CHAPTER 28

A PREDICTION MODEL OF IRREGULAR WAVE RUN-UP HEIGHT ON COASTAL STRUCTURES

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ABSTRACT

The characteristics of irregular wave run-up on coastal structures are discussed related with spectrum shape and grouping parameters of incident waves using the results of 200 cases of hydraulic model experiments. It is clarified that wave run-up is affected by the effects of the irregularity of incident waves and the slope configurations of structures.

A statistical model to estimate the run-up height from the incident wave properties is proposed considering 90 % confidence intervals. Also, the simple probability distribution model of irregular wave run-up height is developed and proved to be useful to the design of coastal structures.

1. INTRODUCTION

Irregular wave run-up is an important factor for the design of coastal structures. However, the published data on the irregular wave run-up are fairly limited and hardly applicable to the design (e.g.,Bruun,1985 ; Ahrens ,1988). It has been emphasized that the charateristics of run-up waves according to the wave grouping or spectrum shapes of the incident waves should be clarified, and there is necessity for developing a prediction model to estimate the irregular wave run-up height (e.g.,Kobayashi and Cox, 1990).

In this study, the characteristics of irregular wave run-up on rough permeable coastal structures have been investigated through a series of model experiments to develop a statistical prediction model of irregular wave run-up height on the structures. Among the many governing factors on wave run-up, the effects of the irregularity of incident wave and the slope configurations of structures are studied and discussed in priority in order to improve the predictive capability of the model. To verify the applicability of the model,

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some comparative discussions are made using some reported experimental data and / or some conventional formulas for run-up height estimation.

MODEL EXPERIMENTS AND DATA ANALYSIS

Important governing parameters on wave run-up related with irregularity of ocean waves can be summarized as follows with conventionally considered parameters in equation(2).

$$\frac{R_{u1/n}}{H_{1/n}} = f\ \{\ \overline{j(\,)},\ Qp(\varepsilon),\ \xi_{1/n}\ ,\ \ldots\ldots\} \tag{1}$$

$$\frac{R_u}{H} = f\ \{\ h_c/h_o,\ h_o/L_o,\ d/l_a,\ H/h_o,\ \theta(\text{slope type}),\ k,\ i,..\} \tag{2}$$

where, R_u is the run-up height , H the incident wave height, $\overline{j(\,)}$ the mean run-length of a wave group, Q_p the spectrum peakedness parameter, ε the spectrum width parameter, ξ the surf similarity parameter, subscript $_{1/n}$ means the $_{1/n}$ significant value, h_c/h_o relative crest height, h_o/L_o relative water depth, d/l_a relative roughness, θ the slope angle, k the permeability, i the sea bottom slope.

Assuming the conditions of permeable deep-water breakwater, infinite crest height, constant roughness, and bottom slope i= 1/40, a series of model experiments are carried out to discuss only the effects of eq.(1) and slope type. In the experiments, A 2-dimensional wave flume with 30m length, 0.7m width and 0.95m height is used. A seperator in the middle of the wave flume is set up in order to measure both the incident and run-up waves simultaneously as shown in Fig. 1. The incident wave height is measured by a capacitance type wave gauge, and the run-up height is measured by the run-up measuring gauge which is set along the surface of structure slope. Model structures which are made up of core and revetment layer have the uniform slopes of 1/3, 1/2, and 1/1.5 and composite slope. Irregular waves are simulated by the impulse response function method. Using 3 kinds of Pierson-Moskowitz spectrum and 3 kinds of Neuman spectrum with different peak frequencies fp, 200 cases of experiments with variation of the power level of wave generator are carried out. More details on experimental conditions are discribed in Ryu and Sawaragi(1986).

The flow for analyzing the statistical characteristics of both incident and run-up waves is shown in Fig.2. Individual incident and run-up waves are defined by zero-upcrossing method. The data of incident waves and run-up waves recorded in an analog data recorder were digitized at 0.05 sec interval for 20 minutes by the A-D transducer and are analyzed by the wave by wave and the spectral analysis method. The real time comparative analysis between the incident and the run-up waves was also applied for the analysis of grouping characteristics of irregular wave run-up.

