TRABZON HARBOUR.

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The Turkish coast of the Black Sea provides, with the exception of Sinop, few, if any, natural harbours. Storms, if seldom of long duration, are sudden and violent.

The produce of the coast district, consisting chiefly of coal, tobacco, filberts, mineral ores, timber and potatoes, together with the ingoing and outgoing trade of the hinterland, gives rise to a considerable medium sized and small craft coastwise traffic.

It is not then surprising that when the government decided to adopt a harbour construction policy and drew up a building programme, two harbours, Trabzon and Eregli, situated at the Eastern and Western end of the Black Sea respectively, should have been at the head of the list.

Trabzon (Trebizond) now has a population of over thirty thousand inhabitants. It is a town with a considerable historical background, having first received mention in 756 B.C., some years earlier than Rome. It is supposed to owe its name to the flat topped hill (now Boztepe) dominating it, likened to a table (trapeza) and owed much of its prosperity to the fact that the Romans conducted their military campaigns against Persia from this port. Traces of the harbour built by the Roman emperor Hadrian are still extant as are the walls and fortifications of the later Genoese and local Byzantine occupants.

In comparatively recent times much of the town's prosperity was due to the Persian transit trade and that of the Turkish provinces served by the Transit road whose terminus is Trabzon.

Fig.1 shows the position of the port of Trabzon in relation to neighbouring countries. The important role this harbour could play, should free navigation be again established along the Danube, as a link in one of the most convenient routes between the Middle East and Central Europe, will be evident.

Prevailing winds in the Trabzon district blow from the North West and less often from the North. Such winds are invariably associated with bad weather in the spring, autumn and winter months, North East winds with fine dry weather at all times.

The direction of littoral drift conforms to that of the prevailing winds and is from West to East. A coastal area of a steep and rugged nature being responsible for excessive denudation, the large quantities of sand and gravel deposited along the beaches has been causing a comparatively rapid advance of the land over the sea.

Fed by large rivers and exposed to relatively low evaporation the Black Sea disposes of its excess of water by allowing it to flow, by way of the Bosphorus, the sea of Marmora and the Dardenelles, into the Aegean Sea. The volume of water involved is considerable as evidenced by the velocity of the current at many points along the Bosphorus. As may be expected the mineral salt concentration in the water is extremely low. It has been shown by observation that the maximum difference of water level due to the accumulated effects of tide, seasonal river flow and wind, does not exceed 0.40 metres.

Sea captains having long experience of the Black sea divide its surface into two theoretical basins, West and East of a line joining Sevastopol to Sinop. It is generally believed that storms are localized to one or other of these two basins and as the total length of the Black Sea is of the order of 500 miles, say a free "fetch" of 225 miles for each of the basins, the maximum wave height to be expected, based on Stephenson's formula, will be as follows:- Max. wave height = $1.5\sqrt{225}$ = 22.5 feet or 7 metres.

Fig.2 shows the coastline in the immediate neighbourhood of Trabzon, where it was specified that the harbour had to be located, as well as depths of water up to 15 metres. On this sketch are also shown a small breakwater built partly before and partly during the 1914 - 1918 war, two small jetties A and B used for the loading and unloading of goods, a small jetty at C for passenger service and a fourth small jetty at D, within the comparative shelter of the small breakwater, partly demolished at the close of the 1914 - 1918 war. Loading and unloading facilities consisted of one very old hand operated 10 ton stationary crane at (a) and one mechanically operated 3 ton mobile crane at (b). All the jetties mentioned above were accessible to craft having a maximum draft of around 2.50 metres and were exposed to wave action and therefore useless in rough weather.

Communications within the site were limited to the main Trabzon - Iran transit road skirting the South-Eastern end of the site and the coastal road forming the Southern and Western boundaries by continuing in a Northerly direction to the root of the main breakwater.

Basic requirements for the new harbour consisted of a primary basin having an approximate area of 450000 M2, a quay wall 400 metres long, a secondary small craft basin 100000 M2 in area, the depth of water within the primary harbour basin being not less than 10 metres.

It has already been mentioned that the direction of litteral drift had been observed to be from West to East. Observations of surface and underwater currents led to the conclusion that in the neighbourhood of the projected main breakwater the velocity of surface and deep water currents approximated to 550 metres per hour in a West - East direction. The results of wind observations have been incorporated in the "wind rose" shown in figure ( ), though no accurate information regarding the maximum velocity of wind to be expected was available at the time when work was begun. Borings made in the sea bottom, especially along the projected location of the quay wall and carried to a depth of 20 metres below normal sea level, showed the sea bottom to consist of alternate layers of sand and gravel.

Abundant stone, though not always of good quality, is to be found in the immediate surroundings of Trabzon. All rock in the neighbourhood is volcanic, varying in nature between andesite and volcanic tuff. Figure ( ) shows outcrops of rock determined by a preliminary survey as presenting features favourable for the location of a quarry. No boring machinery being available, detailed surveys, essential in this type of rock and in large scale work when for the sake of economy, all the rock excavated along a wide quarry face has to be put to good use, could not be made. Samples of rock taken from the most promising quarry sites, Nos 1,3,5 and 6 and analysed, determined the fact that the rock was generally suitable for use in a breakwater. The rock in the small breakwater opposite quarry site No 1, consisting of stone taken from that quarry, had weathered well during the 40 years the breakwater had been in existence.

Good sand and gravel were observed to be available along the shore at all times within a distance of 2 kilometres of the site.

The general conditions may now be summed up as follows:-

1. Winds affecting the harbour blowing from the West, North - West and occasionally from the North causing a wave height of about 5.50 metres.
2. Direction of littoral drift and surface and under water currents from West to East, the velocity of the latter being of the order of 550 metres per hour.
3. A good sea bottom with depths not exceeding 15 metres along the location of the breakwaters. No rock excavation anticipated.
4. Rock abutment and comparative protection for the root of the main breakwater.
5. Suitable rock and good sand and gravel available near the site.
6. Difference in water level due to the sum of the effects of tide, seasonal river flow and wind not exceeding 0.40 metres.
7. Mineral salt concentration in the water low.
8. The harbour primary and secondary basins to have an approximate area of 450000 M2 and 100000 M2 respectively, the depth of water in the primary basin being not less than 10 metres and the quay wall 400 metres long.

A general arrangement of the entire site is shown in fig ( ). Installations and plant will be mentioned as they come into use during the progress of the work. On this plan are shown at:

I. The primary harbour basin.
II. The secondary harbour basin.
A. The main breakwater, 850 metres long.
B. The secondary breakwater, 440 metres long.
C. The lee breakwater, 293 metres long.
D. The quay wall, 444 metres long.
E. The rock fill harbour boundary wall.
F. The limit of dredging at -10 metres.

Conditions were judged to be appropriate for making use of as much rock as possible in the breakwaters, supplementing the bigger grades with artificial blocks should the yield of the quarry not prove to satisfy requirements. The breakwaters were therefore to be essentially graded rubble breakwaters.

The existence of abundant supplies of good quality gravel and sand near the site, expediting the making of cheap concrete, together with the good sea bottom along the line of the projected quay wall led to the adoption of a concrete block construction for the latter work.

There can be little doubt that the rock outcrops at quarry sites No.3 and 6 showed promise of yielding good quality stone, certainly better than that at No.1, but the temptation offered by the location of the latter quarry as presenting possibilities for a very compact site added to the general uncertainty occasioned by the unavailability of detailed knowledge of the quality of the rock at any of the other quarry sites led to the adoption, at least temporarily, of quarry No.1, shown in figure ( ).

The order in which the main works were to be undertaken may now be mentioned:

Partial construction of the secondary breakwater with the object of protecting the floating plant.
Construction of the main breakwater.
Dredging the foundation trench for the quay wall and dredging the primary harbour.
Completion of the secondary breakwater and building of the lee breakwater.
Construction of the quay wall.
Construction of the harbour boundary wall and completion of earthaand sand fill behind this and the quay wall.

Although the construction of the principal works, as ennumerated above, follows the order in which the building of these works was undertaken a certain amount of overlapping, especially in the preparatory stages, of necessity took place. It would perhaps be advisable, for the sake of simplicity, to overlook this fact and treat each individual work separately.

