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Acquisition of Data from Single Layer Armour Units in Breakwaters Using Radio Telemetry

Acquisition des données expérimentales par radio-télémesures provenant d'unités de blindage a simple couche de brise-lames

Messdatenfernerwerbung von einschichtigen Wellenbrecherblendungseinheiten

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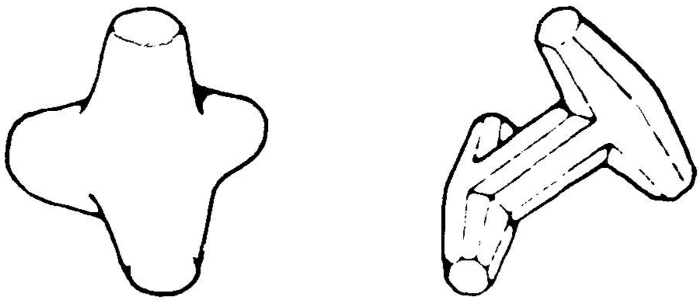
SUMMARY
Armouring units are used to face rubble mound breakwaters and to dissipate the energy of incoming waves. Special types of single layer units have been developed which derive their strength from being placed tightly together in a regular matrix. A major research project has been established to assess the strength of these units in service and to develop design methods for improving their hydraulic and structural performance. A trial installation is described which was used to assess the feasibility of transmitting data both by cable and by radio telemetry through the spray environment.

RESUME
Des unités de blindage sont utilisées en face de brise-lames à blocs pour dissiper l'energie des vagues arrivantes. On a mis au point des unités spéciales à simple couche et de grande résistence grâce à un assemblage très serré en matrice régulière. Un important project de recherches a été défini pour évaluer la résistance en service de ces unités et pour établir des méthodes de dimensionement pour améliorer leurs performances hydraulique et structurale. On décrit une installation d'essai qui a été utilisée pour apprécier la practicabilité de la transmission des mesures soit par câble, soit par radio-télémesures à travers l'environnement des jets d'eau.

ZUSAMMENFASSUNG
Blendugseinheiten werden gegenüber von Klotzwellen brechern verwendet um die Wellenkraft zu gestreuen.
Besondere einschichtige Blendugseinheiten wurden entworfen, deren Festigkeit durch eine enge matritzenregelmässige Zusammenstellung geleistet ist.
Es wurde ein erheblicher Forschungsplan aufgestellt, um die Gebrauchs wiederstandsfähigkeit dieser Einheiten zu schätzen und Bemessungsverfahren zum Verbessern deren Fluss- und Strukturleistungen zu entwerfen. Diese Artikle beschreibt eine Probeeinrichtung und die Messdatenübertragungsfähigkeit entweder mittels Kabeln oder radiofernmessung zu bewerten.

1. INTRODUCTION

Rubble mound breakwaters and similar coastal structures are normally protected from the worst effects of wave action by rock or concrete armour. Rock armour is used where available in sufficient sizes, quantity and quality. Conventional concrete armour units include the Tetrapode, Dolos, Stabit, Fig. 1, although many other types have been suggested and sometimes used. They are generally laid randomly or irregularly in two layers, with variable attitude and interlock between the units, giving a mean armour layer porosity of 30-45%. Since the units rely on self weight for their stability, they are generally very large varying in size from 5 to 90 tonnes.



(a) Tetrapode (b) Dolos (c) Stabit

Fig. 1 Various conventional armour units.

Recent failures of a number of major breakwaters and subsequent research has identified problems in the design and use of irregularly-placed concrete armour units of these types. Under wave action, small rocking movements occur which lead to collisions between adjacent units. If the consequent impact and bending stresses exceed the tensile strength of the concrete, cracking occurs which may lead eventually to complete fracture.

Recent developments in the UK have produced a family of single layer armour units which derive their strength and stability from being placed tightly together in a regular matrix. Such units, which are much smaller and lighter than conventional units, employ porosity within rather than between them to dissipate wave energy. The first single layer armour unit to be developed was the Cob, Fig. 2(a), designed by Coode and Partners. The Cob unit is essentially cubic, with square apertures in each side meeting in a cubic central void. It provides a layer porosity of 55-60%. Between 1973 and 1975 approximately 8700 2t Cobs were deployed on the new La Collette breakwater at St. Helier, Jersey [1,2]. Further Cobs were used on Das Island in the Arabian Gulf.

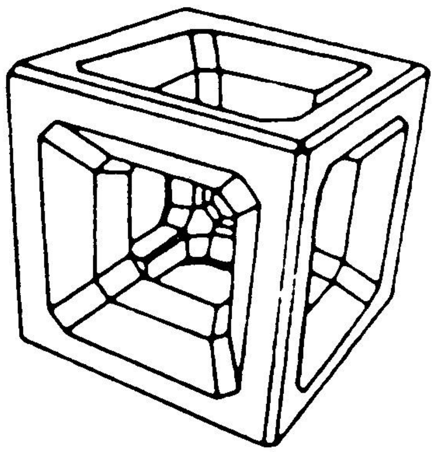


Fig. 2(a) Cob armour units.

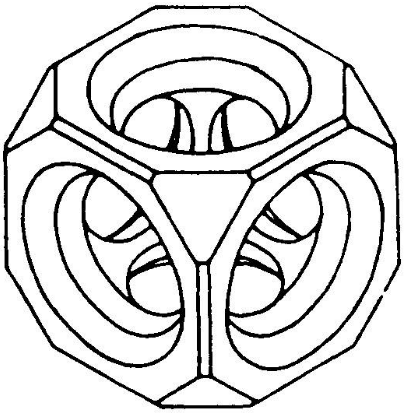


Fig. 2(b) SHED armour units.

In 1981, Shephard Hill Ltd. developed an alternative hollow-cube unit, the SHED, Fig. 2(b), with a similar level of mean layer porosity. This unit embodies a spherical central void within an essentially cubic external form. Approximately 4200 2t SHEDS were positioned on the new Albert Pier sea wall in Jersey during 1981-83. Some 2700 similar SHEDS, were also used in the new breakwater at Bangor, N. Ireland, and a further 3700 in a new breakwater near Limassol, Cyprus. They have also been used in a sea wall in Oman.

