(*Paper No. 1740.*)

“On the Removal of Sunken Rocks in Brest Harbour.”

By H. WILLOTTE, Engineer of Roads and Bridges.

THE first serious attempts to remove the obstruction known as La Rose rock were made in 1857, when Mr. Verrier, then executive engineer, and since director, of maritime works at Brest, employed divers who succeeded in blasting 2,000 cubic mètres (2,616 cubic yards) of rock, and thus obtaining a depth of $5\frac{1}{2}$ mètres (17 feet) at low-water spring tides.¹ The increased dimensions of iron vessels soon rendered this depth insufficient, and Mr. Verrier was instructed to prepare plans for the further removal of rock so as to reduce the obstruction to a plane surface 8 mètres (25 feet) below low water of equinoctial spring tides. In July 1876, Mr. Verrier submitted to Mr. Director Dehargne a report and estimate, which, being deemed satisfactory, was approved by the Council of Maritime Works in the following month, and immediate inquiries were set on foot as to the best means of carrying out the enterprise. As it stood the project completely met the aspirations of the maritime interests, for it assured to vessels entering the river Penfeld a deep-water channel 300 feet wide. But it required for its execution the employment of air-compressing apparatus, always costly and necessitating much skilled labour.

As a preliminary, invitations were issued to several contractors of known experience in hydraulic works, suggesting that they should address to the Minister of Marine proposals and drawings of the apparatus they would adopt for carrying out the operations. It was desired, before submitting the undertaking to public competition, to know what measures a contractor would take in organising his plant on a satisfactory scale; for the works had to be carried out under particularly unfavourable conditions, and would entail constant and minute care. Apart from the disadvantages inherent to the employment of compressed air, provision must be made for carrying on the work night and day, without interruption, for it was indispensable that time should not be lost every morning in filling the caisson with air. It was further necessary

¹ Mr. Verrier has described these operations, which cost 70,000 francs, in two detailed notes published in the “*Memorial des Travaux Hydrauliques de la Marine*,” 1862.

to take precautions against the heavy seas so frequent at the mouth of the Penfeld, and above all (a condition to which the authorities attached the greatest importance) to be able to clear the channel completely at stated times, in order to allow free access to the port for government vessels. This latter condition, which it is believed has not previously been exacted, in works of a like nature, imposed upon the contractors the employment of plant of extreme portability and consequently of special design.

The invitation of the Ministry of Marine elicited two responses. The first of these (in point of date) was submitted by Mr. Fouquet, manager of the Batignolles Engineering Works (formerly Ernest Gouin and Co.). He proposed to divide the work into three distinct operations, to be carried out in succession. First, the blast-holes were to be bored over the whole surface of the rock. The diving-bell, or compressed-air caisson, was then to be removed and the charges to be simultaneously exploded under the greatest available head of water (which undoubtedly presented many advantages). Lastly, a distinct compressed-air apparatus was to be employed to remove the shattered material. The details of construction and of working the proposed plant were carefully considered and well wrought out, and every care was taken that the operations should be prompt and efficient. The principle of the method proposed allowed for continual displacements of the apparatus.

The second proposal emanated from Mr. Hildevert Hersent, who proposed to execute the work entirely by means of a single apparatus (diving bell), 10 mètres long and 8 mètres wide. A section of this bell is shown in Fig. 1. The entire work of boring the holes, charging and exploding them, and extracting the broken rock was to be done in this vast caisson, covering an area of 80 square mètres (2,624 square feet), which would only necessitate removal as the work progressed.

The two projects were submitted to the judgment of Mr. Paul Etienne, then executive engineer of maritime works at Brest, who reported that he found them equal in merit and in prospect of success, and recommended that tenders should be obtained from the respective parties and the work let to the lowest bidder. In the result, Mr. Hersent got the contract, the terms being that he should remove the obstruction within two years, at a cost of 62½ francs per cubic metre of rock, and 10 francs per cubic metre of sand (say 50s. and 10s. 6d. per cubic yard respectively). On the assumption that 12,000 cubic mètres would have to be removed from La Rose rock, the probable cost of that improvement will be

780,000 francs (£31,200); but it was besides stipulated that the contractor should remove on the same terms the submerged rock at the entrance to No. 5 dock, known as the Brest basin. This supplemental work, estimated at 385,000 francs, will make the actual cost of the improvement of the port 1,200,000 francs (£48,000).

