Wave transmission at low-crested structures

Stability of Tetrapods at front, crest and rear of a low-crested breakwater

R.J. de Jong
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delft hydraulics

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Master of Science Thesis

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PREFACE

This thesis is presented in order to obtain the Master of Science degree at Delft University of Technology, Faculty of Civil Engineering.

The report deals with two subjects, namely "Wave transmission at low-crested structures" and "Stability of Tetrapods at front, crest and rear of a low-crested breakwater". The study was performed from January till July 1996 at DELFT HYDRAULICS, location *'de Voorst'*.

I would like to thank both Boskalis Westminster Dredging BV and DELFT HYDRAULICS for their financial support during this study.

Finally I would like to thank the members of my thesis committee for their advise, support, critical comment and never failing motivation:

- Prof.ir. K. d'Angremond — DELFT UNIVERSITY OF TECHNOLOGY
- ir. W.H. Tutuarima — DELFT UNIVERSITY OF TECHNOLOGY and Boskalis Westminster Dredging BV
- dr.ir. J.W. van der Meer — DELFT HYDRAULICS
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Rutger de Jong
Delft, August 1996

SUMMARY

This report is the result of the Master thesis of the author, at Delft University of Technology, Faculty of Civil Engineering. The study was performed at DELFT HYDRAULICS, in cooperation with Boskalis Westminster Dredging BV.

Despite the many studies and experiments that have already been performed on the subject of low-crested breakwaters, one has still not yet been able to completely comprehend wave transmission and damage inflicted on breakwaters. The knowledge of the processes occurring at low-crested breakwaters is still limited. Moreover only a small number of experiments is available.

This two-part report is an attempt to contribute to the enhancement of the understanding of the wave transmission at low-crested structures and the stability of low-crested breakwaters with an armour layer of Tetrapods.
Part A of this report deals with the derivation of new transmission formulae, **Part B** deals with stability of Tetrapods at the three segments, Front, Crest and Rear of a low-crested breakwater.

During the derivation of the new wave transmission formulae first the external dimensions of the breakwater are taken into account. Secondly the influence of permeability has been investigated.

Part A: In this investigation, using various model tests, the following dimensionless parameters appear to describe wave transmission satisfactory: relative crest height, R_c/H_{si}, relative crest width, B/H_{si} and the breaker parameter, ξ. The choice for these parameters as well as the influence found in literature and the results obtained in this study, are discussed.

One parameter which theoretically should influence wave transmission, namely D_{n50}, has not been taken into account. There are two reasons for it: First the wave height, H_{si}, has frequently been used to create dimensionless parameters. Secondly the influence of the relative wave height, H_{si}/D_{n50}, was tried to take into account as the third parameter. Since there will always be difference between the proposed functions describing the influence of first two parameters and the data points used for it, it becomes difficult to bring into account the influence of a third parameter, H_{si}/D_{n50}.

Two different functions have been derived. One predicting the transmission coefficient, K_t, for permeable structures and one for impermeable structures. For both functions the maximum and minimum values have been determined. Also the standard deviations are given.

Part B deals with the derivation of a stability formula for Tetrapods units at low-crested breakwaters. The following non-dimensional parameters appear to give a good description of the development of damage: the relative crest freeboard, R_c/D_n, the stability number, $H_{si}/\Delta D_n$, the fictitious

wave steepness, s_{om}, the number of waves, N and the layer thickness coefficient, k_{Δ}.

The data used in this investigation can not be described by the existing Van der Meer formula for Tetrapods. The influence of the wave steepness appears to depend on the type of wave breaking, surging or plunging. Since the Van der Meer formula is only applicable for surging waves and the new data contains only plunging waves, the influence of the wave steepness for the new data points is not well described by the existing formula.

An amplification factor on the stability number, N_s, depending on R_c/D_n, appears to be present. For structures with a crest freeboard lower than $R_c/D_n=2$ the stability of the Tetrapods at the Front + Crest segment strongly increases.

For the Rear segment a design diagram has been derived. Minimum stability is reached for R_c/D_n between 0.0 and 1.0. In this diagram the influence of the number of waves and of the wave steepness, s_{om}, are taken into account. The influence of the layer thickness coefficient, k_{Δ}, is not present in the data. For a relative crest freeboard of $R_c/D_n \cong 4$ it appears that damage may develop very quickly. Once damage at the Rear has been initiated a slight increase in wave height may cause failure of the breakwater.

From a comparison between the design diagram and the newly derived stability formula it appears that the Rear segment is never normative regarding stability. From this comparison it can also be concluded that a reduction of the nominal Tetrapod diameter at the Rear is very often applicable.

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A_e	Erosion area around still water level	[m²]
A_t	Cross sectional area	[m²]
B	Structure width	[m]
B_c	Crest width	[-]
B_n	Bulk number	[-]
D_n	Nominal block diameter	[m]
D_{15}	Sieve diameter, diameter of stone which exceeds the *15%* value of sieve curve	[m]
D_{85}	*85%* value of sieve curve	[m]
D_{n50}	Nominal diameter	[-]
g	Gravitational acceleration	[m/s²]
H_i	Incident wave height	[-]
H_{m0i}	Significant incident wave height, calculated from the energy density spectrum	[m]
H_{si}	Significant incident wave height, average of highest one-third of wave height	[m]
H_t	Transmitted wave height	[-]
$H_{1/3i}$	Significant incident wave height, average of highest one-third of wave heights	[m]
$H_{2\%}$	Wave height exceeded by *2%* of the waves	[m]
h	Water depth	[m]
h_c	Armour crest level, relative to the seabed	[m]
h_t	Depth of toe below still-water level	[m]
k_Δ	Layer thickness coefficient	[-]
K_D	Stability coefficient	[-]
K_t	Wave transmission coefficient	[-]
k	Probability that x will not exceed a certain value, for Normal distribution with $\mu = 0$ and $\sigma = 1$	[-]
L	Wave length	[m]
L_0	Deep water wave length	[m]
L_p	Deep water wave length	[m]
n	The number of layers of Tetrapods	[-]
n_v	Volumetric porosity	[-]
N	Number of waves in a storm	[-]
N_a	The number of Tetrapods at a certain area	[-/m²]
N_{od}	Number of units displaced out of the armour layer, per width D_n across armour face	[-]
N_{omov}	Number of moving units	[-]
N_{or}	Number of rocking units	[-]
N_s	Stability number	[-]
N_s^*	Spectral stability number	[-]
M	Mass of an armour unit	[kg]
M_{50}	Mass of unit given by *50 %* on mass distribution curve	[kg]
P	Notional permeability factor	[-]
$P(x)$	Probability that x will not exceed a certain value	[-]
p	Probability density of x	[-]
R	Dimensionless freeboard	[-]
R_c	Crest freeboard, level of crest to still-water level	[m]
R_p^*	Dimensionless crest freeboard	[-]
R_u	Run-up level relative to still-water level	[m]

LIST OF SYMBOLS (continued)

$R_{u2\%}$	Run-up level exceeded by 2% of the incoming waves	[m]
S	Dimensionless damage	[-]
s_{om}	Fictitious wave steepness based on mean wave period	[-]
s_{op}	Fictitious wave steepness based on peak wave period	[-]
s_p	Wave steepness with local wave length	[-]
t_a, t_f, t_u	Thickness of armour, filter or underlayer	[m]
T_p	Spectral peak period	[s]
Q	Dimensionless overtopping discharge	[-]
q	Mean discharge	[m³/s/m]
α	Structure front face angle	[deg]
β	Angle of wave attack with respect to the structure	[deg]
Δ	Relative buoyant density	[-]
γ_b	Reduction factor for berm	[-]
γ_f	Reduction factor for slope roughness	[-]
γ_h	Reduction factor for shallow fore shore	[-]
γ_β	Reduction factor for oblique wave attack	[-]
$\mu(x)$	Mean of x	[-]
$\sigma(x)$	Standard deviation of x	[-]
ρ_c	Mass density of concrete	[kg/m³]
ρ_r	Mass density of rock	[kg/m³]
ρ_w	Mass density of water	[kg/m³]
λ_p	Local wave length based on peak period	[m]
ξ	Surf similarity or breaker parameter	[-]
ξ_m	Surf similarity or breaker parameter, based on T_m	[-]
ξ_{mc}	Critical surf similarity or breaker parameter	[-]
ξ_p	Surf similarity or breaker parameter, based on T_p	[-]

1. INTRODUCTION

One of the main aims of breakwaters is improving the tranquillity in designated areas to facilitate cargo handling or to protect natural shore lines to seabore and wave action. Economic considerations often indicate that the structural integrity of the breakwater shall be such that the structure is able to survive severe weather conditions without major damage. The functional requirements, however, do not always require that absolute tranquillity is maintained under such conditions. Since the volume of material involved in the structure and thereby its costs, is proportional to the square of its height, it is worthwhile to consider the minimum crest level as carefully as the structural strength of the armour layer.

Therefore it is necessary to give a good prediction for the wave transmission. Two well known formula describing wave transmission were derived by Van der Meer (1990b), see Figure 2-8 and by Daemen (1991), see Figure 2-9 and equation 2.13. Disadvantage of the first is that much scatter still remains. Disadvantage of the second is that, since use is made of the nominal diameter to obtain non-dimensional parameters, the approach is not valid for structures which have no characteristic diameter or which have low or zero permeability.

In this report prediction formulae for wave transmission at low-crested as well as at submerged structures are determined. Starting from external dimensions of the structure (and not D_{n50}) a basic transmission formula is derived, which includes the influences of crest width and slope angle. Formulae for permeable- as well as for impermeable structures are derived. **(Part A)**

Since low-crested structures allow much wave overtopping not only the front slope of the breakwater is attacked by the waves, but also the crest and the rear side are exposed to wave attack. Many formulae describing stability of the armour front slope can be found in literature. However, there are only a few investigations carried out on the stability of the whole breakwater section. For the stability of a rock slope Burger (1995) has derived some design graphs predicting the stability of the front, the crest and the rear. However, there is not one formula available describing the stability of a low-crested breakwater with an armour layer of Tetrapods. In this report it is attempted to gain more insight in, especially, the influence of the relative crest freeboard and the rear section of such a breakwater. **(Part B)**

Since two different subjects are dealt with, this report has been divided in the following sections:

- a general part, describing the governing parameters for design of breakwaters (Chapter 2)
- Part A, dealing wave transmission (Chapter 3 till 7)
- Part B, dealing with stability of Tetrapods (Chapter 8 till 12)

The outline of Part A, "Wave transmission at low-crested structures", is as follows: In Chapter 3 the influence of hydraulic parameters and parameters describing the geometry of the breakwater, -as can be found in literature-, are described. Chapter 4 describes the various data sets used in this investigation. An analysis of the available data is given in Chapter 5. Also the most important parameters are discussed. In Chapter 6 a new formula describing wave transmission for permeable- and for impermeable structures is derived. The maximum and minimum values as well as the reliability of the formulae are also given in this chapter. Finally the conclusions and recommendations as can be drawn from this study are given in Chapter 7.

The outline of Part B, "Stability of Tetrapods at front, crest and rear of a low-crested breakwater", is as follows: In Chapter 8 the influence of hydraulic- as well as structural parameters, -as can be found in literature-, are described. Chapter 9 gives a short description of the two data sets used in this study. Also some problems regarding the significant wave heights at shallow water are discussed. An analysis of the influence of various parameters on data set used for the derivation of the new formula, H2061 (Delft Hydraulics 1994), is given in Chapter 10. In Chapter 11 a new empirical stability formula for damage to the Front + Crest segment together is derived. A design graph has been given for stability of the Rear segment. A comparison between the Van der Meer formula and the new formula is also given. The reliability of the formula is discussed and a comparison between stability of Front + Crest with Rear is made. Finally the conclusions and recommendations as can be drawn from this study are given in Chapter 12.

2. DESIGN OF BREAKWATERS

The following sections describe the governing parameters for the design of breakwaters. Wave parameters as well as structural parameters are given. The structural response and the stability of armour layers will also be discussed.

2.1 WAVE PARAMETERS

The wave conditions, which are important for design of breakwaters, are given by:

- H_s or H_{m0} — incident wave height at the toe of the structure, given by significant wave height (average of highest *1/3* of the waves) or based on the energy density wave spectrum ($4\sqrt{m_0}$);
- T_p — peak period based on spectral analysis;
- β — the angle of wave attack;
- h — water depth at the toe of the structure.

Wave height

At deep water the wave height distribution can be described using a Rayleigh distribution. However, in shallow water waves will break. Therefore the wave height distribution can not longer be described using a Rayleigh distribution. Other characteristic values which are often used in those situations are $H_{2\%}$ or $H_{1/10}$. An advantage of using H_s in shallow water is that it is a safe approach. The truncation of the wave height exceedance curve due to breaking is not taken into account.

