Chapter 18

QUANTITATIVE RESEARCH ON LITTORAL DRIFT IN FIELD AND LABORATORY

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INTRODUCTION

The Coastal Engineering Laboratory of the University of Florida is at present carrying out a combined field and laboratory research program to gain quantitative information on littoral drift longshore as well as perpendicular to the shore. The laboratory utilizes modern tracing technique by luminophores including a scanning (counting of grains) machine and experiments in a wave tank where a current is passed through waters agitated by waves propagating parallel to or perpendicular to the current action.

FIELD RESEARCH

GENERAL

Sediment transport is caused by a combination of shear stresses by wave and current action. The wave induced shear stresses "break loose" the material from the bottom while the longshore currents transport it longshore. A research program on littoral drift must combine wave and current action. The research procedures described below are based on the philosophy that although it is not possible to understand the complex problems in full unless research penetrates down in the very details (refs. 4, 10, 11, 17, 19), it is still possible to secure results of scientific and practical value by considering an integrated part of the problem, including a variety of details to be looked into when the integrated problem has been analyzed to the extent this is possible. The procedure, therefore, may be said to follow the pattern of penetrating into the problem "from above".

MODES OF TRANSPORT

It is known that bed load transport takes place in two different modes - partly in a fast moving sheet-layer on the surface of the bottom and partly in bulk movements as slowly migrating waves on the bottom, perhaps in a multiwave system with one wave creeping on the top of the other as observed in the Mississippi River (ref. 16). The situation on the seashore may be similar to the situation in rivers although the surf zone has its peculiarities. The existence of migrating waves has been clearly demonstrated, e.g. by surveys on the Danish North Sea Coast (ref. 3), in Florida (ref. 6), in Holland (ref. 23) and in Japan (ref. 22).

Sheet-Layer Movement

The thickness of the sheet-layer depends upon the forces exerted upon the bottom and their variation with time. Under the influence of these stresses, sand particles travel parallel to the wave crests (longshore) when the oscillating water particles are mainly in vertical movement and they migrate perpendicular to the wave crests (and to the shore) below wave crests and troughs. Tests on sheet-layer movement are now in progress. In the field quantitative research is undertaken using luminescent tracers. Experiments using fluorescent tracers are mentioned in refs. 6, 12, 13, 24 and 25.

With respect to research on sheet-layer movement the following procedure is used at experiments in progress at Fernandina Beach, Florida, for grant by the National Institute of Health, Education and Welfare.

Tracer material is dumped by diver or from helicopter in soluble plastic bags on the updrift side of an 800 ft. long pier extending in the ocean up to 15-20 ft depth at M.S.L. Sampling is undertaken from the pier. Fig. 1 shows a schematic of the instrumentation as installed on the pier. Sampling equipment consists of four bed load traps and four suspended load traps. The bed load traps are raised and lowered from the pier deck to the bottom. The bed load trap is about 3 ft long, 2 ft wide, 8 in high, streamlined (turtle-shaped) box with steel sides and plexiglass top. It has doors controlled from the pier at each end. To avoid excessive scour around the trap and its openings, a steel apron is attached to the bottom of the trap. The trap is placed with open doors parallel to shore. After a few minutes, doors are closed and water jets circulate the water in the trap at the same time as vertically slitted pipe in the middle of the trap sucks up the material to the pier (Fig. 2). Details of this phenomena are explained by the fact that the sand moves along the bottom in a circular path and the pressure gradient directed toward the center causes sand movement toward the center.

The suspended load pump sampler has three vertical intakes pointing upwards. Laboratory tests have proven that vertical intake-samplers are not fully accurate for sediments much coarser than 0.06 mm, but the error experienced for coarser sediment (0.1-0.2 mm) is, on the other hand, less than about 20%, if the velocity in the intake does not deviate much from the actual current velocity. Because of the eddy turbulence at the bottom where concentrations are highest, the actual concentrations are being checked by other sampling methods.

The sampling arrangement on the pier permits four bed load traps and four suspended load samplers to be operated with four electrically powered pumps by an easily assembled, valved pipeline system.

During the test which may run for several hours continuous sampling is carried out by which the "number of grains versus time relationship" is obtained. If n tracer grains are trapped per unit time, one has with v_x = travel velocity of grains, b = thickness of sheet-layer, w = width of trap-opening and k_1 a soils constant:

$$w.b.v_x = n.k_1$$

$$b = \frac{nk_1}{wv_x} = k_2 \frac{n}{v_x} \quad (k_2 = \frac{k_1}{w}) \qquad (1)$$

"b" indicates the thickness of the "imaginary layer" of coated grains and is very small (a fraction of grain size). The corresponding number of non-coated grains coming from the same bottom area as the coated grains is unknc

