

## Port of Tema

by

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Mr R. C. H. Russell (Director, Hydraulics Research Station) said that quantitative data on the movement of ships at berths was rarely obtained and there was none in the case of Tema, but by all accounts the berths were remarkably quiet. There had been no case of a ship having to put to sea because of ranging.

208. The contribution of the Hydraulics Research Station to this happy state of affairs was rather a modest one. There were three major factors in determining the movement of moored ships at berths, only one of which had been studied at the Hydraulics Research Station:

- (a) the waves in the vicinity;
- (b) the attenuation of waves by the harbour;
- (c) the response of the ship and its mooring system to waves.

At the time when the harbour was designed there were virtually no wave records. None of the few records that were obtained was harmonically analysed because there were no techniques for making use of such analyses.

209. Again, at the time the Hydraulics Research Station was making its investigation, in 1955, no information on the response of typically moored ships to waves was available. One had merely mariners' views that waves around 1 ft high—some said waves around 2 ft high—were just tolerable for a ship lying alongside. The only one of the three problems that was amenable to study was the attenuation of waves by the harbour, and this was examined minutely in an undistorted model built to a scale of 1:120.

210. Fig. 9 showed a typical response curve, one of a large group which together revealed the performance of the harbour. The ordinate was the maximum wave-height found wherever it occurred along one berth expressed as a ratio of the steady wave-height at sea; the diagram showed how this ratio varied with the period of the waves. The abscissa covered a range of periods from  $7\frac{1}{2}$  to 45 seconds. The figure showed that in the 10-s period wave band responses were very satisfactory, around  $1/20$ . At the long end of the scale, around 45 s, the response rose to one third and there was another whole set of data relating to waves with periods extending from 40 s to 5 min, which showed responses generally in excess of unity.

211. One wondered whether the harbour's freedom from the very long waves in the 40-s to 5-min period band was due to the absence of such waves on this particular coastline. The speaker was inclined to think that this was not the explanation. On the contrary the waves normally reaching Tema formed a regular swell from distant storms and were precisely of the type likely to set up surf-beats.

212. It could be demonstrated that very long waves, or surf-beats, were not too troublesome provided they were not accompanied by shorter period swell. One found that rather stiff ropes were desirable, giving the ship a natural period shorter than that of the surf-beats. The speaker thought that the great success of the design in excluding swell had led to quiet berths in spite of the presence of surf-beats from time to time. Unfortunately this must remain a matter of conjecture because no wave records were available.

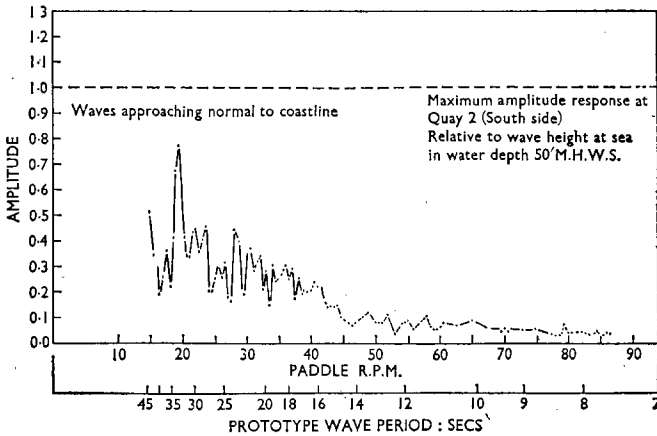


FIG. 9: TEMA HARBOUR: SCHEME A

213. One would not now normally contemplate building a major harbour without adequate records. Not only was the reliability of wave-recorders very much greater, but much more use could now be made of wave records. A combination of harmonic analyses of the records together with response curves derived from models enabled the waves at berths to be correctly determined.

Sir Eric Millbourn (Deputy Chairman, National Ports Council) said that he wished it to be understood that his contribution was of a non-technical nature.

215. He knew of no major port which was started *de novo* since the end of World War II other than Tema. It was quite remarkable that a port which at one period of its planning was estimated to deal with certain traffics, had seen those traffics doubled, twice in the course of construction. Probably the most remarkable thing about Tema was the way in which it had had to be expanded when it looked as though it was about to be completed.

216. One of the most difficult tasks Mr Scott and his colleagues had had to face was the ever-changing 'personality' of the client. There was some reference to this in the Paper, but it was not only General Managers who came and went during the construction of this great port; there was a complete change of Government. This project was started under a Colonial Office regime, but slowly Ghana gained her independence so that she became a self-governing Republic within the Commonwealth. Different people had different ideas, and the Engineer had had to adjust his plans and his ideas to what the ever-changing Client required.

217. The port as such had taken a fair time to construct and bring into operation, and all the changes to which he had referred (even now the port was not completed) must have given the Engineers quite a problem.

Mr J. Duvivier (Messrs Lewis and Duvivier) said that when Tema Harbour was planned there were no natural harbours in the Gold Coast and shelter against the ocean swell had to be created artificially. This meant that large quantities of hard rock were needed, and in this respect Tema was particularly well endowed, with an unlimited quantity of first-class material available not more than 20 miles from the coast. A depth of 45 ft at a distance of about 3500 ft from the shore line was needed to provide an adequate area of sheltered water and a safe entrance without an excessive mass of material being required for the construction of breakwaters. A hydrographic survey showed that all these requirements could be met at Tema. A depth

of about 40 ft inside the outer breakwater and 30 ft in the vicinity of the proposed jetties or quays was necessary without having to carry out more dredging of soft material needed for reclamation, and here again the site appeared to be ideally suited for the purpose.

219. However, it seemed to him that the programme of quay construction parallel to the shore might have been imposed on the Engineers against their will and that development on these lines had not been a part of their original plan for the development of the harbour. Incidentally, Quay 3, which was referred to in §§ 43 and 47 as an alternative site for four or five additional berths, was not shown on the plan in Fig. 3. Was he correct in assuming that Quay 3 was the second of the two proposed finger quays referred to in § 23 and, if so, where was it to be built?

220. As a result of the decision to provide the additional berths at Quay 1, a very large amount of extremely costly rock dredging—over 800 000 cu. yd at 49s/cu. yd—had had to be carried out. Would Mr Scott say whether the layout of the harbour would have been varied if it had been known in advance that development was to proceed on these lines?

221. Perhaps the Author would also be good enough to enlarge on the subject of littoral drift, which might have been a most formidable factor to contend with, although, in the event, it seemed not to have been a factor of any consequence.

222. The reasons which prompted Sir William Halcrow & Partners to recommend Tema as the most suitable site for the construction of a new port were summarized in §§ 6 to 17. Would Mr Scott give an indication of the physical difficulties of establishing a deep water port at Ada, to which he referred, and in what respects was Tema better than Teshie?

223. The subject of littoral drift was referred to very briefly in § 7 yet he was sure that the threat of littoral drift must have been paramount in the minds of the Engineers when the time came to advise the Government to build at Tema.

224. They would presumably be aware that at Lagos, which was only 250 miles east of Accra, the Port Authority had been pumping more than half a million cu. yds of dredged sand over the eastern mole to check the erosion which threatened to outflank it.

