CHAPTER 60

WAVE TESTS OF REVETMENT USING MACHINE-PRODUCED INTERLOCKING BLOCKS

by

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SYNOPSIS

Continued demand for relatively low-cost shore protection, in bays, estuaries, and comparable bodies of water has resulted in accelerated investigation in this area. Further, there is a great demand for a system that can be constructed by the individual property owner without recourse to a contractor or special construction equipment. Work along these lines gained impetus through the successful installation of a light-weight concrete-block revetment in 1962. This paper reports on the further development of light-weight block revetments through tests in the Large Wave Tank at Coastal Engineering Research Center (CERC). Two types of blocks were tested on a 1 on 2 slope, one a machine-produced tongue-and-groove type weighing 75 pounds, and the other a hand-produced shiplap type weighing 150 pounds, the latter having twice the surface area of the former. In all, ten tests were made with wave heights ranging from 1.5 to 6.2 feet and wave periods ranging from 3.0 to 6.0 seconds. During the tests observations were made regarding the displacement of blocks and the vertical movement of the face of the slope when attacked by waves. Data derived from the tests have provided information which has resulted in the development of a machine-produced block which remained stable under the continuous attack of 4.7-second 4.8-foot breaking waves. Comparative tests showed that the machine-produced tongue-and-groove blocks have greater stability than the hand-produced shiplap type.

INTRODUCTION

For some time the need has been evident for a type of low cost shore protection for bay and estuary areas that can be installed, by property owners, without recourse to a contractor or special construction equipment. Studies along this line initiated by engineers of CERC in 1962 resulted in the development of a light-weight (75 pound) shiplap-type interlocking concrete block. The block, as developed, consisted of two 8" x 16" x 2" mass-produced concrete blocks bonded together with epoxy adhesive in a manner to form a shiplap edge. The first installation using these blocks to form a revetment was made at Friendship House property on the Patuxent River at Benedict, Maryland

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in May 1962. To date the installation has functioned properly and is in excellent condition. The cost of the revetment as installed was less than one-half of that estimated for the installation of a conventional-type rock revetment. The results of this development have been published in the Center's Miscellaneous Paper series[1].

Following the Benedict installation, another revetment was constructed in 1964 near the mouth of the Choptank River in the vicinity of Oxford, Maryland. Officials of the State of Maryland have reported that this installation is presently in excellent condition and is accomplishing its mission.

Due to the success with the type of block mentioned above, commercial interests, in order to reduce costs, explored the possibility of producing an interlocking block on an automatic, concrete-block machine. As a result of this exploratory work, a mould was developed by commercial interest for use in an automatic concrete-block machine. See Fig. 1.

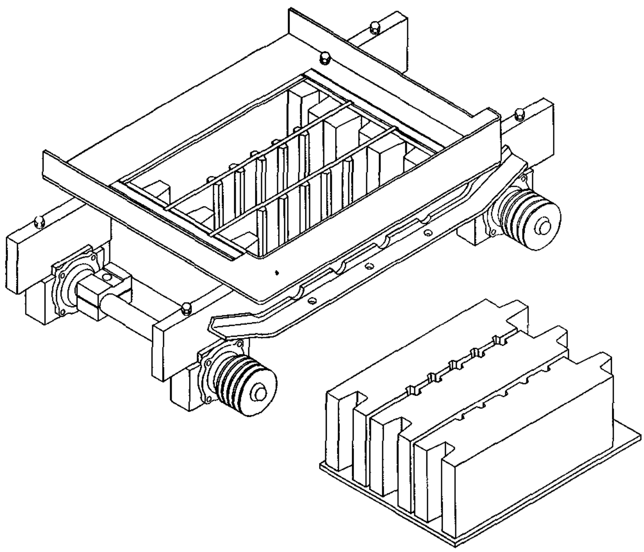

Fig. 1. Interlocking concrete-block mould used in automatic concrete-block machine.