Single layer armour units of these types display considerable advantages over conventional, two layer, randomly-interlocked units, such as Dolos or Tetrapode. Their good hydraulic performance, high resistance to movement under wave action, coupled with low unit weight, afford very considerable cost savings. The world-wide market for advanced coastal engineering techniques is enormous. Potential savings to owners and contractors from the use of hollow cube armour units on breakwaters, sea walls, etc. are thus likely to be significant. However, a number of the early installations employing these units are already showing distress. Clients must, therefore, be satisfied that these much smaller units are sufficiently robust for the purpose for which they are intended.

Design procedures for assessing the hydraulic performance and survivability of such units are based almost universally upon the use of scale model tests. However, it is only very recently that any of these tests have used armour units of correctly scaled strength, and even now this is only possible in very special circumstances. Current design manuals are all based on such testing, few giving any guidance on loads and stresses induced and, hence, the strength required for reliable service over the design life of the structure. The major problem then for the designer is that of assessing loads, and hence the stresses induced, in the generally unreinforced units. This is an area of active research world-wide. It should be noted that all such research is presently concentrated upon the conventional two layer units. The problem of assessing in-service stresses is particularly acute for the single layer hollow cube units due to their comparative fragility.

2. OVERALL PROJECT OBJECTIVES

The overall aim of this research project is to develop a design method to determine the size, shape and strength of single layer armour units. This will enable engineers to design and construct armoured rubble structures using regularly-placed single layer units at significant savings over conventionally armoured structures. The overall project objectives are being investigated by a widely-based multi-disciplinary team comprising specialists in hydraulics, concrete structures, materials, stress analysis, structural models and field instrumentation. The main areas of investigation may be considered under three headings:

(i) assessment of hydrodynamic flow conditions within the units;
(ii) assessment of loading and structural performance; and
(iii) stress analyses of single units and entire breakwaters.

This Paper relates to some initial field work under heading (ii) above only.

3. ASSESSMENT OF LOADING AND STRUCTURAL PERFORMANCE

The assessment of wave- and settlement-induced loadings will require work in both the hydraulics and concrete laboratories, and in the field. Measurements of wave-induced loads are to be made in model tests using suitably strain-gauged model armour units. Such measurements will, however, require very careful calibration with strain measurements from full-scale units loaded under controlled conditions in the laboratory. The assessment of actual loads caused by the effects of construction, transportation, installation, settlement and wave loading, determined from field trials, will also be necessary.

3.1 Field measurements

The intention is to instrument fully six typical armour units for installation in a prototype breakwater in areas subjected to significant wave loading. Two possible structures have already been identified. One of these is La Collette Breakwater, Jersey; the other is a second breakwater currently under construction at Bangor, N. Ireland. The latter structure would offer some advantages in that typical transportation and installation stresses, together with the overall breakwater settlement effects, could be monitored from the start of construction. The wave climate, however, is marginally more severe at Jersey where there is a higher incidence of storms. A final decision on the most appropriate structure to be monitored fully will be made in the near future.

3.2 Laboratory studies

The first priority is to develop casting and external vibration techniques to permit the embedment of intrumentation within the units without damage. Due to the urgency of installing units in the field to obtain data from two successive winters during the duration of the project, the six instrumented units designated for installation will be cast at the earliest opportunity.

It is then anticipated that a number of additional units will be cast for a programme of laboratory testing. The controlled conditions in the laboratory will permit more extensive instrumentation of the test units with surface-mounted electrical resistance strain gauges than those to be installed in the field. The exact loading to be applied to these units has yet to be determined but will include quasi-static, dynamic and impact loading as indicated by the early results from the field trials. This phase of the research will be complemented by some limited finite element analysis of single units. This will enable the stress distributions due to the applied loads to be verified. It will also permit an extension of the theoretical assessment of unit strength to a variety of other load cases and unit shapes.

4. ACQUISITON AND HANDLING OF DATA FROM FIELD TRIALS

4.1 Data required

The overall aim of the field trial is to provide data which will ultimately assist the engineer in the design of economic but safe breakwaters. The problem with such field trials is that the loadings are random in nature and site specific. However, although the loadings are random, they are the random output of a determinimistic system with a random input, i.e. the wave climate. In other words, for the data to have significance for future designs, it needs to be normalised with respect to something readily measurable at future sites. Given that the data can be normalised in some way with respect to a vague input wave climate, there are two other important factors which make the data site specific. One is the detailed modification of the waves as they approach the breakwater due to local sea bed topography; the other is the way in which the units are constrained within the matrix, including the effects of static loading distribution due to self weight or settlement. The former can only be handled realistically by using probabilistic or other uncertainty techniques. The latter may be overcome, to some extent, by determining the initial points of contact between adjacent units.

Another important factor to be considered is the relative importance of the various types of loading data. One of the purposes of combined field and full scale laboratory tests will be to show whether it is satisfactory to design on the basis of eqivalent static loads or whether impact loading and load spectra must also be considered in the generally unreinforced units. In addition to self weight loading, it is intended that the field trials should also measure the transportation, placement and settlement loads on the units as these may contribute significantly to eventual failure. The instrumented units should therefore be capable of being handled in exactly the same way as normal units and should look identical as far as possible. A remote telemetry system is clearly essential for retrieving data during the transportation and placement phases.

4.2 Instrumentation

Instrumentation in each of the six units is to be of three types:

(a) Vibrating wire strain gauges embedded in the concrete of each leg of the units, to provide a strain history of shrinkage and creep in the concrete, and to determine the effects of gravity and settlement loading as a result of the position of the unit in the matrix;

(b) Electrical resistance or solid piezo crystal strain gauges and accelerometers in three-axis arrays, for the measurement of dynamic loading during significant events (e.g. impact during installation, storm loading, etc.).

(c) Pressure cells to measure wave pressures and contact pressures between units directly.

Type (a) instrumentation is fundamental for an understanding of the long-term performance of armour units. It will provide invaluable data for the subsequent global stress analysis of rubble mound breakwaters. Instrumentation Types (b) and (c) are essential for the assessment of dynamic and impact loading effects and general structural performance. However, whereas results from Type (a) instrumentation may be obtained at regular intervals by access to the units at low water, the remaining instrumentation yields transient signals. These must be either stored for later retrieval or transmitted directly by cable or radio to an adjacent land station for subsequent processing.

