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TECHNICAL COMMUNICATION

Effect of Wave Groups on Wave Run-Up

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ABSTRACT

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This paper presents two simulation methods for wave groups and shows their application in the laboratory. Research results on the run-up of wave on a sloping breakwater are summed up with the key point on the influence of wave groups on wave run-up.

ADDITIONAL INDEX WORDS: *Breakwater, wave simulation, harmonic analysis, waves.*

INTRODUCTION

Test research for the run-up on a slope dike with irregular waves has been performed for two decades. One of the questions under discussion is the effect of wave groups on the wave run-up on a slope dike.

The common agreements through the research are as follows:

(1) The Iribarren number I_r should be considered in the run-up values $R_{p\%}$ with various probabilities $R_{p\%}$ of exceedance and its characteristic values R_s and $\overline{R}$, under the attacks of irregular waves. The factors such as the wave steepness, the slope ratio of dike, the slope ratio of sea bottom and so on are considered comprehensively.

(2) The parameter of spectral bandwidth, ϵ, is considered to affect the run-up: the wider-band spectrum produces the higher value of run-up, while the narrower-band spectrum produces a lower value.

(3) The maximum value of the run-up of the strong wave groups, R_{max}, is 10% larger than the maximum value of run-up of the weak wave groups and the effects of wave groups on the significant value R_s and on the mean value R of run-up are not large under the attack of irregular waves.

METHODS FOR SIMULATING WAVE GROUP AND THEIR APPLICATIONS IN LABORATORY

There are two methods for simulating wave groups: The first is proposed by Professor Y. Goda, Yokohama University of Japan, in which the strength of wave group depends on the width of spectral peak and the lifting factor of spectral peak. The coefficient of spectral peakness was derived by Tucker and expressed by Q_p.

$$Q_p = \frac{2\int_0^{\infty} fs(f)\,df}{\left[\int_0^{\infty} s(f)\,df\right]^2}. \qquad (1)$$

It is obvious that if the spectral peakness coefficient reaches the expected value, the wave group simulated in the laboratory would satisfy the needed requirement.

Based on the above principle, we employed and developed the program for harmonic superposition of irregular wave profile calibration software package in the wavemaking system imported by the Nanjing Hydraulic Research Institute and proposed a correlation of the coefficient of the spectral peakness Q_p with both the length of run of wave height J and the mean length of run of wave height $\overline{J}$ so as to simulate wave groups of various strengths.

The second method introduced by Funke and Mansard of Hydraulic Laboratory in the State Research Committee of Canada is Smooth Instantaneous Wave Energy History (SIWEH) which is used to estimate groupedness factor GF so as to simulate wave groups of different strengths. The expression of GF is:

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$$GF = \frac{\sqrt{\frac{1}{T_R}\int_0^{T_R}\left[E(t) - \bar{E}\right]^2 dt}}{\bar{E}} \quad (2)$$

in which

$$E(t) = \frac{1}{T_P}\int_{-\infty}^{+\infty} \eta^2(t - \tau)Q(\tau)\, d\tau. \quad (3)$$

From the principle mentioned above, we applied and developed the iterative program in the irregular wave profile calibration software package in the imported wavemaking system to obtain various values of GF which are used to simulate wave groups of different strengths.

EFFECT OF WAVE GROUP FOR THE RUN-UP ON A SLOPE DIKE

The measured data show that the damage of coastal construction caused by wave forces which are produced by wave groups is larger than that by an individual wave. They also found that the effect of wave groups on the harmonic oscillation in the harbour and the movement of the mooring structure and its resonance could not be neglected.

A series of experimental research of wave run-up on a slope dike with irregular waves has been performed in the Netherlands and Britain. The first focal point is to study the method for calculating the characteristic values of run-up on a smooth-impermeable slope dike covered with stone or protected with various concrete armour units. And, then, related calculation curves and tables are introduced. The second focal point is to study the probability distributions of the wave run-up. It is suggested to adopt $R_{2\%}$ while determining the elevation of the dike crest for designing the coastal protection.

Recently, a series of experiments has been conducted at the Wallingford Hydraulic Research Institute. It is found that a single probability density function could not be used to make a fitting example of the wave run-up value on various slope dikes protected with concrete armour units or stones. Therefore, they suggested that it is more accurate to use the experimental data to estimate the characteristic values of the wave run-up than to use a single theoretical probability density function.

Model tests of wave run-up with slope ratios of 1/5, 1/10, 1/20, and 1/30 under the attack of random waves with strong and weak groups have been conducted by Y. Iwagaki, Professor of Kyoto University. The results show that the maximum value of run-up R_{max} caused by a strong wave group is 10% larger than that caused by a weak wave group.

In the early 1990's, we performed a series of experiments of the effects of wave groups on the wave run-up on a slope dike with steeper slope.