STATISTICAL CHARATERISTICS OF THE INCIDENT WAVES

The characteristics of the spectral shape, the statistical wave height/ period distributions and wave grouping properties used

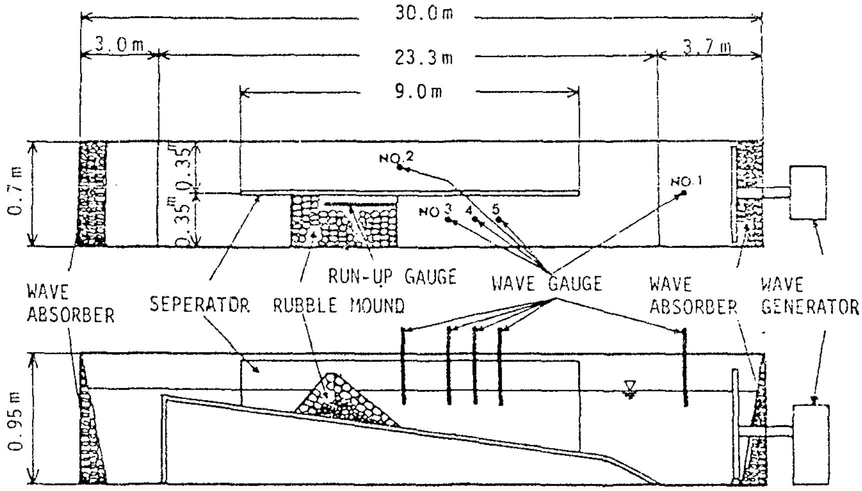


Fig.1. Layout of test flume and model structure.

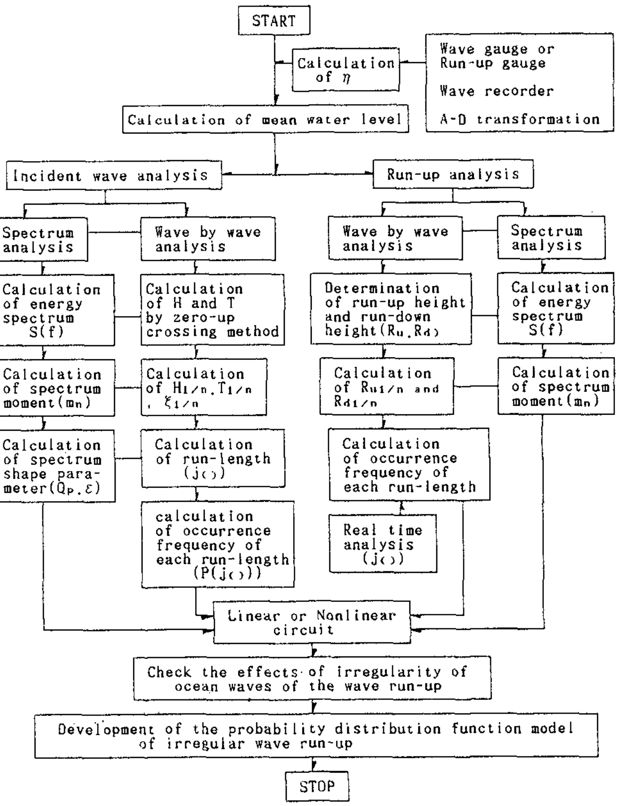


Fig.2. Flow for the analysis of incident and run-up waves.

in the experiments were compared with those of random ocean waves for the reliability of the study.

Wave height and period are very important factors in wave-structure interaction such as wave run-up. An example of the joint distribution of relative wave height ($H/\overline{H}$) and period ($T/\overline{T}$) of experimental waves is shown in Fig. 3. In the figure it can be seen that wave period ($T/\overline{T}$) increases with the increase of wave height in the smaller waves ($H<\overline{H}$), but wave periods are distributed around $T/\overline{T}$ = 1.1 in the wave field higher than arbitrary critical value($H>\overline{H}$). Therefore, the relations among the representative wave periods can be expressed as follows:

$$T_{1/3} \fallingdotseq T_{1/10} \fallingdotseq T_{max}$$

It is identified from the above results that joint distribution of wave height and period has a good agreement with the analyzed results of field data by Goda(1985). In other words, it can be stated that the simulated irregular waves used in model tests represent random ocean waves fairly well.

