CHAPTER 175

"Double U block" and "Iblock" ——the armour blocks of two new types

S. W. TWU*, S. C. LIN**, S.G. CHANG***

Abstract

A total of eleven new types of blocks are developed for this project. After performing a series of model tests for them and having a consideration of easy casting, two types of blocks are selected and presented here in this paper. They are named "Double U block" and "I block", respectively. The two have been compared with several existing types which have been widely used in Taiwan. It is shown that the Double U block is an excellent type of block with high stability and low reflection coefficient. The I block has an advantage of easy casting, although it is not outstanding in other characteristics.

I. INTRODUCTION

In the last two or three decades, concrete armour blocks have been commonly used in Taiwan for the construction of harbors and shore-protection structures. These blocks are usually Tetrapod, Dolosse, Holtripod and Shake. However, no matter what type of blocks are used, they are destroyed very often because the waves appearing around the coast of Taiwan are so awful, either in winter monsoon seasons or typhoon periods. Furthermore, when these damage occurs, it always extend to the block-covering structures or even to the back-side areas protected by them. The back-side areas are known as wharves, land or resident areas. Taiwan is a densely-populated area, naturally, the land is very valuable. Under this circumstance it is painful to tolerate any land loss due to wave attacks. So, it is reasonable to predict that the concrete armour blocks will be used more extensively for the shore-protection structures in the future. Consequently, we are looking forward to developing one or two types of armour blocks which are superior to those used currently in Taiwan.

* Prof., Hydraulics and Ocean Engineering Dept., Cheng-Kung University, Tainan, Taiwan, R.O.C.
** Assoc. Prof, Hydraulics and Ocean Engineering Dept., Cheng-Kung University, Tainan, Taiwan, R.O.C.
*** Research assistant, Tainan Hydraulic Laboratory, Cheng-Kung University, Tainan, Taiwan, R.O.C.

II. DESIGN PROCEDURE

A good concrete armour block should share a number of characteristics, such as good stability, good interlocking effect, low reflection coefficient and easy casting. Among them the stability is the most important. It is common thing that the coastal structures are covered with concrete armour blocks. Some of them, such as off-shore breakwaters, are even piled up entirely by concrete blocks. The primary function of these blocks is to dissipate the wave energy and to scatter the wave force, so that the structure might not be destroyed by waves. If the blocks slide down or move away from its place during the wave attacks, the structure will lose its protection layer. Afterward, a damage to the structure occurs. Hence, good stability takes priority of all other characteristics of the armour blocks.

The second required characteristic is the wave-energy-dissipation ability. If the blocks are placed inside a harbour, it is expected not to produce large amount of reflection waves to the water area. Generally speaking, the lower the reflection coefficient, the better the armour block.

In addition to the two characteristics mentioned above, there is another whcih is also very important, that is the casting feasibility. Good blocks should be easy to cast as they are being formed. So that the construction work can smoothly under way. Following the above rules, both the staffs of Tainan Hydraulic Laboratory and the Department of Hydraulics and Ocean Engineering start the design work for the new types of blocks. Finally, eleven types are finished.

III. TESTS FOR STABILITY

To pick the superior ones from these eleven types of blocks, a number of model tests have to be carried out. All of these tests are performed in a wave flume made of concrete, which has a length of 75 m with 1.0 m in width,and 1.2 m in height. One side of the flume is casted with sheets of glass with 36 m in length.

Among these tests the stability test is the most important, and is conducted first. In this test, all types of blocks have the same weight, 150 gm, and are placed on the same site with a slope of 1:1.5 and with water depth of 20cm. The inclined-face model is placed on a bed slope of 1:10, which is 4 m in length and ends in connection with the horizontal flume bed where is 52.9 m away from the wave maker. The sketch for this model is shown in Figure 1.

In this test a wave period of 2 sec is adopted. The wave height is adjusted so that they break and impact just on the tested blocks. For convenience of comparison, the stability situation of these blocks are divided into five degrees as follows: (Michael, 1974; Paul, 1971)

(1) 1st degree: All the tested blocks stand still against wave attack.

(2) 2nd degree: Part of the tested blocks shake with waves, but their final mean position never change.
(3) 3rd degree: A few tested blocks are slightly moving, but the majority remains stable.
(4) 4th degree: The tested blocks move slowly and continuously until the armour layer is destroyed.
(5) 5th degree: The tested armour layer is destroyed in a short time.

