CHAPTER 164

CRITICAL RUN-UP HEIGHT ON THE SEA WALL

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ABSTRACT

This study aims at clarifying the difference between irregular and periodic wave run-ups on a slope or a sea wall. Since hydraulic phenomena on a slope are the induced result of an interaction between a running up wave and a back-wash. The run-up height, therefore, has to be investigated in terms of a back-wash properties in addition to run-up wave properties. The experiments which are so designed that waves can run up on a slope without meeting back-wash, were conducted to evaluate the back-wash effects. The relative run-up heights R_r/H_0 of periodic waves in these experiments reached up to about two times as high as those of periodic waves which have the same steepnesses.

The run-up heights of irregular waves on a slope were also investigated experimentally. There are no clear relations between R_r/H_0 and H_0/L_0 as those for periodic waves ordinary observed, and they distributed widely. The upper-most value of R_r/H_0 in the distribution for any H_0/L_0 was almost equal to the value in the above experiment. The uppermost (critical) relative run-up heights R_r/H_0 for the given H_0/L_0 and slope may exist. The differences between the critical and ordinary run-up height of periodic waves on the sea wall were also experimentally investigated. The difference is prominent when a sea wall is set on-shore from the shore-line. It reaches up to about 4 times when a sea wall is set a little on-shore from the shore line.

Some statistical discussion on the probability of the situation in which the critical run-up may be brought about is given at the last part.

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1. INTRODUCTION

Traveling time t_d from the maximum run-up point on a slope to the still water level (SWL) is given by Gunbak(1977) as

$$t_d/T= \sqrt{1/\pi} \cdot 1/\cos\alpha \cdot 1/\sqrt{\xi} \qquad (1)$$

where T is a incident wave period, α is an angle of a slope, ξ is the surf similarity parameter. Run-up time t_u to the maximum point from SWL is also given by him as

$$t_u/T=0.7\ \xi^{-1/2} \qquad (2)$$

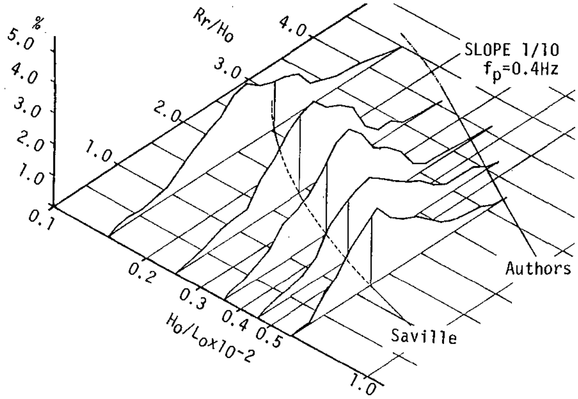
The time left t_1 for the down-wash front to retreat down to SWL without meeting the next run-up becomes

$$t_1/T=1-t_u/T=1-0.7\ \xi^{-1/2} \qquad (3)$$

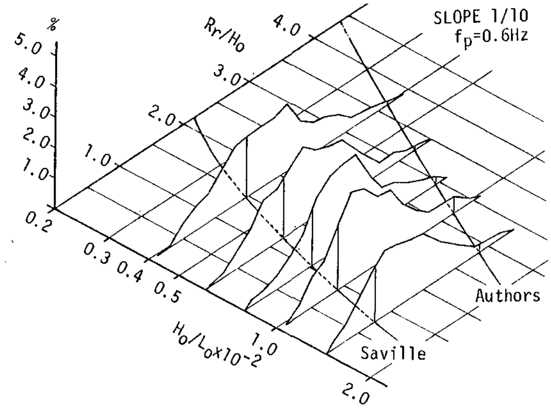
In the region $\xi < 1.6$, no interaction between run-up and down-wash takes place above SWL on a slope. Roos and Battjes (1976), however, gave a region, $\xi < 2.5$, for the same situation. Consecutive waves in the region $\xi > 1.6 \sim 2.5$, may interact with each other above SWL on a slope more or less.

