CHAPTER 160

Laboratory Study on Beach Processes due to Random Waves

Ryuichiro Nishi, Michio Sato and Kazuo Nakamura

Abstract

The beach processes due to regular waves, grouping waves and random waves are studied. The beach models which consist of coarse or fine sand are set to consider bed load and suspended load sediment, respectively. To obtain the equivalent beach topographics between regular wave and random wave conditions, the concept of same energy flux and same representative wave height are applied.

1. Preface

Natural beach conditions are dominated by random waves and three dimensional sediment transport(Goldsmith,1982, Nishi,1989),etc. Much data concerning coastal processes has been collected through experimental and theoretical studies. Regular waves and wave flume have been used mainly in these studies. Recently some reports on beach processes due to random waves have also been published(Dette,1986, Hsiang,1976, Irie,1986, Mimura,1986, Nishi,1988, Tsuchiya,1974).

It is necessary to study beach processes due to random waves in order to correlate knowledge gained from studies under regular wave conditions. It is also important to define regular wave characteristics for coastal and beach process experiments based on the natural random wave record. It seems that the hydraulic model experiment is the first step to correlate the physical phenomena between the numerical and full scale models. The wave irregularity, wave groupiness, the effects of infragravity waves and grain size distribution, as well as the three dimensional sediment transport on beach processes and sea level fluctuation have to be taken into account in the model experiments.

The following points are the results of this laboratory study.

1) Development of a measuring system which can simultaneously process numerous topography and wave data.

2) The effect of wave irregularity on beach deformation by the

1 Research associate, Dept. of Ocean Civil Engineering, Kagoshima Univ. 1-21-40 Korimoto, Kagoshima-shi, JAPAN
2 Professor, Dept. of Ocean Civil Engineering, Kagoshima Univ.
3 Technical officer, Dept.of Ocean Civil Engineering, Kagoshima Univ

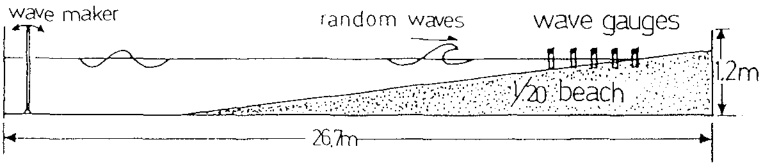

Fig.1 Wave basin.

Table 1 Wave conditions.

Wave type	Case	H1/10	H1/3	Hmean	Period
Experimental series A					
Regular wave	A-1			9.5cm	1.2sec
Grouping wave	A-2			2-13.5cm	1.2sec
Random wave	A-3		13.2cm	9.3cm	1.2sec
Experimental series B					
Regular wave	B-1			4.0cm	1.0sec
Regular wave	B-2			5.0cm	1.0sec
Regular wave	B-3			9.0cm	1.0sec
Regular wave	B-4			12.5cm	1.0sec
Random wave	B-5	9.7cm	7.6cm	4.8cm	1.0sec
Random wave	B-6	13.3cm	10.5cm	6.6cm	1.0sec
Random wave	B-7	15.4cm	12.1cm	7.6cm	1.0sec
Random wave	B-8	18.0cm	14.2cm	8.9cm	1.0sec
Random wave	B-9	23.2cm	18.3cm	11.4cm	1.0sec
Experimental series C					
Regular wave	C-2			8.9cm	1.2sec
Random wave	C-3		7.6cm	4.9cm	1.2sec
Random wave	C-4		11.9cm	7.8cm	1.2sec
random wave	C-5		14.1cm	9.3cm	1.2sec

action of random waves, grouping waves and regular waves on the movable bed beaches which consist of coarse(0.6mm) or fine(0.29mm) sand.

3) The effect of three dimensional sediment transport on beach deformation.

2. Experiments

A wave basin 26.7m long, 14m wide and 1.2m deep, as shown in Fig.1, was used. Two separate 1/20 slope movable bed beaches, which consist of 0.29mm and 0.6mm medium grain size sand, were set to find the effect of suspended sediment and bed load, respectively.

