Study to Determine Acceptable Wave Climate in Small Craft Harbours

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Canadian Manuscript Report of

Fisheries and Aquatic Sciences 1581

March 1980

STUDY TO DETERMINE ACCEPTABLE WAVE CLIMATE IN SMALL CRAFT HARBOURS

by

Northwest Hydraulic Consultants Ltd.
Vancouver, British Columbia
Prepared under DSS contract 04SZ KF 802-8-2112
for Small Craft Harbours Branch, Department of
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ABSTRACT

Northwest Hydraulic Consultants Ltd. 1980. Study to determine acceptable wave climate in small craft harbours. Can MS Rep. Fish. Aquat. Sci. 1581: 165 p. + 11 figs. + app.

This study was carried out to provide more rational criteria for establishing the acceptable level of wave agitation in harbours used by small craft.

Recommended criteria have been developed based on field measurements, hydraulic model tests, mathematical analysis and interviews with small craft owners, marina operators, marine engineers and others with an interest in the field. These criteria take into account the wave period, frequency of wave generating events, type and size of craft, type of moorage and humanistic factors which in aggregate determine the acceptability of any wave climate.

RESUME

Northwest Hydraulic Consultants Ltd. 1980. Study to determine acceptable wave climate in small craft harbours. Can. MS Rep. Fish. Aquat. Sci. 1581: 165 p. + 11 figs. + app.

L'étude a servi à fournir des critères plus rationnels pour l'établissement d'un niveau acceptable de mouvement des vagues dans les ports utilisés par les petits bateaux.

Les critéres recommandés ont été définis à partir de mesures sur le terrain, d'essais au moyen de modèles hydrauliques, d'analyses mathématiques et d'entrevues avec des propriétaires de petits bateaux, des exploitants de ports de plaisance, des ingénieurs navals et d'autres personnes ayant un intérêt en ce domaine. Les critères tiennent compte de la période de la houle de la fréquence de génération de la houle, du modèle et de la taille du bateau, du genre de mouillage et des facteurs humains qui, dans l'ensemble, déterminent l'acceptabilité du mouvement des vagues.

SUMMARY

A widely accepted rule of practice for the design of wave protection for small craft harbours has been that the height of waves within the harbour should not exceed one foot. Of course, with almost any harbour, if one waits long enough, a storm will occur that will create waves in excess of this limit so that some qualification is required. One such qualification that has been used is that this height should not be exceeded more than once every ten years on average. A one year time period has also been used on occasion. This rather rigid specification does not consider the many variables that affect the amount of distress experienced from waves of a given height so that applied to one set of conditions it can result in an unsatisfactory harbour and applied to another it can result in funds wasted for overprotection. The study reported herein reviewed this rule and, after examining the many variables affecting wave distress in marinas, recommended an improved set of criteria. These criteria better reflect the conditions that the designer must consider to achieve an acceptable wave climate.

To provide the background and data necessary to formulate the criteria, the study undertook a number of diverse tasks as described briefly below:

Literature Review. The available literature on marina design and on the response of small moored craft to waves was reviewed. Most papers on marina design cite a wave height criteria similar to one stated above but no primary reference in which the criteria is substantiated was discovered. Several

papers warn against long period surges of low height that cause boats to be damaged as they surge fore and aft in their moorings. There have been very few studies of moored small craft and these have been highly idealized and have concentrated on surging. There have been field, analytical and model studies of floating breakwater response which were found helpful in providing a general understanding and in suggesting methods to be applied to this study. Studies of the response of large ships were not much assistance because different forces dominate the response.

Marina Visits. Marinas in British Columbia, Ontario, Quebec and Nova Scotia were visited and lengthly discussions were held with the operators to evaluate the types and extent of wave distress. These included very well protected marinas as well as those experiencing wave problems, including one in Nova Scotia which suffered from a hurricane in 1974. Formal records of wave damage seldom existed and wave damage to boats or walkways seems not to be the largest cost factor. More important is lost revenue from space vacated because of wave problems. The marinas experiencing the most wave action ameliorated the problem by additional maintenance and patrols and by using better mooring practices.

Formal Interviews. Formal interviews of marina users were planned and conducted by a team of environmental psychologists who prepared a separate report on their findings which is attached as an Appendix and also is summarized in the main report. The main concern of users is for the safety of their boat when it is left alone. Few expressed any distress with waves while attending or using their boats. Questionnaires were also mailed to marina operators. Significantly, they rated the more common storms as most distressing, rather than the rarer storms. There was a significant correlation between the self imposed ratings of the marina and the wave heights that they said proved troublesome. This varied from 1.0 feet for marinas ranked very low in wave distress to 2.8 feet for marinas ranked very high. Insurance underwriters seemed to consider fire more of a problem than wave distress in marinas.

Boat Response Measurements. A main part of the study was devoted to model tests of boat response to waves using a 2.5 foot long model of a deep fin sailboat. The boat was moored to a walkway with lines that incorporated the correct elasticity. The response of the boat to waves of different periods was measured in heave, surge and pitch for head seas and heave, sway and roll for beam seas. Characteristic curves were plotted dimensionlessly so that they could be applied to any size boat of that configuration. The greatest response occurs for wave periods between 2 and 6 seconds for the normal range of yacht sizes. Field measurements were made of the response of a 24 foot boat similar to the model and the agreement was acceptable. A wave recorder installed at the site of the field tests provided the wave data.

Analytical Study of Boat Response. Several simplified analytical methods to produce response curves were tried and the best results were obtained using a modified slender body approximation with linear elastic mooring lines. Response curves were obtained for four hull types: a deep fin sailboat, a full keel sailboat, a planning powerboat and a displacement type powerboat. The response curves were quite similar for all four hull types so that there was no need to differentiate between boat types in establishing criteria. This was substantiated in discussions with marina users and owners.

Limits of Boat Motion. Boats are usually tied against a walkway and their motion must be limited so that they will not impact and suffer damage. The different types of motion, heave, pitch, etc.,were examined to determine the natural limits that should be imposed on them. For instance, roll, if not limited, can cause masts and rigging of adjacent sailboats to tangle. It can also cause hanging fenders to be dislodged. Other motions have similar limits. These limits, combined with the response curves, provide limits to the wave heights. These limits were determined in establishing the wave criteria.

Wave Criteria. A fair number of variables affect the response of boats and it would be impractical to have the criteria reflect all of these variables. The important variables chosen were: the direction of the wave, the wave period, and the frequency of the wave event and the degree of wave climate required. Two directions were selected, head seas and beam seas; three wave period ranges, less than two seconds, between two and six seconds and greater than six seconds; three wave events, the fifty year event, the one year event and the one week event; and three degrees of wave climate, excellent, good and moderate. The actual criteria are given in Table 10.2.1 on page 158 of the report. The criteria are expressed in wave heights and range from 2.5 feet for head seas in a fifty year event with a moderate wave climate to 0.2 feet for beam seas in a weekly event and an excellent wave climate. In addition to the limit on wave height a second limit on horizontal water motion was added for wave periods greater than 6 seconds. For these longer waves the horizontal motions can become quite large. Horizontal motion criteria vary from 5.0 feet to 0.6 feet for the same conditions as above.

Recommendations. Several recommendations were made:

1. That the criteria be adopted provisionally pending further data on wave damage.
2. That all operators be encouraged to keep a log or a diary documenting wave damage.
3. Moorage methods for resisting large surges be given further study.
4. That good moorage practice be actively promoted.
5. That the effect of wave motion on the new types of manufactured floating walkways be investigated.

NOTATION

A	added-mass matrix
B	the dampening coefficient matrix
B_w	beam
C	stiffness matrix
d	still water depth
D	draft
F	the exciting force vector
f	frequency
g	gravitational constant
h	wave height
k	wave number = $2\pi/\lambda$
L_w	waterplane length
M	mass matrix
S	area and moments of area of waterplane profile
s	seak ratio
T	wave period
t	time
x	lengthwise horizontal coordinate
y	vertical coordinate
z	beamwise horizontal coordinate
ξ	amplitude of vessel motion
ω	wave frequency (radians/sec)
λ	wave length

Subscripts

1	surge
2	heave
3	sway
4	pitch
6	roll
w	waterplane values

I. INTRODUCTION

As the need for small craft harbours expands and naturally protected sites are developed to their limit, less attractive sites which require augmented protection need to be considered. The degree of protection provided depends to a large degree on the exposure of the site and the extent or cost of the breakwater to be provided. Engineering techniques are available for assessing the exposure and fairly accurately determining the wave climate within the harbour for a given expenditure for breakwater facilities. What is not available is a set of criteria by which to judge the degree of user satisfaction to be provided by the breakwater.

Rule-of-thumb criteria exist such as the requirement frequently imposed by the Department of Public Works that waves greater than one foot in height should not recur more often than every ten years. While such criteria are backed by long experience of harbour engineers, they are often applied arbitrarily without qualification and without sound knowledge of the effect that reducing or exceeding the criteria will have on the quality of the harbour. There is, therefore, a need for workable, substantiated criteria which takes into account the variables that can arise in marina design and that provides some measure of the quality of protection provided. The criteria should consider the type and size of boats, the moorage conditions and the level of useage as well as the frequency and characteristics of the waves incident on the harbour.

Recognizing this need, Northwest Hydraulic Consultants Ltd. (NHCL) submitted to the Department of Supply and Services (DSS) an unsolicited proposal for a study of acceptable wave climates in small craft harbours. The study was to include a literature review, an inspection of a number of harbours across Canada, interviews with marina owners and operators, extensive interviews with boat owners, field measurements and model studies of boat response to waves and a numerical analysis of boat motion while moored. The data so gathered would be collected and evaluated to arrive at the best possible workable criteria. Recognizing the importance of the proposed study, the Small Craft Harbours Branch (SCHB) of the Ministry of Fisheries and Oceans agreed to sponsor the study and participate as the Scientific Authority. It was recognized at that time that the work proposed had little precedence and that it would not be wise on this account to fund an exhaustive study to provide unchallangeable criteria. On the basis that all criteria forthcoming would be provisional, DSS Contract 04SZ KF802-8-2112 for this stucy was initiated on March 8, 1979.

The study was conducted by NHCL under the leadership of Dr. Albert G. Mercer, a principal of the firm. Supporting NHCL in this work were Dr. Michael Isaacson, Associate Professor of Civil Engineering at the University of British Columbia (UBC) who supervised the model studies and performed the numerical analysis of boat motions; and a team from the Department of Environmental Psychology of U.B.C., composed of Dr. Lawrence M. Ward, Professor, Dr. James A. Russell, Associate Professor and Nicole Clement, graduate student who designed, conducted and analysed the interviews with the boat owners. Their report is attached as Appendix A. Valuable guidance and help was provided by Michael Mulcahy from SCHB in Ottawa, the Scientific Authority for the study and by the regional staffs of SCHB especially Warren Parkinson and Arthur Ryll from the Pacific Region. Finally, appreciation is extended to all marina operators and boat owners who freely gave their time and cooperation to the successful completion of the study.

II. SCOPE OF WORK

The scope of work for this study was defined contractually by dividing the work into a number of tasks with specific, detailed explanations and instructions for each. The work followed closely these tasks as reproduced in edited form below:

Task I - Literature Review

A review of the technical literature relevant to all studies, analyses, etc., described below including:

1.1 Standards and criteria currently accepted for small craft marinas with regard to wave agitation and vessel movements.

1.2 Theoretical analysis and model studies of response of small craft and floats to wave action.

1.3 Field studies of wave motion and the resulting small craft motions.

Task 2 - Interviews and Meetings

Marina operators, small craft owners, insurance underwriters, engineers and scientists concerned with small craft harbours will be interviewed to obtain the benefit of their experience, learn of their concerns and obtain their suggestions. Interviews would be held at the following places across Canada in addition to B.C.:

- Ottawa, Ontario
- Kingston, Ontario
- Burlington, Ontario
- Quebec Yacht Club, Quebec City, Quebec
- Northern Yacht Club, North Sydney, Nova Scotia

Either the Fishermans Cove or Eagle Harbour marinas will be the primary location in terms of field measurements and wave recording. Other marinas to be visited will include:

- Kingston Marina, Ontario
- Schooner Cove Marina, British Columbia
- Beach Gardens Marina, British Columbia
- One other to be identified by NHCL

At each location assessment will be made to the following to provide additional information for Task 3:

- Distribution of vessel sizes
- Mooring procedures
- Berth layouts used
- Quality of mooring lines
- Quality of mooring cleats

Discussions will be held with operators and users with regard to limits of acceptable wave conditions. Details of dates, and specific times that damage occurred as a result of wave action to be noted along with details of the damage. Later, desk analysis will be undertaken to determine probable wave conditions causing damage. Where possible SCHB will supplement these analysis with wave hindcasting information.

Task 3 - Determination of Input to Vessel and Float Movement Analysis

Input to the vessel response to wave motion analysis consists of details of the craft, details of the mooring arrangements, details of the location of the piers relative to the mean location of the vessel, details of pier characteristic if floating, details of the mooring lines and water depths.

To provide this input, studies will be undertaken to classify types of vessels and mooring arrangements to be representative of the broad range of craft using marinas. These studies will be as follows:

3.1 <u>Classification of pleasure craft</u> - Existing data of number of types and sizes of vessels using marinas will be summarized. From these data, classes of pleasure craft will be developed and typical vessel characteristics (suitable for ship response analysis determined to represent each class) determined.

3.2 <u>Classification of mooring arrangements</u> - Existing data on sizes of berthing facilities to be summarized and classified. Mooring arrangements can be reasonably expected in a marina for various berthing layouts will be determined (including single point moorings). Classification will include distance between piers and typical sizes. Mooring arrangements will consider typical types of strengths of mooring ropes and mooring cleats.

3.3 <u>Classification of floating piers</u> - Data on types of floating piers including mooring arrangements will be summarized. Classes of floating piers will be developed and typical pier characteristics developed to represent each class.

Task 4 - Determination of Acceptable Vessel and Float Movements

The output from the ship response analysis limits above which motions are unacceptable, will be determined. These limits will include the following:

4.1 Limits of ship roll so that adjacent sailing craft will not interlock masts.

4.2 Limits of mooring line/cleat strengths so that mooring lines will not break.

4.3 Limits of vessel movement so that vessels will not collide with adjacent pier walls.

4.4 Limits of acceleration and velocity that make the access to the boat hazardous or use of the boat in the moored state unacceptable to the occupant.

The limits will be developed for different vessel classes, pier classes, and mooring arrangements.

Task 5 - Theoretical Analysis of Vessel and Float Response to Wave

The response of vessels will be calculated for all of the vessel classes, pier classes, mooring arrangements and wave conditions where the analysis is applicable. The range of wave input considered will be as follows:

5.1 Significant wave periods up to 12 seconds.
5.2 Significant wave heights up to 1.0M.
5.3 Wave direction relative to the fore/aft line of the vessel of 0° and 90°.

The analysis will also be undertaken for floating piers and for vessel/floating pier combinations where possible.

The free floating response characteristics of the typical vessels representing each class are also to be tabulated.

The output of each analysis will include the following for review against the limits established in Task 4.

a) maximum movements of extremities of the vessel
b) maximum loads in mooring lines
c) maximum acceleration and velocities of some locations on the vessels
d) maximum angle of roll

The following will also be considered in undertaking the vessel response analysis:

- Wind Effects: On most occasions severe wave agitation may be accompanied by high winds. Discussion of wind effects on moored vessels to be included particularly with regard to how damage caused by wave action may be increased by the drag force imposed by high winds. Direct wind damage, however, is beyond the scope of this study.
- Current Effects: Discussion of effects of river and tidal current on vessel response are to be included. A current may, for example, hold a vessel secured with a single point mooring broadside to the direction of the wave advance.
- Ship Waves: Waves generated by vessels in the marina should be considered as input in addition to the wind generated waves.

- Vertical Walls: Effects of a vertical wall close to the vessel should be discussed.

Numerical analysis results for conditions close to resonance cannot be considered reliable and these will be explored with model studies. It is the intention that all possible simplifying assumptions will be applied in this analysis and that model studies will be used to substantiate those assumptions where necessary.

The purpose of the study is to determine the conditions that produce limiting response motions. Cases where the response is clearly greatly in excess of the stipulated limits or cases where the response is negligible will not be given close scrutiny or analysis.

Task 6 - Model Studies

Model studies will be conducted to support the theoretical analysis, provide preliminary criteria for vessel movement and produce recommendations for a further program of hydraulic testing to be considered outside the scope of this proposal.

These model studies will be conducted using state of the art techniques. Care will be taken to accurately represent the hydrodynamic characteristics of the model ship and floating wharf. The non-linear characteristics of the mooring lines will be accurately represented. The vessel model to be used will be a minimum of 2 ft. in length, a larger model being used if possible.

The exact scope of model tests will include:

- 1 Hull type
- 2 Mooring conditions - floating dock
  - fixed dock
- 1 Depth
- 10 Wave lengths
- 3 Wave heights
- 2 Wave directions (Head and Beam Seas)

Data collected will include:

- wave height and period
- chart recorder traces of the 3 components of motion. To be analysed with suitable procedures to provide useful parameters for this report.

Task 7 - Field Measurements

Field measurements will be made of natural response periods of typical boats and access floats. Measurements will also be made of relative movements of boats and floats in a fairly exposed marina. The effect of different mooring arrangements will be evaluated including vessels moored to buoys.

It is understood that SCHB are prepared to install a wave recording system, complete with long term recording capabilities at either the Fishermans Cove or Eagle Harbour marinas, and for a period of approximately one year. The resulting analysed wave data including computer analysis and hindcast wave data will be supplied at no cost to NHCL.

NHCL will document within reason all damage occurring at this location during the recording period and over the past few years as a result of wave action and relate this damage to wave conditions at the time.

SCHB will also make provisions for NHCL to obtain direct wave data from the wave gauge by providing a hook-up for a chart recorder.

Task 8 - Selection of Critieria

With the assistance of federal representatives and with the support of the findings of the study, preliminary criteria for harbour sheltering would be proposed, reflecting such variables as:

1. range of boat types and sizes to be protected
2. type of moorage provided
3. harbour characteristics such as water depth
4. frequency of storms or wave events
5. wave lengths anticipated

Preliminary criteria for excellent, adequate and marginally acceptable sheltering will be designated. This would be accomplished at a workshop-type meeting in Vancouver.

Task 9 - Humanistic Aspects

The humanistic aspects that determine unacceptable limits to wave agitation will be derived. The analysis will involve the following:

- Literature review of user concern with vessel motion.
- Theoretical study of vessel motions causing possible anxiety to users.
- Interviews with users with regard to anxiety and vessel motions.

The specificity of these tasks was intended to provide firm guidance for the performance of the study even though the importance of different factors in establishing criteria was not yet fully understood. In general, the study closely adhered to the instructions with some minor exceptions. These are explained in the appropriate places in the body of the report.

III. PREVIOUS WORK

At the early stages of the project a fairly intensive effort was mounted to discover the extent of previous work related to wave climates in small craft harbours. This included research on:

1. existing wave climate criteria and wave characteristics affecting wave climate.
2. field and model and numerical evaluation of the response of moored small craft.

This search involved several phases including:

1. Enlisting the services of the Canada Institute for Scientific and Technical Information and also a private abstract searching firm to make computer searches of their abstract lists. They both searched the Engineering Index and the Maritime Research Information Service (MRIS). The latter is particularly relevant since it abstracts over 200 journals and agencies publishing world wide. The lists of abstracts provided by the two organizations were somewhat different since they depend on the combinations of key words used in conducting the search.

2. Contacting, by letter or by telephone, agencies or groups in Canada and the U.S.A. likely to be interested or involved in these areas to inquire about their experience, especially their ongoing research.

3. Pursuing likely leads from reference lists in related papers, etc., to contact persons who have contributed knowledge relating to wave climate criteria.

In addition to these efforts by NHCL, Dr. Ward's group undertook a separate search directed to humanistic aspects and Dr. Isaacson searched for analytical methods of arriving at boat response.

The results of their searches are contained in Dr. Ward's report, Appendix A, and in Section IX, Analytical Determinations of Small Craft Response, of this report.

In general, it appears that there has been remarkably little done or written on criteria for small craft harbours or marinas or on response of small moored craft. There is a great deal of peripheral material on such topics as large vessel response, breakwater performance, etc., but papers or references directly related to wave climate criteria in marinas are rare. Yachting magazines have occasional articles on mooring and anchoring but NHCL was able to discover only one trade magazine directed to marina operators or owners. With some few exceptions, this study would seem to be entering a new area of investigation. The little previous work that has been done is discussed in the remaining paragraphs in this section.

3.1 Existing Wave Criteria and Wave Action in Small Craft Harbours

There have been several comprehensive papers that cover the general subject of marina design and all make reference to some wave criteria which comes reasonably close to specifying a 1 foot significant wave height. None make any attempt to substantiate these values and no primary reference to this type of criteria could be found.

Dunham and Finn (1974)*, in their comprehensive report on marina design for the U.S. Army Corp of Engineers, state:

*See Section XIII References

> The normal criteria for acceptable maximum wave heights are about 2 to 4 feet in the channel entrance and 1 to 1.5 feet in the berthing areas, depending on the characteristics of the using craft. Generally, if waves can be attenuated to a height of 1 foot in the berthing areas, their horizontal oscillations will not be troublesome, and any longer-period resonant effects will go unnoticed.

They emphasize the problems associated with surge, which they define as waves of long period and great length with low height. They state:

> The most troublesome aspect of surge in a harbour is its horizontal water motion or oscillation, which causes stress in mooring lines and anchorage systems and can make the maneuvering of boats into slips difficult. Ordinary wind-generated waves that penetrate the entrance of a harbour may acquire the characteristics of surge in the inner basins. If the period of the surge oscillations in the basins correspond to the period of the sea or swell outside the entrance, then the exterior sea or swell is the cause of the surge within the harbour.

The harbour may also resonate to some low frequency of the exterior sea that is not very prominent in the spectrum. In fact, it now appears (private conversation with Joe Ploeg of the National Research Council) that the waves in a "random" sea spectrum are not so random and large waves come in a regular pattern (every 7th wave as fisherman and seamen will testify) and these large wave groups can resonate a harbour in a very long period that coincides with the timing of their group occurrences.

The ASCE Task Committee on Small Craft Harbours have published a manual (1969) on small craft harbours and they recommend simply "In general, wave heights in the mooring basin should be reduced to a maximum of approximately 0.5 ft. to 1 ft." They also warn against surges:

> Long period waves (those with periods in excess of 20 sec) must also be considered in harbour siting. These waves may be generated in the open sea by barometric pressure pulsations or locally by surf beat. The small amplitude waves are generally not critical but are undesirable for small craft harbours. The larger amplitudes may damage a craft or their mooring facilities. The most common damage is from the high velocities in the wave causing excessive stress on mooring lines or the bumping of the hull against the pier. The excess stress often breaks lines or damages boat cleats or decking. The long periods make the waves very susceptible to refraction effects. Therefore, if long waves occur, refraction analysis is required.

Lee, a member of the Task Committee, in a separate paper (1964), makes these comments on wave critiera.

> ...present criteria for maximum allowable wave height is based generally on the knowledge of small boat operators and the opinions of those closely connected with small craft harbours. It is generally considered that wave heights in recreational craft harbours should be reduced to one foot or less. This is often very difficult when it is considered that wave energy varies as the wave height squared.

He mentions ongoing research on wave criteria and this is discussed later in this section.

Le Mehaute (1976), writing about harbours in general, says this about small craft harbours:

> Small craft harbour requires very small wave agitation. 20 cm (8 inches) would be considered as the maximum by many pleasure boat owners, even though harbour masters may consider that 40 cm (16 inches) is acceptable, if the boats are properly moored - which is often not the case.

Launching ramps require also to be built in an area where the water is very calm (less than 10 cm). The corresponding sheltering coefficient can only be achieved if the marina is located inside a large harbour already protected by an offshore breakwater. If the marina is directly exposed to the offshore, a succession of breakwaters and/or narrow entrances are necessary in order that the wave dies out by successive diffraction and dissipation. For the same reason, floating breakwaters for marinas are only feasible in already sheltered areas. Moored small craft have a period of resonance on their mooring system of 4 to 8 seconds. They are not susceptible to seiche effect.

Fishing vessels and trawlers are generally of larger size (say from 15 to 600 BRT) and rugged. Also, the professional fishermen are ready to cope with larger wave agitation. As a result, in most cases harbour designers may accept a 80 cm (32 inches) wave as a maximum wave height criteria for commercial fishing boats.

Seiche, used here, is an extremely long, low surge. They create rather weak velocities which exert rather minor mooring forces on small craft but which cause difficulties with the mooring of larger ships.

The International Commission for Sport and Pleasure Navigation under the Permanent International Association of Navigation Congresses (PIANC) was formed to study small craft harbours internationally. Writing for the Commission, Bertlin (1976) defines a reasonably sheltered area as one in which the 10 year maximum significant wave height is less than 400 mm (16 inches), but he provides no justification for this criteria.

Reflecting Canadian practise with the Department of Public Works, Glodowski, et al (1977) writing about model studies of the Kingston Olympic Marina states: "For the purpose of this study significant wave height of 1 foot defines the limit of acceptable wave conditions......While a pleasure boat may move significantly with one foot waves and cause some discomfort to occupants, damage will not occur if the boat is properly secured." The layout that was recommended "reduces the wave conditions such that the wave height in the harbour will not exceed one foot for the storm occurring on average only once each year".

Finally, Kamphuis, 1979, writing on small harbour design, states "Incoming waves larger than 0.5 m (20 inches) will create enough disturbance within the marina, especially if the perimeter is very reflecting, that small craft, even when moored properly, will sustain considerable damage". He concludes:

> In our basic research, we have come across very little literature concerning marina design specifically. Most work refers to agitation in harbours and marina design is often considered to be "mini-harbour" design.
>
> But marinas have their own specific problem. How can we reduce the short, steep "unimportant" waves to below a threshold of about 0.3 m at which time lines and fittings begin to break? The solutions are not simple, neither are they cheap.

3.2 Response of Moored Small Craft

There are only three projects related to the responses of moored small craft that have come to the attention of NHCL, all sponsored by the U.S. Army Corps of Engineers. Two were completed in the 1960's and the other is ongoing.

The first, reported by Raichlen, (1966) purported to deal with small moored vessels but, in fact, was a highly idealized laboratory study in which the vessel was a rectangular block constrained to move only in the "surge" direction. The block was located close to a perfectly reflecting basin wall so that it was subjected only to standing waves. The motion was restrained by linear springs. The distance from the wall, the strength of the spring and period of the waves comprised the independent variables. An analytical solution based on damped oscillatory motion with one degree of freedom was formulated and the experimental results compared. Added mass and dampening due to the water were determined experimentally by comparing the natural period of oscillation in air and in calm water and by noting the rate of attenuation. Wave lengths varied from 0.67 to 10 times the "hull" length. The results show that the motion in surge has a high resonant peak at the natural frequency of the vessel (which depends on the spring constant) and that, for weaker springs, this motion was as much as 9 times the wave height. For stronger springs it was much less or about 0.9 times wave height. There was no attempt to relate the results to actual marina conditions. This study was clearly intended to be the first part of an extensive program to examine the response of small craft when moored.

The second study, also reported by Raichlen (1968a), was a continuation of the first and included some calm water measurements of the natural periods of actual boats. The theoretical analysis was expanded to include non-linear mooring forces but it was necessary to exclude hydrodynamic dampening in order to obtain a closed form solution. Also the solution provided only the first harmonic of the boat response with a rational to show that higher harmonics are, for most purposes, negligibly small.

The primary report (Raichlen, 1968b) includes an extensive study of elastic properties of mooring lines, emphasizing hemp, but including nylon which is used almost universally at the present time. The data for nylon shows a linear relationship between tension and elongation, up to about 10 percent elongation, and for greater strains elongation varies with tension to about 2/3 power. Nylon is shown to have 3 to 4 times the stretch of dacron making it useful as a shock absorbing mooring. The data also shows different stress-strain curves for new nylon and broken in nylon but the comment is made that the line must be heavily stretched to break it in and that small craft moorings probably never achieve this level of stretching. Breaking strengths of three strand nylon are also given and representative values are 3700 lbs for 3/8 inch line, 6400 lbs for ½ inch line and 10,400 lbs for 5/8 inch.

Field studies were conducted on a 26 foot power boat (7000 lbs fully loaded) to determine its natural response in a calm moorage. The boat was moored in a U-shaped slip with 2 bow lines and 2 stern lines. To measure the response,the boat was pulled ahead (or astern) in its moorings and released and its motion recorded with a movie camera. The natural period of oscillation varied considerably according to the amount of slack in the lines. Zero slack (taut) resulted in 2 to 3 second periods while 8 inches of slack in each line resulted in 20 second periods. The data is shown to agree reasonably well with the analytical predictions.

The analysis also predicts the peak response to standing wave conditions but no data is given to substantiate these results. Nevertheless, they do show that slack lines result in much greater response in surge than do taut lines. This, of course, confirms the common requirement of spring lines. Taut lines keep the natural period of response as low as possible, hopefully lower than the natural period of the waves.

The third study, which is ongoing, consists of taking single frame movie footage of yachts in a marina on a steady basis. The motions of the yachts will be measured from the movie frames and compared with wave bouy data. No results are available at present (1979) but will be from the U.S. Army Corps of Engineers, at the completion of the program.

In addition to these small craft tests, a program of analysis, laboratory tests and field tests on floating breakwaters has been sponsored by the U.S. Army Corps of Engineers and conducted by faculty of the University of Washington. Floating breakwaters have some properties in common with small craft as can be appreciated when breakwater cross-sections are compared with small craft profiles. The lengths (widths in the case of breakwaters) and drafts are of the same order of size. Of course, breakwaters are long in the direction of the wave crests, while small craft are quite slender. This length provides quite a simplification in the analysis and testing of breakwaters because they can be considered two dimensional, while small craft are highly three dimensional.

Adee and Martin (1974) describe a two dimensional theoretical analysis of the motions and mooring forces of floating breakwaters. The breakwater can have a fairly general cross-section, including a twin pontoon arrangement. The wave motion is treated as a linearized boundary value problem of potential flow, that is the boundaries (the water surface and the breakwater) move but the displacements are not large. The movement of the breakwater is computed on the basis of the hydrodynamics of the surrounding fluid, ignoring mooring contraints. The solution provides the three components of motion and the magnitude of the transmitted wave. Mooring forces are determined using a static catenary analysis and matching the displacements to the forces required. The major shortcomings are that only small motions are treated (linearization), that potential flow without friction or flow separation is assumed and that the role of mooring forces in influencing the motion is ignored. Nevertheless, Adee (1976) reports good agreement with flume data when the radiation dampening (caused by energy lost due radiated waves) is multiplied by two to account for viscous dampening

As part of the floating breakwater program, field measurements were made of breakwater performance at several sites on the coast of Alaska and Washington. Instrumentation was provided to measure the incident and transmitted waves, the wind speed and direction, the mooring forces and the accelerations associated with the three motions of the breakwater (heave, sway and roll). Christensen and Richey (1976) summarize the results of these tests and make comparisons with analytical predictions by Adee. They state that the numerical model gives good predictions for the transmitted response, slight under estimation of anchor cable forces and an over estimation of breakwater motion responses.

A somewhat more realistic mathematical model of the response of a floating breakwater is described by Isaacson and Fraser (1979). It attacks the same problem as Adee but uses a more refined approach. The hydrodynamics are still treated linearly but a finite element approach is used. The main advance is that the effect of the mooring cables on the breakwater motion are incorporated by considering the cables to have a linear dynamic response centered around the static catenary position, and by feeding both the non-linear static catenary forces and the linear dynamic forces into the breakwater response analysis. The steady drift force caused by the waves is also incorporated to tension the seaward anchors more than the shoreward ones.

Isaacson finds that the moorings substantially affect the breakwater motion and thereby the wave transmission, with tauter cables allowing less motion. Because of the non-linear mooring forces, steeper waves also cause porportionately less breakwater motion and less transmission. Although the curves generated resemble existing model and prototype data, no direct comparisons between theory and actual performance are made.

The forces associated with mooring large vessels can be very large and they must be determined with some degree of certainty before an acceptable mooring design can be achieved. For this reason there have been a number of field, model and analytical studies of large vessels conducted and reported in the literature. These are of limited value to this study because the conditions are quite different in as much as parameters important to large vessels can be neglected in studying small vessels and vice versa. For instance, much larger dockside motions, relative to the vessel size, can be tolerated in small craft harbours because the problem of handling the fendering forces is much less severe.

A rolling motion of 15 degrees could be tolerated in a small craft marina but would be disasterous at a tanker terminal. As a result, the design waves are not nearly as steep for large vessels as for small craft, so that linear approximations are more successful. Also, it is possible to restrain certain motions of small craft by taut moorings using reasonable sized mooring lines, whereas large vessels would exert enormous loads if restrained this way. Large vessels are also much more regular in shape, resembling for most purposes a large rectangular prism while small craft, expecially sailboats, have shapes and inertial properties that are difficult to define in any simple terms. Most important is the fact that for large vessels it can be assumed that the mooring line forces have a negligible effect on the vessels' oscillations whereas they are very important for small craft.

Physical modelling represents one method of determining mooring motions and loads for large vessels but the costs are considerable and the number of parameters that can be varied is limited. Mathematical modelling has become an alternative that promises to replace much of the need for physical models. One such model, MOSA2, is described by Seidl (1978). Basically MOSA2 computes movement of a moored vessel in its six components. It is based on strip theory whereby the hull is divided into cross-sectional slices so that each slice heaves, rolls and sways under the action of the waves. All six components of the ships motion can be formed by these three motions of the slices. In large vessels the cross-section shapes are quite regular and the forces involved when the cross sections heave, roll or sway in a calm sea are fairly readily evaluated. So are the forces on a section imposed by the presence of wave action. These can then be integrated over the entire vessel to obtain the coefficients necessary to solve the six equations of motion to obtain the boat response. In some instances, one component of motion will cause a force that affects another component and the motions are said to be coupled and the corresponding equations of motion must be solved simultaneously. This can be done readily for periodic waves.

MOSA2 has the ability to compute the various forces on the different sections and to integrate them to obtain the necessary coefficients. If the mooring forces are linear, and the waves regular, MOSA2 can solve the six equations of motion to obtain the motions and corresponding mooring forces. If the waves are irregular and mooring forces are still linear, MOSA2 can compute the spectrum of vessel motions and mooring forces that corresponds to the sea spectrum. This can be called a frequency domain solution. Step by step integrations through time (time domain solutions) are also possible with MOSA2 with a non-linear mooring system. Non-linear mooring systems can also be handled on a periodic basis if the assumption can be made that the mooring forces are not strong enough to affect the vessel motions. Unrestrained motions are computed first and the forces necessary to extend the moorings the required amount are then computed directly.

Complex programs such as MOSA2 are not considered appropriate for small craft response for several reasons. The irregular hull geometries of small craft are not suited to the strip theory approach, and also moorings are non-linear and have a strong affect on boat response. (Time domain solutions are costly and time consuming). Furthermore, viscous damping associated with flow separation around a vessel's hull may be more important for the larger relative motions of a small craft. On the other hand, the degree of accuracy required for satisfactory design of large vessel moorings is much more than required for the small vessel responses needed for this study and a much simplified analysis will do.

IV. EXISTING CONDITIONS IN SELECTED CANADIAN MARINAS

Six marinas were visited in British Columbia and six more in eastern Canada to determine the conditions that exist and the wave distress that has been experienced in typical Canadian marinas. In all marinas visited, discussions were held with the owners or operators and information was sought as to wave conditions experienced, the damage that has occurred and any other relevant information that could be provided. The most extensive study was directed at the B.C. marinas because they were close to the base of operations for NHCL. The visits to eastern Canada were included so as to be cognizant of the differences and similarities that might affect marinas across Canada. In B.C., wind records were searched to determine past wind storms and wave hindcasts were made to estimate significant wave heights outside the marina. The operators were asked about records or recollections they had regarding these storms. In addition wave measuring instruments were placed at one group of B.C. marinas.

4.1 B.C. Marinas

The locations of B.C. marinas investigated are indicated on a map of the Strait of Georgia on Dwg. 4.1.1. The Strait is sheltered by Vancouver Island and generously provided with islands and mountain fjords to make it ideal for pleasure boating. The marinas include Mosquito Creek within Vancouver harbour, the Fisherman's Cove group and Eagle Harbour Yacht Club near Vancouver, Schooner Cove on Vancouver Island and Beach Gardens further north near Powell River. Wind records are available from meteorological stations at Point Atkinson, Ballenas Island and Merry Island located also on Dwg. 4.1.1. Point Atkinson winds are a good measure of the wind at the Fisherman's Cove group and Eagle Harbour. Ballenas Island is close to Schooner Cove but there is no meteorological station near Beach Gardens except for Merry Island which is 35 miles to the SE at the other end of Malaspina Strait. Winds are not important at Mosquito Creek inside Vancouver harbour.

Table 4.1.1 lists the strong wind events, recorded during the years 1974 thru 1977 at these stations. The cut off was 30 mph at Point Atkinson and 40 mph at the other stations. This table will be used to identify storms at these marinas for later discussion.

4.1.1 Fisherman's Cove Group and Eagle Harbour Yacht Club

As shown on Dwg. 4.1.2, there are three separate marinas in Fisherman's Cove, Thunderbird Marina deep within the cove, West Vancouver Yacht Club nearer to the entrance and Fisherman's Wharf at the entrance. Located nearby in another cove is the Eagle Harbour Yacht Club. These marinas received the most study. A wave staff was located at the seaward end of the Fisherman's Wharf floats and a wave rider buoy was located off the entrance to measure the outer harbour waves. These were installed and maintained for one year from April 6, 1979 by the Marine Environmental Data Services Branch.

Thunderbird Marina is completely protected from wave action because of its location and the West Vancouver Yacht Club receives only occasional surging which never causes any real problem. Fisherman's Wharf does receive good wave action from a westerly wind but the fetch to the west is only 3 miles so that a breakwater has never been provided.

TABLE 4.1.1

STRONG WIND EVENTS NEAR B.C. MARINAS

EXCEEDING 40 mph (30 mph AT POINT ATKINSON)

Date	POINT ATKINSON			BALLENAS ISLAND			MERRY ISLAND		
	Duration above 20 mph (hrs)	Peak Wind (mph)	Direction	Duration above 30 mph (hrs)	Peak Wind (mph)	Direction	Duration above 30 mph (hrs)	Peak Wind (mph)	Direction
8 3 74							9	41	E
9 3 74	8	41	E				22	44	E
17 11 74				6	41	ESE			
12 12 74				3	40	ESE			
14 12 74				3	41	ESE			
4 1 75				4	40	E			
5 1 75				8	48	ESE			
7 1 75				6	43	E			
30 1 75				16	44	E			
31 1 75				7	43	E			
15 2 75				4	40	E			
19 2 75	3	49	W						
17 3 75	6	40	E	6	40	SE			
21 3 75				14	49	SE			
30 3 75	9	46	W						
19 4 75	4	39	W						
7 8 75							6	40	SE
3 10 75							3	44	SE
24 10 75				4	46	E			
25 10 75				8	44	SE			
6 11 75	7	42	SE				9	49	E
12 11 75				6	41	SE	7	44	E
13 11 75	14	40	SE	12	46	ESE	12	48	E
13 2 76				2	40	SE			
10 3 76				12	46	SE			
23 3 76				8	42	ESE	13	42	E
21 2 77				(Incomplete records			15	43	ESE
25 2 77				June 76 to Oct. 77)			7	45	ESE
6 3 77							5	40	ESE
25 5 77							6	45	ESE
27 5 77							5	39	SE
1 11 77	4	38	E	11	46	E	10	45	E
6 11 77				8	40	E			
9 11 77				8	40	E			
12 11 77	4	36	E	5	41	ESE	9	41	ESE
14 11 77							8	40	SE
5 12 77				7	42	E			
8 2 78				6			6	43	SE
7 3 78				10	44	E			

There is a much longer fetch to the southeast but the harbour is quite well protected from that direction. Eagle Harbour is naturally protected from the west but very open to the southwest and has had some bad experiences from storms in that direction. Fortunately, the winds very seldom blow with any strength from the southwest. In fact, none of the wind records of Table 4.1.1 show a southwest wind. Three events with winds from the west at Point Atkinson are listed, all occurring in 1975.

TABLE 4.1.2

WAVE HINDCAST FOR STORMS AT FISHERMAN'S COVE

Date	Peak Wind Speed (mph)	Direction	Fetch (Miles)	Significant Wave Height (ft)	Significant Wave Period (sec)
19 2 75	49	W	3	4.4	4.3
30 3 75	46	W	3	4.0	4.0
19 4 75	39	W	3	3.5	3.7

If these winds were from the WSW over the 12 mile effective fetch these storms would produce a significant wave with about 7 foot height and 5.5 sec period.

As mentioned above, a wave rider buoy was installed in the open sea in front of Fisherman's Cove and a Kelk gauge was installed on piling at the seaward end of the gasoline service float in the entrance to Fishermans Cove. A wave rider buoy is a tethered float that rides on the water surface, measures its own motion with an accelerometer and transmits the data to a shore based tape recorder. The kelk gauge is a staff, fixed firmly to a pile or wall, that measures water level directly and feeds the data to a tape recorder.

Both instruments were set to sample for twenty minutes every three hours. The tapes obtained were sent to Ottawa to be analysed by computer which analysed the data to provide the wave spectrum, the peak period and the significant wave height for each sample. The computer also produced monthly summaries of the data. Table 4.1.3 summarizes the monthly data available. According to this table, the wave climate is rather quite and does not change much from month to month. The highest seas were recorded in October with a significant wave height of 2.9 ft. for one timed interval. The kelk gauge data was not available for that period unfortunately. The highest waves in the harbour entrance were recorded in the spring months when the wind is mostly from the west. The highest significant wave height recorded in the harbour was 1.5 feet in April. In the harbour entrance, conditions were calm over 90 percent of the time and the wave height was less than 1 foot over 98 percent of the time.

Both wave and wind data were collected for specific high wave events during the spring and these are listed in Table 4.1.4. The wind data is from Point Atkinson. Twelve events are shown from April 6 to June 6 with significant wave heights in the harbour entrance varying from 1.6 feet to 0.5 feet. Most are associated with a west wind but three events resulted from east winds at Point Atkinson. These are likely diffracted waves from around Point Atkinson. The wave heights recorded at the wave rider are, of course, higher than those at the kelk gauge but the peak periods are also higher and more widely scattered. The spectral analyses for the wave rider buoy is very irregular with many peaks. Apparently the longer waves approach from directions that prevent them from entering the harbour.

TABLE 4.1.3

SUMMARY OF MONTHLY WAVE DATA AT FISHERMAN'S COVE

	Wave Rider, Outside of Fisherman's Cove				Kelk Gauge, Entrance to Fisherman's Cove			
Month	No. of Observations	Percent Calm	Significant Peak	Wave Height in Feet Exceeded 2% Time	No. of Observations	Percent Calm	Significant Peak	Wave Height in Feet Exceeded 2% Time
April	171	61	2.1	1.7	138	93	1.5	0.7
May	244	60	1.6	1.3	200	92	1.2	1.0
June	228	62	1.6	1.3	238	85	1.3	1.0
July	221	67	1.5	1.0	248	92	1.2	0.8
August	247	60	1.2	1.0	248	95	1.0	0.5
September	233	63	2.4	1.6	165	97	1.0	0.2
October	247	64	2.9	1.4	-	-	-	-
November	190	74	1.6	1.0	-	-	-	-

TABLE 4.1.4

SUMMARY OF HIGH WAVE EVENTS AT FISHERMAN'S COVE

(SPRING OF 1979)

Date	Peak Hourly Wind At Point Atkinson in MPH	Peak Wave Height and Peak Period Wave Rider		Kelk Gauge	
April 6	W 34	1.8 ft.	4.5 sec.	1.6 ft.	2.5 sec.
April 7	E 23	1.0	3.0	0.5	3.0
April 12	E 36	1.7	3.9	-	
April 13 3 am	E 30	2.1	3.6	-	
April 13 6 pm	W 17	1.7	3.6	-	
April 16	W 24	1.5	4.1	-	
April 22	W 17	0.7	2.5	0.5	2.8
May 9	W 21	1.2	3.7	-	-
May 18	W 31	1.5	2.3	1.2	2.4
June 5	W 30	1.4	2.4	1.1	2.8
June 6 1 am	W 34	1.6	5.0	1.3	2.5
June 6 10 am	W 34	1.4	4.2	1.0	2.8

Thunderbird Marina is a large, rather deluxe, commercially operated marina with a wide range of services located well within a very protected harbour so that wave distress is not a problem. It has a capacity of 862 boats and 745 boats were in moorage when NHCL made its survey. Sailboats amounted to 45 percent of those present. The sailboats ranged from 15 feet to 43 feet with 90 percent between the sizes of 19 feet and 30 feet. The average length was 23 feet. Powerboats ranged from 14 feet to 46 feet with 90 percent between 15 and 32 feet and an average length of 22 feet.

The boats at Thunderbird are moored to wooden fingers 3 feet wide with styrofoam flotation and these are connected to walkways 5 feet wide made of concrete pontoons fastened together with wooden stringers. The boats are moored by fastening to rings held to the fingers by eye bolts. Photo 4.1.2 shows the badly frayed line in use by one boat owner in this quiet marina. In the NHCL sampling, less than 25 percent of the boat owners here used more than 2 lines. The operators of the marina report virtually no wave distress and no incidents of damage due to waves of any kind.

The West Vancouver Yacht Club is a well established private club in a location that is almost as well sheltered as Thunderbird Marina. Some of the entrance swell reaches the outer floats and it is susceptible to the boat wash of the larger boats entering or exiting Thunderbird Marina. Nevertheless, damage or distress due to waves is non-existant. The capacity of the marina is 240 boats and NHCL counted 207 moored at the time of survey of which 70 percent were sailboats. Sailboats ranged from 20 feet to 50 feet in length with 90 percent between 24 and 40 feet in length. The average sailboat length is 33 feet. Powerboats ranged from 18 to 55 feet in length and also averaged 33 feet long.

The floats at the West Vancouver Yacht Club are also concrete and quite similar to Thunderbird. It was found that, in general, heavier moorings were used, partly because the boats were larger and partly because of the greater experience of the club members. Braided or three-strand nylon was common with diameters ranging from ½ inch to 1 inch. Most boats used 3 or 4 lines but very few used full length spring lines in this well protected marina. Moorage was typically against a finger float attached to the main walkways. Floats were aligned so that the boats faced the entrance swell but were beam to the wash from passing boats.

Fisherman's Wharf Marina, at the entrance to Fisherman's Cove, is principally a yacht sales and repair basin with moorage for 80 boats, divided between yacht sales and individual use. The mixture is approximately 40 percent small powerboats (average length is 17 feet) and 60 percent sailboats with an average length of 25 feet. The moorage is open to the westerly seas described earlier and experiences the wave climate measured by the kelk gauge.

The boats are moored to wooden fingers connected to wooden floats buoyed up by styrofoam. The floats are getting old and need regular maintenance to replace broken planks or loose connections (Photos 4.1.3). The wave that comes in adds to the maintenance problem and a float gave away on at least one occasion causing boats to bash against each other until help came. The damage was only cosmetic. Day to day movement of the floats weaken them so that they are vulnerable to even moderate wave action according to the owners.

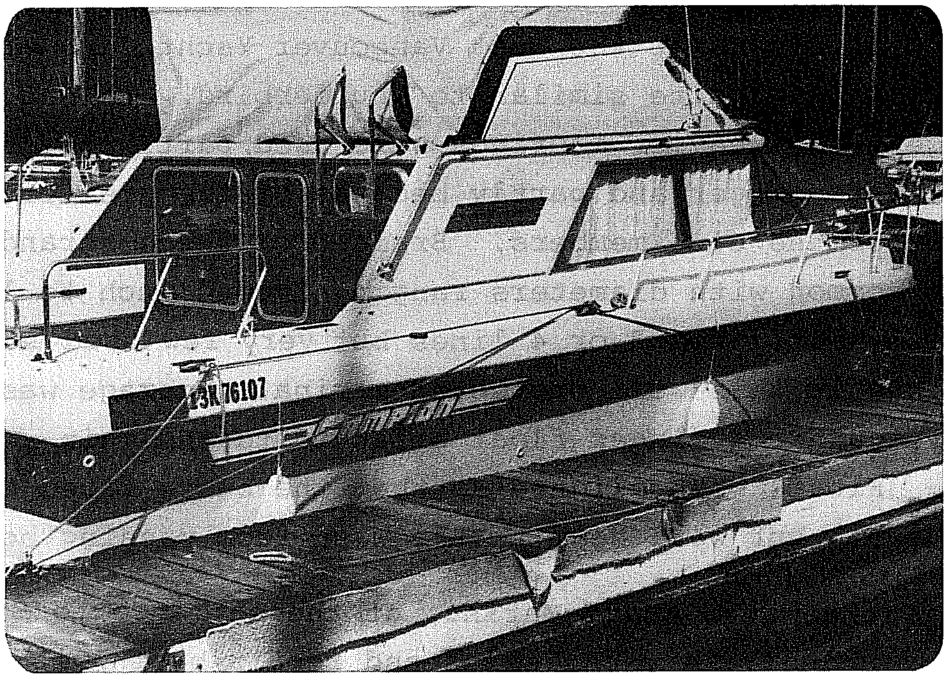


Photo 4.1.1. Powerboat moored to a wooden finger at Thunderbird Marina with spring lines fastened to a cleat at mid-ships.

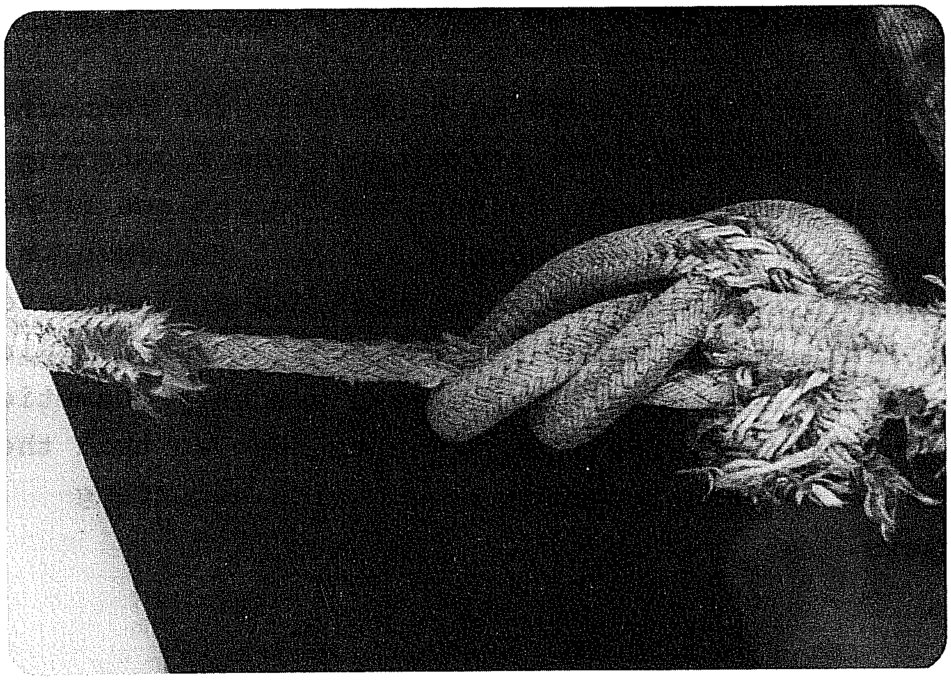


Photo 4.1.2 Badly frayed braided nylon mooring line at Thunderbird Marina.

The operators insist on proper moorage practice and this marina had the highest usage of spring lines of any we visited (Photo 4.1.4). At least ninety percent of the boats had four lines including two springs. Rather than using slack breast lines some boat owners use rubber or coil spring shock absorbers (Photo 4.1.5). Mooring lines are attached to the floats using steel rings fastened by eye bolts.

The smaller power boats at Fisherman's Wharf are moored with stern mooring rods (Photo 4.1.6) that hold the boat rigidly but are hinged to allow movement in heave and pitch.

No records are kept of boat or float damage at Fisherman's Wharf but the operators were not able to recall any boat damage other than an occasional scrape, broken rub rail or pulled deck cleat. Float maintenance is an ongoing low level activity at this marina. The operators expressed the opinion that any boat properly moored (springs and breast lines) and properly fendered can withstand much more wave action than can the floats. The marina, however, experiences only relatively short waves that cause high heave and pitch but relatively little surge.

The Eagle Harbour Yacht Club has moorage for 90 boats including those moored at buoys near the harbour entrance. The mixture is approximately 65 percent sailboats with an average length of 27 feet. The powerboats average 24 feet in length. The club has a history of wave problems and corresponding attempts at solution. The entrance is deep so that breakwaters must be the floating type. Prior to 1970, protection was provided by an old naval hull but it sank during a storm taking with it a yacht that was moored alongside. Several other floating breakwaters have been

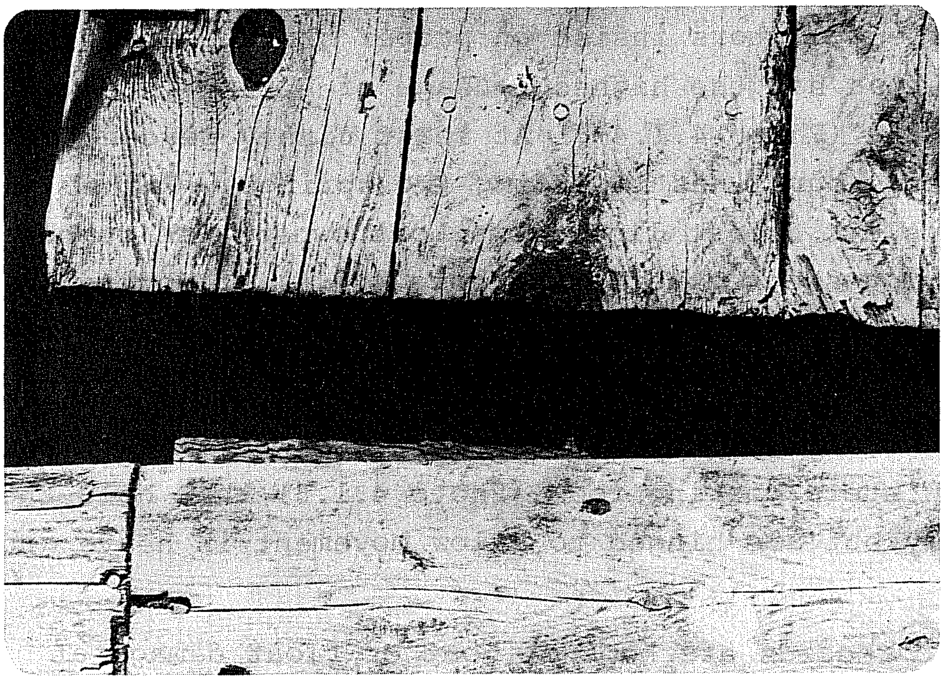


Photo 4.1.3 Worn planks where floats connect at Fishermans Wharf Marina.

