven, it was loaded until it began to move. Possibly the latter resistance is sometimes the greater, usually it is doubtless much less, for most materials require a less force to change their form slowly than rapidly. A substance like clay, that is plastic, might resist driving piles very strongly and yet furnish a very much smaller resistance to a permanent load. Not knowing the relation of the two resistances, a formula which does not include that relation (*i. e.*, the character of the soil), may be, even for isolated piles, much in error. The only way to get a reliable formula seems to be to determine for characteristic, well defined, and carefully described soils, the ratio between the resistances given by some good formula like Rankine's, and the actual load which will start the pile very slowly down and keep it going.

"In soft material a certain load spread over the surface will carry the whole of it down bodily to considerable depths. As soon as a sufficient number of piles in this area are driven and loaded, they will do the same, and additional piles are useless. In such a case the economical intervals for piles could only be found by experience."

I submit herewith Mr. Roy's table of experiments:

A table of experiments on the compressibility of soil of New Orleans, La., made by Mr. John Roy, in the years 1851 and 1852.

Experiment.	No. bearings.	Size of bearing, in square inches.	Weight in pounds, applied.	Weight to the square inch, in pounds.	Sinkage, in inches.	No. days to each experiment.	Depth of boring or trench, in inches.	Place of experiment, distance from the river, in yards.
1	1	¼ × ¼ = $\frac{1}{16}$	6.375	102.000	3½	30	12	1760
2	1	½ × ½ = ¼	25.500	102.000	7	30	12	1760
3	1	¾ × ¾ = $\frac{9}{16}$	57.375	102.000	11	30	12	1760
4	1	1 × 1 = 1	102.000	102.000	11	30	12	1760
5	1	1 × 1 = 1	102.000	102.000	11	30	12	1760
6	1	1 × 2⅞ = 2⅞	293.250	102.000	26¾	30	12	1760
7	1	4 × 4 = 16	1632.000	102.000	78	30	12	1760
8	1	1 × 16 = 16	1632.000	102.000	33	30	12	1760
9	1	4 × 4 = 16	1632.000	102.000	120	161	48	1760
10	1	¼ × ¼ = $\frac{1}{16}$	1.125	18.000	⅜	3	12	1760
11	1	¼ × 1 = ¼	4.500	18.000	⅝	3	12	1760
12	1	½ × 1 = ½	9.000	18.000	⅝	3	12	1760
13	1	¾ × 1 = ¾	13.500	18.000	⅝	3	12	1760
14	1	1 × 1 = 1	18.000	18.000	⅝	3	12	1760
15	1	1 × 1 = 1	36.000	36.000	2½	51	12	1760
16	1	¾ × 1 = ¾	27.000	36.000	1¾	51	12	1760
17	1	½ × 1 = ½	18.000	36.000	1¼	51	12	1760
18	2	2½ × 8 = 40	642.000	16.050	⅞	99	6	1760
19	4	1 × 1 = 4	170.000	42.500	⅛	42	0	1760
20	2	6 × 12 = 144	2552.000	17.720	⅛	107	0	400
21	2	6 × 12 = 144	3362.400	23.350	$\frac{3}{16}$	182	0	400
22	2	6 × 24 = 288	15580.000	54.097	1	48	0	300
23	1	20⅞ × 20⅞ = 432	18703.000	43.300	4½	26	96	400
24	1	12 × 12 = 144	5132.000	35.640	¾	20	96	400
25	1	24 × 24 = 576	23150.000	40.200	6¼	38	36	300
26	1	Weight increased.	45724.000	79.380	13¼	40	36	300
27	1	Weight increased.	57600.000	100-000	18½	55	36	300
28	1	1 × 1 = 1	102.000	102.000	6	68	48	333
29	1	Weight increased.	202.000	202.000	18	121	48	333
30	1	4 × 4 = 16	1632.000	102.000	16½	68	48	333
31	1	Weight increased.	3232.000	202.000	54½	121	48	333
32	1	1 × 1 = 1	102.000	102.000	1	49	48	300
33	1	Weight increased.	202.000	202.000	7	87	48	300
3[illegible]	1	4 × 4 = 16	1632.000	102.000	7	51	48	300
35	1	Weight increased.	3232,000	202.000	61½	87	48	300

NOTES.—Nos. 23 and 24 were made at the new Custom House, by a Commission of U. S. Engineers, appointed by the Treasury Department.

