

## THE USE OF COMPRESSED AIR IN TUBULAR FOUNDATIONS, AND ITS EMPLOYMENT AT THE SOUTH ST. BRIDGE, PHILA.

BY D. M. STAUFFER, C. E.

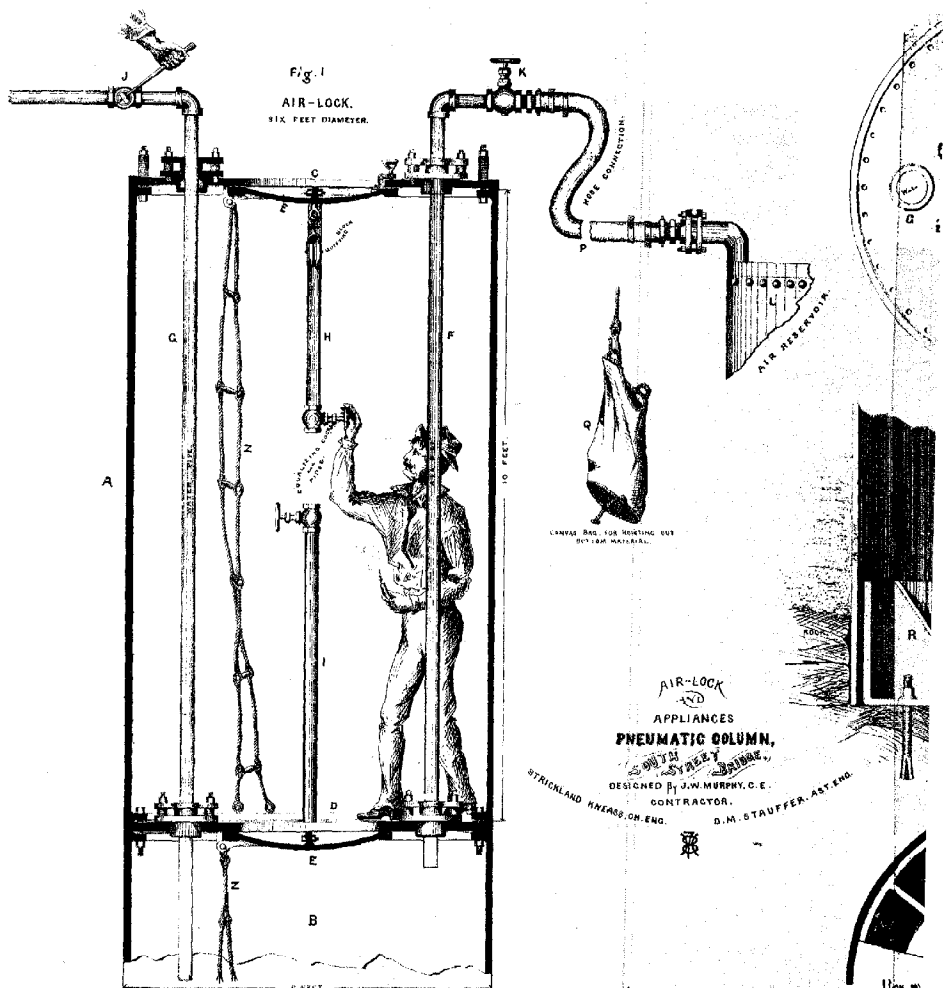
The employment of compressed air in founding submarine structures is of comparatively recent date, very recent, in fact, among American engineers; but the magnitude and importance of the two great works carried forward on this principle, at St. Louis and at the East River, have attracted general attention in its direction. By the use of this new agent the bridging of the Mississippi is almost an accomplished fact, despite its deep beds of quicksand, and scouring tendencies, so destructive to the work of the engineer.

The expense attending the process is necessarily very great, but the advantages to trade and rapid transit in spanning streams hitherto considered impassable by other means than boats much more than compensate for the outlay of funds.

With the exception of the official reports of chief engineers, and such hasty and imperfect descriptions as a newspaper reporter might give the public, little has been written on this subject in the United States. The methods employed in prosecuting the work are unknown to the generality of readers; and even the engineer, in search of knowledge of details, must generally translate from a foreign tongue before he can get what he wants.

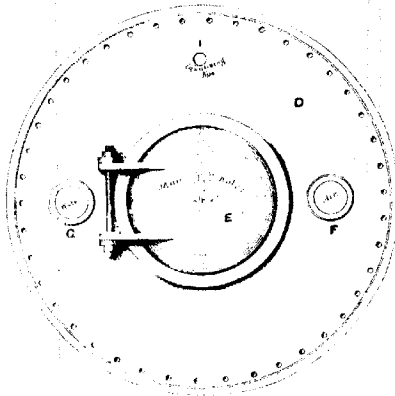
Under these circumstances it is, perhaps, well to commence our article by giving such a short sketch of the origin and progress of the pneumatic process as the very meagre data at hand will allow.

