Pile Foundations.

The remains of bridges known as Trajans, show that piles were employed for engineering purposes by the Ancient Romans. We find also in the submerged villages, discovered beneath the waters of lakes in Switzerland, numerous huts founded upon timbers driven firmly into the earth which once formed the shore. In the Thames, there are piles in good preservation, said to have been driven by the Romans fifteen hundred years ago.

The rapid progress of engineering science since that time has failed to show that this form of foundation can often be superseded to advantage by any other. Piles supports of various forms, and distinguished by different names, are still constantly employed in structures of great importance and magnitude. The use of wooden piles however is not always practicable, sometimes on account of the great depth of the water where the foundation is to be made, sometimes owing to the unstable character of the bottom, sometimes to its hardness, and again on account of the liability to decay which exists in timber placed under sea water. The Teredo Navalis, a marine worm of small size, causes the rapid destruction of any wood exposed to its attack. To obviate these difficulties, piles of iron have been substituted for those of wood, occasionally solid, but for the most part in a tubular form, filled with rubble masonry or concrete. The resistance of the earth and the strength of wood limit the depth to which wooden piles may be driven, and when they are necessarily of great length, the blows of a ram or hammer produce little effect in driving them. As iron piles are not dependent upon this method of driving, the use of the latter is much more feasible in cases where there exists a great depth of water. When the material is iron, the piles can be made of any desired length, and can be sunk in places where timber would fail to penetrate, even when shod with iron. Again, where rapid currents cause scouring in the bed of a river, iron tubular foundations possess a great advantage over wooden piles, inasmuch as they derive their chief support at a level far below the scour line. In the case of wooden piles, if any considerable scour should take place about a pier or single pile, their supporting power is much weakened, for example, it is well known to engineers that if two wooden piles are driven, one to the depth of thirty feet, and the other twenty feet, into the earth, the former will sustain a load three times greater than the latter, and consequently the removal of earth about piles of this kind, to the extent of one third, of the depth of their penetration, will destroy two thirds of their supporting power; whereas iron piles, deriving two thirds of their support from the area of their base, are little affected by any considerable amount of scour. We see therefore that in any case where scour is likely to take place, the employment of iron piles, where sufficient supporting power can be obtained, insures safety of the piers and structure, even where circumstances are very unfavorable to permanence in the character of the bottom.

There are cases however where, in order to obtain a firm support, it would be necessary to sink iron cylinders to a great depth into the sand or mud, involving great expense on the score of material and labor, and where at the same time wooden piles would answer every purpose; could they be protected from the ravages of worms. The exigencies of such a case were admirably met in the construction of a rail-road bridge recently built over the Seekonk river at Providence R.I. which I will proceed to describe.

An old bridge, built in 1835 near the site of the present structure was found to be unsafe, and in 1866 measures were taken to secure the erection of a new bridge. Although new piers had been put in and new piles driven, the worms had worked so rapidly as to endanger the safety of the entire structure: the old piles were almost destroyed, and those recently driven were found to be badly eaten. An examination of the character of the bottom showed that at the depth of about fifty feet below the surface of the water at low tide, there exists a hard-pan of gravel and clay with a soft mud of variable depth, and this in turn, is covered with a layer of oyster shells about four feet in thickness, firmly packed together, forming a firm, hard bed over which the river flows. The greatest depth of water at low tide is about twenty five feet. These facts having been ascertained, a consultation was held among the engineers to devise a foundation which should be at once strong,

durable, and and not too expensive.
Piers composed of wooden piles possessed every qualification except durability. If the timber could, by any means, be protected from the worms, there were few other difficulties to be met. Various attempts have been made to give this protection to wooden piles by means of Burnetizing, saturating with creosote, encasing with copper etc, but all have proved unsuccessful. The piles of the old bridge were found to be attacked by the worms only in that portion between the river bed and the level of low water; in no case had they bored beneath the mud. From this fact, the engineers concluded it would be sufficient to protect the timber from the surface of the water to the top of the mud, and finally adopted the following plan as being best suited to the requirements of the case on the score of economy and safety.

Wooden piles were to be used as a means of support for the superstructure and for protection against worms, it was proposed to surround the piles with cast iron cylinders, penetrating a short distance into the mud. The details of the execution of this plan were collected from the engineers employed upon the work: they were for the most part given me during an interview with Col. J. A. Monroe, the Superintendent of the work, to whose courtesy I am indebted for a minute description of the process of construction.

