Hydraulics Research
Wallingford

THE EFFECTIVENESS OF GROYNE SYSTEMS
Physical Model Study of Groynes on a Beach

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SUMMARY

This report covers a programme of physical model tests carried out as part of Phase II of a research project investigating the effectiveness of groyne systems in modifying the beach environment.

The physical modelling was assisted by two field surveys undertaken in November 1983 and October 1984 at Sea Palling in Norfolk. The aim of the programme was to calibrate the physical model using the prototype field data and then study the effectiveness of the Sea Palling groyne system. Following this, various other groyne layouts would be tested and their effectiveness checked by varying groyne parameters and flow and wave conditions and identifying their effects.

In the event full validation was not possible and so a series of comparative tests were carried out using a fixed bed model of the beach at Sea Palling and modelling, with one exception, vertical impermeable groynes. Experiments were undertaken initially on a series of hypothetical groyne layouts up to and including a field of seven groynes. In the second series, comparative tests on a three-groyne system of similar configuration in plan to that at Sea Palling, was carried out.

This final report in the series covers the work carried out between May 1982 and June 1985. Other volumes, maintained as a project record by CIRIA and HRL, cover respectively the Summary Report (Volume 1), records of existing groynes (Volume 2) and field data collection (Volume 3 Part 1).

The physical model study was part of a collaborative project co-ordinated by CIRIA with additional funding under MAFF Commission B - Marine Flood Protection, by the Ministry of Agriculture, Fisheries and Food (MAFF).

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CONTENTS

TABLES

FIGURES

1 INTRODUCTION

Groynes have been used as a means of coastal protection for many years but as yet there have been no clear guidelines laid down for their installation and there is a distinct lack of definite design methods.

Although there is a good understanding of the inshore marine climate and the ability, using mathematical models to predict the effect of shoreline structures on the beach shape, it seems that it is not common practice to make full use of these techniques.

This current research project was promoted by the Construction Industry Research and Information Association (CIRIA) and follows an earlier literature review, conducted by Hydraulics Research Ltd (HRL). This review was extended in the first phase of the CIRIA research project to consider the particular problem being faced around the coastline of the United Kingdom and a set of recommendations and conclusions then drawn up (Ref 1).

One of these recommendations was that physical model studies should be undertaken to investigate such variables as groyne geometry, beach head structures (ie sea walls), beach profile and groyne type in a controlled environment. An initial series of tests were proposed to look at and resolve any problems with measurement techniques and with the provision of boundary conditions associated with the generation of alongshore currents. Other tests would concentrate on investigating waves, currents and their inteactions with different groyne systems. It was recommended that these studies should be carried out using a fixed bed model and validated using prototype measurements. Therefore in May 1982, HRL were commissioned by CIRIA to carry out these studies in a large wave basin.

The objective of the physical model experiments was to study the effects of different groyne systems (in terms of groyne geometry and structure and beach head), under different wave conditions (ie height, period and direction), on the currents that those waves create. It was intended that the physical model should be validated and calibrated using data obtained from specific prototype measurements. The decision was also made, for this phase of the project, to carry out the model tests using a fixed (concrete) bed. Although this precludes direct assessment of sediment motion, it does facilitate measurement of both the waves and the currents they create.

It was anticipated that this would lead to a clearer understanding of the hydrodynamic processes operating in and around a groyne system, from which deductions could be made on their effectiveness in controlling the movement of beach material.

In particular, attention was focussed on the likely performance of groyne systems on sandy coasts, ie beaches of shallow slope. (Generally, less difficulty has been found in designing groynes for shingle beaches.) On sandy beaches groyne performance can be extremely variable from site to site, and their effectiveness in promoting healthy upper beach levels is often doubtful.

In order to validate the model, prototype measurements were required. Insufficient funding was available to CIRIA to commission this work directly, but the Imperial College of Science and Technology (ICST) obtained grant aid from the Science and Engineering Research Council (SERC) for a research project which included carrying out field data collection along the lines suggested in phase one of the CIRIA report. Results from the work carried out by ICST and their sub-contractor (Ceemaid Ltd) were made available to the CIRIA project and an attempt was made to use this data to validate the physical model.

This report describes tests carried out in the physical model at Wallingford during the period from May 1983 to June 1985. These tests were split into three parts, namely,

1. Establishing experimental techniques and procedures
2. Attempting to validate the model against prototype conditions with the aid of field data, and
3. Investigating the effect of a number of hypothetical groyne layouts of different heights, lengths and spacings on flow conditions in and around the groyne systems.

The philosophy of the model design and details of its construction are given in Chapter 2. The first set of tests, to establish modelling techniques is described in Chapter 3. Chapter 4 describes the work carried out to validate the physical model against prototype measurements and Chapter 5 describes the tests carried out on a variety of hypothetical groyne layouts to study the effects of changing groyne geometry. Finally, Chapter 6 summarises the main findings and conclusions of the project.

All the figures in this report are prefixed with either 1, 2 or 3. This was done to differentiate between stages of the modelling programme. Figures prefixed 1, are connected with the experimental stage when techniques and procedures were established. Prefix 2 relates to the first series of tests (see Chapter 5, section 5.1) and the figures prefixed 3 are relevant to the second and last series of groyne experiments (Chapter 5, section 5.2).

2 MODEL DESIGN

It is clear that the use of a physical model to assess the effectiveness of a groyne system has many advantages over say, direct field measurement of groyne behaviour. The investigator can for example, specify precisely the incident wave conditions, the water level and the geometry of the groyne system used in any test. In addition he can rapidly alter the groyne layout and then repeat experiments under similar hydrodynamic conditions.

On the other hand, the use of a scale model has limitations, some obvious and others more subtle. It is physically impossible simply to scale down reality and as a consequence no model can correctly represent or reproduce all the characteristics found in a prototype situation. Inevitably some phenomena will be imperfectly reproduced and it is therefore necessary to identify those which are considered to be most important and design the model to reproduce those correctly.

The first decision made in the choice of parameters was the model scale. It was clearly necessary to study a reasonable length of coast to ensure that a sufficient number of groyne bays could be reproduced in the model while also allowing adequate space at either end of the beach to dissipate any model "end effects". This scaled reduction of the prototype must be of sufficient size to ensure that wave heights and periods were large enough to avoid distortion by surface tension and capillary effects but small enough to allow the model to be built, equipped and operated at reasonable cost.

In view of the foregoing, a scale of 1:36 was chosen (in both the vertical and horizontal planes) and an existing wave basin at Wallingford extended to 36.5m by 25.0m to accommodate the model. This enabled approximately one kilometre of beach to be represented in the model, with incident waves of up to 83mm (3 metres prototype) in height. The maximum water depth was 300mm (10.8m prototype). Wave periods of between 0.5 and 1.33 seconds (3 and 8 seconds prototype) could be generated, and this covered the range expected to be encountered during the field study. The dimensions of the wave basin allowed waves to be generated from an angle normal to the beach to about 25 degrees away from it. This range of angles covered the expected wave crest approach angle during the ICST/Ceemaid field measurements, and indeed on many coasts of the UK.

In the prototype situation, waves usually have a considerable spread of energy over both direction and period. Although it is possible to build a model wave generator to reproduce such a multi-directional complex sea state, it would have been impractical for the present study, both in terms of collecting calibration data and in trying to set appropriate boundary conditions for a rapidly changing sea state. Apart from the delay and considerable extra expense involved in obtaining the necessary equipment, there would also have been the need for extremely sophisticated field wave recording and analysis equipment to provide suitable input data.

It was therefore decided to use two 15m long, hydraulically operated paddles working in tandem, which produced long-crested waves from a single direction. These wave generators are capable of producing waves of random height and of specified frequency spectrum, but were used in the main to generate wave trains of uniform height and single period. This method of producing waves is clearly a great simplification of what occurs in nature and the question of whether a groyne system will behave "typically" under the action of long crested uni-directional waves cannot be resolved from the present model tests. Comparison between runs with uniform and random wave heights, however, did not suggest that this simplification would be too misleading; the main difference was that the steady current patterns were more difficult to observe in the latter case due to the higher rate of dispersion in the random waves. It is also argued that (a) both types of wave train showed a similar flow pattern (a view shared by committee members) and (b) this similarity results from the large inertia of the wave induced flows around the groyne field which is not affected to any great extent by variations from wave to wave.

The majority of groynes to be found around our shores are built on beaches composed of sand and shingle. The problems associated with scaling the properties of such materials are considerable and it is extremely difficult to find a model beach material which will accurately reproduce the movement of sand on a prototype beach. It is also very difficult to measure waves and currents especially in a mobile bed model in shallow water and so a positive recommendation had been made in a previous study (Ref 1) to use a fixed (concrete) bed model. There was thus no need to consider model sediment as a parameter.

It was realised that the model would require calibration against observation on a prototype beach. This is a requirement for any type of scale model. A likely consequence of representing a sandy beach by using a fixed concrete bed in a model is that the bed roughness is unlikely to be correct. It is therefore normal to change (usually to increase) the roughness of the model surface to ensure that prototype velocities are correctly scaled. This strategy was foreseen as likely for the groynes model.

A further limitation with a fixed bed model was that although it was possible to model a particular initial beach topography, as measured in the field study, it was not possible for the waves to realign the beach during a particular test. This precluded direct determination of the efficiency of a particular groyne system in either retaining beach material or increasing the beach width.

On the other hand this would not be guaranteed using a mobile bed, where the problem of scaling the bed material are formidable as mentioned above. The advantage of a fixed bed model is that it enables the measurement of current velocities even in very shallow water, from which at least a qualitative assessment of sediment movement and groyne performance can be made.

In most prototype situations it is the interaction of groynes and the wave induced alongshore currents that is most important. Of course all groyne systems around the UK coast are influenced to some degree by tidal effects. However this was not thought to be particularly important at the beginning of the study especially as the more important parameters were to be measured landward of the breaker line where tidal effects are negligible. Therefore a positive decision was made to exclude tidal effects from the modelling process. As will be seen later (Section 4.2), this led to some difficulty in calibrating the model. This decision was not taken because it was intrinsically impossible to include tides and their effects; indeed tidal modelling is routinely carried out in laboratories all over the world. However it would have added considerably both to the expense and to the number of parameters to be tested within the relatively short timespan envisaged for the study. For example tests may equally well have been carried out with the same groyne geometry and wave conditions but at various states of the tide. However, it was decided to concentrate on the effects of the groyne systems, both on the waves and the currents that those waves created rather than on the effects of say tidal currents and varying water levels. On a similar basis it was also decided to exclude wind effects.

As with all scale models, while some physical processes will be well scaled, eg the propagation of waves, it is necessary to check that the model does not give unrealistic results for other phenomena. In particular because water viscosity is unaltered while other parameters are scaled down, it was always considered likely that there would be some difficulty in matching model velocities against those recorded in the prototype. This is a standard problem which occurs frequently in tidal models and is overcome by artificially roughening the bed surface to obtain correctly scaled current velocities.

It was also necessary, as discussed in the next chapter, to provide an external flow circulating system to overcome the fact that the model had finite boundaries whereas in nature the beach would be much longer and there would be a natural input and outflow of currents at either end of the stretch of beach being modelled.

During the first phase of this research project, a large number of references describing laboratory tests on groynes were reviewed (Ref 2). The vast majority of these tests however, were carried out using a bed of granular material and the effects of the groynes assessed by the response of the mobile bed. Although this is a most direct method of carrying out such an assessment, it has serious flaws as mentioned above.

In March 1983, before design and construction of the model had begun, a visit was made to Delft University in the Netherlands to talk to Dr P J Visser who had been recently involved in investigating alongshore current flows in a wave basin (Ref 3). His valuable advice was of great help in setting up the circulatory system. A Dutch report entitled "Influence of groynes on the form of the coastline" (Ref 4) was also translated although this only proved to demonstrate the difficulties of physical modelling, the value of accurate moulding and the need for an external recirculation system mentioned already.

As will be seen in the following chapter, the results from these previous studies proved to be very useful in establishing experimental procedures for this study.

3 EXPERIMENTAL TECHNIQUES

The first stage after construction of the physical model was to establish suitable operating techniques and most importantly to assess the best methods of measuring the speed and direction of the currents.

It was necessary in the first instance to devise a method in which alongshore currents, generated by obliquely breaking waves, were allowed to flow naturally without causing unacceptable circulation within the wave basin. This was done by installing an external pipe system which allowed the alongshore flow of water to be extracted at the downdrift end of the beach by means of an axial flow pump and re-introduced at the updrift end. This arrangement is shown in Figure 1-1 and Plate 1-2. Flow measurement was made by means of an ultra-sonic flowmeter situated in a straight length of the (external) pipe and linked to an electronic flow recorder.

The distribution at the updrift end of the model beach was effected by a series of channels, 12 in all, installed parallel to the beach in the updrift wave guide wall. Each channel was equipped with its own gate which could be operated independently. Variation of the current flow pattern was achieved by placing baffles in the individual distribution channels and adjusting them until the required velocity profile was obtained. The aim was to supply and extract the correct flow at either end of the model beach whilst allowing the currents to be driven by the obliquely incident waves within the working area. The effect of this was to minimise disturbance at either end of the beach, and to avoid as far as possible unwelcome flow circulation within the model basin.

As well as the external flow system, a series of pressure tappings were inserted in the model beach, with pipes from these pressure holes leading to a batch of stilling wells enabling wave set up to be monitored if required.

Initially a 15 metre long (540 metres prototype) stretch of beach was modelled without groynes, with a uniform slope of 1:29 based on the mean profile of a sand beach surveyed at Chapel St Leonard on the East coast. One 15 metre long wave generator was installed in the model and placed at a 10 degree angle to the beach. Wave guide walls placed at each end and perpendicular to the paddle, extending right up to the beach to constrain the waves on to the slope but leaving an opening at the top of the beach for the alongshore flows to pass unhindered. This set up is shown in both plan and section in Figures 1-1 and 1-2.

At this early stage with no proving data available, it was decided to run the wave generators using regular waves with a period of 1.167 seconds (7 seconds prototype) and a height of approximately 0.083m (3 metres prototype). This was for two reasons; firstly, this tied in with the experimental work done by Visser (Ref 3) on a similar slope and ensured that appreciable alongshore currents were produced, and secondly it was what was thought to be a reasonable estimate of the conditions to be found on the east coast. Visser's experimental velocity profiles for a particular uniform sloping beach were converted to suit the 1:29 slope of the physical model by means of a mathematical model.

Two different types of instrumentation to measure the alongshore currents (ie ultra-sonic and electro-magnetic miniature current meters) were tested. Although both types worked reasonably well in deeper water, problems were encountered in the highly turbulent surf zone where the presence of entrained air bubbles made the ultra-sonic meter unreliable. The electro-magnetic meter functioned well except near the bed of the model where the water, forcing its way between the bed and the disc shaped sensor head of the meter, tended to give inaccurate results.

The electro-magnetic current meter was used in all but the shallowest areas of the basin and mean velocities calculated using the following equations:

1. In the constant depth part of the basin
   $\bar{V} = 0.25(V \text{ surface} + 2V \text{ middepth} + V \text{ bed})$
2. On the sloping beach
   $\bar{V} = 0.5(V \text{ surface} + V \text{ bed})$

the 'bed' velocities being measured just above the floor of the model (10-15mm) while the 'surface' velocities were taken with the head of the instrument just below the trough of the waves.

In the shallow water zone at the top of the beach, various techniques were used including float tracking. It was found after considerable experimentation that the most favourable way to measure shallow water flows was by injecting dye and following its movement by means of a video camera suspended directly above the injection point. This had the advantage of measuring the speed (a digital clock is superimposed on the video screen) and also the direction of the currents within the groyne field. It was found that by following the head of the central spine of the main dye streak it was possible to measure the trace, in most cases for at least one metre. It was also possible, in the deeper water, to check the velocity of the dye with the electro-magnetic current meter. Later it was found that the most convenient way to observe current flows near the bed was to mix the dye with a solution of sucrose which made it just heavy enough to remain in the lower strata.

Wave heights and periods were measured in the model using standard HRL twin wire wave probes.

Finally, in order to obtain a first estimate of the likely current along the model beach, created by the obliquely breaking waves, a mathematical model was developed at HRL using the theory given by Longuet-Higgins (Ref 5, 6). His approach was to calculate the momentum of the incoming waves and hence the lateral thrust they exert in the surf zone. Then, by taking into account frictional effects, it was possible to derive a simple expression for the total alongshore current, using the direction and height of the waves just outside the breaker zone. That same momentum causes an increase in the mean water level within the surf zone called 'set up' which can also be calculated theoretically. In the context of modelling the set up is important from the point of view of altering the across-shore distribution of the littoral currents. For example a large set up will increase inshore water depth and hence the discharge on the upper part of the beach.

It is not appropriate here to reproduce the formulation of the theory, but simply to quote the equation of greatest importance, namely:

$$Q = Kg^{\frac{1}{2}}H_b^{5/2} \sin 2\alpha_b$$

where:

Q is the total alongshore discharge

H_b is the height of the waves as they just start to break

α is the angle between the beach contours and the wave crests at the point of breaking,

g is the acceleration due to gravity, and

K is a non-dimensional coefficient which depends on the frictional characteristics of the beach, the intensity of horizontal mixing and the ratio of local depth to breaker height.

Although more recent work has been carried out into modelling the processes which affect the coefficient K, the methods and numerical values proposed by Longuet-Higgins proved to be quite accurate enough for the initial design of the experiments. By later comparison of the model results and the above formula, it was possible to make a more satisfactory evaluation of K and anticipate the discharge required for different model situations (see Figure 1-3 for comparison of mathematical model and physical results).

3.1 Instrumentation

To obtain the direction and magnitude of the alongshore currents, circulatory flows within the model basin and wave heights and periods, various instruments were employed. These instruments, mentioned briefly above, were:

Electro-magnetic current meter

This meter has a discus shaped sensor head 35mm in diameter with four electrodes situated in two diametrically opposed pairs. A magnetic field is set up in the water by means of a coil in the sensor head carrying an electric current. Water flowing through this field produces a potential difference which is detected by the two pairs of electrodes. This potential difference is calibrated in known flows giving a measurement in two planes.

Ultra-sonic current meter

This acoustic device comprises a sensor with four diametrically opposed vertical prongs which measure the travel time of sound pulses between each pair of prongs in two horizontal directions, providing an output which is a direct measurement of the flow in both directions. The signals from both channels are used to compute the resultant speed and direction of flow.

The resolution of both current meters is of the order of 4mm per second which compares favourably with the standard miniature propeller current meter (20mm per second). Both the above current meters, however, were relatively new and untried and prone to teething problems.

Twin-wire wave probes

Waves in the model were measured by standard HRL wave probes spaced across the width of the wave generator and shoreward of it. They consist of two parallel 1.5mm diameter wires set vertically 12.5mm apart and energised with a high frequency alternating voltage. The conductance between the wires is proportional to the depth of immersion (and the conductivity of the water) and the probe can resolve water level changes of 0.1mm.

Ultra-sonic flow meter

This is an obstructionless flow meter set into the pipe system to determine the amount of alongshore current recirculation. It is attached to a converter which measures the time differential created by liquid flowing through the sensor tube. This measurement is converted to a voltage which is displayed by a digital output.

Axial flow pump

Used to pump the flows from the downstream end of the model back to the upstream end via the pipe system. It is controlled by a rheostat which can vary the flow from 0 to about 90 litres per second.

4 VALIDATION AGAINST PROTOTYPE MEASUREMENT

4.1 Initial validation (prior and following the October 1983 field survey)

Following the initial testing described in the previous chapter, the next task was to extend the model beach by a further 16 metres in the alongshore direction. This gave a total prototype length of over one kilometre as shown in Figure 2-1. This was sufficient to examine beach conditions without serious end effects within the modelled area. The second wave generator was installed to run in parallel with the generator already in position, and the initial experimental tests re-run to confirm their repeatability on the extended beach. The wave guide wall openings together with the velocity profile of the alongshore currents were adjusted and calibrated against previous experiments (see Ref 3).

Attention was then focussed on calibrating the physical model against prototype data. The site chosen, Sea Palling in Norfolk, was a good one, having three groynes set on an almost straight and predominantly sandy beach, with a considerable stretch of open coast on either side. This arrangement therefore allowed measurements to be made, not only within a groyne system unaffected by neighbouring coastal works, but also on the open beach on either side. In addition, it was reasonably easy to model this situation in the wave basin because of the simplicity of the conditions at each end of the beach.

In October 1983, before the first field survey, a series of preliminary physical model tests were undertaken on a groyne field built on a uniform sloping beach. Three groynes were set at the top of the beach with lengths and spacing similar to those estimated at the site chosen for the prototype experiments. Members of the Steering Group and the survey contractor (Ceemaid Ltd) were then invited to Wallingford to view the model and the flow patterns generated around the groynes. This also allowed the survey contractor to get a general feel for the current flows and to help him decide where to place his survey instruments.

The field data collection took place during October and November 1983, but was severely hampered by storms which destroyed much of the equipment deployed and eventually forced the survey team to abandon the programme. As a consequence, only a small amount of data on waves, currents or beach topography was obtained. However, there was sufficient information to re-mould the physical model to represent a typical winter profile and the wave generators were moved to the more oblique angle of 26 degrees to the shoreline. This approach angle was suggested by the field experiments. With no valid proving data at this stage, it was decided to continue running the model with the wave height and period used in the setting up procedure described in Chapter 3 (see Figure 2-14 for the plan layout).

Recirculation within the basin was measured at sections L and M and also along section F in the constant depth area seaward of the beach (Figure 2-2). Spot checks were carried out at points throughout the basin and wave set up was monitored during each test. With the wave height and period judged to be comparable with the anticipated conditions at Sea Palling, the alongshore currents were adjusted to the required profile, thus obtaining a minimal recirculatory movement within the basin. Optimisation of the alongshore flows was important. If currents were either too fast or too slow they caused unwelcome recirculation within the basin and non uniformity of both the incident waves and the flow along the beach. Just enough flow needed to be pumped through the system to ensure that the input velocities were similar to those created by the obliquely approaching waves. These recirculatory flows are shown in Figure 2-2 together with the flows at sections L and M within the basin.

Following these adjustments, the survey contractor expressed the opinion that the model was exhibiting the same general behaviour that was observed during the field experiments at Sea Palling.

After these preliminary tests, whilst awaiting further data from the field experiments, a series of tests were carried out (in December and January) on 1, 3 and 4 groyne systems (Tests 1 to 5), using wave and current data obtained in previous research on alongshore currents (Ref 3). Later the beach was re-profiled to a more realistic shape using an approximate beach profile from Sea Palling. However, it was soon apparent that little was to be gained from the very limited data available and this attempt at validation was brought to a close. Attention was then turned to testing hypothetical groyne systems (Tests 6 to 25) and these are described in Chapter 5.1.

After these tests, when radar photographs taken during the Sea Palling experiments became available in March 1984, it was seen that the offshore wave approach angle was much more oblique than those earlier assumed (up to 45 degrees relative to the shoreline).

At this late stage the model was not altered because,

(a) It was not possible to reproduce the external flow rate anticipated and it would be difficult to obtain the correct wave angle in the basin.
(b) This obliqueness was considered to be unrepresentative of the bulk of conditions under which systems would operate, and
(c) There was no current data on which to calibrate.

4.2 Final validation attempt (following the October 1984 field survey)

Following the failure to obtain validation data in 1983, a second field survey attempt was made in October 1984 with a completely re-designed instrument system.

The intention, for this final stage in the physical model programme, was to simulate the Sea Palling groyne field and calibrate the model from the October 1984 field survey data. Following this it was intended to study the effects of changing various parameters of hypothetical groyne systems under a variety of wave conditions and tidal levels.

As the field survey data started to become available from the October 1984 experiments, the top of the model beach area was re-moulded. These upper beach contours stretching to about 1750mm (63m prototype) seaward of the baseline, were obtained from beach levels measured along the prototype run-up gauges placed on the upper beach and shown in plan in Figure

3-2. Run-up gauge 1 provided the contours north and updrift of groyne A, (the updrift groyne) while run-up gauges 2, 3 and 4 supplied the beach profiles between groynes A and B. Further levels were obtained from beach dips taken at either side of the groyne king piles.

With no beach levels available south ie downdrift of groyne B, (middle groyne) profiles to the north of this groyne were 'mirror imaged' as shown in figure 3-3, to provide the beach contours to a point some 4000mm (145m prototype) south of groyne C (the downdrift groyne). From this point the contours were flared out to blend with the existing slope at the downdrift extremity of the beach. The lower beach area had to be estimated, there being very little field data available at this time. The typical winter beach profile given in the 1983 field survey (and shown in figure 2-7) was used. These lower beach contours were blended into the original uniformly sloping beach at approximately 5100mm (184m prototype) seaward of the model baseline at the top of the beach (Figure 2-8).

The model beach was again constructed as a 'fixed' bed tapering down to the floor of the basin some 9700mm (350m prototype) seaward of the top of the beach. Water depth in the offshore (floor of the basin) area, remained, except where stated, at 300mm (10.8m prototype depth corresponding to -9.4m ODN at the bed) to simulate the depth at mean high water of spring tides.

When the prototype groyne levels became available, the model groynes were designed, built and installed into the model's upper beach. Groyne heights at their seaward end were estimated from photographs.

The wave generators were positioned in the constant depth part of the basin and at an angle of 15 degrees as shown in figure 3-1. This gave a 30m long wave crest (1080m prototype). No radar plots were available at this time but the breaking angle measured in the model tied in well with the angle (10 degrees) visually observed at the beach. Initially only maximum and minimum wave elevations were available from the offshore wave rider buoy, and it was also necessary to estimate the wave period. The offshore significant wave height was therefore calculated by applying the Tucker-Draper (Ref 8) method of analysis explained below.

Assuming initially an 8 second wave period (1.33 seconds model) over the 20 minute data gathering period, gives 150 wave crossings. Using the Tucker-Draper charts, this gives a factor f of approximately 0.6, so the significant wave height H_s can be estimated using $H_s = f \times H1$ where H1 is the height of the highest wave crest added to the lowest recorded trough obtained from the offshore buoy data. From the initial data, H1 was given as 2.015m so giving $H_s = 0.6 \times (2.015m) = 1.209$ metres (prototype). To represent this using a regular wave train, this figure was multiplied by 0.7071 to give 0.85 metres prototype (0.024m model). This wave analysis was later amended, when more data became available, to an Hs of 0.87m and a 6.05 second period.

In view of the stratification of the flows noticed (see Chapter 6), currents in and around the groyne field were measured at both mid-depth and bed level. It was however, found that the currents although stratified, generally followed a similar pattern. Thus the flow patterns in the relevant figures indicate a typical velocity and direction through the depth. There was a continual interchange between model and survey data analysed at this time and quite often it was the physical model that suggested problems associated with the prototype data rather than the other way around.

The model measurements were also supplemented by introducing anthracite granules (see Section 5.2), in and around the groyne bays to determine any likely accumulation areas.

As model calibration progressed it became clear that comparison between model and prototype, in terms of current velocity and direction, was unsatisfactory and despite lengthy experimentation could not be rectified. It was found that with the wave conditions predicted, the alongshore currents in the model were concentrated in a narrow band within the groyne bays, with the velocities tapering off seaward of the breaker zone. The data from the field experiments however, gave an increase in velocity at the pod positions (wave and tidal measuring stations) outside the breaker line, which was thought probably due to tidal currents.

A meeting with the Steering Group's working party was arranged at which it was decided that:

(a) the model's lower beach should be re-profiled to simulate an extended profile (recently received), of the section offshore of run-up gauge 3, and

(b) ICST would analyse fully the field survey data and no further work would be done by HRL with the partly analysed data.

The model's lower beach was accordingly re-moulded to the given profile. This profile was used for the whole of the lower beach area and blended in with the existing profile as shown in figure 3-2.

Model results were still not compatible with the prototype and calibration was suspended awaiting the ICST analysis. This analysis could not resolve the inconsistencies and at a further meeting it was finally agreed that the currents being measured at the site were indeed influenced to a large extent by tidal currents. The pod positions were too far offshore to record the wave induced currents except for pod 5 which gave rather strange readings and was, on its own, insufficient; in addition there was not enough back up prototype information from visual observations or float tracking in the surf zone. In view of all this, together with the fact that there was insufficient time to change to a mainly tidally influenced model and there was not enough data within the groyne area for calibration, it was decided to abandon the validation exercise.

To maximise use and value from the model, an alternative test programme was implemented and a series of comparative tests were devised based on the Sea Palling beach profile and these are described in Chapter 5 below.

Much later in the research project after the model tests were complete, further data obtained from field experiments on the Lincolnshire coast indicated that velocities measured in the physical model were probably rather too high. After allowing for scaling (by a factor of 6) it seems likely that the model velocities were between a factor of 1.0 and 2.0 above what would actually occur on a beach.

In view of this, it appears that further experiments with a roughened beach would have been worthwhile, although the limited timescale would have made this difficult.

5 TEST PROGRAMME

5.1 Hypothetical groyne systems (first test series)

Clearly there is a virtually infinite variety of tests that could be carried out on hypothetical groyne systems and it was necessary to choose a representative selection to be examined in the available time. Attention was focussed on vertically faced groynes which predominate around the coast of the UK and a series of plan layouts were chosen to try and identify the effects on the alongshore currents of changing groyne orientation, elevation, length and spacing under different wave conditions.

The overall philosophy of these tests was not to develop an optimum system for a particular site, but rather to investigate the effect on flow patterns of changing one or more of the parameters. In the sequence of tests carried out it was thus possible to isolate parameters which were of paramount importance (ie elevation and length) and those which had a lesser influence on the flow fields (ie orientation and spacing).

The experimental schedule, together with details of the model layout, significant wave height, return period, alongshore current flow, angle of wave approach and the tidal state, are shown in Table 3. These tests can conveniently be sub-divided into four segments:

1. Tests 1 to 5

These initial tests (1 to 5), were carried out with the original 1:29 uniformly sloping beach modelled with the waves approaching at an angle of 10 degrees. The groynes were spaced 2780mm (100m prototype) apart in preparation for experiments anticipated at Sea Palling.

The direction and velocity of the flows in these and subsequent tests were measured using dye injection and videoing the resulting traces from a camera suspended directly above the model, supplemented in deeper water by an electro-magnetic miniature current meter.

The modification of the alongshore currents and the consequent re-arrangement of flow patterns due to groyne layouts were studied, modelling:

(a) 1 groyne (test 1)
(b) 3 groynes (test 2) and,
(c) 4 groynes (tests 3, 4 and 5).

Test 1 was on a single groyne, 2220mm (80m prototype) long with an elevation of 38mm (1.37m prototype). This was estimated to be of a length similar to that of the groynes at Sea Palling and fairly typical of a 'sand beach' groyne although its height above the beach at its seaward end was somewhat higher than is normal.

The results of this test can be seen in figure 2-4 and show clockwise eddies, both updrift in the shelter of the groyne and also on its downdrift side. Seaward flowing currents were evident along the groyne's downdrift edge. The external flow field was little affected.

Test 2 involved three groynes. The plan layout was estimated by the field surveyor as being similar to the prototype dimensions of the groynes at Sea Palling. The two outer groynes were 2220mm (80m prototype) long with the centre groyne 420mm shorter at 1800mm (65m prototype).

The results (Figure 2-5) show eddies in both bays. Clockwise eddies were also evident both updrift of the updrift groyne and downdrift of the downdrift groyne. Velocity of the external flows remained largely unaffected.

Test 3 comprised a field of four groynes, as test 2 above with an added fourth short, 1800mm (65m prototype) groyne placed downdrift of the other three.

Groyne spacing remained the same at 2780mm (Figure 2-6).

This four-groyne system gave similar clockwise eddies in each bay as observed in the previous test, with areas of slack or dead water inshore. The external flows were again little affected.