The smooth-impermeable slope dikes covered with concrete board are adopted with the ratios of slope m = 1.5, 2.0 and 3.0 in the model tests. The water depth is 60 cm for each case.

JONSWAP spectrum is used in the experiment. The strengths of wave groups are expressed by the groupedness factor GF.

The wave elements used in the tests are:

$GF = 0.629$, $H_{1\%} = 11.78$,
$\bar{H} = 5.43$ cm, $\bar{T} = 1.72$ sec,

$GF = 0.814$, $H_{1\%} = 12.32$,
$\bar{H} = 5.09$ cm, $\bar{T} = 1.72$ sec,

$GF = 1.041$, $H_{1\%} = 13.14$,
$\bar{H} = 4.89$ cm, $\bar{T} = 1.66$ sec.

The waves used in the tests are calibrated before the formal tests. The difference of the wave energy spectral densities between the measured and the expected is less than 5%. The calibrated curves of wave energy spectral density for three GF are shown in Figure 1.

Through analyzing the measured data, the ratios of each wave height of exceedance probability $H_{1\%}$ against each mean wave height $\bar{H}$, for the ratios of slope m = 1.5, 2.0 and 3.0 for the groupedness factors GF = 0.629, 0.814 and 1.014 are obtained and listed in Table 1. The coefficients $K_p = R_{p\%}/R_{1\%}$ for each case are listed in Table 2. $R_{p\%}$ and $R_{1\%}$ are the wave run-up with exceedance probability P% and 1% respectively.

The effecting coefficient of wave group K_{GF} is applied to express the influence level of wave group for wave run-up on a slope dike. K_{GF} is the ratio between $R_{1\%}*$ and $R_{1\%}$. $R_{1\%}$ and $R_{1\%}*$ are all the wave run-up with 1% of the exceedance probability. In order to make a comparison, the value of $R_{1\%}*$ is estimated with formulas in the 2.06.04-82 specification promulgated in 1986 and perfected recently by the former Soviet Union. The value of K_{GF} in relation to the slope ratios m = 1.5, 2.0 and 3.0 and the groupedness factors GF = 0.629, 0.814 and 1.041 are listed in Table 3.

Through the analysis of the characteristic values of the test data, the following results can be obtained:

(1) The significant value of run-up R_s

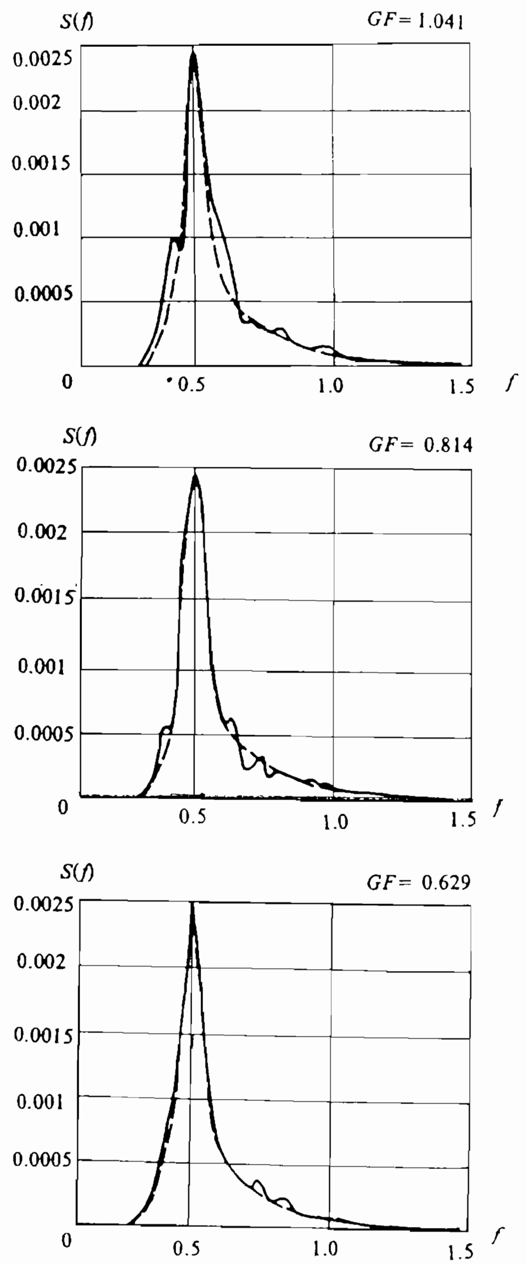

Figure 1. Calibrated curves and theoretical curves for wave spectrum.

$$R_s = R_{12\%} - R_{16\%}\text{, averaged } R_{14\%},$$

the average value of run-up

$$\bar{R} = R_{40\%} - R_{50\%}\text{, averaged } R_{46\%}.$$

(2) The mean values of K_{GF} for the three slope ratios are

$$GF = 0.629 \qquad K_{GF} = 0.86,$$
$$GF = 0.841 \qquad K_{GF} = 1.05,$$
$$GF = 1.041 \qquad K_{GF} = 1.21,$$

(3) Figure 2 illustrates the correlation curves of GF and dimensionless value $(R_{1\%}/H_{1\%})$, $(\bar{R}/H_{1\%})$, for m = 1.5, 2.0 and 3.0, respectively (see Figure 2).