Fig. 4 shows the distribution of spectral peakedness parameter Qp by means of the irregular wave data used in model tests compared with field data at Utsira. It can be understood from the figure that most of ocean waves exist mainly in the range of spectral peakedness parameter $1.0 \leq Q_p \leq 3.0$ and that the distribution of Q_p from model tests is also satisfactorily simulated compared with irregular waves in the ocean. Where Q_p have been defined as following equation by Goda (1985).

$$Q_p = \frac{2}{m_o{}^2} \int_0^{\infty} f\, S^2\ (f)\ df$$

where the spectral moments is

$$m_n = \int_0^{\infty} f^n\ S(f)\ df$$

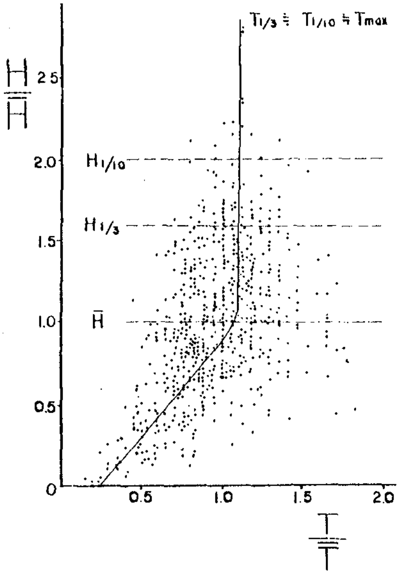
f the frequency, S(f) the energy density of the frequency f.

RUN-UP CHRACTERISTICS OF IRREGULAR WAVES

Grouping Characteristics of Run-up Waves

The grouping characteristics of run-up waves related with the incident wave grouping is important for the stability analysis of rubble mound structures and overtopping control measures on the design of coastal structures(Ryu and Sawaragi, 1986).

One typical example of time histories of incident waves and their corresponding run-up waves is phenomenally shown to examine the cross-correlation in Fig. 5. In the experiment, both incident wave data and run-up wave data are obtained at the same time. In the figure, it can be known that the higher run-up wave groups appear under the the higher incident wave groups attack on steep slopes.



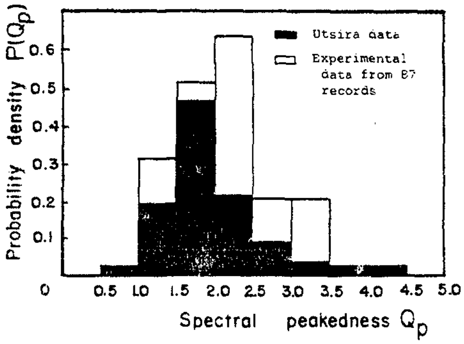
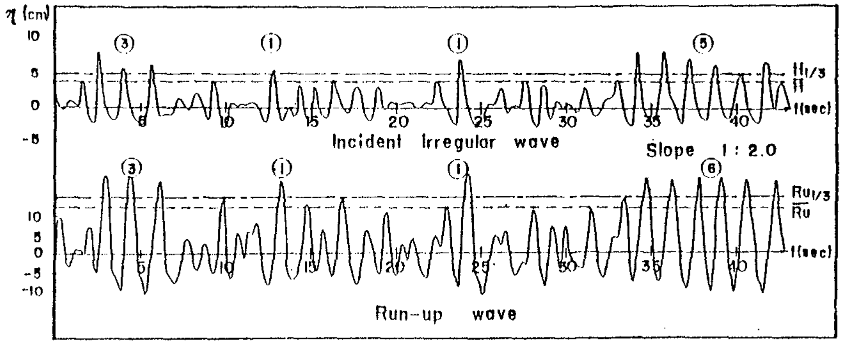


Fig.4. Occurrence probability P(Qp) of spectral peakedness parameter Qp.

Fig.3. Joint distribution of wave height($H/\bar{H}$) and wave period($T/\bar{T}$).