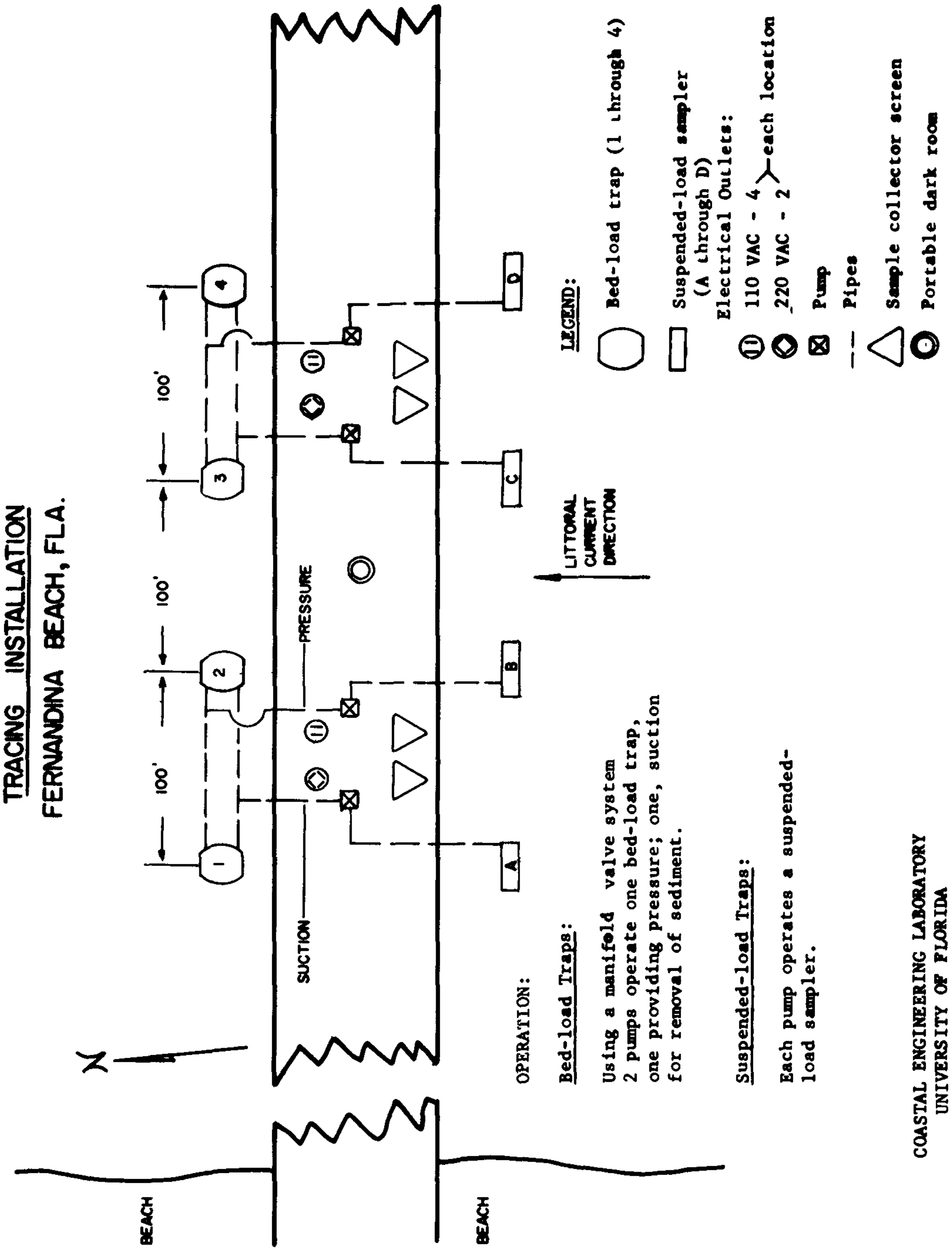
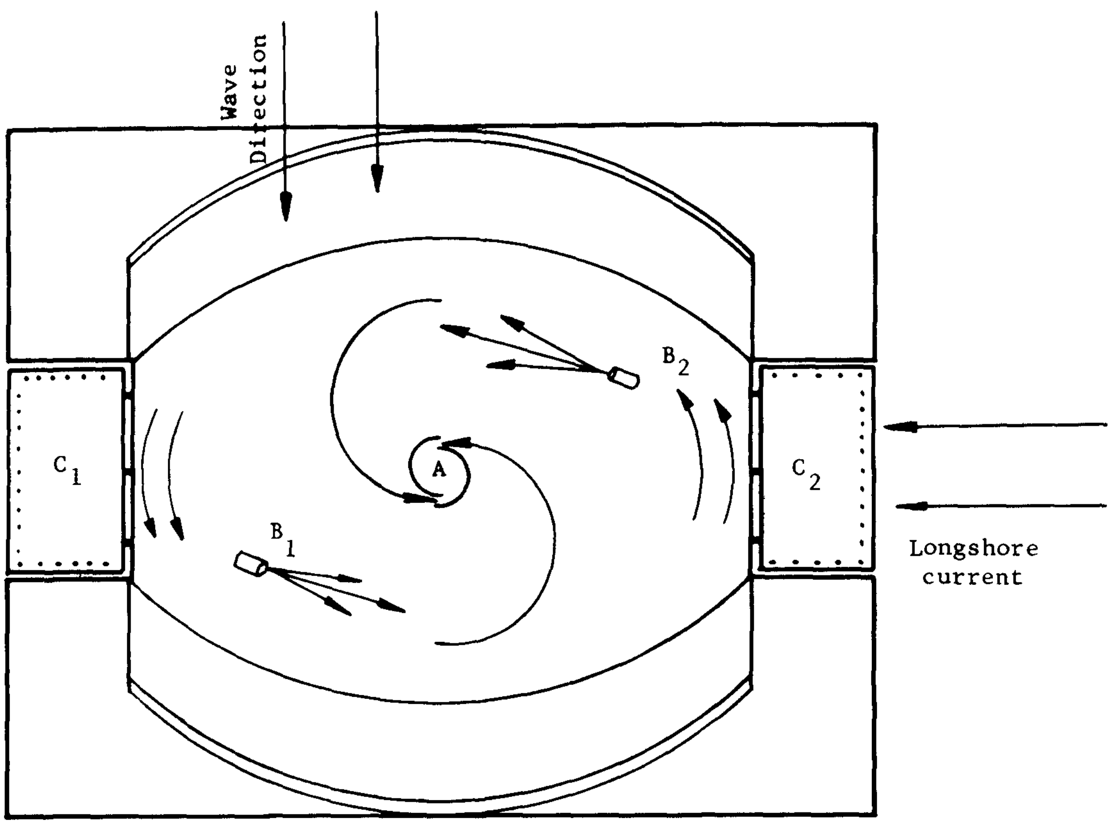


FIG 1 SCHEMATIC INSTRUMENTATION INSTALLED ON FERNANDINA BEACH PIER, NE, FLA.

PLAN VIEW OF BED-LOAD SAND TRAP



Operation:

Step 1. Close doors C_1 and C_2

2. Inject water at 15 psi at B_1 and B_2

3. Apply suction at A

4. Filter discharge from A for sand sample

FIG. 2. FLOW IN BED-LOAD TRAP

Most grains trapped in the period immediately following the dumping of tracer grains come from the area close to the pier as described below.

Assuming relatively heavy (measurable) concentrations, coated grains wil arrive at the pier in a stream which most likely will increase rather rapidly to a maximum value and then fade out.

When sheet layers of maximum concentration of coated grains have reached the pier, discharge of material from the injection area has its maximum value The corresponding maximum thickness of material arriving from the injection area is:

$$B_{max} = \frac{N}{n_{max}} \cdot \frac{n_{max}}{V_{n_{max}}} \cdot k_2 \qquad (2)$$

when N is the total number of grains trapped per unit time.

Next the assumption is made that the ratio $\frac{N}{n_{max}}$ is a characteristic value for release of material from the injection area valid for the various sheet-layers sliding on the top of each other with different velocities. Considering the fact that the tracer material spreads out on the bottom and mixes with non-coated grains, this assumption seems correct.

The total thickness of the fast moving sheet-layer (up to maximum concentration) may then be found by an integration:

$$B_{total} = \sum_{j=1}^{j=j_{max}} \frac{N}{n_{max}} k_2 \frac{n_j}{v_j} = k \frac{N}{n_{max}} \sum_{j=1}^{j=j_{max}} \frac{n_j}{v_j} \qquad (3)$$

where j refers to the number of sheet layers sliding on the top of each other.

The total quantity of material in all sheet-layers may be found by direct observation of the quantity Q_{total} trapped. The total rate of transport including fast as well as slow moving sheet layers is:

$$Q_{total} = Q_{fast} + (Q_{slow}) = k_2 \frac{N}{n_{max}} \sum_{j=1}^{j=j_{max}} \frac{n_j}{v_j} \cdot v_j + (Q_{slow}) \qquad (4)$$

The characteristics of the "slow" or "slower moving" sheet layer may be determined by continued long range observations beyond maximum concentration and will finally include the migrating humps of material which has erosion slopes updrift and deposit slopes downdrift.