At the opening stages of the work no machinery was available. The excavation of the considerable quantities of overburden at the quarry was done by hand with pic and shovel, the material being moved by means of wheel barrow, single horse cart, ox waggon and motor lorry. Drilling of holes for the excavation of rock was also done by hand, gunpowder or dynamite being used for blasting according as requirements called for a greater proportion of larger sized or smaller rock. Excavated earth was moved to such preliminary works as levelling of the site, deviation of the main transit road ( ) normally passing in front of the quarry, railway and coastal road embankments to the root of the main breakwater and the fill ( ) at the root of the main breakwater undertaken with the object of providing space for the erection of machinery to be used while building that work.

The Secondary Breakwater.

Built to serve the double purpose of protecting the floating plant and acting as a loading jetty for the smaller rock into barges during the construction of the harbour works and also to form the Western and Northern boundaries of the secondary small craft harbour, this breakwater is shown in plan on the general arrangement of the site plan mentioned above. Three sections of the breakwater are also shown in fig. ( ).

The limb of this breakwater running in a North-South direction already existed when the work was taken in hand, having been built around the year 1900 as a rubble breakwater, the largest stone blocks not exceeding 6 to 7 tons in weight. A temporary harbour had been constructed during the 1914-1918 war by sinking ships along a line closely following the location of the present East-West section of the breakwater. This latter section was later destroyed, but the debris, lying over the greater part of the length at an average depth of between one and six metres below normal water level, was judged to afford a sufficiently solid foundation for the new breakwater which would, after a comparatively short time , come under the protection of the main breakwater. The rather exaggerated width of the greater portion of this work was necessitaded by the intended future erection of two derricks, the first to be used for the purpose of unloading material and plant and the second chiefly for loading the smaller grades of rock into barges to be dumped into the core of the main breakwater. Space occupied by railway lines also had to be provided for.

It will be seen from the sections, fig. ( ), that the average height of rock fill above normal sea level was 2 metres, protecting layers of bigger rock, measured horizontally, being four metres thick on the weather side and two metres thick on the harbour side, sizes of individual blocks in these layers varying from one ton to six tons and half a ton to one and one half tons respectively.

Ramps constructed in the quarry against which carts and lorries could back facilitated the loading of the bigger rock with the aid of crowbars the smaller sizes being loaded individually by hand or with spades. The smaller rock having been tipped in position within the limits of the breakwater core, the protective layers of the bigger grades were then unloaded in position, jacks and crowbars expediting this work.

That portion of the breakwater on which plant was to be installed was protected on the weather side and above sea level by a masonry wall and rock fill in the manner shown on the first of the three sections, the remaining length having no additional protection save for a layer of bigger rock on the top surface, applied with the object of preventing the smaller rock, forming the core, from being washed out by over topping waves.

During a violent storm occurring on Christmas Eve of 1948, while construction was in progress, a breach was opened up on the weather side of the breakwater. There was however no breakthrough, the damage was quickly repaired and the work completed without further incident.

The Main Breakwater.

Before any decisions could be taken regarding the nature of the plant required for the construction of the main breakwater the sections and grades of the rock, as well as the weight of the artificial blocks to be used, had to be known. Fig. ( ) shows two typical theoretical sections at depths of 8.00 and 13.50 metres of water. Grades of rock were as follows:

O.A.	Quarry waste	0 - 2	Kgs. weight.
K 1.	Rock	2 - 500	" "
K 2.	Rock	500 - 2000	" "
K 3.	Rock	2000 - 10000	" "
K 4.	Rock	10000- 25000 and over	" "
S.B.	Artificial blocks 2.00x2.00x3.00 metres 30 tons weight.		

It will be seen that the core of the breakwater, to be dumped in position by bottom opening hopper barge, consists of quarry waste and K 1 grade rock, the top level of this core having been fixed at 2.50 metres below normal water level to permit dumping by this means. For the bigger grades of rock it was decided to employ a derrick of 15 tons capacity capable of dumping the contents of steel skips carrying a net load of 12 tons of rock, followed by a 40 ton capacity cantilever crane with fixed boom, here referred to as a transporter, both these cranes travelling on rails laid on the breakwater at a level of 2.20 metres above normal water. Three DISTINCT means of placing rock and artificial blocks in the breakwater would thus be available: Bottom opening hopper barges towed into position for dumping the breakwater core consisting of quarry waste and K1 rock, a 15 ton derrick operating from the breakwater with skips and dumping K1, K2, K3 and occasional K4 grades of rock, a 40 ton transporter placing individual K4 material and all artificial blocks.

Reference to the sections, fig. ( ), will show that a maximum working radius of approximately 30 metres would be required for the derrick and transporter on the weather side, the derrick alone dealing with the smaller grades and lesser distances required on the harbour side of the breakwater. A study of the same characteristic theoretical sections will show the following approximate distribution, by area and by weight, of the various grades of rock and artificial blocks within the sections:

Grade	Section -8.00	Section -13.50	Average (area)	Average (Wt.)
K1 and O.A.	28%	41%	35%	32%
K2	22%	20%	21%	20%
K3	25%	25%	25%	26%
K4	12%	7%	9%	11%
S.B.	13%	7%	10%	11%

The option to alter the proportions of the various grades of rock, as shown in the theoretical sections, to suit the run of the quarry, was reserved.

A decision having thus been reached regarding the method of placing the rock and artificial blocks in the breakwater, the plant necessary for the quarrying, grading, loading and transport of rock at the average rate of 2000 tons of rock per 10 hour working day, as well as the loading and transport of the corresponding number of artificial blocks had to be planned.

Since natural blocks, because of their superior bedding and wave breaking properties are to be preferred to artificial blocks, and keeping in view the fact that a considerable number of such blocks weighing over 25 tons, in addition to the artificial blocks weighing 30 tons, would be in use, it was decided to adopt standard gauge railway transport throughout.

The laying of rails in the quarry to within a comparatively small distance of the face, the fact that semi stationary derricks were made available for loading the full skips onto the railway wagons added to the greater facilities offered for grading by small scale blasting with wagon drill and jack hammer, led to the adoption of this method of quarrying.

General after war trade conditions were responsible for the impossibility of obtaining plant as specified. Below is a list of the best compromise obtainable, the various units reaching the site in shipments spaced over a period of 3 years.

Quarrying.

1 Stationary electrically driven air compressor 1720 ft.3/min. capacity.

2 Portable diesel air compressors 6 M3/min. capacity.

3" diameter steel air pipe.

2" diameter steel water pipe.

1" and 3/4" diameter rubber air hose.

4 Wagon drills drilling up to 20'.

12 Jackhammers drilling up to 15'.

10 Jackhammers drilling up to 6'.

1 Well drill with 5" diameter bit.

Wagon drill and jackhammer steels.

Wagon drill and small jackhammer jackbits.

1 Forge and drill bit former and sharpener for intermediate jackhammer steels.

2 Small centrifugal pumps.

Grading and loading of Rock.

2 Electrically driven 15 ton derricks, 30 M. working radius, travelling but not self propelled.

4 Diesel crawler cranes 4 tons capacity.

1 Diesel crawler crane 60 tons capacity.

2 Diesel 2 yard capacity excavators.

1 Diesel 1200 litre capacity excavator.

1 Diesel 1 yard capacity excavator.

1 Diesel 1/2 yard capacity excavator.

Slings and chains.

Transport.

5 Diesel shunting locomotives 88 H.P.

26 Flat top bogie wagons 40 tons capacity.

7 Flat top wagons 30 tons capacity.

Rails, sleepers, fishplates etc.

32 Right and left hand switches.

2 Derailing ramps.

1 Jim crow for bending rails.

102 Ten to twelve ton net capacity steel stone skips.

4 Decauville locomotives approximate weight 3 tons.

16 Decauville tipping wagons.

1 Mile decauville railway track and 4 switches.

4 Tipping lorries capacity 5 tons.

4 Hydraulic jacks 24 tons capacity.

Railway type weighbridge 60 tons capacity.

Rock and Block laying Equiptment.

