Design and Analysis of Seawall

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Abstract: **Coastal erosion has become a serious problem in recent times. The problem has become acute particularly in view of the encroachment by man of the coastal areas for development. Erosion of coastal line is continuous, causing loss of valuable land at the rate of 3 m to 6.5 m per year. During the past 20 years, various types of coastal works have been tried to evolve a satisfactory design which will withstand the severity of the waves and storms. A popular method of combating coastal erosion is construction of seawalls.**

These seawalls are generally of rubble mound type. Rubble mound seawall is the cheapest mode of construction compared to other types of seawall construction. The present cost of protection of one meter is Rs. 1, 00, 000/-. In the absence of any specific design method, Hudson's formula is generally used to arrive at the size of stones to be used for seawall. In practice, it is generally observed that seawalls have failed more often, giving room to doubt whether Hudson's formula is applicable to the design of seawalls or whether the failure mechanism is something else which is overlooked in design.

The present investigation deals with the experimental studies conducted to investigate these aspects.So seawall design for 1:3 and 1:5 seaward slopes are made and tested in the wave flume. It is found that the scour at the toe is the main reason for failure. So it is proposed to add an apron of 2 m long extending from the toe of the seawall which is found to be the best as per the model studies.

Keywords: Coastal works, rubble mound, Hudson's formula, scour at the toe.

INTRODUCTION

The coastal areas are of important economic and recreation value, for many developmental activities like establishing of industries, ports etc., on and around these areas. Also, the increasing population concentration in these regions has made the adjacent land more valuable, as these are being used for habitation, agriculture, fishing and recreation. However, these areas have always been plagued with the problem of wind and wave erosion. The erosion also leads to damage and destruction of coastal highways, railways, bridges, industries and other coastal installations. So, the protection of these coasts in order to prevent erosion and loss of valuable land has become imperative.

The problem of sea erosion has been a challenging one to the Coastal Engineers for a long time. The aggressive nature of sea and its catastrophic effects on the people living near the shore and on their valuable assets have to dealt with properly, so that security of the human life and property are assured. So, it is now up to the coastal Engineer to plan and design the preventive measures he likes to take.

At place where there is severe erosion continuously occurring over a period of years, it is necessary to construct some sort of remedial measures to protect the area behind it. Considering the various methods, it is found that the construction of Rubble-mound seawall is the cheapest mode. The seawall can be constructed by ordinary labourers without the use of machinery. Another advantage is that the construction can be extended year by year depending on the availability of funds.

So it is proposed to design and test a seawall. Seawall sections with various seaward slopes of 1:3, 1:4, 1:5 and 1:6 are designed. The section with higher seaward slope is preferred when the area availability for the construction of seawall is less. The section with 1:6 seaward slope gives a viable size for the armour stones which can be handled by 6 or 8 labours without the use of cranes. The cost also reduces with the armour size.

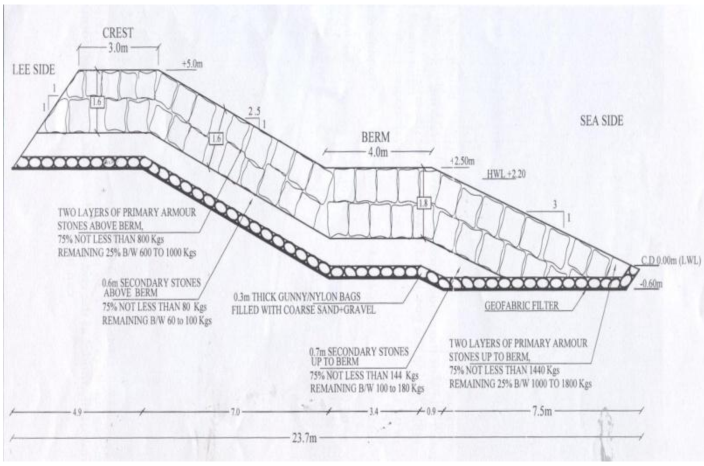
Design Details

Details of Seawall section having slope of 1:3
Scale adopted for model studies 1:16.76
Berm width: 4.00 m
Toe slope: 1:1
Beach slope: 1:16

