CHAPTER 38

PATTERN OF WAVE-INDUCED EROSION UNDER CAISSON-TYPE BREAKWATER

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ABSTRACT

When caisson-type breakwaters or wharves are built in areas exposed to severe wave attack, adequate precautions must be taken to ensure that all parts of the foundations are protected from erosion The joint between abutting caissons is a particularly vulnerable location

This paper describes patterns of erosion which may be expected at joints between caissons resting on sand or gravel foundations for a number of joint configurations The results are based on model studies Criteria are given for estimating scouring velocities through joints and sizes of particles moved Suggestions are made for minimizing the risk of erosion An example of erosion under a prototype structure is given

INTRODUCTION

One of the advantages of the rubble or similar type of breakwater is its relative immunity against suddenly disastrous damage under wave attack For these types of structure, the choice of design criteria are not quite so critical as in the case of wave reflecting, gravity structures such as reinforced concrete caissons or cribs which are to be founded on a sea bed which is not resistant to scour

A foundation failure beneath a gravity type structure can result in either complete collapse or excessive settlements The causes of foundation failure are usually inadequate bearing capacity of the underlying soil strata or scour of foundation material by waves or currents Even if the structure does not collapse, the excessive settlements which may occur reduce the effectiveness of the breakwater because

- overtopping is likely to be increased
- joints in the structure are opened up
- movements of deck traffic may be adversely affected
- appearance of the structure suffers

Repairs to such a structure tend to be expensive. Hence a relatively conservative approach to the design of caisson-type breakwaters is warranted and extra attention should be paid to the foundations

PROTOTYPE FOUNDATION PROBLEMS

This investigation was initiated to clarify the mechanism by which extensive foundation damage was caused to a recently installed prototype installation. Fig 1 illustrates the settlement of the prototype which occurred during the first year after complete construction

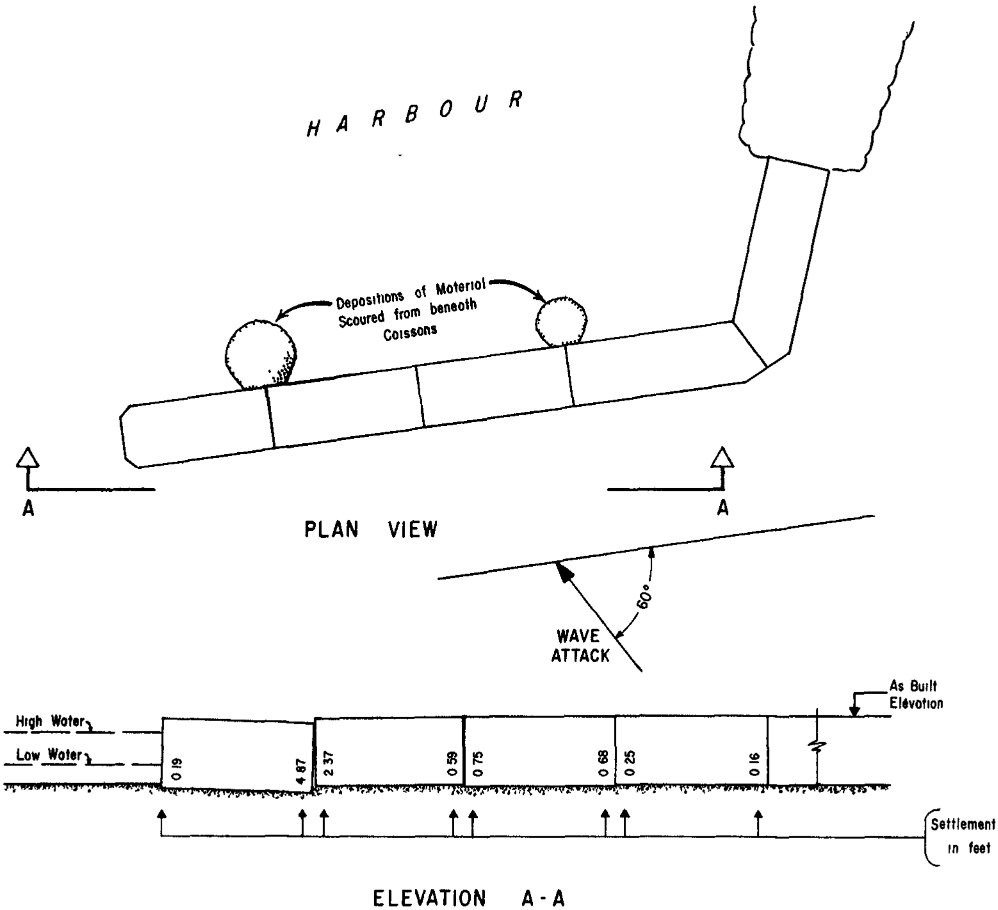


FIG. 1 SETTLEMENT OF PROTOTYPE DURING FIRST YEAR AFTER CONSTRUCTION.

