THE MULBERRY HARBOURS

By

SIR BRUCE G. WHITE, K.B.E.,
F.C.G.I., M.I.C.E., M.I.Mech.E., M.I.E.E.

Brigadier, late Director of Ports and
Inland Water Transport, War Office.

THE
MULBERRY HARBOURS

By

SIR BRUCE G. WHITE, K.B.E.,
F.C.G.I., M.I.C.E., M.I.Mech.E., M.I.E.E.

Brigadier, late Director of Ports and
Inland Water Transport, War Office.

THE MULBERRY HARBOURS

THE subject I write about is a vast one and may be treated from the angle of organisation and background, technical details of the numerous items of equipment, the different aspects of harbour engineering involved, or the actual operation itself. It will have to be a case of compromise and I will endeavour to cover the above headings in a more or less general manner and tell of some matters which have not hitherto received mention. I do so with the knowledge that the technical and detailed aspects of much of the equipment will be the subject of papers read before the various Technical Institutions.

The whole undertaking was a very great, risky and complicated engineering project, the parts of which had to be ready in advance of " D " Day and actually move to the far shore at the same time as the first assault troops, to enable the building of the Harbours to be carried out in action during the fi , da of the nv o Engineering and military warfare each being a complete science, the integration of the two was probably one of the most difficult parts of the operation.

I will first touch upon the background of the scheme leading on to the nature of the organisation which was so necessary to enable it to be carried out. For this I have to go back to May, 1940, when, having served in the last war in the Royal Engineers, Inland Water Transport Section, and being on the emergency reserve, I was called up and posted as a Major on the War Office Staff in the Directorate of Transportation, Royal Engineers, my responsibility being designated " Ports." At this point I would mention a question which was often asked, " Why are soldiers responsible for ports? Surely this is the work of the Navy ' T the uninitiated this may appear a reasonable argument as ports are connected with the sea and the Navy's work is on the sea. The building and control of harbours are normally the work of civilian harbour engineers and operatives, whereas the work of the Navy is running fighting ships. This has always been the practice and it is interesting to know that this was recognised by Mr. Winston Churchill, whom I heard at a meeting use words generally to the effect that seamen go down to the sea in ships and it is in their absence that the landsmen build harbours and refuges to which are brought back the fruits of their service.

At a meeting in 1940 harbour construction and operation were agreed between the Services to be an Army responsibility, the Naval responsibility being confined to Naval bases Thus charged, it was clearly a duty of the War Office to build up an organisation to carry out that work and all that it implied in whatever form or wherever required. The importance of this was brought home more strongly on the fall of France when it was clear, to me at least, that, whereas in previous wars we had employed established ports in friendly countries, from then onwards the enemy would where possible render each port inoperative before leaving it.

Harbour engineering is always a long and tedious business and it was clear that ways and means would have to be found by the full use of originality and improvisation to provide special equipment and technique to shorten the period of construction. The form which the organisation took was a specially selected staff of engineers at the War Office to deal with the many facets of harbour engineering, both for control and design. For operation, a large force of R.E.'s—again officered by experts in various branches—was built up and formed into Port Construction and Repair Port Operating, Port Maintenance, Repair Shops, Dredging, I W.T and numerous other forms of specialised companies. This force eventually reached a total of 1,332 officers and 51,740 personnel, and served on the beaches and in the harbours in all parts of the world. I am pleased to place on record that, in the whole of the military forces that I employed, the officers were civilians who joined for particular duties.

As it was thought unlikely that rapid repair work could be done in the captured por s, ing gard to the difficulties of sea communication in the early stages five small ships were obtained to ensure that the necessary plant could be moved to th sites. These ships were officered and manned by R E personnel, and were fitted out to War Office requirements with workshops, pumps, pumping nd compressed air plants, diving equipment, diving bells, and heavy derricks, and, in addition, carried a great variety of construction equipment. These ships served in all theatres and greatly helped in the problems of clearance and repairs of captured ports.

Realising that in carrying out my responsibilities I would meet many problems which I was not qualified to solve, I decided that "top brains" were required, namely engineers experienced in various aspects of harbour and sea engineering and drawn from consultants, contractors, dock authorities and canal companies. Accordingly I approached the Dock & Harbour Authorities Association, Canal Association, Federation of Civil Engineering Contractors, and Railway Executive and other bodies, with a view to obtaining permission for their members whose services I desired to employ to assist the War Office, their normal duties permitting. I received most enthusiastic support from these bodies with the result that a register was formed of about 150 engineers whose fees were agreed by the Treasury, and there was thus available for instant call a great force of experienced civilians. Later, a group of ten contracting firms, skilled in harbour works, was formed with a view to supplementing the field force should the latter prove inadequate in numbers for the work in hand.

Great use was made of the elements of this organisation and, working on the principle that even the wildest looking proposal might have the germ of a useful idea and that every idea was to be carefully examined and tried, much progress was made in the preparation for what lay ahead by the provision of special equipment and the training of troops in its use.

In connection with the training of the field force, many opportunities existed, for great demands were made on the ports by the military for loading at a time when berths were being greatly reduced in number by enemy action. Under a programme arranged with the harbour authorities, a number of berths which had fallen out of use were reinstated or new berths built to the requirements of the Army.

Again, in the early days, about 120 cranes, no longer required at London and Southampton and East Coast ports, were dismantled and re-erected in West Coast and Scottish ports all this work being undertaken by specialised military units. Numerous piers and wharves, constructed out of steel trestling, were erected in many places round the coast for the use of the Army, and also for the Navy and the American forces. It is interesting to note that the first supplies for the bases provided by the Americans were landed on wharves built for the purpose in one of the Scottish lochs. Then there were two military ports in Scotland, providing 1? deep water berths in all, and which were built entirely by military personnel under War Office direction It was on all these, and particularly on the two military ports, that the difficult sides of harbour engineering were encountered and used for training In connection with all these works, extensive dredging operations were required. and although dredgers were available, there was a great shortage of trained crews. Here numerous dredgers were manned by the military, and dredging crews trained. In short, it was the special military organisation employed and trained on a great variety of sea work, combined with the civilian assistance, that was really the background for the carrying out of Mulberry.