Si No	Particulars	Proto	Model
1.	Breaker wave height	2.679 m	0.16 m
2.	Wave period	8 seconds	1.95 seconds
3.	Time duration (1 cycle = 24 hr 50 min)	6 hr 12' 30"	1 hr 30' 59"
4.	Tidal range	1.60 m	0.096 m
5.	Storm surge	0.3048 m	0.0182 m
6.	Primary armour layer thickness	a. 1.80 m b. 1.60 m	a. 0.1074 m * b. 0.0954 m **
7.	Weight of each primary armour stone (W)	a. 1440 kg b. 800 kg	a. 0.306 kg * b. 0.170 kg**
8.	Secondary armour layer thickness	a. 0.70 m b. 0.60 m	a. 0.0417 m * b. 0.0357 m **
9.	Weight of each secondary layer stones (W/10)	a. 144 kg b. 80 kg	a. 0.0306 kg * b. 0.0170 kg **
10.	Seating of toe	0.00 m	0.00 m
11.	High water level	2.20m	0.131 m
12.	Mean water level	1.30 m	0.0775 m
13.	Low water level	0.00 m	0.00 m

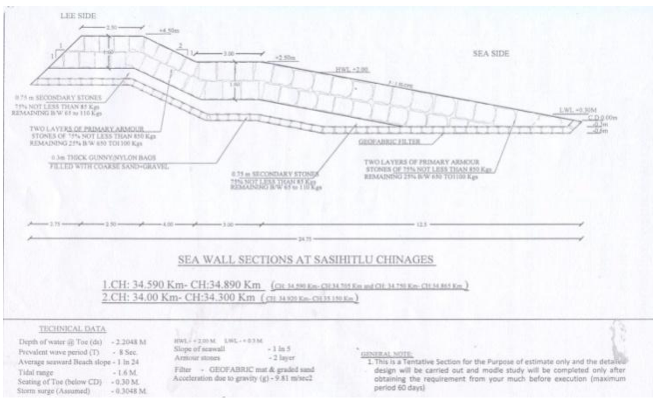
*From Toe to Berm end.

**From Berm end to Crest end.



Details of Seawall section having slope of 1:5
Scale adopted for model studies 1:14.06
Berm width: 3.00 m
Toe slope: 1:1
Beach slope: 1:24

Si No	Particulars	Proto	Model
1.	Breaker wave height	2.596 m	0.184 m
2.	Wave period	8 seconds	2.14 seconds
3.	Time duration (1 cycle = 24 hr 50 min)	6 hr 12' 30"	1 hr 39' 20"
4.	Tidal range	1.60 m	0.114 m
5.	Storm surge	0.3048 m	0.022 m
6.	Primary armour layer thickness	1.6 m	0.114 m
7.	Weight of each primary armour stone (W)	850 kg	0.306 kg
8.	Secondary armour layer thickness	0.75 m	0.054 m
9.	Weight of each secondary layer stones (W/10)	85 kg	0.0306 kg
10.	Seating of toe	0.30 m	0.022 m
11.	High water level	2.00 m	0.143 m
12.	Mean water level	1.30 m	0.0775 m
13.	Low water level	0.30 m	0.022 m



Model Study

For the purpose of model study in the laboratory a two dimensional wave flume of dimension 44.5 m * 1.50 m * 1.0 m having a glass panel side at one end and a flap type wave speed dynodrive motor at the other end capable of generating only monochromatic waves.

The wave generating unit consists of Variable speed mechanical motor, Gear box, Fly wheel, Flap unit.

During the model study we will control two parameters

1. Control on wave height.
2. Control on wave period.

Control on wave height: height of the wave in the model can be controlled by operating the screw in fly wheel.

Control on wave period: wave period can be controlled by regulating the speed of motor.

A sectional model of the seawall with granite armour stones with a model to proto scale was laid on a sand bed using High Density Polythene (HDPE) mat as filter. A bed profile slope was provided beyond the toe. The model was run to a period corresponding to 6 hr 12.5 min in proto.

The seawall section drawing and beach slope is plotted on the glass frame in the model then the sand is shaped as per the beach slope and seawall section. HDPE mat will be put on shaped seawall section. In the model study instead of using gunny bags we will use a sand layer of defined thickness on the HDPE mat, in proto gunny bags will be used. Two layers of secondary armour stone is placed on the sand layer then two layers of primary armour stone will be placed.

Each primary armour stone and secondary armour stone is weighed and counted before using in the model study.