Although Saville (1962), Van Oorschot et. al. (1968), Battjes (1971), and Gunbak (1977) showed the validity of the Saville's "hypothesis of equivalency" between periodic and irregular wave run-ups in some degree, these values t_d, t_u and t_1 may be different from those of irregular waves which have the same zero-up-cross properties. Because the repetitive effect of the back wash to the next run-up is constant in case of periodic wave run-up. On the contrary, due to the random nature, back-wash effect on the next run-up differs wave by wave in case of irregular wave run-up. In this case, waves with the same properties do not bring about the same run-up height, since a deceleration effect of the back-wash differs wave by wave. This random nature of back-washes must be taken into account when irregular wave run-up on a mild slope is investigated.

In this study, irregular wave run-ups are investigated to show that there are large differences between periodic wave run-ups, firstly. Secondly, experiments which is so designed that an incident wave runs up without meeting the back wash, are conducted and the existence of the critical (upper most) value of R_r/H_0 for H_0/L_0 is shown. Thirdly the same technique is used to investigate the critical run-up heights on the sea walls. Lastly the possibility of the chance in which such critical run-ups may take place is discussed statistically with the theory of wave groups.



(a) f_p=0.4Hz



(b) f_p=0.6Hz

Fig.1 Distributions of the relative run-up height of the irregular waves

2. IRREGULAR WAVE RUN-UPS

A wave tank used in the experiments was 27m long, 0.75m deep and 0.5m wide with glass side walls. At one end of the tank, an irregular wave generator was furnished (Kimura et al.,1976) and at the other end, a smooth slope of 1/10 was installed. A channel section of 2m long, 2cm wide and 1 cm deep was mounted into the center of the slope. The run-up wave gauge of a capacitance wire type was so set in the channel that the wire keeps the equal level to the surface of the slope. Wave gauges were set at h=50cm , 45cm, 20cm, 15cm, 10cm, 5cm and 2cm along the slope in which h is water depth. A water depth at the horizontal bottom was 50cm. Five Pierson-Moskowits type wave spectra, the peak frequencies f_p of which were 0.4Hz, 0.6Hz, 0.8Hz, 1.0Hz and 1.2Hz, were simulated. Since the experiments were conducted to investigate the run-up heights in terms of the incident wave properties, one-to-one correspondence between incident and run-up waves is the necessary condition in the present study. Two cases, f_p=0.4Hz and 0.6Hz, were selected among them, which almost fulfilled the condition. On the average, two or more incident waves formed a single run-up in other cases.

Incident wave properties such as zero-up-cross wave height and period were measured at h=20cm (f_p=0.4Hz) and h=15cm (f_p=0.6Hz) respectively. These two points were almost outside of the breaking zones respectively. Measured wave properties were transformed into those for deep water wave by the linear wave theory, e.g. H_0, L_0. Run-up height R_r was measured vertically from SWL to the maximum run-up point of the wave front.

One typical property of the result is that the relation between measured R_r/H_0 and H_0/L_0 in both cases showed wide scattering. No clear relation between them is estimated as in the periodic wave case (Saville,1953). Figure 1 shows frequency distributions of R_r/H_0 in individual narrow ranks of H_0/L_0. The upper and lower bound of the ranks are listed in Table-1. Transformation of irregular waves due to their dispersive nature from the point h=20cm or 15cm where incident waves were measured to the shore-line was observed to be small. Therefore these wide distributions of R_r/H_0 in the figures may depend on a random characteristics of waves.

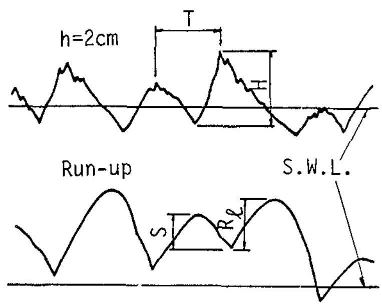


Fig.2 Definition of the properties R_ℓ , S, H and T.

Table-1 Properties of the run-up distributions

f_p=0.4Hz

$H_0/L_0 X10^3$	1-2	2-3	3-4	4-5	5-7
$(H_0/L_0)_i X10^3$	1.52	2.50	3.52	4.48	5.75
R_S/H_0	2.52	1.88	1.58	1.39	1.22
R_r/H_0	2.32	2.13	1.90	1.88	1.77
Prob.$(R_r/H_0>R_S/H_0)$ (%)	38	65	70	72	77

f_p=0.6Hz

$H_0/L_0 X10^3$	3-5	5-7	7-9	9-12	12-20
$(H_0/L_0)_i X10^3$	4.06	6.01	7.94	10.29	14.54
R_S/H_0	1.47	1.20	1.04	0.93	0.74
R_r/H_0	1.94	1.71	1.66	1.54	1.33
Prob.$(R_r/H_0>R_S/H_0)$ (%)	70	77	88	86	87

Another feature is that a significant part of the distribution exceeds the experimental result of periodic waves R_S/H_0 by Saville (i=1/10). The larger H_0/L_0 becomes the higher portion of the data which exceed the Saville's result becomes as listed in Table-1. Nearly 90% of data exceeds the dotted line R_S/H_0 ~ H_0/L_0 when $(H_0/L_0)_i$=0.0145 in figure (b).