The various sensors together with the pre-processing and transmission hardware must be embedded in the units in such a way that the structural and hydraulic performance matches that of a standard unit as closely as possible. The aim then is to keep everything within the concrete section with only a cable connector and a flush mounted antenna being visible on the surface of each unit.

It is envisaged that a fully instrumented unit will require two 3-axis accelerometers and 6 strain gauge channels. However, since the strain gauges themselves are reasonably cheap, more gauges may be installed with a voting decision system on which elements to use at any particular time. Thus the transmission system is being designed to output a maximum of 12 channels of data per unit.

4.3 Data handling

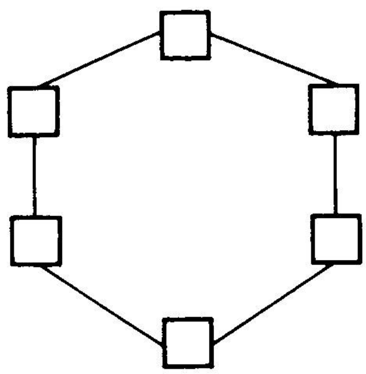
The general wave drag load and wave input load have very different characteristics and need to be sampled at about 25 Hz and 400 Hz respectively. A continuous sampling rate of 400 Hz would produce an unmanageable amount of data very quickly. A system is therefore proposed which can switch between sample rates with a rolling memory in such a way that the lead up to a triggering event can also be captured (pre-trigger operation).

If a base wave period of 8 seconds is assumed, i.e. one main impact lasting 2 seconds (say) every 8 seconds, this produces an average data rate from each unit of 3 kbytes/sec or 25 Mbytes/day of unprocessed data. This can be reduced (by approximately 25%) since any unit will spend at least 6 hours either out of the water completely or well submerged out of the main inpact region. However, this is still a restrictive amount of data.

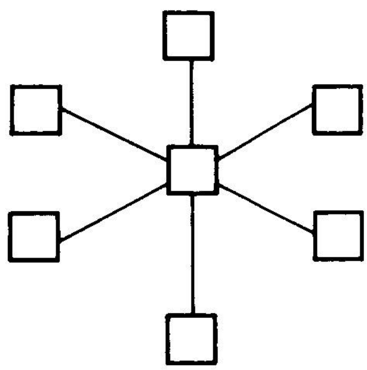
To deal sensibly with a scheme for the collection of raw data, it is necessary to reconsider what data is really needed. It may be argued that by taking just one channel of raw data from each type of sensor and only recording the statistical variation of the others, the signals associated with these remaining channels could be effectively reconstructed if desired. The philosophy to be adopted then will be to keep raw data storage and transmission to a minimum. Each unit must therefore have sufficient computational power to provide running averages of maximum, minimum, mean and standard deviation of each channel. In addition, raw data and a running average spectrum will be kept for a few selected channels only.

5. TELEMETRY AND TELECOMMAND SUBSYSTEM

The arrangement so far described comprises several identical intelligent armour units each capable of originating data. As such they constitute a distributed instrumentation system. In this context it is possible to consider the instrumented units as a local network and hence analyse the topologies appropriate to such an arrangement. The basic alternative schemes [3] are illustrated in Fig. 3 where the ring and star networks form the basis of two arrangements providing distinct performance regimes.



(a) Ring topology



(b) Star topology

Fig. 3 Alternative network topologies

The philosophy of the ring and star topologies are based upon cable transmission systems. The cabled network, in this case a shared resource and units in the network, can gain access via an asynchronous demand assignment arrangement or a synchronous polled system from the network coordinator system. A cabled network essentially needs a signal carrier which, in its simplest form, is the twisted pair. However, one such cable serving multiple units clearly has capacity problems in that it has a fixed bandwidth (typically data rates in excess of 1200 bands are unreliable). So far the system envisaged is incapable of supporting the higher sampling rates of 400 Hz; to go beyond this a balanced cable network would be needed to handle higher data rates. A networked intelligent instrumentation system has been investigated by Barton et al [4] where the network is built around the Ethernet system. Again the nodes or instruments share the network and the transmission capability is assigned to the data gathering instruments on demand. Other systems based on packet switching [5] are also applicable in which the data is actively retransmitted by several nodes, different routes for the data path being selected as demand requires.

An alternative for the cabled network is the radio network. Here there are many schemes, some analogous to the cabled network. The schemes most relevant to consider in this context are bandwidth efficient arrangements which include both access protocol and modulation techniques.

A system worthy of consideration is the radio pocket network described by Davies [6] which, like the cable packet switched network, employs nodes which receive and retransmit data packets independantly through the system in the presence of severe interference. The arrangement is illustrated in Fig. 4 in which the data packets have block identities and originator identities. In the generalised transmit/receive system there must also be a destination identity which indicates to a repeating station the destination of the data packet.

	Destination	Originator	Block No.	Data

Preamble/sync.

Fig. 4 General data packet format.

The attractions of such an arrangement to the current application are clear. A packet network offers flexibility and tolerance to congestion in both a cable and radio system. However, such a network requires several alternative interconnect paths which are not supported in the simple star or ring topologies. In the case of a radio network, more than one radio channel needs to be supported. This would occupy 12 channels for the 12 devices in a single unit per channel assignment. However, time division multiple access schemes allow channel sharing to enable variable data rate transmissions to achieve high bandwidth utilisation.

5.1 Modulation scheme

For a radio network, the environment is of paramount importance in controlling performance. In the sea shore environment it is anticipated that spray and foam will cause severe attenuation in both short and longer term events. It can be shown that attenuation by airated water forms a considerable problem. However, several transmission techniques exist which can cater for the deep fading environment. McGeehan et al [7] have described a scheme which provides a linear modulation channel having good performance in a very narrow bandwidth in a severely fading environment.

5.2 Proposed system

The proposed telemetry and telecommand system is depicted in Fig. 3. Here the network is cabled as a ring but with additional star network capability being provided by a radio system. In this configuration the network can support two cable breaks per unit with the telecommand radio channel supporting data transmission in this contingency mode. An optimal degradation strategy will be developed to cope with radio channel allocation. The radio system will be implemented with narrow band linear modulation techniques. This will provide bandwidth efficiency and good performance during fades. When some or all the units are submerged, telecommand processes will cease or be diverted to the cabled network as required.

