SECT. II.—OTHER SELECTED PAPERS.

No. 1,540.—"The Foundations of the New Capitol at Albany, New York." By WILLIAM JARVIS MCALPINE, M. Inst. C.E.

THE Author has not met with sufficient information to establish a rule for determining the load which may be safely imposed by a structure upon earth of a specific character and condition. The degrees of consistency and compactness in different kinds of earth, and their mixtures, and, above all, the extent of moisture therein, so affect the supporting power as to discourage any attempt at a formula for practical use. The nearly universal rule seems to be, to depend upon the previous experience of the locality, or upon observations of structures supported on similar earths in like conditions; in fact, to guess at, what the Author believes may, in most cases, be determined with considerable precision, and avoid on the one hand the unnecessarily costly foundations which are so frequently observed, and, on the other hand, those inappropriate and insufficient foundations which cause the destruction of the superstructure.

He was requested ten years ago, to devise plans for the foundations of a large and costly State building, which had to rest upon soil apparently equable and stable, but which proved, on careful examination, to lack these qualities to a remarkable extent. It was also found that the earth, to a great depth under many portions of the foundations, received and parted with a considerable amount of moisture with the changing seasons. The circumstances of the case did not allow the use of piles or inverted arches; it was, therefore, necessary to spread the base of the walls over such an area as would afford the requisite sustaining power, and also to protect the clay and sand from any excess or deprivation of its natural degree of moisture, so as at all times to derive from it the same degree of support. The importance of the work warranted the expense of experiments to determine the questions above referred to. In the absence of any similar or equally extensive experiments, the Author is induced to submit the present ones, in the hope that an explanation of the methods adopted, and the results attained, will prove serviceable.

The structure, though a single building, may be considered as a collection of a dozen large ones, with great differences of elevations, and weights upon the lower walls, and yet so bonded together as to require that the pressure of each of the parts should be the same per square foot on the earth beneath. This object has been fully accomplished; and when the structure is loaded to the maximum extent of 200,000 American tons, the Author believes that it will not compress the earth upon which it rests more than three-fourths of an inch, and exactly the same under every part thereof. The building measures nearly 300 feet by 400 feet on plan, and has three main stories and a basement. The lower walls are 110 feet high, but those of the corner towers, pavilions, and main tower, are of much greater height.

The ground covered by the structure sloped eastward at the rate of 1 in 25. The pit was excavated to a depth of 5 feet below the natural surface at the south-east corner, and 25 feet at the north-west corner. The excavation, together with the borings which were made in the bottom of the pit, fully exhibited the character of the earth. The lower strata (termed in the locality "blue clay," and "Albany clay") are more than 100 feet in thickness, resting upon the Hudson river argillite (a clay slate), the two forming the banks of the river for 30 miles of its course. The "blue clay" contains from 60 to 90 per cent. of alumina, the remainder is fine silicious sand. It also contains many nodules of clay, highly charged with carbonate of lime in the form of rings and discs about an inch in diameter. Overlying the blue clay was a mass of earth from 1 foot to 35 feet deep, composed of the same clay mixed with sand of different degrees of fineness, in proportions varying to such an extent as, when saturated, to render it in some places, a semi-fluid, while in others it was nearly pure sand, and very porous. This material occurred in veins and strata, large and small, above and below the level fixed for the foundation. One of the largest of these veins of viscid earth passed diagonally across the foundation, and at a depth of 6 to 20 feet below the bottom of the pit. It was 200 feet long, and from 5 to 25 feet wide.[1] Other veins and strata of less size, were found extending across the bottom, and sometimes terminating in pockets in the blue clay. Borings, from 10 to 30 feet deep, were made in several places below the bottom of the pit, which showed the substratum

[1] This vein was dug out, and replaced with clay and sand artificially mixed, moistened, and slightly rammed in layers, so as to render it as similar to the adjacent natural material as possible.

to be blue clay; and a well which had been sunk close by, to a depth of 100 feet, was entirely in the blue clay.