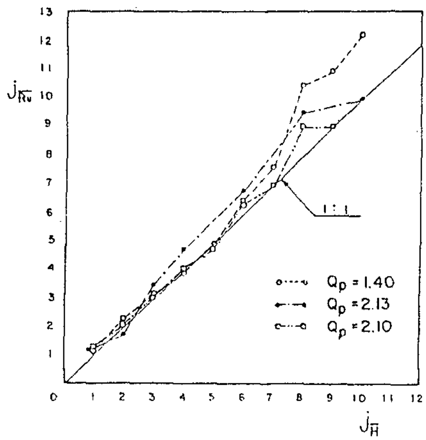


Fig.5. Time histories of incident and run-up waves.

Fig.6. Relations between the run-lengths of higher incident waves($j_{\bar{H}}$) and those of run-up waves($j_{\bar{Ru}}$).

Where the number inside the circle indicates the run-length.

Fig. 6 shows some examples of the analyzed results for 3 different cases of Q_p by the real time analysis technique. In the figure, it is shown that the run-lengths of run-up waves ($\overline{j_{\overline{Ru}}}$) exceeding mean run-up height $\overline{R_u}$ are nearly the same or a little larger than those of incident waves ($\overline{j_{\overline{H}}}$) exceeding mean wave height $\overline{H}$. This means that foregoing broken waves or back washes do not affect so much on the motion of following waves on steep, permeable and rough slopes contrary to the results on gentle slopes (Sawaragi and Iwata, 1984).

The Effects of the Irregularity of Ocean Waves on the Wave Run-up

Fig.7 shows the relative run-up heights of irregular waves according to spectrum shape parameters Q_p and ϵ, respectively. It can be understood from the figure that the statistical run-up height becomes larger with the decrease of spectral peckedness parameter Q_p and with the increase of spectral width parameter ε as the corresponding tendency with the above illustrated Q_p. This tendency is more remarkable in higher run-up heights ($R_{u1/10}$ / $H_{1/3}$, $R_{u1/3}$ / $H_{1/3}$) than in mean run-up height ($\overline{R_u}$ / $H_{1/3}$).

The results of this study are similar to those of Van Oorschot and D'Angremond(1968) on steep slopes but opposite to those of Mase et al.(1983) on gentle slopes. Therefore, it can be stated that the characteristics of wave run-up heights due to spectrum shapes reverse at the boundary of structure slope 1/4 or 1/5.

In order to analyze the wave grouping effects on the wave run-up, various definitions which can represent the grouping effects are used such as the mean run-length of higher waves ($\overline{j_{Hc}}$), that of ξ^* ($\overline{j_{\xi^*}}$) and that of conditional ξ^* of higher waves ($\overline{j_{(Hc|\xi^*)}}$) satisfying the resonance condition on the slope (Ryu and Sawaragi, 1986).

As the same tendency with Fig.7, the extreme run-up heights decrease with increasing the mean run-length of $\overline{j_{Hc}}$, $\overline{j_{\xi^*}}$ and $\overline{j_{(Hc|\xi^*)}}$ as shown in Fig.8, Fig.9 and Fig.10. This is remarkably apparent with increasing of slope angle.

A Prediction Model of Irregular Wave Run-Up Heights

Fig. 11 shows the statistical distribution of irregular wave run-up heights on various slopes. In the figure, the distribution of irregular wave run-up heights provides a good approximation to the Rayleigh distribution on the slope steeper than 1 on 2, but it is overestimated in higher run-up on the slope milder than 1 on 3. It seems mainly due to the permeability effects but more detail experiments are required to discuss the above mentioned mechanism.

It is not possible that the irregular wave run-up height can be directly estimated from the incident wave characteristics in the above mentioned distribution. Therefore, it is necessary to derive the relations between surf similarity parameter $\xi_{1/n}$ and normalized irregular wave run-up height $R_{u1/n}/H_{1/n}$.

