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THE PROFILE STABILITY ON THE ARTIFICIAL SAND BEACH NOURISHMENT

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Abstract

A thorough study concerning the artificial sandy beach slope stability is studied in this paper. The performance analysis of the cross shore profile was using experimental approaches. A 2 (Two) - dimensional physical model was set up in the laboratory wave flume. The initial slopes (n) of the artificial sand beach model are n = 1:6. This study result also compared with some theories established from previous research. The results indicate that the sandy beach slopes are adjusted due to wave attack to form either steeper or flatter stable slopes. The range of stable slopes (n_f) are 3 ≤ n ≤ 12. It was observed that the sand particles at the lower part of the slope are transported upward and deposited at a higher part of the slope and vice versa. Experimental result showed the stability of beach profile with the utilization of bar as well as berm. The result also showed significant correlation between stabilizing slope (\(\tan \alpha\)) and wave steepness (\(H_0/L_0\)).

Key Words: Sandy beach profile, wave, experiment and theory.

1. INTRODUCTION

The main issue of coastal area is erosion problem caused by wave attack and human activities such as the construction of beach structures. One of beach protection methods that considered as environmental friendly is artificial beach nourishment. It has been increasingly applied in Indonesia as a coastal protection technique. However, the standard guide to design a sand beach profile that correspond to the condition in Indonesia is not yet available. Therefore, accurate design is highly needed in order to obtain the stable sand beach profile.

The slope profile influenced by wave energy other natural forces that attack its1,2. Figure 1 shows one example of artificial sand beach nourishment which built in Sanur Beach, Bali Island, Indonesia.

The main objective of this study is to determine the sandy beach slope profile characteristic, especially the stability of sandy beach slope profile under various wave conditions.

Fig. 1. Example, survey and study result, the change of sand beach nourishment’s slope at Sanur Beach, Bali Island, Indonesia. (Research Centre for Engineering Studies, GMU in collaboration with BWS Penida, 2009)3
2. EQUILIBRIUM SAND BEACH PROFILE

Swart (1974) did the research on the changing of slope profile with sand particle diameter \( (d_{50}) \) 0.11 mm to 0.227 mm. The profile was divided into 3 zones, where those zones have different sediment transport mechanism. They are, zone 1 (backshore) is above wave run up \((R_u)\), zone 2 (D – profile) where sediment transport due to the waves occur. Zone 3, the transitional area formed by bottom movement.\(^4\)

The result showed that in zone 1, the wider diameter of sediment particles, the sooner the stable slope occurs. In zone 3, the wider the diameter of sediment particle, the slower the stable slope occurs.\(^4\) Setyandito et al. (2009, 2010, 2011) has been doing the research on the changing of sandy beach profile with the sand diameter 0.23 mm – 1.4 mm.\(^5\) \(^6\) The profile divided into 3 zones where each zone has different sediment transport mechanism. The zones shown in Figure 2.

\[ \frac{R_u}{H} = \xi \text{ for } \xi < 2.3 \quad (1) \]

Fig 3 shown that at \( \xi = 0 \) to \( \xi = 2.5 \) there is an increase of \textit{run-up}; and it decreasing at the \( \xi = 4.25 \), then after that it remain constant.

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 (\(\xi\)) has been done by Setyandito et al.\(^5\) also Mahendra\(^6\) (research done at Gadjah Mada University, Indonesia). A comparison of relative run-up for smooth and permeable slope has been given by Losada, Gimenez-Curto (1981)\(^7\) and Setyandito et al. data (2009) also Tech AdvComm and Battjess and Roos (1974), plotted on Figure 3.

The data are taken from Ahrens and McCartney (1975), Günbäk (1979) and Day &Kamel (1969) \(^7\); all data correspond to perpendicular wave incidence.

\[ \text{Area of Study} \]

\[ \begin{align*}
R_u & \quad \text{Wave Run Up} \\
F & \quad \text{Freeboard} \\
\text{DWL} = \text{Run up} \\
\text{DWL} + \text{Ru} + F & \quad \text{Design Water Level}
\end{align*} \]

Fig 3. Division of sandy beach slope profile.\(^{10}\)
Table 1. The correlation between sand particle’s diameter ($d_{50}$) and stable sandy beach slope

<table>
<thead>
<tr>
<th>Sand Diameter</th>
<th>Protected Beach</th>
<th>Unprotected Beach (Open)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm.</td>
<td>$n$</td>
<td>$m$</td>
</tr>
<tr>
<td>0.2</td>
<td>25 – 40</td>
<td>6 - 10</td>
</tr>
<tr>
<td>0.3</td>
<td>12 – 20</td>
<td>6 - 10</td>
</tr>
<tr>
<td>0.4</td>
<td>7 – 12</td>
<td>6 - 10</td>
</tr>
<tr>
<td>0.5</td>
<td>6 - 10</td>
<td>6 - 10</td>
</tr>
</tbody>
</table>

3. 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 surf zones. In this research, the initial slope used is $n = 6$, with sand diameter $d_{50} = 0.275$ mm. The wave flume used is defined in figure 4, with regular wave.