1 Tug 120 H.P.

2 Bottom opening hopper barges capacity 120 tons.

2 Electrically driven 30 metre radius 15 ton self propelled travelling derricks.

1 Electrically driven 35 metre working span fixed boom block laying transporter capacity 40 tons.

Rails, sleepers, timber baulks, fishplates etc.

Concrete Block making Plant.

1 Washing and screening plant capacity 250 cub. Yds. per 10 hour day.

1 Diesel 1/2 yard dragline.

1 Self propelled diesel gantry crane capacity 60 tons.

1 Electrically operated travelling but not self propelled derrick capacity 3 tons.

3 Concrete mixers capacity 400 litres.

Collapsible steel forms.

Rails, sleepers, fishplates etc.

Block lifting tackle.

2 portable belt conveyors.

1 Centrifugal pump.

Power Plant.

3 Diesel electrical generating units 300 K.W.A. capacity with switchboards.

1 Transformer 400 to 6000 volts 400 K.W.A. capacity.

2 Transformers 6000 to 400 volts 250 K.W.A. capacity.

1 Centrifugal pump.

Underground and overhead electrical cables, posts, insulators etc.

Workshop.

1 Lathe 12"

1 Lathe 71/2".

1 Metal planing machine.

1 Mechanical metal saw.

1 Mechanical drill.

3 Welding sets.

2 Blacksmiths forges.

Electrical repairs shop and equiptment.

Carpenter's shop with circular saw.

Metal workers and carpenters tools.

Spare parts store.

Auxiliary Plant and Equiptment.

2 Chaseside shovels.

1 Seven ton and 1 five ton steam derrick.

3 Sets divers equiptment.

24 Steel skips 5 ton capacity.

The shortage, or evencomplete absence of skilled labour needed in the erection and operation of machinery and plant presented one of the main difficulties at the outset. Ships doing the regular coastal service not being capable of unloading single units weighing more than three tons, plant had to be dismanteled accordingly before shipment, thus accentuating erection problems. A few of the units such as locomotives, excavators, crawler cranes, the weight of whose parts, after the maximum admissible dismantling, still weighed more than three tons were shipped on specially chartered vessels. A 4 ton capacity crawler crane, weighing 12 tons, arriving at the site before suitable unloading plant had been erected, was loaded into a 20 ton capacity timber lighter and after having survived three days of storm anchored out at sea was beached with the aid of improvised capstans. The lighter was then sawn in half and the crane moved out under its own power.

Among the first plant to be delivered were a 5 ton and a 7 ton steam derrick. These were unloaded and erected at the secondary breakwater and at the root of the main breakwater respectively, with the object of unloading the plant, coming within their capacity, to be erected at these points. The erection and operation of these two derricks proved to be a training ground for future erectors and operators. With the aid of the 5 ton derrick at the secondary breakwater was unloaded and erected the 15 ton derrick by means of which was later landed the heavier plant, while the 7 ton derrick at the root of the main breakwater landed and erected the 15 ton main breakwater derrick which in turn erected the transporter. An operation accompanied with considerable hazard, but completed successfully was the unloading of 5 locomotives, each weighing 22 tons, by a 15 ton derrick erected by unskilled labour, supplied with inadequate electrical power and worked by an operator who had never handled a derrick before.

Since the original quarry, situated opposite the secondary breakwater (Q) had to be abandoned at an early stage of the progress of the work, a detailed description of the layout at this quarry will not be undertaken though the reasons which led to its abandonment will be briefly mentioned.

It will be remembered that, no boring machinery being available, an estimate of the nature of the rock back of the quarry face could not be made. Excavation of the rock and dumping into the main breakwater was begun on July 10, 1949, on a 90 metre face the quality of the rock deteriorating as it was worked back. Pockets of volcanic ash and large quantities of unsuspected overburden occurred with increasing regularity.

The steeply upward sloping back of the quarry site, excluding all possibility of removing overburden except by tipping it into the quarry floor, delayed excavating and grading operations considerably. It was early realised that out of the excavated material the proportion of waste, unfit for the breakwater and only fit to be dumped into the fill, was out of all proportion to actual requirements. By the end of May 1950 it had become evident that a decision in favour of a change to a new quarry site had to be taken and the formalities necessary for effecting the change over were undertaken while a survey was made of the immediate surroundings keeping in mind the following essential requirements:

1. A quarry the height of whose working face would at no time exceed 30 metres, allowing blasting, barring and loading to be carried out at the same time within the area served by one derrick - about 55 M.
2. A quarry with a level, or nearly level, top allowing the overburden to be removed independently, without interference with blasting and loading of rock in the quarry floor.
3. A fairly homogeneous rock throughout so that approximate requirements of 75% good quality rock for the breakwaters and 25% inferior quality rock or overburden for the fill should be obtainable.
4. The quarry to be situated as near the present site as possible with easy access.

The site for a quarry closely agreeing with the above requirements was located between the sea shore and the coastal road at a distance of 1850 metres East of the present quarry. Trial pits sunk with the object of determining the depth of overburden and the quality of the rock led to the conclusion that the quantity of overburden would not exceed 60000 tons, that the rock, a volcanic tuff resembling andesite, was homogeneous throughout and that the quarry would probably yiels large blocks and little waste.

Requirements for a shift to the new quarry were as follows:

1. Appropriation of land formalities.
2. Approximately 2000 metres of railway line.
3. Building of a temporary railway bridge of 63 metres total span.
4. Building of a number of small culverts along the railway line.
5. Erection of overhead electric power line including accessories.
6. Dismantling and re-erection of plant and equiptment.
7. Buildings and sheds for housing plant at the new quarry.

The authorization necessary for making the shift to the new quarry was received towards the middle of July 1950.

Considerations of appropriation of land and property and intersection of roads and streets, with the necessary delays involved, were instrumental in leading to the decision of locating the railway line along the beach, in spite of the rock protection this would necessitate at certain points where the location approached the sea line. Levels at the old site, the bridge and the quarry, together with the necessity of providing head room for culverts and keeping down grades, led to the adoption of an average level of +3.50 metres for the fill which is continuous throught. The material for the fill consisted chiefly of earth and quarry rubbish, was provided by the old quarry for the section between the old quarry and the bridge and by the new quarry for the section between this and the bridge; this material having been loaded by mechanical shovel into self tipping 5 ton lorries and tipped in position. At points where it could be done conveniently and with the object of speeding up the work, sand and gravel from the beach were pushed up to the fill by buldozer, the lorries tipping over this. culverts, with spans varying between 1.50 and 4.00 metres, were built with concrete foundations and masonry abutments the sleepers resting directly on timber beams, 0.30 by 0.30 metres in section, strutted where necessary and located under the rails. A number of concrete pipe culverts of 0.40 and 0.60 metres internal diameter were also constructed. Balast consisted of broken stone, coarse and fine gravel and in places of coarse sand. Banks exposed to sea action or scour were protected by tipping rock out of the wagons at the required places. The single track railway line had been completed by the end of October 1950.

Located between the 50 metre masonry arch road bridge and the sea the railway bridge (fig.) consisted of nine spans of seven metres each. A considerable number of timber baulks of 30 cm. by 30 cm. section and lengths varying from 4 to 6 metres being available at the site, it was decided to make use of these for the beams and the struts of the bridge. This condition led to the adoption of an intermediate span of 7 metres, investigation having shown that with equal longitudinal strutting the assumed maximum ten ton wheel load would be supported successfully by two superimposed baulks assumed to be stressed independently as beams. The foundations consisted of concrete blocks 5.00x1.20 x2.20 metres supporting piers made of 4 circular section timbers of 0.25 metres diameter placed in pairs under the rails. Suitable cross bracing and 1 inch diameter bolts held the structure together. The bridge had been completed by the end of September 1950.

While the railway line and the bridge were in course of construction the Eastern side of the old quarry was exploited to the extent made possible by conditions there. One 2 yard excavator was sent to the new quarry to excavate earth for the railway line out of the Quarry floor and a buldozer was put to work scraping and shifting the overburden off the level top and placing it on either side of the effective quarry face. The earth excavated out of the quarry floor was transported by means of the 4 five ton tipping lorries available, supplemented by a number of lorries hired on the local market.