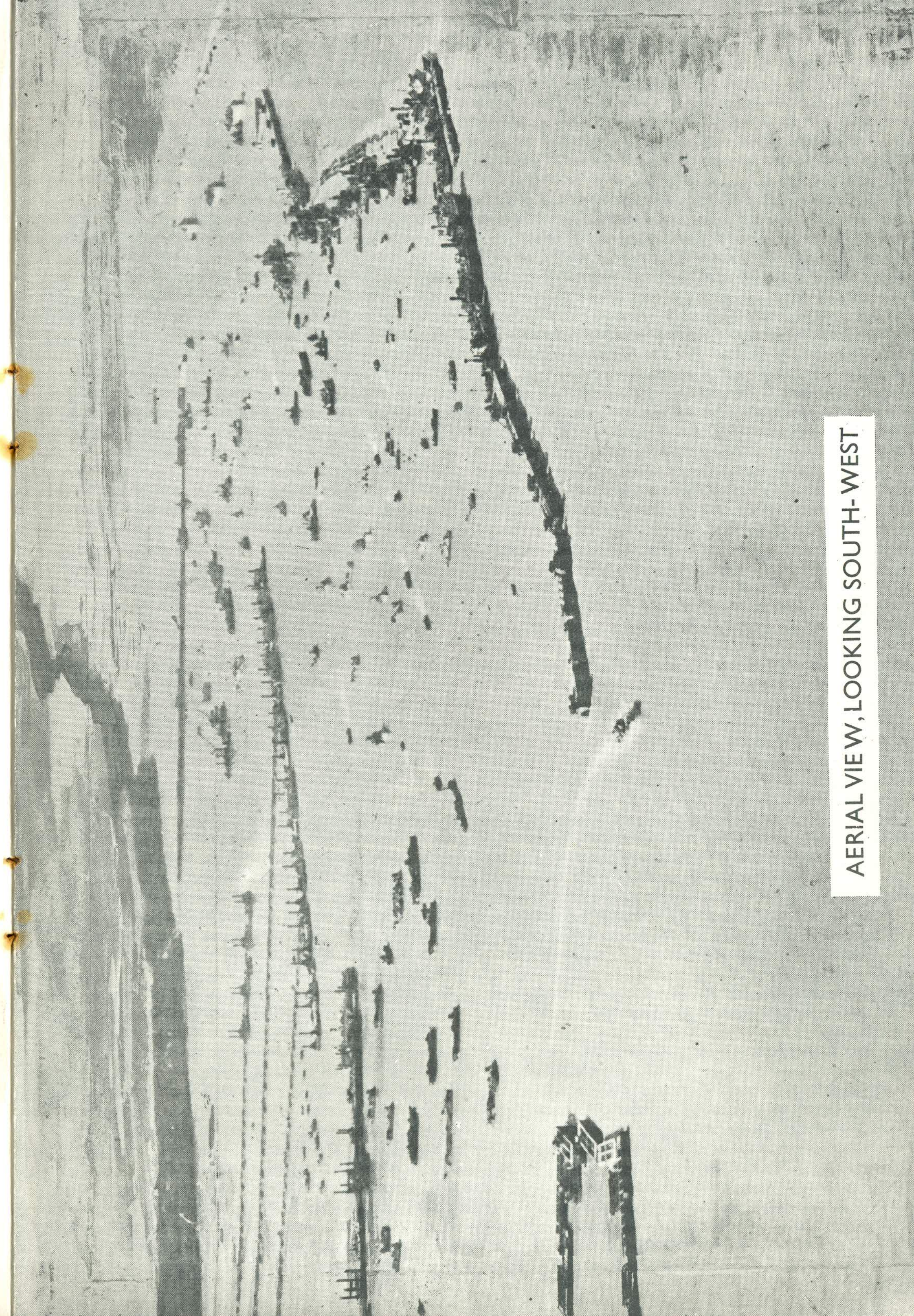
Mention should now be made of one group of equipment which ultimately played a prominent part in the scheme; this was the spud pontoon pierheads and floating roadways—code word "Whale"—which was developed in prototype form in 1942. Mr. Winston Churchill, having since Gallipoli days pressed without success for some portable equipment by which ships engaged in shore landings could remain floating when discharging cargo, issued a further appeal in the form of the following Minute.—

"Piers for Use on Beaches:

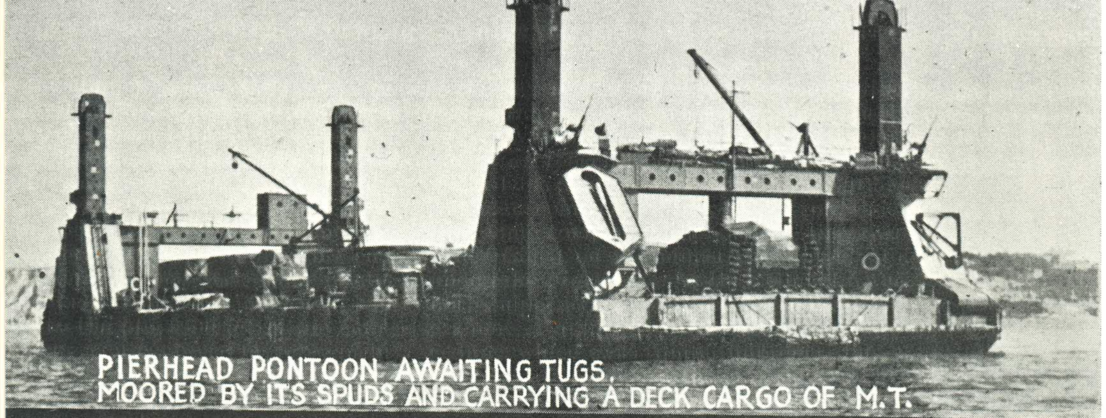
They must float up and down with the tide. The anchor problem must be mastered. Let me have the best solution worked out. Don't argue the matter. The difficulties will argue for themselves."

The Minute was considered at a meeting of all Services but was received coldly as being impracticable. I claimed the right at least to attempt a solution as the problem fell within my responsibility. As a result, the team at the War Office produced the answer in seven days. The solution took the form of pontoon pierheads embodying spuds for moorings as used on certain types of dredgers, and with it an ingenious floating roadway consisting of 80-ft. flexible girders designed to carry 40-ton tanks, mounted on concrete pontoons, moored to the sea bed. This equipment was designed to withstand conditions under wind force 6, to which it proved equal, as was shown by a prototype built in quick time between September, 1942, and February, 1943, and tried out on an exposed part of the Scottish coast.