For the 1st and 2nd degree, they are considered excellent in stability. In the 3rd degree a few blocks are removed at the start of the test, but later on nothing

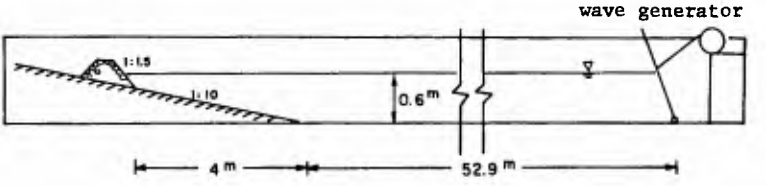

Fig 1. The sketch for the wave flume.

more happen. Therefore, the 3rd degree stability is still acceptable. If these definitions are compared with the percentage of damage. The 1st degree can be considered as zero percentage of damage. The zero percentage should fall on the transition between the 1st and 2nd degree . The 2nd degree will be equal to 0-2% damage, and the 3rd degree approximately 2-4% damage. In the 4th degree the damage percentage depends on time and therefore it will increase with increasing duration of wave attack. In the long run it will be totally destroyed. For the 5th degree total failure will occur in a short time. So, those types of blocks that reach the 4th or 5th degree in a short time are naturally not qualified. Based on the above criteria, four types of blocks are left for further tests that include tests for Kd value and reflection coefficients. After all these tests have been performed, a consultation with Chang-Ming Corporation, who financially supports this project, is held. In that meeting, we focused our attention on the stability and casting feasibility for selecting work. Consequently, two types of blocks, named "Double U block" as shown in Photo 1 and "I block" as shown in Photo 2,

Photo.1. Double U block

Photo.2. I block

are selected. To realize the superiority of the two new types, they are compared with a number of types which have been widely used in Taiwan, such as Holtripod, Dolosse and Shake. So, a number of additional tests for all these existing types have also been conducted. In case of uniform placing in two layers, Double U block and I block are compared with Holtripod and Shake in terms of the number of breaking waves needed to attack to reach the indicated stability degree. The results are shown in Figure 2. The case for uniform placing in one-layer is shown in Figure 3. For the case of pell-mell placing in two layers, the

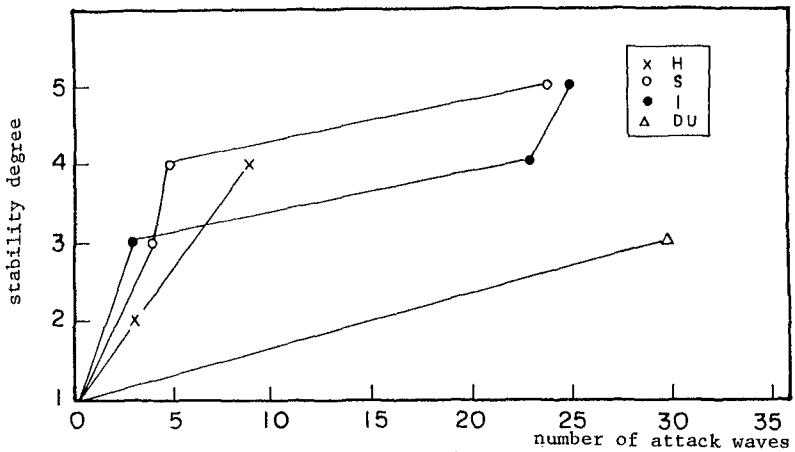

Fig 2. Relationship between stability degree and number of attack waves needed to reach that degree when blocks are uniformly placed in two layers.

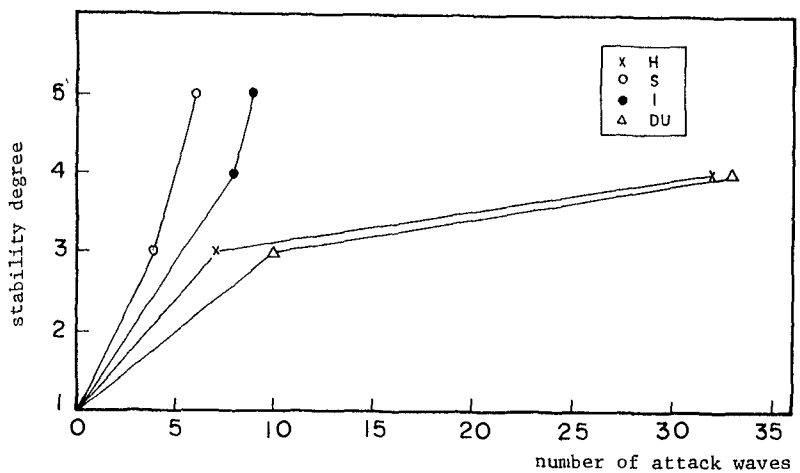

Fig 3. Relationship between stability degree and number of attack waves needed to reach that degree when blocks are uniformly placed in single layer.