The model studies were carried out to know the effect of waves on seawall for a period of 5 day cycle. As it was not possible to stimulate the actual wave conditions with the existing facilities in the laboratory, monochromatic waves were made to act on the seawall with the help of flap type wave generating unit. Each day cycle consisted of four levels starting from the level corresponding to Mean Sea Level (mean water level), being increased to High Water Level, lowering to Mean Water Level again and finally reaching the Low Water Level. Thus the sequence of operation being

M.W.L	H.W.L	M.W.L	L.W.L

At the end of each level the profile of the structure namely, structure settlement and beach profile oscillation were measured. Any dislodgement of primary and secondary armour stones beyond the toe were observed and counted visually. The operation for the remaining days was repeated without disturbing the so changed profile till all the levels were completed [i.e. 4(level) * 5(cycle) = 20 levels in total]. At the end of 5^{th} day (i.e. 20^{th} level), the primary and secondary units were separated, counted, weighed and tabulated which was considered as loss or damage to the structure. The total number of primary armour stones dislodged beyond the toe is less than 1% it is concluded that the design id safe.

Photographs of Model Study

Figure (a) Side view of the seawall model before running.

Figure (b) Top view of the seawall model before running.

Figure (c) View of model at 5^{th} day cycle, good beach formation can be seen.

RESULTS AND DISCUSSION

Model Study Readings for Seawall having Slope of 1:3

Initial Readings

Si. No	Chainage (m)	1	2	3	4	5	Average Initial Reading (cm)
1.	0.00	35.0	34.0	33.5	34.0	35.0	34.30
2.	0.05	34.0	34.0	33.5	33.0	32.5	33.40
3.	0.10	35.0	34.0	33.0	33.5	32.5	33.60
4.	0.15	30.0	29.5	28.0	29.5	27.5	28.90
5.	0.20	30.0	31.0	32.0	27.0	29.5	29.90
6.	0.25	28.5	27.5	26.0	27.0	27.5	27.30
7.	0.30	27.0	26.0	25.5	25.5	25.5	25.90
8.	0.35	25.0	25.0	25.0	25.5	25.0	25.10
9.	0.40	25.0	22.5	24.0	24.5	23.0	23.80
10.	0.45	23.0	23.5	22.5	23.5	23.5	23.20
11.	0.50	22.0	21.5	24.0	23.5	21.5	22.50
12.	0.55	23.0	21.5	23.0	23.5	21.5	22.50
13.	0.60	23.0	21.5	23.0	21.5	20.5	21.90
14.	0.65	22.0	21.0	20.0	21.5	19.5	20.80
15.	0.70	21.0	19.5	19.5	20.0	19.5	19.90
16.	0.75	19.0	18.0	18.5	18.5	18.0	18.40
17.	0.80	17.0	17.5	16.5	17.5	18.5	17.40
18.	0.85	17.0	16.0	14.5	14.5	16.5	15.70
19.	0.90	14.0	15.0	13.5	14.0	14.0	14.10
20.	0.95	11.0	10.0	12.0	10.5	12.5	11.20
21.	1.00	9.00	9.50	11.0	12.0	13.0	10.90
22.	1.065	8.50	8.50	10.5	9.5	10.0	9.40
23.	1.10	8.00	9.00	7.5	9.5	9.5	8.70
24.	1.15	8.00	9.00	9.00	10.5	9.5	9.20
25.	1.20	8.0	9.00	8.5	10.0	10.5	9.30
26.	1.245	9.00	9.00	8.50	9.50	9.50	9.18

