THE STABILITY OF GAMAPOD AND MIXED (GAMAPOD AND RUBBLE) ARMOR LAYER MODELS

Radjanta Triantofilia *) and Shinta Susetyowati**

ABSTRACT

Manmade material for armoring breakwater slope has been widely used. The advantages of this type of material are numerous such as its efficiency, cost effectiveness, and stability against wave attack. It was shown that a stability coefficient of about twice that of tetrapod was achieved by gamapod materials under the same condition.

The promising material was mixed with rubble mound to form a mixed armor layer. This was then tested under wave attack. The result showed that the mixed material was more stable when compared with gamepod armor layer. It was also found that the mixed armor layer follows a different character of stability curve.

PREFACE

The development of coastal area for many purposes such as housing, central business district, recreation and many others has increased the need for coastal protection, especially in areas of high wave energy. Breakwater and revetment are examples of coastal structures commonly used to protect the coastal area. Many types of these structures have been proposed, each with its own character and function to suit the field condition. One of the typically cheap construction is the rubble mound type. The usually as to minimized the construction cost, consists of the core, the armor layer and the filter between the core and the armor layer. The core is made of relatively fine material whilst the armor layer was designed to protect the core from wave attack. The filter is designed as to ensure that no-core material may be washed out. The armor layer stability was known to depend on the character of the material such as the weight, the shape and the density, besides many other external factors. The shape of the material determines the interlocking effect which play a very important role in the armor layer stabilization.

Other failure of the armor layer may be caused by the breaking down of the material. As the material becoming smaller and reformed due to breaking process, they become less stable, which finally caused total failure of the armor layer (Jensen, 1984 and Van Deur Meier, 1987). Breaking down processes may be caused by:

1. rocking of the material
2. low quality of material

The first of the above reason of failure may be reduced by maximizing the possibility of material movement. A mixed armor layer was hoped to reduce the possibility of rocking and also producing higher stability of the material.

STABILITY OF ARMOR LAYER

Armor layer material should be designed to withstand wave attack. The stability of individual or group of material depends largely on the weight and the shape of the material due to interlocking effect as has been mentioned before. The interlocking between material produce additional force to the weight of a unit or group of material, making a unit or group of material weigh more than their own weight and becoming more stable.

Figure 1 shows the forces on a single armor unit. This is a typical force that acts on the material as the wave run down. In such a condition the forces on the material consisted of: drag and inertia force, due to wave run-down, lift force (due to difference of velocity above the material and under the material), friction force (due to the friction between material and the slope roughness). A simplified calculation for single armor unit yield the well-known Hudson formula as follow:

\[ W = \frac{\rho g H^2}{K_d (\frac{H}{L})^2} \times \text{crges} \]

where:

- \( W \) = weight of armor layer material
- \( \rho \) = density of water
- \( K_d \) = stability number
- \( \alpha \) = angle of breakwater slope
- \( H \) = wave height

The wave height used in equation 1 may be \( H_s \) (significant wave height) or \( H_{10} \) depending on the appropriate \( K_d \).

Although the equation has some shortcomings (see for example Jensen 1984, it has been proven to be applicable in most cases of rubble mound breakwater. The \( K_d \) coefficient (stability number) accommodates not

*) Dr. Radjanta Triantofilia, Ph.D. Lecturer, Fac. of Eng., GMU
**) Shinta Susetyowati, S.T. - Formerly student at Fac. of Eng., GMU

40 MEDIA TEKNIK No.2 Tahun XVIII Edisi Agustus 1990 No. ISSN 0216 - 3012
only the friction between the material and the slope but also between the materials, and other deviations from the condition where the equation was derived.

The weightier is the material (due to interlocking effect of individual) the higher is the stability against wave attack. However, increasing the weight of individual material caused an increase in layer thickness and the total volume of the armor layer material. This is not happened when only the interlocking effect is increased. The advantage of the interlocking effect is therefore the reduction of armor layer cost. It is on this ground that many effort to develop new type of material having high degree of interlocking is carried out.

GAMAPOND MATERIAL

Gamapond is a type of man made material which has been shown to have relatively high degree of interlocking. The cross section of the material was shown in figure 1. The stability number was tested against irregular wave condition of Bretschneider wave energy spectrum showed to be about 10-18. Beside the high stability number, it is also relatively simple and therefore easy to make. These factors are very promising to produce an efficient armor layer. A disadvantage of this material to the sharp edges at the feet joint. This may caused stress concentration which might introduce cracking. The disadvantage may be compensated by utilizing fiber concrete for the material. The fiber concrete has been shown to have high strength against stress and strain especially due to collision.