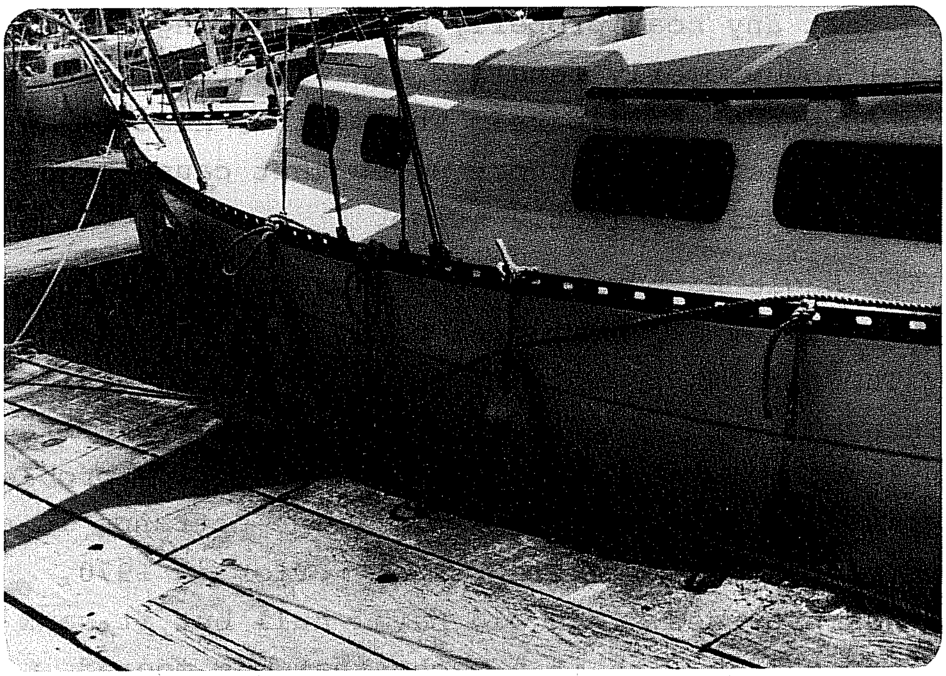


Photo 4.1.4. Yacht properly moored with spring lines and breast lines at Fisherman's Wharf Marina.

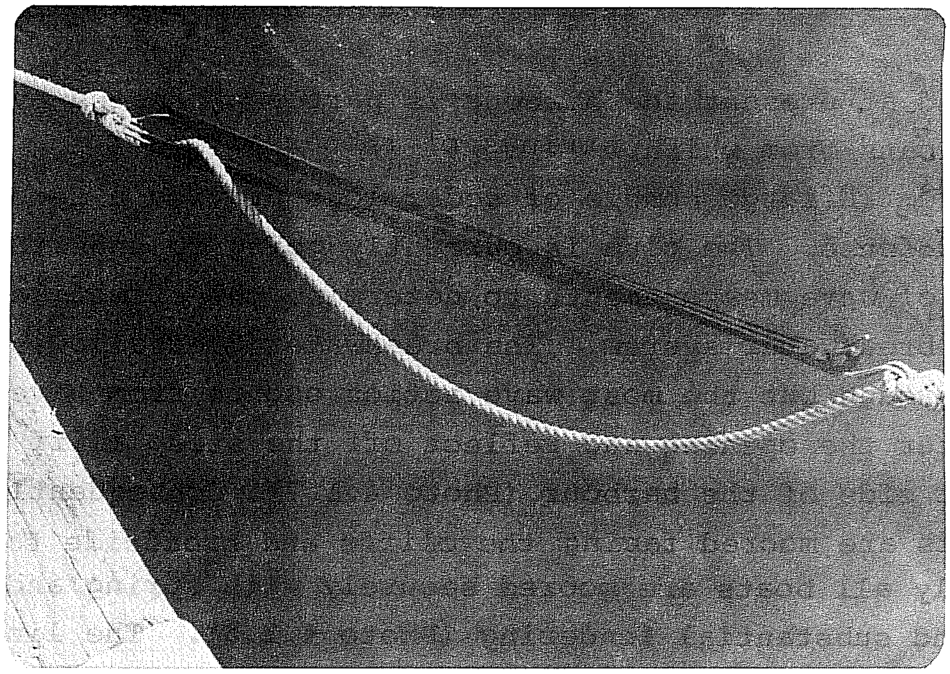


Photo 4.1.5 Breast line with rubber shock absorber at Fisherman's Wharf Marina.

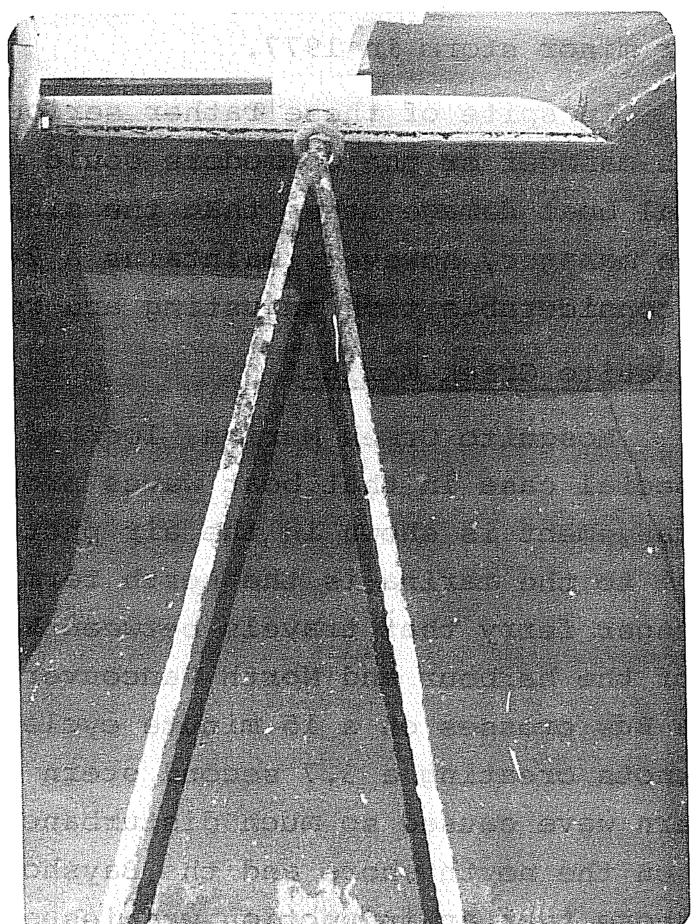


Photo 4.1.6 One of a pair of stern mooring rods that permit heave and pitch but restrain all other motions.

tried and at present the harbour is partly protected by steel floats from which strings of rubber tires are suspended. A large bundle of cedar logs provide a second row of defense. The club is currently going to undertake a program of wave measurements to determine the effectiveness of this breakwater system. The breakwater does allow some swell through but the most wave action occurs from waves that enter the opening and reflect off the steep cliff on the east side of the harbour (Photo 4.1.7). Consequently the boats are moored facing the cliffs and broadside to the swell. Virtually all boats are moored securely with spring and breast lines and substantial fendering (Photo 4.1.8). The lines are tied to a wooden rail that is bolted to the wooden floats. Most of the floats are new, having replaced older floats that broke up following a breakwater failure during a rather minor storm in 1977.

In spite of these rather serious conditions neither the club manager or the Commodore could provide instances of actual boat damage other than the sinking mentioned above. The club manager, however, maintains a 24 hour patrol and spends considerable time adjusting and replacing lines.

4.1.2 Mosquito Creek Marina

Mosquito Creek Marina, located in Vancouver harbour, is a special case in that boat waves provide the wave distress. The arrangement is shown in the air photo on Dwg. 4.1.2. Adjacent to the marina is the north terminal of the Sea Bus, a passenger ferry that travels between Vancouver on the south shore of the harbour and North Vancouver on the north shore. The Sea Bus crosses on a 15 minute cycle and used to travel at 13 knots creating a 3.7 second stern wave 2 to 3 feet high. The stern wave caused so much disturbance in Mosquito Creek Marina on the north shore and the Bayshore Marina on the south shore that an injunction was issued to reduce the speed of the Sea Bus, particularly as it approached the terminals.

Photo 4.1.7 Yachts moored broadside to entrance swell at Eagle Harbour Yacht Club, B.C.

Photo 4.1.8 Yacht at Eagle Harbour Yacht Club, with heavy fenders to protect against beam seas.

Presently the wave height reaching Mosquito Creek amounts to about 0.7 feet and the complaints have subsided. This marina was placed on the list of marinas for Dr. Ward's group to interview because of the boat wash problem. There were instances of boat and dock damage cited but in all cases the amount of damage was small.

4.1.3 Schooner Cove Marina

Schooner Cove Marina is a commercially operated marina catering mostly to sport fishermen but providing some moorage to small commercial fishing craft and also to sailboats belonging to a local yacht club. With existing floats, the capacity of the marina is 370 boats. NHCL counted 56 sailboats ranging from 14-foot to 50-foot and averaging 25 feet in length with 80 percent between 20 and 30 ft. long. The number of power boats were 198 ranging from 12 feet to 50 feet in length. The average length was 21 feet and 90 percent were less than 24 feet long.

The marina is protected from southeast swells by a rubble mound breakwater (Photo 4.1.9) but the entrance is still wide enough to allow strong wave action into the marina. The floats are wooden with styrofoam flotation and are continuous with very few connecting points (Photo 4.1.10). Even the fingers are solidly attached. The floats are kept in position with wooden piling (Photo 4.1.11). The moorage cleats are wooden and only fastened to the docks with spikes. They can be pulled out by continuous yanking from a mooring line but this may be a benefit if it prevents the more expensive boat cleats from breaking off. Mooring practices were not as consistently good as expected in this marina with its history of high wave distress. Few boats used spring lines and most boats were tied with rather short lines that were pulled tight. A good number of boats had chafing gear, such as mooring lines threaded through rubber hoses, to prevent abrasion. Many had rubber or coil-spring shock absorbers in their lines. All these were adaptions to the wave conditions experienced at the marina.

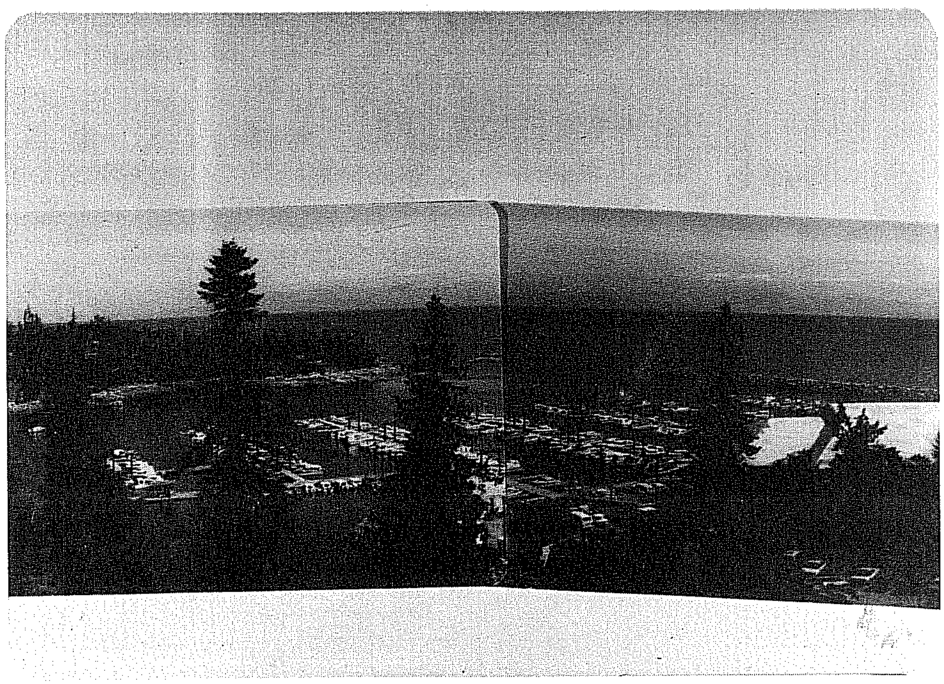


Photo 4.1.9. Panorama view of Schooner Cove Marina looking east showing rubble mound breakwater to south east.

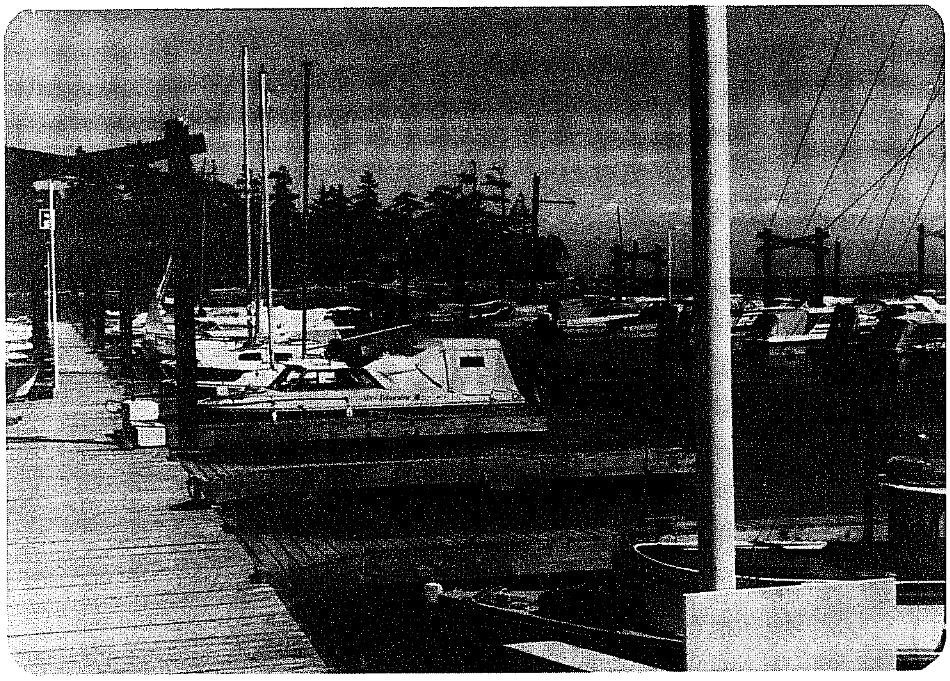


Photo 4.1.10 Continuous Float and Finger Construction at Schooner Cove Marina.

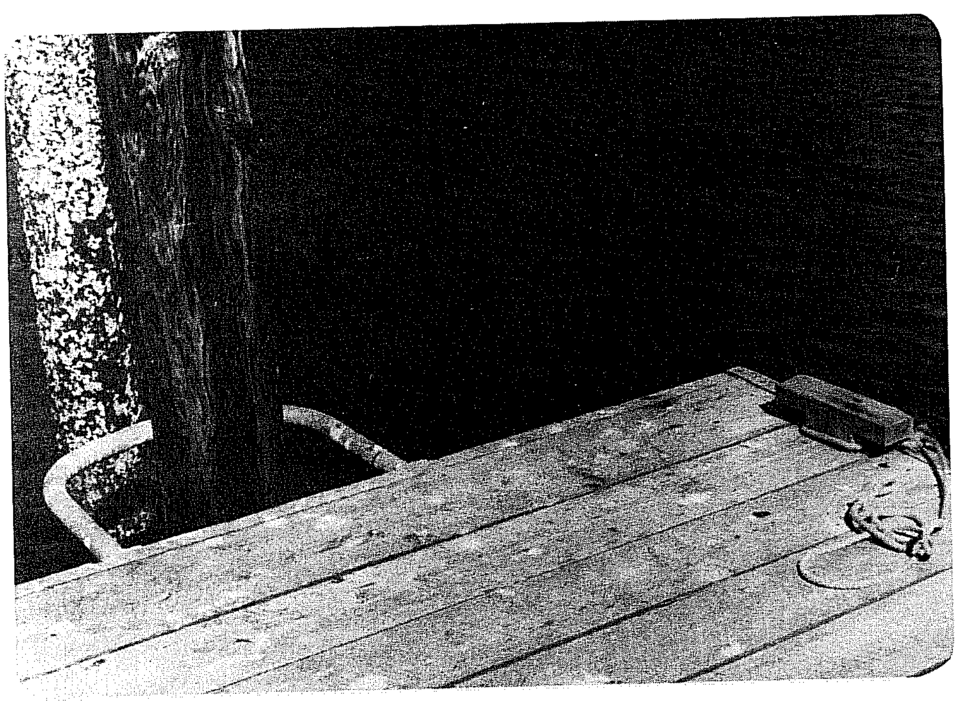


Photo 4.1.11 Float and Timber Pile Attachment and Wooden Mooring Cleat.

The entrance to Schooner Cove is open to waves from the east to the southeast but the easterly fetch is limited to about 2 miles by the Winchelsea Islands and the Ada Islands. And the southeast direction is limited by Southery and Maude Islands. However, the ESE is open for 40 miles. An effective fetch based on the ESE direction is approximately 10 miles. For winds around 45 mph, the significant wave for this fetch would be approximately 6 feet high with a period of approximately 5 secs. Nevertheless, there would be swells rolling in from the 40 mile fetch. They would have approximately an 8 second period. The height of the swell as it passed through the maze of offshore islands would be difficult to forecast. Table 4.1.1 shows an average of 6 events a year with winds in excess of 40 mph (but none exceeding 50 mph) at Ballenas Island with directions of E, ESE or SE. (At least 2 per year from the ESE). All these events occurred in the winter between October and March when many of the smaller boats are stored on land.

The wide opening at Schooner Cove permits some of this wave action to enter the harbour to create strong wave conditions along the north half of the marina away from the floats which are kept in the south half. Winter storms have destroyed the northernmost floats on several occasions and have created a regular repair and replacement problem. Annual costs for maintenance are estimated to be in the neighbourhood of $5000 per year.

The operators of Schooner Cove do not keep a record of boat damage but Dr. Ward's group found that owners reported damage occurring to about one boat in ten per year with an insurance claim for about one boat in one hundred per year. On this basis,total damage to boats could amount to about another $5,000 per year. This would give a total estimate of $10,000 or $27 per boat per year, based on the marinas capacity.

4.1.4 Beach Gardens Marina

The Beach Gardens Marina is located in a very exposed location with absolutely no natural protection and within a quarter of a mile of Grief Point. The harbour was formed by two rubble mound breakwaters extending from the shore as shown in Photo 4.1.12. The entrance faces southwest towards Texada Island approximately 2 miles away.

The marina was designed to accommodate 150 boats on a system of floating wooden walkways and fingers, but when visited by NHCL only 45 boats were at moorage. Approximately 30 percent of these were sailboats. The average size of all boats was 27 feet. All of the walkways were in place but less than half the number of fingers had been installed. The operator said that moorage was hard to sell here because of the wave problem from winter storms. He described 10 foot waves approaching from the southwest crashing over the breakwater at high tide and throwing logs into the marina area. In this wave action, walkways were lifted over the tops of the restraining piles and set free. Boats were sent crashing into the floats and it was impossible to walk on them. Winter storms from the southeast blow along Malaspina Strait over a fetch of 28 miles and impinge directly on the south breakwater. Substantial quantities of rock have been sloughed off the breakwater in the few years since it was built (Photo 4.1.13). At high tide, the sea crashes over the top of the breakwater setting up waves and surges in the harbour. The entrance is 250 feet wide and the southeast swell passing the entrance contributes to the wave action in the marina through diffraction.

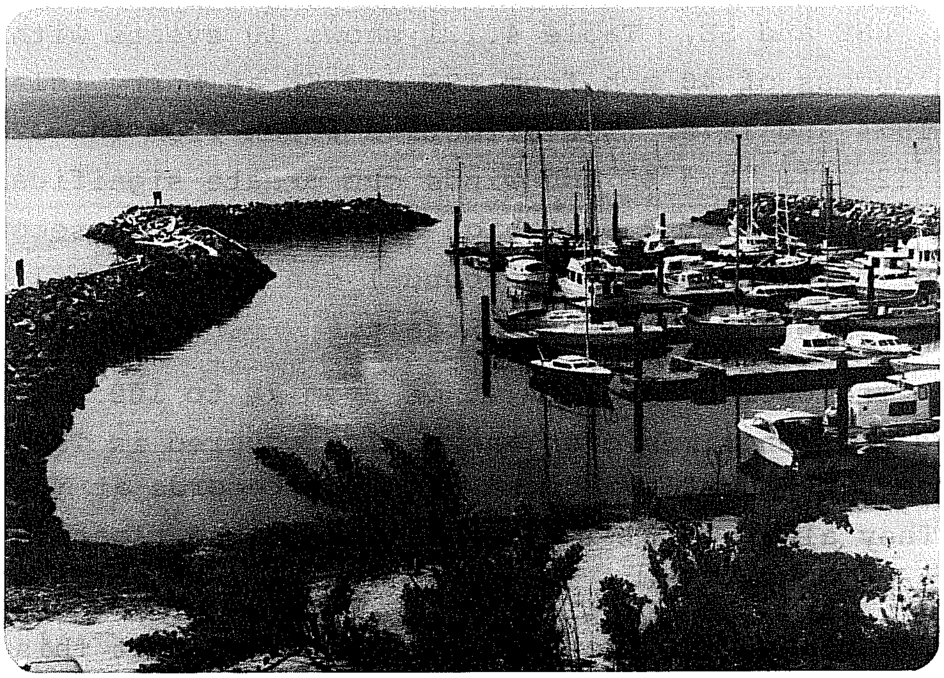


Photo 4.1.12 Beach Gardens Marina looking towards the southwest at the entrance and Texada Island in the background.

Photo 4.1.13 South Breakwater at Beach Gardens Marina showing logs cast up by wave action and void created by sloughed rocks.

The closest wind records are at Merry Island 35 miles away. The severe winds at Merry Island are from the east, ESE and SE. Table 4.1.1 shows 10 events with winds in excess of 40 mph from ESE and SE at Merry Island between 1974 and 1978. The effective fetch from the SE is about 12 miles and 45 mph winds can create significant waves in the order of 7 feet high and periods of 6 seconds. Longer period waves (up to 7 seconds) can develop utilizing the entire length of Malaspina Strait.

The operators claim winds from 70 to 100 mph occurring a dozen times over the period covered in Table 4.1.1. This exceeds by about two times the wind records at Merry Island. They also claim 6-8 foot surging of the floats during these storms.

Their costs in securing the floats against this action, particularly for special steel piling, was the order of $120,000. This would represent $25,000 per year or five times the cost at Schooner Cove. They also state that there have been over 30 insurance claims regarding boat damage and that some insurance brokers refuse insurance to boats moored there. No confirmation of these statements have been established and it conflicts with the answers provided to the SCHB questionnaire in Section V. Nevertheless, the wave distress at Beach Gardens is high and the maintenance costs are appreciable.

4.2 Marinas in Ontario, Quebec and Nova Scotia

The marinas visited in Eastern Canada were chosen to provide a variety of conditions to compare with the B.C. marinas. The Ontario marinas included the Portsmouth Olympic Harbour, the Port Credit Yacht Club, and the Port Credit Harbour, all on Lake Ontario. The Quebec Yacht Club was visited in Quebec City and the Northern Yacht Club, North Sydney, Nova Scotia.

There are some obvious differences in Eastern Canada and one of them is ice. Boating is restricted to the summer months and the boats are brought out of the water for the winter. In Ontario, the marinas are often in shallow, dredged basins. Shoreside quays (Photo 4.2.1) or fixed walkways on light piling are often used rather than floats. This makes contact of the moving boat with the fixed dock somewhat harsher than with a floating dock and boats are often tied off the dock with anchors (Photo 4.2.2).

4.2.1 Portsmouth Olympic Harbour

This harbour, located in Kingston, Ontario, at the east end of Lake Ontario,was designed for the 1976 Olympics and has been operated as a recreational facility since then. It has been plagued by wave problems from inception and an investigation and model study (Glodowski, et al, 1977) was conducted but the recommendations have not been fully implemented. The harbour is open to the south and protected from the southwest,where the strongest winds come,by an old concrete quay and a new fabricated concrete extension that is not completely solid and lets some wave action in. The entrance faces the southeast and southeast winds blow frequently enough that wave action from this direction is important. Hindcasting shows that a significant wave height of 3 ft. can be expected on average 16 hours per season from the total of all wind directions. The particular problem is that the harbour has vertical walls that reflect the waves and the study showed that a 2.5 ft. wave height (one in ten year significant wave from the southeast)could result in 3.3 ft. wave heights in the harbour itself.

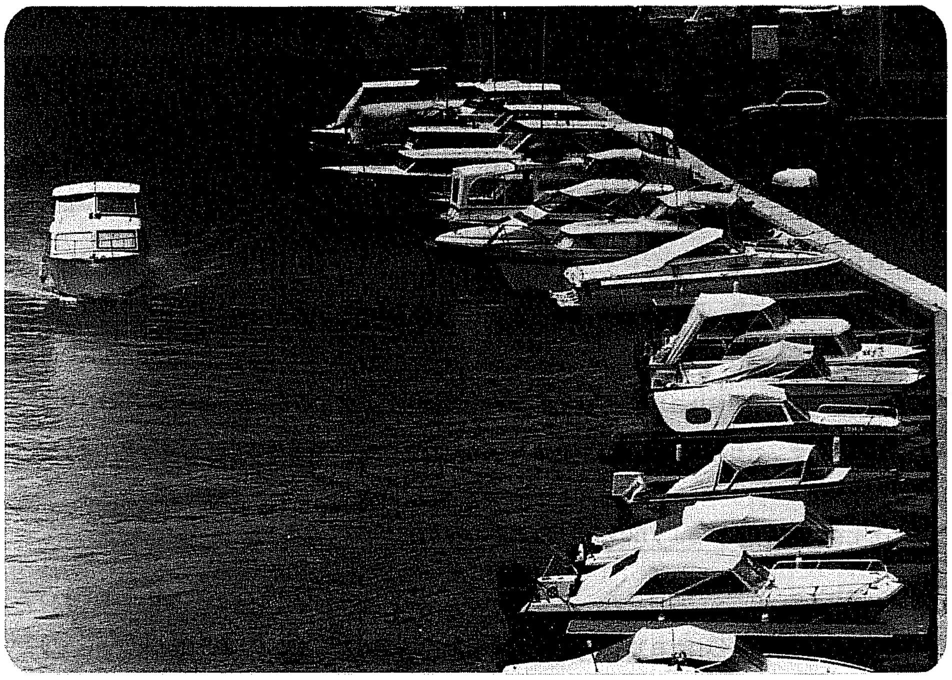


Photo 4.2.1 Boats moored against the shore in a dredged river channel in Ontario.

Photo 4.2.2 Sailboat held off from shore by stern anchors in Ontario.

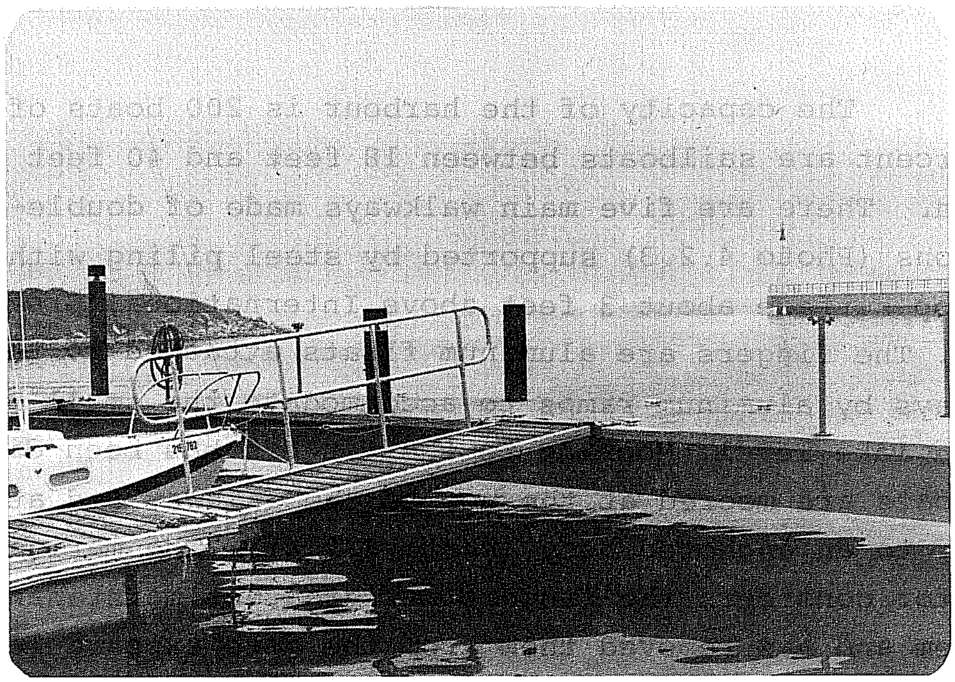


Photo 4.2.3 Fixed concrete walkways with floating aluminum fingers at Portsmouth Olympic Harbour.

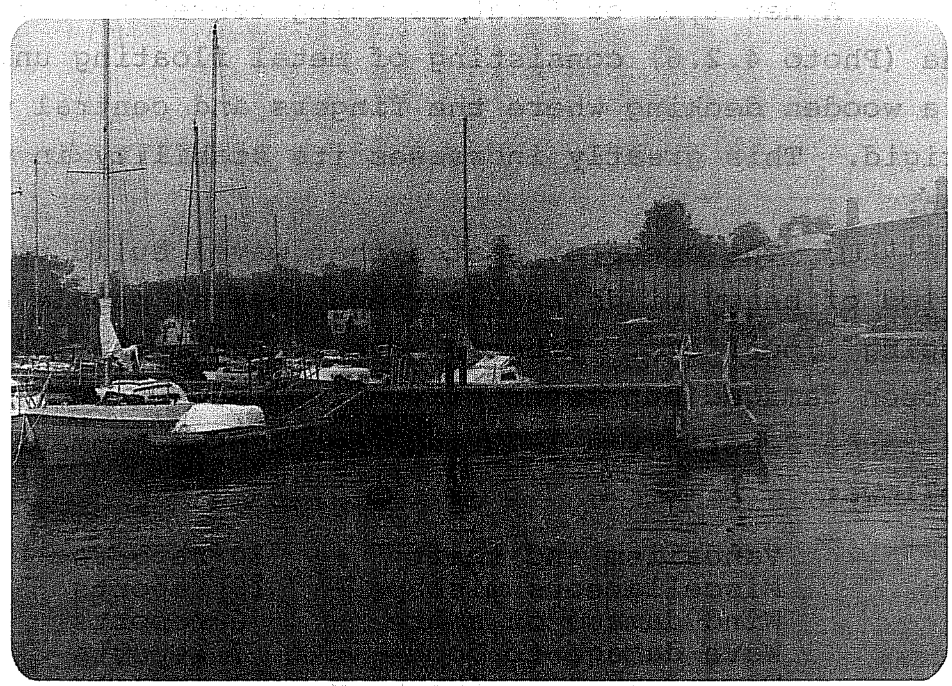


Photo 4.2.4 At Portsmouth Olympic Harbour, boats are moored to the concrete walkway and to stern anchors but not to floating fingers.

The capacity of the harbour is 200 boats of which 90 percent are sailboats between 18 feet and 40 feet in length. There are five main walkways made of double-T concrete sections (Photo 4.2.3) supported by steel piling with the top surface about 3 feet above International Great Lakes Datum. The fingers are aluminum floats attached to the concrete walkways by aluminum ramps to accommodate the small rise and fall of the lake level. Mooring to the fingers has been discouraged and boats are moored at the bow to the walkway and at the stern to an anchored buoy (Photo 4.2.4). The marina operator considers the fingers his greatest maintenance problem and has removed them from the more exposed locations and would like to dispose of all of them. In these more exposed locations the bow of the boats are kept at least five feet from the dock (Photo 4.2.5). Lines are commonly protected with chafing gear and with shock absorbers.

A new type of float is being tested at Portsmouth Marina (Photo 4.2.6) consisting of metal floating units with a wooden decking where the fingers and central walkway are rigid. This greatly increases its stability in wave action.

The operator states that waves build up after a period of heavy winds and it keeps several people busy replacing lines, etc. Fingers have broken loose. Boats have been damaged but never staved in. He has kept a file of "Occurrence Reports" in 1978 and they can be summarized as follows:

Vandalism and theft	-	30 reports
Miscellaneous mishaps	-	15 reports
Wind damage on shore	-	6 reports
Wave damage to docks	-	7 reports
Wave damage to boats	-	14 reports
Broken lines, etc.	-	12 reports
Total		84 reports

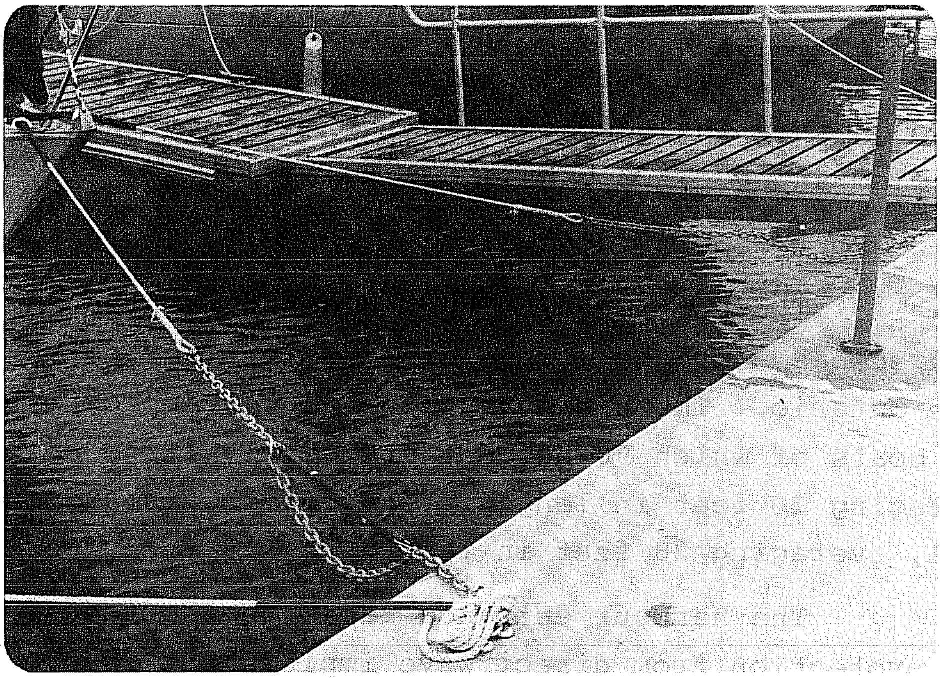


Photo 4.2.5 Boats at Portsmouth Olympic Harbour moored far from the dock to prevent damage due to surging and also to stagger their rigging.

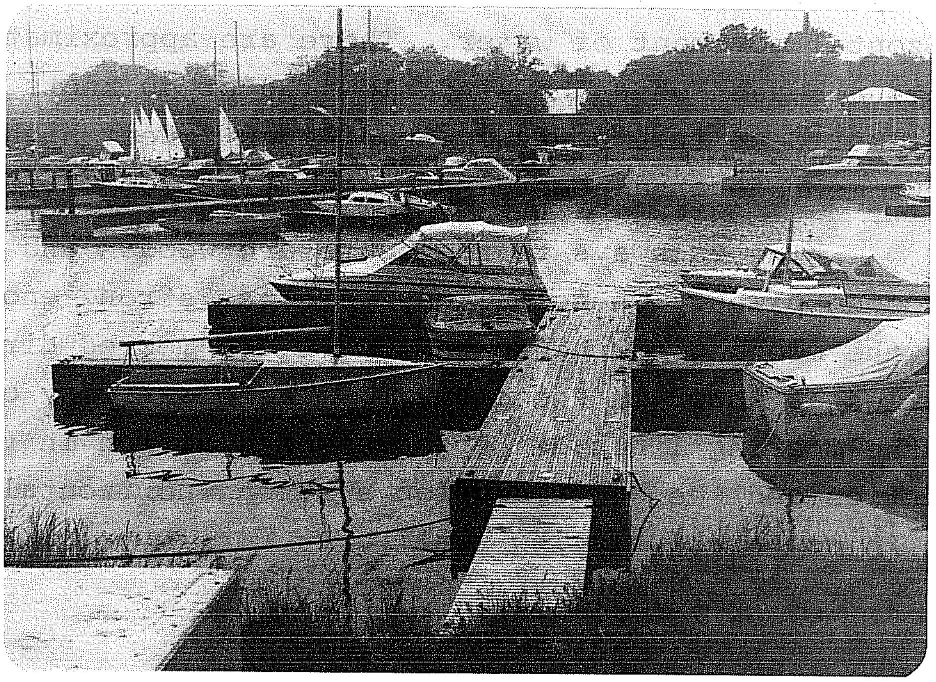


Photo 4.2.6 Experimental float unit at Portsmouth Olympic Harbour with fingers and walkway rigidly connected for increased stability.

The storm related reports were generally not too serious although they included one sinking, one boat awash and one dismasting.

4.2.2 Port Credit Yacht Club

The Port Credit Yacht Club is located in a dredged basin at the mouth of a small river emptying into Lake Ontario. The basin has moorage for approximately 200 boats of which 90 percent are fairly large sailboats averaging 30 feet in length. The powerboats are large as well, averaging 28 feet in length.

The harbour entrance faces the southeast (Photo 4.2.7) but protection from direct wave impingement is provided by the narrow river entrance and a land fill on which the clubhouse is built. However, a serious condition occurs with winds blowing along the shore from the NE. The longer waves are refracted and diffracted into the river mouth and move up into the harbour as a long low surge with considerable horizontal movement of water. There are approximately 6 bad events a season when the wind blows 30 or 40 knots and the waves build up in 6 hours or so. Waves 2 feet high have developed in the moorage area according to the Vice-Commodore.

The walkways to the boats are wooden and supported on wooden piles. These walkways are not strong enough to take the mooring forces so the boats are moored directly to piles as shown in Photo 4.2.8. The elasticity of the piles and the mooring lines set up a resonant action in the surge direction and the boats develop a strong horizontal motion even in comparatively low swell.

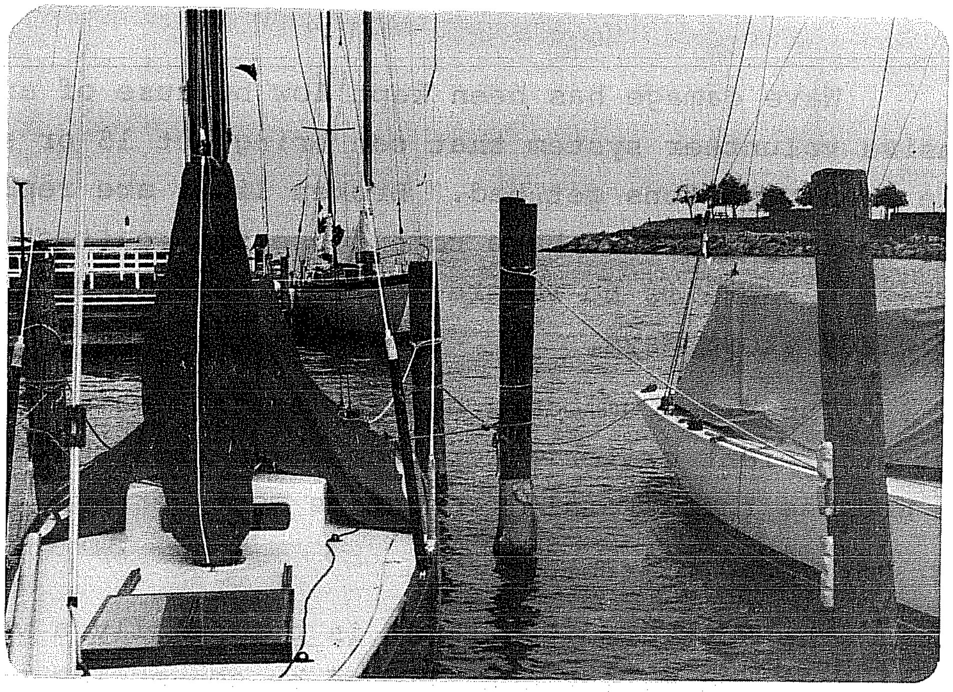


Photo 4.2.7 Boats moored to piles in the Port Credit Yacht Club.

Photo 4.2.8 Boats moored to piles without fingers at the Port Credit Yacht Club.

Wave damage has been kept low because of an extensive volunteer system that can bring out 15 or so people when conditons get bad. Broken lines are replaced and lines to piles that have come loose are reattached elsewhere. There is no record kept of specific damage or of windy storm days.

The Vice-Commodore emphasized that wave height is not sufficient criteria for long waves in a shallow basin because the lateral movement is most serious.

4.2.2 Port Credit Harbour

The Port Credit Harbour is potentially a very large and well serviced marina established by converting an old steamer dock and warehouse into a small boat harbour. The large warehouse contains marine supply outlets and repair services and provides an extensive winter storage area. The boats are moored to floating walkways and fingers that are kept in place by anchors and chain rather than piling because of the water depths present. The moorage presently occupies only 50 percent of the total harbour area. During storms, the harbour is attacked by heavy seas but is well protected by a concrete quay, an extensive rubble mound breakwater and a grounded "laker". Waves in the harbour are always less than 1 foot high even though the sea often breaks over the laker.

There is moorage for about 400 boats at floating fingers and the average length is about 30 feet. At least 90 percent are sailboats because the area is most suited to sailing and because there are not many good destinations for power boats.

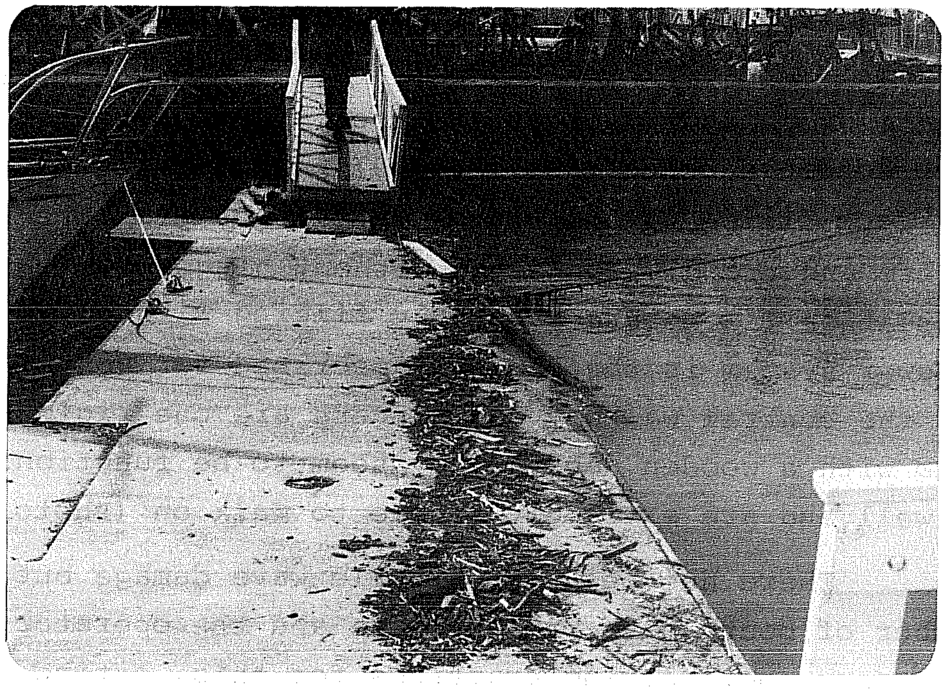


Photo 4.2.9 Hollow concrete walkways without foam flotation at Port Credit Harbour.

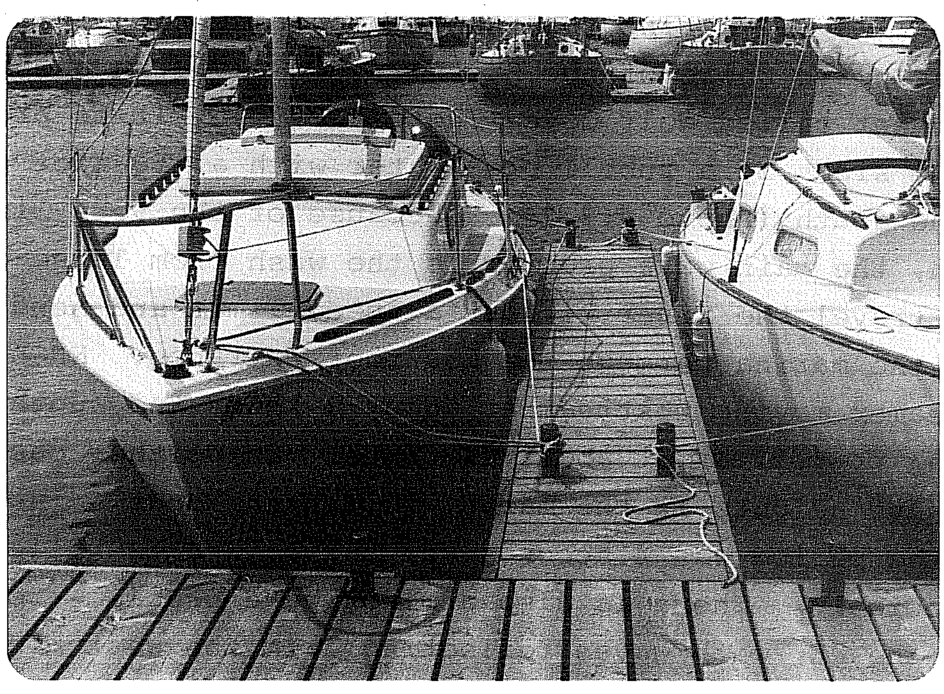


Photo 4.2.10 New rigid steel floats with wooden deck at Port Credit Harbour.

Two float systems are used. The older system consists of hollow concrete boxes (Photo 4.2.9) post tensioned together with the joint face filled with a sponge rubber gasket. The fingers are also concrete and rigidly connected without hinges for articulation. Some are presently filling with water and sinking. The newer system is the same as described for Portsmouth where the central walkway and fingers are one rigid steel system with a wooden deck. They seem to be functioning very well and are extremely stable to walk on (Photo 4.2.10).

There has been very little wave damage but a number of boats have broken loose and the operator blames very poor mooring practices for this, citing one boat tied with electric wire. No records are kept of storm events or damage.

4.2.4 Quebec Yacht Club

The marina for the Quebec Yacht Club is located on the north shore of the St. Lawrence River in a shallow embayment called Wolf Cove (Photo 4.2.11). It is protected on all sides by a rubble breakwater with a 150 foot gap to the south (Photo 4.2.12). Because of the very limited fetch, the main wave problem is the wash from large steamers that travel the river without a speed limit and send waves into the marina through the 150 foot entrance. NHCL clocked a steamer moving upstream at about 9 knots and another moving downstream at about 12 knots. In neither case were the wave heights in the marina more than about 6 inches but the period was 4 seconds and the sailboats rolled appreciably. There is also a minor wave problem from wind from the NE, with waves reflecting from the west breakwater.

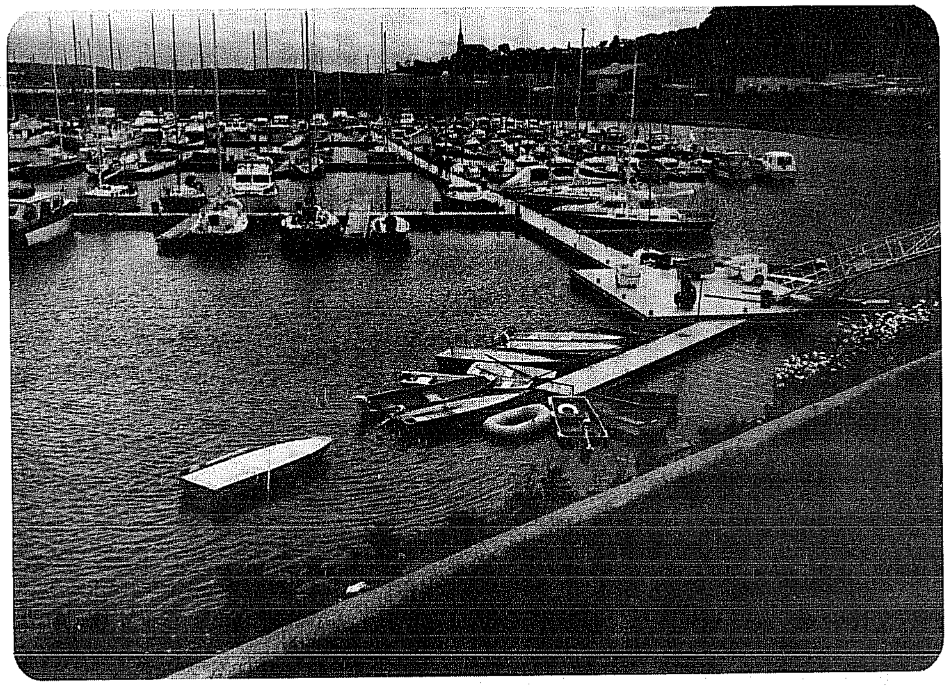


Photo 4.2.11 Quebec Yacht Club basin with hollow steel floats.

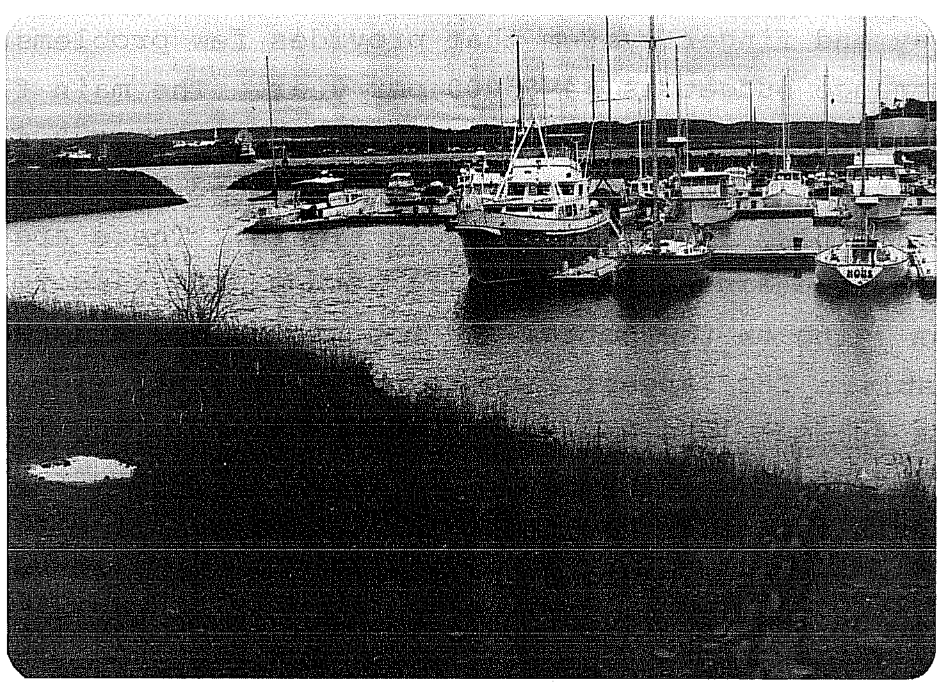


Photo 4.2.12 Steamer traffic on the St. Lawrence in front of the breakwater entrance at Quebec Yacht Club.

The marina holds 280 boats averaging 32 feet. The registry lists 295 boats, with the following breakdown.

Length	Number of Sailboats	Number of Power Boats
<20	3	1
20-23	23	5
24-27	67	12
28-31	29	30
32-35	30	23
36-39	19	8
40-45	15	9
46-50	3	5
>50	1 (52 ft)	2 (57 & 67 ft)

They seem to be moored well with frequent use of spring lines. There is ample use of large bumpers. However, the marina operators say that bumpers rise up sometimes and fail to protect the hull.

Moorage is made difficult by the 20 ft. spring tides that must be accommodated and that makes a system of piles unworkable. However, the club has an excellent floating walkway and finger system that provides few problems. The maintenance budget is $4-$5000 per year. The main floats are steel boxes (Photo 4.2. 13) 6 feet wide and about 2 feet deep and 40 to 60 feet long and joined by hinged pins with 3 inches of play for yawing between floats. There are two or three very heavy chains (Photo 4.2.12) strung from side to side of the marina lying on the bottom and the floats are attached to the cables. The largest fingers are also 6 ft. wide steel floats 40 feet long and spaced 40 ft. apart. The floats have a 4" x 4" hardwood rub rail about 18" above the waterline and boats sometimes get under this and break it off. There are also wooden fingers 25 feet long and about 40" wide spaced 25 feet apart (Photo 4.2. 14). These are supported by steel drums at the outside end. There are also 18 ft. fingers with the same construction spaced 18 ft. apart.

Photo 4.2.13 Steel floats and moorage cleats at Quebec Yacht Club.