1st Mean Water Level Readings

Si. No	Chainage (m)	Initial Reading (cm)	1	2	3	4	5	Final Reading (cm)	Difference (cm)
1.	0.00	34.30	34.00	34.50	33.50	34.5	35.5	34.4	-0.10
2.	0.05	33.4	34.25	33.0	33.5	34.0	35.0	34.0	-0.60
3.	0.10	33.6	34.5	34.0	33.0	33.5	35.5	34.1	-0.50
4.	0.15	28.9	33.0	29.5	28.5	32.0	31.5	30.9	-2.00
5.	0.20	29.9	32.5	29.0	28.5	31.5	26.5	29.6	0.30
6.	0.25	27.3	30.0	27.0	27.5	26.5	27.5	27.7	-0.40
7.	0.30	25.9	26.5	25.5	26.0	26.5	24.5	25.8	0.10
8.	0.35	25.1	26.0	25.5	25.0	25.0	24.5	25.2	-0.10
9.	0.40	23.8	26.0	24.0	24.5	25.5	23.5	24.7	-0.90
10.	0.45	23.2	25.0	24.0	23.5	24.0	24.5	24.2	-1.00
11.	0.50	22.5	23.0	24.0	22.5	23.5	21.5	22.9	-0.40
12.	0.55	22.5	24.0	24.0	22.5	24.0	21.5	23.2	-0.70
13.	0.60	21.9	23.0	24.0	24.0	22.5	21.5	23.0	-1.10
14.	0.65	20.80	23.0	21.0	22.0	22.5	21.0	21.90	-1.10
15.	0.70	19.9	21.0	21.5	19.5	21.0	20.5	20.7	-0.80
16.	0.75	18.4	19.5	19.5	20.0	19.0	18.5	19.3	-0.90
17.	0.80	17.4	17.0	19.0	18.0	18.0	19.0	18.2	-0.80
18.	0.85	15.7	17.5	17.0	14.5	14.5	17.0	16.10	-0.40
19.	0.90	14.1	16.0	14.0	13.5	14.5	13.5	14.3	-0.20
20.	0.95	11.2	11.0	11.0	12.5	13.5	12.50	12.1	-0.90
21.	1.00	10.9	9.50	11.0	12.5	13.5	12.5	11.8	-0.90
22.	1.065	9.4	9.00	9.50	10.5	10.0	12.5	10.3	-0.90
23.	1.10	8.70	8.70	9.00	8.50	10.0	9.50	9.5	-0.80
24.	1.15	9.20	9.00	9.50	9.00	10.5	7.50	9.10	0.10
25.	1.20	9.30	9.50	9.50	9.00	10.0	8.50	9.30	0.00
26.	1.245	9.10	8.5	9.00	9.00	10.0	9.00	9.10	0.00

Observation: the breaker wave height breaks at chainage 1.4m from the toe, wave run up to 0.50 m to 0.80 m.

Remarks: partial beach formation taken place from toe to chainage 0.3 m. One primary armour stone dislodged from toe portion.

1st High Water Level Readings

Si. No	Chainage (m)	Initial Reading (cm)	1	2	3	4	5	Final Reading (cm)	Difference (cm)
1.	0.00	34.3	33.0	31.5	32.0	32.5	31.5	32.1	2.20
2.	0.05	33.4	33.0	32.0	32.0	31.5	32.0	32.5	1.30
3.	0.10	33.6	31.0	31.5	30.5	32.0	31.5	31.3	2.30
4.	0.15	28.9	30.0	30.5	30.0	29.5	31.0	30.2	-1.30
5.	0.20	29.9	31.0	30.0	29.0	27.5	30.0	29.5	0.40
6.	0.25	27.3	30.0	29.5	28.0	27.5	28.5	28.7	-1.40
7.	0.30	25.9	28.0	26.5	27.0	28.5	26.5	27.3	-1.40
8.	0.35	25.1	27.0	25.0	25.5	26.0	24.5	25.6	-0.50
9.	0.40	23.8	27.0	25.0	25.0	34.5	24.9	27.28	-3.48
10.	0.45	23.2	24.0	24.5	23.5	23.5	25.5	24.2	-1.00
11.	0.50	22.5	23.0	24.5	24.0	24.0	22.5	23.6	-1.10
12.	0.55	23.2	23.5	23.5	24.0	24.0	22.5	23.5	-1.00
13.	0.60	21.9	23.0	23.5	24.0	24.0	22.5	23.4	-1.50
14.	0.65	20.8	22.0	22.5	21.0	21.5	20.5	21.5	-0.70
15.	0.70	19.9	21.0	20.5	20.0	20.5	19.0	20.2	-0.30
16.	0.75	18.4	21.0	19.0	17.0	18.0	17.5	18.5	-0.10
17.	0.80	17.4	17.5	18.0	17.5	18.0	18.5	17.9	-0.50
18.	0.85	5.70	17.0	17.5	15.5	15.5	17.0	16.5	-0.80
19.	0.90	14.1	16.0	15.0	13.5	15.0	13.5	14.6	-0.50
20.	0.95	11.2	12.0	12.5	13.0	13.5	14.0	13.0	-1.80
21.	1.00	10.9	12.0	12.5	13.0	13.5	14.0	13.0	-2.10
22.	1.065	9.4	10.5	11.0	12.0	10.5	10.5	10.9	-1.50
23.	1.10	8.70	10.0	10.5	10.0	10.5	10.0	10.2	-1.50
24.	1.15	9.20	9.0	10.0	9.5	10.5	10.5	9.90	-0.70
25.	1.20	9.30	8.0	9.50	8.50	10.0	8.50	8.90	0.40
26.	1.245	9.10	10.0	9.0	9.0	9.5	9.5	9.4	-0.3

Observation: the breaker wave height breaks at chainage 0.6 m from the toe, wave run up to 1.1 m.