Non-dimensional run-up heights of irregular waves with respect to surf similarity parameter $\xi_{1/n}$ are shown in Fig. 12. Where solid

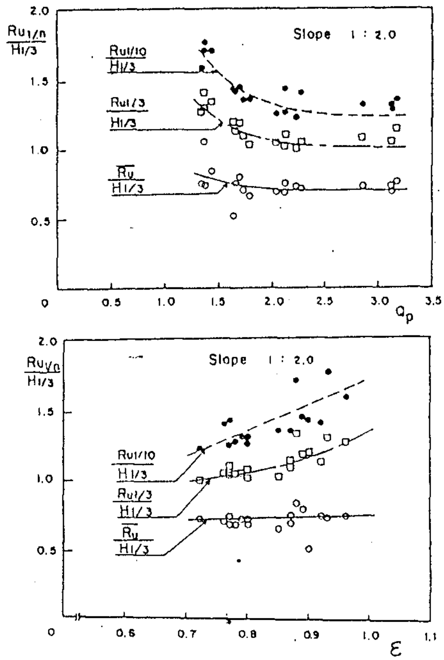


Fig.7. Spectral shape effects on wave run-up heights.

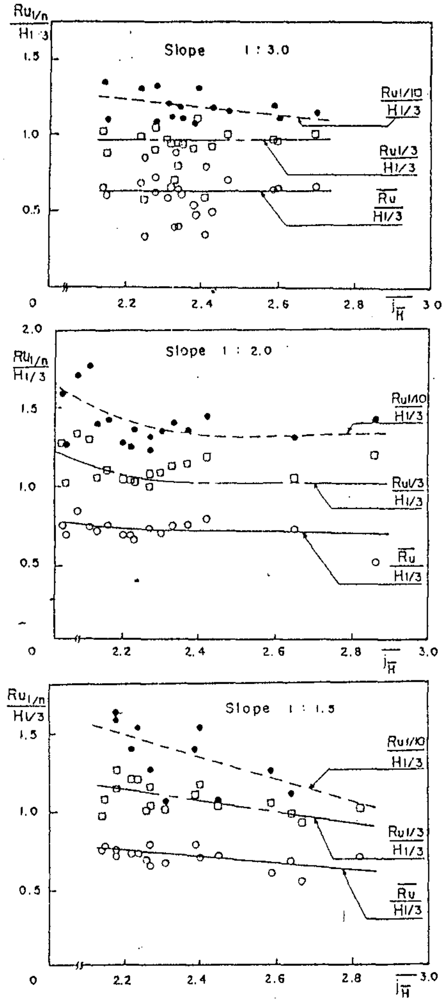


Fig.8. Irregular wave run-up versus $\overline{j_H}$.

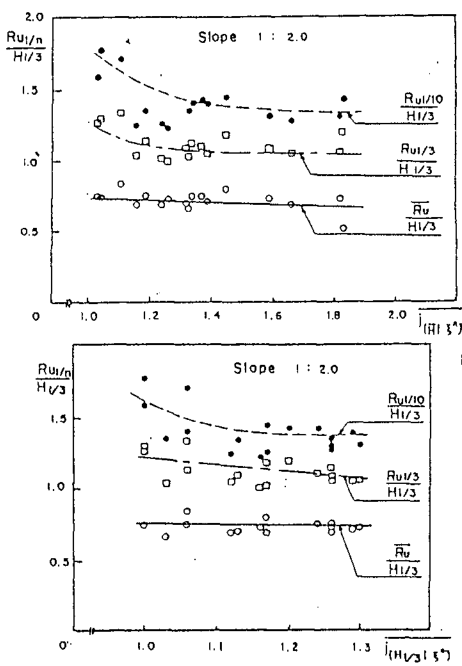


Fig.10. Irregular wave run-up versus $\overline{j_{(H_{1/3}|\xi^*)}}$.

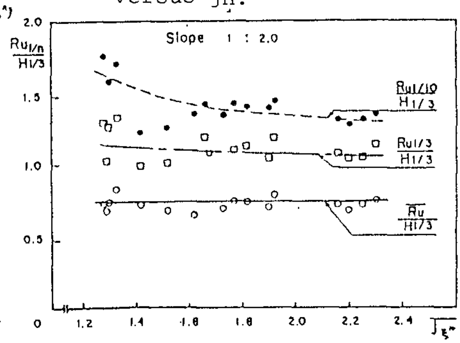


Fig.9. Irregular wave run-up versus $\overline{j_{\xi^*}}$.

