THE MECHANISM OF DEPOSITION OF HEAVY MINERALS ON THE BEACH BY WAVE ACTION

by

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Abstract

A wave tank and a wave generator was developed in stages in the laboratory to obtain different types of waves, wave breakers and currents. Tests on movement of sand were carried out using actual beach sand comprising heavy minerals of a wider range of grain sizes under pure waves, currents and a combination of waves and currents. It was found that the transportation and deposition of sand uniformly over a stretch of artificial beach is caused neither by pure waves nor by pure currents but by a combination of waves and currents.

1. Introduction

There is a huge deposit of heavy mineral sands such as ilmenite, rutile, zircon, monazite & garnet on the beach at Pulmoddai in the North-East coast of Sri Lanka. (See figure 01.) No such deposit is found elsewhere in the country. No research has been carried out to determine the actual process by which these minerals have been brought from somewhere to this location. The beach sands are of different grain sizes ranging from 63 to 300 microns and the minerals are fully liberated into individual minerals. Each year, it is observed that large quantities of heavy minerals are brought from the sea by waves and deposited on the beach during monsoon season.

Observations of cyclic events during a period of one year show that it is only during the monsoon season that heavy mineral bearing sands move to the beach in large quantities. Even in this period, sand does not move to the beach during days in which waves are breaking in the sea away from the beach. In the off-monsoon season when waves are not violent, the sand that has already got deposited on the beach goes through a process of separation and sorting, resulting in a beach of very high grade heavy minerals exceeding a heavy minerals grade of 85%.

Note : Ilmenite and rutile are black in colour and during this period the beach becomes a black sand beach.

2. Test Apparatus

For this purpose a Wave Tank out of 06mm steel plates, 3660mm (L) x 1830mm (W) x 760mm(D) in size, fitted with a wave plate, driven by an arrangement of a fixed rpm electric motor, with four interchangeable driving wheels arrangement to obtain four different rpm at wave plate, and a wave plate driving disc with five hole positions to obtain five different wave amplitudes was originally fabricated. However, waves could not be generated with this tank. Instead, water was splashed at the centre of the tank spilling over the tank forming wave resonance. The tank length was then extended by another 1830mm and tests were repeated. But no improvement was observed. Thereafter the tank length was further extended by another 2440mm. with a slope in the form of a beach and tests were repeated. Waves were formed. However, different shapes of waves could not be obtained at the selected four rpm positions and at the five wave amplitudes. The Motor was then replaced with a variable speed electric motor. The wave tank sides (front and rear) were fitted with wave absorbers (sponge sheets and wire mesh), and the two longitudinal sides were cut and fitted with transparent perspex sheets. The Beach-end side was welded to a launder connecting it to the side of the tank with a pipe. (See Fig. 02 & 03.) Beautiful waves of various shapes were formed by varying the motor rpm and wave plate amplitude.

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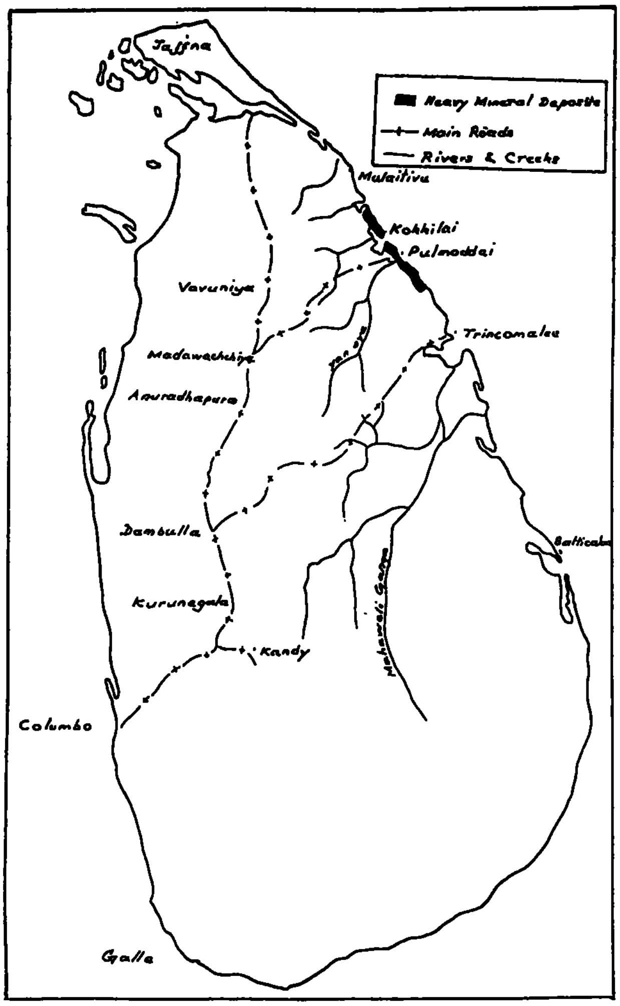