High-production machines currently being used in modern block-plant operations will produce six three-block pallets per minute or 1,080 blocks per hour. A view of one of the high-production block machines now in use is shown on Fig. 2. Fig. 3 is a schematic sketch showing a typical sequence in the automatic production of concrete block.

1. "Concrete-Block Revetment Near Benedict, Maryland" by Jay V. Hall, Jr., and R. A. Jachowski, Misscellaneous Paper No. 1-64, U. S. Army Coastal Engineering Research Center, Washington, D. C.

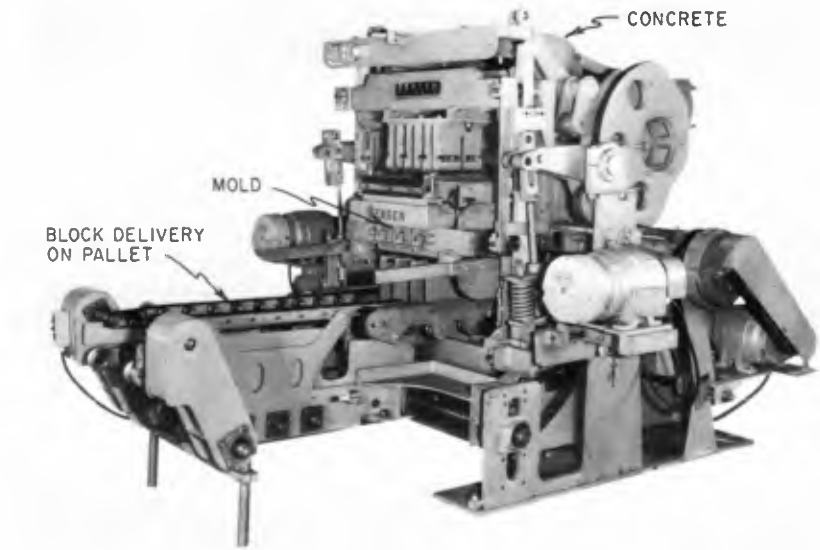

Fig. 2. Automatic concrete-block machine.

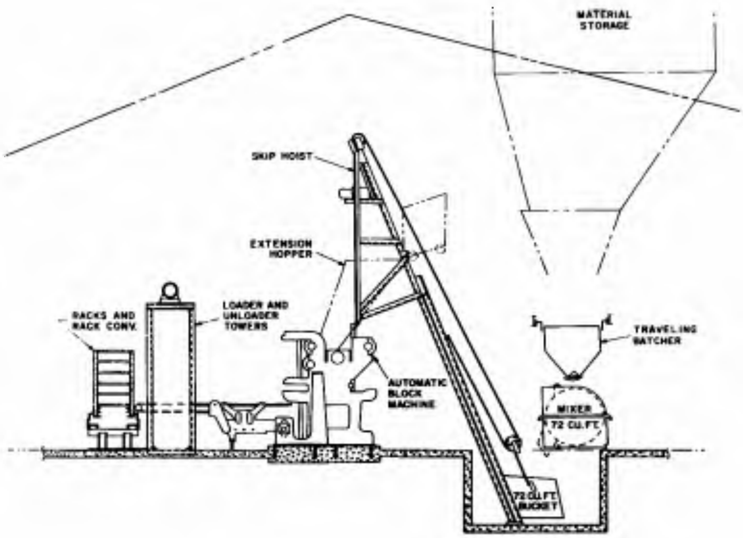

Fig. 3. Typical sequence of automatic production of concrete block.

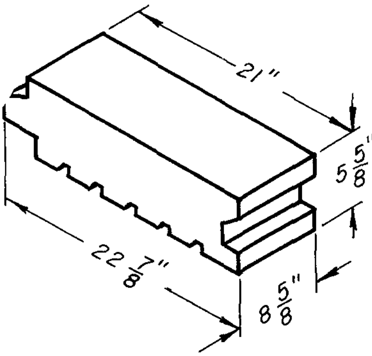

Fig. 4. Machine-produced concrete block.