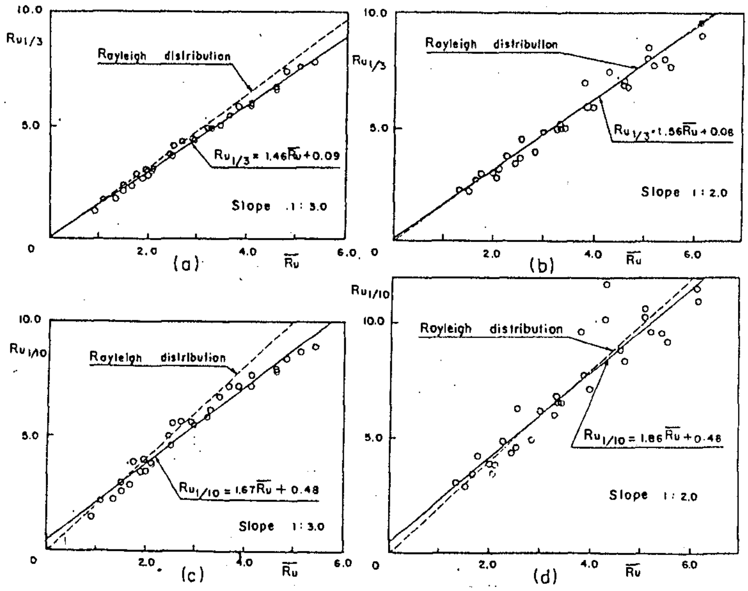
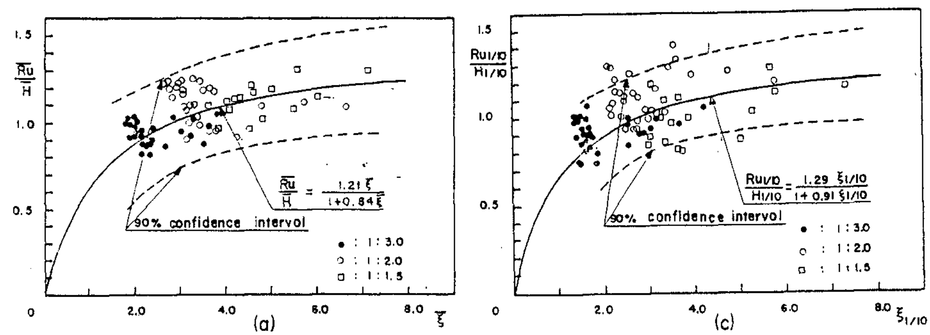


Fig.11. The statistical distribution of irregular wave run-up heights on various slopes.



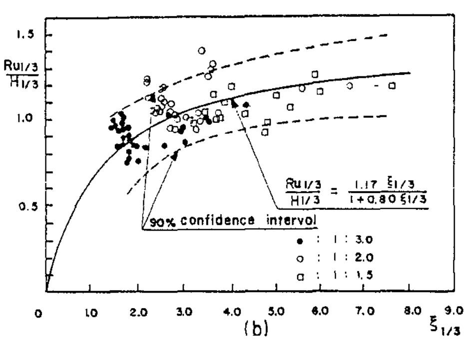


Fig.12. Irregular wave run-up height as a function of surf similarity parameter.

lines denote the regression curves and dashed lines denote 90% confidence interval by eqs. (7), (8) and (9).

The basic formula for estimating the wave run-up height is given as follows

$$R_u = \frac{a\xi}{1 + b\xi} H \tag{3}$$

The regressive curve fitting formulas of the relative run-up heights are as follows

$$\frac{\overline{R_u}}{\overline{H}} = \frac{1.21\overline{\xi}}{1 + 0.84\overline{\xi}} \tag{4}$$

$$\frac{R_{u1/3}}{H_{1/3}} = \frac{1.17\xi_{1/3}}{1 + 0.80\xi_{1/3}} \tag{5}$$

$$\frac{R_{u1/10}}{H_{1/10}} = \frac{1.29\xi_{1/10}}{1 + 0.91\xi_{1/10}} \tag{6}$$