The resulting flow patterns around these groyne fields for the above tests are shown in figures 2-4, 2-5 and 2-6 respectively. The arrows in the figures signify the direction of the alongshore currents with their respective velocities shown alongside. The extent of the wave run-up and the still water levels are shown as dashed or dash-dot lines. As can be seen in all three tests, there is a significant seaward running flow along the downdrift edge of the groynes, while groyne influence on flows is evident for at least a groyne length either side of the systems. In the four-groyne layout, flow in the first two compartments was similar in pattern to those with the three-groyne system. The direction of eddy flow will of course depend on the incident wave angle.

Tests 4 and 5 were as test 3 with,

(a) the camera at an oblique angle to try and encompass the whole groyne field and
(b) general video shots of the groyne field to combine with test 3 and to show the CIRIA Steering Committee the effectiveness of the dye injection technique.

In January 1984, following the field survey at Sea Palling (Oct/Nov 1983), a profile of the beach was supplied by ICST. This is shown in Figure 2-7 and was stated to be a 'typical' profile. It gives a cross section of the beach down to mean low water. Beyond this an estimated profile was given to extend the section seaward to about 180 metres from the top of the beach. To model these prototype contours, the upper part of the hitherto uniform beach slope was broken out and re-moulded to this cross section (shown in Figure 2-8) along the whole beach length with the exception of a transitional length at each end.

2. Tests 6 to 10

After the beach had been re-moulded, a 3 groyne system was constructed with estimated elevation, groyne lengths, spacing and orientation to simulate the groyne field at the Sea Palling site. Groynes 1 and 3 were constructed to be 2306mm (83m prototype) long while the central groyne was made 417mm (15m prototype) shorter as shown in figure 2-1. The angles of each groyne relative to the beach were estimated (there were no data available at this time) from the largest Admiralty chart available and taken as 0, 6 and 13 degrees respectively (running from north to south) from a line perpendicular to the beach. Each groyne was embedded into the winter profile so that the seaward ends of the groynes protruded 38mm (1.37m prototype) above the beach profile while their landward ends had an elevation of 19mm (0.68m prototype). These are shown in figure 2-10, and are referred to as 'high' groynes in table 3 and the text below. The distance between the groynes, and their actual height relative to the beach were estimated.

Tests 6 and 7 were run to check the direction and velocity of the alongshore currents, together with wave conditions. The parameters for these tests are shown in Table 3.

The flow patterns shown in figure 2-11 indicate that the external flows are largely unaffected by the groyne field. Within the bays however, current velocities were slowed and eddies formed with areas of slack water in the shallows. Backward flowing currents were formed close to the water's edge downdrift of the terminal groyne.

The next set of tests 8,9 and 10, were run with the lower wave height of 2.8m prototype, similar to that in tests 1 to 5. The results of tests 8 and 9 are shown in figure 2-12. Test 10 was run with the same wave and current conditions but with an increased water depth of 330mm (as opposed to the normal depth of 300mm) to simulate mean high water springs plus one metre. The results of this test is shown in figure 2-13.

The flow patterns around the above systems were investigated with the (offshore) wave crest angle still at 10 degrees to the beach and again approaching the coast from a north-northeast direction. More definite eddy patterns formed with the higher water level (Test 10) as more of the groyne length became effective. These eddies tend to push the flows out of the bays at their updrift end, forcing the external currents offshore. Test 8 was similar to tests 6 and 7 with slow, mainly clockwise eddies within the bays and backward flowing currents downdrift of the terminal groyne.

3. Tests 11-16

Early in 1984, H.R.L. were given the observed offshore wave approach angle as 26 degrees. It was just possible in the existing wave basin to move both paddles to this angle and keep them together as can be seen in the plan view of the model shown in figure 2-14. The wave generators were accordingly moved to this angle and tests 11 to 16 carried out using the same 'Sea Palling' beach plan shape as in the previous tests. Changes to the various parameters in this sequence of tests are shown in Table 3.

Test 11 - The zero crossing period was increased in relation to the previous tests to 8.5 seconds and wave heights decreased to 2.2m prototype. Flow patterns are shown in figure 2-15. The alongshore flows produced a weiring effect over the seaward crest of the outer groynes. The clockwise eddies formed in the updrift bay tended to push the flow coming over the updrift groyne seaward. Slack water areas were noted downdrift of each of the groynes. External flows seemed little affected by the groyne field.

Test 12 - The wave period was changed back to 7.2 seconds as used in the previous tests while the wave heights remained at 2.2m prototype. The results of this test are shown in figure 2-16. Slack or slow flowing eddy currents formed in the updrift bay while in the downdrift bay the alongshore flows, slowed slightly by the turbulence updrift, were pushed seaward at the downdrift groyne. An eddy formed downdrift of this terminal groyne encouraging seaward flowing currents along its downdrift edge.

Test 13 - The same wave period (7.2 seconds prototype) as the previous test with an increase in the significant wave height to 2.8m prototype and with a 30% increase in the alongshore flows. For the next three tests the groynes were lowered into the beach to stand 28mm (1.0m prototype) high at their seaward end running flush into the beach at their landward end as shown in the example in figure 2-10.

Test 14 - In this test the wave heights were decreased to 2.1m prototype, similar to the 'high' groyne test 12. The resultant flow patterns are shown in figure 2-18.

Test 15 - Keeping these lower wave heights, the zero crossing period was increased to 8.5 seconds prototype to correspond to the 'high' groyne test 11. The results are shown in figure 2-17.

Test 16 - For the final test in this batch, wave heights were increased to 2.8m prototype and the alongshore flows increased by 30%. This compares with test 13 on the higher groynes.

It was evident from the foregoing tests that groyne elevation is a crucial factor in interrupting the alongshore currents and the consequent flow patterns within the groyne bays. The angled waves approaching the beach create a split flow along each side of the groynes. Groyne elevation influences the effects of this split flow. Also as the water level rises, the alongshore flows, spilling over the groyne crests create a weir effect as mentioned above. This extra water alters the circulation pattern in the bays.

4. Tests 17-25

This, the last programme of tests in this first series, was carried out using a 7-groyne system and with the angle of wave approach still at 26 degrees, the effects to the flow pattern were investigated by altering (a) spacing, (b) alignment, (c) elevation, and (d) groyne length.

All tests in this set were with a "high" groyne profile (see Figure 2-10).

Test 17 - Length of each groyne and the distance between each groyne was 1080mm (39m prototype) ie 1:1 spacing. (Fig 2-20). All the following tests (18 to 25) had a similar layout to test 17 with the amendments shown against each test number.

Test 18 - Wave height reduced to 1.1m prototype. Rate of pumping of the alongshore currents was also reduced by 28% (Figure 2-19).

Test 19 - Intermediate groynes (2, 4 and 6) shortened by 25% to 812mm (29.25m prototype). All other parameters remained the same. (Fig 2-21)

Test 20 - In this test the groyne spacing was doubled to 2160mm (78m prototype). Groyne lengths remained the same at 1080mm giving a 1:2 length/spacing ratio. All other parameters as test 17 above. (Fig 2-22)

Test 21 - Groyne spacing changed to 1625mm (58.5m prototype), ie a 1:1.5 length/spacing ratio. All other parameters as test 17 above. (Fig 2-23)

Test 22 - As the above test except that the intermediate groyne lengths were shortened by 25% to 812mm. (Fig 2-24)

Test 23 - Groynes angled by 10 degrees facing updrift. (Fig 2-25.) The effect of varying the length of the groynes and altering the spacing ratio from 1:1 to 1:2, was small.

Test 24 - Groynes angled by 10 degrees facing downdrift. (Fig 2-26)

Test 25 - As the above test but using random waves with a significant wave height of 2.2m prototype. (Fig 2-27)

There seems little advantage gained by inclining the groynes at 10 degrees either updrift or downdrift to the perpendicular, despite the alongshore current in the model being consistently in one direction.

5.2 Hypothetical groyne systems (second test series)

It was decided to retain the beach contours moulded for the comparison between the physical model and the field experiments carried out at Sea Palling, for the final series of physical model experiments, and to vary groyne parameters, water levels and environmental conditions as shown in Table 4. It was also found convenient to refer still water level (SWL) in the basin to the corresponding tidal stage at Sea Palling (eg 300mm water depth was equivalent to mean high water springs). In the first tests in this series, the groyne field was similar in profile to those at Sea Palling. In fact these hypothetical tests were based on the Sea Palling system, although they were not intended to be a study of that particular beach, as the model had not been satisfactorily validated. For each test, current and flow patterns were measured by dye, injected at 0.5 metre (18m prototype) intervals, in plan, both along and down the beach. There was a runnel just seaward of the groynes which was left insitu and all the following tests had their groynes terminating on that line. This is a commonly observed feature of groyne fields on sandy coasts and therefore felt worth retaining. Dye mixed with sucrose was used to measure the flows near the bed and each excursion recorded, as in the earlier tests, via the video camera suspended directly above the beach.

In this second and final series of tests it was found useful to not only measure currents but also to study the sediment transport at the sea bed with particles of anthracite which gave an indication of how sediment may be moved in the prototype. Scattered at strategic points, the material was allowed to migrate in and around the groynes showing up areas where it was likely to accumulate. It was not, however, meant to simulate the beach material at any specific site.

Tests carried out in this final phase are numbered 31 to 43. The gap in the test numbers, between this and the first series, was to differentiate the 1984 series and avoid confusion with the first series of tests completed after the 1983 field experiments. These tests were aimed at:

1. examining the flow patterns around the three groyne system at mean high water, neap tide,
2. and at mean tide level,
   and to study the effects of;
3. elevating the groynes by 0.5 metres,
4. elevating the groynes to 1.0 metre above normal,
5. roughening the top of the beach,
6. cladding the groynes with stone,
7. using stone clad T-shaped groynes,
8. using stone clad fish-tailed groynes,
9. placing a vertical sea wall along the top of the beach, and
10. cutting slots in groyne A to simulate damage.

The relevant parameters for the following tests (31 to 43) are given in Table 4.

All these tests were run using regular waves and with the offshore wave approach angle at 15 degrees to the beach. Comments made after each test refer to the groynes as A, B and C. A is the updrift groyne, B the middle groyne and C the downdrift groyne. The alongshore flows running from the top of the respective figures down.

Tests 31 and 32

The first two tests (31 and 32), were carried out to study the effects of different water levels and the wave and current parameters remained unchanged. Groyne heights were as at Sea Palling.

Test 31 - The water level in this test was reduced by 14mm (0.5m prototype), to simulate mean high water neaps. Wave heights at the paddle were 24mm (0.87m prototype) with a period of 1.01 seconds (6.05 seconds prototype). Figure 3-7 shows the resulting flow patterns. The results indicate that the updrift groyne had little effect on the alongshore flows at mid-depth. The current near the bed tended to move inshore downdrift of the groyne. Clockwise flowing eddies formed updrift and inshore of groynes B and C through the depth and accumulation of the anthracite granules was evident at these points, with slow downdrift movement over the groynes from this accumulation.

Test 32 - The water level in this test was reduced a further 14mm to simulate mean tide level. Wave height and period was as for the previous test. The results of this test are shown in Figure 3-8.

Seaward flow was evident along both sides of the updrift groyne through the depth, with a small clockwise eddy inshore on the updrift side. Some offshore material in the vicinity of the updrift groyne (A) transported around the end of the groyne and into the first bay. In both groyne bays clockwise eddies formed at either side with a compensating anticlockwise flow inshore in the centre of each bay. This was more evident at mid-depth. Deposition of material occurred inshore on the updrift side of groynes B and C with a steady flow downdrift over the groynes at their landward end. No retention noted updrift of groyne A.

It is worth making the point here that submerged long groynes at one tidal level will become emerged short groynes at a lower level. It is therefore difficult to know at what tidal level one should test or assess a groyne system. Most of the tests carried out in this series were with the water level simulating mean high water springs and with the groynes elevated one metre above the field measurements for maximum effect. It was decided at this point to increase the wave heights to record 1.5m (prototype) at pod A, while the wave period was reduced slightly to 6.0 seconds (prototype). This was done to study what was deemed a more realistic wave climate.

Tests 33 to 35

Test 33 - Groynes raised by 0.5m prototype. Results are shown in Figure 3-9. A similar pattern to that noted in test 31 with a more pronounced seaward flow along the updrift sides of groynes B and C. No retention of material updrift of groyne A, a small accumulation inshore and updrift of groyne B with a steady flow over the groyne at its landward end. Some retention also inshore between groynes B and C with again a steady downdrift feed over the landward end of the downdrift groyne (C).

Test 34 - As the above test with the upper beach roughened with metal strips as described below. This configuration is shown in Plate 3-5, while the resulting change in the flow patterns in and around the groynes is shown in Figure 3-10. The main difference noted was an eddy which formed inshore and updrift of the updrift groyne (A). This was confirmed with the anthracite granules which accumulated inshore and updrift of the groyne. Accumulation was also evident updrift and inshore of the two downdrift groynes. A slight eddy formed near the seaward end of the downdrift groyne (C) on its downdrift side.

These metal strips were 0.08m wide and 1.22m long. Placed 0.23m apart, they covered an area from 6m (216m prototype) updrift of the groyne field to approximately the same distance beyond the downdrift groyne. Running from the set-up line seaward, they protruded approximately 5mm above the beach.

Test 35 - Groynes raised a further 0.5m to a total of 1.0m prototype above normal with the upper beach roughened as above. The interruption to the alongshore flow pattern is shown in Figure 3-11.

Little difference to test 34, with material accumulating inshore and updrift of each groyne.

Tests 36 to 40

Test 36 - For this and all the remaining tests in this section, the groynes were elevated as in the previous test, 1.0m above normal. All roughening was removed and Figure 3-12 shows the resulting flow patterns.

More turbulence evident within the groyne bays with a generally clockwise motion along the updrift side and inshore of the two downdrift groynes (B and C). Anticlockwise flows formed in mid bays and along the downdrift side of groynes A and B. Material reaching the updrift side of groyne A was transported seaward along the groyne and accumulations were confined to updrift and inshore of groyne B and an area just offshore and updrift of the downdrift groyne (C).

Figure 3-14 shows the velocity profiles at sections updrift and downdrift of the groyne field with and without roughening.

Test 37 - A vertical sea wall was placed parallel with the beach in approximately 1.0m (prototype) of water (at still water level) and 1.425m (51m prototype) seaward of the baseline as shown in Figure 3-13. The flow patterns in these shortened groyne bays were very mixed and it was decided not to pursue this because of time constraints. This type of experiment warrants a separate study.

Test 38 - All three groynes were clad with stone seaward of the set-up line as shown in Plate 3-6. Figure 3-15 shows the flows in and around the groyne fields during this test. It was noted during this test that some stones were being washed away midway down groyne C, mostly on the downdrift side. Clearly they were not heavy enough and larger stones with a prototype weight of 2 tonnes would have been more appropriate.

Clockwise eddies formed inshore and updrift of groynes B and C, and inshore and downdrift of groyne C. An anticlockwise eddy at the seaward end and downdrift of groyne A suggests a deposition area and is evident at both mid-depth and near the bed.

The stones used in tests 38 to 40, were limestone chippings typically 35-40mm - 20-25mm in size and represented rocks of approximately 1 tonne weight in the prototype.

Test 39 - As test 38 above but with stone clad T-pieces added to the end of each groyne. These T-pieces were placed symmetrically, perpendicular to the groyne at the same elevation and protruded 140mm (5m prototype) either side as shown in Plate 3-7 and Figure 3-16. Downdrift scour was effectively eliminated and material tended to collect at the seaward end of the T-pieces then transported slowly inshore. Turbulence was noted at the seaward end of the updrift groyne (A) with clockwise eddies along the updrift side of groyne C and inshore on its downdrift side.

Test 40 -Again as test 38 above but with stone clad (Y-shaped) fishtails added to the seaward end of each groyne. Each fishtail was 140mm (5m prototype) long and angled at 120 degrees from the groyne as shown in Plate 3-8 and Figure 3-17.

A large clockwise eddy formed just seaward of the updrift groyne (A) stretching almost to groyne B with an anticlockwise eddy downdrift and just inshore of the fishtail at groyne A. This situation was reflected in the movement of near bed currents, with a large anticlockwise eddy in the same area. Further eddies along the updrift side of the downdrift groyne

(C) suggest deposition of littoral material in these areas. As with the T-pieces, material collected at the Y-intersections and was transported slowly into the groyne bays while on the downdrift sides scour is effectively curtailed.

Tests 41 to 43

Test 41 - With all stone removed this was as test 36 but with groyne A, the updrift groyne, damaged. This was done by cutting three 10-12mm (0.36 to 0.43m prototype) vertical slots at discreet intervals in the seaward half of the groyne (ie at 7, 22, and 36m prototype from the groyne tip). Figure 3-18 shows the resulting flows in the groyne field. No obvious large scale changes. The eddy down drift and level with with the seaward end of groyne A, found in the previous test had moved inshore into the first bay, allowing the flow to sweep round the end of the groyne possibly inducing scour. Eddies formed along the updrift sides of groynes B and C. All in all, little noticeable effect probably due to the damage not being extensive enough.

Test 42 - The original groynes were replaced in this test, by permeable ones. As is seen in Plate 3-9, these groynes were of PVC material, 10mm thick and cut to give a 50% permeability. The resulting flow patterns are shown in Figure 3-19. A reduction in the alongshore flows was noted with clockwise eddies forming up drift of groynes B and C at the bed. At mid-depth this eddy was evident only updrift of groyne C.

Test 43 - This, the last test, was as test 36 but with alongshore currents overpumped to give a similar velocity at Pod A to that found in the prototype (Figure 3-20).

Large clockwise eddies formed updrift of groynes B and C pushing flow seaward. Otherwise the flows were little affected, the weiring over the groynes allowing some deposition of material along the updrift face of all three groynes. External flows were also little affected.

Finally for all the results, shown in plan in the relevant figures, the arrows indicate the dominant flow patterns through the depth, while the figures give an indication of the flow velocity. For the above tests the figures also show the spread and accumulation of the anthracite granules giving an indication of where sediment build up may occur.

The flow pattern observations shown in the figures are a mean of the 'just below the surface' and 'just above the bed' velocities measured on the sloping beach. It is not feasible to relate these to the actual rate of sediment movement. This would depend, among other things, on grain size and density of the beach material which in turn are influenced by wave conditions and water depth. Detailed information on sediment motion can be found in articles such as those by Ippen (Ref 10) and Bijker (Ref 11).

Although some stratification in flow was noted on the upper beach and commented upon in this report, it was not practical to describe definitively, because of the shallowness of the water.

6 SUMMARY OF RESULTS AND CONCLUSIONS

Before commenting on the model results, it is worth reviewing the behaviour of a groyne system in general terms.

The first and most direct effect of constructing a groyne system on a beach is to alter the pattern of the currents, and hence the accompanying sediments, flowing parallel to the coast. In particular currents along the top of the beach and within the groyne bays will be reduced. On an open beach the current velocity profile is similar to that shown schematically in figure 1-4, which is based on the work of Longuet-Higgins (Ref 5,6) It can be seen that the maximum current lies slightly landward of the breaker line but noticeable velocities are also created seawards of this line.

The effects of a groyne field on such a profile is demonstrated in figure 3-5, which shows results from the three-groyne system studied in the physical model. The current profile on the open beach is shown as a dashed line and can be compared with the profile within the groyne field shown as a solid line. It can clearly be seen that currents have been reduced landward of the groyne tip. However, further seawards the currents are greater than the open beach profile and extend farther offshore.

This increase in current strength is a common feature, and on a sandy beach may cause a lowering of beach levels along a line just beyond the groyne tips.

If the groynes are surface piercing and impermeable over a large proportion of the surf zone width then the flow patterns are particularly distinct within each groyne bay although the velocities may be quite small. In such a situation it is not unusual to have flows travelling in completely opposite directions on either side of a groyne. Clearly this phenomenon produces strong lateral forces on a conventional groyne and will exploit any gaps in the planking.

When the groyne crests are below the water surface, then only a proportion of the alongshore current is diverted offshore, leading to a strongly stratified flow within the groyne bays. A particular feature of the submerged groynes was the 'weiring' effect of the alongshore flows over the groyne crests. This however was largely restricted to the surface layers, and near the sea bed the onshore and offshore flows still occurred. This is important since the greatest sediment motion occurs at this level. Clearly then groyne elevation is an important parameter in the effect that a groyne field has on the beach.

Turning now to specific results from the initial test programme (Chapter 5, Section 1), tests 1 to 5 (Figs 2-4 to 2-6) investigated, with the offshore wave approach angle at 10 degrees, the interruption to the alongshore currents and the subsequent alteration of the flow patterns caused by the introduction of 1, 3 and 4 groynes on the upper beach. All the tests in this section, with one exception, were with the water level in the model simulating mean high water springs. The exception being test 10, where the water level was raised by one metre prototype above mean high water springs.

In the physical model it was found that all groyne systems tend to split the alongshore flow into two regimes, one the 'internal flow field' on the upper beach and the other the 'external flow field' which passes seaward of the groynes in the alongshore direction. This external flow can be and generally is to some degree, influenced by the circulatory flow within the groyne bays.

Two important results noted in these tests were that; (a) with vertical impermeable groynes such as those tested, the internal flows circulating within the bays, created rip currents which ran along the downdrift side of each of the groynes. These flows could be strong enough to cause erosion along the length of the groyne and the consequent risk of undermining. Secondly, (b) the forcing of the alongshore flows seaward due to groyne placement, created a strong current passing around the groyne tips, and was strong enough to cause erosion gullies and possibly undermine the groyne structure.

Tests 6 to 10 studied the effect of three groynes on a foreshore moulded to a profile of the beach at Sea Palling and with an offshore wave approach still at 10 degrees to the shoreline. In each of these tests (Figs 2-11 to 2-13) the water level simulated mean high water springs with the exception of Test 10 where the water level was increased by one metre prototype to MHWS plus 1.0m.

One effect noticed immediately was the backward flowing currents on the upper beach downdrift of the terminal groyne, with a divergence of flows about one groyne's length downdrift (Fig 2-12). With the increase in water depth in test 10 (Fig 2-13), more definitive eddy patterns formed within the groyne bays as more of the groyne length became effective. The seaward flowing rip currents were also more pronounced forcing the external flows offshore.

For the next series of tests (11 to 16) the offshore wave approach angle was more oblique, at 26 degrees to the shore. This was as a result of data received from the field survey. The same 'three groyne system' was used and the effect of both 'high' and 'low' groynes were studied (see Fig 2-10).

From these tests it was clear (Figs 2-15 to 2-18)that apart from an increase in the velocity of the alongshore flows, groyne elevation was most important, as mentioned above. The angled waves approaching the beach split along each side of the groynes. This influenced the water levels within the bays creating an imbalance and affecting the inshore circulation pattern. Groyne elevation in turn affects this split flow. With the lower groynes (tests 14 to 16) the alongshore flows also spilled over the crests creating a 'weiring' effect and imposing a shearing force in the surface layers of the water. These stratified flows within the bays are extremely complex. The higher groynes were more effective in slowing down the alongshore internal flows but in showing a vertical face to the incoming angled waves created a circulatory flow within the bays and set up seaward flowing currents along the downdrift side of the outer groynes.

The next series of tests (Figs 2-19 to 2-27) were undertaken on a field of seven groynes, perpendicular to the beach and investigations included both changing the intermediate groyne lengths and their spacing.

There is no doubt that the effect of longer groynes on flow was greater as they interrupted more of the alongshore current. In contrast, the effect of changing the groyne spacing along the beach was much smaller within the limits tested and there seemed little advantage in a length/spacing ratio of 1:1 compared with say 1:2 on the basis of the beach modelled. There also appears little advantage in changing groyne orientation to 10 degrees either side of the perpendicular to the shoreline as far as current generation is concerned, despite having the alongshore current always in the same direction. This however may not be true with a tidal flow situation.

Groyne spacing for a small angle of approach is perhaps not critical. However, for varying and large angles of wave incidence the spacing must become more important.

The second and last series of tests (Chapter 5, Section 2) were conducted on a three groyne system similar in plan to that at Sea Palling. With the exception of the first two tests below, the water level in the model, simulating mean high water springs, remained the same for all tests. In addition to the dye/camera measurement of flow, a granular material was scattered on the bed of the model and allowed to migrate in and around the groyne field to give an indication of how and where mobile material would tend to accumulate. In the first two tests (31 and 32) the effect of different water levels, simulating mean high water neaps and mean tide level were studied.

The tests (Figs 3-7 and 3-8) showed very different results. The lower water level producing the most disturbance within the groyne field. The granular material in this test, at mean tide level, flowed along the groyne tips with little entering the groyne bays. In contrast, at mean high water neaps, material was pushed landward into the bays.

All the following tests were made with the water level simulating mean high water springs.

Raising the groynes had a similar effect (tests 33 and 36, Figs 3-9 and 3-12) to that of lowering the water levels above.

Tests studying the effect of roughening the upper beach (34 and 35, Figs 3-10 and 3-11), showed that the alongshore currents were slowed sufficiently to promote a build up of material inshore and updrift of the first, updrift groyne. Flows around the groyne tips forced the external flows offshore, while material accumulated inshore and updrift of the two downdrift groynes.

The higher groynes (test 35) contained the flows more effectively, forming eddies within the bays.

A vertical seawall was placed in the model parallel with the shoreline, within the effective groyne field, and standing in one metre of water (test 37, Fig 3-13).

The effect of this wall and the subsequent wave reflections caused much agitation of the water within the bays, with little eddy formation and high dispersion. The groynes, shortened because of the wall, were largely ineffective.

An alternative groyne design was incorporated in this next test set, retaining the original groynes but cladding their sides with rubble. In the first of these tests (Test 38,Fig 3-15) all three groynes were clad on both sides with rubble from the set-up line seaward.

No dramatic change in flow formation was observed.

For the next test (Test 39, Fig 3-16) rubble clad T-pieces were added to the seaward end of each of the three groynes.

The addition of the T-pieces resulted in a dramatic reduction in flows adjacent to the groyne stems, although there were still strong currents at the updrift tip of the first (updrift) groyne which could cause problems. This however could indicate one way of avoiding scour along the groyne length and thus reduce maintenance.

An essentially similar situation was evident in the next test (Test 40, Figure 3-17) when the T-pieces were replaced by rubble clad fishtails. Material also accumulated within the Y-shaped intersection at the groyne tips and transported slowly into the bays.

Tests conducted with the updrift groyne damaged (Test 41, Fig 3- 18) produced no large scale changes to that of test 36, the undamaged state. This was possibly because the damage was too localised.

In the next test (Test 42, Fig 3-19), the impermeable groynes were replaced with permeable ones. The permeable groyne system tested was one with a 50% voids ratio. With this system many of the potential problems associated with surface piercing groynes were greatly reduced, and the alongshore current magnitude was diminished due to turbulence at each groyne. This type of groyne would be worth further investigation although the associated disturbance around each individual post could cause localised erosion.

The final test (Test 43, Fig 3-20) was carried out on the vertical impermeable groynes with the alongshore currents overpumped to give a similar velocity to that found at Pod A (Figure 3-4) in the field experiments at Sea Palling. Large eddies formed within the groyne bays with the alongshore flows 'weiring' over the groyne crests. Otherwise internal flows seemed little affected although the external flows showed an expected increase in velocity and were pushed seaward by the rip currents running along the downdrift side of the groynes.

The main conclusions from these tests can be summarised as follows;

(i) Groynes that project above still water level create relatively weak circulatory flows in the intermediate bays, at the expense of diverting a proportion of the alongshore currents seawards past their tips. Currents in such groyne bays often have a reverse flow near the water line and seaward flowing rip currents on the downdrift side of a groyne.

(ii) The longer such groynes are, the greater their effect, but their length should be less than the width of zone in which alongshore currents occur naturally. If groynes are too long then there is a risk of losing sand from the beach system.

(iii) Groynes with crests below the water surface lead to strongly stratified flow in the groyne bays, and divert less of the alongshore drift offshore. Although there will be less scour at the end of such groynes, or along their downdrift face, their effectiveness in retaining or attracting beach material is less but how much so is not easy to determine.

(iv) Varying the groyne length/spacing ratio between 1:1 and 1:2 on the model beach seemed to have a rather small effect on current circulation patterns and was of little advantage in terms of current generation. This however was based on a limited incident wave angle and does not imply that length/spacing ratio is unimportant in groyne design.

(v) There seemed to be no advantage in inclining groynes at 10 degrees, either updrift or downdrift, to the perpendicular; despite the alongshore currents in the model being consistently in one direction.

(vi) A groyne consisting of a row of vertical individual piles (eg Plate 3-9) reduced flow close to the shore without creating substantial increases elsewhere. Such a groyne type merits further investigation although turbulence in the area of the individual piles may cause localised beach scour. Any research in this context would, however, need to be either "on-site" or use a much larger model scale to obtain the correct turbulence and permeability factors.

(vii) Rubble mound groynes seemed not to create any substantial improvement in flow patterns until they are extended to have a broad seaward end (eg Plates 3 -7 and 3-8) ie a T-head or a Y-head. The addition of such 'heads' did improve the flow pattern and also merits further investigation.

(viii) Although using random waves in some experiments led to a much higher dispersion and turbulence, they did not seem to produce any major change in the pattern of steady currents.

(ix) Tidal currents although important do not appear to have much effect on the travel of beach material which is predominantly wind and wave induced (Ref 9) landward of the breaker zone.

It has been pointed out in the foregoing chapters that full validation of the physical model against field data was not possible and that the Steering Group advocated the testing of hypothetical groyne systems. The following observations, repeated in the summary report (Vol 1, Phase II) of March 1986, identifies the outcome of the amended physical model studies.

The initial tests in the model and later improvements introduced into the programme, have led to the development in the techniques for carrying out scale model tests of groyne systems.

The tests carried out to study the effects of particular layouts have given a valuable insight into the basic hydrodynamics of groynes. In particular the tendency for a strong seaward flowing current to occur close to the downdrift face of a straight, vertical sided impermeable groyne has been identified, and methods to counteract this unwelcome characteristic have been tested. It has also been possible to identify the more important parameters governing the performance of a groyne system on a sand beach (eg height and length), in contrast to less important ones (eg groyne orientation, spacing and wave direction). However, the latter are more important when considering shingle beaches.

Although the model studies have been carried out with a fixed bed, thus preventing direct evaluation of the effect of groynes on sediment movement, the ability to both measure and observe the current patterns created has been a major advantage. The introduction of a sediment 'tracer' in the later stages of the project also enabled areas of likely erosion and deposition to be predicted.

The physical model was not fully validated against prototype measurements, but a number of meaningful comparisons can be made. A review of the results from the physical model tests shows that at model scale the wave induced currents were similar in magnitude to those inferred from data measured at Anderby Creek and Sandilands on the Lincolnshire coast. The standard scaling factor from model to prototype using Froude scaling would be 6.0 corresponding to the model linear scale of 1:36. However, the differences in wave height and possible differences in wave direction at the breaker line need to be considered.

Wave heights used in the physical model were two to three times greater than the equivalent prototype values. Further, the results from the physical model showed a reasonably linear relationship between peak current velocity and incident wave height. The possible differences in wave direction at the breaker line cannot be accurately evaluated, but theory dictates that current velocities should be practically linearly dependent on the breaker line angle for small angles of incidence.

Consideration of the above leads to the conclusion that in the absence of additional roughening of the physical model bed, the velocities in the physical model were approximately twice to three times the equivalent prototype values. Tests with an artificially roughened model bed reduced the velocities to 50% which is consistent with similar experiments carried out elsewhere (Ref 3). In this case the model current velocities would have been one to one and a half times the equivalent prototype values demonstrating the original supposition that artificial roughening of the physical model would be appropriate. It is also demonstrated that there was some overlap between the physical model and field studies results. In addition the wave heights used in the physical model (approx 1.0m Hs at prototype) were not large in relation to the size of storm waves that could feasibly occur on the East Coast. It might thus be deduced that the physical model results without bed roughening may be related to rather higher wave heights which are well within the range of typical storm events.

