MECHANICAL COMPRESSION OF THE GROUND IN THE CONSTRUCTION OF FOUNDATIONS.

BY EMILE GUARINI.

M. Ducloux, directing engineer of the Société des Fondations par Compressions Mecaniques du Sol, recently delivered before the Société Belge d'Ingenieurs et Industriels a very interesting lecture upon the foundation method employed by the Société, and which consists in compressing the ground by treating it with concrete in such a way as to compress it laterally and depthwise.

In matters of construction, the question of foundations is one of the most important and difficult, and, in most cases, becomes the subject of numerous studies. The entire stability of an edifice, in fact, depends upon the adaptation of its foundation to the ground upon which the building is to rest. So it is necessary to examine the nature of the ground by boring, to ascertain the thickness of the strata and calculate their resistance, and to render wet ground firm by drainage, etc.

It is principally when it is a question of loose argillaceous, sandy, wet, or filled-in ground that the matter becomes complicated and puts the experience and sagacity of the engineer to the test. It becomes necessary for him to select from among previously employed methods the one best adapted to the particular case in hand; and such a selection is always difficult, even when it is not hazardous.

The cases that may arise are very numerous, and the solutions of the questions that are capable of intervening are manifold. For the consolidation of loose soil, various processes have been recommended. We shall not recall the methods to which recourse has been had up to the present, since they are well known and may be found described in all technical works, but shall confine ourselves to the one that formed the subject of M. Ducloux's lecture and which is based upon the Dulac process, the conception of which is more recent.

An endeavor has for a long time been made to consolidate unstable ground by the use of piles. The piles, which are of wood and set very close together, compress the earth laterally, and increase its stability through the resistance that they impart to it. The idea has occurred also, and has sometimes been put in practice, to substitute for such consolidation by wooden piles a reinforcement by masses of sand or concrete. The ground is prepared by sinking piles and then withdrawing the piles so as to leave cylindrical holes which are afterward filled in with concrete in order to maintain the compression.

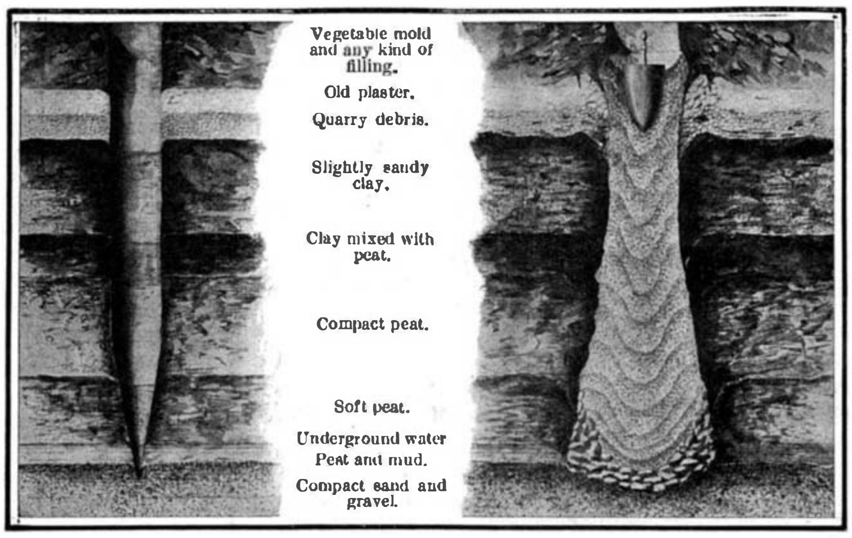
The Dulac process offers some analogy to this method, and may be considered as an improvement upon the rudimentary one. It is more complete in its action, and is designed to form in the ground, whatever be its composition, rigid bearing points resting through a base of adequate width either upon the natural soil or upon earth that has been rendered properly resistant by mechanical treatment, such as ramming.

Girders or beams are secured to the bearing points, which thus become rigidly connected, so that the whole constitutes an indeformable mass.

The apparatus employed are relatively simple and not very numerous. They consist of a pile-driver, say 40 feet in height, and three rams of appropriate form and size with automatic nippers.