225. At Cotonou in Dahomey, which was only 150 miles east of Accra, the French were planning a harbour, of about the same size as Tema, which was now under construction. They were legislating for one and a half million cubic metres of siltation per annum to the west of the harbour and a comparable amount of erosion down-drift to the east.

226. There was also the example of Madras, described in a paper presented to the Institution by Sir Francis Spring in 1913,<sup>5</sup> which aroused considerable interest among harbour engineers at the time, and, later, the case of Vizagapatam, described in a paper by Ash and Rattenbury in 1935.<sup>6</sup> Mr Scott had told him in 1958, when he was looking into certain matters in connexion with siltation and erosion at Cotonou, that there had been little or no tendency for drift material to accumulate to one side or another of the harbour projections at Tema, and circumstances had, as far as he was aware, proved Mr Scott to be right.

227. It was usually possible to determine the direction of littoral drift by observation and inference, but it was not possible to evaluate the drift over a period of time without extensive surveys using radioactive or fluorescent tracers, unless one was able to measure the rate of accumulation against the updrift side of a barrier such as a groyne or a breakwater, neither of which existed at Tema in those days.

228. Conditions at Takoradi, which was about 130 miles east of Tema, would presumably have been taken into consideration. Could Mr Scott say whether the harbour arm at Accra held up a measurable amount of drift?

229. When he visited Ghana in October 1959 there were no visible signs of accretion. Would Mr Scott say whether this was due to the absence of any effective littoral

drift or to the reflection of the waves from the western arm causing a reverse drift over a certain distance to westward of the harbour?

230. Would Mr Scott say whether there had been any measurable erosion of the coast line east of the harbour and whether any further hydrographic surveys had been made along the south side of the western arm and in the entrance, and whether any siltation of the sea bed had occurred?

231. It might be of interest to record that at Cotonou the estimate of a million and a half cubic metres a year of littoral drift, which naturally could only be derived from the evidence available at the time, was actually based on an observation of the phenomenon which had occurred when the steamship s.s. *Aquitaine* was driven ashore near Cotonou, and, to quote from the report, was 'almost instantly joined to the beach by a tombolo or sand spit'. This seemed to him at the time to be rather slender evidence on which to base the design and economics of a new port, but in fairness to the Engineers he had to record that in a paper presented to the 9th Congress on Coastal Engineering at Lisbon in 1964<sup>7</sup> the author mentioned that advantage had been taken of the construction of the new harbour to arrive at a more precise estimate of the amount of drift, and that further investigations tended to confirm the earlier estimate. Incidentally, a model investigation of littoral drift in relation to the proposed harbour, using granulated pumice as bed material, showed that the littoral drift of sand extended seaward of low water mark to a depth of 5 or 6 metres at a distance of 350 metres from the shore, the major portion along the bar and the lesser portion between the inshore channel and high water mark.

Mr J. E. G. Palmer (Rendel, Palmer & Tritton) said that he intended to touch very briefly on what seemed to him the most important points, which, in spite of several readings of the Paper, he had not been able to get entirely clear.

233. With regard to the depth at the entrance, the 7-fathom contour did not appear on the general layout of Fig. 3, where it looked as if it were only -40 ft; from the chart shown during the introduction to the Paper, however, it looked as if the entrance had reached -42 ft and that, of course, was what was needed as there would undoubtedly be 45 000-ton oil tankers coming in drawing 38 ft, with 4 ft under the keel.

234. With regard to the main breakwater, he would have been pleased if Mr Russell could have said a little more about his model tests on the profile. The height was raised, as a result of the model tests, from 8 ft to 13½ ft above mean high water springs, and the Paper stated that the original profile would have proved 'barely adequate'. This implied that it would have been safe to adopt an appreciably lower level as the run-out level for the construction plant, the crane, the railway tracks and so on; a lower level would have had the advantage of giving a greater width of breakwater behind the plant, and more room for shunting lines and passing loops. The quantity of rock to be placed on the run-out would also have been less, and this would have resulted in some saving of time, so that sheltered water would have been available sooner for the works inside. Under the system he had suggested, the usual capping parapet could have been built on the run-back, serving to anchor the rocks firmly in place. With regard to the lee breakwater and fishing harbour breakwaters, how had the model tests resulted in the figure of 13½ ft being used for the level of these breakwaters on the lee side?

235. Mr Duvivier had already mentioned that the original layout of the harbour showed eight berths on two finger piers plus only four berths along Quay 1, although expensive rock dredging was clearly foreseen, and that was the justification for the finger pier. The dredged level then was to be only -27 N.L.D. He agreed with Mr Duvivier that the exact position of Quay No. 1 was the critical decision in the whole layout of Tema Harbour. To give another example, in Aden Oil Harbour the whole layout was planned so as to avoid all rock dredging whatsoever. The reason for this was so that the harbour could be brought into commercial use at the earliest possible date, and in fact the first crude oil tanker brought in its load of oil and un-

loaded it 21 months after the start of the works. Quay No. 1, as far as he could make out from the cross section, had been built at about the -18 ft contour, and since the original planning the water depth had been increased to -29 N.L.D., so that in the construction up to 11 ft of rock cutting (over 800 000 cubic yards) had had to be faced; this had taken three years to do. Would there have been an appreciable saving in time if Quay No. 1 had been sited in deeper water?

236. This was not the first harbour where the original quarry had had to be abandoned; this led either to a re-pricing or else to a complete change of contract. What he would like to know (if the figures could be produced at this late date) were the calculations which justified the Contractor in taking the risk of opening up at Tetedwa, when the Consulting Engineer had drilled and found good rock at Mampong.

237. There were two figures of cost the Author might like to check. First of all, with regard to the cargo quays, the rather ingenious, lean-back pre-cast 10-ft wide quay worked out at about £650/ft. The cost per cargo berth, excluding fishing harbours, shipyard, and so on, was approximately £2½ million. This compared roughly with some of the major harbour extension schemes recently recommended by the National Ports Council in this country.

238. Ghana now had two excellent deep water ports, Tema and Takoradi, both designed by British consulting engineers and both built by British contractors.

Mr J. H. Jellett (Chief Docks Engineer, Southampton Docks) said that he found this history of the construction of a complete new port particularly fascinating. At Southampton the authorities were about to embark on an extension so large as very nearly to constitute a new port. It was likely to take certainly as long as and probably longer than it had taken the Port of Tema to reach its present stage. He could not help comparing, with considerable mental relief, the conditions under which they would be working at Southampton, in almost complete shelter, and with fairly tractable soil, with the problem Mr Scott had had to face, where he was pushing back the Atlantic on one side and hewing his anchorages more or less out of the living rock on the other. The work of digging out these anchorages was certainly dredging on the heroic scale, and he hoped he could infer from the exchanges Mr Duvivier had recorded that this was not going to require any continued large effort of maintenance dredging to keep them there.