To Dr. Lawrence Halker Potts, of London, is generally ascribed the credit of first conceiving the idea of making use of air pressure in founding engineering works. His was the "vacuum," or "exhausting," process, in which the normal atmospheric pressure was utilized. His apparatus consisted of the iron cylinder to be sunk, a chamber capable of being exhausted by an air-pump, and a flexible hose connecting the cylinder and the exhaust-chamber, furnished with a stop-cock. The cylinder is tightly closed at top, provided, however, with a trap-door, opening downwards. When the cylinder is placed in position the chamber is first exhausted by the pump, and when the vacuum is as complete as possible, connection is made between this chamber and the cylinder by opening the stop-cock, and the air in the cylinder rushes in to fill the vacuum, leaving, of course, a partial

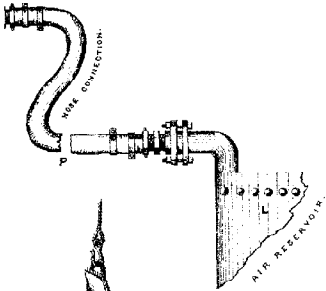


SOUTH STREET BRIDGE, PHILA. PLATE I.

Fig. 2.



DIAPHRAGM.



CANVAS BAG FOR BEATING OUT  
DUST AND MOISTURE.

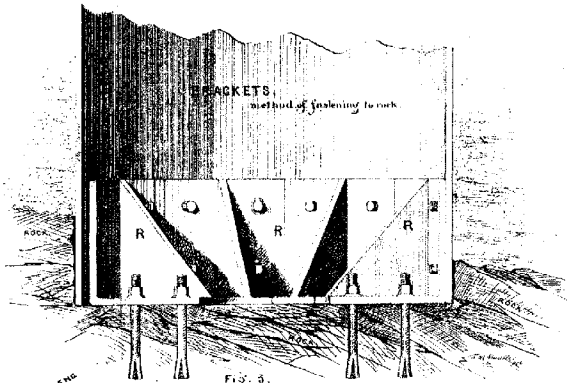


Fig. 3.

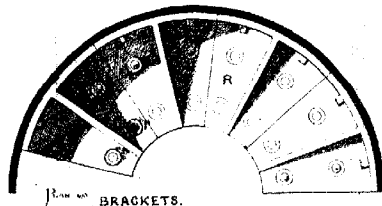


Fig. 4. BRACKETS.

AIR-LOCK  
APPLIANCES  
**PNEUMATIC COLUMN,**  
J. W. MURPHY, C. E.

DESIGNED BY J. W. MURPHY, C. E.  
CONTRACTOR.  
D. M. STAUFFER, ASST. ENG.

STICKLAND, HINEAGS, CH. ENG.



vacuum in the cylinder itself. The atmospheric pressure on the top of the cylinder, then being in excess, acts downwards with a force equivalent to almost one ton per square foot of area; this is augmented by the weight of the iron cylinder; this pressure is also transmitted through the water to the mud and soil beneath, and if they be soft they will be forced up inside the column, that being the point of least resistance. By opening the trap-door and scooping out the mud from the inside, by any means convenient, we prepare for a repetition of the process, until the desired depth is reached. The method of Dr. Potts is only applicable in soft soil and sand, free from logs and boulders. Crude as was this first attempt, it marks an important era in engineering science, and was as fruitful of good results as novel in application.

France claims the honor of improving upon the Potts method, by substituting compressed air for the vacuum, giving us the *Plenum* process, as it is called, which had the marked advantage of enabling them to exchange for the blind work of the dredging bucket the intelligence of man; for, though life was impossible in the rarified air, man could exist and work in compressed air, as had long been exemplified in the diving-bell.

This new process was first applied about 1850 to the foundation of the bridge of Macon, across the Soane, and very soon after, by Mr. John Hughes, at the Rochester bridge, England. Messrs. Friger, Mougel and Cavé, engineers of the Macon work, on account of local difficulties, instead of the usual stone piers, substituted cast-iron columns, extending to and immediately supporting the superstructure of the bridge. These columns, or hollow cylinders, were 10 feet in diameter, cast in sections and bolted together. The process of sinking them was essentially the same as that which we will fully describe further on; so we will pass on to the next step, merely citing this as the first example of the kind.

The "*Caisson method*," in which the iron cylinders were enclosed in a pier of solid masonry, starting from the roof of a caisson or rectangular box of wood or wrought-iron, and resting immediately on the rock-bed, was the next modification of the *Plenum* process. This latter plan was first adopted at Kehl, on the eastern border of France, in a railroad bridge across the Rhine. Any attempt to found the piers at this place by means of the old-fashioned coffer-dam would have been not only tedious but costly, if, indeed, not impossible, on account of the necessity of completing the foundations to the water-

line, between two floods in the river, the exceedingly rapid current, and the indefinite depth of the bed of mud, sand and gravel.

At first the Friger process, as employed at Macon, was proposed ; but this was also deemed impracticable, from the amount of time that would be consumed in extracting through a contracted "air-lock" the great mass of material that must be raised in going the depth required. Another objection was the costly weight of metal that iron cylinders would leave hidden under water. Some other plan must be devised, and to M. Fleur-Saint Denis, the engineer in charge, we owe the idea of a caisson.

