CHAPTER 71

LONGSHORE TRANSPORT AT A TOTAL LITTORAL BARRIER

Richard O. Bruno and Christopher G. Gable

ABSTRACT

Analysis of longshore transport at a littoral barrier is presented. Channel Islands Harbor, California was selected as the study site because its offshore breakwater and jetties form a unique complete littoral barrier. Through repetitive surveys an accurate determination of longshore material transport in one direction was made. Measured transport rates ranged from 160,000 to 1,284,000 cubic meters per year. Utilizing visual observations of surf parameters, estimates of longshore wave thrust were computed. The range of wave thrust was 145 to 1,988 Newtons per meter. Comparison of the relation of wave thrust and longshore sediment transport is made. This study indicates that in an environment of high transport, nearly twice as much transport is predicted under corresponding wave thrust as that of the data summarized in the Coastal Engineering Research Center's Shore Protection Manual.

INTRODUCTION

The relation between longshore material transport and nearshore wave thrust (energy) is of vital interest to coastal engineers concerned with design and maintenance of navigation and beach erosion control projects. Past field and laboratory studies have produced an empirical relationship now widely used. However, these studies were conducted in areas where total transport may not have been measured. In this study, Channel Islands Harbor, California was selected because an offshore breakwater and jetties form a unique sand trap (Figure 1). This site is considered a nearly total littoral barrier to longshore transport. A further advantage to this site is its exposure to a high wave energy climate and high transport rates not encountered in previous studies. Dredge records from this harbor show annual transport in excess of one million cubic meters. The objective of this study is to reevaluate the empirical relationship between nearshore wave thrust and longshore material transport.

Coastal Engineering Research Center, Kingman Building, Fort Belvoir, Virginia 22060

Coastal Engineering Research Center, Field Office, Port Hueneme, California 93043

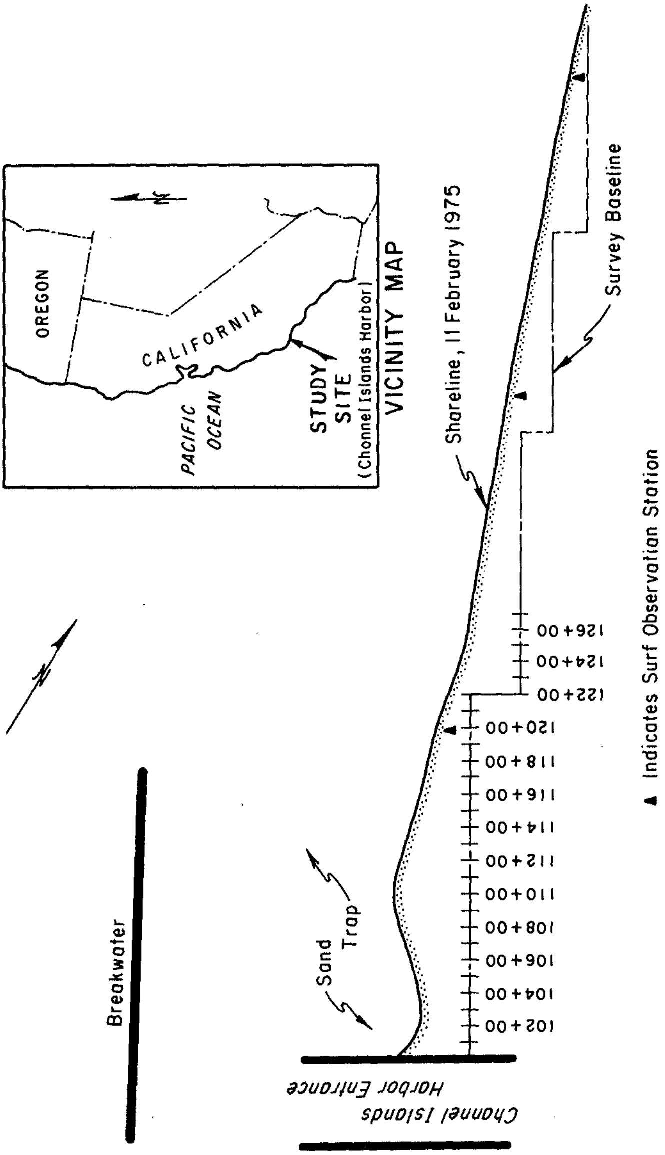


Figure 1. Longshore Transport Study Area.

DATA COLLECTION

The data collection program consists of periodic bathymetric and topographic surveys and routine collection of wave data from which longshore transport and wave thrust can be estimated.

Assistance in making surveys was provided by the Corps of Engineers, Los Angeles District. For these surveys a base line parallel to the shore was established. Profile lines, normal to the baseline, were spaced at about 30.5 meters (100 feet) for a distance of about 823 meters (2700 feet) as shown in Figure 1. At each of these stations elevations were measured from the baseline to the detached breakwater. Surveys were scheduled at intervals of 4 to 6 weeks although this scheduling was frequently modified due to survey crew availability, equipment failures, and unfavorable surf conditions.

Table 1 summarizes survey data, showing survey dates, ranges surveyed, type of fathometer calibration, survey method, and qualitative estimate of overall data quality. The notation "standard" survey indicates an analog fathometer record was made and the survey vessel was located by standard survey techniques of the Los Angeles District. For this method the vessel operator was directed by a man onshore to steer along the profile line. At ten second intervals the analog recording was marked and vessel position was recorded via plane table and alidade.

The notation "hybrid" indicates an analog fathometer record was made and position of survey vessel determined by use of electronic ranging equipment. Under this method the vessel operator was directed by a man onshore to steer profile lines, but the position of the vessel was monitored by telemetering the data to a field office where a minicomputer was used to produce a real time plot of position. By this monitoring of the survey in progress errors in positioning were determined and eliminated. For recording the data an electronic timer was used which simultaneously marked the analog record and recorded the vessel's position on magnetic tape every two seconds.