The sequence of operations required to complete the change over from the old to the new quarry may be summarized as follows:

1. The removal of earth out of the new quarry floor before the rainy season.
2. The stripping of the overburden a sufficient distance back from the new quarry face to allow for free working during the winter months.
3. Preparing the quarry floor at the Eastern end of the new quarry for the erection of the first 15 ton derrick.
4. Erection of buildings for housing stationary compressor, workshop, transformer, drill sharpening equiptment etc., water supply.
5. Dismantling of stationary compressor and erection at new quarry.
6. Dismantling and erection of first 15 ton derrick at the new quarry.
7. Preparing the quarry floor at the Western end of the new quarry for the erection of the second 15 ton derrick.
8. Moving of excavators and other plant from one quarry to the other as required.
9. Dismantling and erection at the new quarry of the second 15 ton derrick.
10. Final abandonning of the old quarry.

The change over to the new quarry having been undertaken while the old quarry was still workable plant only remained idle during the short period required for transport from one quarry to another. No fall in the tonnage of all grades of rock and waste was therefore noticable as the following figures will show:

Production January - March 1950, 34110tons.
Production April - June 1950, 51716 tons.
Production July - September 1950, 87500 tons. (period of change over).
Production October - December 1950, 104098 tons.

High voltage transmission of electrical energy to the new quarry was thought to be advisable, the distance between the power station and the new quarry being a little under 2000 metres. A 400 KW transformer stepping up the voltage from 400 to 6000 at the powerstation end and a corresponding 300 KW transformer at the quarry end reducing the voltage to the normal 400 volts were installed. The bigger transformer at the generating end also took care of the main breakwater electrical installation where high voltage transmission had become necessary. Timber posts carried the overhead wires. The installation had been completed before the end of September.

The winter of 1949 - 1950 had been an extremely severe one. High winds blowing from the North-West caused heavy seas the maximum wave height having been estimated at between 5.50 and 6.00 metres. Heavy falls of snow and exceptionally low temperatures (8 to 10 degrees centigrade below zero) were recorded. These conditions prevailed, with little respite, for the greater part of the months of January and February. At the end of 1949 the main breakwater, being built out with a top width of 14.00 metres at an average level of +2.00 metres with a temporary raised protective portion on the weather side, had reached a length of 160.00 metres. Although the grading, as represented in the theoretical sections had been approximately adhered to the protective layer of K4 rock was deficient both quantitively and in size of individual blocks. During the period mentioned above a 15.00 metre length at the end of the breakwater was carried away to a depth of 2.00 metres and three small breaches were opened up at intermediate points which, however, were filled up during the short periods of comparative calm a breakthrough being thus avoided.

The arrangement of rails laid on the breakwater is clearly shown in figs.(   ). Also shown in the same figures is the arrangement of timber baulks 0.30 x 0.30 metres in section laid under the sleepers along the location of the three outer rails with the object of reducing local settlements in the newly dumped rock. Between the twin 113 lb/yd. transporter rails seen at the extreme right and left were laid two standard gauge tracks of 75 lb/yd. rails for rock transport, the 15 ton derrick utilizing one each of the outer transporter and railway track rails as seen in fig.(   ). The damage done to the rails during winter storms throughout the duration of the work was negligible.

The Quarry. Although the old quarry was finally abandoned on January 10th, 1951, the great majority of the plant and equiptment had been moved to the new quarry and work was well under way by the end of 1950. In contrast to the previous winter the weather continued mild and comparatively dry. After the preliminary blasting and cleaning up operations in the floor and the disposal of the plant the quarry, looking towards the 150.00 metre wide face, presented the following appearance:

Two 15 ton derricks in the right and left corners of the face running on rails placed between the railway lines (fig.) and the side of the quarry; the derricks so erected as to sweep an arc covering the face of the quarry and the railway lines. Working in conjunction with each derrick a two yard excavator and a 4 ton crawler crane. Operating between the two derricks a 60° to crawler crane, one 1200 litre excavator and one 4 ton crawler crane.

One 1 yd. excavator kept in reserve.

Working along the quarry face at various levels usually three wagon drills and a number of jackhammers.

On the top of the quarry occasionally a buldozer stripping overburden and continuously a 1/2 yd. excavator loading earth into lorries for removal to the fill.

To the left of the quarry face and protected by a shoulder of rock, the stationary compressor (S.K.) with air pipe leading to the top of the quarry and into the quarry floor, the workshop and drill sharpening equiptment (W.S.) and facing the sea on the shelving beach the dinamite store (D.S.). At the end of the railway line oil tanks (O.T.).

The rail system adopted is shown in fig.( ).

A characteristic pattern for blasting, adopted after a good deal of experiment, was as follows:

On the horizontal top of the quarry and an average distance of 4.00 metres back of the vertical face 50 mm diameter and 6.00 metre deep wagon drill holes spaced 2.20 metres apart, the charge being composed of 2.400 Kg. 82% nitroglycerine content dinamite at the bottom of each hole followed by 7.200 Kg. 56% nitroglycerine content dinamite well tamped and the hole topped up with sand. One detonator per hole was used with the usual wire leads, the charge being exploded electrically by magneto. The ledge obtained after such a blow was usually clean, requiring a minimum of barring, but had a downward slope which was levelled out by means of small-scale blasting with jackhammer drills. A second blow with holes drilled vertically from this ledge, following exactly the same pattern as before, brought the excavation to approximately 10.00 metres above the quarry floor, the total height of the quarry face varying between 25 and 30 metres.

The third and last blow was done with horizontal holes, at floor level, drilled into the face with a slight downward slope given to the holes with the object of preserving the level of the quarry floor. Charge, length and diameter of holes, were in every particular similar to conditions for vertical holes with the exception of spacing which, in consideration of the greater mass to be shifted, was reduced to 1.60 metres. This blow with horizontal holes, the rock being broken up but remaining in position, gave the most satisfactory grading and the biggest proportion of larger blocks. When drilling with the heavier jackhammers the 25 mm diameter holes about 4.50 metres deep were charged with 1.500 Kg. of dynamite the nitroglycerine content of which varied according to the grading required. The spacing of the holes in this case was 1.50 metres back of the face the distance apart being 1.20 metres. No blasting with horizontal holes was attempted with these drills.

Light jackhammer drill's drilling up to 2.50 metres dealt with such minor blasting operations as levelling shelves, levelling the quarry floor and breaking up blocks upwards of 40 tons in weight. High nitroglycerine content dynamite was mostly used in such cases.

As a general rule end holes, especially when occurring at the shoulder forming the end of the face, were duplicated, the distance between holes then not exceeding 0.50 metres. This applied especially to blasting with horizontally drilled holes.

The shattering effect of a dynamite with a high nitroglycerine content is unsuited for blasting in brittle rock when a high proportion of big blocks is required. The rock being quarried, varying in structure between a volcanic tuff and an andesite, never yielded the proportion of ~~bigge~~ bigger grades as required by the theoretical breakwater sections. Blasting with low nitroglycerine content dynamite alone proved to be unsatisfactory by reason of the failure to obtain a clean break along the line of the bottom of the drill holes. This gave rise to a great deal of barring of rock by hand accompanied with expense and delay. A high grade dynamite was therefore introduced at the bottom of the wagon drill holes whose shattering effect dislodged the rock where it was most firmly embedded while the low grade dynamite above pushed the rock forward with a minimum of disintegration. It has already been mentioned above that the proportion of these two grades of dynamite giving the best results for that particular rock was established by experiment.

It was found that the wagon drills drew 5 cubic metres of air per minute, drilled an average of 4.00 metres of hole per hour requiring one ~~ordin~~ ordinary steel bit for every 18.00 metres of hole drilled; the heavy hand drills drawing 2.500 cubic metres of air per minute, drilling 6.00 metres of hole per hour and requiring a new bit for every 20.00 metres of hole drilled.

