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Small Craft Harbours Branch

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WHEATLEY HARBOUR MODEL STUDY

by

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Table of Contents

Abstract

A physical model of Wheatley Harbour on the scale of 1:60 was built to study various means of reducing storm waves from the east at the entrance, and of reducing wave agitation inside the harbour. A number of offshore rubble mount breakwaters were tested, and all eliminated breaking waves due to storms at the entrance, the greatest concern of the fishermen using the harbour. The best configuration reduced the storm waves by about 50% in height and should provide ample protection. Wave agitation inside the harbour was simply and effectively reduced by placing rubble along one wall of the entrance channel.

To compliment the physical model, the littoral drift in the Wheatley area was predicted by considering the wave climate hindcasted from the wind climate. Considerable sediment moves both ways along the shore, but the predominate direction is towards the southwest. An offshore breakwater for protection against east waves will cause some deposition of sediment in its lee, and there will likely be a continued need for dredging of the channel. However, the breakwater should not form a complete barrier to littoral drift, so there should be little danger of shore erosion due to its presence.

RESUME

Un modèl physique du port de Wheatley, établi à l'échelle de 1/60, a été construit pour étudier divers moyens de réduire les ondes de tempête provenant de l'est, à l'entrée, et de réduire l'agitation des ondes à l'intérieur du port. Un certain nombre de brise-lames formés de fragments de roche empilés ont été mis à l'essai au large des côtes et ont éliminé complêtement le déferlement des vagues dû aux tempêtes à l'entrée, principale préoccupation des pêcheurs utilisant le port. La meilleure configuration a réduit la hauteur des ondes de tempête d'environ 50% et devrait fournir une protection suffisante. L'agitation des ondes à l'intérieur du port a été réduite de façon simple et efficace en plaçant des fragments de roche le long d'une paroi du chenal d'entrée.

Pour compléter le modèl physique, on a effectué des prévisions de l'apport vers le littoral dans la région de Wheatley en tenant compte du climat des ondes établi à partir de prévisions *a posteriori* du climat des vents. Une quantité considérable de sédiments se déplacent dans les deux sens le long du rivage, mais surtout vers le sud-ouest. Un brise-lames placé au large pour protéger des ondes venant de l'est causera un certain dépôt de sédiments du côté sous le vent, et il est probable qu'il faudra constamment draguer le chenal. Cependant, le brise-lames ne doit pas fermer complètement le chenal à l'apport vers le littoral pour réduire le danger d'érosion du rivage attribuable à sa présence.

1. Introduction

Wheatley harbour is one of the most important fishing harbours on Lake Erie. Because of its economic importance, a number of capital works have been undertaken in recent years to improve it. Most recent of these, currently underway, is an expansion of the inner harbour to accommodate the increasing fishing fleet.

The entrance to the harbour is hazardous during storm conditions, so consideration has been given to improve the entrance. The Small Craft Harbours Branch, Fisheries and Marine Directorate requested the Hydraulics Research Division to carry out a model study of the harbour. In response to this request Dick and Lau (1976) prepared a note which outlined the approach that the Hydraulics Research Division would take to respond to the request.

Subsequently, a study team was set up which included personnel from Small Craft Harbours, Department of Public Works and the Hydraulics Research Division. Draft terms of reference were set down and are reproduced here:

a) To define the problems to be solved, to define acceptable criteria and to review various engineering solutions.

b) To recommend to Small Craft Harbours the more acceptable solutions for improving the sea state conditions in the Wheatley Harbour entrance during storms.

c) To recommend if further studies will be required and the nature of those studies.

d) To consider the littoral drift and shore regime for the Wheatley Harbour area and to make recommendations as to the more likely actions to alleviate silting conditions.

e) To make recommendations as to the additional further research work or studies which might be required to reduce silting of the entrance by littoral drift.

f) To report progress regularly to Mr. M. H. Moffatt, SCH, and to Dr. T. M. Dick, HRD, CCIW.

The study team met with representatives of the fishermen at Wheatley to obtain first hand information of the navigation problems at the harbour entrance.

The Hydraulics Research Division was responsible for construction and testing of a physical model. Close collaboration with the Department of Public Works was maintained. Wave data for the model tests were provided by DPW, and their representatives participated in the tests of various remedial works examined in the model. The Hydraulics Research Division also undertook a study of the sediment processes in the Wheatley area.

The complete work of the study team will be described in another report. The purpose of this report is to summarize the work performed in the Hydraulics Research Division. To this end, the physical model is described in section 2. In sections 3 and 4, the tests for south and east waves are summarized. The results of a numerical longshore sediment study are summarized and discussed in section 5.

2. Model Construction and Instrumentation

After some preliminary studies, Dick and Lau (1976) determined that a model scale of 1:60 would be the most appropriate for this study. This scale would allow operation of an undistorted model, with minimum depth in the model being about 5 cm with respect to chart datum. The model was designed as a mirror image of the prototype, along the long axis of the harbour, so that it would fit in the hammerhead beach area of the wind-wave flume for the required wave approach angles.

It is not practical to operate the flume with only a few centimetres of water in it. (Waves must propogate about 85 m down the flume before reaching the model). It was therefore necessary to raise the model off the floor so that the waves travelling down the flume would be in relatively deep water. Preliminary tests with 30 cm of water in the flume showed that suitable waves could be propagated to the test area, so a base framework to raise the model about 30 cm off the floor of the flume was chosen.

The base was constructed with 2" x 10" x 12' kiln dried spruce, treated with two coats of spar varnish to minimize water absorption. It was anchored to the floor every 4 ft (1.22 m) using 3/8" lead concrete anchors. (See figure 1 for details.) The base was shimmed and planed to level its top surface to within $\pm$ 1/32" ($\pm$ 0.79 mm) using a Wilde automatic level.

The fixed bed model was then constructed on this base, and was made of wood so that it could be floated and rotated as a unit to change the angle of approach of the waves. All pieces of the model were treated with three coats of spar varnish before assembling.

A 3/4" plywood platform was placed on the frame base and was taken to be the 3.2 m prototype depth (referenced to chart datum). The harbour and adjacent depth contours were sketched out on this platform. The harbour walls were then placed on the platform to within an estimated error of $\pm$ 2 mm. The bathymetry of the model was made by laying sheets of plywood, one on top of the other and cut along the contour lines as shown in figures 2 and 3. Within the harbour itself, two configurations were to be tested, the harbour as it existed according to hydrographic surveys of 1974 and 1975, and the final design, dredged condition. Two dredged depths were specified on the DPW drawing: 8 ft grade (9 ft subgrade) and 10 ft grade (11 ft subgrade). For model construction 8 ½ ft (2.6 m) and 10 ½ ft (3.2 m) were used. The plywood for the latter was installed first, and the 1974-75 bathymetry added on top, so it could be subsequently removed easily.

The contour intervals drawn from the hydrographic field sheets were 0.4 m and 0.2 m (prototype). The model was constructed so that the depth between two contours was level and at the depth of the deeper contour. The transition between levels was smoothed by filling with plasticine with a slope of approximately 1:10. The combined errors of sketching, cutting, and placing the plywood for the contours was estimated to be $\pm$ 5 mm of the locations established in figures 2 and 3.

The changes of 0.4 and 0.2 m in prototype depth were made with ¼" (6.35 mm) plywood sheets and 1/8" (3.18 mm) masonite sheets in the model. Use of these standard thicknesses resulted in a small error in the depths. The ¼" plywood corresponded to 0.381 m prototype versus the contour interval of 0.4 m, and the 1/8" masonite corresponded to 0.191 m prototype versus the contour interval of 0.1 m.

The reference depth for construction of the model (top of the platform) was 3.2 m (prototype). The largest depth difference from 3.2 m was on the shoal south-west of the end of the east pier. The shoal was at 1.4 m, so the difference was 1.8 m. The error due to use of the standard thicknesses was 0.086 m (prototype) or 0.143 cm in the model.

Contours were added lakeward of the 3.2 m contour, down to 4.4 m, which corresponded to the top of the base framework. A plane sloping beach of slope 1:20, consisting of plywood on an anchored framework, was added to provide a smooth gentle transition down to the flume floor.

The shoreline east of the east pier was not important in this study and was replaced by a plane sloping beach (1:27) made of plywood, which provided satisfactory wave absorption.

At locations in the harbour where it was not considered necesary to model the bathymetry, such as the mouth of Muddy creek and the shallow pond beside the Omstead works, rubberized animal hair was installed to prevent wave reflection.

When the model was rotated to study waves approaching the harbour obliquely, the rear section of the harbour was cut off at 391.5 m (prototype) north of the south end of the east pier and terminated with rubberized hair. The rear section was cut off to ease the installation of the model. The tests with south waves had shown that there was very little reflected wave energy propagating from the rear towards the entrance, so that the rubberized hair was installed to absorb the wave energy that would have travelled into the rear section.

Three views of the model are given in plates 1 to 3.

Random waves were used to test the model. The waves were generated with a piston type mechanical wave machine. The machine was programmed to generate waves with a JONSWAP spectrum (Hasselmann et al, 1973), with suitably scaled peak period and characteristic wave height. Some of the tests for south waves used waves generated by wind.

The probes used to measure the waves were of the single wire capacitance type. The wire was 24 gauge stranded copper with Teflon insulation. The outside diameter was 0.045" (1.14 mm). The bottom end of the wire for each probe was insulated and rigidly fastened in a hole countersunk into the floor of the model. After installation, the hole was filled flush to the floor with plasticine. The locations of the probes are shown in figure 4.

Calibration of the probes was repeated frequently throughout the tests to ensure the integrity of the data. After suitable amplification and filtering, the signals from the wave probes were digitized and the digital time series stored in a mini computer. All data reduction was done using this computer.

3. Tests with Waves from the South

At the meeting with fishermen from Wheatley, it was learned that wave agitation at the north end of the harbour had increased since the dredging out of the north basin and the closure of the pond beside Omstead's plant. This agitation is observed for south winds.

Because of potential problems that this wave agitation could cause and the need to gain experience with the model, the first tests were done with waves out of the south.

W. Baird (DPW) analyzed wind records from Long Point and Windsor and determined that the deep water wave conditions that were suitable for the tests had a period of about 5 s and a characteristic height of about 1.8 metres. Refraction calculations showed that just off Wheatley, in about 4 metres of water, the waves are travelling N 17° W and are about 20% smaller in height. This direction is such that the waves are travelling almost straight into the harbour.

The model was therefore aligned with the axis of the wind-wave flume so that at the control wave gauge the waves would be travelling straight at the harbour. The desired characteristic wave height was about 1.5 m.

Several wave types were generated: two using machine generated random waves with peak period of 5 s and two amplitude settings; three using wind only: 50% fan speed which gave $T \simeq 5$ s; 40% fan speed ($T \simeq 4.5$ s); and 35% fan speed ($T \simeq 4$ s). (The peak period, T, is the reciprocal of the frequency corresponding to the maximum of the wave energy density function.)

The different wave types gave, in general, fairly consistant results. Typically, the wind generated waves at 50% fan speed had the correct peak period but contained somewhat more energy than desired. The 40% wind speed gave about the right amount of energy, but with a peak period of about 4½ s. The 35% wind speed generated waves slightly too small, with a peak period of about 4 s. The machine generated random waves were programmed to give exactly 5 s peak period waves and only differed slightly in energy, for the two amplitude settings (12 and 14).