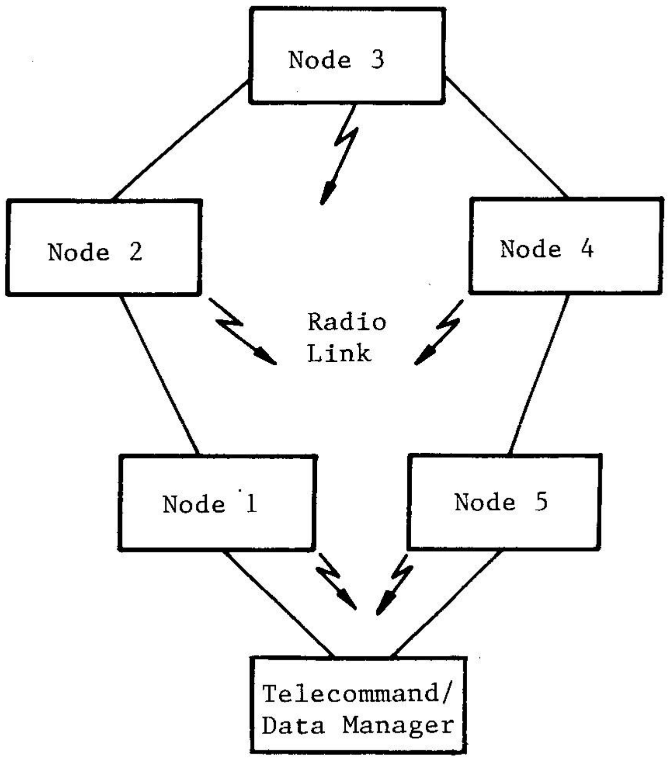


Fig. 5 Proposed network.

6. PRELIMINARY FIELD TRIALS

The project is still in its infancy and many major decisions are yet to be taken which will determine its eventual direction. However, the central feature of the project is the provision of real data from field trials for the necessary calibration of subsequent laboratory and analytical studies. Before embarking on extensive field trials, answers to a number of important questions are needed. These uncertainties include:

(i) the feasibility of using cables or radio telemetry for data transmission;
(ii) the survivability of instrumentation and surface-mounted cabling;
(iii) levels of strain and acceleration likely to be encountered during storms;
(iv) problems associated with installation and prevailing site conditions.

A very limited preliminary field trial was therefore proposed to answer some of these questions. It would also provide experience of the difficult working conditions on site and yield information for the design of equipment for deployment in subsequent field studies. The initial proposal was to test cable survivability during the winter storms of 1986-87 on La Collette Breakwater, Jersey, Figs. 6 and 7. This limited trial was later extended to include the installation of some simple surface-mounted sensors on the Cob units together with an instrumentation canister containing amplifiers and radio telemetry equipment. The data signals from the instrumentation could then be sent simultaneously up the cable and by radio telemetry to a land station close by (Figs. 8 and 9).

6.1 Cable installation

The preliminary trials were conducted with a very flexible 10 mm diameter, 14 core cable with a central cord of high tensile Kevlar and an outer polyurethane

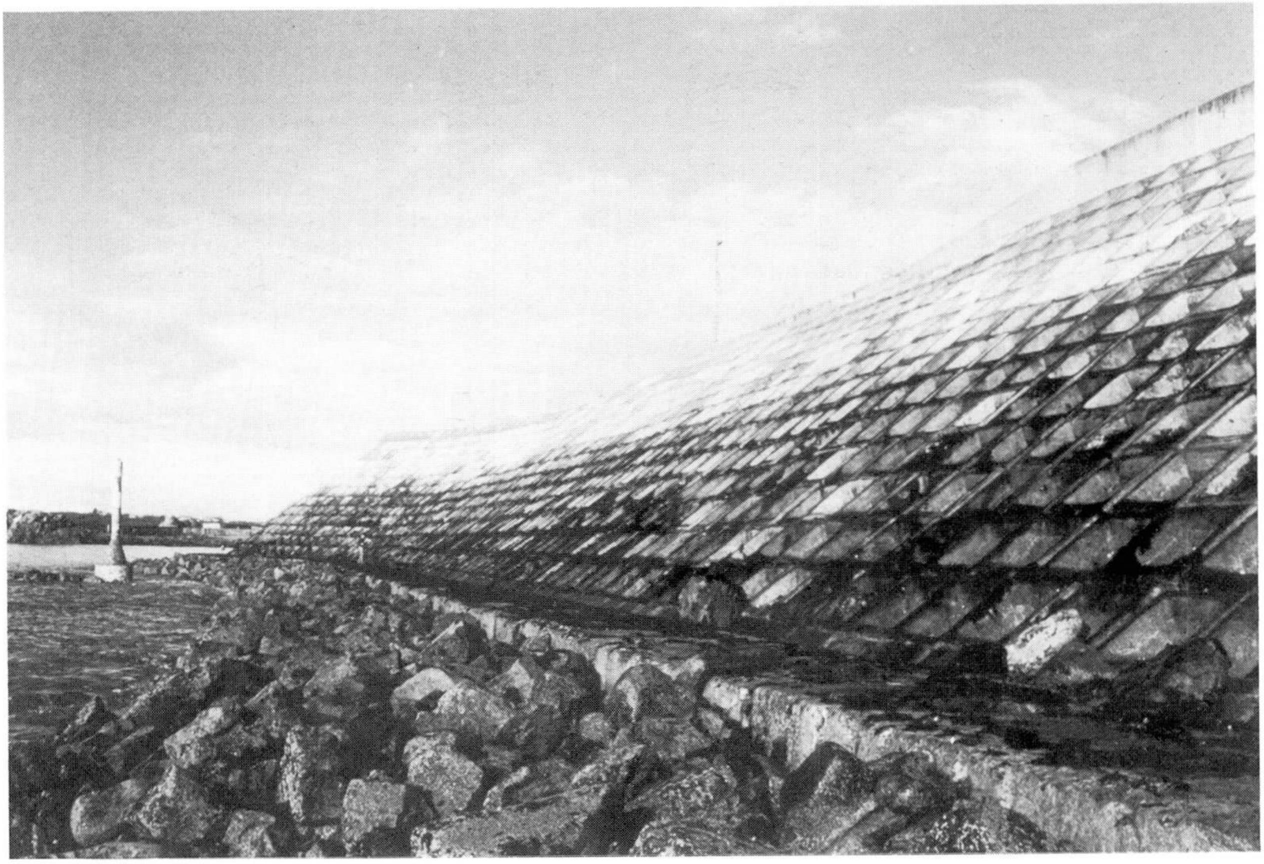


Fig. 6 La Collette as seen from the toe berm.