Wave period

The influence of the wave period is often described using the deep water wave length related to the wave height at the toe of the structure, resulting in a fictitious wave steepness:

$$s_{op} = \frac{2\pi H_s}{g T_p^2} \tag{2.1}$$

However, most breakwaters are made in shallow water. In fact the wave length at the structure will differ from the deep water wave length.

Surf similarity parameter

Wave action on slopes is often described by using the surf similarity, or breaker parameter, or Irribarren parameter:

$$\xi_p = \frac{\tan\alpha}{\sqrt{s_{op}}} \tag{2.2}$$

This parameter is also used to describe the type of wave breaking on a beach or structure. Battjes (1974) has described different breaker types, depending on ξ. Figure 2-1 gives an overview of these breaker types.

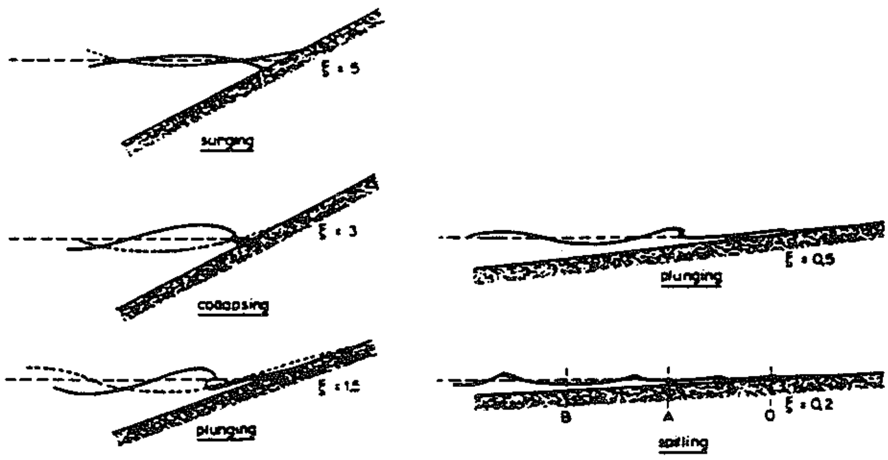

Figure 2-1 Breaker types depending on ξ

2.2 STRUCTURAL PARAMETERS

There are a number of parameters which characterise a breakwater. These parameters are:

- α angle of structure seaward slope;
- B_c crest width;
- D_n nominal block diameter of armour unit;
- h water depth in front of structure;
- h_c armour crest level relative to the seabed;
- h_t depth of toe below still water level;

  P notional permeability factor given by Van der Meer (1988a);
- t_a, t_u, t_f thickness of armour, underlayer, filter;
- R_c crest freeboard related to still water level.

Figure 2-2 gives an overview of these governing parameters.

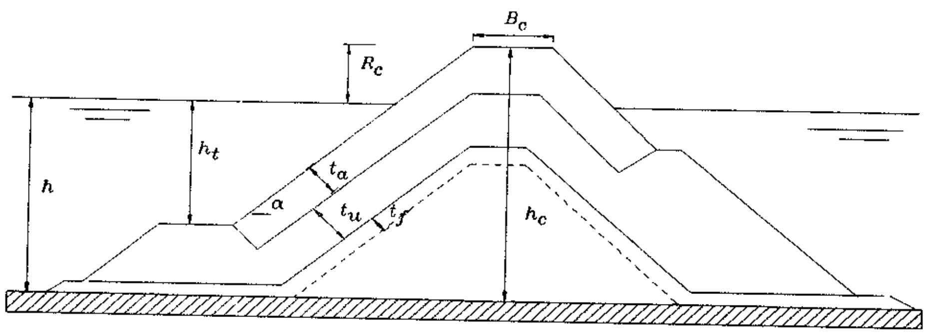

Figure 2-2 Governing parameters related to a cross-section of the breakwater

Nominal diameter

The nominal diameter of an armour unit of rock is related to its average weight. That is the *50 %* value on the mass distribution curve:

$$D_{n50} = \left(\frac{M_{50}}{\rho_r}\right)^{1/3} \tag{2.3a}$$

where M_{50} = median mass of unit

ρ_r = mass density of the rock

The nominal diameter of a concrete element is given by:

$$D_n = \left(\frac{M}{\rho_c}\right)^{1/3} \tag{2.3b}$$

where ρ_c is the mass density of the concrete element

Stability number

The most important parameter describing the relation between the wave condition and the response of the structure, is the stability number:

$$N_s = \frac{H_s}{\Delta D_{n50}} \tag{2.4}$$

where Δ is the relative buoyant density, which is described by:

$$\Delta = \frac{\rho_r}{\rho_w} - 1 \tag{2.5}$$

The stability number is also used to give a classification to the different types of breakwater slopes. Small values of $H_s/\Delta D$ give structures as caissons or breakwaters with large armour units. Large values imply gravel or sand beaches.

Another stability parameter is given by Ahrens (1987). Ahrens included the local wave steepness in a so called spectral stability number:

$$N_s^* = N_s \, s_p^{-1/3} \tag{2.6}$$

The local wave steepness, s_p, in this formula is calculated using the local wave length from the Airy theory.

Permeability

It is often very hard to compare the permeability of different kind of structures. Mostly only the indication permeable or impermeable is given. Van der Meer (1988a) introduced the notional permeability factor P, which is roughly defined as:

$P = 0.1$ impermeable breakwater
$P = 0.4$ breakwater with core, filter and armour layer
$P = 0.5$ breakwater with only core and armour layer
$P = 0.6$ homogeneous structure, which consists only of armour rocks

Figure 2-3 gives an overview of the different kind of structures. This figure can be used to make an estimation of factor P. It is also possible to use numerical models, that describe the wave action on and in structures.

It should be noted that this permeability coefficient, P, has no physical meaning, it is only a mathematical way of taking into account the permeability of a structure.

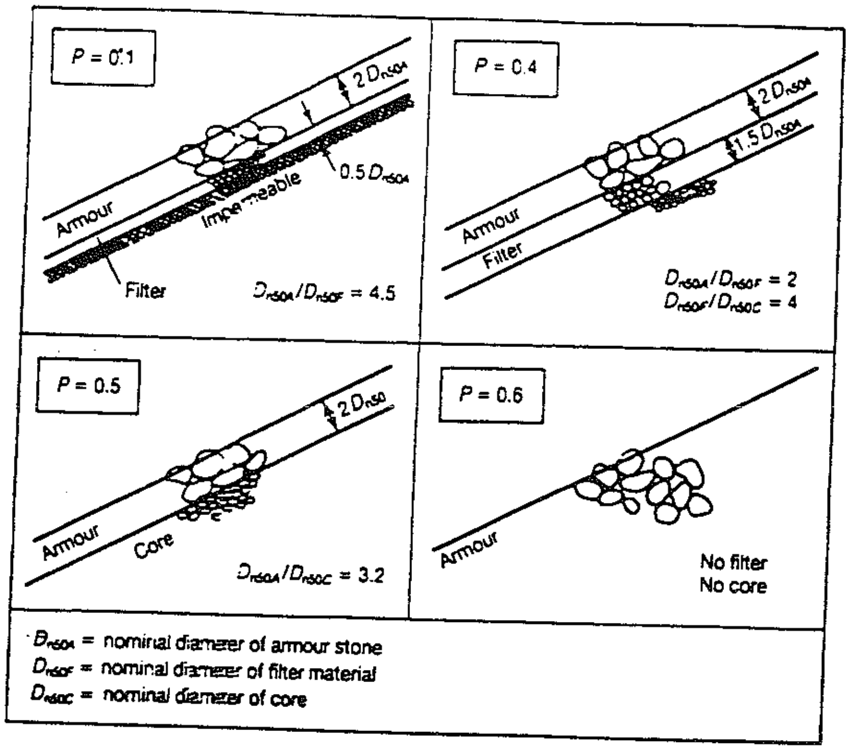

Figure 2-3 Notional permeability factor P for various structures

Crest freeboard

The height of the freeboard, R_c, is measured from still water level to the top of the structure. This top is well defined for structures such as dikes, or breakwaters with a crest of asphalt. However, how to define the crest height for breakwaters with armour of rocks or concrete? In this report it is assumed that a freeboard of zero is reached when all stones of the crest are under the still water line. A few tops extending above the water level is allowed.

2.3 STRUCTURAL RESPONSE

The behaviour of a statically stable structure can be described by the development of damage. This damage can be given as a percentage of displaced rocks out a specific area. A disadvantage of this way of defining damage is, that it is difficult to compare various structures, because every time a different area is used.

Another way is to describe damage related to the erosion-area around still water level. Comparing various structures is possible by making the damage dimensionless by dividing it by the square of the nominal diameter:

$$S = \frac{A_e}{D_{n50}^2} \tag{2.7}$$

where A_e = erosion area around still water level

A physical description of the damage, S, is the number of squares with a side D_{n50} which fit into the erosion area.

For breakwaters with an armour layer of concrete elements another description of damage is suggested by Van der Meer (1988b). Damage is defined as the relative damage, N_o, which is the actual number of displaced units related to a width (along the longitudinal axis of the breakwater) of one nominal diameter, D_n.

A distinction can be made between units displaced out of the layer and units rocking within the layer.

N_{od} = number of units displaced out of the armour layer
N_{or} = number of rocking units
N_{omov} = number of moving units
= $N_{od} + N_{or}$

The difference between N_{od} and S is that S includes displacement and settlement, but does not take into account the porosity of the armour layer. Generally S is about two times N_{od}.

2.4 HYDRAULIC RESPONSE

The following sections will give a short description of the hydraulic response of a breakwater to the wave conditions. Wave run-up, wave overtopping and wave transmission are discussed.

2.4.1 Wave run-up

Wave action on a structure will cause the water surface to oscillate over a vertical range, generally greater than the incident wave height. The design run-up level will be used to determine the level of the crest, the upper limit of protection or as an indicator for possible wave overtopping (and therefore wave transmission).

Wave run-up is often indicated by $R_{u2\%}$, see also Figure 2-4. This is the run-up level, vertically measured from the still water level, which is exceeded by two percent of the incoming waves.

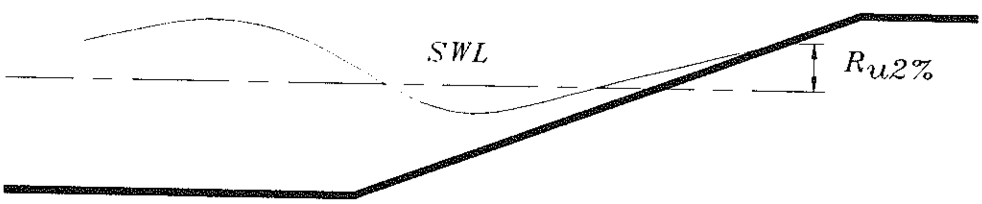

Figure 2-4 Wave run-up level $R_{u2\%}$

Van der Meer (1993) concluded that the existing formulae for run-up on impermeable smooth slopes can not be adapted for the use on permeable rough slopes. Two formulae for the wave run-up were given by Van der Meer. One that gives the run-up as a function of the surf similarity parameter, see also Figure 2-5 and equation 2.8 and one which describes wave run-up as a Weibull distribution, see eq. 2.9.