As the bridge now stands, it consists of four spans, three fixed, and a draw. The first span, beginning at the western shore, is one hundred and thirteen feet long, the second, one hundred and eight, the third, one hundred and fifty-four; this is supported at its centre by the pier on which the draw turns. The fourth is a short span of only twenty one feet in length, connecting the draw with the eastern shore.

The piers consist of solid clusters of piles strongly bolted together, and encased in iron cylinders; the space between the cylinders and pile clusters is filled with concrete. The westerly pier has two clusters of twelve piles each; the clusters are distant sixteen feet from centre to centre: the pier next east of this is the same in every particular.

The draw pier has seven clusters, five containing nine piles, and two composed of twelve. Directly under the centre of the draw is one of the small clusters, around this, the others are arranged as shown in the drawing marked Draw Pier.

The first step in the work was to make a thorough examination of the river bed where the cylinders were to be sunk, in order to ascertain if any obstacles such as old piles, boulders, wrecks etc. existed to interfere with their descent. After all obstructions were removed, the question arose as to the best method of driving the piles, inasmuch as the greatest care and exactness would be necessary in order to locate them precisely.

For this purpose it was decided to erect a temporary platform, and as a support for this, piles were driven about the places where the piers now stand; then, by means of hard pine capping and heavy spruce plank, a firm platform was constructed in such a manner as to leave openings or bays nine feet square, the centres of which were to correspond precisely with the centres of the pile clusters designed to be driven in each bay.

On the 15th of July 1867, the first pile for the piers was carefully put into position and the driving begun. It was a matter of considerable anxiety among those in charge of the work to test the accuracy of the first driving. When the pile was driven home, measurements were made but no important deviation discovered, and from this time to the completion of the work, the workmen seemed to acquire additional skill with every pile driven.

The clusters were formed of square timber as follows. — The first pile driven was sharpened by cutting equally from four sides, the bevel commencing about eighteen inches from the lower end, leaving that end about four inches square. The second pile—intended to fit closely against the first—was sharpened only on that side farthest from the pile already driven; and all those presenting only one side to the piles standing in position were sharpened on one side only, while those fitting into a corner were sharpened on the two sides not abutting against the other sticks; by this means the closest contact between the piles was insured, and when all had been driven to the desired depth, the tops of the piles in each cluster were drawn closely together by strong bolts passing through the centre of each pile from side to side of the cluster, the power being applied to a nut at one end of the bolt. Each cluster then is equivalent to one enormous wooden pile, fifty-two inches through in one form, and forty two, in the other. The different forms of the clusters are shown in Figs. I and 2. of the drawings

It was found difficult to obtain timber in sufficient quantity long enough to reach from hard bottom to the proposed height for the piers, consequently but one pile of the requisite length was used in each cluster; for the rest, sticks fifty feet long were first driven to the hard-pan, leaving the top just above low water mark; they were then pieced out to the necessary lengths, an inch-and-a-quarter bolt running entirely through each cluster above and below the joint.

The cylinders for the two piers west of the draw, are of six feet exterior diameter; those used in the draw pier are five feet in exterior diameter, for the small clusters, and six feet, for those containing twelve piles. They were cast in sections, four and one half feet long, with a flange on the inside at both ends four and five-eighths inches wide. On the lower edge of the bottom cylinder, the flange is omitted. These flanges are pierced with holes, through which the sections are bolted together with one and one-eighth inch bolts, the sections six feet in diameter having in each flange twenty four holes, and the others, twenty holes. The castings were taken from the foundry without removing the scale and were thickly covered with roofing cement, which readily adhered to the scale, forming therewith a firm and durable surface. The sections were carried to the platform on a scow, and were slowly lowered over the piling by means of a strong screw, six feet in length with three threads to the inch. This screw, running through a nut, supported a strong framework of oak and iron, from which the cylinders hung by the upper flange as they were lowered into position. The framework or cross-head, as shown in the drawing, has four equal arms of such a length as to allow them to pass by the flanges into the cylinder; by means of heavy iron slides, the length of these arms was increased by slipping the ends of the slides under the top flange of the cylinder to be supported. The bottom cylinder was lowered for a short distance over the piling and supported by strong oak props, reaching from the top of the piles to the under side of the flange: the next section was placed upon this and bolted to it, the cross-head introduced beneath the top flange, and the weight of the two sections transferred from the props to the screw by turning it a little, and raising the cylinder to allow the removal of the props. The sections were then lowered by the screw, four men turning it at the ends of a strong iron bar. When the cylinder had been lowered the depth of one section, props were again introduced under the top flange, another section was bolted on, and the work proceeded as before until the bottom of the river had been reached.