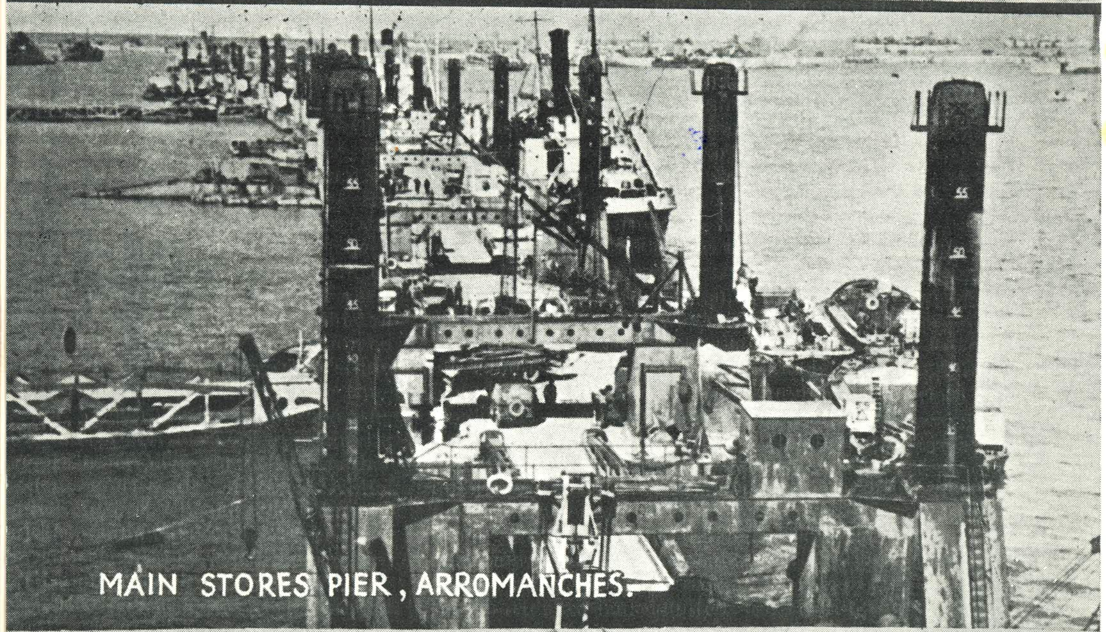
There had been many cases of floating bridges, but none so far had been constructed to be moored and serve in a seaway with appreciable wave action. Many interesting and ingenious details were incorporated in this floating roadway to make it suitable for its difficult rôle in operations. Further, it had when mounted on its pontoons, to be capable of being towed 100 miles in lengths of at least 500 ft. and be so manoeuvrable and equipped that each section could be



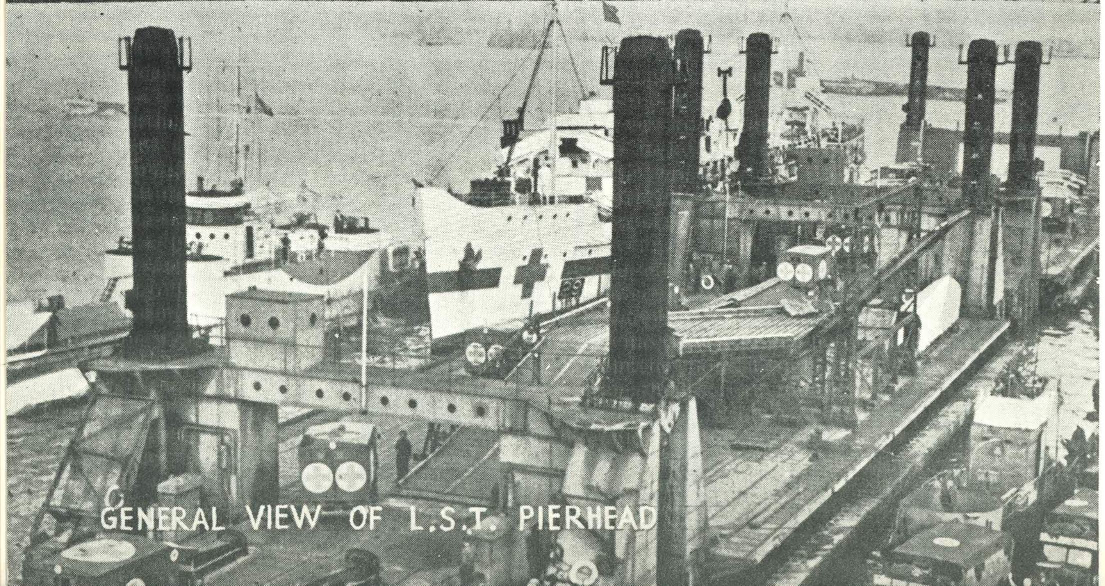
AERIAL VIEW, LOOKING SOUTH-WEST



PIERHEAD PONTOON AWAITING TUGS, MOORED BY ITS SPUDS AND CARRYING A DECK CARGO OF M.T.



MAIN STORES PIER, ARROMANCHES.



GENERAL VIEW OF L.S.T. PIERHEAD

placed into position under battle conditions in a matter of minutes. It was evident, early on, that no ordinary methods of mooring the pontoons would succeed, but this was overcome and the mooring of a pontoon fore and aft was executed in under ten minutes by the use of specially designed mooring shuttles which, complete with ropes and anchors, were carried on the deck of the roadway and launched into the sea on arrival on the far shore.

The prototype roadway was mounted on concrete pontoons made of precast vibrated concrete panels assembled in a framework with in-situ vibrated joints. Although the panels were only 1¼ in. thick the pontoons were watertight and, with a system of timber fendering, were generally suitable for the purpose. However, with the roadway in position, these pontoons between high and low water mark would have to sit on the bottom at low tide, and it was feared that they might not be suitable for this duty. A design for steel pontoons was therefore prepared, but at that time the demands for steel were greater than the supply, and in the end a compromise was made with about equal quantities of concrete and steel pontoons, the latter being used at the shore end of the roadway. It was a credit to the designers that the concrete pontoons behaved as well as they did, and it subsequently transpired that they were quite able to " sit down " without harm, on a comparatively level beach.