Both of these methods used an amphibious vehicle, known as LARC V for the bathymetric portion of the survey. The LARC enables measurement of the survey line to be continued through the surf zone by using rod and level methods when the vehicle's wheels contact the bottom. Profile lines were measured over the dry beach areas by standard level and rod transects.

Equally important to the data collection program are the

TABLE 1 - SUMMARY OF SURVEY DATA

DATE	RANGES SURVEYED	FATHOMETER CALIBRATION	METHOD USED	DATA QUALITY
14 APR 74	101 - 122	LEADLINE	STANDARD	5
7 MAY 74	101 - 127	LEADLINE	STANDARD	6
18 JUN 74	101 - 127	LEADLINE	STANDARD	0
30 JUL 74	101 - 127	LEADLINE	STANDARD	7
20 AUG 74	101 - 127	LEADLINE	STANDARD	7
24 SEP 74	101 - 127	LEADLINE	STANDARD	7
6 NOV 74	101 - 127	LEADLINE	STANDARD	4
7 JAN 75	101 - 127	LEADLINE	STANDARD	5
11 FEB 75	101 - 122	LEADLINE	STANDARD	6
4 MAR 75	101 - 127	LEADLINE	STANDARD	7
27 MAR 75	101 - 127	BAR CHECK	HYBRID	0
14 APR 75	101 - 127	BAR CHECK	HYBRID	7
6 MAY 75	101 - 127	BAR CHECK	HYBRID	9
1 AUG 75	101 - 127	BAR CHECK	STANDARD	9
13 AUG 75	101 - 127	BAR CHECK	HYBRID	9
16 SEP 75	101 - 127	BAR CHECK	HYBRID	9

surf data. Figure 1 shows the sites where twice daily surf data were collected using procedures developed under the Coastal Engineering Research Center (CERC), Littoral Environment Observation (LEO) program (Bruno and Hiipakka, 1973; Berg, 1968). These data include observations of surf conditions, local winds and littoral currents. For this study the estimates of breaker height and breaker direction were of primary concern. To aid in estimating the breaker direction the observer is provided with a protractor on the data form. Longshore current data is also considered in this report. Longshore currents were measured using small packets of dye which disperse upon injection in the surf zone. The observer measures the distance the dye travels parallel to the shoreline. Current speed is estimated from the movement of the dye patch centroid over a one-minute period and current direction is noted. Surf zone current velocities are not uniform; therefore, the width of the surf zone is estimated as well as the distance from the shoreline to the point of dye injection. To augment the surf data two wave gages were installed 1300 meters upcoast of the trap at six meters depth. However, gage data have not yet been analyzed and are not used in this report.

ACCURACY

Late in the study it was found the "standard" surveying method was not providing the reliable, accurate data desired. Figure 2 shows profiles plotted from "standard" surveys. These data are on a line sheltered by the breakwater and at a point beyond normal sand deposition. To verify no deposition divers measured underwater reference stakes and determined there was no change in bathymetry at this point. These plots indicate that unacceptable errors were introduced on several surveys. These errors were a result of poor position data, poor fathometer calibrations, and errors in data reduction.

The "standard" surveying method assumes that the LARC is on line for all fixes and that the instrument man has precisely marked its position simultaneously with the fathometer mark. This is not always true and errors which occur can never be recovered. Even with no errors produced in field collection, reduction of working scale plane table data sheets is limited to an accuracy of about 3 meters which is seldom attained.

In the "hybrid" method an electronic timer was employed to simultaneously mark the fathometer at 2 second intervals and to control the recording of the LARC's position. As a result the human errors in determining position are eliminated. Position accuracy, which was limited by the electronic ranging equipment, was found to be about 2 meters and is consistently attained.

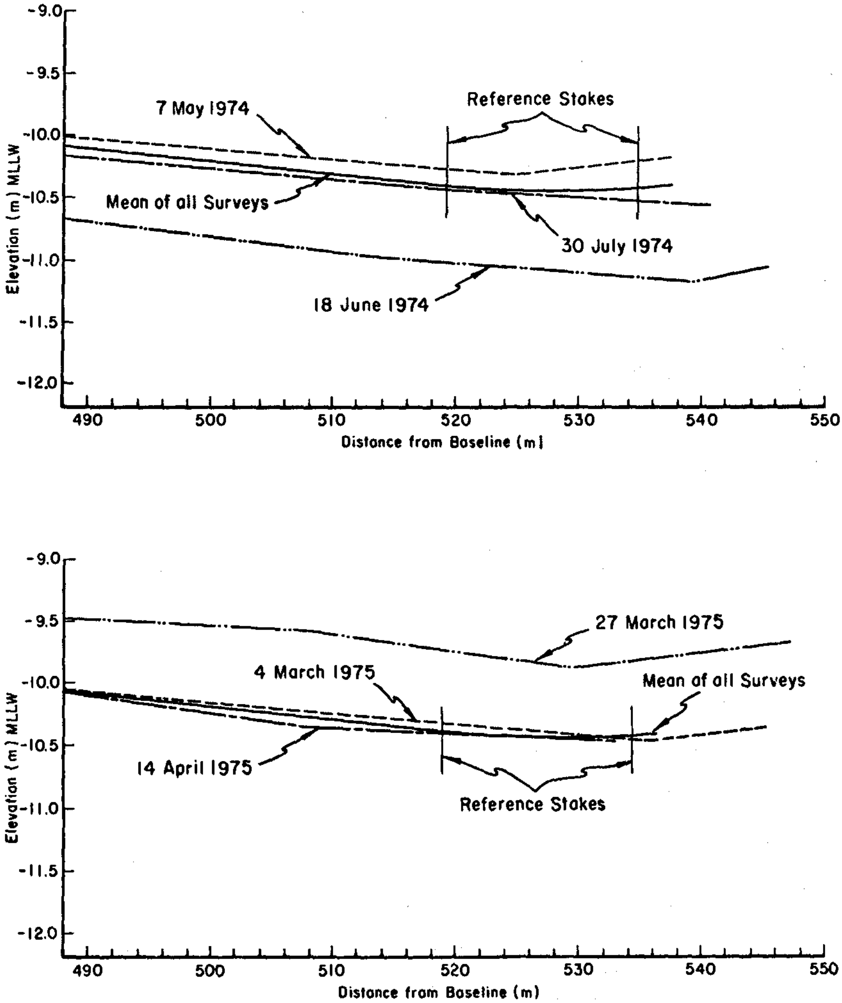


Figure 2. Illustrations of Survey Errors at Reference Station.