The pile drivers are actuated by a steam windlass. Some are rotary and mounted upon two superposed tables with a circular base, while others are mounted upon platforms with a rectangular base. The type employed depends upon circumstances. The first are particularly well adapted for work at the bottom of an excavation. The automatic snaffles form a special apparatus which is supported by a chain carrying pulley blocks, and the operation of which presents no complication.

One of the rams is placed upon the pile driver. The snaffle grasps its rod, which terminates in a top-shaped head. When the engine is in motion, the chain winds around the windlass and the snaffles ascend and carry along the ram. At a certain point of the cheeks there is a ring the height of which is regulated at will. This ring has the form of a double funnel. When the upper part of the snaffles, which grasp the head of the ram so much the more firmly in proportion as the latter is heavier, reaches the ring in question, the lower part opens and allows the ram to escape and drop. The snaffle then descends by its own weight and grasps the ram again and lifts it anew to the ring. As we have already said, three kinds of rams are used in the process. The first, of ogival form, has a base of 24 inches in diameter. It is placed point downward, and falls in this manner. Its weight is 3,300 pounds. Another and heavier ram is of conical form and called the perforator. It has a base of 28 inches and weighs 3,520 pounds. Its drop is about 40 feet.



The Ground is First Bored; the Boring Filled With Clay, Which is Rammed Down.

It is either solid or hollow. When solid, it presents at its lower part a small cavity in which is stored a quantity of the earth with which it comes into contact. When hollow, it is designed to render the work easier when the operation is performed in incompressible and wet earth. It is then composed of a truncated cone which is in two parts that are assembled in the direction of a diametric plane, and that are capable of pivoting around an axis of assemblage. It operates after the manner of a punch, which cuts a mass of earth out of the ground. It is provided with a notch that serves for opening it. For this purpose, a catch that holds the two pieces is unfastened, and a wedge is introduced into the notch. The two constituent parts of the wedge pivot upon each other and disengage the earth.

Compressed Earth Pile Dug Out for Examination.

The third, or test ram, is designed for testing the resistance of the ground, either before or after the operation. It has the form of a truncated cone and falls with its wide base (of 32 inches diameter) downward. Its weight is 2,200 pounds. The measurement of the resistance is effected very simply, the latter, in fact, being inversely proportional to the mean depth attained by three or four blows of the ram.

In practice, it is generally granted that half the work produced by the fall is expended in vibrations, etc., while the other half is utilized and capable of serving as a basis for the estimation of the resistance by square inches. This, the height of fall of the ram being given, is simply deduced from the weight of the ram and the surface of the base.

Calculations show that penetrations of 40 inches and 4 inches correspond respectively with resistances of 15.6 and 13.2 pounds to the square inch.

The method of work varies according as the ground is accessible to the laborers and the machines, or as to whether it is constantly covered with water. If, for example, it is desired merely to consolidate filled-in ground with a view to the construction of a building of considerable weight, the earth is submitted to the action of the ram after the excavations, for the walls have been affected.

Holes from 40 to 60 inches in depth are thus formed in the ground. These are filled about a third full with hard material, which is rammed down, and then a new charge is introduced and rammed down, and so on. The ground, strongly compressed, takes on a consistency which rapidly increases and which may be rendered uniform. The operation is not nearly so simple when it is performed in wet earth, and particularly in earth constantly covered with water.

In wet soil an excavation is made that gives a well of which the sides, compressed by the ram, have sufficient tightness. If seepage of water occurs, clay is introduced into the hole and the operation is begun again.