The harbour was then tested under five conditions:

1. The old harbour with mean water level (MWL)=chart datum-0.5 m.
2. The old harbour with MWL=chart datum + 1.0 m (a level somewhat more than the long term average level in the summer and less than recent summer levels).
3. The harbour as of autumn 1976 (north basin dredged and pond at Omstead's closed off) with MWL=chart datum-0.5 m.
4. The harbour as of autumn 1976 with MWL=chart datum + 1.0 m.
5. The design harbour with MWL=chart datum + 1.0 m.

The results of the two tests run at chart datum -0.5 m showed that the waves were severely attenuated inside the harbour, such that the characteristic wave height, H_c, at the north end was of the order of 0.1 mm in the model or 1.0 cm in the prototype. Waves of this size are too small to be measured with any accuracy so that tests with this water depth were not pursued. For completeness these results are included as figures 5 and 6.

Tests run at the representative high water (chart datum + 1.0 m) resulted in waves which were everywhere measurable. The most striking feature of the results is the attenuation in wave height northward in the harbour.

The results for all wave generating modes are summarized for the old harbour and the autumn 1976 configuration, with high water, in figures 7 and 8. Of interest is the increase in wave agitation at the north end of the harbour in figure 8. Waves at gauges 7 and 8 are always less than 0.4 m in the old harbour and above 0.3 m (mostly above 0.4 m) for the autumn 1976 configuration. This result is in qualitative agreement with the fishermen's observations and adds confidence in the model.

The results for the design harbour are shown in figure 9. The wave agitation in the new harbour is much the same as in the old harbour at the south end, but is more vigorous at the north end.

Based on the data summarized in figures 5 to 9, it was decided to use the random waves generated by the wave machine, with T= 5 s and the output of the wave synthesizer set at the value of 12 for all subsequent tests for south waves.

These tests were carried out on variations to the designed harbour, in search for a variation that would reduce the wave agitation inside the harbour. Six variations were examined. Five were various configurations of offshore breakwaters, and the sixth was the introduction of rubble along the west wall of the harbour in place of sheet steel piling. The locations of the offshore breakwaters are shown in figure 10. The location of the rubble along the west wall is also shown in figure 10. All rubble for these tests was modelled with smooth pebbles, median diameter 10 mm.

The results for the six variations are plotted in figure 11. There is a small spread in the wave heights measured at wave gauge number 1s, so, to make the comparisons among the variations simpler, the wave heights have been normalized with respect to gauge number 1s(for each test) and plotted in figure 12.

Some of the variations result in wave heights very similar to the design harbour, notably the east number 2 and west number 2 breakwater combination. the east breakwater and the east and west breakwater combination provide the most shelter of all the breakwater combinations.

The most successful variation in terms of reducing the waves inside the harbour is the rubble along the west wall. The wave height at gauge number 5s(which is only about 20 m in from the start of the rubble) is slightly below that for all other tests, and at gauges 7s and 8s,the wave heights are markedly less than for all other tests. Qualitative observations of the waves in the south basin also indicated that the water there was less agitated.

The tests show quite clearly that rubble placed along the west wall is superior to all other variations tested. The method of protection, should it be necessary, would undoubtably be the least costly, because the rubble can be placed from land, in relatively shallow water. The only obvious disadvantage would be a possible hazard to navigation due to the slight reduction in the channel width.

4. Tests with Waves from the East

The major concern about the entrance to Wheatley harbour is the difficulty boat operators encounter entering the harbour under storm conditions. This situation was discussed at length with fishermen from Wheatley. They reported that they have great difficulty entering the harbour when a severe storm develops out of the east or north-east. The waves are of such a height and period that many of them are breaking just offshore of the east pier. Under these conditions, a fishing boat can be grounded in a wave trough and then be hit abeam by the following breaking wave crest, resulting in partial or compete loss of control, damage and danger to human life. The breaking waves were reported to come in groups of two or three separated by several non-breaking waves, so that the fishermen's method of avoiding the problem is to linger offshore for a relative calm interval and then make a run for the harbour entrance, hoping to get in the lee of the pier wall before more breaking waves arrive. Any structure west of the east pier such as the breakwater proposed in the DPW Entrance Improvement Study (March, 1975) was considered undesirable by the fishermen. They want clear water there should extreme manoeuvres become necessary.

It was decided, by the study team, that the most suitable solution to the problem would be some kind of offshore breakwater which would reduce the wave heights offshore from the east pier to acceptable levels for navigation, but which would still allow some wave energy to pass which would be able to maintain some level of longshore sediment transport to continue. That is, the breakwater would not be such as to be a complete littoral barrier, which would only result in the formation of an undesirable shoal.

Examination of hindcasted wave data (prepared by DPW) showed that the important storm waves from the east and north-east had periods of 5, 6 and 7 seconds with deep water heights of 6, 9 and 12 feet respectively. The shoreline east of Wheatley is oriented approximately N67^{o}E, so it was not considered realistic to have deep water waves approaching from a more northerly direction than this. Refraction calculations were run for the three wave periods and the two wave directions: from the E and from N67^{o}E. The refraction results were determined for water depth of 4.0 m. The directional spread for all conditions was from N85^{o}E to S76^{o}E. . Time restraints only allowed for testing one angle so that waves coming S80^{o}E at the 4 m contour were chosen to be representative. Thus the axis of the model was aligned at 170^{o} to the flume axis. The north section of the harbour was cut off at 391.5 m north of the south end of the east pier. The refraction calculations showed that the 5 s waves were decreased in height by about 8%, 6 s waves about 2%, and 7 s waves increased by about 3%.

The wave machine was run in the random mode with peak periods corresponding to 5, 6 and 7 s in the prototype. The wave heights were adjusted according to the results described above and the wave conditions monitored at the harbour entrance. It was soon evident that these wave conditions represented an over design situation. Almost every wave broke as it approached the area of interest offshore from the east pier of the harbour. Furthermore, the results were not significantly different for the three peak periods. Based on these considerations, the spectrum with peak period of 6 s was selected, and the wave height was adjusted to give a value of about 2.2 m at the most offshore probe. With these input conditions, the waves were breaking in the vicinity of the harbour entrance in the manner described by the fishermen, and the wave characteristics were realistic as determined by hindcasting and refraction calculations.

With the input wave conditions established, preliminary tests were carried out on a number of breakwater configurations. The breakwaters were composed of crushed limestone, and no attempt was made to simulate impermeable cores in the breakwaters. The results of the preliminary tests were used to determine locations and shapes of the breakwaters to be tested in more detail. All configurations subsequently tested had impermeable cores, simulated with a section of plywood. All rubble material was modelled with "3/4 in. clear" crushed limestone, which had a median grain size of about 18 mm (model). For ease of installation, all the breakwaters were located with respect to the lakeward end of the east pier, as shown in figures 13 and 14, which summarize the locations and configurations of all breakwaters tested. All the breakwaters were tested with the channel dredged out to a depth of 3.2 m below chart datum. Some of the breakwaters were also tested with the dredged channel, offshore from the east pier, filled with sand to simulate the undredged condition. The mean water level used was chart datum plus 1.5 m, which allowed for high water plus a set up due to storm winds.

To reduce the large volume of data collected to a manageable amount, only the characteristic wave heights, as measured at each probe, are presented in this report. These heights are presented in table 1. (Refer to figure 4 for the locations of the probes.) The tests were conducted over three days and a control run was done each day with no breakwater. Probe 1e was the offshore probe used for control and for all tests the wave height were within 5% of 2.2 m. Probes 3e, 4e and 5e (especially 5e) were also control probes in the sense they were used to determine whether or not the wave activity inside the harbour was greater or less than that observed for waves from the south. The characteristic wave height at probe 5e never exceeded 0.6 m even with no breakwater and was typically 0.4 m. This result indicated that the wave activity inside the harbour would not be greater than that due to south waves.

Probes 6e and 7e were situated so as to measure the wave activity in the channel offshore from the east pier, and of the shoal area east of the channel. Probe 2e was at the end of the east pier. Probe 6e was used to measure the general effectiveness of the breakwaters in reducing the waves in the offshore channel area, the important location as far as navigation is concerned. Probe 2e was used primarily to show whether or not a given breakwater extended far enough shoreward to give protection right at the end of the east pier. Probe 7e was used to indicate the level of wave activity on the shoal behind the breakwater.

A result common for all breakwaters was the complete elimination of breaking waves in the vicinity of probes 6e, 7e and 2e. However, the relatively short breakwaters, located close to the entrance, configurations A, B, H and K, still admitted waves of considerable height in the channel (1.3 to 1.9 m at probe 6e). Furthermore, their proximity to the channel means that any build up of sand in their lee could extend into the normal navigation area, negating their usefulness.

Similarly, configurations D and G admitted relatively large waves in the channel (1.6 to 1.8 m of probe 6e). These two breakwaters, both with gaps in their centres, were tested because it was felt that they would be more successful in maintaining the movement of sand, rather than causing it to deposit as a shoal. This feature is countered somewhat by the marginal protection provided.

The configurations L and M provided quite good protection (H_c=1.2 m at probe 6e) and were reasonably well removed from the channel. They were, however, farthest offshore and in the deepest water so that their costs may well be the greatest.

Configuration C also provided reasonable protection (H_c=1.2m at probe 6e), but is probably too close to the channel and could cause too much deposition of sand in the channel area.

The two most promising configurations are E and F. The wave heights at probe 6e were in the range from 1.0 to 1.4 m. Configuration F provided margnally more protection at probe 6e, and due to its extra length would have a larger protected area in the channel. It probably is sufficiently far away from the normal navigation area so that deposition of sand would not be a problem to vessels entering the harbour.

The trade offs between providing sufficient protection for navigation and not completely blocking littoral drift are arbitrary and to a certain extent subjective. Complete elimination of waves is the ideal for navigation, but this would lead to a significant blockage of littoral drift, and the formation of shoals, which in turn cause navigation problems. Unfortunately, quantitative data on the sand movement, are beyond the capability of this study.
The results of this study do suggest that a breakwater like configuration

F would probably provide sufficient protection while allowing some wave energy to be maintained, in storm conditions, to prevent complete blockage of littoral drift. A discussion of the longshore sediment transport is given in the next section.

The final selection of the protection for the harbour entrance is to be reported on by the study team. Their report will take into consideration a larger range of factors than just the results of these model tests.

5. Longshore Sediment Transport at Wheatley

The shoreline in the vicinity of Wheatley Harbour is made up of unconsolidated material; primarily sand to the south-west and till bluff with a small sand beach to the north-east. This type of shoreline is susceptible to erosion and to sediment movement along its length, due to the action of waves. Any structure extending out into the lake will influence longshore movement of sediment and could cause problems of undesirable erosion or deposition. The present east pier is an example of such a structure. Any other structure placed in the lake will also influence, to a greater or lesser extent, the longshore movement of sediment. An example is an offshore breakwater near the harbour entrance. The importance of a structure's effect on sediment movement not only depends on the structure type and its location but on the amount and direction of the sediment that is moving in the littoral zone. In this section, the movement of sediment will be examined.

A numerical model was run to obtain an estimate of the amount of sediment movement. The model used was the same one used to study the longshore sediment transport at Point Pelee (Skafel, 1975). The offshore wave climate is required as input data to the model.

Using data from Richards and Phillips (1970), a table showing the yearly percentage frequency of occurrence of the various wind classes for ice free conditions was prepared (Table 2). Only winds from the east, south-east, and south will produce significant waves at Wheatley and so,for these directions, effective fetches and mean water depths were determined (Table 3), and then the waves hindcasted for the mid-point of each wind class, and listed in Table 4. (Winds from all other directions are blowing offshore or nearly so, so that the waves generated will be small).