This caisson was a rectangular box-like structure, closed at the top, and made of wrought-iron, in dimensions 23 ft. x 19 ft. Through the roof of this box were pierced three circular openings, surmounted by shafts of sheet iron, the centre one 5 feet, and the side tubes each 3 ft. 3 in. in diameter. The two smaller tubes were each capped by an "air-lock," similar in purpose and vital arrangement to such as will be fully described further on. These locks gave access and egress to and from the working chamber, through the medium of the tube connected with them. The central shaft was open at top and bottom, with its lower edge extending a little below the level of the bottom edge of the chamber ; through it a chain of dredging buckets worked, scooping out a hole which was also lower than the bottom level of the caisson or chamber, and lifted to the surface of the water any material thrown in that hole. These tubes were lengthened as the caisson settled towards the bottom, so as always to keep their tops above water. When the compressed air is forced into the side tubes and the caisson communicating with them, the water in these parts is driven out, and kept out, to the level of the bottom of the working chamber or caisson ; but, as the central shaft extends below that level, its bottom edge is under water, and the whole central shaft is filled with water to the normal level of the river. The air pressure in the working chamber, acting on this water column, a little more than counterbalances it, and prevents it from flowing into the working chamber. This water column forms a means of communication between the inside of the caisson and the open air, and through it all the earth taken out by the workmen from the body of the caisson and under its edges is lifted to the surface by the dredge, the men throwing all such material into the hole under the central shaft.

Several of the caissons just described were placed side by side, but communicating to form the support for one pier. Surmounting the

outer edges of the caissons was a wooden casing, or box, extending to and above the surface of the water, and kept above that level by successive additions of timber as the caisson slowly settled towards its final bed. This casing was kept filled with beton, poured in from time to time, which served both to form the body of the pier, and to counterbalance by its weight any upward force exerted by the compressed air. When the desired depth was reached, the caisson and the shafts were likewise filled with beton, and a firm and, of its kind, economical foundation for the pier secured.

The Kehl process is, in fact, essentially the same as that employed to-day at St. Louis and in the East River bridge, modified by such improvements as more mature experience might suggest, and substituting for the beton solid masonry, started upon the roof of the caisson.

These three methods—the Vacuum, the Plenum with iron cylinders and the Plenum in caissons, constitute about the limits of the application of compressed air to engineering works on land.

Having now introduced, in a general way, the process and its history, we come to the more detailed explanation of the method of sinking "pneumatic cylinders," as performed at the bridge over the Schuylkill at South street, Philadelphia.

The process used is the Plenum with iron cylinders. These cylinders are cast from Government cannon, originally made from cold-blast charcoal pig, securing an unexceptionable material to start with.

Their diameters are 8 ft., 6 ft. and 4 ft., respectively, according to the position they occupy in the structure, and they extend from their footing in the bed-rock at the bottom of the river to the superstructure of the bridge, and immediately support it. The bridge was planned for two fixed spans and a draw, necessitating a pier at each end of the draw and a pivot pier. Each end pier is formed by two of the 8 ft. columns, and the pivot pier by a cluster of nine columns, a 6 ft. column in the centre supporting the pivot of the draw, and a surrounding circle of eight columns, 4 ft. in diameter, carrying the track on which the draw revolves. This circle is 36 ft. in diameter from out to out, while the pier columns are placed with their centres directly under the main chords of the bridge, making them 36' apart from centre to centre, and at right angles to the centre line of bridge.

Among the local difficulties to be met and overcome in this work,

the principal were the small amount of holding ground for the cylinders,—that is, the comparatively shallow depth of material overlying the bed-rock,—and the rise and fall of a tide of 7 ft. found at this point, requiring great care and attention to the clamps and pressure gauge.

The bed of the Schuylkill at the site of the bridge is a micaceous gneissic rock, undulating in surface, with an overlying strata of sand and tough, compact mud, intermingled with gravel and small boulders. Lying directly on the rock, considerable quantities of drift-wood were found, its appearance evincing great age and a long occupation of its present position. The average depth of this bottom material is about thirty feet at the western pier columns, diminishing to only five feet at the eastern pier. At the draw the thickness is about eighteen feet.

The columns are cast in sections, ten feet in length, of the iron before mentioned,  $1\frac{1}{4}$ " thick, with inside flanges,  $2\frac{3}{4}$ " wide by  $1\frac{1}{4}$ " thick, at top and bottom of each section. The flanges are pierced with bolt-holes, 5" apart, centre to centre, for  $1\frac{1}{4}$ " bolts. The bottom flange is omitted in the section forming the bottom of the column when in position, for greater facility in penetrating the soil. This edge is square, and not bevelled, or brought to a cutting edge, as is generally done, as it is important to retain the full value of the thickness of the column for a bearing surface on the rock. A 10' section of the 8 ft. column weighs 14,600 lbs., of the 6 ft. column, 10,800 lbs., and of the 4 ft. column, 6,800 lbs.

As many of these sections as the depth of water may require are bolted together, the joints being carefully luted with a preparation of red and white lead and cotton fibre, so as to be perfectly water and air tight. The distance through the bottom material to rock being small, and the depth of water averaging at mid-tide only about 22 ft., five or six sections were sufficient to reach the rock and at the same time to extend some distance above the water surface.

