The Sinking and Lining of Shafts*

The Avoidance of Heavy Fixed Pumping Expense After Completion of Mines

By Francis Donaldson

WHEN mining was begun in America, timber was cheap and plentiful, the deposits of virgin coal and ore were widely distributed and could be reached at no great depths, and the development of the rectangular timbered shaft was the natural result. Nowadays shafts are becoming deeper, mining installations more and more expensive and mining men are beginning to think they could possibly get better results by a partial return to European methods, and by the use of permanent linings. European shafts are generally circular, about twenty feet in diameter, and where the rock is moderately dry they are lined with brick, excluding the water that may occur in the fissures. As the shafts are sunk, and at intervals of about seventy-five feet, iron curb rings are placed as follows:

A cast iron ring made of sections bolted together with a groove or gutter on the inside (see Fig. 1) is placed in a notch cut in the rock. With this curb as a foundation the brick lining is built up to the ring above. As a rule the brickwork is built from a staging or platform suspended in the shaft in such a way that the sinking bucket can go up and down without interference. The lining is placed rapidly, as many as 3,000 bricks a day being laid by one man. The water that comes in through various seams in the rock is drained through passages in the curb ring to the gutter and conducted thence to a pipe in the shaft running down to the pump. The interior of the shaft is thus made absolutely dry and none of the water can fall into the shaft and interfere with the operation of the cages.

Fig. 2.—Sections of German type of tubbing made with internal flanges and connected by heavy bolts.

Where the rock is very wet the Europeans do not believe in pumping and keeping 3,000 or 4,000 horsepower in boilers to run pumps, so they use a shaft lining made of cast iron plates, sometimes as much as 2½ inches thick; this is very heavy of course, but effective. There are two types of plates or "tubbing," the German and the English. The sections of German tubbing (Fig. 2) are made with internal flanges and are connected by heavy bolts; the English tubbing sections have external flanges and are so constructed as to lock together without bolts or gaskets (Fig. 3) and are made watertight by wedging. The English sink straight through the wet rock into an impervious stratum and then set a curb ring upon which the regular tubbing is built up.

In 1838 the Murton shafts were sunk and there they handled 9,300 gallons of water from a depth of 450 feet where the impervious rock began. This is a greater quantity than we are able to handle in sinking in this country to-day with all modern appliances. It is generally known that the Europeans are away ahead of us when it comes to difficult mining propositions.

The Kind Chandron process has been developed to bore a shaft 15 feet in diameter from the top to a depth of 600 or 700 feet, to line it with cast iron tubbing and to seal it to an impervious stratum without a man going down into the shaft. The Europeans have also evolved a sinking drum system similar to our caisson method but on a more extensive scale. They sink a circular masonry caisson for 50 or 60 feet, building into the upper part a cast steel reaction ring, then build up circular cast iron tubbing with an outside diameter slightly smaller than the inside diameter of the caisson. From the bottom to the under side of the reaction ring a heavy cutting edge is provided. Powerful hydraulic jacks are placed between the reaction ring and the top of the tubbing, and the whole thing is jacked down, rings being added and the material being removed with a grab bucket. In that way they have penetrated five or six hundred feet in quicksand

without anybody going down into the shaft. In this country when we go down 150 feet without anybody going in the caisson, we think we have done a particularly remarkable piece of engineering.

Fig. 1.—A cast iron ring with a groove on the inside is placed in a notch cut in the rock.

Brick or cast iron will not wear out; they are safe against fire, and in a long-lived mine are cheaper in the end than less permanent linings. On the other hand they call for a circular shaft, and in a shaft with several compartments rectangular construction is much more economical and includes less waste space than any other. In Europe the development has been largely due to the geological conditions. The Europeans have been forced toward their methods by the fact that the coal and the minerals are all deep down; they have had to go down through great depths of marl and limestone. Ninety per cent of the total footage of shafts in this country is in solid rock, and our problem is to meet the European requirements of safety, permanence and the exclusion of water without going to the great expense that they are put to in lining.

In pursuance of this idea a number of mining companies in this country have sunk shafts and lined them with concrete. The pioneers in this field sank two elliptical shafts in West Virginia about 200 feet deep and lined them with concrete. About three months after the mine started operation there was an explosion which wrecked the mine and killed eight or ten people, but the shafts were not injured in any way, and the operation of the cages was not stopped for an hour. They were able to go right ahead and proceed with their work of rescue and the rehabilitation of the mine itself.