240. On the change in design of the breakwater, Messrs Halcrow & Partners had two points on which to congratulate themselves. One of these was the almost unique characteristics of the Clients, who were prepared to admit that any extra cost involved in this change was the product of their own over-haste. On a previous occasion on which overhaste was discussed he remembered suggesting that a reasonable period should be allowed to the engineers after requirements had been laid down to arrive at a design that was the best for the job. That had not been the case here, and the Consulting Engineers were to be congratulated on the outcome, and particularly on the fact that their own first empirical design was sufficiently near the mark to allow of alteration to meet the revised requirements with practically no further increase in cost than would have been involved if these requirements had been known at the outset.

241. He was interested to see the old controversy of cranes versus ships' gear being revived again by the account of modifications with an estimate of a reasonable complement of cranes made by the Consulting Engineers being cut down on grounds of economy because the shipping interests said they would use their own gear, and the next cycle starting again when it was found that more quay cranes were in fact required. This point would be controversial for a very long time. Quay cranes were at a disadvantage here by virtue of the fact that they could be and were subjected at intervals to waves of activity costing as separate units. He had never heard

that a shipowner felt himself obliged to carry out activity costing on the handling gear fitted to his ships.

242. He noted that the capacity of cranes chosen for Tema was 3 and 5 tons. This was adequate for general cargo but if container traffic increased and was carried in ships not fitted to handle it for themselves, probably a minimum of 20 tons capacity would be needed. Had any consideration been given to this development?

**Mr A. J. Leggatt** (Messrs Nachshen, Crofts and Leggatt) said that the construction of the Port of Tema had been an operation of historic magnitude. He was personally proud to look back some 13 years to the time when he was one of Mr Scott's assistants engaged on the design at Tema.

244. The Author had been very modest in his claims for the quay wall. The cross section in Fig. 6 showed a considerable saving in material content over the more usual triangular wall, and the fact that the Contractor was able to average 100 ft of construction in 11 days supported the claim that this was indeed an economical design.

245. The evolution of the cross section of the wall was an interesting process. They had started with the classic triangular shape, narrow at the coping level and broad at the base. There was then the problem of supporting the back crane rail, and at the same time they had had to put a large gallery in the capping block for a cocoa conveyor (since removed).

246. The first solution was to adopt a rather inelegant system of columns so that the crane gear was not supported on the fill. This became clumsy, and the work below the capping block became massive. The temptation to make the capping block wider so that the crane rail could be included on it was very strong. It was then realized that the main mass of the wall was centred in the capping block, and therefore all that was needed below it was a system of block work sufficiently wide and so positioned that it was symmetrical about the envelope of resultant thrusts. Concentrating the main mass of the wall in the capping block, which was above the water level, provided a bonus in that the unsubmerged or full density of the material could be utilized, whereas with the conventional triangular shape a very large part was below water and only the submerged density was effective.

247. The extremely low tidal range at Tema helped in formulating the shape of the wall, and such an exciting conclusion might not have been reached in areas with a wider tidal range.

248. The cross section of the wall certainly presented a novel appearance, but, like so many things in engineering, its counterpart could be found in the past. The docks designed by Mr Little in 1935 contained a number of brick retaining walls which leaned back against their load in much the same manner as this quay wall. Some old dock walls conforming more with the hull shape of the contemporary vessel also reminded one of the quay wall at Tema.

**Mr E. I. Loewy** (Sir William Halcrow & Partners) said that Mr Leggatt had shown in his contribution that he had obviously been concerned with the quay wall, but he had been too modest to mention that the actual design derived largely from his own efforts, and in its original form was only 9 ft thick. It was therefore most economical, but in view of the unconventionality it had been decided to add a foot as a precaution. Mr Loewy wished to give further information about the fishing harbour, which provided a good example of the special function of the engineer in the development of so-called emergent nations.

250. Ghana had never been short of food, but the diet, as in so many tropical lands, was chronically deficient in protein. In temperate climates the normal way of making good this deficiency was by means of animal products, but this was not a very easy method to follow in Ghana, because of the climate and lack of pasturage. It was a rather sad commentary on the colonial regime that the alternative source of protein, the harvest of the sea, was not effectively investigated until the end of the

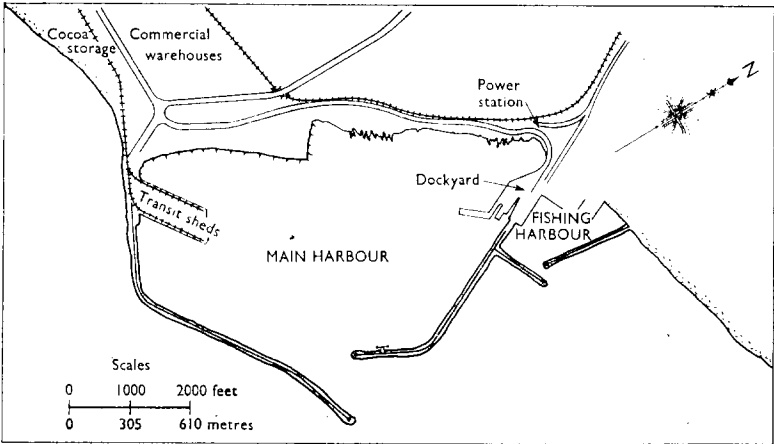


FIG. 10: FISHING HARBOUR DEVELOPMENT, 1954

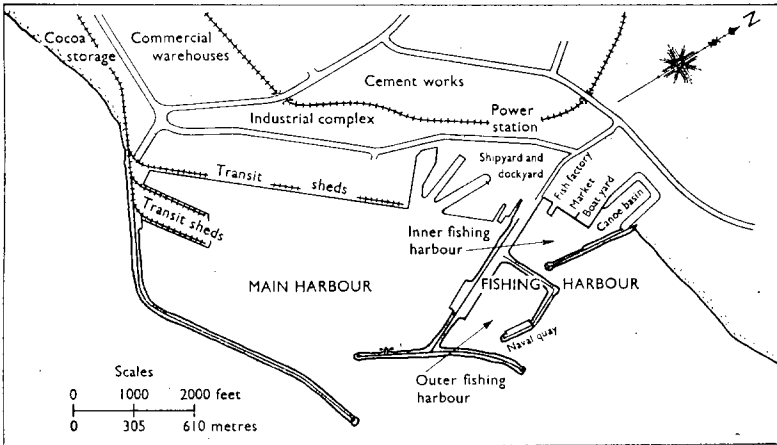


FIG. 11: FISHING HARBOUR DEVELOPMENT, 1965

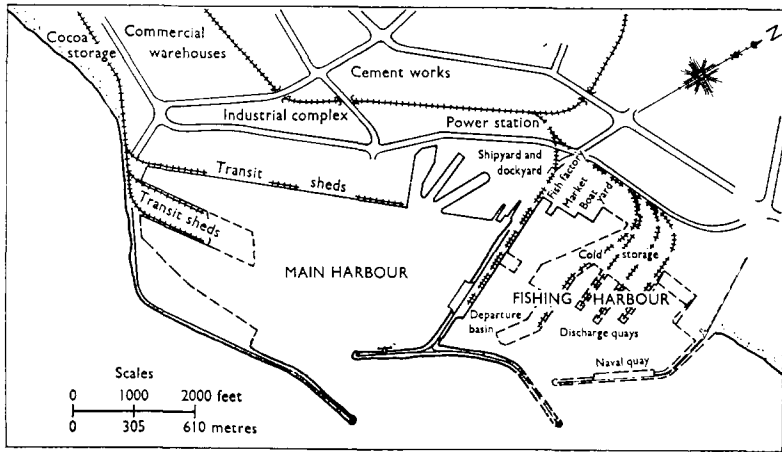


FIG. 12: FISHING HARBOUR DEVELOPMENT, PROPOSAL 1975

colonial era. The Fisheries Department under the colonial regime had some dedicated officers, but they were chronically starved of resources. At the start of the fishing harbour project the boats in use were largely dug-out canoes. These made day voyages, and their productivity was no more than some 2 ton/a per boat.