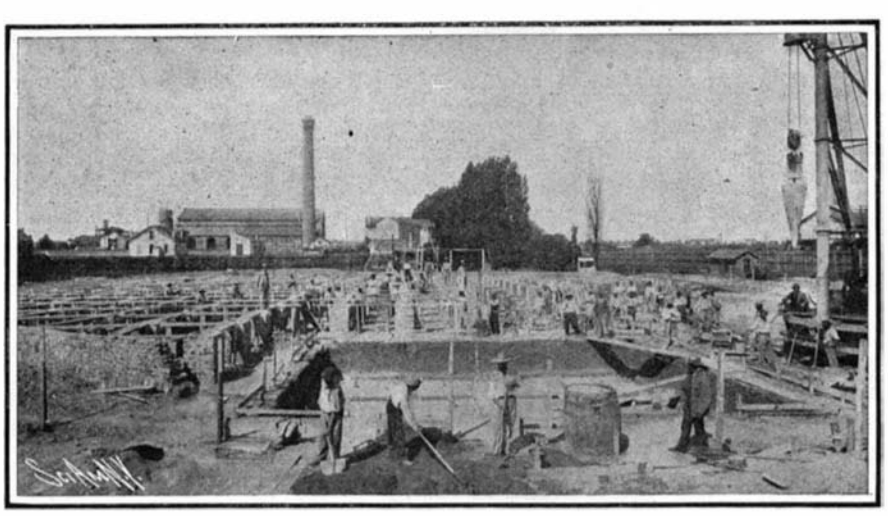
It is easy to obtain a well of temporary permeability that may be filled with large stones. These may be driven laterally by the ogival ram, and then a new charge be introduced and rammed down, and so on, until there has been established a sort of inverted "mushroom" produced by the lateral expansion of the materials thrown into the well. The filling in is completed with materials of proper resistance firmly compressed.

Finally, if the ground is still more watery, the process employed is as follows, the same apparatus being used: A light *batardeau* is established around the site reserved for the foundation that it is proposed to construct; and in this way is formed an inclosure which is filled in with vegetable mold or ordinary earth, which expels the water to such an extent that there is obtained a sort of platform upon which the different apparatus may be installed. Then the ramming of the ground is begun. By means of the perforating ram a well is formed into which is emptied one or two wheelbarrowfuls of argillaceous earth. The blows of the ram drive the earth laterally in a stratum which is reinforced by new charges, and there is thus formed an argillaceous casing of from ½ an inch to 1½ inch in thickness.

The operation of perforation should be conducted slowly in order to obtain a proper subsidence of the earth. The thickness of the internal tight coating should be proportionate to the pressure of the water, which latter increases in measure as a greater depth is reached. It is well, therefore, that the work of ramming be pushed and the quantity of clay introduced be increased.

This part of the work is effected first by means of the perforating ram, and then by the tamping one when hardpan is approached. It widens the mouth of the hole made by the perforator and prepares the base that it is desired to obtain. The concrete introduced is designed to prevent the water from rising through pressure from beneath, and it must therefore be used in adequate quantity. Angular materials also are introduced and submitted to a vigorous ramming. These materials, owing to the concrete that is poured in in order to fill the interstices, and to the ramming to which they are submitted, constitute a perfect masonry.

Finally, in all cases, masonry pillars are formed that have a wide bearing surface upon the ground, and the diameter of which is proportionate to the hardness of the ramming. These pillars transfer directly to the ground the pressure that the structure exerts upon them. These operations are repeated as many times as need be, in order to obtain a succession of strong pillars that have the same form as if they were built on ground that was quite accessible. The materials introduced into the ground are always strongly compressed.



Rammed Earth Foundations for a Building.