These wide distributions of R_r/H_0 are presumably brought about by occasionally different effect of back-washes on the next run-up waves.

To investigate the back-wash effects, the relations between the properties in Fig.2 were measured and analyzed. T is an interval of the incident bore crests at h=2cm. This is almost equal to the zero-up-cross wave period measured just outside the breaking zone. H is a height of the bore from its toe to crest. S is a vertical distance from the former crest of the run-up wave to its crossing point with the next run-up. And R_ℓ is a vertical distance from the crossing point to the next run-up wave crest.

Figures in Fig.3 show the averaged relations between measured values. Totally these properties of 1000 waves in the case of f_p=0.4Hz were measured. Measured data were divided into ranks of T and S. The region of the ranks are listed in the figures. Data of H are divided into three groups of the same size in individual ranks of T and S. Symbols in the figures are plotted at the centers of individual ranks. Almost linear relations exist between R_ℓ and H while T is small. And the

slope of their relation increases with decreasing S. Since, the larger S becomes the more back-wash is accelerated on the slope, and the more the next wave which runs up against the back-wash may lose its energy.
The effect of T is indirect on the contrary. The larger T becomes the shorter time interval in which a back-wash acts on the next run-up on the slope reduces. If T is larger than a traveling time of a run-up and -down on the slope, this property gives no effect on the next wave run-up. If T is small, on the contrary, two or more incident waves form a single run-up since the next wave runs up before the former run-up reaches its maximum. In the selected two cases (f_p=0.4Hz and 0.6Hz), these two extreme situations in T were seldom. A run-up wave is, therefore, affected somehow by a back-wash of the former run-up wave. From Fig.3, we may conclude that the smaller the back-wash effect reduces the higher wave runs up. This situations may take place when the former wave height is very small or the time interval of consecutive bores is very large i.e. S is very small or T is very large. The former situation is so called "jump of waves" (Burcharth,1980). Its probability of realization is not negligibly small (Section 5). The latter situation in T is also possible because T has a statistical nature (Longuet-Higgins, 1975, Kimura, 1981 and etc.).

3. CRITICAL RUN-UP HEIGHT

The upper-most (critical) run-up height may take place when run-up wave meets no back-washes on a slope. To investigate the critical run-up height, the facilities shown in Fig.4 was used, which could realize a run-up of waves on a slope with no back-wash effect.

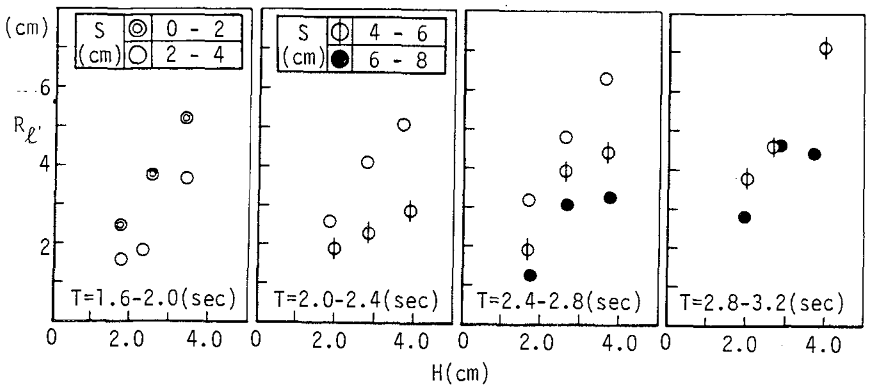


Fig.3 Relation between R_ℓ and H.