In equation (4), the $\frac{N}{n}$ ratio is independent of the direction of travel of material (or direction of arrival of material to the bed trap) but the design of the trap must assure that the material is derived from the actual longshore movement of sheet-layer only and not from the drift perpendicular to shore. This is secured by exact longshore placement of the trap by the apron bottom protection around it and by its streamlining. Checks on proper functions are made by divers.

The detailed mechanics of the bed transport is complex and it is necessary to accept that records will demonstrate considerable irregularities. Two main factors may be responsible for this - the systems of migrating sand waves and the rip currents. Fig. 3 shows schematically how migrating sand waves on the bottom may interfere with the longshore drift when the instrumer pier is located on a crest and in a trough of a migrating wave (Fig. 3). Assuming that the littoral drift goes from left to right and that tracer material is dumped on the places indicated by A, B, C (crest located at pier) and I, II, III (trough located at pier). Figs. 3-b/c indicate the expected concentration of tracer particles from samples taken at the pier as function of time considering that the sand wave(s) are creeping from left to right and that this process causes higher drift on the updrift side of the wave th on the downdrift side, where some accumulation takes place or where the migrating sheet layer get thinner. The actual quantity of material trapped by the bed load traps on the pier will vary accordingly.

The indicated relative concentrations of tracer material in Fig. 3 are based on modes of transportation in rivers. While tracer material dumped at locations III, B and C may give useful results on the sheet layer movemen material dumped at I, II and A may be clogged or covered up to such extent that results may demonstrate very low concentration in the samples or perhap "no concentration at all" because almost all the tracer grains dumped were buried by the migrating sand waves. Meanwhile, by dumping of various color schemes in strips along the shore, knowledge will be gained about the mechan of movement of the migrating wave and the thickness of the sheet layers whic by-pass the migrating sand waves.

The share of responsibility for movement of bed load transport in sheet layers and in migrating bottom waves may depend greatly upon wave and currer conditions. Under calm or moderate wave conditions, a considerable higher percentage of migration may take place in the slow moving sand wave than unc more severe wave conditions, where the sheet movement may be dominating. Ir other words, the actual bed load movement will vary in quantity not only wi shifting wave and current conditions but also with the actual situation witl respect to migrating sand waves on the bottom. We may get an idea about th order of magnitude of the net sheet layer drift versus the net bulk drift i migrating waves by considering the situation at Fernandina Beach, Florida, N.E. Atlantic coast. Most likely most of the bed transport takes place inside the 20 ft. contour located approximately 300 yds. from shore. The net quantity moving southward is estimated to be approximately 400,000 cu yds/y or approximately 4 cu yds/yd/day. A migrating wave may move 1-2 yds per da in downdrift direction and its height above the bottom may be 1 yd. This gives quantities of averagely 1-2 cu yds/yd/day which in turn means that up to half of the total net bed transport may take place in migrating waves. Consequently, the irregularity in sheet layer transport may be of the order $\pm$ 50%. Most likely this figure is too high for most conditions in the fiel

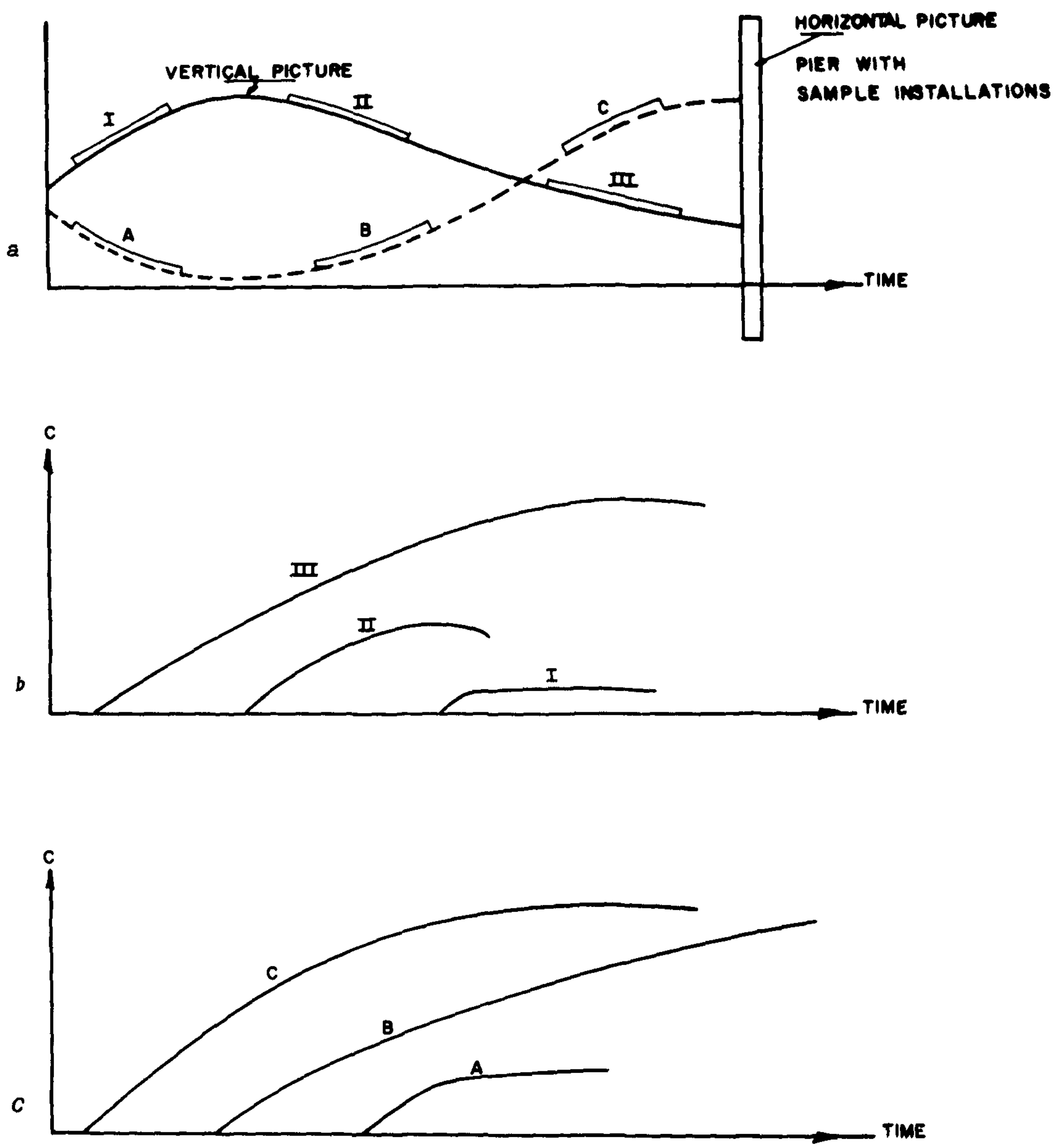


FIG 3 INTERFERENCES BY MIGRATING WAVES WITH LONGSHORE BED-LOAD TRANSPORT
(c=CONCENTRATION OF TRACER MATERIAL)

Another reasons for irregularity is the rip currents. Reference is made to Fig. 4. If no rip current exists at the pier, no difficulty will be encountered because the rip currents will transfer the material downdrift to its full extent. If they did not do so, a headland would be formed in the shore. Meanwhile, if the rip current is located at the pier, the concentration versus time diagram may become very confused and the trap would not give reliable results. This situation, therefore, must be avoided.