In view of the uncertainty of the effect on the equipment of enemy action, the design had to allow for replacement of any part of the roadway which might be damaged in action. This was accomplished, and at no time were the roadways inoperative.

Another item of equipment which was ultimately to prove of value was three concrete caissons, the biggest of which had a displacement of 3,000 tons. These were built on slipways and launched sideways. This equipment offered valuable experience in towing and sinking large concrete masses, besides enabling certain design factors to be checked. The data proved of great value when the " Phoenix " breakwater units came to be designed.

In the meantime the Admiralty were experimenting with a form of floating breakwater called " Lilo," consisting of a series of rubber bags 200 ft. long with concrete sinkers which practically submerged the bag, the whole being moored to the seabed. The idea embodied a principle which the War Office had tried out experimentally but abandoned as unsound, a decision which was later justified by certain trials. Theoretical calculations proved that its effectiveness would be impaired in a big tide range, due to mooring difficulties and, in any case, its one chance of success depended upon very heavy moorings which were in extremely short supply.

By 1943 clamour for the Second Front was growing apace, but little did those who shouted loudest know of the difficulties involved or of the immense amount of work which had already been accomplished. Of the difficulties of invasion it is well to mention that all ports on the French coast were very heavily defended and a frontal assault at any of these would have led to sheer massacre, as those who had hitherto adhered to this policy learned from the Dieppe raid. The assault on the beaches was made more difficult by the fact that the beaches were flat, i.e. 1 in 100 slope, which, with a tide range of up to 30 ft., gave a distance of approximately three-fifths of a mile between high and low water level. With these flat beaches the big landing craft were found to ground aft and left a " water gap," as it was termed, with a drop into about 6 ft. of water. These beach conditions and more particularly the excessive tide range added very greatly to the difficulties in designing special equipment, and did not escape Hitler's notice, as he indicated in at least two of his speeches when comparing the task of invading England with that of the Continent.

In the preparation for the invasion of the Continent, I and those with me experienced great difficulty in impressing upon those who had carried out the invasion of North Africa or served in the Mediterranean, that there was a fundamental difference between these operations and those which confronted us in the English Channel. In the Mediterranean there is virtually no tide range, whereas in the Channel we had to design for a range of tide of as much as 30 ft. One extraordinary fact emerged from the many discussions in which we took part, namely that tides were generally viewed by those we talked with—including seafaring men— in a horizontal direction, and not in terms of the vertical depth of water which occurred between low and high tide.

In anticipation of the need for artificial harbours involving a breakwater system, the War Office, amongst other things, experimented with wave suppression by means of compressed air. This had been tried in the U.S.A. and in Russia, but abandoned on account of the immense power which would have to be available in the form of compressed air. I took steps, however, in June, 1943, to form a committee of four of the leading harbour engineers in this country who were given the task of studying a section of the coast-line of France with a view to advising whether the hydrographical and topographical conditions were such as to make possible the building of artificial harbours.

In August and September of 1943 the Quebec Conference assembled and it was there that the invasion plan—" Operation Overlord "—was first discussed and considered by the Joint Staffs. Briefly, the plan was to invade over a stretch of coast 60 miles long and lying between Ouistreham and Varreville. There were to be five assault beaches and in order to ensure the build-up of supplies for five Divisions in the event of unfavourable weather, there were to be two artificial harbours, one for the British at Arromanches, and one for the Americans at St. Laurent; the parts of these harbours to be prepared in advance, towed over and placed with the assault.

The staff requirements called for the provision of sheltered water by fourteen days after " D " Day; the harbours to suitably accommodate the unloading of the following supplies daily :—

	American Harbour		*British Harbour*	
By No. of days after	Supplies Tonnage	No. of Vehicles	Supplies Tonnage	No. of Vehicles
4	1,200	—	1,800	—
8	3,000	1,250	4,000	1,250
14	5,000	1,250	7,000	1,250

Sheltered water to be provided by the harbours for a period of 90 days, allowing for a wind force of up to 6 to enable ships anchored or alongside the harbours to discharge their supplies into landing craft, and also to allow of the operation of small craft between the ships and the beaches at all states of the tide.

The harbours to be of sufficient size to provide for the following vessels at all conditions of tide :—

15 Liberty ships to take up and leave their moorings ;

20 Coasters to proceed alongside, to leave the piers, or to anchor ;

About 400 craft of various types, and, in the event of adverse weather, to provide shelter for about 1,000 other small craft which would be working on the beaches.

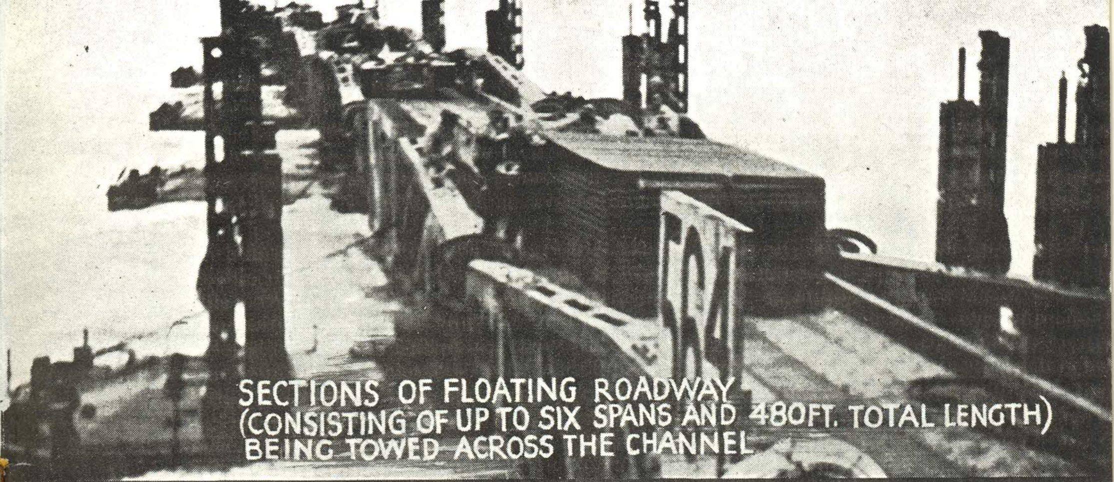
At the meetings in Quebec and Washington did not terminate until well into September, and all the equipment for the two harbours had to be ready for moving to the far shore on May 1, 1944—the earliest " D " Day—it was all too clear that a great deal had to be done, and difficult work at that, in a very short time. This shortage of time was probably the most difficult part of the whole scheme, and, without the organisation which had been built against such an eventuality, it is correct to say that the harbours could not have been designed, supplies ensured and all arrangements made in the short time available.