These wave data were then used in the numerical model, the output of which was a distribution of longshore sediment transport rates along the shoreline in the vicinity of Wheatley. After the transport rates were corrected for frequency of occurrence for each wave type, the mean values for about 5 km of shoreline centred around Wheatley were calculated and are shown in Table 5. The values of longshore transport rates are potential values, assuming there is sufficient supply of sediment available.

Waves from the east transport sand towards the south-west, as indicated by the negative values in Table 5. The total value is larger, about 213 x 10^3 $m^3 yr^{-1}$. Waves from both the south and south-east move sediment to the north-east (positive values), and the combined volume is only about 73 x 10^3 m^3 yr^{-1}. The net movement indicated is about 140 x 10^3 m^3 yr^{-1} towards the south-west. Three times as much material moving south-west as north-east should show up at the Wheatley jetties as considerably more material deposited on the east side compared to the west.

Examination of the bathymetry as derived from the hydrographic field sheet (Canadian Hydrographic Service, field Sheet Number 3873, see also figure 2 on which some of the contours are reproduced) reveals that, while there is considerable deposition on the east side of the east pier at Wheatley, there is almost as much on the west side. This fact supports a hypothesis that the amount of material moved in each direction is more equal than determined above, with some more material moving to the south-west. The apparent contradiction between the bathymetric evidence and the model results can be explained relatively easily, at least, qualitatively.

The distribution of the transport rates in the immediate vicinity of Wheatley are such that, for each wave condition, the gradients with respect to distance along shore are relatively small. For east waves, the rates decrease slightly, suggesting some deposition, assuming sufficient material is already in motion from upwind. The rates for east waves continue to decrease westward, down to the tip of Point Pelee where the transport rates approach zero. This material that passes Wheatley, moving westward, is distributed along the length of Point Pelee and will be available for transport back again by south and south-east waves. It may also be lost off the tip of Point Pelee due to subsequent north-east waves (Skafel, 1975).

South waves produce transport rates towards the north-east that are increasing slightly near Wheatley, suggesting some erosion. The transport rates will eventually decrease and go to zero north-east of Wheatley where the shoreline takes on an east-west direction. Thus all material passing by Wheatley will be deposited and become available for transport back again.

South-east waves cause transport rates to the north-east, that are decreasing slightly at Wheatley, indicating some deposition. Not far from Wheatley, the shoreline becomes aligned south-west to north-east, so that the transport will drop to zero, and all material will be deposited and be available for move back by east waves. Some of the sediment deposited north-east of Wheatley be south and south-east waves could be moved further east by south-west waves, but the volumes involved would likely be small due to the fetch limitation on the waves and the orientation of the shoreline.

From the above description, it appears that almost all of the material moved towards the north-east will be available to be transported back because it is deposited fairly near Wheatley. Material moving south-west may go as far as the south end of Point Pelee so not all of it will be likely to find its way back again. The net result would be a net loss of material towards the south-west, assuming that the volumes moved by the various waves are compatible. That is, assuming the volume that can be transported by east waves is greater than the total due to south and south-east waves.

The shore south-west of Wheatley is composed of sand so that the potential rates for south and south-east waves in table 4 are realizable. However, north-east of Wheatley, except within about 2 km, the shore is composed of low bluffs of material ranging from clay to gravel. Kamphius (1972) estimated that only 20 to 25% is sand size. Clearly this reach of shoreline is not a ready source of sand for longshore transport so that the potential rate of 213 x 10^3 m^3 yr^{-1} will not be attained. It has been estimated that about 200 x 10^3 m^3 yr^{-1} of the bluff material between Wheatley and Port Alma is eroded, of which 50 x 10^3 m^3 is sand and gravel (see St. Jacques and Rukavina, 1976). Given that all material from south and south-east waves was deposited north-east of Wheatley, it could be completely carried back by the potential from the east with sufficient potential remaining (about 140 m^3 yr^{-1}) to move the estimated 50 x 10^3 m^3 yr^{-1} of sand and gravel eroded from the bluffs south-westward.

Considering all these factors, the longshore movement of sediment may be summarized as follows. About 72 x 10^{3} m^3 yr^{-1} moves towards the north-east. Most of this plus an additional 50 x 10^3 m^3 yr^{-1} (eroded from the bluffs) for a total of about 120 x 10^3 m^3 yr^{-1} is moved back south-west, leaving a net drift rate of about 50 x 10^3 m^3 yr^{-1} towards the south-west. Furthermore, the region is in a zone of erosion because the east waves have the potential to move more material than is available.

In section 4, it was found that an offshore breakwater would provide sufficient protection for safe navigation into Wheatley harbour. Configuration F in figure 13b was thought to provide the best compromise between protection and sufficient wave action to maintain some movement of sediment. The sediment movement around this breakwater is discussed below, in light of the preceeding general discussion of longshore sediment transport at Wheatley.

From figure 13b, it can be seen that the proposed offshore breakwater lies on a line running N8^{o}E. Waves from the south travel at approximately N35^{o}W in the breaker zone. Assuming the same direction at the offshore breakwater, the angle between the wave rays and the breakwater is about 43^{o}. The effective length of the 72 m breakwater becomes about 50 m. This distance is only about twice the wavelength of 5 s waves, somewhat more for smaller periods. The breakwater, therefore, does not significantly interfere with these waves, although some sand would likely deposit in its lee. The area of deposition would be east of the channel.

Waves from the south-east travel approximately N50^{o}W, and form an angle of about 58^{o} with the breakwater, giving it an effective length of about 60 m, about 2½ times the wavelength of 5 s waves.

Slightly more interference with the wave field can be expected, and somewhat more deposition of sand will occur, and it will be in a direction towards the end of the east pier. Sufficient diffraction around both ends of the breakwater should prevent deposition from occurring as far away as the channel area.

Waves from the east travel about N70^{o}W and form an angle of about 78^{o}with the breakwater, resulting in an effective length of about 70 m, about 3 times the wavelength of 5 s waves, and twice the wavelength of 7 s waves. The effective length is greatest for this wave direction, but the wavelengths are longer, so that the length to wavelength ratio is not appreciably different, for storm conditions. The breakwater shelters the channel so some deposition can be expected there. The amount of deposition may be moderated somewhat by the fact, described above, that east wave can transport more material than supplied. Therefore, the reduced waves may still cause considerable movement, allowing material to pass through the channel area.

Dredging of the harbour and entrance channel is necessary under the present conditions, and there is no reason to believe that dredging requirements will be reduced with the addition of an offshore breakwater. It would appear, however, that dredging requirements will not increase drastically. Because it is not possible to make more than qualitative statements about the effects of an offshore breakwater, it will be necessary to monitor the situation closely should one be constructed.

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St. Jacques, D. A. and Rukavina, N. A., 1976. Lake Erie Nearshore Sediments, Port Burwell to Point Pelee, Ontario. CCIW Unpublished Report, August.

Skafel, M. G., 1975. Longshore Sediment Transport at Point Pelee. CCIW Unpublished Report, October.

Table 1. Characteristic wave heights in metres at all wave probes for all the breakwater configurations, east waves. See figure 4 for probe locations and figures 13 and 14 for the breakwaters. Random waves with peak period = 6 s prototype were used throughout. Result are listed by date of test and whether the channel was filled with sand or dredged. Probe 1e was the control probe.

Breakwater Configuration	PROBE 1e	6e	7e	2e	3e	4e	5e
16 Feb 77 Channel filled							
none	2.1	2.2	2.3	1.8	0.9	0.6	0.5
A	2.1	1.7	1.6	0.9	0.6	0.5	0.4
B	2.1	1.6	1.5	0.9	0.6	0.5	0.5
C	2.2	1.2	1.1	0.9	0.7	0.6	0.5
D	2.2	1.8	1.2	1.3	0.8	0.6	0.5
E	2.1	1.4	1.1	0.8	0.6	0.5	0.4
F	2.1	1.2	1.0	0.9	0.7	0.6	0.3
G	2.3	1.6	1.7	1.5	0.8	0.6	0.4
17 Feb 77 Channel filled							
none	2.2	2.4	2.4	2.0	1.1	0.7	0.6
A	2.1	1.9	1.8	1.3	0.8	0.6	0.5
B	2.1	1.4	1.2	0.9	0.7	0.4	0.3
C	2.2	1.2	1.0	1.0	0.7	0.5	0.4
D	2.2	1.7	1.3	1.4	0.8	0.6	0.4
E	2.2	1.2	1.1	0.9	0.6	0.5	0.4
F	2.2	1.0	1.0	1.1	0.8	0.5	0.4
G	2.1	1.8	1.4	1.3	0.8	0.6	0.4
18 Feb 77 Channel dredged							
none	2.2	2.4	2.4	2.0	1.0	0.7	0.5
E	2.1	1.1	1.2	1.0	0.6	0.7	0.4
H	2.1	1.7	1.0	0.8	0.5	0.6	0.4
K	2.2	1.3	0.9	0.9	0.5	0.5	0.4
L	2.2	1.2	1.1	0.9	0.6	0.6	0.4
M	2.2	1.2	1.5	1.0	0.6	0.5	0.4

Table 2. Wheatley yearly percentage frequency of occurrence of onshore winds by direction and speed classes, for ice free conditions (i.e.excluding January and February). Mean speed for each class in metres per second is given in parentheses. Derived from Richards and Phillips (1970).

Speed class, kts	E	SE	S
6-10 (4.1)	2.152	1.742	2.744
11-15 (6.7)	3.341	2.151	3.978
16-20 (9.3)	2.56	1.354	2.346
21-25 (11.8)	1.202	0.352	0.739
26-30 (14.4)	0.573	0.103	0.22
31-35 (17.0)	0.178	-	-

Table 3. Effective fetch lengths and mean water depths for wave generation at Wheatley, for the three directions in table 2.

Direction	Length, km	Depth, m
E	113	22
SE	81	19
S	41	12

Table 4. Hindcasted waves for each wind speed class of table 2 and fetch length and water depth of table 3. The wind speeds used are the means of each class. (Characteristic wave height = 1.416 times rms wave height.)