Fig. 01 - Location of Heavy Mineral Deposits At Pulmoddai

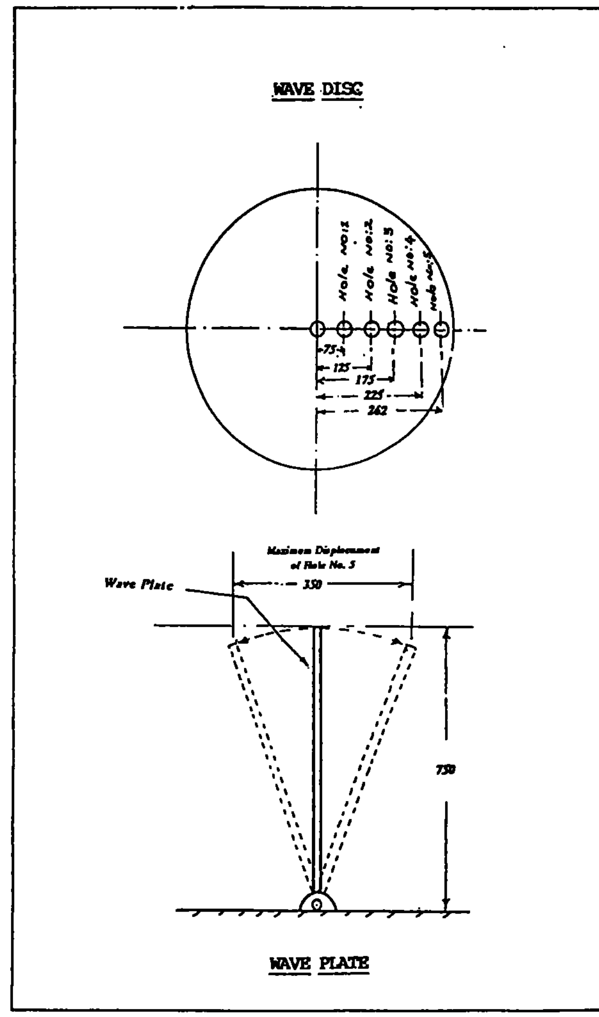


Fig. 3- Wave Disc (Driving Wheel) and Wave Plate

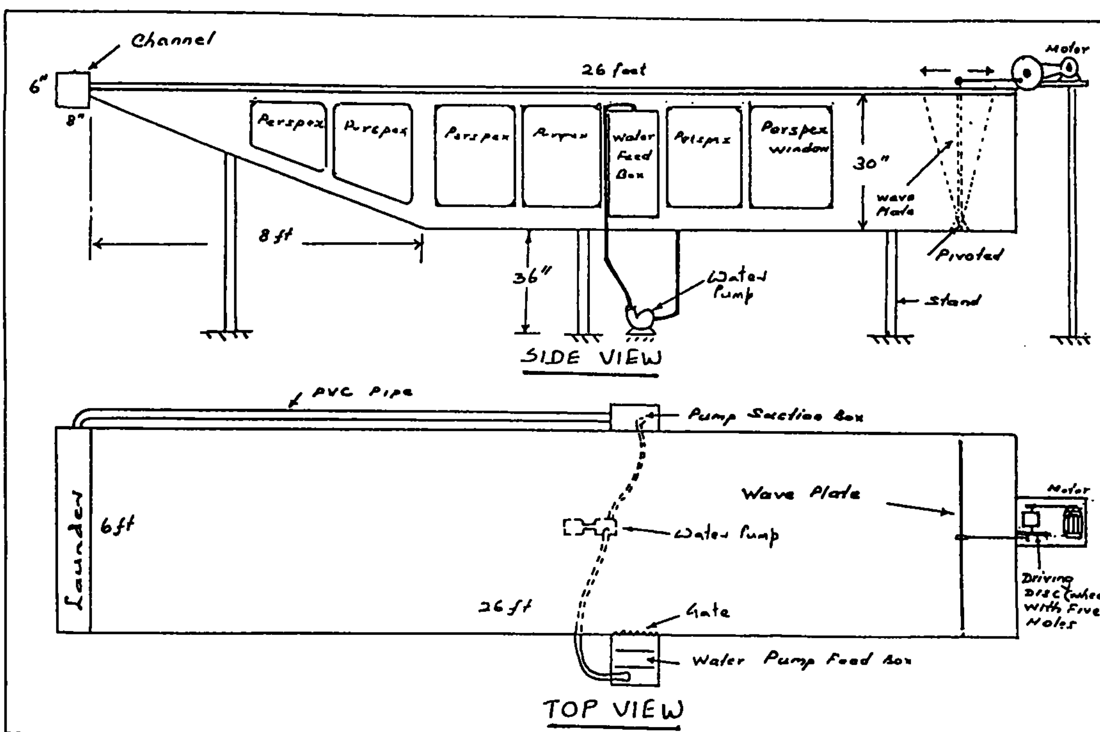


Fig. 02 - Wave Tank, Wave Generator and Water Pump Arrangement

3. Experiments & Observations

3.1 With water alone :

Following tests were carried out after filling the tank with fresh water.

(I) Keeping the water depth in the tank and the wave plate amplitude fixed and varying the rpm.

(II) For the same water depth, the above test was repeated for five different amplitude positions (i.e. Five different hole positions in the wave plate driving disc)

(III) The above tests were repeated for different water depths.

The results of the above tests indicate that the wave height increases as the rpm of the wave generator is increased and reaches a peak and then decreases. The same is true for different wave generator amplitude positions. However, the wave height increases with the increase of wave generator amplitude. Plunging waves were formed at higher amplitudes of the wave generator. (See Fig.04.)

3.2 With water and the sand bed :

The bottom of the wave tank was covered with sand upto a thickness of 115mm - 150mm using beach sand and the beach side (inclined plate) was also covered with beach sand to form an artificial beach. The same experiments under 3(i), (ii) & (iii) done before with water alone were repeated with sand bed. Sand motion was observed through the perspex sheet windows.

At a given water depth and frequency, as the amplitude of the wave generator increased and reached a particular amplitude, the sand grains started to move to and fro, When the test was continued at this initial motion setting, sand ripples were formed.