The earth in its natural condition at midsummer contained from 27 to 43 per cent. of moisture. When the samples were thoroughly dried and pulverised and again fully saturated (without dripping), they absorbed from 39 to 46 per cent. of water. The blue clay ordinarily held about 40 per cent., and when dried, again absorbed about 43 per. cent. It was, therefore, as a rule, completely saturated in its natural state. It was upon this kind of earth that the subsequent experiments of the supporting power of the clay were made. The pure clay, obtained by separating it from the sand, weighed 116 lbs., and the sand so separated 80 lbs. per cubic foot; but, when they were again mixed in different proportions, the weight of the mixture was less than the proportionate means between them. Earth taken from the same places as the samples, varied from 81·5 to 101·4 lbs. per cubic foot, depending upon the proportions of the clay and sand; and these weights show, to some extent, the relative supporting power of the earth at the places from which the samples were taken.

It was originally intended to support the structure upon wooden piles, of which a considerable number had been procured before the Author was entrusted with the direction of the work. Many comparatively large buildings in Albany have been supported upon wooden piles driven into the blue clay, or upon thick planks laid under the walls. In a few cases the wood used for this purpose has been found in tolerable preservation [1] half a century after it had been buried in the blue clay; but, generally, such timber was much decayed at the end of a quarter of a century; and several heavy buildings, after having stood firm for twenty years, began to settle, and the walls to crack, in consequence of the decay of the wooden supports and the unequal settlements therefrom. It appears that when the clay had been kept constantly moist, the wood did not materially decay in half a century; but, wherever the moisture was drawn off, the wood did not last more than twelve years. In this case, even if a wooden foundation could have been arranged so as to be kept constantly wet, it would have ultimately decayed; and its use was, therefore, inadmissible. Cast-iron piles of white iron could be relied upon for a century or more, but would also have eventually decayed.

[1] In digging the trenches for the street pipes of the new waterworks at Albany, the Author had occasion to remove many of the old pine water-pipe logs, of which only the sap wood was decayed. They had been buried in the blue clay for more than half a century.

The use of sand and concrete piles, made by boring or driving holes into the clay and filling them with these materials, was also considered. For reasons which will subsequently appear, inverted arches could only be used under a part of the structure,[1] and it was deemed advisable to have but one system of support. The Author, therefore, finally determined upon the plan which has been executed.

In most buildings, except where spires or towers are introduced, the weight is nearly equably imposed upon the several foundation walls; but in the Capitol the main and pavilion towers are much higher and heavier than the adjacent walls. The extremely heavy fire-proof floors, loaded as they will be frequently with dense crowds of people, books, &c., must necessarily carry their load to two only of the four surrounding walls, and, with some of the roofs acting in the same manner, will produce very unequal pressures upon the foundations.

The weight of the whole building and its contents when in use will be 200,000 American tons. The area of the base of the exterior and court walls, and the rear walls opposite, is about 24,000 square feet, and sustains an average of 6½ tons per square foot on the basement walls. The main tower, which weighs 30,000 tons, has an area of 2,508 square feet, equal to 12 tons per square foot upon its foundation walls. The weight on the foundation under the exterior walls of the corner towers is 47 tons per lineal foot; on the interior walls of the same towers, it is only 39 tons; and on the adjacent division walls, 23½ tons. Still greater differences in the weight on adjacent walls occur in other parts of the building, especially at the main tower, where the weight is 134 tons per lineal foot, and on the adjacent walls but 47 tons and 39 tons. Passing round the exterior walls of one quarter of the structure (the remainder being a repetition of the same sized walls), the weights to be supported per lineal foot are successively as follows: commencing at the main tower, 134 tons (which may possibly be increased); the adjacent walls are 47 tons per lineal foot for 60 feet; next, 44½ tons for 60 feet; next, 47 tons for 120 feet (turning the corner tower); next, 44½ tons for 60 feet; next, 67 tons for 18 feet; and next, 50 tons for 52 feet to the centre of

[1] It was necessary to arrange to carry two-thirds of the weight upon the exterior, rear, and court walls, which are separated 120 feet on two of the fronts, and only 90 feet on the other two. Inverted arches spanning three very unequal spaces would have imposed unequal loads upon the clay beneath, and their use would have defeated the design of distributing exactly the same weight upon every part of the clay beneath the structure.

the south or north front. On the rear of each of these walls, the interior wall is loaded with 39 tons, and the division walls with $8\frac{1}{2}$ to $23\frac{1}{2}$ tons per lineal foot.