The research program in progress concentrates on moderate to heavy wave conditions and, so far, does not include general sampling over the bottom area contaminated by tracer particles. Such procedure would undoubtedly be of value in case of wave and current conditions causing a relatively slow bed load transport which makes it possible to follow the spreading of tracer particles on the bottom by continued sampling. The distribution of tracer particles may then be explored simultaneously. Ref. 21 mentions the so-called p-q statistical approach which proved to be useful for a laboratory channel. Most likely it will not have much bearing to conditions on a sandy seashore bottom. Another interesting theory by the Wallingford Laboratory (ref. 20) utilizes a theoretical approach by which the dispersion of tracer material by diffusion combined with advection is considered. The theory is applied for a shingle beach and the results seem reasonable even though the theoretical explanation so far seems to be of a speculative nature.

Sand particles are moving fast in the top sheet layer, which within a few hours may have traveled some few thousand feet.

Figure 5 demonstrates the results of a preliminary test on tracing from Fernandina Beach pier in N.W. Florida. Fifty pounds of tracer sand was dumped by diver on the updrift side of the pier at each of the depths 2.5 ft, 6 ft, and 6 ft depth (M.L.W.) at distances 50 ft (Station I, 125 ft (Station II) and at 200 ft from the M.L.W. line. Waves were in this case very moderate with $H_{1/3}$ = about 2 ft only. Distance of dumping place from the pier was 250 ft. Bed-load samples were picked up at the pier by scrapers and by a pump (suspended load). From Fig. 5 it may be seen that the samples (bed as well as suspended load) have a rather pronounced peak of concentration. Concentrations of 10^{-2} to 10^{-7} were recorded but after three hours concentrations were negligible or zero which probably is an indication of a very rapid sheet layer drift combined with burial of the tracer material. Initia velocities were highest in the uprush zone (up to about 0.5 ft/sec) and lowest in the trough inside the (not much developed) bar (about 0.1 ft/sec).

Scanning of the results are made by a photoelectric scanner. This instrument was developed for the purpose of accelerating the part of littoral sand transport research known as analyzing of samples.

In essence, the instrument provides a reduction in the time of analysis of fluorescent tracer particles concentration in samples. The scanner, in this process, differentiates for four colors simultaneously counting each and tabulating these counts. The mechanical principle lies in free fall during which the tracer particles mixed well with the uncoated sand are excited for their quality of fluorescence and this is detected by photocells. The resulting signal is decoded by a threshold decision logic circuitry into the proper color and guided for recording into its respective channel.

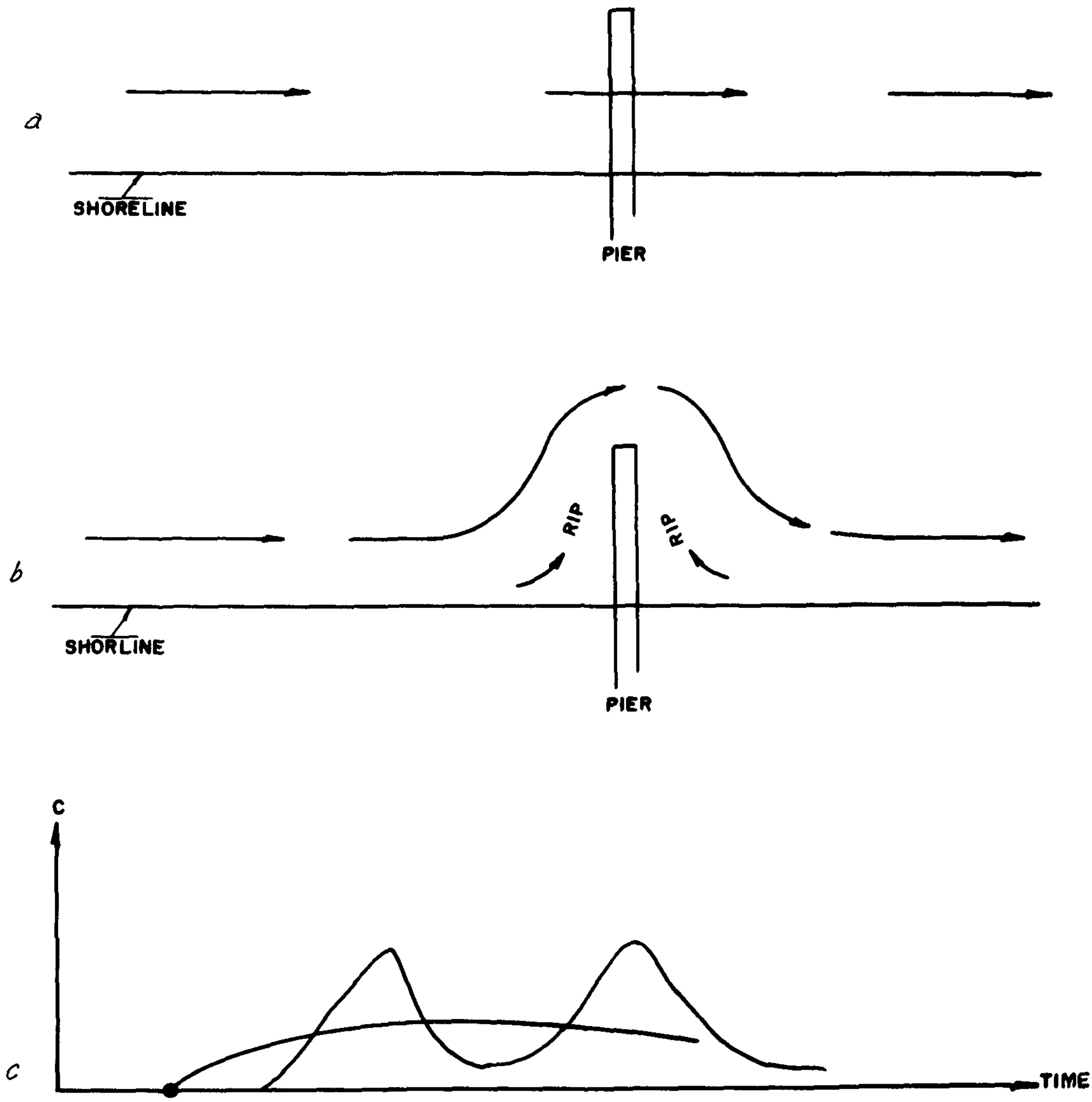


FIG 4 INFLUENCE BY RIP CURRENTS ON LONGSHORE SEDIMENT TRANSPORT

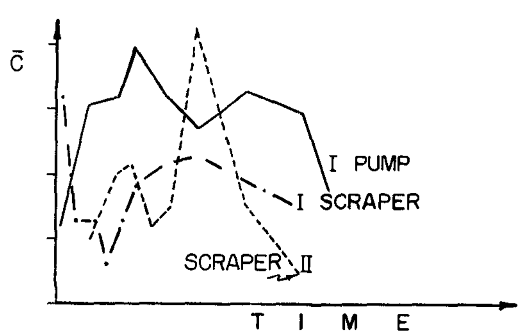


FIG 5 RESULTS OF PRELIMINARY TESTS
ON BED-LOAD TRACING

The rate of fall is variable between 20,000 - 40,000 particles per second.