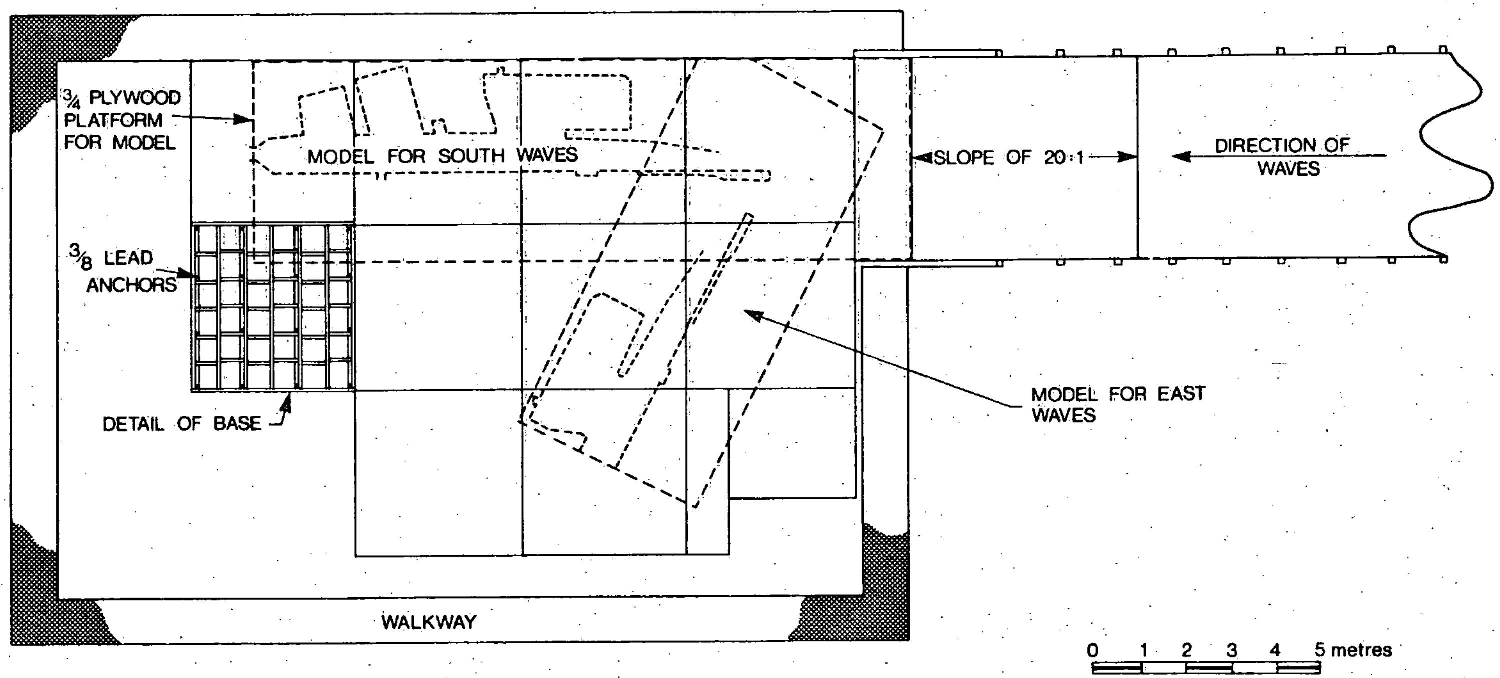
Wind Speed ms^{-1}	Direction	RMS Wave Height, m	Peak Wave Period, s
4.1	E	0.3	2.57
	SE	0.3	2.47
	S	0.2	2.19
6.7	E	0.6	3.43
	SE	0.6	3.24
	S	0.4	2.82
9.3	E	1.0	4.04
	SE	0.9	3.81
	S	0.7	3.28
11.8	E	1.3	4.53
	SE	1.1	4.26
	S	0.8	3.64
14.4	E	1.6	4.92
	SE	1.4	4.63
	S	1.0	3.95
17.0	E	1.9	5.27

Table 5. Mean longshore sediment transport rates for each wind class at Wheatley. (Positive: towards the north-east.)

Wind Speed Class, ms^{-1}	East Wind	S, m^3yr^{-1} South-east Wind	South Wind
4.1	- 2,700	1,100	1,200
6.7	-22,000	7,000	9,800
9.3	-63,100	11,600	19,100
11.8	-59,400	5,000	10,200
14.4	-44,100	2,600	5,200
17.0	-21,600	-	-

Net: -140,100 m^3yr^{-1} (towards the south-west)

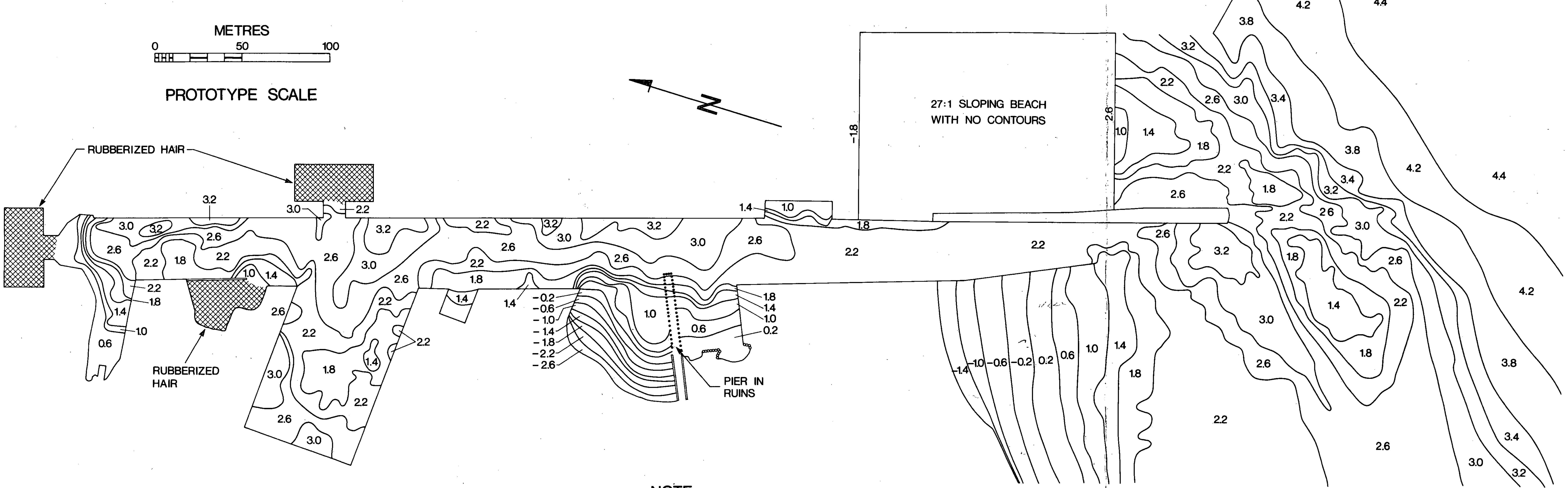
Gross: 285,700 m^3yr^{-1}



LOCATION OF MODEL IN HAMMERHEAD BEACH

FIGURE 1

WHEATLEY HARBOUR (BEFORE EXPANSION)



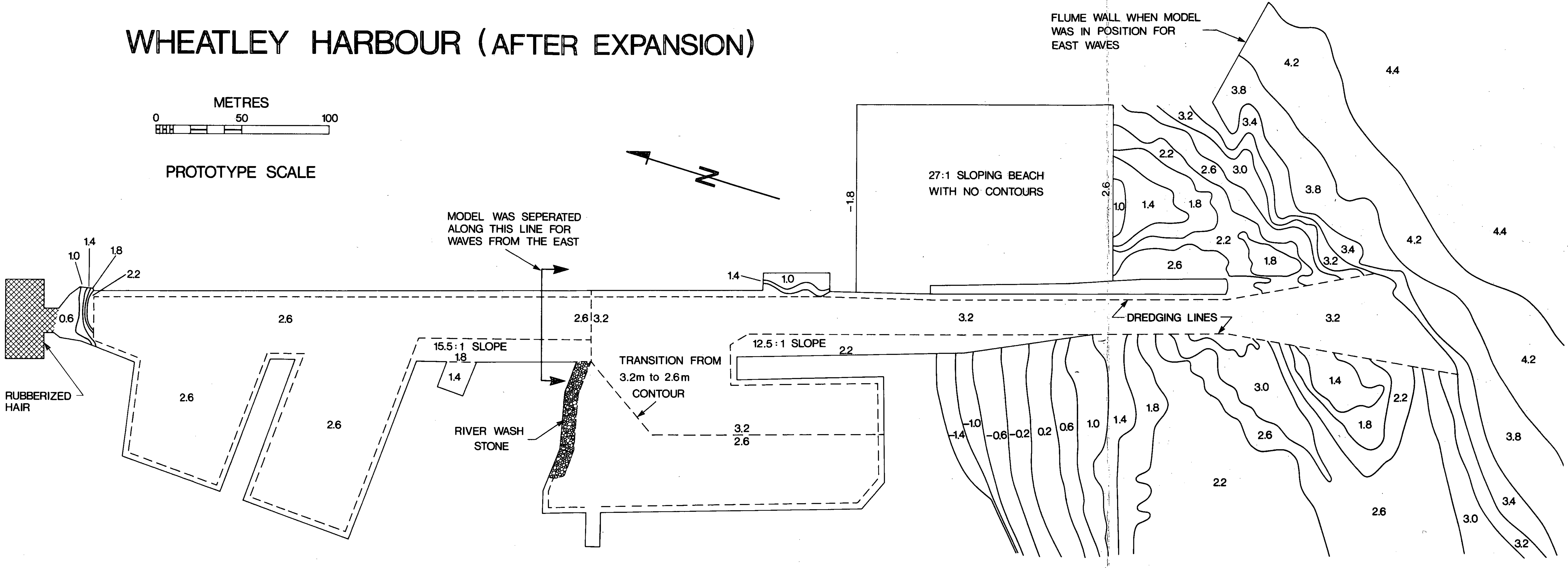
DRAWING TAKEN FROM CANADIAN HYDROGRAPHIC SERVICE
FIELD SHEET Nº 3873 (1974–75)

NOTE:–

1. Model was constructed as shown but in a mirror image.
2. Rubberized animal hair was used to absorb waves in areas shown.
3. Pier in ruins was represented by 1/4" diameter wooden dowels with an open space of 50%
4. All contours in metres referenced to chart datum 173.3m a.s.l., negative values are above datum. Harbour walls are at -1.8m.

FIGURE 2

WHEATLEY HARBOUR (AFTER EXPANSION)



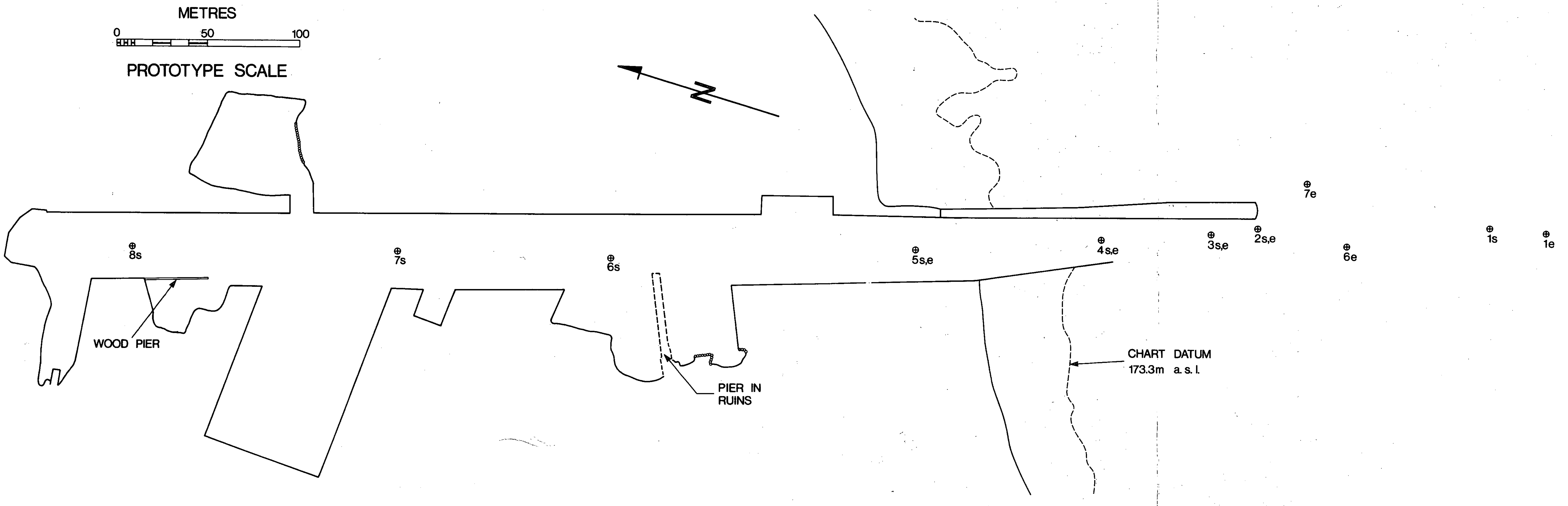
DRAWING TAKEN FROM CANADIAN HYDROGRAPHIC SERVICE
FIELD SHEET Nº 3873 (1974–75)
DETAILS FOR HARBOUR EXPANSION TAKEN FROM
PUBLIC WORKS CANADA DRAWING
ONTARIO REGION PROJECT Nº 08215106002
DATE 19/5/76
DESIGNED BY R. RICHARDS

NOTE:–

1. Model was constructed as shown but in a mirror image.
2. The contours from the harbour walls to the dredging lines where on a 3:1 ratio unless otherwise indicated.
3. All contours are in metres referenced to chart datum 173.3m. a.s.l., negative values are above datum. Harbour walls are at –1.8m .