Some phenomena can be observed from Figure 2 and Tables 1–3:

(a) It can be observed from the curves in Figure 2 that when slope ratio m = 1.5 and m = 3.0 and wave groupedness factor GF = 0.629, 0.816 and 1.040, $\bar{R}/H_{1\%}$ decreases as GF increases, but when m = 2.0, $\bar{R}/H_{1\%}$ increases along with the increase of GF, and an inflection point occurs, the value is near GF = 0.8. Meanwhile, in the range of values of GF used in the tests, $R_{1\%}/H_{1\%}$ corresponding with m = 2.0 is larger than that corresponding with m = 1.5 and m = 3.0

(b) Figure 2 also shows that for the same test conditions (m = 1.5, 2.0 and 3.0, GF = 0.629, 0.814 and 1.041), $R_{1\%}/H_{1\%}$ begins to increase as GF increases, and when GF is about 0.8, the inflection point occurs and $R_{1\%}/H_{1\%}$ decreases very slowly as GF increases. In the range of values of GF used in the tests, $R_{1\%}/H_{1\%}$ corresponding with m = 2.0 is larger than that corresponding with m = 1.5 and m = 3.0.

(c) It can be seen from the wave values listed in Table 2 that the distribution coefficient of wave run-up is related to groupedness factor, and its value decreases as GF increases. When GF = 0.629, the values of K_p obtained from tests approximate to the values in the "Harbour Engineering Technique Specification" of China, and when GF = 1.014, the difference between the two values is rather large. The value from the tests is 17%–44% smaller than the values from the specifications.

The above analyses can lead to some preliminary conclusions as follows:

(a) For m = 1.5 and m = 3.0 the value of run-up with 1% of exceeding probability $R_{1\%}$ increases with GF and the effect of GF on the value of significant run-up R_s is not obvious and the value of average run-up $\bar{R}$ decreases as GF increases. The main reason is that the high waves are broken continually on the slope dike and the run-down point of the current after the wave breaking is low. It limits the following wave run-up, and then

Table 1. *Distribution of wave height (H_i /$\bar{H}$).*

GF	P (%)							
	1	2	5	10	20	30	40	50
0.629	2.17	1.98	1.95	1.70	1.43	1.24	1.11	0.95
0.814	2.42	2.35	1.95	1.71	1.43	1.22	1.06	0.94
1.041	2.70	2.30	1.95	1.71	1.43	1.32	1.08	0.94
Rayleigh distribution	2.42	2.23	1.95	1.71	1.43	1.24	1.08	0.94

Note: JONSWAP Spectrum, r = 3.3. GF = 0.629, $\bar{H}$ = 5.43 cm, $\bar{T}$ = 1.72 sec; GF = 0.814, $\bar{H}$ = 5.09 cm, $\bar{T}$ = 1.71 sec; GF = 1.041, $\bar{H}$ = 4.87 cm, $\bar{T}$ = 1.66 sec

leads the mean run-up to decrease as GF increases.

(b) From the viewpoint of wave run-up, it can be seen that the slope ratio m should not be taken as 2.0, especially when GF is near 0.8 in the design work because the value of run-up then increases more obviously. The accurate peak position of inflection point can not be determined in this paper because of the limitation of tests conditions; and, therefore, a further investigation is necessary.

(c) It can be seen from the data listed in Table 2 that when GF = 0.629, the distribution coefficient of run-up K_p agrees quite well with that in the Harbor Engineering Technique Specifications of China (1987), but it decreases as GF increases. The reason is mainly the same as mentioned above. The further study of the dependence relation for GF and K_p is needed.

(d) The experiments of wave run-up under the action of wave groups are conducted in conditions without wind and only using JONSWAP spectrum. Further studies are expected on the effect of the wave groups for the run-up on a slope dike with wind and various spectra adopted.

SUMMARY AND CONCLUSIONS

On the basis of model tests, investigations on the effect of the wave group for the wave run-up on a slope dike are conducted. The results of the model tests show that wave run-up is obviously affected by the wave group when m = 2.0 and m = 3.0. $R_{1\%}$ corresponding to GF = 1.040 is 13% larger than that corresponding to GF = 0.629.