This study was conducted with three experimental series A, B and C. In the first experimental series A, the beach topographies were measured by the bamboo stick system. The beach topographies were measured at 672 evenly spaced points (50cm intervals) by visual measurement at 0.0, 0.5, 1.0, 2.0, 4.0, 8.0, 12.0, 24.0 hours. The incident wave field were measured at the same time. The wave characteristics of random waves, grouping waves and regular waves were chosen to satisfy the same energy wave flux conditions. The schematic graphs of these waves are shown in Fig.2. The BretschneiderMitsuyasu spectrum defined by eq.(1) (Mitsuyasu,1971) was used for generation of random waves in this study.

$$S(f_n)=0.257\left(\frac{H_{1/3}}{T_{1/3}}\right)^2 f_n \exp(-1.03(T_{1/3}f_n)^{-4}) \tag{1}$$

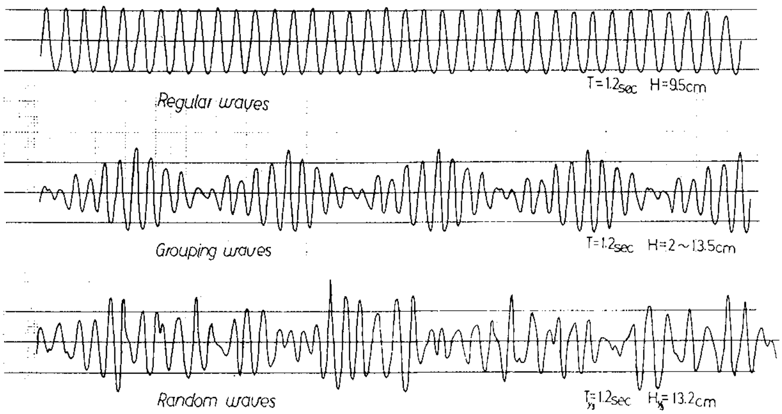

Fig.2 Schematic diagram of waves.

In the second experimental series B, automatic topography measurement system(Fig.3) was used as same as series C. The topographies were measured at 2800 evenly spaced points(30cm intervals) at 0.0 , 0.5, 1.0, 2.0, 4.0, 8.0, 12.0, 24.0hrs. The wave fields were also measured by 30 wave gauges at the same time. The wave gauges were set in 1.0m spacing parallel to the shore and moved by 0.5m offshore.

The wave characteristics of random waves and regular waves were chosen to satisfy the same characteristic wave heights, viz.

(i) regular wave height equals maximum wave height
(ii) regular wave height equals significant wave height
(iii) regular wave height equals mean wave height

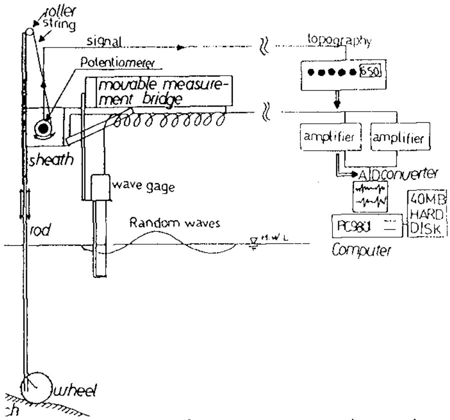

Fig.3 Automatic measurement system for wave and topography.

In the third experimental series C, the beach consist of fine (0.29mm) sand were used to investigate the suspended sediment transport. The wave heights were also chosen as those in experimental series B. The wave conditions are shown in Table 1. The installation of instruments are shown in Fig.5. The nearshore current systcms were observed by dye(MnO_4 solution) and tracer(fluorescent light).

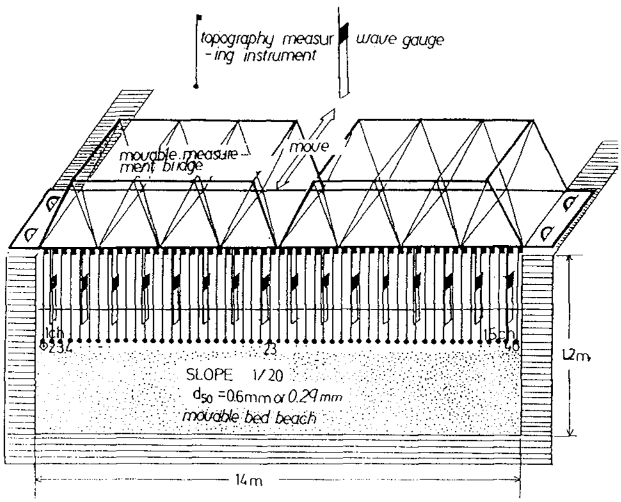

Fig.4 Installation of wave gauges and topography measuring instrument.