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Tables

Table 1: Initial Alongshore Current Flows from Mathematical Model

MODEL					PROTOTYPE	
Depth offshore (metres)	Angle at paddle (deg)	Wave height (metres)	Wave period (secs)	Alongshore discharge (litres/sec)	Wave height (metres)	Wave period (secs)
0.30	10	0.078	1.167	73.27	2.808	7.002
0.30	26	0.061	1.167	95.14	2.196	7.002
0.30	26	0.061	1.417	88.85	2.196	8.502
0.30	26	0.078	1.417	174.19	2.808	8.502
0.30	26	0.078	1.167	187.42	2.808	7.002
0.30	38	0.028	1.417	16.05	1.008	8.502
0.30	38	0.042	1.417	36.95	1.512	8.502
0.30	38	0.056	1.417	97.38	2.061	8.502
0.30	38	0.069	1.417	159.38	2.484	8.502

Beach slope 1:29

Table 2: Initial Model Proving Parameters

		Model	Proto
	A	1	36
Waves (regular):			
* Period	A,B	1.20 sec	7.20 sec
* Mean height	A,B	0.06 sec	2.16 sec
Still water depth	A,B	0.30m	10.80m
* Adjusted angle of incidence ie paddle angle relative to the beach	A,B	10 deg	
Measured angle of incidence ie at the breaker line	A,B	8.3 deg	
Mean width of surf zone to wave run-up line	Sz	3.95m	
Alongshore current opening (updrift) ie 12 channels, each 0.4m open	1.6 x Sz	4.8m	
Alongshore current opening (downdrift) ie to wave run-up line	1.2 x Sz	3.66m	
Wave run-up line (from model origin)		1.70m	
* External current recirculation		50 l/s	
* Beach slope (uniform)	A	1:29	

A - parameters unchanged throughout model proving tests

B - in constant depth part of basin

* - final model parameters shown in Tables 3 and 4

Table 3: Test Parameters - Hypothetical Groyne Systems (First Test Series)

Date	Test No	Groyne arrangemant	Hp m	Tz s	Wave Angle	Tidal State	Q l/s
Preliminary tests carried out in November/December 1984.							
23.1.84	1	Single groyne	2.8	7.2	10	MHWS	45
24.1.84	2	3 No. perp groynes	2.8	7.2	10	MHWS	45
25.1.84	3	4 No. perp groynes	2.8	7.2	10	MHWS	45
26.1.84	4	4 No. perp groynes	2.8	7.2	10	MHWS	45
27.1.84	5	4 No. perp groynes	2.8	7.2	10	MHWS	45
For the above tests the groynes were laid on the top of the uniformly (1:29) sloping beach and were 1.37m prototype high.							
Model broken out and replaced by the 'typical winter profile' of the Sea Palling beach (Figure 2-7)							
22.2.84	6	3 No. Sea Palling 'high' groynes	3.3	7.2	10	MHWS	45
23.2.84	7	3 No. Sea Palling 'high' groynes	3.3	7.2	10	MHWS	45
27.2.84		Alignment of alongshore current altered.					
1.3.84	8	3 No. Sea Palling 'high' groynes	2.8	7.2	10	MHWS	45
2.3.84	9	3 No. Sea Palling 'high' groynes	2.8	7.2	10	MHWS	45
5.3.84	10	3 No. Sea Palling 'high' groynes	2.8	7.2	10	MHWS +1m	45

Table 3: Continued

Wave generator angle changed to 26 degrees normal to the beach

22.3.84	11	3 No. Sea Palling 'high' groynes	2.2	8.5	26	MHWS	70
23.3.84	12	3 No. Sea Palling 'high' groynes	2.2	7.2	26	MHWS	70
27.3.84	13	3 No. Sea Palling 'high' groynes	2.8	7.2	26	MHWS	90
28.3.84	14	3 No. Sea Palling 'low' groynes	2.1	7.2	26	MHWS	70
29.3.84	15	3 No. Sea Palling 'low' groynes	2.1	8.5	26	MHWS	70
30.3.84	16	3 No. Sea Palling 'low' groynes	2.8	7.2	26	MHWS	90
9.4.84	17	7 No. perp groynes 1:1 spacing	2.2	7.2	26	MHWS	70
10.4.84	18	7 No. perp groynes 1:1 spacing	1.1	7.2	26	MHWS	50
12.4.84	19	7 No. perp groynes 1:1 spacing, inter groynes 25% short	2.2	7.2	26	MHWS	70
13.4.84	20	7 No. perp groynes 1:2 spacing	2.2	7.2	26	MHWS	70
17.4.84	21	7 No. perp groynes 1:1.5 spacing	2.2	7.2	26	MHWS	70

Table 3: Continued

18.4.84	22	7 No. perp groynes 1:1.5 spacing, inter groynes 25% short	2.2	7.2	26	MHWS	70
25.4.84	23	7 No. perp groynes 1:1 spacing, angled 10 degrees updrift	2.2	7.2	26	MHWS	70
26.4.84	24	7 No. perp groynes 1:1 spacing,angled 10 degrees downdrift	2.2	7.2	26	MHWS	70
27.4.84	25	7 No. perp groynes run using random waves	Hs 2.2	7.3	26	MHWS	70

NOTES

1. For tests 6 to 13 and 17 to 25, all groynes were set in to the beach and were 1.37m (prototype) high at the seaward end and 0.7m (prototype) above the top of the beach profile at the landward end (see Figure 2-10).

2. For tests 14 to 16 inclusive, the groynes were 1.0m (prototype) high at the seaward end and flush with the beach at the landward end (see Figure 2-10).

Q = Total recirculatory flow (l/s model)

Hp = Wave height of regular waves (prototype)

Tz = Wave period

Wave angle = The angle at which the wave generators were positioned relative to the beach.

Hs = The significant wave height (i.e. average height of the one-third highest waves).

Table 4: Test Parameters - Sea Palling Groyne Systems (Second Test Series)

Date	Test No	Groyne arrangement	Hp m	Tz secs	Wave angle	Tidal state
20.3.85	31	water level -0.5m	0.87	6.05	15	MHWN
25.3.85	32	water level -1.5m	0.87	6.05	15	MTL

Change wave height to record 1.5m at position A (see Figure 3-4), reduce wave period to 6.0secs and retain water level at +1.4m ODN(MHWS). Regular waves.

Date	Test No	Groyne arrangement	Hp m	Tz secs	Wave angle	Tidal state
1.4.85	33	groynes raised 0.5m	1.50	6.00	15	MHWS
4.4.85	34	groynes raised 0.5m upper beach roughened	1.50	6.00	15	MHWS
12.4.85	35	groynes raised 1.0m upper beach roughened	1.50	6.00	15	MHWS
16.4.85	36	groynes raised 1.0m	1.50	6.00	15	MHWS
26.4.85	37	groynes raised 1.0m vertical sea wall	1.50	6.00	15	MHWS
1.5.85	38	groynes raised 1.0m and clad with stones	1.50	6.00	15	MHWS
3.5.85	39	groynes raised 1.0m stone clad T-pieces added	1.50	6.00	15	MHWS
9.5.85	40	groynes raised 1.0m stone clad fishtails added	1.50	6.00	15	MHWS
15.5.85	41	groynes raised 1.0m groyne A damaged	1.50	6.00	15	MHWS

Table 4: Continued

28.5.85	42	groynes raised 1.0m permeable groynes	1.50	6.00	15	MHWS
21.5.85	43	groynes raised 1.0m alongshore current overpumped	1.50	6.00	15	MHWS

Wave parameters are in prototype units

Figures

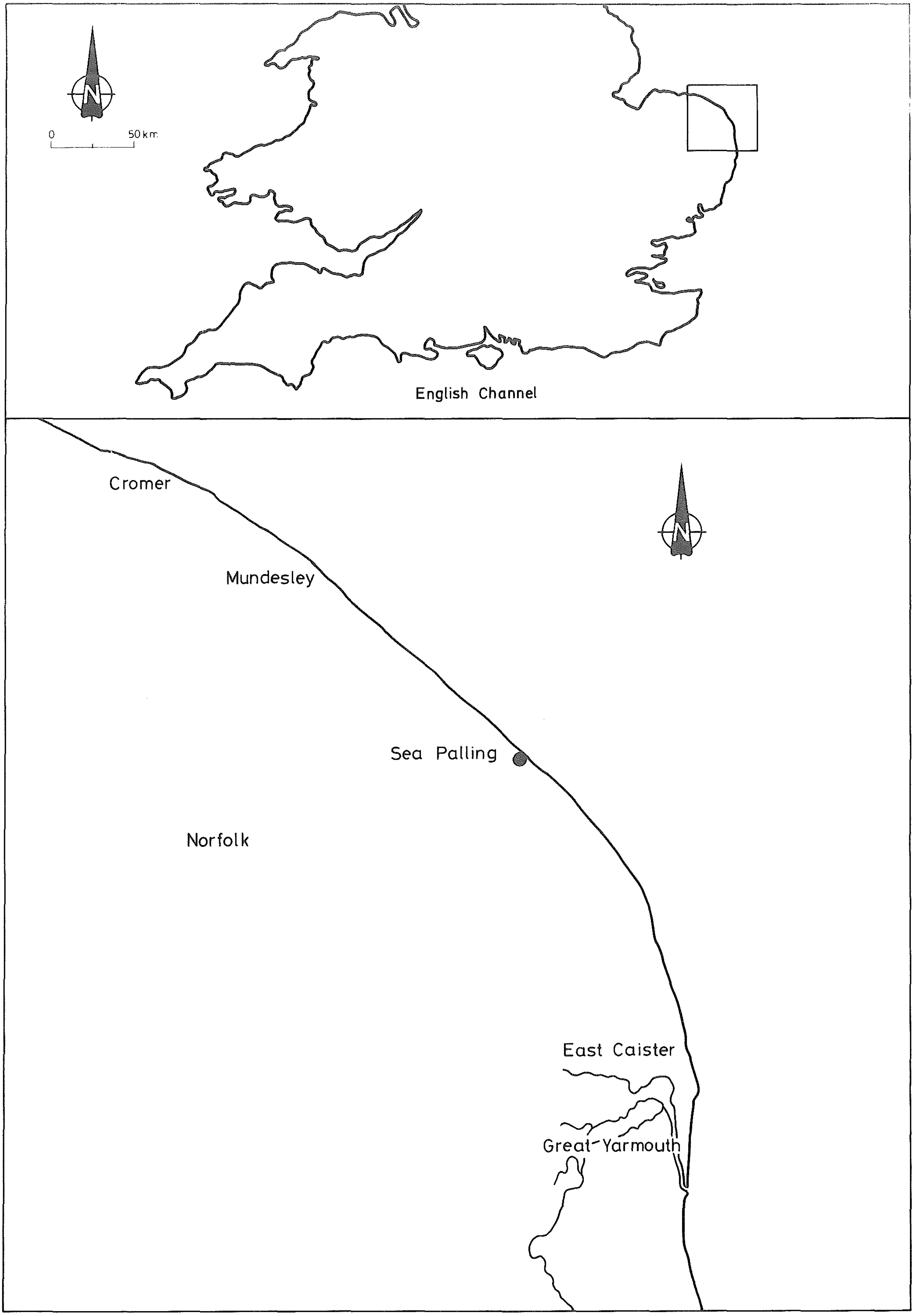


Fig 1 Location plan

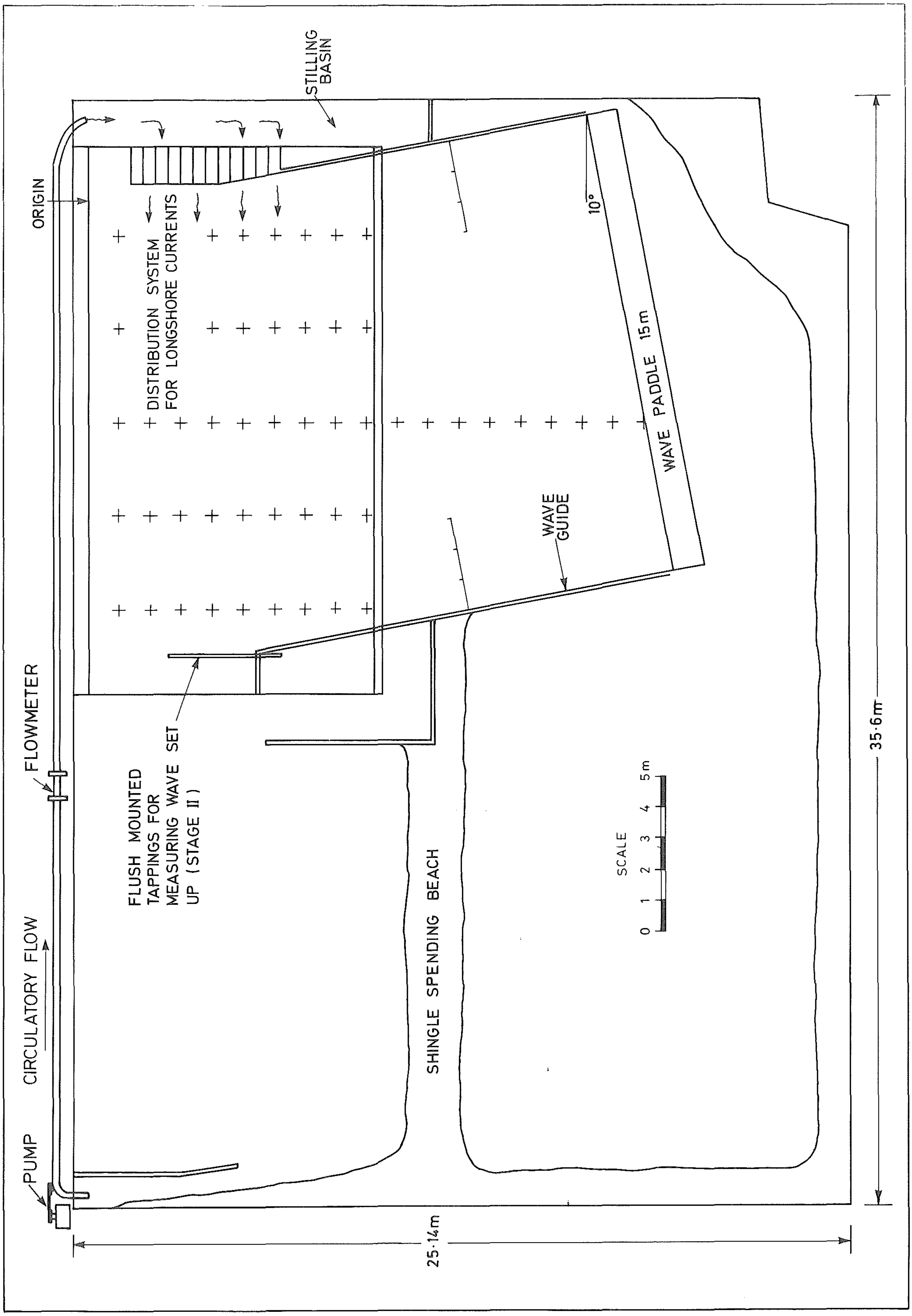


Fig 1·1 Plan layout of stage I - Experimental techniques

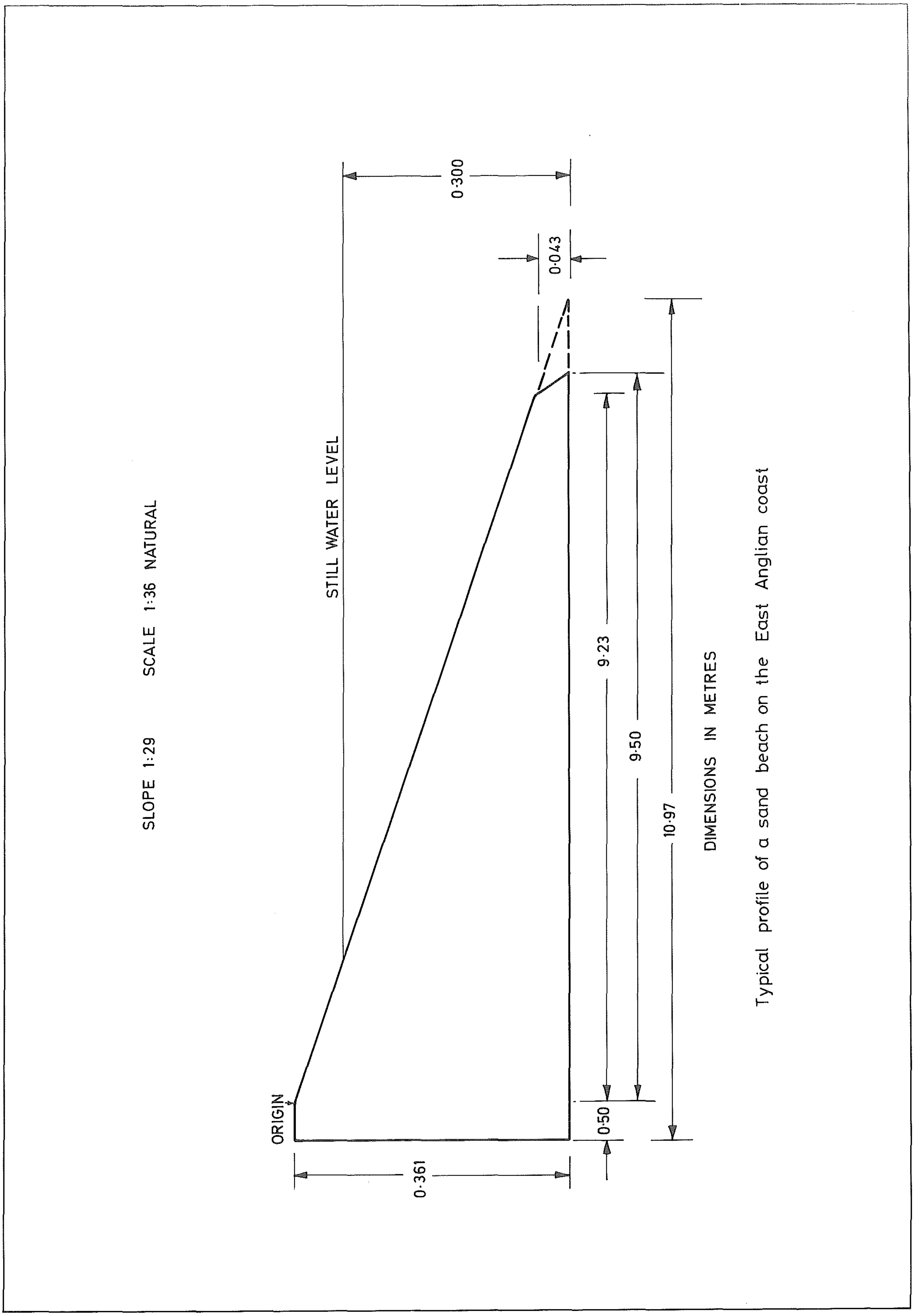
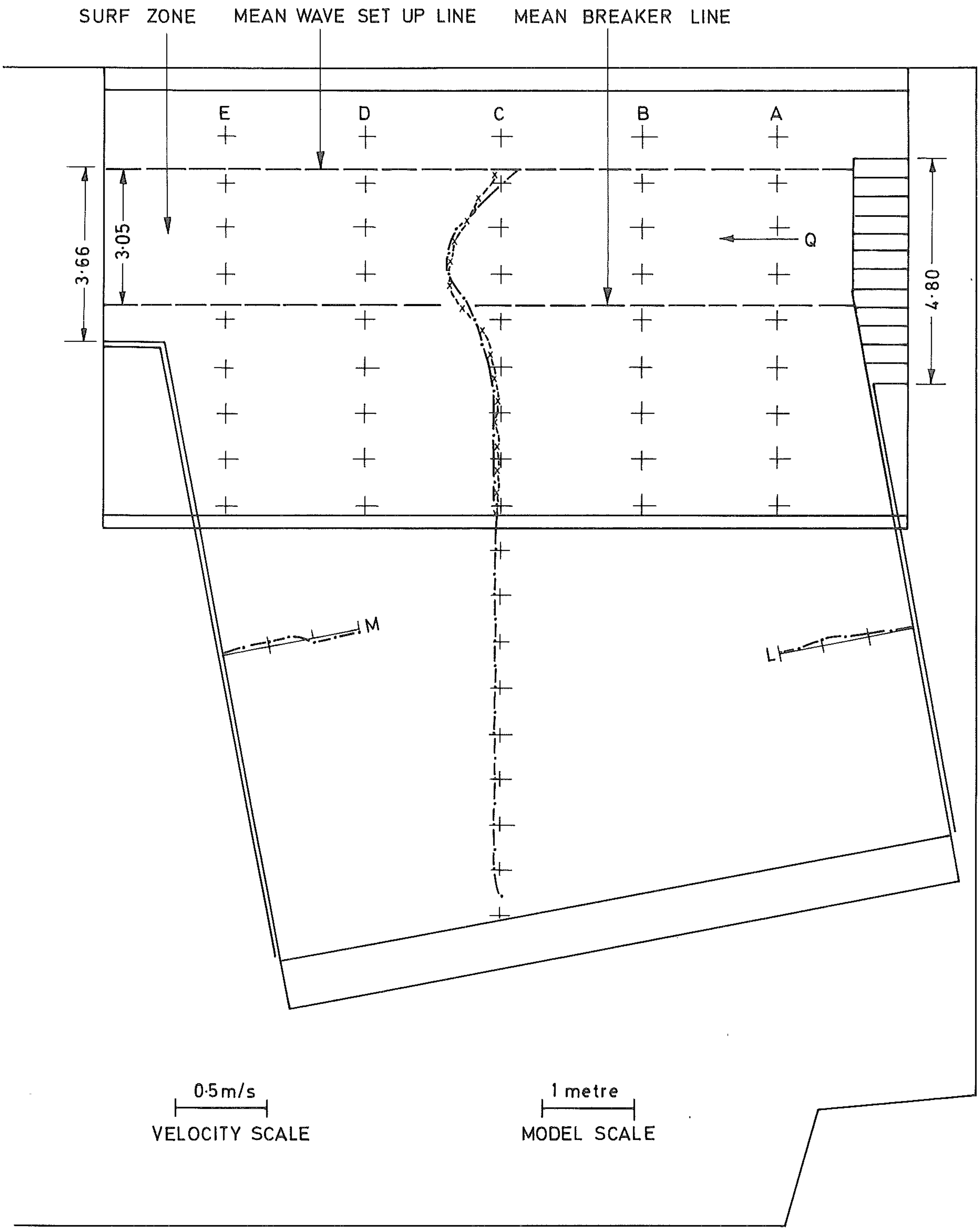


Fig 1·2 Section through uniformly sloping model beach



x = VELOCITY PROFILES FROM VISSER'S MODEL MODIFIED VIA MATHEMATICAL MODEL

· MODEL PROFILE AT C, L and M

Q = 50 l/s

Fig1·3 Velocity profiles at mid position - experimental techniques

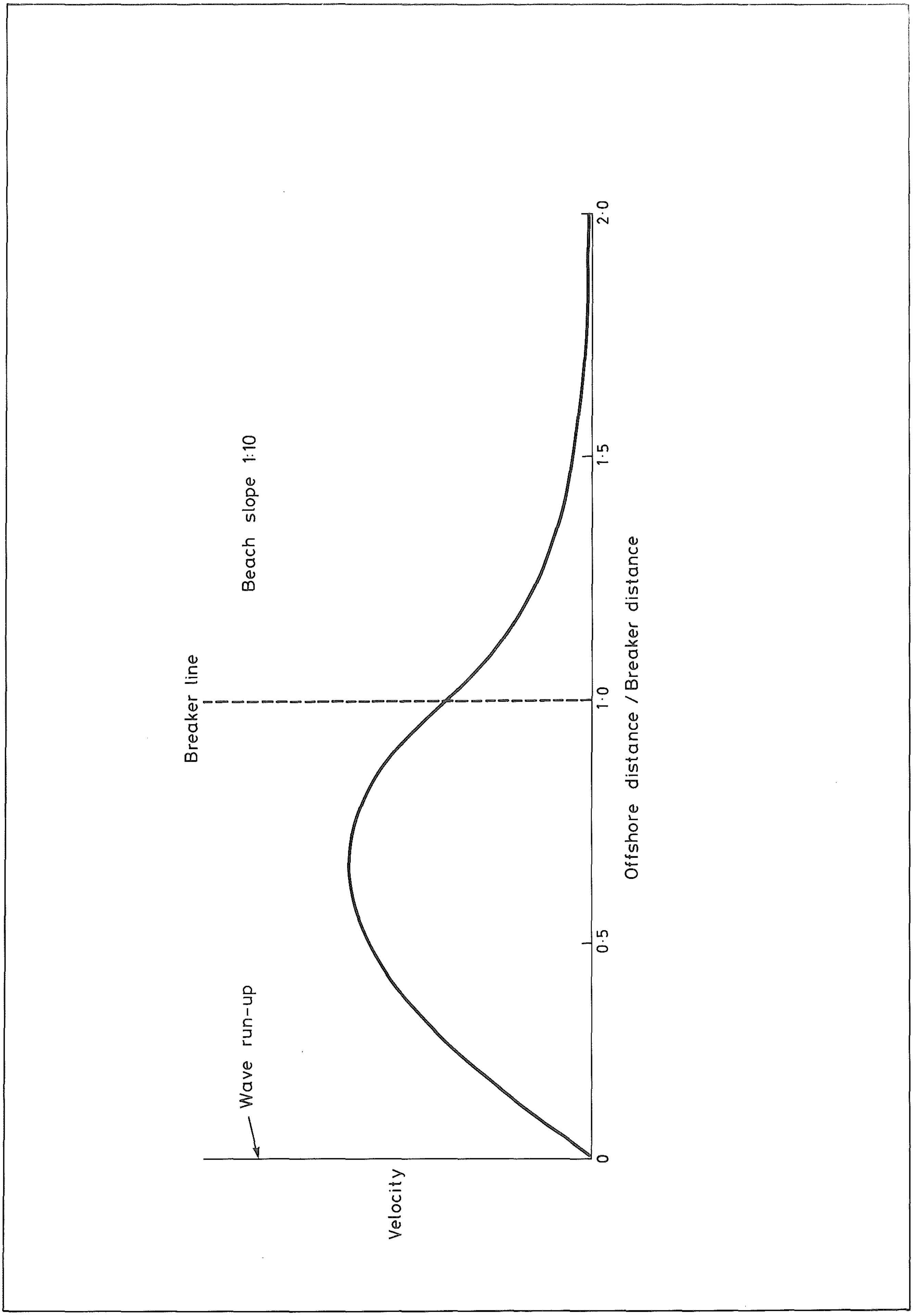


Fig 1·4 Theoretical alongshore current profile (Longuet – Higgins 1970)

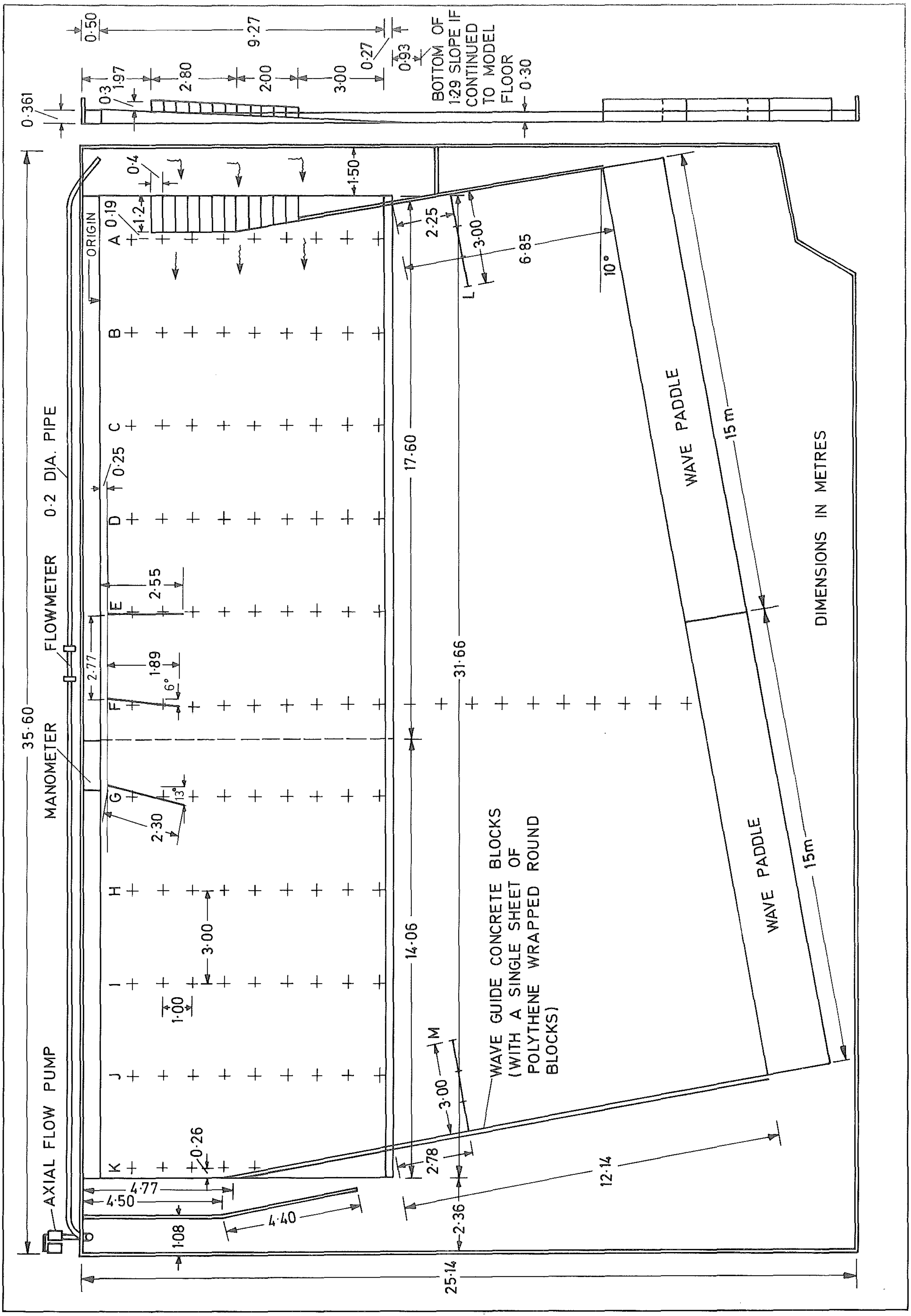


Fig 2·1 Plan of wave basin - for tests 1 to 10 (with Sea Palling groyne system)