Remarks: partial beach formation taken place from toe to chainage 0.35 m. Dislodging of armour stone at toe could not be seen due to beach formation.

1st Mean Water Level Readings

Si. No	Chainage (m)	Initial Reading (cm)	1	2	3	4	5	Final Reading (cm)	Difference (cm)
1.	0.00	34.3	33.5	34.5	35.0	34.5	33.5	34.2	0.10
2.	0.05	33.4	34.0	34.0	34.5	34.0	33.5	34.0	-0.60
3.	0.10	33.6	31.0	33.0	32.5	34.0	32.5	32.6	1.00
4.	0.15	28.9	31.0	30.50	32.0	30.5	31.5	31.10	-2.20
5.	0.20	29.9	31.0	30.0	30.5	32.5	31.0	31.0	-1.10
6.	0.25	27.3	31.5	29.5	30.0	28.0	27.5	29.3	-2.00
7.	0.30	25.90	27.0	29.5	27.0	30.5	26.5	28.1	-2.20
8.	0.35	25.1	27.0	25.0	25.5	25.0	25.0	25.54	-0.30
9.	0.40	23.8	26.0	25.0	25.5	25.0	25.5	25.4	-1.60
10.	0.45	23.2	26.0	25.0	25.0	24.0	25.5	25.1	-1.90
11.	0.50	22.5	23.0	25.0	23.5	24.0	22.0	23.5	-1.00
12.	0.55	22.5	23.5	24.0	24.5	24.0	22.5	23.7	-1.20
13.	0.60	21.9	23.0	22.5	23.5	24.0	21.0	22.8	-0.90
14.	0.65	20.8	22.0	22.5	21.0	21.5	20.5	21.5	-0.70
15.	0.70	19.9	22.0	22.5	20.5	22.0	18.5	21.1	-1.20
16.	0.75	18.4	22.0	19.0	19.0	19.0	18.5	19.05	-1.10
17.	0.80	17.4	17.0	17.5	16.0	16.5	17.0	16.8	0.60
18.	0.85	15.7	17.0	15.5	24.5	25.0	24.5	21.3	-5.60
19.	0.90	14.1	14.5	14.0	14.0	14.0	12.5	13.8	0.30
20.	0.95	11.2	12.0	12.5	13.0	13.5	12.5	12.7	-1.50
21.	1.00	10.9	10.5	11.5	12.5	12.0	10.0	11.30	-0.40
22.	1.065	9.40	10.0	11.0	12.0	10.5	10.0	10.7	-1.30
23.	1.10	8.70	9.00	10.5	10.0	10.0	10.5	10.0	-1.30
24.	1.15	9.20	9.50	10.0	9.50	10.5	8.50	9.60	-0.40
25.	1.20	9.30	8.00	10.5	9.50	10.5	9.50	9.60	-0.30
26.	1.245	9.10	9.50	9.50	8.50	10.0	9.00	9.30	-0.2

Observation: the breaker wave height breaks at chainage 1.2 m from the toe, wave run up to 0.6 m.

Remarks: Beach formation taken place from toe to chainage 0.35 m.