A water tight wave reflection board which was movable upward, was installed on the slope at h=20cm, (Case-II). A water tight block was put at h=9cm in addition to that for Case-II, and all water shore-side of the block was pumped into the interval between the block and the board, (Case-III). The run-up without these facilities were investigated for comparison, (Case-I). The water depth at the flat bottom was 35cm. Run-up height R was measured vertically from SWL to its maximum run-up point on the slope.

The techniques used in the experiments were as follows. In case-II, the reflection board was removed upward when a water surface of a standing wave just crossed SWL upward at the board. This was the instance when a front of an incident zero-up-cross wave just reached the board. Since shore-side of the board was still water unless the board was removed, the incident zero-up-cross wave propagated and run up on a slope with no effect of the former wave. Although small deformation around wave front was observed, overall deformation due to the discontinuity seemed to be negligibly small within the range of waves used in the present study. In Case-III, a slow oscillation started on the slope when only the shore-side block was removed quickly. The generated wave traveled back and forth within an interval between the slope and the reflection board for a while. The board was removed at the same instance as for Case-II. In addition to the timing in case-II, the timing of the block to remove was so adjusted as a result that the run-up wave just passes

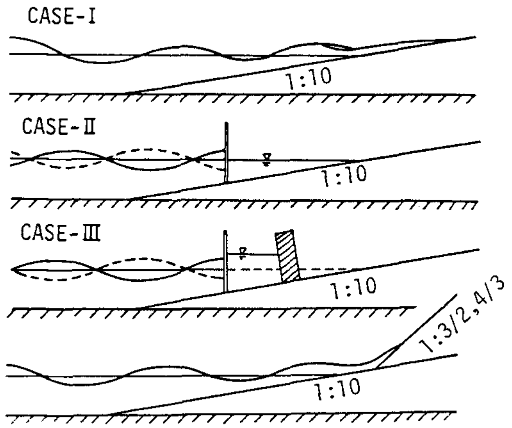


Fig.4 Experimental facilities

over the slow oscillation when it reached the second maximum on the slope. Energy loss of run-up wave due to friction loss on a dry bed might reduce with this technique.

Three different periodic waves T=1.72s, 1.21s and 0.74s were experimented. Wave heights were changed gradually until they started to break in individual cases. Figure 5 shows the relations between experimented values of R/H_0 and H_0/L_0. The solid line shows the result in Case-I. It agrees well with Saville's results.

The broken lines II_1 (T=1.72s), II_2 (T=1.21s) and II_3 (T=0.74s) show the averaged relations between R/H_0 and H_0/L_0 for individual wave periods in Case-11. Individual lines give different relations between R/H_0 and H_0/L_0. R/H_0 keeps an almost constant value where H_0/L_0 is small but decrease quickly when wave starts to break on the slope. In Case-I, plunging or collapsing type break takes place around the shore line. Breaks do not take place, however, when H_0/L_0 is small in Case-II and III. In the larger region of H_0/L_0 than the points where the broken line breaks in individual cases, waves break also and the values of R/H_0 reduce quickly.

Circles in the figure show the relation between R/H_0 and H_0/L_0 for Case-1I1. The same wave periods and wave heights as in Case-II were used in the experiments. Plotted data form almost the parallel line to those for Case-1. And their values are almost double of those for Case-I for the same H_0/L_0. Incident waves start to break at almost the same value of H_0/L_0 as in Case-II. R/H_0 in the large region of H_0/L_0 also reduces rapidly as in Case-II. The differences between broken lines and circles may not come only from friction loss on the slope. There may be affected

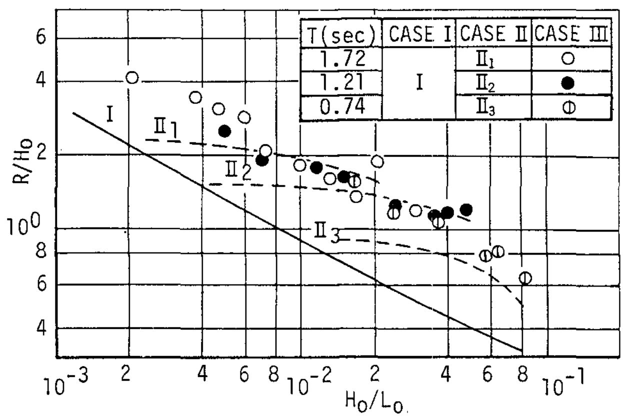


Fig.5 Relation between R/H_0 and H_0/L_0 on the 1/10 slope.

