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Interim Report
HYDRAULIC MODEL OF ALBERNI HARBOUR

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JOINT COMMITTEE ON OCEANOGRAPHY

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Pacific Oceanographic Group,
Nanaimo, B.C.
December 1, 1950.

PACIFIC OCEANOGRAPHIC GROUP
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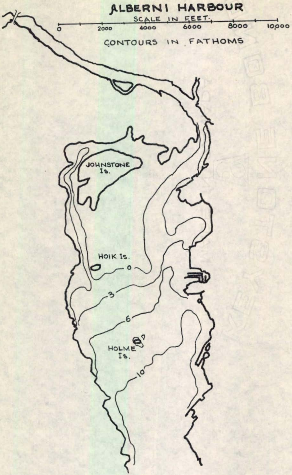
ALBERNI HARBOUR
SCALE IN FEET.
0
2000
4000
6000
8000
10,000
CONTOURS IN FATHOMS
JOHNSTONE Is.
HOIK Is.
0
3
6
HOLME Is.
10

Figure 1

PACIFIC OCEANOGRAPHIC GROUP

Interim Report

HYDRAULIC MODEL OF ALBERNI HARBOUR

(File N 7-22 December 1, 1950)

A distorted scale,hydraulic model of Alberni Harbour is being constructed to study dynamics of the mixing of fresh and salt water in the inlet, disposal of pulp mill sewage, and the effects of proposed physical changes in the harbour. This work has many fundamental aspects involving the construction and use of hydraulic models in oceanographic research, and the study of Alberni Inlet,which is typical of many British Columbia fiords.

The first phase of the research requires the construction of a suitable model which will reproduce the known oceanographic conditions, which were studied by Tully (3). This will be followed by study of the effect of some physical changes which are proposed to facilitate industrial development of the area. Further work is proposed on the fundamentals of estuary behaviour.

In the earlier studies Tully used a small model which has since been destroyed. Although it inspired the present work, its construction and small scale did not allow for the precision or detail envisaged in the present work.

This is the first model to be built in the new Ocean Model Laboratory at the Pacific Biological Station. The work is under the direction of Dr. J.P. Tully, Oceanographer in Charge. The cost of the undertaking is being shared by Messrs. Bloedel, Stewart and Welch, Ltd., and by the Pacific Oceanographic Group, and is being undertaken by the author in partial fulfillment of the requirements for a master of science degree in mechanical engineering at the University of British Columbia.

Facilities

The laboratory is of temporary frame construction, 20 feet by 40 feet; an office and washroom occupy a space of 8 feet by 20 feet. The laboratory floor is gravel; concrete piles, which extend to hardpan, are used to support the model.

The water supply is

	Maximum Supply	Maximum Head
Fresh Water	0.03 c.f.s.	43 feet
Salt Water	0.11 c.f.s.	31 feet

Fresh water is supplied from the Biological Station water system, which is maintained by surface drainage. During the months of July to October inclusive, no fresh water is available to the laboratory owing to low rainfall in the area. Salt water is supplied from Departure Bay by a manually controlled electric pump to a standpipe of 1685 cubic feet capacity located beside the laboratory.

Work shop facilities are limited to hand tools in the laboratory, and a bench saw, and plumber's tools located in a work shop some 200 yards from the laboratory. The machine work required for the model is being done in the shops of the University of British Columbia.

Outline of Construction

This model presents an essentially new problem because no literature on the control mechanism of stratified flow models is available.

Tully showed that the distribution of salinity in Alberni Harbour was consequent on the properties of the sea water and fresh water entering the region and their respective dynamics. He concluded that if the boundary conditions were fulfilled, and the distribution of salinity in the model agreed with that in nature, dynamic similarity was accomplished.

The contours of the model provide the physical boundaries. The river discharge is reproduced to scale by manual adjustment of an accurately calibrated weir. The tidal phenomena is simulated by introducing sea water during the rising tide and removing mixed sea and river (fresh) water during the falling tide. A control mechanism adjusts the rate of exchange so that the tidal height follows a predicted cycle,regardless of the change of area in the model with tidal height or the rate of river discharge.

The tidal control originates in a modified form of the Kelvin tide computer, in which the four major components are produced. This provides the essential features of the tide including the semi-diurnal tides of different height, the bi-weekly cycle of spring and neaps, and the annual sequence,within small limits. This computer is much more accurate than that used on hydraulic models to date. A slightly more accurate method is available in the electronic chart follower,* which is beyond the resources of this research.