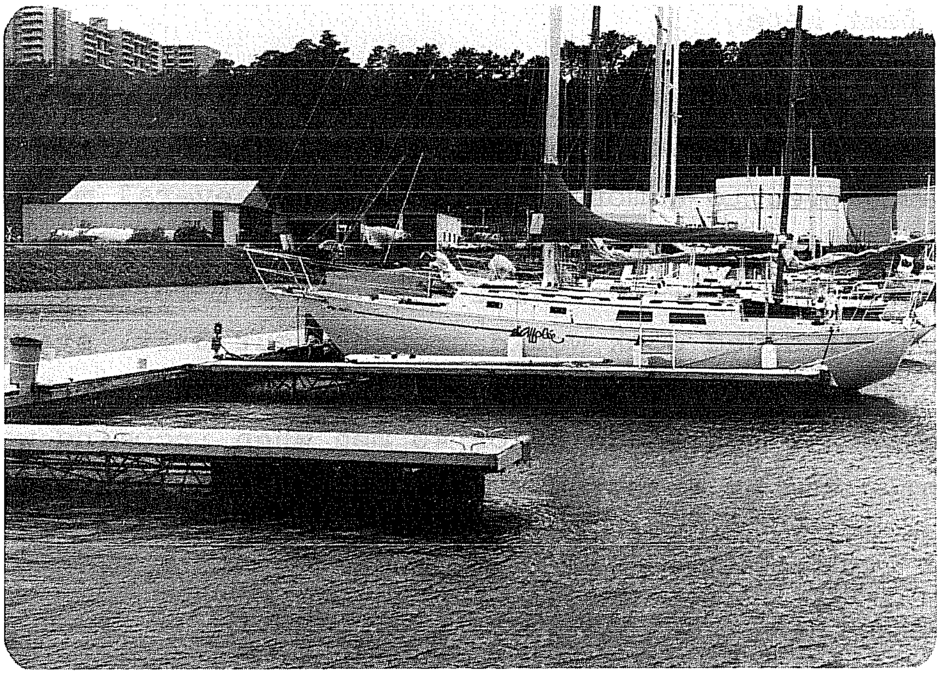


Photo 4.2.14 Fingers supported by steel drums at Quebec Yacht Club.

A boater located near the entrance was questioned and he said that masts commonly interlock unless the boats are staggered. He has a 27 ft. boat moored with spring lines and he said his boat surged about 2 feet by stretching the lines and he had to relocate it during a strong NE wind about 2 weeks ago.

4.2.5 Northern Yacht Club

The marina for the Northern Yacht Club sits on the northwest shoreline of a large bay at the mouth of the Sydney River in Cape Breton, Nova Scotia. It is open to the southeast but protected from the prevailing southwest winds by a rubble breakwater (Photo 4.2.15). There were only 14 boats in the marina when visited by NHCL but some boats were away at the central lakes. Most are moored offshore on buoys but some of the sturdier powerboats are moored against shoreside docks. The tide range is only 4 feet here.

Winds as light as 20 mph from the south are sufficient to make moorage at the dock hazardous and the boats are moved to a more sheltered area several miles away. With a fetch of about 3 miles, these winds could raise about a 1.5 ft. wave but near perfect reflection from the vertical sided dock would create about 3 ft. standing waves. The boats moored to buoys are said to be taken to shelter when winds reach 35 or 40 mph when incoming waves 3 ft. high can be expected. Reflections from the wall would increase this somewhat at the buoys.

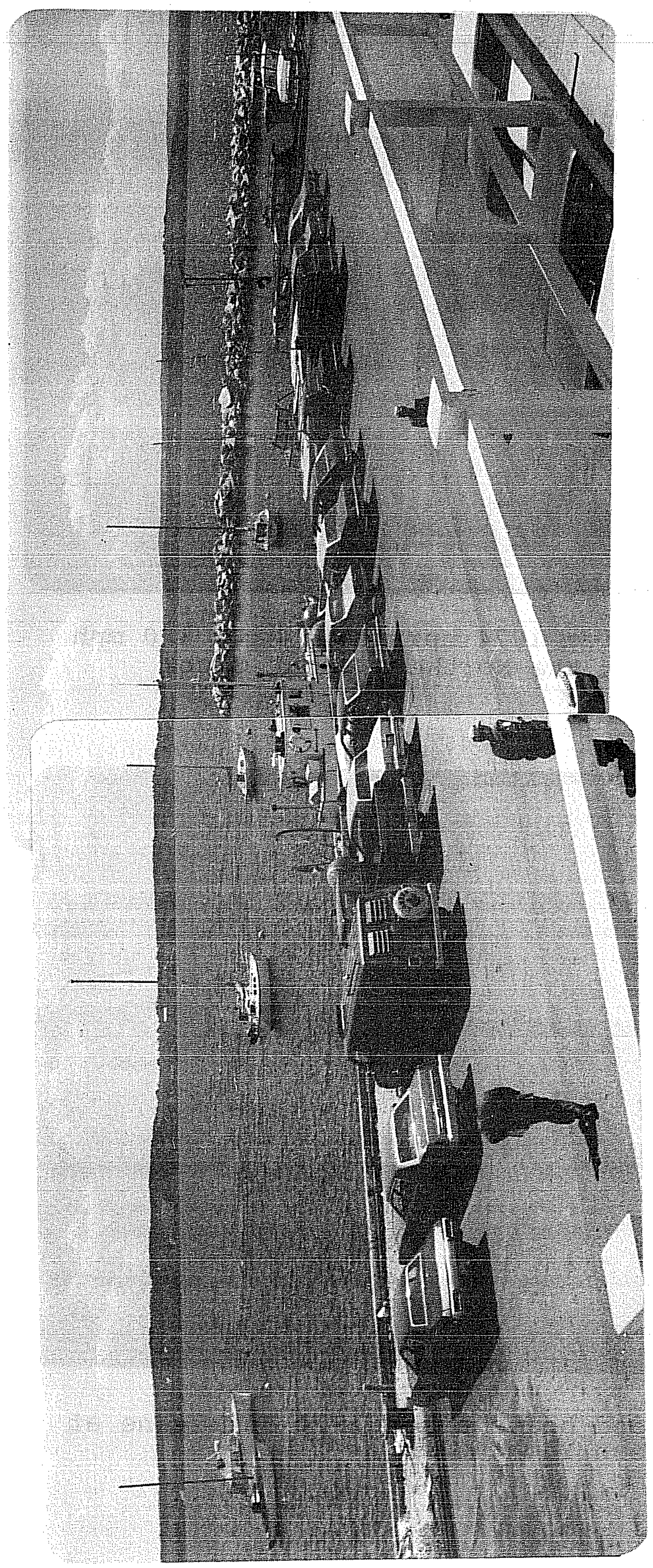


Photo 4.2.15 Moorage basin for Northern Yacht Club open to the southeast but protected from prevailing southwest winds by a breakwater.

Photo 4.2.16 Sea during 1974 hurricane with 120 mph winds at the Northern Yacht Club.

Photo 4.2.17 Stranded boats after 1974 hurricane at Northern Yacht Club.

In October 1974, a hurricane passed over North Sydney, and winds suddenly reached 120 mph from the south. A number of photos were taken during the storm (Photo 4.2.16 and Photo 4.2.17) and waves appear to be 6 feet high or more. The photos show that at least 8 boats washed ashore from their buoys but the damage does not appear to be great. Two boats were reported sunk.

The biggest problem, besides the need to seek shelter during storms, is replacing frayed mooring lines. All boats are moored with double lines for security.

V. CONCERNS OF MARINA USERS AND OPERATORS

An important input into the establishment of wave criteria is the concerns of marina users and operators. However, these concerns are difficult to evaluate. For example, one user concern would obviously be for the safety of his boat and would be heightened if he had suffered damage previously. On the otherhand, if he visited the marina infrequently and hadn't experienced rough conditions he might express a lack of concern when actually the general wave climate for the marina was unacceptable. For marina operators, wave conditions are a constant annoyance, causing wear on float connections, loosening of mooring cleats, parting of frayed moorage lines, etc., and sometimes are a source of real peril requiring extraordinary action to prevent major damage to boats and property. If the cost of providing better protection lies with the operator, he might tend to downplay damage to maintain the reputation of his facility. On the otherhand, if assistance from government sources were likely, he might exaggerate both the conditions and the effects in the hopes of upgrading his facility and so increase its marketability and reduce his maintenance problems. As a result, evaluating and interpreting the concerns of boat owners and marina operators for use in establishing criteria can be a difficult task.

Three approaches to gather and evaluate these concerns were used, namely:

1. A special sub-project undertaken by Dr. Ward and his associates to survey the psychological aspects of user and operators concerns, resulting in the report attached hereto as Appendix A. This sub-project reviewed the problem of how people of different background percieve hazards. A questionnaire was designed and 203 boat owners in B.C. were

interviewed. The results were then analyzed statistically and interpreted. Because of the control imposed by the questionnaire and the skill of the interviewer, the results of this sub-project were considered of greatest value in interpreting people's concerns regarding wave distress.

2. A questionnaire was mailed by SCHB to 25 marina owners in Ontario and B.C. soliciting their help and comments. Twelve replies were received and the results were analyzed to look for common components of wave distress and also any particular problems that should be recognized and considered in establishing criteria.

3. Informal interviews with marina operators throughout Canada at the time of visiting the marinas described in Section IV. These interviews were unstructured and although attempts were made to obtain generalized comments, the interview usually reverted to a discussion of the particular short comings of the operator's own marina and how they could be remedied. These interviews did help to identify the range of concerns of marina operators and the difficulty they encounter.

The three approaches and their results are discussed in the following paragraphs of this section.

5.1 Sub-project on Psychological Aspects of Peoples' Concerns

The purpose of this sub-project was the evaluation of humanistic factors that would affect wave climate criteria. These were to be determined by interviewing boat owners to obtain responses according to a specific questionnaire. At the onset, it was considered that physical humanistic limitations, such as the ability to negotiate heaving walkways or the susceptibility to motion sickness, might be important but these factors were downrated by virtually all respondants. What were important were the psychological aspects, mainly how peoples' perceptions compared with the reality of the situation, because these affected the evaluation of their responses.

5.1.1 Literature Review

A review of relevant behavioural science literature revealed essentially no material related to marinas, but there was considerable information on hazard perception and on motion sickness. It was possible to make some generalizations about hazard perception from studies of flood hazards and crop failure hazards, for example.

In perceiving hazards, a discrepancy can be expected between non-professionals (boat owners) and professional scientists and technical personnel because of differences in their personal experience and technical training, particularly in the use of probability models. Non-professionals tend to underestimate the probability of the occurrence of hazards and to place more confidence in the ability of technological improvements such as breakwaters to eliminate hazards. Also, since professionals tend to see more severe problems than lay people, it is possible that the professional personnel may see severe problems in an area such as wave action in marinas, whereas it may be a minor concern among small craft owners themselves.

In general, it would appear that one's role viz-a-viz the environment is the major factor in determining one's evaluation of an environment. Even among users of the same resource, one might anticipate variation in preceptions such that, e.g., sail boat owners may display differential sensitivity to wave action in small craft harbours than do power boat owners. The attention paid by sailors to specific aspects of wave and wind action is likely to be reflected in heightened awareness of, or an altered level of tolerance to, wave action. It could also be anticipated that differences in resource use and its associated economic impact would alter preceptions, ie., the attitudes of recreationalists as contrasted to commercial boaters might differ.

A heightened awareness of hazard potentials might also be expected after aversive personal experience (such as losing a boat), although its effects may be compounded by the individual's personality.

The tendency for individuals (both technical and lay) to overgeneralize from small samples, accounts for a general inability to accurately project future occurrences of a natural hazard. In the case of marina users, peoples' perception of wave action will, for the most part, be circumscribed by their past experiences. More specifically, individuals find it difficult to deal with the uncertainty of random events. As a result they tend to construe them as cyclical or patterned. This strategy can be used to allay fears depending upon frequency of the event. Therefore, despite the relatively high awareness of past experience, marina users may be deluded in their perceptions of future events such as rarely occurring but severe storms. This is well illustrated by a survey elsewhere in which 90% of the respondents experienced storms, but only 66% of them expected them in the future. In addition, only half of the respondents who had experienced damage, anticipated damage in the future.

Variation in perceptions of natural hazards is greatest when they occur with moderate frequency. Thus, small craft owners in marinas with moderately hazardous conditions should provide the greatest range of attitudes towards security of the marina, anxiety for the boat, annoyance at the degree of marina exposure, etc., as compared with users of very quiet or very stormy marinas. In this instance it is important to realize that the attitudes held by the individual may not be too useful.

There can also be a tendency for owners that keep their boats in marinas subject to damaging wave action to justify their actions to themselves by ignoring physical evidence of damage potential. This type of accommodation of beliefs and values to behaviour could be particularly prevalent where a boat owner has an added commitment to his moorage, as in the case of a private yacht club.

A review of the literature on motion sickness reveals that there are a number of theories attempting to explain the phenomenon. Presently the sensory rearrangement theory is the most accepted. It suggests that when there are repeatedly misleading and conflicting inputs determining the relationship between eye and head, or head and body, or both, motion sickness may be triggered. Motion sickness, as generated by wave action, is primarily concerned with visual-inertial rearrangement. For example, a person may suffer seasickness while standing on the side of the boat looking at the wave action. His experience of motion will be correlated with the ship's movements, yet appear to be uncorrelated with the apparently random action of the waves. Another situation where motion sickness is likely is when there is an adequate sense of motion in the absence of the expected visual signals. This could happen when an individual is subject to wave action while working or remaining inside a boat.

Research into the specific characteristics of wave action that evoke motion sickness has concentrated on periodic linear acceleration, since it is the major component in most motions of importance. Much of the comprehensive experimental research was conducted using a hydraulically-driven elevator cabin that was designed to accelerate vertically in an 18-foot shaft. By manipulating the acceleration of the cabin, operators could simulate a wide variety of wave-forms. It was found that the major factors characteristic of symmetrical wave action relevant to motion sickness are the amount of energy expended (ie., applied to the individual) by the wave and the period of the wave. In general, the graph of incidence and seriousness of motion sickness has a function of wave frequency (for constant energy) as a maximum at about 15-20 cycles per minute (period about 3-4 sec.). In contrast, amount of motion sickness is an increasing function of wave energy (amplitude), with no maximum apparent. Somewhat paradoxically, moderate frequency and energy levels seem to be especially effective in creating nausea and vomiting. In one experiment, over half of a group of naval officers subjected to wave action with amplitude of 7 feet at 22 cycles per minute became sick within 15 minutes.

The constant movement on boats and floats in small craft harbours may cause motion sickness among some of the small craft users. However, it would be anticipated that this would be a minimal annoyance, as boaters (especially those with experience) would be a self-selected group in terms of recreational choice. It is unlikely that individuals with a high susceptibility to motion sickness would select this activity. Although it would be estimated that working within the confines of a boat subject to wave action would often lead to motion sickness, this situation may be offset somewhat by prolonged exposure to wave action associated with boat work, which may lead to adaptation and increase in seaworthiness. Nonetheless, some degree of motion sickness appears to be an inevitable feature of marina life. This should be minimal, however, since there is protection from high amplitude waves. The most likely place for motion sickness to occur in the marina would be in boats with a wave response period of 2-4 sec. when waves with that period (about 15-30 cycles per minute) are present in the marina. The coincidence of boat period with wave period would lead to high amplitude motion of the boat, and thus its occupants, at just the frequency optimal for inducing motion sickness.

5.1.2 The Field Study

The purpose of the field study was to survey the attitudes of boat owners in marinas having different wave climates. The marinas chosen were the six B.C. marinas described in Section 4 plus Mosquito Creek Marina located within Vancouver harbour where heavy boat waves are a problem. The marinas can be characterized as follows:

Thunderbird Marina - 862 boat, commercially operated marina, located deep in Fisherman's Cove with approximately 60%/40% sailboat/power boat split. Very little wave action.

West Vancouver Yacht Club - 240 boat, privately operated marina located towards the entrance of Fisherman's Cove with 75 to 80 percent sailboats. Some minor wave action from the entrance and from passing boats.

Fishermans Wharf - 80 boat commercially operated, marina located in the narrow entrance to Fisherman's Cove with 60% sailboats. Subject to moderate wave action from the entrance and from passing boats.

Eagle Harbour Yacht Club - 90 boat, privately operated marina with 65% sailboats located in a small Cove next to Fisherman's Cove with poor entrance protection and subject to heavy wave action at times.

Schooner Cove Marina - 370 boat, commercially operated marina with 25% sailboats and 75% power boats, mostly for recreational fishing. Very exposed entrance partially protected by a breakwater but subject to heave action from long period waves.

Beach Gardens Marina - 150 boat commercially operated marina with 25% sailboats constructed on a exposed shoreline by a complete perimeter of rubble breakwater subject to very heavy wave attack that overtops the breakwater and causes distress within the marina.

Mosquito Creek Marina - 600 boat, commercially operated marina with 35% sailboats located within Vancouver harbour and protected from storm waves but subject to heavy boat wash especially from the Sea Bus, a ferry that passes every 15 minutes.

The questionnaire used, Table 5.1.1, was developed to provide a structure to the interviews of boat owners and was filled in by the interviewer based on the answers received. There were 203 boat owners approached and interviewed, all by a single interviewer who reported that there were few if any refusals. The results of the interviews are summarized in Tables 5.1.2 and 5.1.3. Some of the questions required numerical answers and some required subjective answers that were rated 1 to 5. Table 5.1.2 shows for each marina the mean and standard deviation of the responses to each such question. Some questions required open ended responses which are summarized in Table 5.1.3.

The first section of the questionnaire, questions 1 through 7, is concerned primarily with background factors that might affect the owners' perceptions of the marina. The second section, questions 8-15, requires the boat owners to rate their preceptions of various types of wave action in their own marina in terms of the degree to which this is a problem. The final section, questions 16-20, asks for open responses that was hoped would provide information that would aid in interpreting the quantative data.

The respondents in general were experienced boaters having owned boats for an average exceeding ten years for all marinas, except Fisherman's Wharf. A number of new boat owners moor there because of an associated yacht sales company. The size of boats owned averages 23 to 28 feet, except at the West Vancouver Yacht Club where the average is 32 feet.

TABLE 5.1.1

Marina Project Questionnaire

1. Boat Location
   1. Fiserhman's Wharf
   2. West Van
   3. T-bird
   4. Eagle
   5. Schooner
   6. Beach

   Pick No. ☐☐☐☐☐

   Slip No.

2. Type of Boat (1) Sail (2) Motor ☐

3. Type of Chine (1) Hard (2) Soft ☐

4. Size of Boat ☐☐

5. How long have you had a boat moored in this marine? (Yrs.) ☐☐

6. How long have you been a boat owner? (Yrs.) ☐☐

7. How many days of your life have you spent boating? ☐☐☐☐☐

8. To what extent is wave action in this marine a problem?

   8.1 In very serious storms (1 in 5 yrs)) ☐

) no use

   8.2 In common storms (5-20/yr)) ☐

   8.3 Everyday use ☐

   1 = no problem 2 = mild problem 3 = medium problem
   4 = severe problem 5 = very severe problem

9. To what extent are you annoyed by the wave action in this marina? ☐

   1 = not at all 2 = somewhat 3 = moderately
   4 = very 5 = extremely

   9.1 In what ways? ________________________________

10. To what extent does the wave action in this marina make you anxious?

    10.1 for yourself ☐

    10.2 for your boat ☐

    10.3 for the contents of your boat ☐

    10.4 for your guests/passengers ☐

    1 = not at all 2 = somewhat 3 = moderately
    4 = very 5 = extremely

11. Have you ever been motion sick (exp. nausea) in this marina (before taking boat out)? If so, how many times did this occur since you've been here? ☐☐

12. How much of a problem is motion sickness in general in this marina? ☐

    1 = none 2 = mild 3 = moderate 4 = severe 5 = very severe

13. To what extent is ("normal") wear and tear on your boat, mooring lines, fenders, etc. caused by wave action in this marina a problem? ☐

    1 = none 2 = mild 3 = moderate 4 = severe 5 = very severe

14. Has your boat ever been damaged (not wear and tear) as a result of wave action in this marina? If so, how many times since you've been here?

    14.1 No Insurance Claim ☐

    14.2 Insurance Claim ☐

15. Overall, how satisfied would you say you are with this marina? ☐

    1 = not at all 2 = somewhat 3 = moderately
    4 = very 5 = extremely

16. Why did you choose this marina?

17. Did you move to this marina from another? If so, why & which?

18. What's the best aspect of this marina?

19. What's the worst aspect of this marina?

20. What physical aspect would you most like to change about this marina?

TABLE 5.1.2

Questionnaire Data Summary: Means and Standard Deviations

MARINA

Variable (Questions)		Fishermans Wharf		West Vancouver Yacht Club		Thunderbird		Eagle Harbour Yacht Club		Schooner Cove		Beach Garden		Mosquito Creek	
		Means	Standard Deviations	Means	Standard Deviations	Means	Standard Deviations	Means	Standard Deviations	Means	Standard Deviations	Means	Standard Deviations	Means	Standard Deviations
(4)	Boat size (ft)	22.93	4.48	32.45	10.36	26.21	5.51	27.42	4.08	25.48	6.40	25.35	7.82	28.41	1.32
(5)	Marina time (yrs)	1.27	0.59	8.90	6.80	7.19	5.92	5.83	4.51	4.46	6.09	2.22	0.90	34.1	0.57
(6)	Owner time (yrs)	8.27	10.48	19.75	10.83	18.96	14.02	10.08	6.85	15.52	14.47	15.57	11.92	10.41	1.63
(7)	Time on boat (days)	826	1002	1227	772	1672	1987	1477	1970	1229	1966	1430	1180	1128	270
(8.1)	Serious storms (1-5)	2.70	0.82	1.35	1.09	1.04	0.21	4.26	0.92	4.09	0.86	4.35	0.83	1.44	0.14
(8.2)	Common storms (1-5)	1.60	0.62	0.95	0.39	1.00	0.00	2.46	0.83	2.96	0.99	3.35	0.98	1.15	0.09
(8.3)	Ordinary use (1-5)	1.00	0.00	0.95	0.39	1.00	0.00	1.12	0.34	1.20	0.50	1.52	0.90	2.33	0.22
(9)	Annoyance (1-5)	1.40	0.63	1.05	0.22	1.11	0.48	1.75	0.79	2.28	1.20	3.17	1.15	2.37	0.26
(10.1)	Anxiety-self (1-5)	1.20	0.41	0.95	0.22	1.02	0.15	1.00	0.00	1.33	0.82	2.30	1.29	1.15	0.12
(10.2)	Anxiety-boat (1-5)	1.60	0.63	1.20	0.70	1.00	0.00	2.4	0.92	2.61	1.26	3.44	1.20	1.74	0.17
(10.3)	Anziety-contents (1-5)	1.00	0.00	1.10	0.45	1.00	0.00	1.12	0.45	1.44	1.05	2.26	1.14	1.26	0.11
(10.4)	Anxiety-guests (1-5)	1.13	0.52	1.10	0.45	1.00	0.00	1.00	0.00	1.61	0.95	1.52	0.79	1.30	0.14
(11)	Motion sickness (times)	0.00	0.00	0.00	0.00	0.00	0.00	1.08	2.14	0.72	2.38	0.35	0.93	0.41	0.30
(12)	Sickness problem (1-5)	1.00	0.39	1.05	0.39	1.00	0.00	1.24	0.62	1.43	0.62	1.43	0.81	1.33	0.12
(13)	Wear and tear (1-5)	1.80	0.77	1.20	0.52	1.15	0.36	2.25	0.90	2.54	1.03	2.70	1.18	2.41	0.23
(14.1)	Damage-no claim (times)	0.07	0.26	0.10	0.31	0.02	0.15	0.92	1.82	0.50	1.11	0.28	0.72	0.30	0.15
(14.2)	Damage-claim (times)	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.51	0.06	0.25	0.00	0.00	0.00	0.00
(15)	Satisfaction (1-5)	3.20	0.77	4.40	0.50	4.50	0.59	3.75	0.74	3.61	0.65	3.39	1.27	3.04	0.16
	No. of responses	15		20		48		24		46		23		27	

To question 8, regarding the extent to which waves are a problem, respondents rated every day waves on an average as "no problem" to "mild problem" in all marinas except at Mosquito Creek where the mean rating was 2.33, between "mild problem" and "medium problem". Common storms were rated between "no problem" and "mild problem" for all marinas except Eagle Harbour, Schooner Cove and Beach Gardens which were rated on average 2.46, 2.96 and 3.35, with 3.00 representing a medium problem. Serious storms (once in 5 years) were rated "no problem" to "mild problem" at West Vancouver Yacht Club, Thunderbird and Mosquito Creek, but a mild to medium problem at Fisherman's Wharf and a severe problem at Eagle Harbour, Schooner Cove and Beach Garden.

To question 10, concerning anxiety, most responders registered "none at all" for themselves, for contents of their boats and for guests at all marinas except Schooner Cove and Beach Gardens where ratings extended into the "somewhat" category. More concern for their boat was registered in virtually all cases with concern averaging 3.44 at Beach Gardens, midway between "moderately" and "very". It was reported that a number of owners had withdrawn their boat from this marina because of its wave climate.

Motion sickness within the marina was ranked very low (questions 11 and 12) for all marinas, although respondents at Eagle Harbour admitted to an average of one occurrence during their occupancy there.

Damage was the subject of questions 13 and 14. The wear and tear to the boats' moorings and fenders, etc., was rated as "none" at the very sheltered West Vancouver Yacht Club and Thunderbird Marina, as "mild" at Fishermans Wharf, but "mild" to "moderate" at the remaining marinas. Actual wave related damage was reported in all marinas. Respondents at

Fisherman's Wharf reported only one incident which did not result in an insurance claim, West Vancouver Yacht Club reported two incidents and no claims and Thunderbird reported two incidents with no claims. Eagle Harbour on the otherhand reported a total of 22 incidents and 5 insurance claims among 24 respondents. Schooner Cove respondents reported 23 incidents resulting in 3 claims. Beach Gardens reported 6 incidents and no claims and Mosquito Creek reported 9 incidents and no claims. Of 203 respondents, only 8 insurance claims related to wave damage in marinas had ever been made. This includes 4 marinas whose operators have sought federal help for additional wave protection.

Overall satisfaction with the marina (question 15) includes all aspects of marina useage and the rating tended to the high side with the best ratings given to West Vancouver Yacht Club and Thunderbird and the lowest to Fisherman's Wharf and Mosquito Creek. The reasons for these ratings are provided in the open responses to Questions 18, 19 and 20 (Table 5.1.3). To Question 18, (What is the best aspect of the marina?) only West Vancouver Yacht Club and Thunderbird received mention for their sheltered location. Proximity to the boating area was mentioned most often as the best aspect except at Beach Gardens where maintenance and facilities were stressed predominately. To question 19, (What is the worst aspect of this marina?) a wide variety of answers were given with only Eagle Harbour, Schooner Cove and Beach Gardens respondents mentioning exposure or breakwaters. Boat waves were mentioned only by 4 persons at Mosquito Creek. These four marinas also were the only ones where answers to Question 20 (What physical aspect would you most like to change about this marina?) dealt with additional wave protection. At Eagle Harbour, 54 percent of the respondents mentioned this, 70 percent at Schooner Cove, 91 percent at Beach Gardens and 19 percent at Mosquito Creek.

Table 5.1.3

Responses to Open Ended Questions

Questions		Fishermans Wharf	West Vancouver Yacht Club	Thunder-bird	Eagle Harbour Yacht Club	Schooner Cove	Beach Garden	Mosquito Creek
16. Why did you choose this marina?	Proximity to boating & fishing area	(3)	(2)	(20)	(4)	(10)	(6)	(3)
	Proximity to home	(4)	(10)	(20)	(3)	(19)	(6)	(16)
	Moorage available	(5)		(7)	(o)	(9)	(6)	(13)
	Boat bought on premises	(5)						
	Club and/or privately owned		(7)		(4)	(4)		
	Facilities & maintenance			(12)		(6)	(3)	
	Protection from exposure			(7)		(2)		
	Proximity to work			(4)				(2)
	Security			(2)		(2)	(3)	
	Social Environment			(2)	(3)			
	Private moorage spot					(2)		
	Moorage rates						(3)	
18. What is the best aspect of the marina?	Proximity to boating area	(11)	(14)	(25)	(12)	(20)		(5)
	Proximity to home	(2)	(2)				(4)	(7)
	Sheltered location		(10)	(18)				
	Maintainence & facilities			(8)		(11)	(13)	(9)
	Protection from vandalism/security			(3)		(6)		
	Everything			(3)				
	Small size				(4)			
	Yacht Club				(7)			
	Wharf manager/management					(17)	(5)	
	Nothing					(2)	(2)	
	Reasonable rates						(4)	(2)
	Social environment							(5)
19. What is the worst aspect of this marina?	Moorage rates	(2)		(17)		(4)		
	Lack of security	(5)		(4)				
	Narrow channels & slips	(3)	(5)					
	Lack of maintenance & facilities	(3)				(5)		(10)
	Marina too small and/or crowded		(5)	(4)				
	Nothing		(8)	(16)	(5)			(4)
	Winter ice			(2)				
	Exposure of marina e.g. swells				(10)	(18)		
	Breakwater				(3)	(6)	(14)	
	Parking					(6)	(6)	
	Physical layout of the marina							
	Dirtiness						(2)	
	Movement due to sea bus							(4)
	Floating driftwood		(2)					(6)
20. What physical aspect would you most like to change about this marina?	Deepen and/or widen channels & berths	(5)	(10)	(8)				
	Increase security	(3)		(2)				(2)
	Fix and/or widen floats	(3)	(4)			(2)	(5)	(6)
	Additional services and/or maintenance	(6)		(3)		(4)		(12)
	Nothing	(2)	(6)	(22)	(3)	(2)	(4)	(4)
	Decrease moorage rates			(4)				
	Increase boat lifting capacity			(2)				
	Increase covered moorage			(2)				
	Add restuarant facilities			(9)		(2)		
	Breakwater				(13)	(32)	(21)	(5)
	Increase parking					(9)		
	Change physical layout (e.g. entrance)						(13)	
	Add water and waste facilities						(3)	(2)

Only responses received more than once are listed.

Since the answers to the questionnaires were computerized they could be investigated statistically to see what significant correlations could be established. Significantly, there were no strong correlations between the various types of individuals (sailboat vrs powerboat owners, boat size, length of time at the marina or length of time owning a boat) and the answers given to the remaining questions. There was a weak, but significant negative correlation between length of time at the marina and rating of common storms as a hazard and a weak positive correlation between length of time at the marina and satisfaction with the marina. Mosquito Creek Marina was something of an exception in that boat size was positively correlated with most of the questionnaire answers and negatively correlated with marina satisfaction, suggesting that larger boats suffer more from the particular wash caused by the Sea Bus.

There were strong correlations between the questionnaire answers and the marinas, as has already been identified. It was possible, because of this to find statistically homogeneous groups of marinas, depending on the question asked. From this analysis, it appears that West Vancouver Yacht Club and Thunderbird are never different. Fishermans Wharf usually groups with these two and sometimes with Eagle Harbour. Schooner Cove and Beach Gardens are always perceived to have more problems than any of the others and are in a group by themselves. On the basis of these analysis the marinas can be ranked in the order given above according to perceived severity of wave action.

The results of the field study can be interpreted to indicate that differences in wave action across presently existing marinas affect boat owners' perceptions of wave action as a problem, induce differences in anxiety for self, boat, boat contents, and guests, affect perception of and experience of motion sickness, and cause differences in wear and tear and damage to the boats themselves. However, of all these variables, only wave action during storms, wave-action-caused anxiety for one's boat, and wear and tear on the boat were perceived to be significant problems, and then only in the most exposed of the marinas studied. Very little motion sickness was reported and it was not thought to be a serious problem. This is probably because boat owners tend to stay away from the marina during storms when wave action in the marina might be intense enough to induce motion sickness. The everyday wave climate of all of the marinas examined (except Mosquito Creek with a boat-wash problem) was apparently quite good. Thus, although we would expect the marina situation to be ripe for reports of motion sickness, apparently boat owners' use habits are such as to minimize this potential problem.

Overall, satisfaction with existing marinas appeared to be quite good, despite the severe wave action some experienced during storms. The differences in wave action did cause differences in overall satisfaction, and about 25% of the variance in satisfaction judgements across all marinas could be accounted for by wave-action problems. However, in no case was the average satisfaction rating less than "moderate". On the otherhand, this may be somewhat deceptive, since it appeared that across the six marinas, the more severe wave action problems were often associated with an increased level of patrol and security services (in terms of man-hours spent), as well as better facilities and better maintenance of equipment. These apparently went some way toward compensating the boat owners for the poorer wave climate and increased risk of damage to their boats.

There are a number of factors that would tend to influence the interpretation of the questionnaire data. Among these the most important are the following: 1) the amount of damage insurance held by respondents was not assessed, and informal comments revealed that individuals with a lot of insurance tended to feel considerably less anxious about wave action problems; 2) sometimes individuals reporting low anxiety had apparently reduced their anxiety by taking elaborate precautions to moor their boat securely; 3) it could not be acertained to what extent people who experienced boat damage had moved their boats and were thus inaccessible for interviewing; 4) experienced damage was obviously lessened by the heroic efforts of some marina staff to retie boats, etc. during storms.

Even with the above qualifications in mind, however, a remarkable convergency was found between the data collected in the field study and the impressions garnered from the existing literature on hazard perception. Perhaps the most striking example of this is the contrast between the views of the marina managers (and more experienced boat owners, eg. commodores of clubs) and the average boat owners. In nearly every case, the managers or more experienced boat owners found problems due to wave action to be more severe in their marinas than did other boat owners. This is quite in line with our expectations from the literature that more technically competent and experienced individuals, as well as those in a decision-making or management position, would tend to underrate the quality of a resource (eg. a marina) and perceive more severe hazards and higher damage potential than would less technically competent, less experienced individuals in a resource-user position. Neither point of view is necessarily more valid than the other. Rather both should be taken into consideration when evaluating possible changes in a hazard-prone environment.

The sub-project concluded that the relative lack of major psychological problems associated with wave climate in existing small craft harbours indicates that physical factors may be allowed to be the dominant influence in the determination of optimum standards without the expectation that this will lead to major unforeseen psychological consequences.

5.2 Questionnaire to Marina Operators

To supplement the findings of the sub-project, a separate questionnaire was prepared by NHCL and mailed by SCHB to marinas in Ontario and B.C. This questionnaire was directed to marina operators rather than boat owners. Of the twelve replies received, six were from B.C. marinas, five were from Ontario and one was unidentified. Both Schooner Cove and Beach Gardens, the two most exposed marinas investigated in this study, were among the responders. The replies are summarized in Table 5.2.1. At the start of the questionnaire, the operators were asked to rate the level of wave distress at their marina and to state the cause. Four rated the level as "low" or "very low", two rated it as "moderate" and four as "high" or "very high". Only three mentioned boat waves as a cause of wave distress.

One of the purposes of the questionnaire was to identify and rank the types of distress that waves caused in marinas in general. Eight types were suggested and the operators were asked to rank them 1 to 8 from greatest to least. In the replies, boat damage and dock damage were rated equally great with an average rating of 2.6 each. Anxiety of boat owners, with an average rating of 3.5, was the next most important type of distress. It is interesting that marina operators do recognize this factor and that four actually placed it first. On the otherhand, it was ranked 6, 7 and 8 by other operators, indicating a wide variation of attitudes in this respect. Discomfort aboard boats was universally ranked close to last (7 or 8) as a type of distress, confirming the findings of the sub-project. The remaining types of distress, worn lines and fenders, need for extra patrols, need to move boats to more shelter, and danger of working on floats, all received similar ratings (very close to 5) suggesting that these were

TABLE 5.2.1

REPLIES TO SCHB QUESTIONNAIRE TO MARINA OPERATORS

Reply No.	Marina Name	Self Rated Level of Wave Distress	Causes of Distress	Ranking of Types of Distress: Boat damage.	Deck damage.	Worn lines, fenders, etc.	Extra patrol.	Need to move to safer moorage.	Danger of working on floats, etc.	Discomfort aboard boats.	Anxiety of boat owners.	Other Types of Distress Mentioned
1	Powell River, B.C.	-**	wind storms, ferry wash	1	2	3	4	5	6	7	8	-
2	Ganges Harbour, B.C.	high	-	1	2	4	(7.5)*	5	3	(7.5)	6	-
3	Schooner Cove, B.C.	very high	incoming waves	2	3	4.5	8	4.5	6	7	1	-
4	Beach Garden Resort, B.C.	high	storms overtopping breakwater, boat wash	6	2	5	4	7	1	8	3	Difficulty of maneuvering
5	Tsehum Harbour, B.C.	very low	good breakwater protection	2	3	(7)	4	5	(7)	(7)	1	-
6	Pedder Bay, B.C.	very low	totally protected harbour	1	2	3	6	5	4	8	7	-
7	Unknown	low	-	3	1	(6.5)	(6.5)	(6.5)	4	(6.5)	2	-
8	Sault Ste. Marie, Ont.	moderate	exposed to SE storms	2	1	5	6	3	7	8	4	-
9	Kingston, Ont.	-***	wind storms	2	6	4	3	7	5	8	1	Embarrassment of marketing a wave susceptible harbour
10	Durham Cruise Marina, Ont.	very low	protected by outer harbour	4	2	6	3	1	7	8	5	-
11	Penetanguishene, Ont.	high	wind and passing crusiers	(5)	(5)	(5)	(5)	(5)	(5)	(5)	1	-
12	Hamilton, Ont.	moderate	westerly winds	--- not completed --								-
			Average	2.6	2.6	4.8	5.2	4.9	5.0	7.3	3.5	
			Standard Deviation	1.9	1.6	1.3	1.7	1.7	1.8	0.9	2.6	

*not rated and assigned average of unrated values
**not self rated but considered low
***not self rated but considered high

TABLE 5.2.1

REPLIES TO SCHB QUESTIONNAIRE TO MARINA OPERATORS (Continued)

Reply No.	Marina Name	Ranking of Wave Condition for Causing Distress at Marina: Biggest storm in 10 years.	Biggest storm each year.	Waves occurring 10 times a year.	Ship waves.	Most Damaging Component of Boat Motion at Marina	Estimated Maximum Wave Height in Marina in Feet	Wave Requiring Protective Action: Height in Feet	Length in Feet	Boat Types Most Distressed	Records Kept of Wave Related Incidents	Invited Additional Comments
1	Powell River, B.C.	4	3	1	2	pitching and rolling	1.5 inside breakwater	1	-	larger boats near break-water	only insurance claims	pleasure craft owners accept less wave distress than commercial craft
2	Ganges Harbour, B.C.	4	3	1.5	1.5	heaving	4 at docks	3	20 to 30	all boats	no	40-50 mph wind storms in winter
3	Schooner Cove, B.C.	3	2	1	4	surging, pitching, rolling	7 reflected	2	80	all boats	yes	-
4	Beach Garden Resort, B.C.	4	3	1	2	heaving, rolling, swaying	2	2	30	all boats, smaller are worse	only reported damage	needs higher breakwater
5	Tsehum Harbour, B.C.	3	2	4	1	surging, pitching	2 passing boats	0.5	-	very variable	no	-
6	Pedder Bay, B.C.	(3)	(3)	(3)	1	heaving	1.5 passing boats	0.75	-	all boats	no	-
7	Unknown	(3)	(3)	1	(3)	surging	1.5 outside floats	1	-	small vessels	no incidents	larger boats kept in more exposed areas
8	Sault Ste. Marie, Ont.	(3)	1	(3)	(3)	-	-	-	-	-	no	breakwater would eliminate problem
9	Kingston, Ont.	3	2	1	4	-	(referred to NRC report for these questions)					
10	Durham Cruise Marina, Ont.	1	2	3	4	surging, heaving	2 at entrance	2	10	no effect on boats	no significant events	increase watch when over 40 knot winds forecast
11	Penetanguishene, Ont.	(3.5)	2	(3.5)	1	heaving, surging, rolling	2 entire marina	-	-	all boats	no	harbour patrol and signs to limit boat speed needed.
12	Hamilton, Ont.	(3)	1	(3)	(3)	pitching	4 west face of marina	3-4	12 - 14	smaller boats	no	ice problems in spring are more serious
	Average	3.1	2.2	2.2	2.6							
	Standard Deviation	0.8	0.8	1.2	1.2							

recognized equally as types of distress but not rated too seriously. When asked to suggest other types of distress, one mentioned the difficulty of maneuvering in the marina and another mentioned a personal distress he felt in trying to market a marina with a recognized wave problem.

The next question attempted to assess the importance of frequency of wave activity in causing overall wave distress and asked that four specified wave conditions be ranked 1 to 4, from most important to least important. These were:

- the wave condition created by the biggest storm in 10 years
- the wave condition created by the biggest storm each year
- the wave condition created by winds that blow up to 10 times a year
- the wave condition created by other events such as passing ships

The ten year storm was rated least important (3 or 4) by all respondants except one who rated it most important but who rated his marina as experiencing very low wave action. The implication here is that marina operators are more concerned about the more frequently occurring storms and as a result wave criteria based only on rare events may not be adequate. Ship waves were rated most important (1 or 2) at six marinas indicating that ship waves are an important problem and should be addressed in establishing criteria. On average, however, the marina operators rated the storms that occur once a year, or more often, as the worst cause of wave distress. These storms contribute to the wear and tear that weakens connections which, without constant maintenance, give way and set boats adrift.

The next question was more technical in nature and asked which boat motion was the most damaging, specifying as choices - heaving, surging, swaying, pitching, rolling and yawing and asked for some explanation. This may have been confusing to some who mentioned wave surge and heave rather than boat motions. Nevertheless, there was a discernable pattern to the answers. Yawing was never mentioned and swaying was mentioned only once. Both of these motions are associated with quartering or beam seas. Rolling (due to beam seas) was mentioned four times, supposedly because this causes a problem with sailboats when masts collide. Surging was mentioned four times as well but may have been confused with wave surges. In any case, the surging of boats, causing the bow to ram the dock ahead, can be a serious problem with the long low waves in shallow harbours that are commonly called surges. Heaving and pitching are the most commonly observed boat motions and both were named five times. The fact that they were not named more often indicates that the other motions are also important in contributing to damage.

The marina operators were asked to estimate the maximum wave height which occurs in their marina and also the wave height and length at which they begin to take some protective action. Answers to the first varied from 1.5 feet to 7 feet and to the second varied from 0.5 feet to 3 or 4 feet. Wave lengths mentioned varied from 10 feet to 80 feet (the 80 foot figure was actually given as 4 which was interpreted by NHCL to mean seconds) but there were only 5 replies to this part, too few to evaluate.

The estimated maximum heights can be related to the distress rating by a linear least squares fit (R^2 = .42). The least squares fit values are shown in Table 5.2.2 below.

TABLE 5.2.2

LEAST SQUARES FIT OF ESTIMATED WAVE HEIGHT TO SELF RATED LEVEL OF DISTRESS IN MARINAS

Self Rated Level of Wave Distress	Estimated Wave Height in Feet Maximum Wave	Troublesome Wave
Very low (1)	1.4	1.0
Low (2)	2.2	1.5
Medium (3)	3.0	1.9
High (4)	3.8	2.4
Very High (5)	4.6	2.8

This table provides a reasonable consensus of how marina operators rate wave heights to wave distress. In interpreting this table it must be remembered that the wave heights are only visual estimations and subject to the limitations of recall. Also, it does not indicate what level is acceptable. It can be supposed that a rating of "low" is acceptable while "medium" seems to imply some criticism of the conditions.

Also shown in Table 5.2.2 are the results of a linear least squares fit ($R^2 = 0.49$) of the estimated wave height at which extra precautions are taken (troublesome wave). These results definitely show that marinas with greater wave distress learn to handle the wave problem by adopting better moorage practices so that higher waves are handled routinely.

To the question "Does this wave distress affect all boats or only boats of a certain type or up to a certain size?" the majority replied "all boats", three mentioned small vessels and one mentioned large vessels. The later qualified his remarks by stressing that the larger boats were kept near the breakwater where the waves were higher. That all boats are affected corresponds to the findings of the sub-project. Significantly, there was no mention of boat type which also agrees with the sub-project finding that there were no apparent correlations between boat type and distress.

To the question "Do you routinely keep a record of wave related incidents?" only three of the twelve responded positively and these all had wave climates rated as "high" or "very high". Two of these answers were qualified to suggest that records were kept only when there were some written accounts provided to the operator. Keeping a diary or log would seem to be simple and routine practice but no evidence of this was found in any marina, except for one that did have a standard report form for all types of incidents.

Finally, opportunity was provided for the marina operators to make additional comments and most used this to identify specific needs for their marina. One operator did note that pleasure craft owners would accept less wave distress than would commercial craft owners.

5.3 Informal Interviews with Professionals

Informal interviews were also held with various professionals involved with small craft harbours, including marina operators, engineers with SCHB and DPW, and insurance underwriters. These were conducted both by NHCL and by Dr. Ward's group and mostly during visits to different marinas across Canada. Comments that were obtained specific to certain marinas have been discussed in Section III. Comments regarding the general area of wave distress and wave criteria are discussed here but without reference to those individuals providing the comments or the marina involved.

Most marina operators criticize boat owners for inadequate moorage practices stating that they are reluctant to invest either the money for adequate equipment or the time to secure their boat properly. One operator cited a case where a boat broke loose when tied with a piece of electric wire. Nevertheless, no posters or notices were seen in any marina specifying proper moorage practices or suggesting improved methods. One operator stated he insists on the proper use of spring lines and breast lines and the boats in that marina were well moored, but most of the others expressed the attitude that it was of no use to try to correct people's mooring habits. Most marinas that experience wave action mount extra patrols during wave events and retie loose moorings and some replace broken lines and bill the owners later.

Some operators state that, properly moored, small craft can be quite safe moored alongside floating walks for even quite severe waves. This seems to be true for boats moored with their bow towards the oncoming waves with taut spring lines and loose breast lines and with fenders that stay in position. However, they also note exceptions that cause problems. Long period waves in shallow water impart strong fore-and-aft motions to boats that can cause them to ram their bows against to the walk ahead of them. Clearances of four or five feet are provided in some marinas subject to this action. Also in many marinas the wave action is not simple and there are strong secondary waves caused by reflections that cause the boats to sway, yaw and roll. In heavy wave action the bow or stern can ride up over the walkway or get caught below an overhang and suffer damage. Operators also comment on rigging and masts of sailboats tangling due to strong rolling action so that they have to stagger the boats to prevent this from happening.

A major concern of operators is the maintenance of walks. In most marinas the walks float so that they rise and fall with the tide and also with wave action. Older types are essentially long wooden rafts that are connected loosely to each other by chains so that they rub and bash against each other under wave action causing the connections to weaken. Newer types are often made of concrete (or sometimes steel or aluminum) and are particularly vulnerable to the damage caused by loose connections. These are tending to be made semi-rigid and continuous without articulated joints in order to avoid this damage. As a result they are not as compliant to wave action as were the old wooden floats. This type of construction is particularly vulnerable to large seas because high internal stresses are created. Operators express concern that they cannot evaluate the different systems that are being proposed and several have suggested that this study approach this problem.

When discussing strong wave events in the past, operators are usually able to remember what happened to particular floats because they repaired them but are usually vague as to the damage sustained by boats. As a general rule, damage records are not kept by marina operators so that an actual tally of damage cannot be made. Instances of substantial damage to boats due to wave action seem rather rare. There are instances where boats have been swamped and sunk and where they have broken loose and have been driven ashore but even in these cases the damage can be surprisingly small. Modern fibreglass hulls are capable of withstanding a great deal of bashing and still require only a cosmetic resurfacing. In most cases the cost of repairs seems to be less than the insurance deductible and claims are not made. This is substantiated by the results of the sub-project.

Operators report that most damage occurs when something breaks loose and boats drift into each other. It might be a dock connection, a dock cleat, a boat cleat or a frayed mooring line that gives out. New mooring lines, even as small as ¼-inch are very strong and will not part.

If the strain is large it is almost invariably the cleat that fails,either at the boat or the dock. Moorage lines do fray at points of contact, however, and the fraying action can be quite rapid in severe wave situations. The largest strains occur when slack lines suddenly become taut subjecting the freely drifting boat to a rapid deceleration. Operators insist that proper moorage with taut springs and loose breast lines prevent the sudden jars that cause these kinds of failure.

Discussion with marine brokers reveal that wave damage occurring in marinas accounts for a very small part of their claims. There has been a number of claims for damage due to wave action from passing boats, ie. the Sea Bus, but this seems to be because the claimants could hope to recover from those that caused the damage. Fire in marinas seems to account for far mor claims (and more serious claims) than does wave action. Marine brokers, in general, were more interested in governmental action in promoting fire and safety standards than in wave criteria. None of the brokers volunteered data on the number or amounts of claims in their files related to wave damage.

Engineers with SCHB and DPW are acutely aware of the importance of designing harbour protection to limit the wave action in marinas. They work extensively with marina owners to provide assistance in improving the protection of existing marinas and planning the protection needs of new marinas. They make extensive use of physical models to determine the degree of protection that a particular design will provide. The criteria that is most often applied in Canada is that the storm with a 10 year recurrance interval should not result in waves greater than 1 foot in height. This criteria would seem to be quite severe in comparison with the results of the project questionnaires, because one would expect there would be much less wave action during all of the more frequent and less violent storms. One operator, however, complained that the criteria was inadequate when applied to his shallow marina because he experienced very long, low swells that caused heavy boat motions when wave heights were much less than 1 foot.

The engineers commented as well that the 1 foot criteria would be very expensive to achieve in instances where floating breakwaters were the only economical alternative. Somewhat greater wave action could probably be tolerated during severe storms if lesser storms could be adequately protected against.

VI. CLASSIFICATION OF SMALL CRAFT AND MOORAGE SYSTEMS

At the beginning of the study it was considered that a number of variables might influence the wave criteria and that data should be collected in the field to determine these variables. Since many of these variables, such as boat type are not readily quantified, a set of tentative classifications were set up as listed in Table 6.0.1. They differentiated between boat types and sizes, moorage arrangement, walkway and slip type, mooring line type, mooring cleat type and degree of exposure. At the time of visiting the B.C. marinas all the boats were counted and their type and size were noted and, in addition, approximately every tenth boat was surveyed as to these classifications.

As it turns out, these classifications have very limited value because the variable has little or no affect on wave criteria; because the data is too limited to assess any affect; or because the variable cannot be controlled in designing a marina. In instances where it is of some importance, such as the boat size or the type of moorage, the data taken has been extracted and presented in earlier sections. The affect or lack of affect of these variables is discussed briefly below.

Boat type and size would seem to be very important in governing wave distress. It is well known, for instance, that larger boats fare better in open water and that sailboats do better than most powerboats in rough water. Yet, when the question of size and type was put to operators none were able to say that any type was particularly more vulnerable, with some obvious expectations. For example, sailboats present the extra hazard of having their masts

TABLE 6.0.1

TENTATIVE CLASSIFICATIONS FOR WAVE CLIMATE CRITERIA

Sailboats

S 1	less than 27.5 feet	Typical 24'
S 2	27.5 feet to 40 feet	Typical 30'
S 3	40 feet or more	Typical 45'

Power Boats (Planning)

P 1	less than 20 feet	Typical 16'
P 2	20 feet or more	Typical 25'

Power Boats (Non-Planning)

D 1	less than 30 feet	Typical 25'
D 2	30 feet or more	Typical 40'

Tentative Mooring (Slip) Classifications

M 1	single buoys	(no piers)
M 2	fore and aft buoys	(no piers)
M 3	stern clamps	
M 4	bow clamps	
M 5	along main walkway	
M 6	single slips	
M 7	double slips	
M 8	covered double slips	

Tentative Walkway Classification

F 1	Fixed
F 2	Wooden Floating
F 3	Concrete Floating (articulated)
F 4	Concrete Floating (rigid)

Tentative Mooring Line Classification

L 1	3 strand nylon rope (stretchy, flexible)
L 2	3 strand dacron rope (less stretch, less flexible)
L 3	3 strand polypropylene (hard, floats, little stretch)
L 4	Braided nylon
L 5	Braided polyester

Tentative Cleat Classification

C 1	Wooden cleat or rail nailed down
C 2	Wooden cleat or rail through bolted
C 3	Steel ring through bolted
C 4	Metal cleat through bolted
C 5	Metal cleat screwed or lagged

and rigging entangling when rolling heavily. This finding that boat type and size are not too important was supported later in the analytical and model tests. The exception is between commercial and recreational craft. Commercial craft are built rugged to withstand abuse so that scars and dents are regarded as natural, while most recreational craft owners are distressed at the smallest scrape. This study is restricted to recreational craft.

The mooring classification is undoubtedly the most important and the most controllable variable in affecting wave distress. Moorage to a single floating buoy where the boat swings to face the wind and waves provides the least distress, but is also the least desirable because it requires the most area per boat and is the least convenient for users. Moorage to a rigid wall produces the greatest distress because the wall does not yield to the boats movement and because it reflects the wave to virtually double its amplitude to form standing waves.

The walkway classification is an important variable but a difficult one to assess. Walkways are one of the chief victims of wave distress and walkway maintenance is one of the main problems of marina operators. Different types have varying tolerance to wave distress, but not enough is known at this time to make a sound judgement. Wooden walkways are flexible and can absorb a great deal of impact punishment until the wood weakens due to wear or rot. Concrete, on the otherhand is durable but very fragile on impact so that continuous designs are developed that avoid points of contact. However, little is known about how such semi-rigid designs can withstand the flexing caused by waves. Concrete, so far, is most successful in very quiet marinas. The type of walkway to be used in a new marina is a design decision but more information is needed on the resistance of different types of wave action before this decision can be made properly.

Mooring line arrangement is important because the mooring lines have a great deal to do with boat response. However, the mooring lines can be readily changed to suit the wave climate without incurring great cost. The situations to be avoided most is a slack line that becomes taut with a snap while the boat is in a high velocity part of its orbital motion. This is the reason for specifying taut spring lines. Breast lines should be slack enough that the boat can swing out nearly its full orbit before bringing them taut. Taut breast lines should be avoided as well because a passing wave crest exerts a very high upward force on any boat which will snap a worn breast line or jack a cleat loose.

Providing taut spring lines may not be sufficient for long low waves in shallow water because of the large horizontal water velocities. The elasticity of the lines and the mass of the boat form a naturally resonant system that can coincide with the wave period and cause large resonant response with extra large boat motion and large line stress. This undoubtedly happens at the Port Credit Yacht Club (Section 4.2.2). If this action is suspected, the spring constant can be increased by taking up slack or by doubling or tripling the lines; or decreased by adding a steel spring into the line. In any case, the type of mooring line should not affect the selection of a wave climate criteria, it should be chosen to conform with the wave climate that exists.

