### CHAPTER 111

# WAVE TRANSMISSION THROUGH VERTICAL SLOTTED WALLS

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### ABSTRACT

This paper deals with the wave transmission through a vertical slotted wall. In an experimental study the transmission coefficient has been investigated as a function of the shape of the wall elements (rectangular shape and H-beam shape), of the ratio of solid wall to total wall lenght (wall-element ratio) and of the wave approach direction.

The test results for a wave direction perpendicular to the wall are compared with previous investigations and theoretical derivations. For an oblique wave approach the test results are described by a semi-empirical formula. This formula, combined with a theoretical solution for perpendicular wave approach is used to describe the transmission coefficient for any angle of wave approach.

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# INTRODUCTION

For solving certain coastal engineering problems, some times an artificial construction is wanted, which should be permeable with respect to currents and sedimentation problems, on the other hand the same construction should give a sufficient protection against wave action. Such a construction could be a vertical slotted wall.

The general physical process, when a wave passes a vertical slotted wall, is shown in Fig. 1. The energy balance can be stated as follows:

$$E_I = E_T + E_R + E_V$$

where  $E_I =$  wave energy of the incident wave  $E_T =$  wave energy of the transmitted wave  $E_R =$  wave energy of the reflected wave  $E_V =$  wave energy loss

The wave damping effect may be described only by the transmitted wave energy compared with the incident wave energy or (instead of wave energy) by the transmitted wave height compared with the incident wave height.

The purpose of the study described in this paper, therefore was to obtain the "wave transmission characteristics" for vertical slotted walls with respect to

- the ratio of the impermeable part of the wall to the total wall
- 2. the shape of the wall elements
- 3. the wave approach direction

## DEFINITIONS AND NOTATIONS

The transmission coefficient  $\kappa_{\rm T}$  is defined as the ratio of the transmitted wave height  ${\rm H}_{\rm T}$  to the incident wave height  ${\rm H}_{\rm T}$ :

$$\kappa_{T} = \frac{H_{T}}{H_{I}}$$

The wave height after passing the slotted wall, also will be influenced by diffraction due to the geometry of the basin behind the wall. Therefore the transmitted wave height  $H_T$  must be defined directly behind the wall as shown in Fig. 2 which also shows some possible configurations of a slotted wall combined with adjacent impermeable walls.

The gaps extend over the total water depth (Fig. 1). Therefore the "wall-element ratio" W is given by (Fig.3):

$$W = \frac{b}{e}$$

where b is the width of each wall element and e is the centerline space of the elements. 100.W gives the relative wall-element ratio in %.

The direction of wave approach to the wall is defined by the angle ß as shown in Fig. 4.

# EXPERIMENTAL EQUIPMENT AND PROCEDURE

The experiments were conducted in a wave basin 0.5 m deep, 6.7 m wide and 35 m long (Fig. 5). The test area was 6.7 m wide and 25 m long. The basin was equipped with a combined flap- and piston type wave generator for regular waves. The upper and lower strokes could be adjusted independently to reproduce the horizontal particle velocity distribution for any desired wave period and wave height as accurate as possible. TRANSMISSION THROUGH WALLS





At one side of the vertical slotted wall a wave absorber was placed which separated a wave basin behind the wall. At the other side of the slotted wall the transmitted wave was separated from the incident wave by a movable impermeable guide wall. For the wave direction  $\beta = 0^{\circ}$ (perpendicular to the wall) these guide walls were situated on both sides of the slotted wall to ensure a constant width. The wave directions  $\beta$  included  $0^{\circ}$ ,  $45^{\circ}$ ,  $67.5^{\circ}$  and  $90^{\circ}$ .

The shapes and the dimensions of the wall elements are listed in the following table:

shape of the wall-element	rect b:t	ang = 1	ular :0.1	ilar rectangular 0.1 b:t = 1:1.5		ular : 1.5	rectangular b:t =		rectangular b:t=		H-beam b:t=1:2	
Dimensions [cm] t b		3	10.0			1:0.75 1:0.5 4 (6)		1: 0.66 1: 1.33				
W	0.5	0.6	0.75	0.4	0.5	0.68	0.6	68	J.6	0.75	0.425	0.61

Each test series (with a constant wave direction ß, a constant wall-element ratio W and a given shape of the wall-elements) comprised about 12 runs, each with a different wave. The parameters of these waves were varied in steps in the range of:

wave	height	H <sub>I</sub> :	4	CM	to	14	сm
wave	lenght	L:	80	cm	to	300	cm
wave	period	T:	ο.	7 sec	to	1.7	sec
wave	steepne	ss $\frac{n_{I}}{L}$	1	: 12	to	1:	40

The water depht of 35 cm was held constant for all tests.