It will be seen, by the above table, that, contrary to the general opinion, a larger surface sinks more than in proportion to its area.

A very interesting article on this subject appears in the number of Van Nostrand's Engineering Magazine for October, 1881. It is entitled "Note on the Friction of Timber Piles in Clay" by Arthur Cameron Hertzig, Assoc. M. Inst. C. E.

Very respectfully, your obedient servant,

G. WEITZEL,
Major of Engineers.

WASHINGTON, D. C.,
November 25, 1881.

Brig. Gen. H. G. WRIGHT,
Chief of Engineers, U. S. A.

GENERAL:

In compliance with your request, I have the honor to enclose herewith a copy of the letter referred to in General Weitzel's letter to you of the 4th ultimo.

It is proper for me to add that I have taken advantage of the delay in the printing of the letters of General Weitzel, to add the formulæ referred to in my letter, and such remarks as have been suggested by further consideration of the important question presented by him.

Very respectfully, your obedient servant,

GEORGE H. ELLIOT,
Major of Engineers.

Major Elliot to General Weitzel.

Washington, D. C., 21st September, 1881.

Your letter of the 4th of August to the Chief of Engineers, relating your experience in the foundation of the Martello tower at Proctorsville, La., has suggested a comparison of the pile driving formulæ accessible to me.

Assuming, in these formulæ, the case of the test pile at Proctorsville, which was thirty (30) feet long, twelve (12) by twelve and one-half (12½) inches at top, eleven (11) by eleven and one-half (11½) inches at bottom; which weighed sixteen hundred and eleven (1,611) pounds, and was driven by a ram weighing nine hundred and ten (910) pounds, falling five (5) feet at the last blow; the last blow driving the pile three-eighths (⅜) of an inch, the discrepancies between the results are remarkable. The extreme supporting power of this pile, obtained from some of these formulæ, is as follows:

	Pounds.
Nystrom	18,971
Mason	52,556
Weisbach	52,556
Trautwine	58,302
Rankine*	128,509

Major Sanders' formula does not give the extreme supporting power of the pile, but the safe load only—in this case, 18,200 pounds. McAlpine's formula in this case gives a negative result, as it always does when $W + .228\sqrt{F}$ is less than 1, W representing the weight of the ram in tons, and F its fall in feet.

Assuming another case, a case in which the weight and fall of the ram are much greater, the discrepancies are still more remarkable. Say that the pile is of the same size and weight as the one at Proctorsville; that it makes the same penetration at the last blow, and is driven by a two thousand (2,000) pound ram, falling twenty-five (25) feet. The extreme supporting power and safe load in this case, according to the various authorities, are stated in the following table, in which, you will observe, the relative positions of the names of these authorities are not the same as in the preceding table.

* Assuming the modulus of elasticity to be 750 tons.

Names of authors of formulæ and rules.	Extreme supporting power of the pile in pounds.	Safe load in pounds.
McAlpine (1)	185,069	61,689
Trautwine (2)	219,117	73,079
Hodgkinson (3)	403,450	40,345
Nystrom (4)	490,824	81,804
Rankine (5)	810,000(6)	81,000
Do. (7)	851,200	130,954
Mason (8)	886,080	221,520
Weisbach (9)	886,080	48,739
The Dutch Engineers (10) . . .	886,080	110,760
Stevelly (11)	886,080	. . . .
Sanders (12)	. . . .	200,000
Haswell (13)	. . . .	200,000
Rondelet (14)	. . . .	69,375
Perronet (15)	. . . .	125,802
Rankine (16)	. . . .	150,000
Mahan (17)	. . . .	150,000
Wheeler (18)	. . . .	150,000
Rankine (19)	. . . .	30,000
Mahan (20)	. . . .	30,000
Wheeler (21)	. . . .	30,000

(1) McAlpine's formula is $P = 80\,(W + .228\,\sqrt{F} - 1)$, in which P represents the extreme supporting power of the pile in tons, W the weight of the ram in tons, and F its fall in feet. (Journal of the Franklin Institute, 3d series, Vol. LV.). His co-efficient of safety is ⅓.