Cleat classification is somewhat the same as mooring line classification. There are good cleats and bad cleats. A good cleat does not have abrupt edges that localize the stress on the mooring lines to increase abrasion and wear. Wood is good in this respect because it will share the wear. Cleats should also be secure, but spikes driven through wood are not secure because, just as they are driven home by repeated hammer blows, they can be hauled out by repeated mooring line tugs.

The data collected with regard to these classifications reflect current conditions and shows how practices adapt to different wave climates and, where relevant, these adaptions have been discussed in earlier sections. The actual classifications have no further use and should not be allowed to perpetuate into marina design.

VII. LIMITS OF ALLOWABLE MOTION

One step in establishing wave criteria is to establish limits of allowable motion for moored craft and, if possible, for floating walkways. When these limits are set, the response of boats to different wave conditions can be determined to arrive at suitable wave criteria. One drawback to this procedure is that only one limit will be the critical one and the other limits will not be significant. Since it would be desirable to establish criteria for both frequent storms and rare storms as well as criteria reflecting excellent, good and marginal wave climates, a great many rather arbitrary limits would be set that would have no ultimate value. The procedure preferred by NHCL is to select a series of wave criteria and determine the consequential motions and then make a composite judgement of the overall acceptability. This way, focus is properly placed on the actual controlling limits. In this section motions will be discussed in a general way, especially as to the consequences of exceeding these motions. First, however, will be discussed the desirability of having a range of criteria.

7.1 Conditions for Wave Climate Criteria

Wave climate criteria should reflect the frequency of recurrence of the design storm and this is acknowledged when a return period of 10 years is adopted for design as is often the case. One return period may be sufficient for design especially when designing for the prevailing winds. The same winds occur year after year and the wind with a 10 year recurrence is not much different than for 50 years. For instance, at Portsmouth Olympic Harbour the 10 year wind from the southwest is 53 mph while the 50 year wind is only 64 mph.

However, if the Harbour is naturally sheltered from the prevailing wind and rarer events such as the hurricane at the North Sydney Yacht Club, pose the most serious threat, design to the 10 year wind would be seriously misleading. NHCL recommends that wave climate criteria be based on three recurrence intervals. One would be a 50 year recurrence and the criteria would ensure the safety of all properly secured craft in the harbour and would enable experienced staff to operate on the walkways but would accept cosmetic damage to craft and repairs to walkways and fingers. The second would be the condition that occurs once a year for which the criteria would ensure that all properly moored craft and floats survive unscathed provided the marina is properly patrolled. The third exists mainly for boat wash but it could also refer to seasonal prevailing winds in that it would apply to the condition that exists on average at least once each week. For this condition, persons should be able to walk and transport materials on the walkways and carry on normal activities on their boats,requiring that boat motions should be considered moderate. In designing wave protection for a harbour, the designer would usually find one of these three to be the most severe and would design for that condition.

Wave climate criteria should also be flexible enough to accommodate some measure of the quality of protection such as marginal, good and excellent. A very large, heavily used marina offering full amenities, would probably want,and could afford,the protection necessary to procure an excellent wave climate. On the otherhand, a small rather exposed marina would be satisfied if the wave climate were marginal. Going one step further, a marina design might be acceptable if it ranked marginal at the 50 year recurrence interval and good for the other two. Unless, it is stated somewhere what is marginal, what is good and what is excellent, these judgements might not be made and all marinas might be forced into the one criteria (one foot wave height?) resulting in bad design.

7.2 Conditions for Limits

At the onset of the study it was thought that motion limits might involve accelerations and velocities as well as displacements. The affects of accelerations and velocities, however, are difficult to rationalize and most limiting conditions become a function of displacement. The response of persons to motion do involve accelerations and velocities, but this response has been shown to be relatively unimportant to wave distress. Displacements govern the relative position changes between the ship and the float as well as the elastic hawser forces. The limits will be discussed in terms of head seas and beam seas and of four types of moorage - to an anchored buoy, to a floating walkway, to a fixed open walkway, and to a solid wall.

7.2.1 Limits for Movement at a Buoy in Head Seas

A boat adequately moored to a buoy in head seas can withstand a great deal of wave action, the limit being when the lines fray loose or the anchor drags. The experience at North Sydney suggests that yachtsmen seek better shelter at wave heights above three feet but many boats survived the hurricane driven winds that must have created waves exceeding six feet in height. It would seem an unlikely event that harbour protection would be designed primarily for this type of moorage because of its wasteful use of space but this usage might be employed in more exposed areas of a harbour as in the case of Eagle Harbour. No more need be said about this condition except that wave heights should probably not exceed three feet once a year and in designing for a 50 year storm sufficient anchor weight should be provided.

7.2.2 Limits for Movement at a Buoy in Beam Seas

A boat moored to a buoy automatically heads into the sea or the wind but sometimes the wave has refracted obliquely to the wind or a second reflected wave approaches the boat. This condition causes very bad rolling and yawing response in addition to pitching and heaving usually with a great deal of water over the deck. There is no reason to believe that it will not survive the same seas as for pure head seas and the same limits are recommended. Smaller, open boats may swamp under these conditions but their positive flotation will keep them afloat.

7.2.3 Limits for Movement to a Floating Walkway or Finger in a Head Sea

Provided the rudder is lashed in the neutral position, a boat in head seas will only heave, pitch and surge under the action of the waves. At the same time the floating walkway or finger is moving with the same motions but usually to a lesser extent. Heave forces are very strong so that the heave of the float and the boat are usually nearly the same and need not be considered for this case. Admitted, the heave of the float may be somewhat less than the heave of the boat if the float is long and relatively inflexible such as at the Quebec Yacht Club.

Surge and pitch are much less for the float and can be neglected compared to the pitch and surge of the boat. Pitching needs to be limited so that neither the bow or the stern ships water or that the breast lines become taut and strain the cleats. Excessive pitching also can cause the fenders to ride up from between the boat and the dock and become ineffective.

Surging is a difficult motion to consider because the elasticity of the spring lines plays an important role. If the resonance between the natural period in surge and the period of the waves is established,very large surges and high mooring line forces will result and these are difficult to predict. It must be assumed that this type of resonance will be detuned by the boat owners or marina operators. Otherwise, surge is limited only by the clearances between obstacles ahead or behind the boat.

7.2.4 Limits for Movement at Floating Walkway or Finger in Beam Sea

Roll, sway and heave are the motions associated with a beam sea. The relative motion in heave between and a floating walkway and a boat are even more likely to be compensating in a beam sea than a head sea and once more heave can be neglected. Roll causes the gunwales to rise and fall dislodging hanging fenders and also the tangling of masts in sailboats. Sway, like surge, is a difficult motion to analyse. Boats should be moored so as to be as free in sway as possible. When a boat is restrained from swaying by its breast lines while it is still in a high velocity part of its orbit it will be yanked hard by the breast lines to towards the dock. It must hit the dock with an equally hard force in order for momentums and impluses to balance. Ideally, breast lines should have enough slack to accommodate the full natural movement of the boat in sway. Sway then is limited by the clearance between adjacent boats.

7.2.5 Limits for Movement at a Fixed Walkway or Finger in a Head Sea or a Beam Sea

Fixed walkways differ from floating walkways in that they don't heave so that boat heave must be considered. Otherwise the limits are the same. In heavy seas it is common to find boats either caught under or on top of overhanging ledges, so that these ledges limit the allowable heave. Another limit is the displacement of hanging fenders due to heave action. It must also be pointed out that maximum heave occurs when the crest or trough of the wave is under the boat while maximum pitch (or roll) occurs midway between crest and trough so that the two events are not simultaneous and additive.

7.2.6 Limits of Movement of a Solid Wall in a Head or Beam Sea

The limits for movement when moored at a solid wall depends on whether the sea is moving along the wall or impinging on the wall and being reflected. If the sea is running parallel to the wall the limits are the same as for a fixed walkway, whether the boat is parallel to the wall and receiving a head sea or normal to the wall and receiving a beam sea. If the sea is impinging on the wall, both the incident wave and the reflected wave must be considered. The combination of the incoming wave and the reflected wave produces a standing wave situation or "clapotis" whereby the sea has little vertical motion at fixed points (nodes) one half wave length apart and maximum rise and fall at points (loops) midway between the nodes. One loop is located at the wall and the closest node is one quarter wave length away. At the loops the horizontal motion and the water surface slope is always zero while the change in water level is twice the height of the incoming waves. Therefore, right at the wall, heave would be doubled but all other motions tend to be cancelled. At a node the heave would be zero but water surface slope and horizontal wave motion would be doubled. Boats moored pointing towards the wall could be centered close to the nodal point for certain wave frequencies, in which case surging and pitching could be double that for a fixed or floating walkway. This case is the one investigated by Raichen (1966).

VIII. BOAT RESPONSE MEASUREMENTS

Crucial to establishing wave climate criteria are measurements of the response of moored boats to wave action. To systematically measure boat response over a range of wave conditions a series of model tests were conducted. Because of budget limitations only one boat type was modelled, but by applying different scaling factors a range of full size boats of that type can be represented. The elasticity of mooring lines is an important factor and this characteristic was also modelled. To support the model results, measurements were also made of the response of two full size yachts at Fisherman's Wharf Marina where the Kelk gauge was installed. Other field measurements such as roll periods were made at different times during the course of the study and these are described as well in this section and related to the model tests.

8.1 Scale Model Tests

8.1.1 Description of the Model

The yacht model used in these tests was a modification of a 36-inch long commercially available model of a high-performance fin-keel racing sloop built for radio control operation. It was selected because its configuration was similar to sailboats using small craft harbours. However, it required modification. A side view of the modified model is shown with two typical boats in the 24-foot range in Dwg. 8.1.1. Specifications for the modified model and for six different sailboats are given in Table 8.1.1. Several dimensionless ratios are provided in this table for comparison purposes.

TABLE 8.1.1

COMPARISON OF MODEL AND PROTOTYPE SAILBOAT SPECIFICATIONS

	Swiftsure 24	Bayfield 25	Bayfield 32	Mirage 26	Grampian 26	Kirby 25	Moc
Basic Specifications							
L_o Length overall (ft)	23.67	25.00	32.00	26.16	26.00	25.16	
L_w Length waterline (ft)	20.75	19.67	23.25	21.67	21.75	20.75	
B Beam (ft)	7.62	8.00	10.50	9.25	8.33	8.75	
D Draft (ft)	4.16	2.92	3.75	4.33	4.25	4.16	
W_t Displacement (lbs)	2900	3500	9600	5200	5600	3100	
W_b Ballast (lbs)	1450	1300	4000	2200	2600	1150	
Characteristic Dimensionless Ratios							
$\frac{B}{L_w}$ Beam/Length	.367	.407	.450	.427	.383	.422	
$\frac{D}{L_w}$ Draft/Length	.200	.148	.161	.200	.195	.200	
$\frac{W_t}{\gamma L_w^3}$* Displacement Ratio	.0052	.0074	.0122	.0082	.0087	.0056	
$\frac{W_b}{W_t}$ Ballast/Displacement	0.50	0.37	0.42	0.42	0.46	0.36	

*γ is specific weight of water.

The unmodified model was narrower than the prototypes but had more draft and ballast to compensate for this. The reason for this was that the model was made strictly for racing while the prototypes are largely compromises having racing/crusing characteristics. To make a more representative model, 0.50 feet was removed from the mid-section and 0.30 feet was removed from the keel and the ballast was reduced by 3.0 lbs to effect the 2.5 foot long modified model listed in the table. This model then corresponded closely to the Swiftsure 24. Prototype tests have been conducted on a Swiftsure 24 and a Bayfield 25 at Fisherman's Cove. Photo 8.1.1 shows the model installed in the U.B.C. wave basin before water was added. The mast and rigging were not in place when the photo was taken but were in place for all tests conducted (Photo 8.1.2).

8.1.2 Description of Moorage Conditions

Moorage against both a fixed and floating walkway (dock) was modelled. The same dock model was used for both with the constraints changed to represent the different conditions. To arrive at appropriate model characteristics a typical wooden dock, 5 feet wide and 40 feet long, was replicated. The dock was assumed to have a 2 inch wooden deck 12 inches above the water level with buoyancy provided by styrofoam blocks and with longitudinal stiffness provided by 12" by 2" wooden side boards. The weight of this dock and its stiffness were computed and these quantities were incorporated in the model which was 0.5 feet wide and 4 feet long. The model dock would sag one inch in the middle when supported in the air at each end.

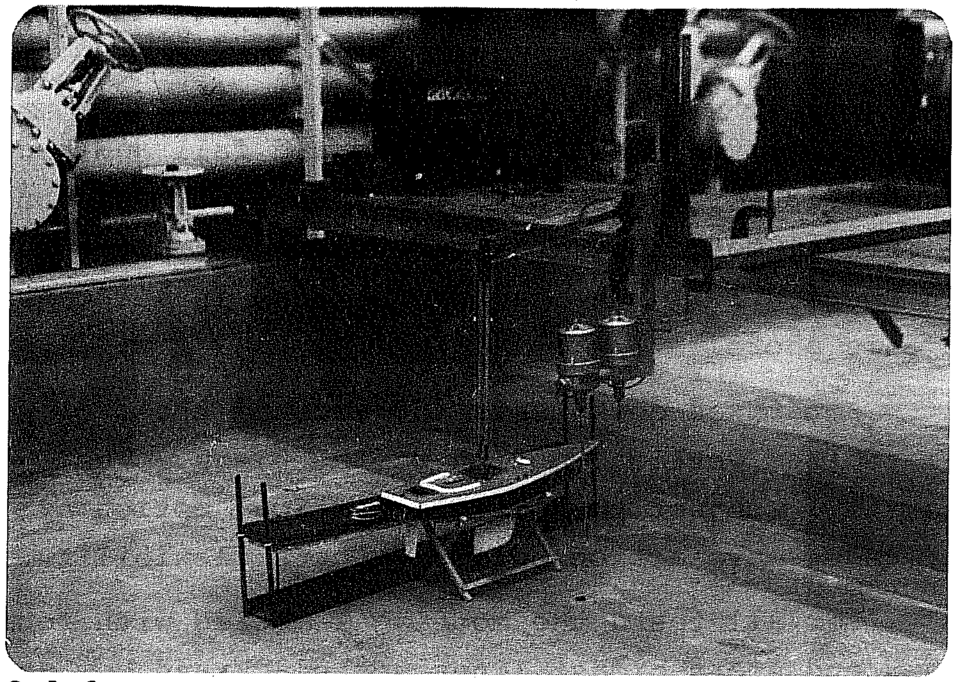


Photo 8.1.1 Model in the U.B.C. wave basin without water.

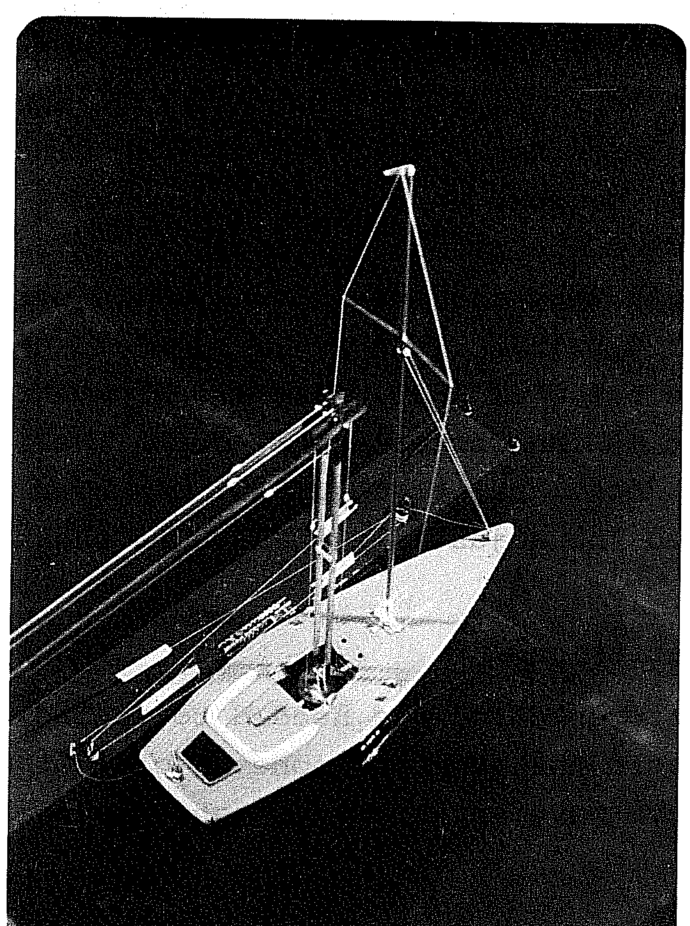


Photo 8.1.2 Model in the U.B.C. wave basin with water.

Freely floating, the model would rise and fall and bend under the action of the waves. The model dock was constrained against lateral motion by four vertical model piles as shown in Photo 8.1.1. The sag of the dock in air can be seen in this photo.

For fixed dock tests the ends of the dock were constrained from vertical motion at the piers. The dock was still subject to a little vertical motion at mid span under wave action because of its flexibility.

For all tests the model was moored with four lines, bow and stern breast lines set slack and bow and stern spring lines set at a small initial steady state tension. The lines were modelled to represent the elasticity of ½-inch braided nylon line commonly used for moorage. Tests of this line by NHCL showed that it would stretch 10 percent at a tension of 490 lbs. and that the extension was linear for loads up to that value. The lines were modelled with nylon cord (about 1/32" diameter) with the elasticity provided by rubber strips (1/64" x 3/16") of sufficient length that the model lines would stretch 10 percent at a tension of 0.5 lbs. This would simulate ½-inch nylon line at a scale ratio of 1:10. The lines were fastened to the model yacht at the centerline at deck level, led through pulleys on the dock, and attached to the rubber strips which were fastened to the adjustable anchorages shown in Photo 8.1.2.

8.1.3 Instrumentation

Instrumentation was needed to record wave height and also to record the three components of boat motion in the plane of wave movement. Wave height was measured by a commercially available Robert Shaw capacitance-type water level transducer similar to those used at NRC. Motion was more difficult to measure because commercial instrumentation such as accelerometers are expensive and are also heavy for a model of this size.

A motion transducer was designed by NHCL making use of relatively inexpensive precision potentiometers. It was a hinged-arm transducer as shown schematically in Dwg. 8.1.2 and in Photo 8.1.1. The hinged-arm operates as three parallel systems capable of measuring heave, surge and pitch (alternatively heave, sway and roll) simultaneously. Heaving of the boat rotated the heave arm as shown in the drawing and this rotated the large gear attached to the arm which rotated the smaller gear attached to the heave potentiometer. The arm was 2.0 feet long and the gears were 3 inches and 3/8 inches in diameter respectively. Surging rotated the surge arm and this rotation was transmitted by a parallel cable system to the second large gear which rotated a small gear attached to the surge potentiometer. Pitching rotated a pitch plate and this pitching was transmitted by parallel cables to a third gear set and to the pitch potentiometer. The three motions were incorporated into the single hinged-arm system with only second order crossover effects which were negligible for the motions to be tested. The effective mass of the system was approximately the mass of a single person on a real craft and therefore negligible. The actual operation of this transducer has been discussed along with the test results. The output of the water level transducer and the motion transducer were recorded on a multi-channel strip chart recorder.

Motion of the floating dock was measured by noting the rise and fall of the dock at the restraining vertical piling. Hawser forces were measured by noting the peak amount of extension of the rubber strips throughout the motion.

8.1.4 Description of the Wave Basin

The wave basin at UBC was approximately 45 feet long, 16 feet wide and could take water depths up to 2 feet. The basin was provided with a wave absorbing beach on the end opposite to the wave generator. The wave generator was a hinged paddle with controls to vary the frequency up to 2 Hz and amplitude of motion up to 0.8 feet. Only regular waves could be produced.

8.1.5 Test Procedure and Checkout of Instrumentation

Some preliminary tests were carried out to measure the static or calm water characteristics of the model but the main body of tests were run to determine the motion response of the model to waves of different period and height. The static tests were necessary to locate the center of gravity and to relate both angle of roll and pitch to the moment of forces causing these displacements. The calm water characteristics determined were the natural period in roll and the natural period in pitch. These determinations were made with the motion transducer in place as though its inertial components were part of the model being tested.

The applied moment of forces and the resultant roll and pitch are plotted dimensionlessly in Dwg. 8.1.3 along with similar data obtained on the Swiftsure 24. The comparison between the model and the large scale boat is good considering there has been little attempt to make the two hulls completely similar to each other.

The natural periods of the model were measured to be 1.1 secs in roll and 0.64 secs in pitch. The period in roll was relatively easy to determine because the model would oscillate in roll for a number of cycles before full dampening was achieved. In pitch, the oscillation was dampened in about two cycles so that it was necessary to analyse the motion transducer trace using the theory of damped oscillations to obtain a period. Because of the high dampening it was not possible to obtain a period for pitch in the Swiftsure 24 but the period in roll was measured to be 2.6 secs. Expressed as $T_6 \left(\frac{g}{L_w}\right)^{\frac{1}{2}}$ the dimensionless periods in roll become 4.2 and 3.2 for the model and the Swiftsure 24 respectively. It was not possible to measure a period in heave for either the model or prototype because of the high order of dampening present.

The key to successful wave tests was the proper operation of the motion transducer. Although the transducer arms were made of balsa wood and thin rectangular brass tubing, they did have some mass and some minimum joint friction. The resisting forces imposed on the boat due to joint friction were extremely small because of the large moment arms between the joints and the boat and are, therefore, completely negligible. Incidently, the motion transducer was pivoted and hinged to allow complete freedom of motion in the three components of motion not being measured.

The masses of individual parts of the transducer can be transferred analytically to an equivalent at the point of application on the model and this mass is different for each motion measured. Pitching (rolling) did not move the transducer arms so that no significant extra mass was involved for this motion. Surging (swaying) moved only the vertical arm and the added mass, expressed as weight for convenience, amounted to .04 pounds or 0.8 percent of the model's mass. Heaving moves both arms and the added mass amounted to 0.20 pounds or 4.0 percent of the model's mass. As mentioned before, these added masses are approximately what would be imposed by an extra passenger on a 25 foot yacht.

The weight of the transducer did have a serious effect that was remedied in the initial set up period. The weight of the transducer caused the model to drift ahead or astern and a neutral position could not be maintained. When the weight was counterbalanced by just the right amount, the model would neither drift away from the neutral position or towards the neutral position in a calm sea. The counterbalance (Photo 8.1.3) increased the mass for heave at the boat to 0.4 pounds. It did not affect the other motions. This counterbalance was used for the majority of the tests but on review it was later suggested that a low tension spring would produce the same counterbalancing effect without this extra mass. A comparison test with the counterweight and the spring showed that recorded heave was 80 to 85 percent lower with the counterweight. It also showed that recorded surge was 85 percent lower using the counterweight, even though the counterweight should not affect surge. Surge turns out to be a variable with a high degree of non-linearity because the mooring constraints act mainly on surge. The surge data consequently shows more scatter than the other data and this 85 percent figure may just be a reflection of this scatter. In any event, tests subsequent to this experiment were run with a spring counterbalance and the significance to the results will be discussed later.

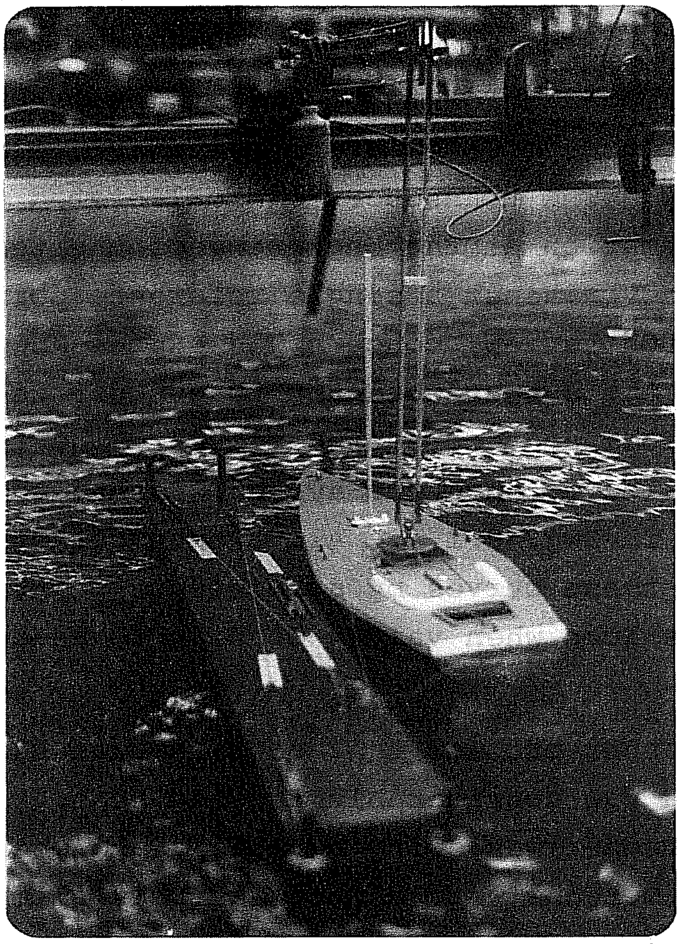


Photo 8.1.3 Motion transducer with counterweight in plastic bottle.

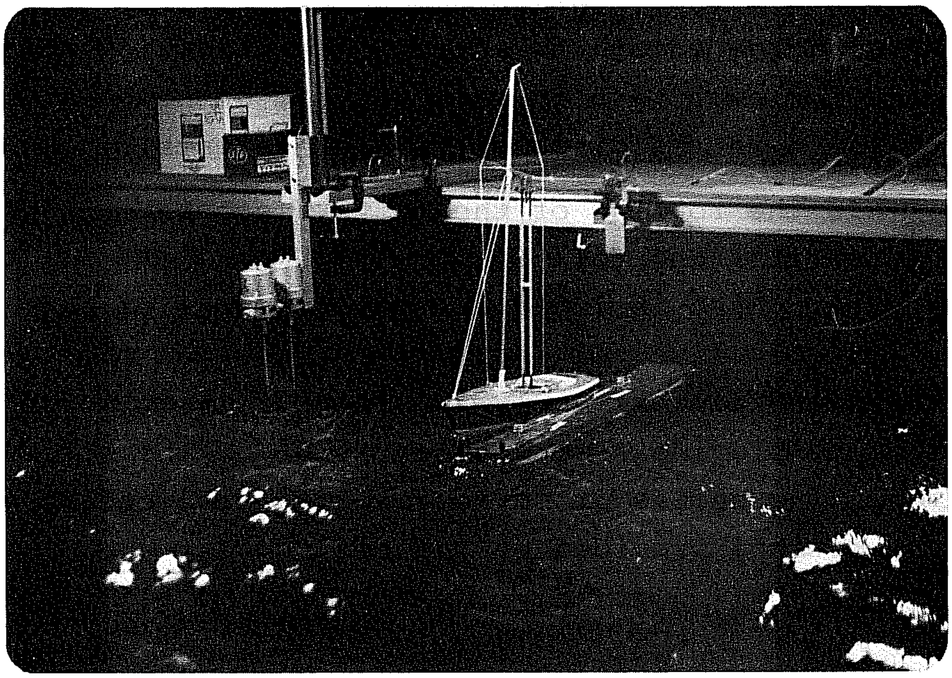


Photo 8.1.4 Model moored in a head sea with a 0.56 second period.

Calibration of the motion transducer was simplified because potentiometers are inherently stable electronically. The transducer was calibrated over its range of application at the beginning of the tests and checked each day against a single reference point for each motion. On review, concern was expressed with hysterisis in the output when the transducer is measuring increasing values and decreasing values. The transducer was relcalibrated to show the hysterisis and the results are presented in Dwg. 8.1.4. All transducer output was reduced using these curves by selecting a point midway in the hysterisis loop when values of peak-to-peak motion were required.

Another problem that occurred was that the model would roll and yaw considerably in head seas. It turned out that the rudder was swinging freely and when it was clamped these motions were almost entirely eliminated. Of course, good moorage practise requires that the rudder be lashed when the boat is left at the dock. Roll and sway were measured with a tape for each test run but the values were never large enough to affect wave criteria and are not presented for each test in this report, although some values are mentioned in the discussions of the tests.

In the routine of the tests, measurements were made of the rise and fall of the dock and these are included in the data. Also included are measurements of peak hawser forces for each line for each test. Numerous photographs were taken and approximately 300 feet of 16 mm movie film were shot to provide some documentation of the motions involved. One series of movie film was analysed to compare with the motions provided by the transducer.

8.1.6 Test Results

A series of 148 tests, in which wave period, wave height and wave direction varied, were run and documented. The results were tabulated in Table 8.1.2. Tests 1 through 16 were the first tests run and because of difficulties with the testing technique these conditions were rerun as Tests 115 through 138. All of the tests were run with a water depth of 12 inches except for Tests 115 through 138 which were run at 18 inches depth. The latter tests had the largest wave period and at these periods the 12 inches depth was too shallow for the wave generator to function properly. Photo 8.1.4 shows the model being tested in a beam sea. Photos 8.1.5 through 8.1.10 show the response of the model in both head and beam seas for different wave lengths.

The data of the table has been arranged in columns beginning with a column headed Test No. The wave periods tested ranged from 2.0 secs to 0.5 secs. The corresponding wave lengths varied from 12.8 feet to 1.3 feet. These waves would scale up at 1:10 scale to be from 6.3 to 1.6 second waves with lengths from 128 to 13 feet. Wave heights ranged from 2.8 inches to 0.3 inches which scale from 28 inches to 3 inches at 1:10 scale (Table 8.1.3). While these heights do not appear large, the model boat and dock motions were sometimes quite severe.

Wave direction has been noted in the table as either head or beam referring to the orientation of the model relative to the wave. The dock motion has either been identified as fixed or the vertical peak to peak motion measured at the piles has been noted. The floating dock motion was commonly less than the wave height but in several instances dock motions as high as 3.5 inches were recorded. The peak-to-peak boat motions are recorded in inches for heave, surge and

TABLE 8.1.2

SUMMARY OF MODEL TEST RESULTS

Test No.	Wave Period (sec.)	Wave Height (in.)	Wave Direction	Height of Dock Motion (in.)	Measured Boat Motions (Peak to Peak) Heave (in.)	Surge (in.)	Sway (in.)	Pitch (Deg.)	Roll (Deg.)	Peak Hawser Forces (Pounds) Bow Breast Line	Bow Spring Line	Stern Spring Line	Stern Breast Line
17	1.20	1.45	Beam	-	1.72	-	1.50	-	23.2	<.005	.015	<.005	<.005
18	1.20	1.55	B	Fixed	1.92	-	1.20	-	19.1	.020	.075	.075	"
19	1.20	1.80	Heave	Fixed	1.08	1.60	-	8.6	-	.050	.150	.150	"
20	1.20	1.50	H	2.10	1.44	1.65	-	8.3	-	.080	.200	.200	"
21	1.20	1.05	H	.75	.72	0.70	-	2.9	-	<.005	.025	.025	"
22	1.20	1.05	H	Fixed	.72	0.60	-	4.2	-	.020	.010	.010	"
23	1.20	.85	B	Fixed	1.08	-	0.80	-	10.5	.020	.010	.010	"
24	1.20	.90	B	.75	.84	-	0.80	-	10.5	<.005	<.005	<.005	"
25	1.20	.55	H	.50	.60	.20	-	1.8	-	"	"	"	"
26	1.20	.60	H	Fixed	.48	.20	-	1.8	-	"	"	"	"
27	1.20	.60	B	Fixed	0.60	-	.30	-	5.0	"	"	"	"
28	1.20	.60	B	.50	0.60	-	.40	-	6.0	"	"	"	"
29	1.00	2.10	B	1.25	2.35	-	1.65	-	38.9	.250	.250	.150	.200
30	1.00	2.00	B	Fixed	2.95	-	1.55	-	38.6	.150	.200	.100	.150
31	1.00	2.05	H	Fixed	1.44	1.35	-	10.2	-	.050	.150	.150	<.005
32	1.00	2.15	H	3.50	1.25	1.25	-	14.1	-	.025	.105	.150	"
33	1.00	1.35	H	2.00	.96	1.00	-	8.5	-	.040	.100	.100	<.005
34	1.00	1.30	H	Fixed	1.08	.95	-	7.4	-	.050	.175	.175	<.005
35	1.00	1.30	B	Fixed	1.80	-	1.15	-	18.7	.075	.075	.100	"
36	1.00	1.30	B	1.00	1.68	-	1.40	-	16.6	.125	.150	.100	.125
37	1.00	0.70	B	.75	.78	-	.90	-	12.8	.050	.200	.050	.050
38	1.00	0.75	B	Fixed	.90	-	0.80	-	17.0	.025	.040	.040	.025
39	1.00	0.90	H	Fixed	.42	0.45	-	3.4	-	.010	.070	.070	<.005
40	1.00	0.80	H	1.00	.60	0.60	-	3.4	-	.015	.050	.050	"
41	.90	2.35	H	2.25	1.85	0.80	-	15.0	-	.050	.100	.200	.020
42	.90	2.45	H	Fixed	1.80	0.75	-	14.4	-	.100	.125	.200	.030
43	.90	2.60	B	Fixed	3.50	-	1.60	-	32.8	.150	.150	.100	.150
44	.90	2.40	B	2.50	3.50	-	2.15	-	34.4	.225	.125	.125	.225
45	.90	1.80	B	1.75	2.20	-	1.20	-	23.4	.150	.150	.100	.150
46	.90	1.80	B	Fixed	2.50	-	1.20	-	28.1	.125	.125	.100	.125
47	.90	1.80	H	Fixed	1.50	0.70	-	12.2	-	.050	.125	.125	.025
48	.90	1.85	H	2.25	1.50	0.70	-	12.0	-	.050	.100	.100	<.005

TABLE 8.1.2 (cont'd)

SUMMARY OF MODEL TEST RESULTS

Test No.	Wave Period (sec.)	Wave Height (in.)	Wave Direction	Height of Dock Motion (in.)	Measured Boat Motions (Peak to Peak) Heave (in.)	Surge (in.)	Sway (in.)	Pitch (Deg.)	Roll (Deg.)	Peak Hawser Forces (Pounds) Bow Breast Line	Bow Spring Line	Stern Spring Line	Stern Breast Line
49	.90	0.85	H	1.00	0.60	0.20	-	4.2	-	.015	.050	.050	<.005
50	.90	0.95	H	Fixed	.48	0.20	-	4.0	-	.025	.060	.060	"
51	.90	0.70	B	Fixed	.96	-	0.60	-	7.8	.025	.025	.025	"
52	.90	0.70	B	0.75	0.84	-	0.80	-	11.0	.020	.050	.050	"
53	.80	2.45	B	2.00	2.52	-	1.85	-	15.7	<.005	.200	.100	<.005
54	.80	2.30	B	Fixed	2.76	-	1.65	-	14.4	.150	.200	.200	.150
55	.80	2.30	H	Fixed	1.32	0.30	-	19.3	-	.075	.100	.200	.025
56	.80	2.30	H	0.50	1.44	0.35	-	19.2	-	.100	.025	.100	.175
57	.80	1.50	H	0.50	0.72	0.20	-	11.0	-	.050	.075	.075	<.005
58	.80	1.60	H	Fixed	0.60	0.30	-	11.5	-	.050	.050	.100	"
59	.80	1.70	B	Fixed	1.36	-	1.20	-	11.4	.100	.100	.100	.100
60	.80	1.60	B	1.10	1.14	-	1.15	-	11.3	.100	.075	.075	.050
62	.80	0.90	H	0.50	0.60	0.15	-	7.0	-	.040	.075	.075	<.005
63	.80	0.95	H	Fixed	0.36	0.20	-	7.2	-	.025	.050	.075	"
64	.80	0.90	B	Fixed	0.84	-	0.65	-	5.2	<.005	.025	.025	"
65	.80	1.10	B	0.75	0.96	-	0.90	-	7.9	.050	.030	.030	.050
66	0.71	2.80	H	1.00	1.44	0.20	-	20.3	-	.200	.100	.175	<.005
67	0.71	2.75	H	Fixed	1.20	0.25	-	20.8	-	.200	.100	.150	.050
68	0.71	2.65	B	Fixed	3.10	-	1.55	-	14.0	.100	.200	.200	.100
69	0.71	2.75	B	1.75	3.06	-	1.70	-	13.2	.075	.150	.150	.075
70	0.71	2.00	B	1.00	2.04	-	1.30	-	10.5	.200	.100	.100	.200
71	0.71	2.00	B	Fixed	1.80	-	1.30	-	10.0	.150	.100	.150	.150
72	0.71	2.15	H	Fixed	.96	0.20	-	16.2	-	.075	.125	.125	.075
73	0.71	2.00	H	0.50	.60	0.10	-	14.8	-	.075	.125	.125	.075
74	0.71	1.15	H	0.50	.42	0.10	-	8.2	-	.050	.050	.050	<.005
75	0.71	1.45	H	Fixed	.76	0.10	-	10.5	-	.075	.050	.050	<.005
76	0.71	1.20	B	Fixed	1.28	-	.70	-	5.0	.125	.100	.100	.125
77	0.71	1.30	B	0.75	.96	-	.80	-	5.0	.050	.050	.050	.050
78	0.63	2.05	H	1.25	0.90	0.20	-	13.7	-	.150	.050	.075	<.005
79	0.63	2.20	H	Fixed	1.02	0.14	-	11.7	-	.125	.025	.050	"
80	0.63	2.00	B	Fixed	1.80	-	1.05	-	6.8	.075	.020	.100	.150
81	0.63	2.00	B	1.00	1.50	-	1.17	-	6.7	.100	.100	.100	.100

TABLE 8.1.2 (cont'd)

SUMMARY OF MODEL TEST RESULTS

Test No.	Wave Period (sec.)	Wave Height (in.)	Wave Direction	Height of Dock Motion (in.)	Measured Boat Motions (Peak to Peak) Heave (in.)	Surge (in.)	Sway (in.)	Pitch (Deg.)	Roll (Deg.)	Peak Hawser Forces (Pounds) Bow Breast Line	Bow Spring Line	Stern Spring Line	Stern Breast Line
82	0.63	1.70	B	1.00	1.00	-	1.23	-	6.2	.050	.050	.050	.075
83	0.63	1.90	B	Fixed	0.90	-	1.17	-	8.4	.100	.100	.100	.150
84	0.63	1.80	H	Fixed	0.30	.30	-	12.2	-	.075	.050	.050	<.005
85	0.63	1.85	H	1.00	0.32	.17	-	13.4	-	.150	.050	.050	"
86	0.63	0.50	H	0.50	0.15	.05	-	2.4	-	.025	.025	.010	"
87	0.63	0.55	H	Fixed	0.20	.10	-	2.8	-	<.005	.010	.010	"
88	0.63	0.35	B	Fixed	0.20	-	0.24	-	1.8	"	.020	.020	"
89	0.63	0.40	B	0.50	0.25	-	0.24	-	1.5	"	.015	.015	"
90	0.56	1.60	B	1.00	0.60	-	0.71	-	11.4	"	.075	.075	.050
91	0.56	1.70	B	Fixed	0.65	-	0.82	-	8.7	"	.100	.075	.075
92	0.56	1.50	H	Fixed	0.45	.12	-	7.3	-	.150	.075	.075	<.005
93	0.56	1.70	H	0.50	0.40	.12	-	6.8	-	.075	.025	.025	"
94	0.56	1.50	H	0.50	0.35	.12	-	6.5	-	.050	.025	.025	"
95	0.56	1.50	H	Fixed	0.30	.12	-	5.4	-	.050	.015	.015	"
96	0.56	1.40	B	Fixed	0.60	-	0.55	-	10.6	.050	.050	.050	"
97	0.56	1.50	B	1.00	0.90	-	0.93	-	8.7	.050	.075	.075	.050
98	0.56	0.75	B	0.75	0.45	-	0.35	-	4.8	<.005	.050	.025	.010
99	0.56	0.65	B	Fixed	0.35	-	0.50	-	5.3	"	.025	.015	.025
100	0.56	0.70	H	Fixed	0.10	.08	-	1.9	-	.015	.010	.010	<.005
101	0.56	0.75	H	0.10	0.05	.06	-	2.1	-	.010	.010	.005	"
102	0.50	1.55	H	0.50	0.15	.23	-	5.4	-	.025	.025	.025	"
103	0.50	1.10	H	Fixed	0.10	.12	-	2.4	-	.050	.050	.050	"
104	0.50	1.60	B	Fixed	0.40	-	0.52	-	7.6	.020	.025	.025	.025
105	0.50	1.45	B	0.50	0.40	-	0.47	-	7.1	<.005	.025	.025	.015
106	0.50	0.90	B	0.50	0.25	-	0.09	-	3.6	"	.010	.010	.010
107	0.50	0.65	B	Fixed	0.15	-	0.30	-	3.8	"	.010	.010	.015
108	0.50	0.65	H	Fixed	0.10	.03	-	1.9	-	.015	.010	.010	<.005
109	0.50	0.65	H	0.10	0.05	.03	-	1.1	-	.010	.005	.005	"
110	0.50	0.30	H	0.10	0.00	.00	-	0.6	-	<.005	<.005	<.005	"
111	0.50	0.30	H	Fixed	0.05	.03	-	0.4	-	"	"	"	"
112	0.50	0.30	B	Fixed	0.10	-	0.06	-	0.7	"	"	"	"
113	0.50	0.30	B	0.10	0.15	-	0.06	-	0.7	"	"	"	"

TABLE 8.1.2 (cont'd)

SUMMARY OF MODEL TEST RESULTS

Test No.	Wave Period (sec.)	Wave Height (in.)	Wave Direction	Height of Dock Motion (in.)	Measured Boat Motions (Peak to Peak) Heave (in.)	Surge (in.)	Sway (in.)	Pitch (Deg.)	Roll (Deg.)	Peak Hawser Forces (Pounds) Bow Breast Line	Bow Spring Line	Stern Spring Line	Stern Breast Line
115	2.00	2.49	H	3.00	2.40	1.10	-	5.5	-	<.005	.020	.020	<.005
116	2.00	2.49	H	Fixed	2.30	0.60	-	5.5	-	<.005	.020	.020	"
117	2.00	2.49	B	2.25	2.40	-	2.50	-	12.0	.020	.015	.015	.020
118	2.00	2.49	B	Fixed	2.40	-	2.85	-	18.2	.020	.015	.015	.020
119	2.00	1.85	B	1.50	1.90	-	2.00	-	7.5	<.005	.020	.020	<.005
120	2.00	1.85	B	Fixed	1.94	-	2.10	-	12.0	.015	.020	.020	.015
121	2.00	1.85	H	Fixed	1.64	0.30	-	12.0	-	<.005	<.005	<.005	<.005
122	2.00	1.85	H	2.25	1.60	0.40	-	12.0	-	"	"	"	"
123	2.00	0.75	H	0.50	0.70	0.20	-	1.0	-	"	"	"	"
124	2.00	0.70	H	Fixed	0.60	-	-	-	-	"	"	"	"
125	2.00	0.70	B	Fixed	0.60	-	.60	-	2.0	"	"	"	"
126	2.00	0.70	B	0.50	0.70	-	.70	-	2.0	"	"	"	"
127	1.50	2.67	H	2.75	2.40	2.50	-	10.0	-	.025	.400	.400	.025
128	1.50	2.67	H	Fixed	2.50	1.20	-	12.5	-	<.005	.350	.350	.025
129	1.50	2.67	B	3.50	2.50	-	2.80	-	24.0	.030	.100	.100	.030
130	1.50	2.55	B	Fixed	2.70	-	2.40	-	18.0	.030	.100	.100	.030
131	1.50	1.80	B	Fixed	1.60	-	2.20	-	13.0	.010	.040	.040	.010
132	1.50	1.80	B	2.00	1.60	-	2.60	-	18.0	.010	.030	.030	.040
133	1.50	1.80	H	2.25	1.60	1.30	-	8.0	-	<.005	.250	.250	<.005
134	1.50	1.80	H	Fixed	1.60	1.20	-	8.0	-	<.005	.250	.250	<.005
135	1.50	.93	H	Fixed	.70	0.40	-	4.0	-	<.005	.015	.015	<.005
136	1.50	.93	H	1.25	.80	0.50	-	4.0	-	<.005	.015	.015	<.005
137	1.50	.93	B	1.25	.80	-	1.80	-	7.0	<.005	<.005	<.005	<.005
138	[illegible]	.93	B	Fixed	.80	[illegible]	1.60	-	8.0	<.005	.010	.010	<.005
139	1.00	2.55	B	2.50	[illegible]	[illegible]	3.00	-	36.0	.150	.150	.150	.150
140	1.00	2.55	H	2.50	1.60	1.60	-	17.0	-	.050	.250	.250	.050
141	.90	2.44	H	2.50	1.40	1.20	-	18.0	-	.020	.300	.300	<.005
142	.90	2.32	B	2.50	2.40	-	3.00	-	27.0	.100	.200	.200	.100
143	.80	2.49	B	2.50	2.70	-	2.80	-	23.0	.100	.200	.200	.100
144	.80	2.55	H	1.50	1.00	.40	-	20.0	-	.050	.100	.100	<.005
145	.71	1.62	H	1.00	.65	.80	-	12.0	-	.010	.020	.020	<.005
146	.71	1.85	B	1.50	1.60	-	1.00	-	10.0	.010	.020	.020	<.005
147	.63	1.85	B	1.50	1.60	-	1.20	-	10.0	.010	.020	.020	<.005
148	.63	1.85	H	1.25	.60	.10	-	10.5	-	.025	.010	.010	<.005

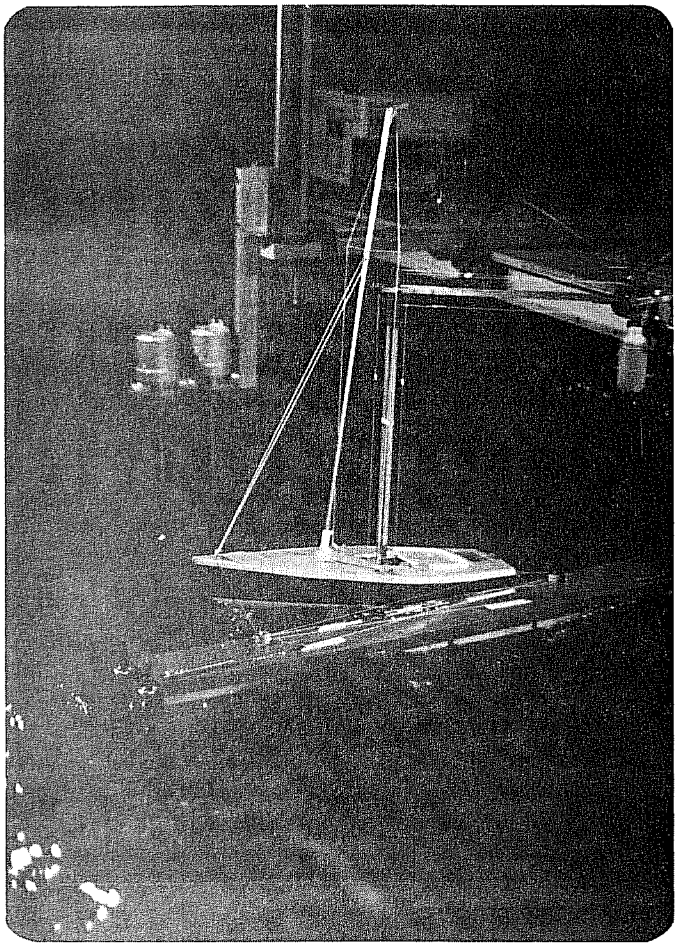
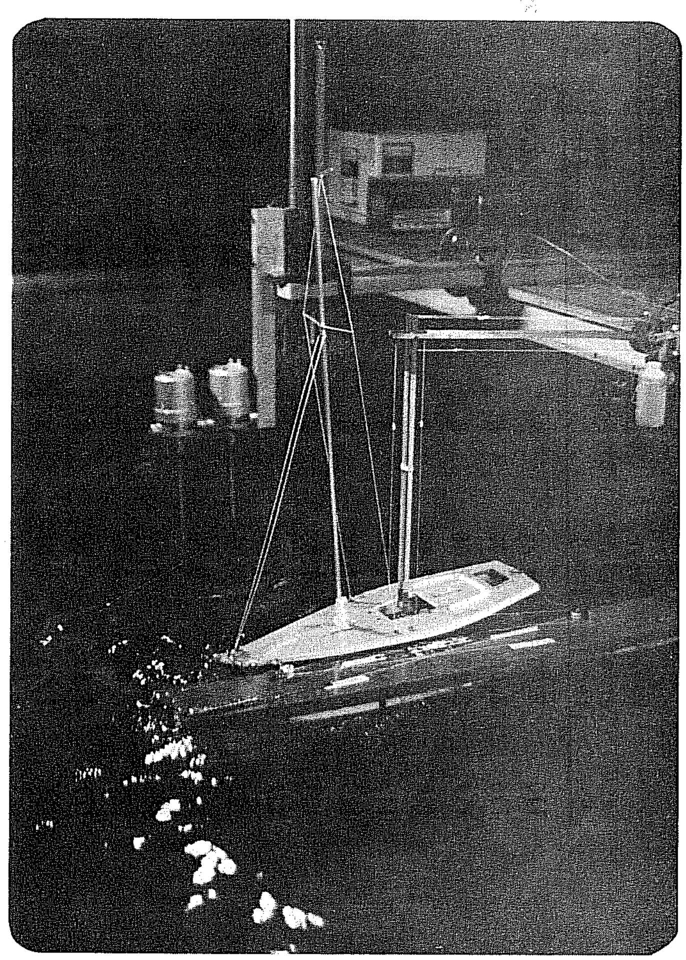


Photo 8.1.5.

Model bow rising on a head sea with a wave period close to resonance in pitch (0.63 seconds).

Photo 8.1.6.

Model bow falling in a head sea with a wave period close to resonance in pitch.



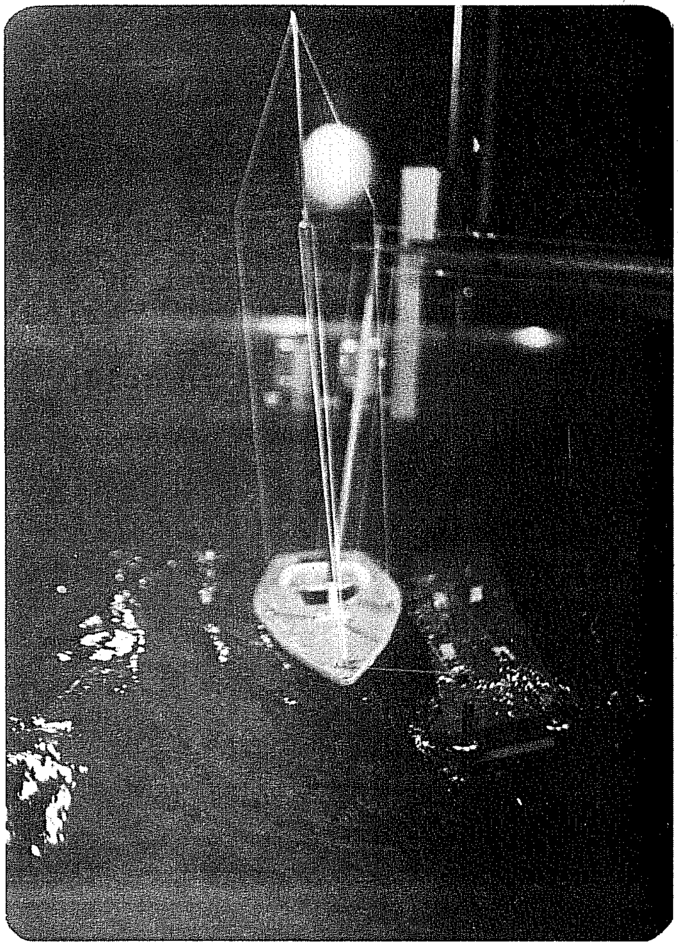


Photo 8.1.7.

Model in the trough of a beam sea with a wave period of 0.63 seconds.

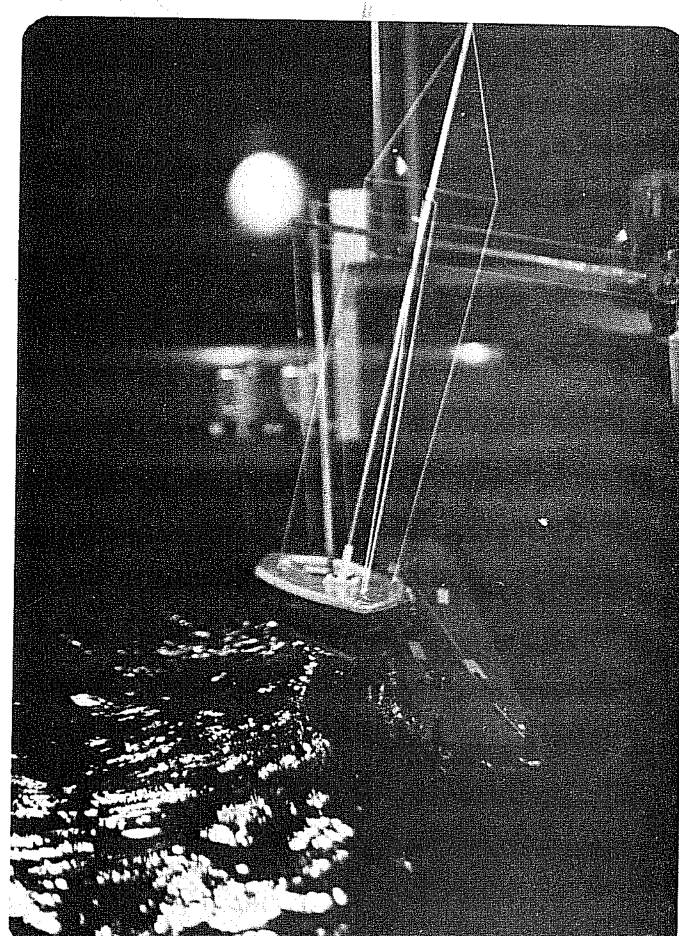


Photo 8.1.8.