new types are compared with Dolosse and the results are shown in Figure 4. It is found that Double U block is superior to all the compared ones. I block performs approximately the same as Shake and Holtripod if they are uniformly placed in two layers, and performs approximately the same as Dolosse if they are pell-mell placed in two layers. However, Figure 3 shows that I block is better than Shake but inferior to Holtripod as they are uniformly placed in single layer.

IV. TESTS FOR Kd VALUE

Kd values of armour blocks are usually calculated,by Hudson's formula

$$K_d = \frac{\gamma H^3}{W(S-1)^3 \cot\theta}$$

where W is the weight of individual armour block. γ and S are the specific weight and specific gravity of armour block, respectively. θ is the angle of armour-block slope with horizontal. H is the wave height.

Aside from the above-mentioned factors, Kd value for a given type of blocks is also closely related to the percentage of damage adopted for determing H in the Hudson's formula. In this study one percent of damage under the attack of nonbreaking waves is adopted. Two methods of placing are used for the test. One of them is uniform placing in two layers, and pell-mell placing in two layer is the another. In order to accurately measure the wave height the armour-block model is placed directly on the horizontal flume bed, rather than on an inclined bed, to keep the generated waves from shoaling effect. So, the water depth between the wave-maker and armour-block model is constant, i.e. 45cm. For a practical consideration, models of three armour-block slopes, i.e. 1:1.33, 1:1.5 and 1:2.0, are

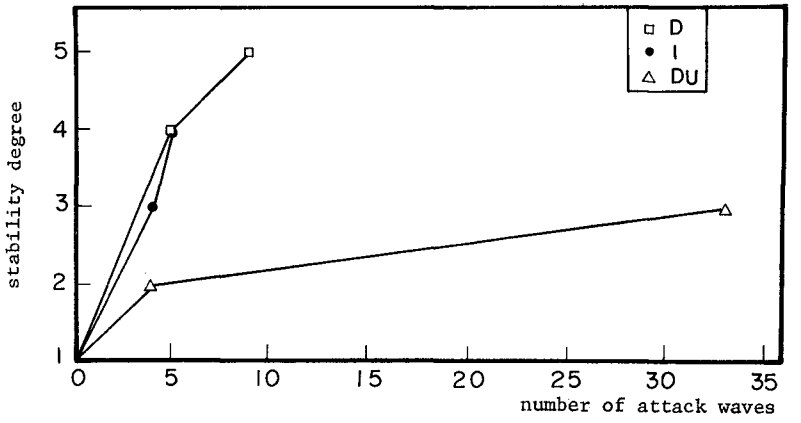

Fig 4. Relationship between stability degree and number of attack waves needed to reach that degree when blocks are pell-mell placed in two layers.

used. Wave periods of 1.5, 1.8, 2.0 sec are generated. The duration for each run is 30 mins. For a given type of blocks, the wave height in a run is adjusted by a little higher than that in the preceding run until one percent of damage to the mound of armour block meets. Dolosse has also been tested for Kd value in this study. So that they could be compared with each other under the same condition. The resulting Kd values are shown in Table 1. Five cases of them are crossed meaning that none of the waves generated in the wave flume could make any damage to them.

According to Hudson's formula, Kd is independent of wave period, but in this table it is found that Kd varies proportional to wave periods. It is indicated that Double U block has a Kd value higher than Dolosse, and I block is lower.

Table 1. Kd Vaule for the tested blocks.

block / wave period / armour-block slope / method of placing		Double U block			I block			Dolosse		
		1.5	1.8	2.0	1.5	1.8	2.0	1.5	1.8	2.0
uniform placing in two layers	1:1⅓	20.9	29.5	30.4	18.8	23.3	26.2			
	1:1.5	18.3	24.7	31.1	21.1	24.7	28.1			
	1:2.0						22.9			
	average	25.8			23.6					
pell-mell placing in two layers	1:1⅓	17.8	22.2	26.2	13.9	21.1	23.8	13.4	21.4	24.1
	1:1.5	22.3	27.3	27.0	11.8	16.6	15.4	13.7	21.7	22.7
	1:2.0	14.4	19.8	20.0	13.9	14.5	14.5	13.5	21.2	17.2
	average	21.9			15.6			18.8		

The uniform placing method for Double U block shown in the table is a method named here as side-by-side method,and is shown in Photo.3. If another special uniform placing method named here as riding method, shown in Photo.4, is adopted, then the blocks would give a Kd value so high that we don't even know how high it is, because none of the waves generated in the flume can destroy them. Although the riding method could offer such a high stability, it would take much more amount of armour units to cover a given area, and produce much higher reflection coefficient, than the side-by-side method, which will be shown later.