The formulae for run-up as a function of the surf similarity parameter can be given by:

$$\frac{R_{ux}}{H_s} = a\xi_m \quad \text{for } \xi_m < 1.5 \tag{2.8a}$$

$$\frac{R_{ux}}{H_s} = b\xi_m^c \quad \text{for } \xi_m > 1.5 \tag{2.8b}$$

The coefficients a, b and c are given dependent on the exceedance level, x. For permeable structures the run-up is limited to a maximum, given by:

$$\frac{R_{ux}}{H_s} = d \tag{2.8c}$$

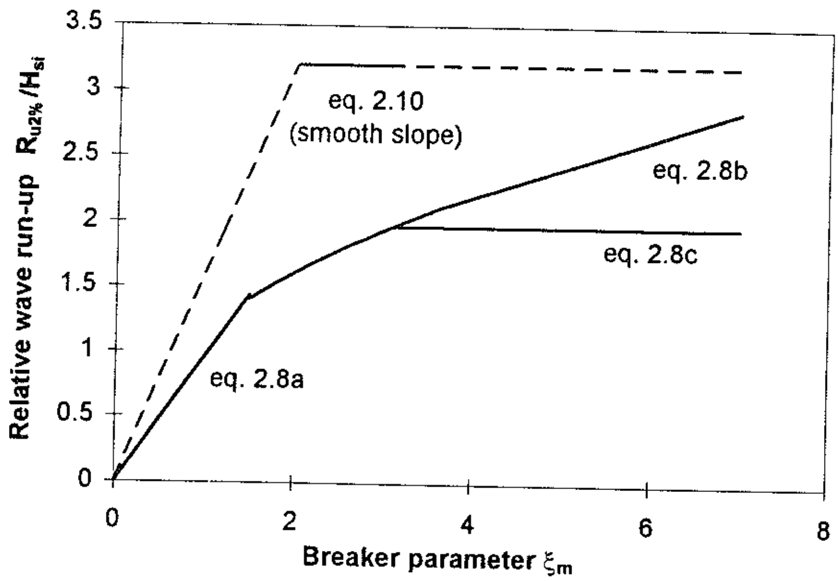

Figure 2-5 Relative 2 % run-up on rock slopes

The other method, describing wave run-up by a Weibull distribution is given by the following formulae (Note that this formula is only valid for rubble mound slopes with $\cot\alpha \leq 2$):

$$R_{up} = b(-\ln p)^{\frac{1}{c}} \tag{2.9a}$$

in which:
- p = probability
- R_{up} = run-up level, exceeded by $p * 100\ \%$
- b = scale parameter
- c = shape parameter

The scale parameter, b, is described by:

$$\frac{b}{H_s} = 0.4\, s_{om}^{-0.25} \cot\alpha^{-0.2} \tag{2.9b}$$

The shape parameter, c, depends on the type of wave breaking:

for plunging waves:

$$c = 3.0\xi_m^{-0.75} \tag{2.9c}$$

for surging waves:

$$c = 0.52 P^{-0.3} \xi_m^{P} \sqrt{\cot\alpha} \tag{2.9d}$$

The transition between the equations for surging and plunging waves is described by a critical value of the surf similarity parameter, ξ_{mc}:

$$\xi_{mc} = \left[5.77 P^{0.3} \sqrt{\tan\alpha}\right]^{\frac{1}{P+0.75}} \tag{2.9e}$$

For dikes and revetments Van der Meer and Janssen (1994) gave a prediction formula based on the surf similarity parameter. Reduction factors were used to take slope roughness (γ_f), oblique wave attack (γ_β), a berm (γ_b) and a shallow foreshore (γ_h) into account. This formula is given by:

$$\frac{R_{u2\%}}{H_s} = 1.6\gamma_h \gamma_f \gamma_\beta \xi_{eq} \tag{2.10}$$

with a maximum of $3.2\,\gamma_h\,\gamma_f\,\gamma_\beta$

in which: $\xi_{eq} = \gamma_b\,\xi_{op}$
γ_h, γ_f, γ_β and γ_b are reduction factors

In Figure 2-5 the dashed line represents this equation. They also concluded that a berm only has influence as long as its position is between $\sqrt{2}\,H_s$ above or below still water level.

2.4.2 Wave overtopping

Wave overtopping, see Figure 2-6, occurs when wave run-up exceeds the crest freeboard. Many formulae which describe wave overtopping can be found in literature. All formulae are expressed as a function of some sort of dimensionless crest freeboard.

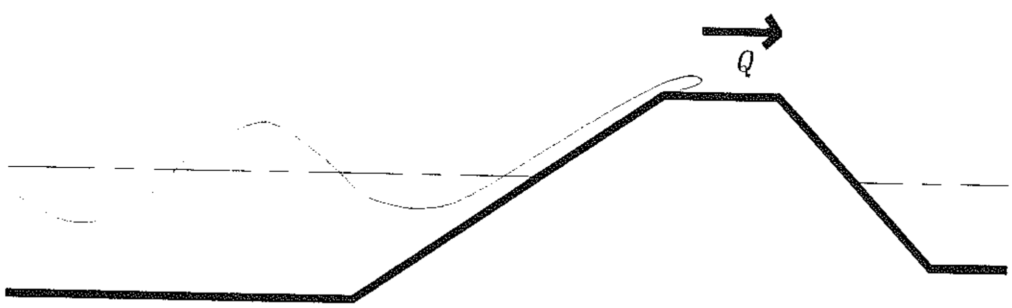

Figure 2-6 Wave overtopping

Owen (1980) gives the following expression:

$$Q = a\, e^{\frac{-bR}{\gamma}} \tag{2.11a}$$

in which Q and R are given by:

$$Q = \frac{q}{\sqrt{gH_s^3}} \sqrt{\frac{s_{om}}{2\pi}} \tag{2.11b}$$

$$R = \frac{R_c}{H_s} \sqrt{\frac{s_{om}}{2\pi}} \tag{2.11c}$$

in which: q is the mean discharge expressed by m^3/s per m
a and b are given dependent on the slope angle

De Waal and Van der Meer (1992) concluded that wave overtopping is dependent on the type of wave breaking. They suggested different formulae for surging and plunging waves. In these formulae they used the same reduction factors as described in equation 2.10 to compensate for roughness, berm, etc.

2.4.3 Wave transmission

Wave transmission is the phenomenon that wave energy will overtop and pass through the breakwater, see Figure 2-7.

Transmission is expressed by the ratio transmitted to incident wave height:

$$K_t = \frac{H_t}{H_i} \tag{2.12}$$

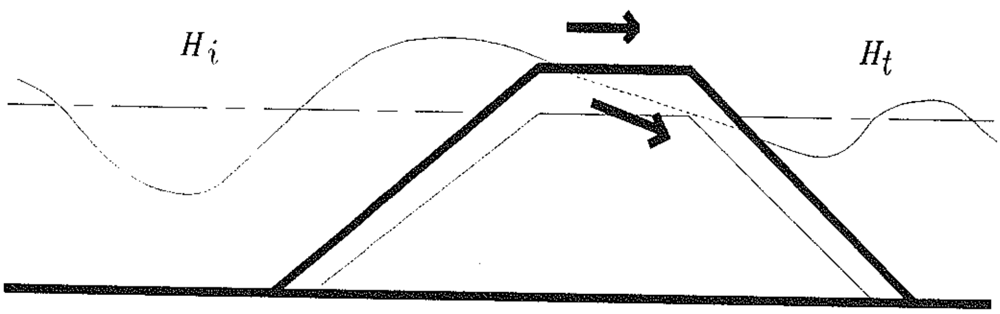

Figure 2-7 Wave transmission through and over a breakwater

The governing parameters related to transmission are: structural geometry, permeability, the crest freeboard, crest width, surface roughness, water depth and the hydraulic parameters: wave height and wave period.

Most formulae express K_t dependent on a dimensionless crest freeboard. Van der Meer (1990b) gives K_t dependent on the ratio crest freeboard divided by the wave height, R_c/H_i, see Figure 2-8.

Disadvantages of this expression are that all influence of the wave height is lost when R_c becomes zero, resulting in large scatter and that not much information on breakwater properties are taken into account, which also leads to considerable scatter around the proposed line.

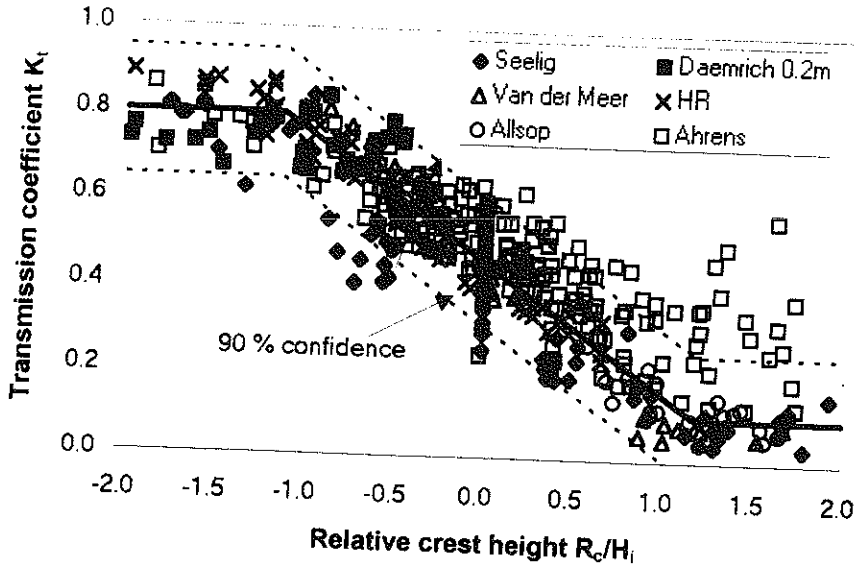

Figure 2-8 Wave transmission versus relative crest height

Daemen (1991) used another parameter to create a dimensionless crest freeboard, namely D_{n50}. Daemen concluded that, besides a dimensionless crest freeboard, there are other parameters which also have large influence on the transmission coefficient. These parameters are the fictitious wave steepness (s_{op}), the relative wave height (H_{si}/D_{n50}) and the relative crest width (B_c/H_{si}). Formulae which make a distinction between conventional and reef type breakwaters were derived. Figure 2-9 gives this expression for K_t.

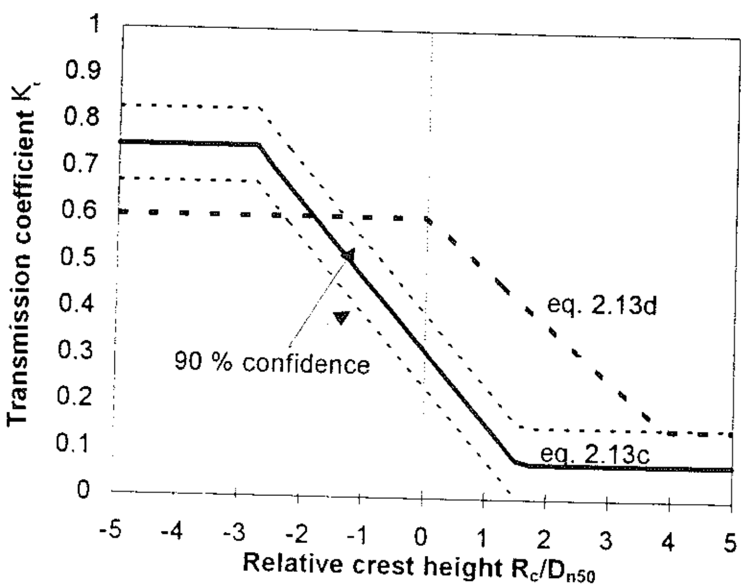

Figure 2-9 Wave transmission according to Daemen (1991)

The formulae describing this K_t are given by:

$$K_t = a\frac{R_c}{D_{n50}} + b \tag{2.13a}$$

in which the coefficient a is given by:

$$a = 0.031\frac{H_i}{D_{n50}} - 0.24 \tag{2.13b}$$

the coefficient b for conventional breakwaters is:

$$b = -5.42 s_{op} + 0.0323\frac{H_i}{D_{n50}} - 0.0017\left(\frac{B}{D_{n50}}\right)^{1.84} + 0.51 \tag{2.13c}$$

and the coefficient b for reef type breakwaters is:

$$b = -2.6 s_{op} - 0.05\frac{H_i}{D_{n50}} + 0.85 \tag{2.13d}$$

Both functions represent linear decreasing lines for increasing relative crest height. Maximum and minimum transmission are expressed as follows:

for conventional breakwaters:

$K_{t,max} = 0.75$ and $K_{t,min} = 0.075$

for reef type breakwaters:

$K_{t,max} = 0.60$ and $K_{t,min} = 0.15$

The formulae are valid for:

$1 < H_s/D_{n50} < 6$ and $0.01 < s_{op} < 0.05$

It can be concluded that this way of expressing K_t gives considerably less scatter. A disadvantage, however, is that this approach is not valid for structures which do not have a representing nominal diameter, such as rubble mounds with an asphalt filled crest.

In Chapter 3 the influences of all governing parameters for wave transmission will extensively be discussed.

2.5 ARMOUR LAYER STABILITY

The old Hudson formula is given by:

$$M_{50} = \frac{\rho_r H^3}{K_D \Delta^3 \cot\alpha} \tag{2.14a}$$

in which K_D is a factor depending on rock type and accepted damage

'No-damage' according to Hudson is a condition where up to 5% of armour stone may be displaced. According to SPM (1984) the wave height to be used is $H_{1/10}$, being the average of the highest *10 %* of all waves.

The formula can also be written in the form of a stability number:

$$\frac{H}{\Delta D_{n50}} = \left(K_D \cot\alpha\right)^{1/3} \tag{2.14b}$$

Some disadvantages of the formula are:

- wave period is absent in the formula. The wave period has influence on the type of wave breaking;
- the formula is only valid for non-overtopped and permeable core structures. It is easy to imagine that permeable structures act different from impermeable ones;
- only regular waves were used to derive the expression;
- the storm duration is not present in the formula;
- the formula is only valid for $1.5 < \cot\alpha < 4.0$

Van der Meer (1987a) has found new formulae which include all above mentioned short comings of the Hudson formula. Again Van der Meer makes a distinction between plunging and surging waves.