The ripples were symmetrical and stable. Their height and the length were measured. It was observed that the ripple height increased as the frequency (wave generator rpm) increased. The sand ripples formed were almost stationary and symmetrical. The shape and position of sand ripples were plotted on a tracing paper fixed on to the perspex plate on the longitudinal side of the wave tank every two hours for eight hours at a particular setting and observed that the ripples were fully formed after about one hour. The rip-

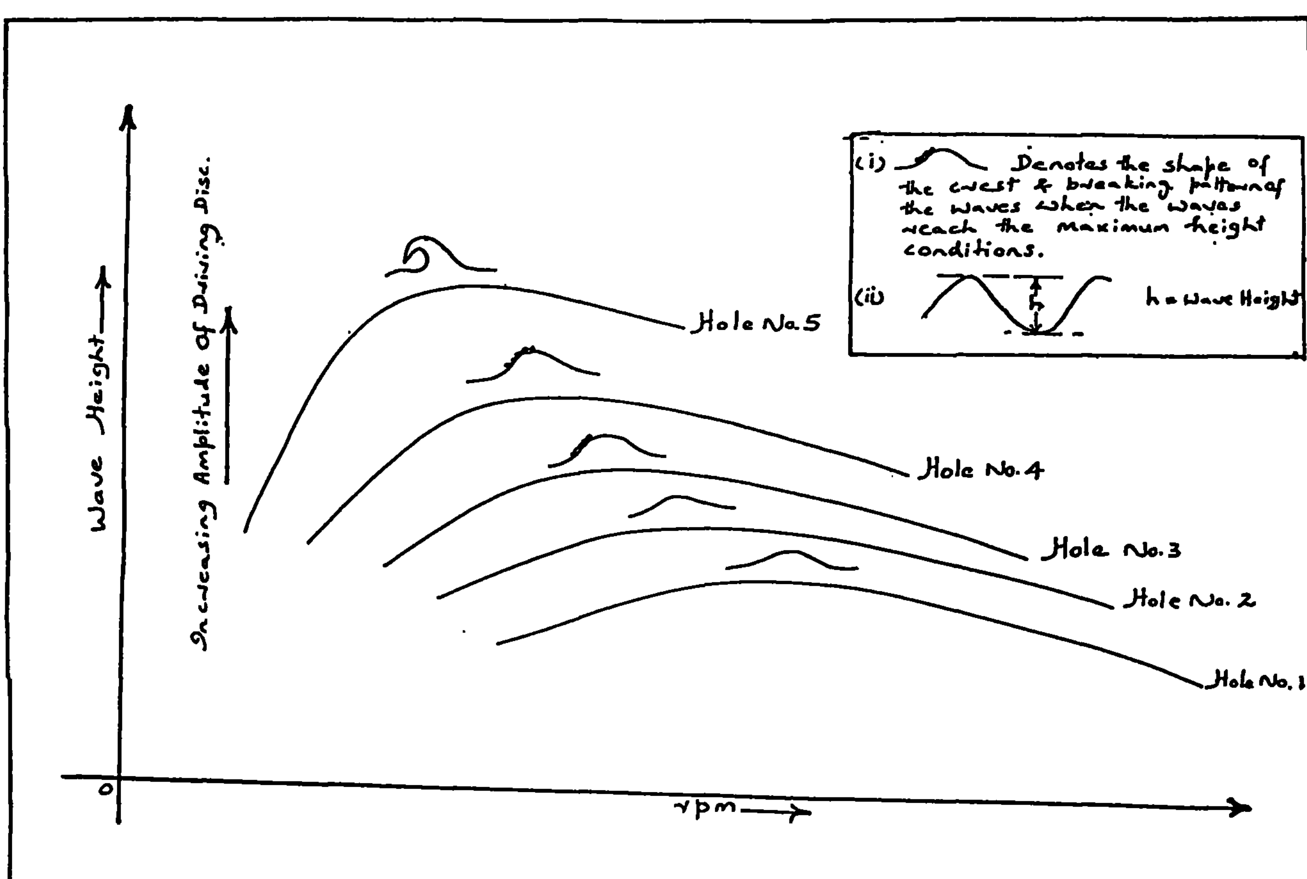


Fig. 04 - Rpm vs Wave Height

ples so formed did not change with time, provided the settings (water depth, amplitude and frequency) were not altered. Ripple height and length, wave height, rpm, water depth etc. were recorded(see Table 01). After eight hours, sand was allowed to settle, and the tank was very slowly dewatered and the ripple pattern inside the tank was roughly plotted on a sheet of paper. Sand samples in three locations were taken and any change in the original position of the sand bed was studied. In these tests with water waves, it was observed that there was no noticeable shifting of the sand on to the beach.

(iv) *Honeycomb type openings. (Fig. 08)*
Flow of water across the tank was very uniform. Negligible cavities at the suction and delivery ends were formed. This gate was used for the creation of currents in the rest of the experiments.

3.4 With the combination of waves and currents :

Wave tank bottom was laid with a homogenous mixture of beach sand (known heavy mineral sand percentage and grain size) upto a thickness of 115-150 mm.

Table No.01 - Influence of Wave Length, Wave Height and Wave Period of Oscillatory Water Waves on Sand Bed At Different Water Depths

Wave Disc Hole Position No. 5

Water Wave			Average Water Depth Mm	Average Ripple	
Period Sec.	Length mm	Height mm		Height mm	Length mm
2.28	3630	150	28	6.5	54
2.00	1560	100	26.5	6.4	53
1.78	1620	135	27	9.7	75
1.50	2040	150	27	9.6	68
1.42	2510	295	28	11.7	81
1.30	1600	270	26.5	9.3	70

3.3 Introduction of water currents :

As a current generation arrangement, two square openings were made on the two longitudinal sides of the wave tank 4570mm. from the wave generating side and covered with boil boxes. A 3"/2" slurry pump driven by a 15 HP, 1440 rpm, 3 phase Motor, with the suction side connected to the bottom of one boil box and the delivery side connected to the top of the other boil box was installed.