To prevent the cylinder turning with the screw, a frame was built around the cylinder at the level of the platform, leaving a small space for the insertion of wedges so adjusted as to allow the descent of the cylinder without permitting it to turn. When the bottom section had reached the bed of the river, it was supposed that the cylinder would penetrate the crust of shells by its own weight, but the shells were so firmly imbedded and locked together that it was found impossible to force the cylinder through, even with a weight of thirty-five tons applied to the top. It was evident that the crust must be broken-up and loosened about the pile clusters in some way, and for this purpose a single pile was used, which was repeatedly driven and withdrawn, until the shells were thoroughly loosened about the piling, and then, upon lowering the cylinder, it was found to penetrate the crust about two feet. Ten tons of rail-road iron piled on top, forced it down another foot, and then, by rocking the cylinder to and fro with powerful levers, it was quickly sunk to the desired depth. All the other cylinders were sunk in this manner.

Seven sections were used to

incase each cluster of the west piers, making the cylinders thirty-one and one-half feet in length; eight were placed around each cluster of the centre pier, and five around each one in the draw pier, making the cylinders thirty six, and twenty-two and one-half feet long, respectively. These cylinders penetrate from four, to six feet below the top of the crust, and extend upwards to a height of ten inches above the piling in the draw pier, and sixteen and twenty inches above on the other piers.

When the cylinders were sunk as far as desired, the water was pumped out, and the space between the cylinders and piling filled with beton, the composition of which was one part cement two parts sand and three parts stone. At the bottom of the cylinder the stones used were as large as would readily pass down between the piling and the flanges: these were regularly reduced in size to the top, where they are no larger than beans.

On the top of the piling, slabs of a strong slaty stone, called North River Stone, were laid in cement as far up as the lower side of the top flange, to which they give support and prevent any settling of the cylinders.

The piles composing the clusters are of hard pine, of uniform size throughout their whole length (twelve and fourteen inches square).

The capping of the draw pier is of oak timber, thirteen by fourteen inches, fastened as shown in the drawing, that of the two piers west of the draw is of yellow pine timber, twenty-five feet long, scantlings, nine by twelve inches, and twelve by fourteen inches. All the capping is firmly held down by bolts running through the upper flanges of the cylinders. The joints and seams are calked and pitched, and the whole is well covered with pitch and tar: for the lower surfaces, coal-tar was used.

There seems to be no probability of any scour taking place about the piers, on account of the peculiar nature of the river bed, but to guard against the possibility of such an occurrence, firm ballast for the substructure was made as follows. - Coarse rubble stones was thrown between and around the cylinders for a considerable distance, on the top of which was placed refuse from puddling furnaces, known as slag, to the depth of a foot; on the top of this, bags filled with oyster shells were thrown, and over these, another layer of slag, a foot in thickness. The chemical action of the salt water will cause the iron in the slag to rust together, forming with the stones and shells a solid mass which no current, however strong, can affect.

In view of the many difficulties encountered, the execution of this may be regarded as a triumph of engineering skill, for in no other way could the foundation have been built so rapidly, permanently, and - most important of all - so <u>cheaply</u>.

A brief description of the ordinary form of tubular foundations, and the mode of sinking them may not be out of place.

The plan of sinking iron cylinders by means of compressed air seems to have been originated in 1841 by M. Triger, who used it while sinking a shaft in a mine on an island of the Loire near Angers; this was the origin of the plenum process, so called. Some years before, a process had been patented in England by Dr. Potts for sinking cylinders by the employment of an air pump to exhaust the air inside; by this means, an external pressure of great power was obtained on the closed top to force the cylinder down. This method, called the vacuum process, was however found to be useless when the cylinder encountered any obstacle in its descent, which the edge of the tube could not easily cut through.

A few years after M. Triger had published his invention, the plenum process was first employed on a large scale in the construction of a bridge over the Medway at Rochester in England. The vacuum process had been tried at the beginning of the work, but the timbers of an old bridge, deeply imbedded in the mud were encountered, and, in order to cut through these, the compression process was substituted for the vacuum. At Peterboro' also, the foundations were begun on the plan of Dr. Potts, but it was found that the tubes could not be sunk, even through a compact material free from logs or stones. After these and some other attempts, the plan of sinking by a vacuum was for the most part abandoned, and the plenum process came into general use. A synopsis of the practise of this system is as follows.

