A Theoretical Study of Flow Characteristic Due to Wave Run Up – Run Down

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Abstract: *Nature has its own mechanism to protect coastal area. Predicting the evolution of beach profile especially the sand beach slope is important, in terms of coastal protection and environmental sustainability. Sand beach stability depends on the rate of sediment transport both long shore and cross-shore. The dynamic of beach alignment and slope may be resulted from the fluctuation of long shore and cross shore sediment transport. The beach profile characteristics, especially the stability of sand slope profile under various wave conditions, is probably the most important issue relevant to sand beach design. Flow characteristic is an important parameter to understand the dynamic of the stable condition process. This paper is focus on the study of flow characteristic of the stable slope profile due to regular wave on* $R_u – R_d$ *area. The flow velocity on stable slope was studied using both theoretical and experimental approaches. A two-dimensional physical model was set up in the wave flume with regular wave. The experiment included the preliminary activities such as literature study, analysis of some recent interrelated research, investigation of new information, design for the experiment models and media, equipment for data acquisition, experiment's materials, plan for calibration procedure and simulations.The results indicated that the K coefficient of the* U_{Ru}/U_{Rd} *depend on the angle of slope and wave steepness. In general for the slope of n = 6, the similarity between* U_{Ru} *and* U_{Rd} *is 0.89 – 1.2, with K = 6 – 8. Other results showed that the stable slope depend on parameter function in K coefficient and* U_{Ru}/U_{Rd}.

Keywords: *Flow characteristic, run up – run down, beach profile, wave, and EBP theory.*

1. INTRODUCTION

1.1. Background

The dynamic of alignment and stable slope are resulted from the fluctuation of long shore and cross shore sediment transport. The sand beach profile characteristics, especially the stability of alignment and sand slope profile under various wave conditions and various geometric structure, is probably the most important issue relevant to sand beach design.

The erosions (see figure 1.) and sedimentations naturally take place in these sand beaches because of the hydrodynamic force as the wave force. The wave from the deep sea is approaching the shoreline with large energy that can cause erosion if there is a lack of beach protection. Furthermore, it is evident that the calamity caused by extreme waves due to climate changes has a direct relevance to the run-up and run-down motions on a near shore beach. Consequently the occurrence of wave motion near shoreline is of great importance to many applications in hazard mitigation and coastal protection, such as beach nourishment and alongshore infrastructure. This paper considers the theoretical study of flow characteristic on the stable slope profile due to regular wave on $R_u – R_d$ area, especially for impermeable smooth slope.