It is only lately that the European requirement for the exclusion of water has been met, and that has been done on the Catskill Aqueduct. The condition has been met by cement grouting. The company who took charge of the work had a contract for the Rondout Siphon, which was a deep circular pressure tunnel under the Rondout Valley. The tunnel was about 5

Fig. 4.—A rectangular construction shaft lined with timber.

miles long, and it was expected that they would meet considerable water. They did not, however, except in one shaft which was put down on a fault between limestone and conglomerate; great quantities of water were encountered here. This shaft was sub-let to a Pennsylvania contractor; he struck about 1,500 gallons of water per minute, put in all the pumps he could get and could not do anything with it. The shaft had reached a depth of 350 feet when it stuck. There had been a lot of water coming in on the side of the shaft (Fig. 4), a rectangular construction shaft by the way, lined with timber, and when the sinkers struck two or three more fissures in the bottom and got still more water it was the last straw and it broke the back of the pumps. Mr. John P. Hogan, a Division Engineer of the Board of Water Supply, then suggested that cementation be tried, and it was tried there for the first time in this country. The shaft was full of water, so they put in a platform as low as they could, installed a diamond drill, and drilled six 90-foot holes in the bottom of the shaft. They pumped them full of cement grout, forcing it through the diamond drill casings. Before they went much farther they encountered another leak of about 750 gallons a minute; as they drilled the bottom the water poured in through the machine drill holes they were going to shoot. So they simply plugged up those holes, then removed the plugs one at a time, drove in pipes connected to a grouting machine, pumped grout into the holes and cut the water off that way. By that means they were able to reduce the flow until they could put in a permanent pump station and handle the water.

The next shaft on the aqueduct where water was encountered was Shaft No. 4 (which I had charge of) in New York city, Borough of the Bronx. We went ahead and made good time until we got to a depth

Fig. 3.—Sections of English type of tubbing have external flanges and lock without bolts or gaskets.

of about 100 feet. We were then drilling into the bottom when we struck a stream of water of about 150 gallons a minute in the first hole we drilled. We plugged that with a hard wood plug and cut the water off, drilled another hole and got the same flow and so on all around the shaft. We drilled 12 sump holes, all pointing in, and got water in all of them but two. We saw there was no use pumping them and we got ready for grouting. As soon as each hole cut the water bearing seam we plugged it, as stated above, with a tapered wooden plug. After all the holes in the sump had been drilled and plugged in this way, we made the grout connections one at a time so as to restrict the flow of water into the shaft. Each connection is made with a piece of 2-inch or 2½-inch iron pipe about three feet long. This is threaded at one end and given a long taper at the other. The tapered portion is made rough on the outside by nicking it with a chisel. A heavy iron "stop-cock" is screwed to the pipe, the tapered end is wrapped in several thicknesses of burlap, the wooden plug is then removed from the drill hole and the tapered pipe driven in, the stop-cock being left open. This is the most exciting and wettest part of the job. After the pipe has been driven in hard the stop-cock is closed.

In this case we put connections in all the wet holes before grouting. The grouting machine or tank used on the Aqueduct was the Canniff machine (see Fig. 5) in which the grout is mixed by air. It is built like an air lock with a door on the top through which cement, sand and water are introduced, a 2-inch discharge opening in the bottom and air connections top and bottom. The discharge opening is connected to the grout hole by a heavy rubber hose. Another 2-inch stop-cock is placed at the outlet of the tank and a 2-inch by 1-inch tee is placed between the hose and the cock attached to the pipe in the drill hole. Into the side opening of this tee a 1-inch stop-cock is screwed.

The machine is taken to the bottom of the shaft, is connected to one of the holes and is also connected to the high pressure air supply. The 2-inch stop-cock on the machine is closed and the other is opened. The door in the top is opened, a sack of cement, three or

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four buckets of water, and, if the cavity to be filled is large, a sack of fine sand, are poured in, the air connection at the bottom is opened and the air allowed to bubble through and mix the grout. Then very quickly the door is closed, the lower air connection is closed, and the discharged connection and the upper air connection are opened and the air enters and drives the grout into the cavity. A man stationed at the 1-inch stop-cock keeps opening into a crack; when air shows instead of grout he closes the 2-inch stop-cock and the machine is recharged. If the cavity is open the charge is pushed in in three or four seconds, and by working continuously over a thousand batches can be placed in twenty-four hours.

In one hole on the Aqueduct we put in 4,000 sacks of cement before we got the fissure filled up. In Shaft No. 4 we put in about 100 in the first fissure. A little farther down in this shaft we encountered a layer of sand. The rock is folded very much; The sand was formed by the crushing of the rock due to the folding, was pretty fine and was carried up out of the drill holes by the water. Grout will not permeate sand and we had to continue drilling holes and pumping in grout, boosting the pressure at the end from 100 to 400 and 500 pounds to the square inch. We tamped that sand so full of cement that when we sunk through it it was compacted like sandstone. We found big balls of grout when we cut through it, some as big as a man's fist and some as big as his head.