by the slow oscillation in addition, i.e. forward current and apparent water depth induced by this oscillation. These differences may take place in real sea conditions when mean water level changes due to surf beat, for example. Such effects in Case-111 as forward current and apparent water depth change give little change when incident wave properties reach the breaking condition in Case-11 and 1II, since an averaged value of plotted data in Case-III passes through the bends of lines in Case-11. The plotted data in Case-III may give a relation between the upper-most run-up height R/H_0 for H_0/L_0 on the slope of 1/10. The above lines in Fig.1 (a), (b) are the mean relation between R/H_0 and H_0/L_0 for Case-111. These lines almost pass the upper bound of the distributions. Therefore the situations in the Case-I1 and III may take place in irregular wave run-ups. This may be the reason why a large portion of the irregular wave run-ups exceed the values for periodic waves.

4. RUN-UP ON THE SEA WALL

The critical run-up height on a sea wall is investigated in this section using the same techniques in the former section. Two sea walls i=3/2 and 4/3 were used (i is a slope). Run-up height on these sea walls at several locations along the slope (1/10) were measured. Figure 6 shows the relation between relative run-up height R/H_0 of periodic waves on the 4/3 slope and d/L_0 (d is a water depth at toe of the sea wall). The steepness of the incident waves in individual figures are H_0/L_0=0.017 (top), 0.031 (center) and 0.041 (bottom) respectively. Since the wave period (wave length) is constant in each figure, i.e. T=1.72s (top), 1.21s (center) and 0.74s (bottom), d/L_0 practically indicates the water depth at the toe of the sea wall.
Therefore these three figures show practically the change of R/H_0 in terms of water depth. Circles and triangles are the results in Case-1 and 1I respectively. Run-up heights in Case-1 are larger than those for Case-I1 in a offshore region, and gradually decrease with decreasing water depth. The run-up heights for Case-II, on the contrary, keep almost constant value or show a little increasing nature with decreasing water depth unless $d/L_0 < -0.01$. Inequality of plotted values for Case-1 and I1 is reversed a little off the shore-line in individual cases.
Figure 7 shows the relative depth d/L_0 at the reversal points in Fig.6 in terms of H_0/L_0. 1n the below region of the line, irregular waves may bring about the larger run-up heights than those by periodic waves on the sea wall.
Figure 8 (a),(b) and (c) show the run-up heights on the 3/2 slope. The sea wall was installed (a) at the shore line, (b) 30cm and (c) 50cm on-

shore from the shore line along the slope. The wave periods experimented were 1.72s, 1.21s and 0.74s. In each figure, circles, triangles and circles with an oblique line show that those are the results for Case-I, II and III respectively. The decreasing nature of R/H_0 with respect to H_0/L_0 for Case-I becomes slightly milder than that in Fig.5. Although this tendency reduces with a distance from the shore-line to the sea wall. R/H_0 increases more or less with H_0/L_0 unless waves do not break on the slope in Case-II. When wave start to break, R/H_0 reduce very quickly with H_0/L_0. The upper-most values of R/H_0 are about (a) 2.5, (b) 4.0 and (c) 3.5 times as large as those for Case-I.

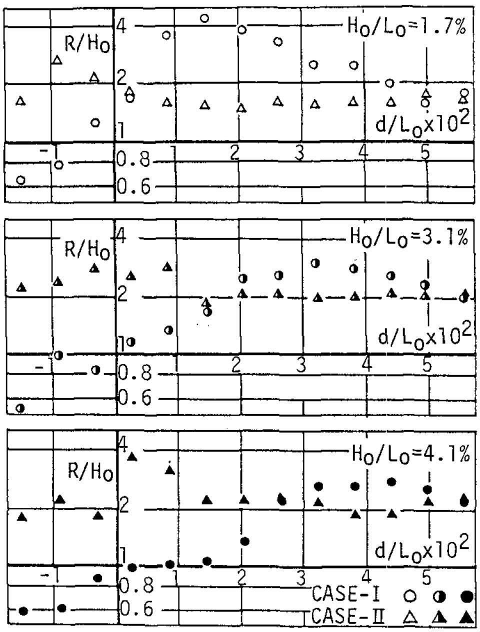


Fig.6 Change in R/H_0 with respect to d/L_0 (sea wall:4/3, slope:1/10)