The waves were measured with a movable parallel-wire resistance type wave gauge. Both the incident wave  $H_I$  and the transmitted wave  $H_T$  were measured and averaged in cross-sectional profiles, the incident wave  $H_I$  about 5 m in front of the slotted wall, the transmitted wave  $H_T$ 

directly behind the slotted wall (Fig. 2). The incident wave also was measured in a longitudinal section profile, to separate the reflexion effect. In the case of wave direction  $\beta > 45^{\circ}$  for the calculation of transmitted wave height mean values, about 0.5 m of the total wall lenght on the wave absorber side has not been considered to eliminate second order effects due to diffraction extensively.

### EXPERIMENTAL RESULTS

In the first instance the transmission coefficient  $\kappa_{\rm T}$  was plotted as a function of the wave steepness  $\frac{\rm H_I}{\rm L}$ . As an illustration Fig. 6 shows some results of 4 test series for a H-beam shape wall element with a constant wall-element ratio W = 0.61. The scattering of the data may be influenced additionally by the effect of re-reflection and second order effects caused by diffraction.

A straight line has been fitted to the data, which then has been used for other computations and plots. Fig. 6 also shows a slight decrease of the transmission coefficient with increasing wave steepness. The influence of the relative water depth  $^{\rm d}/{\rm L}$  is found to be negligible for these test conditions, which is also in agreement with previons investigations [1].

#### 1. RESULTS FOR WAVE DIRECTION $\beta = 0^{\circ}$

Fig. 7 shows the effect of different shapes of wall elements and wall-element ratios W. It can be seen, that the shape of the wall elements has only a small influence.

Fig. 8 shows the effect of the thickness t of the wall. As expected,  $\kappa_{\rm m}$  decreases with increasing thick-





FIG. 7 TRANSMISSION COEFFICIENT  $K_T$  VERSUS WALL-ELEMENT RATIO W



FIG. 8 TRANSMISSION COEFFICIENT  $K_{T}$  VERSUS WALL THICKNESS T

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ness. It should be noted, that this effect is strengthened with increasing wall-element ratio W. However, the influence of the thickness, which is proportional to the wall friction area, is small.

## 2. RESULTS FOR WAVE DIRECTION $0^{\circ} < \beta \leq 90^{\circ}$

For wave directions  $\beta > 0^{\circ}$  the influence of the shape of the wall elements is more important than for  $\beta = 0^{\circ}$ . Figs. 9 and 10 show the results for  $\kappa_{\rm T}$  as a function of the wave direction for different ratios W and shapes of the wall elements.

In all cases with wave direction  $\beta = 90^{\circ}$  the transmission coefficient  $\kappa_{\rm T}$  has about half the value of that for  $\beta = 0^{\circ}$ . This can readily be explained by the effects of diffraction due to the presence of the adjacent solid wall on one side (wave absorber), which can be seen as a semi-infinite impermeable breakwater.

Generally it must be considered, that the transmission coefficient  $\kappa_{\rm T}$  for  $\beta >> 0^{\rm O}$  (especially for  $\beta > 75^{\rm O}$ ) contains a part of the diffraction effects. These diffraction effects depend on the relative wall lenght  $^{\ell}/L$  (wall lenght  $\ell$  compared to wave lenght L), which in this study has been in the range  $1.0 < \ell/L < 3.75$ .

The test results shown in Figs. 9 and 10 can be described by the following semi-empirical formula:

$$\kappa_{\rm T\beta} = 0.5 \kappa_{\rm TO} \cdot (1 + \cos^{\rm d}\beta)$$

- were  $\kappa_{T\beta} = \text{transmission coefficient for any wave direction } \beta$ 
  - $\kappa_{TO}$  = transmission coefficient for the wave direction  $\beta = 0^{\circ}$ 
    - a = shape coefficient of the wall element



FIG. 9 TRANSMISSION COEFFICIENT  $K_T$  VERSUS WAVE DIRECTION



FIG. 10 TRANSMISSION COEFFICIENT K<sub>T</sub> VERSUS WAVE DIRECTION

The values for the shape coefficient were found to be

a = 0.5 for rectangular shape b:t = 1:1.5 a = 1.0 for H - beam shape b:t = 1:2

The differences in  $\kappa_{\rm T}$  comparing the tested wallelement shapes especially for  $\beta = 67.5^{\circ}$ , probably are generated by eddy formation behind the wall of the H-beam type.