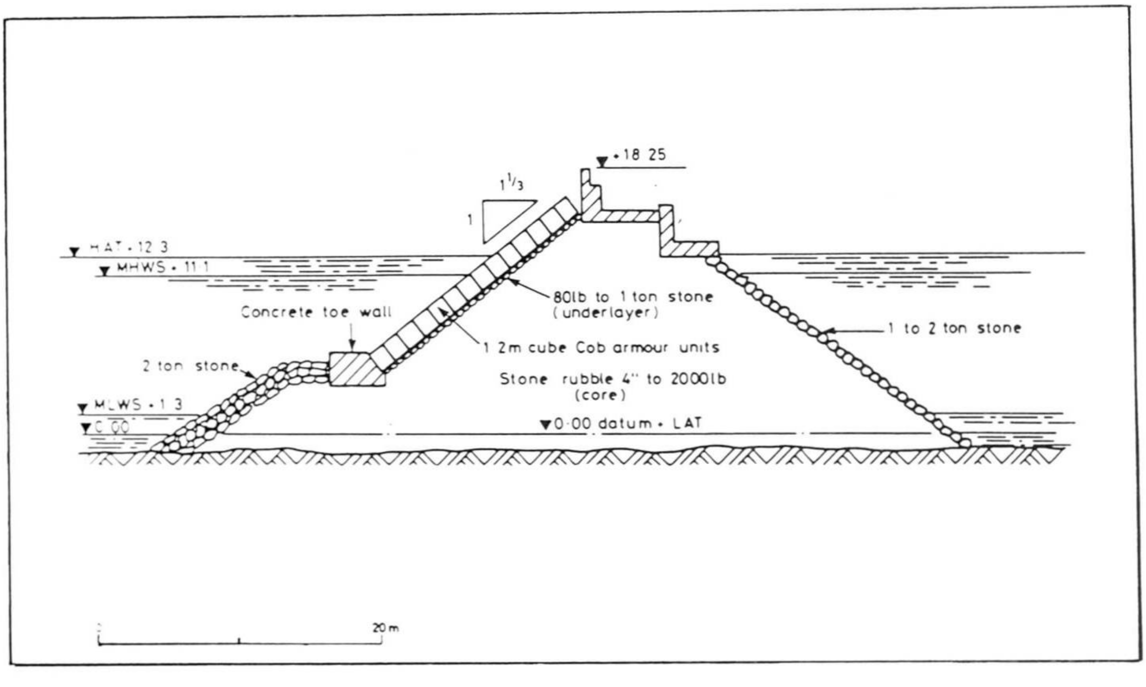


Fig. 7 Typical cross-section of La Collette breakwater.

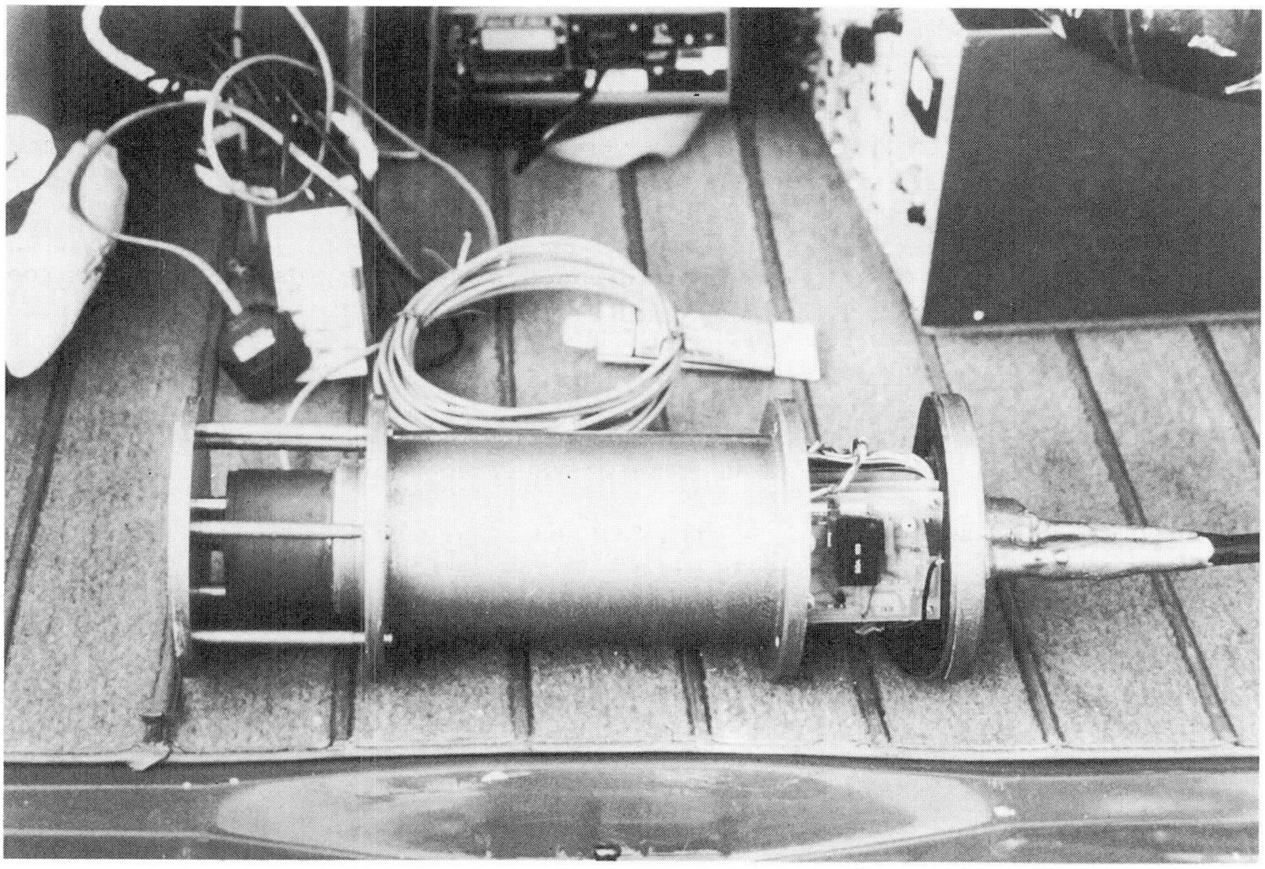


Fig. 8 Instrumentation canister with capping plate open.