The formulas of 90% confidence interval for regression curves are as follows:

$$\frac{\overline{R_u}}{\overline{H}} - (1.66)(0.17)\sqrt{1 + \frac{1}{83} + \frac{(\overline{\xi} - 3.34)^2}{107.90}} < \mu\frac{\overline{R_u}}{\overline{H}} \mid \overline{\xi}$$
$$< \frac{\overline{R_u}}{\overline{H}} + (1.66)(0.17)\sqrt{1 + \frac{1}{83} + \frac{(\overline{\xi} - 3.34)^2}{107.90}} \tag{7}$$

$$\frac{R_{u1/3}}{H_{1/3}} - (1.66)(0.12)\sqrt{1 + \frac{1}{83} + \frac{(\xi_{1/3} - 3.11)^2}{137.27}} < \mu\frac{R_{u1/3}}{H_{1/3}} \mid \xi_{1/3}$$
$$< \frac{R_{u1/3}}{H_{1/3}} + (1.66)(0.11)\sqrt{1 + \frac{1}{83} + \frac{(\xi_{1/3} - 3.11)^2}{137.27}} \tag{8}$$

$$\frac{R_{u1/10}}{H_{1/10}} - (1.66)(0.15)\sqrt{1 + \frac{1}{81} + \frac{(\xi_{1/10} - 2.86)^2}{110.77}} < \mu\frac{R_{u1/10}}{H_{1/10}} \mid \xi_{1/10}$$
$$< \frac{R_{u1/10}}{H_{1/10}} + (1.66)(0.15)\sqrt{1 + \frac{1}{81} + \frac{(\xi_{1/10} - 2.86)^2}{110.77}} \tag{9}$$

where μ is a function of confidence interval.

The probability distribution function of ξ proposed by Bruun and Günbak(1978) is as follows:

$$P(\xi) = \frac{8 \cdot \xi_d^4}{\xi^5} \exp\left(-2\,\xi_d^4 \cdot \xi^{-4}\right) \tag{10}$$

where $$\xi_d = \frac{\tan\theta}{\left[(2\pi/g)(H_{1/3}/\bar{T}^2)\right]^{1/2}} \tag{11}$$

where θ is slope angle, $H_{1/3}$ significant wave height and $\bar{T}$ mean wave period.

Using eq.(5) among eq.(4), eq.(5) and eq.(6), one may solve for $\xi_{1/3}$ as follows

$$\xi_{1/3} = \frac{R_{u1/3}/H_{1/3}}{1.17 - 0.8(R_{u1/3}/H_{1/3})} \tag{12}$$

Changing random variable from $\xi_{1/3}$ to $R_{u1/3}$ / $H_{1/3}$ in eq.(12) through Jacobian transformation, the following formulas are obtained;

$$d\xi_{1/3} = \frac{1.17}{\left[1.17 - 0.80\,(R_{u1/3}/H_{1/3})\right]^2}\, d\frac{R_{u1/3}}{H_{1/3}} \tag{13}$$

$$\frac{d\xi_{1/3}}{d\dfrac{R_{u1/3}}{H_{1/3}}} = \frac{1.17}{\left[1.17 - 0.80\,(R_{u1/3}/H_{1/3})\right]^2} \tag{14}$$

combining eq.(10), eq.(11) and eq.(14), eq.(15) is obtained as:

$$p\left(\frac{R_{u1/3}}{H_{1/3}}\right) = \frac{8\,\xi_d^{\,4}}{\left[\dfrac{(R_{u1/3}/H_{1/3})}{1.17-0.80(R_{u1/3}/H_{1/3})}\right]^5} \cdot \exp\left[-2\xi_d^4\left(\frac{R_{u1/3}/H_{1/3}}{1.17-0.80(R_{u1/3}/H_{1/3})}\right)^{-4}\right]\frac{d\xi_{1/3}}{d\dfrac{R_{u1/3}}{H_{1/3}}} \tag{15}$$

Consequently, substituting eq.(14) into eq.(15), the probability distribution function of irregular wave run-up height can be expressed as eq.(16):

$$p\left(\frac{R_{u1/3}}{H_{1/3}}\right) = \frac{9.36\xi_d^4\left(1.17-0.80\dfrac{R_{u1/3}}{H_{1/3}}\right)^3}{\left(\dfrac{R_{u1/3}}{H_{1/3}}\right)^5} \cdot \exp\left[-2\xi_d^4\left(\frac{\dfrac{R_{u1/3}}{H_{1/3}}}{1.17-0.80\dfrac{R_{u1/3}}{H_{1/3}}}\right)^{-4}\right] \tag{16}$$