251. The very early designs of the harbour, made in 1951, therefore provided only two small 300-ft jetties inside the main harbour, estimated to cost about £100 000, and the annual catch anticipated was about 1000 tons. These jetties were not built, however, because of the strong objection of the client, at that time the General Manager of the Railways. He and his various successors would not under any circumstances agree to allow fishing boats inside the new harbour, and suggested that external facilities should be provided.

252. This enabled the then Fisheries Department to obtain some reasonable allotment of funds in relation to the whole project, and a completely separate fishing harbour was designed in 1954. Accommodation for some 300 canoes, 50 motor boats, and four small trawlers handling some 5000 ton/a was provided. Water depth inside the separate new breakwaters was 12–18 ft at M.L.W.S. and space was provided on reclaimed land areas, for market buildings, cold store, ice factory, etc. Fig. 10 showed the general arrangement.

253. The work was completed, as the Author had explained, in 1959, as part of the main harbour contract, at a cost of about £1 million. However, around this time came the great surge of new thought and endeavour following independence. Surveys of potential supplies of fish, and processing and marketing researches were made. At the same time, with independence, came numerous offers of ships from many countries, ranging from Norway to Japan.

254. The conclusion reached by about 1962 was that an annual catch of about 30 000 tons should be aimed for, with a resident fleet of about 200 canoes, 90 motor boats, and 12 trawlers. A completely new range of quays, piers, wharves, and water and alongside facilities was designed for this purpose. The works had been completed at a further cost of about £2 million. The general arrangement was shown in Fig. 11.

255. There was a much more dramatic increase later, arising from the Ghana Seven Year Development Plan. This envisaged a catch of 250 000 ton/a by 1972. Of this amount, it was expected that about 200 000 tons would be handled at Tema.

This was a figure which compared with the amount of fish handled at many major fishing ports in the world. The fleet was planned to include some 50 large deep-sea trawlers. The canoes, on the other hand, would by then become relatively unimportant. The scheme worked out to meet this situation was shown in Fig. 12. The estimated cost of this project was of the order of £7 million, and when it was finished the fishing harbour would be nearly as large as the main harbour.

256. If this project were completed, it would be a phenomenal development, though of a type that was taking place elsewhere, notably in Peru. In order to feed the exploding world population it was essential to nourish and exploit a similar explosion in the world's fish population. Water covered 70% of the world's surface and the world annual catch had already been doubled in the last 15 years from 25 to 50 million tons. This figure could probably safely be multiplied by two, or even by ten. This great expansion of the fishing harbour at Tema was probably a pattern for the future.

**Mr George Wilson** (Port of London Authority) said that when he read the Paper he was interested in relating the total cost to the capacity of the port. The Author had mentioned £35 million for 12 berths; £3 million per berth was generally considered to be a high starting cost which should diminish as the development of the dock or harbour proceeded. This raised the question of the amount of cargo it would be possible to pass through the port. Although the cargo had increased every year it was still not a large figure. For instance, Dover handled 1.3 million tons, Preston 1.96 million and St Malo about 1 million tons so that the current figure for Tema of 1 million tons was not yet very great and did not even seem to equal the potential of the existing 12 berths.

258. Containers had been mentioned and this raised the question of the amount of space available. It seemed fortunate that it had been decided to provide a quay along the shore-line despite the cost of rock dredging because this made land at the rear of the sheds available in sufficient quantity to deal with container traffic. Lorry parks were provided in this plan. In London 4% of the traffic arrived by rail, 47% by barge and 49% by road. Lorry traffic was heavy because 36% of lorries carried loads of less than 10 cwts and 50% carried loads of less than 1 ton. With container traffic the number of vehicles required to carry a given tonnage of cargo would reduce, but the tonnage of cargo was likely to increase.

259. A recent survey dealing with current general cargo traffic had shown that the maximum number of lorries arriving on the closing date for the despatch of a ship from a 600-ft berth was 250. Over a five-week period the average number of lorries unloaded to serve a line of eight berths was 52 per berth per day. This information had been obtained in order to plan a lorry park to serve the line of berths. The park had been made remote from the operating area and was designed to accommodate the maximum number of lorries less a queue of 10 vehicles at each berth.

260. It was important to know that the lorry drivers liked using the park and the smoothing of the flow had resulted in a considerable increase in throughput. This might be as much as 20% but the figure had not yet been established. For planning purposes 70 lorries or 120 cars were allowed per acre.

261. The rock dredging had already been discussed but it would be interesting to have the Author's views on which of the three methods mentioned was preferable.

262. Mr Wilson suggested that the 860 h.p. of the diesel tugs was high, and thought that a Voith Schneider tug was a better proposition than a screw type. From tests which had been carried out in London it had been shown that a screw tug with a 20-ton pull when manoeuvring was never able to exert that pull for long enough for this to be effective. A Voith Schneider tug which could pull sooner and hold on for longer could do the same work with a 15-ton pull. It was only fair to mention that a 15-ton pull was the maximum so far achieved with a single Voith Schneider propeller. If a higher pull was required two propellers were needed and the cost of the tug became uneconomical.

**The Secretary** (Mr A. McDonald) referred to § 85, where it was stated that the transit sheds were built in steelwork, the reasons therefor being set out.

264. In 1959 he had had the privilege of going over this excellent project with Professor Pippard. On that occasion Mr McDonald had asked why the sheds were being built in steel, in view of the highly corrosive atmosphere there and the future headaches there would be for the Engineers concerned with maintenance. The reply was inconclusive; but the reason given in the Paper was that the Engineers were doubtful of the ability of any contractor to construct concrete-framed buildings of 85-ft clear span with the labour available in Ghana at that time. The same sort of work, both in reinforced concrete and prestressed concrete, was then being done further along the coast, in Nigeria so that there was really no reason why they could not have been built in concrete.

265. With hindsight would the Author still have designed these transit sheds in steel, in the light of the extremely corrosive atmosphere at Tema?

The following contributions were received in writing:

**Mr T. J. Llewellyn** (Taylor Woodrow Constr. Ltd) wrote that the construction of Tema Harbour over the preceding 13 years was a great civil engineering achievement, reflecting boldness in layout and design on the part of the Consultants. The preliminary works contracts alone (£2 962 994) being major contracts in their own right.