3. Results

The purpose of this study is to discover how to correlate knowledge gained under regular wave conditions to that gained under random wave conditions to find a characteristic wave for beach deformation from natural random wave records obtained on the natural beaches .

In regards to the above points, the knowledge which obtained from this study is still limited. This study consists of three experimental series, therefore results are discussed separately. The general results through series A to C are discussed in the final section.

3.1) Experimental Series A.

The purpose of series A is to find "how to obtain the equivalent beach topographies among the action of regular waves, grouping waves and random waves". To obtain the equivalent beach profiles due to each waves, the same energy flux concept was applied. The wave conditions of the three waves were chosen to satisfy the same energy wave flux. This concept is as follows,

$$W_{reg} = \frac{1}{8} \rho g H^2 C_g \tag{2}$$

$$W_{group} = \frac{1}{8T_z} \sum_{1}^{\infty} \rho g H_m^2 C_{gm} \tag{3}$$

$$W_{ran} = \frac{1}{8} \sum_{1}^{\infty} \rho g H_n^2 C_{gn} \tag{4}$$

$$= \sum_{1}^{\infty} \rho g S(f_n) C_{gn}$$

(deep water wave approximation)

$$= \sum_{1}^{\infty} 0.78 \rho g S(f_n)/f_n$$

$$= 0.0854 \rho g H_{1/3}^2 \tag{5}$$

where, W reg, W group, W ran ; the energy flux of regular waves, grouping waves and random waves. The Bretschneider-Mitsuyasu spectrum was applied for $S(f_n)$.

$$S(f_n) = 0.257 \left(\frac{H_{1/3}}{T_{1/3}^2}\right)^2 f_n^{-5} \exp(-1.03(T_{1/3} f_n)^{-4})$$

$$C_g = nC = \frac{1}{2} \left(1 + \frac{2kh}{\sinh 2kh}\right)\left(\frac{gT}{2\pi} \tanh \frac{2\pi h}{L}\right)$$

Therefore, this concept can be written as follows.

$$W_{reg} = W_{group} = W_{rand} \tag{6}$$

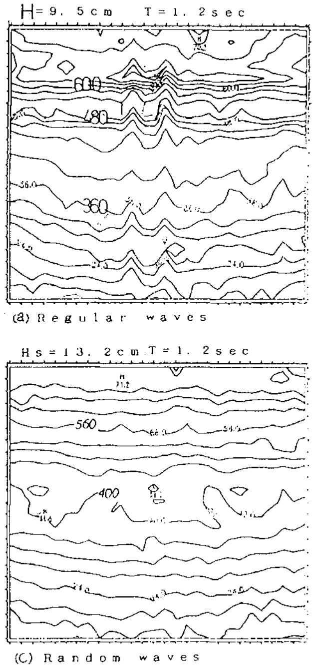

Fig.5 Beach topographies.

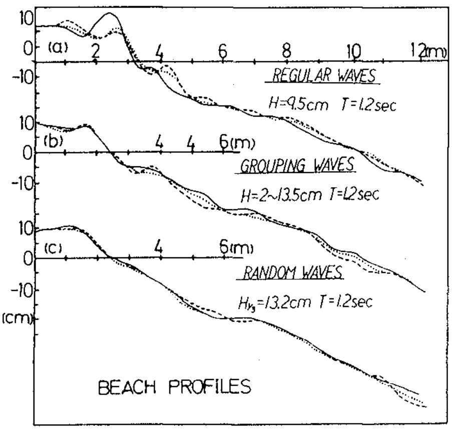

Fig.6 Beach profiles (series A).

Twenty eight on-offshore profiles were measured at 50cm intervals for single measurement of topography. The beach topography caused by random waves is somewhat smooth compared to the other topographies. The mean profiles are calculated based on these lines and are shown by a solid line in Fig.5. Beach profiles caused by regular waves, grouping waves and random waves do not result in equivalent beach profiles. There are also representative beach profiles under the rip current and mass transport areas, which are shown by a broken line and a dot line respectively. Nearshore circulations are more easily generated by regular waves in the wave basin experiments compared to the wave action of random waves. Related beach profile differences exist between the rip current areas and the mass transport areas.