In addition to positional errors, fathometer calibrations and data reduction procedures were found to produce errors. Under the "standard" method leadline soundings were used for fathometer calibration. In taking leadline soundings numerous factors determine accuracy including skill and care of the operator, motion of the vessel, and roughness of the water's surface. Later surveys utilized a bar lowered at 5 foot intervals under the fathometer for calibration. This type of calibration removes human factors and is complete in that it shows any non-linearity which may occur in the fathometer readings.

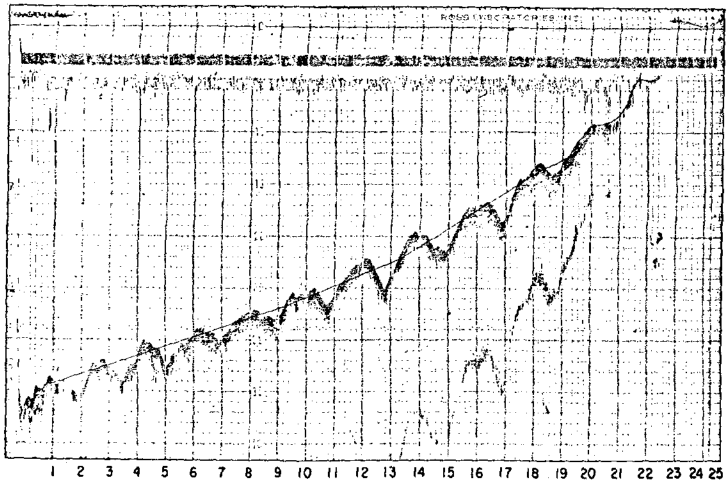
Another source of error which was discovered lies with uncertainty in interpreting the fathometer records. Figure 3 shows two profiles both with similar features which appear to be waves, but in fact on one record these features are the irregular bottom left after dredging. For this reason under the "hybrid" method all data reduction was performed by the authors, who were present at the time of data collection and noted conditions as records were being made.

The last column in Table 1 labeled "survey quality" is a subjective rating from 0 (poor) to 10 (good). These values were determined by the authors after examining the data on hand, field notes, and all profile plots. By using this approach it was determined that data collected 18 June 1974 and 27 March 1975 should be discarded as unreliable.

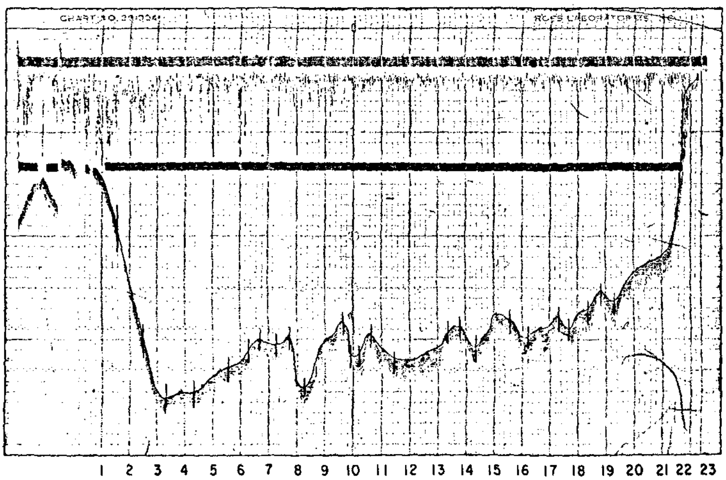
ANALYSIS

Table 2 is a summary of the analysis showing the survey intervals selected for computations, transport rates, longshore thrust, longshore thrust times wave velocity, and longshore currenta.

Transport rates were determined by calculating volume changes between surveys. It is assumed that all material deposited into the trap was a result of longshore energy from upcoast; effects of reversal in the wave direction and resulting diffraction around the detached breakwater have been ignored. Diffraction can be illustrated in the case where wave approach ia directly onshore. In this case there would be no general longshore component of wave energy. However, due to diffraction, a local zone of longshore wave thrust would develop as shown in Figure 4, (Weigel, 1962). The expected results would be an erosional zone and a depositional area downcoast (to the southeast). If both the local erosion and deposition zones are included in the total area used to calculate volume changes, this shore-parallel wave approach would result in no net volume change. In this study, the area of volume computations was



RANGE 124+00 – FATHOMETER RECORD WITH WAVES



RANGE 104+00 – FATHOMETER RECORD WITHOUT WAVES

Figure 3. Fathometer Record of Regular Bottom with Waves and Irregular Bottom without Waves.