The detectable colors are spectrally established. A change to another color, however, is possible using slight modification in the detecting assembly.

One difficulty associated with that kind of experiments is that tracers often have a very substantial coating which will not wear off easily. The result is that it may take several months before a tracer experiment can be repeated using the same colors as used at earlier experiments. This problem may be solved by the use of smaller quantities of tracers of a different color mixed up with larger quantities of the "basic tracer", e.g. red, red plus 10% green, red plus 10% yellow and red plus 10% blue; or red, red plus 50% yellow, red plus 50% orange and red plus 50% blue. If concentrations in a certain area are known from detailed sampling, one particular test may also be continued by mixing, e.g. red (concentration c_1) red (concentration c_2) and red (concentration c_3) with an equal amount of a different tracer and this procedure may even be continued by the use of more "indicator tracers". But sampling must be careful and the use of core samplers is necessary. Scanning has to be partly visual if the scanner is only able to handle a few colors.

TRANSVERSAL MOVEMENT OF MATERIAL

Material movements in the bottom profile are partly of long term feature caused by fluctuations of the sea water table and partly a seasonal fluctuation which is the reaction of the bottom profile to the seasonal chnage of wave and current action.

Ref. 5 and paper by Rhodes Fairbridge printed in these proceedings mention the interrelation between rise of sea level and beach erosion (shoreline recession). Ref. 5 explains that even small sea level rises (e.g. the eustatic rise of 1.2 mm per year) may cause shoreline recessions of 100 times the magnitude of the rise in Florida.

TABLE 1

Mean Dimension of Vertical Short-Term Seasonal Fluctuation, Tokai, Japan

0 - 6 meters	0 - 20 ft	0.0 meters
6 - 9 meters	20 - 30 ft	0.15 meters

TABLE 2

Mean Dimension of Vertical Short-Term Seasonal Fluctuation
Bovbjaerg, Danish North Sea Coast

0 - 6 meters	0 - 20 ft	0.40 meters
6 - 9 meters	20 - 30 ft	0.70 meters

Table 1 (Tokai, Japan) explains that seasonal fluctuations of bottom profiles with bar depth 3 meters corresponding to $H_{1/3}$ = 3.75 m (heavy storms) almost entirely takes place inside the 6 m (20 ft) depth contour where erosion and deposit balance each other (ref. 22). Table 2 (Bovbjaerg, Danish North Sea Coast) indicates that profile fluctuations with bar depth 4 m (13 ft) corresponding to $H_{1/3}$ = 5 m (17 ft)(heavy storms) take place beyond the 9 m (30 ft) depth contour. Migrating sand waves on the bottom are, however, in this case interfering with the seasonal fluctuation of the profile (ref. 3). Various research on the Californian shore indicate that although seasonal fluctuations are mianly restricted to the 0-9 m (0-30 ft) area the nearshore littoral drift may extend up to about 20 m (60 to 70 ft) depth.

Fig. 6 shows the bottom profile at Jupiter Island, S.E. Florida where, at present, tests on offshore dredging by dragline scraper are being run. Fluorescent sand material is dumped at various depths in the profile to check on the operation of the drag scraper.

Similar scraper tests have been carried out in England using a "submersible scraper" invented by the Hydraulic Experiment Station in Wallingford. Tests were rather successful but heavy equipment has so far not been put in action. In Florida the following basic equipment is involved: (a) a three-drum Sauerman drag scraper unit powered by a diesel motor; (b) a three cubic yard (2 m^3) bottomless crescent drag bucket; and (c) an offshore anchor arrangement including an anchored barge to which the dragline cables are attached. It is possible to shift the anchor barge from the shore. With the barge located about 300 m (1,000 ft) from shore, the excavation takes place about 200 m (700 ft) from shore at about 3.5 m (12 ft) depth. The production is about 50 m^3 (80 cu yd) per hour but may increase when more experience has been gained. Fig. 7 shows the scraper operation power unit and Fig. 8, the bucket on its way toward the beach filled with sand material scraped up in the offshore borrow area.

So far the tracer tests have shown that the scraper generally picks up its material where it is desired in the borrow pit, but that it may sometimes loose some material on its way to shore and then picks up new material closer to shore. Tracer material is injected in the pile on the beach and the migration of this material is being observed. At the same time the accumulation of material in the borrow area is surveyed in order to see how fast material is accumulated and what kind of material it is. Tracers of various colors are injected at various distances from the borrow hole. Aerial