After the blocks leave the mould on their pallets they are steam-cured for 24 to 30 hours. The controlled batching and curing process used produces a concrete block having a compressive strength of 5,000 pounds per square inch. At the present time, the block as produced by this method can be marketed for about $0.70 each. This block appeared to be well designed, however the stability of any revetment constructed with it would depend on the durability of the mechanical interlock since the block would not be stable by its weight alone. Inasmuch as the full-scale block was available for test, see Fig. 4, CERC staff decided to conduct the investigation on a prototype basis in the Center's Large Wave Tank since the anticipated design wave for the block revetment was not expected to exceed the capability of the facility.

TEST FACILITIES

The Large Wave Tank is 15 feet wide, 20 feet deep and 635 feet long. With a water depth of 15 feet, the tank requires 1,000,000 gallons of water. The wave-generating mechanism is a vertical bulkhead, 15 feet wide and 22 feet high, mounted on a carriage which moves on rails. A piston-type motion is transmitted to the bulkhead by two arms, 42.75 feet long connected to two driving discs. These discs, each 19 feet in diameter, are driven through a train of gears by an 800 HP, variable-speed DC motor. The wave-generating mechanism is capable of producing wave periods between 2.6 and 24.8 seconds with a maximum working wave height of 6 feet, in the 15-foot normal operating depth.

TEST SECTION

The test structure was built in the tank on a 1 on 2 slope as shown in Fig. 5. The embankment was composed of Potomac River sand with a medium diameter of 0.4 millimeter then covered by a sheet of woven plastic filter cloth, a 6-inch layer of Maryland Number 3 crushed stone with a median particle size of about 0.5 inch, and finally by the interlocking blocks arranged as shown on Fig. 6. The sides and toe of the block revetment were securely fastened in place with steel angles and plates.

Fig. 7 shows the revetment in place ready for testing. The vertical pipe in the center of the Figure is a lift gage instrumented to record the vertical movement of the surface of the slope.

