PROTOTYPE TESTING OF DOLOSSE TO DESTRUCTION

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ABSTRACT

The Dolos, a type of armor unit, has been used widely for breakwater and shore protection works in the world. However, it has been reported that the armor layers of several breakwaters have been damaged by wave action, and it is probable that the breakage of Dolos has been the cause of that failure.

In this paper, static and dynamic tests using Dolosse units are described. 4t reinforced units and 4t, 0.4t and 0.04t unreinforced units were used.

In these tests, concrete surface and reinforcing bar stress of Dolos, and impact load were measured.

The results of these tests were as follows:
(1) From the both tests i.e. the static load test and the drop test, stress was greatest in the corner between the chamfer and the stem. Cracks occurred at this point.
(2) In the static load test, comparing the results of both units with reinforced and unreinforced chamfer, it became clear that the reinforcement of the chamfer could reduce the magnitude of the stress concentration.
(3) In the drop test, the drop height which made cracks was almost constantly independent of the weights of the units. And it could be considered that there was little influence of increasing the concrete strength as to the breakage of Dolos

1. INTRODUCTION

The Dolos is a type of concrete armor unit that has a high degree of interlocking capability. Dolosse have been

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used at many port and harbor locations (1, 2). However, recently, it has been reported that the armor layers of several breakwaters have been damaged by wave action (3), and it has been considered that the breakage of Dolos is one probable cause of this damage. Consequently, the problem related to the structual strength of Dolos has been discussed. O.J. Lillevang and W.E. Nickola (4) examined the stress distribution of Dolos model with some shapes of chamfers under static load by using the three-dimensional photoelastic stress analysis, and suggested the shape of the chamfer to reduce the concentration of the tention stress. H.F. Burcharth (5) did the drop and pendulum tests using 1.5t to 20t Dolosse, and proposed a method for the design of impact loaded Dolosse. C. Galvin and D.F. Alexander (6) proposed a theoretical relationship between wave height and concrete strength of armor units. And there were some papers of tests related to the breakage of Dolosse prior to using them to breakwaters, for example, S. Barab and D. Hanson, C.A. Walter and D.R. Clark (7, 8).

In the case of a composite type breakwater with armor layer which are filled completely with armor units of the same size, it is considered that the lowest units will be subject to the static load caused by the dead weight and the units of the exposed side will suffer from the impact load resulting from rocking.

As armor units in these two situations are prone to some damage, we made static load and drop tests using Dolosse and also measured the stresses in some parts of units.

2. TEST CONDITIONS AND PROCEDURE

Assuming the load conditions, two different types of tests were performed. The static load test was performed to simulate the condition of a dead load of units caused by settlement, and the drop test was instigated to simulate the impact resulting from rocking under wave action. Fig. 1 shows the test methods.

4t reinforced and 4t, 0.4t and 0.04t unreinforced units were used in these tests. The waist ratio was constant at 0.32. Table 1 shows the test program, Fig. 2 shows the geometry of units, and Table 2 shows the mix proportions of concrete. Tensil strength test results of steel bars and bar arrangement drawing are given in Table 3 and Fig. 3, respectively.

In the static load test, the vertical fluke of the unit was fixed by a support equipment. There were two different loading conditions. One was imposed on the mid point of the horizontal fluke and the other was on the tip point. A hydraulic jack was used for loading. Photo. 1 shows the

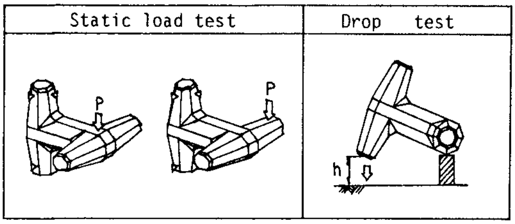
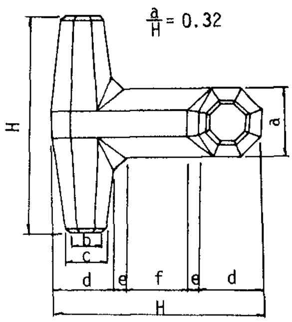


Figure 1 Test Method

Table 1 Test program

Test		Weight of unit (t)	Reinforcement (kg/m³)	Concrete strength (MPa)
Static load test	Imposed on the mid point of the horizontal fluke	4	75	20.6
			92	
			151	
			0	20.6
				29.4
				39.2
	Tip point		92	20.6
			151	
Drop test		4	92	20.6
			151	
			0	20.6
				29.4
				39.2
		0.4	0	20.6
		0.04	0	20.6



