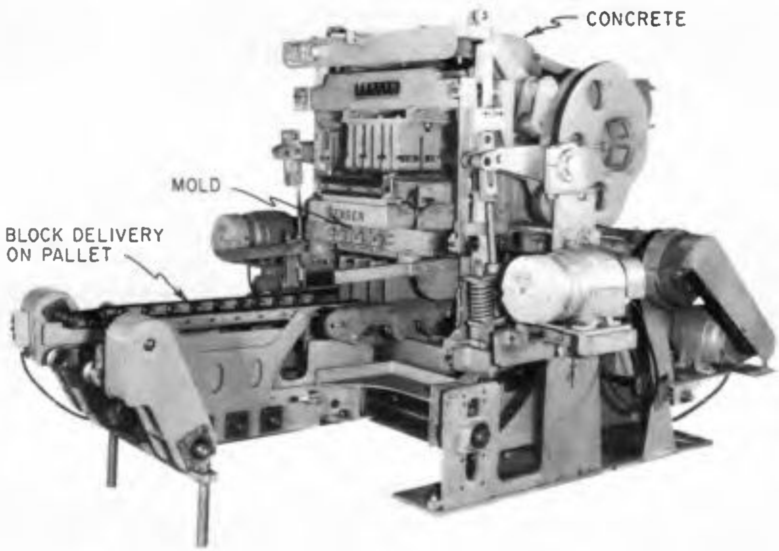

Fig. 2. Automatic concrete-block machine.

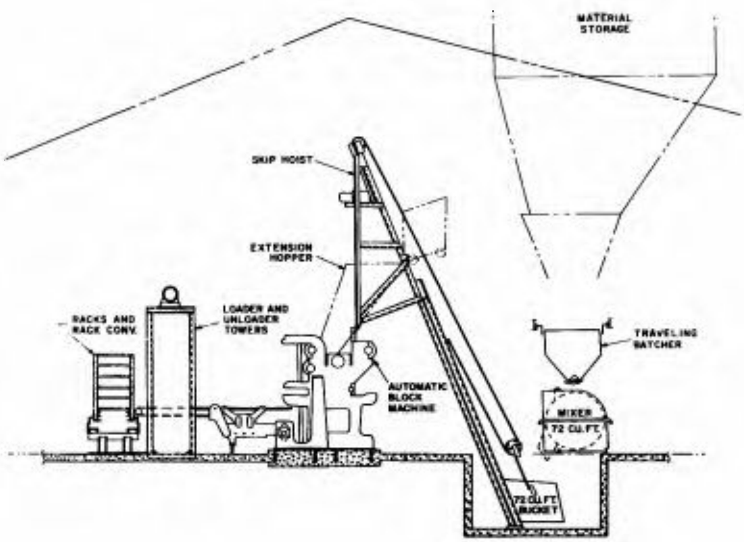

Fig. 3. Typical sequence of automatic production of concrete block.

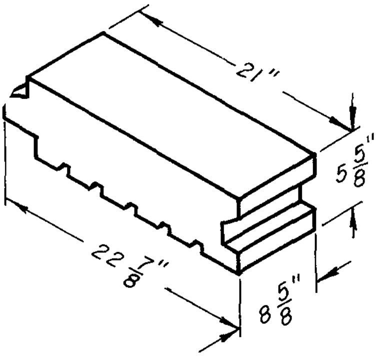

Fig. 4. Machine-produced concrete block.

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.