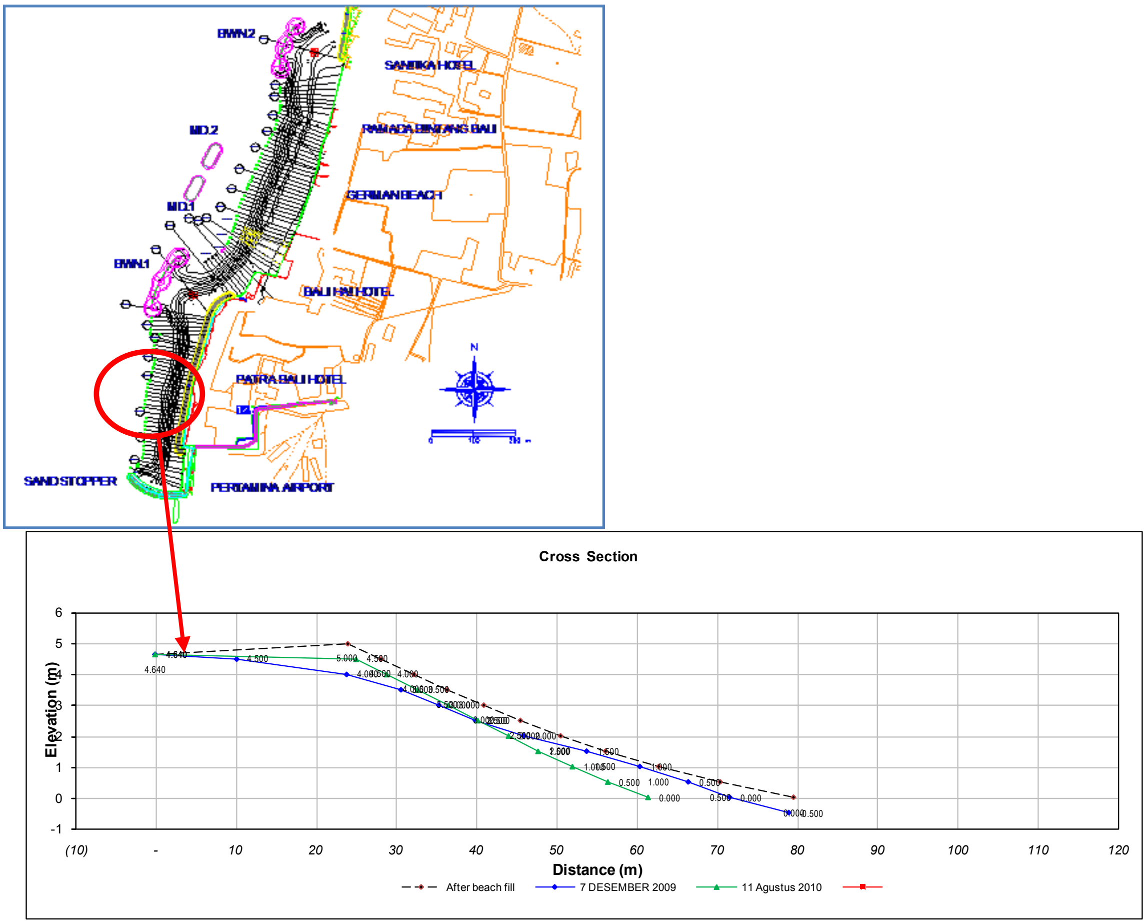

Figure 1 Example, survey and study result, the change of sand beach nourishment's slope at Kuta Beach, Bali. (Source: Setyandito, et. al. 2009, and Research Centre for Engineering Studies, GMU and BWS Penida, 2009)

1.2. Run Up – Run Down on Sloping Sand Beach

The run-up height, R_u, is defined as the maximum elevation of the water line above the undisturbed water line. The prediction of run-up levels on smooth slopes is generally well documented and most work has been based on tests using regular waves (Allsop et al.,1985, Yuwono 1990). Run-up height was also intensively studied by Battjes & Roos (1974) and The Technical Advisory Commitee (1974). Hunt (1959) synthesized wave run-up for wave breaking on the slope as:

$$\frac{Ru}{H} = \xi \quad \textit{for } \xi \quad \textit{approximately} < 2.3 \qquad (1)$$

Irribaren number (ξ) represent empirical formula from result of laboratory study and analysis for structure with sloping surface to various material type.

$$\xi = \frac{tan\alpha}{(H/L_0\,)} \qquad (2)$$

Where, *H is* wave height, L_0 is deep water wave length and α angle of slope's structure. This empirical formula (ξ) hereinafter will be used for theoretical study in this paper.

Zhang (1996) mentioned that some plane problems of run-up and reflection of wave's incident normally on a sloping beach have been investigated by Carrier & Greenspan (1958), Carrier (1966), and Tuck & Hwang (1972) based on Airy's model. He also said that the numerical calculations have been given by Pedersen and Gjevik (1983) using the nonlinear dispersive long-wave model and Kim et al. (1983) based on the Euler model. For the case of three-dimensional coastal dynamics, Carrier & Noiseux (1983) evaluated the oblique run-up and reflection of long waves on a plane beach connected to an open ocean based on linear long-wave theory, assuming the nonlinear and dispersive effects negligible. Other research upon it has been performed by Fuhman et al. (2007). He considers the numerical simulation of non linier wave run up within a highly accurate Boussinesq-type model.

The run up characteristic for sand beach profile's variation with variation of slope (*n*), stable slope (n_f) and wave steepness (H/L_0), also Irribaren Number (ξ) has been done by Setyandito et al. (2009) also Mahendra (2010) (research done at Gadjah Mada University). A comparison of relative run-up for smooth and permeable slope has been given by Losada, Gimenez-Curto (1981) (Yuwono, 1990) and Setyandito et al. data (2009) also Tech Adv Comm and Battjess and Roos (1974), plotted on figure 2. The data are taken from Ahrens and Mc Cartney (1975), Günbak (1979) and Day & Kamel (1969) (Taken from Yuwono, 1990); all data correspond to perpendicular wave incidence.