Table 2 – Data Summary

Survey Dates		Transport Rate $\left(\frac{\text{meters}}{\text{year}}\right)$	Wave Thrust $\left(\frac{\text{Newton}}{\text{meter}}\right)$	Wave Thrust X Wave Velocity $\left(\frac{\text{Newton-meter}}{\text{meter-second}}\right)$	Longshore Current $\left(\frac{\text{centimeters}}{\text{second}}\right)$
4/17/74	5/7/74	1,194,000	1,988	547	45
5/7/74	7/30/74	689,000	1,276	349	36
7/30/74	8/20/74	537,000	644	159	27
8/20/74	9/24/74	426,000	611	152	22
9/24/74	11/6/74	500,000	689	183	36
11/6/74	1/7/75	1,284,000	665	167	34
1/7/75	2/11/75	1,174,000	877	245	44
2/11/75	3/4/75	716,000	801	208	36
3/4/75	4/14/75	954,000	712	190	66
4/14/75	5/6/75	1,108,000	545	133	35
5/6/75	8/1/75	402,000	366	89	34
8/1/75	8/13/75	160,000	390	84	18
8/13/75	9/16/75	430,000	145	29	21

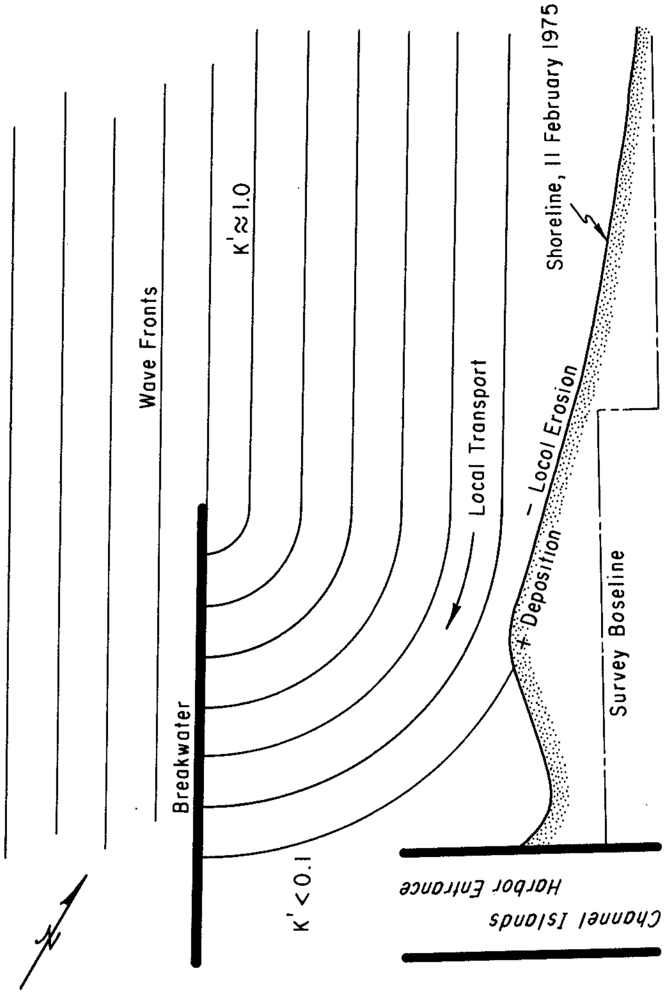


Figure 4. Wave Diffraction Pattern with Incident Waves Normal to the Breakwater (after Wiegel, 1962).

extended 300 meters beyond the north end of the breakwater to include diffraction effects. Diffraction diagrams (Weigel, 1962), indicate that diffraction transport is included for all wave approaches from the West or North which are predominant at the study site. Under periods of wave reversals only small errors are introduced by diffraction since most of the erosion and part of the deposition are included in the area of volume calculation.

Deposition from upcoast (northerly) transport during times of reversals in wave direction can be examined. The area of the trap seaward and upcoast of the jetties will show deposition due to reversals. Figure 5 is a plot of the first profile upcoast of the jetties. Survey dates of spring 1974 and fall 1975 are plotted and show the total change at this profile over the period of the study. This plot shows little deposition at the end of the jetty. Detailed examination of all profile data enabled the authors to define the area of deposition attributable to influx of material from north (upcoast) to the trap. No significant deposition was measured at distances more than 425 meters from the baseline. By using 425 meters from baseline as an outward boundary to calculate volumes, errors due to influx of material from reversals is minimal.

The area used in volume change calculations is between the baseline and 425 meters offshore and the north jetty and 670 meters upcoast. Over this area we expect a volume accuracy of within ±5,000 cubic meters.

In 1972 Longuet-Higgins summarized his earlier work and presented an expression for the momentum flux tensor component which he termed lateral thrust. This lateral thrust, or longshore wave thrust, is "the flux towards the shoreline of momentum-parallel-to-the-coast". It is given as:

$$H = E(c_g/c)\cos\theta \sin\theta \tag{1}$$

where E is wave energy density, c_g the local group wave velocity, c the wave velocity, and θ the wave angle. Longuet-Higgins gives an expression for E as:

$$E = 1/8 \rho g h^2 \tag{2}$$

where h denotes wave height, ρ the water density and g the acceleration of gravity. The expression for H, valid outside the breaker zone, implies the waves exert a longshore thrust on water and sediment inside the surf zone. It is therefore