(2) Trautwine's formula is $P = \frac{\sqrt[3]{F} \times W \times .023}{p + 1}$, in which P and F are the same as in McAlpine's formula; W the weight of the ram in pounds, and p, the penetration at the last blow, in inches. His co-efficients of safety are from ⅙ to ½, "according to circumstances." In this case and in similar cases, I have assumed the arithmetical mean. In this case, ⅓.

(3) This case supposes that the pile is driven to the bed rock through soft mud, and is not supported at the sides. I have assumed in Hodgkinson's rule (Mahan's Civil Engineering, p. 80), $\frac{1}{10}$ as a co-efficient of safety.

(4) Nystrom's formula is $P = \frac{W^3\,F}{p\,(W \times w)^2}$, in which P represents the extreme supporting power of the pile in pounds; W the weight of the ram, and w the weight of the pile—both in pounds; F the fall of the ram, and p the penetration at the last blow. His co-efficient of safety is ⅙.

(5) Rankine has a *rule* that "the factor of safety against direct crushing of the timber should not be less than 10."

(6) Resistance of the pile to crushing.

(7) Assuming in his *formula* the modulus of elasticity to be 750 tons. His formula is

$P = \sqrt{\frac{4\,W\,F\,e\,s}{l} + \frac{4\,e^2\,s^2\,p^2}{l^2}} - \frac{2\,e\,s\,p}{l}$ in which P represents the extreme support-

These discrepancies show that some of these formulæ, or, at least, some of their factors of safety* are misleading, and it seems to me that all of them which have not been based upon experiments on the capacity of soils to sustain *pressures*, must be so.

Let us see what supports a loaded pile.

I conceive that there is below the bottom of the pile in ordi-

---

ing power of the pile in tons; W the weight of the ram, and e the modulus of elasticity, both in tons; F the fall of the ram, l the length of the pile, and p the penetration at the last blow, all in feet, and s the average section of the pile in square inches. His factors of safety for use with his formula are "from 3 to 10."

(8) Colonel Mason's formula is $P = \frac{W^2}{W+w} \times \frac{F}{p}$, in which P represents the extreme supporting power of the pile; W the weight of the ram; w the weight of the pile; F the fall of the ram, and p the penetration at the last blow. His factor of safety at Fort Montgomery was 4.

(9) Weisbach's formula is the same as Mason's. His co-efficients "for duration with security" are from $\frac{1}{100}$ to $\frac{1}{10}$, the arithmetical mean of which is $\frac{1}{18.18}$.

(10) Quoted in Proceedings of the Institution of Civil Engineers (British), Vol. LXIV. Their formula is the same as Mason's. Their factors of safety are from 6 to 10. I have assumed the arithmetical mean of these, to find the mean co-efficient of safety.

It may be a question in this case, whether the mean co-efficient of safety should be $\frac{1}{7.5}$, $\frac{1}{7.74}$ or $\frac{1}{8}$. $\frac{1}{7.74}$ is the *geometrical* mean of $\frac{1}{6}$ and $\frac{1}{10}$, which are the co-efficients of safety corresponding to the extreme factors of safety, and it was used by the Engineer of the Portsmouth (England) Docks, as a mean co-efficient, to find the safe value of P for the piles of his work, from the formula and factors of safety of the Dutch Engineers. A similar doubt arises in finding a mean co-efficient of safety from Rankine's factors of safety.

(11) Quoted in Thomas Stevenson's "Design and Construction of Harbours." His formula is the same as Mason's. No factor of safety is given.

(12) The extreme supporting power of a pile is not given in the formula of Major Sanders, which he contributed to the Journal of the Franklin Institute and which may be found in Vol. XXII., (3rd Series). The formula is $P = \frac{WF}{8p}$, in which P represents the safe load of the pile, F the fall of the ram, and p the penetration at the last blow.

(13) Major Sanders' formula adopted by Haswell.

(14) 427 to 498 pounds to the square inch of head of pile. Quoted in Professor Vose's "Manual for Railroad Engineers."