Model riding on the crest of a beam sea with a wave period of 0.63 seconds.

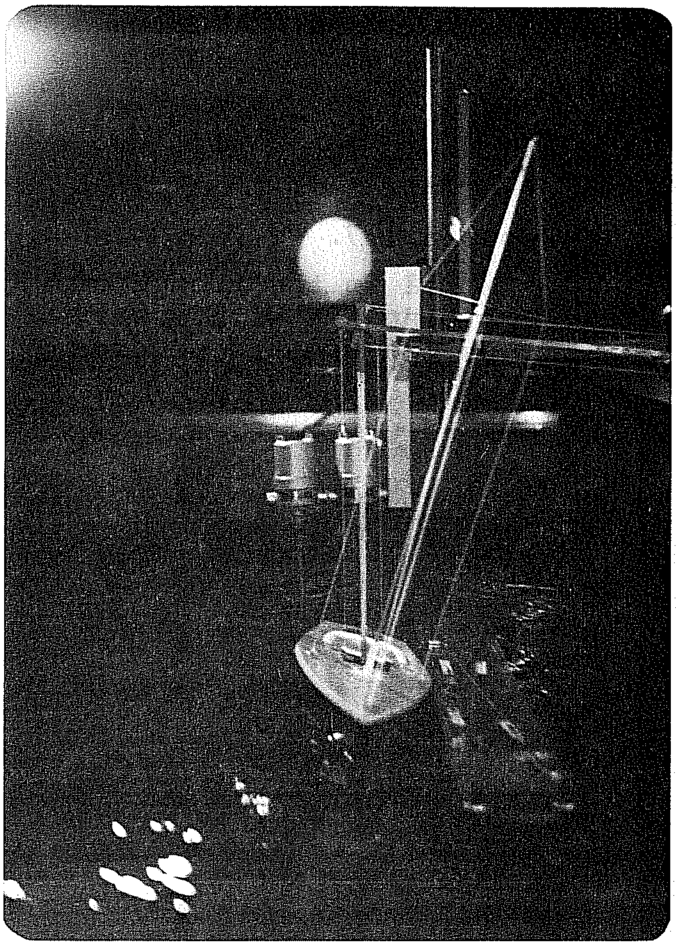


Photo 8.1.9.

Model on the crest of a beam sea with wave period (1.0 seconds) near the natural period in roll.

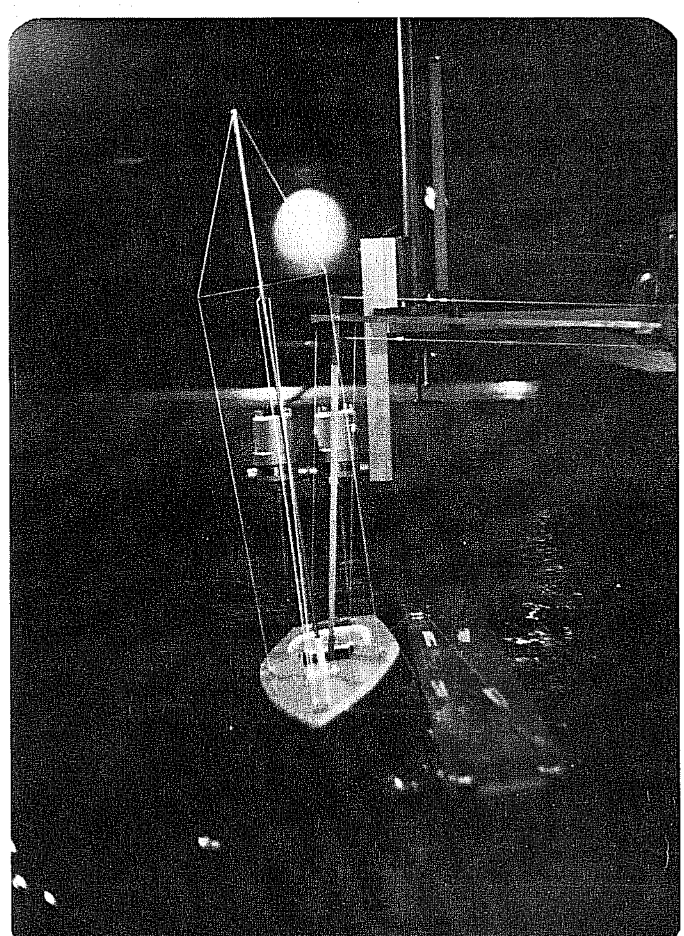


Photo 8.1.10.

Model in the trough of a beam sea with wave period of 1.0 seconds.

sway and degrees for pitch and roll. Heaves as high as 3.5 inches were recorded for beam sea conditions and 2.5 inches for head seas. Surge was heavily restrained by taut spring lines so that the magnitudes were generally small (less than 1.65 inches) except for one value of 2.50 inches that was recorded. The corresponding peak tension in the spring lines was 0.4 lbs which scales up to 400 lbs at 1:10 scaling. Larger values of sway were recorded in beam seas (up to 3.0 inches) with peak tensions in the breast lines reaching 0.15 lbs. The amount of sway depended greatly on the amount of slack left in the breast lines under calm water conditions. Pitching motions with peak to peak swings as high as 20 degrees were recorded while rolling motion swings reached 38 degrees.

Table 8.1.3 has been prepared to assist in interpreting the model results for boats of different size. The quantities of Table 8.1.2 should be multiplied by the factors given in Table 8.1.3 to provide prototype values. The model moorage lines represented ½ inch lines on a 25 foot boat. For other size boats the equivalent line diameters are shown in Table 8.1.3 as well.

TABLE 8.1.3

INTERPRETATION OF TEST RESULTS TO FULL SIZE BOATS

Quantity		Multiplier to be Used			
		20 ft. boat (S=8)	25 ft. boat (S=10)	30 ft. boat (S=12)	40 ft. boat (S=16)
Wave Length	S*	8	10	12	16
Wave Period	$S^{1/2}$	2.8	3.2	3.5	4.0
Linear Displacements	S	8	10	12	16
Angular Displacements	1	1	1	1	1
Equivalent Moorage line Diameter		0.36"	0.50"	0.66"	1.01"
Moorage Line Tensions	S^3	512	1000	1728	4096

*S = scale ratio

The amount of motion realized depended greatly on the wave period as will be bought out in the dimensionless plots to be discussed next.

The data of Table 8.1.2 has been made dimensionless and plotted on Dwgs. 8.1.5 and 8.1.6 for head and beam seas respectively. One diagram on each drawing applies to floating dock moorage and the other to fixed dock moorage. The abscissa is the actual wave length (corrected for depth effects) divided by the waterplane length and the data spans values of this ratio from 0.58 to 5.8. This covers practically the full range over which the effects of wave length cause a change in boat response. Beyond this range the response generally approaches asymptotic values.

Heave, sway and surge have been made dimensionless by dividing by the wave height. Pitch has been made dimensionless by multiplying the pitch measurements expressed in radians by one-half the waterline length and dividing by the wave height. The resulting value approximates how high, relative to wave height, the bow or stern rose and fell due to pitching action. The roll has been treated the same way except that the beam has been substituted for waterplane length.

If the response of the model were linear with wave height, all the data with different wave heights for one wave period would coincide. The spread of the data indicates either non-linear effects, a lack of consistency in the phenomena, or the degree of data taking and instrumentation accuracy. Evidently all three effects were present to some degree. The motion transducer exerted some friction forces and added mass to the model as discussed. To evaluate these effects, movie footage was taken of several tests with the transducer in place and with it removed. This data has also been plotted on Dwg. 8.1.5 and it fell within the scatter of the transducer data indicating that the transducer did not grossly misrepresent the model motions.

For both wave lengths tested, the heave with the transducer was about 90 percent of heave without the transducer. (The transducer was counterbalanced with a spring rather than a counterweight). In only one of the movie film tests was surge significant and the result with the transducer was 14 percent higher than without. This test was at a wave height near resonance in surge and the added mass of the transducer could reasonably have caused that effect. In pitch, the results were virtually identical with and without the transducer for the longer wave and for the shorter wave the transducer result was 8 percent higher. This difference was difficult to rationalize except that it be caused by the natural randomness of the phenomena.

Observation of the waves and model motion showed there to be a fair component of randomness that would be reflected in the data. Waves reflecting from the beach end of the basin can generate a secondary standing wave pattern that affects the results. The action of the mooring lines and the intermittent contact with the dock also contributed to the randomness. There was also the coupling between motions that changed subtly during a test causing one component to increase in size at the expense of another and vice versa.

Much of the data scatter must be attributed to a lack of linearity with wave height. For instance, the low wave series data for pitch in head seas (Dwg. 8.1.5) generally plotted appreciably below the medium and high wave series which tended to plot together. Because of the gently sloping hull lines fore and aft, the waterplane geometry changed dramatically as the boat pitched so that non-linearity was to be expected. The same degree of non-linearity was not evident in the roll results because the waterplane did not vary much with roll.

Some of the variability of the data was caused by higher order harmonics. For instance, the longest wave tested had a period of 2.0 seconds and the model had a natural period of about 0.65 seconds in pitch. The resulting transducer trace showed a third harmonic with amplitude larger than the main motion. Large sub-harmonics were also frequently present. In some tests the model would regularly impact with the dock only every second wave. The wave form also displayed higher harmonics at times, especially at the lower frequencies. These harmonics in the wave and the response caused fairly strong irregularities in the data especially when resonance occurs in the harmonic.

Overall, a great deal of attention was paid to reducing the amount of scatter in the data and Tests 115 through 148 were mainly directed to rerunning other tests to improve the consistency of the plots. While there existed a fair degree of scatter, the data defined a very strong dependence between model response and the wave length and that was the main purpose of the tests.

Heave clearly approached the wave height asymptotically for short waves. In beam seas, the heave data showed a resonance condition at about 0.9 secs but similar resonance was not evident in the head sea data. Evidently, in head seas the model length diffuses the effectiveness of the resonant wave in heave because it takes much longer for the wave crest to pass under the boat than it does in beam seas. The heave in the model did not depend noticeably on the fixity of the dock because the moorage did not constrain heave to any extent.

The response of the model in surge depended very much on the character of the moorage lines because it was moorage lines that furnished the restoring force. The resonance in the surge data depended on the combined natural period of the boat and moorage line. At the shorter waves, the dimensionless surge approached zero asymptotically but at the longer waves the surge appeared to approach some value above zero but less than one, which would depend on the elasticity of the lines.

The behaviour in sway in beam seas was much the same as surge because the taut spring lines stretched to provide restraint when the model moved away from the dock in a swaying motion. Spring line tensions as high as 0.200 lbs were noted under beam sea conditions. The tensions were not linear with distance from the dock, however, because the line extension would not be linear due to the high angle between the line direction and motion direction. In addition, the slack breast lines limited the amount of sway to about the point where they became taut. The breast lines showed tensions as high as 0.150 lbs under some beam sea tests.

In swaying motion, the model tended to find a mean position so that the impluses from periodic tensions on mooring lines pulling towards the dock balanced the rebound impluses due to periodic impact against the dock. High mooring line impulses resulted in high impact impulses. An elastic bumper would increase the length of time in contact with the dock so that the same impulse could be generated with less impacting force. The presence of a bumper would not change the sway motion appreciably but would reduce the impacting force.

As sway was very sensitive to the non-linear mooring conditions, the data exhibited consider scatter, particularly at the wave length/waterplane ratio of 4.1 (1.5 second wave) at which a resonant condition was set up. At this wave period even the low wave test resulted in surge to the limit of the breast line slack.

At a ratio of 5.85 (2.0 second wave) the resonance was not apparent and the data grouped in a more linear fashion. The asymptotic value of the sway to wave height ratio appeared to approach zero for short waves but its value for long waves was not clearly indicated and it could be expected to be related to the slack in the breast lines.

Pitch and roll were clearly the strongest motions observed and also the least complicated because the mooring lines did not restrain these motions appreciably. There was a high degree of non-linearity with wave height, however, as discussed earlier. Pitch and roll tended to zero asymptotically for both short and long waves and exhibited a strong resonant peak at close to the natural frequency for these motions. Pitching in head seas did not result in strong contact with the dock but rolling in beam seas resulted in very strong interaction, with the model tending to roll on up over the dock (Photo 8.1.8).

Finally, the results of the theoretical analysis of Section X are shown on Dwgs. 8.1.5 and 8.1.6 to emphasize the excellent correlation with the model results. It can be concluded that the model tests results are adequate to show quantitatively and dependance of the response of a sailboat to different wave lengths with sufficient accuracy that wave length can be made variable in formulating wave criteria. The data has more scatter than one would like to see and suggestions for reducing scatter in conducting similar tests in the future include:

1. Improve the wave generation, filtering and absorption to improve the condition of the sea in the basin by eliminating unwanted harmonics.

2. Improve the motion transducer to reduce the amount of friction and hysteresis present. Basically, the transducer worked well and was a good choice for these tests.

3. Run additional tests to define more clearly the non-linear effects at certain specific wave periods.

4. Mount load cells on the hawser lines for more accurate line tension measurements.

One might suggest a larger model capable of utilizing more sophisticated instrumentation and requiring a comparably larger test facility to generate similar waves, but it would be unlikely that the results would be of any greater value in helping to formulate wave criteria than those already obtained.

8.2 Field Measurements

The field measurement program developed into several short term activities including:

1. Calm water tests mostly on a Swiftsure 24 sailboat (see Dwg. 8.1.1) to obtain data for comparison with the model.
2. Wave tests on a Swiftsure 24 and a Bayfield 25 for comparison with model response data.

These tests are discussed briefly below.

8.2.1 Calm Water Tests

In calm water it is possible to measure a few response characteristics that can be used for comparison with the model's characteristics. The majority of measurements

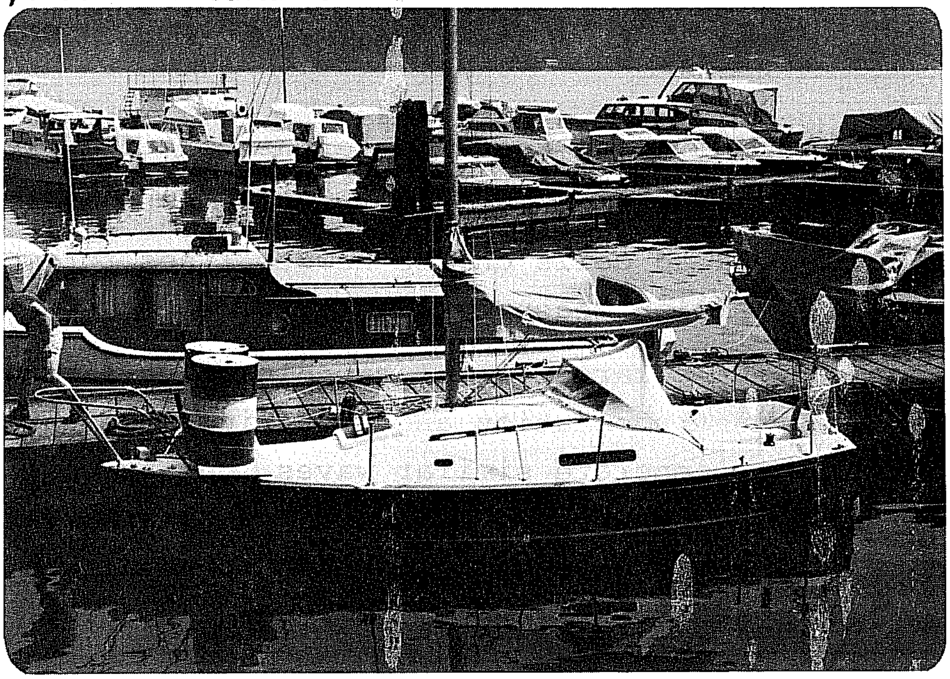


Photo 8.2.1 Swiftsure 24 sailboat with water-filled drums on the bow to apply a pitching moment.

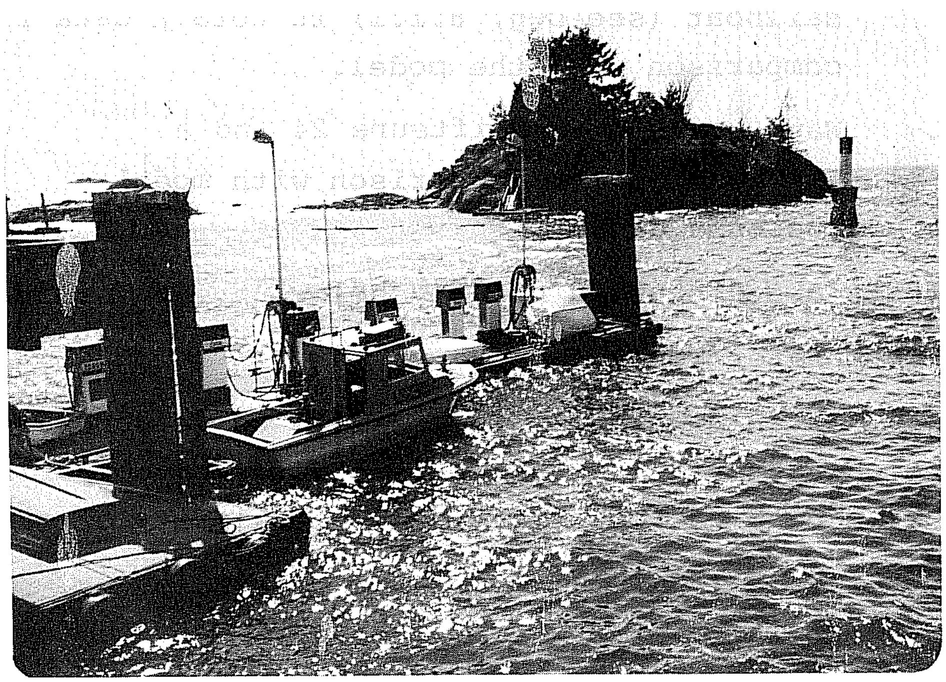


Photo 8.2.2 Gasoline Service Barge at entrance to Fisherman's Cove. Kelk Gauge is on seward piles.

were made on the Swiftsure 24 shown in Photo 8.2.1 with drums on its deck. These drums were filled with water to apply a pitching moment which was used to compare the pitching moments to the resultant static pitch angles as shown in Dwg. 8.1.3. Roll moments were applied by hanging a barrel over the side on a halyard to obtain a static angle of roll. The results are suprisingly linear considering the high angles of pitch and roll obtained and the large difference in waterline shape at these different angles.

Attempts were also made to time the natural periods of roll and pitch on full scale boats. These oscillations in pitch turned out to be too highly damped to be able to time them but oscillations in roll were sustained long enough for accurage measurement. Table 8.2.1 presents the results for a number of boats measured.

TABLE 8.2.1

NATURAL PERIOD IN ROLL IN CALM WATER

Type of Boat	Waterline Length in Feet	Period in Seconds	$T_6 (\frac{g}{L_w})^{\frac{1}{2}}$
Swiftsure 24 sailboat	20.7	2.6	3.24
C and C 27 sailboat	23.3	3.0	3.53
C and C 33 sailboat	28.5	3.7	3.93
Full Keel sailboat	26	3.3	3.66
Drop Keel sailboat	21	2.6	3.22
Displacement hull power boat	28	2.7	2.89
Displacement hull power boat	26	3.1	3.45
Cris Craft planning hull	29	2.2	2.32
Bayliner planning hull	21	2.1	2.60

The range in the period of roll is quite small considering the variety of hull shapes tested. As should be expected, sailboats with their deep keel have the larger period.

8.2.2 Wave Response Tests

The wave response tests were conducted at the gasoline service barge (Photo 8.2.2) at Fisherman's Cove where the Kelk wave gauge was installed. The Swiftsure 24 sailboat was moored alongside the barge with taut springs and loose breastlines as in the model tests with the bow heading into the waves (Photo 8.2.3). The tests were conducted between 11:00 am and 3:00 pm on May 18, 1980. The Kelk gauge sampled at 1:00 pm reading a 1.2 foot significant wave height and a 2.4 second peak period. This was one of the highest wave situations recorded that spring.

Measurements where taken with a surveyor's level and a level rod first placed on the bow, then at the mast and then at the stern. Maximum and minimum readings were taken over a period of one minute each location. This data was analysed to obtain the maximum movement, the average movement and the "significant" movement, that is the average of the largest one-third of the movements. From the bow and stern measurements it was possible to get corresponding values for pitch and from the mast measurement values of heave were obtained (corrected for pitch). The same data was obtained for a Bayfield 25 that tied up taking on gas (Photo 8.2.4). Finally, the Swiftsure was moored broadside to the waves (to the lee of a float) and a series of ten photographs were taken at the moments of greatest roll. These were also analysed for average maximum and significant roll. The number of measurements were very consistent between the Swiftsure and Bayfield and amounted to a period of 3.2 seconds, longer than given by the Kelk data but more consistent with the wave rider data.

The results are presented in Table 8.2.2 below:

TABLE 8.2.2

FIELD MEASUREMENTS OF BOAT RESPONSE

	Average Value	Maximum Value	Significant Value
Head Seas			
Swiftsure in Heave (ft)	.28	.49	.43
Swiftsure in Pitch (degrees)	3.7	6.7	5.2
Bayfield in Heave (ft)	0.37	0.67	.52
Bayfield in Pitch (degrees)	5.3	11.0	8.1
Beam Seas			
Swiftsure in Roll (degrees)	16.8	26.0	22.0

There was very little movement in surge and this was not recorded. The action in the beam seas was unpleasant enough that only the photographs were taken and no attempt was made to take heave or sway measurements.

The results were made dimensionless in the same way as the model results and plotted on Dwgs. 8.1.5 and 8.1.6. The values in pitch seem low but heave and roll show good agreement with the model data.

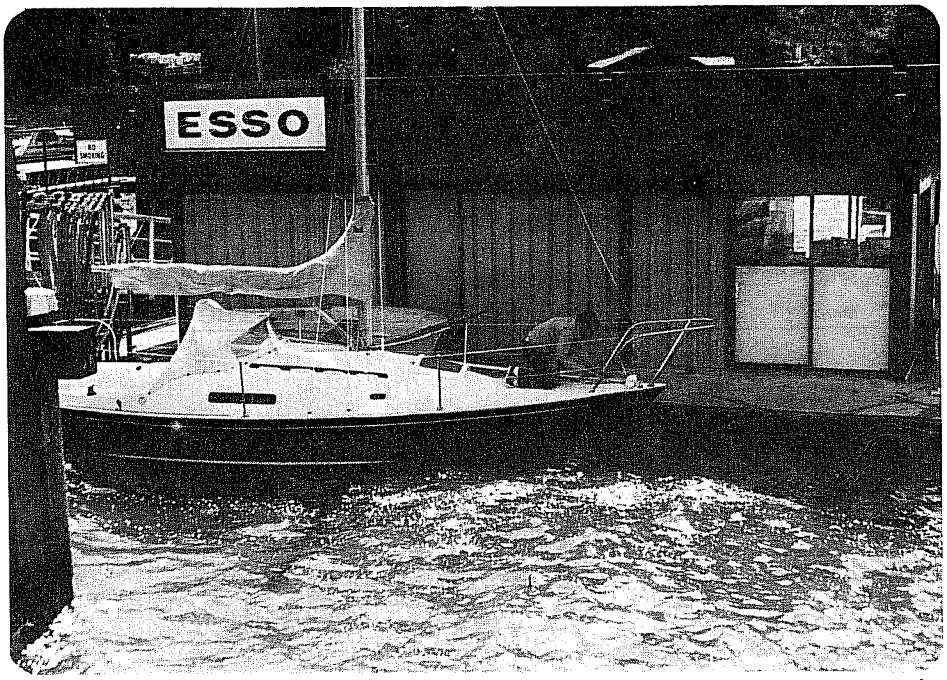


Photo 8.2.3 Setting up for wave response measurements on a Swiftsure 24 sailboat at the Gasoline Service Barge.

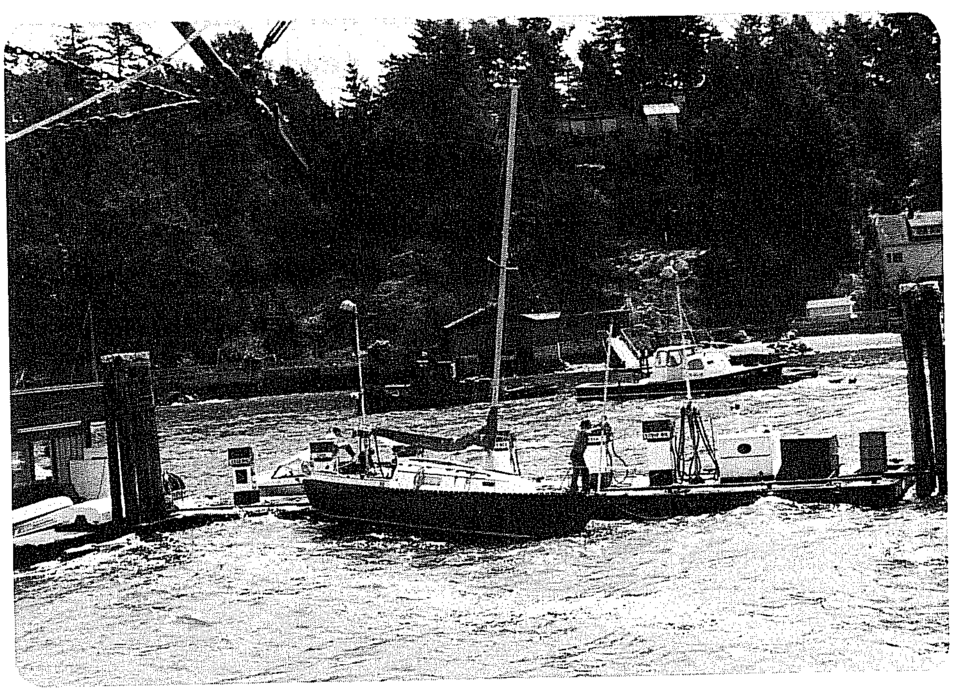


Photo 8.2.4 Measuring the rise and fall of the bow of a Bayfield 25 sailboat.

IX. ANALYTICAL DETERMINATION OF SMALL CRAFT RESPONSE

Since it was not possible to physically model all types of craft or to model the full range of wave conditions desired, it was necessary to see if a hydrodynamic analysis could be used to extend the model results. A review was made of existing analytical procedures to determine which would be the most promising way to proceed.

9.1 Background to Analysis Procedures

The hydrodynamic analysis of a freely floating body responding to wave action is well known and has been reviewed, for example, by Wehausen (1971) and Newman (1977). In the following (x, y, z) is a Cartesian coordinate system with the origin at the deck level vertically above the body's centre of gravity, x is measured in the vessel's forward direction, y vertically upward and z sideways. In a linear analysis the vessel is taken to oscillate harmonically in six degrees of freedom with displacements given as $\mathrm{Re}\left\{\xi_j\ e^{i\omega t}\right\}$, with $j = 1$ corresponding to surge, $j = 2$ to heave, $j = 3$ to sway, $j = 4$ to roll, $j = 5$ to yaw and $j = 6$ to pitch.

The equations of motion of an unrestrained floating body can be expressed in terms of the complex amplitudes ξ_j by a matrix equation:

$$\left\{-\omega^2\left([M] + [A]\right) + i\omega\ [B] + [C]\right\}(\xi) = (F) \quad \ldots\ldots \quad (1)$$

where $[M]$ is the mass matrix, $[A]$ the added-mass coefficient matrix, $[B]$ the damping coefficient matrix, $[C]$ the stiffness matrix, and (F) the exciting force vector. In this notation the components F are the exciting force complex amplitudes, with corresponding time varying forces given as Re $\left\{F_j e^{i\omega t}\right\}$. The exciting force may usefully be considered to be comprised of two components: the Froude-Krylov force F_k due to the undisturbed incident wave pressure field, and a second component F_d due to the diffracted wave pressure field.

The mass matrix components and stiffness matrix components are simply derived for a given body configuration and density distribution. (eg. Wehausen 1971, Salvesen, Tuck and Faltinsen 1970, and Newman 1977). The mass matrix components are the body mass, the mass moments of inertia and mass products of interia. The hydrostatic stiffness matrix components are given in terms of the vessel's waterplane profile, and the locations of the centres of gravity and buoyancy.

In general, the matrices $[A]$ and $[B]$, and the vector (F) are obtained from a solution to the governing radiation/diffraction boundary value problem. This usually derives from the assumptions of a linear motion (small amplitude waves) and an irrotational flow (flow separation effects neglected). The Laplace equation for the velocity potential in the fluid region is solved subject to specified boundary conditions, and this may be done, for example, by various finite element or integral equation methods (eg. Garrison 1974) or by a strip approach for slender bodies (eg. Newman 1977).

In the case of a moored body the various terms in the equation of motion, Eq. (1), may be extended to reflect the influence of the moorings on the body's motion. In the usual case the moorings may be treated as linear springs with constant coefficients and the stiffness matrix can be modified to incorporate these (eg. Yamamoto and Yoshida 1978).

In general, the spring constants depend on the equilibrium position taken up by the mooring/vessel system under wave attack and this must first be derived by a static analysis. Seidl (1978) has described this procedure as applied to a computer program solving for ship motions in all six degrees of freedom.

An assumption generally made in the procedures described is that the mooring system is too light and flexible to affect the vessel oscillations. However, in the case of slack moorings and relatively light boats, this assumption becomes unrealistic. Isaacson and Fraser (1979) have described a solution (in two-dimensions) for a floating breakwater which does not make this assumption: the characteristics of the mooring system are combined with those of the breakwater and an expanded set of equations of motion for the combined body/mooring system is then solved.

In the present study the complete hydrodynamic analysis of a moored vessel in six degrees of freedom would be unwarranted because of the enormous effort and cost entailed and because the common assumptions (linear mooring system, linear motions, negligible flow separation effects, etc.) may be unrealistic. The intention has been instead to investigate simplified analytical procedures which would adequately predict measured responses over specific ranges of conditions.

These analyses are restricted to head seas (with only surge, heave and pitch motions occurring) and to beam seas (with only heave, sway and roll motions occurring) and only to specific simplified mooring arrangements.

9.2 Analysis Procedures Adopted

Three separate methods of approximation have been investigated. These are the long wave approximation (LWA), the slender body approximation (SBA) and a non-linear (slack/elastic) mooring approximation and they are briefly outlined below.

Long Wave Approximation

A long wave approximation may be made when the wave length to vessel length ratio λ/L_w is large. According to the long wave approximation, the exciting force components can be expressed directly in terms of the added-mass and damping coefficients and the vessel's hydrostatic characteristics. The underlying theory is given by Newman (1977) and appropriate expressions for the exciting force complex amplitudes may thereby be derived. These may be written in terms of $F' = 2F/h$ as follows:

Head Seas:

$$F'_1 = \frac{ik}{\omega^2}\left[-\omega^2(m + a_{11}) + i\omega b_{11}\right] \quad \text{(2a)}$$

$$F'_2 = S - \omega^2(m + a_{22}) + i\omega b_{22} + kS_1 \quad \text{(2b)}$$

$$F'_6 = S_1 + ikmy_B + ikS_{11} \quad \text{(2c)}$$

Beam Seas:

$$F'_2 = S - \omega^2(m + a_{22}) + i\omega b_{33} \quad \text{(2d)}$$

$$F'_3 = -\frac{ik}{\omega^2}\left[-\omega^2(m + a_{33}) + i\omega b_{33}\right] \quad \text{(2e)}$$

$$F'_4 = ik(my_B + a_{34}) + ikS_{33} + \frac{k}{\omega} b_{34} \quad \text{(2f)}$$

These equations for the exciting force can be substituted into the RHS of the corresponding equation represented by Eqs. (1) to obtain expressions for peak displacements which can then be solved. Since some terms appear on both sides of the equations there can be considerable simplification through cancellation.

In the above $k (= 2\pi/\lambda)$ is the wave number, y_B is the y ordinate of the centre of buoyancy, S is the waterplane area, and S_1, S_{11} and S_{33} are the waterplane area moments defined as follows:

$$S_1 = \int x \; b(x) \; dx \quad \text{(3a)}$$

$$S_{11} = \int x^2 \; b(x) \; dx \quad \text{(3b)}$$

$$S_{33} = \int \frac{1}{12} \; b^3(x) \; dx \quad \text{(3c)}$$

where $b\ (x)$ is the sectional beam of the waterplane profile and the integrals are taken over the waterplane length L_w of the vessel.

The added-mass and damping coefficients for Eq. (1) are frequency dependent and should be calculated by solving the wave radiation problem. As part of the approximations carried out in the present analysis, estimates of a_{ij} and b_{ij} (frequency dependent) have been obtained by using published data of the coefficients for related reference configurations. They include the data of Kim (1965, 1966) for ellipsoids of different beam/length and draft/length ratios, and the data of Vugts (1968) for various sectional shapes. All cross coefficients have been taken equal to zero except a_{34}, b_{34} which couple roll and sway in beam seas.

Viscous effects are known to alter the damping coefficients from the predicted potential theory values, particularly for roll motions, but the corrections are difficult to estimate. Adee and Martin (1974) have included the viscous components of damping by simply doubling the calculated wave damping coefficients. In the present case, available experimental and theoretical results of drag coefficients in an oscillatory flow past the flat plate (Bearman, Graham and Singh, 1978 and Graham 1978) have been used to estimate corresponding values of viscous damping coefficients for vessels (including the model) containing deep keels.

9.2.1 Slender Body Approximation

The slender body approximation provides an alternative approximation procedure which is valid for shorter wave lengths of the order of the boat length. This depends on the beam/length ratio being small so that certain terms in the equations of motion which are proportional to higher orders of this ratio may be neglected. In this approximation, the actual Froude-Krylov forces are used in the RHS of Eqs. (1), rather than using Eqs. (2). Simplifications are made by neglecting certain terms in the LHS of Eqs. (1). The method is outlined by Newman (1977) and those terms of Eqs. (1) which are included in this approximation are indicated by an X in Table 9.2.1. For example, in the heave mode, the hydrostatic restoring force and the Froude-Krylov component of the exciting force are the dominant terms, and all other terms are omitted.

Since mass or stiffness terms are neglected for the various modes of motion as indicated in the table, resonance behaviour is not predicted for most cases: that is, the resonant frequencies are assumed to occur outside the wave length (frequency) range considered.

TABLE 9.2.1

TERMS INCLUDED IN ANALYSIS

	Mass	Added Mass	Damping	Stiffness Hydrostatic	Stiffness Mooring	Exciting Force Froude-Krylov Force	Exciting Force Diffraction Component
Head Seas							
Surge	X	(X)	(X)	0	(X)	X	
Heave	-	-	-	X	-	X	
Pitch	-	-	-	X	-	X	
Beam Seas							
Heave	(X)	(X)	(X)	X	-	X	
Sway	X	X	X	0	-	X	X (0)
Roll	(X)	(X)	(X)	X	-	X	

X Term included in slender body approximation

(X) Additional term included in modification to slender body approx.

0 Term not applicable to this component of motion (equal to zero).

(0) Term taken to be zero in modification.

\- Neglected term in slender body approximation and modification.

In order to predict the resonance features found for most modes of motion, an attempt has been made to include additional terms beyond those used in the formal approximation and these are indicated by an (X) in Table 1.

9.2.2 Slack/Elastic Mooring Line Approximation

The non-linear analysis required for a slack/elastic mooring line can be idealized as that pertaining to a spring-mass-dashpot system with non-linear spring characteristics and subjected to a known (exciting) force. In an investigation into the response of moored vessels to waves, Raichlen (1968) has considered various non-linear spring characteristics in the representation of the mooring system. However, this was coupled with a relatively simplistic approach to the hydrodynamic analysis in which the exciting force was considered as wholly inertial with a constant inertia coefficient.

It can be shown that the equilibrium position ξ_o of the vessel is an order of magnitude smaller than the oscillation amplitude. Thus the equation of motion may be written as:

$$m\ddot{\xi} + r\dot{\xi} + s\xi = Fe^{i\omega t} \quad \text{.........................} \quad (4)$$

where m is the body mass (including added-mass),

r is the damping constant, and

$$s = \begin{cases} o \text{ for } \xi < o \\ c \text{ for } \xi > o \end{cases}$$

and c is the elastic constant of the mooring. This non-linear ordinary differential equation can be solved by a Ritz approximation procedure (eg. Harris and Crede, 1976) in which a Fourier series representation of ξ is used. The method is algebraically lenghty when several terms are used to represent ξ, but the fundamental component providing the best fit can readily be obtained by this procedure. The results may be expressed as

$$\xi = Xe^{i\omega t} \quad \text{.............................} \quad (5a)$$

with the amplitude of the motion given by:

$$|X| = F \left\{ \left(\frac{k}{2} - m\omega^2\right)^2 + r^2\omega^2 \right\}^{-\frac{1}{2}} \quad \text{..........} \quad (5b)$$

and the phase relative to that of F given by:

$$Arg\ (X) = tan^{-1} \left[\left(\frac{k}{2} - m\omega^2\right)/r\omega \right] \quad \text{.........} \quad (5c)$$

These equations were used to compute the vessel's surge and sway response to a slack/elastic moorage.

9.3 Moorage Conditions Analysed

Application of these approximations to different moorage arrangements has been accomplished by considering different cases. In all, seven cases have been evaluated as outlined in Table 9.3.1.

The preceding outline describes how the various terms in the equations of motion have been approximated. The application of these equations to the various cases outlined in Table 2 was as follows:

Case 1: Head Sea - Freely Floating

Both the long wave approximation and the standard slender body approximation were applied to this case. The heave and pitch equations had to be treated as coupled because the stiffness cross-coefficient relating heave and pitch (c_{24}) could not be taken as zero. These equations had to be solved simultaneously. The surge equation could be treated as uncoupled and solved

TABLE 9.3.1

LIST OF CASES TREATED IN ANALYSIS

Case No.	Wave Direction	Mooring Restraint	Degrees of Freedom
1	Head	Freely floating	Surge, Heave, Pitch
2	Head	Linear mooring, restraining only surge.	Surge, Heave, Pitch
3	Head	Slack/linear elastic mooring for surge only.	Surge, Heave, Pitch
4	Head	Stern hinge links.	Heave, Pitch
5	Beam	Freely floating.	Heave, Sway, Roll
6	Beam	Slack/linear elastic mooring for sway only.	Heave, Sway, Roll
7	Beam	Stern hinge links.	Heave, Roll

directly. With the long wave approximation for surge, direct subsitution of Eq. (2a) into Eq. 1 gave a particularly simple result for the dimensionless surge amplitude $\xi_1' = 2\xi_1/H$:

$$\xi_1' = coth\ (kd) \quad \text{.........................} \quad (6)$$

That is, the surge motion would follow the horizontal motion of surface water particles.

Case 2: Linear Mooring in Head Sea Restraining only Surge.

The heave and pitch relationships were treated as in Case 1 but the stiffness coefficient in surge c_{11} was given the value of the spring constant for the mooring lines rather than a zero value. Thus, only the surge response was different for this case.

Case 3: Slack/Elastic Mooring in Head Sea Restraining only Surge.

Again, only surge would be affected for Case 3. This would be the case where the boat is restrained by a single fore-and-aft line and the boat drifts to the position where the impulse supplied by the mooring line just compensates for the wave forces causing the drift.

The surge exciting force for surge can be calculated using either the long wave or slender body approximations. The equivalent linear response can then be calculated using Eqs. 5 with the same elastic constant as was used in Case 2.

Case 4: Stern Hinge Restraint in Head Sea.

The typical stern hinge is a rigid linkage that allows the stern to move vertically but restrains rigidly any fore-and-aft motion. Thus surge would be zero for this case but heave and pitch would be the same as in Case 1. The force resisted by the stern hinge would be the exciting force for surge as obtained in Case 3.

Case 5: Beam Sea-Freely Floating.

In a head sea, as discussed before, heave and pitch are treated as coupled while surge is not. In the case with a beam sea the heave motion can be considered uncoupled and it is the sway and roll motions that must be treated as coupled, because of the lateral resistance of the keel applicable to both sway and roll. Both the long wave approximation and the standard slender body approximation result in heave motions identical to the wave height in a beam sea for all wave lengths. The additional terms used in the modified slender body approximation produces a much more realistic response characteristics for a freely floating boat.

Case 6: Slack/Elastic Mooring in Beam Sea Restraining only Sway.

In a beam sea the major restraint to a boat moored at a dock is to the motion in sway, provided the lines have sufficient slack to allow the boat to heave and roll. If the boat is moored on the leaward side of the dock the wave forces will cause the boat to drift away from the dock until the periodic impulse provided by the mooring lines is sufficient to offset the drift forces. The restraint is then a slack/elastic one. It has not been possible to apply the slack/elastic analysis to the coupled sway and roll relationships for a beam sea so this case has not been analyzed. The case of a boat moored on the seaward side of the dock is still more complicated because of the additional periodic impulse received as the boat slams against the dock. This also has not been analyzed.

Case 7: Stern Hinge Restraint in a Beam Sea.

The usual linkage of a stern hinge restrains only sway in a beam sea. Roll and heave are relatively unrestrained provided the hinge linkages are long enough. Heave would be as in Case 5 but roll would now be uncoupled because the effect of sway or roll would be zero.

9.3.1 Effect of Floating Dock Motion

The effect of the floating dock would be especially difficult to analyze because of its flexibility. Also, it turned out that the motion of the dock was not too important in determining the motion of the boats. This was because the analyses all assumed that only lateral motions were affected by mooring constraints while the dock itself was restrained from moving laterally. The motion of the docks are important to marina operation, however, as is the relative motion between the boat and the dock. Restrained against lateral motion, the flexible docks are subject to heaving, rolling and flexing. The flexing can be longitudinal bending or twisting in torsion. The movement of the dock and the boat can be somewhat out of phase as a result of dampening, etc., but there is sufficient correspondence between the two motions that a generalization can be made, namely that the relative motion between boat and dock is less for a floating dock than it would be for a fixed dock because of the tendency for the dock to move with the boat. This, at least provides an upper limit to the relative motions for a floating dock.

9.4 Analytical Results

The analyses described were applied to the four different hull configurations shown in Dwg. 9.4.1 with specifications shown in Table 9.4.1. Hull 1 is the model and is representative of sailboats with a deep fin keel. Hull 2 is a full keel sailboat with relatively much less draft but still substantial ballast provided by the weighted keel. Hull 3 is a powerboat designed to plane at speeds above its hull speed and Hull 4 is

TABLE 9.4.1

DIMENSIONLESS CHARACTERISTICS OF TYPICAL RECREATIONAL BOAT HULLS

		Hull #1 Model Fin Keel Sailboat	Hull #2 Full Keel Sailboat	Hull #3 Planning Powerboat	Hull #4 Non-Planning Powerboat
	Basic Specifications				
L_o	Length Overall (ft)	2.50	41.0	42.0	35.67
L_w	Length Waterline (ft)	2.19	35.0	36.67	33.33
B	Beam (ft)	0.80	13.0	14.25	12.0
D	Draft (ft)	0.49	4.75	3.5	3.75
W_t	Displacement (lbs)	4.95	24,000	30,000	17,500
W_b	Ballast in Keel (lbs)	2.80	10,000	-	-
	Characteristic Dimensionless Ratios				
$\frac{B}{L_w}$	Beam/Length	.365	.371	.389	.360
$\frac{D}{L_w}$	Draft/Length	.224	.136	.095	.112
$\frac{W_t}{\gamma L_w^3}$	Displacement	.00755	.00897	.0102	.00757
$\frac{W_o}{W_t}$	Ballast/Displacement	0.56	0.42	-	-

a non-planing powerboat sometimes called a displacement hull. While each boat has a different length their characteristics can all be reduced to dimensionless ratios for comparison purposes and this has been done in Table 9.4.1. The different quantities needed to complete the mass, stiffness, added mass and dampening matrices discussed earlier were obtained from or based on measurement taken from the designer's layout drawings. These quantities were also made dimensionless by dividing by appropriate powers of the waterline length, the specific weight of water and the acceleration of gravity. The dimensionless numbers so obtained are listed in Table 9.4.2 for reference purposes. Some of the added mass terms and dampening terms are dependent on the wave length and values for five different wave lengths are tabulated.

The results of the different analyses are shown for Hull 1 on Dwg. 9.4.2 where the response in the different modes of motion are plotted against wave length. The responses have been made dimensionless by dividing by the wave height so that a value of one represents the same response as the wave. The wave length has been made dimensionless by dividing by the waterplane length of the hull. In all of these analysis the necessary coefficients have been obtained as a result of direct measurement on the model or by reference to value published in applicable texts. There has been no adjustment to fit the data obtained in the model tests.

In every case the slender body approximation (modified as discussed earlier) provides a much better representation than the long wave approximation.

For head seas, both heave and pitch equations are coupled so that the results are interdependent. For both heave and pitch the LWA produces results close to

TABLE 9.4.2

NUMERICAL VALUES USED IN ANALYSIS FOR DIMENSIONLESS MATRIX TERMS

	Hull 1	Hull 2	Hull 3	Hull 4
Mass Terms				
m_{11}, m_{22}, m_{33}	0.00763	0.00897	0.0102	0.00757
m_{66}	0.000718	0.0009	0.001	0.0008
m_{44}	0.000412	0.00045	0.0005	0.00038
m_{24}	0.000697	0.000610	0.000357	0.000265
Added Mass Terms				
@ $\omega^2 L_\omega/g = 0.3$				
a_{11}	0.0018	0.0026	0.0020	0.0025
a_{22}	0.0294	0.0306	0.0294	0.0306
a_{66}	0.000844	0.000844	0.000844	0.000844
a_{33}	0.000124	0.000122	0.000119	0.000116
a_{44}*	0.00012	0.0001	0.00009	0.00009
@ $\omega^2 L_\omega/g = 1.0$				
a_{11}	0.0018	0.0026	0.0020	0.0025
a_{22}	0.0294	0.0306	0.0294	0.0306
a_{66}	0.000844	0.000844	0.000844	0.000844
a_{33}	0.000133	0.000133	0.000130	0.000129
@ $\omega^2 L_\omega/g = 2.0$				
a_{11}	0.00195	0.00275	0.0021	0.0026
a_{22}	0.025	0.0283	0.0254	0.0283
a_{66}	0.000906	0.000906	0.000906	0.000906
a_{33}	0.0000981	0.000089	0.000082	0.000077
@ $\omega^2 L_\omega/g = 5.0$				
a_{11}	0.0018	0.0025	0.00193	0.0024
a_{22}	0.0148	0.0153	0.0148	0.0153
a_{66}	0.000844	0.000844	0.000844	0.000844
a_{33}	0.0000356	0.000032	0.0000288	0.0000268
@ $\omega^2 L_\omega/g = 10.0$				
a_{11}	0.0009	0.0013	0.0010	0.0012
a_{22}	0.0103	0.0115	0.0103	0.0118
a_{66}	0.000469	0.000469	0.000469	0.000469
a_{33}	0.0000163	0.0000151	0.0000134	0.0000125

*Not dependent on wave length.

	Hull 1	Hull 2	Hull 3	Hull 4
Stiffness Terms				
c_{22}	0.2031	0.2143	0.2480	0.2587
c_{66}	0.01671	0.01037	0.01686	0.01714
c_{44}	0.00147	0.00166	0.00182	0.00198
c_{26}	0.0248	-0.0001	-0.0183	0.0158
Damping Terms				
@ $\omega^2 L_\omega/g = 0.3$				
b_{11}	0.00525	0.00550	0.00528	0.00547
b_{22}	0.055	0.057	0.055	0.058
b_{66}	0.0	0.0	0.0	0.0
b_{33}	0.00064	0.00096	0.00048	0.00048
b_{44}	0.000146	0.00022	0.00011	0.00011
b_{34}*	0.000938	0.0011	0.0	0.0
@ $\omega^2 L_\omega/g = 1.0$				
b_{11}	0.00525	0.00550	0.00528	0.00547
b_{22}	0.055	0.057	0.055	0.058
b_{66}	0.0	0.0	0.0	0.0
b_{33}	0.00064	0.00096	0.00048	0.00048
b_{44}	0.000146	0.00022	0.00011	0.00011
@ $\omega^2 L_\omega/g = 2.0$				
b_{11}	0.00525	0.00550	0.00528	0.00547
b_{22}	0.070	0.075	0.070	0.080
b_{66}	0.00008	0.00008	0.00008	0.00008
b_{33}	0.0024	0.0036	0.0018	0.0018
b_{44}	0.00055	0.00082	0.00041	0.00041
@ $\omega^2 L_\omega/g = 5.0$				
b_{11}	0.00611	0.00657	0.00618	0.00644
b_{22}	0.068	0.074	0.068	0.075
b_{66}	0.00037	0.00037	0.00037	0.[illegible]
b_{33}	0.0065[illegible]	[illegible]0984	[illegible]92	0.00492
b_{44}	[illegible]015	[illegible]0224	0.00112	0.00112
@ $\omega^2 L_\omega/g = 10.0$				
b_{11}	0.00661	0.00690	0.00675	0.00680
b_{22}	0.037	0.042	0.037	0.044
b_{66}	0.00037	0.00037	0.00037	0.00037
b_{33}	0.00656	0.00984	0.00492	0.00492
b_{44}	0.0015	0.00224	0.00112	0.00112

the SBA for longer waves but they diverge rapidly for shorter waves. The SBA plots will be seen to agree very closely with the measured data over the full range of wave lengths tested. Heave response is shown to be equal to the wave height for longer waves (greater than 5 times boat length) but diminishes for shorter waves until it reaches zero for wave lengths approximately one-half the boat length. Pitch response for longer waves (greater than 4 times the boat length) follows the pitch (slope) of the wave surface. It diminishes for shorter waves approaching zero for wave lengths about one half the boat length. Neither heave or pitch have a resonant condition in head seas under the SBA and this will be supported by model data.

The response in surge is more complex because surge is heavily constrained by the moorage lines. Free floating response results in large amplitude motion at long wave lengths. This corresponds to the large horizontal amplitude of the oribital motion of the water for these long waves. In fact, as discussed earlier, the long wave approximation provides results identical to the horizontal amplitudes of the wave orbit. Moorage constraint reduces the surge motion drastically for long waves. The curves for linear elastic moorage constraint are applicable to a boat moored with fore and aft spring lines that are just taunt at equilibrium. The response is similar to a spring-mass-dashpot system with a resonance peak occurring with waves approximately three times the boat length. The resonance period depends heavily on the elasticity of the moorage line. The resonant peak for the SBA is only slightly above the LWA free floating response suggesting that this LWA curve may provide a reasonable upper limit for surge response for any moorage system. Slack/elastic constraint computations also show a resonant response. This constraint is appropriate for a single line at the bow attached to a single point moorage.

In beam seas, sway and roll are closely coupled and must be treated together. Although moorage constraint is important to sway and roll, the coupling make the constraint difficult to handle so that only free response curves are shown here. Here again the SBA (modified) will be shown to provide a better representation of response than the LWA when compared with model results. Roll has a strong resonant condition (unlike pitch which doesn't show resonance) when waves are 2.5 times boat length. The roll reaches at least 3 times the equivalent slope of the water surface. The frequency of roll at resonance is very close to the natural period of roll noted in still water. The free floating response in sway shows large responses for long waves but these responses would not be realized with a moored craft. These sway curves are, therefore, quite invalid for a particular craft moored in a particular manner but they likely represent envelope conditions that can be used in a general way for evaluating response in sway.

Heave response in a beam sea shows a broad resonance condition with boat response as much as 25 percent greater than the wave height. However, as with head seas the heave response ratio approaches unity for long waves (greater than about 7 boat lengths) and approaches zero for short waves (less than about one third the boat length).

The results presented can be made applicable to craft of different sizes simply by multiplying by the appropriate power of the boat length. Different types of craft have different characteristics and these differences as shown in Dwg. 9.4.3 for the four hull types discussed earlier.

All of the response curves shown are computed using the modified SBA as described earlier. The curves show that responses are very similar except for those responses involving resonances which include heave in a beam sea and surge with linear elastic constraint. (Sway with moorage constraint also is subject to strong resonances but is not included here for reasons already discussed.) The resonance in heave is not strong so that the differences between hull types is not large. Nonetheless they are large in surge. Also the response values at the resonant peaks are not too reliable because they vary greatly with amount of damping that is present. As a result, the responses in heave, pitch and roll appear to be reasonably predictable but the responses in surge and sway can only be predicted with a sizeable degree of uncertainty.

9.5 Secondary Effects on Ship Response

The analysis treats response in head and beam seas where only three components of response are of any significance. In quartering seas. all six components of response, including yaw, are activated and interact so that full analysis becomes very complex. In marinas subject to heavy wave action the boats are moored so that the heaviest waves approach head on. There is usually secondary wave action, however, that approaches the boats on the beam or on the quarter. Also, in the case of boats moored to a single bouy, the wave forces normally cause the boat to orient itself head on but wind and current can cause the boat to drift away from a head on position.

Some simplifying assumptions can be made to oblique waves that support some useful generalizations. If a wave approaches at an angle θ measured from a head-on direction the component of the water slopes in the head-on direction are reduced by cos θ, so that pitch should be reduced by this factor. Also, the component of the horizontal motion of the water particles is reduced by the same factor so that surge should also reduce by the same amount. Thus, when the angle is 90 degrees, or a beam sea condition, both pitch and surge become zero as expected. The same logic applies to roll and sway, which should vary from zero in a head sea to a maximum value in a beam sea. Of course, yaw, which is ordinarily minimal in a head and beam sea reaches some maximum in oblique seas and its effect on the other motions cannot be simply rationalized.

Nevertheless, in a general way and neglecting yaw, the measured motions in a head and beam sea can be expected to be sufficiently close to their maximum values under any sea direction that they will serve as guidelines for wave criteria.

X. PROVISIONALLY RECOMMENDED CRITERIA

A great deal of data has been assimilated and a wide range of opinions sought and given, but when it comes to establishing criteria there are very few, if any, absolute limits to fall back on and a great range of variables and unknowns to cast doubt on the final results. It is clear, however, that a single value, such as one foot, does not always lead to a satisfactory or economical design. The opposite condition, of having criteria that changes with every significant input variable, is equally unsatisfactory. The path chosen has been to try and sort out the absolutely essential variables which have a real impact on wave climate suitability and to reflect this in as simple a fashion as possible.