Table 2. *Distribution of wave run-up.*

GF	m	P (%)							
		1	2	5	10	20	30	40	50
0.629	1.5	1.00	0.98	0.87	0.79	0.66	0.58	0.51	0.46
	2	1.00	0.90	0.83	0.73	0.64	0.53	0.49	0.47
	3	1.00	0.98	0.95	0.84	0.70	0.66	0.59	0.55
	max	1.00	0.98	0.95	0.84	0.70	0.66	0.59	0.55
	mean	1.00	0.94	0.88	0.79	0.67	0.59	0.53	0.46
0.814	1.5	1.00	0.94	0.72	0.67	0.53	0.47	0.39	0.35
	2	1.00	0.75	0.70	0.66	0.55	0.51	0.47	0.41
	3	1.00	0.85	0.76	0.67	0.66	0.54	0.47	0.42
	max	1.00	0.94	0.76	0.67	0.60	0.54	0.47	0.42
	mean	1.00	0.85	0.73	0.67	0.56	0.51	0.44	0.39
1.041	1.5	1.00	0.77	0.58	0.51	0.43	0.38	0.33	0.30
	2	1.00	0.76	0.67	0.59	0.49	0.44	0.39	0.34
	3	1.00	0.82	0.73	0.64	0.52	0.41	0.36	0.30
	max	1.00	0.82	0.73	0.64	0.52	0.44	0.39	0.34
	mean	1.00	0.87	0.66	0.58	0.48	0.41	0.36	0.31
CH		1.00	0.96	0.91	0.86	—	0.76	—	0.68
HE		1.00	0.94	0.87	0.80	0.71	0.66	0.60	0.55

Note: CH—calculation according to the Specifications of Soviet Union; HE—calculation according to Specifications of Harbour Engineering Technique of China.

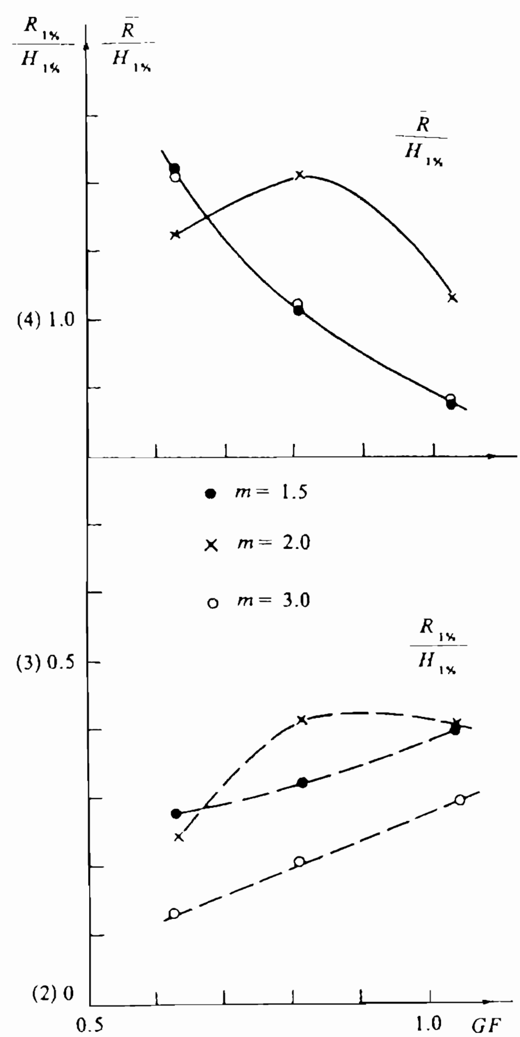

Figure 2. Relations of $\bar{R}/H_{1\%}$, $R_{1\%}/H_{1\%}$ and GF.

When m = 1.5, $R_{1\%}$ corresponding to GF = 1.041 is 10% larger than $R_{1\%}$ corresponding to GF = 0.629. Therefore, in the design of coastal protection engineering and determination of a breakwater crest elevation, the effect of wave groups should be taken into account especially for the coastal protection engineering of the nuclear power plants constructed along the coast.

Table 3. *Values of $\bar{K}_{GF}$.*

GF	m	$R_{1\%}$	$R_{1\%}$	$K_{GF} = R_{1\%}/R_{1\%}$	$\bar{K}_{GF}$
0.629	1.5	0.341	0.302	0.886	0.86
	2	0.354	0.292	0.825	
	3	0.295	0.266	0.902	
0.814	1.5	0.320	0.325	1.045	1.05
	2	0.333	0.348	1.045	
	3	0.277	0.298	1.076	
1.041	1.5	0.306	0.369	1.206	1.21
	2	0.319	0.368	1.154	
	3	0.271	0.340	1.255	

Note: JONSWAP Spectrum, r = 3.3, $\bar{K}_{GF}$ = average value of $\bar{K}_{GF}$ for m = 1.5, 2 and 3

Some problems are expected to be further studied because of the limitations of the test conditions.

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