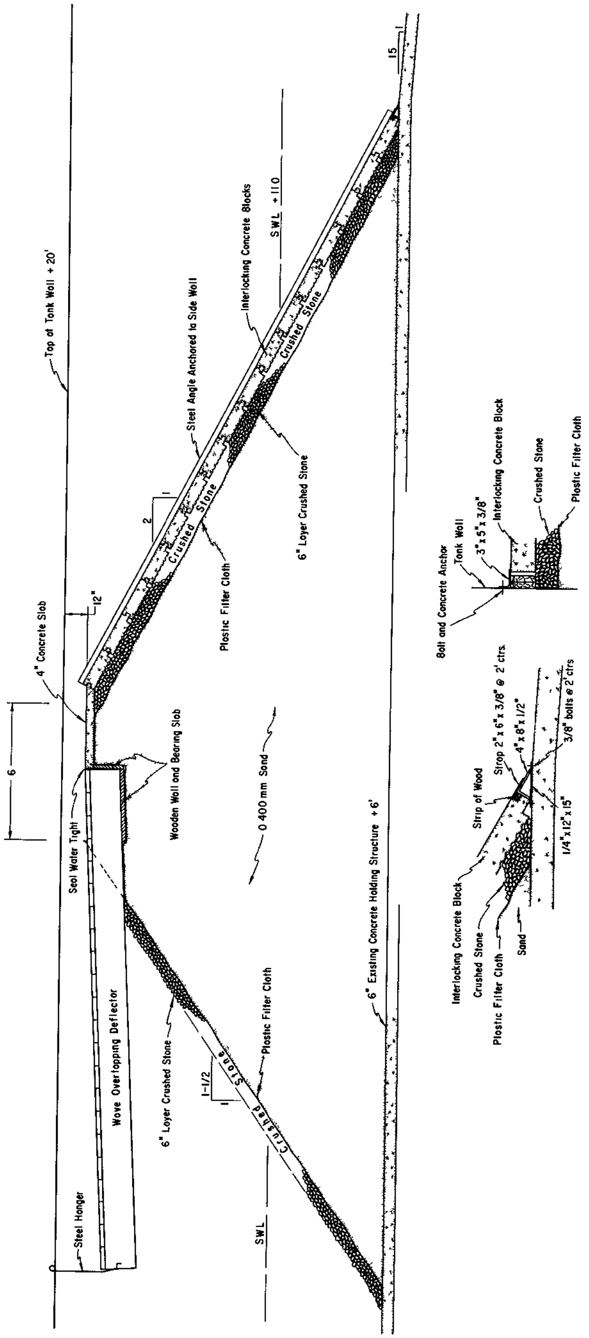

Fig. 5. Test section installed in CERC large wave tank.

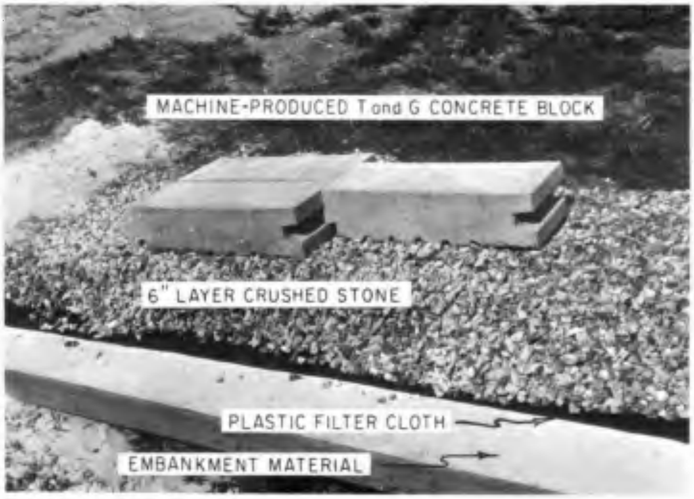

Fig. 6. Method of placing machine-produced block.

Fig. 7. Concrete block revetment in large wave tank.

TESTS

In all, ten tests were made; eight with the machine-produced tongue-and-groove block, and two with the hand-produced shiplap block. The tongue-and-groove block was tested with waves varying in height from 1.5 to 6.2 feet, and in period from 3.0 to 6.0 seconds. The shiplap block was tested with 4.0-foot, 6.0-second and 4.8-foot, 4.7-second waves. Data relative to the tests are summarized in Table I.

It can be seen in Table I that early in the tests (Run #2) of the tongue-and-groove block excessive hydrostatic pressure was being built-up beneath the blocks causing them to lift. This excessive movement of the surface of the revetment resulted in the fracture of the lower lip forming the groove of the block. This in turn allowed the wave and hydrostatic pressures to remove it from the face of the revetment. In order to correct this condition a three-sixteenth inch wire spacer was inserted between the blocks to form a relief area to reduce the pressure. After installation of the wire, lift measurements on the average dropped 50 to 90%.

In continuing the tests, the revetment was found to be stable under the continual four-hour pounding of a 4.8-foot, 4.7-second breaking wave. Wave conditions were then changed and the revetment was subjected to a 6.2-foot, 3.8-second breaking wave. In the first few minutes, the surface of the slope appeared to be settling in the center and failure appeared to be imminent. In view of the above, the test was stopped after 5.6 minutes.