The Van der Meer formulae for stability of a breakwater with an armour layer of rock are:

for plunging waves:

$$\frac{H_s}{\Delta D_{n50}} = 6.2 P^{0.18} \left(\frac{S}{\sqrt{N}}\right)^{0.2} \xi_m^{-0.5} \tag{2.15a}$$

for surging waves:

$$\frac{H_s}{\Delta D_{n50}} = 1.0 P^{-0.13} \left(\frac{S}{\sqrt{N}}\right)^{0.2} \sqrt{\cot\alpha}\, \xi_m^{P} \tag{2.15b}$$

The transition from plunging to surging waves can be calculated using a critical value of ξ_{mc}:

$$\xi_{mc} = \left[6.2 P^{0.31} \sqrt{\tan\alpha}\right]^{\frac{1}{P+0.5}} \tag{2.15c}$$

Van der Meer used S to describe damage, see section 2.3. $S = 2\text{-}3$ is equal to the 'no-damage' level in the Hudson formula.

The above mentioned formulae are not valid for breakwaters with an armour layer consisting of concrete elements. The 'strength' of concrete elements is not only its weight, but also the interlocking. For breakwaters with Tetrapods Van der Meer (1987b and 1988b) found:

$$\frac{H_s}{\Delta D_n} = \left(3.75 \frac{N_{od}^{0.5}}{N^{0.25}} + 1.0\right) s_{om}^{-0.2} \tag{2.16}$$

This formula describes only damage due to displacement out of the layer, large and slender concrete units can however, also break due to rocking. The total number of moving units (N_{omov}) may give a good indication for displacement and broken units. To take this into account the following formula has been derived by Van der Meer:

$$\frac{H_s}{\Delta D_n} = \left(3.75 \frac{N_{omov}^{0.5}}{N^{0.25}} + 0.85\right) s_{om}^{-0.2} - 0.5 \tag{2.17}$$

An extensive discussion on parameters involved with stability of Tetrapods will be given in Chapter 8.

PART A

Wave transmission at low-crested structures

3. DESCRIPTION OF PARAMETERS INVOLVED

Transmission, the phenomenon that wave energy will overtop and pass through a breakwater, has already been briefly described in section 2.4.3. The following sections will deal with the parameters which have influence on wave transmission. These parameters are:

1. **Hydraulic parameters**
   - Wave height
   - Wave period (and therefore wave steepness)

2. **Geometry of the breakwater**
   - Crest height
   - Crest width
   - Slope angle

3. **Material properties of the breakwater**
   - Permeability
   - Slope roughness

It should be noted that the influences of the various parameters discussed in the following sections, are those influences as they are found in literature.

3.1 WAVE HEIGHT

According to Daemen (1991) an increasing significant wave height, H_s or H_{mo}, will lead to a decreasing transmission coefficient for low-crested breakwaters which are non-overtopped (!). An increasing wave height will lead to more energy dissipation inside the breakwater and therefore to a lower K_t. The ratio H_s/D_{n50} has large influence on this phenomenon.

For non-overtopped permeable structures a lower ratio of H_s/D_{n50} will lead to a higher K_t than a high ratio of H_s/D_{n50}. This can be explained as follows: if the wave height is lower than the nominal diameter of the armour layer, the waves will pass rather easily through the breakwater. A high ratio however, will lead to more turbulence and therefore to more energy dissipation.

For low-crested breakwaters which are overtopped, a larger wave will give a higher potential run-up level and therefore more overtopping, which means more wave transmission.

For submerged structures the influence of the wave height is slightly different from the one for low-crested structures. At submerged structures a higher wave height will lead to a lower K_t. A larger wave will be more affected by the crest of the breakwater than a lower wave (low waves can pass unhindered). However, when the crest height is far below the still water level the breakwater crest has lost its influence and every wave may pass unhindered. So an increasing wave height will now lead to an increasing wave transmission coefficient. (Of course the maximum wave transmission coefficient is *1.0*)

3.2 WAVE PERIOD

In general the influence of the wave period is brought into account by using the fictitious wave steepness. A longer wave period means a lower wave steepness, see eq. 2.1.

Waves with a low wave steepness will, for non-overtopped low-crested structures, propagate much easier through the structure. Also, for overtopped structures, a lower wave steepness will increase the run-up and therefore the overtopping rate. However, Allsop (1983) concludes that wave transmission is not dependent on the wave period or wave steepness.

When submerged breakwaters are considered, the influence of the wave period is not quite clear. Van der Meer (1990) found that longer waves can pass unhindered, while shorter waves are influenced by the breakwater. Powell & Allsop (1985) noted the opposite: a higher wave period leads to a decreasing K_t. They used the parameter R^*_p, see eq. 3.1, to describe the influence of the crest freeboard. However, Van der Meer (1990) concluded that this is not a good parameter to describe wave transmission at submerged structures. Perhaps this is also an explanation for the difference between Van der Meer and Powell & Allsop with regard to the influence of the wave period.

3.3 CREST FREEBOARD

The Crest Freeboard (= R_c), the distance between the Still Water Level and the top of the breakwater, is one of the most important parameters for wave transmission, especially for impermeable breakwaters. It is clear that for low-crested structures the lower the R_c the higher the wave overtopping will be and with that the wave transmission.

Two manners of making R_c dimensionless are often found in literature. Namely by dividing it by a significant wave height, H_s or H_{mo}, or by a nominal stone diameter, D_{n50} or D_n. Both have their disadvantages.

For the first parameter, R_c/H_{si}, all influence of the wave height on the dimensionless parameter seems to be lost when R_c becomes zero. This results in large scatter in the values of wave transmission for $R_c/H_{si} = 0$.

The second parameter, R_c/D_{n50} (Daemen 1991), has as main disadvantage that not all structures have a representing nominal diameter (structures with an asphalt filled crest). So the parameter can not generally be used for other structure types.

Another way for taking the influence of the crest freeboard into account is given by Powell & Allsop (1985):

$$R_p^* = \frac{R_c}{H_{mo}}\sqrt{\frac{s_{op}}{2\pi}} \tag{3.1}$$

As can be seen from formula 3.1, also R^*_p is a dimensionless parameter. Besides H_{mo} also the fictitious wave steepness, s_{op}, is taken into account. Van der Meer (1990) concluded that this R^*_p is not a better parameter than R_c/H_{si}. For $R_c/H_{si} > 0$, R^*_p is a good parameter, but for submerged structures, $R_c/H_{si} < 0$, the use of R^*_p leads to a larger scatter of the values of wave transmission coefficient.

According to Ahrens, who used $R = R_c/H_{si}$, transmission changes from transmission over the breakwater to transmission through the breakwater for $R > 1.5$. For $-1 < R < 1.5$ both transmission through and over the breakwater are important.

Aminti & Franco (1988) concluded that both the percentage of overtopping waves and the corresponding discharge decrease exponentially with increasing crest height. Since overtopping has large influence on wave transmission it can be concluded that wave transmission will probably also decrease exponentially with increasing crest height.

Davies and Kriebel (1992) presented a parameter which takes into account the run-up level:

$$R = \frac{R_c - R_u}{H_{si}} \tag{3.2}$$

in which R_u is the potential run-up level.

Both for low-crested and submerged structures this new parameter led to a reduction of the scatter. They concluded that for $\frac{R_c - R_u}{H_{si}} < -0.4$ there is hardly any transmission through the breakwater anymore.

In general it can be said that the higher the crest freeboard the lower the wave transmission. For submerged structures this is also true, but for very high negative values of R_c, $R_c/H_{si} \leq -4$, the breakwater has lost most influence on wave transmission. The wave transmission coefficient, K_t, will then be 1.0.

3.4 CREST WIDTH

Generally a wider crest will decrease the transmission of the waves. At low-crested structures a larger crest width, B_c, will lead to a longer way for the waves to overtop the structure and therefore to more energy dissipation. Result is that a larger crest width will lead to a lower K_t. A large crest width also means a large structure width (a large cross sectional area), so a long way for energy to pass through the structure and thus a lower K_t. Kondo & Toma (1972) concluded that the wave transmission coefficient decreases exponentially with increasing ratio crest width divided by wave length, B_c/L.

According to Daemen (1991) the influence of B_c for submerged structures is as follows: an increasing crest width will force the waves to break. This leads to energy dissipation and therefore to a lower K_t. However, small crest widths, present at most of the breakwaters, have no influence on wave transmission at all. During the authors investigation it became clear that this is not true. Even small relative crest widths, B/H_{si} do show influence on wave transmission.

3.5 PERMEABILITY AND/OR POROSITY

The influence of permeability and porosity are often interrelated. Note that it is possible to have a porous structure which is impermeable. Regarding permeable or impermeable it is hard to indicate the permeability of a structure. Van der Meer (1988a) has given an indication on permeability by using a notional permeability factor, P. This parameter has already been described in section 2.2. Daemen (1991) concluded that this parameter, P, is not a correct parameter to describe permeability for wave transmission. "This parameter is derived from the ratio of the nominal stone diameter of armour layer and core. But, as the upper part of the structure is most involved, the waves will be mostly affected by the permeability of the armour layer."

For low-crested breakwaters the influence of permeability is as follows: a higher permeability will lead to more transmission through the structure. However, a more permeable structure often gives a reduction on wave run-up and therefore to a lower overtopping rate. It is difficult to say whether this higher permeability will lead to an increase or a decrease of K_t. Daemen (1991) noted that the height of the core relative to the wave height is important, because the core is much less permeable than the armour layer.

At submerged structures permeability has not much influence. This is because, at submerged structures, transmission is dominated by overtopping. However, an increase in permeability will potentially lead to an increase of wave transmission.

In general the sensitivity towards permeability and/or porosity increases as R_c/H_{mo} increases. This is because of the fact that with increasing R_c/H_{mo} wave run-up becomes more important.

3.6 BULK NUMBER

Ahrens has proposed to characterize the porosity of the structure by the Bulk Number (the number of stones in the cross-section):

$$B_n = \frac{A_t}{D_{n50}^2} \tag{3.3}$$

in which A_t is the cross sectional area

He concluded that wave transmission at low-crested structures is apart from the dimensionless crest freeboard ($R = R_c/H_{si}$) also dependent on a factor which represents wave steepness times "porosity", P:

$$P = \frac{H_s A_t}{L_p (D_{n50})^2} = s_{op} B_n \qquad (3.4)$$

in which L_p is the deep water wave length

Daemen (1991) concluded that wave transmission in not dependent on the Bulk Number. Whether this is true in general can not be said. His transmission formulae are independent on the Bulk Number because of the manner of derivation of the transmission formulae. Part of the formulae were derived for a relative crest height of zero, $R_c/H_{si} = 0$, for which only the upper part of the structure is involved and not the whole structure, as described by the Bulk Number.

3.7 SLOPE ANGLE

For low-crested breakwaters the slope angle has some influence on the wave run-up, see eq. 2.9b and 2.9d and therefore on wave transmission. However, this influence is very small and only present for very smooth or gentle slopes. According to Daemen (1991) the slope angle has only influence on very smooth slopes.

For submerged structures the slope angle has negligible influence, since the slope angle mainly affects the wave run-up which is not present for submerged structures.

3.8 SLOPE ROUGHNESS

In literature not much is written on slope roughness in accordance with wave transmission. However, most formulae which describe wave run-up make use of reduction factors for roughness of the armour layer. It is clear that the rougher the slope, the lower the run-up height will be. (More energy dissipation on the slope.) So it can be said that the rougher the slope the lower the wave transmission will be.

For submerged breakwaters the influence of slope roughness is small. Since the breakwater crest width has only influence when it is large in comparison with the wave length, the roughness of the crest will also only have effect for large crests widths.

4. DESCRIPTION OF AVAILABLE DATA SETS

Various sets of data on wave transmission were gathered by Van der Meer (1990a) and were briefly described by Daemen (1991). This short description will be repeated in the following lines. Also the data from the tests by Daemen and data gathered by the author will be described in this chapter. A general overall view on al the data sets is given in Table 4-1.

Seelig (1980)
Seelig measured wave transmission for a large number of structure cross sections, mostly with monochromatic waves, but also with random waves. He used permeable- as well as impermeable structures. These were the first tests in the CERC flume with random waves. Maybe this is the reason why very large values of the wave steepness were reported, up to *0.10*, which is physically impossible. At a wave steepness of *0.05* to *0.06* the waves will break. These data must be handled with suspicion. The various cross sections tested with random waves have an armour layer consisting of stone with a large nominal diameter (D_{n50}). Figure A1.1 in Annex 1 gives the various cross sections. Table A2.1 in Annex 2 gives the various test data.