267. He noted (Fig. 2) that the quarry access railway had been laid in the preliminary works contract adjacent to the Tetedwa faces of the Shai Hills quarry site. The Contractor had later to abandon this quarry and construct additional temporary works to reach another quarry face situated at Mampong. This move resulting in 'a lump sum payment and re-pricing of the whole contract'.

268. Mr Llewellyn asked if it was the intention of the Consultants that each tenderer should carry out 'intensive diamond drilling' to prove beyond doubt the suitability of the various possible Shai Hill quarries so that his tender could reflect the full cost of all additional temporary works necessary to gain access to the best quarry face. Could this not have been done under preliminary work contracts so that all tenderers could have priced the main contract work with more information available?

269. He also wished to ask if a comparison of dredging costs for rock broken up by the Civil Engineering Contractor using the Lobnitz rock breaker and the Dredging Contractor using drills and explosives could be given.

**Mr C. St John Bird** (Messrs Bird & Robertson, Johannesburg) wrote that the Author had stated in § 2 that 'little serious thought had been given to the provision of a second deep water port until the publication of Halcrows' report in 1951'. The writer wished to mention that the Ringer's Report referred to in § 3 was based on model experiments conducted by Professor Thijssse at the Waterloopkundig Laboratorium at Delft, the data for which were collected over a period of about five years. This Report by these two internationally experienced engineers was available before the issue of Halcrows' Report.

271. The Author's reasons for choice of site were given in § 17. Some further details of the physical and other aspects of the two sites were given in Table 6.

272. It was obvious from this Table that Ada had not the limitation of size, depth and ground available for shore installations as pertained to Tema, and construction costs would also be less. Developments could have been made to suit requirements. It would not have been necessary to construct the harbour area at once as at Tema. The White Paper (1952) figure of £11 000 000 was for initial development and £16 000 000 for the final construction when the work was authorized. To date it had cost £35 450 000 and was incomplete. Had the port been constructed at Ada, the writer was confident that the cost would have been appreciably less. For a young

TABLE 6

	Tema	Ada
Distance to Accra . . .	17 miles	70 miles
Shore inclination . . .	42 ft in 4000 ft	49 ft in 3500 ft
Entrance depth . . .	42 ft at breakwater	To suit requirements
Nature of harbour . . .	Built in open sea—break-water protection	Built in estuary with protected entrance to sea
Main harbour area . . .	About 93 acres as measured on plan. Fishing harbour 33	1270 acres available up to N. end of Kennedy Island
Nature of bed . . .	Rock and sand	Sand only
Breakwater rock . . .	Shai Hills 21 miles	Sogankope 15 miles
Transported by . . .	Rail	Barge
Quantity required . . .	4 780 000 cu. yds	800 000 cu. yds
Dredging . . .	In rock 829 000 cu. yds. In sand—not stated	In sand 4 000 000 cu. yds
Reclamation . . .	5 000 000 cu. yds	Dredged sand used for levelling site
Operation lay-out . . .	Area restricted (see Section 136)	Ample level ground available

developing country without unlimited financial resources, cost was a serious consideration, especially in the initial stage, and should carry weight in the choice of site, provided it fulfilled requirements. The additional haul for Accra goods was not critical and should not be a deciding factor. Surely the same development of townships, etc, induced by the construction of Tema was bound to take place at Ada, under the more favourable conditions, and it was in addition far enough away from Accra not to have been taken over thereby.

273. In § 6 the Author mentioned that the considerable physical difficulties of establishing a deep water port at the proposed site at Ada had decided the Consultants against that site. What were these physical difficulties? Would the Author kindly enumerate them?

274. The West African Aluminium Company proposed to construct the port, using bar boats for this purpose to enter the estuary; the river works would be undertaken simultaneously to provide access to the dam site by barge transport. For the aluminium industry, Ada was the better site. This could have been wholly located on the river with the smelter at Kpong and river transport used. Ample water was available, and ground for the disposal of the considerable amount of slurry associated with bauxite reduction to alumina. The smelter was the largest consumer of power produced, and transmission losses would be minimized by locating it close to the dam. With the smelter at Tema, now incorporated with Accra, the disposal of wastes and noxious fumes would cause a nuisance undesirable in a capital city.

275. With competent investigation, planning and subjection to model test, an economical solution was found for all aspects required for the port at Ada. These included measures for preventing scour in the approach channel, compensating erosion to the east, the self closing of the mouth, other future conditions consequent on construction, and numerous problems such as that of the best form of breakwater and size of required material. The existing regime of the river, taken from data collected, was made the basis of proving the model (Delft Report, vol. 1). These were used until the model reproduced the actual conditions correctly. Indications given by the model were consistent and corroborative. The writer claimed that the above could be deemed 'serious thought given to a second deep water port before 1951'.

276. As stated in § 10 'a battle had to be fought with the local proponents of the Ada Site'. The matter was referred to Messrs Coode, Vaughan-Lee, Frank and Gwyther of London. Mr Bird quoted the following passage from a letter written to Mr Gwyther by Professor Thijsse confirming the discussion during his visit to the Laboratory on 27 February, 1952:

'Mr Gwyther told us that he had been asked to answer two questions: (1) can a port for ocean going ships be built at Tema? (2) will a port there, in the foreseeable future, be liable to heavy shoaling requiring excessive dredging? It is evident that the answer to (1) is "yes" and to (2) "no". The time when sand would appear at the entrance is probably 50 years.

A port at Tema would be similar to that at Takoradi; to project the harbour inland is not feasible owing to cost. The whole would be built out to sea. This is possible, but still expensive. My answer to the questions does not solve the problem. There are other more important questions, such as is Tema the correct place to build the harbour, and how does it compare economically with other possible sites?

There are great advantages in the port at the Volta Estuary. From here economic transport into the catchment is possible. The Lower Reach with the stabilized flow is particularly adapted to bulk transport, such as aluminium traffic and products from the North and thereto. Great developments can be expected in the Territories (as stated in Halcrows' Report 1951). It is therefore economically indicated that the harbour be located in the Estuary and the railway avoided. It is very fortunate that there is at the Mouth of the Volta a place so suitable for construction of a port that it is not easily surpassed. There is a harbour basin present in the Estuary. Only a comparatively slight amount of dredging is necessary to create sufficient depth along the line where the quays would be constructed. The spoil will serve to raise low places where the harbour installations are planned. This area is flat and is easily accessible by railway, which may connect the harbour to the existing system. The consequences of constructing the harbour at the river mouth had been studied in our laboratory. The result was favourable. The following advantages of a port at the Volta Mouth are apparent (1) economically the right place; (2) construction at a price very much lower than the price asked for a harbour on the open coast; (3) size easily adapted to the requirements of all users; (4) the distance from Accra is no real disadvantage. In my opinion there is no choice. The correct place for the harbour is at the Volta River Mouth.

(signed) Professor J. Thijsse.'

**Mr R. L. Robertson** (Messrs Bird and Robertson, Johannesburg) suggested that with reference to the previous investigations for harbour sites on the Gold Coast, it might be of interest to note that the construction of harbours had been linked to mining activity sponsored by private enterprise.