In order to compare the stability of the tongue-and-groove block with the more generally used shiplap block, the revetment was rebuilt with the latter type shown in Fig. 8. The block was placed over the same underlayers as the tongue-and-groove block tested. The method of placing the shiplap block is shown in Fig. 9. The revetment as constructed was tested with a 4.0-foot, 6.0-second wave and a 4.8-foot, 4.7-second wave. As in the previous tests, the need for spacers in the joints to relieve hydrostatic pressure beneath revetment was immediately apparent. After installation of the spacers, a test was run using a 4.0-foot, 6.0-second wave. Upon completion of the test, 6 to 10 blocks were found to be slightly displaced. As a final test, the revetment was rebuilt and subjected to a 4.8-foot, 4.7-second breaking wave,

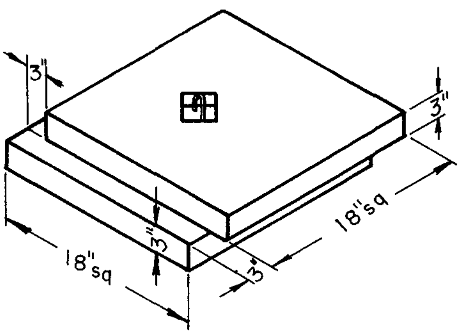

Fig. 8. Hand-produced shiplap concrete block.

Table 1

RUN	WATER DEPTH		WAVE HEIGHT	WAVE PERIOD	LIFT		DURATION OF TEST	REMARKS
	Seaward of Revetment	Toe of Revetment	Toe of Revetment		Max	Avg		
	Feet	Feet	Feet	Seconds	Inch	Inch	Hrs — Mins	
INTERLOCKING CONCRETE BLOCK REVETMENT								
1	11 0	5 0	1 5	6 0	0 19	0 15	4 — 0	No damage to revetment
2	11 0	5 0	2 7	3 0	0 34	0 18	1 — 49	Test stopped after 1 hour 49 minutes One block dislodged due to high uplift pressure
3	11 0	5 0	2 1	4 0	0 03	0 02	4 — 0	Revetment rebuilt using block with modified tongue and groove design and higher test concrete Spacers added between blocks to reduce uplift pressure
4	11 0	5 0	2 7	3 0	0 06	0 04	4 — 0	No damage to revetment
5	11 0	5 0	2 9	6 0	0 05	0 05	4 — 0	No damage to revetment
6	11 0	5 0	4 8	4 7	0 09	0 06	4 — 0	Toe plate failed and repaired during run No damage to revetment
7	11 8	5 8	4 1	3 75	0 13	0 08	4 — 0	No damage to revetment
8	14 4	8 4	6 2	3 8	0 19	0 09	0 — 56	Test stopped after 56 minutes due to excessive slope settlement Slope failure appeared to be imminent
SHIPLAP CONCRETE BLOCK REVETMENT								
9	11 0	5 0	4 0	6 0	0 04	0 04	4 — 0	End of run, 6 to 8 block slightly raised and cocked
10	11 0	5 0	4 8	4 7	0 07	0 05	0 — 37	Revetment repaired Test stopped after 37 minutes due to slope failure

Fig. 9. Method of placing hand-produced shiplap concrete block.

the same condition under which the tongue-and-groove block remained stable. After 37 minutes of operation, the revetment failed and the test was discontinued. Data relative to these tests are shown on Table I.

RESULTS

The tests have shown the machine-produced tongue-and-groove concrete block to be stable under the attack of a 4.8-foot, 4.7-second breaking wave while the hand-produced shiplap block having about twice the area and weight failed under the attack of a 4.3-foot, 6.0-second period breaking wave.

The results of the tests further disclosed that some improvement could be made in the design of the tongue-and-groove block. As indicated by the test, a relief slot could be built into the block to reduce the uplift pressure. The relief area roughly equivalent to that provided by the spacers used in the test was provided by depressing one side of each block one-quarter inch over about two-thirds of the length of the block. The relief area as formed is shown on Fig. 10.

Observations made during the tests indicated that more flexibility should be built into the interlocking joint between blocks to prevent a rupture of the tongue or lips of the groove. In order to provide this flexibility the shape of the tongue-and-groove was modified to provide a spur-gear type of mesh. The block as modified is shown on Figure 10.