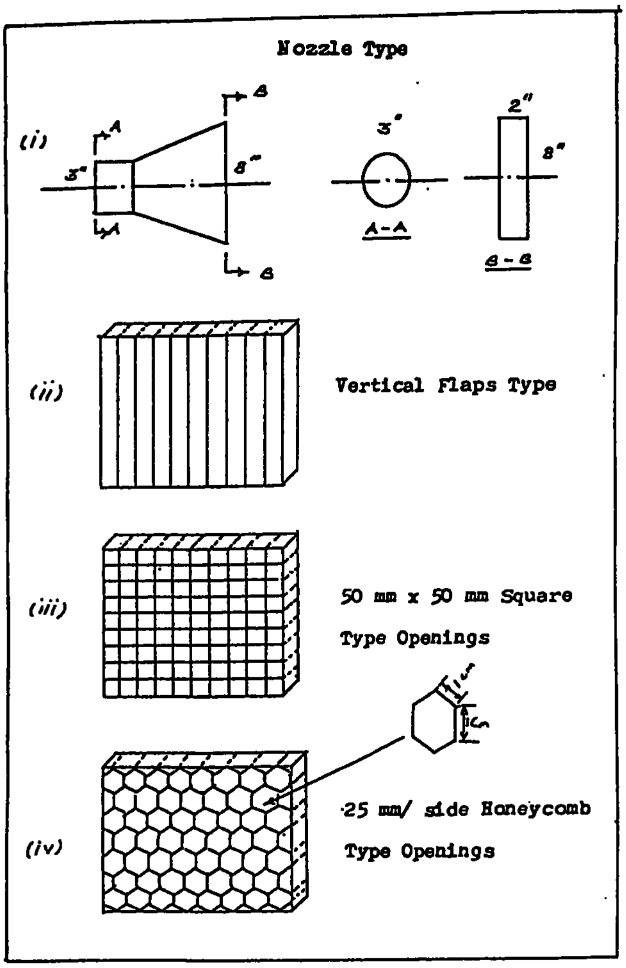
Water was delivered without waves, across the tank using four types of gates and water velocities across the tank were measured using a capillary tube.

(i) *Using the tapered nozzle with a square/oval shape outlet (Fig.05)*
Large pits (cavities) were formed in the sand bed at the delivery and suction ends. No uniform flow (currents) was formed.

(ii) *Using the vertical flaps arrangement (Fig.06).*
Slight improvement, but still pits were formed.

(iii) *Using the square openings arrangement (Fig. 07).*
Vast improvement in the uniform flow across the tank with small pits ,

An inclined beach was also made using same sand. Fresh water was slowly pumped into the tank through a hole in the bottom of the tank using a gate valve control arrangement without disturbing the sand bed. The tank was filled upto a predetermined height. The wave plate amplitude was set at the lowest (Hole No.01) and the wave generator was started. The generator rpm was increased very slowly from zero until the " initial motion " of sand grains on the top surface of the sand bed took place. The rpm was then further increased slightly and allowed to run continuously for eight hours. A long transparent sheet of paper was fixed onto the perspex sheet to cover the entire perspex window and the ripple pattern on the sand bed was traced on the sheet every two hours. Frequency, wave height, ripple length, ripple height, water depth etc. were recorded. This experiment was repeated the following day with the introduction of currents (starting the pump) and the motion of the sand grains on the sand bed was observed through the perspex window. See Fig. 09. As before, the ripple pattern was traced on a transparent paper every two hours. Fig. 10, 11, 12, 13, 14.



Different Types of Gates Ftted on to the Water Inlet Side of the Wave Tank

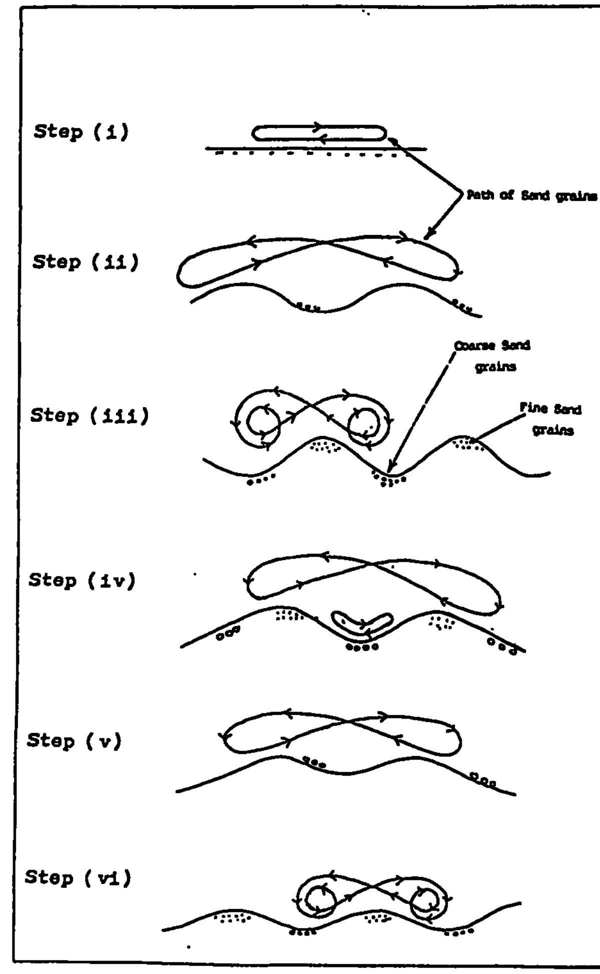


Fig. 9- Cyclic Repettion of The path of sand Grains and Thereby Shifting of Sand Ripples in the Forward Direction.