To define the implementation of wave theory towards experiment data, the early basic experiment of wave condition in wave flume plotted in to the correlation graph of $H_i/h$ terhadap $h/L_i$ with logarithmic scale in figure 4. It is shows that almost all data are in Airy’s wave theory especially in Airy intermediate depth and shallow water.

4. RESULTS AND DISCUSSION

4.1. Equilibrium Slope Profile

Experiment result of equilibrium sandy beach slope profile measured by bed profile, analized and shown into graph of stable slope shown in figure 5 and figure 6. In those figure, show the example of equilibrium sandy beach slope with stroke 12 cm. wave period ($T$) = 1.5 s., wave height ($H$) = 2.2 cm.

Fig. 3. Sketch model of permeable sandy beach slope with wave flume.

Fig. 4. Experiment data of wave type on wave flume, $T = 1 – 4$ s., Stroke 12, 16, 18, with division area of wave theory.

Fig. 5. Equilibrium sandy beach profile, Stroke 12 cm. $H = 2.2$ cm., $T= 1.5$ cm. (from video running)

Fig. 6. Equilibrium sand beach profile (slope), Stroke 12 cm. $H = 2.2$ cm., $T= 1.5$ cm. (from data analysis)
Table 2. Experimental result of slope of Equilibrium sandy beach profile (based on definition of cross shore profile by Setyandito (9) (11))

<table>
<thead>
<tr>
<th>Stroke (cm)</th>
<th>H (m)</th>
<th>Hs (m)</th>
<th>n</th>
<th>n &lt;i&gt;1&lt;/i&gt;</th>
<th>n &lt;i&gt;2&lt;/i&gt;</th>
<th>n &lt;i&gt;3&lt;/i&gt;</th>
<th>n &lt;i&gt;3&lt;/i&gt; max</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>1.0</td>
<td>0.010</td>
<td>6.45</td>
<td>6.95</td>
<td>6.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>0.012</td>
<td>6.72</td>
<td>7.28</td>
<td>6.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>0.010</td>
<td>6.04</td>
<td>6.49</td>
<td>6.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>0.009</td>
<td>6.85</td>
<td>7.23</td>
<td>6.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>0.011</td>
<td>6.56</td>
<td>6.77</td>
<td>6.54</td>
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</tr>
<tr>
<td></td>
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<td>0.007</td>
<td>7.15</td>
<td>7.28</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>4.0</td>
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<td>6.32</td>
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</tr>
<tr>
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<td>1.0</td>
<td>0.031</td>
<td>4.00</td>
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<td>3.96</td>
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</tr>
<tr>
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<td>7.40</td>
<td>8.23</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>0.017</td>
<td>5.07</td>
<td>6.30</td>
<td>5.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>0.016</td>
<td>6.60</td>
<td>7.09</td>
<td>6.30</td>
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</tr>
<tr>
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<td>5.71</td>
<td>5.84</td>
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<tr>
<td></td>
<td>4.0</td>
<td>0.014</td>
<td>5.89</td>
<td>6.09</td>
<td>6.30</td>
<td></td>
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</tr>
<tr>
<td>18</td>
<td>0.9</td>
<td>0.061</td>
<td>4.55</td>
<td>5.28</td>
<td>4.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>0.034</td>
<td>3.99</td>
<td>3.61</td>
<td>3.72</td>
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<tr>
<td></td>
<td>2.0</td>
<td>0.017</td>
<td>5.24</td>
<td>5.52</td>
<td>5.28</td>
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<tr>
<td></td>
<td>2.5</td>
<td>0.020</td>
<td>5.60</td>
<td>6.26</td>
<td>6.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>0.020</td>
<td>5.12</td>
<td>5.12</td>
<td>5.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.5</td>
<td>0.020</td>
<td>6.67</td>
<td>7.51</td>
<td>7.11</td>
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<tr>
<td></td>
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<td>0.018</td>
<td>6.68</td>
<td>6.47</td>
<td>6.06</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. shows experiment result of stable slope (equilibrium sandy beach profile condition). It is shown from the result, the stable slope is \( n_{H} = 3 - 12 \), where \( n_{H} \) is the slope profile between the lowest wave run down (\( Rd \)) to the highest wave run up (\( Ru \)) (Fig. 2).