Credit for the conception of building invasion harbours must go to the planning staff—a mixed force of Army and Naval officers. Planners, however, are not engineers, and it was felt that, before that part of the plan dealing with artificial harbours could be accepted, the opinion of the organisation which would design, provide and build them was necessary.

As I was responsible for ports, I flew to Quebec, together with Mr. R. D. Gwyther, M.C., M.I.C.E., and a staff officer, and at the same time the Admiralty sent a small party who had been experimenting with the floating breakwater already mentioned above. At Quebec we joined forces with the American Service experts to consider the feasibility of building artificial harbours and the ways and means of constructing the many individual components, in particular the breakwaters. Arising from these deliberations, the use of blockships for breakwaters was ruled out, as it was confined to comparatively shallow waters, the limitation being imposed by the moulded depth of the available vessels. In view of the 24-ft. tide range, this was a wise decision, and attention was turned to the floating breakwater, which had possibilities for certain applications but was purely of an experimental nature. It was, however, considered somewhat dangerous, as in the event of its breaking its moorings it could do damage to other equipment and to the shipping which it was designed to protect. The general opinion was that the breakwaters could only be provided by relying upon a system of mass connected to the bottom of the sea.

A Joint Committee studied at Washington the layout of the harbours to meet Staff requirements at the two points on the French coast selected by the planners. These plans received considerable study for until this was done it was impossible to determine the quantity of equipment which would be required, and upon this depended their practicability or otherwise. In the layout of the harbours, spud pontoons and floating roadways, whose usefulness had already been approved, were incorporated.

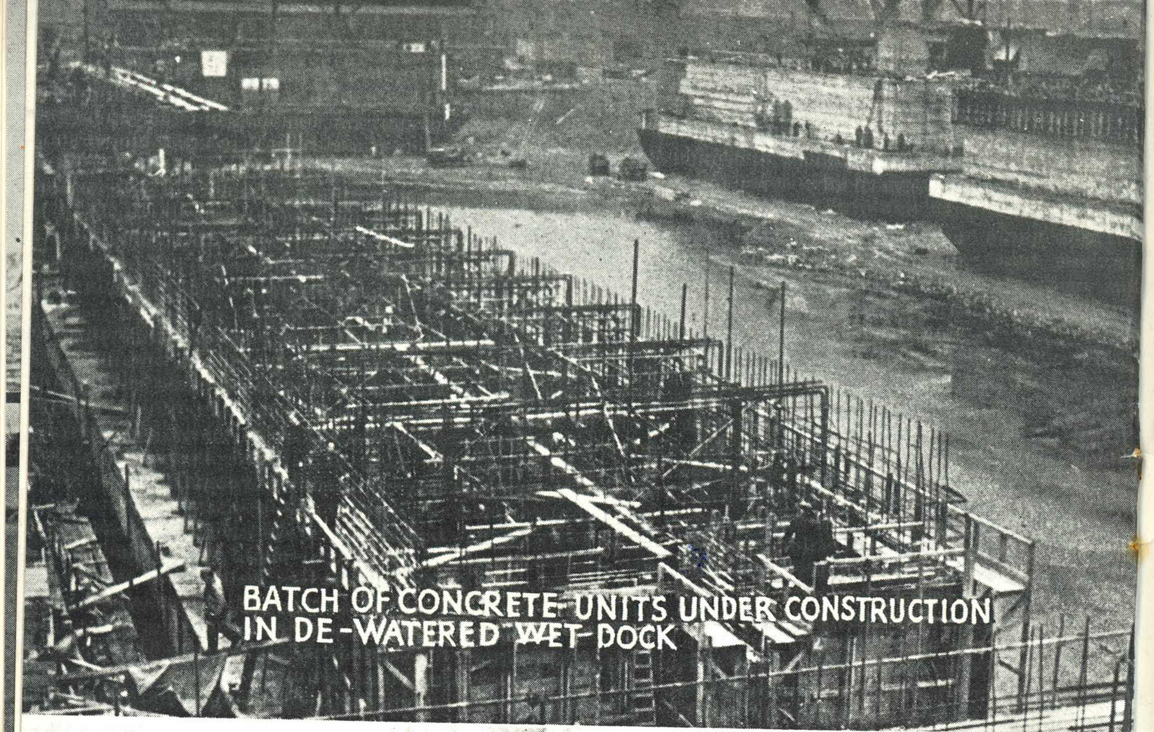
Being responsible for the construction of harbours, I was asked whether the plan could be accomplished, the time then remaining before the date selected for the assault being eight months. I was able to