V. TESTS FOR REFLECTION COEFFICIENT

Wave-energy-dissipation efficiency of a armour block is always indicated by the reflection coefficient and run-up value. A superior armour block should gives a lower reflection coefficient and run-up value. Two armour-block slopes, 1:1.5 and 1:2.0, are used in this test to estimate

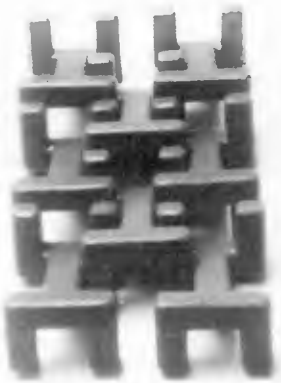

Photo.3. side by side method for Double U blocks

Photo.4. riding method for Double U blocks

the reflection coefficient. The wave periods include 1.0, 1.5 and 2.0 sec., and five varied wave heights are generated for each wave period. The water depth in the flume, as shown in Figure 1, is 60 cm in front of the wavemaker and 20 cm at the model toe. A technique developed by Goda (1979) to resolve the incident and reflected waves from the records of composite waves is used. Two simultaneous wave records are taken at adjacent locations in front of the armour-block model, and all the amplitudes of Fourier components are analyzed. From these Fourier components the amplitudes of incident and reflected wave components are estimated. According to Goda, as long as the spacings between the model and the wave gauges are kept in a proper range, the reflection coefficient can be accurately measured by the above incident and reflected wave heights. Goda suggested

$$L_{max} = \frac{\Delta \ell}{0.05} > L > \frac{\Delta \ell}{0.45} = L_{min} \qquad \ell \geq 0.1\, L$$

Where $\Delta \ell$ is the spacing between the wave gauges, ℓ is the spacing between model and the gauge adjacent to the model, L_{max} and L_{min} are the maximum and minimum wave length of the attack waves, respectively. In this test ℓ = 60cm and $\Delta \ell$ =50cm are used, and they are in effective range as Goda suggested.

For convenience of comparison, three existing types of blocks have also been tested in addition to the new ones. Holtripod and Shake are compared with the new ones for the case of uniform placing, and Dolosse are for the case of pell-mell placing. The results are shown in Figure 5 to 10. In each case the reflection coefficients are calculated by taking average over five varied wave heights. The results are shown in Table 2. Both results of the side-by-side method and riding method for Double U block are all shown in Fig.5 and Fig.6, in which the side-by-side method is

Table 2. Reflection Coefficient

armour-block slope	wave period	uniform placing, one layer				uniform placing, two layers				pell-mell placing, two layers		
		Double U	I block	Shake	Holtripod	Double U	I block	Shake	Holtripod	Double U	I block	Dolosse
1:1.5	1.0	0.232	0.213	0.214	0.318	0.195	0.270	0.219	0.227	0.131	0.171	0.062
	1.5	0.394	0.503	0.338	0.392	0.250	0.393	0.341	0.334	0.276	0.296	0.284
	2.0	0.603	0.657	0.591	0.492	0.544	0.637	0.565	0.564	0.512	0.420	0.507
1:20	1.0	0.243	0.349	0.259	0.250	0.180	0.301	0.294	0.198	0.178	0.175	0.161
	1.5	0.368	0.374	0.330	0.360	0.239	0.289	0.305	0.273	0.164	0.255	0.237
	2.0	0.497	0.584	0.504	0.575	0.474	0.584	0.543	0.514	0.546	0.530	0.519

indicated by DU without bracket, and the riding method by DU with bracket. In the remaining figures the results of riding method for Double U block are omitted. From these datas it is found that Double U block, side-by-side method, has a reflection coefficient approximating to Shake and Holtripod as the blocks are uniformly placed in single layer. While I block has a little higher value. For uniform placing in two layers, Double U block, side-by-side method, is less than Shake and Holtripod. I block is a little higher. For pell-mell placing in two layers, Double U block and I block show approximately the same results as Dolosse. While the riding method for Double U block is adopted, it shows a reflection coefficient higher than all the compared ones.