Weight (t)	H	a	b	c	d	e	f
4	2239	716	386	458	669	125	651
0.4	1038	332	178	212	310	58	302
0.04	482	154	82	98	144	27	140

(mm)

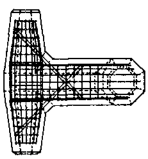
Figure 2 Geometry of units

Table 2 Concrete mixture

Concrete strength (MPa)	Slump (cm)	Max. diameter of agg.(mm)	W/C (%)	S/A (%)	Cement ($kg m^3$)	Water ($kg m^3$)	Sand ($kg m^3$)	Aggre-gate($kg m^3$)	Additive ($kg m^3$)
20.6	10	25	55.5	38.5	251	139	743	1186	0.628
29.4	10	25	44.5	35.0	320	142	680	1184	0.800
39.2	10	25	34.5	34.5	421	145	612	1162	1.053

Table 3 Test results of reinforcing bar

Standard	Diameter (mm)	Strength	Results (MPa)
SR-24	13	Yield strength	294
		Ultimate tensile strength	428
	16	Yield strength	331
		Ultimate tensile strength	478



reinforcement: 13mm and 16mm bars
concrete cover layer: 65mm
Figure 3 Bar arrangement drawing

Photograph 1: The situation of the static load test

Photograph 2: The situation of the drop test

situation of the static load test.

In the case of the drop test, the horizontal fluke was supported in a way to keep the stem level. Then, the vertical fluke was lifted up to a predetermined height and dropped onto a concrete slab of 1 meter thickness by use of a quick release device. Drop height started at 2 cm and increased every 2 cm. Some of the drop test units were provided with load cells at the bottom of the vertical fluke to measure the impact load. Photo. 2 shows the situation of the drop test.

In both tests, several strain gauges were placed on the reinforcing bar and the concrete surfaces of each test unit in order to measure the strain.

3. TEST RESULTS

3-1 Static load test

3-1-1 In the case of imposing a load on the mid point of the horizontal fluke

Stress concentrated on the corner between the chamfer and the stem due to the bending force. Cracks occurred at this point. Photo. 3 shows the breakage of Dolos. From the results of unreinforced units shown in Table 4, it is considered that the ultimate imposed load which caused cracks increased slightly as the compressive strength of concrete increased. Fig. 4 shows the relationship between the concrete surface stress and static load.

In the case of reinforced units, cracks appeared in that corner under the static load which was almost as large as the results of unreinforced units. Fig. 5 and 6 show the stress distribution of the reinforcing bar using the units with the chamfer reinforced and unreinforced, respectively. Stress concentrated on the corner revealing themselves as corresponding cracks.

In the case where the chamfer was not reinforced, the reinforcing bars placed at the stem yielded under a smaller imposed load compared to that of the reinforced chamfer. It is apparent that reinforcement of the chamfer is effective.

3-1-2 In the case of imposing a load on the tip point of the horizontal fluke

The results of cracking were different between 92 kg/m^3 and 151 kg/m^3 reinforcement units.

In the case of the 92 kg/m^3 reinforcement unit, cracks occurred in the corner between the chamfer and the stem, and

Photograph 3: The breakage of Dolos (Static loac test)

Photograph 4: The cracks of the stem (Static load test)

Table 4 Static load test results (unreinforced unit)

Weight (t)	Design compressive strength (MPa)	cracking static load (kN)	Breaking static load (kN)
4	20.6	61.7	73.5
	29.4	71.5	80.4
	39.2	80.4	93.2

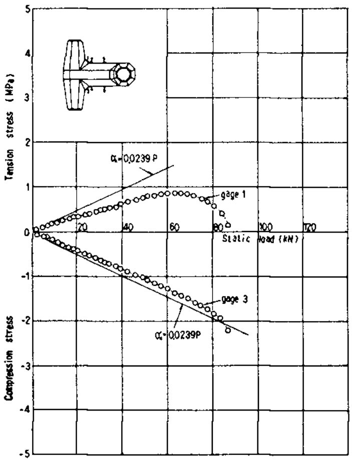


Figure 4 Relationship between concrete surface stress and static load

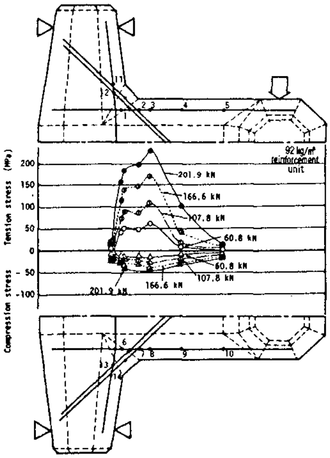


Figure 5 STRESS DISTRIBUTION OF REINFORCEMENT
(imposed on the mid point of the horizontal fluke)