FIGURE 3

WHEATLEY HARBOUR (BEFORE EXPANSION)



DRAWING TAKEN FROM CANADIAN HYDROGRAPHIC SERVICE
FIELD SHEET Nº 3873 (1974–75)

NOTE:–
⊕ Wave probe location for south (s) and east (e) wave directions.

FIGURE 4

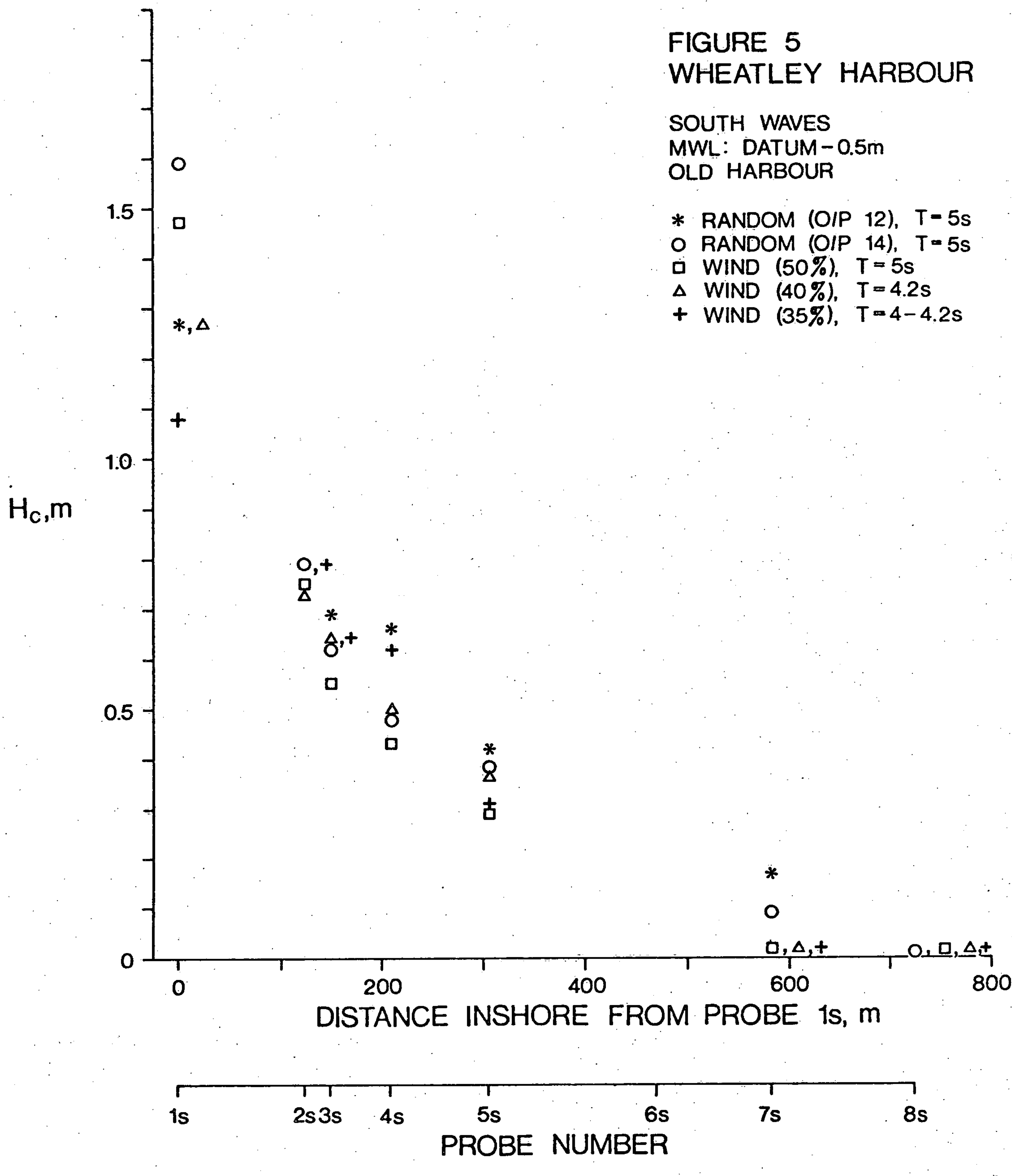


FIGURE 5
WHEATLEY HARBOUR
SOUTH WAVES
MWL: DATUM - 0.5m
OLD HARBOUR
* RANDOM (O/P 12), T = 5s
o RANDOM (O/P 14), T = 5s
□ WIND (50%), T = 5s
Δ WIND (40%), T = 4.2s
+ WIND (35%), T = 4 - 4.2s
1.5
1.0
0.5
0
H_c,m
0
200
400
600
800
DISTANCE INSHORE FROM PROBE 1s, m
1s
2s
3s
4s
5s
6s
7s
8s
PROBE NUMBER

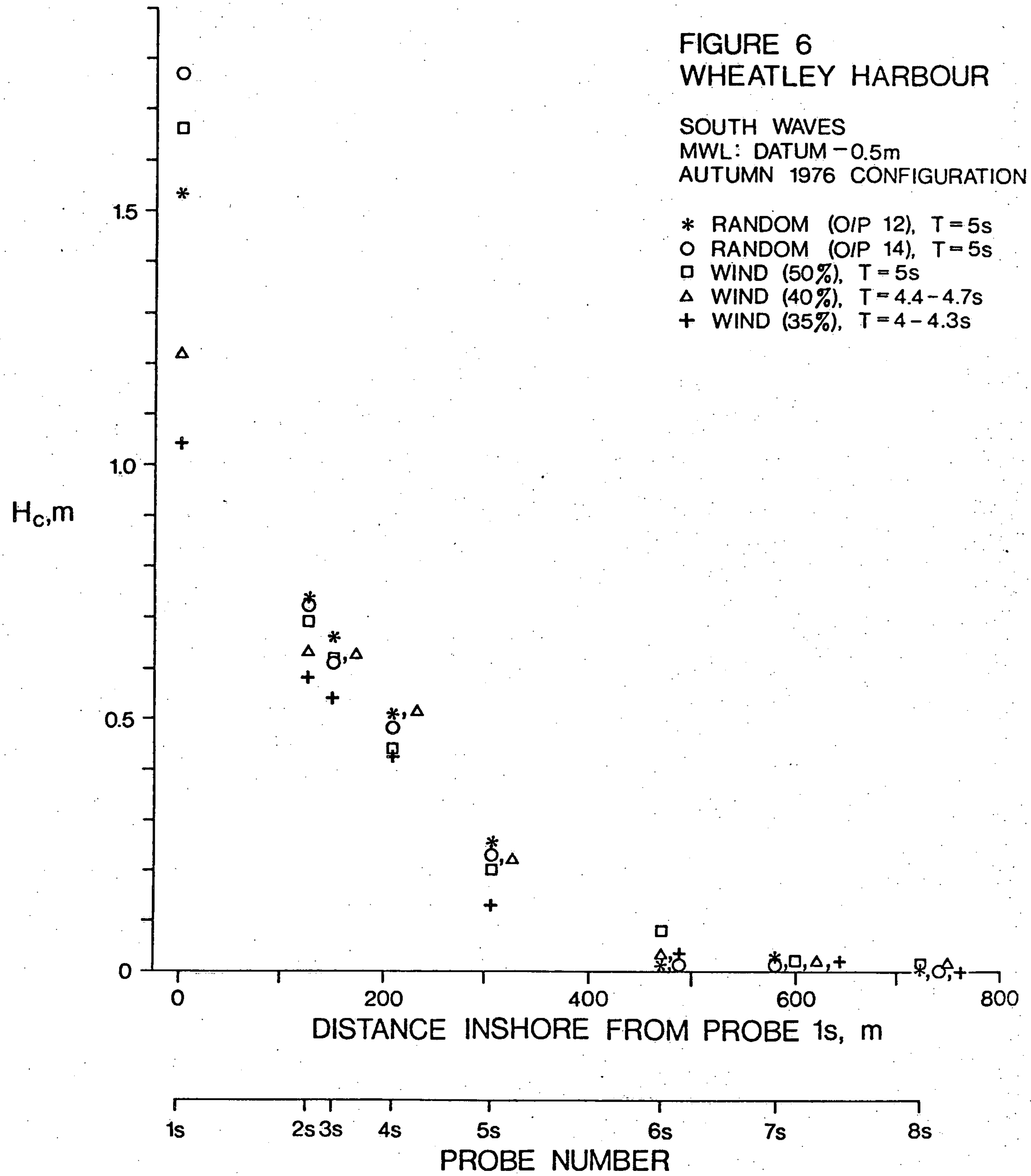


FIGURE 6
WHEATLEY HARBOUR
SOUTH WAVES
MWL: DATUM − 0.5m
AUTUMN 1976 CONFIGURATION
* RANDOM (O/P 12), T = 5s
○ RANDOM (O/P 14), T = 5s
□ WIND (50%), T = 5s
△ WIND (40%), T = 4.4 − 4.7s
+ WIND (35%), T = 4 − 4.3s
H_c,m
1.5
1.0
0.5
0
0
200
400
600
800
DISTANCE INSHORE FROM PROBE 1s, m
1s
2s
3s
4s
5s
6s
7s
8s
PROBE NUMBER