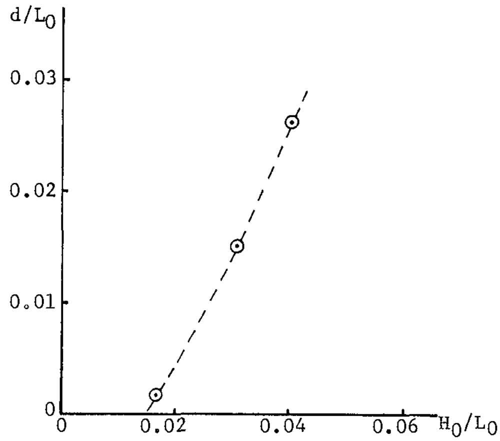


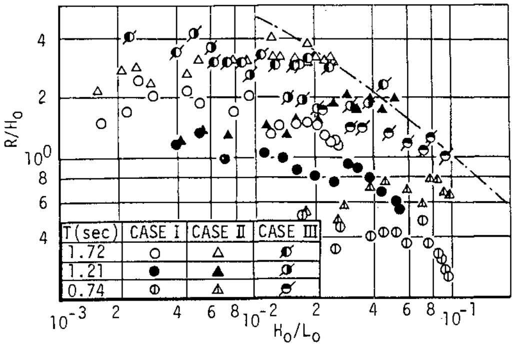
Fig.7 Relative depth at the reversal points of the run-up height.

The relation between R/H_0 and H_0/L_0 for Case-III is different from that for Case-II, however, the maximum R/H_0 value and its H_0/L_0 are almost the same as those for Case-II. The existences of the critical run-up heights shown with the dotted lines in the figures can be presumed.

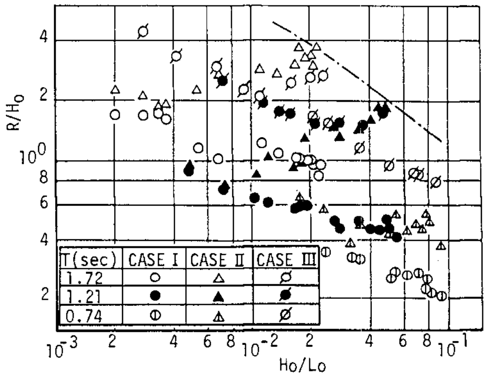
5. JUMP OF WAVE HEIGHTS

The experiments were so conducted that waves run up without any effects of the back-wash on the slope or sea walls in Sections 3 and 4. And the existences of the critical run-up heights are eventually shown. This situation could practically realize in a real sea condition. For example, when a large wave runs up just after a small wave, i.e. jump of wave heights (Burcharth,1980), the above situation may take place on a slope. Table-2 gives the probability that consecutive wave heights H_1 and H_2 fall in the listed region in the vertical and horizontal column, (Kimura,1980). The correlation coefficient used in the theory is that for the Pierson-Moskowits type irregular waves. Since about 10^4 - 10^5 waves attack on a sea wall within a single storm, mentioned situations may take place with a considerable frequency.

(a)



(b)



(c)

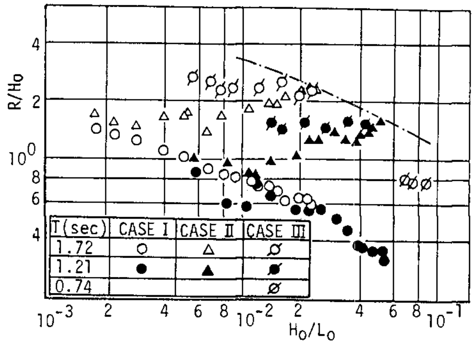


Fig.8 Relations between R/H_0 and H_0/L_0 (sea wall:3/2, slope:1/10)

Table-2 Prob.($H_1<h_1, H_2>h_2$)

		$H_2/H_{1/3}$			
	h_2	1.0	1.25	1.50	1.75
	h_1				
$H_1/H_{1/3}$	0.1	0.0019	0.0005	0.0001	-
	0.2	0.0073	0.0019	0.0004	0.0001
	0.3	0.0157	0.0043	0.0009	0.0001
	0.4	0.0272	0.0074	0.0015	0.0002
	0.5	0.0403	0.0112	0.0023	0.0004

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