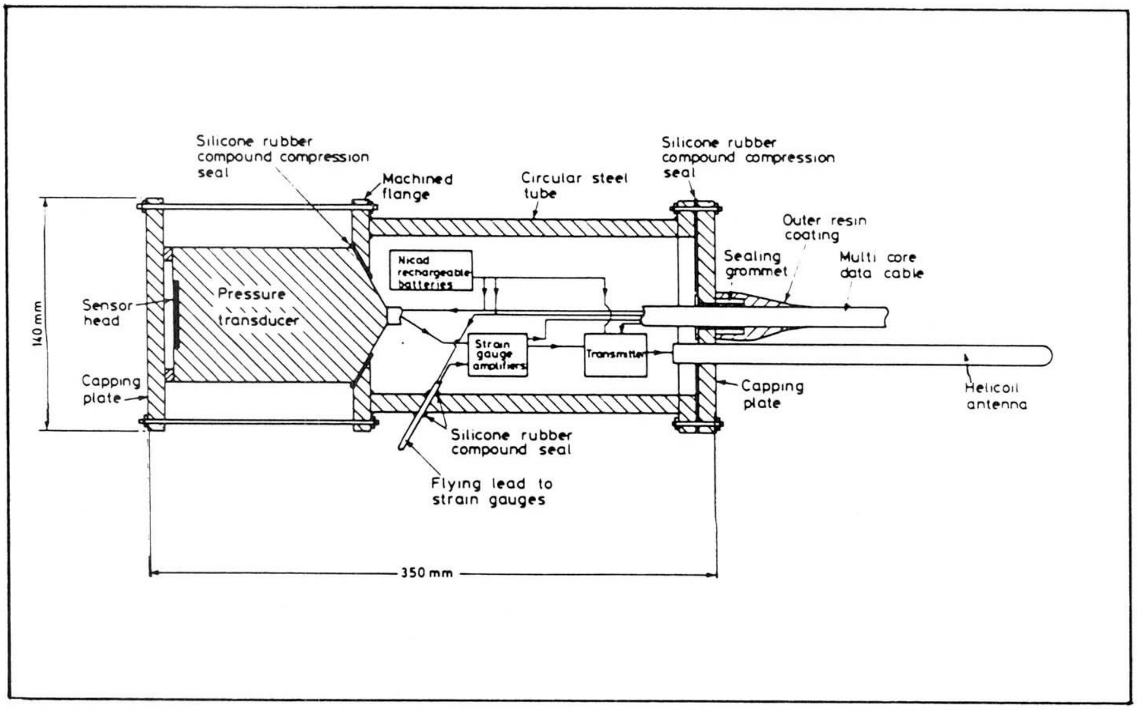


Fig. 9 Schematic section through instrumentation canister.

sleeve. There was some doubt as to whether this cable would be sufficiently robust to span between points of attachment. Moreover, if the data cable were to be tightly stretched and clamped between units, it might either restrain unit movement or become damaged if any significant movement occurred. For these various reasons it was decided to protect the data cable with an outer load-bearing sheath for the length of the armour unit slope. The sheathing selected was 20 mm diameter fibre-reinforced clear PVC tube.

A cable route was selected on the breakwater and deployment began as the tide ebbed below mid-water level. Kemfix threaded studs were inserted in the top and bottom corners of the seaward face of each Cob along the selected cable path. Having placed all the studs, the cable was positioned down the face of the breakwater, Fig. 10. It was then tensioned and clamped with substantial clamps which had been prefabricated from 6mm stainless steel. These were hooked over the sheathed cable at each stud position and secured using stainless steel nuts and washers. Total deployment time was approximately 3 hours.

Weather conditions remained quite calm for several weeks after deployment. The first severe storm occurred during late March 1987. On March 26 the maximum wind speed recorded at Jersey Airport Meteorological Station was 31 knots (Beaufort force 7), direction south south west. Conditions worsened the following day with a peak wind speed of 48 knots (Beaufort force 10) from west south west veering to the north west as the depression passed through. This would suggest that the data cable was subjected to direct incident waves of considerable but unmeasured magnitude. Inspection of the cable directly after the storm and on a subsequent site visit indicated that the cable was completely intact with no apparent abrasion or damage to the sheathing.

6.2 Instrumentation

During the first phase of the trial, an attempt was made to measure two parameters, namely wave-induced water pressure and concrete strain. The basic design philosophy was to produce a waterproof housing on the bottom end of the data cable to act both as a junction box and to encase relevant electronic components. Power supply, signal processing and data recording equipment were stored in a secure hut on the breakwater roundhead. The data cable ran from the hut, over the parapet wall and down the armour layer to the instrumented Cob unit. From there it passed into the instrumentation canister which was rigidly secured to the unit.

Conventional foil strain gauges were mounted in the centre of the upper longitudinal limb of the selected Cob. The surface of the concrete was cleaned using an electrical grinder and then thoroughly dried using an electric hot air blower. The cleaned areas were coated with rapid hardening Araldite resin into which the strain gauge elements were embedded. In the same way, a cable path was cleaned between the instrument canister and strain gauges for attaching the flying lead to the concrete with resin. In general, the resin bonding worked very well given the short time available for preparation and curing.