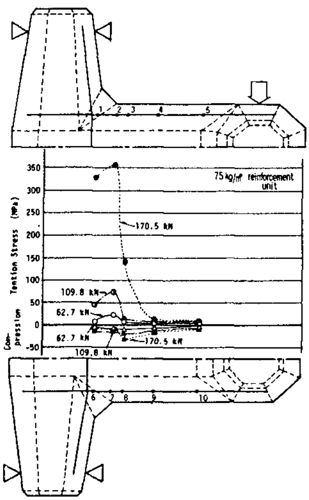


Figure 6 STRESS DISTRIBUTION OF REINFORCEMENT
(imposed on the mid point of the horizontal fluke)

progressed toward the stem at 45°. Ultimate breakage was identified as shear rupture due to bending and torsion forces. Photo. 4 shows the cracks of the stem. Fig. 7 shows the stress distribution of the reinforcing bar. From the result of the relationship between the reinforcing bar and static load shown in Fig. 8, the stem and chamfer bars placed at the corner section ultimately yielded at about 170 KN.

While in the case of 151 kg/m^3 unit, cracks appeared in the corner with a small imposed load, and thereafter new cracks occurred and progressed inthe stem at 45°. Ultimate breakage was identified as sheer rupture due to tortion force. Fig. 9 and 10 show the stress distribution of the reinforcing and static load, respectively.

3-2 Drop test

Cracks occurred in the corner between the chamfer and the stem identical with the results of static load test.

From the results of unreinforced units shown in Table 5, it is considered that the drop height which crack occurs is almost constant independent of the weight of the units and concrete strength. Photo. 5 shows the broken unit.

In the case of the reinforced units, stress concentrated on the corner and cracks occurred at this point, too. But the units didn't separate into two pieces. The stress distribution of the reinforcing bar is shown in Fig. 11.

Impact load and impact time were also measured by using load cells. Fig. 12 shows the relationship between the impact time of the load and the drop height. Fig. 13 shows the relationship between the impact time of the load and the weight of the unit. From these results, it can be assumed that the impact time of the load is almost constant independent of the drop height while using the same weight of the unit, and the ratio of the impact times is almost equal to the ratio of their characteristic length i.e. Dolos height.

From the results of the relationship between the maximum impact load and drop height shown in Fig. 14, it is considered that the impact load is proportional to the square root of the drop height and the ratio of the impact loads is equal to the square of the ratio of their characteristic lengths under conditions of the same drop height.

As the ratio of the concrete surface strain is almost equal to the square of the reciprocal of the ratio of their characteristic lengths under conditions of the same impact

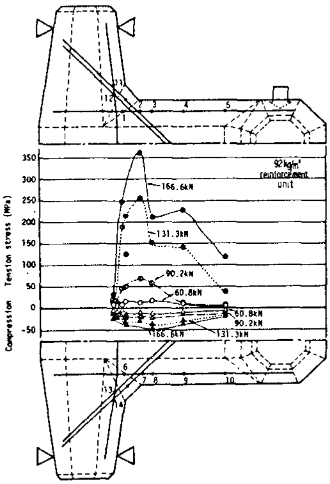


Figure 7 STRESS DISTRIBUTION OF REINFORECEMENT

(imposed of the tio point of the horizontal fluke)

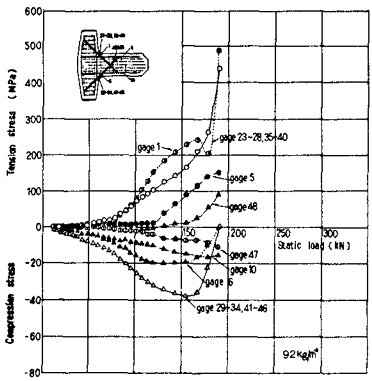


Figure 8 Relationship between reinforcing bar stress and static load

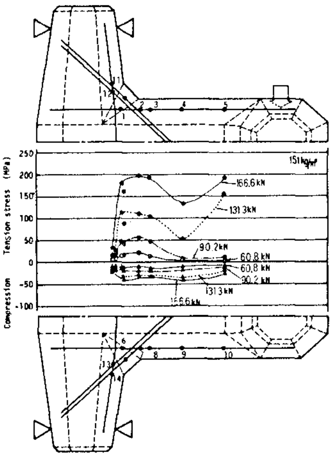


Figure 9 STRESS DISTRIBUTION OF REINFORCEMENT
(imposed on the tip point of the horizontal fluke)