278. In 1897 Messrs Coode, Son and Matthews carried out an investigation and discussed the possibilities of various sites from Axim to the Volta River. Apart from small improvements at Accra no work was done because of the restricted finances of the Government. In 1920 Messrs Stewart and McDonnell also investigated the possibilities of various sites and a deep sea harbour at Takoradi, justified by the important mines in the western area, was constructed.

279. In 1925 Kitson<sup>8</sup> drew the attention of the Government to the possibilities of making aluminium, but the Government did not proceed with the necessary investigations to confirm this. In 1939 the West African Aluminium Company approached the Government with a request to carry out investigations on the Volta River and were granted permission. A reconnaissance report was furnished recommending further investigations as very little data were available. The company obtained concessions over the areas in which operations were proposed. The war intervened and the work was started again in 1944, culminating in the Bird Report of 1949.

280. In this report Ada was suggested as the harbour for the aluminium industry and the Government, as being the most economical site available, with the added advantage of using the river as a natural waterway for the aluminium development and for barge traffic to the interior. This conclusion was reached after lengthy model experiments to prove that the harbour entrance could be stabilized. At Ada there was ample scope for the development of a deep water harbour for the needs of the colony and other industries, constructed in the quiet water of the estuary, and all dredging was in sand.

281. In the Halcrow Report of 1951, Tema was recommended as the deep water harbour, as it was near to Accra. This harbour had now been constructed, but as stated in § 33 no berths had yet been provided for the aluminium industry although this was, at that time, the prime reason for providing a harbour. The construction of Tema was made possible by the proving by private enterprise of the power potential of the Volta River and the favourable economics of producing aluminium from the local bauxite. Had it not been for private enterprise taking the risk of proving the scheme, the writer considered it highly probable that the Volta potential would still lie dormant.

282. Neither Coode, Son & Matthews nor Stewart and McDonnell considered either Tema or Teshi, in spite of their propinquity to Accra, but both spent a considerable time in investigating the Volta River mouth.

283. Mr Robertson quoted the following excerpts from the Stewart and McDonnell Report in regard to the Ada/Tema controversy.

'We endorse the suggestion of Messrs Coode, Son & Matthews in their report of 1897, that if it is intended to use the mouth of the Volta as a branch boat port, a qualified pilot should be maintained there, as however much the mouth of the River may alter in location, a constant minimum depth of from 10 to 12 ft on the bar is reported in all the surveys made.' (p. 8, § 19)

In 1912 the value of exports and imports in bar boats of about 600 tons had amounted to over £700 000.

'It has to be observed, however, that there does not appear to be any special reason why the River (Volta) below Amedika should not be improved, if desired. The matter would require careful study, but there are certainly no visible insuperable objections to the carrying out of such improvements.' (p. 46, § 48)

This was confirmed by West African Aluminium Co. in their studies.

'A general description of this portion of the coast would not be complete without mentioning the Vernon Bank, an extraordinary elongated shoal situated off Prampram [shown in Fig. 2 of the Paper]. It consists of a narrow spit extending from the shore for about 12 miles in an E. by N. direction with depths up to about 6 fathoms on it, and a least depth of 4 fathoms three miles from its shore end. On its northern side the depths run from 8 to 9 fathoms, the spit thus forming a natural sunken obstruction to seaward. Its formation is described in the Admiralty Pilot as being very irregular, sand, gravel and stones and narrow ledges of rock all being present.' (p. 42, § 34(e))

It had been reported to the Chairman, West African Aluminium Ltd, by one of his staff that in conversation with Mr Sulley, Master of the coastal vessel *M.V. Petit Fary* (350 tons burthen, plying between Takoradi and Lome, carrying petrol) that owing to a breakdown in his engines about the middle of August 1952, he made for a shallow area known to him off Tema. He anchored  $1\frac{1}{2}$  miles off Tema in 24-28 feet (4-4½ fathoms) of water. As this bank was close to Tema, had any provision been made to give warning to deep sea craft?

**Mr D. C. Coode** (Senior Partner of Coode & Partners) wrote that his connexions with the Port of Tema went back to 1952, when his firm was asked, with the agreement of the Author's firm, to give a second opinion as to the possibility of the port silting up when completed, because of the ingress of sand from the sea. Having visited Tema, inspected the site of the proposed harbour and collected the available data, his firm reported that in their opinion silting of the harbour was unlikely. It would be interesting to hear from the Author whether in fact any silting had been observed.

285. While in Ghana Mr Coode was pressed by a number of people, mainly shipping firms, to express an opinion as to the advantages of Tema as compared with Ada as the site of the new harbour. Not being within his firm's terms of reference it was of course out of the question to express any opinion on this aspect. Although not in possession of all the facts and information available to the Author Mr Coode had often wondered why Tema was selected in preference to Ada. It was appreciated that Tema was closer to Accra but surely a large proportion of the imports to be handled, and the majority of the exports, would be for or from up-country and therefore close proximity to Accra did not seem essential. Secondly, Tema appeared to be capable of only a limited number of berths, whereas development at Ada would be almost limitless. Thirdly, to provide increased depth at Tema would necessitate expensive rock dredging whereas the entrance to Ada could to a very large extent be deepened by the construction of training moles, as at Lagos in Nigeria further along the coast, thus producing natural scour.

286. In § 10 of his Paper the Author himself pointed out that Accra and Tema had already become virtually one, but this could never have happened with the port at Ada. Had the Author ever had any regrets over rejecting Ada as the site for the port and what were the difficulties to which he referred in § 6?

287. To cover a project of this magnitude in one paper of limited length must in itself have presented the Author with considerable difficulty and he was to be congratulated on the result. It was a pity space had not permitted the inclusion of some photographs and a drawing showing the elevation of the blockwork in the quay walls. Perhaps the Author might find space in his reply to include these.

288. Mr Coode wrote that he found some difficulty in finding in the Paper the final length of breakwaters constructed at a cost of £4.95 m., the total length of quays costing £4.84 m. and even the length of each berth. It would appear however that the breakwaters cost in the order of £413/ft run and the quay walls some £440/ft run. The Author did not state what the overall costs covered, but assuming the cost of the quay walls did not include dredging the foundations nor the backfilling, Mr Coode would question the implication of § 77 wherein it was suggested that the quay wall design was economic. In Lagos, quay walls designed for a dredged depth alongside of 32 ft, and, including a rubble base, were constructed at a cost of some £310/ft run in 1950-55 and at a cost of £377/ft run in 1962-65. Whereas at Tema the stone had had to be transported a distance of 21 miles from the quarry, in Lagos the quarry was 60 miles away.

289. Table 1 tended to confirm the statement made by the Author in § 37 that the development in the port was ahead of demand. The tonnage of cargo handled per berth had steadily declined since 1962 but at no time had the handling rate exceeded 280 ton/ft of quay wall per year and in 1963/64 the rate had fallen to 160, compared with a rate of 300 tons in Lagos.