(15) From his rule found in *Œuvres de Perronet*. "*Nous estimons, pour ces raisons, que l'on ne doit point charger les pilots de 8 à 9 pouces de grosseur, de plus de cinquante milliers; ceux d'un pied, de plus de cent milliers; et ainsi des autres à proportion du quarré de leur diametre ou de la superficie de leur tête.*"

1 millier = 1079.22 pounds. 1 pied = 12.8″.

(16) 1,000 pounds to the square inch of head of pile.

(17) The same.

(18) The same.

(19) "Piles standing in soft ground by friction."

(20) "Piles which resist only in virtue of the friction arising from the compression of the soil."

(21) "When they resist wholly by friction on the sides."

* By the term "factor of safety," which is used by many of the authorities on foundations, is meant the number which is to be multiplied into the working load, in any case, to find the "extreme supporting power" of the pile, or the resistance of the soil, to which, for safety in that case, the pile is to be driven.

The term "co-efficient" of safety is used by McAlpine. It is a fraction which is to be multiplied into the "extreme supporting power" of a pile to find its safe load. It is the reciprocal of the corresponding "factor of safety."

nary soils, a conoidal mass of earth, *a*, *b*, *c*, *d*, (Fig. 1.) the particles of which are acted upon by pressures derived from the weight of the pile and its load, and the form and dimensions of which, depend on this weight and on the kind of soil; * that at every section *e*, *f*; *e*, *f*, of the pile below the surface of the ground, the particles of earth in contact with the pile, are, by reason of friction, pressed downward, and that these pressures are distributed (spread) in the same way that the pressure at the foot of the pile is distributed; that is, through the particles of the earth surrounding the pile, which are limited by conoidal surfaces, of which, (in homogeneous soils,) the pile is a common axis. †

Are the particles of earth within these conoids of pressure and distant from the pile, acted upon by the blows of the ram?

General Tower, in remarking upon a recent device by a citizen of Virginia, for an armor protection of fortifications, consisting of a thin iron or steel plate backed by springs, said that even if the plate were one foot thick, suspended by chains, and without any backing whatever, it would be penetrated by a shot from an 81-ton gun in about $\frac{1}{1400}$ of a second, and before the plate could move perceptibly.

Is it not probable, reasoning from analogy, that the blows of the ram upon the head of a pile reach only the particles of earth which are in contact with or very near the foot and the sides of the pile; that the action (occupying only a small fraction of a second) is too quick to be communicated to more distant particles composing the conoids of pressure, and that subsequently the forces which hold these particles in place may be disturbed, and the particles may yield, under continued pressures communicated successively through the pile, and the particles of earth in contact with, and near the pile?

It might appear at first sight, that if pressures are more distributed laterally in the earth below and around a pile, the resistance to pressures must be greater than the resistance to blows, but the truth is, that it cannot be said that one is greater or less

* None of the books available for reference, throw any light on this subject. Rankine has a theory concerning the pressures within an earthen mass derived from its own weight, but he gives no results of experiments (if any have been made), touching the action of earth under exterior pressures.

† In sticky soils, no doubt, the action of the particles of earth adjoining a pile, is, in part, one of drawing or pulling downward the particles of earth exterior to them, and the distance to which this action extends, depends on the degree of adhesion of these particles.

than the other, except by empirical comparisons between the effects of blows and the results of pressures.

When these comparisons in the case of any kind of soil have been made, the true relation between these effects and these results may be discovered, and correct and reliable factors of safety for use with formulæ for the sustaining power of piles, into which formulæ enter the terms common to all pile driving formulæ, (viz., the weight of the ram, its fall, and the average penetration of the last blows,) may be made for that kind of soil, but I think it evident that no pile driving formula or factors of safety based only on theoretical deductions from the formula $Ps = \frac{Mv^2}{2}$, can be relied on, even for single isolated piles, or for piles driven at considerable distances apart.

Now let us examine the case of an ordinary pile foundation in any compressible soil. Say that the piles are driven three (3) feet apart, in rows the same distance apart, from centre to centre.

Would a safe load for this foundation be equal to the safe load of a single isolated pile in that soil, multiplied by the number of piles ?