With regards to the three dimensional sediment transport, the schematic diagrams of sediment drift and hydraulic phenomena in the nearshore zone under regular wave conditions are shown in Fig.7.

Sediment transport is closely related to concave points in the crescentic longshore bar. The floats with fluorescence paint showed zig-zag motion on the crescentic bar due to wave breaking and rip-currents. This movement is related to sediment transport, and suggest that there are cases where the sediment drift direction is not the same as that of corresponding currents. This phenomena could not be generated thoroughly in this case , due to random waves. Some researchers have discussed the relationship between the edge waves and the rhythmic topographies. However, those relationships are not discussed here in detail.

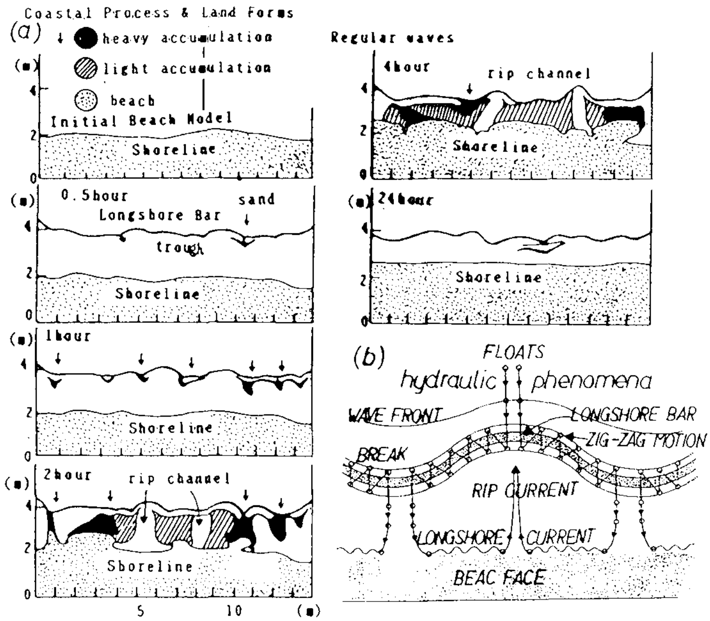

Fig.7 Schematic diagram of
(a)coastal process and sand drift
(b)hydraulic phenomena in the nearshore zone.

3.2) Experimental Series B.

The application of the concept of same energy wave flux have been discussed in the previous section. It does not result in equivalent topographies. Therefore, the method of the same representative wave heights was examined here. This concept is based on the statistical analysis of random waves. The three methods for comparison of the topographies due to regular and random waves are employed. The concepts are as follows,

(i) one-tenth maximum wave height equals regular wave height
(ii) significant wave height equals regular wave height
(iii) mean wave height equals regular wave height.