290. Mr Coode disagreed with the Author's statement in § 42 regarding the draught of vessels trading to West Africa. Freetown, in Sierra Leone, had a considerable depth, and the quay walls had a depth alongside of at least 32 ft below L.W.O.S.T. In Lagos the quay walls were designed for a future dredged depth of 32 ft. Until recently the official draught at the entrance was 27 ft but this was now being increased. At Port Harcourt, also in Nigeria, the recent wharf extension was designed for a depth alongside of 32 ft; the original wharf was being reconstructed to allow the same depth. A channel had been dredged across the bar at the Bonny entrance to a depth

of 45 ft, while the river up to Port Harcourt had been dredged to a minimum depth of 35 ft. It seemed therefore that a depth of 28 ft for future berths at Tema was short-sighted.

291. It would appear from § 79 that some 60 blocks were set per week to achieve the rate of 50 ft/week. This was equivalent to some 10 blocks per day which seemed very slow. In Lagos a rate of 30 blocks per day had been quite normal and a rate of up to 50 blocks per day had been obtained on a number of occasions.

292. Mr Coode noted that rubber fenders had been installed at the quay walls. With such a small rise and fall of tide would it not have been possible to fix a horizontal timber fender at a level of about +5.00, at half the capital cost? He would be interested to know why, in a sheltered harbour, bollards of 100-ton capacity were required when no ship's rope would take such a strain, nor probably would the ship's bollards.

293. Finally Mr Coode questioned the Author's statement in § 85 regarding the inability of the local labour to build concrete framed buildings of 85-ft clear span. At the present time contractors in Lagos were building prestressed concrete framed sheds of 150-ft clear span. West African labour was perfectly capable of undertaking such tasks provided the European supervision was adequate. If the Author had said the European supervision rather than the local labour was of doubtful quality, Mr Coode could have accepted his statement.

The Author in reply said that Mr Palmer had made a very constructive proposal in § 234, but the Contractor preferred not to risk building the breakwaters at a lower level to give himself greater width for operational purposes. In the early stages of construction a freak series of waves had appeared from a calm sea and swept over his working area (then at +11 ft) causing some loss of life and much damage to plant and rail tracks.

295. The cross section of the lee breakwater referred to in the last sentence of § 234 and shown in Fig. 5, was in fact the maximum cross section which applied only to its outermost length. The top level varied from this level downwards as it approached the shore, in accordance with the indications given by the model experiments, and rose at its junction with the south breakwater of the fishing harbour where a build-up of waves was indicated.

296. The answer to § 236 was that the quarry railway was built as part of the proposed Tema-Kpong railway and was terminated at Tetedwa, thus giving the Contractor the choice of quarry sites. Ease of access to Tetedwa compared with the cost of the rail spur and road necessary to reach Mampong had no doubt influenced the Contractor in his choice of Tetedwa.

297. The development of container traffic (§ 242) was regarded as a future possibility and the quay wall would be capable of accommodating a 20-ton crane or one of even greater capacity.

298. Mr Wilson had quoted a figure of £35 million as the cost of twelve berths (§ 257) but this total figure included the whole fishing harbour, all the warehouse areas, dry dock and fitting-out quay slipways, workshops and much else in addition to the breakwaters. There were also thirteen berths including the oil berth. The cost per berth was therefore nearer £210 000. The cargo handling capacity of the twelve dry cargo berths would be over 3 000 000 tons, the oil berth already handled over 1 000 000 tons with under 50% utilization and the thirteenth berth now nearing completion would handle over one quarter of a million tons of bauxite, etc. inwards and 220 000 tons of aluminium outwards.

299. The traffic figures mentioned in §§ 258, 259 and 260 were not directly applicable to Tema where rail traffic still provided a high percentage of the total, but the Author would have liked to have had more space available for future expansion of lorry parks which he considered would be necessary.

300. Mr Llewellyn had made an interesting point by suggesting that the preliminary works contracts could perhaps have covered a full exploration of parts of

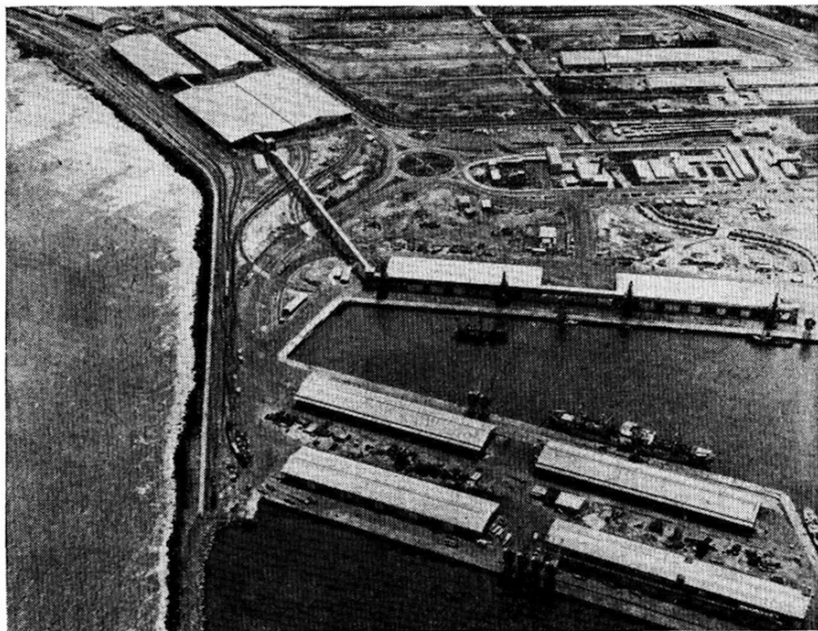


FIG. 13: GENERAL LAYOUT

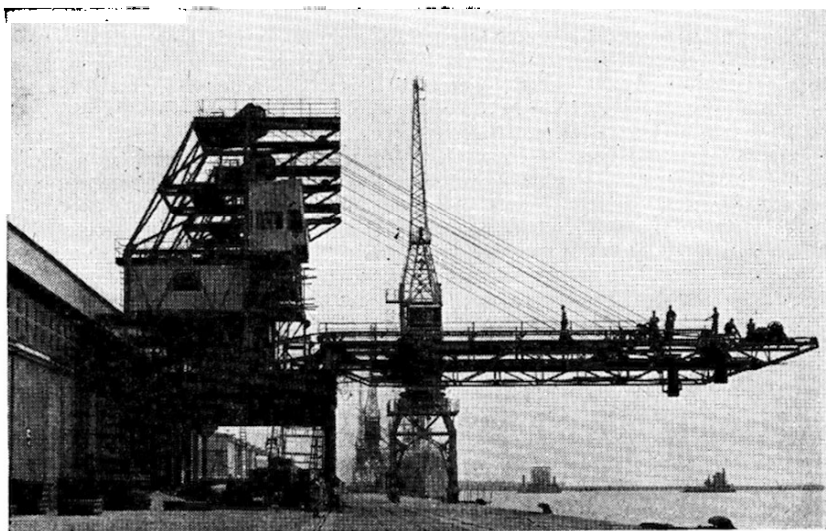


FIG. 14: COCOA OUTLOADER

the Shai Hills to determine the best quarry site. There was no doubt that this could have been arranged and, in fact, such a proposal was considered, but the time and expenditure necessary were not acceptable to the Client at that time and only the Mampong site was explored to the extent of trial blasting. In view of the very high output and the different grades of rock demanded of the quarry, a great responsibility rested upon those who had to make the final choice. Furthermore, the methods of blasting and mining to be adopted had to be closely linked with the assessment of the best quarry site. Such matters lay essentially in the field of expertise and experience of the Contractor and it was therefore concluded that, beyond the basic explorations proving that good sites were undoubtedly available in the hills, all further investigations and interpretations should be made by the Contractors. The fact that a lump sum was paid to the Contractor in connexion with the relocation of the quarry sites did not mean that the Engineers necessarily agreed with it!