It was suspected that the problem was cauaed by erosion by wave action of the foundations which began at an inadequately closed joint between abutting caissons and extended progresaively under the caissons A laboratory atudy was undertaken to

(a) Obtain a better inaight into the erosion phenomenon,

(b) Deviae the most effective way to prevent this problem in future installations,

(c) Assist in the design of an appropriate repair method for the damaged structure.

EXPERIMENTAL STUDY OF EROSION PATTERNS

Some of the testa were carried out in a 2 ft wide wave flume where erosion patterns were studied at a joint between abutting caissons under perpendicular wave attack Additional tests were performed in a 16 ft wide wave flume on a partial model of the prototype structure where erosion patterns were atudied under wave attack inclined at an angle of 60° from the face of the structure, which corresponded to the direction of predominant wave attack in the prototype

For all tests, the wave period was kept constant at 9 0 seconds The depth of water at the structure was 30 feet, although a few tests were run in the 16 ft wide flume for water depths of 12 feet (prototype dimensions, based on the Froude law, are used throughout this paper)

A sample of the test results are shown in Fig 2

The scour patterns shown in Fig 2(a) were obtained in the 2 ft flume with 4 foot incident waves acting 2½ hours, the bed material had the same critical speed of erosion as coarse sand (0 5 mm) does in the prototype Quite similar patterns resulted from tests carried out at a 6¼ foot incident wave height and with a bed material which behaved the same from the point of view of critical speed of erosion as 2 inch gravel in the prototype

Although the period of time of 2½ hours corresponded in no way to an "equilibrium state" in the erosion process, widespread damage had resulted even from a relatively light wave action The erosion was not confined to the joint itself, but extended several feet away from it, underneath the caissons

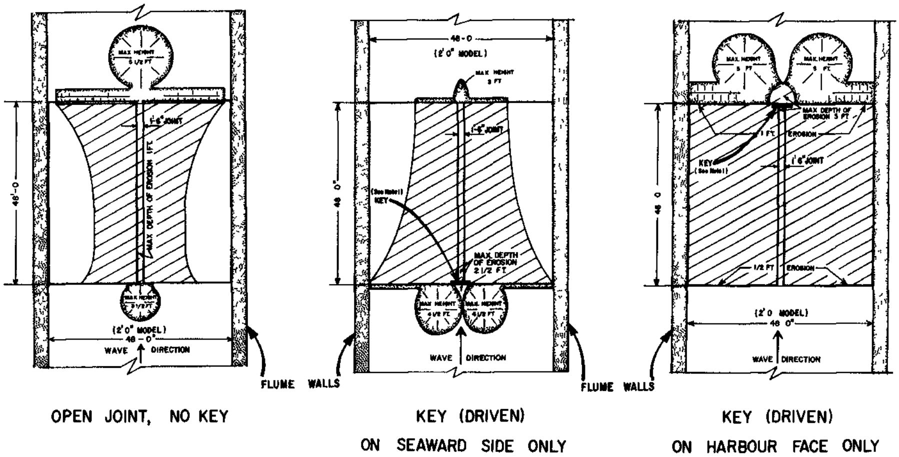
The tests conducted in the 16 ft wide flume, under oblique wave attack, led to similar scour patterns, as evidenced in Fig 2 (b)

The fluid motions in the joints between caissons was observed visually in the 2 ft wave flume A complex wave motion prevailed, made up of an incident wave component coming from the seaward face, which combined with a reflected component from the harbour side, the phase lag between the two wave components depending on the incident wave period and on the width of the caisson In each of the two tests series carried out in the 2 ft flume it was noted that if the incident wave which initiates erosion at the node of the clapotis is H, the erosion in the joint commences for an incident wave of approximately 0 75H Since the nodal velocity varies linearly with the wave height the velocity through an open joint may be estimated at approximately 25% higher than the nodal velocity in the clapotis existing in front of the structure. Thus as a first approximation for perpendicular wave attack:

$$V = 1.25 \quad \left(\frac{2\pi H}{T}\right) \quad \left(\frac{1}{\sinh 2\pi d/L}\right) \qquad (1)$$

No success was achieved with tentative methods of sealing the joints, such as a single key placed either at the seaward or at the harbour face of the joint, or a double key arrangement (one at each face of the caisson). Even when the keys were driven into the foundation soils, piping developed around the edge of the keys and led progressively to the erosion patterns shown in Fig. 2.