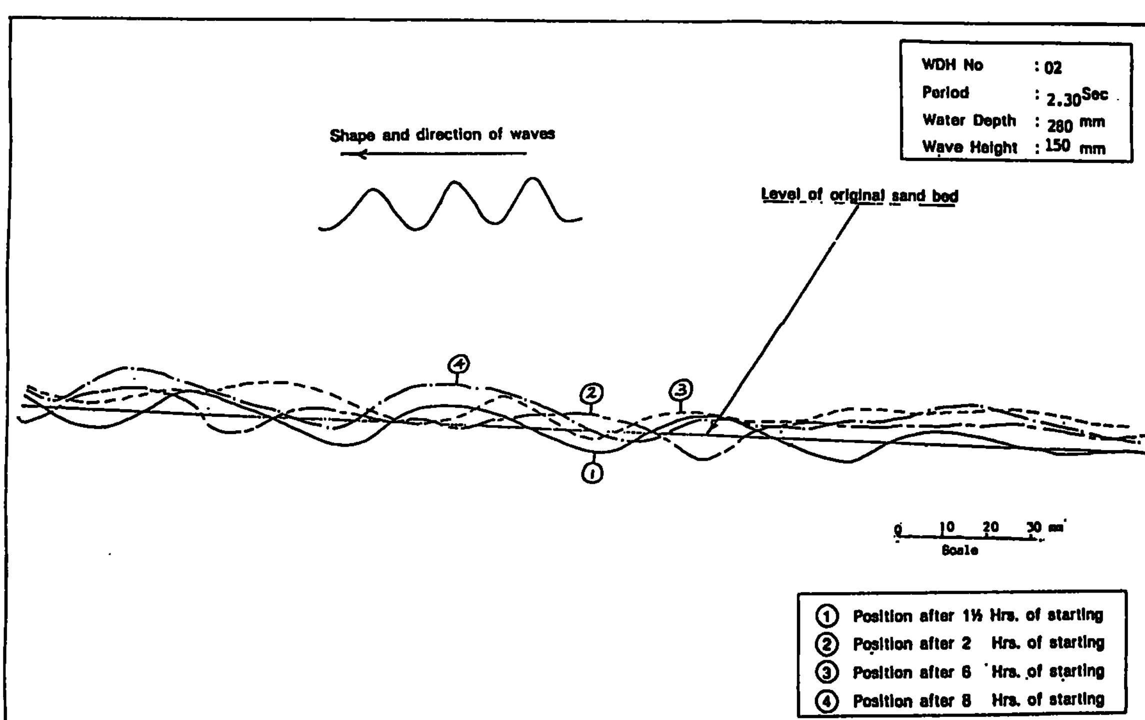


Fig. 10 - Change of Ripple Pattern & Position With Time

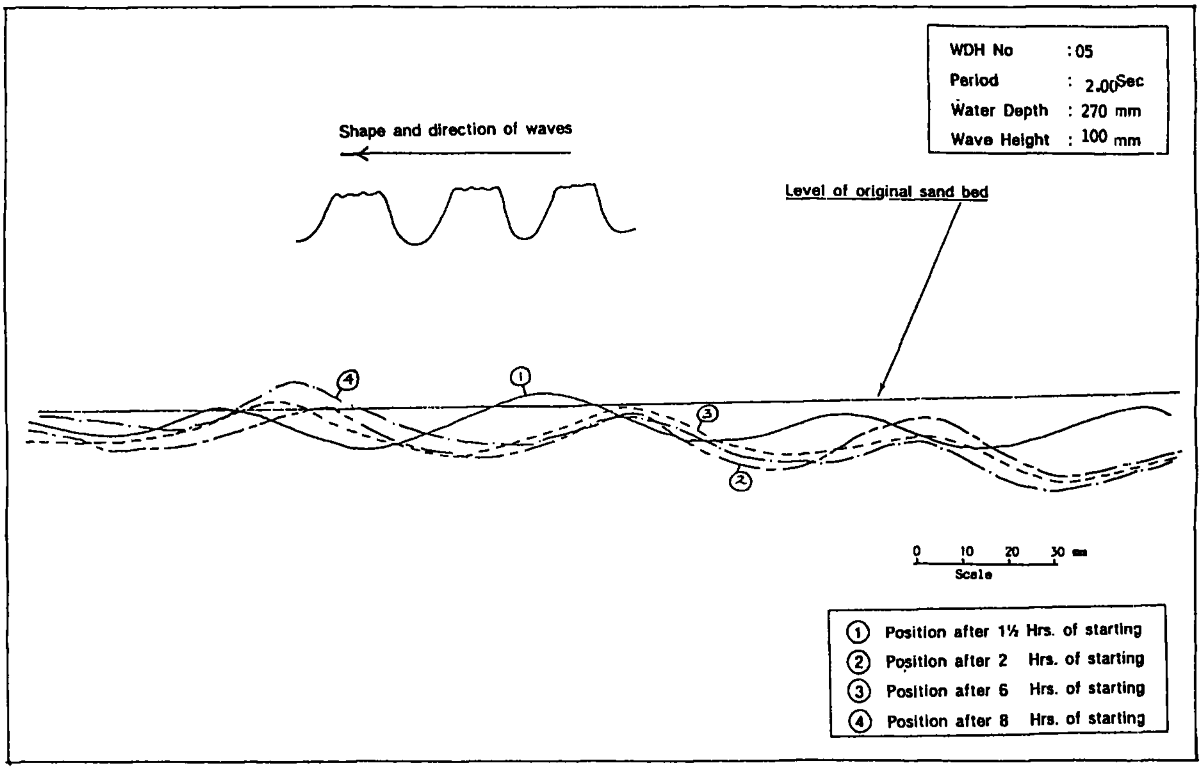


Fig. 11 - Change of Ripple Pattern & Position With Time

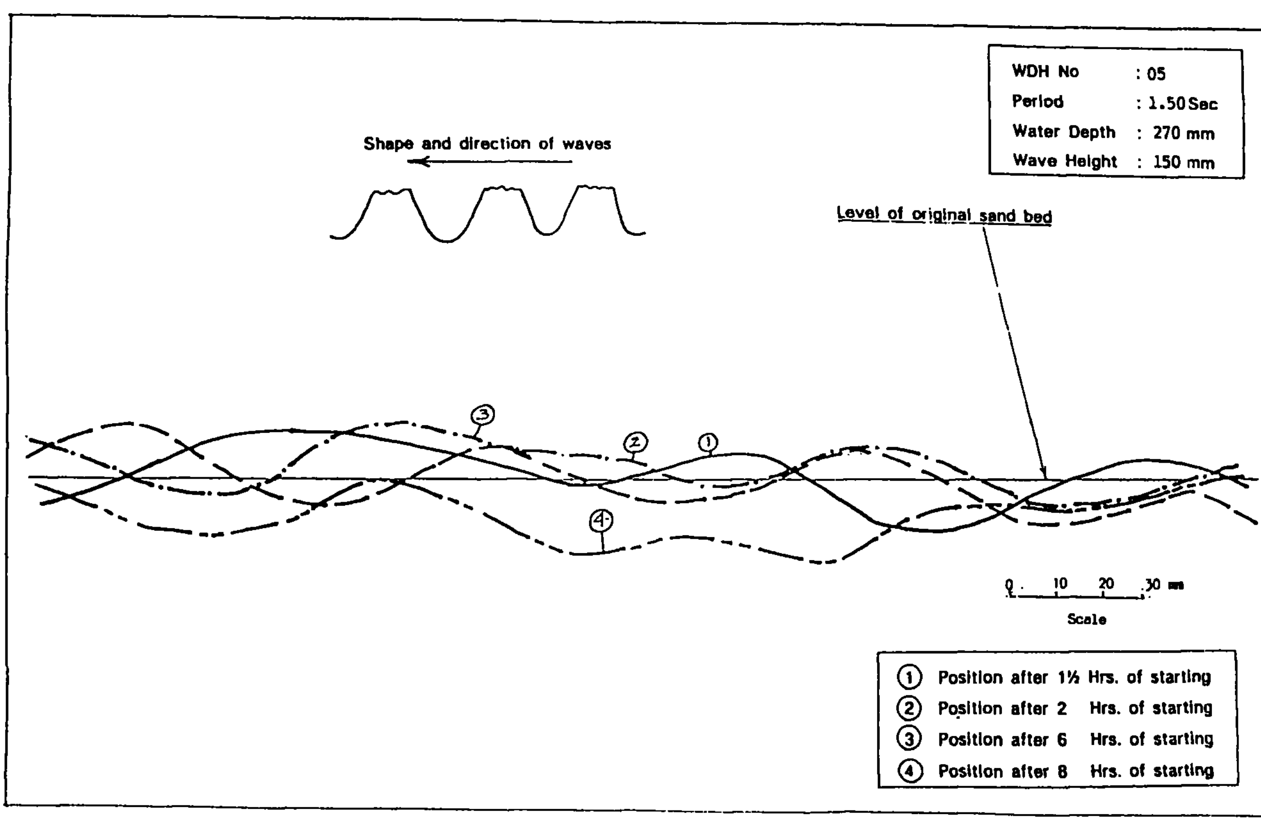


Fig. 12 - Change of Ripple Pattern & Position With Time

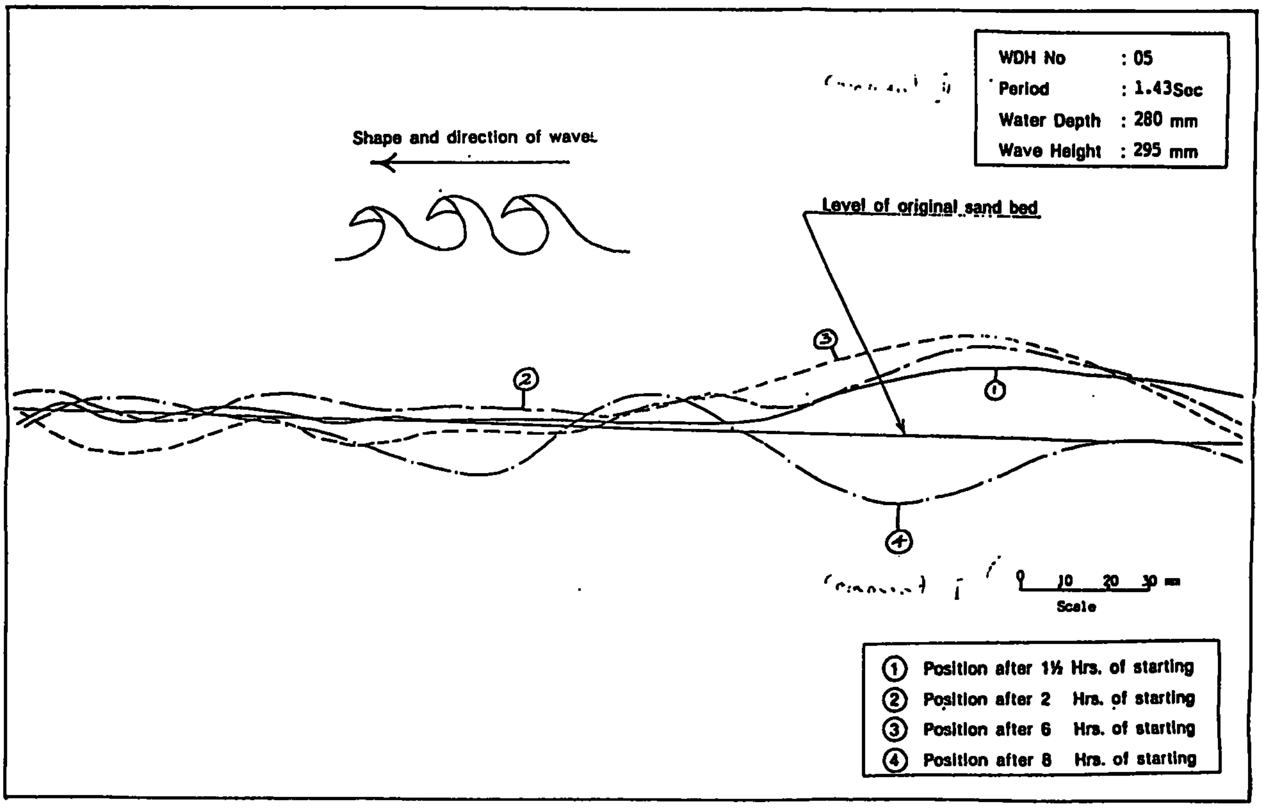


Fig. 13 - Change of Ripple Pattern & Position With Time

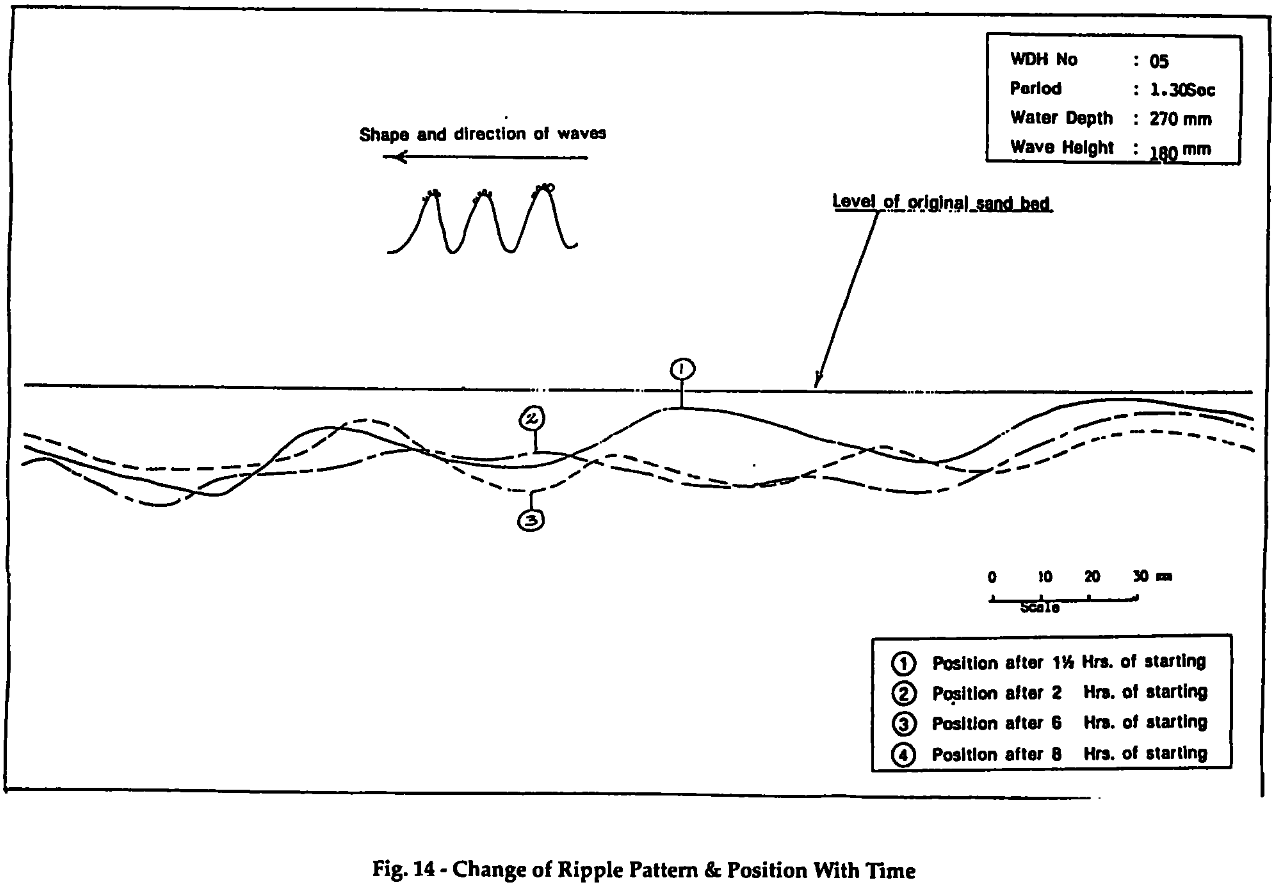


Fig. 14 - Change of Ripple Pattern & Position With Time

3.5 Scale Factor:

The artificial beach of the wave tank upto a water depth of 600 mm with the gradient of approximately 5 is similar to that of a natural beach. Therefore, the sand movement in the artificial beach is similar to that in the sea beach in actual practice. But, in the case of the wave tank pure water waves and currents are in two fixed directions whereas in the sea, waves and currents are in several directions at any given time and constantly changing. However, the rest of the tank bed is flat and at a depth of approximately 600 mm. The effect of the water waves on a sand bed at a depth of 600 mm below water surfaces would be identical to the effect of sea water waves on the sand bed at the bottom of the sea at a higher depth provided that the sea water waves are strong enough to reach the sea bed. The scale factor of the wave length and amplitude of the water waves created in the wave tank should be proportionately increased in size to determine the effect at higher water depths as occurs in the sea. Hence, the scales of the wave tank experimental results such as wave length, height, period can be increased proportionately to determine the effect of waves on the sand bed at higher depths in the sea. Sand used in the artificial beach is the actual heavy mineral beach sand and hence the motion of sand grains are similar to the grain movement in the actual sea beach and therefore application of scaling factor for sand grains does not arise.