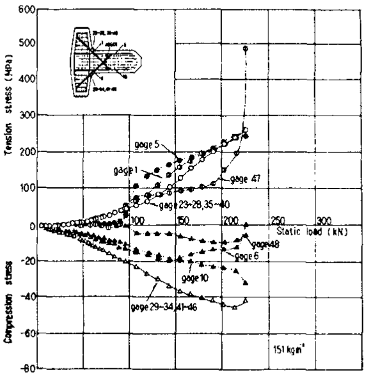


Figure 10 Relationship between reinforcing bar stress and static load

Table 5 Drop test results (unreinforced unit)

Weight (t)	Design compressive strength (MPa)	Cracking drop height (cm)	Breaking drop height (cm)
4	20.6	7	12
	29.4	10	14
	39.2	14	18
0.4	20.6	14	18
0.04	20.6	16	20

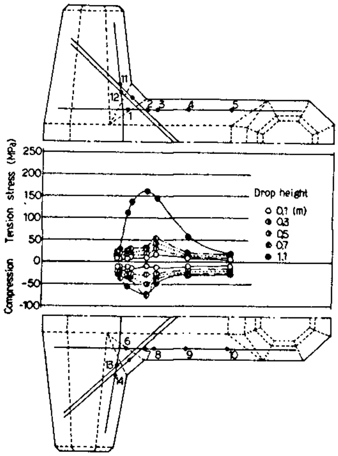


Figure 11 Stress distribution of reinforcement
(Drop test)

Photograph 5: The breakage of Dolos (Drop test)

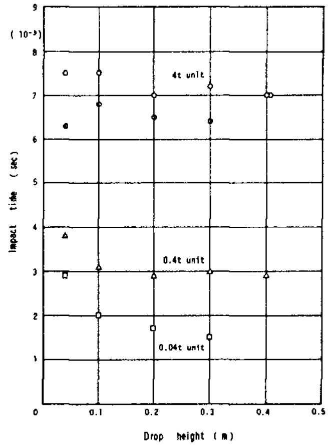


Figure 12 Relationship between impact time and drop height

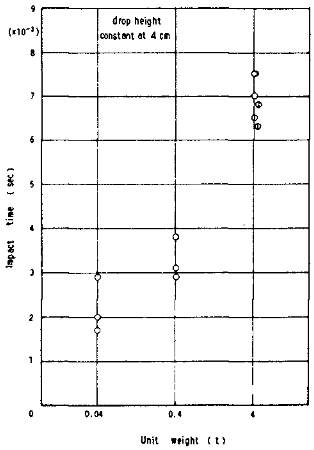


Figure 13 Relationship between impact time and unit weight

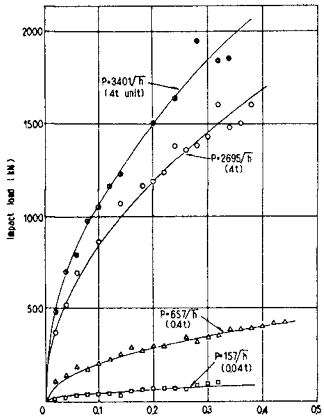


Figure14 Relationship between impact load and drop height

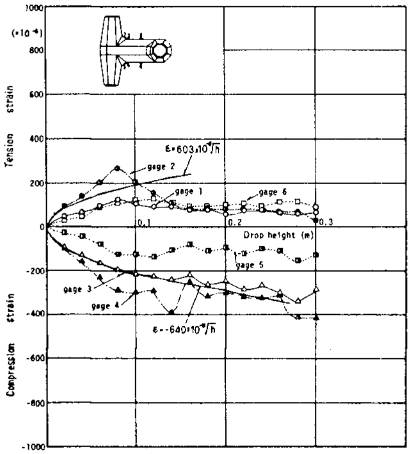


Figure 15 Relationship between concrete surface strain and drop height

load, the maximum strain on the concrete surface is proportional to the square root of the drop height as shown in Fig. 15. This results in the stress of the concrete surface being constant independent of the weight of the unit under conditions of the same drop height.

4. CONCLUSIONS

Stress distribution, the influence of the concrete strength and weight of unit for the breakage of Dolos, and impact load were obtained through these static load and drop tests.

The result of these tests were as follows:
(1) From the both tests, i.e., the static load test and the drop test, stress was greatest in the corner between the chamfer and the stem. Cracks occurred at this point.
(2) In the static load test, comparing the results of both units with reinforced and unreinforced chamfers, it became clear that the reinforcement of the chamfer could reduce the magnitude of the stress concentration.
(3) In the drop test, the drop height which made cracks was almost constant independent of the weights of the units. And it could be considered that there was little influence of increasing the concrete strength as to the breakage of Dolos.

5. REFERENCES

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