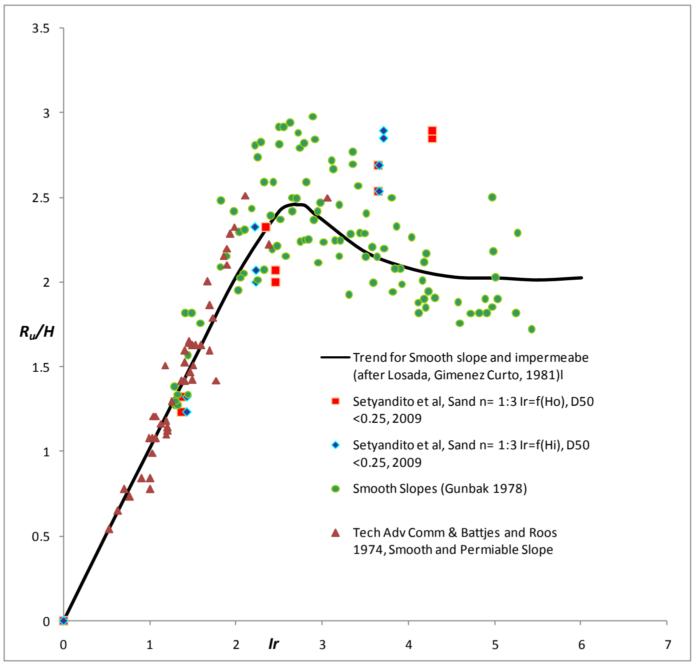

Figure 2 Wave R_u on smooth and permeable slope, comparison of relative run up for sand and permeable slope. (Setyandito et. al. 2009 and Mahendra, 2010)

1.3. Flow Velocity of Run Up – Run Down on Slope (Up rush Zone)

At the surf zone area, when the wave propagation ends after area breaking waves occurs, it motion replaced by flow of water which run up the sloping beach until its kinetic energy is exhausted (see figure 3). Troy dan Koseff (2006) in Williams S. et al. (2007), investigated the viscous damping of progressive, two-layer interfacial waves that derived theoretical decay rates which were in good agreement with experiments for small amplitude viscous interfacial wave motion over a rigid impermeable bed. This work considered the individual damping contributions from viscous flow within the fluid layers as well as from laminar bottom and interfacial boundary layers.

The spatial energy decay coefficient a used by Troy and Koseff (2006) is related to the imaginary wave number k_i by the energy equation 3.

$$\frac{\partial(c_g\bar{E})}{\partial x} = -\propto c_g\bar{E} = -2k_i c_g\bar{E} \qquad (3)$$

where the time-averaged energy per unit area is defined as

$$\bar{E} = \frac{(\rho_2-\rho_1)g}{2} a_0{}^2 e^{-2kix} \qquad (4)$$

where, ρ_2, ρ_1,are sand and water density, a_0 is wave amplitude.

Dean 1984, proposed that for progressive wave with frictional damping, the change in wave amplitude over one wave length of travel can be found to be,

$$\frac{\eta(x+L)}{\eta(x)} = e^{-2kil} \sim -e^{-\pi\left(\frac{A}{\sigma}\right)} \tag{5}$$

where, $A = \frac{fU_m}{3\pi h}$ (Dean, 1984)

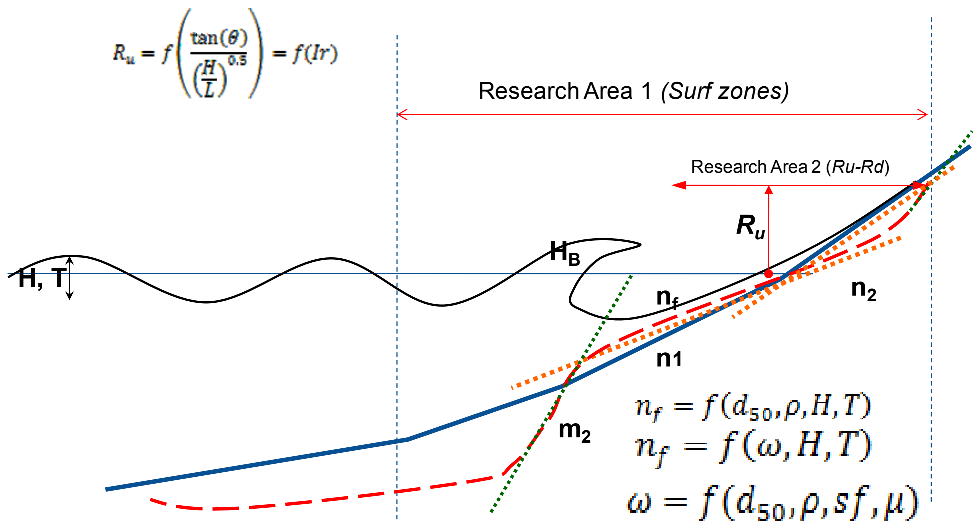

Figure 3 Sketch and definition for surf zones and up rush zones at sand beach slope. In this paper the research area used is $R_u - R_d$ (research area 2). (Setyandito et al. 2009)