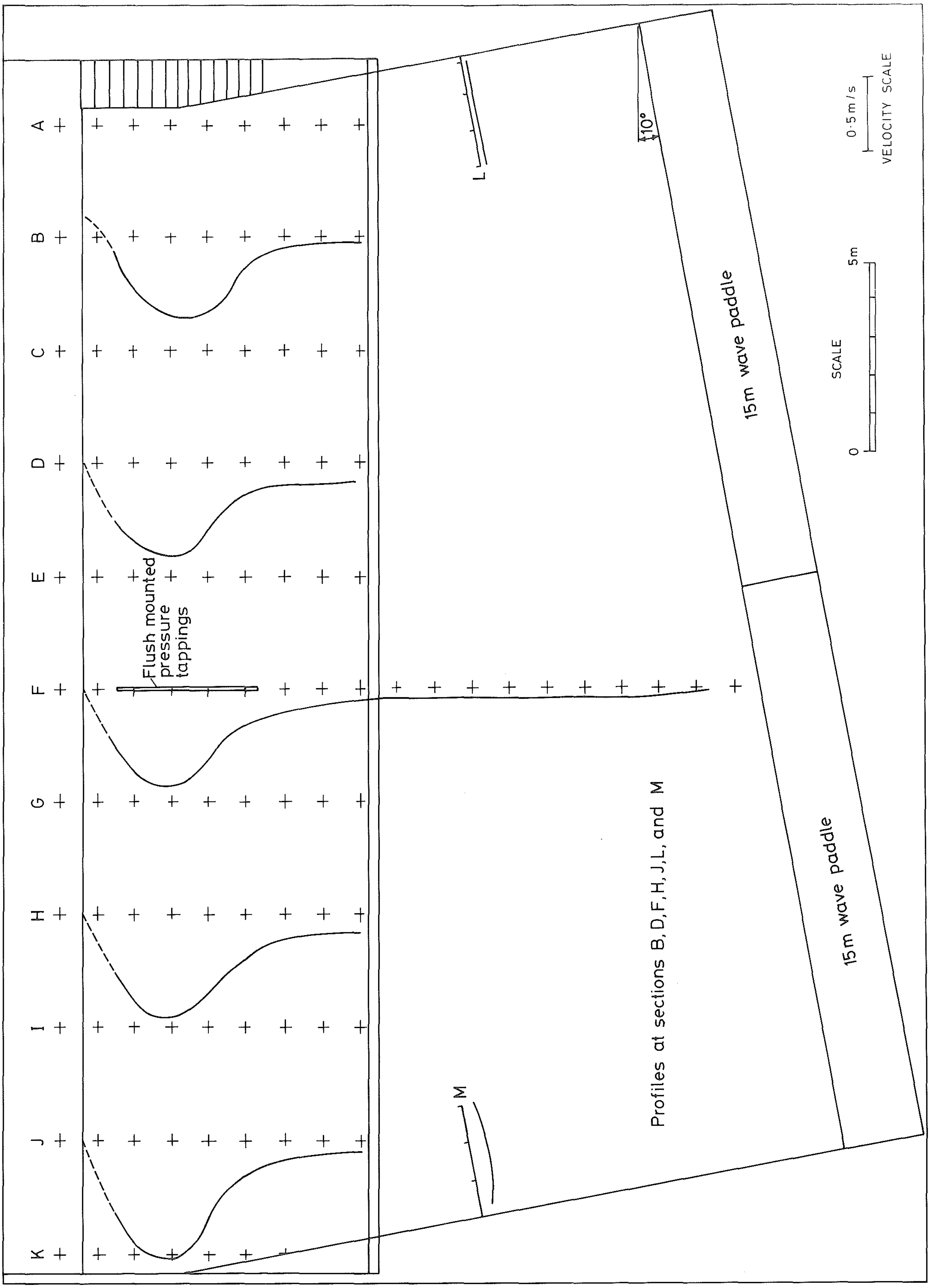


Fig 2·2 Velocity profile- uniform sloping beach

GROYNE ARRANGEMENT	JANUARY					FEB		MARCH									APRIL								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
UNIFORM 1:29 SLOPING BEACH ANGLE OF WAVE APPROACH 10° GROYNES LAID ON TOP OF BEACH																									
Single groyne laid perpendicular to beach	▨																								
3 No groynes laid perpendicular to beach		▨																							
4 No groynes laid perpendicular to beach			▨	▨	▨																				
BEACH BROKEN OUT AND REPLACED BY WINTER PROFILE OF BEACH AT SEA PALLING																									
3 No groynes as at Sea Palling 'high' (see fig 2·10)						▨	▨																		
ALIGNMENT OF LITTORAL CURRENT ALTERED																									
3 No groynes as at Sea Palling 'high' (see fig 2·10)								▨	▨	▨															
ANGLE OF WAVE APPROACH CHANGED TO 26° NORMAL TO BEACH																									
3 No groynes as at Sea Palling 'high' (see fig 2·10)											▨	▨	▨												
3 No groynes as at Sea Palling 'low' (see fig 2·10)														▨	▨	▨									
MODEL TESTS ON A FIELD OF SEVEN GROYNES																									
Groynes perpendicular to beach 1:1 spacing Hp=2·2m																	▨								
Groynes perpendicular to beach 1:1 spacing Hp=1·1m																		▨							
As above, intermediate groynes shortened by 25%																			▨						
Groynes perpendicular to beach, 1:2 spacing																				▨					
Groynes perpendicular to beach, 1:1·5 spacing																					▨				
As above, intermediate groynes shortened by 25%																						▨			
Groynes angled 10° updrift 1:1 spacing																							▨		
Groynes angled 10° downdrift 1:1 spacing																								▨	
As above, random wave pattern																									▨

FOR MODEL PARAMETERS SEE TABLE 3

Hp = PROTOTYPE WAVE HEIGHT

Fig 2·3 Testing sequence – Hypothetical groyne systems (first test series)

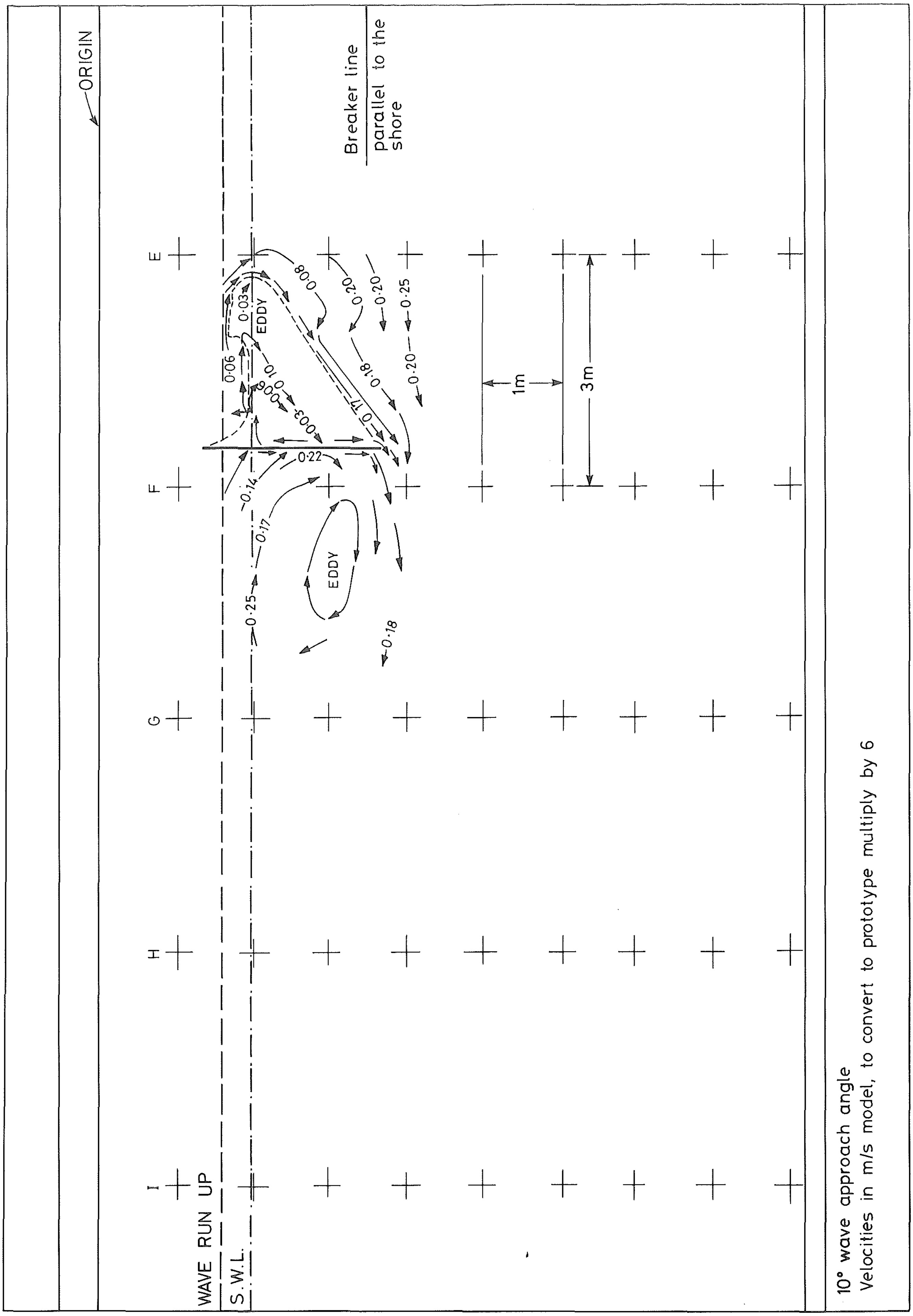


Fig 2·4 1-Groyne system flow pattern(test 1)

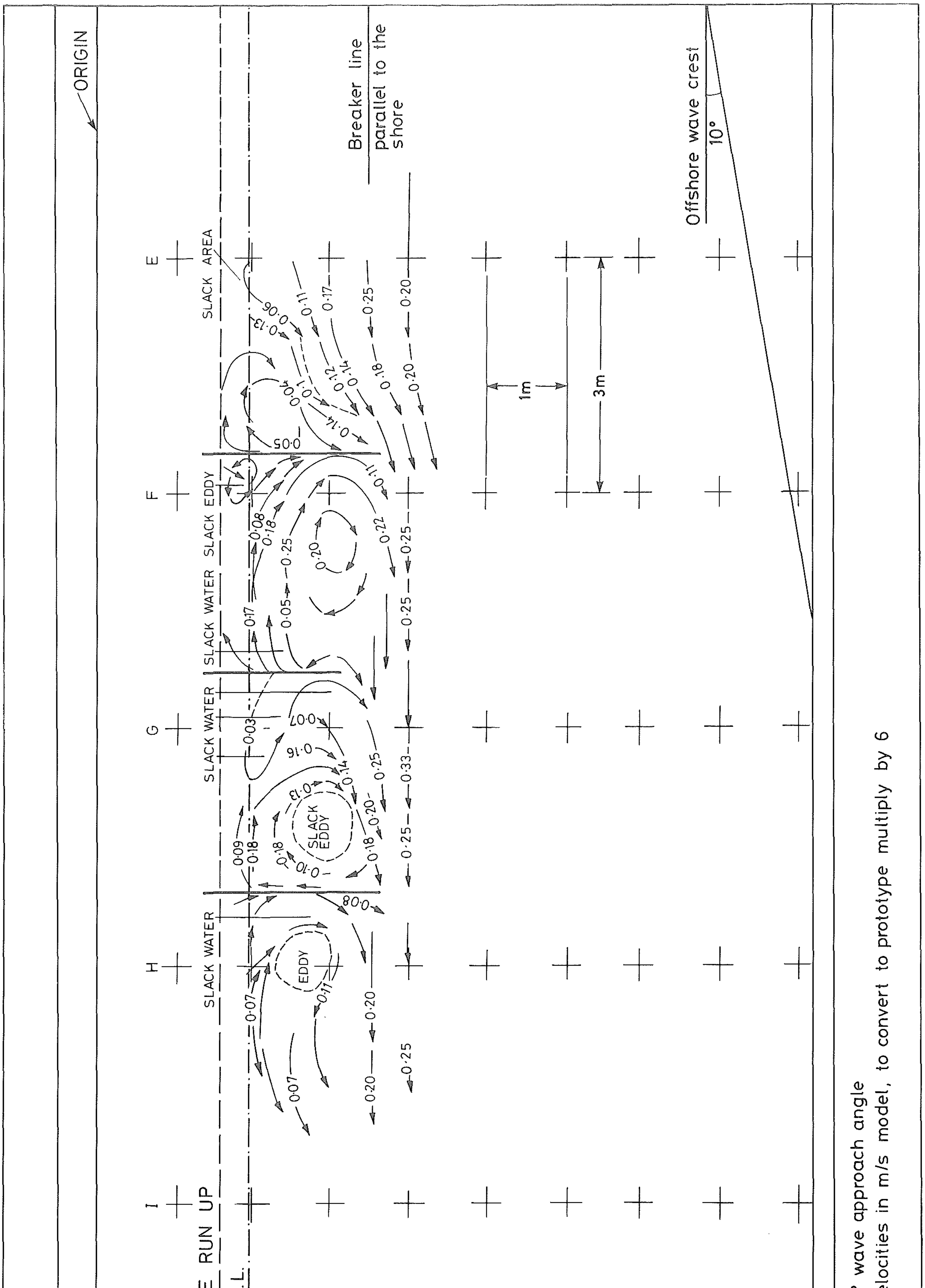


Fig 2·5 3-Groyne system flow pattern(test 2)

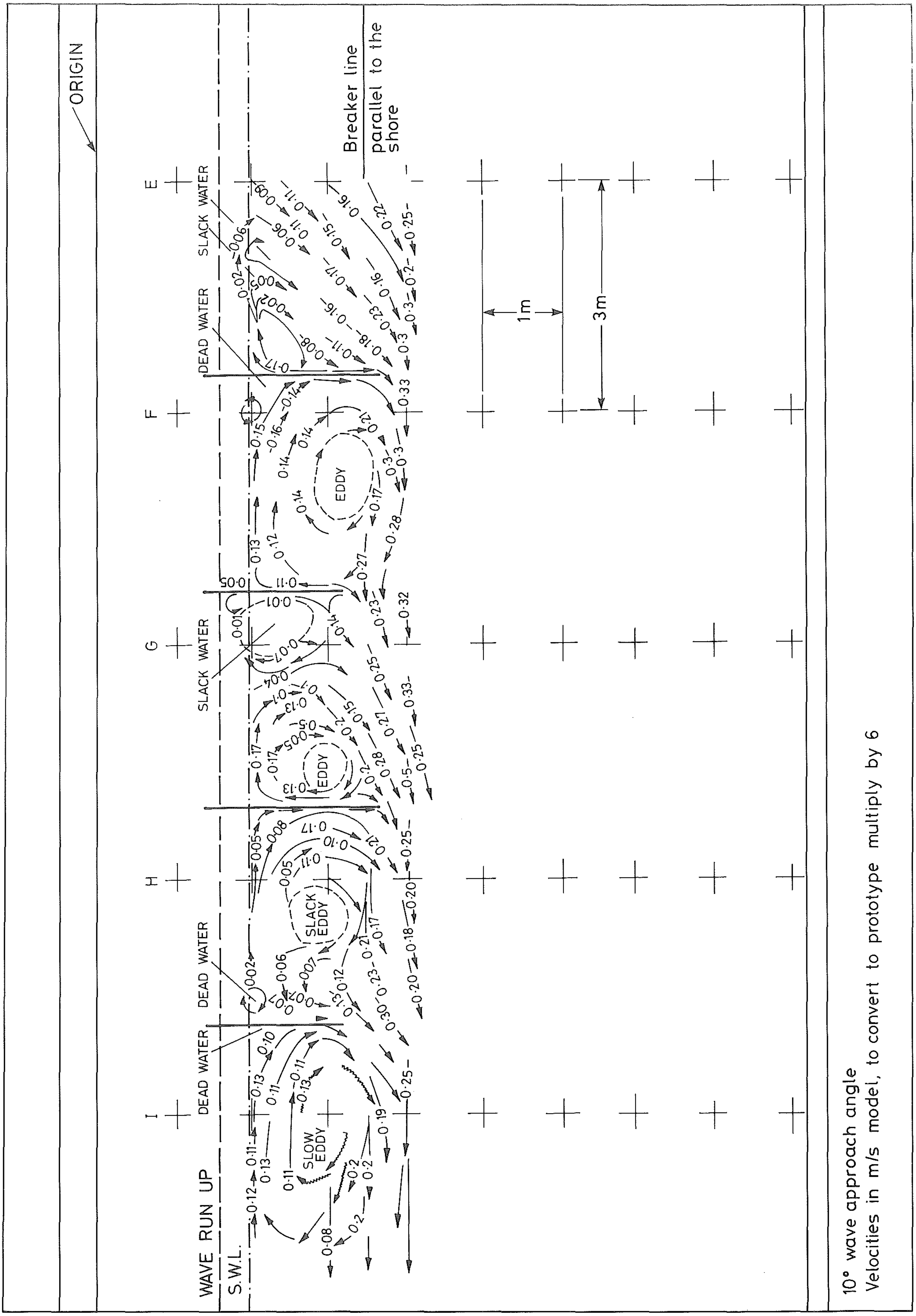


Fig 2·6 4-Groyne system flow pattern,(tests 3,4 and 5)

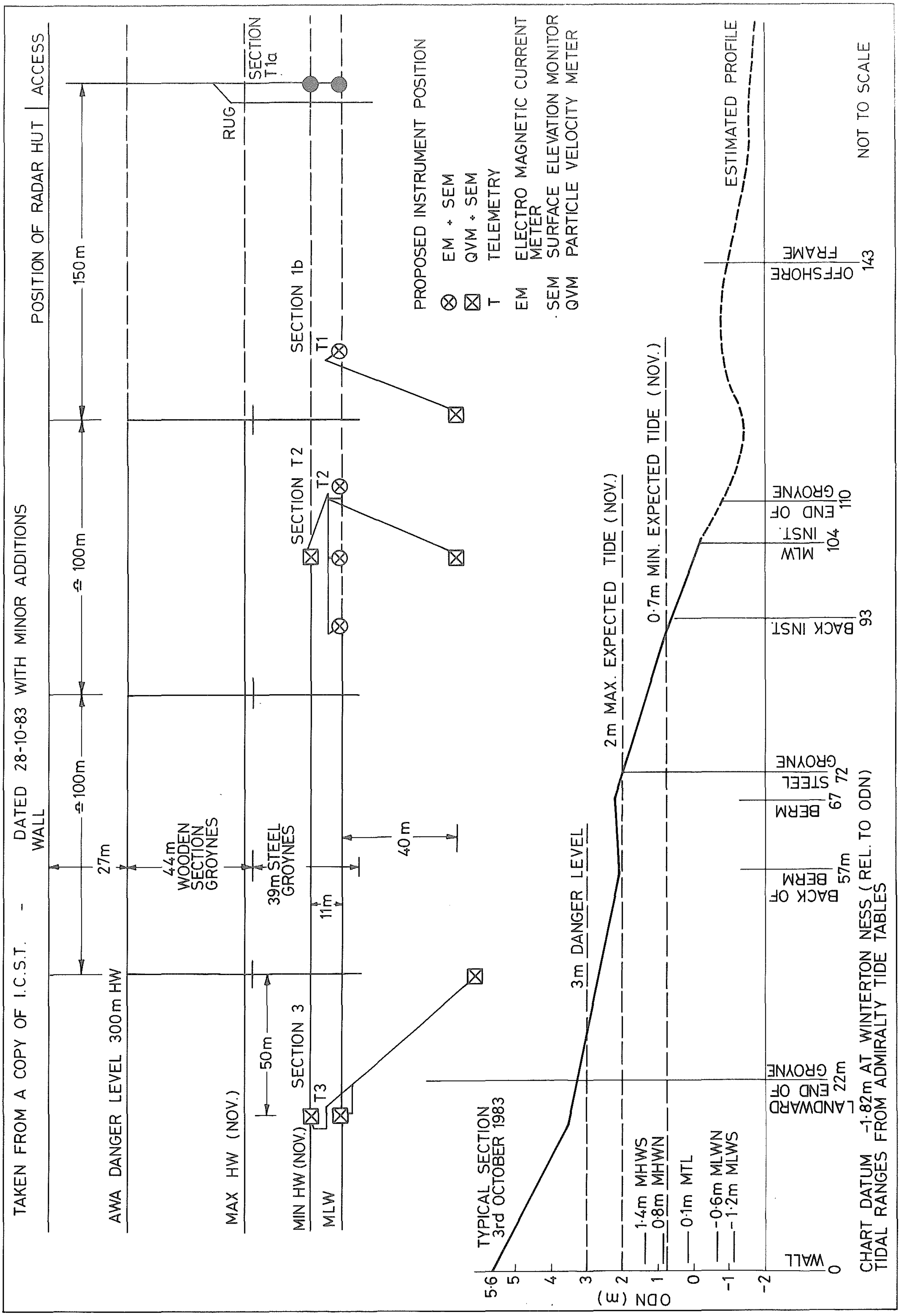


Fig 2·7 Plan and section of Sea Palling site (October 1983)

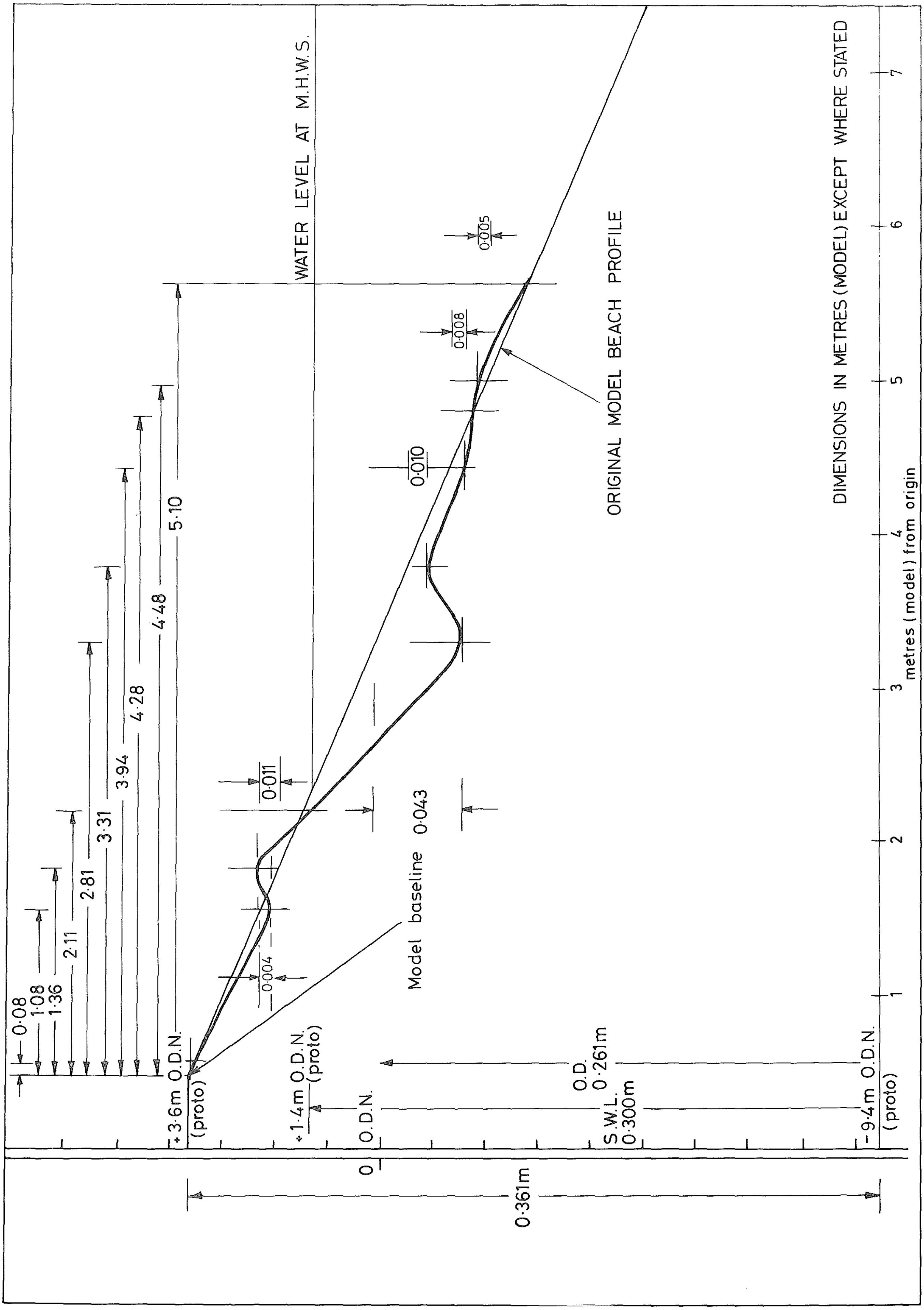


Fig 2·8 Section through Winter beach profile (used for tests 6 to 25)

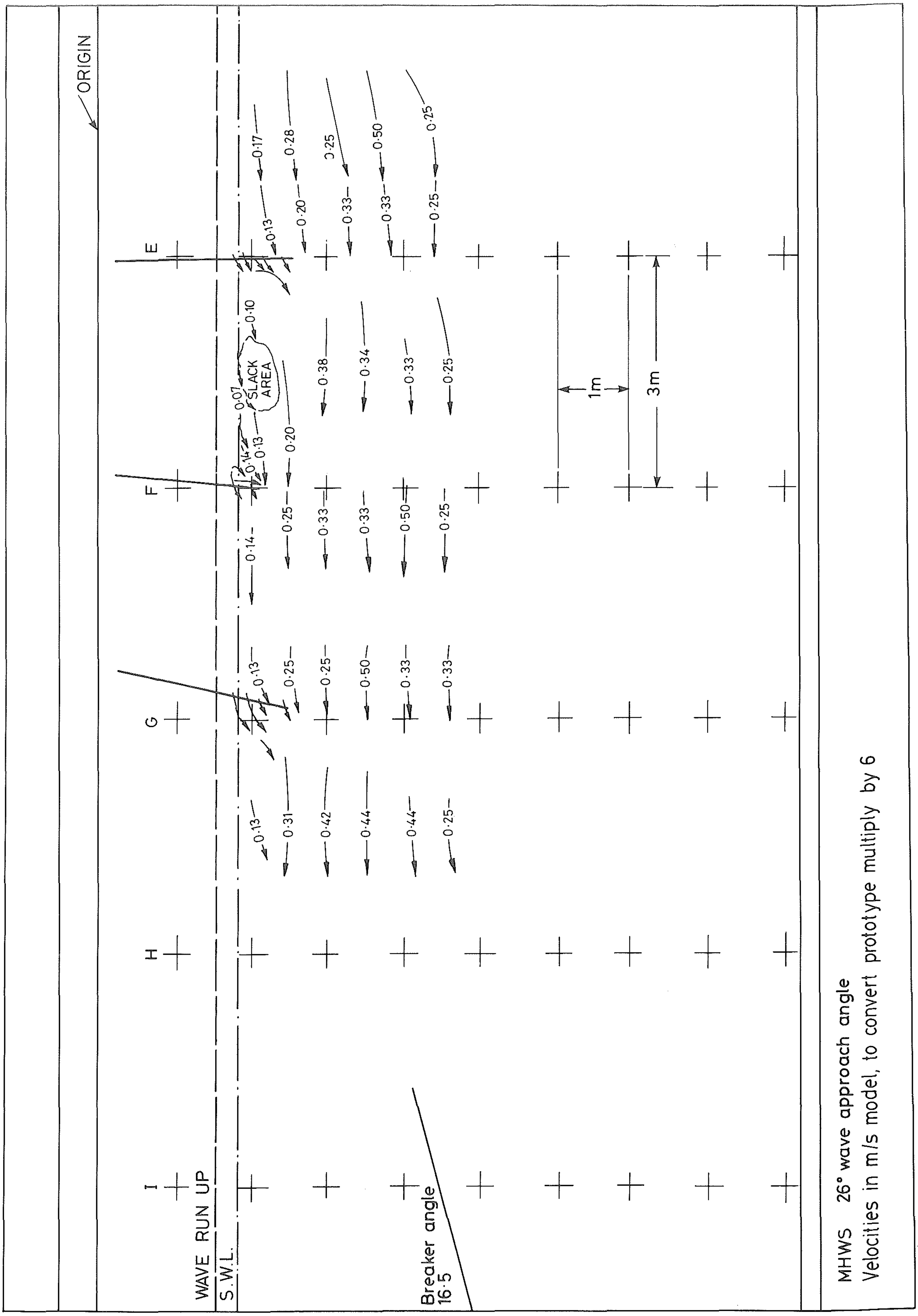


Fig 2·17 Sea Palling groyne system - Test 15

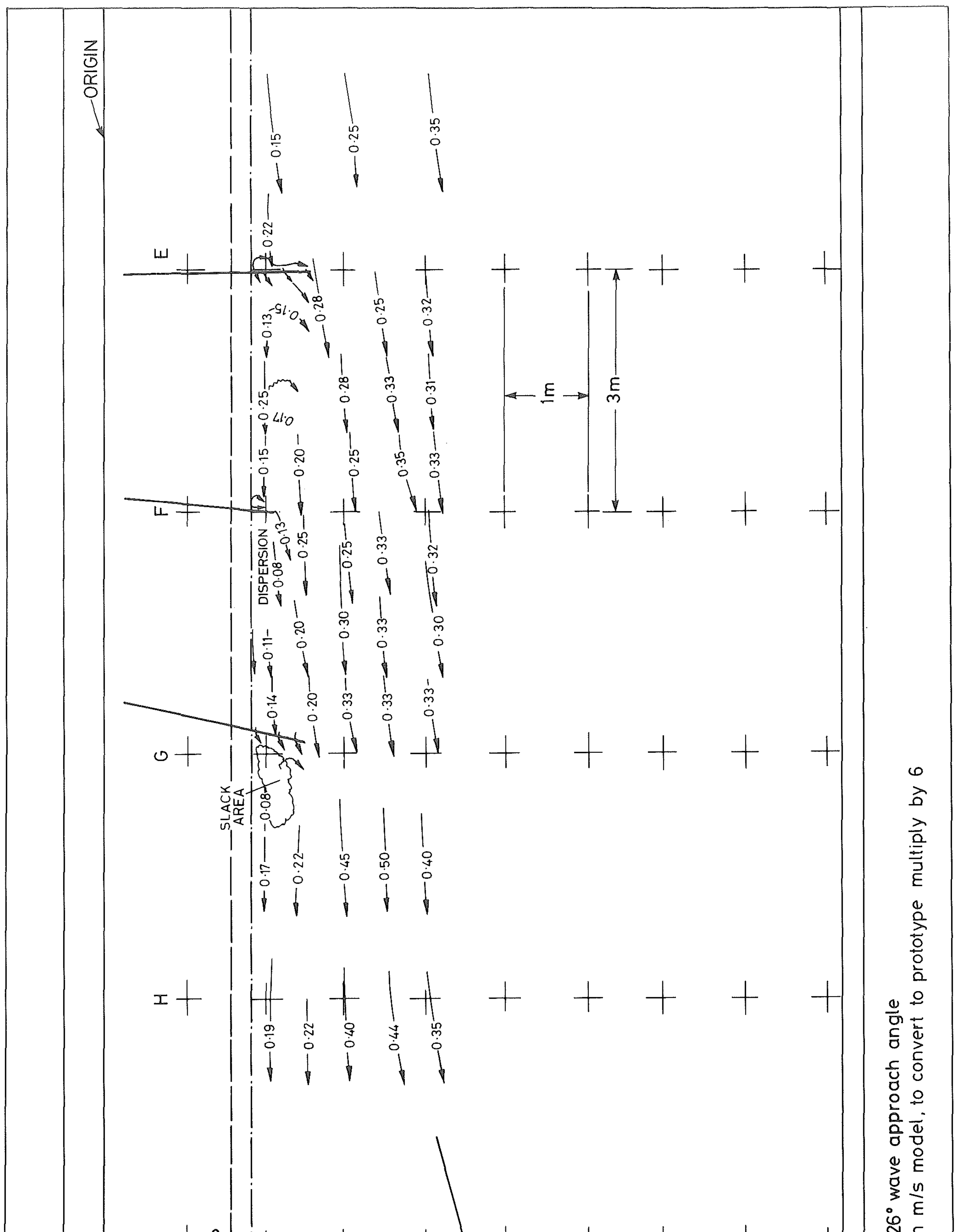


Fig 2·18 Sea Palling groyne system – Test 14

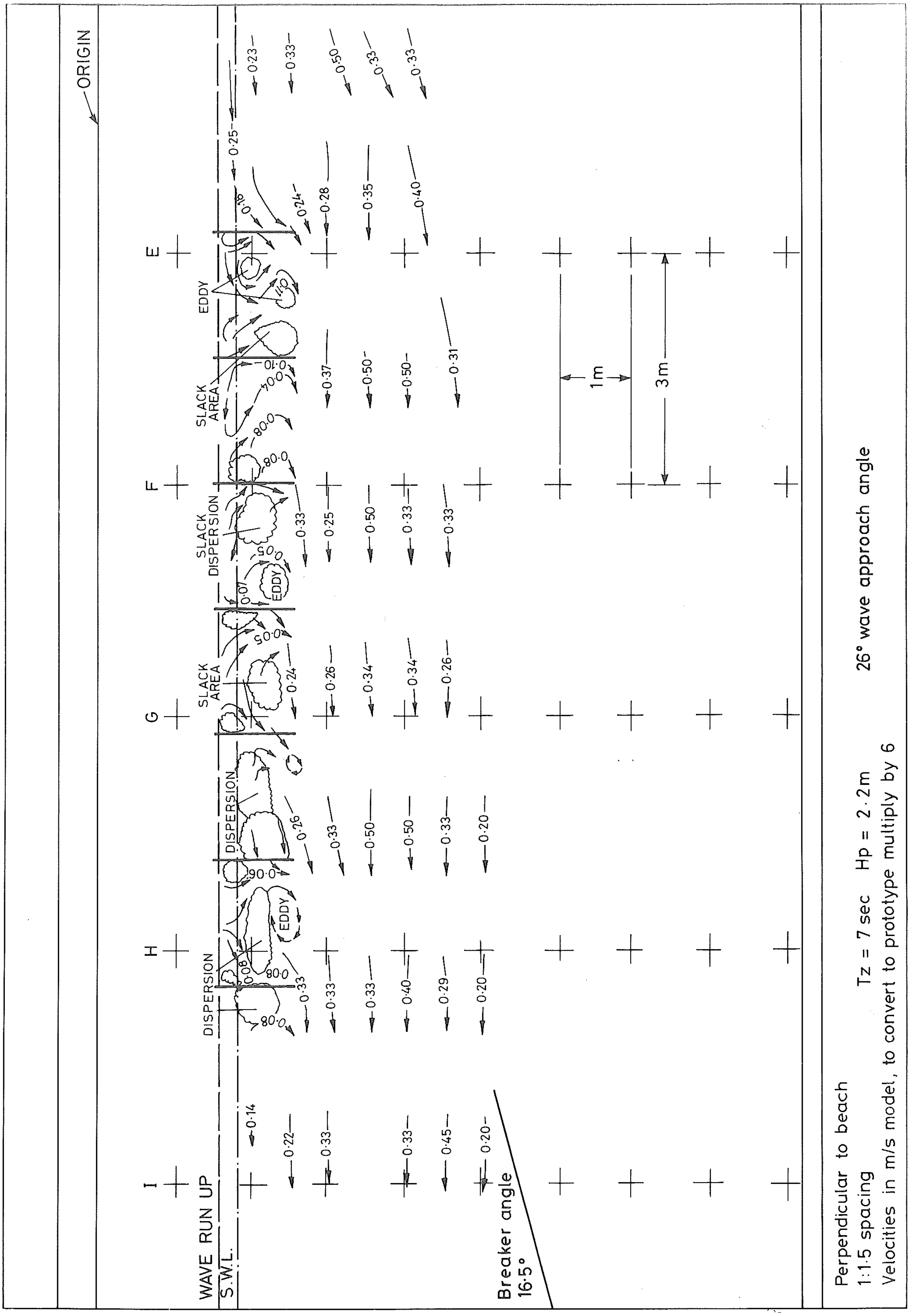


Fig 2.23 7 Groyne field – Test 21 (1:1.5 spacing)