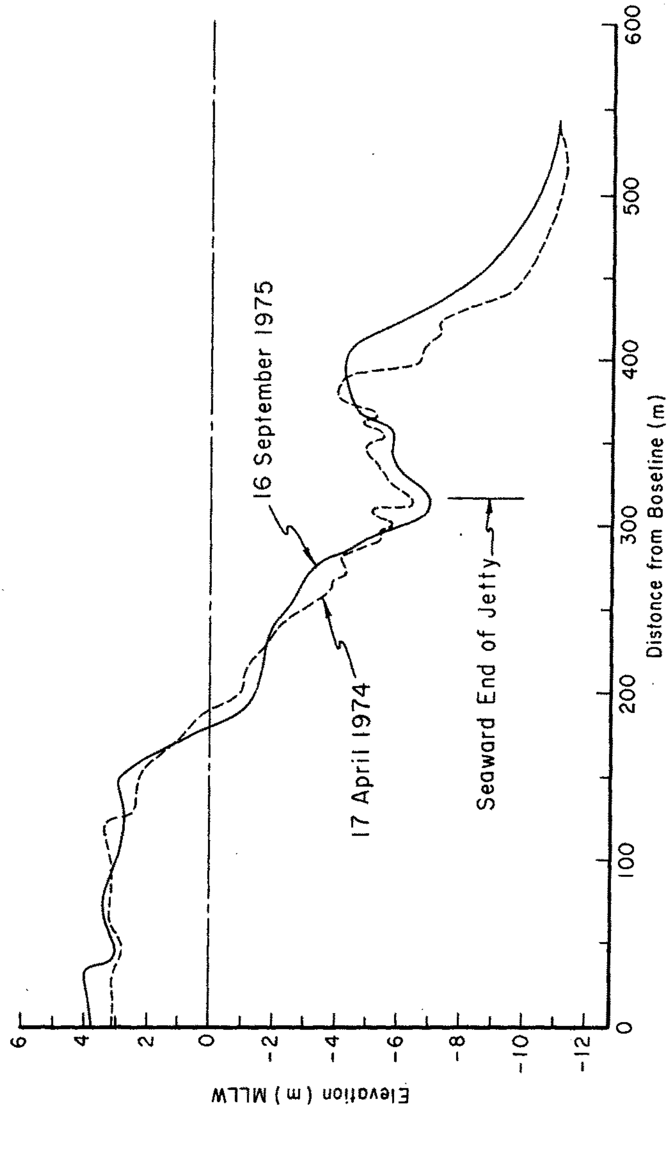


Figure 5. Range 101+00 at Begining and End of Study.

reasonable to expect a direct relation between longshore thrust and longshore transport. At the breaker line $c \cong c_g$, therefore by combining equations (1) and (2) above:

$$H = 1/8 \rho g h_b^2 \cos\theta \sin\theta \tag{3}$$

Unfortunately, previous works of this type have not used H, but rather, have plotted transport rates against an expression which is equivalent to H times the wave velocity c. This expression is given by:

$$Hc = 1/8 \rho g h^2 c_g \cos\theta \sin\theta \tag{4}$$

In shallow water $c_g \cong c \cong \sqrt{gd}$ where d is local depth and g is the acceleration of gravity. At breaking $d = 1.28h$ (Munk 1949); thus, equation (4) can be written as:

$$Hc = \sqrt{1.28}/8 \rho g^{3/2} h_b^{5/2} \cos\theta \sin\theta \tag{5}$$

For comparison with previous work Hc is computed. Values for H and Hc have been calculated using breaker height and angle from the two upcoast observation stations, (Figure 1). Each observation was time weighted to represent a period from mid-time of previous observation to mid-time of next observation. Only those values of "Hc" and "H" toward the trap are considered. These results are tabulated in Table 2.

To complete this analysis the longshore currents are also considered. Longuet-Higgins (1970) derived a theoretical relation for the average longshore current generated by obliquely incident waves which depends only on a horizontal mixing parameter "P" and a reference velocity, "v_0", (v_0 would be the longshore current velocity if there were no horizontal mixing). If one assumes a value for P then v_0 and the average current can be determined from the data collected in this study. Longuet-Higgins indicates that a reasonable value for P is 0.4 for the study area. Assuming P=0.4, average velocity is equal to $55/196 v_0$. But v_0 is given by:

$$V_0 = \frac{V_x}{\left(\frac{10}{49}\frac{X}{X_b}\right) - \left(\frac{5}{7}\frac{X}{X_b} \ln \frac{X}{X_b}\right)} \tag{6}$$

where v_x is velocity at a distance x from the shoreline and x_b is the distance from shore to the breakers. Accordingly average currents toward the trap are given in Table 2.

RESULTS

Figure 6, a plot of transport rate versus time, shows the seasonal nature of the transport in this area. Maximum transport rates were measured during winter and early spring and minimum rates during summer and early fall. These results are consistent with other studies of Southern California. In contrast Figure 7, plot of longshore thrust versus time, does not show high wave thrust expected during winter/spring 1975. Yet this Figure does show the expected high value in spring 1974. However, the expected seasonal trends are evident in Figure 8, a plot of average current versus time. A reasonable explaination for the unexpected low longshore thrust values of winter/spring 1975 is observer error in surf estimates.

Our principal result is the relation between longshore transport and longshore thrust shown in Figure 9. The four outlying points indicated on this Figure represent those data obtained during winter/spring 1975 when high transport was measured but low biasing of observed wave conditions is suspected. Omitting those four points a simple regression line has been plotted. For comparison with CERC Shore Protection Manual (SPM), values of Hc are plotted against transport rate (Figure 10). Note that the regression line of this study predicts nearly twice the transport rate predicted in the SPM.

SUMMARY

In this study repetitive surveys were made at a littoral barrier. These survey data were carefully scrutinized to eliminate errors. Later surveys included the use of electronic positioning equipment for high accuracy. As a result these data represent an accurate determination of longshore material transport through a 16-month period. It is felt that these data are the best estimates of longshore transport measured under field conditions.

Estimates of longshore wave thrust were computed from visual wave observations. Poor agreement with transport rates and longshore currents measured during winter/spring 1975 indicates possible observer bias. These anomalies will be studied in future work.

Comparison of the relation in wave thrust and sediment transport is made. This study indicates that in an environment of high transport, such as the United States Pacific coast, nearly twice as much transport is predicted under corresponding wave thrust as that of the data summarized in the SPM.