Allsop (1983)
The structures tested by Allsop all have large positive values of the crest freeboard. It should be noted that the data points were taken from figures. Figure A1.2 in Annex 1 gives the tested cross section. Table A2.2 in Annex 2 gives the various test data.

Daemrich and Kahle (1985)
The tests of Daemrich and Kahle are tests on a breakwater with an armour layer of Tetrapods. Armour layers of Tetrapods are more permeable than armour layers of rock, which are used in mainly all the other tests. An extremely wide and a normal narrow crest was tested. Figure A1.3 in Annex 1 gives the various cross section. Table A2.3 in Annex 2 gives the various test data. It should be noted that all data points were taken from figures.

Powell and Allsop (1985)
The structures described by Powell and Allsop are homogeneous breakwaters with a very small bulk number. During some investigations on these data it appeared that with given wave height and water depth, severe breaking should have taken place. Therefore the reliability of these data can be questioned. Figure A1.4 in Annex 1 gives the various cross sections. Table A2.4 in Annex 2 gives the various test data.

Van der Meer (1988)
A very extensive investigation on stability of rock slopes and gravel beaches was performed at DELFT HYDRAULICS between 1983 and 1987. A part of the investigation was focused on stability of low-crested breakwaters. Besides, the stability the wave transmission was measured too. Three crest heights were tested, one with the crest well above the water level, one with the crest at the water level and one with the crest well below the water level. Hereby not the water level was changed but three structures with different crest heights were

used. A number of 31 tests with 2 wave periods are available. The cross sections are given in Figure A1.5 in Annex 1, the data in Table A2.5

Daemen (1991)
The tests of Daemen consist of data on low-crested as well as on submerged breakwaters. The breakwater has, just like most of the others, an armour layer and a core; both of rock material. Most tests were performed on a breakwater with an armour layer with a D_{n50} of 0.040 m, a few tests were performed with D_{n50} of 0.061 m. The test concentrated on three parameters: relative crest height (R_c/D_{n50}), relative wave height (H_{mo}/D_{n50}) and fictitious wave steepness (s_{op}). The cross section is given in Figure A1.6, the data in Table A2.6.

DELFT HYDRAULICS report no. H 1872 (1993)
DELFT HYDRAULICS has carried out two dimensional model tests on a breakwater with an armour layer of Tetrapods for a site specific location. During these tests also wave transmission was measured (9 measurements). The crest height was varied by lowering the water depth. Also the wave height and wave period were varied. Figure A1.7 in Annex 1 gives the various cross sections. The test data are presented in Table A2.7a in Annex 2.

DELFT HYDRAULICS report no. H 1872 (1994)
On the same breakwater as mentioned above, three dimensional tests were carried out. During these tests the same parameters as above were varied, but besides this also the direction of wave propagation. This data set contains 30 measurements. The angle of wave attack will be neglected when using these data. The data will be used as if the angle of wave attack is perpendicular to the structure. Figure A1.7 in Annex 1 gives the cross section. Table A2.7b in Annex 2 gives the various test data.

DELFT HYDRAULICS report no. H 2061 (1994)
An investigation on stability of Tetrapods on breakwaters was carried out. During the tests also the wave transmission was measured. The nominal diameter of Tetrapods was varied. Also the wave height, wave period and the crest height were varied during the investigations. Figure A1.8 in Annex 1 gives an example of a cross sections. Table A2.8 in Annex 2 gives the various test data.

DELFT HYDRAULICS report no. M 2090 (1985)
Two dimensional site specific stability tests on a rubble mound breakwater were executed by DELFT HYDRAULICS. During these tests also overtopping and wave transmission were measured. Part of the tests, tests 12 till 18, were performed on a caisson breakwater. Figure A1.9 in Annex 1 gives the various cross sections. Table A2.9 in Annex 2 gives the various test data.

DELFT HYDRAULICS report no. H 2014 (1994)
Wave transmission has been measured for an impermeable smooth submerged breakwater. Figure A1.10 shows the cross section, Table A2.10 gives the test data.

ACCROPODS®
Some wave transmission measurements on a breakwater with an armour layer of Accropods® were performed for a site specific location. The cross section is given in Figure A1.11, the data in Table A2.11.

Test		Hsi or Hmoi m	Rc m	sop -	Kt -	Rc/Hsi m	B m	Dn or Dn50 m	Ir -	Structure	# test
Seelig	bw 1	0.075 - 0.172	0.000 - 0.147	0.007 - 0.056	0.035 - 0.356	0.000 - 1.795	0.300	xxxx	1.630 - 5.756	Impermeable, Conventional	13
	bw 4	0.121 - 0.174	-0.080 - 0.204	0.017 - 0.059	0.071 - 0.543	-0.602 - 1.707	0.400	0.111	1.180 - 2.929	Permeable, Conventional	19
	bw 4w	0.152 - 0.174	-0.184 - -0.100	0.026 - 0.060	0.518 - 0.786	-1.222 - -0.610	0.400	0.111	1.210 - 2.384	Impermeable Core, Conventional	6
	bw 5	0.080 - 0.178	-0.420 - -0.120	0.010 - 0.064	0.652 - 0.922	-4.421 - -0.759	0.400	0.111	2.418 - 6.536	Permeable, Conventional	26
	bw10	0.103 - 0.170	0.090 - 0.210	0.007 - 0.060	0.062 - 0.625	-1.343 - 3.143	0.300	0.161	2.719 - 11.209	Permeable, Conventional	18
Allsop	short	0.049 - 0.173	0.080 - 0.121	0.030 - 0.030	0.070 - 0.380	0.490 - 2.450	0.160	0.040	2.876 - 2.876	Permeable, Conventional	12
	short	0.049 - 0.132	0.154 - 0.154	0.030 - 0.030	0.050 - 0.150	1.170 - 3.150	0.240	0.051	2.876 - 2.876	Permeable, Conventional	5
	long	0.050 - 0.130	0.121 - 0.156	0.007 - 0.080	0.075 - 0.220	0.930 - 3.150	0.160	0.040	5.493 - 8.857	Permeable, Conventional	4
Daemrich and Kahle	Imp	0.024 - 0.212	-0.200 - 0.000	0.006 - 0.026	0.414 - 0.917	-8.000 - 0.000	0.200	xxxx	3.111 - 6.240	Impermeable, Conventional	50
	B = 0.2	0.023 - 0.225	-0.200 - 0.000	0.008 - 0.024	0.361 - 0.897	-8.696 - 0.000	0.200	0.078	3.220 - 5.733	Permeable, Tetrapods, Conventional	51
	B = 1.0	0.023 - 0.218	-0.200 - 0.000	0.008 - 0.025	0.138 - 0.855	-8.333 - 0.000	1.000	0.078	3.158 - 5.797	Impermeable Core, Tetrapods, Conventional	44
Powell and Allsop	2	0.115 - 0.184	-0.141 - 0.079	0.025 - 0.028	0.254 - 0.802	-1.202 - 0.665	3.000	0.076	3.974 - 4.448	Permeable, Conventional	4
	3	0.115 - 0.184	-0.141 - 0.079	0.025 - 0.028	0.327 - 0.864	-1.202 - 0.665	1.500	0.090	3.974 - 4.448	Permeable, Conventional	4
	4	0.115 - 0.184	-0.141 - 0.079	0.025 - 0.028	0.235 - 0.876	-1.202 - 0.665	3.000	0.076	3.974 - 4.448	Permeable, Conventional	4
	5	0.115 - 0.184	-0.186 - 0.033	0.025 - 0.028	0.356 - 0.857	-1.589 - 0.281	4.500	0.076	3.974 - 4.448	Permeable, Conventional	4
	5final	0.143 - 0.243	0.186 - 0.033	0.027 - 0.031	0.433 - 0.851	-1.302 - 0.217	4.500	0.076	3.759 - 4.406	Permeable, Conventional	5
	6	0.115 - 0.184	-0.232 - -0.012	0.025 - 0.028	0.400 - 0.891	-1.977 - -0.075	3.920	0.076	3.974 - 4.448	Permeable, Conventional	4
	7	0.164 - 0.184	-0.277 - -0.058	0.025 - 0.025	0.492 - 0.879	-1.510 - -0.353	3.120	0.076	4.199 - 4.448	Permeable, Conventional	4
	8	0.090 - 0.203	-0.186 - 0.033	0.025 - 0.031	0.302 - 0.980	-2.020 - 0.376	7.000	0.076	3.766 - 4.448	Permeable, Conventional	13
Van der Meer	Rc = -0.09	0.099 - 0.231	-0.095 - -0.087	0.010 - 0.039	0.537 - 0.810	-0.889 - -0.407	0.300	0.034	2.548 - 5.083	Permeable, Crest below water level	11
	Rc = 0.0	0.075 - 0.171	0.000 - 0.014	0.008 - 0.028	0.375 - 0.497	0.000 - 0.171	0.300	0.034	2.970 - 5.772	Permeable, Crest on water level	11
	Rc = 0.125	0.076 - 0.142	0.123 - 0.132	0.008 - 0.024	0.050 - 0.106	0.089 - 1.684	0.300	0.034	3.216 - 5.666	Permeable, Crest above water level	9
Daemen	Dn50 = 0.04	0.032 - 0.148	-0.040 - 0.196	0.010 - 0.042	0.049 - 0.628	-0.652 - 4.027	0.340	0.040	3.260 - 6.628	Permeable, Conventional	48
	Dn50 = 0.061	0.083 - 0.127	-0.057 - -0.010	0.022 - 0.036	0.458 - 0.592	-0.450 - -0.087	0.340	0.061	3.526 - 4.545	Permeable, Conventional	6
H 1872_2d		2.560 - 5.670	3.950 - 6.750	0.021 - 0.320	0.057 - 0.194	0.697 - 1.660	5.000	1.609	3.727 - 4.600	Permeable, Tetrapods, Conventional	9
H1872_3d		3.390 - 6.260	3.950 - 6.750	0.023 - 0.026	0.056 - 0.256	0.631 - 1.301	5.000	1.627	3.074 - 3.275	Permeable, Tetrapods, Conventional	16
		2.340 - 6.000	3.950 - 6.750	0.022 - 0.040	0.059 - 0.283	0.658 - 1.816	5.000	1.696	2.491 - 3.367	Permeable, Tetrapods, Conventional	14
H 2061		0.081 - 0.203	-0.050 - 0.200	0.035 - 0.040	0.027 - 0.607	-1.431 - 5.732	0.200	0.035	3.333 - 3.563	Permeable, Tetrapods, Conventional	11
		0.144 - 0.227	-0.050 - -0.050	0.034 - 0.040	0.572 - 0.604	-0.347 - -0.220	0.200	0.044	3.333 - 3.616	Permeable, Tetrapods, Conventional	5
		0.125 - 0.228	-0.050 - 0.200	0.018 - 0.039	0.038 - 0.601	-0.362 - 1.258	0.200	0.050	3.376 - 4.969	Permeable, Tetrapods, Conventional	16
M 2090		1.380 - 4.200	1.250 - 4.250	0.016 - 0.030	0.036 - 0.321	0.681 - 1.660	8.500	xxxx	xxxxx - xxxxx	Caisson breakwater	7
		0.900 - 4.000	1.000 - 2.000	0.015 - 0.030	0.031 - 0.271	0.500 - 3.390	3.000	0.870	2.704 - 4.273	Permeable, Conventional	32
H 2014		0.144 - 0.206	-0.160 - 0.080	0.021 - 0.041	0.268 - 0.714	-1.000 - 0.412	0.200	xxxx	1.419 - 2.012	Impermeable breakwater	11
Accropods		4.030 - 6.400	3.700 - 5.300	0.023 - 0.029	0.055 - 0.161	0.544 - 1.606	12.74	1.848	4.407 - 5.575	Permeable, Accropode, Conventional	10

Table 4-1 Overall view of data sets

5. ANALYSIS OF DATA

A short description on all data sets used for this investigation has been given in Chapter 4. In this Chapter the influence of parameters like relative crest height, R_c/H_{si} or $(R_c - R_{u2\%})/H_{si}$, fictitious wave steepness (s_{op}) or breaker parameter (ξ), relative crest width (B_c/L_0 or B_c/H_{si}) and permeability will be dealt with.

During the investigation a distinction is made between data on rubble mound breakwaters, breakwaters with an armour layer of concrete elements and impermeable breakwaters.

5.1 MAIN PARAMETER

Figures on wave transmission are often presented as the wave transmission coefficient, K_t, versus a main parameter like crest freeboard divided by the significant wave height, R_c/H_{si} or like 'shortage in crest height' divided by the significant wave height, $(R_c - R_{u2\%})/H_{si}$.

The parameter R_c/H_{si}

It should be investigated whether R_c/H_{si} is a consistent parameter. Does this division give the same result with on one hand constant R_c and variable H_{si} and on the other hand variable R_c and constant H_{si}. This investigation has been performed on all available data together.