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* An electronic chart follower, designed by National Research Council, is in use on the Fraser River model currently under construction at the University of British Columbia.

Model Scale

The scale of hydraulic models and the relation of the quantities to their counterpart in nature is based on Reynolds (1885) (1) analysis of the Froude model law,

$$\frac{V^2}{2gh} = K$$

where V^2 is the mean horizontal velocity, K is a constant for similar systems, g is the acceleration of gravity, and h is the hydraulic head. In terms of the model (m) and prototype (p) this becomes

$$V^2{}_m = 2Kg\,h_m$$

$$V^2{}_p = 2Kg\,h_p$$

and the ratio (b)

$$b^2 v = \frac{V^2{}_m}{V^2{}_p} = \frac{h_m}{h_p} = b_z$$

where z signifies the vertical dimension. The velocity (V) may be analysed dimensionally as the ratio of horizontal length (x) to time (t) so that

$$b^2 v = \frac{b_x^2}{b_t^2} = b_z$$

A horizontal scale

$$b_x = 1{:}1000$$

was chosen to suit the laboratory space and water supply. The vertical scale

$$b_z = 1{:}84$$

was chosen on the basis of current model practice and the rule advanced by Lacy (2) which stipulates that the ratio of horizontal to vertical scale should be

$$b_z = b_x^{2/3}$$

however this does not consider the effects of surface tension so the larger scale was adopted in consideration of this factor.

Having fixed the horizontal and vertical scales, the time and other scales follow from similar analyses of the law, e.g.

Time $b_t = 1:109.1$

Velocity $b_V = \frac{b_x}{b_t} = 1:9.165$

Volume $b_v = b_z b_x^2 = 1:84 \times 10^6$

Model Bed Construction

The model bed is set on eight concrete piers in the laboratory floor. Ten inch square beams rest on the piers and support two by eight inch longerons which form the model base. This heavy construction was employed to insure minimum deflection of the model when filled with water. The dimensions of the model are 23 feet long, 7 1/2 feet wide and 2 1/2 feet deep.

The method of construction of the model basin is shown in Figure 2.

In order to ascertain the effects of proposed physical changes in the harbour, it was decided to mould the model areas where erosion or silting is expected, in a material which behaves in the model similar to that of a harbour bed in nature. This is likely to be more satisfactory than computing erosion from bottom velocity measurements in a fixed-bed model.

In order to accomodate these studies in the tide flats area, this region was left at a scaled depth of seven fathoms when the concrete was poured. The tide flats were later built up with sharp sand to fit hanging profiles. A spray of portland cement and water was used to "fix" the area for testing of control gear. This crust will be removed and adjustments made before the final tests are begun.

A co-ordinate system was used to place the nails shown in Figure 2, consisting of machined rails fixed to either side of the model box and a cross rail complete with vertical measuring rod. The assembly is accurately made and set so that measurements in the

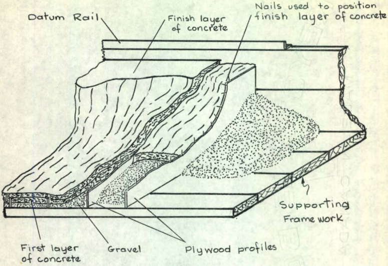


Figure 2

horizontal direction can be made to within 1/16 inch on the model, or five feet in the prototype; vertical measurements can be made to within 1/32 inch on the model or three inches in the prototype. These are equal to the accuracy of the available charts of the area and are considered adequate.

Tide Computer

At Port Alberni the four major tidal components are M_2 due to the moon, S_2 due to the sun, and K, and O, due to the moon's declination. In these terms the tide height at any instant (t, is given by

$$H = Z_o + M_2 \cos(\omega_{M_2} t + \alpha_{M_2}) + S_2 \cos(\omega_{S_2} t + \alpha_{S_2}) + K_1 \cos(\omega_{K_1} t + \alpha_{K_1}) + O_1 \cos(\omega_{O_1} t + \alpha_{O_1})$$

The results of the tide computer are shown graphically in Figure 3 where the sequence for a spring tide (i.e. maximum range) is shown. When the S_2 and M_2 components are in opposition to each other, neap