Between the first and second sections, counting from the top, and on top of the column, were placed two diaphragms, or heavy plates of cast-iron (C and D, fig. 1),  $1\frac{1}{4}$  in. thick, and weighing in the 8 ft. columns 2,800 lbs, in the 6 ft. columns 1,600 lbs., and in the 4 ft. columns 783 lbs. The same bolts hold them in position that unite the two sections of the column. These diaphragms (shown in plan in fig. 2) are pierced with three openings each, besides the central trap, or door, E, that is for the air-supply pipe, F, the water pipe, G, and the

equalizing pipes, H or I; these pipes are common iron gas-pipes, 3 in. in diameter. The door, E, varying in diameter with the column from 20" to 30 in., fits very closely by means of a gum washer, and opens downward; a keeper on the upper side of the diaphragm fastens it when closed. These two diaphragms, with the section of column included between them, form the air-lock, A, which in this work supplants the expensive, cumbersome and independent lock of wrought-iron generally used. The general arrangement of this lock is due to Mr. J. W. Murphy, Contracting Engineer of the bridge. The purpose of the air-lock is to enable the workmen to pass from the normal atmosphere outside the column to the denser atmosphere of the interior, and to prevent the escape of the compressed air while so doing. It is well to mention that lengthening the cylinder by the addition of new sections does not necessitate the removal of the diaphragms; the additional sections are merely bolted to the top of the air-lock, as it matters not whether the lock is under water or not.

To secure the column while the sections are being successively added and bolted together, and to enable it to be brought into position for sinking, a floating support of some kind is necessary. In the bridge in question two ordinary canal boats were used for this purpose, each about 100 ft. long by 17 ft. wide, and drawing  $4\frac{1}{2}$  feet loaded. These boats lay parallel to each other, and about 15 feet apart. Resting on them, and extending clear across the boats and the opening, were two heavy "clamps," each clamp formed of three pieces of timber, each 18 in. x 12 in. (X, fig. 6). These clamping beams were shaped on the inner sides to fit the cylinder, and were capable of being drawn together by means of strong iron rods (Y, fig. 6), furnished with heavy nuts and washers at either end. The cylinder is placed between these two clamps, and is tightly clutched by them, when the nuts on the rods are screwed up. In this way the two boats support the whole load until all is ready to let the column slip to its proper place on the river bottom, the rapidity of the downward motion being beautifully regulated by the friction of the clamps alone, the hoisting tackle still being allowed to retain its hold on the cylinder, as a precautionary measure.

Straddling the opening between the two boats, and with its apex immediately over the centre of this opening, is a substantial four-footed shear, or derrick, M, fig. 6, provided with a heavy lifting tackle, O, fig. 6. By means of this apparatus the first section to form the column is lifted from the deck and lowered into position between the



clamps, X, and there securely held by tightening up the nuts. The hoisting tackle can then be cast loose, and a next section be lifted and placed upon the one already between the clamps, and the two bolted together. By now cautiously slackening the clamps, we may permit the two sections to slip down into the water until the last put on is, in its turn, between the clamps, and there secure it. We now have sufficient head room for putting on a third section, and the process is repeated until the requisite number are joined together. The bottom edge of the column must not yet be suffered to touch the river bottom, but clear it by a foot or two. When the air-lock diaphragms and their proper pipes are in place we are ready for what is technically called the "sink," that is after the boats, with the column supported between them, are hauled into position and held there by their anchors, and line, distance and exact location accurately established. All preliminaries are then completed, and men stationed at the clamping-rods carefully slacken them and allow the column to slowly sink into the mud, seeing to it that it always maintain its vertical position. The water rises within the column, of course, to the river level, and before men can descend into its depths and the work of excavation commence, this water must be expelled and kept out.

The application of the compressed air is the next step in the process, and to supply this latter power we have, stationed on one of the boats before mentioned, at V, Fig. 6, a "Burleigh Compressing Engine" of nine horse power, made at Fitchburg, Mass. This compressor consists essentially of two plunger air pumps, with 10-inch cylinder and 9-inch stroke; they work alternately and vertically, drawing in the air, through a valve in the piston head, in its downward motion, and by the return stroke forcing it into the reservoir, L, through the pipe, N. To prevent the expansion of the metal in the piston head, from the heat generated in the condensing process, and the consequent jamming of the piston in the cylinder, a stream of water, with a little oil added, is constantly fed upon the piston head, keeping it cool and providing an elastic cushion to act upon. The reservoir, L, in which the air is compressed and stored, is 22 feet long by 2 feet in diameter,  $\frac{1}{4}$ -inch boiler iron, and was originally a steam boiler; it is provided with pressure gauge and safety valve. This reservoir will supply the column with compressed air for one-half hour, did any accident happen to stop the pumping machinery, giving the workmen inside that time in which to escape. In the old method, when the air was pumped directly into the cylinder without the in-

tervention of a storing reservoir, even a momentary stoppage of the engine endangered the lives of all in the working chamber.

From the reservoir, L, the compressed air passes through the common gum and canvas hose, P, four inches in diameter, into the supply pipe, F, and discharges immediately into the working chamber, B, below the floor of the air-lock or lower diaphragm, thus passing through the air-lock, A, but having no communication with it. The pipes, F and G, pass through stuffing boxes in the top and bottom of the lock.