10.1 Essential Variables for Wave Climate Criteria

The essential variables for wave climate criteria were discussed separately in earlier sections and are summarized further here with a view to reducing the variables that have to be finally considered.

10.1.1 Wave Direction

Beam seas are more distressing than head seas and do require more stringent criteria. Beam seas cause masts to collide and also cause the boats to sway with direct impact on the walkways. A designer will try to align the boats to obtain head seas but cases will exist when secondary beam waves will be present and separate criteria is required to limit their size. The overall design of a marina protection may be governed by the secondary waves.

10.1.2 Wave Period and Boat Size

The response of boats depends greatly on the wave period (or wave length) relative to the boat size. A single value of wave height for all wave periods does not meet the special surge problems associated with very long waves nor does it capitalize on the boats ability to resist the motion of very short waves.

One of the important inputs to criteria are the boat response parameters. The parameters have been defined for the several components of motion, as the boat motion divided by the wave height. For pitch and roll they are the vertical motions of the extremes of the vessel divided by the wave height. In order to be able to apply the findings to all vessels using a marina (say between 20 feet and 40 feet long) envelope values of the parameters have been selected, using the results of the model tests and the analysis (Dwgs. 8.1.5, 8.1.6, 9.4.3), for three ranges of wave period as shown in Table 10.1.1.

TABLE 10.1.1

ENVELOPE LIMITS FOR BOAT RESPONSE PARAMETERS

Wave Period	(sec)	<2	2 to 6	>6
Wave Length @ 10 ft depth	(ft)	<20	20 to 100	>100
Wave Length @ 50 ft depth	(ft)	<20	20 to 200	>200
<u>Head Seas</u>				
Heave parameter*		0.0	1.0	1.0
Pitch parameter		0.5	2.0	$\pi \frac{L_w}{\lambda}$
Surge Parameter		0.25	2.0	coth (kh)
<u>Beam Seas</u>				
Heave parameter		1.0	1.5	1.0
Roll parameter		1.0	2.0	$\pi \frac{L_w}{\lambda}$
Sway parameter		1.25	1.25	coth (kh)

* Parameters defined in Section VIII.

For example, for head waves between 2 and 6 secs, no boat will respond in surge more than 2 times (circled in Table 10.1.1).

For periods below 2 seconds all boats of this size range (20 to 40 feet) resist motion so that reduced limit values of the parameters can be adopted. Between 2 seconds and 6 seconds the boats may resonate over the different components of motion and higher envelope limits are required. For higher periods the response of all small boats follow the wave motion orbits quite closely so that the response limits can be expressed algebraically. The only difficulty with this range of periods is caused by the mooring line restraints in surge and sway. According to the algebra of the table, the response parameters for these motions get larger as the wave length gets longer. This is because the wave motion orbits get very elongated. With surge, it is possible to restrain this motion with taut spring lines. However, improper restraint can create resonance periods above 6 seconds and consequent large resonant motions and mooring forces. If application of these "free motion" limits for surge cause difficulty in a design then special attention must be given to the surge problem. Sway is much more difficult to restrain then surge because lines restraining sway cannot be kept taut. Sway must be assumed unrestrained in beam seas in accordance with these limits.

10.1.3 Walkway Type and Moorage Conditions

The impact of the type of walkway (floating, fixed or solid wall) depends on the relative motions between the walkway and the boat or on the creation of standing waves due to reflection from a solid wall. This is discussed in more detail in Section VII. It would be desirable for simplification to eliminate this variable from consideration in the establishment of criteria. Floating and fixed walkways differ mainly in their response to heave, but since maximum heave does not coincide with either maximum pitch or roll and since pitch and roll parameters are greater than heave parameters, pitch and roll must govern. Therefore floating and fixed walkways act essentially the same. A solid wall can double the wave action by reflection, but if this doubling is considered when computing or modelling the wave condition in the harbour, it too can be treated the same as floating and fixed walkways. Finally, moorage to a single buoy has already been considered and finalized in Sections 7.2.1 and 7.2.2.

10.1.4 Frequency of Occurrence of Design Events

A single design frequency cannot cover all the wave hazards that should be considered in design. A harbour may be calm for most of the time but subject to rare, intense storms. Another may have persistent waves due to strong prevailing winds or due to heavy marine traffic. The design frequency of occurrence should not be the same for both. NHCL recommends that three recurrence intervals be used - fifty years, one year and once a week.

The 50 year recurrent storm might be considered the worst storm likely in the life of the marina. Cosmetic damage to yachts due to rubbing would be acceptable but swampings or groundings would not. It would have to be safe for skilled marina operators and boatmen to be on the walkways to maintain secure lines and connections and replace fenders. The one year recurrent storm should be protected against to the extent that all properly moored craft and floats would survive unscathed and that the usual marina patrol would be sufficient to secure badly tied boats and replace dislodged fenders. The once a week condition should not disrupt normal marina activities.

10.1.5 Quality of Moorage

Some guidance must be provided for adjusting the criteria to provide different quality moorage. A large convenient harbour can afford a better quality of moorage than can a small remote one. Also, a storm that could be handled in a small marina by a few persons might create unmanageable havoc in a large marina. NHCL recommends that criteria be established for excellent, good and moderate wave climate on the basis of Table 5.1.1, which reflects marina operators own judgement, and that these qualifiers be related to the low, medium, and high wave distress in that table. That is, criteria for an excellent wave climate be set at 0.75 percent of good criteria and criteria for a moderate climate be set at 1.25 percent of good criteria.

10.2 Provisionally Recommended Criteria

As a result of the totality of the investigation NHCL recommends that criteria reflect four variables - the wave direction, the wave period, the frequency of the event and the quality of protection desired. The criteria judged to best meet these conditions are tabulated in Table 10.2.1.

In establishing the criteria for the one year event a great deal of weight was given to the existing one foot criteria since it has been accepted by most authorities and provides satisfactory results in many marinas. It was not the intention of the study to change this criteria but rather to amplify on it. One foot is recommended for all head seas

TABLE 10.2.1

PROVISIONALLY RECOMMENDED CRITERIA FOR
A "GOOD"* WAVE CLIMATE IN SMALL CRAFT HARBOURS

Direction and Peak Period of Design Harbour Wave	Wave Event Exceeded Once in Fifty Years	Wave Event Exceeded Once A Year	Wave Event Exceeded Once Each Week
Head Seas less than 2 seconds	these conditions not likely to occur during this event	less than 1 foot wave height	less than 1 foot wave height
Head Seas between 2 and 6 seconds	less than 2 foot wave height	less than 1 foot wave height	less than 0.5 foot wave heig
Head Seas greater than 6 seconds	less than 2 foot wave height or 4 foot horizontal wave motion	less than 1 foot wave height or 2 foot horizontal wave motion	less than 0.5 foot wave heig or 1.5 foot horizontal motion
Beam Seas less than 2 seconds	the conditions not likely to occur during this event	less than 1 foot wave height	less than 1.0 wave height
Beam Seas between 2 and 6 seconds	less than 0.75 foot wave height	less than 0.5 foot wave height	less than 0.25 foot wave height
Beam Seas greater than 6 seconds	less than 0.75 foot wave height or 2 foot horizontal motion	less than 0.5 foot wave height or 1 foot horizontal motion	less than 0.25 foot wave heig or 0.75 foot horizontal motion

*For criteria for an "excellent" wave climate multiply by 0.75 and for a moderate wave climate multiply by 1.25

except that an additional limitation has been imposed for long period waves, restricting horizontal wave motion to 2 feet. Referring to the envelope response curves of Table 10.1.1, this criteria can result in heave motions of one foot, pitch motions (rise and fall of the bow and stern) of two feet and surge motions of two feet. That is one foot either way from the neutral position. The pitch motions measured at Fisherman's Wharf were of this magnitude and they were as much as one would like to tolerate. Floats could also be walked on with some caution there at that time.

One foot wave heights are too large for beam seas and a 0.5 foot criteria has been selected. The envelope roll parameter for this condition (Table 10.1.1, beam seas 2 to 6 sec periods) shows the deck moving 1 foot at the sides. The corresponding movement of mast tips, assuming the mast height is 4 times the beam, is 8 feet, or 4 feet to either side of neutral. This provides a reasonable margin against tangling masts. The envelope sway movement would be 1 foot for this wave height so that the boat would move one foot from the walkway or finger.

For the fifty year event the criteria has been generally doubled except that the wave heights for beam seas only multiplied by 1.5. In head seas this would limit the heave to 2 ft. or 1 foot each way from neutral and the bow motion to 4 feet or 2 feet each way from neutral. This would send water over the bow of most boats and would probably require the slackening off of breast lines to keep them from becoming taut. Some boats might catch under ledges of fixed docks if care is not taken. However, the majority of boats will ride out this condition if watched. This condition is the condition that operators of marinas with moderate wave problems have said starts to cause them problems (Table 5.1.1). These criteria can result in a boat surge of 4 feet for the envelope condition. Thus, some boats would have to be retied so that their bows do not collide with the obstacles ahead. One serious problem is whether the floats are walkable in this sea. Fixed walkways are generally high enough that this wave will pass under without difficulty. Unfortunately, floating walkways are commonly at right angles to the boats so that they are subject to rolling unless stabilized by the fingers. Operators have talked about crawling on floats in storm conditions and this might have to be resorted to. Life jackets would be a necessity.

Beam seas must be limited by colliding masts and the wave height of 0.75 feet was chosen because it limited the mast tip movement to about 12 feet, or 6 feet beyond neutral. At this value masts would be in imminent danger of colliding. Envelope values of sway of 1.5 feet would also be fairly extreme.

The multiplying factor of 1.25 for moderately acceptable criteria would increase the motions more and would probably require more repositioning of the boats to stop impacting. Walking on the floats would certainly be more difficult and marinas designed to moderately acceptable criteria should have all exposed floats located in the direction of the wave travel with boats tied alongside, as at the more extreme areas of Beach Gardens.

Once a week criteria is intended for day to day wave action from passing boats and from prevailing winds. In general, values are one half the one year event values except that waves less than 2 seconds in period have not been reduced. The response of boats to these short waves, which can occur frequently, is not great and 1 foot waves can be tolerated. None of the other criteria would interfere with the usual run of marina activities.

In general, the criteria of Table 10.2.1, permits a great deal of flexibility in design and increases the assurance that important aspects of wave distress are not overlooked.

XI. RECOMMENDATIONS

The study was successful in accomplishing its purpose and it is recommended that the criteria be endorsed provisionally for use in Canadian marinas. The provisional criteria does not alter existing criteria but expands upon it to cover conditions not considered heretofore. The study uncovered several areas where greater knowledge is needed and it is recommended that consideration be given to additional research into these areas. One area is the evaluation of new types of floats under wave conditions to help operators make sound selections when ordering new facilities. Another is an investigation of methods of mooring small craft so as to resist large horizontal surges. This appears to be the most damaging and least understood aspect of small craft moorage and because of this the provisional criteria herein are presently much too conservative in this respect. Records of wave damage in marinas are almost non-existent and it is recommended that operators be encouraged to keep a daily log of these incidents for later review. Finally, it is recommended that proper moorage techniques be explained to boat owners and that signs be posted at marinas warning of wave hazards and detailing proper moorage techniques.

This study has progressed a long way to improving wave criteria and it is doubtful that more investigation, except as noted above, will be of value until more field information and experience has been gained. No additional model tests or field tests are recommended.

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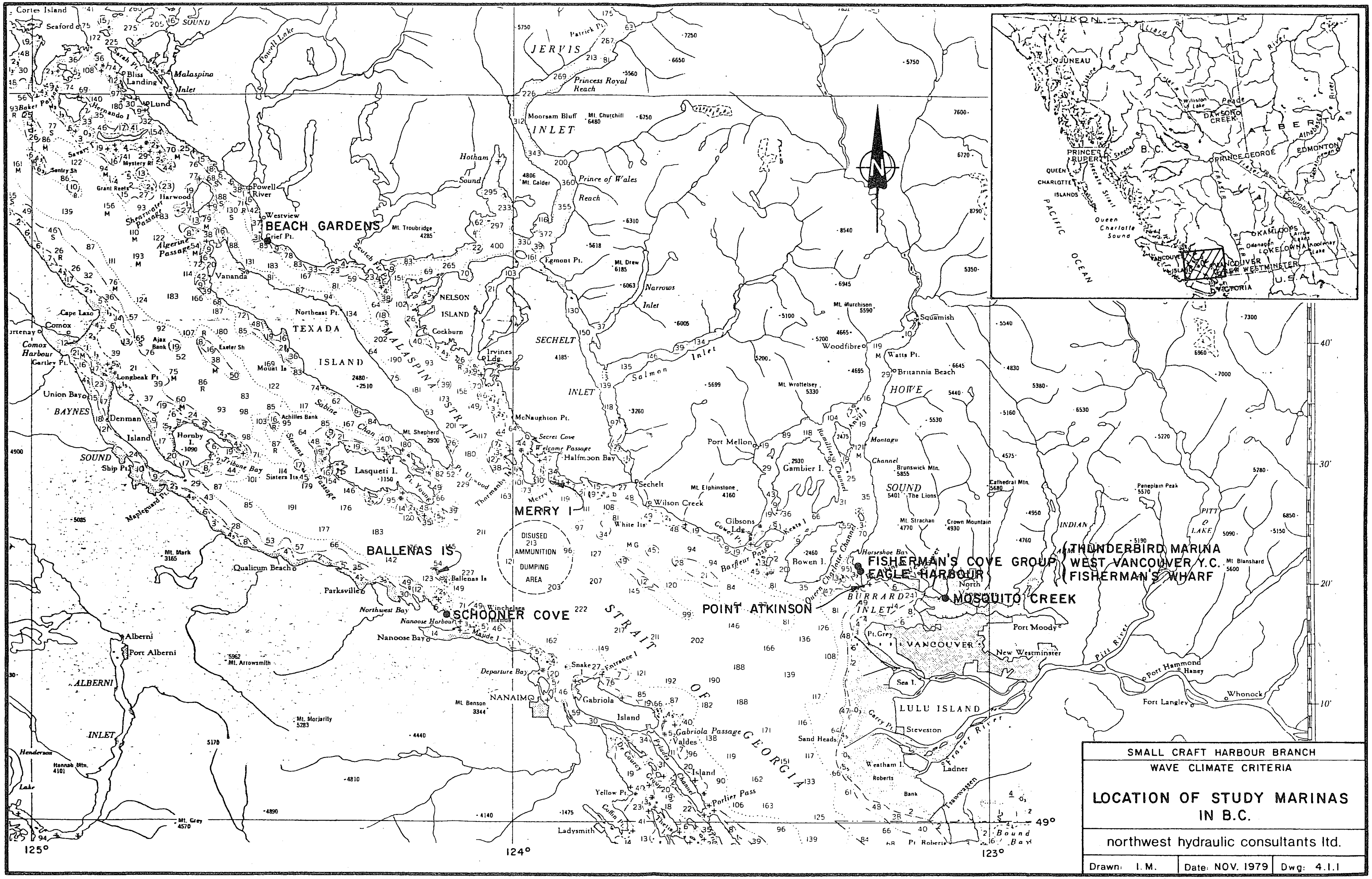
DRAWINGS

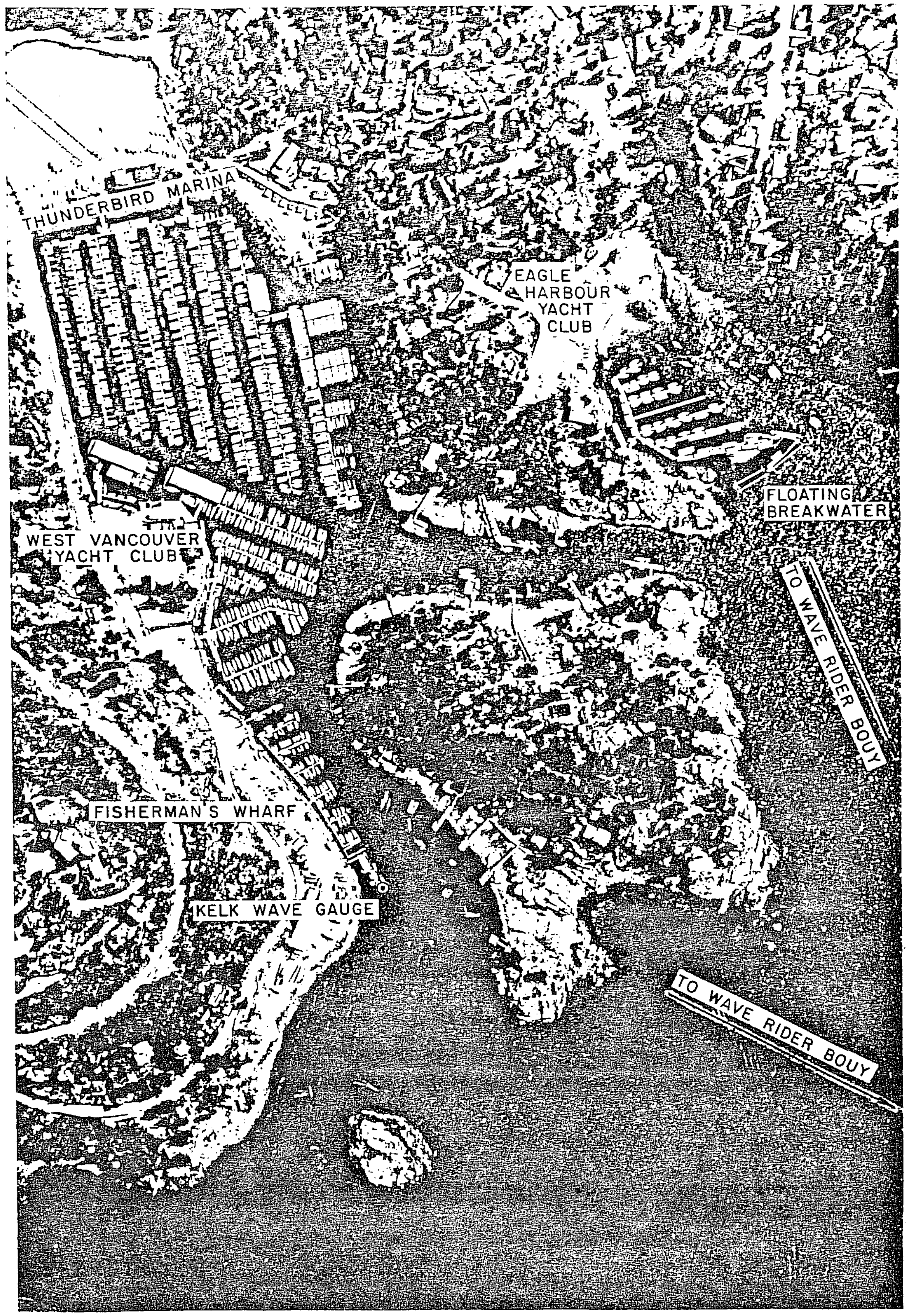


SMALL CRAFT HARBOUR BRANCH
WAVE CLIMATE CRITERIA

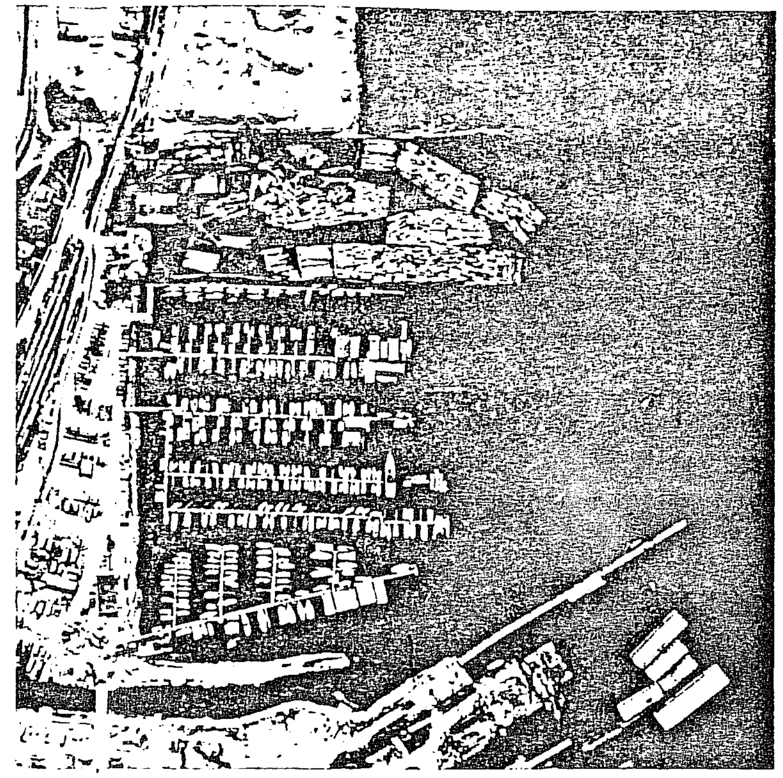
LOCATION OF STUDY MARINAS IN B.C.

northwest hydraulic consultants ltd.

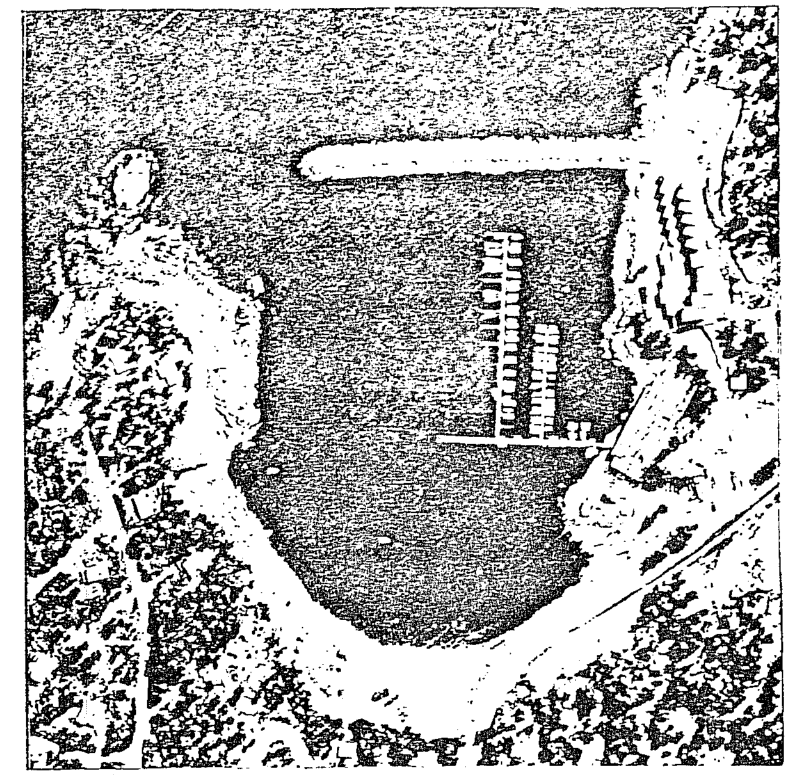
Drawn: I.M. | Date: NOV. 1979 | Dwg: 4.1.1



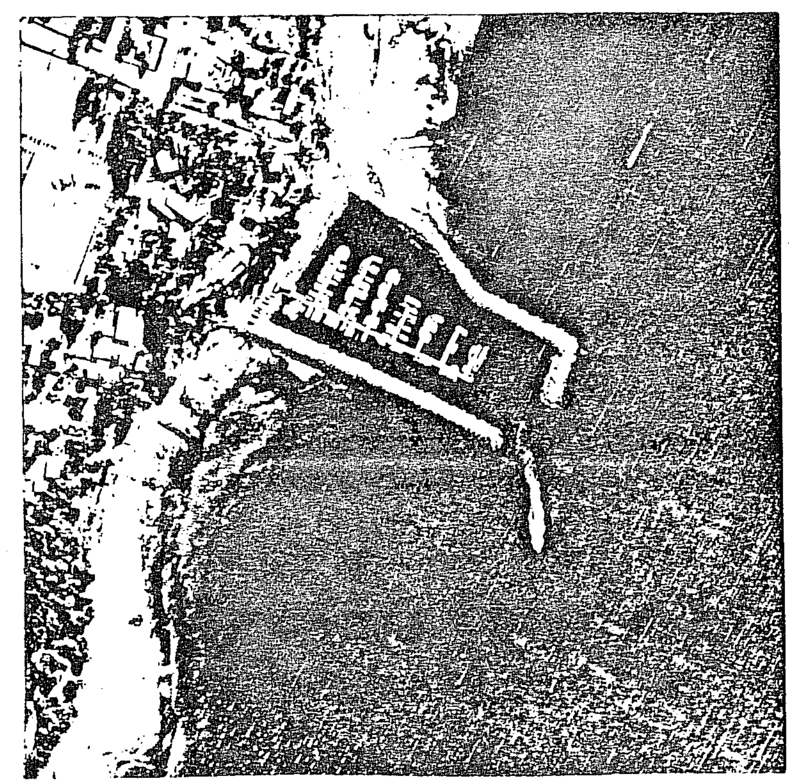
FISHERMAN'S COVE GROUP



MOSQUITO CREEK



SCHOONER COVE
(WITH EARLY FLOATS ARRANGEMENT)



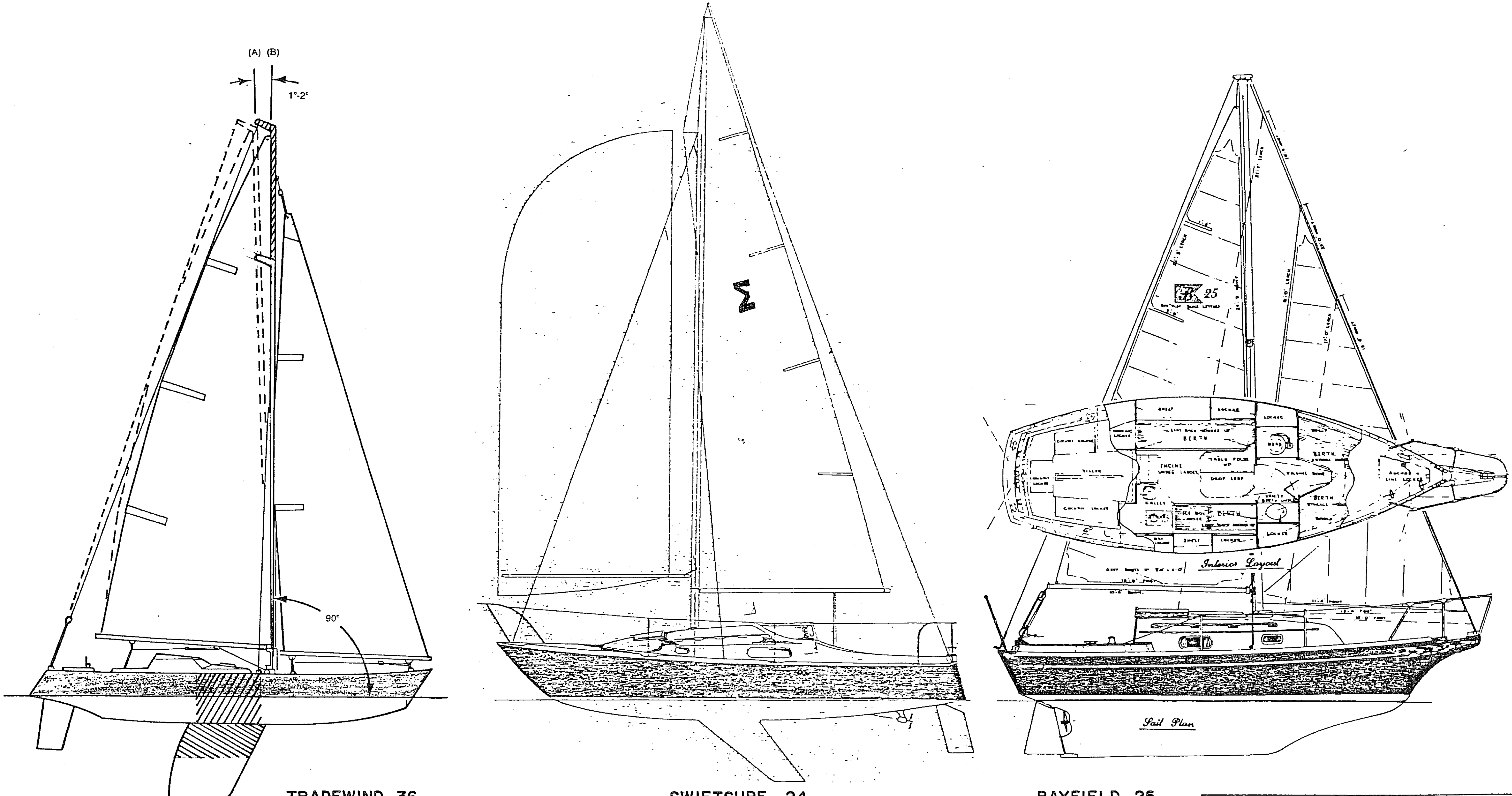
BEACH GARDENS

N

0 500 1000

SCALE IN FEET

SMALL CRAFT HARBOUR BRANCH		
WAVE CLIMATE CRITERIA		
AIR PHOTOGRAPHS OF B.C. MARINAS		
northwest hydraulic consultants ltd.		
Drawn: I.M	Date: MAR. 1980	Dwg: 4.1.2



TRADEWIND 36

(MODEL SLOOP)

SWIFTSURE 24

(FIN KEEL SLOOP)

BAYFIELD 25

(FULL KEEL SLOOP)

NOTE :

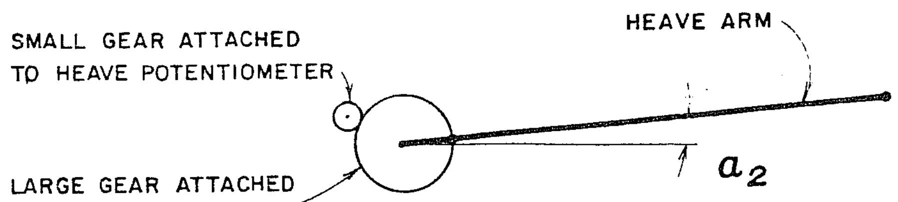
SHADED AREAS REMOVED TO
MODIFY THE MODEL FOR TESTING.

SMALL CRAFT HARBOUR BRANCH
WAVE CLIMATE CRITERIA

MODEL AND PROTOTYPE HULLS

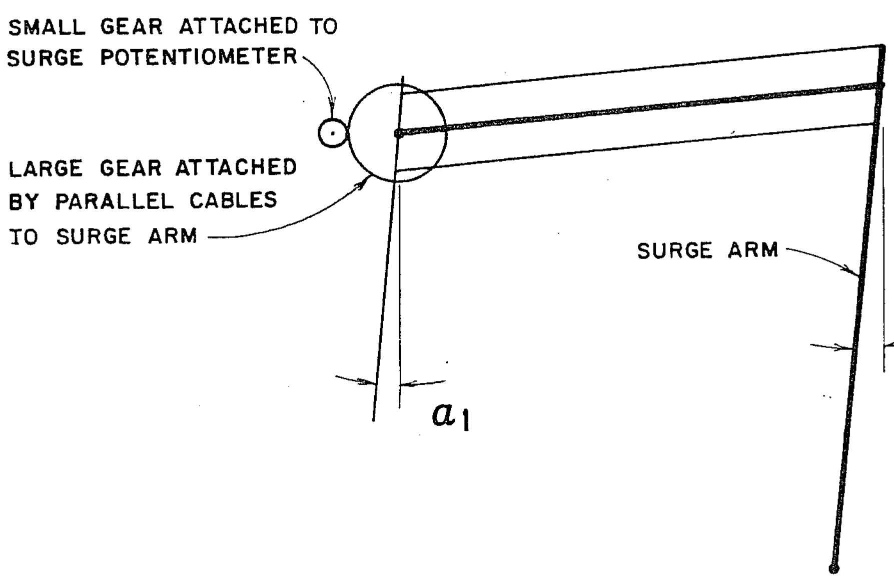
northwest hydraulic consultants ltd.

Drawn: V.U.	Date MAY, 1979	Dwg : 8.1.1



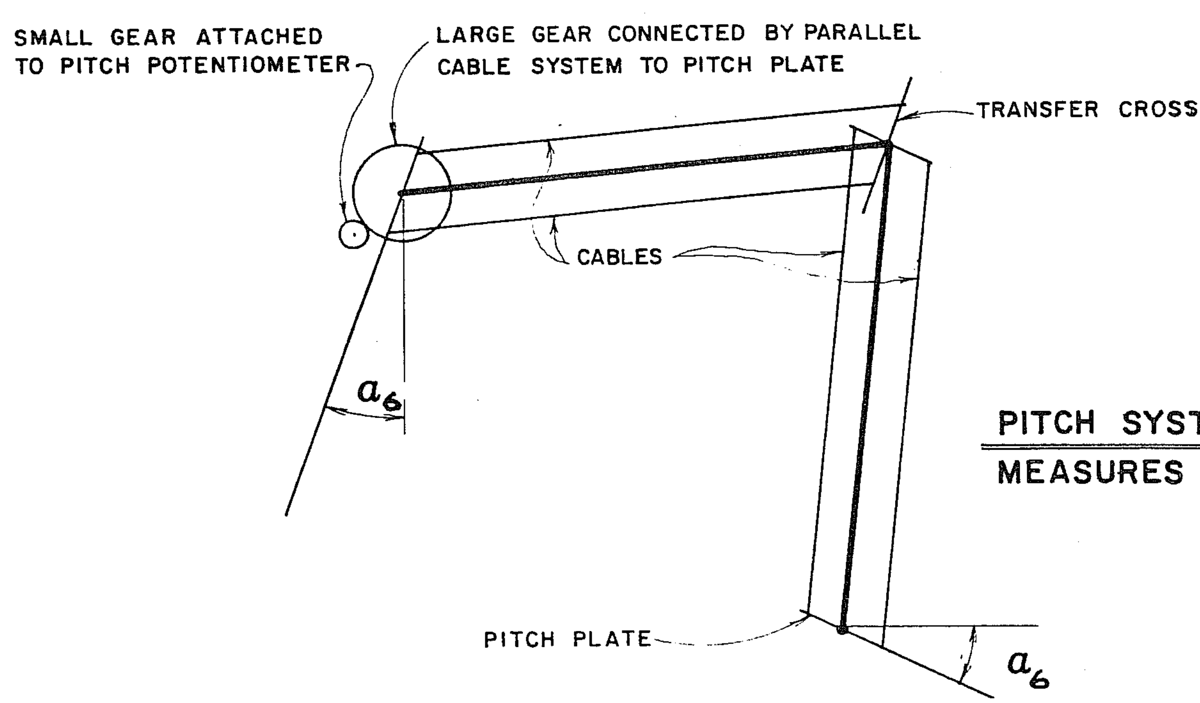
HEAVE SYSTEM

MEASURES a_2



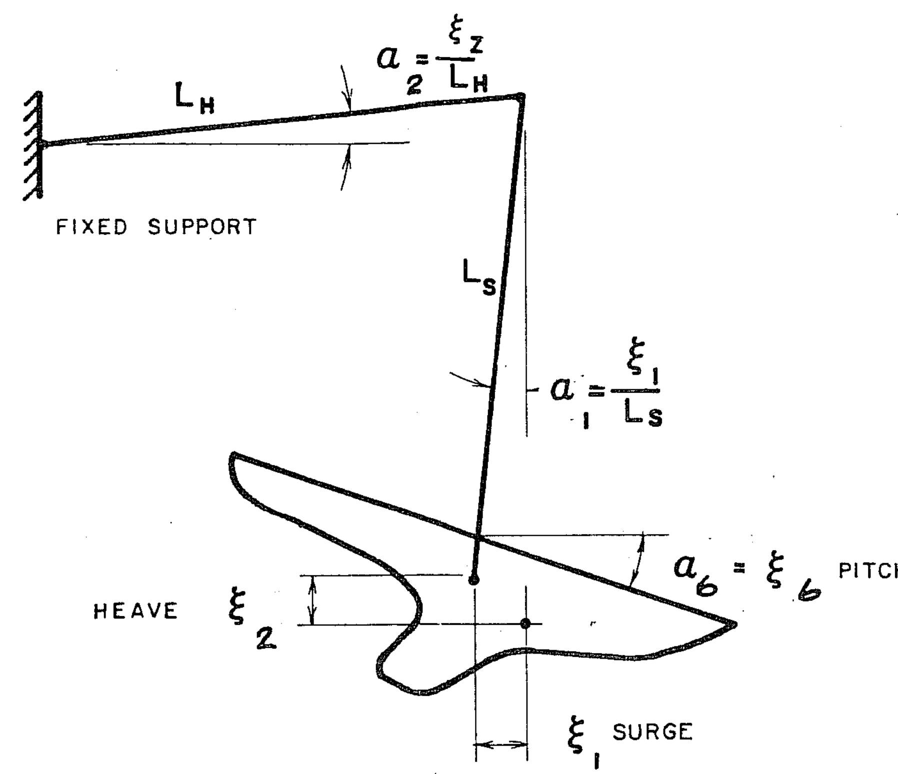
SURGE SYSTEM

MEASURES a_1



PITCH SYSTEM

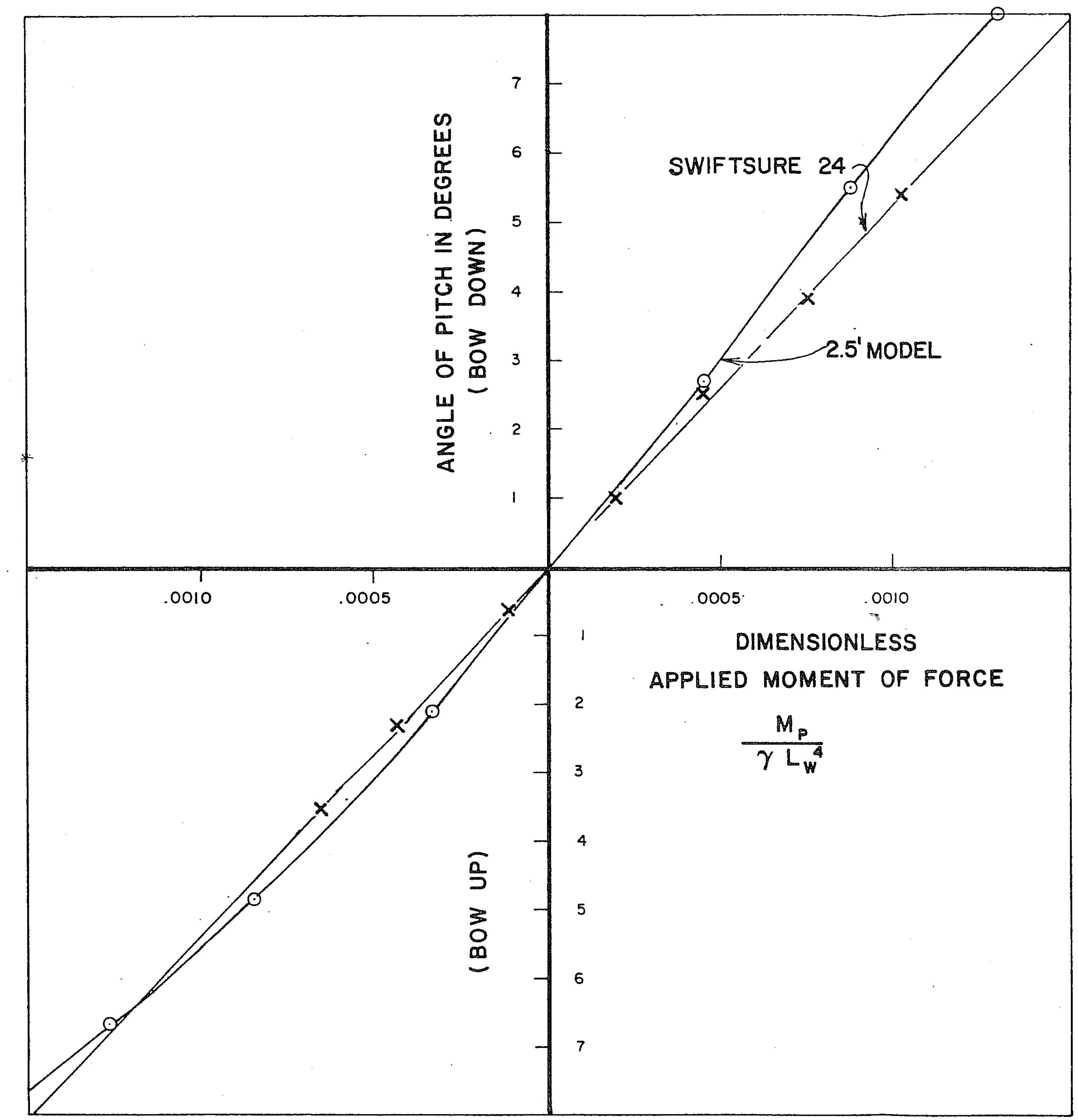
MEASURES a_6



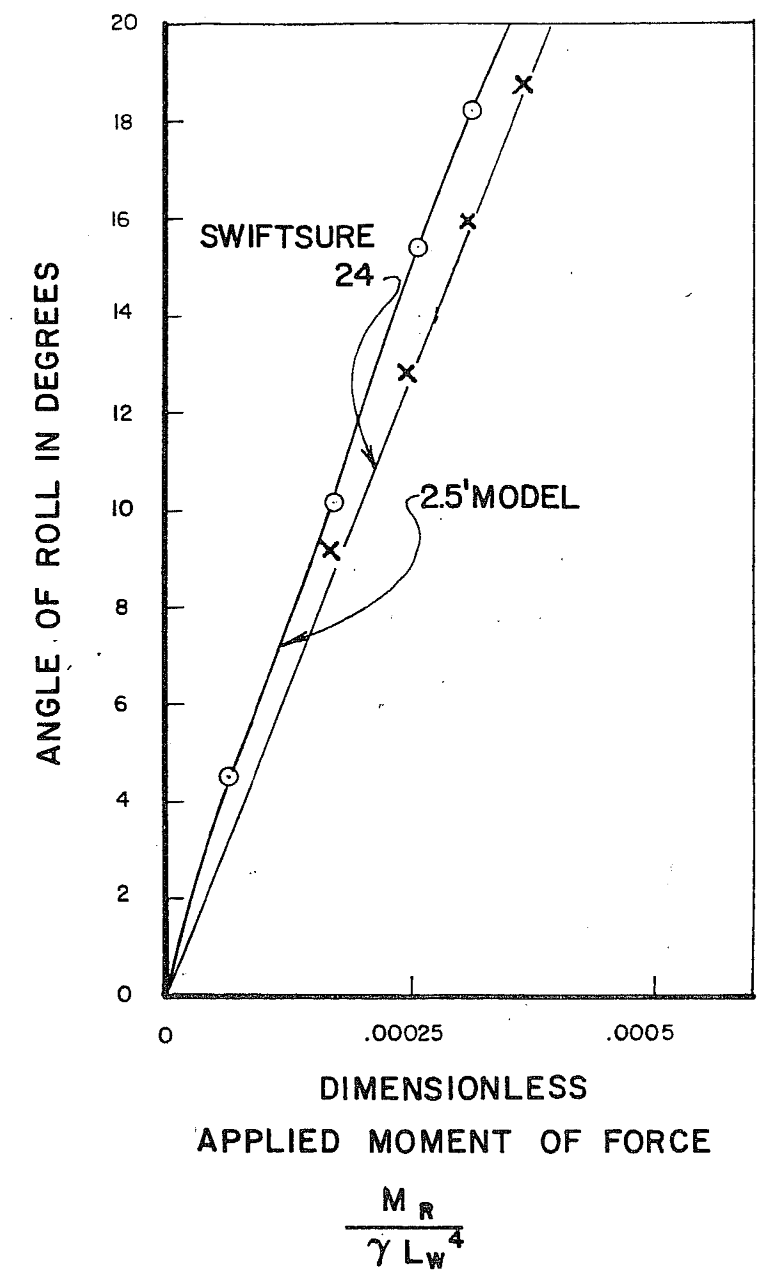
HINGED ARM MOTION TRANSDUCER

MEASURES HEAVE, SURGE, PITCH
ALTERNATIVELY HEAVE, SWAY, ROLL

SMALL CRAFT HARBOUR BRANCH		
WAVE CLIMATE CRITERIA		
SCHEMATIC OF MOTION TRANSDUCER		
northwest hydraulic consultants ltd.		
Drawn: V.U.	Date MAY, 1979	Dwg.: 8.1.2



APPLIED MOMENT OF FORCE VRS PITCH DISPLACEMENT



APPLIED MOMENT OF FORCE VRS ROLL DISPLACEMENT

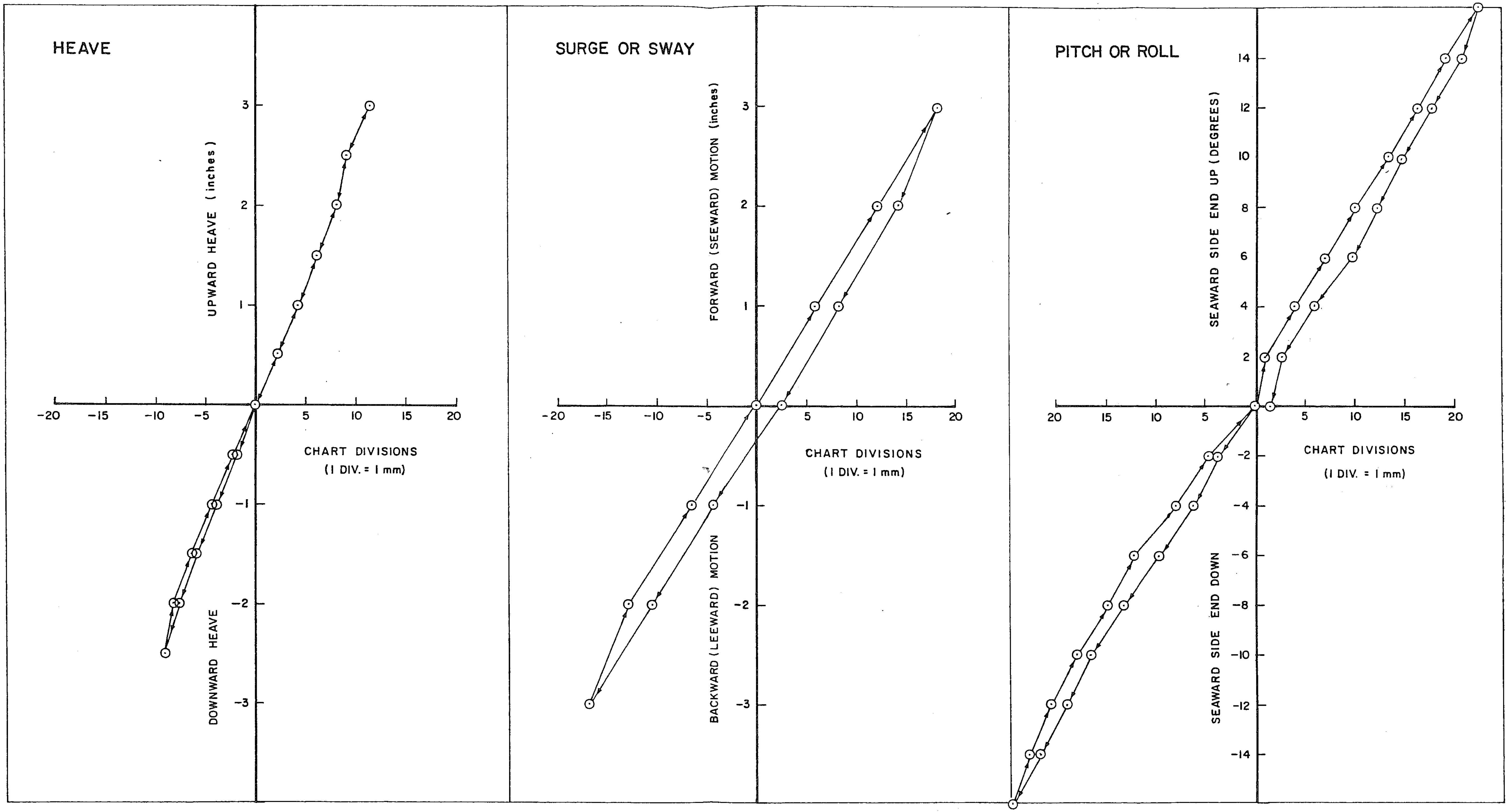
SMALL CRAFT HARBOUR BRANCH

WAVE CLIMATE CRITERIA

MODEL AND PROTOTYPE STATIC PITCH AND ROLL TESTS

northwest hydraulic consultants ltd.

Drawn V. U. | Date JUNE, 1979 | Dwg. 8.1.3

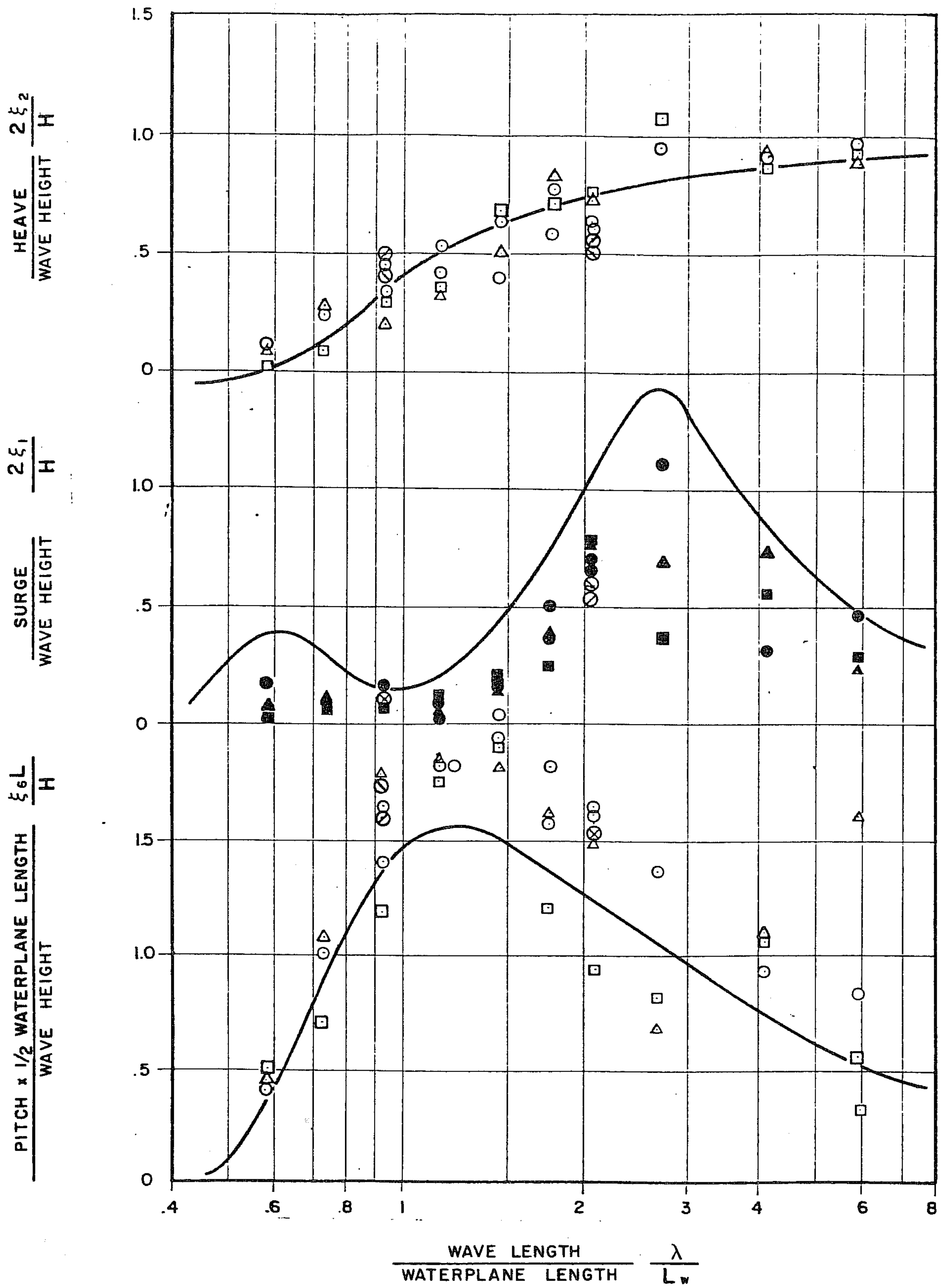


SMALL CRAFT HARBOUR BRANCH
WAVE CLIMATE CRITERIA

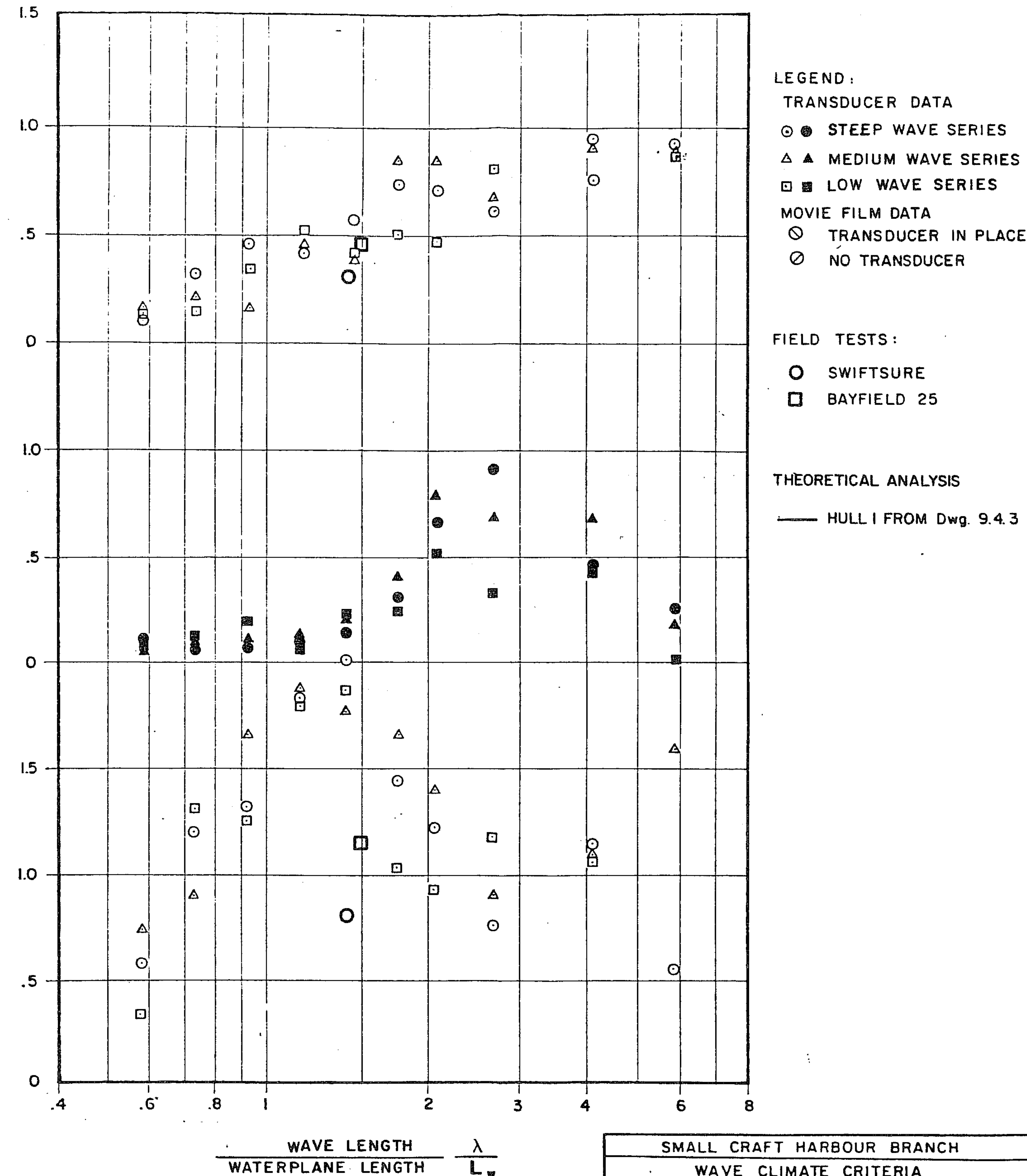
MOTION TRANSDUCER CALIBRATIONS

northwest hydraulic consultants ltd.