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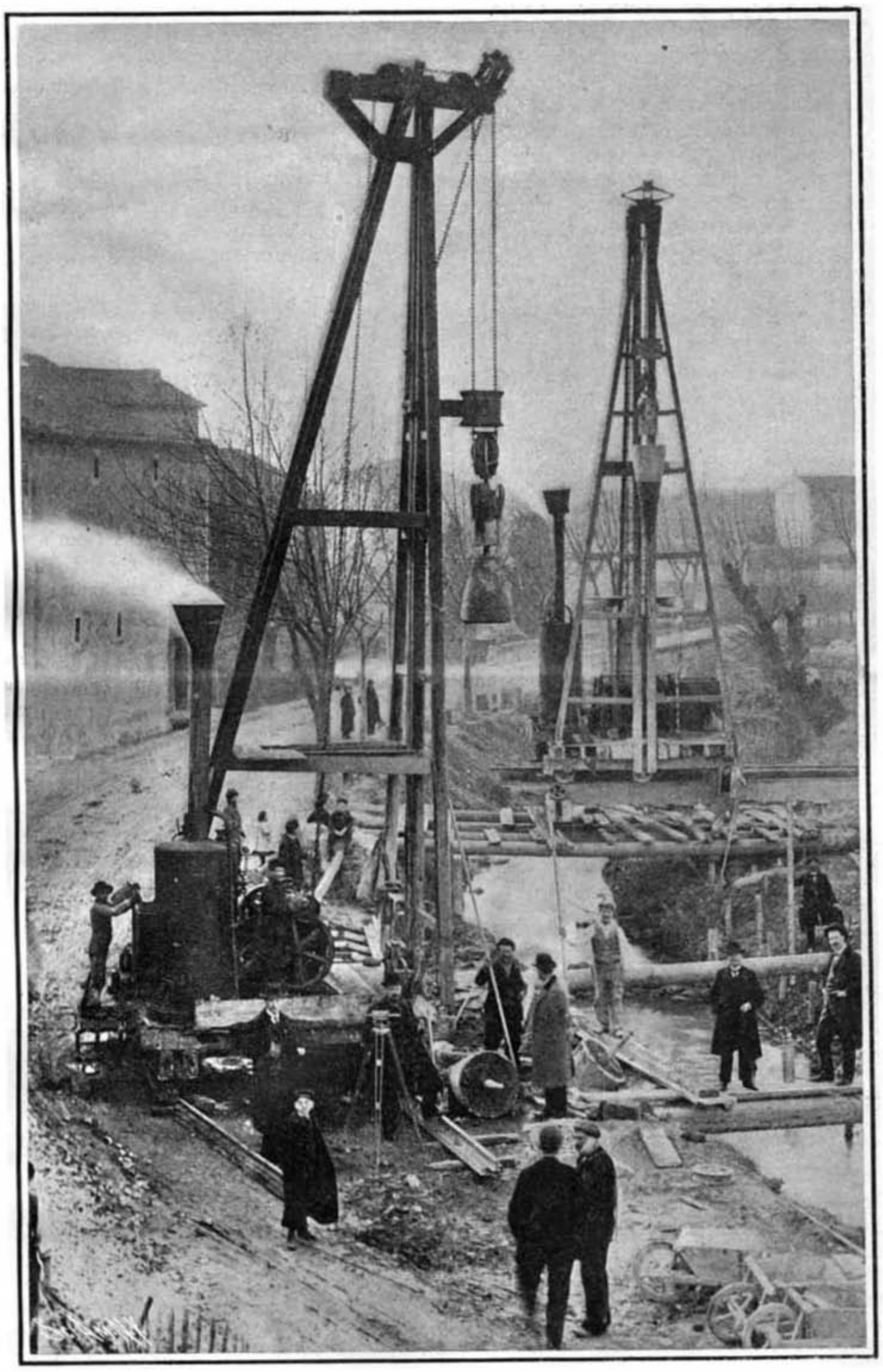
It is possible to dispense with the coffer dam by substituting for the protective lining of clay a cylinder of concrete, reinforced or not. The cylinder may be introduced into the bed of a river so as to emerge from the water, and the water that it contains be exhausted by pumps placed upon a pontoon. Then, after the well has been sunk, it may be filled in as above described, and the concrete cylinder afterward be filled.

It is scarcely necessary to bring into prominence in this place the difference between this method and the processes in which there is no ramming, but merely a pouring of concrete into the well, the sides of which are wanting in stability. On the contrary, the Dulac method affords wells that have strong walls, which are rendered still more compact by the subsidence of the concrete, the quantity of which sometimes exceeds a quintuple of the capacity of the hole. The diameter of the latter is increased, and, from 36 inches at the outset, passes to 40, 44, 48 inches and beyond.