When we wish to force the water out of the cylinder, the lower door, E, must be first securely closed, cutting off all communication with the outer air. Air compressed to a density sufficient to counter-balance the water column in the cylinder is then let in from the reservoir, and a very few minutes will be sufficient to eject all the water from the inside of the chamber, B, forcing it out at the bottom, and to replace it with the compressed air, which, from this time forward, is being steadily pumped in—all excess air vitiated by the breathing of the men escapes from under the lower edge of the column, and rises in bubbles to the surface of the water. When the material to be penetrated is a tough compact mud, impervious to water, the water inside cannot be forced out under the bottom edge of the cylinder, and we must have resource to the water-pipe, G. This pipe extends from the bottom of the cylinder, through the air-lock, to the top, where it ends in an elbow provided with a stop-cock, J. There is also a slip joint near the bottom for lengthening the pipe when necessary. When the stop-cock, J, is opened, the excess of pressure on the surface of any water there may be in the cylinder, B, will force it up through this pipe and out over the top of the column, projecting it with great violence.

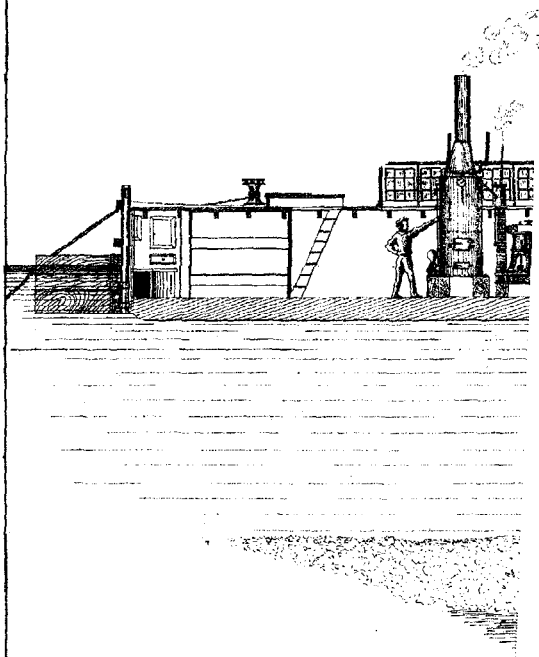
A fact, perhaps, worth notice, is that the *actual* pressure required to lift a column of water a certain height through this pipe, is always *less* than the calculated pressure. The supposition is, that the expansive action of the compressed air in the pipe (for a considerable quantity escapes with the water, being let into the pipe, G, through a hole about  $\frac{1}{4}$ " diameter, purposely left at the slip joint, at a point about 15' above its lower end) assists in the lifting process. With an indicated pressure of 17 pounds in excess of the atmosphere, we raised water 58 feet.

With the water forced out and kept out by the presence of the condensed air, all is ready for the entrance into the column of the workmen; all that part of the column below the floor of the "air lock,"

or the diaphragm, D, is now filled with compressed air, and the problem to be solved is to enter it from the outer air and, at the same time, prevent this condensed air from escaping. This is accomplished as follows: The men descend into the lock, A, by a rope ladder, Z, through the upper door, E, and when in, close the door after them and fasten it; the atmosphere of the air-lock is still of the normal pressure; but to enable them to pass into the denser atmosphere, the air in the lock must be equalized in pressure with it. To do this, they open carefully and very slowly (if it is a first experiment) the equalizing valve, I, in the lower diaphragm, and allow the compressed air to ascend and gradually fill the lock chamber, until the pressure is equal in all parts of the column.

This process consumes more or less time, according to the intensity of the pressure and the experience of the men. The pressure upon the drum of the ear by the compressed air is very painful to the new man, and this dense air must be let in upon him slowly. Three minutes will pass men accustomed to the work through the air-lock, under a pressure of 22 pounds in excess of the atmosphere. When the equalization of pressure is completed, the lower door, E, can be opened, a rope ladder lowered to the bottom, the men descend, and the actual work of excavation begins.