The most interesting piece of grouting was done on the Hudson Siphon, which, as you know, is a deep siphon tunnel under the Hudson River; 14 feet diameter inside the concrete lining, and at a depth of 1,100 feet below tidewater. There was practically no water in the rock and the shaft sinking was done by the city forces. When they got to the bottom they concluded it would be cheaper to turn the job over to a contractor. On the east side of the river the city had driven 200 feet of tunnel through perfectly dry rock when they broke into a stream of water which flowed 300 gallons a minute. They struck it at night, and the shift boss shot his holes and broke away all the rock that should have been there to fasten the grout connections to. When we got the job we saw the next thing to do was to build a concrete bulkhead. We boarded up the face and put in 8 feet of concrete across the full tunnel section (at this point a top heading 7 feet high and 14 feet wide) and then reinforced it with rails. The concrete was mixed 1 : 2 : 4. We let the concrete set for a week and then started grouting. Grout pipes were put through the bulkhead, terminating in the fissures. At an elevation of 1,100 the hydrostatic pressure is 500 pounds per square inch, and we had hard work to force in any grout against it. We had eventually to raise the pressure to about 1,000 pounds per square inch, and to do this we had to use a high pressure plunger pump and pump water in on top of the grout in the tank. We put in two carloads of cement into that hole, and after it was set up for a week we shot the bulkhead out and went ahead with the tunnel.

The contractor for the lower end of the City Tunnel in New York has encountered a good many streams of water at depths up to 500 feet, and has grouted them successfully.

Where we met the sand bed in Shaft 4 we were unable to get the water entirely shut off and we had to rely on the concrete lining to get the shaft entirely dry. In good rock as in the Hudson Siphon a concrete lining is not needed in order to cut off most of the water because if you drill into the seams you can grout them

Fig. 5.—Grouting machine or tank in which the grout is mixed by air.

off. On the other hand if the rock is very much fissured it is practically impossible to grout it. When this is the case it is necessary to design a concrete lining strong enough to withstand the total water pressure that can come against the outside. In the case of an elliptical shaft that lining has to be thicker on the sides than at the ends; you can figure the stresses on the concrete if you are a good mathematician. We have found that 1-2-4 concrete 18 inches thick in a 14-foot tunnel will stand 600 pounds to the square inch. Anything higher than that broke it.

If you met a little stream, just a few drops a minute, a pipe must be set in opposite that stream and the water led through the lining. After this concrete has set up two or three weeks and got good and hard you connect the grout machine to this pipe, drive a little grout in and stop the water. It is absolutely impossible to stop water coming through concrete when it is soft. You have to provide a drain until it sets. In one case we overlooked a small spring and after we had concreted about 60 feet of shaft above it, we noticed the forms bulging over an area of about 10 feet square. We found that the accumulated pressure from the little spring had pushed the lining out over this area and we had to cut it out and replace it.

The question of a water-tight lining brings up the shape of the shaft. The shaft with the maximum

area and the minimum lining is of course circular and this is by far the cheapest shaft to sink. That was brought out on the aqueduct. All the construction shafts at first were made rectangular and lined with timber while the waterway shafts were made circular. On the Rondout Siphon shafts we started out with the idea that the rectangular shafts would be easier than the circular, but it was the other way. When we started the first circular shaft we did not do much the first month. The last month we made 138 feet. The next siphon we moved to we had the same gang, and they knew how, and jumped the progress up to 170 feet in one month in shale. The same gang was then moved across the Hudson River to a granite shaft and we made 183 feet, which is the American record.

The way it was done is this: The drilling is all done on one shift. Enough drills are put into the shaft so that all the holes in the round can be drilled and the sump loaded and shot in eight hours. The other two shifts clean out the shaft and get it ready for the drilling shift the next morning. We drilled 33 holes to a round.

The same method is used in South Africa on rectangular shafts, but in this country it has not been successful in this type. I have tried it in four shafts and it would not work. However, in circular shafts we tried it and made it work.

I mentioned the rectangular construction shafts being slower to sink than the circular. In South Africa they hold the world's record for sinking and the shafts there are rectangular. In this country most rectangular shafts are about 12 feet by 26 feet and about ten to twelve men are carried on a shift. There will be two or three drill runners, three helpers and about six muckers. In South Africa they use 35 to 40 Kaffir men on a shift in a shaft of the same size.

Wherever the entire area of a circular shaft can be used, as for ventilation, a circular shape is best. Where this is not practicable, as in a hoist shaft with several compartments, the best plan is to cut the ends off the ellipse adopted in the case referred to above, and to make a compromise between an ellipse and a rectangular out of our circular arcs. In dry or moderately dry rock the concrete lining need not be over 15 inches to 18 inches thick, but in wet and seamy rock it must be thick enough to resist the hydrostatic pressure after the shaft is lined.

In New York city lately the contractors have been putting in as high as 25 to 30 feet of concrete in a day in a 14-foot circular shaft, and in six days, including getting started, putting the forms in and taking them out again, they will put in 100 to 120 feet.