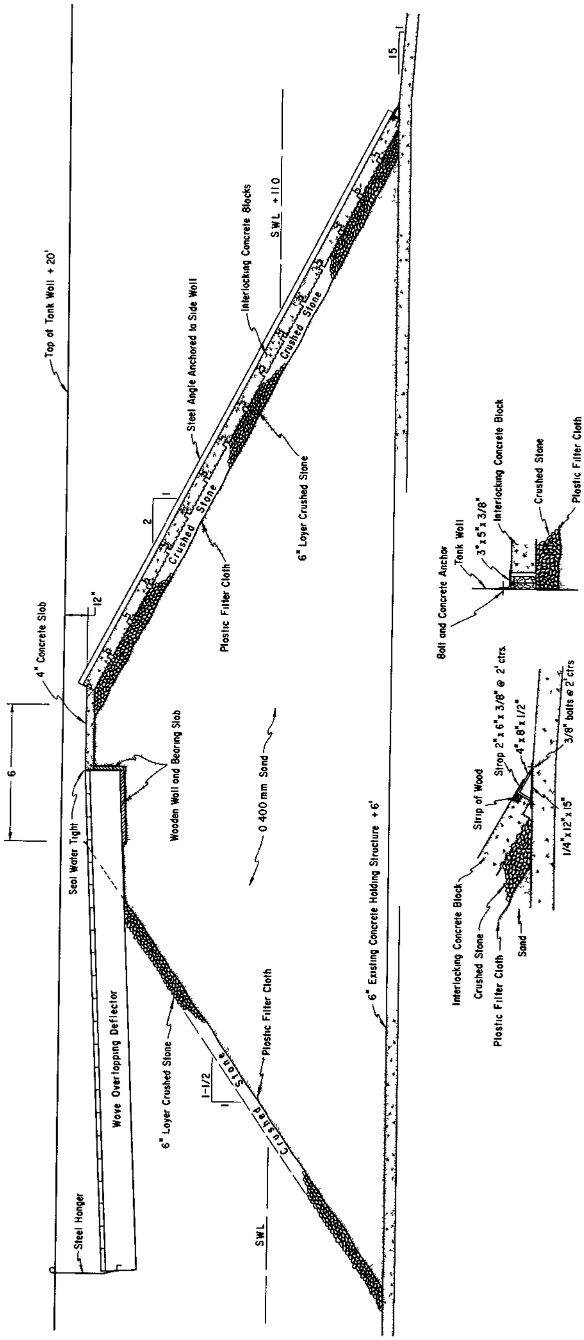

Fig. 5. Test section installed in CERC large wave tank.

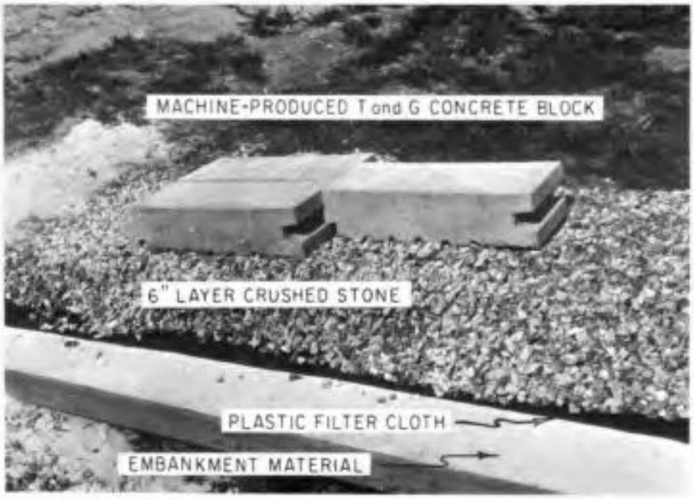

Fig. 6. Method of placing machine-produced block.

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,

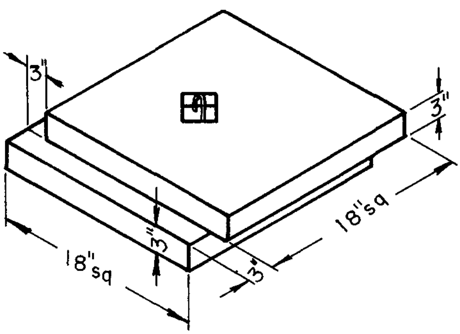

Fig. 8. Hand-produced shiplap concrete block.

Table I

RUN	WATER DEPTH Seaward of Revetment	WATER DEPTH Toe of Revetment	WAVE HEIGHT Toe of Revetment	WAVE PERIOD	LIFT Max	LIFT Avg	DURATION OF TEST	REMARKS
	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.