The exterior walls of cut granite facing, backed with rubble and brick, average 150 lbs. per cubic foot. The floors, including the iron box girders, cross beams, brick arches and covering, average 24 lbs. per square foot. The possible weight of crowds of people upon the floors is taken at 100 lbs. per square foot; the snow upon the roofs, at 2 feet depth, is $12\frac{1}{2}$ lbs.; and the effect of the strongest winds, which may at times be deflected perpendicularly against some of the roofs, is taken at 15 lbs. per square foot. The calculated weight which may come upon each of the walls is as follows: on the corner towers and front foundation walls, 47 tons per lineal foot; on the main east and west front, 50 tons; on the curtains, $44\frac{1}{2}$ tons; on the ventilating tower, 67 tons; on the division walls, extending upwards through four stories, $23\frac{1}{2}$ tons; on the partition walls of two stories, $13\frac{1}{2}$ tons, and of those which extend one story high $8\frac{1}{2}$ tons, per lineal foot. The main tower is designed to be of stone, except the portion immediately below the dome, which, from being so high from view, was proposed to be made of iron. If it should be of stone to the dome, that change, together with some others, would increase its weight to 36,000 tons, equal to 14·4 tons per square foot at the base. Its footing stones were spread to 110 feet square, and the concrete to 125 feet square, and 5 feet thickness. The weight on the clay, with 30,000 tons, is 1·92 ton per square foot; and with 36,000 tons, it would be 2·3 tons; but it was arranged for an underpinning, if necessary.

The Experiments.

For the purpose of ascertaining the sustaining power of the blue clay in its natural condition, two sets of experiments were made; in the first by pressure upon a square foot, and in the second upon a square yard, of the surface. The machine used was a mast of timber 12 inches square, held perpendicularly by guys, with a cross frame for the weights. A hole was dug, 3 feet deep, in the bottom of the blue clay foundation, 18 inches square at the top, and 14 inches at the bottom, The foot of the machine was placed in this hole, and weights from 2,754 lbs. to 23,784 lbs. were applied. Small stakes were driven into the ground, in radial lines from the centre of the hole, and the tops carefully driven to the same level; and by means of a straight-edge any change in the surface of the ground adjacent to the hole could readily be detected and measured.

Table I. shows a continued settlement of the clay under the foot of the machine as the loads were added, but no change in the surface of the adjacent ground was observed until an hour after a weight of 11,844 lbs. had been applied, when an uplift of the surrounding earth was noted, in the form of a ring with an irregular rounded surface, the content of which, above the previous surface, measured 0·09 cubic foot, which is equivalent to a displacement of 1·09 inch of clay in depth under the foot of the machine, or equal to one-fifth of the whole settlement which had then occurred.

TABLE I.

Observation.	Day.	Hour.	Duration.	Weights.		Settlement.		—
				Each.	Total.	Each.	Total.	
			Hours.	lbs.	lbs.	Inches.	Inches.	
1	Mon.	5 P.M.	..	2,754	2,754	0·288	0·288	The weight of the machine.[1]
2	Tues.	9 A.M.	16	..	..	0·612	0·900	
..	”	9 ”	..	2,820	5,574	..	..	First stone added.
3	”	10 ”	1	..	..	0·528	1·428	
..	”	10 ”	..	6,260	11,834	..	..	Second and third stones added.
4	”	11¾ ”	1¾	..	..	4·752	6·180	Uplift noted.
..	”	11¾ ”	..	3,250	15,084	..	..	Fourth stone added.
5	”	½ P.M.	¾	..	..	3·588	9·768	
6	”	1 ”	½	..	..	1·728	11·496	
..	”	1 ”	5 min.	2,890	17,974	0·060	11·556	Fifth stone. Immediate settlement.
7	”	1½ ”	½	..	..	3·288	14·844	
..	”	1½ ”	..	2,980	20,954	..	..	Sixth stone added.
8	”	2 ”	½	..	..	4·128	18·972	Uplift noted.
..	”	2 ”	..	2,830	23,784	..	..	Seventh stone added.
9	”	2½ ”	½	..	..	5·184	24·156	
10	”	3 ”	½	..	..	2·060	26·216	
11	”	4⅓ ”	1⅓	..	..	1·300	27·516	
12	”	5 ”	⅔	..	..	3·084	30·600	Uplift noted.
13	Wed.	5 A.M.	12	..	..	0·600	31·200	
14	”	8 ”	3	..	..	..	31·200	No settlement after 5 A.M.

Observations 12 and 13 are not reliable.