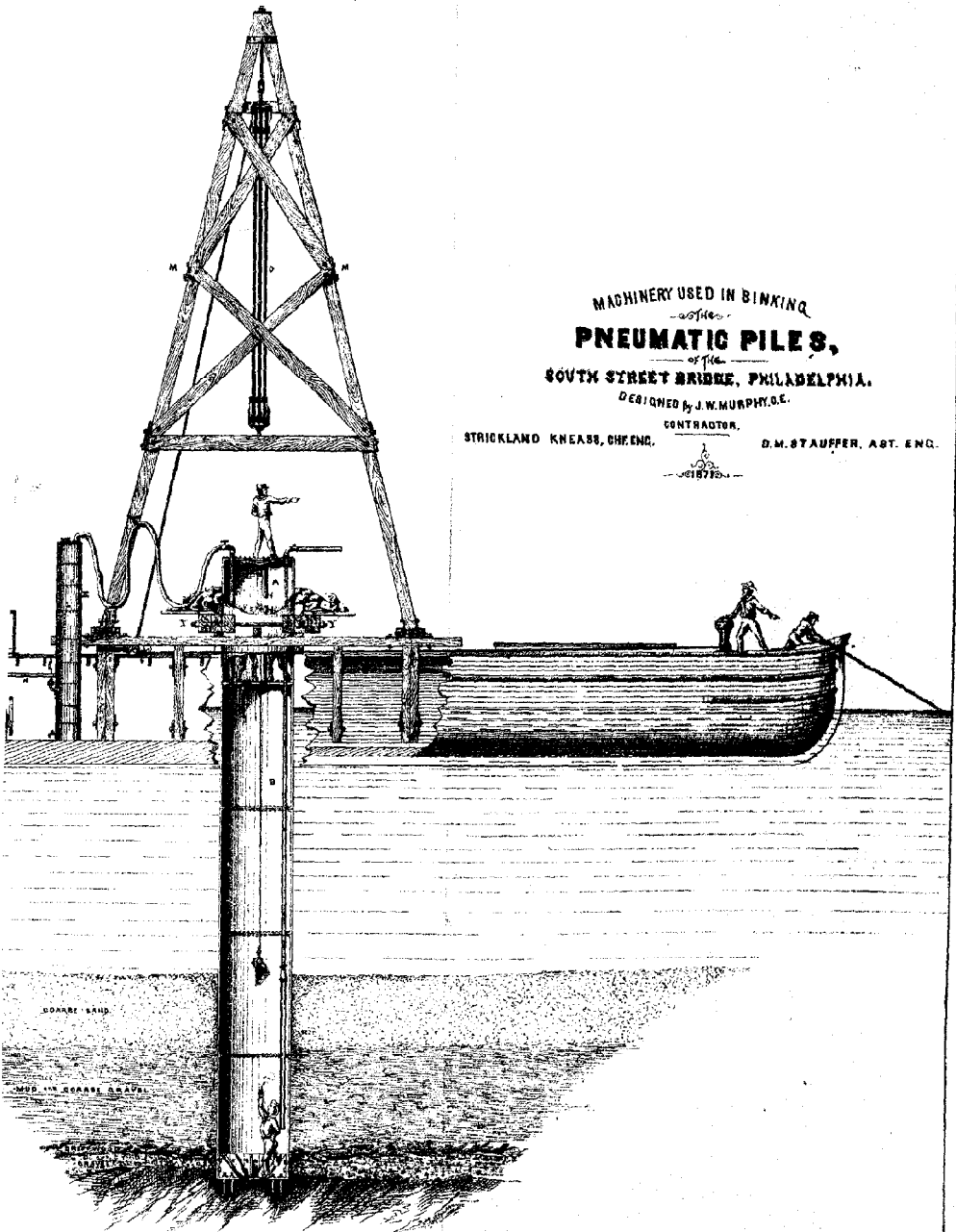
To remove the mud, sand and gravel which now fills, to a considerable height, the lower part of the column, canvas bags, as shown at Q, are used, each containing about a cubic foot of material. In the larger columns, five to six men constitute one working gang; two men fill the bags at the bottom, while the remainder hoist them into the air-lock by means of a block and fall, or "gantling," attached to the bottom of the upper door, E, and stow them around the sides of the lock. Under favorable circumstances, these six men fill and hoist 20 bags per hour, equivalent to about four-fifths of a cubic yard. In mid-summer, on account of the heat inside, the effect of the sun on the iron cylinder, and the compressed air itself, the men cannot work quite so fast; they will average four or five bags less per hour. When working in sand or gravel they can fill the bags faster than when working in tough mud, but as they consume the same time in hoisting, the actual amount of work per hour is about the same. The quantity of material extracted per hour is subject to great variation; driftwood or boulders may appear under the edge of the cylinder, and they must be cut away with hammer and chisel, at a great expense of time, before the columns can sink any further. The work is pushed



Scale 5 feet to one inch.

Photo-Zincography by F. A. Wenderoth, 933 Arch Street, Philadelphia.

Fig. 6.



MACHINERY USED IN BINKING  
— of the —  
**PNEUMATIC PILES,**

— of the —  
SOUTH STREET BRIDGE, PHILADELPHIA.

DESIGNED BY J. W. MURPHY, C.E.

CONTRACTOR,

STRICKLAND KNEASS, CHIEF ENG.

D. M. STAUFFER, ASST. ENG.



forward day and night, the workmen being divided into three gangs, each gang working four hours at a "shift," unless the depth is great and the pressure excessive. When their time is up, and the men are ready to go out, all ascend into the "air-lock," close the lower door, E, tightly, and reversing the process by which they entered, allow the compressed air in the air-lock to escape outside by opening the equalizing valve, H, when the atmosphere of the lock is once more reduced to the normal pressure, the upper door, E, can be opened, and the men are once again in the open air. The bags of *debris* are emptied into the river, and the relieving gang enter and repeat the process.

If the workmen have completely emptied the cylinder to its lower edge before coming out, they make a "sink," as it is called, before the next gang enters. This is done by cutting off communication between the reservoir, L, and the cylinder, B, by shutting the cock, K, and by allowing the compressed air in all the columns to escape through the equalizing cock, I. The water will immediately flow in under the lower edge of the column, and, rising within, fill it. The mass of metal, no longer upheld by the upward pressure of the condensed air, obeys the law of gravitation, and sinks a fresh distance into the soil, and after the water is again forced out, is ready to be excavated as before. The rush of water under the bottom edge, of course, loosens up the material and facilitates the sinking. Sometimes in penetrating tough mud, impermeable to water, the water cannot come in even when the column is emptied of the compressed air; in such a case, the weight of the metal only will act, and the depth sank be only a few inches. In sand and loose gravel, however, the "sink" will average five feet.