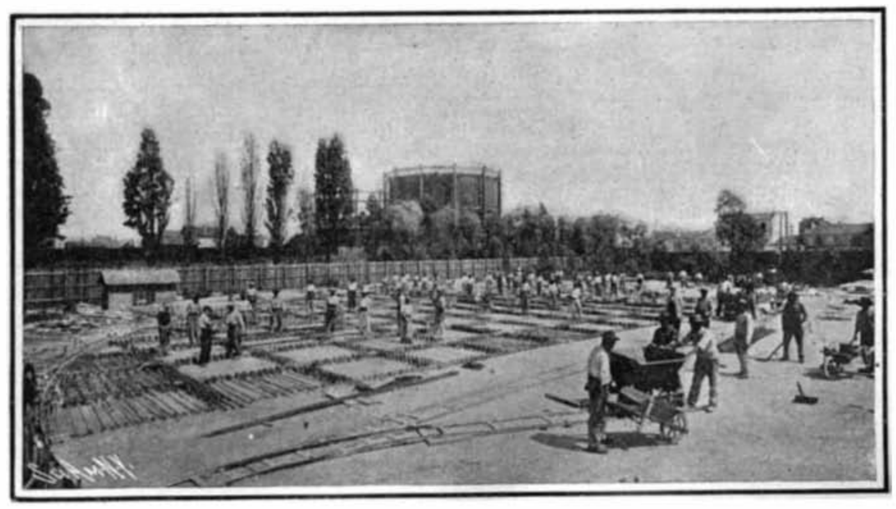
The bearing points should be distributed as uniformly as possible, and their distance apart should vary according to the load that they have to support. As has already been stated, they are generally connected in such a way as to form a more compact and rigid distribution affording greater safety.

Upon the whole, the method substitutes for the excavation of wells by manual labor, a more rapid and surer boring that safeguards the laborers against inundations of the bottom of the well, cavings in, etc., and does away with boarding up, pumping and other analogous operations. It affords a greater resistance for the reason that the contact of the concrete of the pillar with the sides of the hole is always perfectly assured.

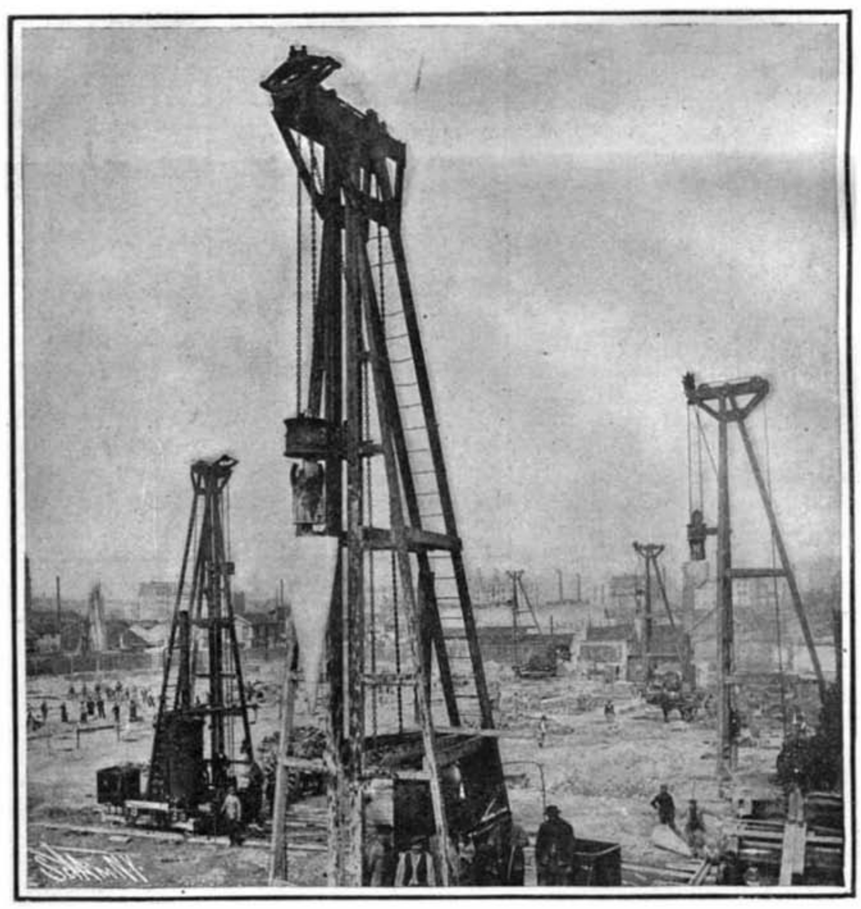
In addition to such arrangements, reinforcements of iron are almost always introduced into the mass of the pillars in order to effect a subsequent connection of the latter. Such reinforcements are arranged circumferentially so as to permit of the passage of the rams and especially of the tamping one, which compresses the materials. The iron reinforcing rods serve not only for connecting the pillars with each other, but also for forming a sort of monolith with the structure properly so called, when it is of protected concrete.