301. Rock dredging was done in many places, to various depths and thicknesses and at various times, so that no single simple comparison between the cost with a rock breaker, and with drilling and blasting, was possible. Dredging was shown taking place in the western corner of the Port in Fig. 13 (which also gave a general idea of the working arrangements of some of the quays, the transit sheds and the four cocoa sheds (top, left)). In addition, outside the harbour entrance, a heavy 32-ton chisel, centre-mounted in a rock-breaker (not by Lobnitz) proved the only possible means. It could, however, be said that when the thickness of rock to be removed inside the harbour was appropriate—between say, 4 ft and 12 ft—the drilling and blasting method was half as costly and twice as fast as rock breaking by chisel. A median price of about £2/cu. yd would be a fair approximation in such circumstances for rock dredging using drilling and blasting.

302. No one with a knowledge of the early history of the Volta Project would wish to deny to Mr St. John Bird and his colleagues the greatest praise and credit for their immense and painstaking investigations prior to 1951. All subsequent workers on the project, including Kaisers who had now been privileged to complete the project, had built on Mr Bird's pioneering work which the Author had always acknowledged in the papers and articles he had written on the Volta River Project. However, as regarded the choice of harbour site, the situation of West African Aluminium Ltd and Mr Bird was basically different from that facing Sir William Halcrow & Partners in 1951. The sole concern of the former was the aluminium industry, its power, distribution, transportation, import and export, etc. They had no brief or opportunity to consider the wider aspects of the economic development of the country as a whole and were in no position to foresee the political independence of Ghana and the dramatic growth in population, trade, industry and influence of the Accra region which had occurred.

303. Ada might not have been a bad choice for an aluminium industry port, and the studies of the Delft Laboratory into the formidable problems of creating a deep-water harbour at the mouth of the River Volta were no doubt painstaking and impressive and indicated possible solutions—though not without leaving many difficult questions of programming, maintenance and costing unanswered. Nevertheless, it could safely be said that, while the aluminium industry had been at least equally well served by Tema both as smelter and port site, the choice of Tema for Ghana's second general deep water port had been a major factor in the country's rapid development in the last ten or fifteen years. About half the country's cocoa crop was scheduled to be exported through Tema, and much use was made of mechanical handling aids, conveyors of many types and four outloaders (Fig. 14). The recent clouding of Ghana's horizons had no relevance in this development and it must be hoped that the future would be the more sure and stable. It was important to realize that, even before Tema became fully operational, the surf harbour at Accra, with all its massive disadvantages of primitiveness, handling, loss and damage, lack of space, etc, was dealing with a peak flow of cargo up to 50 000 tons per month, thus testifying to

the overriding economic importance of the area and region for overseas trade. All this did not mean that the Ada area might not, in due course, have its day or that the benefits of inland navigation on a canalized River Volta would not, in the fullness of time, be realized.

304. Mr Coode's report in 1952, confirming that a port at Tema was unlikely to suffer from serious shoaling troubles, had been a valuable contribution to the success of the project. His questions about the relative merits of various port sites were really answered in the reply to Mr Bird and Mr Robertson. There was no need to regret that Accra and Tema were on their way to becoming one major urban aggregation, as this form of development appeared to be one of the patterns for the future all over the world and the inclusion therein of a major seaport was of inestimable advantage for the region and country.

305. Mr Coode's calculation on the cost of the quay wall was incorrect. He appeared to have taken the total length of quay wall (11 000 ft) quoted in § 77 (which included the fitting-out quay and fishing harbour quays) and divided this into the quoted cost of quays (twelve berths) of £4 841 649, which, in fact, also covered dredging in way of the wall, the rockfill backing and the hearting of Quay No. 2. The figures could not therefore be calculated in this way. The average cost of quay walls comparable to Mr Coode's figures from Lagos was in fact £350 per foot run. The final length of breakwaters was as follows:

Main breakwater	7200 ft
Lee breakwater	4800 ft
South breakwaters	2800 ft
East breakwaters	2600 ft

306. Since expansion of quays and berths had to occur in large steps, it was inevitable that, at any one time, the facilities would be ahead of demand. At Tema there was no doubt that political factors had an influence upon the rate of expansion and, further, that the falling index of cargo handled per foot per year reflected the country's growing economic problems of the last year or two. Efficiency of cargo handling could not be measured by such an index in this case; political factors also came into the matter.

307. On the depth of water alongside the quays, one attraction of the Tema site was the possibility of constructing quays deeper than the basic 28 ft at M.L.W.S. at a later stage when demand arose. A third quay with four or five berths was planned on the south side of the harbour with depth alongside at M.L.W.S. of between 37 ft and 40 ft without dredging. Furthermore, the existing Quay No. 2 already had depths between 30 ft and 32 ft at M.L.W.S. on the south side, and eventual extension was planned. Work had been in train to deepen the oil berth to 40 ft and the entrance to 42 ft below M.L.W.S.

308. Several fendering arrangements, of timber, rubber and combined materials were naturally considered, and the all-rubber diagonal system was eventually adopted on the basis of greater efficiency and reduced maintenance. At the same time, this view was being endorsed by the actual experience of Takoradi Harbour which belonged to the same Administration.

309. The last sentence of § 79 should have read 'At one stage a rate of over 100 lin. ft per week of completed wall was achieved'. In the Paper the figure quoted was 50 lin. ft. On Quay No. 1 during the 12-month period during which the wall was being constructed, the average rate of progress was 53 lin. ft of wall per week. Throughout this period an average of 65 blocks were laid each week. A rate of 130 blocks a week was achieved on several occasions.

310. The use of reinforced or pre-stressed concrete frames for large-span transit shed frames would undoubtedly have been practicable at Tema for the later extensions, but, by that time, really reliable methods of protecting steelwork from corrosion had been evolved for the severe conditions and had been accepted by all parties. It

was very far from being proved that concrete was the better, cheaper and longer-lasting material for large-span buildings in a situation such as Tema.

311. It was curious that the use of 100-ton bollards should be queried (§ 293). One ship's rope or bollard might not be enough for 100 tons but four were and, despite the calm conditions in the port, the model indicated the possibility of small surges. It was considered that these, combined with possible maladjustment of mooring ropes (as well as other emergencies arising out of berthing and unberthing operations) could give rise to severe strains on the main bollards.

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