Proceedure involving grading and loading of the rock was as follows: All the rock, with the exception of individual blocks weighing more than 10 tons, was loaded into skips capable of carrying approximately 12 tons. These skips, lying in the quarry floor, were filled by excavator and crane, then picked up by the derricks or the 60 ton crane and loaded onto the 40 ton flat top railway wagons in the sidings. It has already been mentioned that two 15 ton derricks, each at the right and left hand side of the quarry, worked in conjunction with a 2 yard excavator and 4 ton crawler crane while a 60 ton crawler crane in the centre portion of the Quarry operated with a 1200 litre excavator and a 4 ton crawler crane. Whereas each derrick with its excavator and crane worked as an independent unit the 60 ton crawler crane in addition to loading skips filled by its excavator and crane also worked its way along the quarry face loading directly onto the railway wagons, by means of slings, individual blocks weighing more than 15 tons.

For efficient results excavators and cranes must co-operate closely. The excavator picks up and loads into the skips the smaller rock (K1 # O.A.) while the crane picks up the larger individual blocks thus exposed (K2 and K3) loading them into their respective skips. The bigger rock having been removed the uninterrupted loading of the smaller rock by excavator is assured. Handling of the bigger rock by means of tongs was attempted, but had to be discontinued in favour of slings, because of the difficulties involved in disengaging the tongs after the rock had been placed in the skip. The 4 ton cranes being incapable of dealing with the bigger K3 rock (4 to 10 tons), this additional work was undertaken by the derricks and the 60 ton crawler crane.

Skips filled with the various grades of rock as described above were picked up by the derricks and 60 ton crane and loaded onto the railway wagons, at the rate of three skips per wagon, care being taken to load each wagon with the same grade of rock. Individual K4 blocks, weighing between 10 and 15 tons were loaded directly into the wagons with the 15 ton derricks while the 60 ton crawler crane dealt with rock in the K4 class in its own area in addition to all individual blocks exceeding 15 tons in weight. Slings were used throughout for this work. Inferior quality rock, unfit for dumping into the breakwaters, together with earth and waste were loaded into skips by excavator and despatched, in the ordinary way by rail, to the fill.

<u>Transport</u>. As shown in fig.( ) a single line of standard gauge railway joined the quarry to the main breakwater. From the 60 ton capacity weigh bridge (W.B.) a single branch line led to the secondary breakwater. Three loops were introduced; two in the neighbourhood of the powerstation and the blockyard for shunting purposes, one in front of the old quarry

where trains were formed with wagons containing the grades of rock as required at the breakwaters. A second branch line led to the blockyard. A switch, first laid at the root of the main breakwater and moved forward as this work advanced, provided a double track in front of the derrick. Of the 5 shunting locomotives only 4 were usually available, one locomotive being held for overhauling or repairs, while of the 26 wagons 24 were in general use.

The arrangement of rails around and in the quarry is clearly shown. Beginning with loaded wagons at the quarry in a siding beside one of the derricks the sequence of operations was as follows: The quarry shunting locomotive having pulled one or more wagons out of the siding then pushed them to the section lettered (a) reserved for loaded wagons. A main track locomotive coming in with empties stationed these on the section lettered (b), reserved for unloaded wagons, then coupled onto the loaded ones at (a) and pulling 3 or a maximum of 4 wagons continued as far as the weighbridge. The wagons, having been weighed, were then pushed into the loop in front of the old quarry where trains were formed exclusively of O.A. and Kl rock destined for the secondary breakwater and combinations of grades as required at the main breakwater. All wagons destined for either of the breakwaters were pushed there to well within the range of the derrick booms. The locomotive then uncoupled shunting onto the second track, coupled onto the empty wagons there and pulling them as far as the loop in the neighbourhood of the powerstation, where they were joined by other empties, pushed the train of empties averaging 7 wagons to the quarry at (b). Now coupled onto the empties and pulling them to a point beyond the switch, the quarry locomotive then pushed them onto the derrick tracks where the empties were required. The derrick now picked up the empty skips depositing them at convenient points in the quarry floor, this operation being combined with the loading of the full skips.

The core of the main breakwater consists of O.A. and Kl rock dumped in position by two 120 ton bottom opening hopper barges. Berthed alternately along side the small timber wharf built parallel to the centre portion of the secondary breakwater by the 120 H.P. tug, the barges were filled with O.A. and Kl rock to their capacity by the 15 ton derrick stationed there. This operation was performed by lowering the full skip into the hold of the barge, unhooking the two fotward attachments and withdrawing the empty skip which was replaced onto the wagon before the next full one was picked up and similarly emptied into the barge. Two rods placed on the shore and later on the advancing breakwater, in line with the axis of the breakwater, facilitated accurate dumping of the rock with the barge moving freely.

At the outset the 15 ton derrick, erected on the fill at the root of the main breakwater, tipped rock in shallow water to the maximum extent of its boom radius consolidating this fill with large blocks, up to 15 tons, on the weather side. A special tipping gear had been fitted to the derrick for this purpose. Rails were then laid on the rock thus tipped, following the centre line of the breakwater and in the manner already described (fig.) with timber baulks under the rails, sleepers and baulks being held together with steel dogs. The derrick was then moved to the end of the fill from where tipping, in accordance with the breakwater sections was continued, rails being laid and the derrick again moving forward. During the opening stages of this work no crane capable of loading more than 15 tons being available at the Quarry the derrick was capable of dealing with all grades of rock. When later the 60 ton crawler crane began operating in the quarry and artificial blocks weighing approximately 30 tons were made the transporter (fig.), between whose legs trains were able to move freely, followed up the derrick laying both artificial and natural blocks by means of steel cable slings. Although block laying by means of tongs was tried at the outset the use of slings was preferred as offering the advantage of adaptibility to natural and artificial blocks alike.

While laying of rock was in progress as described above, tipping by barge (fig.) was begun at a depth of water of about 4 metres the end of the underwater fill thus formed being approximately 45 metres ahead of the derrick following up and tipping over this fill.

When the new quarry had reached full production and an improvement in the grading of the rock seemed very unlikely it was found that the proportion of the bigger grades of rock still fell far short of the requirements of the theoretical sections (fig.). The following table gives the average proportions yielded by the Quarry:

O.A. and K1	72 %
K2	6 %
K3	17 %
K4	5 %

A new set of sections, based on these results, were drawn up and the necessary authorization for their application was duely received. The sections drawn up gave the following proportions at the depths shown:

O.A. and K1	69 %	72 %	73 %	75 %	72 %
K2	8 %	7 %	7 %	6 %	7 %
K3	16 %	14 %	14 %	14 %	15 %
K4	7 %	7 %	6 %	5 %	6 %
	- <u>12 M.</u>	- <u>13 M.</u>	- <u>14 M.</u>	- <u>15 M.</u>	<u>Average.</u>

It will be seen that close agreement existed between the proportions of the grades of rock required by the new sections and the yield of the quarry.

All plant available being in continual service during working hours a nine hour working day had been instituted the remaining time being devoted to maintenance and repairs. With a view to increasing rock production still further a second shift, operating between five and nine o'clock in the evening was started in May 1951. In order to avoid the expense of operating the electrical generating plant during the four hour period, independently operated units alone, consisting of the following, were put into service:

The quarry.	One 2 yd excavator. One 4 ton crawler crane. One 60 ton crawler crane.
Transport.	Two 88 H.P. locomotives. Twelve 40 ton flat top wagons. Forty skips.

It was originally hoped that the twelve wagons loaded during the night shift and hauled to the main and auxiliary breakwaters, ready for placing in position the following morning, would indeed be dealt with during the time taken by the quarry to load and despatch the first train. This proved not to be the case since with the limited number of wagons available on the site it was not found possible to supply the quarry with the least number of empty wagons essential in avoiding delays at the beginning of the following working day. In order to supply the necessary number of empty wagons the derrick at the main breakwater and the derrick and barge at the small breakwater worked an hour overtime daily.

As an indication of the maximum production achieved with the plant at the disposal of the job may be quoted the results obtained for all classes of rock and waste during the three monthly period July - September 1951. This figure is 195019 tons representing an average monthly and daily production of 65 000 tons and 2167 tons respectively. The maximum single day production was 2700 tons.

Owing to the fixity of the transporter boom artificial blocks on the main breakwater roundhead had to be placed in position with the aid of a 50 ton floating crane brought to the site for this purpose. This work having been undertaken after the construction of the quay wall the blocks were brought to the quay wall by rail from the blockyard, loaded into barges by a 60 ton crawler crane and towed to the floating crane.