Hollow columns of cast iron, made in sections, are used, from six feet, to twenty feet in diameter, and from half an inch, to one and one-half inches thick. These columns have been driven from seven to seventy-five feet into the sand below low water. They are generally filled with rubble masonry or concrete, on which the superstructure rests, but occasionally the weight is supported by the iron shell. The hollow cylindrical sections are cast with flanges on the inside, by which they are bolted together, one above the other, until the desired length is obtained. The lower section has the lower edge bevelled, and the flange is there omitted to secure a ready descent. The joints are sometimes made tight by means of a cord of rubber, fitting into a groove made to receive it between the flanges, and sometimes are cemented by a composition of iron turnings, sal-ammoniac, and flower of sulphur.

When the column has been lowered into the proper place, with the lower edge resting on the river bottom and the top projecting a short distance above the surface of the water, the process of sinking may commence; and in this process an air-tight chamber, called an air-lock, is used, of the same diameter as the column, usually made of boiler iron, having in the top and bottom plates, man-holes closed by trap doors or lids opening downwards. This air-lock is securely bolted to the top of the column, and connection with air pumps outside is established by means of tubes running through the lock and opening into the interior of the cylinder. When all is ready, the lower man-hole plate is closed, and, by the working of the pumps, air is forced into the column. It was formerly the practise to employ a siphon tube leading from the interior of the cylinder, near the lower end, up through the air lock to the outside, through which ~~the~~ water was discharged by the pressure of the compressed air; it is now however seldom employed, except when the earth becomes so compacted by subsidence about the columns as to prevent the expulsion of water through the open bottom, or when a stratum of clay is encoun-

tered, causing the same difficulty.
The constant and indiscriminate use of the syphon tube is attended by great danger by reason of the rapid expansion of the air pressure; this allows the water on the outside of the column to act by a pressure (due sometimes to a height of twenty or fifty feet) and to burst up through the bottom, inevitably drowning the workmen within.

When the water has been entirely expelled from the cylinder, the workmen enter through the air lock and the work of interior excavation begins, the material excavated being raised in canvass bags to the air-lock by means of a drum, the shaft of which passes through stuffing boxes to the outside, where it is worked by signal. As soon as it is ascertained that the water has been driven out of the column, the workmen enter the air lock and close the upper man-hole, a cock is then opened in the bottom plate, and the compressed air from below is allowed to rush in; when the pressures in the cylinder and air-lock are equalized, the lower man-hole plate falls by its own weight, and the workmen descend into the column below. When the excavation has been carried to a sufficient depth, and all obstructions have been removed below the edge of the column, the workmen ascend into the air lock, and, closing the lower lid, open a cock in the upper plate, allowing the compressed air to escape outside. When the pressure in the air-lock has become equalized with the atmosphere, the upper valve falls, the workmen pass out, and the bags of excavated material are removed. As soon as the workmen have left the cylinder, and all necessary preparation has been made, a large escape valve is opened, which allows the compressed air to escape rapidly. The cylinder, being thus suddenly deprived of the support given by the internal pressure of the compressed air against the top, sinks rapidly

~~sinks rapidly~~, as if from the effect of a powerful blow: at the same time the water rushes rapidly in at the bottom, carrying with it a considerable quantity of sand or gravel under the lower edge, and a large proportion of the resistance to the column's sinking is thus removed. If no obstructions, such as rocks, trees, or timber are met, the column will continue to sink quite rapidly ~~and~~ ~~the~~ while the air is escaping, and for some time afterwards, until the material has stopped scouring under the edges and has become so compacted as to support the weight of the descending cylinder. The depth to which the column settles at one operation is frequently ten or twelve feet, and sometimes more.

When the settling has ceased, the large escape valve is closed, the supply valve opened, and the work goes on as before, until it becomes necessary to put on an additional length of cylinder. In this way the largest columns may be sunk, according to a reliable American authority, to the depth of one hundred feet, and even deeper. European engineers maintain however that eighty-two feet is the extreme limit to which it is advisable to carry the plenum process, on account of the health of the workmen.