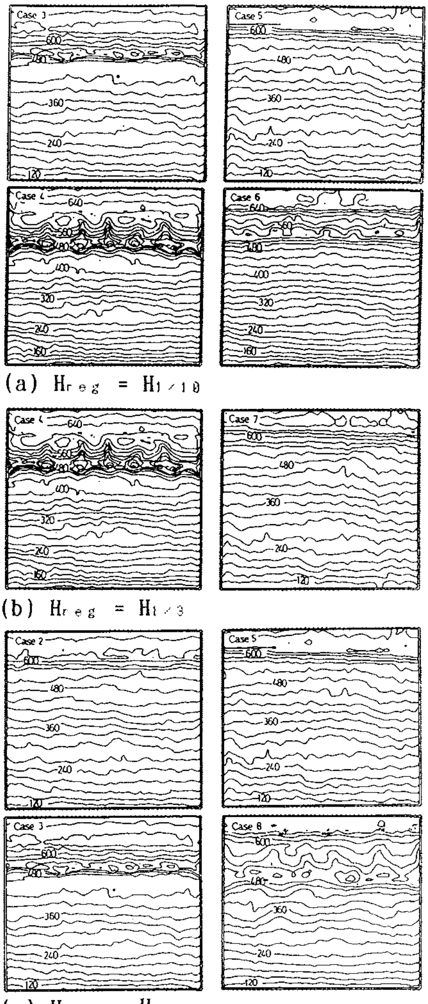

Fig.8 Beach topographies due to regular waves and random waves

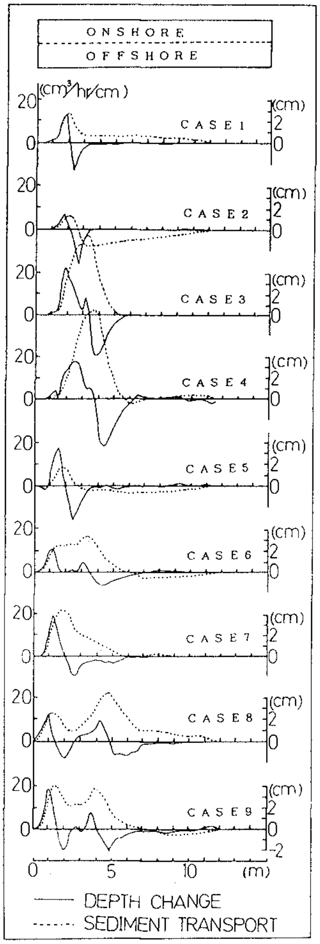

Fig.9 On-offshore sediment transport. and distribution of depth change.

The comparison of beach topographies related to the above concept are shown in Fig.12(a), (b), (c). It does not result in the equivalent topographies between the regular wave and random wave cases.

The mean on-offshore sediment transport rate of both cases and the mean beach profiles are shown in Fig.9 and Fig.10, respectively. The onshore beach profile changes due to random wave action are quite large compared to those due to regular waves, since random waves include many large swash waves. The position of the longshore bar is also farther offshore than in the case of regular waves. Sediment transport due to regular waves is concentrated around the breaking point. The wave breakings of regular wave conditions are generated in a narrow area compared to it of random wave conditions.

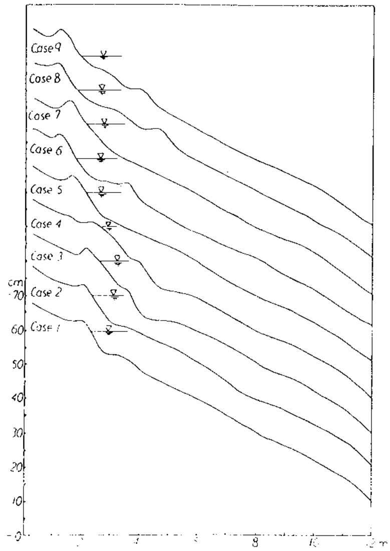

Fig.10 Mean beach profiles (series B).

3.2.2) Comparison of mean beach profile characteristics

As mentioned in section 3.2, any certain characteristic wave which result equivalent beach topographiesas those due to regular waves could not achieved, yet. However,in correlating the knowledge obtained from researches on random waves to that obtained under regular waves, the mean beach profiles are used. The relationships concerning critical water depth for sand movement,shoreline position,berm height, and mean depth change etc.are examined here.

3.2.2.1) Critical water depth for sand movement.

The critical water depth for sand movemcnt in this study is defined, and shown schematically, in Fig.13. The critical water depth proposed by Tanaka and Sato (eq.(8)) is shown by a solid line in this figure. The critical water depth for sand movement under regular wave conditions is deeper by 2cm than the calculated value, but the tendency is similar to equation (8). The data of the random wave experiment vary widely compared to it due to the regular waves. The data with respect to mean wave are much deeper than equation (8).

$$\left(\frac{H}{H_0}\right)^{-1}\left(\frac{\sinh 2\pi h_i}{L}\right)\left(\frac{H_0}{L_0}\right)^{-1} = 1.770\left(\frac{L_0}{d}\right)^{1/3} \qquad (8)$$

The results using significant waves also have some variance , but they distribute around the calculation and are somewhat shallower than the results of regular waves. Therefore , the significant wave characteristics should be applied for the calculation of critical water depth under random wave action rather than mean wave. This corresponds to the results from a natural beach by Sato et al.