Groups of constant crest freeboard were taken and graphs of K_t versus H_{si} were made for constant R_c. These graphs are not shown in this report, only one example is given in Figure 5-1. The conclusions drawn from the graphs are mentioned below.

The conclusions are that within a group of constant positive R_c an increasing H_{si} leads to an increasing K_t. The groups with the lowest R_c gives, for constant H_{si}, the highest K_t. This can also be seen in equations 5.1 and 5.4.

R_c = constant & H_{si} = variable

$$R_c \geq 0: \quad H_{si} \uparrow \rightarrow \frac{R_c}{H_{si}} \downarrow \rightarrow K_t \uparrow \tag{5.1}$$

for vertical lines of constant wave height:

$$R_c \uparrow \rightarrow \frac{R_c}{H_{si}} \uparrow \rightarrow K_t \downarrow \tag{5.2}$$

$$R_c < 0: \quad H_{si} \uparrow \rightarrow \frac{R_c}{H_{si}} \uparrow \; (less\ negative) \rightarrow K_t \downarrow \tag{5.3}$$

for vertical lines of constant wave height:

$$R_c \downarrow (more\ negative) \rightarrow \frac{R_c}{H_{si}} \downarrow \rightarrow K_t \uparrow \tag{5.4}$$

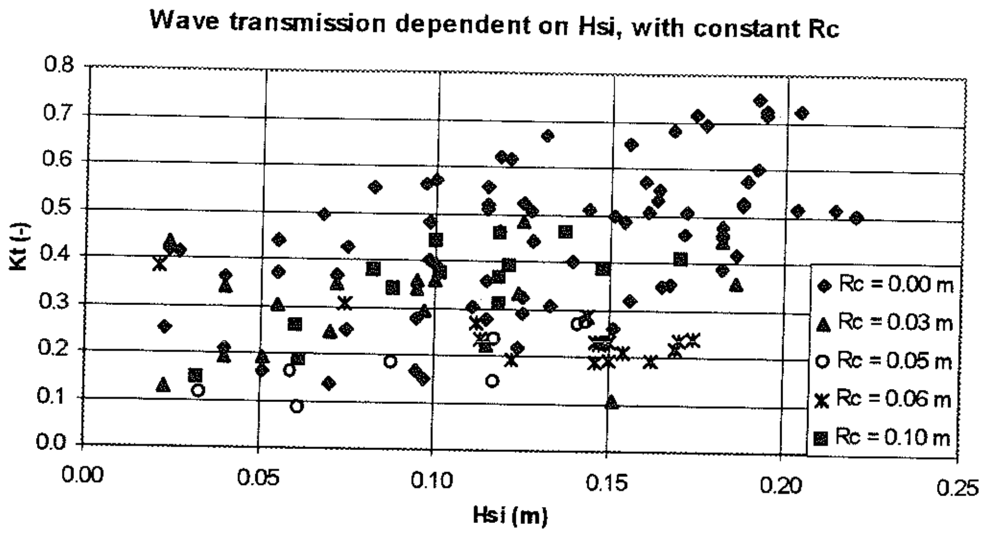

Figure 5-1 Chart used to derive equations 5.1 and 5.2

Also groups of constant H_{si} were made and graphs of K_t versus R_c were investigated. Conclusions drawn from these graphs are shown in equations 5.5 till 5.8.

R_c = variable & H_{si} = constant

$$R_c \geq 0: \quad R_c \uparrow \rightarrow \frac{R_c}{H_{si}} \uparrow \rightarrow K_t \downarrow \tag{5.5}$$

for vertical lines of constant crest height:

$$H_{si} \uparrow \rightarrow \frac{R_c}{H_{si}} \downarrow \rightarrow K_t \uparrow \tag{5.6}$$

$$R_c < 0: \quad R_c \uparrow \rightarrow \frac{R_c}{H_{si}} \uparrow (less\ negative) \rightarrow K_t \downarrow \tag{5.7}$$

for vertical lines of constant crest height:

$$H_{si} \uparrow \rightarrow \frac{R_c}{H_{si}} \uparrow (less\ negative) \rightarrow K_t \downarrow \tag{5.8}$$

As can be seen from eq. 5.2 and 5.5 a more positive relative crest freeboard will lead to a decrease in wave transmission. From eq. 5.1 and 5.6 it is seen that a less positive relative crest height leads to an increase of transmission. Eq. 5.3 and 5.7 also show the same trend: a less negative relative crest freeboard leads to a decrease in transmission. And last eq. 5.4 and 5.8 are also consistent. A more negative relative crest freeboard will lead to an increase of transmission.

So from this short investigation it can be concluded that the parameter R_c/H_{si}, is a consistent parameter and therefore a good parameter to describe wave transmission. In Annex 3 three figures are given to show the scatter when wave transmission is given versus this relative crest freeboard. Figure A3.1 gives wave transmission for rubble mound breakwaters, Figure A3.2 for breakwaters with an armour layer of concrete elements and Figure A3.3 gives wave transmission for impermeable breakwaters.

The parameter $(R_c - R_{u2\%})/H_{si}$
By taking into account the potential wave run-up level, a parameter which describes the 'shortage in crest height' can be constructed, see also paragraph 3.1 and equation 3.2. Many formulae are available to describe wave run-up. Two different formulae for wave run-up, namely eq. 2.9 and 2.10, were used to determine whether taking into account the wave run-up is a good way for predicting wave transmission.

The first, eq. 2.9, is a formula which can only be used for rubble mound breakwaters and for slopes with $cot\ \alpha \leq 2$. The second formula is one which has been derived for dikes and revetments. So neither one of the two formulae can be used on all the data. Yet, this has been done.

Figure A3.4 gives a graph on K_t versus $(R_c - R_{u2\%})/H_{si}$, in which formula 2.9 has been used for the wave run-up. As can be seen from this figure there is not much change in the scatter in comparison with for example Figure A3.1. So this parameter is not a better one than R_c/H_{si}. Another disadvantage is that the formula uses the potential run-up for all structures, low-crested as well as submerged, although wave run-up present at submerged structures is irrelevant.

5.2 WAVE STEEPNESS OR BREAKER PARAMETER

Daemen (1991) found that lines of constant, but different, fictitious wave steepness are parallel to each other and that a higher fictitious wave steepness in general gives a lower wave transmission. He also concluded that the slope angle has hardly any influence on wave transmission. Nevertheless, all formulae on wave run-up and overtopping do make use of the breaker parameter, ξ, in which the slope angle as well as the fictitious wave steepness are taken into account, see eq. 2.2. So it will be investigated whether ξ is a good parameter to describe wave transmission.

On all the data the influence of s_{op} and ξ has been investigated. The same conclusions as Daemen (1991) had drawn, can be drawn from this investigation. Lines of constant fictitious wave steepness are lying parallel and a higher s_{op} will lead to a lower K_t. Similarly trend is found for figures with constant ξ. A higher s_{op} and therefore a lower ξ gives a lower K_t. Figures A3.5 to A3.7 show part of the results.

Since it can not directly be said which of the two parameters is best to describe the influence of the wave period, both parameters will be used separately.

5.3 RELATIVE WAVE HEIGHT

Daemen (1991) used the parameter H_{si}/D_{n50} to give an indication of the permeability of the armour layer. He found that within a group of constant fictitious wave steepness lines of constant relative wave height are lying rotated to each other. In other words lines of lower H_{si}/D_{n50} are steeper than lines of higher H_{si}/D_{n50}. It should be noted that Daemen used another parameter for relative crest freeboard than the author does during this present study, namely R_c/D_{n50}, instead of R_c/H_{si}.

For all the data sets available the influence of the relative wave height H_{si}/D_{n50} within groups of constant s_{op} or constant ξ has been investigated. Again not all results are shown but only the results on the data of Daemen and Van der Meer, see Figures A3.8 and A3.9. General trend in all the figures is that a higher relative wave height gives a higher transmission. This is true for the whole range of R_c/H_{si}. So the lines are not lying rotated to each other as was concluded by Daemen, but are lying parallel.

This difference can be explained as follows: Daemen found that for constant positive R_c/D_{n50} a higher H_{si}/D_{n50} gives more transmission. However, not R_c/D_{n50} but R_c/H_{si} is used in the present study. A constant and positive relative crest freeboard (R_c/D_{n50}) and an increasing relative wave height, means a lower R_c/H_{si} and will therefore lead to a higher wave transmission.

A constant and negative relative crest freeboard (R_c/D_{n50}) and an increasing relative wave height, means a higher R_c/H_{si} (less negative) and will therefore lead to a lower wave transmission. So due to the use of the different parameters for relative crest freeboard, Daemen found rotating lines and this present study finds parallel lines.

An explanation for the phenomenon that an increasing relative wave height gives more transmission, can be that an increasing wave height leads to a higher wave run-up and therefore to more overtopping. This is true for low-crested structures. For submerged structures the explanation is as follows: An increase of wave height means, for constant wave steepness, a larger wave length. The longer the wave length the higher the wave transmission will be.

5.4 RELATIVE CREST WIDTH

For groups of constant fictitious wave steepness the influence of the relative crest width, B_c/L_0 has been investigated. From this investigation it can be concluded that an increasing relative crest width leads to a decrease in wave transmission. This is logical because if the crest width increases the length of the way for the wave to overtop the structure increases and therefore the overtopping rate decreases.

Another way of taking the crest width into account is by dividing it by the incident wave height, B_c/H_{si}. For this parameter the same conclusions can be drawn as for the other dimensionless crest width. Figures A3.10 and A3.11 in Annex 3 show the results for the data of Daemen and the data of Van der Meer.

5.5 DISCARDED DATA

In order to predict wave transmission with high accuracy some physical limitations were taken into account.

All the data with $s_{op} > 0.06$, -waves will break if the wave steepness is higher-, will be neglected from now on. Also data which exceed the limit of $H_s/h = 0.54$ will be neglected. This depth limit will also force the waves to break. And lastly, data with $R_c / H_{si} > 2.5$ or $-2.5 < R_c / H_{si}$ will also be neglected. Both boundaries were taken because outside this boundaries there is hardly any change in wave transmission and therefore it is beyond the scope of this work.

During the research the data sets were not only investigated separately, but also together. So all data with the same wave steepness, relative wave height and relative crest width were investigated.

It appears that some data sets show different trends than the other, while the parameters involved had the same values. These data sets were: Seelig bw5 & bw10, Allsop and Powell & Allsop. The first two data sets of Seelig contain data with very low relative wave height and very high fictitious wave steepness. Daemen (1991) had already made some remarks on these data sets. He concluded that Seelig probably used a deviating definition for the crest height and it is very important to know what this definition was. The same problem also occurs with the data of Allsop (1983) and Powell & Allsop (1985). Also for these data sets Daemen (1991) concluded that probably a different definition of the crest height has been used. As can be seen in Figure A3.1 both data show transmission coefficients which form the upper boundary of the global trend.

6. DERIVATION OF NEW FORMULA

Since most of the available data are regarding rubble mound breakwaters and breakwaters with an armour layer of Tetrapods, the basic formula will be derived for these data sets together. Adaptations will be made for other data sets on impermeable breakwaters.

6.1 BASIC FORMULA

As can be seen from Figure A3.1, which shows the wave transmission coefficient, K_t, versus the relative crest freeboard, R_c/H_{si}, the transmission coefficient first stays low for high values of R_c/H_{si}, then increases in the area of $-1 < R_c/H_{si} < +1$ and finally stays high. Theoretically the increase of the wave transmission coefficient will be a curve with a smooth course from 0 to 1. To arrive at a simple description of wave transmission, the curve will assumed to be a linear decreasing line in the area of about $-1 < R_c/H_{si} < +1$. The wave transmission coefficient may then be described by:

$$K_t = a\frac{R_c}{H_{si}} + b \qquad (6.1)$$

in which a determines the slope of the line
b is the value of K_t at $R_c/H_{si} = 0$

As already mentioned in Chapter 5, there is not a parameter which clearly shows influence on the slope of the line. The following approach is followed to derive the formula: all data on rubble mound breakwaters and breakwaters with an armour layer of concrete elements, Tetrapods, with $R_c/H_{si} = 0$ are taken and investigated on the influence of relative crest width, relative wave height and fictitious wave steepness or breaker parameter. After having determined the influence of above mentioned parameters, all data with other values of R_c/H_{si} than zero will be taken into account. With the found formula for b the influence of any parameter on the slope angle, a, will be determined.