The works were put in hand immediately on the signing of the contract, in November 1877, but, unfortunately the construction of the first diving-bell took much longer than was anticipated, and it was not until the 7th of September, 1878, that the caisson was placed in position over the rock and the apparatus got ready to start. Mr. Hersent at once set about regaining the lost time, and successively ordered two new caissons, one of the same dimensions as the first, the other, smaller, being 5 mètres long and 4 mètres wide, and destined, from its greater portability, to be used for removing spires and irregular masses of rock, so as to obtain a better bedding for the larger machines. But in spite of this further assistance, the contractor was unable to extract the necessary 40 cubic mètres of rock daily in accordance with the terms of the specification; and, after getting together plant worth £8,000, was obliged to apply for an extension of time, which was accorded by the Ministry of Marine. The work at La Rose rock is to be completed by the end of 1880.

Fig. 1 shows the internal disposition of the caisson, which is easily controlled. Above the working-chamber, A, is a large air-tight compartment, B, providing the necessary flotation when the caisson has to be moved. On arriving over the working-site, water is let into the upper chamber until the edge of the caisson touches the rock. Air is then pumped into the working-chamber until it is nearly free of water, when the workmen descend through the central shaft, C, which carries a winding stair, and enter the working-chamber through the air-lock F. The work consists in drilling holes in the gneiss and quartz, which constitute the bulk of the rock, of charging and firing, and of removing the broken material through the vertical spouts E, E. When the blasts are about to be exploded the workmen take refuge in the air-lock, which saves much time, as there is no need for equalising the pressure. On the completion of the work at one site, air is pumped into the flotation chamber and the caisson towed to the next one. Under ordinary circumstances, Mr. Hersent's three compressed-air diving-bells at Brest are disposed thus: On La Rose rock the small and one of the large machines work simultaneously; the other large machine is placed at the entrance to No. 5 basin.

Each of the larger machines can accommodate about twenty-eight workmen, and removes 10 cubic mètres of stuff daily. The men are paid from $3\frac{1}{2}d.$ to $6d.$ per hour at work under pressure.

FIG. 1.

SECTION OF PORTABLE CAISSON. Scale $\frac{1}{100}$.

A, working-chamber. B, flotation chamber. C, shaft. E E, spouts. F, air-lock. G G, upper gates of the air-lock. G₁ G₁, lower gates of the air-lock. M, pipe for supplying air. T, outlet pipe.

There are two sets of miners at each caisson, working in six-hour shifts. Each man works twelve hours daily, and fifty-six men are required for each caisson. The staff of the works includes also a certain number of men employed above water. The small caisson can only contain seven or eight men, and suffices to remove 2·5 cubic mètres of stuff every twenty-four hours. The whole staff therefore numbers about two hundred persons.

The weight of iron in the large caisson is 85 tons (metric), and it is ballasted with 235 tons, of which 140 tons is in concrete blocks arranged above the ceiling of the working-chamber, the remainder being kentledge. This affords a displacement of 320 tons when the caisson is afloat, and on this she draws 5·7 mètres (18 feet 8 inches) of water. The cost of a large caisson is about 50,000 francs (£2,000). The small caisson weighs 35 tons, and carries 40 tons of ballast on a draught of 17 feet. It cost 35,000 francs (£1,400).

The explosive employed at La Rose is gun-cotton, from the State manufactory at Moulin Blanc, near Brest, supplied to the contractor at 5 francs 80 cents the kilogramme (say 2s. 2½d. per lb.), special price for government works. Each kilogramme of explosive removes an average of 10 cubic mètres of rock. In each blast a cartridge is used containing from 90 to 150 grammes (say 3 to 5 ounces); the igniters are of fulminate of mercury, and cost 115 francs per thousand.