[1] The first settlement, noted in observation 1, was due to the weight of the machine, and was not a compression, but only a levelling of the rough inequalities of the clay. The subsequent observation 2, of 0·612 inch, is the compression due to 2,754 lbs. This settlement occurred before 5 A.M.

When the weight had reached 20,954 lbs., and had rested for half an hour upon the clay, a further protrusion was noted. The form of the ring was the same as before, but with more irregularity of surface. The highest part of the protrusion was from 12 to 15 inches from the edge of the pit, where it averaged

0·3 inch high, and sloped off outwardly to an average of 4 feet from the centre of the hole. This uplifted earth measured 0·606 cubic foot, which is equivalent to a displacement 7·272 inches. When a weight of 23,784 lbs. had been applied, and had rested three hours on the clay, the ring in the highest part averaged 0·5 inch high, in the same general form and extent as before noted. The amount of earth thus raised was 1·01 cubic foot, equivalent to a displacement of 12·12 inches under the machine.

Before the lifting of the earth surrounding the machine could have taken place, the materials first displaced from under the machine were doubtless forced among the particles of the earth adjacent to the hole, and compressed that earth to some extent; and this operation was continued until the adjacent earth had become so compacted as to cause the lifts noted in the Table. The Author is of opinion that the compression of the earth below the bottom of the machine continued without any considerable displacement until after a load of 4,000 lbs. or 5,000 lbs. had been applied, and that then the displaced earth found space in the adjoining earth until the load reached 7,000 or 8,000 lbs., when the uplift became visible at the surface of the ground; but that meanwhile the earth directly under the machine was continually more and more compressed in some proportion to the weight added. The small area pressed upon facilitated the escape of the material into the adjacent earth, which weighed only 300 or 400 lbs. per square foot. If the pit had been deeper, or the piston larger, there would have been less displacement.

The second set of experiments was made with the same machine, to the bottom of which was framed a strong base 3 feet square. The pit was sunk 2 feet deep into similar earth, and was 38 inches square both at the top and at the bottom. The stones were put on at intervals of an hour. There was no uplifting of the surrounding earth.

Table II. shows a remarkable regularity in the settlement as the load was increased, and a constant diminution of the increment as the earth became more compacted. At the 6th observation, the weight per square foot corresponded nearly with the 2nd in Table I., and the settlement was almost the same. The base was nine times as large, so that the proportion of escapement of the earth from beneath must at this time have been very small. It is probable, however, that if the weights per square foot had been increased so as to equal those in Table I., a similar uplift would have occurred, though of less extent. The Author derived from the Tables the opinion that the extreme supporting power of this earth was less than 6 tons per square foot, and that the load which might be safely imposed upon the clay was 2 tons per square foot.

TABLE II.

Observation.	Weight.			Settlement.		—
	Each.	Total.	Per Sq. Foot.	Each.	Total.	
	lbs.	lbs.	lbs.	Inch.	Inch.	
Machine placed . .	3,228	3,228	359	..	..	No settlement that could be measured.
1st stone added . .	2,380	5,608	623	0·050	0·050	
2nd „ „ . .	3,300	8,908	990	0·150	0·200	Estimated.
3rd & 4th stone added	6,960	15,868	1,763	0·166	0·366	
5th „ „	2,830	18,698	2,078	0·134	0·500	„
6th „ „	3,250	21,948	2,439	0·124	0·624	
7th „ „	4,420	26,368	2,929	0·096	0·720	„
8th „ „	1,190	27,558	3,062	0·080	0·800	
9th „ „	2,320	29,878	3,320	0·025	0·825	

The notations of the settlement were generally made about an hour after the weight had been applied.

For the purpose of maintaining the clay beneath the structure in the same condition of moisture, a deep puddle wall was extended entirely around the foundation, not only to exclude an excess of water, which might reach it through the veins and films of sand with considerable hydrostatic head, but also to prevent the egress of the natural moisture through similar veins. Although the puddle wall was carried up to the level of the terrace which surrounds the building, yet water might find its way along the face and down the outside of the walls, or possibly through some accidental break in the concrete floors within, and surcharge the clay below. To prevent this, there was spread on the top of the clay, over the whole area enclosed, a depth of 6 inches of coarse screened gravel, the effect of which will be that under the great weight of the building any excess of water in the clay beneath will be forced into this pervious gravel, and flow off through it to the drains which encircle and traverse the foundations. The necessity for these provisions will be apparent, when it is considered that many of the veins of sand extend to the surface of grounds of much greater elevation than the foundations, and that they communicate with imperfectly built street sewers and water pipes; while the same or other porous veins extend beneath the surface to grounds which are much lower. Through these sources the clay under some portions of the structure might be charged with water, while that under an adjacent wall might at the same time be drained of much of its natural moisture, and thus entirely destroy the design of a foundation which should everywhere have an equal sustaining power. It is not an absolute settlement which is to be apprehended, but a greater yielding in one place than in another.