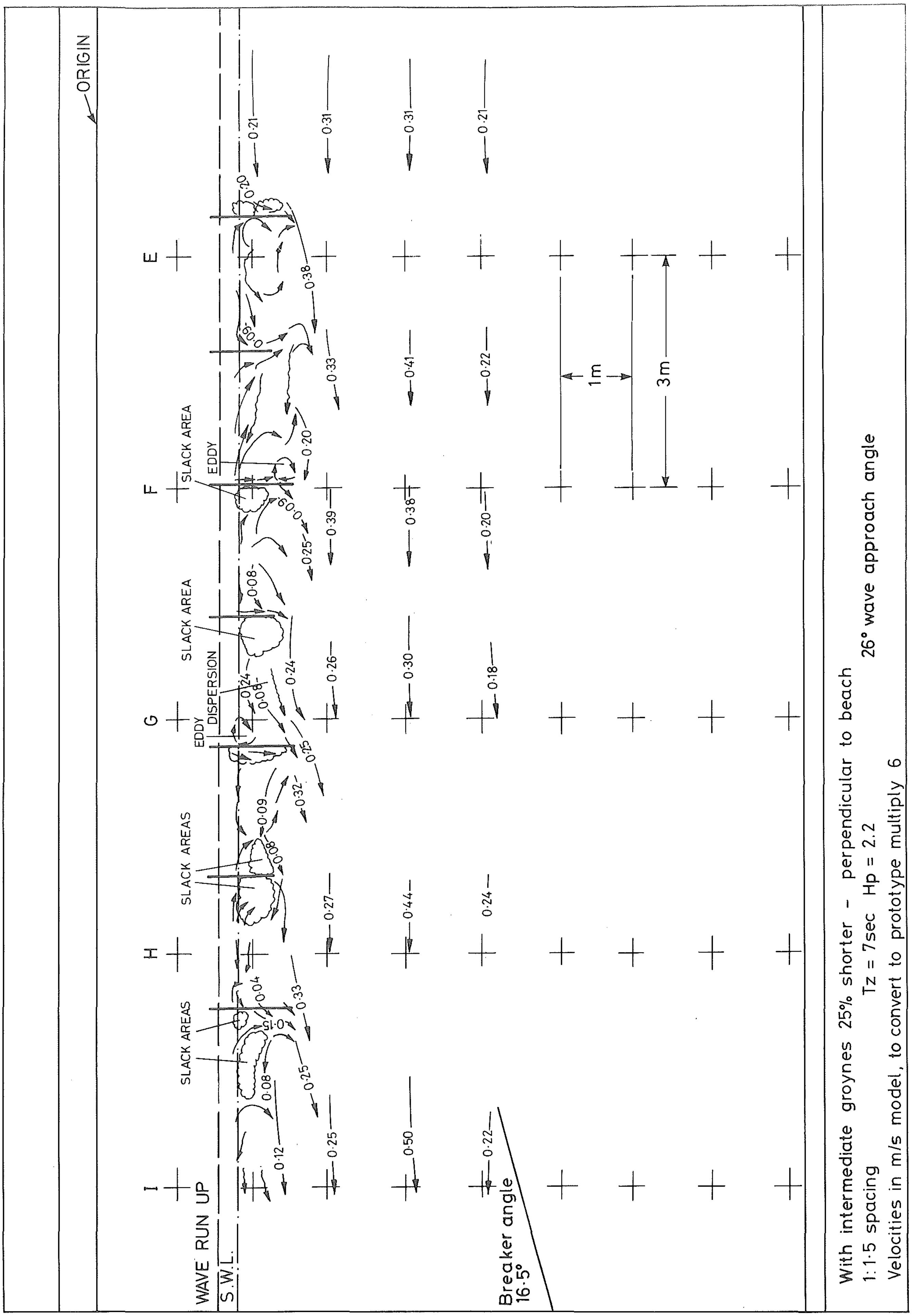


Fig 2·24 7 Groyne field - Test 22 (1:1·5 spacing)

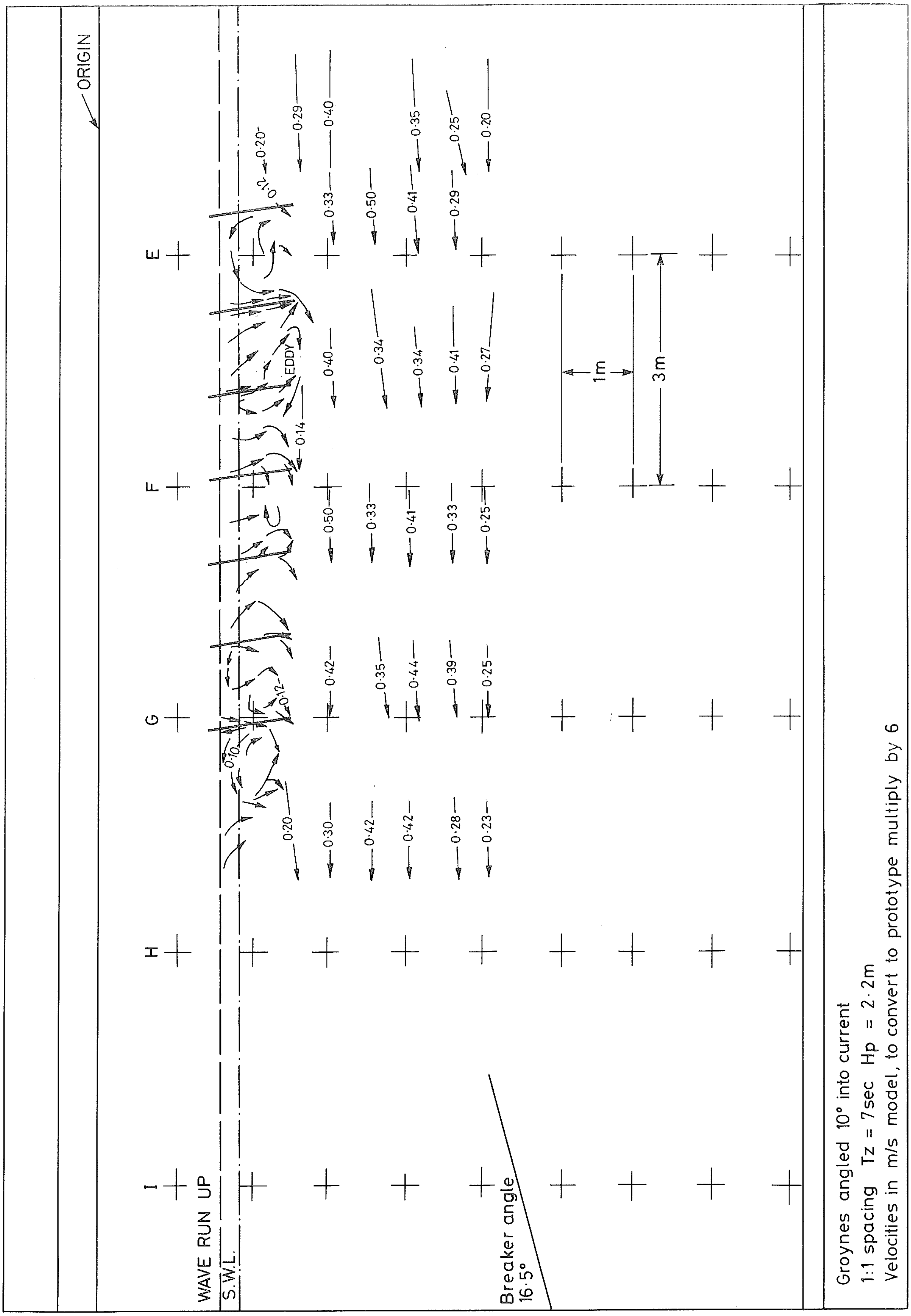


Fig 2·25 7 Groyne field - Test 23 (1:1 spacing angled updrift)

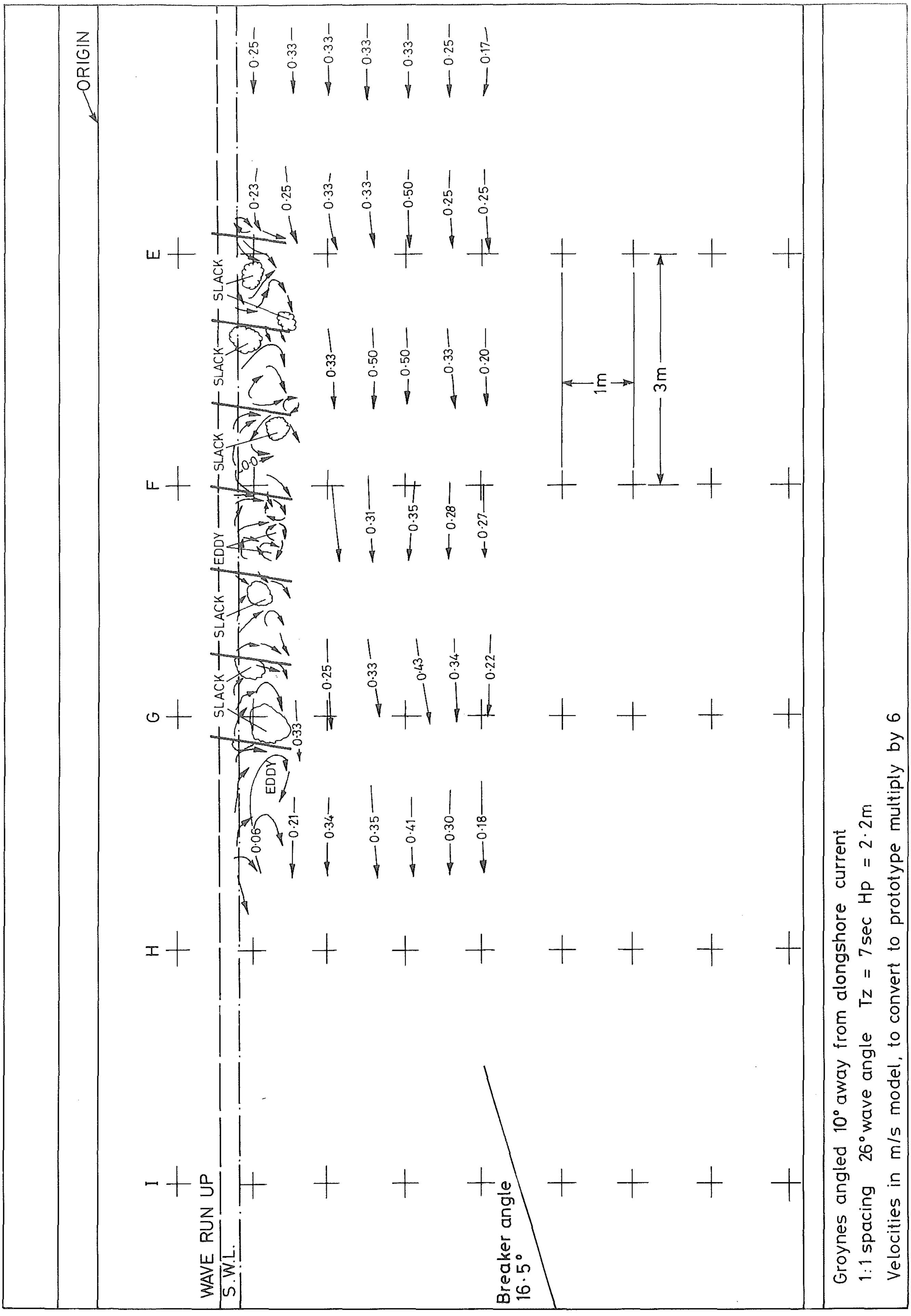


Fig 2·26 7 Groyne field - Test 24 (1:1 spacing angled updrift)