This alternate filling and emptying of bags, and the slow settlement of the column, continued until the bed-rock on which we intended to found our work, was reached. Where this rock sloped it was brought to a level surface by chisels, and all shally and rotten portions removed. This levelling process was to prepare the rock for the reception of the foot pieces, shown at R, Fig. 3—an innovation first introduced, I believe, by Mr. J. W. Murphy, Con. Engineer of the bridge, and made necessary there by the comparatively slight depth of the holding ground. These brackets or foot pieces are in sections, and extend clear around the whole inner circumference of the cylinder, requiring sixteen in each 8-foot column, twelve in the 6-foot column, and eight in each 4-foot column. They are made of cast iron  $1\frac{1}{4}$ -inch

thick, and weigh, in the larger columns, 340 pounds each; in the smaller, 183 pounds each. Each bracket is fastened to the cylinder by four  $1\frac{1}{4}$  inch tap bolts, and to the rock by four bolts 18 inches long, with fox wedges at lower end, and thread and nut on top. They undoubtedly add much to the stability of the work; their holding power has already been severely tested.

When the column is once thus secured to the rock, we may consider the major portion of the work done, and it only remains to fill it carefully with common rubble masonry laid in hydraulic cement. The material for laying the first ten feet of masonry must necessarily be passed through the air-lock, as were the men. Water to mix the cement is pumped in against the pressure in B through the pipe, G, by attaching the hose of a force pump to its upper extremity. When the first ten feet of stonework is in place, extending to and in a manner held down by the projecting inside flange at the top of the bottom section, we may consider the column effectually sealed against the entrance of water from below, and it will be safe to let off the pressure and remove the diaphragm doors, completing the remainder of the work as in an open well.

When all the cylinders are in position the tops will differ in level; some will have descended deeper than others before finding the rock, and extra sections must, therefore, be cast of a length necessary to bring them all to the height required by the plan of the bridge.

As a precautionary measure, a workman is always stationed on guard outside, and on top of the cylinder, whose duty it is to listen for and answer all signals from the men within the column, and to render immediate assistance in aiding the men inside to escape, should any accident occur. Communication is kept up between this guard and the workmen in the working chambers by a telegraphic system of taps with a hammer or some iron instrument on the sides of the cylinder. The following is the "code" ordinarily used:

One blow signifies, "Open water-cock."

Two " " "Shut " " "

Three " " "Attention."

Four " " "We are coming out."

Five " " "Water going down."

Six " " "Water still going down."

Seven " " "Water stops running."

Eight " " "All right."

Four blows, in pairs of two, signify "Danger! Come out immediately."

The signals 5, 6 and 7 refer to the forcing out of such water as may leak in while the men are working. All signals from the inside are repeated by the watchman to show that he understands them.

There is one important effect of the upward force exerted by compressed air that must not be neglected, but, on the contrary, carefully guarded against; and that is the danger of lifting the column bodily, when the pressure per square inch, acting upward on the lower diaphragm, *more* than counterbalances the weight of metal in the cylinder, and the friction on the sides of the column due the material through which it is passing. To overcome this difficulty in the South St. bridge, the heavy clamping timbers, X, Figs. 6 and 7, were raised clear of the boats, and fastened to the cylinder itself, by tightening the clamping rods, as shown in Fig. 6. Upon these beams a platform was placed, which was loaded with a sufficient quantity of stone to overcome any tendency to rise, and augment, as well, the effective weight when a "sink" was made. This same end was attained in the last 8-foot column sunk, by building a platform of heavy timbers inside of the cylinder, two sections or twenty feet below the floor of the air-lock. This platform was weighted with about forty tons of stone; a strong wooden shaft, three feet square, furnishing a means of access to the lower portion of the column.

The time occupied in sinking the pneumatic columns at this place, varied with their position and the quality and quantity of the bottom material. At the draw, with an average depth of eighteen feet of sand, mud and gravel, it required about eight days each from the time of applying the air pressure to its removal, with 10 feet of the masonry in place. At the west pier, with thirty feet of mud, sand and boulders, thirty days were necessary; while at the east pier, where there was only about six feet of gravel overlying the rock, twenty days were consumed. This delay was caused, however, by the great pitch of the rock; it sloped nearly four feet in the diameter of the column. In nearly all the columns, levelling off the rock-bed, drilling the holes for the fox wedge bolts, and attaching the foot pieces, consumed by far the greater amount of time. A 4-foot column was generally sunk and cleared through eighteen feet of mud, sand and gravel in twenty-four hours. The work at the South St. bridge was pushed forward winter and summer, the flow of ice not interrupting in the slightest degree the progress of the work. The compressor engine was started on the first column Oct. 4th, 1871, and on Aug. 29th, 1872, the last of the thirteen columns was in place.