1st Low Water Level Readings

Si. No	Chainage (m)	Initial Reading (cm)	1	2	3	4	5	Final Reading (cm)	Difference (cm)
1.	0.00	34.3	34.0	34.5	35.0	34.0	34.0	34.3	0.00
2.	0.05	33.4	30.5	31.0	30.5	32.0	31.5	31.1	2.30
3.	0.10	33.6	31.5	29.5	30.0	32.0	32.5	31.1	2.50
4.	0.15	28.9	34.0	32.5	30.0	33.0	31.0	32.1	-3.20
5.	0.20	29.9	30.0	29.0	29.0	31.0	31.0	30.0	-0.10
6.	0.25	27.3	28.0	27.5	29.0	31.0	28.5	28.8	-1.50
7.	0.30	25.9	28.0	27.0	27.0	26.5	27.0	27.1	-1.20
8.	0.35	25.1	26.5	25.5	26.5	25.5	24.5	25.7	-0.60
9.	0.40	23.8	25.5	24.0	25.0	24.0	25.0	24.7	-0.90
10.	0.45	23.2	22.0	23.5	24.0	24.0	23.0	23.3	-0.10
11.	0.50	22.5	22.0	22.0	24.0	24.0	22.5	22.9	-0.40
12.	0.55	22.5	23.0	23.0	22.5	23.5	22.5	22.9	-0.40
13.	0.60	21.9	23.5	20.5	23.0	22.0	21.0	22.0	-0.14
14.	0.65	20.85	21.5	22.0	21.5	21.0	20.5	21.3	-0.50
15.	0.70	19.9	20.5	21.5	20.5	20.0	18.0	20.10	-0.20
16.	0.75	18.4	20.5	18.5	19.0	19.5	18.0	19.1	-0.70
17.	0.80	17.4	17.0	17.5	17.0	15.0	16.0	16.5	0.90
18.	0.85	15.7	16.5	16.5	15.0	15.0	15.0	15.6	0.10
19.	0.90	14.1	10.0	13.0	13.0	11.0	12.5	11.90	2.2
20.	0.95	11.2	10.5	10.5	11.0	10.5	11.0	10.7	0.50
21.	1.00	10.9	10.5	10.5	11.0	10.5	11.0	10.7	0.20
22.	1.065	9.40	10.0	9.0	11.0	10.5	10.0	10.1	-0.70
23.	1.10	8.70	9.00	9.00	9.50	11.0	10.5	9.80	-1.10
24.	1.15	9.20	8.00	9.50	9.00	10.5	10.0	9.40	-0.20
25.	1.20	9.30	7.50	9.50	8.00	10.0	9.50	8.90	0.40
26.	1.245	9.10	8.00	9.00	8.50	10.0	9.00	8.90	0.20

Observation: the breaker wave height breaks at chainage 1.6 m from the toe, wave run up to chainage 0.25 m.

Remarks: beach formation taken place up to chainage 0.2 m from toe. Dislodgement of armour stone could not be seen due to the beach formation.

The above tabulation shows the behavioural pattern of seawall for one cycle [4 levels (i.e., M.W.L, H.W.L, M.W.L and L.W.L)]. Similar types of tabulations are made for remaining four cycles and the behavioural pattern of seawall is observed.

Similarly, the model study is conducted for another seawall having slope of 1:5 and at the end of the model study the number of primary armour stones dislodged from seawall are counted for both the seawalls having slope of 1:3 and 1:5 and the percentage of dislodgement is calculated, if the percentage dislodgement is less than 1% then it is inferred that the design is safe.

Slope	Type	Qty/No of stones used	Qty/No of stones Dislodged	Percentage Dislodged
1:3	Primary	1504	6	0.398
1:5	Primary	1285	7	0.544

At the end of 5th day cycle, it was observed that the primary stones dislodged beyond the toe were 6 No's in 1:3 sloped seawall and 7 no's in 1:5 sloped seawall and percentage loss were 0.398 and 0.544 respectively. Which is less than 1%, it is concluded that the design is safe. At the end of each level good beach formation by deposition of sand on the seawall was observed. However, even after the end of 5th day cycle no settlement was observed.

CONCLUSIONS

- From the above table it is observed that the loss of the primary armour stones is only 0.398% and 0.544%.
- This is well within the zero order damage or in other words it is negligible.
- It was observed that the beach was formed in the second day cycle and improved upon in further cycle up to crest.
- Hence, from the above observation it is concluded that the design is safe.

REFERENCES

- Ahrens, J.P. and McCarthney,B.L., "wave period effects on the stability of riprap", Proceedings of Civil Engineering in the oceans, Vol. II, 1975.
- Bruun, P. And Johannesson, P., "parameters effecting the stability of rubble mounds", proc. Of ASCE, J1. Of waterways, Harbours and Coastal Engineering Division, May 1976.
- Bruun, P. And Gunbak, A.R., "Hydraulic and frictional parameters affecting the stability of rubble mounds", PIANC, 1976.
- Bruun, P. And Gunbak, A.R., "New design principles for rubble mounds", Proc. Of 15thCoastal Engineering Conference, Honolulu, 1976.
- Thomsen, L.A., Paul, E.W. and Alfred, S.H., "Riprap stability on earth embankments tested in large and small scale wave tanks", T.M.No.37, U.S. Army corps of engineers, june 1972.

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