Parameter b

For data with $R_c/H_{si} = 0$ it is investigated which of above mentioned parameters is most important, in other words: which parameter shows the best trend. As can be seen from Figures A4.1 till A4.5 in Annex 4 the most promising result is obtained when K_t versus a relative crest width (B/L_0 or B/H_{si}) is considered. *It should be noted that in all the Figures the source of the data and the fictitious wave steepness, s_{op}, are given in the legend.*

Both Figures A4.4 and A4.5 show that for small values of relative crest width, a slight increase in relative crest width leads to substantial decrease in wave transmission. A function describing this relation: enormous decrease for small change in the values of relative crest width and reaching to zero for values of the relative crest width going to infinite, can very well be described by a power function.

Disadvantage however, is that for values of relative crest width going to zero the outcome of K_t will go to infinite. So a maximum value should be taken into account, which is proposed at a value of 1. Moreover, since the influence of other parameters will probably act like reduction factors, it should not give a serious problem.

The proposed function to describe the influence of the relative crest width B/L_0 is:

$$K_t = 0.147\left(\frac{B}{L_0}\right)^{-0.33} \tag{6.2}$$

For the influence of the relative crest width B/H_{si} the proposed function is:

$$K_t = 0.54\left(\frac{B}{H_{si}}\right)^{-0.31} \tag{6.3}$$

It can not directly be said which of the two parameters for the relative crest width describes wave transmission in the best way. Which of the two functions is best depends on the non-dimensional parameters used hereafter.

From now on the influence of B/L_0 is called B_1 and the influence of B/H_{si} is called B_2. To investigate what the influence of the remaining parameters is the following action has been taken: the coefficients 0.147 and 0.54 are neglected and assumed to be a function of either s_{op} or ξ or H_{si}/D_{n50}. These functions are called C_1 respectively C_2:

$$C_1 = \frac{K_t}{\left(\frac{B}{L_0}\right)^{-0.33}} \tag{6.4}$$

$$C_2 = \frac{K_t}{\left(\frac{B}{H_{si}}\right)^{-0.31}} \tag{6.5}$$

Figures A4.6 till A4.8 show the results for known influence of B/L_0, so for C_1, Figures A4.9 till A4.11 show the results for C_2. As was already concluded in section 5.2 an increase in wave steepness should give a decrease in wave transmission and therefore in coefficient C_1. This is not very clear in Figure A4.6. An explanation could be that the influence of the wave period, thus the wave steepness, has already been taken into account by L_0 in the division B/L_0. On the other hand Figure A4.9 does show this tendency, decrease in transmission coefficient for an increase of the wave steepness, in a better way. Therefore not B/L_0, but B/H_{si} is chosen to describe the influence of the crest width.

Since wave run-up and wave overtopping are always given dependent on the breaker parameter, this parameter has also been chosen to describe the influence of the slope angle, but especially the wave period. Figure A4.10 shows the results with the proposed function. This function is:

$$C_2 = 0.64\left(1 - e^{-0.5\xi}\right) \tag{6.6}$$

For a value of ξ going to zero the slope of the structure will be very flat and, as can be seen from Figure 2.5, hardly any wave run-up will take place, thus wave transmission will go to zero. So therefore the coefficient C_2 will have a value of zero for ξ is zero. Figure 2.5 also shows that for infinite values ξ of the wave run-up has reached a maximum. The proposed maximum for the function describing C_2 is *0.64*. This value will later on be checked when all the data, on the whole range of R_c/H_{si}, is considered.

There is one parameter left, from which the influence has not been described yet, namely the relative wave height, H_{si}/D_{n50}. The value *0.64* will be tried to be replaced by a function of H_{si}/D_{n50}. This function is called D_2:

$$D_2 = \frac{K_t}{\left(\frac{B}{H_{si}}\right)^{-0.31}\left(1 - e^{-0.5\xi}\right)} \tag{6.7}$$

Figure A4.12 shows this D_2 versus H_{si}/D_{n50}. It is very difficult to see any influence of this relative wave height. Therefore it is assumed that the relative wave height has no influence on wave transmission and that, for the time being, the value *0.64* in equation 6.6 should be used.

The proposed function for the parameter *b* is given by:

$$b = \left(\frac{B}{H_{si}}\right)^{-0.31} * \left(1 - e^{-0.5\xi}\right) * 0.64 \tag{6.8}$$

Figure A4.13 shows the results of the calculated wave transmission, according to equation 6.8, versus the measured transmission. As can be seen there is still some scatter, but in general the calculated transmission coefficient is very well in accordance with the measured transmission coefficient.

Parameter *a*

The next step in the derivation of the new transmission formula, should be to find a value or a function for the parameter *a*, which determines the slope angle. This is done by using the influence of parameter *b*, described by equation 6.8.

The following function can be obtained for parameter a:

$$a = \frac{K_t - b}{\frac{R_c}{H_{si}}} \tag{6.9}$$

In Figure A4.14 this function a is plotted against the relative wave height. The scatter is so large that it is not possible to assume any relationship. This is also true for other parameters, like relative crest width and breaker parameter. The results of these plots are not given. An average value of -0.4 has been taken for the parameter a. The formula for wave transmission now becomes:

$$K_t = -0.4\frac{R_c}{H_{si}} + \left(\frac{B}{H_{si}}\right)^{-0.31} * \left(1 - e^{-0.5\xi}\right) * 0.64 \tag{6.10}$$

With this known relation it is again tried to find a function of H_{si}/D_{n50} instead of the constant 0.64 in equation 6.10. This is done by using the following relation:

$$D = \frac{K_t + 0.4\frac{R_c}{H_{si}}}{\left(\frac{B}{H_{si}}\right)^{-0.31}\left(1 - e^{-0.5\xi}\right)} \tag{6.11}$$

Figure A4.15 shows this D versus H_{si}/D_{n50}. It can be seen that for $H_{si}/D_{n50} > 3.0$ a constant value of 0.64 for D is reached.

For high, positive, values of R_c/H_{si} a decreasing H_{si}/D_{n50} leads to an increasing value of D. Physically this can be explained as follows: a decreasing relative wave height means an increasing porosity and therefore permeability. For negative values of R_c/H_{si} the opposite occurs: a decreasing relative wave height leads to a decreasing value of D. The phenomenon is physically to be explained as follows: a decreasing relative wave height, which means an increasing D_{n50}, leads to a rougher crest of the structure, which leads to a decreasing K_t.

Two graphs, which are not shown in this report, of measured versus calculated wave transmission coefficient were created. One with a constant value of 0.64 instead of a function dependent on H_{si}/D_{n50} and one with the above mentioned functions. The only difference occurs for the extreme values of K_t, which also corresponds to the extreme values of R_c/H_{si}. For a high value of K_t the function with 0.64 gives much higher values of wave transmission (which are far too high), for low values of K_t, the function with 0.64 gives much lower values of K_t (which are far too low).

So what happens is that Figure A4.15 does not give the influence of H_{si}/D_{n50}, but gives the correction term between measured and calculated wave transmission coefficient.

It is to be concluded that the exact influence of H_{si}/D_{n50}, which is physically to be expected, can not be determined in this way. Therefore, in this report, a constant correction value of 0.64 has to be taken into account.

Finally a plot is made of a calculated K_t, using equation 6.10, versus the measured K_t. This is shown in Figure A4.16

6.2 IMPERMEABLE BREAKWATERS

Three data sets are available on breakwaters with an impermeable armour layer. These data sets are: H2014, Seelig bw1, Daemrich and Kahle Impermeable, see also Figure A3.3. The same procedure as described in section 6.1 will be followed to derive a formula for wave transmission at impermeable breakwaters.

Figure A4.17 shows data with $R_c/H_{si} = 0$. The line drawn in the Figure gives the relation between the relative crest width, B/H_{si} and the wave transmission coefficient, K_t, according to equation 6.3. It is assumed that the influence of the crest width is the same order of magnitude for impermeable as for rubble mound breakwaters. As can be seen there is a lot of scatter, for which no reasonable explanation could be found.

The influence of the breaker parameter, ξ, has been derived using equation 6.5. Doing so the following relation between ξ and C has been found:

$$C = 0.8 \cdot \left(1 - e^{-0.5\xi}\right) \tag{6.12}$$

This is also shown in Figure A4.18. Only the data from Seelig bw1 are not in accordance with the general trend. The main difference between Seelig bw1 and the other data sets is that this data set contains relative high wave heights and short wave periods, which leads to a high wave steepness ($s_{op} \cong 0.05$). As already described in section 3.3 a high wave steepness will lead to a low wave transmission coefficient. Also this high wave steepness can force the waves to break. Because of this breaking the significant wave height should probably be lower than the given H_{si}. So with a lower H_{si} the calculated transmission would be better in accordance with the measured one.

The coefficient b in equation 6.1 now becomes:

$$b = \left(\frac{B}{H_{si}}\right)^{-0.31} * \left(1 - e^{-0.5\xi}\right) * 0.80 \tag{6.13}$$

Since no information is available on the roughness of the slope, there are no other parameters left to include in the transmission formula, apart from the relative crest freeboard. The results of the formula 6.13 are given in Figure A4.19. Only the data of Seelig bw1 are clearly deviating from the calculated K_t. It should be noted that Seelig himself mentions problems with the same points, $R_c/H_{si} = 0$, see Seelig (1980).

It is assumed that the slope angle, a, has the same value as has been derived in equation 6.9, namely *-0.40*. This can also be verified in Figure A3.3. The formula predicting the wave transmission coefficient for impermeable structures now becomes:

$$K_t = -0.4\frac{R_c}{H_{si}} + \left(\frac{B}{H_{si}}\right)^{-0.31} * \left(1 - e^{-0.5\xi}\right) * 0.80 \tag{6.14}$$

This has also been shown in Figure A4.20. As can be seen again, only the data of Seelig bw1, for which the relative crest freeboard is zero, do not fit in.

It should be noted that the maximum value, *0.80* and the minimum value, *0.075*, of the predicted K_t, are only chosen for the time being. The values are chosen based on the averages of the maximum and minimum values of K_t, which are shown in Figures A3.1 till A3.3. A more founded derivation of these values for the maximum and minimum wave transmission will be given in section 6.3.

6.3 MAXIMUM AND MINIMUM

The derived formulae stand for decreasing lines in graphs of K_t versus R_c/H_{si}. The formulae can produce values of K_t which are higher than *1*, for high negative values of R_c/H_{si} and values lower than *0* for high positive values of R_c/H_{si}. As this is physically incorrect and hence not in accordance with the test data, the formulae should be restricted. This can be done in two ways: horizontal or vertical.

The vertical method means that for fixed values of $+ R_c/H_{si}$ and $- R_c/H_{si}$ the minimum respectively the maximum of the wave transmission coefficient is reached. Van der Meer (1990) has used this vertical manner of restricting K_t. The following boundaries were used by Van der Meer (1990):

$$\begin{aligned} &Maximum \quad K_t = 0.80 \quad for\ \frac{R_c}{H_{si}} < -1.1 \\ &Minimum \quad K_t = 0.10 \quad for\ \frac{R_c}{H_{si}} > +1.2 \end{aligned} \tag{6.15a, b}$$

A problem using this method on the new derived formulae is that there will be discontinuities at the boundaries taken for the two horizontal parts of the function. Furthermore this restriction does not safeguard a wave transmission coefficient between *0* and *1*.

The horizontal restriction can be obtained in two manners. The first is to use fixed values for all structures, as has been done by Daemen (1991), the second is to find a value for the maximum and minimum as a function of one or more parameters. Daemen used fixed values of the maximum and minimum independent of any parameter.

These values are:

$$\begin{array}{ll} Maximum & K_t = 0.75 \\ Minimum & K_t = 0.075 \end{array} \qquad (6.16a, b)$$

In this investigation it is tried to give horizontal boundaries dependent on one or more parameters. This is done to achieve that discontinuities will not exist. Figure A4.21 shows K_t versus the relative crest freeboard, R_c/H_{si}, for groups of constant relative crest width, B/H_{si}. The same has been done for groups of constant breaker parameter, ξ, see Figure A4.22. Both parameters do not show a consistent trend in minimum wave transmission. Figure A4.23 shows the same data but now in groups of constant fictitious wave steepness, s_{op}. In Figure A4.24 the data has been sorted by groups of constant relative wave height, H_{si}/D_{n50}. Also in this Figures it is hard to find consistent trends. Therefore it has been chosen to give a constant minimum value to the wave transmission formula 6.10. This minimum value, which is the average of all the minimum values, is:

$$Minimum \quad K_t = 0.075 \qquad (6.17)$$

For the maximum value of K_t, also the average has been taken. This leads to:

$$Maximum \quad K_t = 0.80 \qquad (6.18)$$

This minimum and maximum values are valid for both rubble mound as well as for impermeable breakwaters. This can also be seen in Figures A3.1 till A3.3.