In order to identify the applicability of the model, the probability distribution of wave run-up height is shown with the experimental data

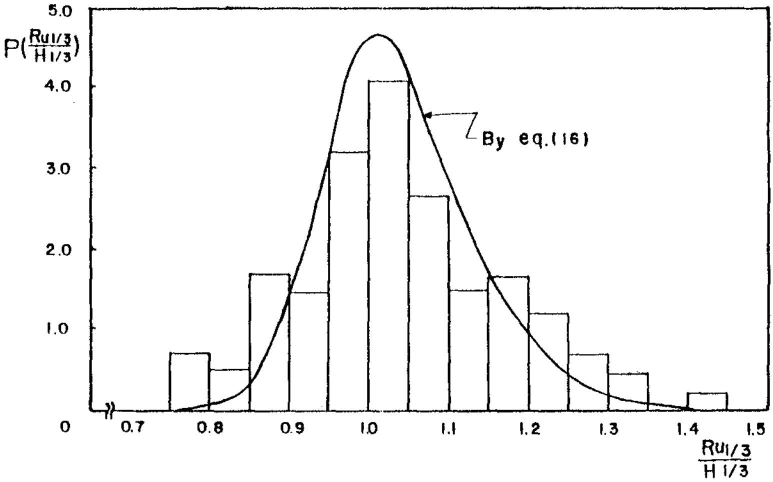


Fig.13. Probability distribution of irregular wave run-up heights on uniform slope.

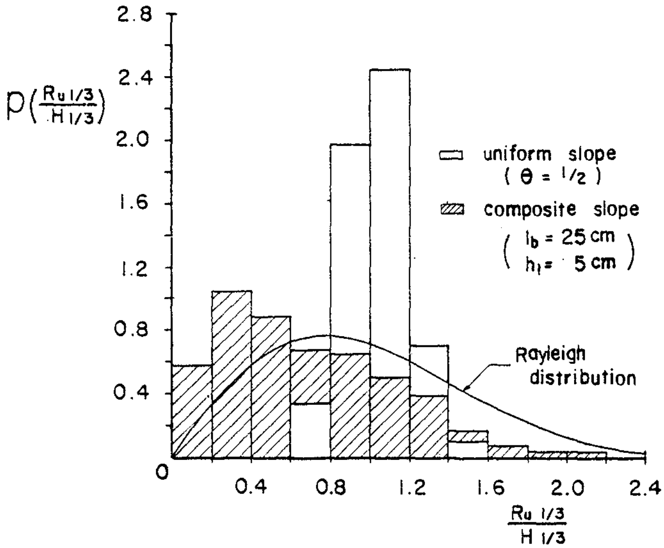


Fig.14. Probability distribution of irregular wave run-up heights on the berm type composite slope.

in Fig. 13. It can be stated from the figure that the proposed model is very useful to predict the run-up height on the permeable rough mound type structures.

In addition, applying the technique used for the uniform slopes, the probability distribution of irregular wave run-up heights on the berm type composite slope is investigated compared with that on the uniform slope and Rayleigh distribution as shown in Fig.14. It is seen that the irregular wave run-up heights are more widely distributed than those on uniform slope and also that the probability density of the run-up height on composite slope is higher in the lower values of $Ru_{1/3}$ / $H_{1/3}$ than that on uniform slope. This means that the attenuation effect of wave run-up height on composite slope is stronger than that on uniform slope due to wave-structure interaction. Furthermore, it can be identified that the distribution of the irregular wave run-up height normalized by wave height has different trend with the Rayleigh distribution.

CONCLUSIONS

Statistical and real time characteristics of irregular wave run-up were studied including the effects of spectral shape and grouping characteristics of incident waves. And the simple probability distribution function of irregular wave run-up heights was developed as a prediction model of the run-up height, and proved to be useful to the deterministic design and applicable to the optimal design concept of coastal structures. However, the experimental conditions could not cover all of the sea state and structural characteristics. Furthermore, the proposed model does not include the effect of grouping of incident waves. These problems will be required to be investigated to develop the more accurately and extensively applicable model.

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