According to Dean (1984), the continuity of flow condition due to the wave can be written in terms of horizontal water particle velocity of the wave multiplied by the cross-sectional area for each region, for long wave,

$$U = \frac{\eta C}{h}$$

or

$$U = \frac{H}{2}\frac{C}{h} \quad ; U \approx f(H, C, h) \tag{6}$$

If the parameter $\bar{E}$ identically with *U*, according to equation 4, based on the wave energy loses due to transmission in bottom condition and considered by breaking down the complex wave number *k* into its real and imaginary part, so that U_{Ru} is define as

$$U_{Ru} = U_0 e^{-2kix} \tag{7}$$

where $k = \frac{2\pi}{L}$ and $U_0 = \sqrt{gh}$; C = wave celerity,

Using equation 2, and replacing *x* with R_u with slope α,

$$U_{Ru} = K\sqrt{\frac{g \tan\propto H}{\left(\frac{H}{L_0}\right)^{\frac{1}{2}}}}\, e^{-4\pi\sqrt{\frac{H}{L_0}}} \tag{8}$$

For Run down (R_d) flow velocity, the following expression which has commonly been used for smooth, impermeable and dry uniform is:

$$U_{Rd} = U_0 + gt \qquad (9)$$

where $U_0 = 0$

For long wave equation,

$L = \frac{gT^2}{2\pi} \tan h\left(\frac{2\pi d}{L}\right)$, with $\tan h\left(\frac{2\pi d}{L}\right) = 1$ in deep water,

The non dimensional parameter which should be consider for stable slope related to flow velocity on up rush zone is $\frac{U_{Ru}}{U_{Rd}}$

Theoretically, the stable slope on sand beach will reach in condition the flow velocity of R_u (U_{Ru}) almost equal to the flow velocity of R_d (U_{Rd}). In this condition, the sediment will move up and down in stable condition.

Finally, theoretically, the equation of flow velocity for stable slope on up rush - up down area may be written as

$$\frac{U_{Ru}}{U_{Rd}} = 2K\left(\frac{\tan \propto}{2\pi}\right)^{\frac{1}{2}}\left(\frac{H}{L_0}\right)^{\frac{1}{4}} e^{-4\pi\sqrt{\frac{H}{L_0}}} \qquad (10)$$

where, U_{Ru} = flow velocity of R_u ; U_{Rd} = flow velocity of R_d ; K = Coefficient, a function of parameters such as a shear stress (σ) and sediment material (ω, d_{50}). ; α = angle slope's structure
H = wave height; L_0 = deep water wave length T = wave period

1.4. Experimental Set-Up

The research intended to develop a model that is capable in simulating the change of sandy beach profile due to the cross shore sediment transport especially in area R_u-R_d. In this research, the fix slope used is n = 6. The wave flume used is defined in figure 4, with regular wave.

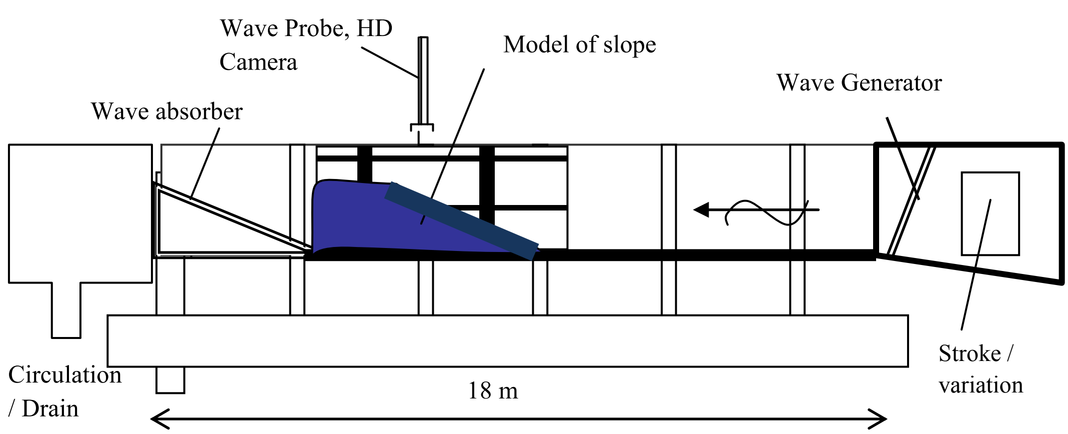

Figure 4 Sketch model of impermeable slope with wave flume (Setyandito, 2009).