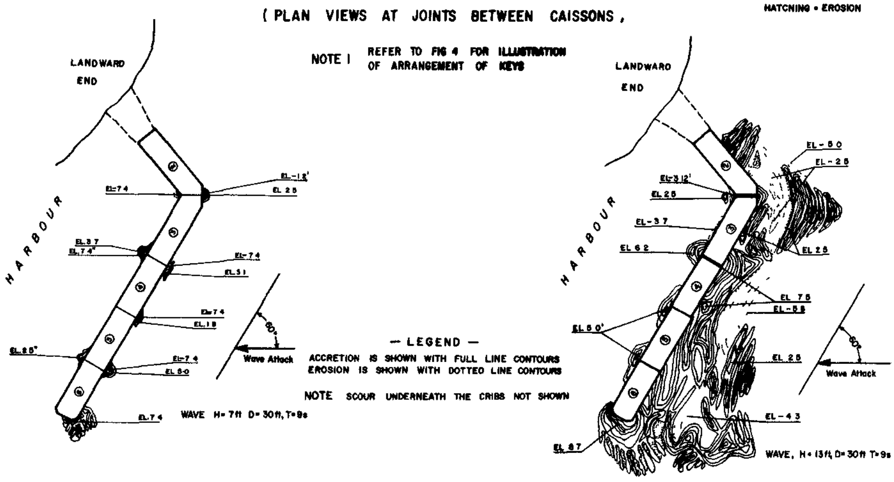
However, a double key arrangement with fill placed in the space between the keys, as shown in Fig. 4 (insert) performed successfully, both in the 2 ft. and 16 ft. wave flumes. When granular material is employed as fill a minimum height is needed in order to prevent piping. Piping effects are proportional to the effective differential head, ΔZ, at the bottom of the clapotis.



(a) TESTS IN 2FT WIDE WAVE FLUME

(PLAN VIEWS AT JOINTS BETWEEN CAISSONS ,

— LEGEND —
SHADING = ACCRETION
HATCHING = EROSION



(b) TEST IN 16FT WIDE WAVE FLUME

(PLAN VIEWS OF PARTIAL MODEL OF PROTOTYPE)

Fig. 2 SAMPLE OF TEST RESULTS SHOWING EROSION PATTERNS

Using

$$\Delta Z = H/\cosh 2^{\pi} d/L \qquad (2)$$

it was found that the height, h, of granular fill required to prevent piping could be estimated with sufficient accuracy from the expression

$$h = 2H/\cosh 2^{\pi} d/L \qquad (3)$$

For coarser types of gravel fill with suitable filters, this height could safely be reduced by 30% - 40%

Figures 3 and 4 are graphical representations of equations (1) and (3) respectively Figure 4 also shows the critical speed of erosion of various sizes of foundation materials based on a typical equation (Ref 1) for critical speed of erosion of particles of diameter, D, larger than the laminar boundary layer

$$Vc = 1\ 75\sqrt{(S-1)\ g\ D} \qquad (4a)$$

$$\text{or } Vc = 3\ 68\sqrt{D} \qquad (4b)$$

where Vc = velocity in feet per second

D = diameter in inches of a spherical stone whose unit weight is 165 lbs per cubic foot

Figure 3 provides a convenient means of making a quick preliminary check to determine if an erosion problem can be anticipated

The investigation did not include study of the effect of variation of the gap width between caissons The tests are considered representative of the gaps which might be expected in normal construction practice i e in the range of 6 inches to 3 feet For wider gaps between caissons, lower velocities, on the average, could be expected

CONCLUSIONS

1. For caisson-type structures exposed to wave action, the most vulnerable part, as far as erosion of the foundations is concerned, is at joints between abutting caissons For direct wave attack, the velocity through an open joint may be estimated approximately by equation (1) Unless the material in the joint is coarse enough to resist this scouring velocity, erosion problems will occur Fig. 3 can be used to make a quick preliminary check to determine if an erosion problem can be anticipated