3.2.2.2) Shoreline changes

A time series of shoreline changes from initial position are shown

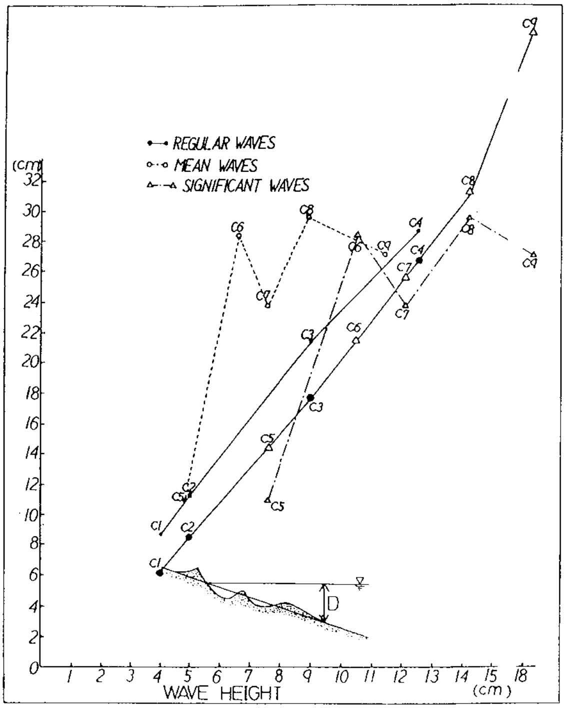

Fig.11 The critical water depth for sediment movement and definition sketch.

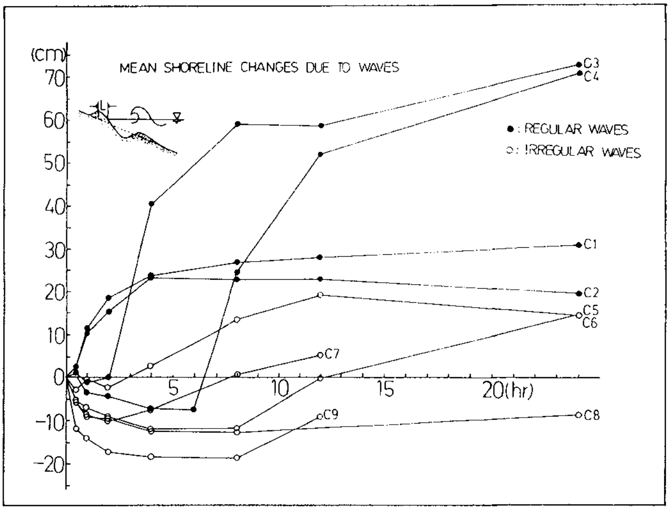

Fig.12 Time series of shoreline changes.

in Fig.14. The shoreline changes due to random waves are smallcr than those due to regular waves. The abrupt changes of shoreline position are caused by the welded bar as shown in Fig.8. The shoreline changes at 12 hours are shown in Fig.15. There are some cases where the same representative waves give the contrast topographies between regular waves and random waves .

3.2.2.3) Berm height

Wave run-up contribute to built the berm , this berm height aftcr 12 hours is shown with respect to the wave height in Fig.16. In contrast to shoreline changes, berm heights due to random waves are higher than those due to regular waves. The probability of a large wave run-up in the random waves is higher than that in regular waves, so that random waves result in higher berms.

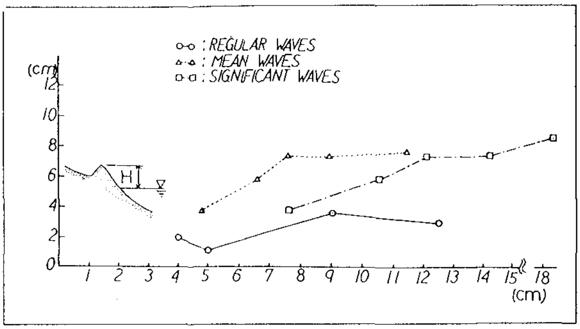

Fig.13 Berm height.

3.2.2.4)Mean depth change

Some researchers have indicated that the topography changes due to random waves are somewhat smaller and smoothed compared to those due to regular waves. To examine this, two graphs are prepared. One shows the distance from onshore limit of beach deformation to offshore one with respect to wave height. The other shows the sum of depth change, also with respect to wave height. These two graphs are shown in Fig.17 and Fig.18. The distance from onshore limit of beach deformation to offshore one

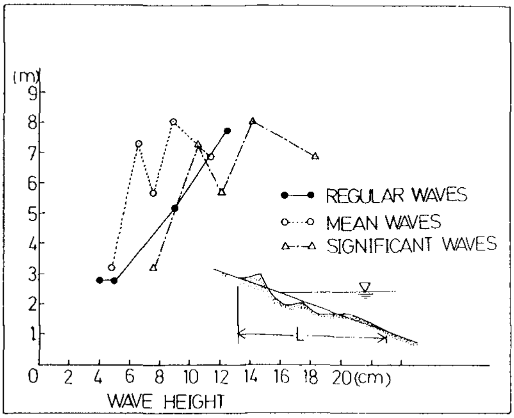

Fig.14 The length of on-offshore depth change limits.