1.5. Wave Run Up – Run Down on Slope

In this sub chapter, there are two laboratory research results using an experimental and theoretical approach. The experimental result between run up velocity U_{Ru} and run down velocity U_{Rd} illustrated in Figure 5. It is a graph of U_{Ru}/U_{Rd} *vs* H/L_0., with fix slope n = 6., comparison between U_{Ru}/U_{Rd} dan H/L_0, where at the slope of n = 6., the ratio of run up dan run down velocity (U_{Ru}/U_{Rd}) is within the range of 0.9 – 2 with the 0.01 < H/L_0 < 0.06.

Theoretically, if there is no sediment movement (erosion or accretion), the value of U_{Ru}/U_{Rd} should be around 1 – 1.2 (stable slope). The data plotting of R_u and R_d of research result graph of *Ir* and R_u/H_o, R_d/H_o *shown in* Figure 6. It explains that the simulation output are within the slope of smooth slope and impermeable.

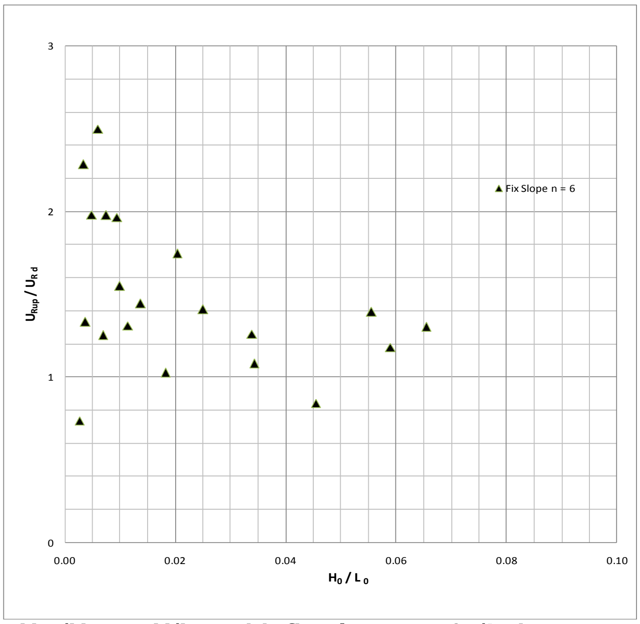

Figure 5 Graph U_{Ru}/U_{Rd} *vs* H/L_0., with fix slope *n* = 6. (Laboratory analysis and data)

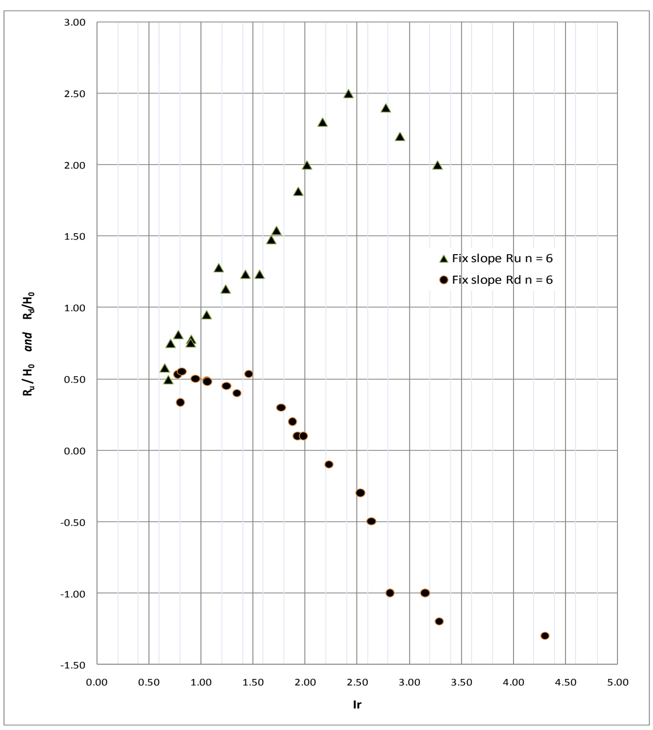

Figure 6 Graph R_u/H *and* R_d/H *vs Ir*., with fix slope n = 6.