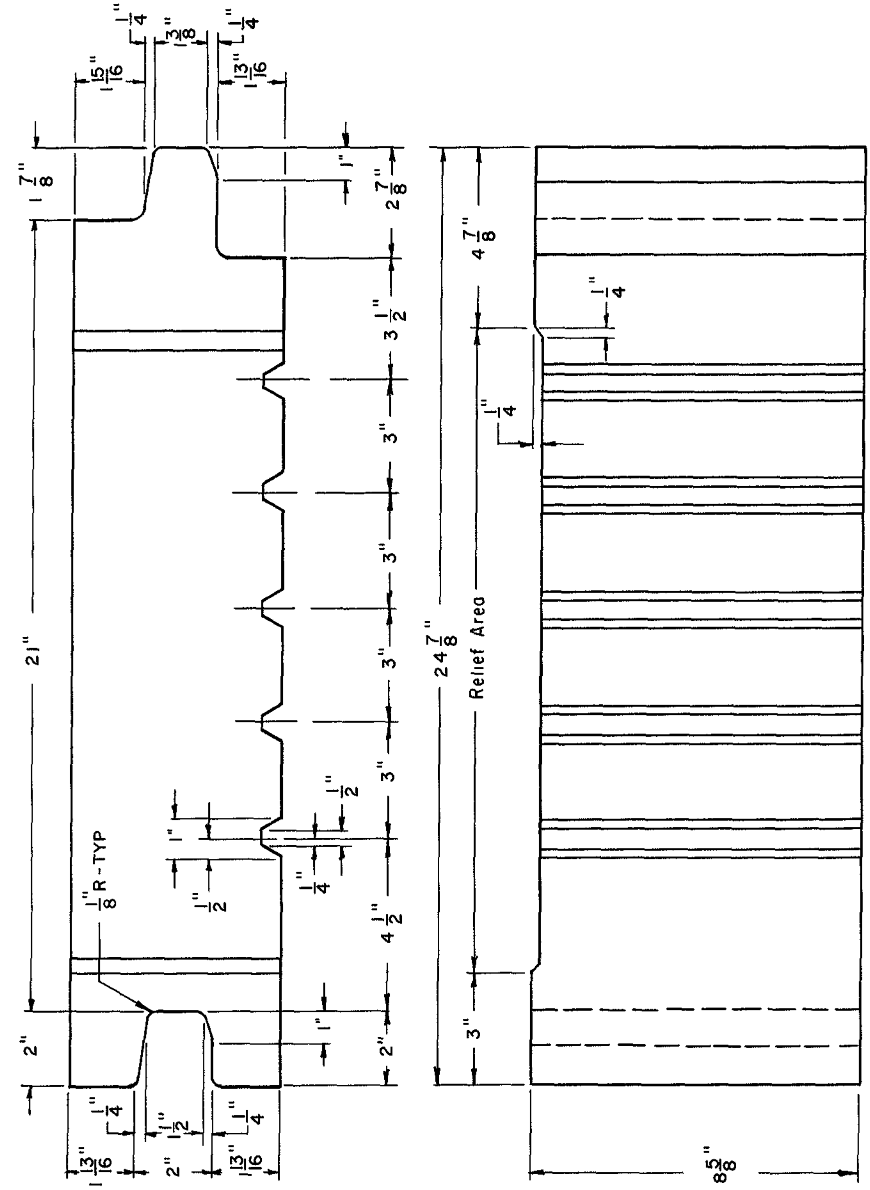

Fig. 10. Machine-produced concrete block developed.

CONCLUSIONS

The study shows that the machine-produced tongue-and-groove block tested can be successfully used in revetments to protect banks in bays and estuaries where the design wave height does not exceed 5.0 feet if an adequately engineered toe protection is incorporated.

ACKNOWLEDGEMENTS

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The tests described and the resulting data presented herein, unless otherwise noted, were obtained from research conducted under the Coastal Engineering Research Program of the United States Army Corps of Engineers by CERC. Permission has been granted by the Chief of Engineers to publish this information.