The bridge at Harlem New York, over the Harlem river, furnishes a good example of the American practise in sinking pneumatic piles. The piers for this were built by Hon. Wm J. McAlpine, late State Engineer of New York, and introduce in their construction a novelty and important improvement in tubular foundations, the conception of which originated with the eminent engineer to whom the work was first intrusted. This improvement consists in an expansion of the base of the column, by extending the concrete filling downward and laterally, in shape like the frustrum of a cone. By this means, the supporting power of the column is very largely increased. This expansion is easily made by driving sheet-piles at an angle of about thirty degrees, under the lower edge of the cylinder when it has reached the required depth. This sheet-piling, inserted in sections of a few feet at a time, acts as a roof or support to the earth or sand above, while the workmen are engaged in putting in the concrete extension beneath. The material through which the columns at Harlem were sunk is fine sand, this is the worst that could have been encountered, as regards the process of expanding the base, yet the workmen soon became so expert as to extend the concrete three feet beyond the column and four feet below, without the use of roofing. The value of this improvement cannot be overestimated, as will be seen by the following example, which I give in the words of Mr. McAlpine. "In the case of a column of three feet diameter, with an expanded iron base of six feet and a farther expansion of the concrete filling to ten feet diameter, and driven forty feet into the earth, the external frictional support would be about one hundred and eighty tons, and the support from the bottom area from four, to eight hundred tons."

Reference has been made above to "an expanded iron base". The lowest section could easily be made conical instead of cylindrical, and it is evident that with the process of interior excavation, this form of base would not in any way impede the descent of the column.

By another ingenious device Mr. McAlpine obtained a great advantage over the ordinary method in sinking the cylinders. The top and bottom of an empty column were sealed, and this was kept constantly charged with air at a high pressure, and was connected by a flexible pipe with the column it was desired to sink. He says - "This reservoir of power was of great advantage in some of the operations, as we could charge the column a second time instantly with air, after it had ceased sinking by the ordinary process, and could repeat the sinking process while the earth adjacent to it was still loose: it also gave us complete command of the descent of the column, so that we could at any instant check it at the desired point."

The most perfect accuracy was attained in the execution of the work at Harlem; none of the columns varied one inch from the position designed. Many obstacles were met in the progress of this work. The descent of a column was repeatedly arrested, in one case, by over thirty large boulders, nearly all of which had to be cut through. One large boulder, weighing ten or twelve tons, was disposed of by undermining it in such a way as to bring it entirely within the cylinder, and then, after removing the air lock, the boulder was hoisted out entire, by means of a derrick. In sinking another column, the workmen had to cut through the hull of a sunken vessel, where the timber was unusually tough and strongly bolted together. This occasioned a delay of only two days. The time occupied in driving these cylinders an average depth of twenty-five feet, through sand, gravel, boulders and timber, expanding and closing the bottom with concrete, was from seven to twenty days for each column. The force of men employed on the work was about thirteen. The machinery and tools employed cost about fifteen thousand dollars, the platform and sheds as much more. The cost of driving in the hard gravel, including cutting through rocks, etc, was about forty dollars per lineal foot. This is double the sum required for cutting through ordinary good earth. The contract price for the columns delivered was eleven cents per pound; they can now be obtained for half that price. The columns were filled with concrete at a cost of one half more than in open air.

The columns composing the piers are fifty feet long, cast in sections of ten feet. The depth of the water about the columns is from sixteen to twenty feet.

In building the Kowno bridge over the river Niemen in Russia, a modification of the ordinary method was adopted. The entire iron works and castings were to be brought from a great distance, and for convenience of stowage and transportation, it was necessary that they should be of some form different from the ordinary cylinder sections used in the pneumatic process: this change of form would of course multiply the joints, and thus occasion a great amount of leakage of the compressed air. To obviate this difficulty, the compressed air was confined to a working chamber only fifteen feet high, at the bottom of the column, closed at the top by a diaphragm plate so arranged that it could easily be removed when desired. This working-chamber was connected with an air lock at the top of the column, by two service tubes of wrought iron, thirty inches in diameter, provided inside with hoisting gear and ladders for the passage of excavated material and the workmen. With this arrangement, it was necessary ~~only~~ to make air-tight only the few joints of the service tubes, the air lock, and working chamber. The sections of the main tube were cut, each into four segments, and bolted together. The inside space above the working chamber and around the service tubes, was thus left available for ballast to sink the column: water was used for this purpose, being more convenient than rails or heavy weights, generally employed.

When the column had been sunk to the proper depth, sufficient concrete filling was introduced to counterbalance the water pressure without, the diaphragm, service-tubes, and air-lock were transferred to another column, and the filling with concrete proceeded in the open air. By this modification of the old process, great economy of time and money was secured.

Respectfully submitted,

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Gradnating Thesis

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