The effect of the compressed air upon the men is nearly always severe the first time they encounter it, but a little experience generally removes all unpleasant sensations. The greatest actual pain felt arises from the abnormal pressure upon the drum of the ear. The tubes extending from the back of the mouth to the bony cavities over which this membrane is stretched, are so very minute that compressed air cannot pass through them with a rapidity sufficient to keep up the equilibrium of pressure on both sides of the drum, for which purpose the tubes were designed by nature; the excess of pressure on the outside causes the pain. These tubes can be distended and the pain relieved, by the act of swallowing, or by closing the nostrils with the thumb and forefinger, shutting the lips tightly and inflating the cheeks. Either action facilitates the passage of the air through the before-mentioned tubes, and establish the equilibrium desired; but the relief is only momentary, and the act must be repeated from time to time, as the pressure in the air-lock increases. This pain is only felt while the air in the "lock" is being "equalized" or compressed. When the lungs and the whole system are filled thoroughly with the denser air the pain passes away, and the general effect is rather bracing and exhilarating than otherwise. You breathe freer, your lungs are expanded, and the whole muscular system seems capable of extra exertion. From the excess of oxygen breathed, you are, in fact, living a physically "fast life;" but the novice, like the "fast liver" of the world at large, often pays rather dearly for his momentary strength; for, on getting outside a reaction sets in, with a general feeling of prostration, lasting, in my own case, at least nearly a whole day after the first two or three encounters with the compressed air. The laborers, by daily experience, soon overcome this feeling, and in the majority of cases feel no bad results, either while at work or afterwards.

The extreme limit or greatest depth at which men can labor, without material injury to themselves, has not yet been reached in works of this nature. Captain Eads, in the process of founding the piers of the St. Louis bridge, has sunk his caissons considerably over one thousand feet below the surface of the Mississippi—a depth never before obtained—and yet by shortening the hours of labor from four hours to one hour, as the pressure increased, little trouble was experienced by the men. Even delicate ladies, according to the Official Report of Capt. Eads, remained in the caisson nearly an hour, without feeling any marked ill effects from the extreme pressure. Out of

the 350 men who, at different times, performed duty in the air chamber at St. Louis, 35 were seriously affected by this unnatural pressure. Of these, twelve died; but the verdict of skilful physicians gave, in more than half the cases of death, totally different causes, though admitting that the effect of the compressed air was the exciting cause. Persons of weak lungs or of intemperate habits have no business there; and even a severe cold in the head, by stopping the eustachian tubes with mucus, will make it impossible to relieve the pain on the membrane of the ear while passing through the air-lock. In such a case there is danger of rupture to the drum of the ear, and the party should be let out immediately.

Owing to the excess of oxygen in the atmosphere of the column, combustion is, of course, more rapid than in air of the normal pressure; a candle is consumed in one-half the time inside, but burning with a flame nearly twice as high gives more light, and a less number is necessary for illuminating purposes. Fire must be carefully guarded against, as even the woollen clothing of the men is no safeguard—it will burn furiously when once ignited. Fire will, too, in this atmosphere, penetrate the most minute crevices. In one of the columns of the South street bridge, the luting of red lead between the sections was accidentally ignited, and though the exposed area was exceedingly small, it burned out that combustible material completely, nearly suffocating the workmen with the fumes of the paint. The excessive amount of smoke thrown off by the burning candles is another source of annoyance. The particles of unconsumed carbon float in the atmosphere, and are breathed by the men, coating the nostrils with its sooty deposit. In larger works of this nature, where roomy caissons are used, other methods of lighting are feasible. At the East River Bridge ordinary burning gas was employed with good effect.

The superiority in stability and duration of tubular foundations over solid piers of masonry, is a question we will not debate; but of their greater economy in time and money, under difficult circumstances, I think there can be little doubt. Their greatest value is apparent, however, in the Western rivers, where the engineer must contend with deep beds of quicksand, liable to scour out to the very bed rock in a rise of the river, undermining and washing away any structure not based on that rock. To attempt to found a bridge, in such a location, by piling cribs or coffer-dams, would be a hopeless task; and it is under just such conditions that the great value of the Plenum Pneumatic Process asserts itself.

We might mention, in closing our article, that the "Plant" used by Mr. I. W. Murphy in sinking the pneumatic cylinders of the South street bridge, is worthy of special notice, from the fact of its combining a severe economy with all the requirements for effective work. The two canal boats, strengthened somewhat by inside bracing, the derrick, the clamps, and one Burleigh Compressor, were about the only appliances used, and they did the work well.

## THE OVERFLOW OF THE MISSISSIPPI RIVER.

No. 2.

By D. S. HOWARD, C. E.

The first step towards reform is a consciousness of its necessity. The Southern papers seem to be united now in condemning the levee system of protection against the overflow of this river, and are discussing the subject of disposing of the surplus waters of the freshets by canals and additional outlets from the lower river.

It is well to take into view every possible means of accomplishing so important an object, before adopting a new system, and to look sharp at every possible objection to every proposition offered. Notwithstanding the old system may be the worst, any new one proposed to supersede it may not be the best; therefore our vision should not only be extended in proportion to the importance of the subject, but every remedy discovered should be subjected to the severest scrutiny. Will the outlet system bear it?

If the outlets are ample for the highest freshets, they will accomplish one object (so would the dykes, if made high enough and strong enough)—the same absence of overflow would follow. The next question that arises is, what would be the relative expense? which can only be determined precisely by a very expensive survey. There are other considerations, however, which may settle the question between these two systems without going into a survey of the outlets. One is, what effect would they have on the bar at the mouth of the river? If they are made navigable, as proposed by some of the papers, and require feed-water from the river in low-water season, it is very plain that navigation at the mouth of the river must suffer at all times, in proportion to the amount of water used by the lateral outlets. This would seem to settle the question between the levees and the lateral navigable canals.

If the beds of the outlets are above low-water they will be of little