VI. TESTS FOR RUN-UP VALUE

In this test the flume bed between the model and the wave generator is horizontal, and the water depth is 60cm. It is known that run-up value for a given type of block is primarily a function of wave steepness and armour-block slope. In addition to that, it is also related with the placing method for the blocks. With two armour-block slopes and three placing methods for the blocks, the test results are expressed as curves showing relationships between relative run-up value and wave steepness, as in Fig. 11-14. It is shown in this figures that the run-up values decrease with increasing wave steepness. And they are smaller in case of pell-mell placing than in case of uniform placing. These resulting run-up values may also be expressed by a formula, as follows

$$\frac{R}{H_0} = a - b\left(\frac{H_0}{L_0}\right)$$

where the coefficient a, b are shown in Table 3

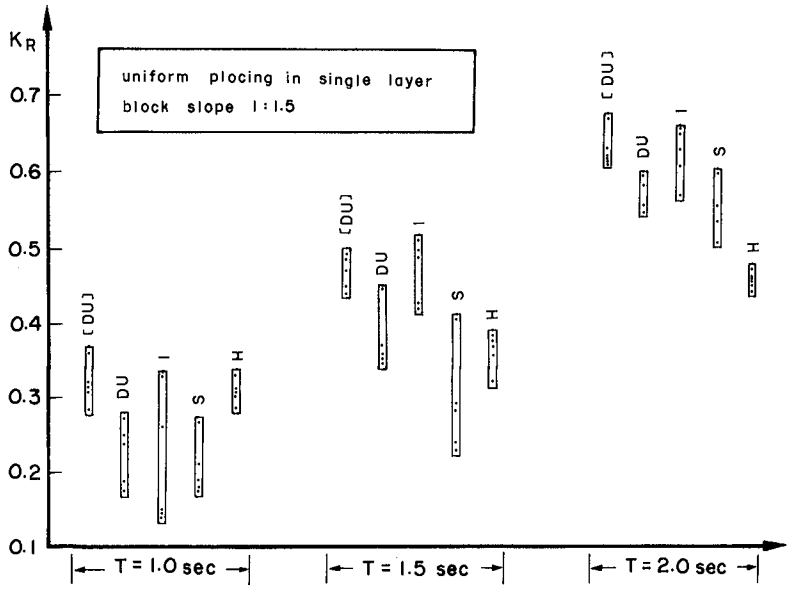