4.2. The Influence of Sediment Parameter to the Stable Slope

Some researcher such as Rector (1954), Eagleson, Glenne, and Dracup (1963), Nayak (1970), Ramah and Eoratthupuzho (1973), Van Hijum (1974), Thompson (1976) (15), and Setyandito dkk (2008) did research on the influence of fall velocity parameter toward stable slope\(^3\).

The result shown in non dimensional graph parameter \( H_0/\omega T \) and stable slope \((n_H)\). The comparison between experiment result with previous result shown in Figure 7.

Figure 7. shows that the stable slope will reach \( n_H = 3 - 12 \). The stable slope is influenced by wave period \((T)\), in same of particle’s fall velocity condition, the higher wave period \((T)\), the higher wave height \((H)\) the flatter the beach slope\(^5\) \(^{11}\).

In Figure 7., the boundary condition in using graph is data which is includein the area experiment result of Setyandito (2008) and experiment result \( n_H \). Experiment result \( n_H \), is value \( H_0/\omega T= 0.02 - 5 \) and stable slope value between \( 3-12 \). If the field measurement values fall outside the range of the study result then, the value from other study can be utilized.

4.3. Formation Criteria of Bem or Bar at the Stable Artificial Sand Beach Profile

The study result of correlation between \( H_0/d_{50} \) and \( H_0/L_0 \) was compared with bigger scale research result conducted by Kraus and Larson (1988), see Figure 9. The border line was drawn in Figure 9, to differentiate between the calm profile (appearance of berm) and the storm profile (appearance of bar). These lines were obtained by following these equations:

\[
\frac{H_0}{L_0} = 0.07 \left( \frac{H_0}{d_{50}} \right)^{-1/5}
\]

(2.)

Fig. 8. Correlation between \( H_0/d_{50} \) and \( H_0/L_0 \), comparison between this study (small scale) using boundary condition of bar, with the big scale Larson (1988) using boundary condition of bar.
4.4. The Influence of Wave Steepness to The Stable Slope

Miche (1944) had also studied the stable slope profile in the area of run up – run down. The comparison result between this study and both Miche (1944) and Larson (1988) show a similar trend. The graph of Miche (1944) present the stable slope of 0.1 \( \leq \tan \alpha \leq 1 \) or slope \( nf_1 = 6.6 \) to \( nf_1 = 3.3 \), with \( 0.001 < H_s/L_o < 0.1 \). This study exhibited the stable slope of \( 0.1 \leq \tan \alpha \leq 0.3 \) or slope \( nf_1 = 10 \) to \( n = 3.3 \), with \( 0.001 < H_s/L_o < 0.01 \). Moreover, at \( H_s/L_o > 0.02 \) and \( H_s/L_o < 0.01 \), stable slope with a bar and berm were formed, respectively.

5. CONCLUSIONS

1. The result of 2D physical modeling analysis shown the occurance of stable slope profile. The steeper the wave would created the flatter slope. The slope of artificial sand beach was influenced by the wave steepness and the sand characteristics. The higher the sand density, the steeper the beach slope.

2. The correlation between slope \( (nf_1) \) and non dimensional parameter of \( H_s/\omega T \) in this study ranged from \( nf_1 = 3 – 12 \) and \( H_s/\omega T = 0.02 – 5.00 \), respectively. The measurement of field data such as wave height \( H \) and wave period \( T \) must be converted to non dimensional parameter, in order to utilize this study result. However, if the field measurement values fall outside the range of this study result then, the value from other study can be utilized.

3. The 2D physical modeling analysis shown the occurance of stable slope profile \( (nf_1) \) which influenced by wave period \( (T) \). For the same of particle’s fall velocity condition, the higher the wave period \( (T) \) the steeper the beach slope (with berm). The correlation between the stable slope in an area of swash-zone \( (\tan \alpha) \) and the wave steepness \( (H_s/L_o) \), shown an erosion or accretion occurrence, both in experiment result and theoretical study.

4. The stable profile would created both a bar or berm. However, it would also not created a bar and berm. The stable slope developed in this study was \( 0.1 \leq \tan \alpha \leq 0.3 \) or slope \( nf_1 = 10 \) to \( n = 3.3 \), with \( 0.001 < H_s/L_o < 0.01 \) where from experiment result, showed that at \( H_s/L_o > 0.02 \), stable slope with a bar were formed.

ACKNOWLEDGEMENT:

The authors would like to express their sincere gratitude to the Directorate of Research and Public Service, Directorate General of Higher Education, Ministry of National Education of Indonesia, through LPPM-UGM for the funding.

The research is being done at Laboratory Hydrology and Hydraulic, Research Centre for Engineering Studies, GMU (PSIT-UGM), affiliated to Laboratory Hydrology and Hydraulic, Department of Civil and Environmental Engineering, Faculty of Engineering GMU. The authors would like to express their sincere gratitude for the opportunity and provided facility.

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