I think not, for, if it be true that below and surrounding the piles, there exist within the soil the conoids of pressure before alluded to, and if the surfaces of these conoids make any considerable angle with the vertical, then the pressure upon the earth below and between the piles, may be much greater in the case supposed, than in the case of an isolated pile.

Let Fig. 2 represent a plan of the piles of this foundation, and let Fig. 3 represent a section through one of the rows. Let *a*, *b*, *c*, *d*, Fig. 3, represent a section through the axis of the conoid of pressure arising from the pressure of the pile and its load, at the foot of the pile *A*, and let *a′*, *b′*, *c′*, *d′*, represent a similar section through the conoid of pressure at the foot of the pile *B*. Let us pass a horizontal plane at any short distance—say eighteen (18) inches—below the feet of the piles (which we suppose to be driven to a uniform depth), and let *i*, *i*, *i*, *i*, and *k*, *k*, *k*, *k*, Fig. 2, represent in plan, and let *m*, *n*, and *m′*, *n′*, represent in section, the areas cut from the conoids of pressure by this plane, and it will be seen that considerable portions of each of these areas, may be acted upon by pressures derived from both of the piles and their loads. The same may be said of the earth within the conoids of pressure surrounding the piles, and it appears therefore, that the forces acting upon the particles of earth below and surrounding a pile, may be in equilibrium, and the particles may be at rest, in the case of a loaded isolated pile, when the equilibrium may be disturbed, and the particles may sink with the pile, when the same load per pile is laid upon a foundation composed of piles driven in the same soil at such distances apart that their conoids of pressure intersect each other.

McAlpine, before constructing the Brooklyn Dry Dock, made experiments with loads upon piles,* and of his formula he says :

"The co-efficient is reliable for such material as was found at that place."

This material was "a silicious sand mixed with comminuted particles of mica and a little vegetable loam, and was generally encountered in the form of quicksand."

McAlpine also says :

"It is very desirable that similar experiments should be made in soils of different kinds, which would make this formula applicable to all the cases usually met with in constructions."

Major Sanders experimented by loading sets of piles of four each, and Colonel Mason made his formula when the fort (Montgomery) which he was constructing on a pile foundation, had been nearly completed.

Which of the other pile driving formulæ and factors of safety given by the authorities I have quoted, were deduced from experiments in loading more than single isolated piles, I do not know, but some of the formulæ appear to have been based only on theoretical considerations, and some of the factors of safety appear to be simply conjectural.

None of the formulæ are accompanied by tables of factors of safety, corresponding to specified kinds of soil.

It is factors of safety that are most needed. There are many formulæ. Doubtless most of them are good, and one of them,— $P=\frac{W^2}{W+w}\times\frac{F}{p}$,—has been worked out independently by several distinguished authors; but can any of them be used safely and confidently, when the factors of safety furnished by the authors of these formulæ produce results so discordant?

* As far as I can determine from his paper read before the Franklin Institute, January 15, 1868, these experiments were made (by means of a lever), upon isolated piles only.

An Engineer having to construct a pile foundation, must take some pile driving formula and factor of safety, as he finds them. He has no time to make proper experiments in the soil he has to deal with, for that would require years of time.

It is not enough for his purpose that an author of a formula prescribes for use with it, a single factor of safety of 3, or of 4, for he knows that that factor can only be a proper one for one kind of soil, and he is not told what the kind of soil is. It may be more, or it may be less easily penetrated than his own. In the former case, by the use of an unnecessarily large factor of safety, he would make his foundation unnecessarily expensive; and in the latter, his foundation would be in danger of yielding, sometime, under its load. Neither is he satisfied to be told to use a factor of safety from 3 to 10; from 6 to 10, or from 10 to 100, "according to circumstances." He wants his own case and its proper factor of safety to be, as far as possible, definitely stated, or else, it seems to me, he would prefer to drive the piles of his foundation in every case of importance, as far as they will go, or to the equivalent of their "absolute stoppage,"* which, he knows, would make his foundation as safe as a pile foundation can be made, though it may be expensive.

I think that the want of reliable and definite factors of safety can, in a manner be supplied, without waiting for experiments made for the purpose.