Drawn V.U.	Date OCT., 1979	Dwg 8.1.4



FLOATING DOCK MOORAGE



FIXED DOCK MOORAGE

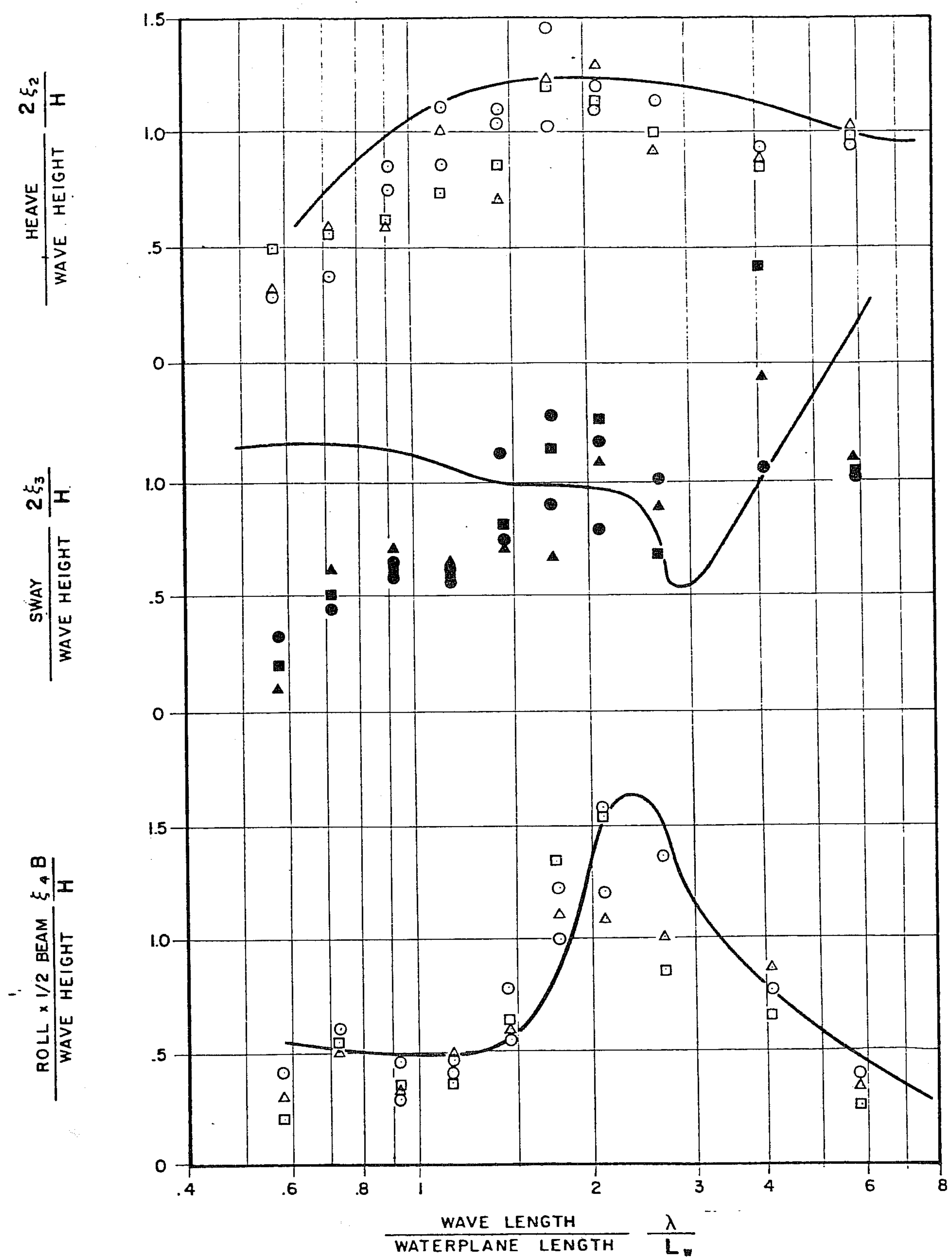
NOTE:
REPRESENTS AMPLITUDE OF MOTION
(ANGULAR FOR ROLL AND PITCH)

SMALL CRAFT HARBOUR BRANCH
WAVE CLIMATE CRITERIA

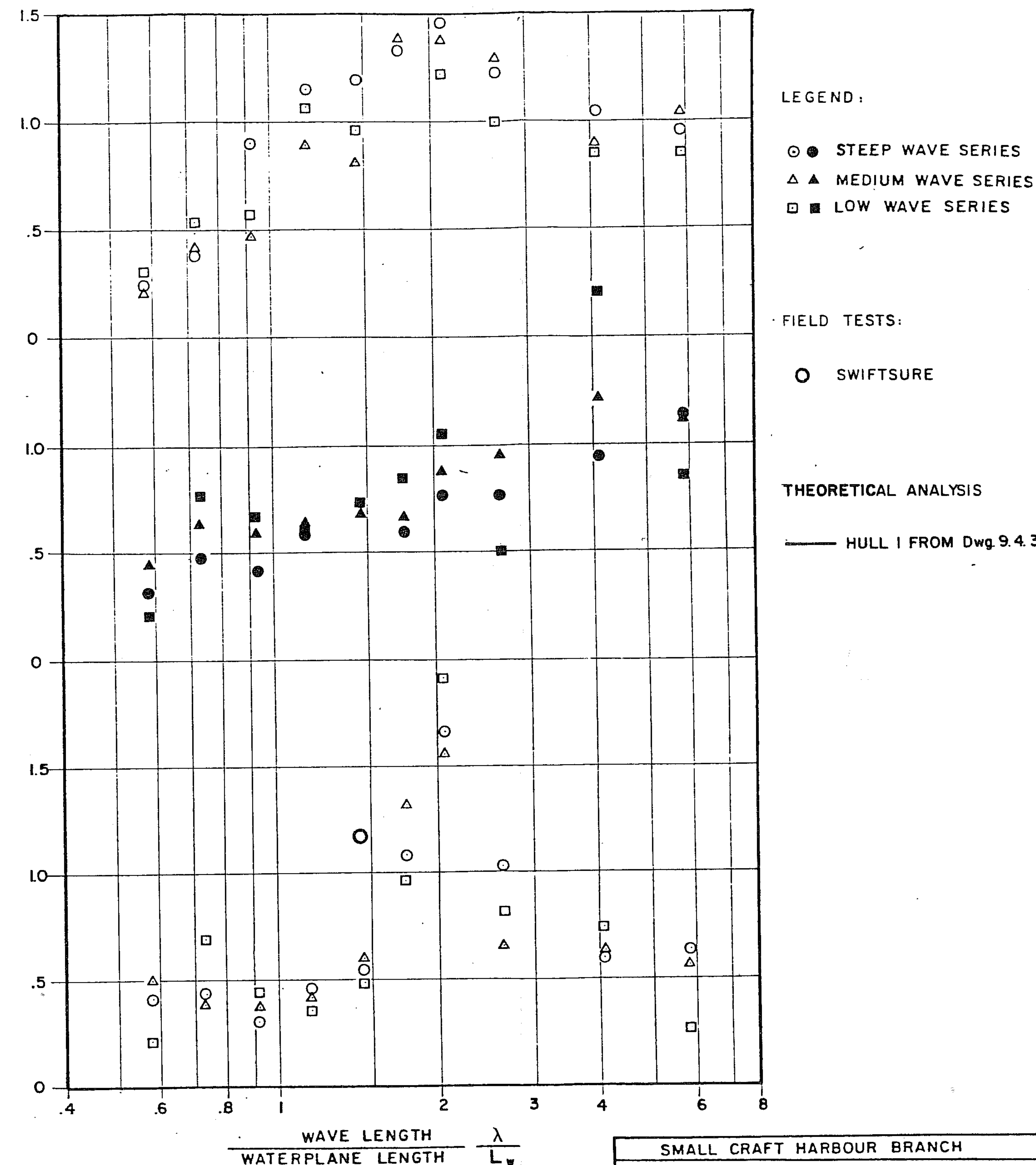
DIMENSIONLESS MODEL TEST RESULTS HEAD SEAS

northwest hydraulic consultants ltd.

Drawn V.U.	Date OCT., 1979	Dwg.: 8.1.5



FLOATING DOCK MOORAGE



FIXED DOCK MOORAGE

NOTE:
ξ REPRESENTS AMPLITUDE OF MOTION
(ANGULAR FOR ROLL AND PITCH)

SMALL CRAFT HARBOUR BRANCH		
WAVE CLIMATE CRITERIA		
DIMENSIONLESS MODEL TEST RESULTS BEAM SEAS		
northwest hydraulic consultants ltd.		
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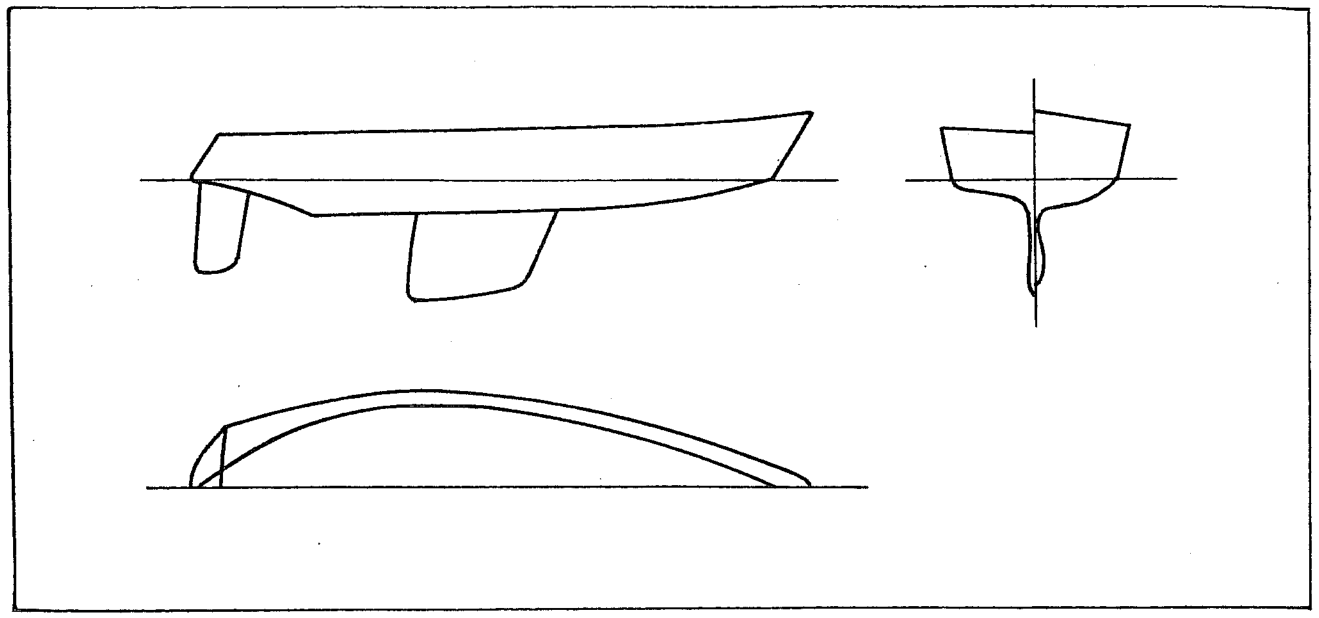
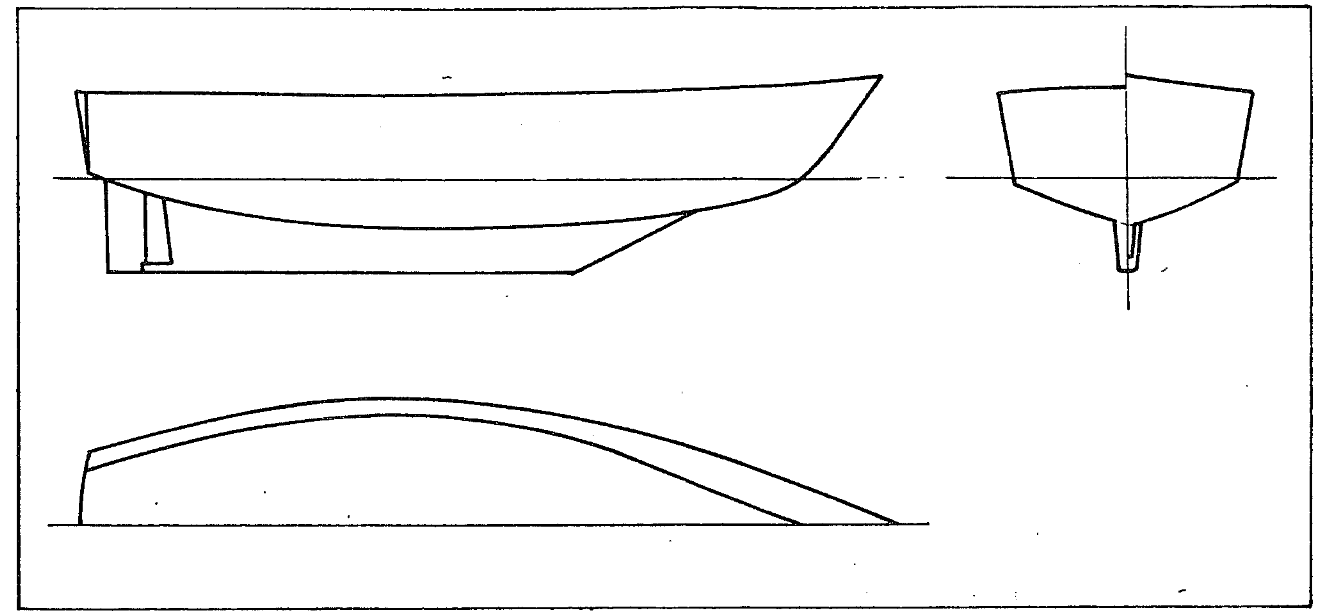
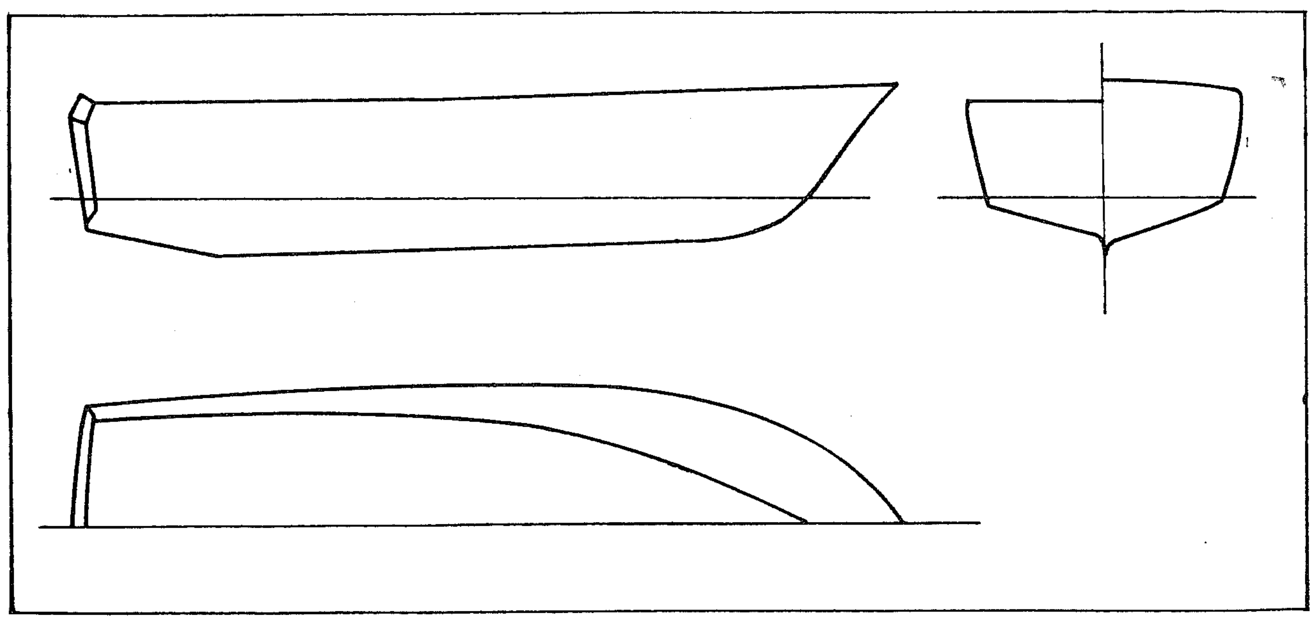


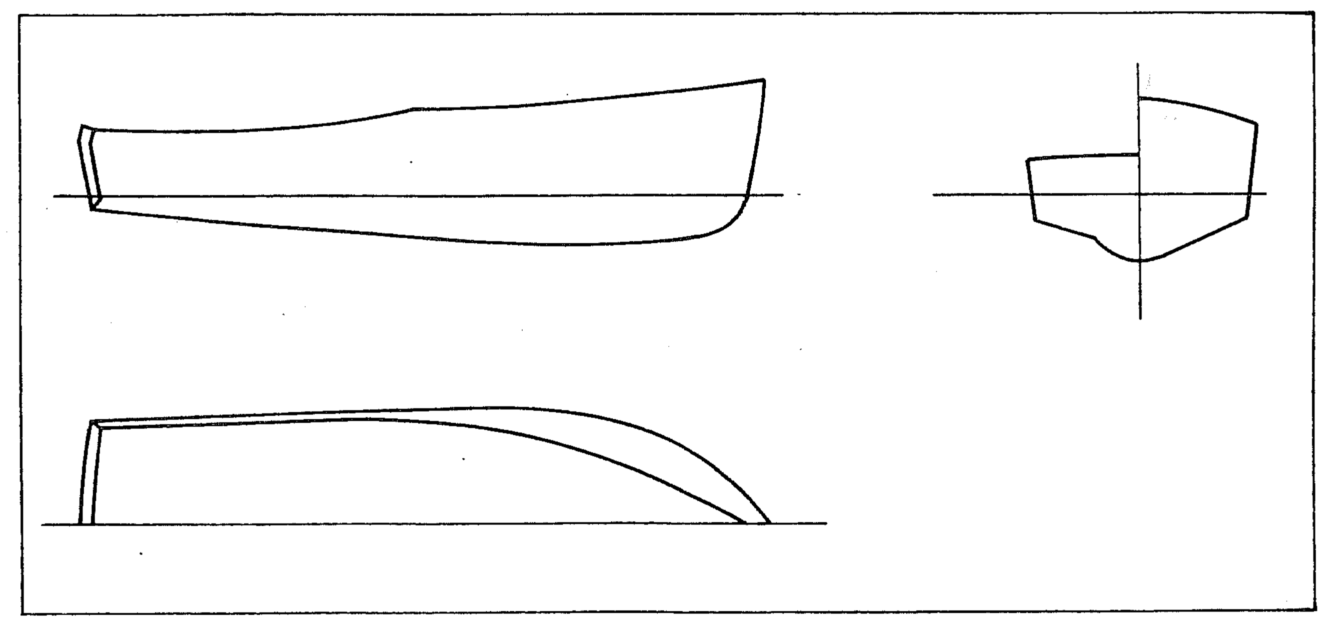
HULL 1 – FIN KEEL SAILBOAT (MODEL)



HULL 2 – FULL KEEL SAILBOAT



HULL 3 – PLANNING POWERBOAT



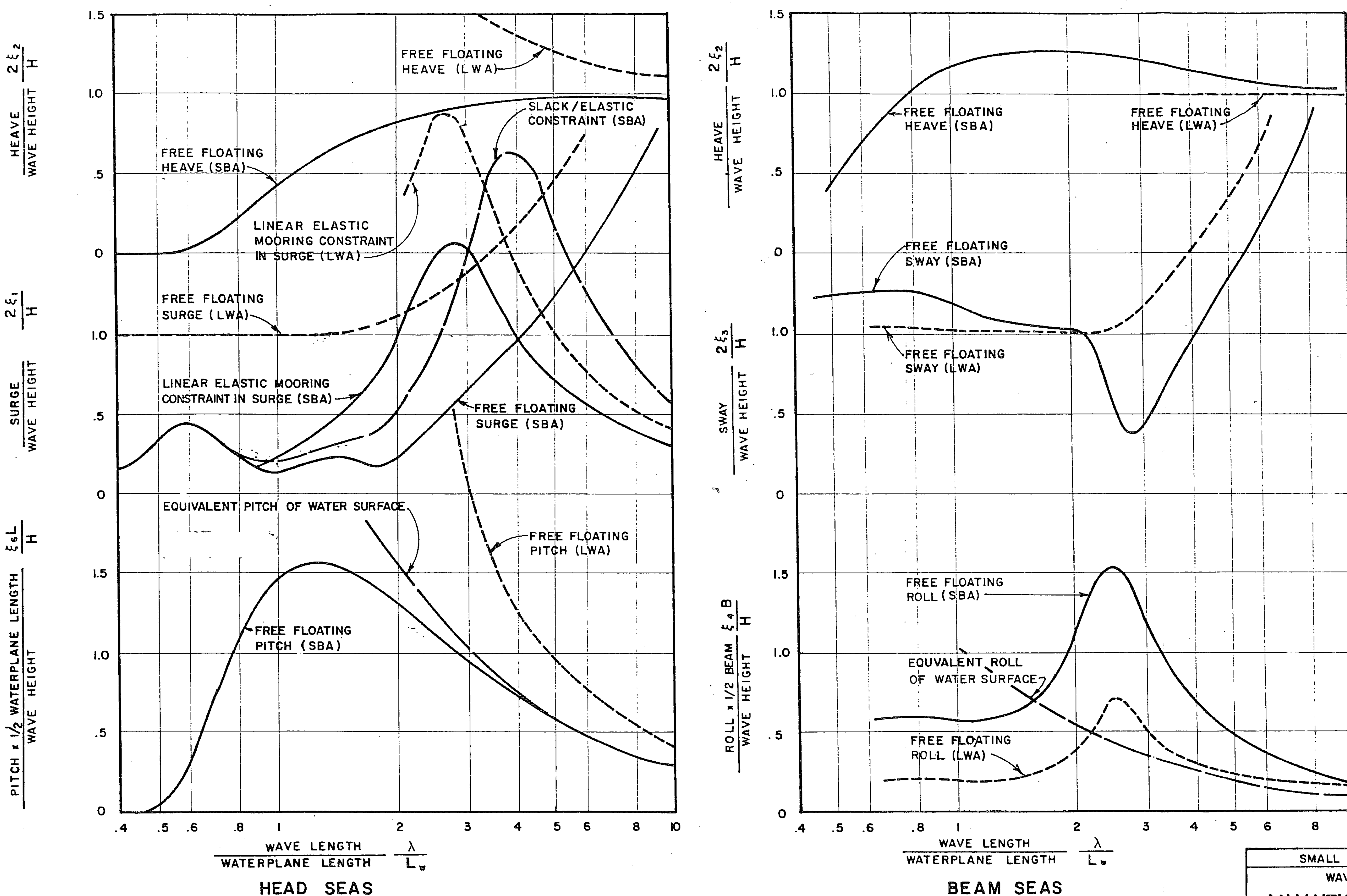
HULL 4 – NON-PLANNIG POWERBOAT

SMALL CRAFT HARBOUR BRANCH
WAVE CLIMATE CRITERIA

HULL CONFIGURATIONS ANALYSED

northwest hydraulic consultants ltd.

Drawn: I.M., V.U.	Date: NOV., 1979	Dwg.: 9.4.1



NOTES :
LWA — LONG WAVE APPROXIMATION
SBA — SLENDER BODY APPROXIMATION
MODIFIED NECESSARY

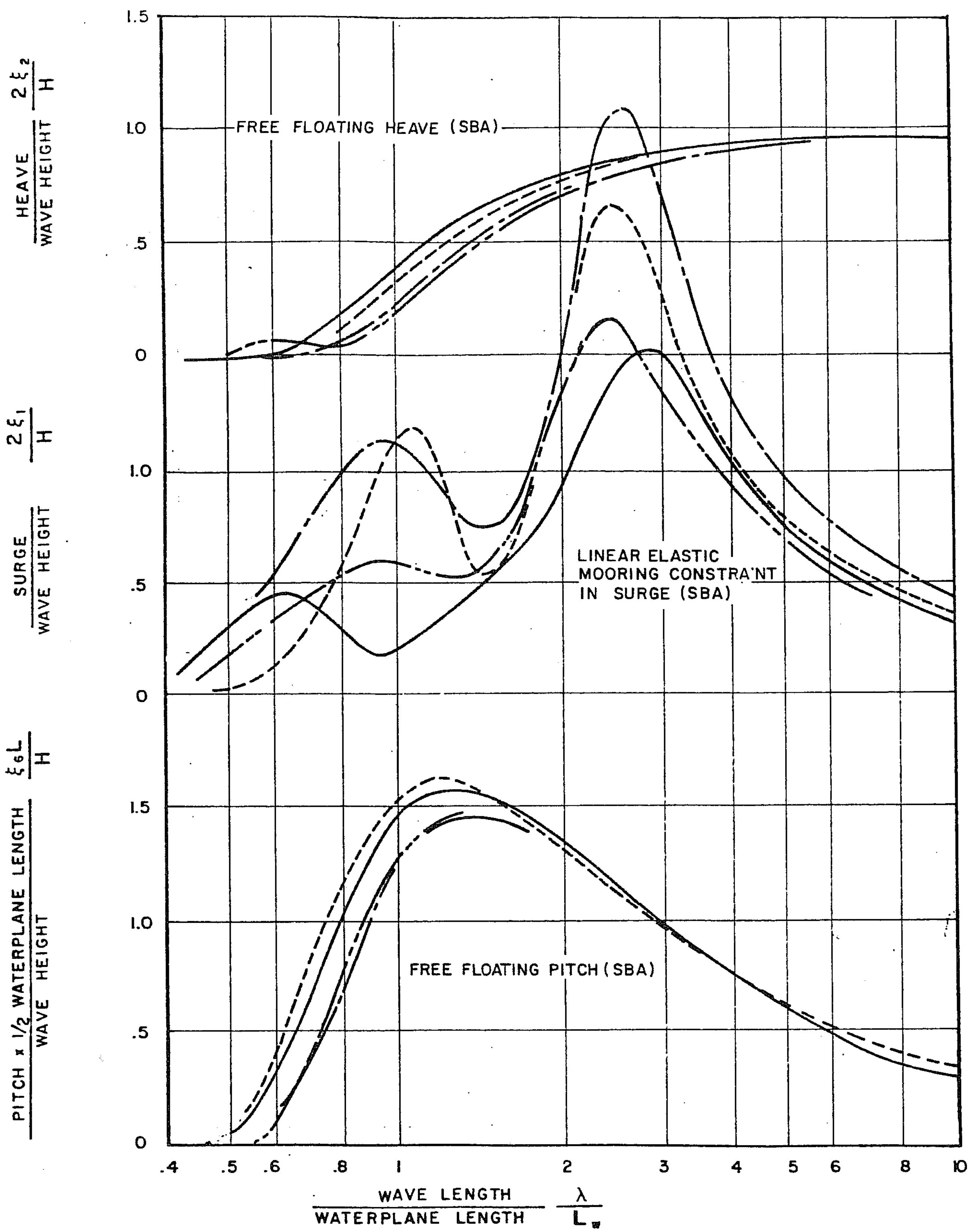
NOTE :
ξ REPRESENTS AMPLITUDE OF MOTION (ANGULAR FOR ROLL AND PITCH)

SMALL CRAFT HARBOUR BRANCH
WAVE CLIMATE CRITERIA

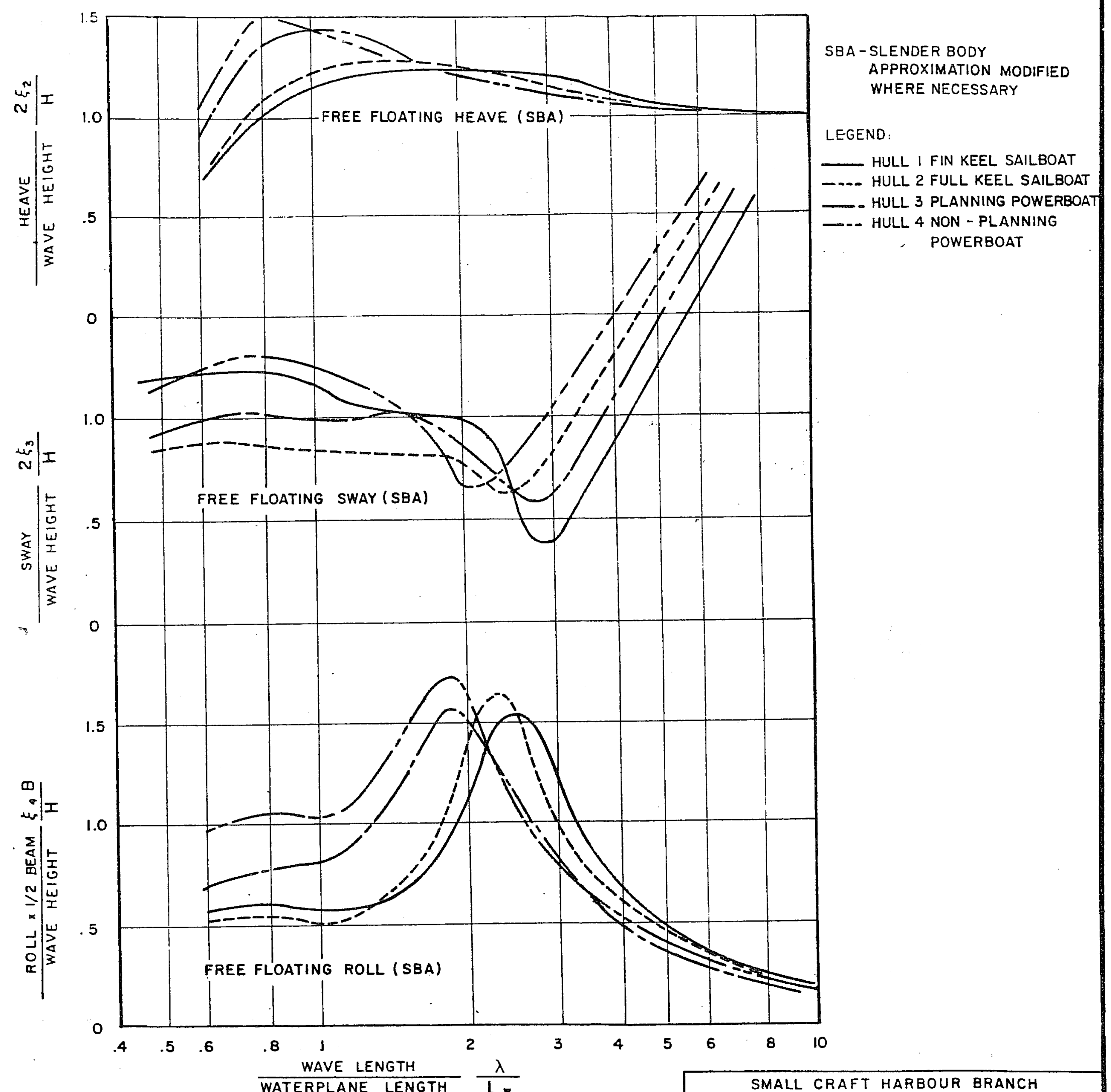
ANALYTICAL EVALUATIONS OF WAVE RESPONSE FOR HULL I

northwest hydraulic consultants ltd.

Drawn: V. U.	Date DEC., 1979	Dwg.: 9.4.2



HEAD SEAS



BEAM SEAS

NOTE:
ξ REPRESENTS AMPLITUDE OF MOTION
(ANGULAR FOR ROLL AND PITCH)

SMALL CRAFT HARBOUR BRANCH		
WAVE CLIMATE CRITERIA		
ANALYTICAL EVALUATIONS OF WAVE RESPONSE FOR 4 HULLS		
northwest hydraulic consultants ltd.		
Drawn: V.U.	Date: DEC., 1979	Dwg.: 9.4.3

APPENDIX A

Psychological Aspects of Wave Climate in Small Craft Harbors

by

Lawrence M. Ward Ph.D.,

James A. Russell Ph.D.,

Nicole Clement B.A.

This report is part of a project undertaken by Northwest Hydraulic Consultants, Ltd. and funded by Science Centre, Science Procurement Branch, Supply and Services Canada.

1. Purpose

The purpose of this report is to contribute information about psychological reactions to wave action relevant to establishing optimum standards of wave action for small craft harbors. The report contains a review of existing literature related to the perception of wave action and induction of motion sickness (Section 2), and reports a field study of boat owners' attitudes toward the marina environment (Section 3). This latter investigation took the form of a guided interview. It allowed us to focus on the response of boat owners to wave action conditions within seven quite distinct harbor environments within British Columbia. Our concern throughout was with subjective impressions of the marina environment as opposed to the more objective physical aspects.

2. Review of Existing Literature

The intent of this study was to explore how different wave patterns might influence a boat owner's perception of possible damage to his craft and his feelings of comfort and physical well-being. This entailed an investigation of the relevant behavioral science literature on hazard perception, comfort and motion sickness. One of the major limitations to obtaining useful information from existing literature was that past research has not dealt directly with marinas. Thus the findings presented here are only an indication of possible factors relevant to the perception of wave action. Another limitation of the literature is the prevalent emphasis on perceptions of infrequent events such as hazards. Relatively little study has been made of the perception of frequent or ever-present problems. The material that is available, and was thought to be of potential value, has been organized into four major sections. The first three deal separately with individual differences in the perception of the environment, perceptual and cognitive biases and limitations, and perceptions of the environment that are a function of historical trends. The fourth section contains a summary of motion sickness research as it relates to a marine environment.

2.1 Individual Differences in Perception

The perception of man's environment probably varies widely across individuals with different backgrounds or purposes. Such characteristics as an individual's position or role with regard to the environment appear to be instrumental in forming impressions and evaluations. For example, scientific and technical personnel tend to have quite different perceptions of, and attitudes toward, their physical environments from those of non-professionals, (Craik, 1970; Sewell, 1971). The differences that have arisen between lay and technical-scientific perception of the environment may in part be due to the difficulty in assessing the available information and data. The lay individual tends to have a limited technical vocabulary, and a limited ability, and even some reluctance, to calculate the objective frequency with which a hazard appears. Resource users (and many others) tend to have difficulty in grasping complicated concepts of probability (Burton, Kates, & White, 1978; Kates, 1962). The marked dissimilarity of perception can be appreciated when comparing the subjective probability estimates of the occurrence of severe frost by fruit growers of Wasatch Valley to demographic projections. The estimated (objective) probability of this event was placed at once in 3 years, yet only 5% of the growers indicated an expectation that frequent or more frequent (Jackson, 1974).

Another area in which popular perception differs from that of the specialist is the degree of confidence placed in technological advances and in particular in protective measures. (Burton, & Kates, 1964). Flood control is an area in which misperception is pervasive. Many flood plains users believe it is possible to completely prevent the hazard. However, experts in flood plain management acknowledge that neither a totally effective measure affording protection against the rare and extremely large flood, nor any effective measure to prevent its catalyst, concentrations of precipitation, is at present available.

Significant differences also exist between professional decision-makers and the lay public in their evaluation of the severity of environmental problems. For example, environmental irritants that professionals consider important were in fact considered relatively innocuous by the general public (Smith, Schuenenan, and Zeidburg, 1964; Medalia, & Kinker, 1965; Page, 1977). In research on water quality problems in British Columbia, public health officials differed from the public in their assessment of the effect of water quality on human health. Similar discrepancies were found in Waterloo County, Ontario. (McMeiker, 1970; Mitchell, 1971).

An individual's role viz-a-viz the environment appears to be one of the major factors in determining the perception of the environment (Clark, et al., 1971; Lucas, 1964; Mitchell, 1971; Constantine & Hanf, 1972). An illustration of this is found in the study of Constantine and Hanf (1972) concerning environmental problems in the Lake Tahoe basin. It was found that professional people were significantly more concerned about possible damage to the environment than were businessmen. One's role in the decision-making process also apparently influences perception. It was found that the relatively powerless local officials were much less concerned with possible damage than were the relevant, more powerful state officials. Some research in this area has focussed on the lack of conformity of environmental perception among resource-users and resource-managers. Resource-managers have been found to underrate seriously the quality of the recreational resource as compared to the user (Clark, et al., 1971; Lucas, 1963). There are also differences of perception among resource-users, even at the level of defining concepts. For example, the perception and definition of "wilderness" has been found to be a function of type of resource use, ie. being a power-boater or a canoer (Lucas, 1964). Canoers have a far more stringent definition of wilderness that indicates a focus on population density and man-made versus natural phenomena.

In a parallel sense, urban vs. rural use of a flood plain area appears to have an effect on the perception of flood plain hazards. Greater sensitivity is displayed by the agricultural land user in terms of awareness of hazard potential (Kates, 1962; Burton, 1962). Thus, we would expect to find that an individual who focusses on a specific aspect of the environment that has affected his use of the environment or resource will experience a concomitant alteration of his perceptions (Burton & Kates, 1964). There is thus a heightened hazard perception in those instances when hazards are directly related to, rather than only incidental to, resource use (Burton, Kates, & Snead, 1969).

The economic impact of the resource characteristics appears to be one of many dimensions that influence the perceptions of resource-users. For example, frequency estimates of hazardous situations are related to their punishment value. Florida citrus growers illustrate this factor. In the colder counties of Florida, they tend to underestimate the frequency of crop damage caused by low temperatures (less than $-3.3^{\circ}C$). This may be because of the relatively high marketability of their damaged produce to orange juice concentrate plants, which diminishes the economic losses. This can be contrasted to the tendency to overestimate tree-damaging temperatures (lower than $-6.7^{\circ}C$), where substantial economic loss is inevitable. (Ward, 1974).

Although the effect of personal experience of an environment on individuals' perceptions is a controversial issue (see Burton & Kates, 1964; Schiff, 1977), the effect of the personal experience of others seems to be of undisputed importance. This was demonstrated in the case of sea-coast dwellers who clearly accepted information obtained from another as evidence about reality. As a result they indicated a high awareness of past environmental events even when they had no personal experience (Deutsch & Gerard, 1955; see also Burton, Kates, & Snead, 1969).

2.2 Perceptual and Cognitive Biases and Limitations

Common responses to the uncertainty of hazards suggest some interesting ways in which people think about natural phenomena. A wide range of common strategies appears to be generated across natural hazard types. These strategies offer explanations for what would appear to be inappropriate behavior in areas high in natural hazard. Kates and Burton (1964) have found that perception of the environment is not simply a function of personal experience, but it is also affected by the interpretation of natural events.

As most natural hazards can be viewed as random phenomena, technical-scientific professionals tend to acknowledge the element of the unknown and strive, with the use of scientific techniques, to find order in natural phenomena in the context of probability theory.

In contrast, lay people tend to react to the unknown by using one of two quite different strategies. First, they may attempt to eliminate their feelings of uncertainty by endowing the random occurrences of natural phenomena with the features of a regular and periodic pattern (Burton, Kates, & Snead, 1969). There is also a tendency to believe that one severe event assures a period of respite. This appears to be particularly relevant to phenomena such as floods and snowstorms (Kates, 1962). An alternative strategy is to transfer the fate of man and environment to an unknowable and omnipotent being, such as God. This type of response has been found to be partly a function of a culture's relationship to nature, occurring mostly in cultures that feel submissive to nature (Kluckhohn & Strodtbeck, 1961).

Another common device used to interpret the occurrence of natural events is the denial of a hazards' existence and/or reoccurrence. Beliefs of this sort would tend to explain reports of crop growers' inability to accurately predict the probability of total crop destruction. Research on tree crops in the Wasatch Valley indicate that after April 15th, there is a .32 probability of total destruction due to temperatures below -6.7 °C. Yet only 4% of the growers expect this occurrence as often as once in 3 years (Jackson, 1974).

The individual, whether professional or layman, is subject to judgemental biases that will influence the decision-making process. Currently there is substantial evidence to support Simon's (1957) theory of "bounded rationality". This theory suggests that the cognitive limitations of decision-makers necessitate the construction of simplified models of the world. These models are a function of the way in which we perceive, think, and learn, yet they are extremely limited in terms of their appropriateness to the real world. But it is the use of these judgemental heuristics and simplification strategies that defines what is perceived as rational behavior (Slovic, Fischhoff, & Lichtenstein, 1976).

Empirical evidence suggests that people systematically violate the principles of rational decision-making when predicting or coping with uncertain events, and that these inadequacies in probabilistic thinking are evident outside the context of laboratory situations. There are a number of areas in which use of heuristics (plans used to solve problems when "surefire" algorithms are not available) leads to serious biases in the decision-making process. For example, even scientists seriously underestimate the error and unreliability inherent in small samples of data (Tversky & Kahneman, 1971). This type of misjudgement can be viewed as an illustration in the belief of the "law of small numbers". "Subjects act as if every segment of the random sequence must reflect the true proportion; if the sequence has strayed from the population proportion, a corrective bias in the other direction is expected" (Tversky, & Kahneman, 1971, p. 106). This is in contrast to the law of large numbers, or the actual laws of chance, which indicate that deviations are not cancelled out but rather diluted as sampling proceeds.

The "availability heuristic" is another form of judgemental bias. Mental availability of an event, based on ease of retrieval of appropriate events and the number of such events, is often a reliable index of its probability of occurrence. Intuitively, it is easier to recall likely and frequent events than unlikely and infrequent events. Yet serious errors may occur if there is reliance upon availability of an event, as it is affected by such unrelated (to probability) factors as recency and salience of an event (Kahneman, & Tversky, 1973). Another problem is that any occurrence that enhances one's ability to recall or imagine an event will increase its perceived frequency. Thus such factors as media coverage, personal experience and community consensus can and may lead to invalid perception of the prevalence of hazardous events.

A final characteristic of an environment that tends to bias the resource-users' perception is the frequency of the occurrence of a natural hazard. The perceived likelihood of a specific event such as a tidal wave can be characterized as a point on a certainty-uncertainty continuum. In the context of the urban flood plain, it has been found that when events are either frequent or infrequent there is minimal variation among the users' perceptions (Kates, 1962). In situations where environmental events occur with moderate frequency variation of perception is the greatest. In this type of situation ambivalence appears to characterize the community, although each individual tends to have firm idosyncratic attitudes and strategies towards possible events.

2.3 Effects of Cultural and Technological Changes

The question of what constitutes a natural hazard is of particular importance when assessing the applicability of past research and estimating the public's reaction to a specific event. The definition of an event as constituting a natural hazard is intricately linked within its cultural, technological, and historical context. The general concept of natural hazard has been defined as an "interaction of people and nature governed by the coexistent state of adjustment in the human use system and the state of nature in the natural events system" (White, 1974, p. 4). Therefore, the labelling of an event as a hazard is related to the ability and the necessity of people to adjust and adapt in the context of their social and physical environment at the time.

It is interaction with the environment that creates hazardous stress and use of resources. In illustration, the decision to occupy a flood plain is the initial move that creates a damage potential situation and may establish changes in the flood regime itself. The human system is thus subject to potentially harmful extraneous forces. It is in particular jeopardy when exposed to extreme events, as they often exceed the capacity of the human organization to cushion and absorb the hazard features. As a result, the devastating public hazards are those with extreme consequences yet low probabilities (Slovic, Fischhoff, & Lichtenstein, 1978).

The concept that natural hazards are those physical elements in the environment that are harmful to and beyond the control of humans, remains the same across history. Yet the defining dimensions of any particular type of hazard alter in response to the changing capabilities of human technology. For instance, as water is increasingly harnessed and transported in various parts of the world, the definition of drought conditions becomes more stringent. The irony is, "it may well be the ways in which man-kin exploits his resources and technology in attempts to cope with extreme events of nature are inducing greater rather than less damage, and that the processes of rapid social change work in their own way to place more people at risk and make them more vulnerable". (Burton, Kates, & White, 1978, p. 1).

2.4 Summary of Hazard Perception Literature

The complexity of natural hazard perception is probably best assessed by White (1974) who has made a thorough study of the perception and estimation of natural hazards. He cites four major categories of characteristics that are crucial ingredients to account for hazard evaluation biases. They are:

1. The frequency and magnitude of the hazards.
2. The individuals' experience in terms of recency and frequency.
3. The impact of the hazard in terms of economic and vocational interests.
4. Personality characteristics.

2.5 Motion Sickness

Motion sickness is another way in which wave action may lead to small craft owners' dissatisfaction with harbor conditions. Research in the area of motion sickness has developed over the last forty years in response to a massive increase in the use of transportation facilities. The first major study of motion sickness was done during World War II when an understanding of its origins was required in order to transport troops successfully by air and water. Currently there are a number of theories attempting to explain the phenomenon. Presently the sensory rearrangement theory is the most accepted (Reason & Brand, 1975).

The sensory rearrangement theory is "based on the premise that situations which provoke motion are all characterized by a condition of sensory rearrangement in which the motion signals transmitted by eyes, vestibular system and the non-vestibular proprioceptors are at variance one with another, and hence--and this is the crucial factor--with what is expected on the basis of previous transactions with the environment" (Reason & Brand, 1975, p. 264). The sensory rearrangement theory is based on two assumptions. The first is the presence of an intact vestibular system, which provides the necessary sensitivity to changes in velocity of the head (accelerations and decelerations). Only such accelerations are implicated as causes of motion sickness. (Money, 1970). The second assumption is that sensory information retained from the recent past may be in conflict with current sensory information.

These assumptions provide a basic insight into how and why certain situations are likely to provoke motion sickness. Every movement of a person requires a coordination of visual, proprioceptive and vestibular input. It has been suggested that when there are repeatedly misleading and conflicting inputs determining the relationship between eye and head, or head and body, or both, motion sickness may be triggered. In this case the problems may be augmented by inappropriate compensation behaviors such as head movement. According to sensory rearrangement theory, disruption of the established calibration in terms of visual-inertial rearrangement or (vestibular) canal-otolith rearrangement is a major catalyst of motion sickness.

Motion sickness, as generated by wave action, is primarily concerned with visual-inertial rearrangement. A typical case is a simultaneous signalling by both eyes and mechanoreceptors of information that is uncorrelated and incompatible with expectations based on past experience in the boat environment. For example, a person may suffer seasickness while standing on the side of the boat looking at the wave action. His experience of visual and vestibular feedback will be correlated with the ship's movements, yet appear to be uncorrelated with the apparently random action of the waves. Another situation where motion sickness is likely is when there is an adequate stimulus to vestibular system and mechanoreceptors in the absence of the expected visual signals. This could happen when an individual is subject to wave action while working or remaining inside a boat.

Motion sickness can be manifest in the absence of apparent overstimulation or sensory conflict. The experience of nausea and vomiting upon return to land after a period on the water was difficult to explain prior to the development of the neural mismatch hypothesis (Reason & Brand, 1975). It postulates the presence of two neural components: one storage unit retains traces about recent sensory signalling, while a second, similar unit compares the trace information with the current influx of information from the senses. When there is agreement between the two units, motion sickness cannot result. However, when there is disagreement or a mismatch of information between the units, then there is a propensity for motion sickness. In the case of "sea head", there may be no overt stimulus, but the mismatch between remembered wave motion and current lack of it triggers the propensity to motion sickness.

It is suggested that approximately 95% of individuals susceptible to motion sickness are capable of some kind of adaptation leading to a decrease in sickness. However, an individual's susceptibility to motion sickness appears to be a function of exposure to the type of movement of a specific vehicle. Adaption to one type of movement is not necessarily associated with a concomitant adjustment to motion associated with another type of vehicle (Gibson, Manning, & Cohen, 1943). In fact, peoples' motion tolerance may be quite specific to the extent that they may have a resistance to wave response patterns of small boats but be highly sensitive to the motion of large boats, or the reverse (Tyler, & Bard, 1949).

Research into the specific characteristics of wave action that evoke motion sickness has concentrated on linear acceleration, since it is the major component in most motions of importance. Much of the comprehensive experimental research was conducted by Wendt and his associates, who developed a hydraulically-driven elevator cabin that was temperature controlled, air tight and sound proof (Alexander, Cotzin, Hill, Ricciuti, & Wendt, 1945). This cabin was designed to accelerate vertically in an 18-foot shaft. By manipulating the acceleration of the cabin, operators could simulate a wide variety of wave-forms. Wendt, et al. (1945) found that the major factors characteristic of symmetrical wave action relevant to motion sickness are the amount of energy expended (i.e., applied to the individual) by the wave and the period of the wave. In general, the graph of incidence and seriousness of motion sickness as a function of wave frequency (for constant energy) is an inverted-U shape, with a maximum at about 15-20 cycles per minute (period about 3-4 sec.). In contrast, amount of motion sickness is an increasing function of wave energy (amplitude), with no maximum apparent. Somewhat paradoxically, moderate frequency and energy levels seem to be especially effective in creating nausea and vomiting. In one experiment, over half of a group of naval officers subjected to wave action with amplitude of 7' at 22 cycles per minute became sick within 15 minutes (Wendt, 1951).

3. The Field Study

3.1 Method

The purpose of this study was to obtain more directly relevant information about boat owners' and marina managers' perceptions of problems associated with wave actions in their marinas than was available from the literature reviewed above. This project entailed in-depth interviewing of boat owners at six British Columbia marinas proposed by Northwest Hydraulic Consultants, Limited. The marinas were chosen to provide a range of physical conditions subject to natural wave action. They were: Fisherman's Wharf, West Vancouver Yacht Club, Thunderbird Marina, Eagle Harbor Yacht Club, Schooner Cove Marina, and Beach Garden Marina. In addition, Mosquito Creek Marina was used as an example of a marina situation where the primary wave action is due to the wake of moving vessels. The use of a questionnaire-guided interview format was decided upon as it provides standardized answers and allows quantitative measurement of attitudes, etc. A working assumption of such attitude surveys is that there is some useful relationship between verbal expression and actual behavior. This assumption has been criticized but it still seems useful (O'Riordan, 1971). Additional information and insight could be achieved by alternate strategies such as the use of in-depth, nonstructured interviews, inventories of the actual amount of effort expended, and inquiries into the amount of money the concerned population is willing to spend on prevention vs. remedy of a problem. (Mulligan, 1978).

The questionnaire used here (see Appendix A) was developed to provide a structure to the interviews of boat owners. The first section of the questionnaire, questions 1 through 7, is concerned primarily with background factors that might affect the boat owners' perceptions of the marina. The literature reviewed indicated that boat owners' perception of wave action could vary as a function of their type of knowledgeable experience (i.e., use of sail vs. power boats, amount of marine experience, and amount of marina experience. The second section of the questionnaire (questions 8-15) requires the boat-owners to rate their perception of various types of wave action in terms of the degree to which this is perceived as a problem. Due to difficulties in labelling types of wave action, descriptions were phrased in terms of the number of occurrences per year. In addition owners were asked to rate the extent to which wave action created annoyance, anxiety, motion sickness, wear and tear, and damage to the boat. Responses, in this instance, were made on bipolar scales. These questions represented the dependent variables of the study, i.e., areas in which the boat owners' perceptions are subject to change as a function of actual presence of wave action and the other aforementioned variables. The final section, questions 16-20, were open-ended in order to allow for a comparative analysis of the pertinence of wave action problems viz-a-viz other issues. It was hoped this area would provide information that would aid in interpreting the quantitative data.

Two hundred three boat-owners were interviewed throughout the months of July, August and September of 1979. In almost all cases the interviewer approached the boat owners within the confines of the marina. Interviews of boat owners were primarily conducted on Thursday, Friday, Saturday or Sunday from 8:00 a.m. to 6:00 p.m., as it proved expedient to utilize periods of high activity at the marinas. Each marina was visited on at least three separate days. Individuals interviewed were boat-owners with no less than four months moorage at the small craft harbor. Obviously the sampling was not random, but was thought to be representative of the range of relevant boat users. In addition, extensive non-structured interviews were conducted with an owner/manager at each of the six primary marinas.