~~It will be seen that close agreement existed between the proportions of the grades of rock required by the new sections and the yield of the quarry.~~

<u>The blockyard</u>: The proportion of large sized natural blocks yielded by the quarry being totally inadequate for the protection of the weather side of the breakwater this deficiency had to be made up with artificial blocks. At the outset, because of the satisfactory results obtained with masonry blocks, which had weathered well as originally used at the secondary breakwater, it was decided to make use of masonry blocks of an approximate weight of 30 tons for the main breakwater. These blocks, whose dimentions were 2 x 2 x 3 metres and whose weight was a little under 30 tons, as compared to the equivalent concrete blocks, had the advantage of cheapness to recommend them.

A blockyard consisting of a double concrete floor, each floor 384 metres long and 5.50 metres wide, a Henderson 2 x 60 ton gantry crane, one line of rails alongside each of the concrete floors and within the span of the gantry crane and one line of Decauville rails on the outer side of the gantry crane, was prepared. Fig.( ). Built within collapsible steel forms the blocks had a proportion of mortar of 35% of the finished volume of masonry and the mix was 350 Kg. cement per metre cube of sand. Twin channels 0.20 x 0.25 in section ran transversely along the under side of the blocks through which slings were introduced for lifting.

The blocks were made in two rows on each of the concrete floors one row being lifted onto the adjacent row at 30 days and the blocks being despatched to the breakwater for laying in position at 50 days. Stone for the blocks was supplied by the old quarry, each single railway line laid within the span of the gantry crane serving the double purpose of feeding the blocks with stone and moving them to the main breakwater. Located outside the span of the gantry crane the Decauville track served for the transport of sand loaded into Decauville skips by a half yard dragline operating at the beach. Fresh water was supplied from the mains by a pipe line laid along the blockyard with vanes fitted at intervals and cement by lorry from the main store.

Difficulties experienced at the outset were in connection with the bonding of the stone within the block and the placing of the blocks in position at the breakwater. Some time elapsed before the masons acquired the facility of giving the necessary vertical bonding to their work, the blocks made during the initial stages being weak in this respect. At the end of a curing period of 50 days laying of the blocks by the transporter was begun. With one or two exceptions attributed to defective construction the blocks stood the lifting by the tongs, supplied for concrete blocks, well. The laying in position was less successful, the blocks having a tendency to break along a plane in line with the points of the tongs.

Laying by means of slings was then tried successfully, and finally adopted, the time factor being of no importance it being possible to lay 20 blocks a day by this method whereas the gantry crane with its slow traversing motion loaded a maximum of 12 blocks during the same period.

After 700 of such blocks had been made and successfully placed in position orders were received to discontinue the making of masonry blocks which were to be replaced by concrete blocks. This change over had been completed by the end of September 1951.

Concrete blocks were made, as before, within collapsible steel forms, three cubic metres of rock being incorporated into each block of 12 cubic metres volume, the dimentions being, as before, 2 x 2 x 3 metres and the average weight a little under 30 tons. The concrete mix consisted of 0.558 M3 sand, 0.630 M3 coarse gravel, 0.213 M3 fine gravel and 300 Kgs. of cement for every metre cube of finished, vibrated concrete. A 450 litre concrete mixer supplied the concrete for 6 blocks per 9 hour working day, the handling of the concrete being taken care of by a three ton travelling electric derrick with special tipping skip.

Sand and gravel were supplied to the blockyard by a washing and screening plant erected near the quarry and having an estimated capacity of 200 M3 per working day. The plant, as supplied, provided for one silo each for sand and gravel; the remaining grade of gravel and the rejects being stocked around the plant. With the object of reducing handling costs a third timber silo was constructed for the second grade of gravel, the rejects being led to a stone breaker erected over the sand and gravel pit, discharging the broken stone directly into the pit from where it was again raised by the bucket conveyor together with the sand and gravel to the screening grids.

Sand and aggregate were transported from the washing and screening plant to the blockyard, over the intervening 2000 metres, in five 30 ton flat top railway wagons converted into silo wagons with a slanting bottom and sliding doors. The wagons were partitioned into three cells whose capacities were proportional to the grades of sand and gravel in use, these wagons being brought by rail under the silos and filled before being despatched to the blockyard.

A Decauville railway line running from the washing and screening plant to the beach carried the sand and gravel loaded into the wagon skips by a half yard dragline operating on the beach. The skips unloaded directly into the conveyor pit, were pushed beyond, picked up by a locomotive operating over a loop and hauled back for refilling at the beach.

<u>The Crest Wall</u>. The crest wall was originally designed as a concrete foundation one metre thick and eight metres wide laid on the levelled main breakwater at 1.25 metres above normal sea level, capped by a concrete wall seven metres wide, 1.50 metres thick on the harbour side and 3.25 metres thick on the weather side. When it was realised that the construction of the crest wall would be carried on at the same time as the making of the quay wall blocks and that the output of the washing and screening plant would not adequately supply both these works with sand and gravel, it was decided to revise the design of the upper crest wall altering the construction from concrete to rubble masonry in cement mortar of a 300 Kg. cement per M3 sand mix and a dressed face.(fig.). The concrete foundation course consisted of a concrete mix of 275 Kg. cement per M3 agregate and sand, 30 per cent per volume of stone being included in the concrete. Work on the crest wall was begun towards the end of November 1952. Plain joints were formed at approximately 15 metres interval.

Construction of the crest wall was begun at the near end of the roundhead and proceeded backwards towards the root of the breakwater, frequent levelling having shown that, with the exception of the roundhead, the remaining portion of the breakwater had ceased to settle. Stone, sand, gravel and cement were fed to the crest wall construction area by the 15 ton derrick moving backwards towards the root of the breakwater as the work progressed in that direction. Stone was supplied from the quarry in skips, by rail, to the derrick. to be unloaded at suitable points for manipulation by ~~the concrete mixing gang or~~ the masons. Sand, gravel and cement were also supplied in skips, by rail, from the washing and screening plant and the store to a 400 litre concrete mixer located on the land side of the derrick, the mixed concrete and mortar being fed to the foundation course and the masonry upper works respectively by the derrick, in suitable skips.

In addition to this work the derrick handled the dismanteled rails, sleepers and timber baulks as it moved backwards and the breakwater surface was levelled preparatory to receiving the concrete foundation course. A barge fitted with a belt conveyor and carrying stone, gravel, sand and cement stood bye to supply, when needed, this material at points which had remained beyond the reach of the derrick.(fig.).

Appreciable settlement no longer occurring at the roundhead the crest wall foundation and masonry upper works were constructed, material being supplied by barge and tipping lorries travelling over the completed crest wall.

One hundred ton bollards, anchored to reinforced concrete sections 5 metres long. as measured along the axis of the crest wall, and consisting of the entire cross section of the wall and foundation (fig.) were introduced at 100 metre intervals along the breakwater and rings were fixed at suitable points in between.these. Concrete and masonry steps and iron ladders leading from sea level to the top of the crest wall, as well as a small reinforced concrete lighthouse at the roundhead were also constructed.

In order to keep the main breakwater artificial blocks clear of the swinging ballast box of the 15 ton derrick during construction of the breakwater, the nearest row of blocks had to be located approximately four metres away from the weather side of the crest wall. It was decided to fill this gap with K2 and K3 natural blocks approximately 16 000 tons of rock being required for this work. The 15 ton derrick not being available a ten ton crane was assembled on one of two timber platforms placed on the level portion of the crest wall. The platform served the double purpose of raising the swinging back of the crane, thus allowing a complete turn to be made, and also of preventing damage to the masonry on which it rested. The crane progressed by crawling onto the second platform and by palcing before it the platform off which it had crawled. Rock was supplied to the crane by barge and in 12 ton skips, the crane raising individual blocks out of the skips and placing them in position.(fig.).

Dredging.

A steam bucket dredger equipped with 1 yd3 capacity buckets together with two 500 ton self propelled deisel barges arrived at the site on October 21st 1951.and was put to work at the Southern end of the quay wall location preparatory to opening up the foundation channel in a Northerly direction. The main breakwater had at this date reached a length of 650 metres affording sufficient protection for dredging operations.