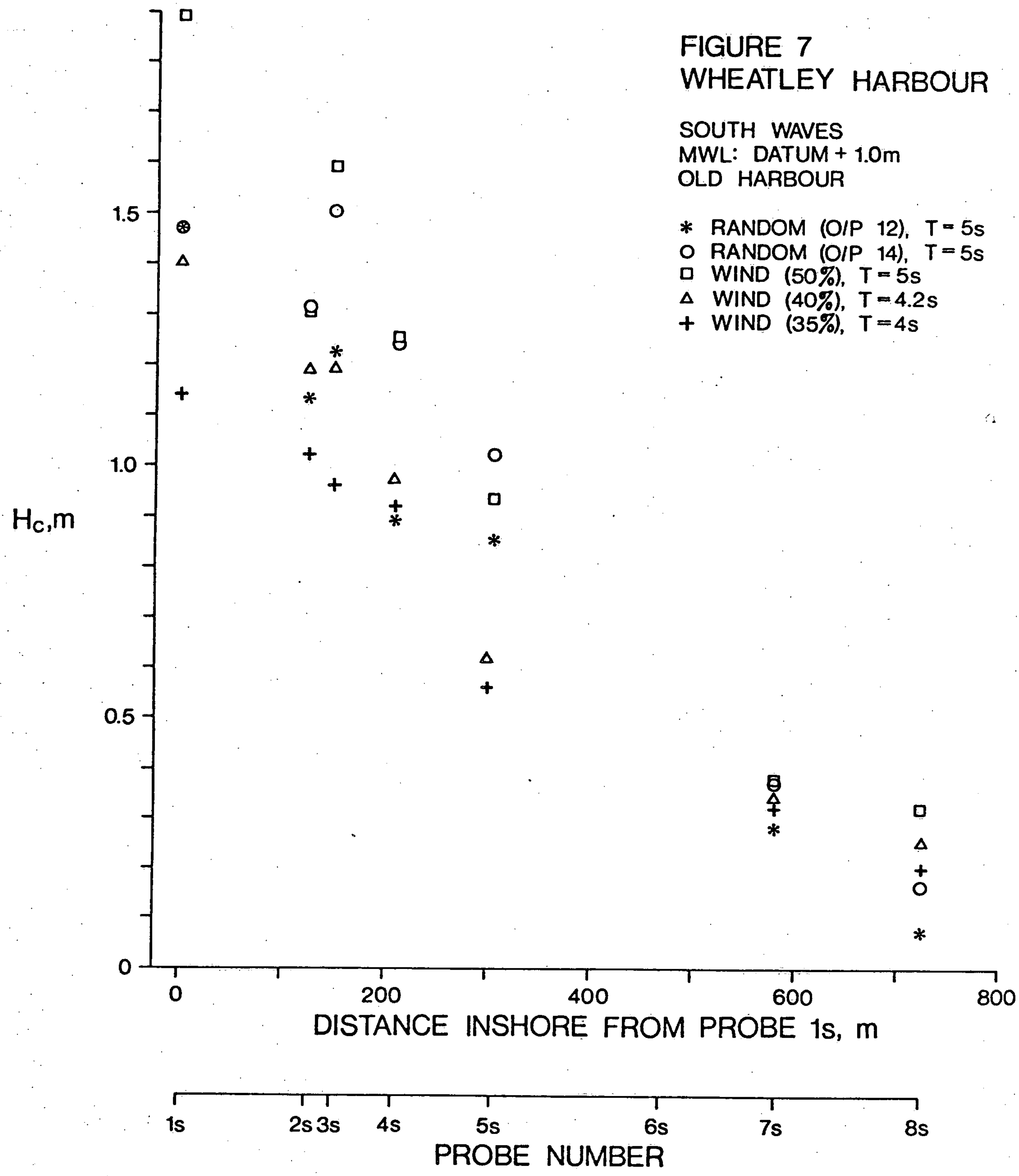


FIGURE 7
WHEATLEY HARBOUR
SOUTH WAVES
MWL: DATUM + 1.0m
OLD HARBOUR
* RANDOM (O/P 12), T = 5s
O RANDOM (O/P 14), T = 5s
□ WIND (50%), T = 5s
△ WIND (40%), T = 4.2s
+ WIND (35%), T = 4s
Hc,m
1.5
1.0
0.5
0
0
200
400
600
800
DISTANCE INSHORE FROM PROBE 1s, m
1s
2s
3s
4s
5s
6s
7s
8s
PROBE NUMBER

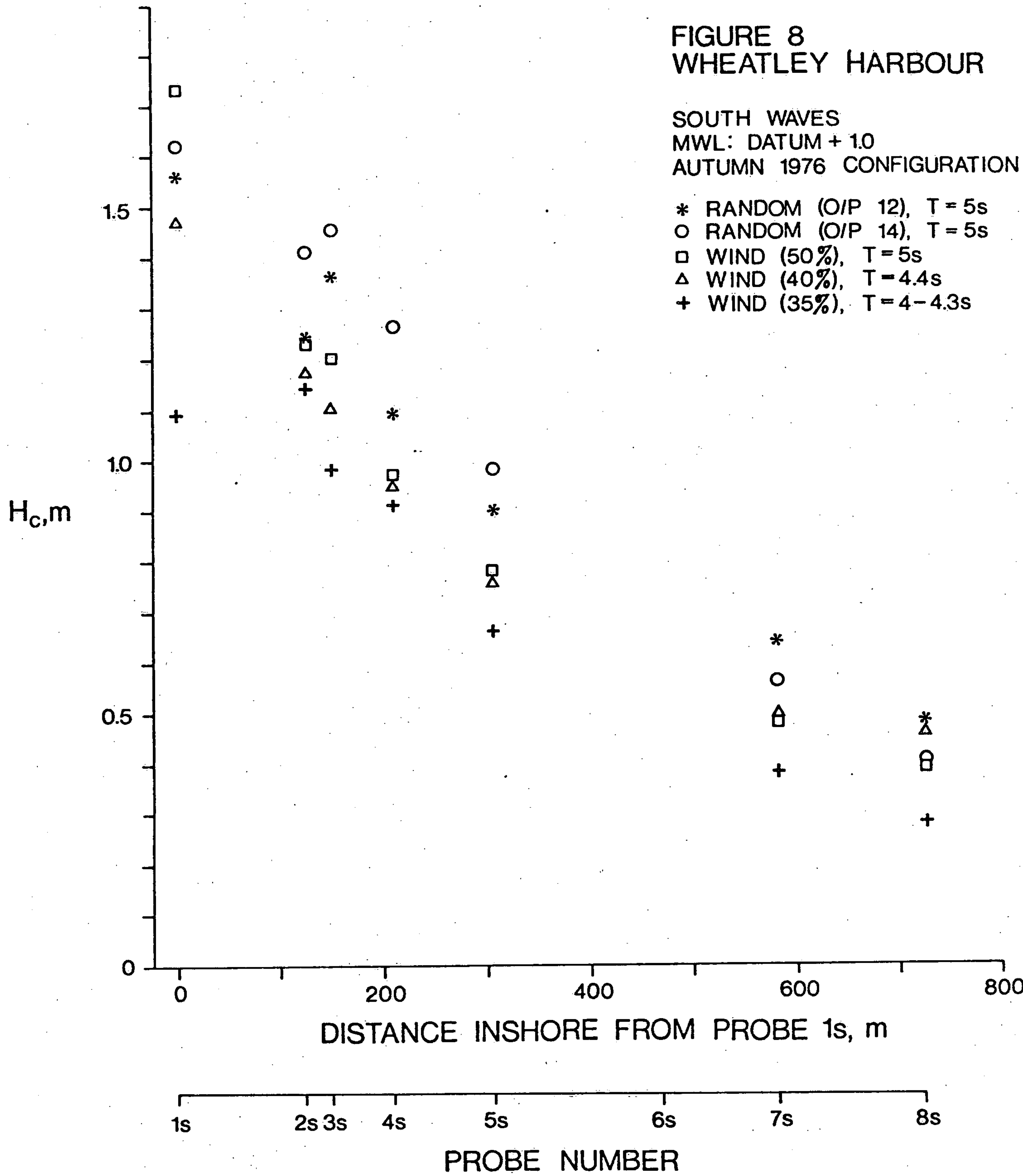


FIGURE 8
WHEATLEY HARBOUR
SOUTH WAVES
MWL: DATUM + 1.0
AUTUMN 1976 CONFIGURATION
* RANDOM (O/P 12), T = 5s
○ RANDOM (O/P 14), T = 5s
□ WIND (50%), T = 5s
△ WIND (40%), T = 4.4s
+ WIND (35%), T = 4-4.3s
H_c,m
1.5
1.0
0.5
0
0
200
400
600
800
DISTANCE INSHORE FROM PROBE 1s, m
1s
2s
3s
4s
5s
6s
7s
8s
PROBE NUMBER

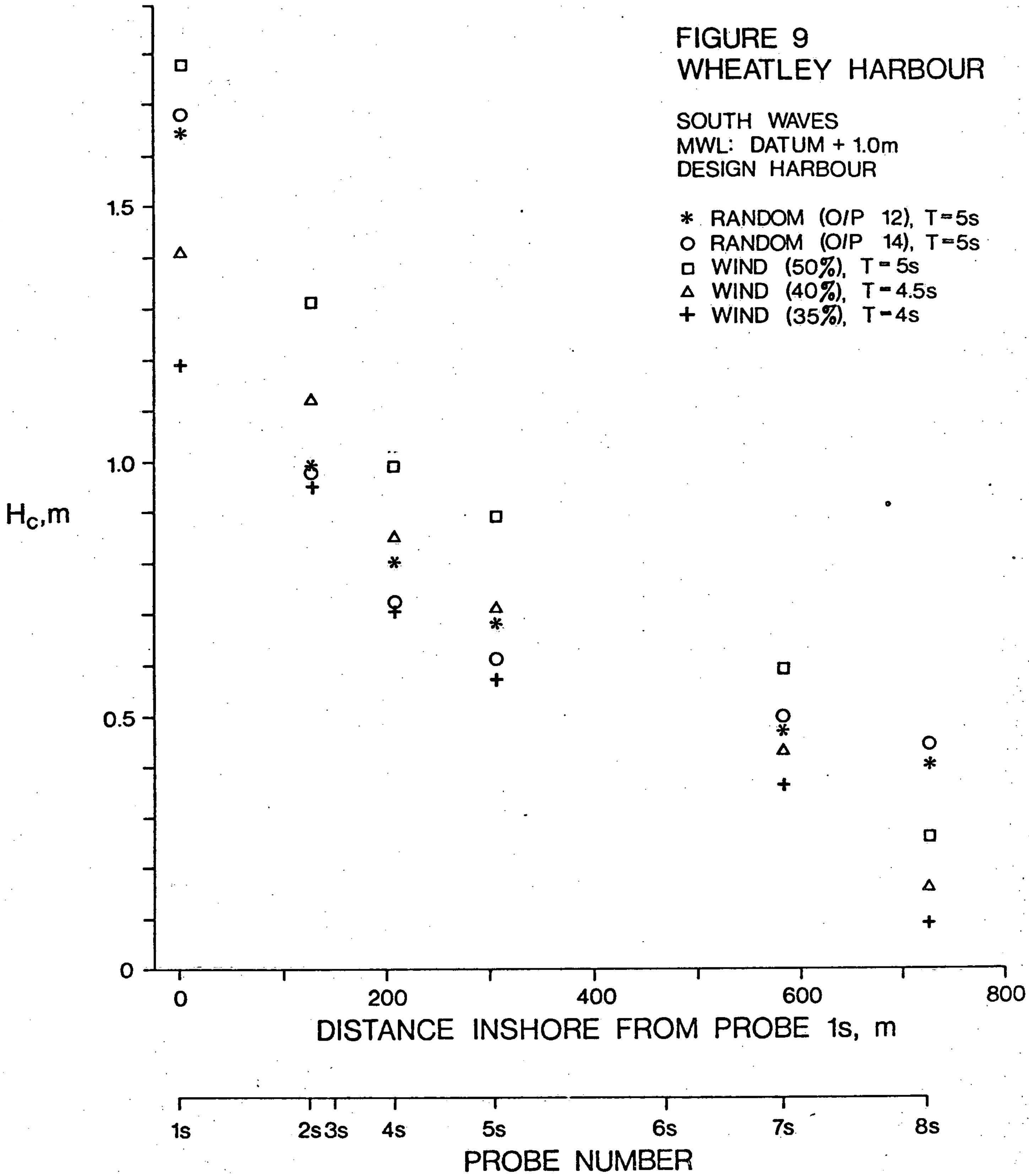
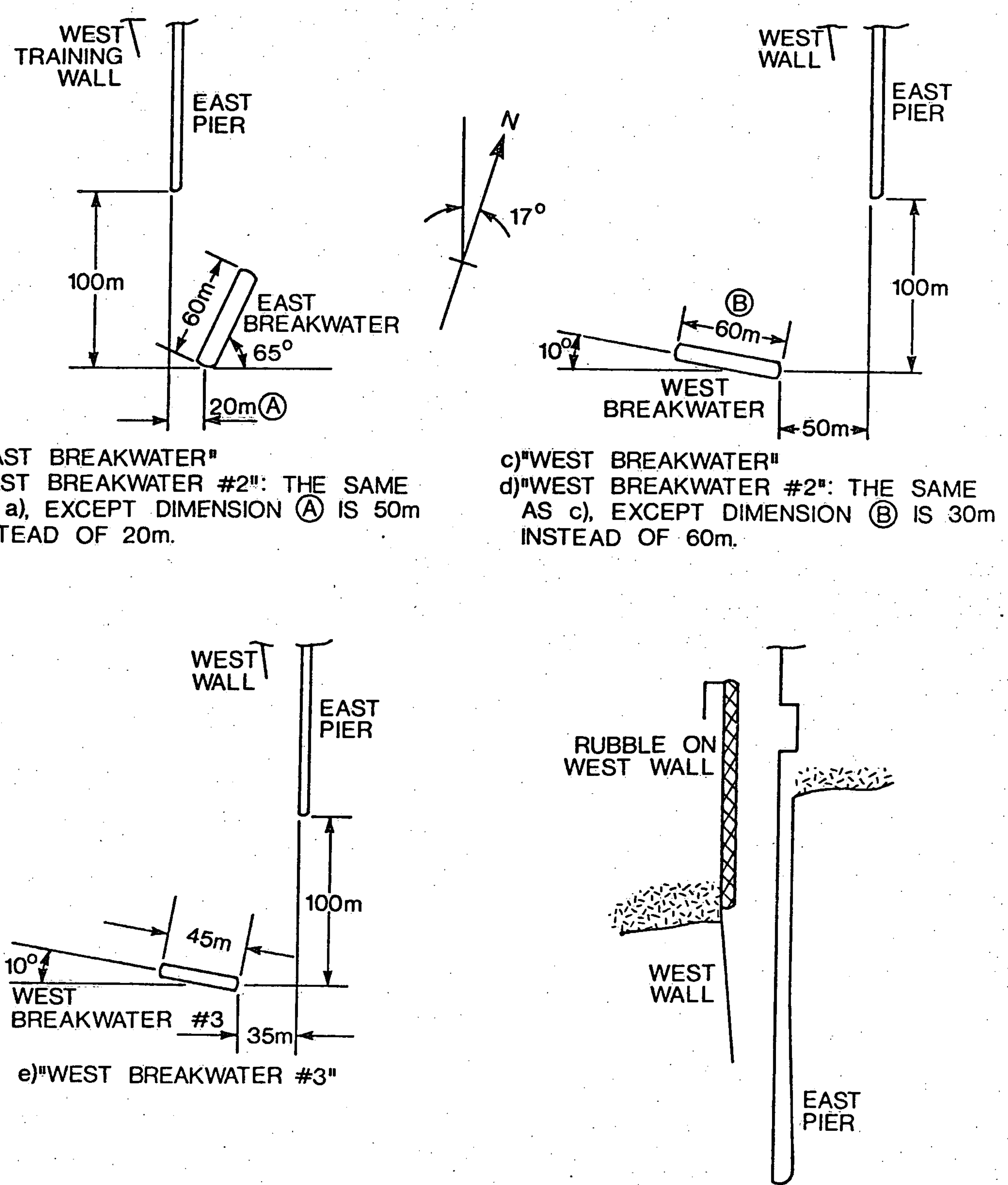