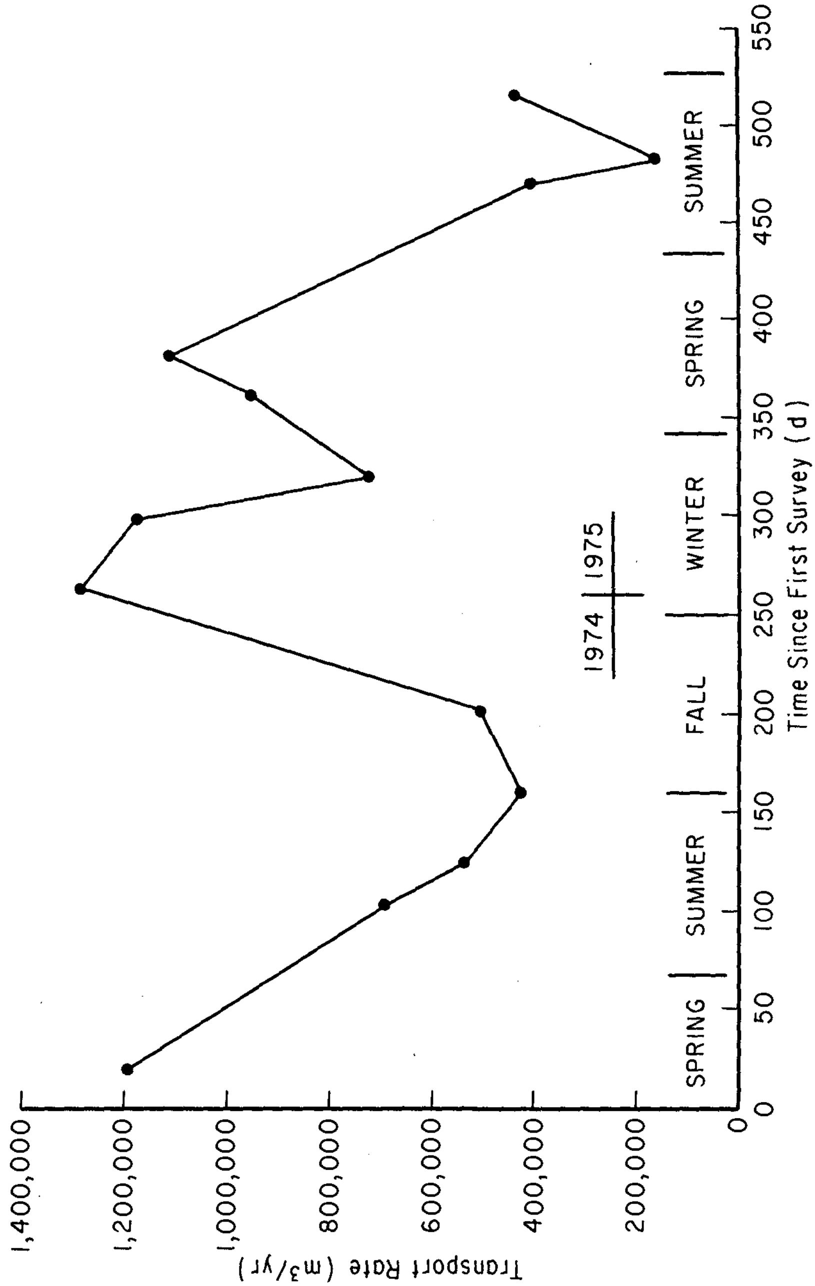


Figure 6. Transport Rate versus Time.