2. In practice, joints between abutting caissons should be effectively sealed if erosion problems are to be avoided To seal the joint, two keys are necessary one on the seaward side and one on the harbour side, with a suitable fill material placed in the space between the keys If a granular fill is used, it should be placed to a minimum height given by equation (3) to prevent piping underneath and around the sides of the individual keys For coarser types of gravel fill with suitable filters, the height given by equation (3) could safely be reduced by 30% - 40%

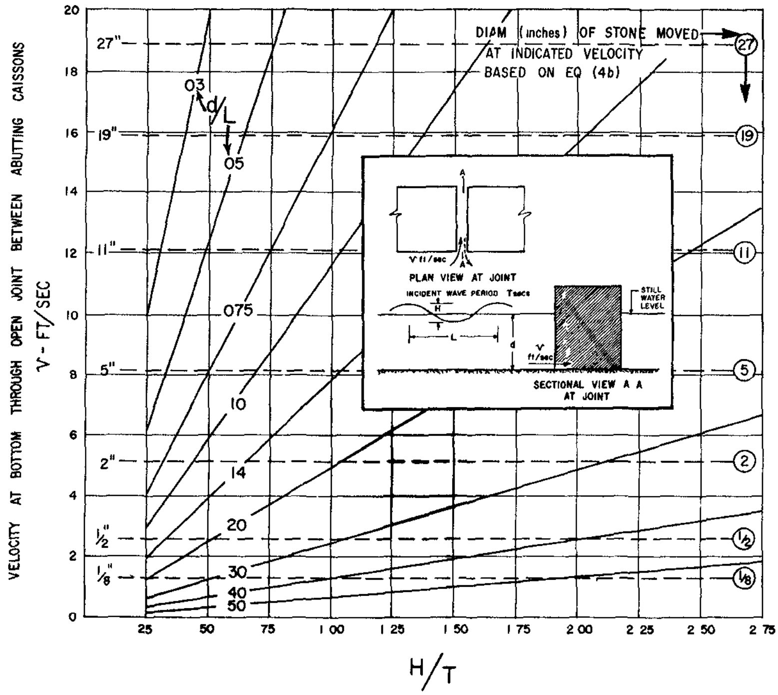


FIG 3 BOTTOM VELOCITY THROUGH OPEN JOINT BETWEEN ABUTTING CAISSONS, AND SIZES OF STONE ERODED, AS A FUNCTION OF WAVE CONDITIONS

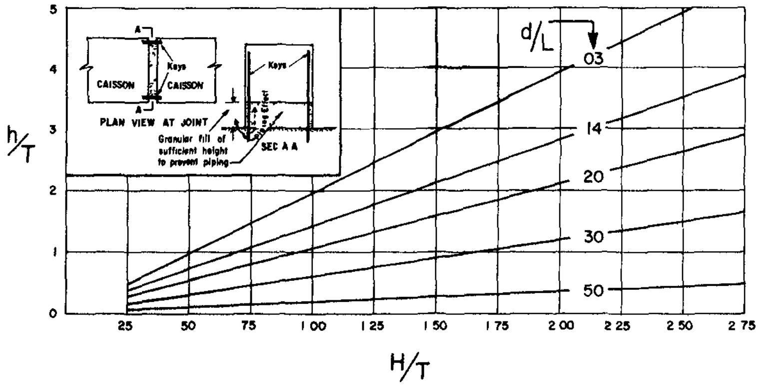


FIG 4 HEIGHT OF GRANULAR FILL IN JOINT BETWEEN ABUTTING CAISSONS TO PREVENT EROSION AND PIPING

REFERENCES

GODDET, J and JAFFRY, P – *La Similitude des transports de sédiments sous l'action simultanée de la houle et des courants* – *LA HOUILLE BLANCHE* NO 2, 1960 p p 136-147

APPENDIX – NOTATION

LIST OF SYMBOLS AS USED IN THIS PAPER

Symbol	Definition	Units
d	depth of water below the still water surface	ft
D	Diameter of rock particle	ft or ins
g	gravitational acceleration (– 32 2 ft/sec ^{2})	ft/sec ^{2}
h	height of granular fill in joint between abutting caissons	ft
H	wave height, amplitude, height of incident wave	ft
L	wave length	ft
S	Specific gravity of a rock particle	
V	wave induced bottom velocity in an open joing between abutting caissons	ft/sec
Vc	velocity which initiates motion of a particle of diameter, D, larger than the laminar boundary layer	ft/sec
ΔZ	differential pressure on the bottom cause by a totally reflected incident wave (clapotis)	ft