Fig.5. Experimental reflection coefficient

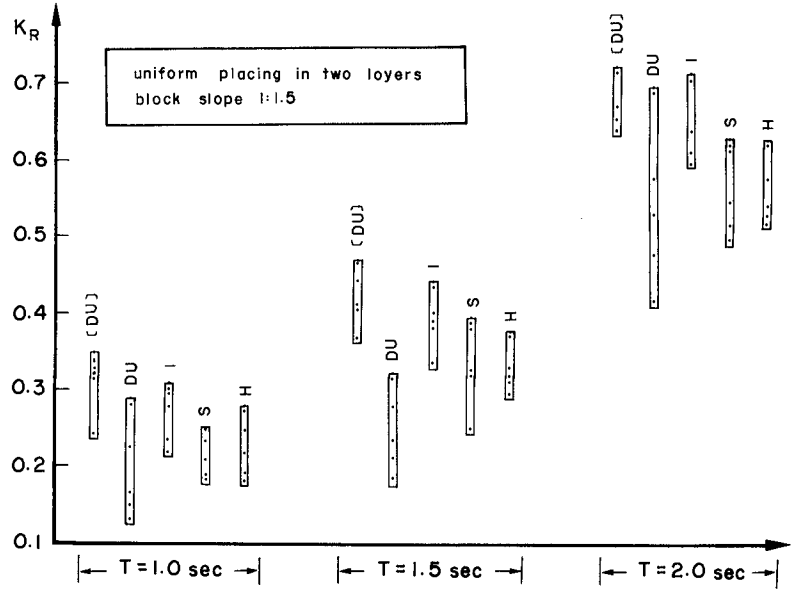

Fig.6. Experimental reflection coefficient

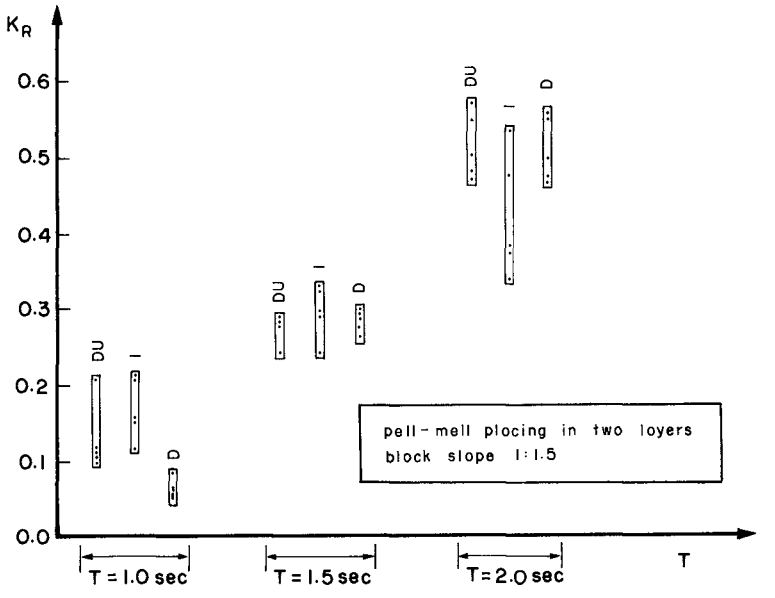

Fig.7. Experimental reflection coefficient

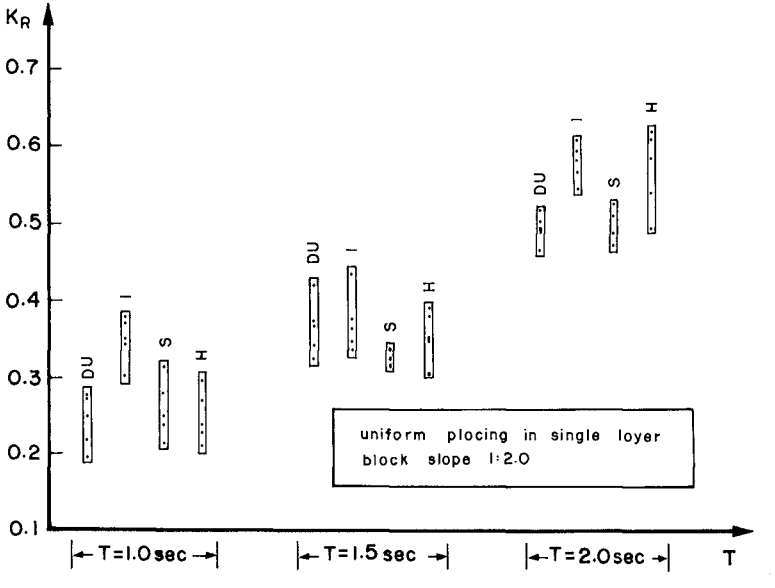

Fig.8. Experimental reflection coefficient

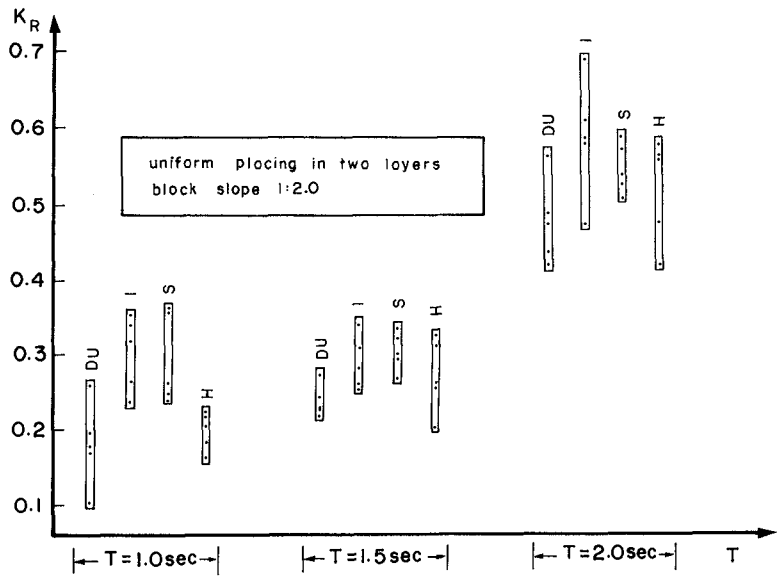

Fig.9. Experimental reflection coefficient

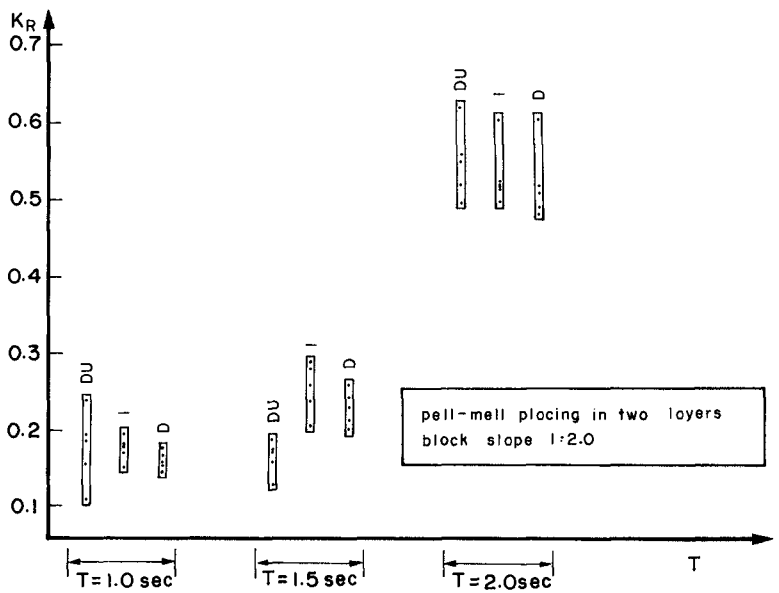

Fig.10. Experimental reflection coefficient

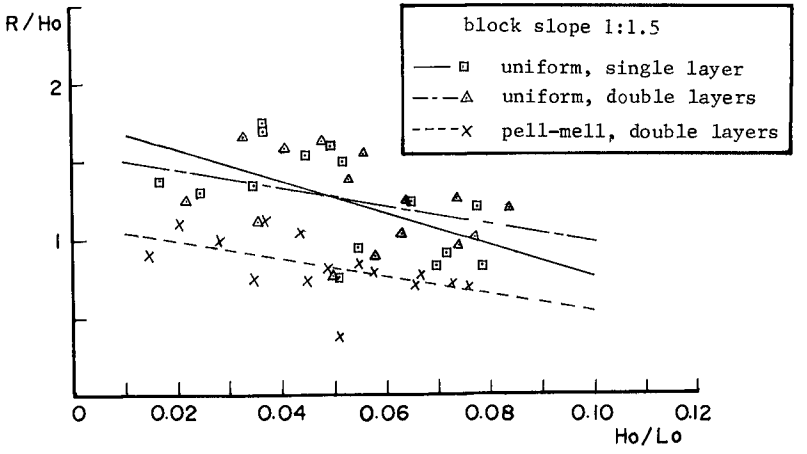

Fig 11. R/Ho∿Ho/Lo for I block

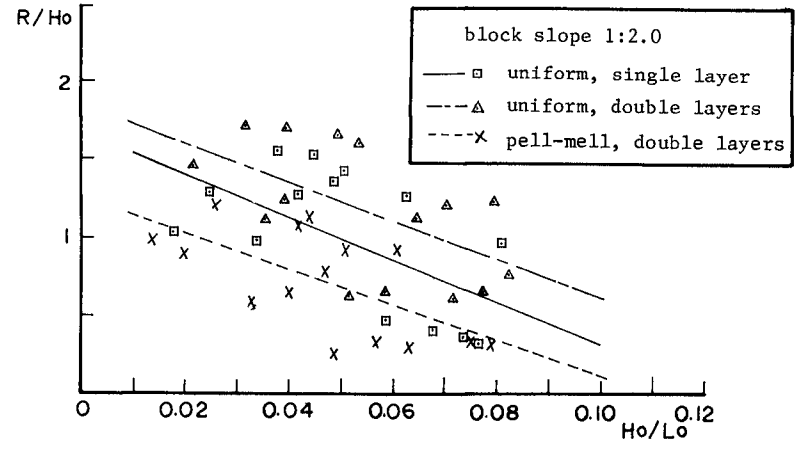

Fig 12. R/Ho∿Ho/Lo for I block

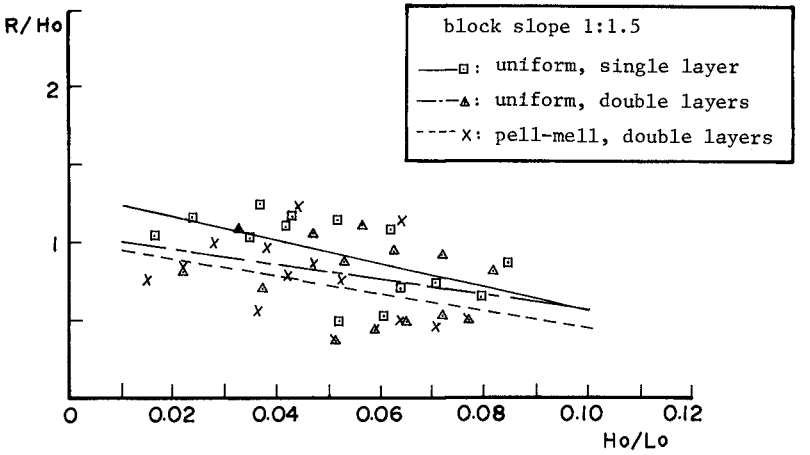

Fig 13. R/Ho∿Ho/Lo for Double U block

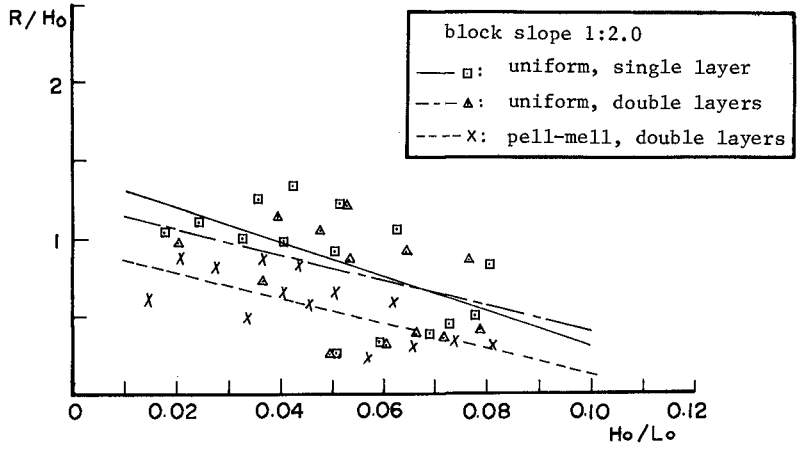

Fig 14. R/Ho∿Ho/Lo for Double U block

Table 3. a, b value for run-up

block slope	method of placing for block / type of block / coefficient	Double U a	Double U b	I-block a	I-block b
1:1.5	uniform, one layer	1.319	7.52	1.775	10.19