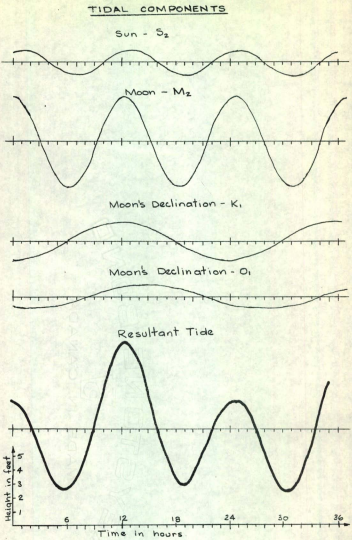
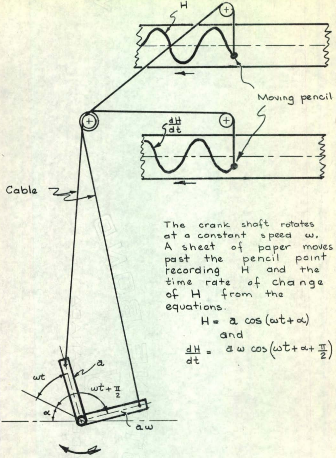

TIDAL COMPONENTS
Sun - S_2
Moon - M_2
Moon's Declination - K_1
Moon's Declination - O_1
Resultant Tide
Height in feet
1
2
3
4
5
6
12
18
24
30
36
Time in hours

Figure 8



The crank shaft rotates at a constant speed ω. A sheet of paper moves past the pencil point recording H and the time rate of change of H from the equations.

$$H = a \cos(\omega t + \alpha)$$

and

$$\frac{dH}{dt} = a\omega \cos\left(\omega t + \alpha + \frac{\pi}{2}\right)$$

Figure 4

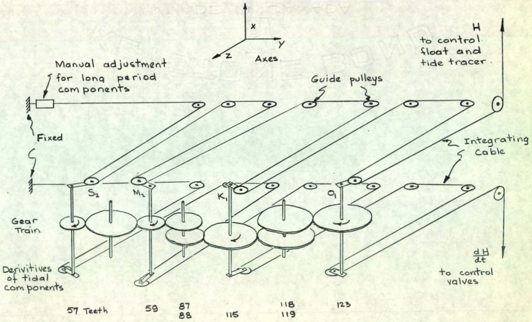

x
y
z
Axes
H
to control float and tide tracer.
Manual adjustment for long period components
Guide pulleys
Fixed
Integrating Cable
S_2
M_2
K_1
O_1
Gear Train
Derivitives of tidal components
$\frac{dH}{dt}$
to control valves
57 Teeth
59
87
88
115
118
119
123

Figure 5

tides (minimum range) result. The diurnal variation (differences in the height of two succeeding high waters) is caused by the two declination terms and is a maximum when their effect is additive. It can be shown that the tidal cycle will never repeat itself, "near repetition" however, occurs frequently, the most obvious case being the monthly repetition of spring and neap tides.

The method of producing and integrating this series is shown in Figure 4 for a simple (one component) system, and in Figure 5 for the compound system being used, where the components are summed on a single cable. Two cranks are fitted 90° apart, on each shaft; one provides the component of tidal height (H) which controls the sea level in the model; the other provides the derivative dh/dt which regulates the flow control valves and determines the rate of flow of tidal water into, and out of the model.

By using cables to sum the tidal components, a maximum error 0.6% is introduced, which is considered negligible. Spur gears are employed to produce the angular velocity ratio between the component cranks. Owing to the expense of precisely reproducing angular velocities, maximum allowable error of 0.0033% was selected arbitrarily and the gearing designed within this limit. This machine will reproduce the tide correctly within less than 5% of maximum range in general, but with a maximum error of 14% occuring once in 18.61 years. The long period tidal components can be set on the computer manually and this will reduce the above figures somewhat.

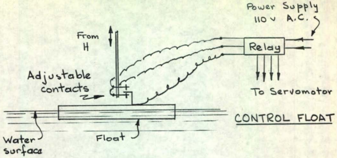
The tide computer may be easily adjusted. The angular position of the components is calculated for the prototype time at which the experiment is to begin, the S_2 component is locked in a known position, and the remaining cranks adjusted to their proper relative positions, and locked to their driving shafts. Power is supplied by a one-quarter horse power induction motor.