FIGURE 9
WHEATLEY HARBOUR
SOUTH WAVES
MWL: DATUM + 1.0m
DESIGN HARBOUR
* RANDOM (O/P 12), T=5s
○ RANDOM (O/P 14), T=5s
□ WIND (50%), T=5s
△ WIND (40%), T=4.5s
+ WIND (35%), T=4s
Hc,m
1.5
1.0
0.5
0
0
200
400
600
800
DISTANCE INSHORE FROM PROBE 1s, m
1s
2s
3s
4s
5s
6s
7s
8s
PROBE NUMBER



a)"EAST BREAKWATER"
b)"EAST BREAKWATER #2": THE SAME AS a), EXCEPT DIMENSION Ⓐ IS 50m INSTEAD OF 20m.

c)"WEST BREAKWATER"
d)"WEST BREAKWATER #2": THE SAME AS c), EXCEPT DIMENSION Ⓑ IS 30m INSTEAD OF 60m.

e)"WEST BREAKWATER #3"

f)"RUBBLE ON WEST WALL"

FIGURE 10. VARIATIONS TO THE DESIGN HARBOUR, FOR SOUTH WAVES

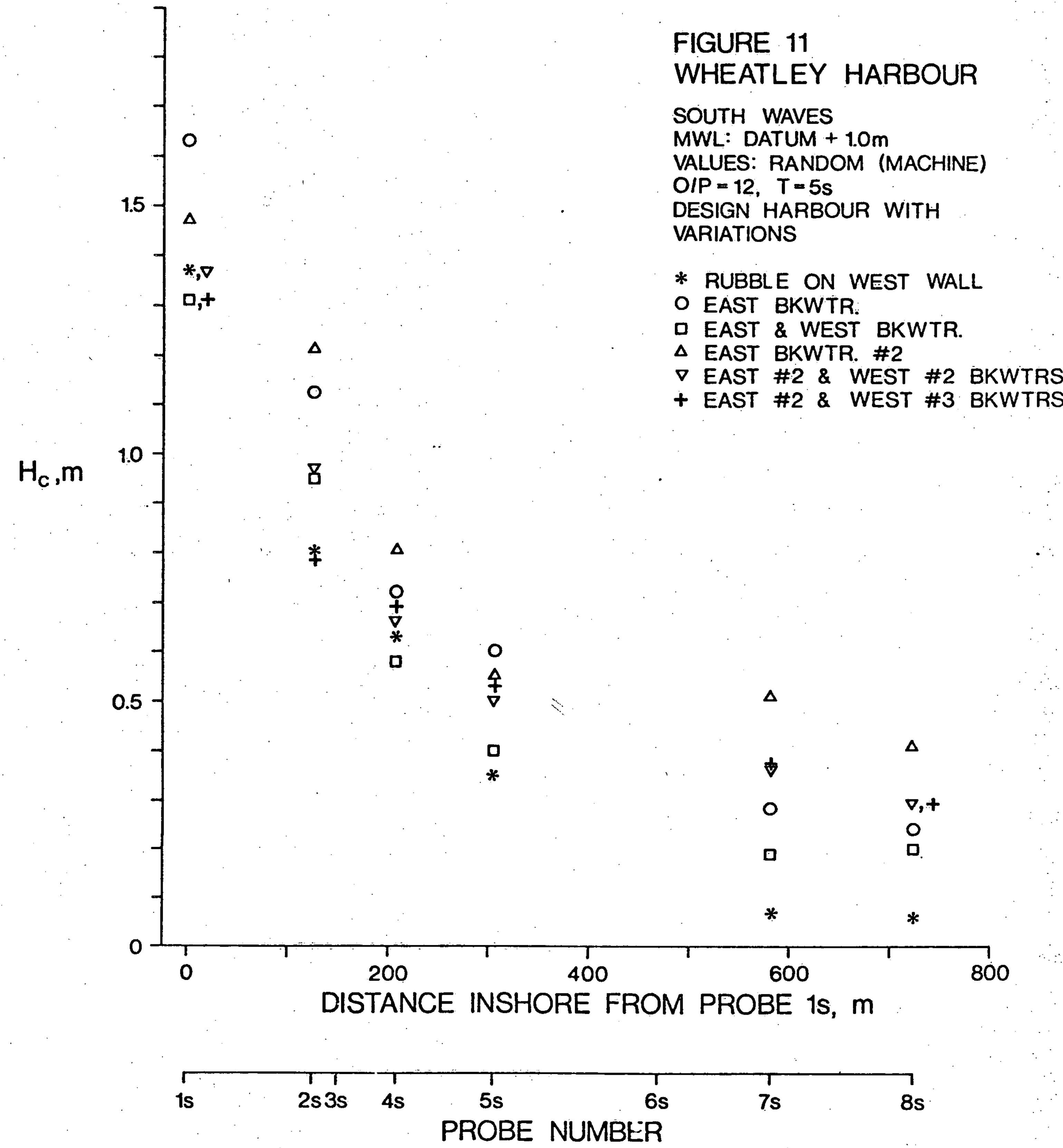


FIGURE 11
WHEATLEY HARBOUR
SOUTH WAVES
MWL: DATUM + 1.0m
VALUES: RANDOM (MACHINE)
O/P = 12, T = 5s
DESIGN HARBOUR WITH
VARIATIONS
* RUBBLE ON WEST WALL
O EAST BKWTR.
□ EAST & WEST BKWTR.
△ EAST BKWTR. #2
▽ EAST #2 & WEST #2 BKWTRS
+ EAST #2 & WEST #3 BKWTRS
H_c, m
0
0.5
1.0
1.5
0
200
400
600
800
DISTANCE INSHORE FROM PROBE 1s, m
1s
2s
3s
4s
5s
6s
7s
8s
PROBE NUMBER