MIXED ARMOR LAYER

Although gamapond material has high stability number, rocking of individual material may happen as has been observed in the model test. Rocking may degrade the concrete quality due to the collision between material. Although such degradation may be compensated using fiber concrete as mentioned above, a reduction of

The test was conducted using irregular wave of Bretschneider wave energy spectrum. It was shown (Triyamadjaja, 1993) that stability number depends on the duration of wave attack. A 7 hours of wave attack was considered to be sufficiently long for a design purpose and therefore was taken as the duration for the test. The Palau Bai breakwater project for example was designed under 7 hour wave attack (Direktorat Jendral Perhubungan Laut, Dep. Perhubungan and Biro Affiliasi Teknik UGM, 1986).
The test was divided into test series. Each series of the test consisted of 3 to 4 runs starting from the lowest wave height where almost no displacement of armor layer material up to the highest wave where the breakwater armor layer was totally destroyed. The displacement after each run the wave was not repaired.

**Filter Material**

Rubble was used as filter material which were placed randomly after the gapped armor layers were set. Volume of filter was varied in order to investigate the stability performance of the mixed material.

**Density of Gapped and Filter Material**

Tiratmadja and Tantrawan (1994) showed that the stability of gapped armor layer depends on the length of the feet. The optimum length of gapped feet is approximately 0.8 times the diameter of the feet.

However they utilised gapped model made of log each adhesive and sand with mixed density of 18 kN/m³ which was much less than that of the prototype. Such a discrepancy might have produced a scale effect on the result. The deviation is basically due to the violation of geometrical similarity as follows:

1. As the density of the material is smaller, the volume of the material becomes bigger for a constant weight. If the larger material is still under water during draw downs, deviation of force loading occur. The bigger material receive larger drag force, inertia force and buoyancy force. This deviation starts to have been accommodated by equation 1, where density of the material and the water was taken into account. However if the material is large enough so that there is a significant difference of submersion, where the whole unit of the small material was submerge whilst only part of the larger material was under water there were not only the magnitude difference of the forces, but also the points where the forces were applied. This deviation is not accommodated by equation 1.

2. The number of large material occupying certain area (less that of smaller material). Movement of a unit material of the larger size give higher damage percentage when compared with the smaller size material.

The investigation of the scale effect was made possible in the present study where gapped model of 2.5 kN/m³ were used.

**Damage criteria**

The criterion of breakwater stability was based on the damage percentage of the armor layer. This is the number of gapped displaced by the wave divided by the total number of gapped units being attacked. The total number of gapped suffering from wave forces was estimated following Van Der Meer (1988). That is the number of armor unit present within the section between

42 MEDIA TEKNIK No. 3 Tahuk, XVIII Edisi: Agustus 1996 No. ISSN 0218- 3012
The slope of the curve in figure 3 may vary with the material.

Equation 2, may be used only when the wave is not breaking before reaching the breakwater so that the Rayleigh distribution is still valid. In reality, breaking wave may occur in front of the breakwater due to lack of water depth. At such a condition, high waves were limited by water depth resulting the violation of Rayleigh distribution and hence equation 2 is not applicable.

This finding shows the importance of the consideration of wave duration in the design of breakwater.

Range of Stability number

The range of the stability of the armor layer was probably due to the random placement of material and the wave condition. Direktorat Jenderal Perhubungan Laut, Dep. Perhubungan and Biro Afiiasi Teknik UGM (1986), showed that the stability of rubble mound armor layer vary considerably under a similar regular wave attack. This means that although the wave condition is similar, the stability number may vary due to the random placement of the rubble.

Other test conducted by Triatmadja and Tanjrawati, 1994 and the present study utilized an irregular wave condition with the same spectrum, and time series showed similar phenomena to that produced by the regular wave attack. These phenomena showed that both the placement and the wave condition affected the stability number of the armor layer.

In fact it is interesting to investigate further the stability of the gamapod armor layer with different density. As the density increases, the volume of a unit gamapod reduces, causing different geometry of the
Figure 4. Geometric distortion of the model caused by different density of gamspod material

Model (figure 4), which may finally result in different stability number. Interestingly the test showed similar results both in the characteristic and the stability number of the armor layer when compared with the previous results of models with different density. In averaged there is almost no difference between the two results. A comparison of gamspod stability number for a certain duration, showed that the range of the stability number was different, but the average between the two is very closed. Therefore it may be said that the increase of density from 18 kN/m³ to 25 kN/m³ has no significant effect on the stability number or, the scale effect was smaller than the variation of the stability number of randomly placed gamspod armor layer.