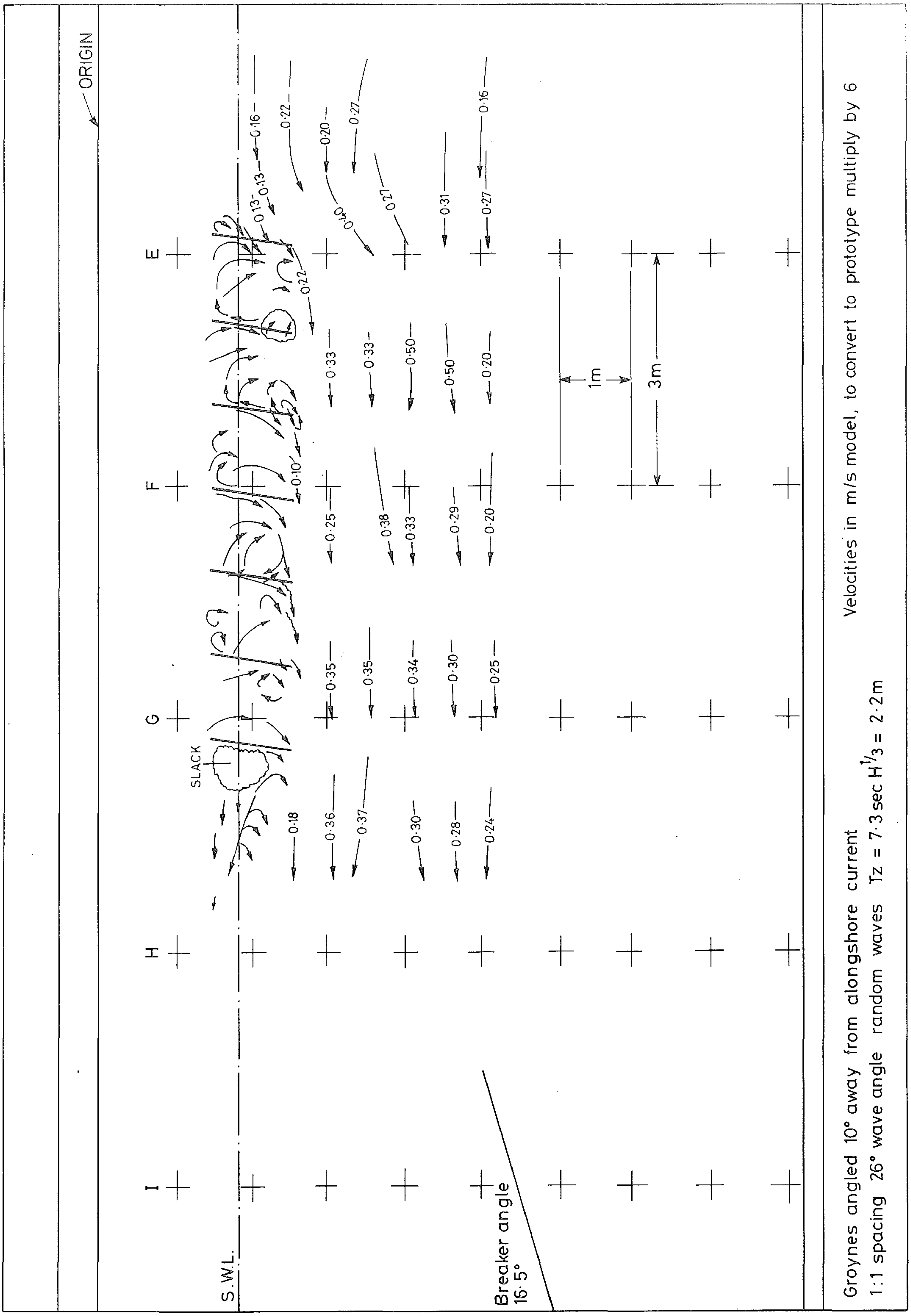


Fig 2·27 7 Groyne field – Test 25 (1:1 spacing angled updrift) random waves

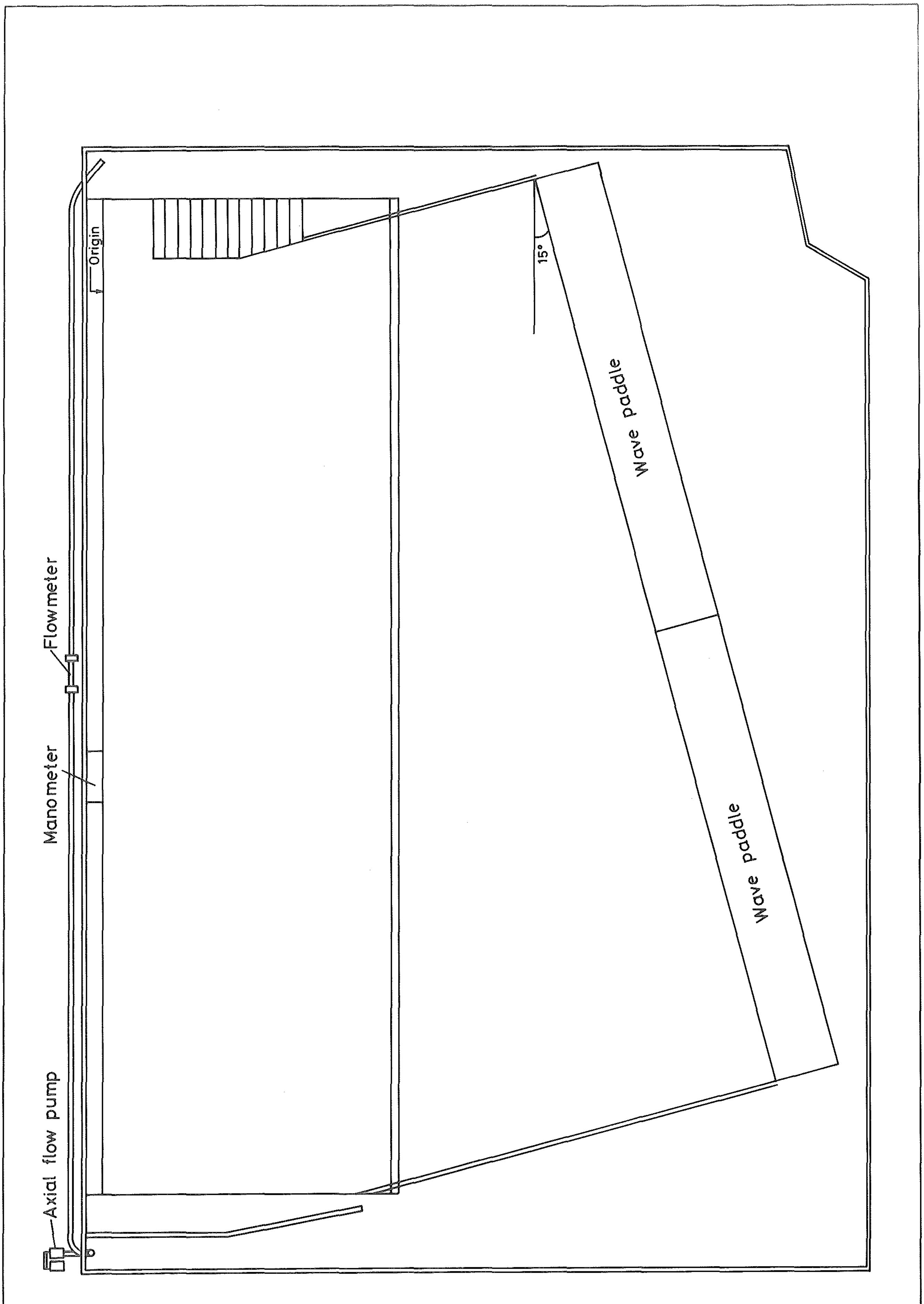


Fig 3·1 Plan of wave basin – wave generator at 15° for tests 31–43

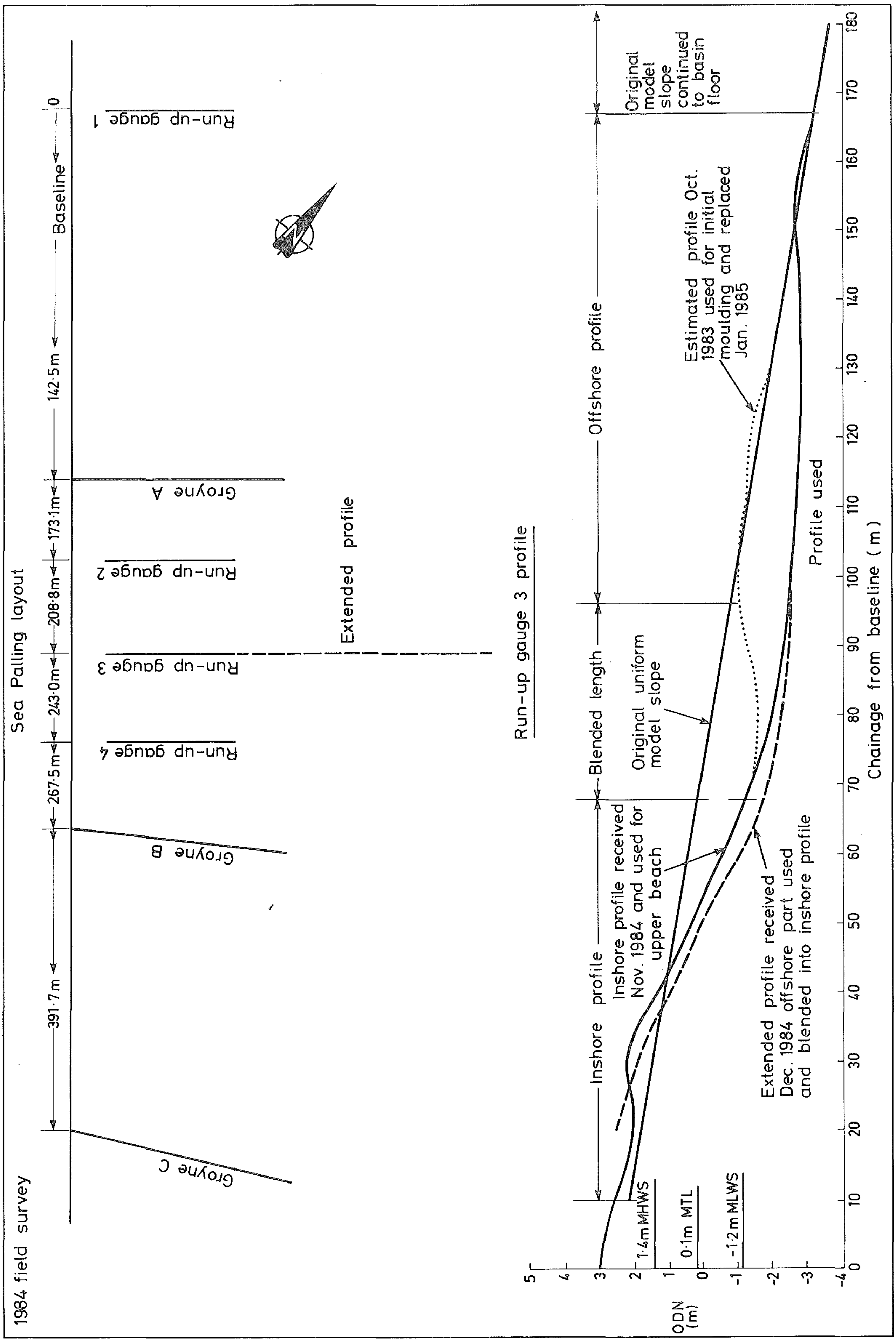


Fig 3·2 Run-up gauge positions and beach profile

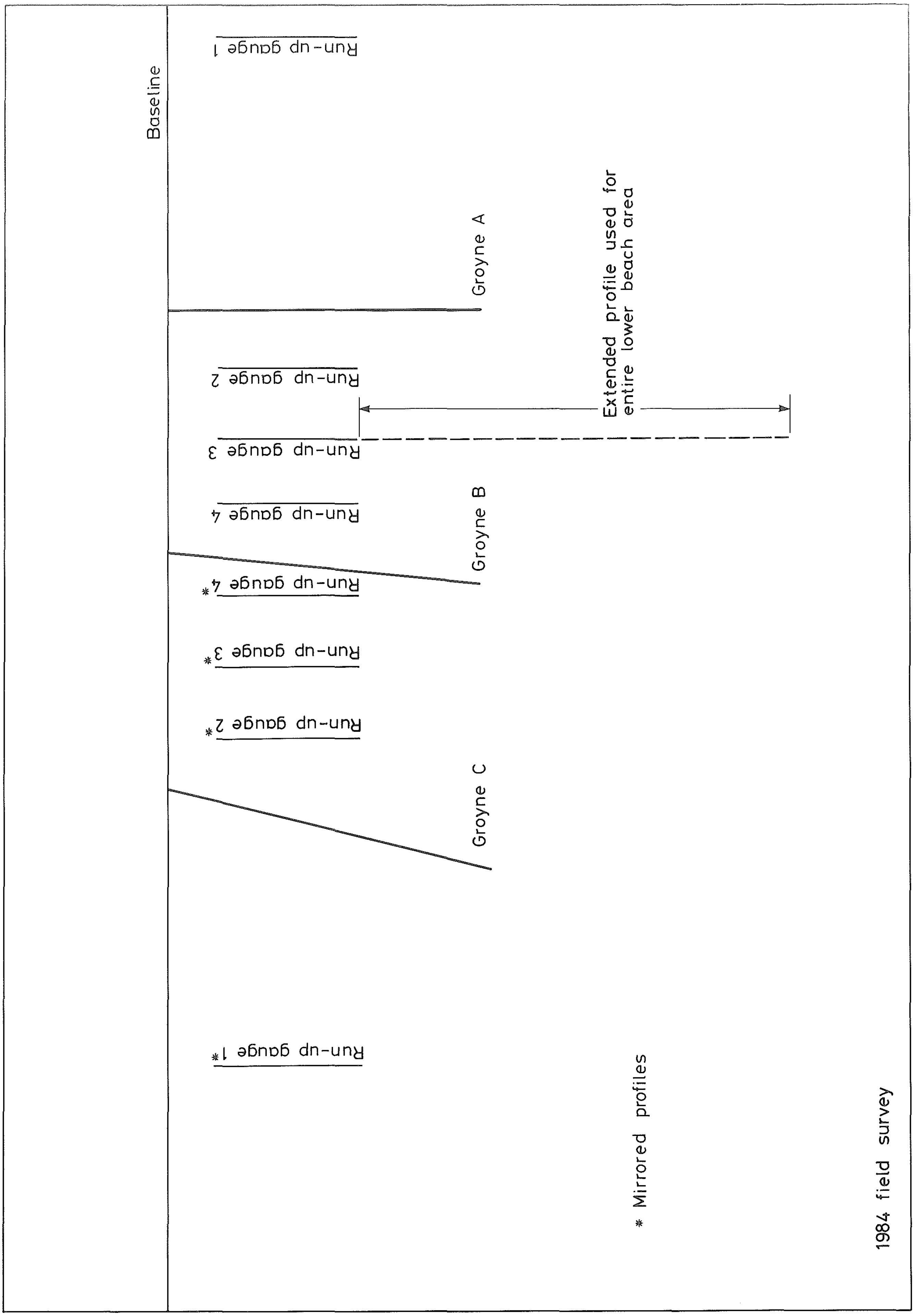


Fig 3·3 Model beach plan (as moulded) showing mirrored profiles

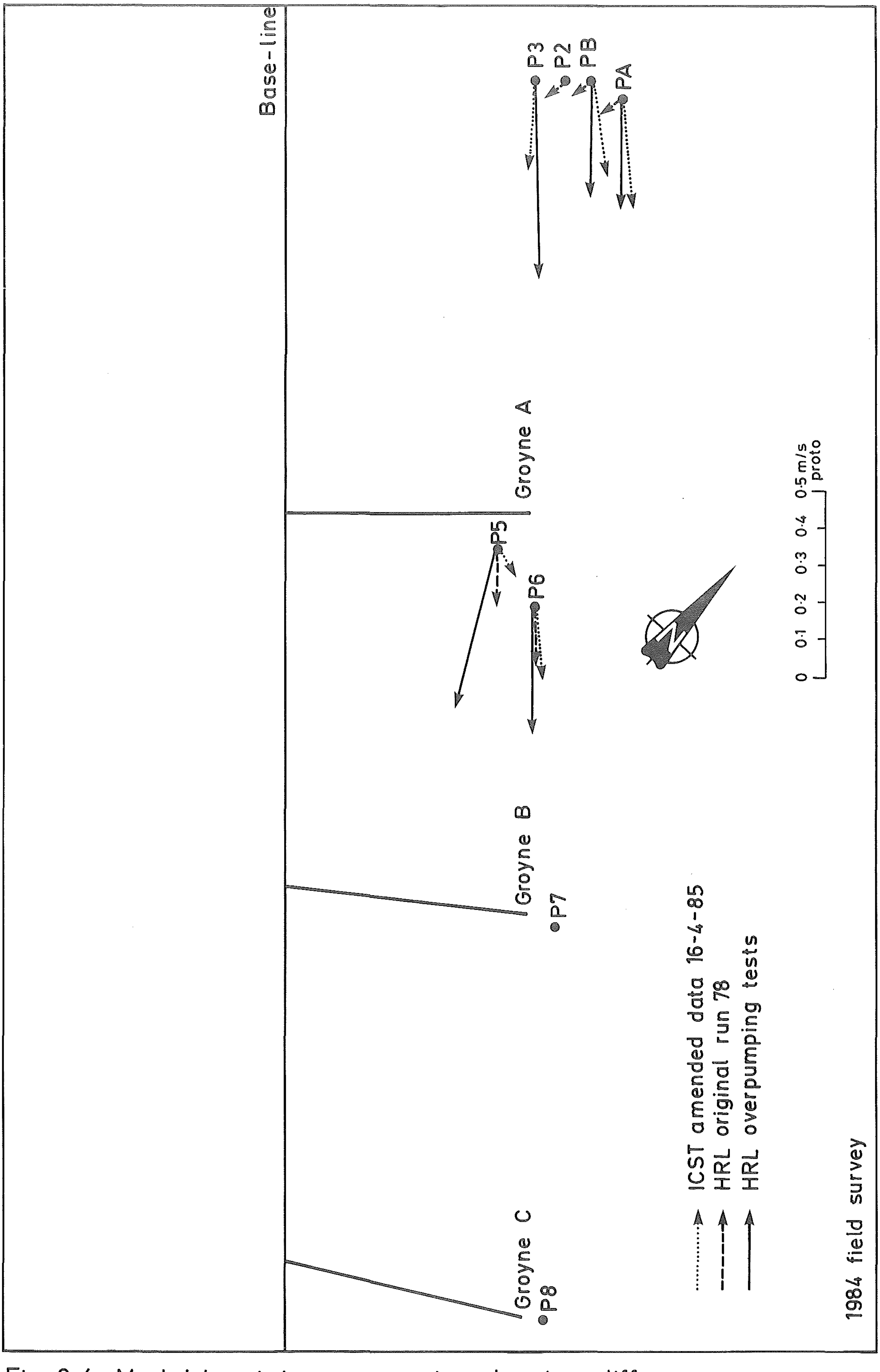


Fig 3·4 Model/prototype currents showing differences

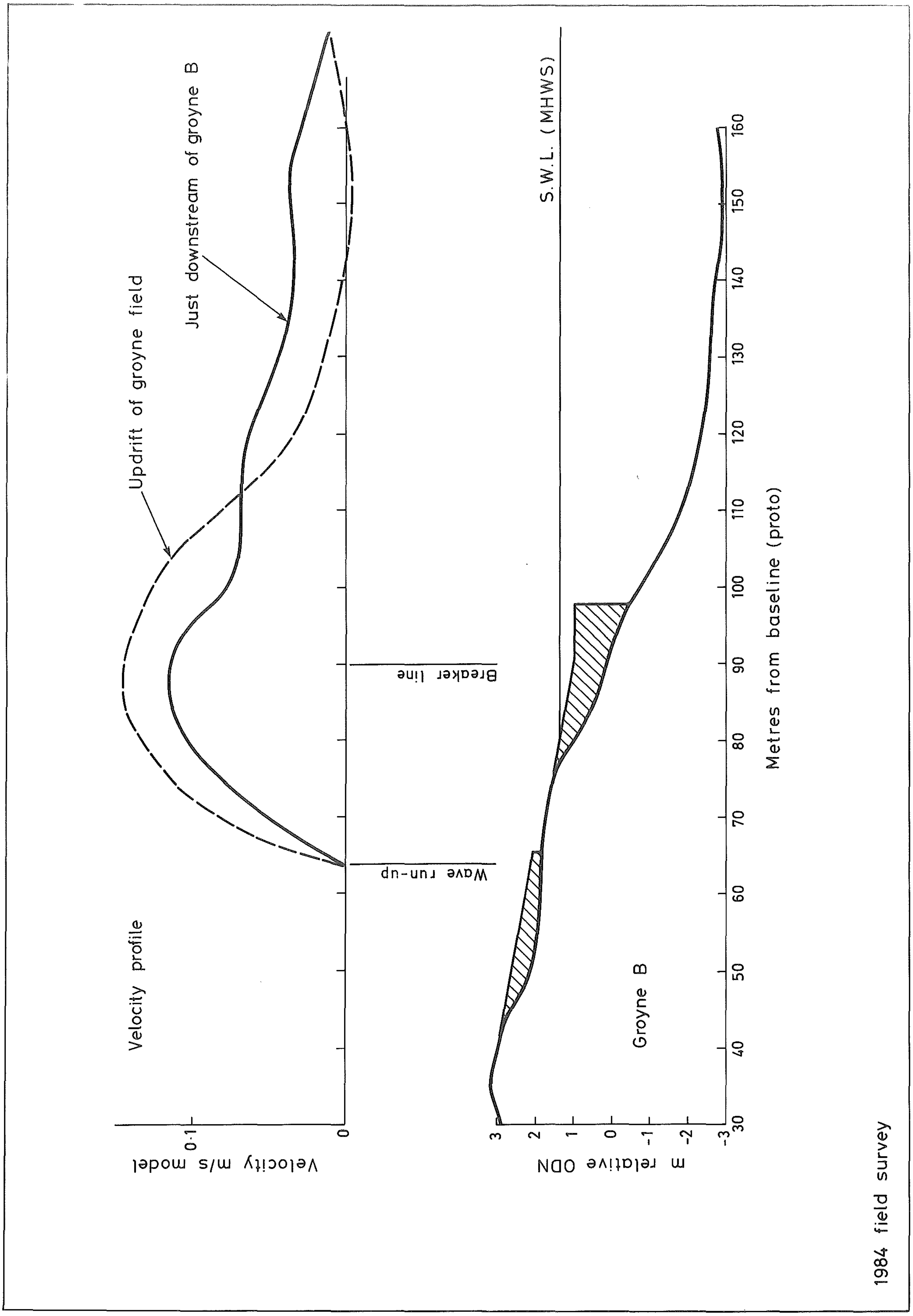


Fig 3·5 Velocity profile – final validation attempt

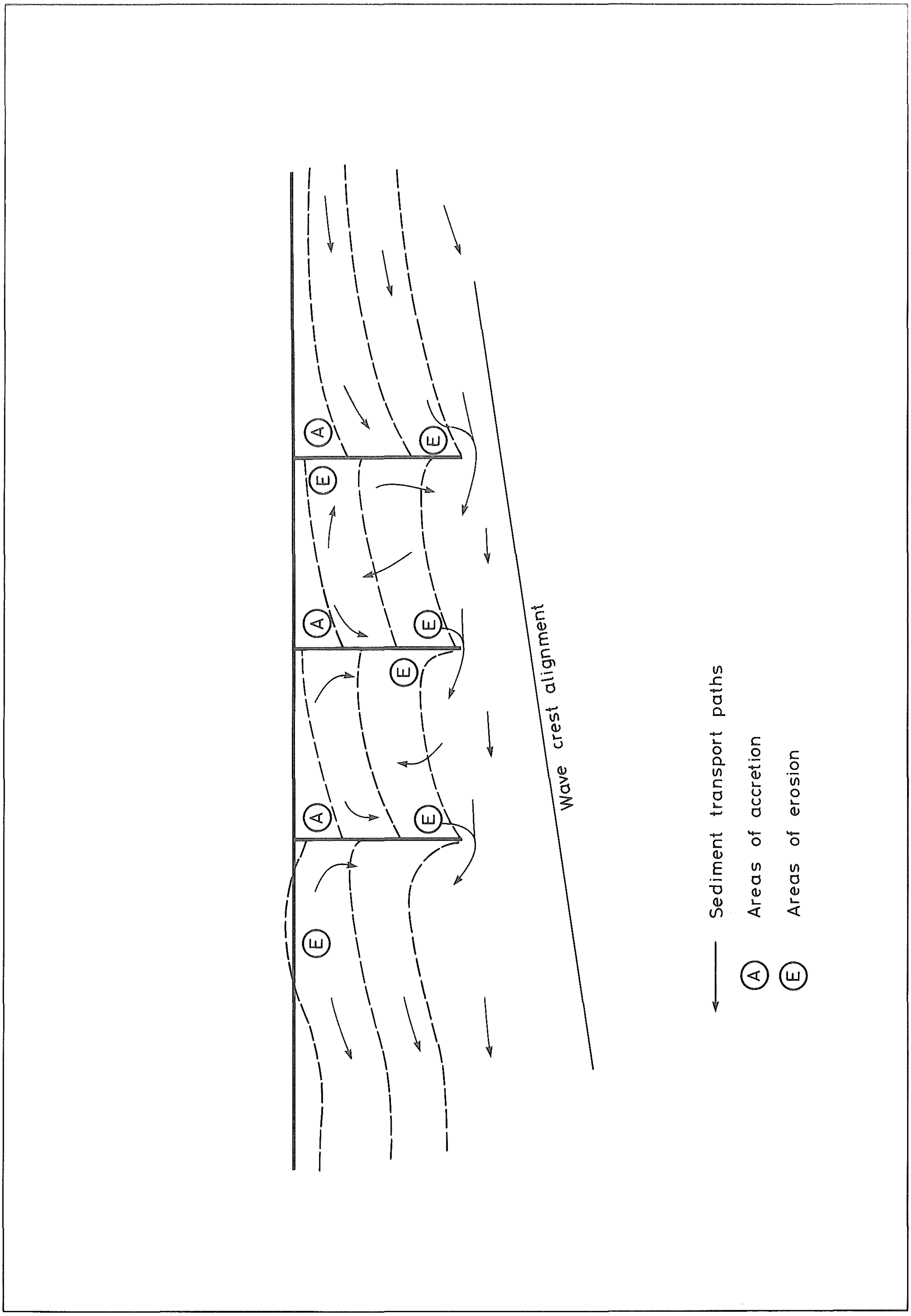


Fig 3·6 Schematic plan view of groyne field

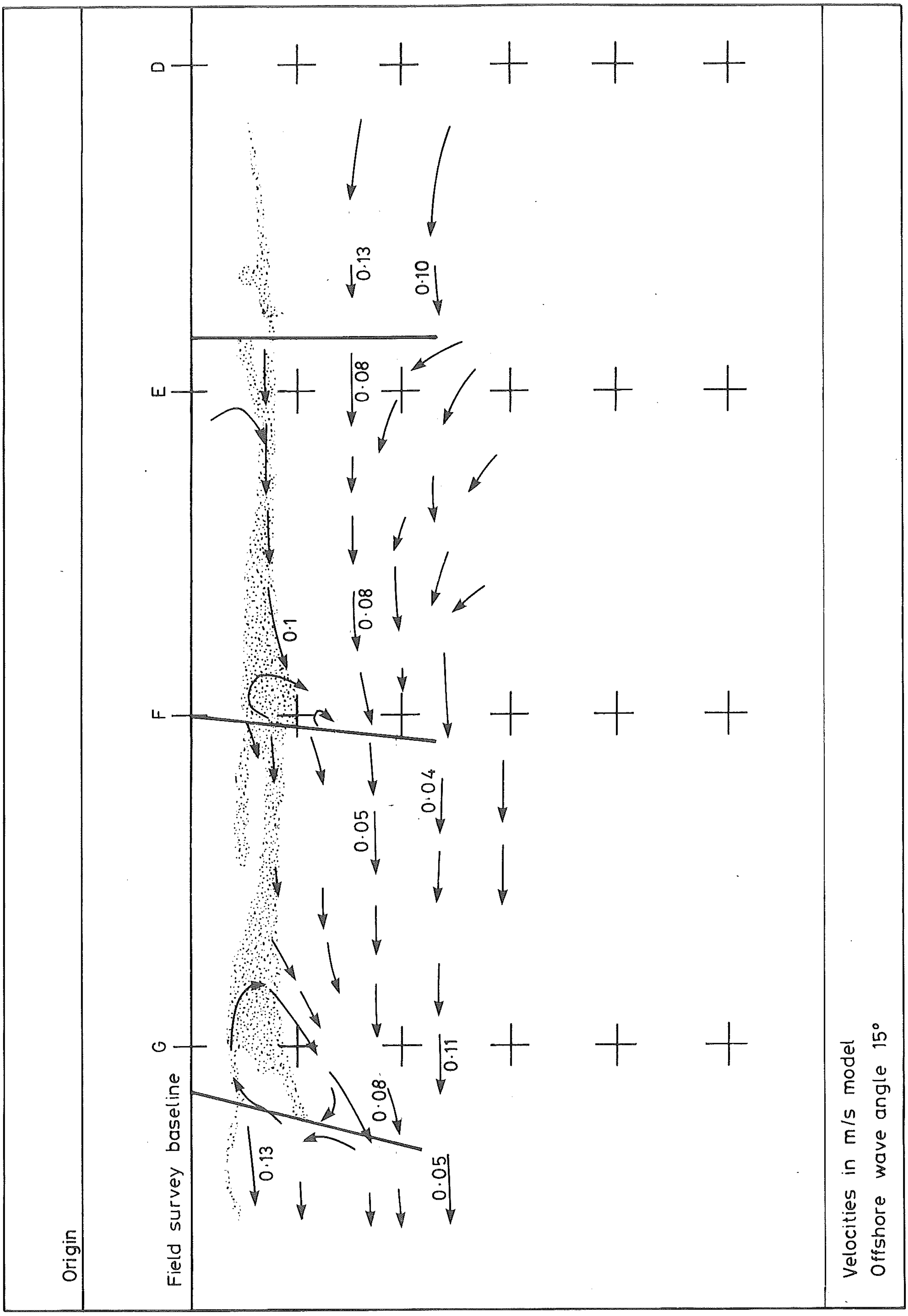


Fig 3·7 Test 31 - MHWN

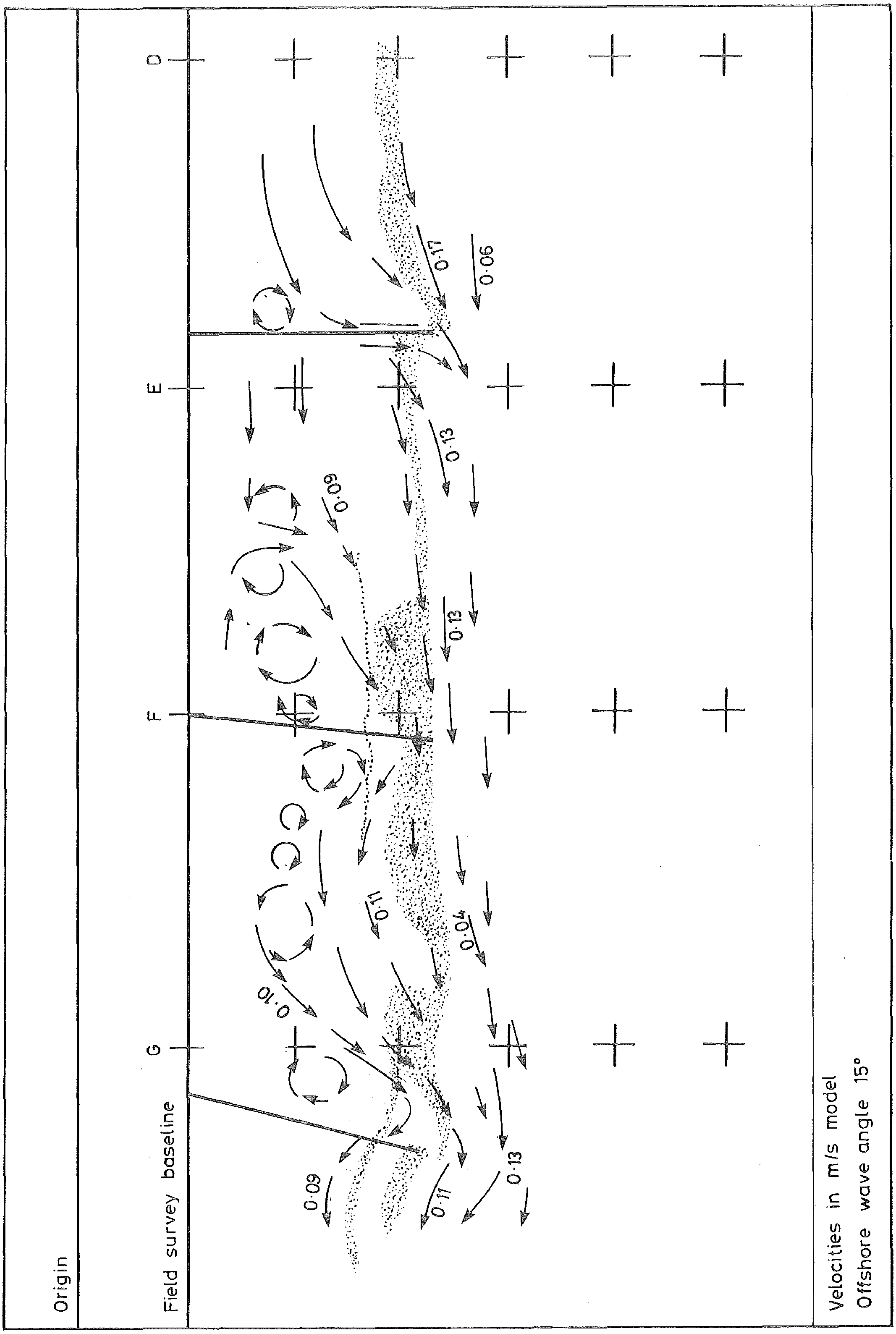


Fig 3·8 Test 32 – MTL

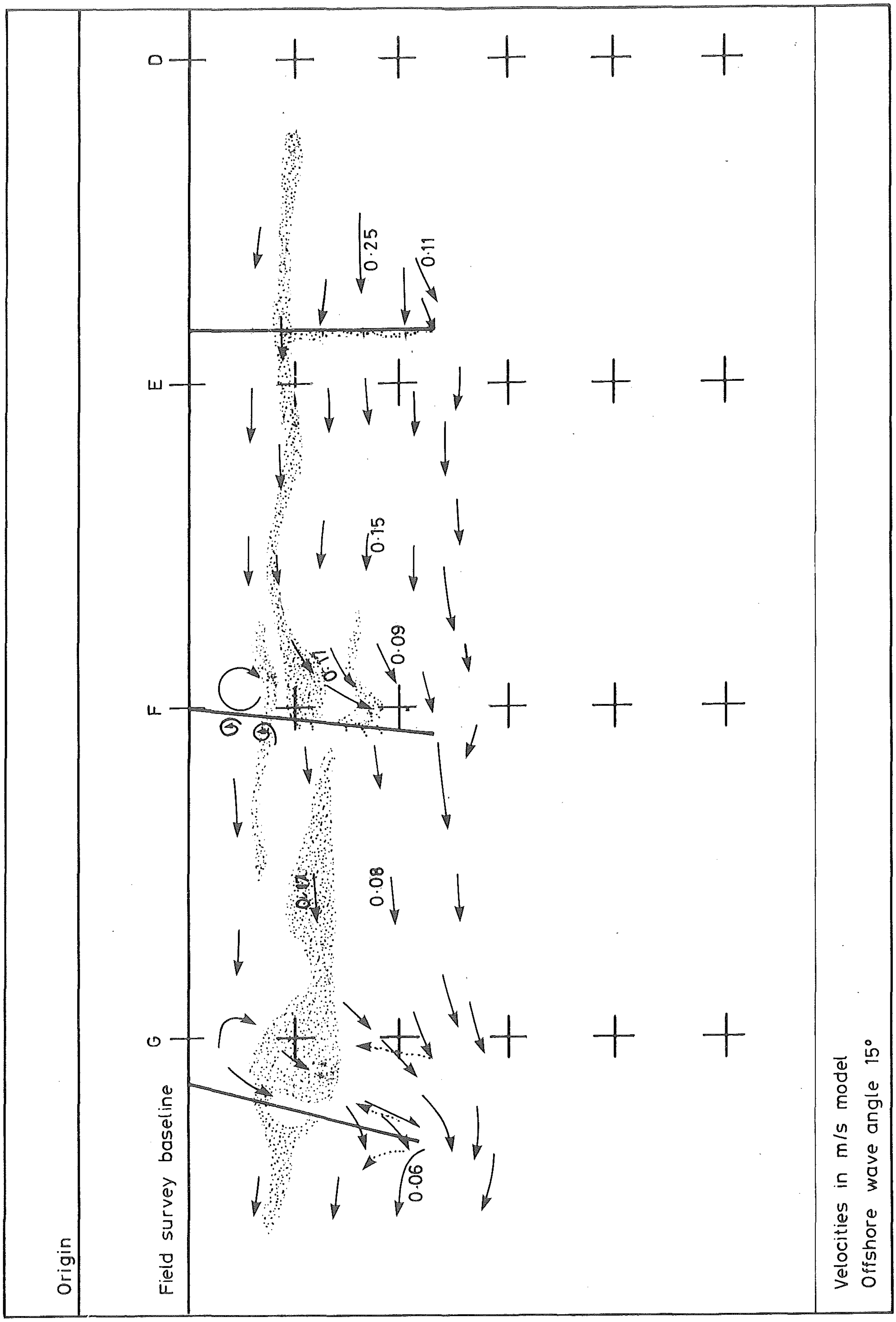


Fig 3·9 Test 33 – groynes raised 0·5m

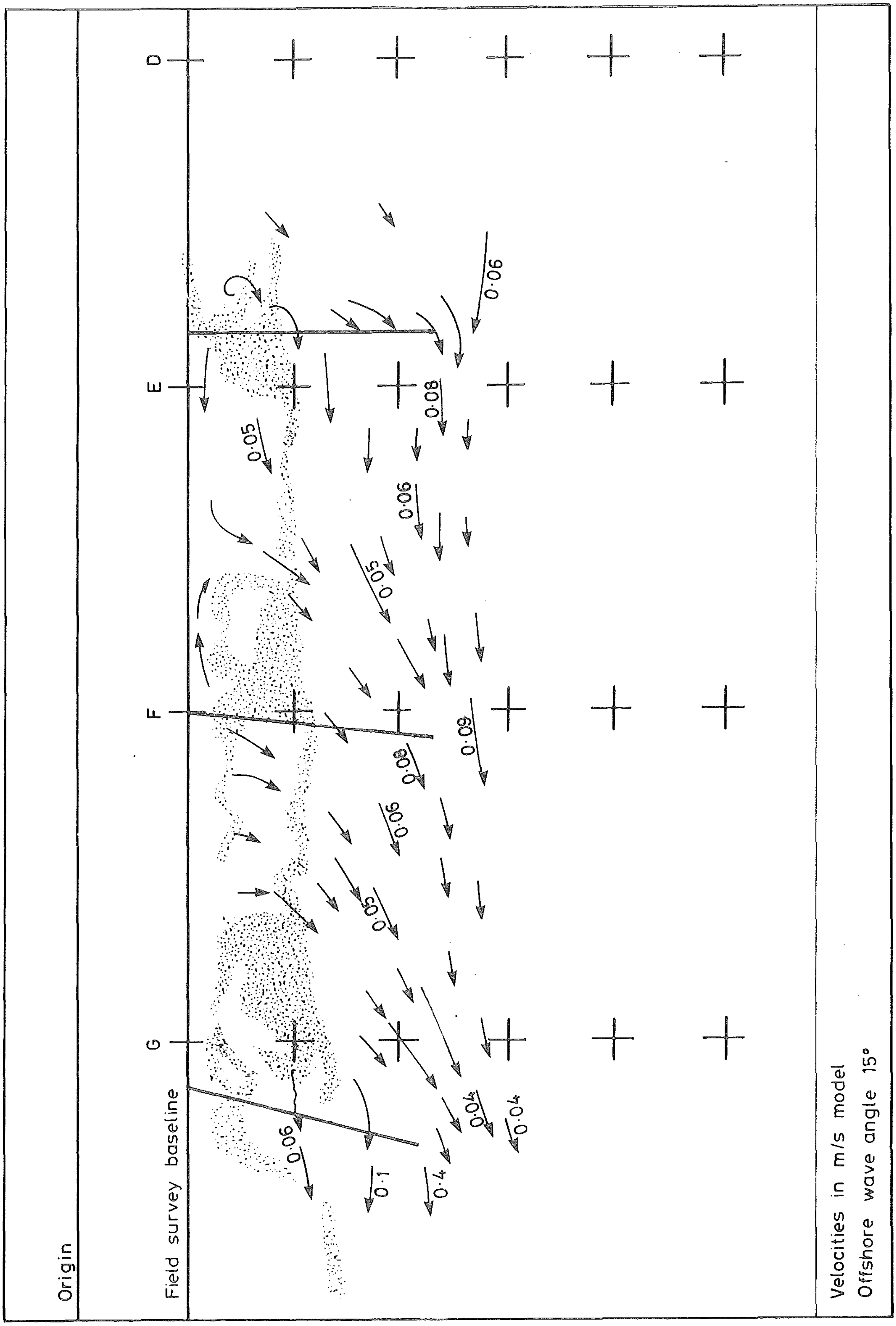


Fig 3·10 Test 34 - groynes raised 0·5m, beach roughened

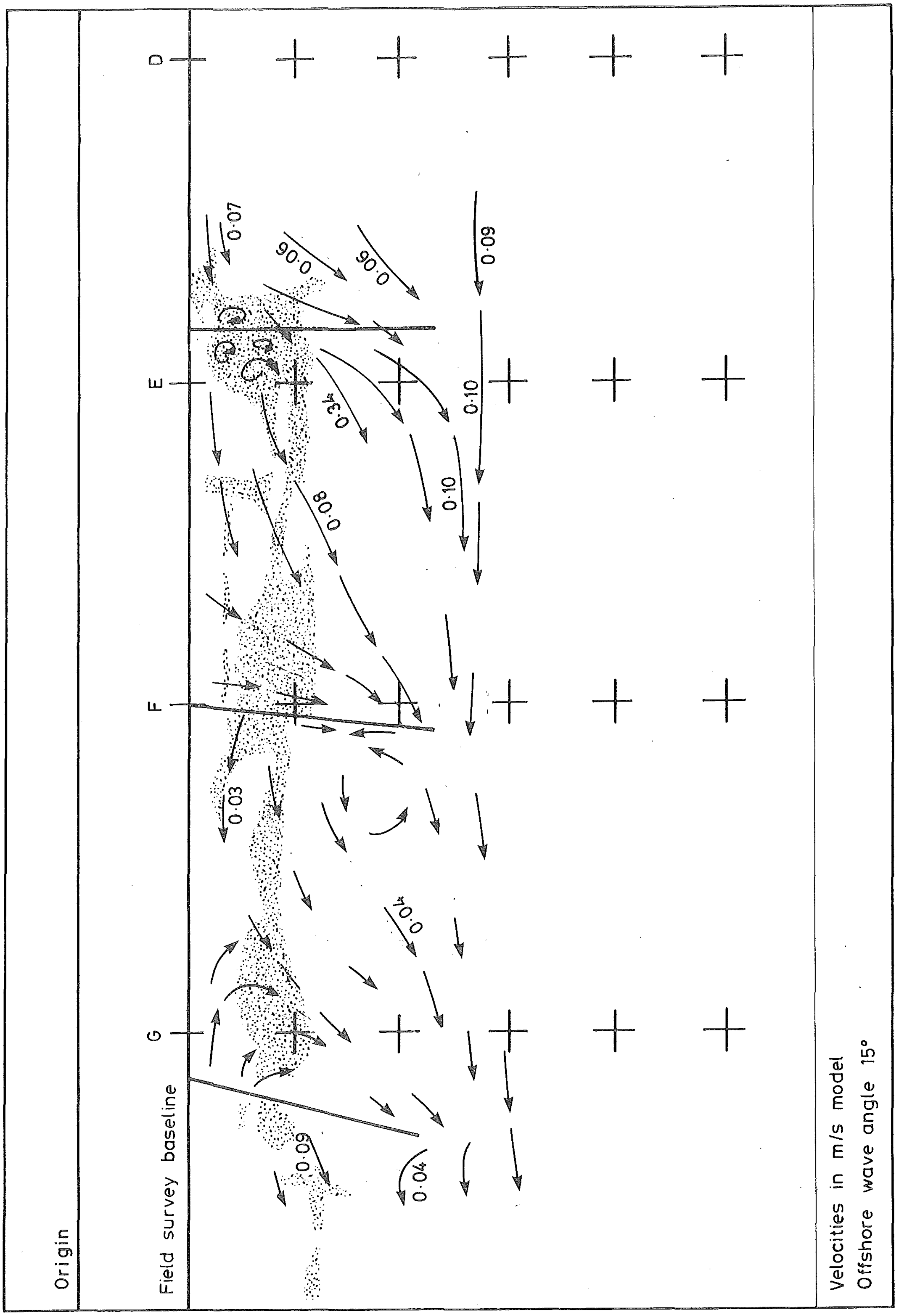


Fig 3·11 Test 35 – groynes raised 1·0m, beach roughened

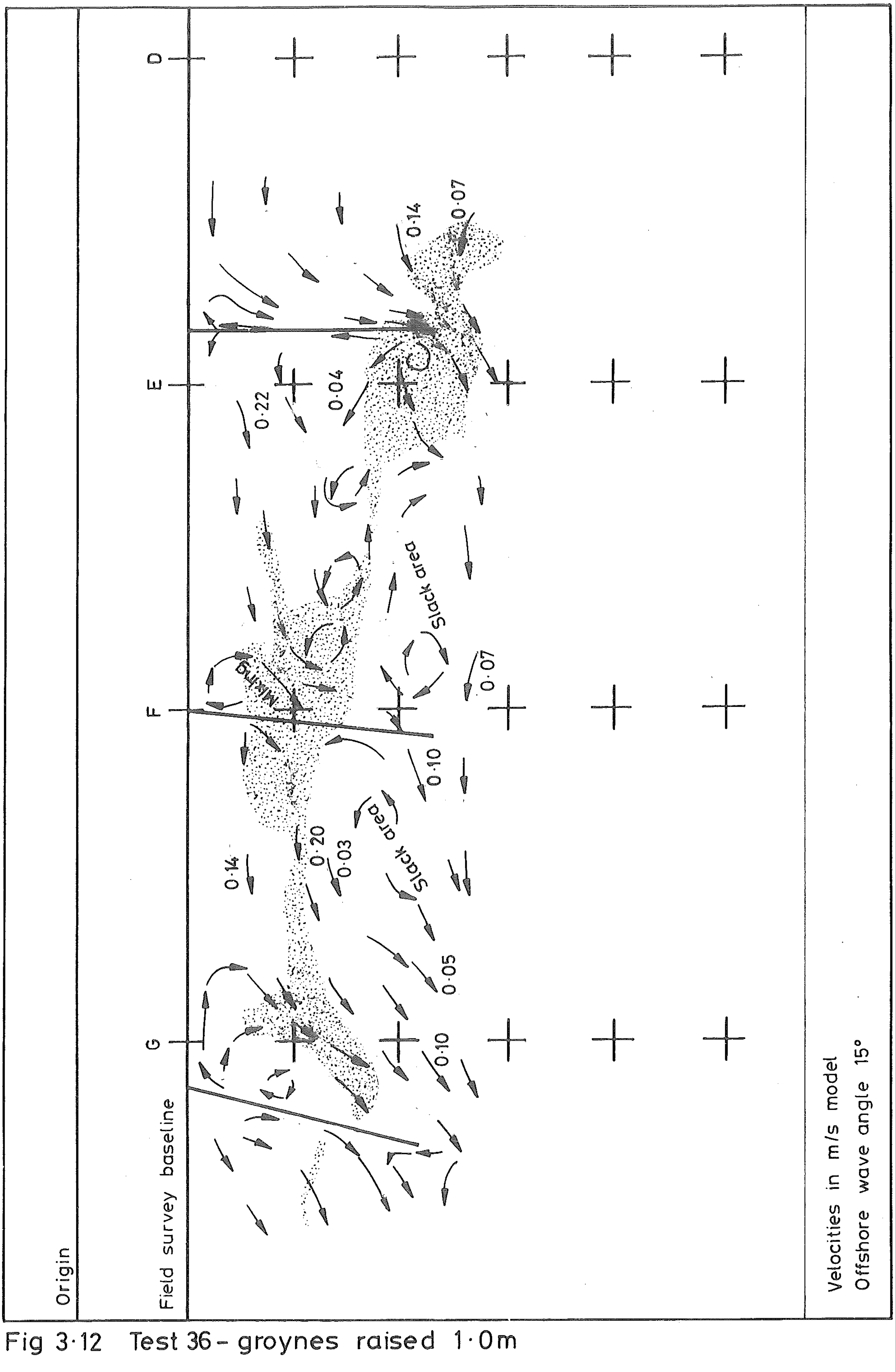


Fig 3·12 Test 36 - groynes raised 1·0m

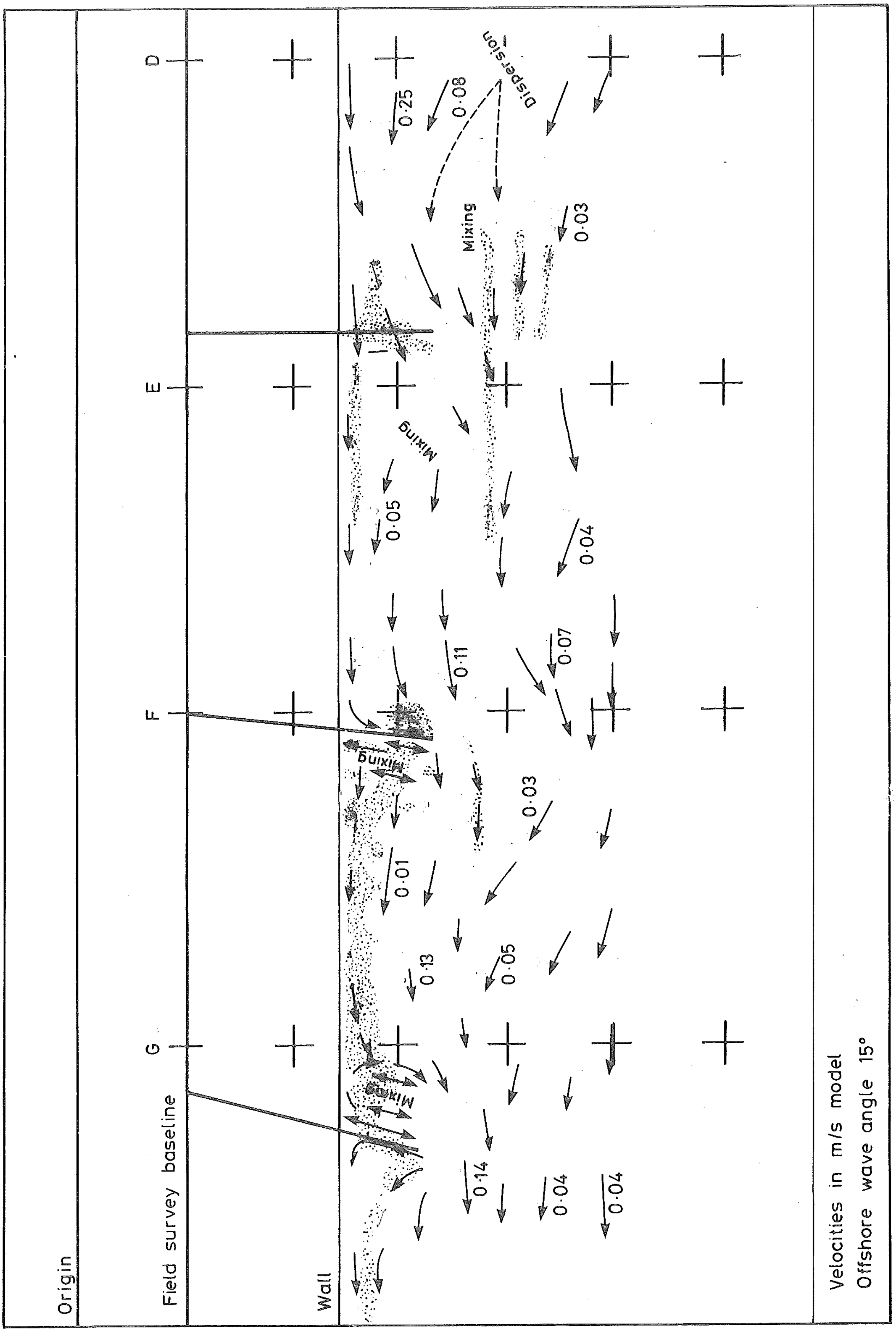


Fig 3·13 Test 37 – raised groynes plus vertical seawall

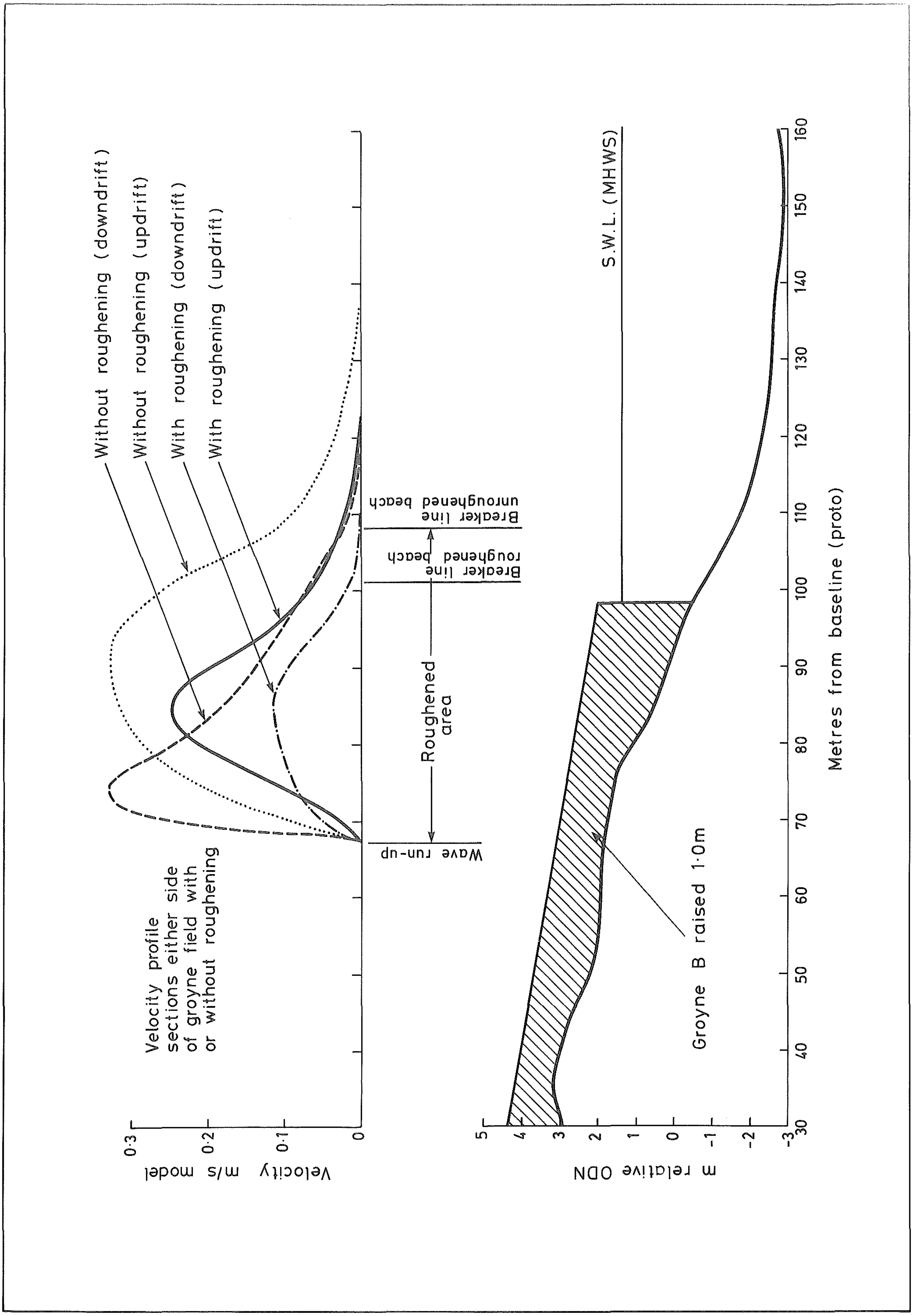


Fig 3·14 Velocity profiles - tests 35 and 36

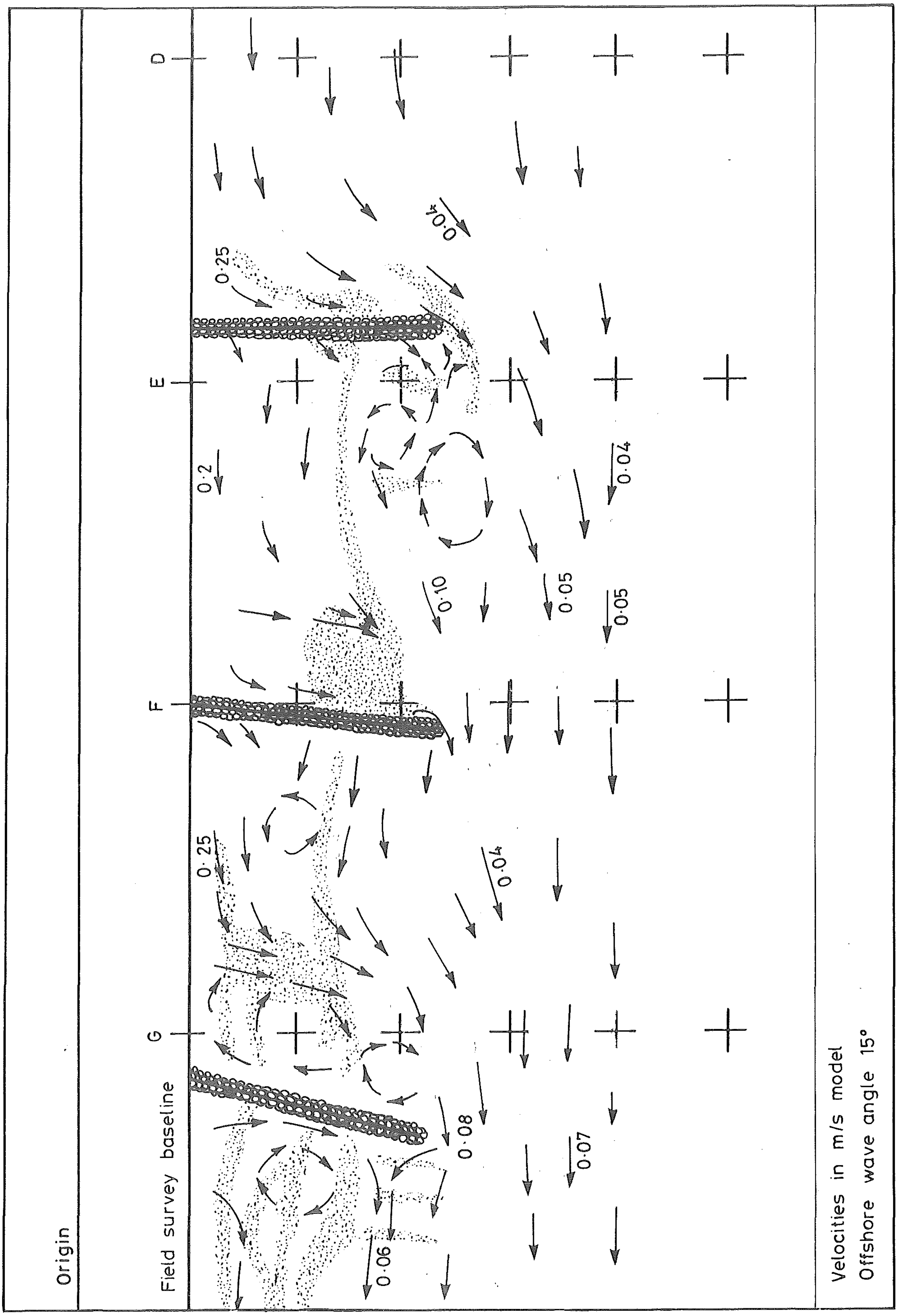