Ram for Testing the Resistance of the Ground.



Laying a Reinforced Concrete Floor on an Earth Foundation.



One of the Perforating Rams at Work.

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Practical Tests of a Model Fireproof Theater.

Some highly interesting tests were recently conducted by the Austrian Association of Engineers and Architects in order to find out the best methods of fireproofing theaters. An iron and concrete theater was especially built with this object in view, embodying all the improvements so far suggested for the purpose, and in this a series of rather conclusive tests was carried out in the presence of experts and representatives of both German and Austrian authorities. In order to examine the phenomena occurring during the fire, a compartment two meters in width had been separated from the auditorium by a well, provided at the top with glass-covered openings.

In the first test the ventilation device above the stage was closed, while that of the auditorium was kept half open, the woven curtain being lowered. After the stage had been set on fire, the woven curtain was seen to bulge out toward the auditorium, and a violent flame projected from underneath the bulge, rapidly filling the auditorium with smoke and deleterious gases. The gas flames first went out as a consequence of the pressure of the hot gases, and the candles, oil, and petroleum lamps subsequently followed their example, owing to the lack of atmospheric oxygen. The electrical lamps, which were likewise provided, were so enveloped with smoke as to become invisible. In the air, filled with carbonic acid gases, pressures up to 160 millimeters water column and temperatures of up to 400 deg. C. were observed, and under these conditions human life would have been destroyed within a few seconds.

In another test the general arrangement was the same as above, with the exception of keeping the stage open until closed by the iron curtain during the fire. The phenomena observed were about the same as in the former case, and even more dangerous to spectators, as the tongues of flame penetrated into the orchestra space.

A third test was then made with the ventilation devices above the stage opened, after the stage had been set on fire, while those of the auditorium were kept closed and the curtains opened. The fire developed as in a large chimney, the smoke gases escaping through the open pit and aperture in the roof, while the auditorium being free from smoke and noxious gases, did not present any danger to the spectators. During this trial the lights were not extinguished. In connection with a fourth test the ventilation outfit above the stage was not opened until after the fire had developed, that above the auditorium being kept closed. In this case the spectators would have been in no way endangered, and the illumination continued to work satisfactorily.

A fifth test was finally made to try the efficiency of the sprinkling apparatus, the stage and the ventilation apparatus above the same being open and the ventilator above the auditorium closed. After the sprinkling apparatus had been turned on a lively spray was poured out of the stage, considerably damping the fire, the steam and smoke escaping through the ventilation apertures in the stage. All open doors proved rather dangerous, owing to the hot draft produced, which carried the smoke, steam, and burning pieces of material into the auditorium. The water spray, however, efficiently eliminated any danger. The above tests have aroused a great amount of interest in continental engineering circles, and will doubtless lead to a more efficient fireproofing of theaters.

Since February 14 the regular passenger traffic with Siberia has been restored as it existed prior to the war, and goods of all categories are now carried without any obstruction as far as the station of Atchinsk, which is 409 versts east of Tomsk. Nevertheless, it would seem that the line to the East is in a bad state of repair, for the Russian Treasury propose to issue in the course of the present year a loan of twelve million rubles for the Chinese Eastern Railway, which is the Manchurian line.