SECTIONS OF FLOATING ROADWAY (CONSISTING OF UP TO SIX SPANS AND 480FT. TOTAL LENGTH) BEING TOWED ACROSS THE CHANNEL

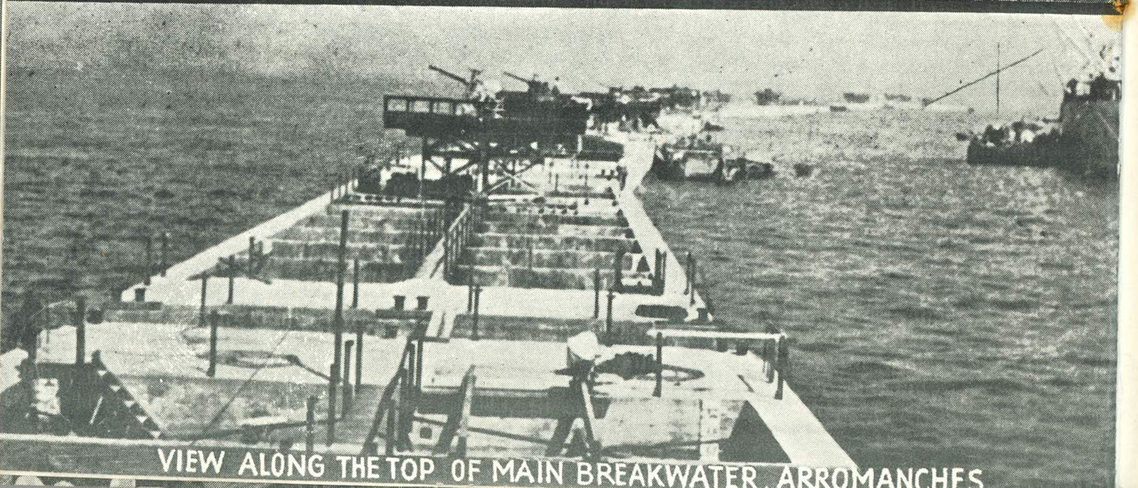
LOOKING DOWN A ROADWAY INTO ARROMANCHES

SECTION OF ROADWAY ON ARRIVAL FROM U.K. BEING LINKED TO ROADWAY ALREADY IN POSITION



BATCH OF CONCRETE UNITS UNDER CONSTRUCTION IN DE-WATERED WET-DOCK

FINISHED CAISSONS BEING TOWED DOWN THE THAMES



VIEW ALONG THE TOP OF MAIN BREAKWATER, ARROMANCHES

answer in the affirmative with full knowledge of the great amount of experimental work which had been successfully completed, having an efficient field force and above all an excellent background. In fact, the only qualification which I stressed was the need to build tugs, as the towing programme was immense. Certain steps towards this end were taken, but more successful results would have been obtained if more heed had been given to the provision of tugs in sufficient numbers, as was proved by subsequent events.

On my return to England it was clear to me that a great deal had to be done in the short time of eight months. The first need was to get the best design for the breakwater caissons, and in anticipation of such a requirement a number of engineers had been asked to prepare designs and submit models to towing trials in the ship tank of the National Physical Laboratory at Teddington. With a certain amount already done, it was necessary to decide upon the most practical type, having regard to the great length required for the breakwaters (29,400 lin. ft. in all), their ability to be towed, their effectiveness and above all the possibility of building so vast a quantity of reinforced concrete in so short a time. Further study confirmed the conclusion that the time available for construction would be the determining factor; I therefore appointed a committee of three contractors who, together with my deputy, Brigadier J. A. S. Rolfe, M.I.C.E., M.I.Mech.E., considered all designs which had been submitted and proceeded to select the most suitable type, bearing in mind all these factors.

The type selected was the vertical-sided caisson 200 ft. long and varying in height from 25 ft. 0 in. for the smallest unit to 60 ft. 0 in. for the largest, according to its use in shallow or deep water. The larger units were for use in 5 fathoms at high water, with a 24-ft. range of tide. Simplicity was the criterion but, in order to ease the difficult operational task of handling the caissons in action, I did insist on the following features as necessities. The caissons had to be scow-ended, as previous experience had shown that this form greatly reduced towing resistance. They had to be regarded as ships, provide accommodation for crews and be equipped with towing bollards. A deck was provided all round the vessels 8 ft. above water line, on which the bollards were fixed and which enabled the crew to work ropes during towing and sinking operations. Subject to these necessities, the design could be as simple as possible and was to involve the easiest form of steel reinforcement.

Having settled the type of unit, the detailed design was undertaken by my staff at the War Office, advised by a small committee of consulting engineers and supplemented by staffs lent by contracting firms. This team completed their work in record time.

Having completed the design, the War Office called on the Ministry of Supply to undertake provision. As that Ministry was not equipped to undertake such a vast programme, I approached the Minister, a procedure which was quite improper for a serving soldier, to press the importance of his Ministry setting up a special department for this work. Fortunately, he at once saw the wisdom of the advice and created a new department; and well it was that he did so, as otherwise the programme could never have been completed. This special department of the Ministry did the almost impossible in obtaining 24 contractors who, with all their other commitments and difficulties of material and labour, constructed caissons—which were given the code word "Phoenix"—aggregating 600,000 tons in the short time of 26 working weeks.

When the question of supply of concrete caissons first arose it was contemplated that the building of at least the bigger sizes, if not all, would be carried out in dry docks which would be available in sufficient numbers, and would have greatly simplified the whole construction. In due course application was made for the requisite number of dry docks, but the Admiralty were not able to agree to release sufficient of these, with the result that other and more difficult methods of construction, involving considerable modification to the design had to be undertaken. In this matter we had counted for certain on the use of the King George V dry dock at Southampton which by its great size and adequate services would have enabled three batches of ten of the biggest caissons to be built in a neighbourhood whence they could be towed away to the far shore. In actual fact, the dock was used by the Admiralty for the assembly of the steel sections of which the floating breakwater—"Bombardon"—was made. The "Bombardon" was developed from the "Lilo" mentioned above, and was a cruciform structure 200 ft. long and 25 ft. overall across the arms, which were 6 ft. thick. These units could more easily have been built on special slipways formed on the shore, as indeed large numbers of caissons had so to be made, and further, as each one had to be towed down the coast to Weymouth after launching, this was a case where facilities might have been better used, if the interests of the scheme as a whole had been considered.

As already mentioned, it is impossible to enter into all the many and interesting details of the construction of the equipment, but it is hoped that these will be dealt with elsewhere. In no case have so many reinforced concrete structures of the same design been built concurrently by as many as 24 contractors, each having different conditions of site to contend with and each being allowed to employ his own methods of construction. If fully recorded, the results would indeed prove of absorbing interest to engineers concerned with ferro-concrete construction work and methods.

In the meantime the Ministry of Supply took in hand through the usual departments a great programme of construction of 23 spud pierheads and 10 miles of floating roadway. It will be remembered that the prototype of these had fortunately been proved but it remained to effect minor improvements and also to design special fitments to adapt this equipment for the particular local conditions to be encountered. As the plan developed, so more requirements were added, each calling for considerable originality in design and raising a further problem of production.

At this point it is well to mention that throughout the designers made the fullest use of welding, and it is correct to say that, had not welding been developed to the extent it had, this vital equipment could not have been completed in time. The ordinary structural methods of joining by riveting or bolting could not have obtained capacity in works already overloaded with equally vital production.

It was in this time of stress of designing all this special equipment that the value of the team which I had formed came to the fore. Their early training never to take "No" for an answer prompted originality, and it was this more than any other factor which brought out the many brilliant items of design which were present in this scheme.