Tidal Flow Control

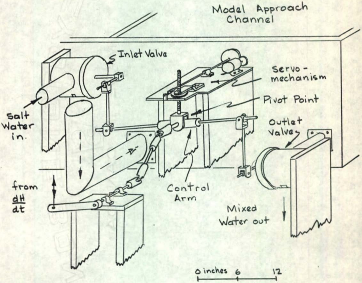
In this model the tidal height is controlled directly as it is in nature and the rate of inflow or outflow is adjusted to produce the required tidal phenomena. This differs from the usual procedure of approximating the rise by controlling the volume of water exchanged, and is necessary because of the complexities of the relations between tidal height, area, and contributions from the river. This is accomplished by a dual mechanism; the amount of water required for tidal rise in the model, assuming it had vertical sides, is added or withdrawn, and automatically corrected to compensate for the changing surface area and river flow.

In the first approximation water is added to the model in proportion to the rate of rise of the tide. This may be evaluated at any instant (t) in a simple system from the general equation of tidal height (h).

$$H = a \cos(\omega t + \alpha)$$



CONTROL FLOAT



CONTROL VALVES

Figure 6

and the rate of rise is

$$\begin{aligned}\frac{dH}{dt} &= a\omega \sin(\omega t + \alpha) \\ &= a\omega \cos\left(\omega t + \alpha + \frac{\pi}{2}\right) \\ &= \frac{Q}{A}\end{aligned}$$

where Q is the rate of water input into a model of area A, and may be evaluated as

$$Q = A a \omega \cos\left(\omega t + \alpha + \frac{\pi}{2}\right)$$

Then if a valve is controlled by the derivative of the tidal height, or simply by an angular argument $\frac{\pi}{2}$ radians (90°) in advance of the tidal height (H) the correct rate of input to a model of rectangular cross section may be accomplished. A schematic arrangement for a one component system is shown in Figure 4.

In principle two sleeve valves, one inflow and the other outflow, are attached to opposite ends of a lever, and operated alternately by rocking the lever about a central fulcrum (figure 6). The correction to the inflow or outflow is accomplished by shifting the fulcrum of the lever in the desired direction, as required by the tidal control float (Figure 6). Two suspended electrical contacts are controlled by the tide computer, and contain a contact from the float between them. If the tidal height in the model lags behind the predicted height during the rise, the float contact and the lower suspended contact complete a circuit which causes a servo-mechanism to shift the fulcrum of the flow control lever so as to open the inflow valve wider, causing an increased rate of rise. Similar corrective actions occur if the rise is too fast, and during the ebb.

Tidal Valves

Brass sleeve valves had to be specially constructed since no suitable type is available commercially. The orifice principle is employed in order that the discharge be reasonably constant for a given opening. Assuming that the valve discharges into air rather than below the surface of water in a reservoir, the discharge Q may be calculated from

$$Q = A' C_d \sqrt{gh}$$

where A' is the area of valve opening in square feet, C_d the discharge coefficient, very nearly 0.62 for circular or rectangular orifices, g is the acceleration due to gravity, and h is the head in feet of fluid. This type of valve varies the discharge by varying the area A' of the orifice. By proper design of approach piping to the valves, the changes in head measured at the valve can be minimized. The valves can be arranged to discharge into air, as required.

A sleeve valve requires very little torque to operate properly and for this reason the tide computer and error control mechanism can be small.

The angular position of the control lever depends only on the rate of change of tidal height (i.e. first derivative) and corrections to the valve opening are added by the servo-mechanism which raises or lowers the fulcrum. Since the inlet valve must be lowered to admit water to the model, the fulcrum will be moved slightly downward during a rising tide in order to compensate for increasing surface area of the model. As the derivative approaches zero, the fulcrum returns to its neutral position. When the outlet valve begins operating, the servo-mechanism will again move the pivot point downward to reverse the effect of changing area, and finally the pivot will return to its neutral position when the outflow is zero.

In order that the machine corrects the errors in tidal height when the derivative is zero, the lever arm of the outlet valve is made shorter than that of the inlet valve. A movement of the fulcrum will then vary both input and output, but the effect on the outlet valve will be greatest. The valves are set so that a slight inflow and outflow occurs at the neutral position of the pivot point.

There is an apparent discrepancy in the operation of the servo-mechanism which occurs when the tide level in the model is less than that required by the tide computer. The fulcrum must move downward to admit more water during a rising tide, and upward to reduce the outflow during a falling tide. This difficulty is circumvented by a switch connected to the derivative cable in such a manner as to reverse the field current in the servo-motor when the derivative is negative.