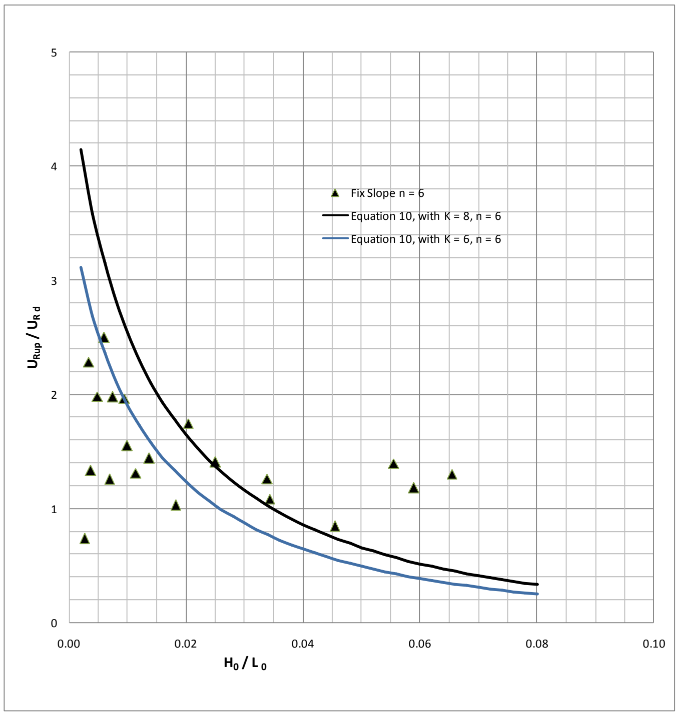

Figure 7 Graph U_{Ru}/U_{Rd} *vs* H/L_0.,
Comparison between theoretical study with data of fix slope n = 6 and data of fix sand slope of n = 6, d_{50} < 0.4 mm.

It is shown in Figure 7., with theoretical approach of equation 10, that the U_{Ru}/U_{Rd} is approximately 0.9 – 1.2 for a fix slope n = 6. A slightly different K value (coefficient value) had caused a big difference of slope and wave steepness parameters.

The minimum and maximum value of U_{Ru}/U_{Rd} shows the occurrence of stable slope, at the wave steepness ranging from 0.02 – 0.0325 with value of UR_u/UR_d from 0.9 – 1.2. The sedimentation will occur when H/L_0 is < 0.02 with K = 6, and H/L_0 is < 0.03 with K = 8. The erosion of the beach slope arise when H/L_0 is > 0.0325 with K = 6 and H/L_0 is > 0.0425 with K = 8

The stable slope indicated by there is no reduction and accumulation of sediment at the slope. It is significantly affected by flow velocity of Run up (U_{Ru}) and flow velocity of Run down (U_{Rd}). From the experiment, this condition occurs if U_{Ru}/U_{Rd} = 0.85 – 1.4.

The result of theoretical approach using the Equation (10) under estimated the experimental result, especially on a smooth and impermeable slope. However, there is potential for challenges ahead, if K value combined with other parameters such as shear stress and the characteristic of material, together with the wave Run up theoretical approach, the model equation could be closer to the measured data.

1.6. Conclusions

1. It can be concluded that the stable slope would be achieved if U_{Ru}/U_{Rd} is between 0.89 – 1.4, with a fix stable slope of n = 6. In this slope, from equation 10, the value of H/L_0 is around 0.02 – 0.0325, within the theoretical approach coefficient K = 6 – 8. The sedimentation will occur when H/L_0 is < 0.02 with K = 6, and H/L_0 is < 0.03 with K = 8. The erosion of the beach slope arise when H/L_0 is > 0.0325 with K = 6 and H/L_0 is > 0.0425 with K = 8
2. The comparison result between theoretical and experimental approach are essential for a small scale equilibrium beach profile (*EBP*) especially the run-up characteristic (R_u) with the phenomenon of *EBP* process.
3. Moreover, it is important to conducted further research using fix slope, with n flatter and steeper than n = 6, also slope with sand material.

4. The theoretical approach in this paper, using R_u as a f(*Ir*) which represent result of empirical study. It is essential for using R_u from theoretical study, also *K* with function of parameters to formulate the theoretical approach of flow velocity in up rush zone.

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