Whilst the design and supply of the special equipment was a great work in itself, it should not be overlooked that the success of the scheme depended upon the correct and successful placing of the equipment on the far shore in the midst of battle. Harbour engineering, as is well known, is one of the most difficult branches of engineering, owing to the many uncertainties and the fact that the engineer is fighting nature to the full extent. In normal practice these difficulties are, in time, overcome by careful survey and studies of the hydrographical conditions. In our case, however, such studies had to be confined to old charts and aerial photographs, although, due to the brave action of Naval personnel, visits by night were paid to the sites and valuable information obtained. For a great deal of the planning reliance also had to be placed upon local knowledge and to a certain extent upon snapshots which, it will be remembered, were called for and in fact received in great number.

It will be recalled that the first plans of the harbour were prepared in Washington by the Joint Committees, mainly with the object of determining quantities of equipment required, but obviously it was necessary at that time to give the greatest consideration to the many aspects of planning; such, for instance, as the correct placing of breakwaters, having regard to contours, entrances and the possibility of scour, etc., whilst meeting the staff requirements for sheltering the shipping and meeting the discharge programme. Soon after my return from Washington these plans of the harbour were reviewed by the committee of four leading engineers already mentioned, working in conjunction with the War Office and collaborating with the Director of Navigation, Admiralty, in connection with navigation aspects.

The planning of the operation meanwhile proceeded in all its many details and the supply position of the equipment was assured for such parts of the plan as had been settled, but more and more requirements were added, involving new designs.

I cannot give enough praise to the services rendered by the N.P.L. of Teddington. Throughout, I made the practice of sending there any problems connected with the floating equipment so that trials with models could be made in the tanks. They accepted all these demands enthusiastically and were at all times ready to give advice based upon a profound knowledge of the subject.

Whilst the Chiefs of Staff had laid down that the harbours were required to be designed to do service for 90 days only, it was apparent to me that the paucity of good ports on the invasion coasts and their battered state, combined with an advance of the invading armies less optimistic than foreshadowed in the plan, might make the continuance of the build-up in winter months a hazardous matter. Seeing that we had put into the harbours so much material in any case, it appeared wise to add that little extra which would make them serve longer than 90 days. I accordingly pressed the matter and the Chiefs of Staff recognised the wisdom of the proposal. Among the measures taken, the M.O.W.T. at the request of the War Office took over two big suction dredgers from the Mersey, and made alterations whereby they could be employed for picking up sand on the far shore and pumping it into the caissons to add weight to them. The caissons were open topped this being considered adequate to meet the known conditions and convenient for building, but the construction proved vulnerable to the exceptionally high seas which were encountered To overcome this disadvantage, steel troughing was prepared for bolting on the caissons to form a roof Other proposals involved the placing of rubble in torpedo nets to diminish scour at points where this might occur. These steps proved beneficial, as the harbour at Arromanches remained in use up to 1945, and considerable elements of it are still intact as I write.

"Operation Overlord" had always been a Combined Operation, as all Services were to be employed and complete co-ordination ensured. Until early 1944 it had been agreed that the Army were to be responsible for the design, supply and building of the harbours, the parts and equipment for which would, however, be integrated in the whole scheme and convoyed to the far shore in common with all other craft and vessels This convoying was one of the most important and onerous parts of the Navy's duties. However, about that time the Admiralty claimed the over-riding responsibility for the provision of the harbours, in spite of the previous agreement The War Office had set the main frame of the Mulberry enterprise by supplying the layouts, designing and arranging of the whole of the equipment and were, by their organisation, fully equipped to accept the responsibility and to co-ordinate the engineering scheme with the military operation. It was, however, decided that the main responsibility was in future to rest upon the Admiralty, the War Office continuing to be responsible for the design and supply of the concrete breakwater units and the "Whale" equipment, and the invading forces for the sinking of the caissons and their maintenance, as also that of the whole of the harbours. Thus it was that at a very late hour responsibility was divided and this as any engineer accustomed to big works knows full well, can only lead to other than the most satisfactory results. It is interesting to note that the Supreme Commander, General Eisenhower, in his Report on the Operation, refers to confusion occasioned by the division of responsibility between the Admiralty and the War Office and their respective forces.

It is desirable to consider in what respects this alteration in responsibility affected the scheme. It will be remembered that it was settled at Washington that the main reliance for breakwaters was to be placed upon the use of concrete caissons and that these were to be put into full production in order to accomplish supply in the time. The building programme, however, was to be reduced later should the floating breakwater be found practicable on the small-scale trial. In point of fact, the rubber bag—"Lilo"—was abandoned by the Admiralty, but in its place the steel "Bombardon" was substituted and produced on a large scale. Sad it is to relate that the deep-water breakwaters were thus provided in duplicate.

About this time it was felt that a greatly increased number of landing and small craft to be employed would in the event of the weather turning against us, require more shelter than could be afforded by the two harbours. It was at first proposed to utilise the "Bombardons" for the purpose of establishing three shelters along the coast. This was, however, abandoned, as the "Bombardons," on account of their moorings, required deep water and the shelter would be too far from the coast. The Admiralty then applied for 70 to 80 old ships, to be sunk as breakwaters, to form five shallow-draught shelters—code word "Gooseberry"—two, however to be in the Mulberry harbours. The three shelters away from the harbours did useful work and probably saved many craft and allowed working in rough weather to continue.

On the Admiralty assuming responsibility, certain modifications to the layout of the harbours took place, as also to the use of the equipment which was employed in their building Whilst minor alterations to the entrances were made the chief departure was the substitution of sunken ships for the shallow water concrete caissons already under construction and the introduction of "Bombardon" floating breakwaters as an outer breakwater situated to the N.W. in the British, and to the N.E in the American harbour

It was however, probably more in the order of placing and equipment that alterations were most pronounced. My staff, as engineers had naturally given full consideration, apart from design, to the method and order of doing things, and their plan was to utilise all available tug power to tow over and place the concrete breakwater units so as to give shelter at the earliest possible moment and to the greatest possible extent. Concurrently, due to the availability of smaller tugs not suitable for the big tows it was also proposed to tow over and place within the sheltered water the landing facilities in the form of "Whale" equipment.

In the Admiralty plan priority was given to the shallow breakwaters to be formed by ships which could move under their own power and concurrently to the towing and placing of the enti e Bombardon" breakwaters, leav.ng the towing of the big concrete units and other equipment to second place It was argued that the shallow breakwaters could be formed more quickly with ships which could move under their own power.