A common practice of builders who have occasion to erect high and comparatively heavy towers and spires, is to groove the lower part into the adjacent walls, so as to allow the heavier ones to slide in these grooves, without breaking the bonding stones. In the present case, the demands of the architect forbad the use of grooving, and hence the necessity for the above provisions.

The main walls of the building are from 5 feet to 7 feet thick, where they rest upon the foundation walls, and bring upon them pressures of from 6 to 9 tons per square foot, which had to be reduced to 2 tons per square foot on the clay. This was accomplished by projecting each of the footing courses beyond those immediately above them. The rule was to commence with a load of 2 tons per square foot upon the clay, 3 tons upon the top of the concrete, and generally 4, 5, 6, or 7 tons upon each succeeding course of stone. The weight on each lineal foot of the top of the foundation walls, divided by the above pressures, gives the exact width of each course of the footing stones, as shown in Table III.

TABLE III.

Parts of the Building.	Load per Lineal Foot.	Required width of Courses. Concrete.		Courses of Footings. 1st.		2nd.		3rd.		4th.		5th.		Main Walls.	
	Tons.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
Corner towers, front	47	23	6	15	8	11	9	9	4	7	10	7	4	7	0
" " rear	39	19	6	13	0	9	9	7	10	6	6	5	6	5	0
Curtains, front . .	44½	22	3	14	8	11	1	8	11	7	5	6	5	6	5
Central fronts . .	50	25	0	16	8	12	6	10	0	8	4	7	2	6	5
Partitions, 4 stories	23½	11	9	7	10	5	11	4	9	3	11	3	5	3	0
" 2 "	13½	6	9	4	6	3	5	3	0	..		..		3	0
" 1 "	8½	4	3	2	5	2	2	2	0	..		..		2	0

The large quantity of stone required in a short time—50,000 tons in four months—compelled a resort to a great many quarries, which furnished stones of different thicknesses, and made it necessary to modify the above exact arrangement; but the principle of the distribution of the load according to the vertical strength of the stone used, was maintained throughout the foundations.

It was necessary to consider how far these projections could be made without danger of breakage of the projecting part of the stone. The pressure in this case tending to break the stone is that due to the weight on the wall above it, divided by the width of the wall and multiplied by the area of the projection, and to treat that result as a load distributed on a beam supported at one end.

To distribute the weight upon the footing-stone courses with certainty, the beds of the limestone and granite were dressed to close parallel joints, so that the weight of each of the upper courses should be carried out to the extremity of the next course below. The vertical joints were only required to be quarry joints, not exceeding 1 inch wide. For certainty and convenience of laying the masonry, the foundation stones were all required to be rectangular blocks, of from 18 to 24 inches in thickness, the breadth to be at least one and a half time the thickness, and the length two and a half times the thickness. The average size of all the stones was 31 cubic feet, equal to 2½ tons, and many of them were from 5 to 8 tons weight. In the foundations of the main tower, the average weight of the granite blocks was 4 tons, and of the projecting blocks 7 tons. The footing courses were spread out equi-distant from the lines of the centre of gravity of the imposed weight above. The exterior stones of the three lower footing courses were all headers from 4½ to 7 feet in length. The longitudinal bonding was made by the interior stone; and in the upper courses, where the projections were smaller, by alternate headers and stretchers of the front stone, as well as the interior. The result of this bonding will be to distribute the weight, and equalise its pressure upon the clay.

The weight of the main tower was so much greater than that of the other walls, and the earth below it so much inferior, that the foundation was placed 7 feet deeper than elsewhere. With this exception, all the walls were commenced at the same level. The spaces between the main exterior, rear and division walls, and under the arches of the central court, were covered with a layer of concrete, made of screened gravel and hydraulic cement, 1 foot to 2 feet thick.