4. Data and Analysis

Hole No. 5 : Wave generator Stroke = 23.5 cm
Average water depth = 27.5 cm

Table 02

Wave period (Sec)	Wave height (cm)	Movement of Ripple Crest in intervals of 2 Hrs. in cm		
		0 - 2 Hrs	2-4 Hrs	4-6 Hrs.
2.31	15	*	3.0	2.2
2.00	10	*	5.0	1.0
1.50	15	*	3.6	3.5
1.43	29	*	6.5	0.5
1.30	18	*	3.0	3.5

* Fully developed ripples were formed with in the first two hours

With pure water waves, sand ripples are formed gradually and become stable in height and shape. The figures given in Table 02 are the measurements obtained from the tracings marked as Fig.10,11,12,13 &14. The tracings show the actual shape and position of a ripple and the corresponding shape of the water waves after the introduction of water currents at every 2 hour interval. The ripples that were stable and stationery under pure water waves start moving after the introduction of water currents across the tank at an angle (not perpendicular) to the direction of water waves. A close look at the sand ripples show that the shifting of sand ripples with time takes place as several steps of "vortices formation and disappearance" as shown in Fig. 09. which start only after the introduction of currents. In pure sinusoidal waves regular occurence of this phenomena does not take place. Introduction of currents causes the wave to be asymmetrical which in turn causes the systematic repetition of "vortices formation and disappearance" thereby moving the sand grains towards the beach.

5. Conclusion

(I) Symmetrical oscillatory water waves cannot transport sand. They can only move the sand grains to and fro, loosen the top layer of the sand bed, form ripples and bring the lighter and fine grained sand to suspension. However in reality these conditions do not exist in the sea. Different waves and currents are moving in various directions and therefore, pure sinusoidal waves never exist. Result is that a sand grain is continuously changing its direction of motion.