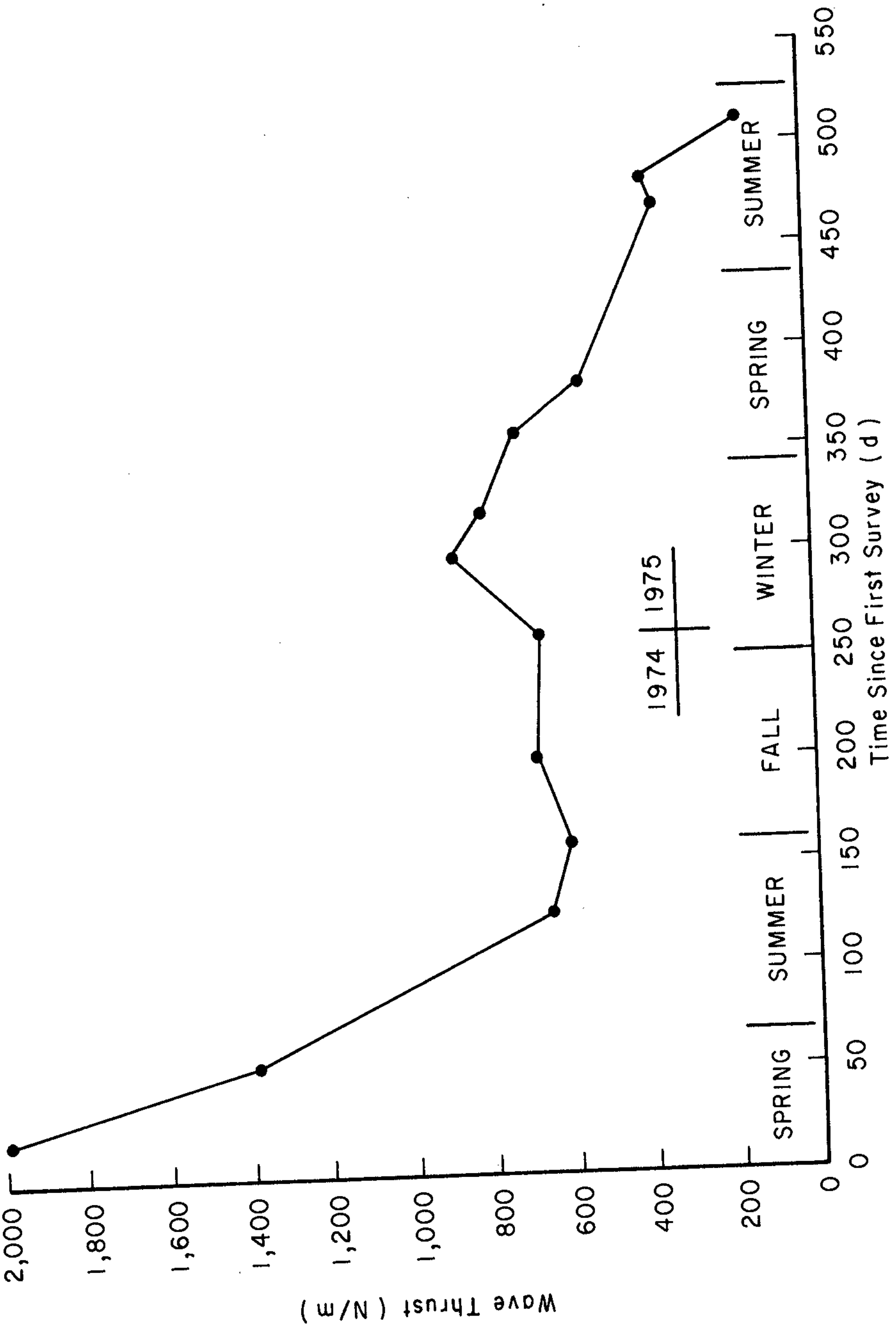


Figure 7. Wave Thrust versus Time.

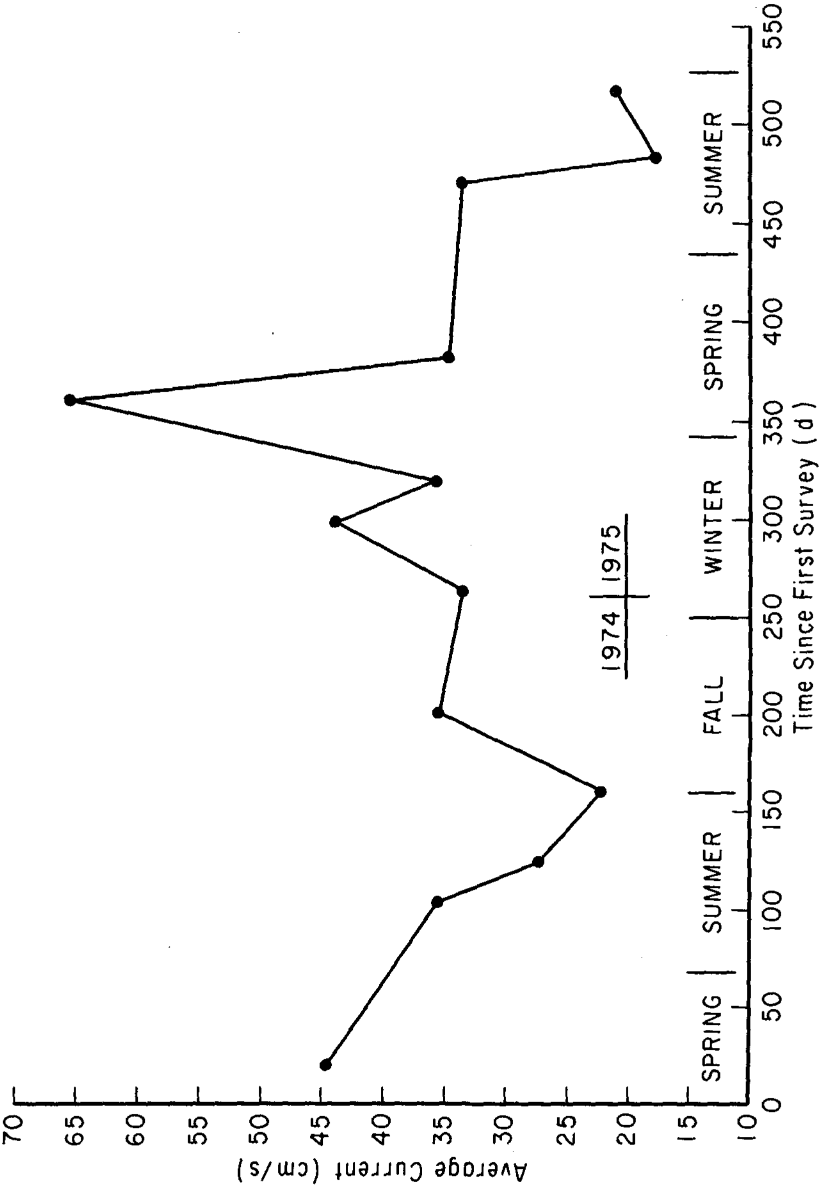


Figure 8. Average Current versus Time.