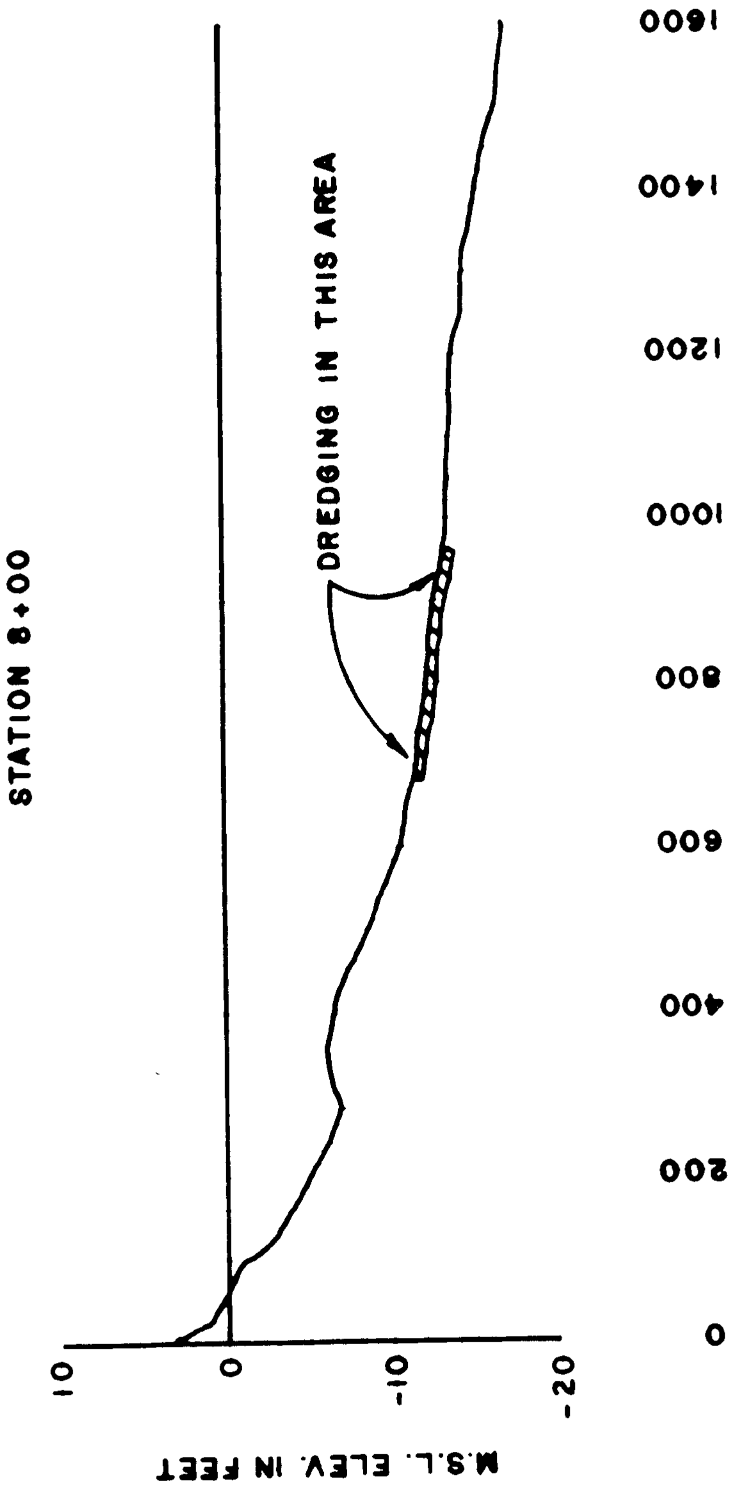


FIG 6 BOTTOM PROFILE AT JUPITER ISLAND, SE FLA.

FIG. 7. DRAG SCRAPER AT JUPITER ISLAND, FLA.: POWER UNIT

FIG. 8. BUCKET OF JUPITER SCRAPER ON WAY BACK TO SHORE LOADED WITH SAND

photography is also being used to observe the operation as well as the development of the borrow area after operation has been shifted to another area. The coastal protection at Jupiter Island is a combination of artificial nourishment by hydraulic dredge from the intracoastal waterway and lagoon behind the barrier, some short adjustable groins and revetments as described in ref. 8.

An evaluation of the efficiency of such scraper operation includes technical as well as economical aspects. Technically, the possibilities for return of material dredged in the offshore bottom and dumped on the beach to the offshore bottom (perhaps in the holes where it came from) must be evaluated. At the same time the cost of the dredging operation must be considered. Even if the possibility for return of material to, say, 8 m (25 ft) depth is only 1/3 of the possibility for return of the material to 5 m (15 ft depth, the price of dredging at 8 m (25 ft) depth (by suction type dredge in offshore waters) may be four times the price of dredging at 5 m (15 ft) deptl (by scraper) and, therefore, dredging at 5 m (15 ft) is still to be preferrec for dredging at 8 m (25 ft) depth which may be found at much greater distance from shore.

Example - Based on preliminary consideration partly of theoretical nature considering the adjustment of an equilibrium beach and bottom profile to a new and higher water table (ref. 5) and partly based on actual - but still inadequate - field observations, the possibility for return of materia from the beach to a certain depth y is given by the expression:

$$F_1 = e^{\frac{-D}{(D-y)}} \qquad (11$$

in which D is the limiting depth for short term ("seasonal") fluctuations of the bottom profile. The price of bringing the material to the beach is base on preliminary experience given by the expression:

$$F_2 = 0.125 \sqrt{y} \qquad (1\text{:}$$

in which y is the depth in meters. For example the cost at 1 m (3 ft) deptl may be $0.125 per cu yd (bulldozer) and the cost at 4 m depth (13 ft) may be $0.25 per cu yad (developed drag scraper operation) while the cost at 9 m depth (30 ft) may be about $0.40 per cu yd (large quantities by hydraulic dredge which may discharge through pipe located on the bottom). My multiplication of expressions (11) and (12):

$$F_1 \times F_2 = 0.125 \sqrt{y}\, e^{\frac{-D}{(D-y)}} \qquad (1$$

Equations (11), (12) and (13) are depicted in Fig. 9. Expression (13) indi cates the relative benefit of dredging of material for nourishment at vario depth omitting the extremes (0 and D depths). It may be seen that dredging at depth D_y is the most expensive procedure while dredging at depths D_x and D_{xx} are of equal benefit because probability and unit price by multiplicati give the same result.

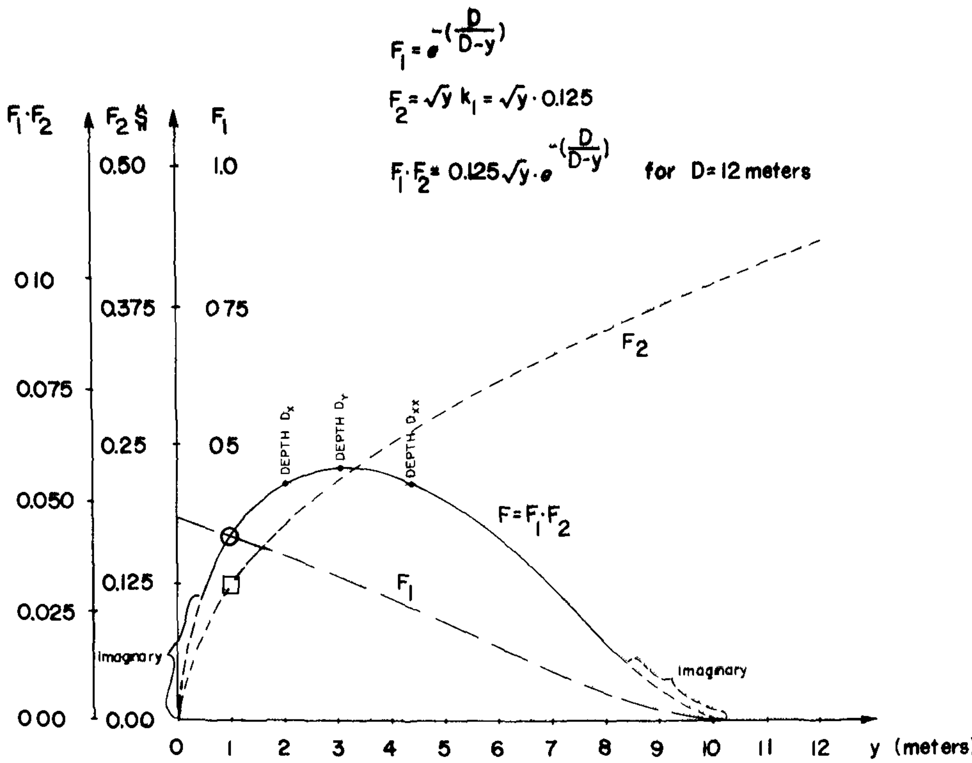
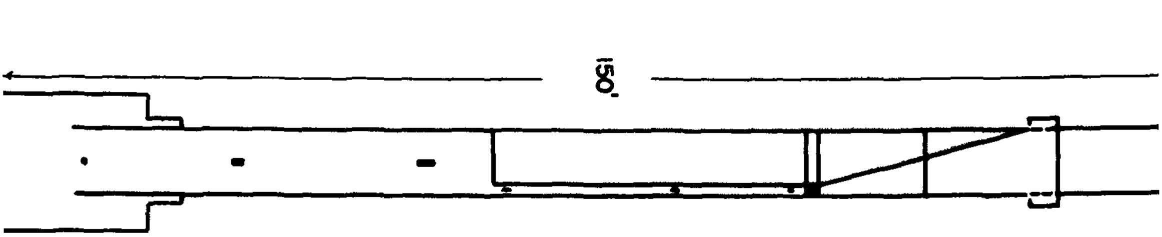