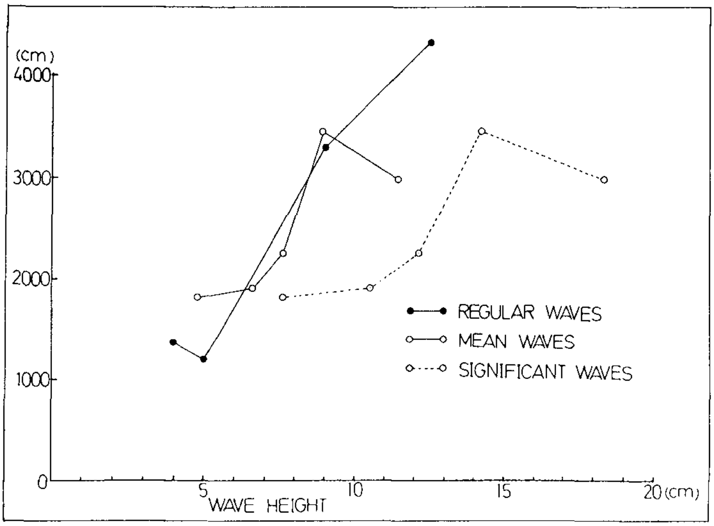

Fig.15 The sum of depth change at 12hours.

caused by regular waves exists between those based on mean and significant waves. The sum of depth changes due to regular waves is nearly equal to those of mean waves and greater than those due to significant waves.

The mean depth change is defined as (sum of depth change) / (length of beach deformation). As a result, mean depth changes due to random waves are smaller than those of regular waves.

3.3) Experimental Series C.

Beach processes were examined by a model consisting of coarse sand (0.6mm) in series A an B. In these experiments , a type III beach (proposed by Horikawa and Sunamura) was not generated. Therefore , a beach model consisting of fine (0.29mm) sand was used to consider the suspended sediment transport and erosion of beach.

3.3.1) comparison based on the same representative wave heights.

Beach topographies based on the same representative wave heights are shown in Fig.19. This seems that the beach topography due to regular waves is characterized by the rhythmic longshore bar, and topography due to random waves is characterized by rhythmic step. These topographies are not similar. Rhythmic topographies are generated in the offshore region on the fine sand beach , but not on the coarse sand beach in this experiments.

3.4) Effect of grain size

The mean beach profiles of fine sand and coarse sand due to same wave conditions are compared and shown in Fig.21. The two upper

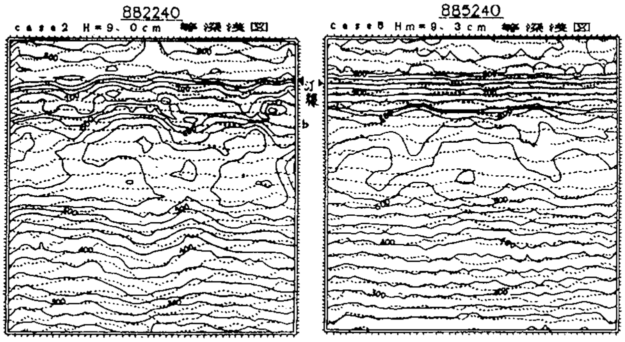

Fig.16 Beach topographies due to regular waves and random waves. $H_{reg} = H_{mean}$ (series c)

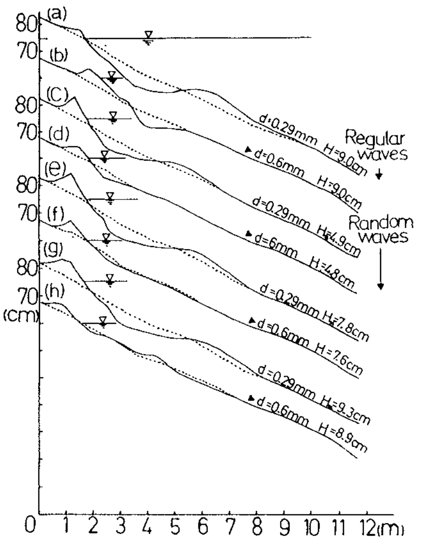

Fig.17 Comparison of profiles of fine sand and coarse sand beaches.