3.2 Results

3.2.1 Characteristics of the six marinas

The information gathered from the interviews of the boat-owners and managers has been used to develop subjective descriptions of the small craft harbors. These descriptions incorporate data from Table 1, where the means, standard deviations and number of interviews are tabled for the questions on the questionnaire. In addition, material obtained in the free-response section of the survey provided insight into the boat owners' perceptions and evaluations of their environment (see Table 5). The subjective descriptions follow .

3.2.1.1 Fisherman's Wharf

Manager: Mr. Don Malcolm

Location: Fisherman's Cove, West Vancouver, B.C.

Maximum boat capacity: 80

Sailboat: 50%   Motorboat: 50%

Boat use: Recreational

Problem Wave Conditions: slight surge

Fisherman's Wharf is a small, privately owned moorage facility that accomodates 80 boats. The mean length of stay at this marina, according to our sampling, was just over 1 year, although the marina manager thought it to be 5 years. As many as 10 moorages are used by Harbor Yacht Sales, which displays and sells yachts at the marina site.

At present, the marina provides hoist and ship-maintenance repair facilities. The boat-owners appear to have chosen this moorage as it was available (in some cases the boat was bought there) and convenient to home. In this instance, the boat owners do not appear to consider its site in terms of wave protection as an asset. According to the manager, Fisherman's Wharf tends to receive a two-foot surge when there are storms from the southwest. This level of exposure is reflected by the boat owners' ratings of wave action during severe storms as a medium problem, relative to that during common storms, which is considered somewhat of a problem, and that during everyday use, which is seen as no problem at all. Wear and tear at this marina is perceived as somewhat of a problem, although there has been only minimal damage incidence. Individuals at this marina are, in general not annoyed nor made motion sick by the wave action, but they do report some anxiety associated with the safety of their boats.

Overall the boat owners have rated Fisherman's Wharf as being moderately satisfactory. Their reservations about the marina appear to be related to its lack of security, small size, poor maintenance of the floats, and the general lack of facilities such as electricity, parking, and washrooms.

3.212 West Vancouver Yacht Club

Manager: Mr. Kinley

Location: Fisherman's Cove, West Vancouver, B.C.

Maximum boat capacity: 240 boats

Sailboats: 75-80% Motor boats: 20-25%

Boat use: recreational

Problem conditions: slight surge of 4-6" on west side

West Vancouver Yacht Club can be characterized as a small private club that combines the advantages of an extremely protected natural harbor with excellent maintainence of facilities and ideal location. It is probably as a result of these factors that the mean length of stay is approximately 9 years.

Wave action, whether during serious storms, common storms or everyday use, was not considered a problem by the boat owners and the manager of the club. Nor did the boat owners express anxiety or annoyance in response to the wave action in the moorage area. In fact, the wave conditions, as far as the boat owners were concerned, result in almost no wear and tear, although Mr. Kinley did note some occurrence on the west side of the harbor. This is probably associated with an occasional surge of 4-6" and wash off boats moving to and from the cruising and moorage areas.

This marina is considered by boat owners to be very satisfactory and some even indicate "it is the best in the Northwest". It provides its members with services of 24 hrs. security, checking of mooring lines and in addition, well-maintained concrete-styrofoam floats. Satisfaction of the marina users appears to be primarily related to its convenience and proximity to the cruising and residential area in conjunction with its sheltered environment in which to enjoy club facilities.

Wave action within the confines of the yacht club is not a concern of the members. In the majority of cases when asked what was the worst aspect of the marina, the members said there was nothing and when asked to suggest an area for marina improvement, a common response indicated an awareness of space limitations in terms of narrow bays and channels. Both the manager and boat users focused on the lack of moorage. Mr. Kinley seemed to be aware of a possible problem with vandalism.

3.213 Thunderbird Marina

Manager: Mr. Barry Sutton

Location: Fisherman's Cove, West Vancouver, B.C.

Maximum boat capacity: 862

Sailboats: 60% Motor boats: 40%

Boat use: recreational

Problem conditions: nil

Thunderbird marina is a large, privately-owned, small craft harbor near Fisherman's Cove, West Vancouver. This marina provides accommodation for 862 boats, which range in size from 16 to 55 feet. The mean length of stay is 7 years, with a turnover of approximately 6-7% per year; this level of transience is associated with the use of moorage facilities by Thunderbird Yacht Sales.

Thunderbird Marina provides its boat owners with a 24 hr. security system, which entails large security patrols and locked gates to ramp-ways. On the premises are ships' chandlery and gas barge, although there are no food services.

The marina is located in the most easterly part of the cove and receives maximum protection from exposure. As a result, boat owners consistently refer to the problem of wave action as nonexistent. This is reflected in their rating of wave action as no problem during severe storms, common storms and everyday use. The boat owners perceived virtually no wear and tear and this is supported by the manager's assessment of time needed to be spent on boat maintenance work. It would appear that this low wear and tear problem is caused as much by wash action as wave action, although the 5 knot speed-limit minimizes this problem.

In general, the boat owners felt the questions asked did not pertain to the environment of Thunderbird Marina as their boats did not suffer the ravages of wave action nor do the owners themselves suffer anxiety, annoyance or motion sickness. In fact the boat owners at Thunderbird Marina gave it the highest ratings of satisfaction given to any of the six marinas, midway between satisfactory and very satisfactory.

When asked why they had chosen Thunderbird Marina, the major consideration was the convenience in terms of its proximity to the boating area (e.g., Howe Sound) and home. Yet the marina's protection from exposure was often cited as an important aspect. Generally, the owners found there was nothing they would like to change or consider the worst aspect of the marina, except the moorage rates. Minor complaints covered the gambit of number of parking spaces available, presence of winter ice, etc.

3.214 Eagle Harbor Yacht Club

Manager: Verne Atkinson

Location: Eagle Harbor, West Vancouver, B.C.

Maximum boat capacity: 90

Sailboats: 65%   Motor boats: 35%

Boat use: recreational

Problem conditions: storms from the south and/or southeast

Eagle Harbor Yacht Club is a privately owned West Vancouver club that has moorage on buoys and slips for 90 boats. This club provides its members with the security of a full-time marina operator who supervises the boats and re-ties mooring lines. This is a particular asset as the marina is situated in a cove that has no natural protection from south or southeast storms. This problem is compounded by the physical characteristics of the ocean bed, which drops off 40-90' making the cost of a new solid breakwater prohibitively expensive, over $1 million dollars. Presently the club is protected by a floating-tire breakwater, which was designed by its members to replace the two breakwaters that have been destroyed in previous storms.

Ambivalence tends to characterize the members' attitudes towards wave action in severe storms. This is probably a function of a number of factors, which include apprehension on the part of the manager and experienced long-term members of the club that the breakwater could come loose and smash into the floats during a storm. The breakwater does not provide adequate protection against large storms. Yet, the newer members appear to be unaware of the risk potential, and boat owners with floating buoys tend to be better off due to the boats' angle to the waves and distance from the float. Mr. Atkinson, who has been the manager for four years, considers wave action during storms that occur once in 5 years to be a very severe problem, although the average member considers it only a severe problem. The manager and boat owners could differentiate between severe and common storms, as the manager considers wave action during common storms to be a moderate problem relative to boat owners' perception of it as a mild problem. Mr. Atkinson and his members considered everyday wave action no problem at all.

Mr. Atkinson appears to be moderately annoyed by the wave action and anxious about the boats, yet the members were only somewhat annoyed by wave action and the only anxiety they felt was related to the boats' safety. It was interesting to note the diversity of reaction to wave action in the marina basin. It ranged from individuals who would be willing to get up at 2:00 o'clock in the morning to check their boats if they felt there was a storm stirring, to individuals who felt there was no problem. Probably the discrepancies between boat owners and the manager's perception was a function of responsibility and constant exposure (see introduction).

There was consensus between the manager and members that wear and tear was only a mild problem. It was recognized that the everyday stress of wave action would weaken the wooden floats such that the presence of large storms could cause severe damage to the floats. Minor damage appears to be a relatively common occurrence, and two major insurance claims due to chains loosening on buoy moorings have occurred during the last four years. Both the manager and boat owners appear to be very satisfied with the marina. This seems to be related to the marina's accessibility relative to the boating areas, availability of moorage and yacht club facilities. There is consensus that the major drawback to this marina is its exposed location and inadequate breakwater.

3.215 Schooner Cove

Manager: Mr. Phil Durrell

Location: Schooner Cove, Nanoose Bay near Parksville, Vancouver Is., B.C.

Maximum boat capacity: 370

Sailboats: 25%   Motor boats: 75%

Boat use: recreational and some commercial boats (fishing boats)

Problem conditions: ground swell in conjunction with south-southeast winds and high tide

Schooner Cove is a privately owned marina near Nanoose Bay between Nanaimo and Parksville on Vancouver Island. It was constructed 8 years ago to provide year-round moorage for the Parksville Recreational area. But due to the increasing popularity of recreational boating, this moorage facility was expanded four years ago to have a maximum boat capacity of 350 boats, which makes it the largest marina from Victoria to Campbell River. At this time the floats were re-directed. They are now parallel to the breakwater in order to minimize the degree of pitching and allow for the natural rolling of the boat.

The current wave action structure at Schooner Cove is a function of the existing 700 ft. breakwater built by the Federal Government. The initial plan was to extend an additional 125 ft. leg into the Sound in order to dissipate the wave action from the southeast. This was not done. The prevailing southeast winds in conjunction with ground swells have led to some boat damage. This is especially prevalent during high tide as the entrance of the marina is widened as the water rises over the rocks located there. The strength of the wave action is reflected in the extensive float damage sustained two years ago when the end of each float parallel to the breakwater was torn off. Damage to boats is generally the result of popping the bumpers and the breaking of mooring lines, which allows excess boat movement. To diminish the likelihood of damage, winter moorage is utilized by less than half the boats, the majority of which are large displacement sail and motor yachts moored to floats in close proximity to the breakwater and shoreline.

Mr. Durrell suggested a more effective method of damage protection would be to minimize the groundswell action by placing a breakwater extending from the far shore along the rocky islets there, incorporating the rock pinnacle and extending across the entrance. This design of breakwater would interrupt the waves so that they would be reflected on to the rocks outside the marina as well as narrowing the marina entrance.

The boat owners interviewed found the wave action during the type of southeast storm that occurs once in five years to be a severe problem, in contrast to that during common storms, which was perceived as only a moderate problem. These responses should be compared to Mr. Durrell's perceptions that wave action in the marina is a very severe problem during nearly all storms. In particular, he felt southeast storms of 50-70 mph could cause the floats and pylons to be destroyed again. His attitude toward the marina tended to coincide with those of the long-term experienced boaters with year-round moorage. Every-day wave action is not considered a problem by either the manager or boat owners.

The boat owners did acknowledge a mild to moderate degree of problem with reference to the safety of their boats, yet relatively no anxiety was felt regarding their own person, guests or contents of their boats. It may be that the anxiety associated with their boats related to their perception of wear and tear as a moderate problem. The minor problems associated with wave action may be a constant reminder of the danger present in this marine environment.

The average boat owner found the marina moderate to very satisfactory despite the very severe chop in the back section of the marina, and the difficulty of navigating in and out during 30-40 knot southeasters. There seems to be a general knowledge that the exposure and groundswell could be diminished by a new breakwater. Despite these drawbacks, a high level of satisfaction expressed by the boat owners appears to be a function of the constantly friendly and dedicated service provided by Mr. Durrell.

3.216 Beach Garden

Manager: Mr. Jim Price

Location: Powell River, B.C.

Maximum boat capacity: 150

Sailboats: 25% Motor boats: 75%

Boat use: mostly recreational and some commercial boats (towing and diving vessels).

Problem conditions: high tides in conjunction with southeast winds.

The Beach Garden Marina is situated on a beach .5 miles southeast of Powell River. The construction of the marina was a result of a dollar-for-dollar share agreement between the Provincial government and the developers of Beach Garden Resort. The purpose of the partnership was to provide sheltered year-round moorage with adequate protection from wind and wave action, and employment for Powell River residents. This development was to provide the recreational facilities necessary to promote the expanding tourist industry associated with night scuba diving. The intention was to provide moorage for a maximum of 150 boats, including a docking area for commercial vessels associated with tourist, fishing, cruising and diving activities. At present, less than 40 boats are utilizing the winter moorage facilities, although 90 boats have year-round moorage contracts with Beach Garden. Mean length of stay in our sample of boat owners was just over 2 years (but it should be noted this statistic is not indicative of rates of transients as the marina was completed only 3 years ago).

Wave action in this marina was considered a problem by both the manager and the boat owners; they found it difficult to distinguish between our definition of very fierce storms and common storms. To illustrate, Mr. Price estimated very severe storms having winds of 70-100 mph occurred a dozen times during the 4 years period. This problem is compounded by high tides and southeasterly winds from the Juan de Fuca area. The manager tended to rate the wave action during both the serious and common storms as very severe problems. This contrasted to the boat owners' rating of wave action during severe storms as a severe problem and that during common storms as a medium problem. The management appears to be particularly sensitive to the problems of the marina as it has attempted to stabilize a network of wooden floats by securing it to 6 concrete filled steel pylons at a cost of $20,000 each. Yet the standard 22 ft. breakwater does not appear to be a sufficient block to wave action as the pylons can be subject to a 6-8 ft. surge. Over a year ago, 60 logs were joustled over the south wall during storm conditions. Ordinary everyday wave action is considered by both management and boat owners to be only a mild problem.

There is consensus between the manager and boat owners that the wave action is felt to be moderately annoying in a number of ways: it limits the amount of year-round moorage, it causes difficulties in gaining access to the harbor, and in some cases, insurance coverage has been refused by brokers. The boat owners are somewhat anxious for themselves and the contents of their boats in contrast to the manager who is extremely anxious for his staff, which provides dawn to dusk supervision including the re-tying of mooring lines and patrolling of floats. Even under these conditions of rough wave action, motion sickness is considered somewhat less than a mild problem.

Wear and tear in this environment is a severe problem for management, although boat owners only considered it a moderate problem. The people interviewed found it difficult to differentiate between wear and tear and damage that would not lead to insurance claims. Mr. Price indicated an incidence of insurance-claim boat damage (over 30 incidents), and non-claimable damage (50 incidents) that was not reflected in the boat owners' data. This type of inconsistency could be accounted for by the self-selection of our sample. It would seem unlikely that the individuals who sustained severe damage due to wave action would leave their boats in a small craft harbor.

Overall the boat owners appeared to be moderately satisfied with the marina in contrast to the manager being somewhat satisfied. The marina users appeared to be surprisingly satisfied given the wave conditions. This response may be related to seasonal use of the marina, and the provision of modern well-kept-up boat facilities, and sampling bias. Both the majority of boat owners and the manager felt that many of the current problems of the marina could be rectified with heightening of the breakwater and changing of the marina entrance.

3.22 Overall Correlations

The independent variables of boat size, amount of time moored in a marina and the number of years as a boat owner, are significantly inter-correlated (see Table 2), but only two correlations with dependent variables reached statistical significance at $\alpha = .01$ level: amount of time moored in the marina with the perceived problem of wave action during common storms (-.22), and amount of time moored in the marina with degree of marina satisfaction (.21). Since these are relatively low, although significant, no more will be said about them here.

The intercorrelations of dependent variables provide an interesting pattern of association. First, the extents to which wave action during serious storms and common storms was perceived as a problem were correlated .84, although each correlated less (.34 and .52) with the perception of everyday wave action as a problem. This indicates that boat owners didn't differentiate between wave action during severe storms and common storms but did differentiate somewhat more between those and ordinary wave action. Second, the degree of annoyance associated with wave action, the perception of it as a problem during serious storms and during common storms, the degree of anxiety associated with wave action on boats, and the perception of wear and tear, all correlated highly with one another (correlations between .6 and .8 - see Table 2). In addition, these variables have the highest correlations of any variables with overall satisfaction (see Table 2). This suggests the hypothesis that overall satisfaction with the marina is mediated by the degree to which wave action is perceived as a problem in these various aspects. To explore this further, we did a stepwise multiple regression with satisfaction as a dependent variable and the 5 variables mentioned above, plus the perception of wave action during everyday use, as independent variables. This would tell us which minimum group of the six independent variables could best predict satisfaction. We found the satisfaction values to be predicted by the equation

$$\text{Satisfaction} = -.32\ (\text{serious storms}) - .25\ (\text{wear \& tear}).$$

The multiple correlation associated with this equation was .52. Thus, the equation could account for 26% of the variance in the satisfaction judgments with just two variables. None of the other variables, if entered, would significantly increase the amount of variance accounted for by the equation. It seems that a good part of boat owners' overall satisfaction with the marinas can be accounted for by peoples' perceptions of wave action as a problem during serious storms, and the perception of wear and tear on the boat and moorings caused by wave action as a problem. This would seem to be important for setting standards for wave action.

3.23 Independent variables

Analysis of variance of the first four variables tabled in Table 1, across the six marinas, showed that all vary significantly at $\alpha = .01$ (i.e., the means were significantly different) except for "the amount of time boat owners had spent boating". Fs and p values for the 4 variables were: 4.66 (.0005), 6.76 (.0000), 3.09 (.0106) and .67 (.6463) for "the size of boat", "number of years moored in the marina", "the number of years of being a boat owner", and "the amount of time spent boating", respectively. Therefore, in all the analyses of variance of dependent variables mentioned below, the size of boat, the amount of time moored in the marina, and the number of years as a boat owner were treated as covariants. Thus, all conclusions about dependent variables differing across marinas are made only after these three independent variables have been partialed out. In addition, preliminary analyses of variance with type of boat as a factor failed to reveal any effect of this variable on any dependent variable. Therefore it is not considered further.

3.24 Analyses of Variance

As mentioned above, we ran one-way analyses of variance (with marina as the independent variable) on the various dependent variables values obtained from the questionnaire-guided interviews. These were actually analyses of covariance, that is, analyses of variance on the dependent variable values from which three co-variate values (the size of boat, the amount of time moored in the marina, and the number of years as a boat owner) had first been subtracted.

Table 1 displays for each marina, the means, standard deviations and ns (numbers of boat owners responding) of the dependent variables before subtracting the total co-variate values. The co-variate value means are also displayed there. Table 3 summarizes the results of the analysis of co-variance on the 13 dependent variables subject to this analysis.

First, notice that the mean values of all variables analysed differed significantly ($\alpha = .01$) across marinas. This indicates that differing physical (and other) characteristics of the marinas do affect peoples' perceptions of the marinas. More specifically, since the questions were directed at problems associated with, and direct perception of, wave action in the marinas, these results indicated that peoples' perceptions of wave action and its associated problems differ across the marinas. Because we controlled for at least some of the obvious other possible causes of these differences, we can be reasonably confident that it really is differences in wave action, exposure, and the general physical environment among the marinas that are causing the observed differences. One obvious additional variable we didn't control for was knowledge about problems, i.e., the ability of knowledge to be transferred from a group to an individual. Thus, we don't know whether the differences in perception observed among marinas was a function of differences in direct experience with wave action or a byproduct of rumours or group norms regarding wave action problems in marinas. Probably both factors are important.

Just how did the marinas stack up? We did Newman-Keuls tests on each dependent variable, using the results of the analysis of covariance, to find statistically homogenous groups of marinas. The results of these analyses are shown in

Table 4. Note we used $\alpha = .05$, a more liberal criterion here. From Table 4 it is clear that marinas 2 and 3 (West Vancouver Yacht Club and Thunderbird) are never different. Marina 1 (Fisherman's Wharf) is often different from but also quite similar to marinas 2 and 3, and marina 4 (Eagle Harbor) also joins 1, and sometimes 2 and 3. Marinas 5 and 6 (Schooner Cove and Beach Gardens) are always perceived to have more problems than any of the others and are also in a group by themselves. On the basis of these analyses we can rank order marinas according to perceived severity of wave action and associated problems as follows: (best to worst); (2,3), (1), (4), (5), (6). Two additional points of interest are that (1) this corresponds mostly to the physical characterization (exposure etc.) of the marinas and their general reputations, and (2) this does not exactly correspond to the inverse of the satisfaction rank order, indicating that wave action is an important but not exclusive determinant of satisfaction.

The actual values of the mean responses also have meaning, since the numbers reflect verbally labelled points on the various scales used to measure the dependent variables (see questionnaire, Appendix A). Looking at Table 1 again, we see that for the variables rating severity of wave action during severe storms and common storms, the perceptions of wave action as a problem ranges from about 1 to 4.3 (no problem to slightly more than a severe problem) and 1 to 3.35 (no problem to slightly more than a medium problem), while for ordinary wave action the range is only about 1 to 1.5 (basically no problem). Thus, even though we were able to discriminate among the marinas on all three variables, we should conclude that really it is only during storms that wave action is perceived to be a problem, and then only at the more exposed marinas. In everyday use, none of the marinas we studied seemed to have a wave action problem. Similar conclusions (that is, that there is no real problem) can be drawn for the variable "anxiety for self" (which ranges from 1 to 2.3; i.e., not at all to somewhat of a problem), "anxiety for contents" (which ranges from 1 to 2.3), "anxiety for guests" (which ranges from 1 to 1.6), reports of motion sickness (basically little motion sickness was reported), "motion sickness as a problem" (which ranges from 1 to 1.4), and the number of reports of non-claimable damage and claimable damage (basically very little damage was reported). On the other hand, "anxiety for boat" (which ranged from 1 to 3.4; i.e., not at all to more than a moderate problem) and the problem of "wear and tear" (which ranged from 1.2 to 2.7, i.e., from no problem at all to a moderate problem) do indicate perceptions of moderate problems with wave action at the more exposed marinas. And although the satisfaction means are all relatively high (they range from 3.2 to 4.5) they still represent a range from only moderate to between very and extremely satisfied. Again, an indication that things could be improved at some of the marinas.

3.25 Responses to open-ended questions

The majority of these are tabulated in Table 5. We categorized the responses according to similarities of meanings to produce this table. Most boat owners appear to be aware of the limited moorage available in marinas within the lower mainland of B.C., i.e., the areas surrounding Greater Vancouver. When it came to choosing a marina site, the majority of individuals appeared to consider first the proximity of the marina to their home and the general boating area. The convenience of the marina seemed to be of primary importance when initially choosing a marina, yet when asked what is the best aspect of the marina, there was normally a focusing on the marina's location both in terms of the boating area and home, as well as the degree to which it was sheltered.

Provision of a wide range of well-maintained facilities is also considered by most individuals as a primary asset.

When asked what is the worst aspect of the marina, the majority of responses indicated the primary factors differed across marinas. In the case of well-protected, sheltered marinas, we find that the average boat owner tends to focus on such characteristics as the width of channels and slips, the degree of maintenance provided, moorage rates and security. The marinas that have been considered least secure in terms of wave action are associated with a focus on breakwater limitations and the physical characteristics of the marina.

3.26 Mosquito Creek Data

Manager: Jerry Nahanee

Location: Near Lonsdale, North Vancouver, B.C.

Maximum boat capacity: approximately 600 boats

Sailboats: 35% Motorboats: 65%

Boat use: recreational

Problem condition: wash from seabus

Mosquito Creek, North Vancouver is a privately owned moorage facility which is subject to the constant wash action of the Seabus (a water-bound commuter service), which runs across the inner harbor from the foot of Lonsdale, North Vancouver to the bottom of Granville Street in Vancouver. The only type of wave action that presents a problem to the boat owners is this everyday occurrence. It physically causes some degree of annoyance and wear and tear. The individuals who tend to find this factor most irritating were those individuals who do their own boat work.

This marina was rated as moderately satisfactory by the boat owners who felt that there were a large number of irritants present at the marina site. This range of complaints indicated that wave action was one of the obvious contributing factors to the boat owners' dissatisfaction.

Tables 1, 5 and 6 summarize the Mosquito Creek data, and compare it to the six marinas data. Characteristic of the Mosquito Creek data is that the pattern of correlations is quite different. First, size of boat correlates significantly with several dependent variables, most notably with "anxiety for contents", "anxiety for selves", "wear and tear", and "satisfaction". It is interesting to note the boat owners of the largest boats tend to be less satisfied than other boat owners. None of these showed up in the correlations of the other marinas. Perceptions of wave action as a problem in storms had a similar pattern, but correlations of the degree to which wave action during severe storms and common storms was perceived to be a problem with the perception of ordinary wave action were reduced to near zero and were not statistically significant. The perception of ordinary wave action rather than perception of severe storms and common storms correlated highly with the variables, "annoyance", "wear and tear", "anxiety for self", "anxiety for boats", "anxiety for contents", and "anxiety for guests". Clearly the different wave action problems (in this case the Seabus) gave rise to a different pattern of correlations. The pattern of intercorrelations among satisfaction and the perception of wave action as a problem during severe storms and common storms, annoyance, wear and tear, and anxiety for boat, contents, self and guests is quite different. In particular, the "anxiety for boats" does not correlate significantly with satisfaction and neither do the perceptions of wave action as a problem during severe storms, common storms or everyday use. The correlation of annoyance with satisfaction is barely statistically significant at the .05 level. The picture here is of satisfaction being much less related to wave action, and an additional factor, that of boat size, entering the picture.

The actual mean responses to the questions reinforced the above interpretation of the pattern of correlations. The perception of wave action problems during severe storms and common storms had values (1.44, 1.15) similar to those at the best of the six marinas, indicating no problem, while the average responses of 2.33 for ordinary wave action is higher than at any of the other marinas (the difference between the mean responses for Mosquito Creek and Beach Gardens was statistically significant, $t = 2.75$, $\underline{df} = 48$, $\underline{p} < .01$), and indicates perception of a problem of a magnitude of between mild and medium on our five-point scale. Boat owners at Mosquito Creek are more than somewhat annoyed by the wave action, but feel little anxiety for themselves or their boats. Again, motion sickness appears not to be a problem, nor does damage. Wear and tear is a mild to moderate problem (2.41) presumably because of Seabus wave action, while at the best of other marinas it is not a problem (a t-test on Thunderbird (1.15) as compared to Mosquito Creek, was statistically significant, $t = 5.82$, $\underline{df} = 71$, $\underline{p} < .001$). Overall, satisfaction is only moderate at Mosquito Creek (the mean equals 3.04). Again, it was significantly different from that at the best of the other marinas (Thunderbird (4.51); $t = 8.90$, $df = 71$, $p < .001$). The conclusion can be drawn that Mosquito Creek is similar to the more exposed marinas studied above but that the peculiar nature of the wave action problem, the Seabus wake, is reflected in a different pattern of correlations and mean responses to the questionnaire items.

4. Discussion and conclusions

4.1 Extrapolations from previous literature

In this section we briefly note some of the more obvious implications of the literature reviewed earlier for the perception of wave action as a problem in small craft harbors.

4.11 Individual differences

The discrepancy between perceptions of resource users and professional scientists and technical personnel is related to biases of technical training, particularly in use of probability models, and relevant personal experience. It would be anticipated that the lay public (boat owners) would have difficulty in generating accurate probability estimates of a hazard occurrence (severe wave action) as their perceptions would probably be biased by personal experience, damage potential and a lack of competence in using technical tools in dealing with complex phenomena.

The confidence of the public in technological advances also affects their perception of the safety of their environment. This has direct relevance to marinas, since the implementation of novel protective measures such as floating breakwaters, new docks, and the rearrangement of docks, could lead to an overconfidence and overrating of a marina's security. Also, since professionals tend to see more severe problems than lay people, it is possible that the professional personnel may see severe problems in an area such as wave action in marinas, amongst small craft owners themselves whereas it may be in actuality a minor concern. That this does happen in marinas is documented in section 3 above and discussed in section 4.2.

In general, it would appear that one's role viz-a-viz the environment is the major factor in determining one's evaluation of an environment. Even among users of the same resource, one might anticipate variation in perceptions such that, e.g. sail- vs. power-boaters may display differential sensitivity to wave action in small craft harbors. The attention paid by sailors to specific aspects of wave and wind action is likely to be reflected in heightened awareness of, or an altered level of tolerance to, wave action. It could also be anticipated that differences in resource use and its associated economic impact would alter perceptions, i.e., the attitudes of recreationalists as contrasted to commercial boaters might differ.

Alternative behavior patterns and heightened awareness of hazard potentials might also be expected after aversive personal experience (such as losing a boat), although its effects may be confounded by the individual's personality and community transference of knowledge.

4.12 Biases and Limitations

The tendency for individuals (both technical and lay) to overgeneralize from small samples, accounts for a general inability to accurately project future occurrences of a natural hazard. In the case of marina users, peoples' perception of wave action will, for the most part, be circumscribed by their past experiences. This tendency is documented in flood plain experience, "the major limitation of human ability to use improved flood hazard information is a basic reliance on experience". (Kates, 1962, p. 140).

More specifically, individuals find it difficult to deal with the uncertainty of random events. As a result they tend to construe them as cyclical or patterned. This strategy can be used to allay fears depending upon frequency of the event. Yet, "the more frequency experience of the individual with the extreme event, the more likely is the estimate of its reoccurrence to accord with statistical probabilities". (Burton, Kates, & White, 1978, p. 102). Thus occurrences that on the human time scale are relatively infrequent may be just the kind of situation where marina users are subject to subjective probability biases. Therefore, despite the relatively high awareness of past experience, marina users may be deluded in their perceptions of future events such as rarely occurring but severe storms. This is well illustrated by a survey in which 90% of the respondents experienced storms, but only 66% of them expected them in the future. In addition, only half of the respondents who had experienced damage, anticipated damage in the future (Burton, Kates, & Snead, 1969).

Another factor that might influence boat owners' estimates of the probability of wave action problems in the future is the use of the availability heuristic. If there have been few or no problems in the past, scenarios of such problems will not be highly available, and estimates of probability could be too low. The availability hypothesis would also suggest that in the case of low physical impact but high frequency events such as everyday wear and tear of wave action there will be a tendency to underestimate its occurrence, as it is not easily recalled or imagined.

It was mentioned in section 2.2 that variation in perceptions of natural hazards is greatest when they occur with moderate frequency. Thus, small craft owners in marinas with moderately hazardous conditions should provide the greatest range of attitudes towards the security of the marina, anxiety for the boat, annoyance at the degree of marine exposure, etc. In this instance it is important to realize that the attitudes held by the individual are not necessarily optimally useful. So far as the cognitive component of attitude is held to be useful, individuals will attempt to be consistent in behavior and affect. (Schiff, 1970). So to the extent that individuals keep their boats in marinas that are subject to damaging wave action, owners must justify their actions to themselves. This type of cognitive dissonance can be diminished by ignoring physical evidence of damage potential, justifying one's choice of moorage (Festinger, 1957). This type of accommodation of beliefs and values to behavior could be particularly prevalent where a boat owner has an added commitment to his moorage, as in the case of a private yacht club.

4.13 Cultural and technological changes

Currently the pressure to develop man-made small craft harbors has brought into focus the question of the perceived and actual presence of natural hazard conditions. The tendency to implement technological advances will ultimately lead to increasing damage potential. The protection provided by such structures as breakwaters in fact limits the damage caused by a common storm. This will gradually alter the boat owners' perceptions, evaluations and anticipations of wave action, perhaps even leading to a complacent over-reliance on technology for protection from wave action-caused damage to boats. However, this is often only a set-up for a major disaster, in which the technology fails in the face of an extreme natural condition (e.g., the breakwater is breached or sunk). For this reason, we shouldn't place too much reliance on the "technological fix", but rather should rely on natural features for such protection (e.g., sheltered harbors). This suggests, however, that when we do use technology to "conquer" nature (e.g., build a marina on an exposed coast), people will tend to under-estimate the damage potential in the face of a technological (breakwater, float, etc.) failure.

4.14 Motion Sickness

The constant movement on boats and floats in small craft harbors may cause motion sickness among some of the small craft users. However, it would be anticipated that this would be a minimal annoyance, as boaters (especially those with experience) would be a self-selected group in terms of recreational choice. It is unlikely that individuals with a high susceptibility to motion sickness would select this activity. Furthermore, exposure to a specific boat and marine environment should lead to adaptation and a concomitant decrease in motion sickness. Although it would be estimated that working within the confines of a boat subject to wave action would often lead to motion sickness, this situation may be offset somewhat by prolonged exposure to wave action associated with boat work, which may lead to adaptation and increase in seaworthiness. In general, recreational (as opposed to commercial) use of boats may also reduce the importance of motion sickness as a problem, as these marina users tend to avoid poorer weather with its high amplitude waves associated with sea sickness.

Nonetheless, some degree of motion sickness appears to be an inevitable feature of marine life. Given the assumptions of the neural-mismatch hypothesis, it seems likely that some motion sickness will occur with wave climate changes whatever the absolute value of the amplitude and frequency. This implies that a limited incidence of motion sickness could be anticipated within the marina. This should be minimal, however, since there is protection from high amplitude waves. The most likely place for motion sickness to occur in the marina would be in small boats with a wave response period of 2-4 sec. when waves with that period (about 15-30 cycles per minute) are present in the marina. The coincidence of boat period with wave period would lead to high amplitude motion of the boat, and thus its occupants, at just the frequency optimal in inducing motion sickness. From this point of view, waves with this period should be made of minimal amplitude within the marina.

4.2 Extrapolations and conclusions from the field study

The results of the field study discussed in section 3. above can be interpreted to indicate that differences in wave action across presently existing marinas affect boat owners' perceptions of wave action as a problem, induce differences in anxiety for self, boat, boat contents, and guests, affect perception of and experience of motion sickness, and cause differences in wear and tear and damage to the boats themselves. However, of all these variables, only wave action during storms, wave-action-caused anxiety for one's boat, and wear and tear on the boat were perceived to be significant problems, and then only in the most exposed of the marinas studied. Very little motion sickness was reported and it was not thought to be a serious problem. This is probably because boat owners tend to stay away from the marina during storms, when wave action in the marina might be intense enough to induce motion sickness. The everyday wave climate of all of the marinas examined (except Mosquito Creek with a boat-wash problem) was apparently quite good. Thus, although we would expect the marina situation to be ripe for reports of motion sickness, apparently boat owners' use habits are such as to minimize this potential problem.

Overall, satisfaction with existing marinas appeared to be quite good, despite the severe wave action experienced at some during storms. The differences in wave action did cause differences in overall satisfaction, and about 25% of the variance in satisfaction judgments across all marinas could be accounted for by wave-action problems. However, in no case was the average satisfaction rating less than "moderate". On the other hand, this may be somewhat deceptive, since it appeared that across the six marinas, the more severe wave action problems were often associated with an increased level of patrol and security services (in terms of man-hours spent), as well as better facilities and better maintainance of equipment. These apparently went some way toward compensating the boat owners for the poorer wave climate and increased risk of damage to their boats.

There are a number of factors that would tend to influence the interpretation of the questionnaire data. Among these the most important are the following: 1) we did not assess the amount of damage insurance held by our respondents, and informal comments revealed that individuals with a lot of insurance tended to feel considerably less anxious about wave action problems; 2) sometimes we found individuals reporting low anxiety who had apparently reduced their anxiety by taking elaborate precautions to moor their boat securely; 3) we could not ascertain to what extent people who experienced boat damage had moved their boats and were thus inaccessible to our interviewing procedure; 4) experienced damage was obviously lessened by the heroic efforts of some marina staff to retie boats, etc. during storms.

Even with the above qualifications in mind, however, we do find a remarkable convergence between the data collected in our field study and the impressions garnered from the existing literature on hazard perception. Perhaps the most striking example of this is the contrast between the views of the marina managers (and more experienced boat owners, e.g. commodores of clubs) and the average boat owners. In nearly every case, the managers and more experienced boat owners found problems due to wave action to be more severe in their marinas than did other boat owners (see section 3.21). This is quite in line with our expectations from the literature that more technically competent and experienced individuals, as well as those in a decision-making or management position, would tend to underrate the quality of a resource (e.g., a marina) and perceive more severe hazards and higher damage potential than would less technically competent, less experienced individuals in a resource-user position. Neither point of view is necessarily more valid than the other. Rather both should be taken into consideration when evaluating possible changes in a hazard-prone environment.

In conclusion, then, we find that the study of psychological aspects of wave climate in small craft harbors is justified by our finding that people are indeed quite sensitive to differences in wave climate across marinas. Although motion sickness does not seem to be a factor important to consider in setting optimum standards for wave climate in marinas, only our study enabled us to find this out. Also, our study implies that a major focus of a set of standards should be people's perceptions of 1) how secure the harbor is during storms, and 2) the amount of everyday and storm-related wear and tear caused by wave action. These probably should be important factors mostly in very exposed locations, however, for we did find (informally, see Table 5) that although boat owners in exposed marinas focused on wave-action-related physical characteristics of the marina, the focus tended to shift to services and maintainence in the better protected marinas. Finally, the relative lack of major psychological problems associated with wave climate in existing small craft harbors indicates that physical factors may be allowed to be the dominant influence in the determination of optimum standards without the expectation that this will lead to major unforseen psychological consequences.

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Table 1

Questionnaire data: Means, standard deviations and numbers responding

Variable (Questions)		MARINA: Fishermans Wharf Means	Fishermans Wharf Standard Deviations	Fishermans Wharf Numbers Responding	West Vancouver Yacht Club Means	West Vancouver Yacht Club Standard Deviations	West Vancouver Yacht Club Numbers Responding	Thunderbird Means	Thunderbird Standard Deviations	Thunderbird Numbers Responding	Eagle Harbour Means	Eagle Harbour Standard Deviations	Eagle Harbour Numbers Responding
*(4)	Boat size (ft)**	22.93	4.48	15	32.45	10.36	20	26.21	5.51	48	27.42	4.08	24
(5)	Marina time (yrs)	1.27	0.59	15	8.90	6.80	20	7.19	5.92	48	5.83	4.51	24
(6)	Owner time (yrs)	8.27	10.48	15	19.75	10.83	20	18.96	14.02	48	10.08	6.85	24
(7)	Time on boat (days)	826	1002	14	1227	772	19	1672	1987	48	1477	1970	24
(8.1)	Serious storms (1-5)	2.70	0.82	10	1.35	1.09	20	1.04	0.21	45	4.26	0.92	23
(8.2)	Common storms (1-5)	1.60	0.62	15	0.95	0.39	20	1.00	0.00	46	2.46	0.83	24
(8.3)	Ordinary use (1-5)	1.00	0.00	15	0.95	0.39	20	1.00	0.00	46	1.12	0.34	24
(9)	Annoyance (1-5)	1.40	0.63	15	1.05	0.22	20	1.11	0.48	46	1.75	0.79	24
(10.1)	Anxiety-self (1-5)	1.20	0.41	15	0.95	0.22	20	1.02	0.15	46	1.00	0.00	24
(10.2)	Anxiety-boat (1-5)	1.60	0.63	15	1.20	0.70	20	1.00	0.00	46	2.4	0.92	24
(10.3)	Anxiety-contents (1-5)	1.00	0.00	15	1.10	0.45	20	1.00	0.00	46	1.12	0.45	24
(10.4)	Anxiety-guests (1-5)	1.13	0.52	15	1.10	0.45	20	1.00	0.00	46	1.00	0.00	24
(11)	Motion sickness (times)	0.00	0.00	15	0.00	0.00	20	0.00	0.00	48	1.08	2.14	24
(12)	Sickness Problem (1-5)	1.00	0.39	14	1.05	0.39	20	1.00	0.00	45	1.24	0.62	21
(13)	Wear and tear (1-5)	1.80	0.77	15	1.20	0.52	20	1.15	0.36	46	2.25	0.90	24
(14.1)	Damage-no claim (times)	0.07	0.26	15	0.10	0.31	20	0.02	0.15	46	0.92	1.82	24
(14.2)	Damage-claim (times)	0.00	0.00	15	0.00	0.00	20	0.00	0.00	46	0.21	0.51	24
(15)	Satisfaction (1-5)	3.20	0.77	15	4.40	0.50	20	4.50	0.59	46	3.75	0.74	24

* The number of the relevant question on the questionnaire (Appendix A) is indicated in parentheses.

**The units in which variable was measured are given in parentheses.

Table 1 - (Continued)

Variable (Questions)		MARINA Schooner Cove Means	Standard Deviations	Numbers Responding	Beach Garden Means	Standard Deviations	Numbers Responding	Mosquito Creek Means	Standard Deviations	Numbers Responding
*(4)	Boat size (ft)**	25.48	6.40	46	25.35	7.82	23	28.41	1.32	27
(5)	Marina time (yrs)	4.46	6.09	46	2.22	0.90	23	3.41	0.57	27
(6)	Owner time (yrs)	15.52	14.47	46	15.57	11.92	23	10.41	1.63	27
(7)	Time on boat (days)	1229	1966	42	1430	1180	20	1128	270	22
(8.1)	Serious storms (1-5)	4.09	0.86	44	4.35	0.83	23	1.44	0.14	25
(8.2)	Common storms (1-5)	2.96	0.99	46	3.35	0.98	23	1.15	0.09	27
(8.3)	Ordinary use (1-5)	1.20	0.50	46	1.52	0.90	23	2.33	0.22	27
(9)	Annoyance (1-5)	2.28	1.20	46	3.17	1.15	23	2.37	0.26	27
(10.1)	Anxiety-self (1-5)	1.33	0.82	46	2.30	1.29	23	1.15	0.12	27
(10.2)	Anxiety-boat (1-5)	2.61	1.26	46	3.44	1.20	23	1.74	0.17	27
(10.3)	Anxiety-contents (1-5)	1.44	1.05	46	2.26	1.14	23	1.26	0.11	27
(10.4)	Anxiety-guests (1-5)	1.61	0.95	46	1.52	0.79	23	1.30	0.14	27
(11)	Motion sickness (times)	0.72	2.38	46	0.35	0.93	23	0.41	0.30	27
(12)	Sickness Problem (1-5)	1.43	0.62	44	1.43	0.81	21	1.33	0.12	27
(13)	Wear and tear (1-5)	2.54	1.03	46	2.70	1.18	23	2.41	0.23	27
(14.1)	Damage-no claim (times)	0.50	1.11	46	0.28	0.72	21	0.30	0.15	27
(14.2)	Damage-claim (times)	0.06	0.25	46	0.00	0.00	23	0.00	0.00	27
(15)	Satisfaction (1-5)	3.61	0.65	46	3.39	1.27	23	3.04	0.16	27

* The number of the relevant question on the questionnaire (Appendix A) is indicated in parentheses.

**The units in which variable was measured are given in parentheses.

Table 6

Questionnaire data: Correlations - Mosquito Creek*

		4	5	6	8.1	8.2	8.3	9	10.1	10.2	10.3	10.4	11	12	13	14.1	14.2	15
**(4)	Boat size	1.00																
(5)	Marina time	0.02	1.00															
(6)	Owner time	0.19	0.06	1.00														
(8.1)	Serious storms	0.38	0.15	0.30	1.00													
(8.2)	Common storms	0.28	0.14	0.12	0.77	1.00												
(8.3)	Ordinary waves	0.17	-0.10	-0.19	0.06	0.12	1.00											
(9)	Annoyance	0.41	-0.13	-0.09	0.20	0.16	0.83	1.00										
(10.1)	Anxiety-self	0.49	0.04	0.05	0.21	-0.08	0.32	0.45	1.00									
(10.2)	Anxiety-boat	0.11	0.14	-0.19	0.14	0.10	0.46	0.42	0.50	1.00								
(10.3)	Anxiety-contents	0.73	-0.10	-0.07	0.28	0.14	0.43	0.59	0.75	0.42	1.00							
(10.4)	Anxiety-guests	0.47	-0.04	-0.26	0.04	-0.14	0.43	0.47	0.43	0.30	0.62	1.00						
(11)	Motion sickness	0.07	-0.14	-0.15	-0.10	0.02	0.35	0.46	-0.07	0.05	0.25	0.16	1.00					
(12)	Sickness problem	0.27	-0.21	-0.38	0.28	0.36	0.38	0.35	0.07	0.30	0.49	0.54	0.25	1.00				
(13)	Wear and tear	0.43	-0.09	-0.27	0.18	0.23	0.62	0.67	0.49	0.69	0.65	0.47	0.13	0.58	1.00			
(14.1)	Damage-no claim	0.12	0.00	-0.17	-0.04	-0.13	0.45	0.40	0.40	0.44	0.33	0.52	0.40	0.19	0.40	1.00		
(14.2)	Damage-claim	0.00	0.00	0.00	0.-0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
(15)	Satisfaction	-0.45	0.16	0.02	-0.35	-0.22	-0.26	-0.40	-0.09	-0.04	-0.34	-0.22	-0.10	-0.18	-0.29	-0.02	0.00	1.00

* Correlation values .50 are statistically significant at the α = .01 level;
values .39 are significant at the α = .05 level.

**The numbers of the relevant question on the questionnaire is indicated in parentheses.

Table 5

Responses to Open-Ended Questions

Questions		Fishermans Wharf	West Vancouver Yacht Club	Thunder-bird	Eagle Harbour Yacht Club	Schooner Cove	Beach Garden	Mosquito Creek
16. Why did you choose this marina?	Proximity to boating & fishing area	(3)	(2)	(20)	(4)	(10)	(6)	(3)
	Proximity to home	(4)	(10)	(20)	(3)	(19)	(6)	(16)
	Moorage available	(5)		(7)	(8)	(9)	(6)	(13)
	Boat bought on premises	(5)						
	Club and/or privately owned		(7)		(4)	(4)		
	Facilities & maintenance			(12)		(6)	(3)	
	Protection from exposure			(7)		(2)		
	Proximity to work			(4)				(2)
	Security			(2)		(2)	(3)	
	Social Environment			(2)	(3)			
	Private moorage spot					(2)		
	Moorage rates						(3)	
18. What is the best aspect of the marina?	Proximity to boating area	(11)	(14)	(25)	(12)	(20)		(5)
	Proximity to home	(2)	(2)				(4)	(7)
	Sheltered location		(10)	(18)				
	Maintainence & facilities			(8)		(11)	(13)	(9)
	Protection from vandalism/security			(3)		(6)		
	Everything			(3)				
	Small size				(4)			
	Yacht Club				(7)			
	Wharf manager/management					(17)	(5)	
	Nothing					(2)	(2)	
	Reasonable rates						(4)	(2)
	Social environment							(5)

*Only responses with n $\geq$ 2 are tabled. So $\sum_{i=1}^{n} P_i \neq 1$.

Table 5 - (Continued)

Questions		Fishermans Wharf	West Vancouver Yacht Club	Thunder-bird	Eagle Harbour Yacht Club	Schooner Cove	Beach Garden	Mosquito Creek
19. What is the worst aspect of this marina?	Moorage rates	(2)		(17)		(4)		
	Lack of security	(5)		(4)				
	Narrow channels & slips	(3)	(5)					
	Lack of maintenance & facilities	(3)				(5)		(10)
	Marina too small and/or crowded		(5)	(4)				
	Nothing		(8)	(16)	(5)			(4)
	Winter ice			(2)				
	Exposure of marina e.g. swells				(10)	(18)		
	Breakwater				(3)	(6)	(14)	
	Parking					(6)	(6)	
	Physical layout of the marina							
	Dirtiness						(2)	
	Movement due to sea bus							(4)
	Floating driftwood		(2)					(6)
20. What physical aspect would you most like to change about this marina?	Deepen and/or widen channels & berths	(5)	(10)	(8)				
	Increase security	(3)		(2)				(2)
	Fix and/or widen floats	(3)	(4)			(2)	(5)	(6)
	Additional services and/or maintenance	(6)		(3)		(4)		(12)
	Nothing	(2)	(6)	(22)	(3)	(2)	(4)	(4)
	Decrease moorage rates			(4)				
	Increase boat lifting capacity			(2)				
	Increase covered moorage			(2)				
	Add restuarant facilities			(9)		(2)		
	Breakwater				(13)	(32)	(21)	(5)
	Increase parking					(9)		
	Change physical layout (e.g. entrance)						(13)	
	Add water and waste facilities						(3)	(2)

Table 2

Questionnaire data: Correlation coefficients - Six Marinas*

		4	5	6	8.1	8.2	8.3	9	10.1	10.2	10.3	10.4	11	12	13	14.1	14.2	15
**(4)	Boat size	1.00																
(5)	Marina time	0.32	1.00															
(6)	Owner time	0.17	0.39	1.00														
(8.1)	Serious storms	-0.02	-0.15	-0.13	1.00													
(8.2)	Common storms	0.03	-0.22	-0.07	0.84	1.00												
(8.3)	Ordinary waves	0.14	-0.04	-0.01	0.34	0.52	1.00											
(9)	Annoyance	0.04	-0.10	-0.00	0.62	0.70	0.48	1.00										
(10.1)	Anxiety-self	0.01	-0.17	-0.07	0.33	0.52	0.51	0.54	1.00									
(10.2)	Anxiety-boat	0.06	-0.11	-0.05	0.72	0.78	0.47	0.79	0.54	1.00								
(10.3)	Anxiety-contents	0.05	-0.01	-0.05	0.31	0.43	0.44	0.56	0.69	0.58	1.00							
(10.4)	Anxiety-guests	0.04	-0.10	-0.05	0.32	0.42	0.39	0.46	0.56	0.47	0.61	1.00						
(11)	Motion sickness	-0.02	-0.04	-0.13	0.20	0.13	0.03	0.14	0.00	0.15	0.05	0.05	1.00					
(12)	Sickness problem	0.02	-0.06	-0.01	0.31	0.32	0.13	0.32	0.21	0.45	0.27	0.27	0.37	1.00				
(13)	Wear and tear	0.11	-0.10	-0.02	0.66	0.68	0.38	0.70	0.38	0.76	0.37	0.35	0.13	0.34	1.00			
(14.1)	Damage-no claim	0.03	0.03	0.08	0.31	0.31	0.10	0.23	0.00	0.27	0.00	0.06	0.00	0.12	0.35	1.00		
(14.2)	Damage-claim	0.02	0.07	-0.09	0.19	0.23	0.10	0.15	0.09	0.24	0.05	0.11	0.19	0.20	0.18	0.14	1.00	
(15)	Satisfaction	-0.08	0.21	0.02	-0.48	-0.45	-0.24	-0.39	-0.20	-0.44	-0.04	-0.10	-0.11	-0.21	-0.45	-0.23	-0.09	1.00

* Correlation values .19 are statistically significant at the α = .01 level;
values .15 are significant at the α = .05 level.

**The number of the relevant question on the questionnaire is indicated in parentheses.

Table 3

Results of Analysis of Covariance

Dependent Variable	F Value	F Probability*
Serious storms	128.55	.00000
Common storms	59.43	.00000
Ordinary use	5.88	.00029
Annoyance	24.66	.00000
Anxiety-self	13.93	.00000
Anxiety-boat	33.16	.00000
Anxiety-contents	12.74	.00001
Anxiety-guests	6.73	.00021
Sickness problem	4.57	.00065
Wear and tear	23.16	.00000
Damage-no claim	4.18	.00172
Damage-claim	2.97	.01366
Satisfaction	13.82	.00000

*These are the probabilities of obtaining an F of the observed value or larger with 5 and 158 degrees of freedom.

Table 4

Results of Newman-Keuls Tests*

Dependent Variable	Homogenous Groups**
Serious storms	(3,2) (1) (5,4,6)
Common storms	(2,3) (1) (4) (5) (6)
Ordinary use	(2,3,1,4) (3,1,4,5) (6)
Annoyance	(2,3,1) (1,4) (5) (6)
Anxiety-self	(2,4,3,1,5) (6)
Anxiety-boat	(3,2) (1,4) (4,5) (6)
Anxiety-contents	(3,2,4,1) (2,4,1,5) (6)
Anxiety-guests	(4,3,2,1) (1,6) (6,5)
Sickness Problem	(3,1,2,4) (1,2,4,6,5)
Wear and tear	(2,3) (1,4) (4,5,6)
Damage-no claim	(3,2,1,6,5) (1,6,5,4)
Damage-claim	(2,3,1,6,5) (1,6,5,4)
Satisfaction	(1,6,5,4) (3,2)

* These test each pair of means to see if they are different at the α =.05 significant level. Means of conditions (marinas) that are not different appear in parentheses together. Order of groups and order of marinas within a group reflects rank order of the mean values.

**1 = Fisherman's Wharf; 2 = West Van. Yacht Club; 3 = T-Bird; 4 = Eagle Harbour; 5 = Schooner Cove; 6 = Beach Garden.

Marina Project Questionnaire

1. Boat Location

   1. Fiserhman's Wharf
   2. West Van
   3. T-Bird
   4. Eagle
   5. Schooner
   6. Beach

   Pick No.

   Slip No.

2. Type of Boat (1) Sail (2) Motor

3. Type of Chine (1) Hard (2) Soft

4. Size of Boat

5. How long have you had a boat moored in this marine? (Yrs.)

6. How long have you been a boat owner? (Yrs.)

7. How many days of your life have you spent boating?

8. To what extent is wave action in this marine a problem?

   8.1 In very serious storms (1 in 5 yrs))
) no use
   8.2 In common storms (5-20/yr))

   8.3 Everyday use

   1 = no problem 2 = mild problem 3 = medium problem
   4 = severe problem 5 = very severe problem

9. To what extent are you annoyed by the wave action in this marina?

   1 = not at all 2 = somewhat 3 = moderately
   4 = very 5 = extremely

   9.1 In what ways? ______________________________

10. To what extent does the wave action in this marina make you anxious?

    10.1 for yourself

    10.2 for your boat

    10.3 for the contents of your boat

    10.4 for your guests/passengers

    1 = not at all 2 = somewhat 3 = moderately
    4 = very 5 = extremely

11. Have you ever been motion sick (exp. nausea) in this marina (before taking boat out)? If so, how many times did this occur since you've been here? ☐☐

12. How much of a problem is motion sickness in general in this marina?

    1 = none 2 = mild 3 = moderate 4 = severe 5 = very severe ☐

13. To what extent is ("normal") wear and tear on your boat, mooring lines, fenders, etc. caused by wave action in this marina a problem?

    1 = none 2 = mild 3 = moderate 4 = severe 5 = very severe ☐

14. Has your boat ever been damaged (not wear and tear) as a result of wave action in this marina? If so, how many times since you've been here?

    14.1 No Insurance Claim ☐

    14.2 Insurance Claim ☐

15. Overall, how satisfied would you say you are with this marina?

    1 = not at all 2 = somewhat 3 = moderately
    4 = very 5 = extremely ☐

16. Why did you choose this marina?

17. Did you move to this marina from another? If so, why & which?

18. What's the best aspect of this marina?

19. What's the worst aspect of this marina?

20. What physical aspect would you most like to change about this marina?