Mixed gamspod-rubble armor layer stability

The gap between gamspod was filled with rubble of certain size. The diameter of the filler was made so that they may penetrate into the gap when dumped on the armor layer. The placement of the filler was therefore random. The volume of the filler was varied from 10% up to 50%. This was aimed at optimizing the volume of the filler material. The diameter of the filler was also varied in order to study the characteristic of the mixed material.

The test showed that when the filler diameter was very small when compared with the gap between gamspod, the filler material was easily washed away or penetrated into the armor layer. The reason is that most of the material do not in contact with gamspod, but only with themselves. This is like a group of rubble material which has much less stability number than the gamspod due to the smallness and less interlocking effect. Therefore there was no improvement of the stability. As the filler material relatively large, some of the filler material interlock with gamspod, and produce additional interlocking effect between gamspod.

The test results showed that the stability increases as the percentage volume of the filler material was increased. The increasing stability of the mixed armor layer was shown to be not significant as the volume of the filler higher than 30%. Table 1 shows the comparison of stability number at 5% damage, between mixed-armor layer of different percent of filler. At filler material less than 20% of gamspod pore volume, there is no significant increase in stability number. In fact a drop in stability number were recorded as the volume of filler material approximately 10% of gamspod pore volume.

The condition at the filler becoming higher than a certain volume is like that of rubble armoring the gamspod material. The rubble (on top of the gamspod) is again may be easily displaced by wave attack as has been explained above. This is probably the reason why there was a slight drop in Kd at filler material volume higher than 30% as shown in table 1. At lower damage percentage (1% and 3%) the stability of mixed armor layer was more than twice of gamspod only armor layer.

Table 1. Comparison of mixed armor layer Kd value of different filler volume (at 5% damage)

<table>
<thead>
<tr>
<th>Vol. of filler</th>
<th>0.1 pv</th>
<th>0.2 pv</th>
<th>0.3 pv</th>
<th>0.4 pv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kd</td>
<td>0.75</td>
<td>1.18</td>
<td>1.56</td>
<td>1.45</td>
</tr>
</tbody>
</table>

p = pore volume of gamspod
K = Kd of mixed / Kd of gamspod armor layer

44 MZDIA TEKNIK No.2 Tahun XVII Edisi Agustus 1996 No. ISSN 0216 - 3012
stability (not shown in table 1). This implies that as damage percentage gets higher, the effect of filler material reduces and that the average slope of the curve (% damage versus Kd at N=2000) of gamapod armor layer was slightly steeper than the mixed armor layer only at low percentage of damage (figure 5). Hence, the mixed material is more stable only at the initial stage of damage.

A range of the armor layer stability was again found in the test results. This was due to the random placement of both the gamapod and the filler material.

The damage curve of the mixed material was compared with the gamapod only armor layer. The comparison of the two curve indicated that the damage of the gamapod only armor layer started earlier than the mixed material. As the number of the displaced gamapod increases, the effect of the filler reduces. The interlocking becomes simply between gamapod and rubble which is certainly less than the interlocking between gamapods. Hence it may be concluded that the stability of mixed material (gamapod and rubble) is higher than the stability of gamapod only for a damage percentage under 10%.

**CONCLUSION**

The conclusion of the research may be summarized as follows:

1. The variation of stability number due to the random placement of armor layer material is higher when compared with the variation caused by scale model effects.
2. The effect of the storm duration is shown to be significant. There is an almost linear correlation between stability number and the duration of wave attack as N>1000.
3. The diameter and the volume of the filler affect the stability of the mixed armor layer. The optimum filler volume is thirty percent of gamapod pore volume. At such a volume of filler the mixed material stability number is 50% higher when compared with that of gamapod only stability number at 5% damage percentage.

**ACKNOWLEDGMENT**

The writers would like to thank the Inter University Center for Engineering Sciences, Gadjah Mada University, especially the Hydraulic and Hydrology Laboratory for providing facilities to conduct the whole test. The writers also pleased to express their gratitude to Dr. Ir. Samsuzin for his valuable comment and suggestion to the original manuscript.

**REFERENCES**

NOTATIONS
D: duration of the storm
G: gravitational acceleration
H: wave height
Hs: significant wave height
Kd: Fd of mixed armor layer/ Kd of granulated armor layer
Kp: stability number
Kv: stability number
M: number of waves during the storm
p: porosity
T: average wave period
W: weight of individual armor material
α: angle of breakwater slope
ρd: density of armor layer
ρw: density of water