# BRIEF REVIEW OF EALIER STUDIES AND COMPARISON OF THE RESULTS

Only for a wave direction  $\beta = 0^{\circ}$  previous work on wave transmission through vertical slotted walls was published.

For perpendicular wave approach test results were obtained by HARTMANN [1] for rectangular-section elements, HAYASHI [2][3] et.al. and WIEGEL [4] for circular-section elements, which are in a fair agreement with the author's results as shown in Fig. 11.

WIEGEL, HAYASHY et.al. and HARTMANN have also derived theoretical equations for the wave direction  $\beta = 0^{\circ}$ .

WIEGEL [4] developed a formula for the transmission coefficient  $\kappa_{\rm T}$  as a funktion of the wall-element ratio W as follows:

$$\kappa_{\rm m} = \sqrt{1 - W}$$

The values calculated from this formula are about 25 % smaller than the measured values.

HAYASHY et.al.  $\begin{bmatrix} 2 \end{bmatrix} \begin{bmatrix} 3 \end{bmatrix}$  studied the transmission effects for the range W = 0.8 to 1.0. He developed the following formula  $\begin{bmatrix} 2 \end{bmatrix}$ :

$$\kappa_{\rm T} = 4 \frac{\rm d}{\rm H_{\rm I}} \varepsilon \left[ -\varepsilon + \sqrt{\varepsilon^2 + \frac{\rm H_{\rm I}}{\rm 2d}} \right]$$

where

$$\varepsilon = C \left(\frac{s}{b+s}\right) / \sqrt{1 - \left(\frac{s}{b+s}\right)^2}$$
 and  $C = 0.9$  to 1.0.

This formula can be transformed to

$$\kappa_{\rm T} = 4 \frac{d/L}{H_{\rm I}/L} \varepsilon \left[ -\varepsilon + \sqrt{\varepsilon^2 + \frac{H_{\rm I}/L}{2d/L}} \right]$$

where

$$\varepsilon = C (1-W) / \sqrt{1 - (1-W)^2}$$

The values calculated by this formula for the range W < 0.8 are more dependent on the relative depht d/L than is suggested by the experiments.

A modification of this derivation for shallow water waves of small amplitude results in the formula [3]

$$\kappa_{\rm T} = 4 \frac{d/L}{H_{\rm o}/L} \varepsilon \frac{a^2 kd}{\alpha \tanh kd} \left[ -\varepsilon + \sqrt{\varepsilon^2 + \frac{H_{\rm o}/L}{2d/L} - \frac{\tanh kd}{a^2 kd}} \right]$$
  
where a = 1.1 and  $\alpha = \left(\frac{kd}{\sinh kd}\right)^2 \left(1 + \frac{\sinh^2 kd}{3}\right)$ 

HARTMANN [1] derived a formula by means of the energy transferability method of GODA and IPPEN for a wave dissipator composed of wire mesh screens. With appropriate assumptions he obtains

$$\kappa_{\rm T} = \sqrt{1 - w^2}$$

This formula is in very good agreement with all experimental results (Fig.11).



FIG. 11 COMPARISON OF THE RESULTS FOR WAVE DIRECTION  $\beta = 0^{\circ}$ 

### CONCLUSION

The experimental results and the comparison with the results for the wave direction  $\beta = 0^{\circ}$  of other authors have shown, that the transmission coefficient  $\kappa_{\rm T}$  depends only slightly on the relative water depht d/L and the wall-element thickness t. More important factors are besides the wave steepness H/L and the shape of the wall elements mainly the wall-element ratio W and the wave direction  $\beta$ .

For a wave direction  $\beta > 0^{\circ}$  it was found, that the influence of the wall-element shape is more important than for a wave direction perpendicular to the wall ( $\beta = 0^{\circ}$ ).

For the wave direction  $0 \le \beta \le 90^{\circ}$  the following formula describes the test results:

$$\kappa_{TB} = 0.5 \kappa_{TO} (1 + \cos^{a} \beta)$$

With that formula, combined with the equation for  $\beta = 0^{\circ}$  derived by HARTMANN, the transmission coefficient  $\kappa_{\rm T}$  for any wave direction may be described by the following formula:

 $\kappa_{\rm T} = 0.5 \sqrt{1 - W^2} \ (1 + \cos^a \beta)$ 

# REFERENCES

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