FIG 9 RELATIVE BENEFIT FROM DREDGING OF MATERIAL AT VARIOUS DEPTHS IN A BOTTOM PROFILE



PLAN

FIG. 10. WAVE TANK FOR TESTS ON BED-LOAD TRANSPORT BY WAVES AND CURRENTS

At this time, results available for checking of the validity of equations 11 to 13 are inadequate. It is clear that only average values may be obtained and that results of single extreme storms may deviate considerably from the average. It should be mentioned that the development of a hydraulic dredge for operation in open seas and discharging to shore through submerged pipeline is progressing. So far, tests are being run by the U. S. Army Corps of Engineers using a converted dredge, the U. S. Comver.

LABORATORY RESEARCH

It is clear that the results of field experiments with bed and suspended load are only valid for the (often complex) conditions under which these experiments were run and in order to gain information useful in practice a great many results under a variety of wave and current conditions are needed. These results must link wave and current characteristics to sediment transportation characteristics. Concerning the hydraulic hcaracteristics, reliance should not be placed on generalized wave and flow patterns alone but efforts should be intensified to determine more detailed data, such as bottom velocities, their directions and fluctuations, turbulence in the grand as well as the small scale. This information in detail is difficult to obtain in the field but may be determined in the laboratory by "prototype experiments" as described below.

TRANSPORT BY WAVE ACTION

Several experiments have been made in flumes on transportation of bed material by wave action and on the distribution of velocities including mass transport velocities. Ref. 21 mentions tests in a wave flume. Near the sand bottom within certain limits of steepness, the bottom drift was always in the direction of propagation of wave action. So was the drift in the water surface, while in the middle drift was seaward or against direction of propagation of wave action.

Similar experiments by Lhermitte (ref. 17) consider the formation of ripples and the influence of viscosity in the bottom boundary layers. These tests do not mention specifically the damping effect caused by loss of energy by friction between fluid and bottom. The friction parameter depends partly upon the bottom configuration (ripples, dunes, smooth, etc.) and partly upon whether the undulating boundary is non-movable or movable. Water velocity and particle velocity cannot be measured separately unless the material is very fine (wash-load) in which case the sediment and water particle velociti are identical.

TRANSPORT BY WAVE AND FLOW ACTION

Propagation Unidirectional

Inman and Bowen (ref. 14) mention tank research on waves and currents running over a sand bed using Bagnold's (refs. 1 and 2) transport formula:

$$i_\Theta = kw \frac{u_\Theta}{u_m} \tag{14}$$

where i_θ is the dynamic transport rate of sand which results when wave stress places sand in motion in the presence of a current, w is the decrement in transmitted power of the waves attributable to bed drag, u_θ is the steady current flowing near the bed in the direction of the wave travel, u_m is the maximum horizontal component of the orbital velocity near the bed and k is the dimensionless coefficient of proportionality. Traps were installed in the sand bottom and the net transport was determined by subtracting the amount of sand trapped at the upwave end of the bed, from that trapped at the downwave end. Estimates of the power expended by the waves was obtained from the decrement in wave height as the wave traveled over the sand bed. The decrement in wave height was found to be about 10^{-3} per unit of distance traveled. Preliminary calculations showed that about one tenth of the total power expended by the waves was in transporting sediments. For low values of the current, a consistent relationship was found between the energy loss of the waves and the work done in transporting the sediment over the bed. Further increases of current velocity created complex flow conditions over the ripples and the theoretical assumptions were no longer valid. Future research was, therefore, recommended to include detailed studies of the current picture.

Wave and Current Action Operating Under An Angle With Each Other

Wave action may be operating under various angles with current activity. Inasmuch as a current running parallel to shore has to turn 90 degrees in order to enter a coastal inlet, angles between current and wave direction of 0 to 90 degrees may occur in the inlet entrance. Longshore currents and wave action responsible for the longshore current activity on the open seashore are not far from being perpendicular to each other.

The relative importance of the two sediment agitating water movements have to be considered. As long as the longshore current movement is predominant it may be expected that it will be associated with friction factors valid for unidirectional flow under similar bottom conditions.

The longshore current theory by Bruun (ref. 7) and by Chiu and Bruun (ref. 9) is based on the statistical distribution of wave heights. It has two approaches. One, "the rip current continuity approach" refers particularly to moderate velocity longshore currents caused by waves of smaller angles of incidence of wave crests.

The other approach is called "the slope continuity approach" and is based on inflow of water from wave breaking under a certain not too small angle with the shoreline which creates a longshore "hydraulic slope" of the water table corresponding to an ideal situation by which the entire cross section of the trough between the bar and the beach has a uniform distributed energy head. The difference between the assumed and actual situation must be expected to reveal itsel in the way that computed currents are on the high side.

With respect to friction factors, it will probably depend upon the relative importance of the longshore current velocity and the velocities of the wave agitated water particles. Both factors are of importance for current and for the littoral drift by action of waves and currents.

With wave action only, the decrement in transmitted power $\frac{dP}{dx}$ may be obtained when the decrement in wave height per unit of distance traveled $\frac{dH}{dx}$ is known. One has:

$$\frac{dP}{dx} = \tfrac{1}{4}\rho g H \frac{dH}{dx} \cdot C_n \tag{15}$$

where C_n is the group velocity. Inman and Bowen (ref. 14) observed that the distribution in wave height was approximately exponential:

$$H = H_i e^{-ax} \tag{16}$$

where H_i is the initial wave and e is the attenuation coefficient $\frac{dP}{dx} = w$ in equation (14) which must be a function of $(\tau_{bottom\ shear})^{3/2}$. If no suspended load is being transported, Bagnold (ref. 2) writes the bed-load transport relation as follows for unidirectional flow:

$$\Phi_b = A^1 (\theta - \theta_t)\theta^{\frac{1}{2}} \tag{17}$$

in which Φ_b is the bed-load transport function =

$$\frac{Q_b}{6D\sqrt{\gamma/\rho}} \quad \frac{(\tan\alpha_o - \tan\beta)}{\tan\alpha} \quad \frac{1}{\sqrt{2\tan\alpha/3\psi}} \tag{18}$$

Q_b = volume transport per unit flow per unit time, ρ = density, D = grain diameter, $\tan\alpha_o$ is the dynamic shear stress ratio just over the bed surface, $\tan\alpha$ is the shear-stress ratio for the grains (friction angle), β = the declination of the bed surface, ψ = the drag coefficient of a single isolated grain, A^1 is a numerical transport-rate coefficient, $\theta = \tau/\gamma$ where τ is the overall (measurable tangential bottom shear stress consisting of a component due to influence of grain on grain and a tangential stress in th grainless fluid, modified by presence of dispersed grains. Quantity θ_t is the general threshold value = τ_t/γ where τ_t is the non-efective applied tangential stress on the stationary bed surface (ref. 4).