The control valve mechanism could have been made much more simply for this model, but the present design was chosen to allow the assembly to be used for other models that may be built in the laboratory. One of these is a theoretical study of a non-tidal situation in which a fresh water stream discharged into a salt ocean of theoretically infinite extent. In order to accommodate this research the mechanism must be such that an increased river flow is accompanied by an increased input of salt water to compensate for increased turbulent mixing. At the same time a total increase in model outflow is required to maintain a constant head in the model. This will be accomplished as described for the case in which the first derivative of the tidal height is zero.

Tidal Control Float and Servo-mechanism

The control float, shown schematically in figure 6, is a large metal box having a natural period of vibration of about one-thirtieth of one second in water. The natural period of the model basin is about 4.6 seconds. Vibrations of the water surface at the natural frequency of the control float could cause the servo-mechanism to lose control of the model, therefore it is important that the period of the control float or its harmonics should not correspond to the period of the model.

The control float compares the actual height of tide in the model with that given by the tide computer and sends a correcting signal through the relay to the servo-motor. By adjusting the float contacts shown in Figure 6, the motor can be made to hunt continuously, thus continously varying the tidal height about the correct value, or the contacts can be adjusted to give no signal when the tide is within a small distance of the correct height. It is expected the latter adjustment will prove more satisfactory since the amount of correction required can be made small by proper adjustment of the control valve linkage.

The servo-motor is one-fiftieth horse power series motor. This drives the pivot point up and down by a worm and worm gear, the latter is threaded at its hub and engages a threaded screw attached to the pivot point.

River Flow

River flow is to be manually controlled in the model, using a 30° Vee notch weir discharging into a basin and overflowing into the Somass River channel. Records of daily observations of the discharge of the Sproat and Stamp Rivers, which join to form the Somass, are available from the Water Resources and Drainage Board, and indicate that adjustment at intervals of 1 1/2 hours (weekly in the prototype) will be sufficient, except in times of freshet. Very accurate reproduction of river flow can be obtained in this manner with relatively little effort.

Verification of the Model

The model will be verified by comparing the distribution of salinity with that observed in nature (Reference 3) under comparable conditions of tide and river discharge.

The validity of the results pertaining to bed movement will be checked by simulating natural conditions existing at some time in the past and operating the model so as to reproduce some phenomena which has been observed to occur. A comparison of the results obtained in the model with the natural phenomena will provide an index of the accuracy of bed movement tests.

Methods of Observation

It is proposed to study the harbour oceanographically as an example of a tidal estuary, and to investigate the consequences of proposed physical changes in the river bed, and its approach to the harbour. This implys that the oceanographic structure and its variations in relation to tide and river discharge be investigated by observing the distribution of salinity, which corresponds to the density distribution since there will be no temperature gradients. Corresponding studies of the currents are required for expression of the mechanics and dynamics of the system. Bed movement study is required to prove the engineering practicability and consequences of the proposed changes.

Salinity will be determined chemically in small samples of water taken from the model at small intervals of depth, simultaneously, by means of small bore glass tubes. Each tube will be connected to a pneumatic cylinder in such a manner as to rinse and fill a pipette when the cylinder is operated.

Current data is to be obtained by direct observation with a small current meter and by photographing the advance of a dye front with a 16 m.m. movie camera. The current meter has not yet been designed and it is expected to require some research before a satisfactory instrument is obtained.

Bed movement can be observed directly during operation of the model and qualitative notes made at that time. The effect of proposed alterations in the model can be determined quantitatively by draining the model after a certain period of operation and surveying the bed by means of the co-ordinate system described. If it is required to determine the effect of harbour alterations over long periods of time, surveys can be conducted during operation.

To facilitate experimental procedures a "tide tracer" is to be built. This device will record the height of tide on a moving strip of paper. Although the tide tracer will be operated directly from the tide computer, periodic observations of actual tidal height will be made and compared with the tide trace. The tide tracer is to be set up at various positions on the model in order to appear in photographs taken during operation.

Present State of the Model.

December 1, 1950. The model bed has been completed except for painting. The control valves, servo-mechanism, and control float have been completed. It is expected that the tide computer will be finished by about December 20th. Installation and adjustment of the tide simulating gear will require considerable time and the model will not be in operation before January, 1951.

Construction of the water sampler, current meter, and tide tracer has not yet begun. It is planned to build these during January and February, 1951.

Tests in the model are to be carried out during May and June, 1951.

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