(II) Pure water currents cannot transport sand evenly over the entire length of a beach continuously and systematically. It can only transport the suspended material irregularly and indirectly. This is true in areas where water waves are not present.

(III) Neither pure water waves nor pure water currents alone can transport sand over a entire length of a beach evenly, continuously, regularly and systematically.

(1V) Currents do not loosen the sand bed and keep the sand grains in suspension as in the case of water waves.

(V) Currents make the symmetrical waves and ripples asymmetrical and therefore, the ripples formed by water waves cannot get stabilised due to asymmetry. Though near sinusoidal waves can be achieved in a wave tank fully developed sinusoidal waves cannot be formed due to reflections from tank side walls. Smooth sides and wave absorbers improve the conditions eventhough such conditions do not exist in the sea.

(V1) As a result of the asymmetry, the ripples undergo a continuous cycle process of formation, deformation and formation thereby moving the sand forward in the direction of waves. In the sea this cyclic process will be a very complicated one due to the presence of groups of waves and currents and their different directions that change rapidly.

(V11) Bulk of the sand moves forward in the direction of water waves as a result of the asymmetry created by the action of currents on waves at the sand bed. Small quantities of light density and coarse grained sand and fine grained denser sand under suspension are moved by the currents. In fact these changes can be observed on the sea beach in seasons of calm and rough weather conditions.