In order to avoid silting of the quay wall foundation trench, it was thought advisable to first dredge a trench 75 metres wide at a depth of ten metres below normal water level, and located along the centre line of the quay wall foundation, within which the foundation trench proper, 15 metres average theoretical width and 1.50 metres depth, would be dredged. The verage depth of water at this point being two metres and assuming the slope the trench sides, where excavated, to be one on three, the quantity of erial to be dredged for the total 400 metre length of the quay wall was mated to be of the order of 320 000 M3. Work in this restricted area omparatively slow, the main trench and later the foundation trench tion having been completed by November 1952. The quantity of material ed by this date was 582 000 M3, far in excess of the estimated M3. This was due to the movement of silt towards the trench from r mouth resulting in a slope much less steep than the estimated e.

edging of the main harbour to a depth of ten metres within the (fig.), as well as the entrance to the small crafts harbour six metres, continued until April 1953 and yielded M3 sisting of sand, gravel and small sea shells.

Extension of Secondary Breakwater.

When loading operations of bottom opening hopper barges intended for the main and lee breakwaters had ceased, the 15 ton self propelled derrick stationed at the secondary breakwater was moved forward, in the direction of the roundhead, and the breakwater extended by dumping rock in the ordinary way with skips, the rock being supplied by rail. Additional rails were added to the derrick and railway track consistent with the progress of the derrick. Since the entire length of this work would at all times remain under the protection of the main breakwater the outer protective layer consisted of K2,K3 and occasional K4 rock, all these grades being within the capacity of the 15 ton derrick. No artificial blocks were used. Sections of this breakwater are shown in figure . A small steel trestle lighthouse fixed onto a concrete base was constructed on the roundhead of this breakwater.

The lee Breakwater.

Dumping of rock at the lee breakwater was begun in May 1952. O.A. and K1 rock was first dumped by bottom opening hopper barge along the location of this breakwater followed by dumping by crawler crane and 12 ton skips. (fig.). A branch railway line, taken from the main line at the appropriate point, the track being continued along the centreline of this breakwater as the 15 ton crawler crane, a converted 2 yd. excavator removed from the quarry, worked its way over the rock fill, supplied the rock.

With the exception of the upper horizontal layer of bigger rock (fig.) the breakwater section was completed on the way out, the final upper layer of rock being placed in position as the rails were dismanteled and the crawler crane travelled backwards towards the root of the breakwater. Because Northerly storms were seen to cause small settlements at the roundhead a number of artificial 30 ton blocks were laid around this point with the aid of the floating crane. A small steel trestle lighthouse, similar to that provided at the secondary breakwater, was constructed on the roundhead.

The Quay Wall.

The total length of the main quay wall is 400 metres, a type embodying the slice work principle with large unbonded blocks forming the whole depth of the wall section having been preferred. A 14 metre long neucleus, consisting of blocks laid horizontally, was formed at the Southern end while the Northern end was joined to the breakwater by means of an auxiliary wall 30 metres long and running parallel to the breakwater. Borings driven to a depth of 20 metres below water level, along the line of the wall, having disclosed the existence of alternate layers of fine and coarse sand and gravel the wall is founded on a layer of rock fill 8 metres wide and 1.50 metres thick. Levels as related to normal sea level are:

Bottom of rock foundation	- 11.50 metres
Top of rock foundation	- 10.00 "
Top pf blocks	+ 0.50 "
Top of quay wall	+ 1.50 "

Fig. shows that the wall section consists of seven blocks 1.50 metres high and that the thickness of each slice is also 1.50 metres. The composition of the blocks was the same as for the main breakwater blocks: 0.840 metres cube gravel, 0.560 metres cube sand and 300 Kg. cement per metre cube of finished vibrated concrete, 0.25 metres cube by volume of rock being incorporated in each metre cube of finished block. An exception to this rule occurred where steel reinforcement was introduce into the blocks to care for tensile stresses which the concrete ~~alone~~ was not judged capable of withstanding alone. No stone was placed near these areas. A reinforced ~~coping~~ concrete coping, one metre thick, designed as a beam to withstand both vertical and horizontal loads and to which the 75 ton bollards and rings were anchored, rests on the topmost row of blocks and is fixed to these by means of six steel reinforcing rods of 16 mm. diameter per block.

As soon as the blockyard had been freed of main breakwater artificial blocks the casting of quay wall blocks was begun. These were made within collapsible steel forms, constructed at the workshop on the site (fig.), two timber boxes 0.35 x 0.35 x 0.15 metres, placed longitudinally 1.50 metres apart, being introduced within the blocks just above their centre of gravity in a vertical and on the centre of gravity in a longitudinal direction. Tapering vertical timber pieces introduced into the boxes during pouring of the concrete and removed as soon as possible after initial set, provided external contact with the cavities formed by the boxes which were not removed.

A block lifting device consisting of two steel rods with hammer heads, passing through the ends of a lifting beam and spaced 1.50 metres apart, was constructed. The hammer headed rods when introduced into the cavities formed in the blocks and rotated through a right angle provided sufficient bearing area for safely lifting the blocks. The reverse operation freed the lifting device which, while providing easy handling for the block, had the advantage of simplicity to recommend it.

Among the methods considered for placing the blocks for the quay wall with the aid of plant available on the site the following may be mentioned:

1. Placing a 60 ton crane on the pontoon available at the site and making use of the combination as a floating crane.

2. Erecting a staging at the head of the quay wall over which the 60 ton crane would travel while placing the first blocks, further travel taking place on the quay wall itself.

3.-Building a rock fill, parallel to the centre line of the quay wall and distant 34 metres from it, along which the main breakwater transporter, ~~which~~ with its boom turned inwards, would be made to travel while laying the blocks.

The first method was discarded when it was discovered, after investigation, that the available pontoon was not adequate for the purpose and that the building of a new pontoon would exceed all reasonable time limits.

Method No. 2 was discarded when it was realized that a staging built in 11.50 metres depth of water to support a 120 ton moving load would be neither an economical structure nor one easily and quickly erected. The width of the quay wall, moreover, would hardly accomodate the heavy crane.

Method No. 3 was adopted as being the one most likely to give satisfactory results. The total quantity of rock needed for the transporter fill was about 30 000 tons, stability investigations for the fill showing a safety factor of 2.8.

Following the completion of the transporter fill, built parallel to the quay wall, the transporter boom was turned inwards, facing East, and the transporter run onto the fill without incident. The turning of the transporter was accomplished by running it back and forth on an 80 metre length of track while curving the rails in the desired direction before each run. A period of 15 days had originally been alloted for this operation, which was actually carried out in half this time, the moving of the track having been greatly speeded up by the aid of a tractor. Independent two rail tracks were used nailed onto half sleepers 125 cm. long and spaced 50 cm. apart. In order to facilitate levelling and shifting of the tracks a layer of sand was first applied to the already consolidated fill at the root of the main breakwater where the operation took place. At no time was there any undue settlement under the sleepers the track having proved adequate for the purpose. The same method of track laying was adopted for the transporter fill.

When the quay wall foundation trench had been dredged O.A. and small K1 rock was dumped into it by bottom opening hopper barge the barge position being determined by sighting off the shore in two directions following the instructions of a diver. Final levelling of the foundation, using ballast as packing material, was done as follows:- A frame 10 metres long and 5 metres wide, consisting of four lengths of rails welded together at the corners, was lowered onto the foundation, the direction and position of the frame being fixed by lowering plumb lines guided by a theodolite operating from the nearby shore. A staff, consisting of a pipe 11 metres long and with a graduated scale fixed to its upper end, was then lowered on to the four corners and intermediate points of the frame while divers packed the underside of the frame with stone to the required level, following the instructions of the operator of a level on the shore. Stone was then lowered in small skips by a four ton crane operating from a pontoon until a roughly level surface had been obtained. The whole operation was then repeated with greater accuracy the irregularities on the surface of the foundation now being filled in with ballast. A piece of tubing was then run along the top of the frame and intermediate points were levelled by adding or removing ballast according to requirements. The rail frame was then removed and replaced for levelling the next ten metre section.