It became apparent after the first tide that water had leaked into the instrumentation canister through a seal damaged during installation. All the strain gauge amplifiers and the radio transmitter were thus destroyed. As a result it was not possible to test the telemetry system or to receive signals from the sensors via the cable link. A second phase deployment was therefore planned in which the instrumentation canister was replaced by a 'Kulite' soil pressure cell, Fig. 11. The sensing element of the cell consisted of a silicone semiconductor plate covered by an oil bath. On top of the oil bath was a force collecting plate covered by a protective layer of silicon rubber. The frequency response of the cell was approximately 2 kHz.

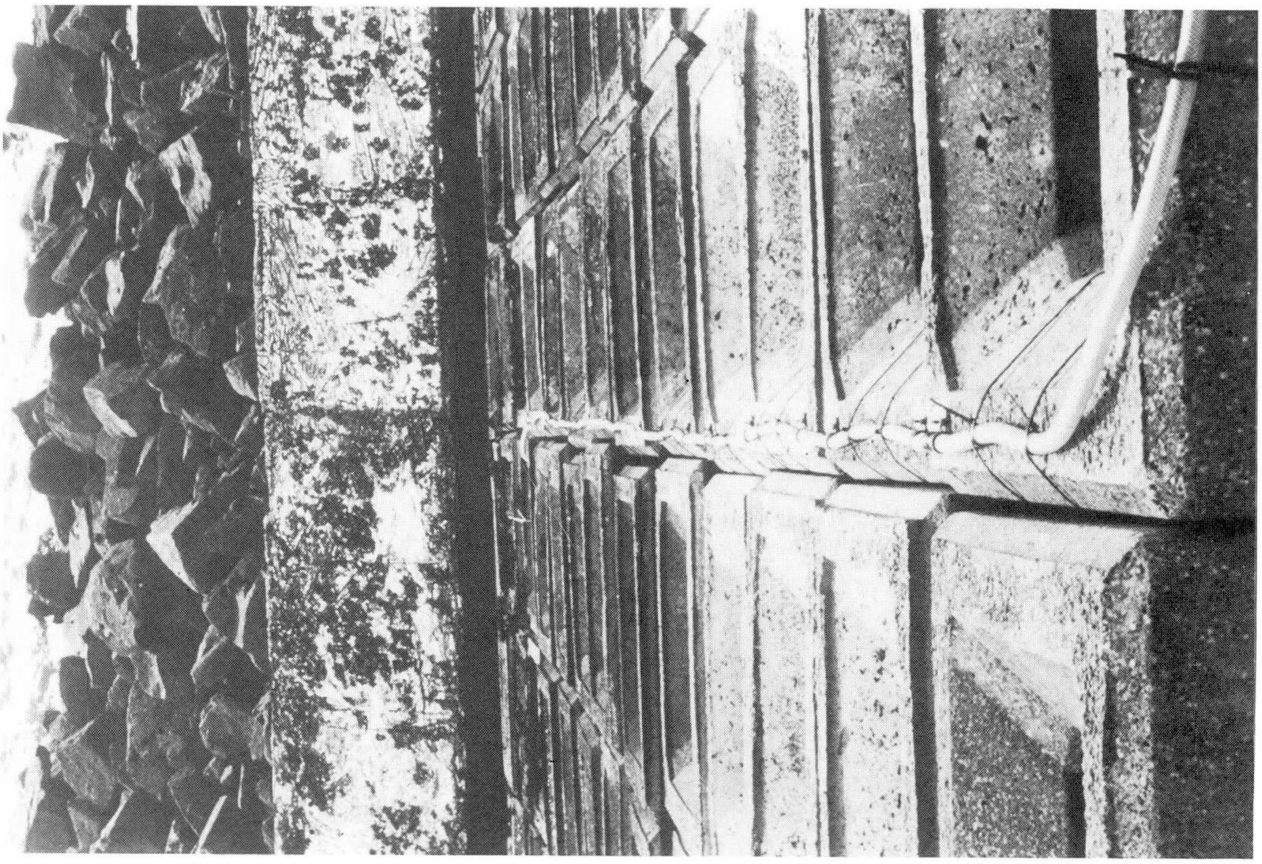


Fig. 10 Data cable attached to face of Cob armour units.