The cost of a concrete lining is greater than the cost of a timber lining by just about the cost of the cement. As a rule, concrete outside the cost of the cement can be put in for the price of the timber; you have to pay for your cement and you have a permanent lining.

By a comparatively small expense and proper preparation, it is possible to make a water-tight shaft and a safe shaft with no delay; we do away with the expense and danger of handling big quantities of water from shafts while they are being sunk, and we do away with the heavy fixed expense of pumping after the mine is completed.

Wooden Water-Pipes

A SHORT time ago there was some interesting correspondence in the *Times* on the subject of old wooden water-pipes. It began with a letter from a correspondent who had noticed that in Oxford Street a number of hollow tree trunks had been dug up, and who made the very sensible suggestion that a specimen of these ancient pipes might be preserved in the London Museum.

The secretary of the Society a few days later drew attention to the offer by the Society of a gold medal in 1804 for the discovery of "a substitute for the elm pipes now in common use for the conveyance of water." This offer was continued until 1816, when it was discontinued, probably because there were no applications for the prize.

A very full description of the wooden water-pipes will be found in Rees's *Cyclopædia* (Edition 1819). The article on "Pipes" speaks of these wooden pipes as being the usual and commonest means for conveying water in mains, lead pipes being used for domestic supplies, and iron pipes being referred to as coming into use. "Within the last few years immense quantities of iron pipes have been laid in all parts of London for the conveyance of water." At first there was, it is stated, great prejudice against their use, and the unreasonable nature of such an objection is very sensibly set forth by the writer of the article.

Reference is made to the Society's prizes, and the method of boring the trunks, by a hand auger or by mechanism, is described. The various lengths were socketed together by a spigot joint, the tapered end of one length being let into the coned out end of the next length. The joint was naturally imperfect, and there was much leakage.

The first letter to the *Times* was followed by a number of others, in which a good deal of information was given about these pipes, perhaps the most interesting being one from "Master" George Pollock, who said that he remembered such pipes being laid down in the early "thirties" of the last century. Mr. Pollock is now in his ninety-third year.

Mr. J. W. Ford wrote that in 1816 the Governor and Treasurer of the New River Company applied to Mr. Vansittart, the Chancellor of the Exchequer, when the iron trade was greatly depressed, for assistance to enable them to substitute iron pipes for the old elm ones. The Chancellor gave them a letter to the Bank of England, authorizing a loan of £100,000, on the condition that the money was to be expended in iron from the Staffordshire foundries. Mr. Ford also mentioned that extraordinary opposition was made to the substitution of iron for wood pipes, one of the objections raised being that the water would produce cancer.

Some further information on the subject has been obligingly furnished to the writer of this note by Mr. W. B. Bryan, the Chief Engineer of the Metropolitan Water Board, who thinks that it is almost impossible to say when cast-iron pipes were first used on a considerable scale for waterworks purposes, but he is satisfied that it was very early in the nineteenth century. The East London Waterworks Company commenced to use cast-iron pipes immediately after the incorporation of the company in 1808. This company had taken over the West Ham and Shadwell works, and the latter companies supplied all their water, as far as Mr. Bryan has been able to ascertain, through wooden pipes; but the East London Company laid down nothing but iron from the year 1808. The New River Company commenced to use

cast-iron pipes about the same time, and up to that time they did not profess to serve above the ground-floor level of the houses, because their pipes were then of wood. But after that date iron pipes were used, and in the year 1816 the iron mains were charged regularly throughout the night, and great benefits arose by reason of the substitution of iron for wood. In the year 1821, Mr. Thomas Simpson, the engineer of the Chelsea Company, stated before a Royal Commission that they had laid down very many iron pipes, and that they were gradually changing the wood for iron. The higher pressures to which water was pumped by the engines of the East London Company in 1807 and 1808, and about the same time by the New River and other companies, necessitated the abolition of the wooden pipes, and Mr. Bryan thinks that for more than eighty years past the use of such pipes has been discontinued for the conveyance of water under pressure in London. It may be taken as practically certain that the old wooden pipes now occasionally dug up in various parts of London, were left *in situ*, and became "dead" as soon as the connection to the new iron pipe had been made.

It may be interesting to note that there is a casual reference to such pipes in the "Natural History of Selborne." Gilbert White, in one of his letters to Thomas Pennant (Letter VI. of the series) describing the forest of Wolmer, refers to tree trunks being found in peat, and dug up by the local cottagers for use as timber. He says that they were often discovered in the winter time by the hoar frost lying longer above them than on the adjacent ground, and he quotes a reference from Hales's "Hæmastatics" as to snow lying longer over drains, etc., "as also where elm pipes lay under ground."—*Journal of the Royal Society of Arts.*