Fig 3·15 Test 38 – raised groynes, stone clad

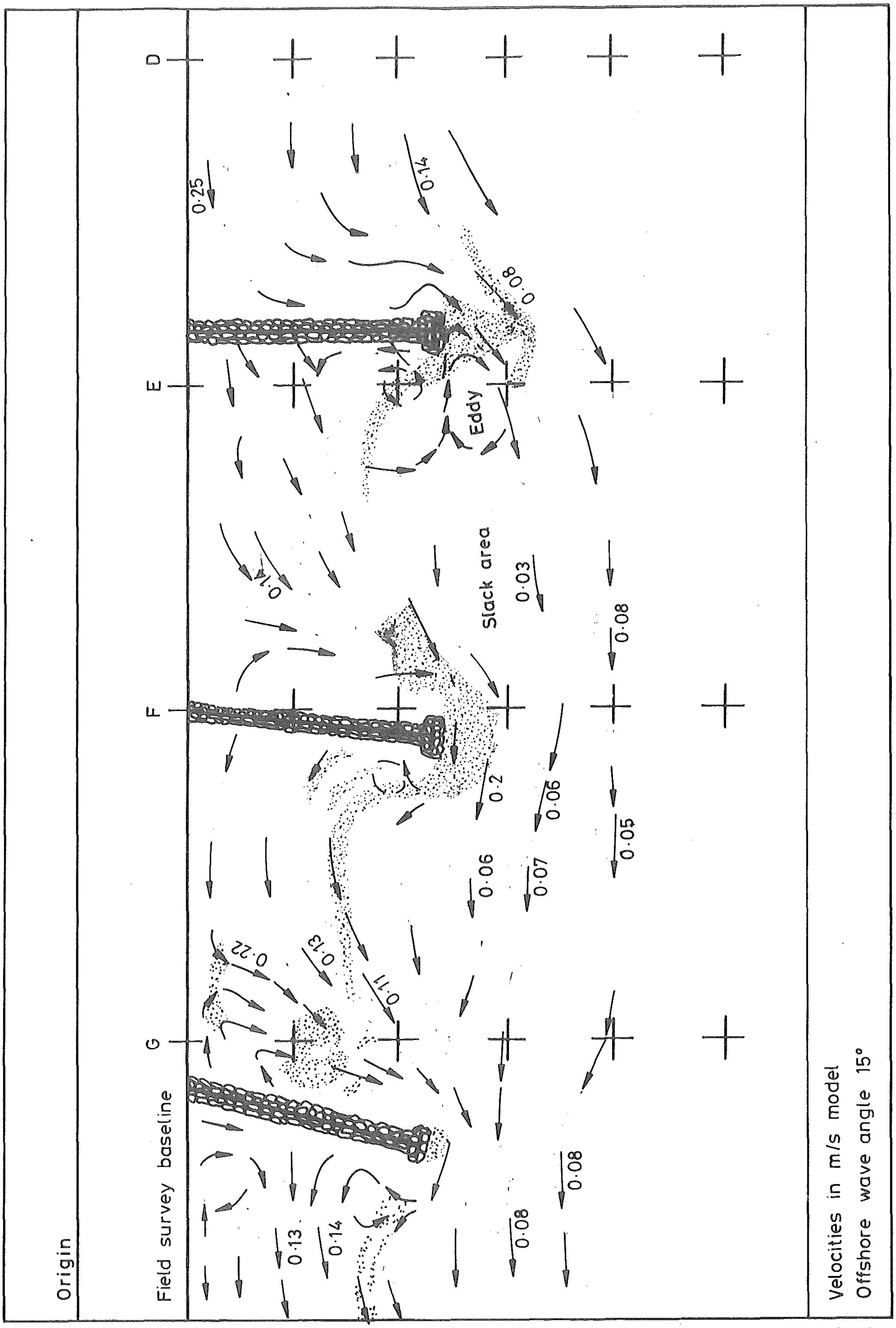


Fig 3·16 Test 39 – raised groynes, with added T-pieces, stone clad

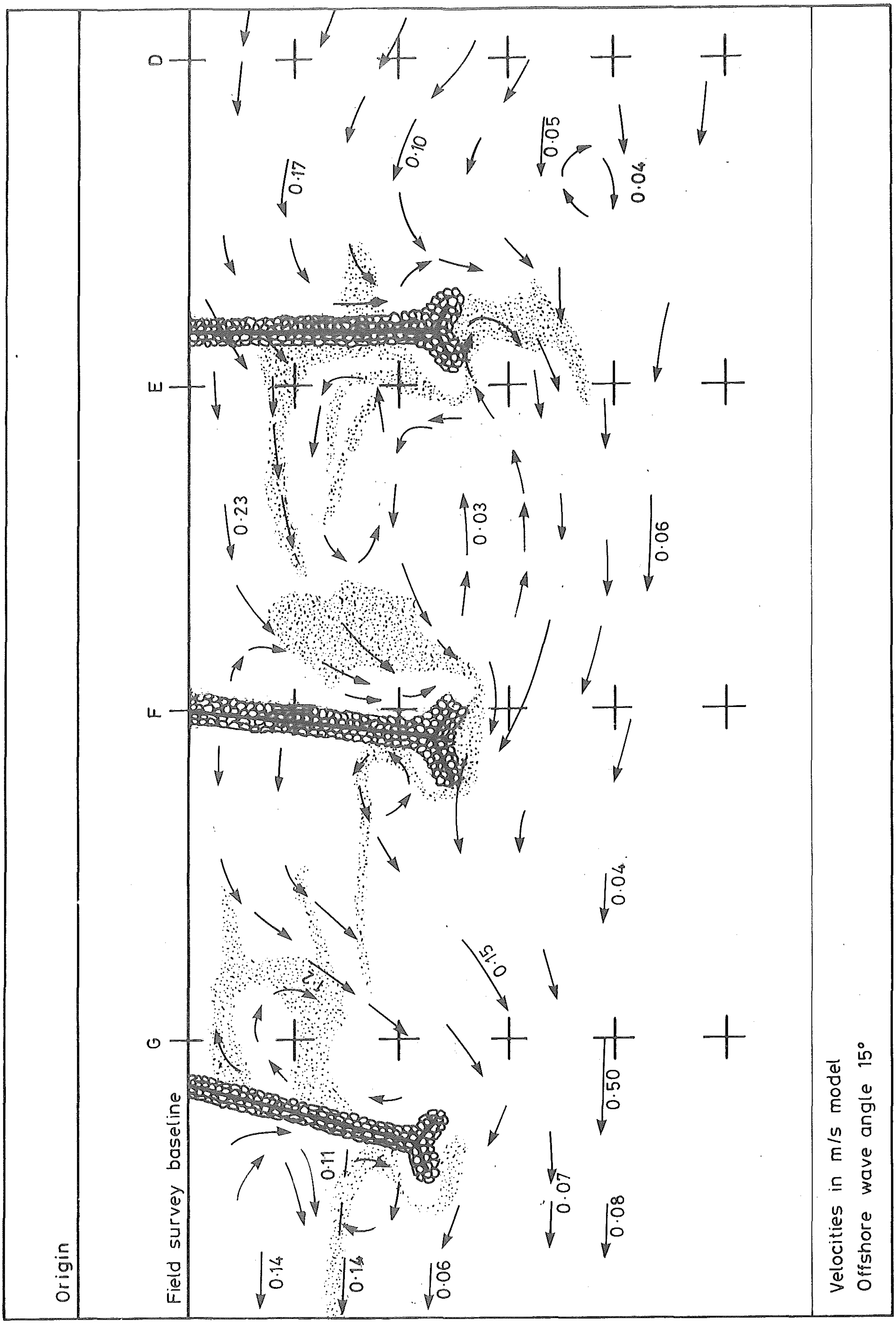


Fig 3·17 Test 40 – raised groynes with fish tails added, stone clad

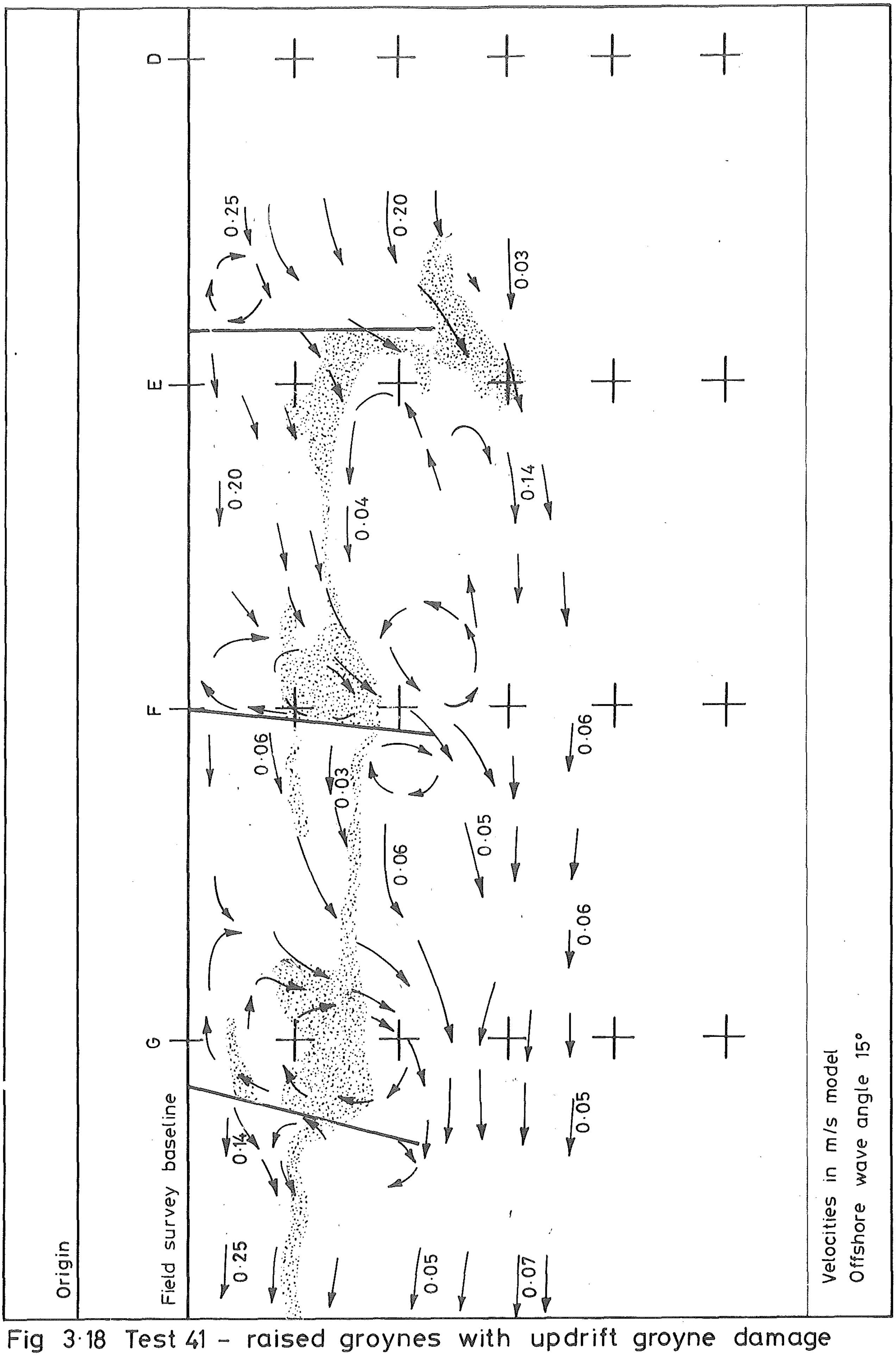


Fig 3·18 Test 41 - raised groynes with updrift groyne damage

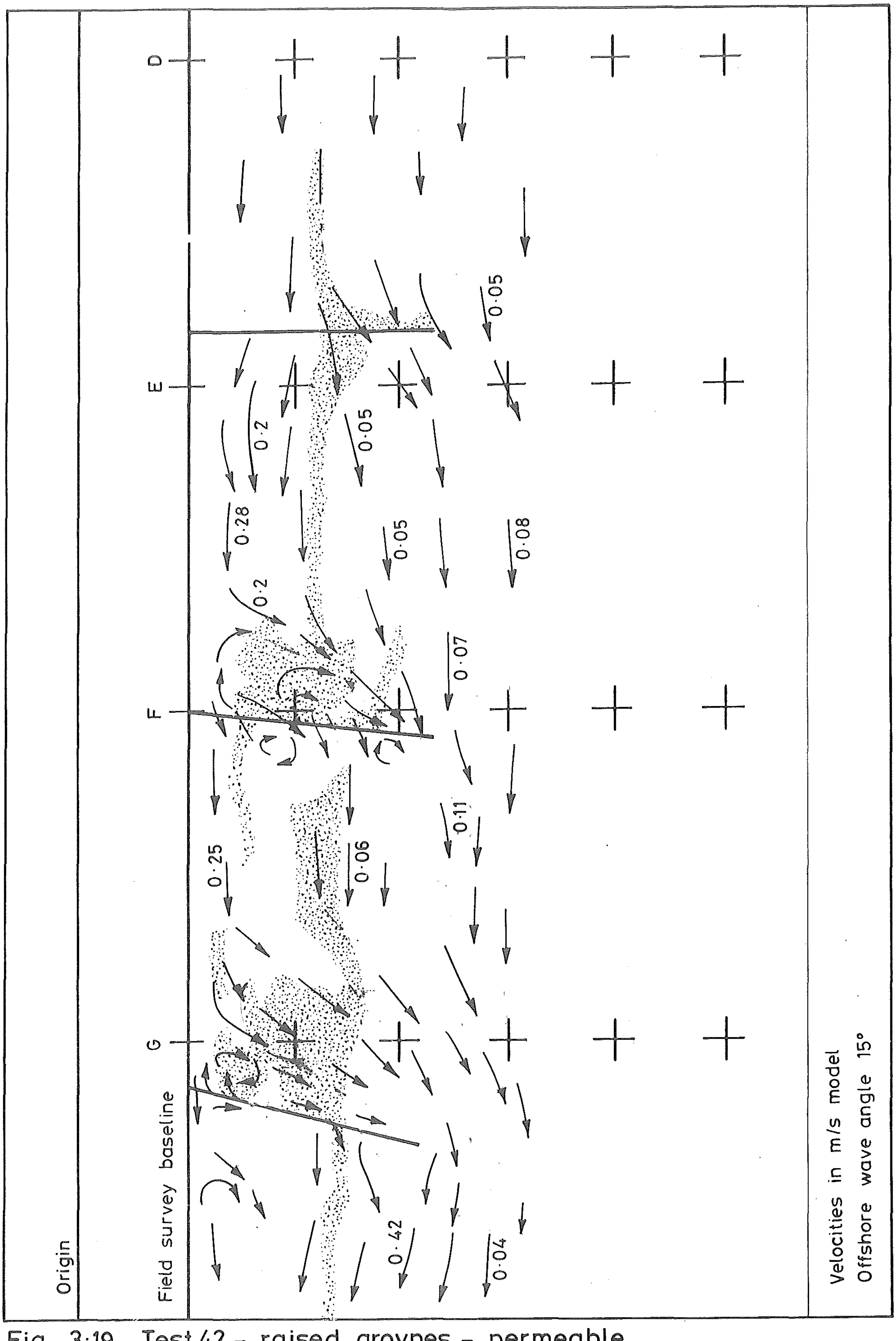


Fig 3·19 Test 42 – raised groynes – permeable

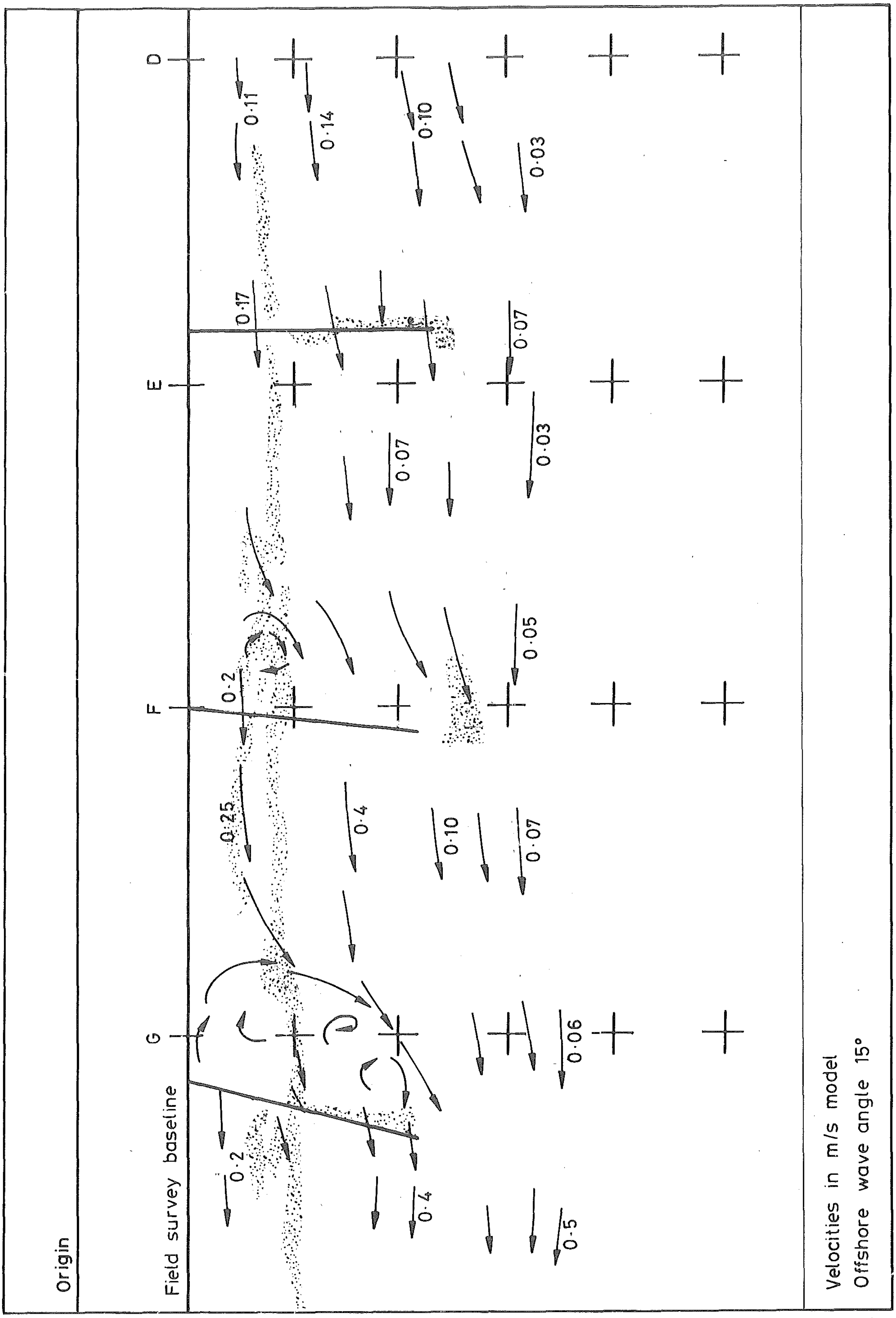
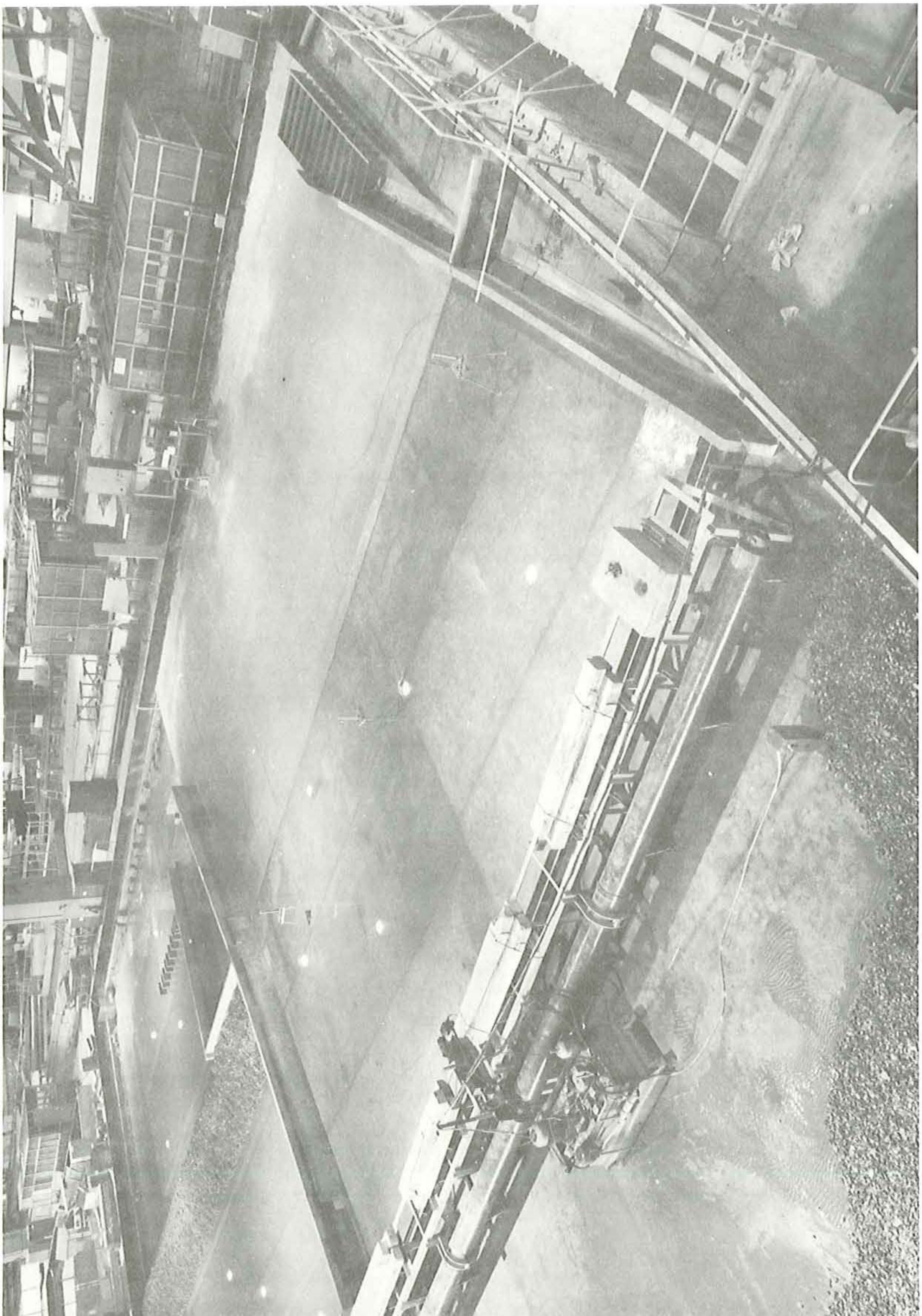
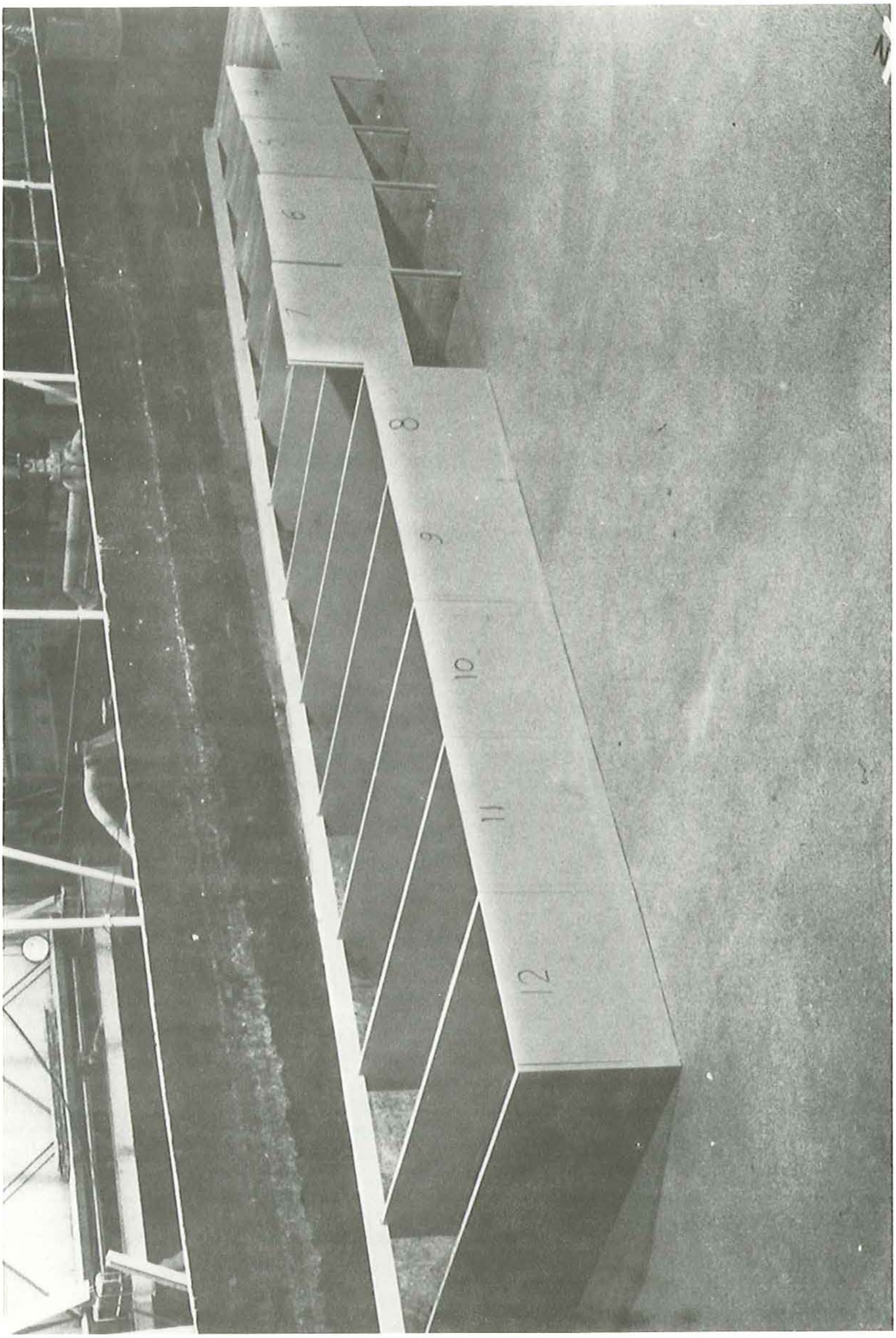


Fig 3·20 Test 43 – raised groynes – alongshore current overpumped

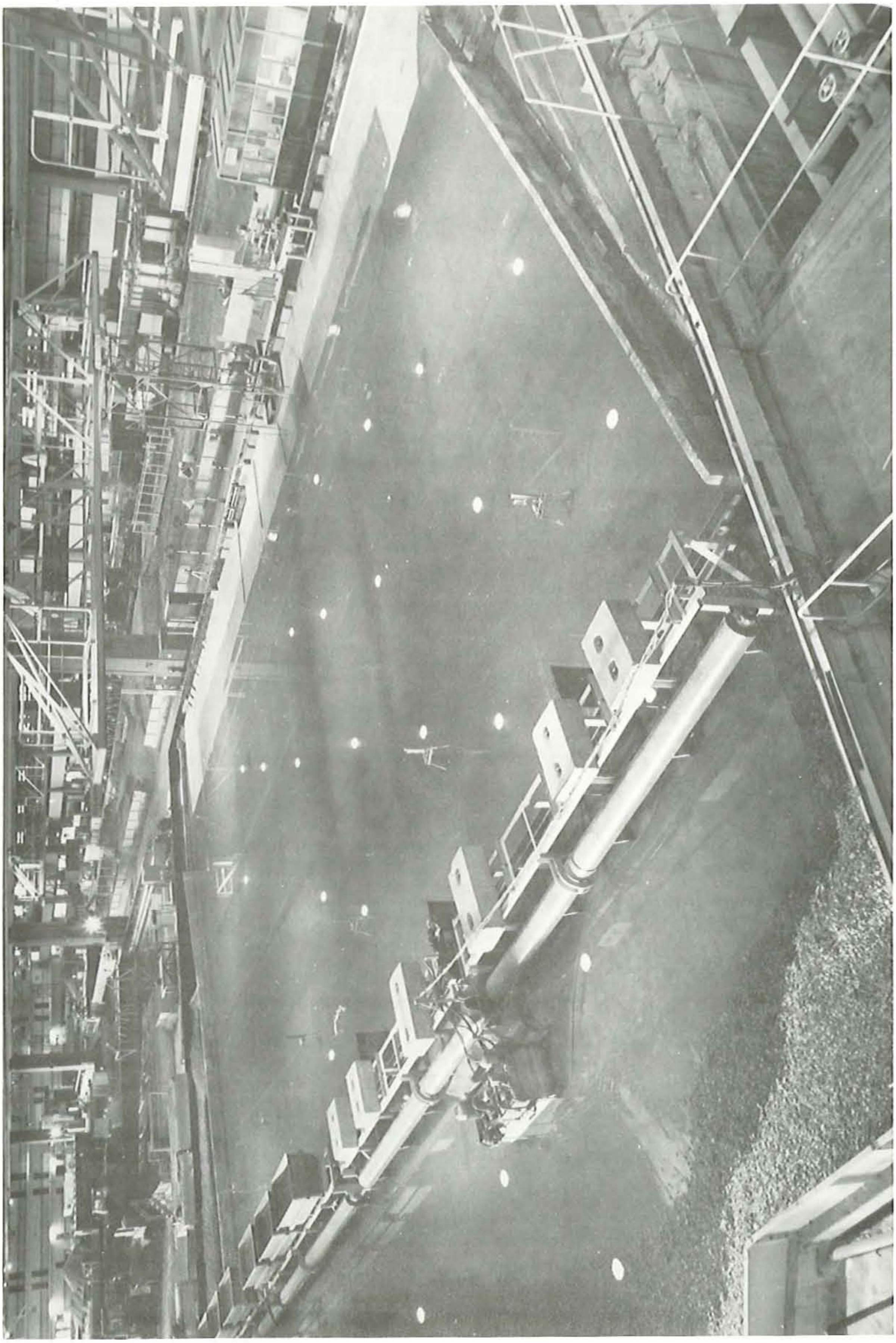
Plates



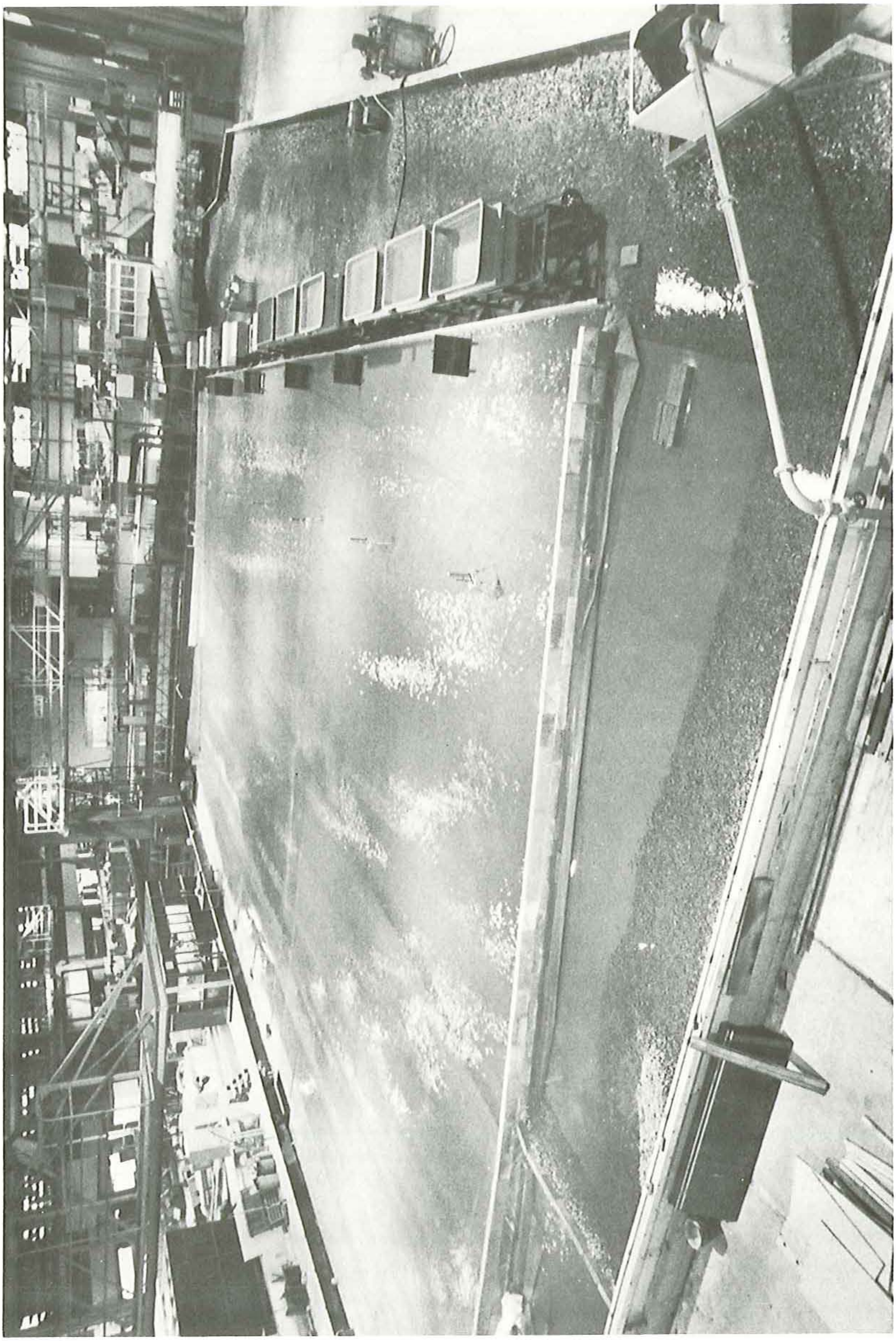
1-1 General view of model basin



1-2 Distribution system for alongshore currents

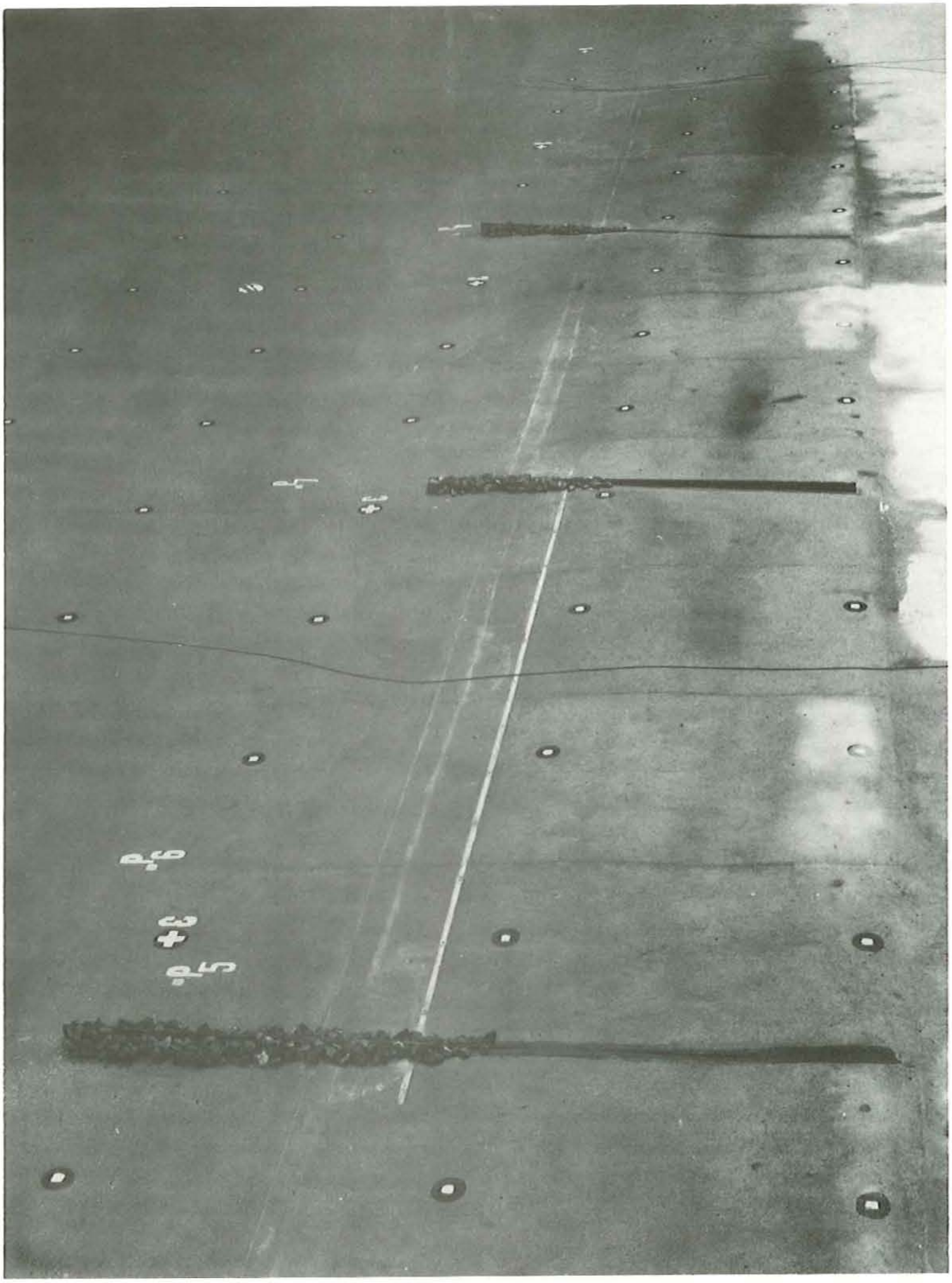


2-3 General view of model basin - wave generator at 10 degrees

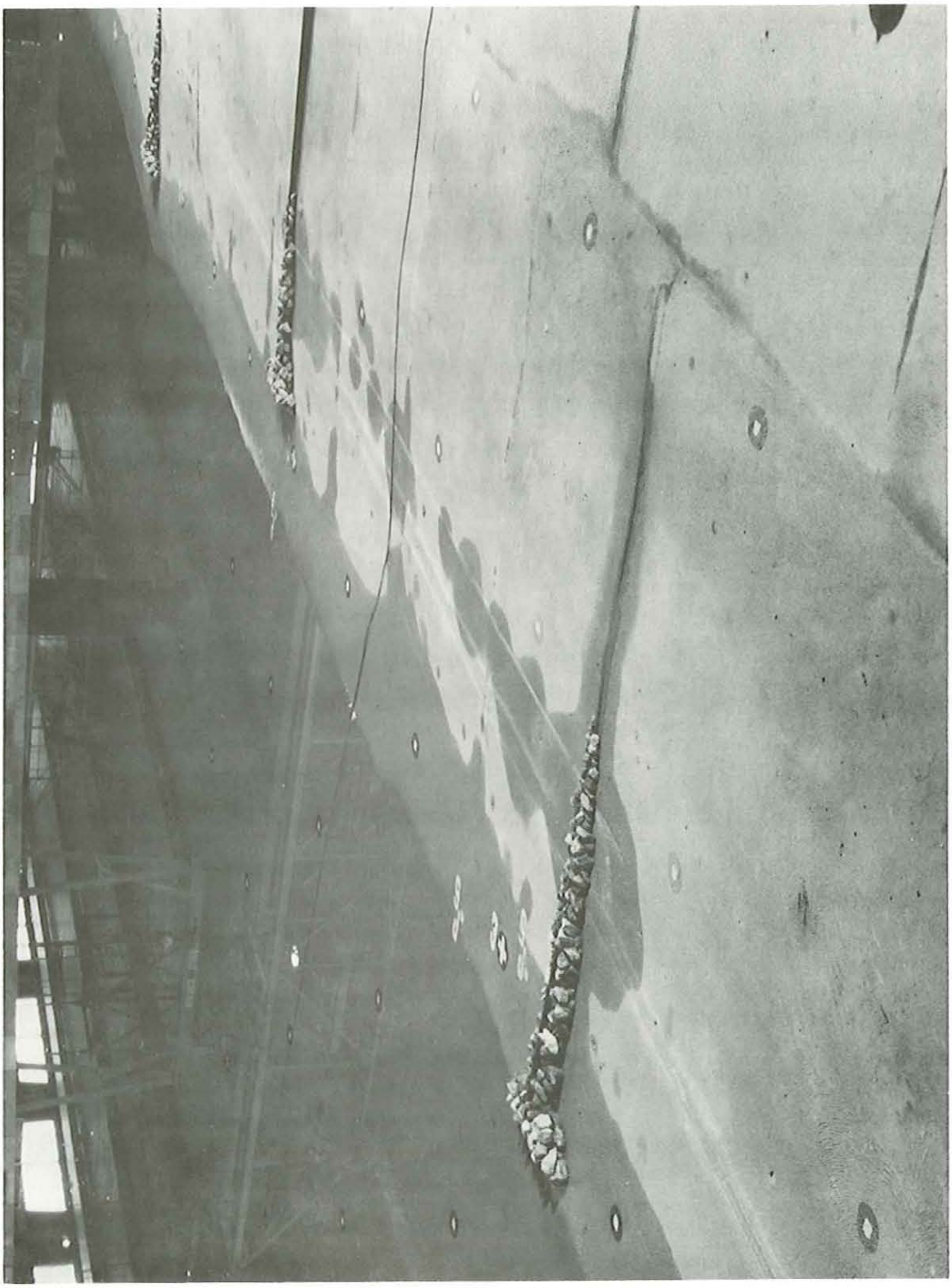


2-4 General view of model basin - wave generator at 26 degrees

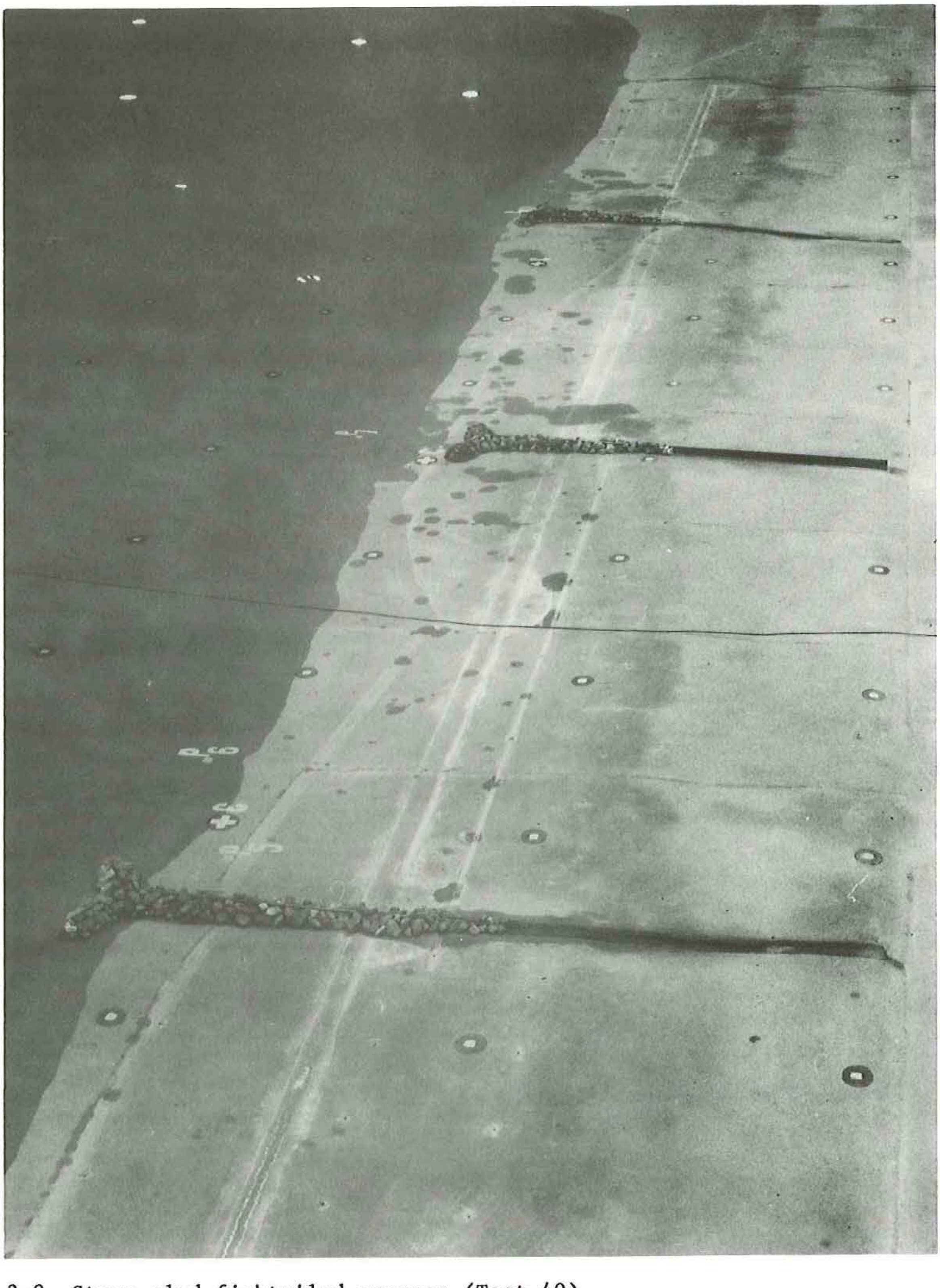
3-5 View of model beach showing roughening strips (Test 34)



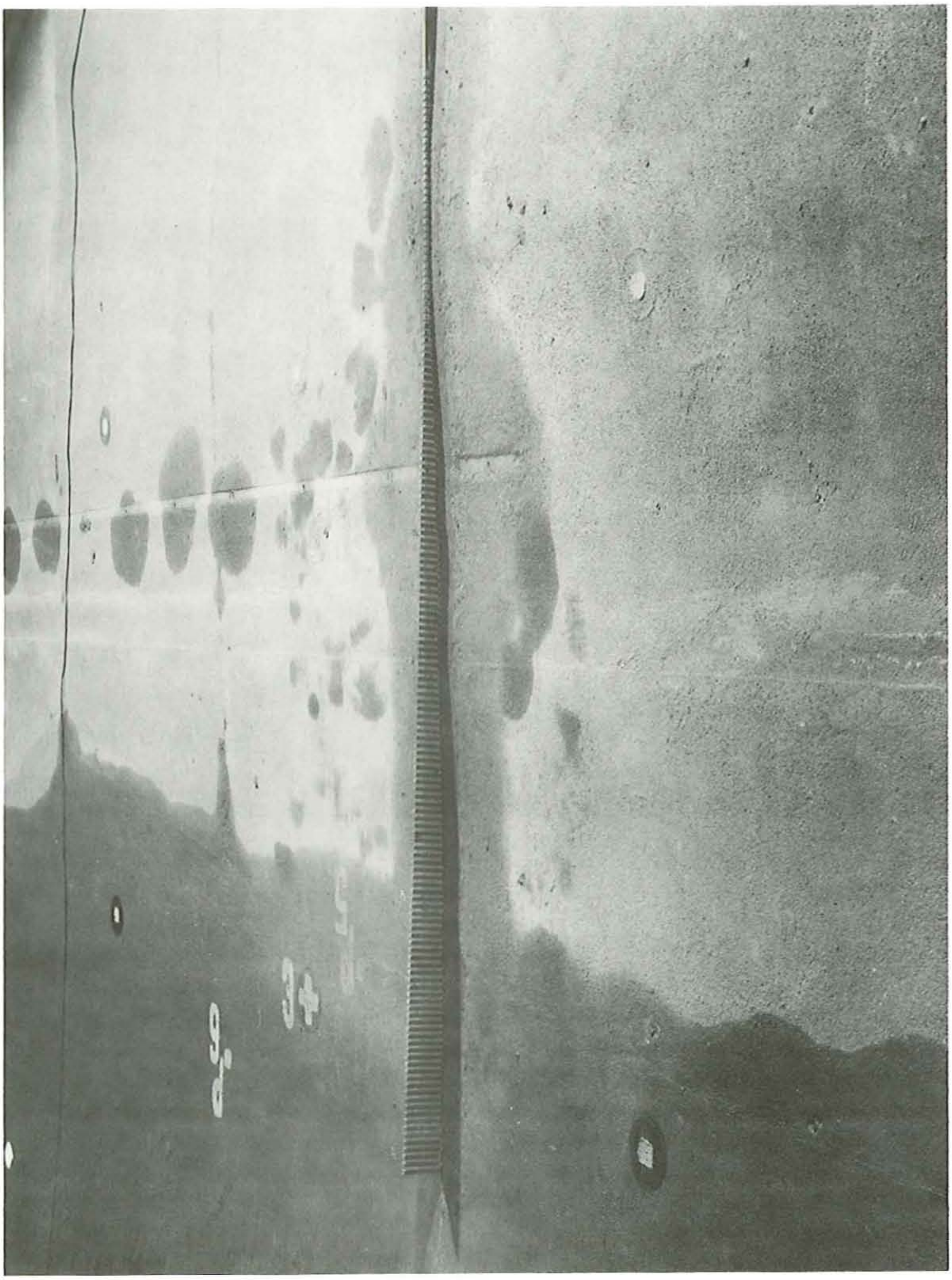
3-6 Stone clad groynes (Test 38)



3-7 Stone clad T-shaped groynes (Test 39)



3-8 Stone clad fishtailed groynes (Test 40)



3-9 Permeable groynes (Test 42)

Appendix

APPENDIX A

CIRIA Research Project 310: Effectiveness of Groyne Systems
Phase II

Proposal for a Physical Model Study of Groynes on a Beach

Stage 1: Establishing Experimental Methods and Preliminary Testing

Parts 1 and 2

Objectives

The objectives of the Stage 1 physical model study will be as follows:

(i) To measure the alongshore currents generated by random waves on a straight, parrallel contoured beach without groynes. The profile of the beach used will be moulded to a mean profile of a stable sand beach on the East Anglian coast .

(ii) To investigate the problems of 'end effects' on the physical model, and to use a pump to supply and recover a carefully regulated alongshore flow at each end of the beach to solve the problems.

(iii) To investigate the effect of the model surface roughness on both the alongshore currents and wave heights on the upper part of the beach. This will be of great value when comparing model and prototype beaches.

(iv) To study the effects of a single groyne on the distribution of wave energy and the alongshore currents. This is the easiest groyne 'system' to study, and should give useful information on the behaviour of the first 'updrift' groyne in a system. It should also be a valuable situation to compare with both prototype measurements and mathematical models.

(v) To study the current and wave distribution for a particular groyne system for comparison with prototype measurements being carried out on the East Anglian coast.