(V111) Concentration of heavy minerals in the sand mixture thus transported on to the beach occurs due to the surging water moving up, perpendicular to the beach and moving back to the sea carrying the lighter sand particles, while leaving the heavy sand particles on the beach.

(1X) The water waves on the surface should be strong enough to create ripples at the bed. If the water depth above the sand bed is large, water waves may not be strong enough to make an influence at the sand bed and hence no ripples are formed. In this situation water currents can not move sand from the bed. (This situation has been observed at sea at Pulmoddai. The ships that are calling at Pulmoddai are anchored in the open sea at a distance of 1 1/2 Km from the beach. The items that have fallen from the ships accidentally while loading, have been recovered in the same location after one year by divers. It was interesting to note that even the items such as beer cans, bottles etc. had not moved away from the original place even after one year even though strong waves existed there).

(X) The water wave/current combination moves the top layer of the sand bed hence the thickness of the bed becomes smaller and smaller with time. This means the depth of the water upto the bed gradually increases. Therefore, the water waves have also to be gradually increased in size to make the initial motion. If this does not happen, the transportation of sand does not take place after sometime as no ripples are formed. In nature, the transport of sand to the beach decreases over the years. This phenomena has already been observed at Polmoddai, where production records show that although there is a large amount of heavy minerals in the sea, the quantities deposited on the beach is less than the amounts deposited 20 years ago.

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