As events turned out, the original plan would have proved th sounder one for, had the placing of the 'Bombardons" been made the last operation, the tugs which were required for towing this equipment could at the outset have been employed for towing the shallow-draft concrete units, and the breakwater would have been formed as quickl as it was with the ships, and the ships thus used would have been unnecessary. It is well-nigh certain that had this order been adopted the harbours would have been in a more complete state when the great storm, thirteen days after "D" Day, struck them, and the absence of the "Bombardons" on that occasion would have resulted in less damage being done to the other structures.

Again the "Bombardons" require a great quantity of heavy steel moorings, which were in very short supply; so much so that, whereas we had counted upon the "Phoenix" caissons being kept afloat in their assembly areas they had through lack of moorings to be sunk the sea bed, thus necessitating their being pumped out immediately prior to the tugs tak ng them away. A better use of the material available would have resulted if by delaying the placing of the "Bombardons' to the last, the moorings could have been used, first for the mooring afloat of the caissons off the British coast, later on being picked up and relaid off the far shore for the mooring of the "Bombardons."

The aim of the ngineer should be to make the best use of the equipment available; it will be seen, however that through interservice aspirations, this noble aim was not realised

When the supplies of equipment in the form of concrete caissons, spud pie h ads and floating roadways came off production it was the Ar y's espon ibility to store and man them in assemb y areas on the South Coast. This involved, as already mentioned, the sinking of the caissons on to the sea bed, an operation which I resisted strongly as being liable to damage the units which had been designed for one "sit" only, especially as one of the areas, at Dungeness, was on a exposed part of the coast with a foul bottom, and also within range of the Cap Gris Nez guns. The use of this particular area did, however, form part of a wide scheme for deceiving the enemy. The pumping out of the caissons prior to their despatch called for a great effort by the Naval Services helped by the Army Units.

The pierheads were mainly built in Scotland and a few in North-West England, all being built on special sites away from shipyards, and sideways launched. After launching they were towed to Southampton, where the spuds were fitted by military units, and other necessary equipment added. They then proceeded to the assembly areas, together with the floating roadway which had been assembled afloat at R.E. Depots with military labour, from parts delivered from manufacturers all over the country. This floating equipment was all parked in the correct order to ensure towing away in accordance with the order of building on the far shore.

It is interesting to record that for geographical reasons the British designed and supplied the whole of the equipment for the American harbour—an outstanding case of reverse lease-lend. From an engineering standpoint, this fact was notable as the Americans are far more accustomed to meeting big demands than the British; further, it is grat fy ng to know that the American Serv ces were not able to improve on our design proposals They we e, however sceptical of our ability to fulfil the programme, but when they expressed concern at the apparent slow progress, I warned them that we British had our ways of doing things, and in the end they had to admit that we were right. In connection with an extension order for "Phoenix," the American naval and military construction units, even with abundant labour, and plant, were unable to show much, if any, improvement in speed and construction over that attained by the British contractors.

As the British designed and supplied the equipment for the harbours, it was essential that the American personnel, who had to man and place the harbours in position on the far shore, should be trained in its use. This was accomplished by taking a number of Americans into our sea depots, where they were trained alongside British personnel. They proved enthusiastic pupils but betrayed that characteristic which was experienced in other fields, namely, that having acquired the rudiments of a subject, they then preferred to develop other uses on their own and without further resort to their instructors. I remember that shortly before "D" Day, going to one of their exercises, I found that they had completely failed to understand one most important feature of the equipment and one which they were then glad to learn.

Carrying out a big engineering work brings with it thrills which attach to few other professions to the same extent. First there is the picture in the engineer's mind of the completed work—then the break up into details for design and the steady evolution of the scheme—until in the end he sees the picture which he had in mind come to life.

I must confess to a gripping of my throat when, on rounding Selsey Bill in a fast launch from Portsmouth, I saw in the evening haze what appeared to be a vast city set in the sea. Here were assembled at random 80 odd "Phoenix" units and sundry equipment and 19 pierheads whose spuds gave all the impression of tall chimneys.

Again I recall the thrill of seeing eventually all the equipment installed at Arromanches forming the great and busy harbour which I had pictured when the plan was first discussed at Washington.

Needless to say, all this great work was not unaccompanied by moments of anxiety, due to failures and things going wrong: Probably the greatest of these was when the report came thirteen days after "D" Day that a storm, of unusual violence for summer, had struck the two harbours and that great damage had been done. I immediately went over with a party of experts to see what steps were required. The British harbour had suffered mainly from damage to "Phoenix" by floating wreckage, but was easily repaired. It is true to say that, by its continuance to act as a harbour during the storm and those early stages of the build-up, it ensured provision of vital supplies for the Army. The American Mulberry had suffered worse and had to be abandoned, although much of the equipment was salvaged for use elsewhere. Here the bottom of fine sand was not nearly so good as that at Arromanches and the "Phoenix" caissons were placed in water which was deeper than that for which they were designed. This partly contributed to their destruction, but the finishing blow came from the floating breakwaters which came adrift from their moorings to the North-East where the storm broke. The pierheads were not fully protected by the breakwaters, and also suffered heavily. I counted 32 L.C.T., which were of about 300 tons gross, apart from other craft, which had been swept on to the floating roadway which, firmly anchored on shore and at the seaward end to a system of pierheads moored by their spuds, had acted like a fish net, and was in the form of a great curve. The pierheads had been dragged inshore, but the roadway remained unbroken, and this was indeed a testimony to those who had designed it.

In conclusion, it is well to draw what lessons we can from this great undertaking. Firstly, it confirmed that British engineers are still second to none in doing things in a big way if given the opportunity. Secondly, it brought out the importance so often overlooked of organisation in any scheme involving numerous types of engineering and that this organisation should be such that the experts are welded into a team, every member of which has only one consideration —the success of the scheme as a whole. Thirdly, the control of advanced forms of engineering which require to be merged into the military operation in all details must be left to those with experience irrespective of military rank. Finally, divided responsibility in all engineering work cannot lead to the best results. This cannot be better expressed than by quoting words used by Professor Abercrombie in one of his reports: "Though the credit of the achievement is due to many the ultimate responsibility or blame must be carried by one."