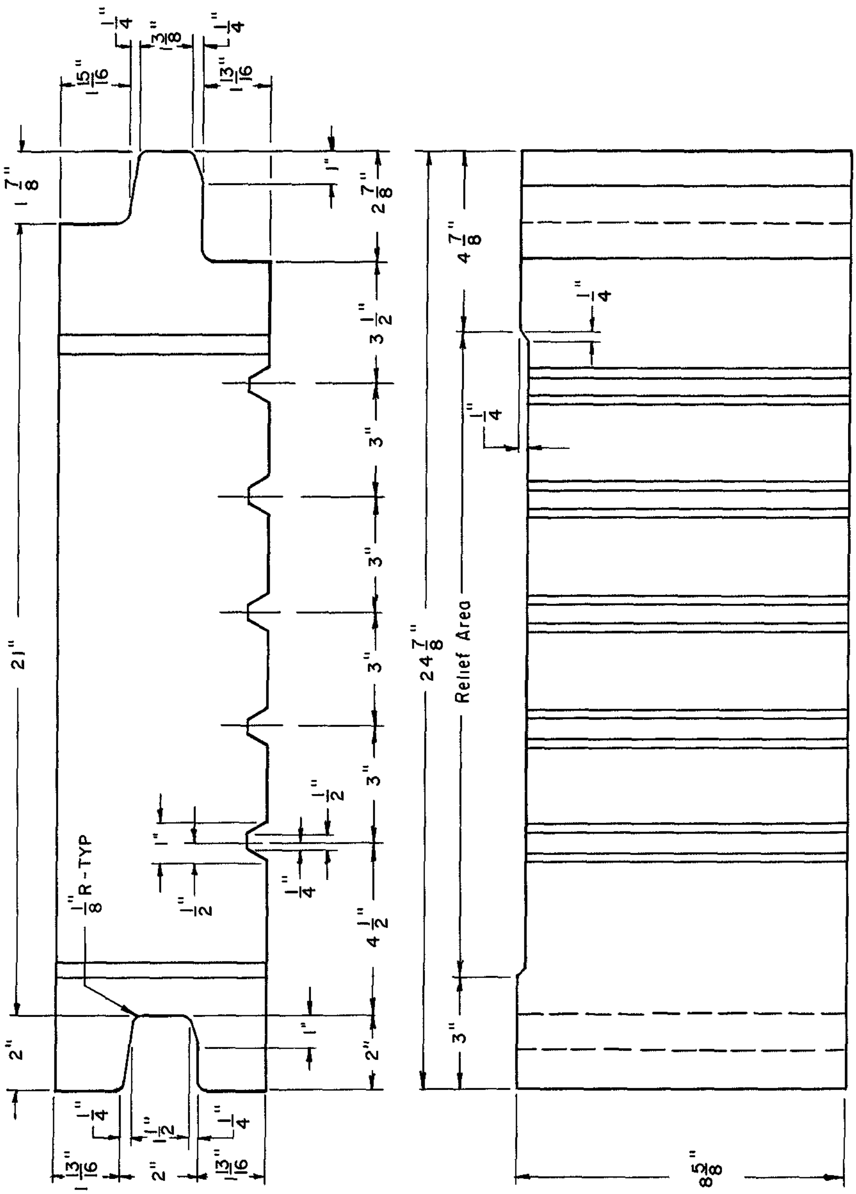

Fig. 10. Machine-produced concrete block developed.

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 assistance rendered by the Coastal Research Corporation, Glen Burnie, Maryland in making available for testing the tongue-and-groove block, on which they have a patent pending, is also gratefully acknowledged.

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.

CHAPTER 61

SCOURING DUE TO WAVE ACTION AT THE TOE OF PERMEABLE COASTAL STRUCTURE

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ABSTRACT

In this paper, the relation between a reflection coefficient of waves and a void ratio of permeable face of a structure is firstly revealed, because of the fact that there is a close relationship between the reflection coefficient and the phenomena of scouring. Before the scouring depth is investigated, the relation of the scouring depth to subsidence is made clear. Then, it is found that the scouring depth which has great influence upon subsidence of blocks, becomes larger with the increment of the coefficient of reflection. Furthermore, a composite cross section which has an imaginary uniform slope of 20 degrees, is proposed as the stable cross section against the subsidence of blocks.

INTRODUCTION

In recent years, various armour blocks, such as Tetrapod, Hollowsquare blocks and Hexaleg blocks have been used for the constructions of a seawall, a breakwater, etc. in Japan, and they were also installed in front of the seawall to protect the overtopping of waves.

They are, however, suffered from scouring at their toe, by which the subsidence of blocks is often caused, even if the weight of blocks is sufficient against wave forces. Particularly, the phenomena of remarkable subsidence of blocks are observed along the coast of Toyama facing the Japan sea. Block structures that are installed in front of a seawall shows such an appearance of subsidence, that the subsidence to a half of an original height is observed for Tetrapod blocks, during winter season.

Therefore, the study on the phenomena of scouring at the toe of a permeable coastal structure, which has a close relation with the subsidence of blocks due to wave action, is required for the coastal structure construction.

The author investigated the scouring at the toe of permeable coastal structure on the experimental basis, and made clear the influence on the scouring depth affected by water depth at the toe, slope of seaward face and incident wave characteristics.