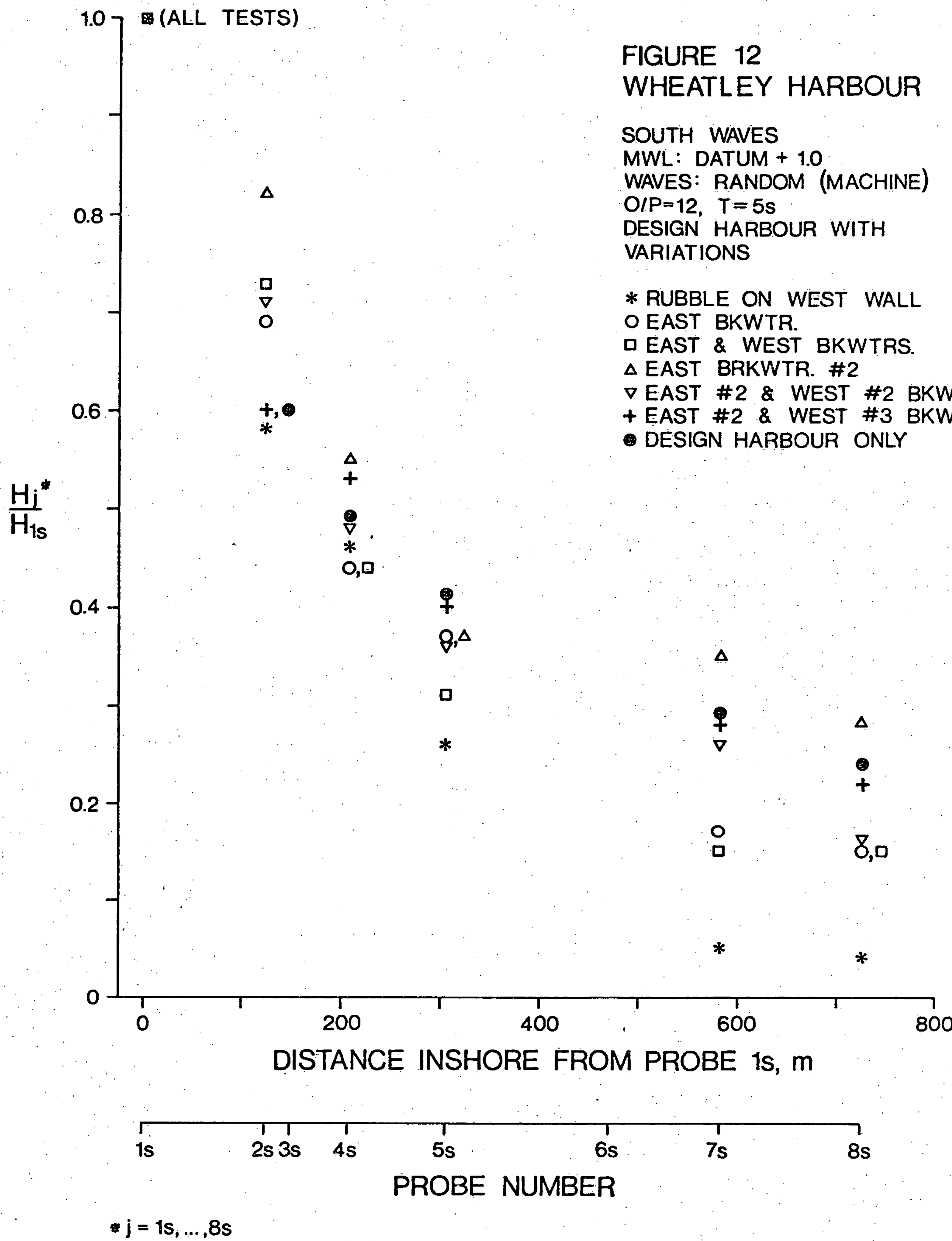


FIGURE 12
WHEATLEY HARBOUR

SOUTH WAVES
MWL: DATUM + 1.0
WAVES: RANDOM (MACHINE)
O/P=12, T=5s
DESIGN HARBOUR WITH VARIATIONS

* RUBBLE ON WEST WALL
○ EAST BKWTR.
□ EAST & WEST BKWTRS.
△ EAST BRKWTR. #2
▽ EAST #2 & WEST #2 BKWTRS.
+ EAST #2 & WEST #3 BKWTRS.
● DESIGN HARBOUR ONLY

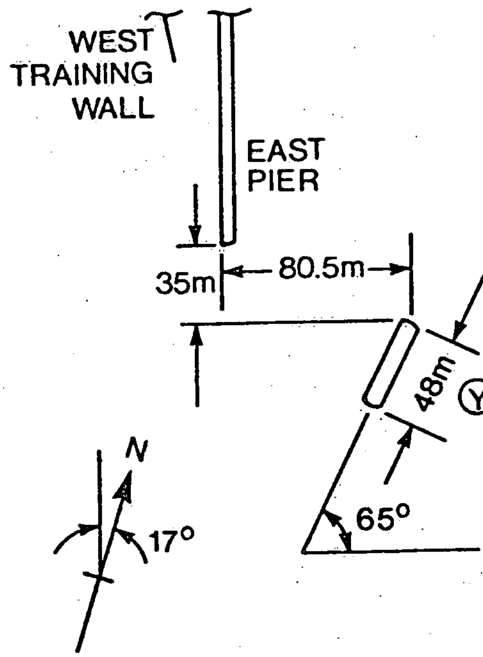


FIGURE 13a. BREAKWATER LOCATIONS FOR CONFIGURATIONS A TO D. ALL ARE RUBBLE MOUNT WITH IMPERMEABLE CORES. INCREASED LENGTH IS ON THE LAKEWARD END OF THE BREAKWATER.

CONFIGURATION:
A: AS DRAWN
B: AS DRAWN, EXCEPT LENGTH, Y=60m
C: AS DRAWN, EXCEPT LENGTH, Y=72m
D: AS DRAWN, EXCEPT LENGTH, Y=72m, AND 24m GAP IN MIDDLE.

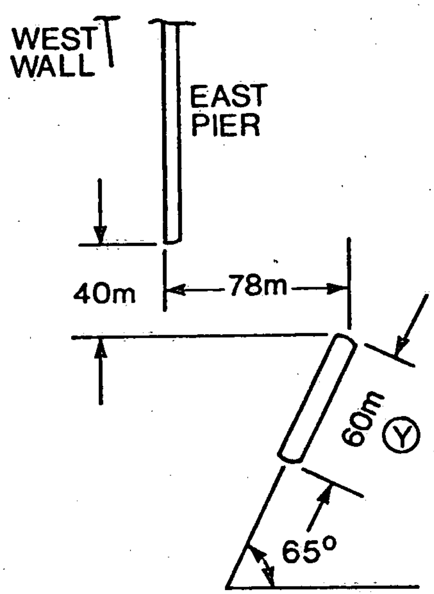


FIGURE 13b. BREAKWATER LOCATIONS FOR CONFIGURATIONS E TO G. ALL ARE RUBBLE MOUNT WITH IMPERMEABLE CORES. INCREASED LENGTH IS ON THE LAKEWARD END OF THE BREAKWATER.

CONFIGURATION:
E: AS DRAWN
F: AS DRAWN, EXCEPT LENGTH, Y=72m
G: AS DRAWN, EXCEPT 24m GAP IN THE MIDDLE

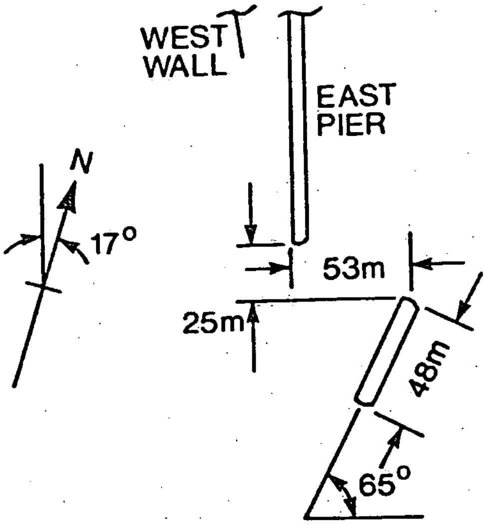


FIGURE 14a. BREAKWATER LOCATIONS FOR CONFIGURATIONS H AND K. BOTH ARE RUBBLE MOUNT WITH IMPERMEABLE CORES.

CONFIGURATION:
H: AS DRAWN
K: AS DRAWN, EXCEPT LENGTH = 60m, BY EXTENSION LAKEWARD.

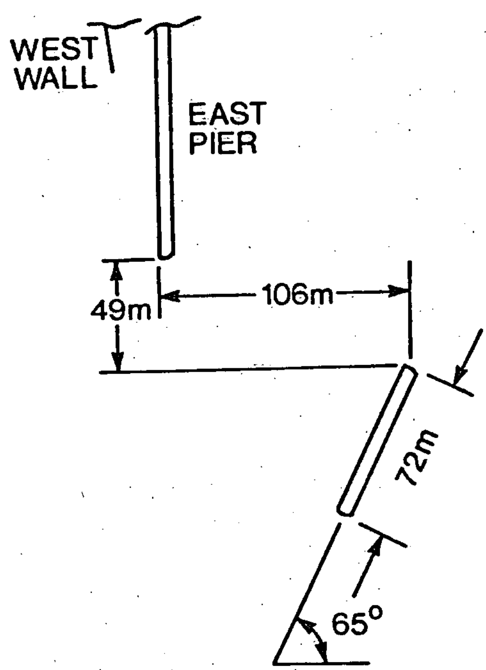


FIGURE 14b. BREAKWATER LOCATIONS FOR CONFIGURATIONS L AND M. BOTH ARE RUBBLE MOUNT WITH IMPERMEABLE CORES.

CONFIGURATION:
L: AS DRAWN
M: AS DRAWN, EXCEPT BREAKWATER MOVED 6m SHOREWARD ON ITS AXIS

PLATE 1. WHEATLEY HARBOUR (before expansion) VIEWED FROM THE NORTH

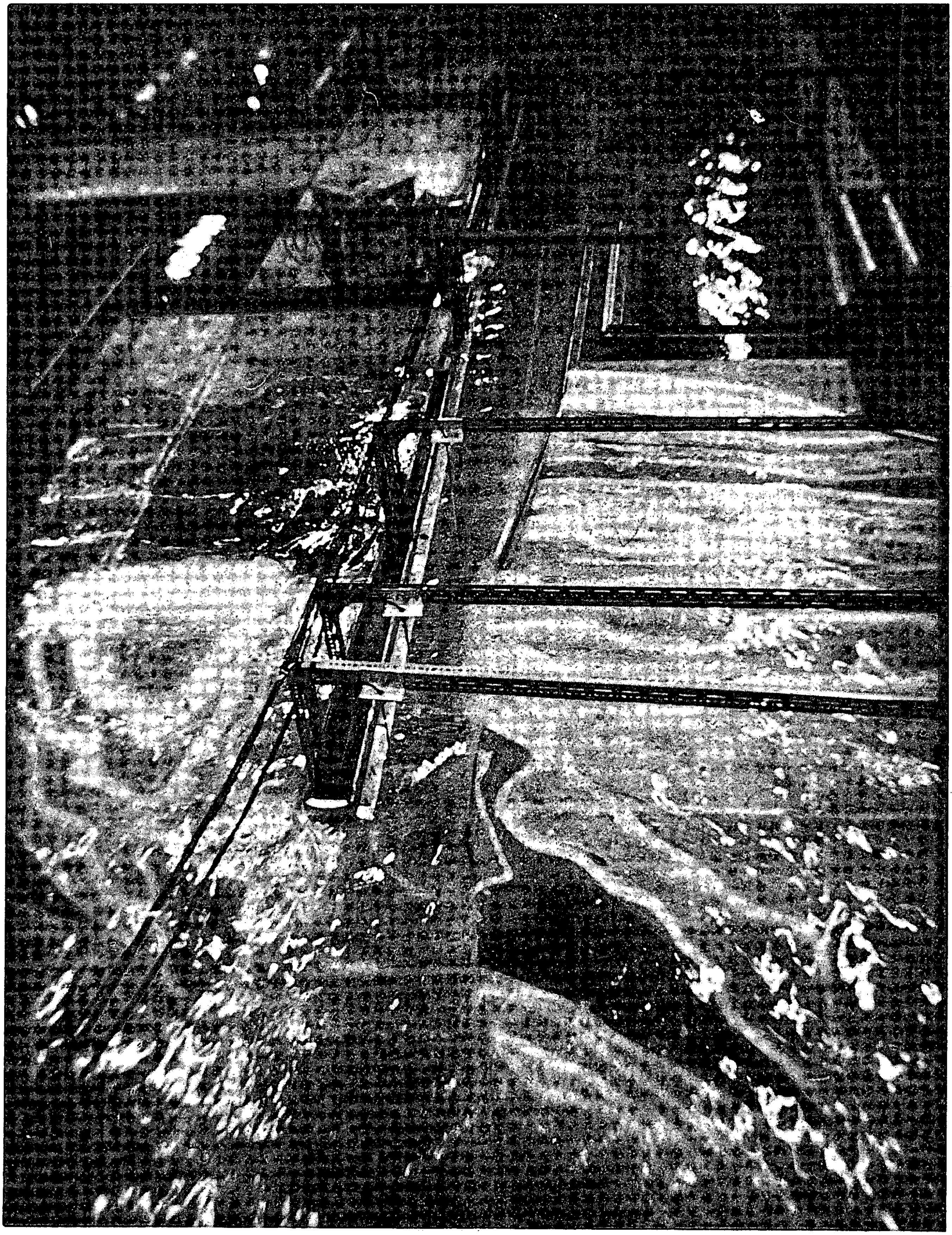


PLATE 2. WHEATLEY HARBOUR (after expansion) VIEWED FROM THE SOUTH

PLATE 3. EAST WAVES BREAKING OFF EAST WALL.