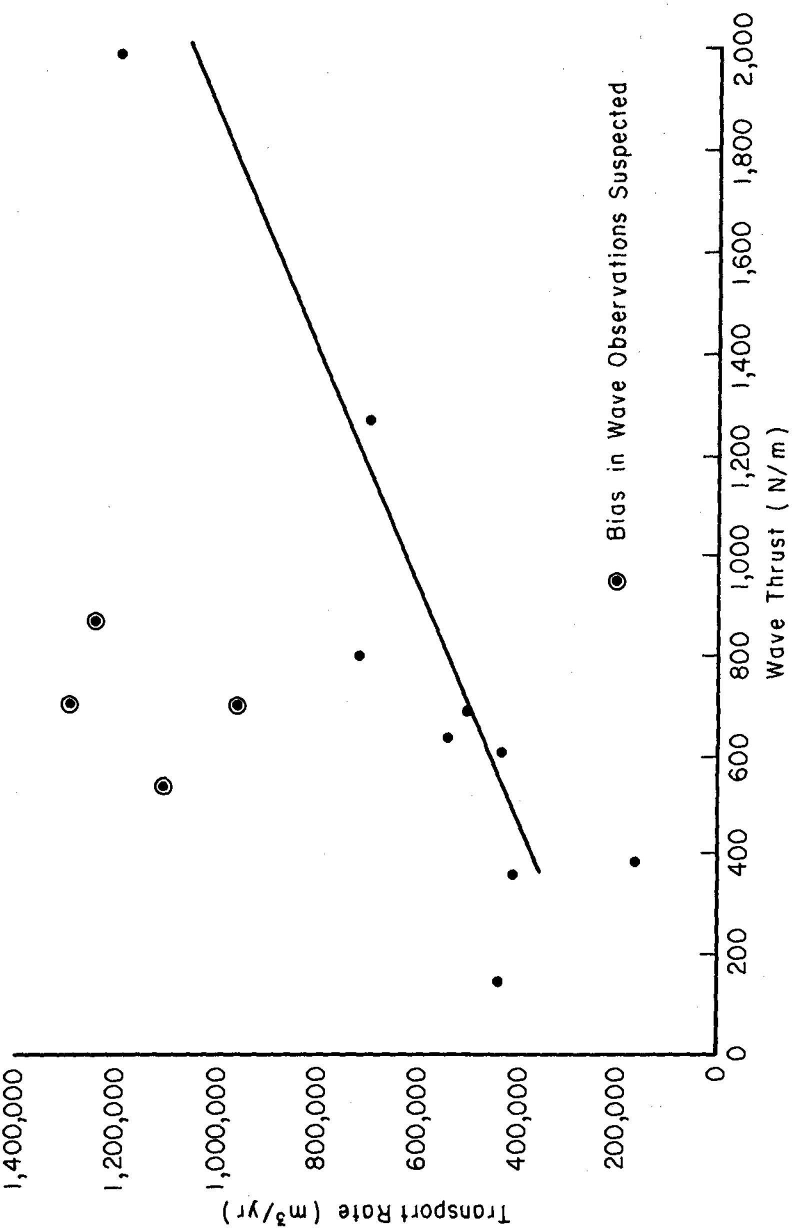


Figure 9. Transport Rate versus Wave Thrust.

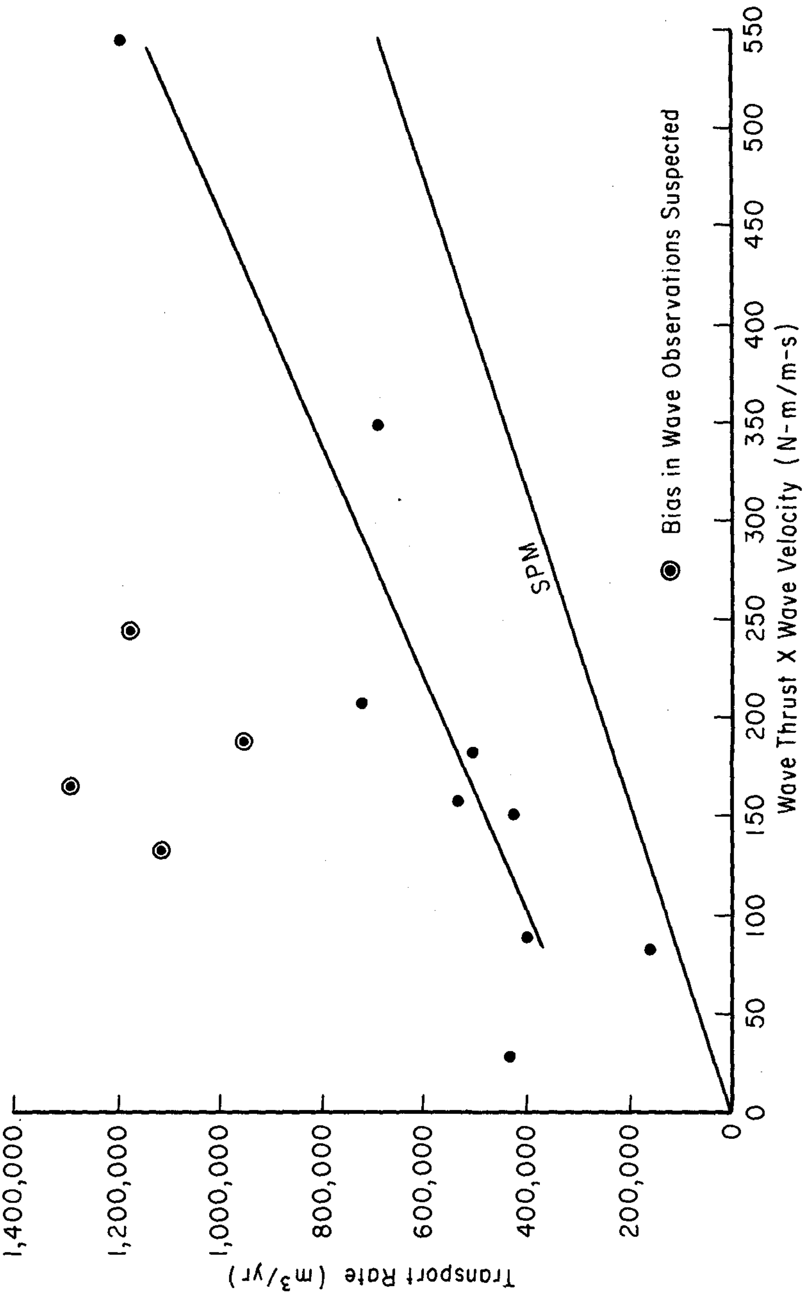


Figure 10. Transport Rate versus Wave Thrust X Wave Velocity.

Thia work has warranted further study and plans are to continue the data collection program through 1977. Future work will address the questions of accuracy of wave measurements, characteristics of sediment, influence of a dredged deposition basin, wave diffraction influence, and factors in additiion wave thrust which contribute to longshore transport of sediment.

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