As soon as an appreciable length of the foundation had been levelled block laying was begun at the Southern end of the quay wall. The block laying system employed avoids all bonding between vertical, rows or nearly vertical, rows of blocks thus allowing each row or slice to settle at will, should local weaknesses be present at foundation level, without affecting adjacent rows. This effect is best obtained with rows inclined to the vertical in the direction of the length of the wall, an angle of about 26 degrees with the vertical having in this case been assumed. The buttress of blocks formed at the extreme Southern end against which the first, and subsequent inclined slices rested, had necessarily to be built of special horizontally laid and bonded blocks.(fig.).

It was thought to be of the greatest importance to lay the first block as accurately as possible in position. For this purpose a temporary tower ten metres high, built of light section steel angles, was constructed in such a way that when the base of the tower, fitted with cleats, was applied to the four corners of the horizontally laid block the four side members of the top of the tower would lie exactly above and parallel to the sides of the block. The arrangement was first tested on land, the necessary adjustments being made before the block and tower were lowered onto the quay wall foundation. The block lifting tackle freely passing through the tower it was possible to lift and move the block and tower at will until the final adjustment had been made. The tower was then removed and all the horizontally laid blocks forming the foundation course of the preliminary bonded section, consisting of 61 special blocks, were placed in position.

Subsequent courses were laid in a North-South direction, the blocks forming the Northern sloping face being placed with care and accuracy, thus providing an even bedding for the first row of unbonded inclined blocks.

A certain amount of settlement in the rock foundation a short time after the laying of the blocks was anticipated, this settlement actually never exceeding 0.15 metres. A one per cent backward slope was also stipulated to make allowance for any forward movement after the fill had been placed. It was found, however, that the fact that the centre of gravity of the wall lay well back of the centre line was responsible for a one per cent settlement slope, this movement taking place within a few days of the laying of the blocks. As it was not anticipated that the thrust of the stone fill placed behind the wall would in any way affect its stability, it was decided to continue laying the blocks vertically on a horizontal foundation. Events justified this method of proceedure.

Blocks lying on the blockyard runway were loaded onto 40 ton wagons by means of the gantry crane or 60 ton crawler crane, were brought by rail, along the transporter fill, to the transporter and picked up for laying in the quay wall. These blocks, the heaviest of which weighed 25 tons, were palced in position with the aid of the 40 ton transporter with ease and accuracy, the system of lifting with hammer headed bolts, the heads bearing just above the centre of gravity of the block greatly contributing towards ease of handling.

Three sets of diver's equipment, the suits fitted with telephones, were available at the site, only one of the two divers employed operating at block placing at any one time.

Each independent slice consisting of seven blocks, the top of the topmost block reaching 0.50 metres above normal water level, was constructed independently the position of each topmost block being checked for alignment, any small inaccuracies present being corrected in the next row.

As soon as an appreciable length of quay wall had thus been constructed the wall was loaded with two rows of blocks placed longitudinally and one block placed transversely, these blocks being allowed to remain in position, usually 15 days, until all settlement had ceased. After loading and final settlement had taken place it was found that the greatest difference in level and spacing between any two rows of blocks, or between any two intermediate individual blocks, was 5 and 6 centimetres respectively.

It has already been mentioned that the Northern end of the quay wall was finished off by adding a 30 metre lenght of wall running parallel to the breakwater in an Easterly direction and 25 metres distant from it. This additional quay wall being intended to accomodate tugs and small craft, it was decided to construct this wall on a stone fill raised to the 7 metre below normal water level. The stone fill was dumped by bottom opening hopper barge the same method of foundation levelling as for the main quay wall being adopted. Both ends of this wall being vertical a bonded, horizontally laid block construction system was adopted the blocks being laid as before with the aid of the transporter.

Over the topmost row of blocks was applied a layer of plain concrete intended to level off the small depressions existing between blocks preparatory to applying the reinforced concrete coping beam a part plan and section of which is shown in fig. . Reinforced, as shown, with 26 mm. diameter longitudinal steel rods and 10 mm. diameter stirrups, this reinforcement was maintained throughout, variations in placing being adopted at points where electrical plug boxes, water vanes and steps were introduced within the beam. The same beam section was maintained over the auxiliary quay wall but with lighter reinforcement. Expansion joints were at 50 metre intervals.

Within the coping beam and running the whole lenght of it, a crane rail, a 2" diameter water pipe, an electrical power cable and a telephone cable were introduced, while (fig.) at (a), (b) and (c) were placed drainage ducts, electrical plug boxes and water vanes respectively, 75 ton bollards and bea rings being anchored into the beam at (d) and (e). Steps leading down to sea level were also included at convenient intervals.

Fenders consisted of treated oak frames 1.60 by 1.40 metres external dimentions, individual members having a cross section of 25 by 20 centimetres, the frames bolted together and anchored 3 metres apart (fig.) to the coping beam by means of four special 26 mm. diameter galvanized bolts. Over these frames were nailed vertical timbers, 15 by 20 centimetres in section and 1.40 metres long.

A fill consisting of O.A. and K1 rock, one metre wide at topmost block level and having a backward slope ~~level~~ of 1:1, was tipped behind the quay wall care being taken to tip the smaller rock against the back of the wall with the object of creating a seal between blocks and preventing the gradual washing out of the finer grained fill with consequent subsidence behind the quay wall. This rock fill was brought to the transporter in 12 ton skips by rail and tipped by it in position when block laying was not in progress.

The Harbour boundary Wall and the Harbour area Fill.

Located along the Southern rim of the harbour basin (fig.) and joining the end of the quay wall to the root of the secondary breakwater a rock wall of appropriate section and consisting of O.A., K1 and K2 rock (fig.) was constructed. Quantities of rock to be transported for this work being comparatively small and the construction of a railway line necessitating a considerable amount of fill at a time when plant for this purpose was in use elsewhere, two 5 ton tipping and two flat top 10 ton lorries were put into service for transport. O.A. and K1 rock were loaded into the tipping lorries at the quarry by ~~18~~ 1/2 yard excavator and tipped directly into the wall, while a 4 ton crawler crane loaded K2 rock into 12 ton skips, carried by the 10 ton lorries, to be palced into the wall individually, or collectively, by a ten ton crawler crane, depending on momentary conditions during construction. The depth of water at the base of the wall varied from zero to 1.20 metres.

The fill behind and beyond the quay wall and the harbour boundary wall consisted chiefly of sand excavated by a 2 yard dragline from within the secondary harbour and the shore opposite the quarry, supplemented by earth excavated by a half yard shovel. The sand and earth were filled into 12 ton skips the former transported by rail, the latter by 10 ton lorry hired on the local market, both being emptied out at the fill with the aid of a 15 ton travelling derrick running on rails or a 30 ton crawler crane. A volume of more than 250 000 M3 of fill was dealt with in this way.

As a result of the enclosure of the harbour basin it was anticipated that the outflow of the sewers discharging into the basin would cause pollution of the water in this area and a desigh for a main sewer discharging into the open sea was prepared. No indications being available as to the future drainage system to be adopted for the town, the outflow to be dealt with by this sewer was based on topographical conditions. The sewer was made to run along the building frontage, with outflow at the root of the main breakwater, having at all points a gradient of 1:1000. A section was provided sufficiently big to allow for direct cleaning and ample provision was made for storm water overflow, two auxiliary outlets allowing excess water to flow directly into the harbour, at the Southern end of the quay wall, in exceptional circumstances. Constructed of two masonry walls on a shaped concrete base (fig.) with a mortar rendering on the inside and a reinforced concrete removable slab cover, this sewer should prove adequate for all purposes until the time comes for a new sewerage system to be installed.

Buildings, roads, pavements and harbour installations forming part of a separate project to be realized ~~later~~ at a later date no mention of these is here possible.

The harbour has been in full use for the last two years. No unusual swell is noticeable within the main harbour in spite of the rather wide harbour mouth, ships entering and leaving the harbour and mooring alongside the quay wall in all weather conditions.

Final acceptance formalities were completed in June 1955.

William R. Cramer

1957