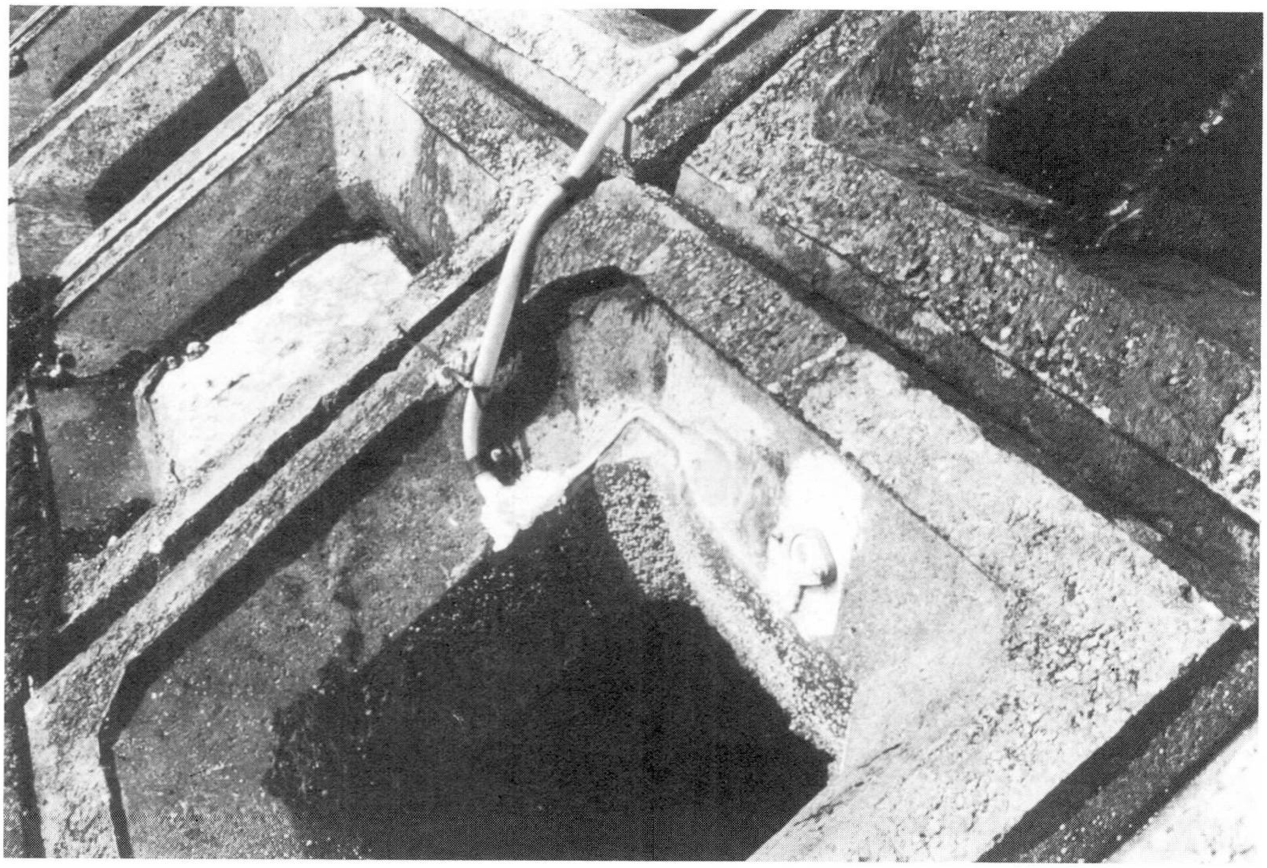


Fig. 11 Pressure sensor and strain gauge attached to Cob unit.

The signal conditioning and recording system was the same as that used for Phase I except that signal amplification was now remote from the sensors and there was no telemetry link. The sensors were activated with a 15V DC supply. Successful results were achieved from the pressure transducer. The conditioned signal had a low signal to noise ratio such that waves of very small amplitude were clearly discernible on the chart record. Some typical traces are shown in Fig. 12.

6.3 Conclusions

Knowledge acquired from the design, construction and deployment of the instrumentation was considerable. The sheathed cable system adopted worked well in terms of ease of deployment and physical survivability. It appeared to be necessary to provide adequate restraint to cable flexure under severe wave attack which might otherwise lead to abrasion and eventual failure. The outer sheathing did not need to be under such tension as to restrain movement of the armour units. The environmental protection provided by the sheathing allows the use of the most suitable data cable which need not itself be heavily armoured.

ACKNOWLEDGEMENTS

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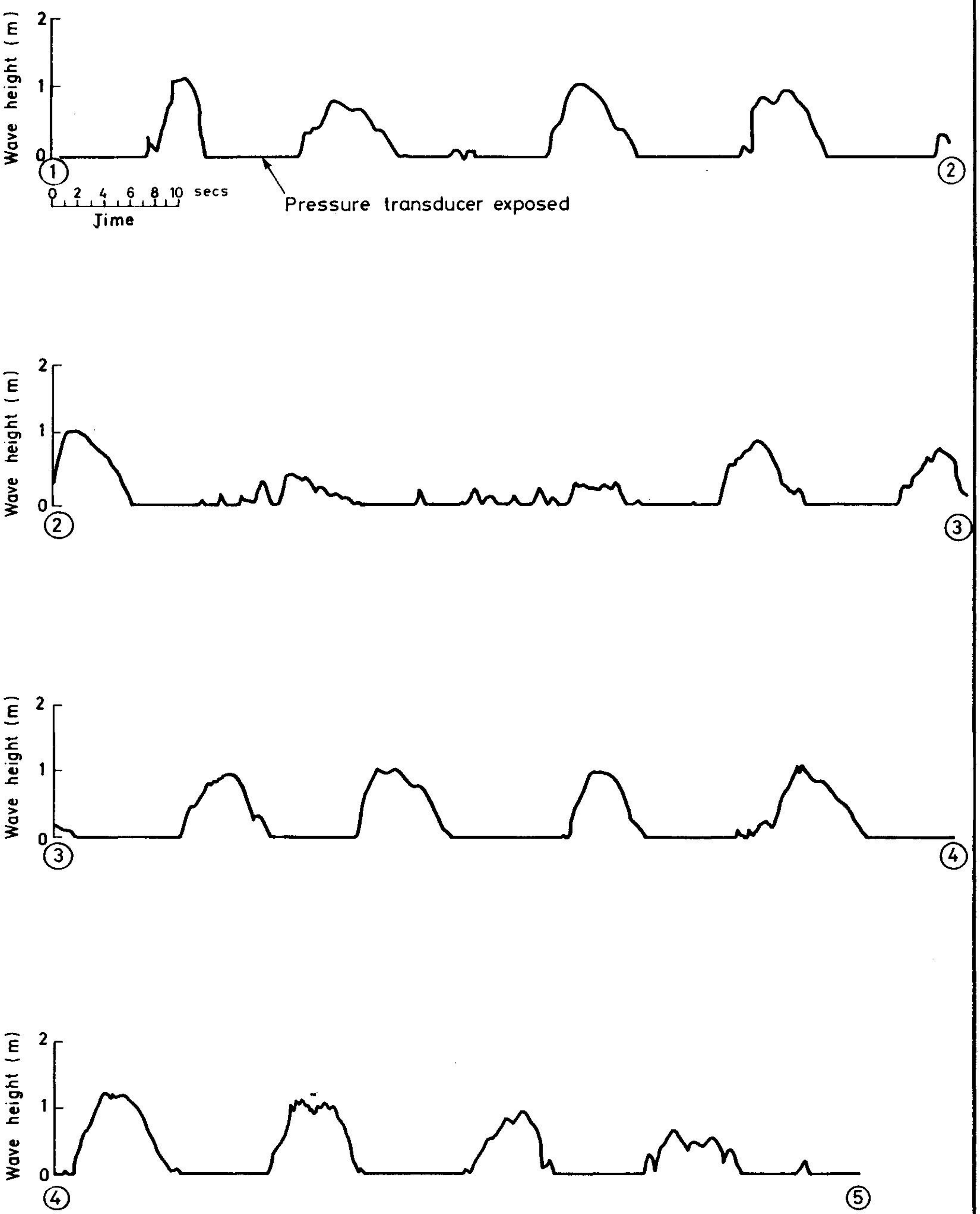

NOTE: The four segments shown above represent one continuous trace ① - ⑤

Fig.12 Sample record from pressure transducer