Without going into details, equations (14) and (17) demonstrate certain similarity. Adding the shear stresses "tearing loose ability" and taking into consideration the material transport, one gets for quantity of material transport:

$$M = \text{Function}\left(\frac{K_{1tv}\sqrt{\tau_1^2 + \tau_{tv}^2}^{\,\beta}\, U_{tv}}{U_{mtot}}\right) \tag{19}$$

where K_{ltv} is a combination of K in equation (14) and a corresponding coefficient for drift by unidirectional flow including soils characteristics as mentioned in Bagnold's bed-load expression. U_{tv} is the velocity of the transversal (transporting) current and U_{mtot} is the maximum vectorial current velocity occurring during one cycle of the wave motion assuming a longshore current of a certain average value. This, in turn, is another "ideal" assumption.

Tests sponsored by the National Science Foundation are now in progress at the Coastal Engineering Laboratory of the University of Florida on littoral drift with a current running parallel to, as well as perpendicular to, the wave action. In all tests the current conditions at the bottom correspond to prototype conditions with water particle velocities of about 0.5 m per sec. maximum.

Figures 10 and 11 show the wave tank. A partition wall separates it in a 2 ft wide and 4 ft wide section. Bed-load traps are installed on the bottom and current velocities are measured partly by a propeller instrument (minimum 2 cm/sec) and partly by photographing buoyant particles (amber). With waves passing down through the tank, currents are run along as well as perpendicular to the direction of wave propagation. The latter is possible because of the T-shaped end of the wave tank where a longshore current is generated by the circulation system indicated in Fig. 11. To avoid eddy formation and dispersion of sand material from the bottom in the upper water layers of the tank, a plastic sheet is put in about 15 to 20 centimeters above the bottom. The longshore current runs below said sheet which does not disturb the general motion of water particles in almost closed paths but hinders the development of free turbulence between the two bodies of water above and below it. This arrangement would be rather fatal to the study of suspended load movement, but inasmuch as the space left between the sheet and the bottom is outside the saltation zone, the sheet will not have much influence, if any at all, on the bed-load transport.

Velocities and velocity profiles close to bottom are measured with fixed (mortared) as well as loose bottom in all the experiments with waves parallel to, as well as in experiments with wave and current action perpendicular to each other. Information on friction parameters are obtained hereby and by measuring head differences.

Bed-load traps and fluorescent tracers are used to detect details of the movement which takes place in sheet layers as well as in sand waves of varying dimensions. Several colors are used injected at different distances from the trap to trace movements in sand waves as bed load. Scanning of the results are made by the photoelectric scanner described earlier in this paper. Results to these tests will be available in the course of 1965 (ref. 15).

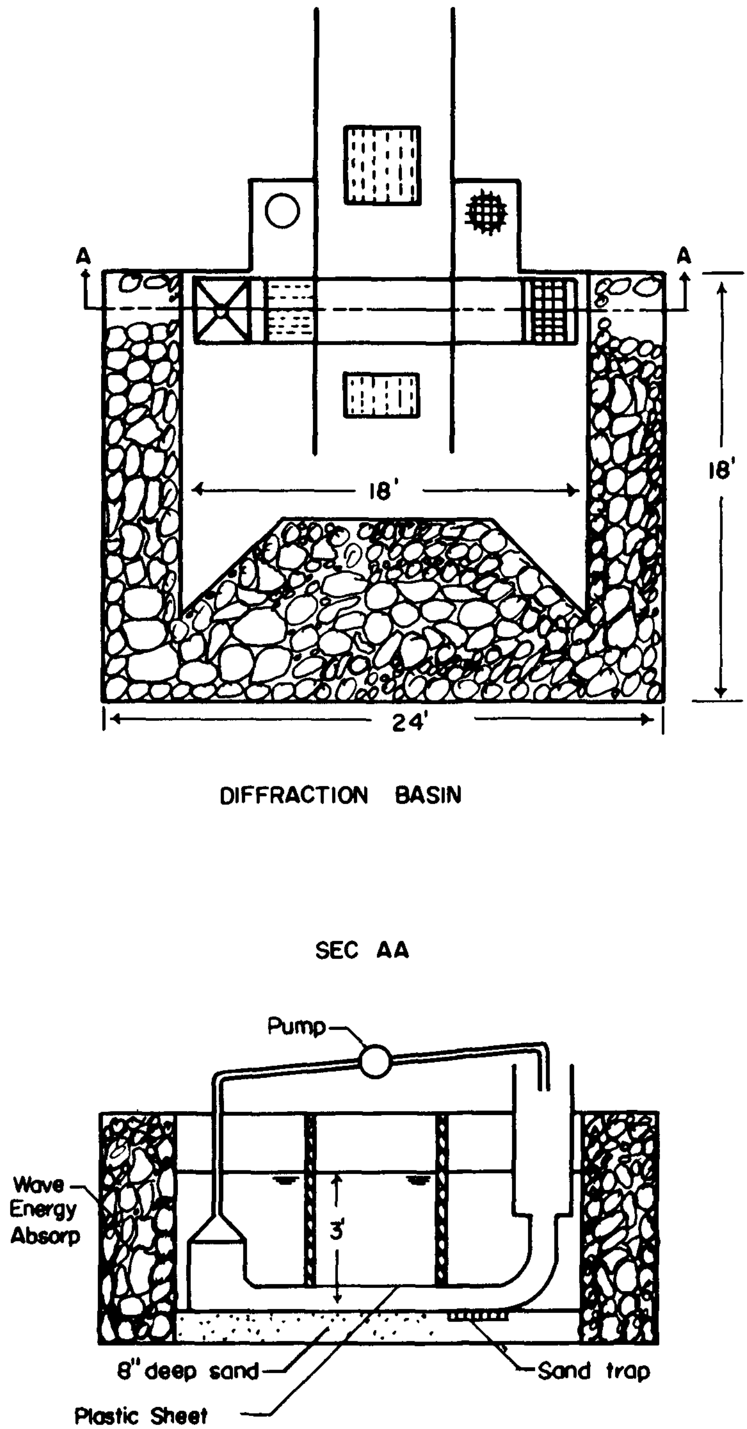


FIG. 11. CROSS SECTION OF WAVE TANK FOR TESTS ON BED-LOAD TRANSPORT BY WAVES PERPENDICULAR TO CURRENTS

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