	uniform, two layers	1.668	5.00	1.563	5.82
	pell-mell, two layers	1.017	5.69	1.100	5.72
1:20	uniform, one layer	1.408	10.90	1.677	13.52
	uniform, two layers	1.228	8.19	1.855	12.35
	pell-mell, two layers	0.947	8.15	1.259	11.41

VII. CONCLUSIONS

1. Double U block shows a stability superior to the existing blocks which have been commonly used in Taiwan. It gives a Kd value much higher than the existing types, no matter what method the blocks are placed.
2. If a riding method of placing is adopted, Double U block would give a very high Kd value, but it also produces a large reflection waves. Except that, with any other method of placing, it can always offer a low reflection coefficient in addition to the high stability.
3. Double U block is a newly developed block. The studies presented here are so far what we have done. It is easy to realize from the shape of the block that a good interlocking relation among blocks plays an important part in its high stability. Therefore, the block has to take large internal tension due to the interlocking effect. Under this circumstance, the Double U block has to be reinforced in actual field.
4. I block performs neither better nor worse than the existing blocks in stability and shows a little worse in reflection coefficient, however, it has an advantage of easy casting. So, I block is also an alternating type of block.

REFERENCE

1. Goda Yoshimi, Yasumasa Suzuki, Yasuharu Kishira, Osamu Kiruchi (1976), "Estimation of incident and reflected waves in random wave experiment." Proc. of the 15th

Coastal Engr. Conf. p.828-845.
2. Michael Brorsen, H. F. Burcharth, Torben Larsen, (1974): "Stability of Dolos Slopes", Proc. of the 14th Coastal Engr. Conf. p.1691-1701.
3. Paul, M.W., Baird, W.F. (1971): "Discussion on breakwater armour units", Proc. of 1st int. conf. on port and ocean eng. under arctice conditions. Trondheim.