While it is difficult, no doubt, to make minute descriptions of soils by giving the proportions of their physical constituents, I think that a table of useful factors of safety, corresponding to quite a large number of the ordinary and easily recognizable soils, could be made for use with any good formula, say Mason's, from the past recorded experiences of the officers of the Corps of Engineers. This could be done by dividing the values of P deduced from that formula, (substituting in each case for W, F, w, and p, the actual weight and fall of the ram, the average weight of the piles, and the average penetration at the last blows) by the actual weights of the structures per pile.

A comparison of all the factors of safety, obtained in this way, which would arise from cases in which foundations in any

---

*$p = .0067''$ when $W = 800$ pounds and $F = 5'$. See Mahan's Civil Engineering. It is the *refus du mouton* described in *Œuvres de Perronet*. By Mason's formula, it appears that this equivalent would be reached when seven (7) blows from a two thousand (2000) pound ram, falling twenty-five (25) feet, would sink a sixteen hundred and eleven (1611) pound pile, one (1) inch.

specified kind of soil have carried their loads for some years without any evidence of settling, would probably show that no two of them would be precisely the same, and that some of them would be excessive. These latter, which would lead to unnecessarily expensive work, and any inadequate factor which might be developed by a failure of a foundation, like the one at Proctorsville, to carry its load, could be rejected. A fair judgment could then be taken in respect of the others, and a single safe and reliable factor for that kind of soil, could be determined on.

From the foregoing considerations, I come to the following conclusions:

1st. Pile driving formulæ should be accompanied by tables of factors of safety, corresponding to all the common and easily recognizable kinds of soil.

2nd. These factors of safety should be determined on after extended experiments on the supporting power of piles,* although approximate factors which could be used without hazard, could be found from examinations of the records of the driving of the piles of actual foundations, provided the weights of the superstructures are known, and descriptions of the soils have been preserved; and provided also, that the foundations have carried their loads during sufficient lengths of time.

3rd. In experiments on the supporting power of piles, the loads should not rest upon single isolated piles, but they should cover a number of piles, driven at those distances apart which are usual in pile foundations.

4th. In every case of construction of a pile foundation, the record of the driving of the piles, should include such a description of the soil, obtained from borings, as would enable an Engineer, having to found a work in a similar soil, to recognize it.

---

* The case mentioned by you shows that the testing by loading should extend over considerable lengths of time. Even the foundations of Fort Montgomery and Fort Delaware have settled more or less.

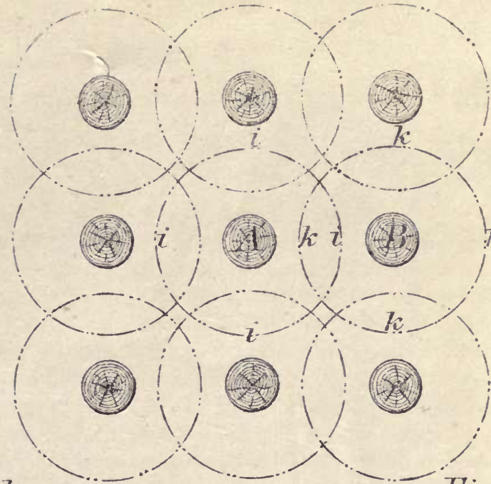

Fig. 2.

Fig. 1.

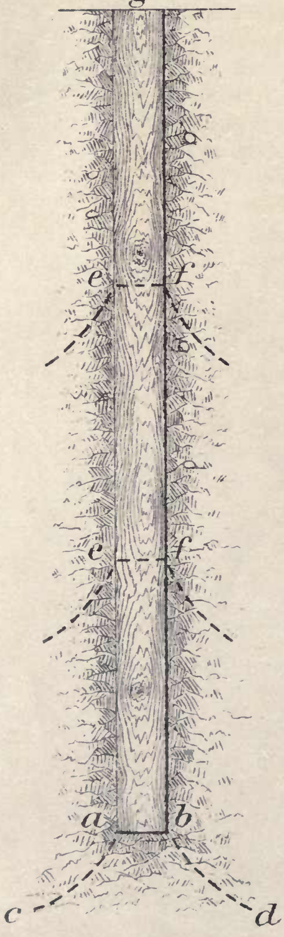

Fig. 3.