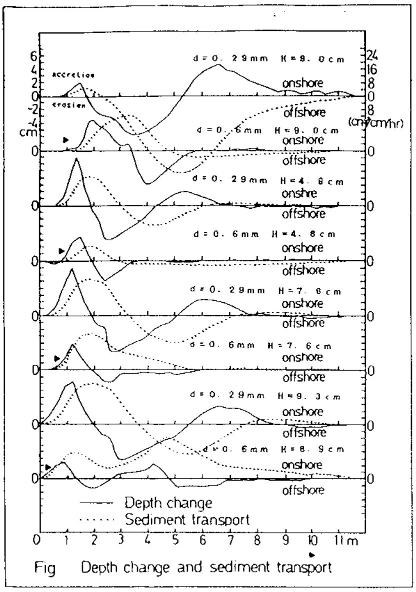

Fig.18 Depth change and sediment transport.

profiles resulted from regular waves and the six lower profiles from random waves . The two upper profiles correspond to the lowest two profiles on the basis of same representative wave height (mean wave height). The beach profiles which consist of fine sand , show a larger topographical change.

4. Conclusion

This paper is a basic laboratory study for beach processes due to random waves. However , the main purpose, "obtaining the equivalent topographies for both regular waves and random waves " , have not been achieved yet.

The conclusions are;

(1) The topography measuring instrument system with A/D converter, dcveloped here, can simultaneously collect numerous accurate data .
(2) Beach topographies due to similar encrgy flux waves result in different topographies.
(3) Beach topographies due to the same representative wave height as regular wave height result in different topographies.
(4) Critical water depth for sediment movement due to random waves can be calculated by using significant wave characteristics.
(5) There are cases where the direction of sediment drift differ from the corresponding longshore and rip-current directions.
(6) Rhythmic topographies were observed in the inshore region of coarse and fine sand beaches, and also in the offshore region of fine sand beaches.

References

(1) Dette,H,H. and K.Ueiczka : Velocity and Sediment Concentration Field Across Surf Zones. 20th Conf. Coastal Engineering, pp.1062-1076, 1986
(2) Goldsmith,V., D.Bowman, K.Kiley, B.Burdick, Y.Mart and S.Sofer : Morphology and Dynamics of Crescentic Bar Systems, 18th Conf. Coastal Eng., pp.941-953,1982
(3) Hsiang Wang and S.S.Liang : Mechanics of Suspended Sediment in Random Waves, JGR.,Vol.80,No.24.pp3438-3494
(4) lrie,Y.,T.Tsuchiya and A.Watanabe : Beach Profile and Cross-shore Sediment Transport Rate Due To lrregular Waves, 32nd. Japanese Conf. coastal Eng., pp.316-320(in Japanese)
(5) Mitsuyasu,H. : Development of Spectrum of Wind Waves(2), 17th Japanese Conf. Coastal Eng., pp.1-7 (in Japanese)
(6) Mimura,N., Y.Otsuka.and A.Watanabe : Laboratory Study on Two-Dimensional Beach Transformation Due to lrregular waves, 20th Conf. Coastal Eng., pp1393-1406
(7) Nishi,R.,M.Sato , K.Nakamura, M.Yaguruma, and K.Matano : Laboratory Study On Beach Processes Due To Regular Waves, Grouping Waves and Random Waves, 34th Japanese Conf. Coastal Eng., pp302-306(in Japanese)
(8) Nishi,R. M.Sato. and K.Nakamura : Coastal Processes in Westcrn Coast of Mt.Kaimon, 44th annual Conf. The Japan Society of Civil Engineers,2. pp.36-39
(9) Tsuchiya,Y. and K.lnada(1974): Experimental Study on Beach Profile Change Due To Wind Waves-Critical Condition for Bar Formation - 21st Japanese Conf.Coastal Eng., pp.219-224(in Japanese)