In designing the caissons, attention was directed specially to providing for the removal of the stuff, so as to reduce to a minimum the loss of air. In ordinary apparatus of the kind a small air-lock is provided, and where only sand has to be removed the sand-pump has achieved much success. But the latter not being available in the present instance, Mr. Hersent's first design contemplated the employment of a sort of noria, of which the buckets were to ascend and descend through two vertical tubes juxtaposed. The buckets were furnished with india-rubber lips, and the interior of the tubes being perfectly true and smooth, they worked therein like a series of pistons in a cylinder. It was hoped by this means to maintain a sufficient pressure in the working chamber, while at the same time providing for the continuous removal of the stuff. Unfortunately this ingenious device did not answer practically. It was found impossible to prevent serious leakage past the buckets, and the apparatus had to be abandoned. The noria was then modified so as to have access to the working-chamber through a special air-lock of small dimensions. A man stationed in this lock shovels in the material till it is nearly full, and then, connection with the working-chamber

being closed, it is removed in the ordinary way. This modification has worked well, and is in use at the present time. Provision was made at first for signalling the men in the working-chamber by means of an acoustic tube or pneumatic telephone, furnished with a vibratory diaphragm, which attained a certain measure of success; but owing to the noise made by the mining picks it was difficult to understand at all times the utterances of the men above; and the tube has been superseded by a system of whistling signals, obtained by allowing the compressed air to escape through a sonorous reed.

Apart from the delay in getting ready the first caisson, the works have been carried out under excellent auspices. The superintendence of the enterprise lay with Mr. Verrier, director of maritime works at Brest, having successively under his orders Messrs. Etienne, Thiébaud, and the Author as executive engineers. The contractor was represented by Mr. Arnaudeau, who directed skilled foremen accustomed to compressed-air apparatus, and a staff of Italian and Breton labourers.

APPENDIX.

NOTE ON THE CONSTRUCTION AND WORKING OF THE PORTABLE CAISSON, OR
DIVING-BELLS USED IN THE FOREGOING WORKS. By H. HERSENT.

THE three caissons are all constructed on the same principle, differing only in size. The working-chamber, which constitutes the lower part, and rests on the rock, is rather more substantially made than the ordinary iron caisson used in compressed-air operations. The height under the ceiling is $6\frac{1}{2}$ feet. A portion of the curb, which is divided into bulkheads, is utilised for stowing away the tools when the machine is moved; the remainder is filled with ballast of rubble masonry in cement. The cells between the girders of the ceiling are filled with concrete, which increases the rigidity of the surface subjected to air pressure, and also steadies the caisson against submarine currents.

The air-lock of the central shaft is situate at the bottom of the flotation chamber, so as to avoid having to ascend the shaft under pressure, and to augment the displacement. A winding stair gives access to it.

The spoil locks are on the upper deck of the caisson at the top of two cylindrical spouts, through which work the buckets. These locks are each furnished with two receivers, from which the spoil is removed alternately, so that the movement of the endless chain is practically continuous. Each lock as now arranged will allow of the discharge of from 25 to 30 cubic mètres per day. The endless chain is worked by friction gearing actuated by crabs placed outside the lock. The mines are discharged by Bickford's fuse. To raise the caisson the compressed air in the working-chamber is allowed access to the flotation chamber, whence it expels the water. The staircases in the shaft render communication easy, and allow of all necessary disposition.

It has been observed that the employment of these diving-bells allows the men to work with great regularity, and that for two years not one of the affectionous ordinarily produced from working in compressed air has declared itself. It is believed that this immunity results from the men having to ascend a staircase of from 30 to 40 feet in height after emerging from the pressure. The shafts can be lengthened or shortened so as to work in water of varying depths.

Consequent upon the success of the machines at Brest, the contractor has undertaken similar work at Cherbourg in respect of the removal of 25,000 cubic mètres, and he is sanguine that the experience now gained justifies the undertaking of such enterprises without any risk of failure.