6.4 RELIABILITY OF THE FORMULAE

The derived formulae are, of course, only valid within the range of the maximum and minimum values of the parameters used to derive the formulae. For Rubble Mound breakwaters and for breakwaters with an armour layer of concrete elements these boundaries are:

$$1.57 < \xi < 6.63$$
$$0.75 < B/H_{si} < 43.50$$

For impermeable breakwaters the following range is applicable:

$$1.42 < \xi < 8.23$$
$$0.94 < B/H_{si} < 8.33$$

To allow for some information regarding the reliability of the derived formulae, the standard deviation of the difference between measured and calculated wave transmission should be known. This standard deviation has been derived as follows. It is assumed that the scatter around the line $K_{t\_measured} = K_{t\_calculated}$ can be described using a Normal-distribution. Now lines of constant difference between the measured and the calculated K_t are drawn, for example ± 0.02 or ± 0.05. Then the percentage of points within these boundaries can be counted. Lines has been drawn in steps of ± 0.01 until all points were within the boundaries. Using a two-sided truncated Normal distribution function with mean, μ, is 0 and a standard deviation, σ, of 1, see Figure 6-1, one can calculate the standard deviation for each boundary. In this way many standard deviations are obtained. The table for the two-sided truncated Normal distribution is given in Table A5.1 in Annex 5. For the standard deviation of the calculated K_t, $\sigma(K_{t\_calculated})$, the average of all the obtained standard deviations per boundary width is taken.

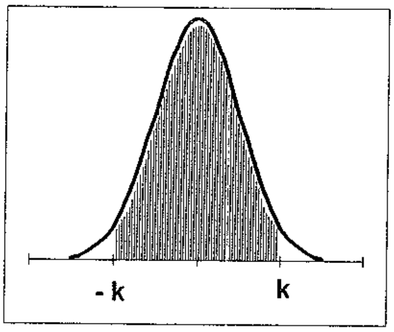

Figure 6-1 Normal distribution N(0,1)

$P(x < boundary) = \%\ within\ boundary$

k can be obtained from the table for a two-sided truncated Normal distribution, by reading the value for the specific probability. With this k the standard deviation for this specific boundary, e.g. 0.01, is calculated using equation 6.19.

$$\sigma\ (boundary = 0.01) = \frac{0.01}{k(boundary = 0.01)} \tag{6.19}$$

An example, in which the standard deviation for the wave transmission formula for impermeable breakwaters (eq. 6.14) has been calculated, is given below in Table 6-1. It should be noted that this Table is derived for data of H2014 and DaKa Imp.

Boundary width	% within boundary	k	St.Dev. σ
0.01	0.1569	0.2	0.050
0.02	0.2941	0.38	0.053
0.03	0.4706	0.63	0.048
0.04	0.6275	0.89	0.045
0.05	0.6471	0.93	0.054
0.06	0.6863	1.01	0.059
0.07	0.7451	1.14	0.061
0.08	0.8039	1.29	0.062
0.09	0.9020	1.655	0.054
0.10	0.9608	2.06	0.049
0.11	0.9804	2.335	0.047
0.12	0.9804	2.335	0.051
0.13	0.9804	2.335	0.056
		Average	**0.053**

Table 6-1 Derivation of standard deviation for eq. 6.13

With this calculated average value of the standard deviation one can obtain the confidence levels of the formula as follows. For the $90\ \%$ confidence levels a value of 1.64 for k is obtained from Table A5.1. The 90% confidence level is now given by $K_t \pm 1.64*0.053$, or $K_t \pm 0.087$. It should be noted that the calculated standard deviation is based on only *53* data points.

The standard deviation for all data on impermeable inclusive Seelig bw1 is *0.072*. If also data of the caisson breakwater from M2090 is taken into account the standard deviation becomes *0.087*.

The same as described above has been done for equation 6.10. The data which were used to obtain the standard deviation were: H1872, H1974, H2061, M2090, Daemen, DaKa 0.2, DaKa 1.0 and Van der Meer. These data sets contain together *313* data points. The standard deviation is *0.060*, which leads to a *90 %* confidence level of $K_t \pm 0.10$. Both the *90 %* confidence level on equation 6.10 and 6.14 are shown in Figure A4.25 respectively A4.26.

At first sight the scatter in the predicted wave transmission coefficient seems large. However, there are a few reasons for this scatter:

- the data are obtained from various sources. This means that different definitions can have been used. Another factot is that when the same test is performed twice in the same flume, different values for K_t will be measured. This is certainly an issue when one performs the same tests at different wave flumes. So the input data already contains some scatter;
- the accuracy of measuring wave height, wave period and structure height;
- curve fitting;
- not all properties of the breakwater have been taken into account.

6.5 DISCARDED DATA SETS

As was already mentioned in section 5.5 the data of Allsop (1983), Powell & Allsop (1985) and Seelig bw5 & bw10 (1980) did not fit in the general trends. However, for all these data equation 6.10 has been used to predict the wave transmission.

For the data of Seelig the results are shown in Figure A4.27. As can be seen the predicted value for bw10 is consequently higher than the measured one. Daemen (1991) obtained the same result. No satisfying explanation has been found. Perhaps a different crest level has been used. For Seelig bw5 the result is better, however, these are of no use, because only large negative values of the relative crest freeboard had been used.

The results on the data of Powell & Allsop, see Figure A4.28, also show a lot of scatter. It should be noted that the breakwaters tested by Powell & Allsop are homogeneous. Daemen (1991) has predicted the K_t by using an adapted formula derived for reeftype breakwaters. However, still without satisfying result. So one can have some doubts about the reliability of this data set.

The result on the data of Allsop is shown in Figure A4.29. At first sight they seem to fit in quite well. However, there is a trend which shows that the difference between the calculated and the measured K_t becomes larger for higher values of K_t. The same trend was already seen in Figure A3.1, which showed that these data sets still had large values of K_t for high values of R_c/H_{si}.

Finally in Figure A4.30 the results for the caisson breakwater of M2090 are shown. What can be seen is that the formula consequently over estimates K_t. A reason for this can be that the conditions for a vertical wall, $\xi = \infty$ and formula 6.12 has reached a constant value of 0.80. However at vertical walls there is much more wave reflection than for a quite steep slope, e.g. $\cot\alpha = 1.5$. Therefore the wave transmission should be lower (energy balance). So the function describing the influence of ξ should probably have a smooth declining slope for high values of ξ, instead of a constant value. From tests performed by Goda (1969) the same trend can be seen, see Figure 6-2. This Figure shows tests of a caisson type breakwater with crest widths of 0.40 m respectively 0.009 m. Both lines reach a maximum value for increasing local wave steepness. When first the influence of the relative crest width according to eq. 6.3 is taken into account, it is to be seen that the influence of the breaker parameter should be lower than the value indicated by eq. 6.12. So both data of M2090-Caisson and Goda give the indication that for infinite values of the breaker parameter its influence is not well described by eq. 6.12. More data on caisson breakwaters are needed to allow for a good prediction of wave transmission.

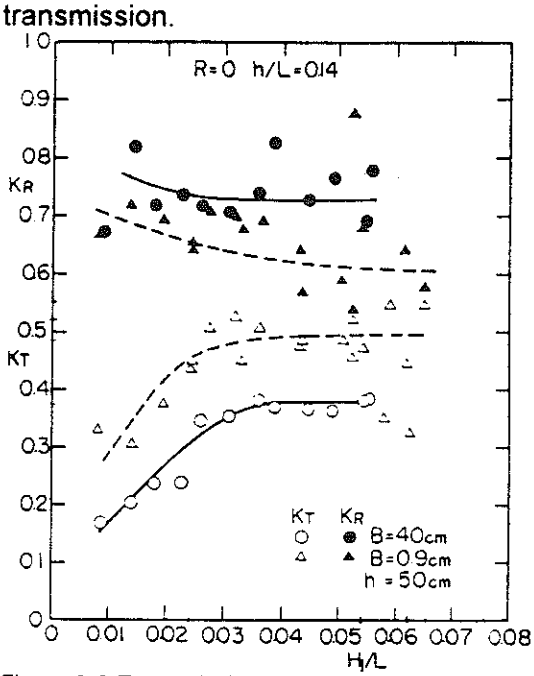

Figure 6-2 Transmission and reflection for caisson breakwater with R_c/H_{si} = 0.

A last remark is made on the data of H1872. When Figures A3.2 and A4.25 are compared it can be seen that almost the same scatter is present at both figures. A reason for this might be that this breakwater is one with a very wide and high berm. So the waves are forced to break on it. Therefore the significant wave height, needed for the prediction of K_t, should result in slightly lower values than given for the toe of the structure.

7. CONCLUSIONS AND RECOMMENDATIONS

In this Chapter the conclusions and recommendations, which can be drawn from the study on wave transmission, are mentioned.

7.1 CONCLUSIONS

- During the investigation it became clear that the following parameters describe wave transmission at low-crested structures satisfactory:

  - crest freeboard R_c
  - wave height H_s or H_{m0}
  - wave peak period T_p
  - crest width B
  - slope angle of front face α

- To enable to comparison of varyious structures it is necessary to use dimensionless parameters. The significant incident wave height was found to be a good parameter to obtain a dimensionless crest freeboard. This wave height has also been used to obtain a dimensionless crest width. Also the deep water wave length has been tested for this purpose, but than the influence of the wave steepness on the transmission coefficient was not clear anymore. The influence of the wave period is very well described by the fictitious wave steepness. Just like in formulae for the prediction of wave run-up and overtopping the influence of the slope angle and the fictitious wave steepness are very well described by the breaker parameter. The governing dimensionless parameters are:

  - relative crest height $\dfrac{R_c}{H_{si}}$
  - relative crest width $\dfrac{B}{H_{si}}$
  - breaker parameter $\xi = \dfrac{\tan\alpha}{\sqrt{s_{op}}}$

- Lines of constant fictitious wave steepness are parallel to each other, a higher wave steepness results in a lower transmission coefficient. A steeper slope causes more wave run-up and therefore more wave transmission. A larger relative crest width leads to a longer way for waves to overtop the structure and will therefore lead to a lower wave transmission coefficient. Lines of constant relative wave height are also parallel to each other. A higher relative wave height will result in more transmission.

- The wave transmission coefficient can, in general, be given by:

$$K_t = a\frac{R_c}{H_{si}} + b \tag{6.1}$$

in which a determines the slope angle of the curve and appears to be independent of any parameter
b determines the value of K_t at a relative crest height of zero, and appears to be a function of the relative crest width and the breaker parameter

- A distinction in the derivation of the new formulae was made between permeable- and impermeable smooth structures. The difference in behaviour can be described satisfactory by a slightly different function for the influence of the breaker parameter.

for permeable structures the formula predicting K_t is found to be:

$$K_t = -0.4\frac{R_c}{H_{si}} + \left(\frac{B}{H_{si}}\right)^{-0.31} * \left(1 - e^{-0.5\xi}\right) * 0.64 \tag{6.10}$$

for impermeable structures the formula is:

$$K_t = -0.4\frac{R_c}{H_{si}} + \left(\frac{B}{H_{si}}\right)^{-0.31} * \left(1 - e^{-0.5\xi}\right) * 0.80 \tag{6.13}$$

- After taking into account the influence of the relative crest width and the breaker parameter, no influence of the relative wave height, H_{si}/D_{n50}, could be found. Daemen (1991) did find much influence of this parameter. The reason for this is that he used another dimensionless parameter for the relative crest height, namely R_c/D_{n50}. That is why he found much influence from H_{si}/D_{n50}, as this is the only way the influence of the wave height was regarded. Not the influence of the division H_{si}/D_{n50} was therefore most important but the influence of the wave height itself. The multiple use of H_{si} to create dimensionless parameters, makes it difficult to find the influence of a parameter like H_{si}/D_{n50}. Another reason for not finding the influence of H_{si}/D_{n50} is that each time a relation between the transmission coefficient and a certain parameter is obtained, some scatter between the proposed function and the data points is accepted. After taking into account R_c/H_{si}, B/H_{si} and ξ as parameter which have influence on K_t, the scatter is too large to find a relation for H_{si}/D_{n50}.

- The minimum and maximum values for the calculated transmission are set on fixed values of 0.075 respectively 0.80. These values are obtained by taking the averages of all minimum and maximum values ($R_c/H_{si} > 1$ respectively $-1 < R_c/H_{si}$). However, it is clear that for high positive values of R_c/H_{si} and for high negative values of R_c/H_{si} the transmission coefficient will decrease respectively increase further to 0

respectively *1*. During this study it has been tried to find one or more parameters which might have significant influence on the minimum value of K_t. Physically this is to be expected. However, there was too much scatter to draw conclusions from the available data.

- The reliability of the derived formulae depends on the scatter in the data used to derive the formula. (The same test will give different values for K_t when performed in different wave flumes.) The standard deviation, σ, of the scatter around the line $K_{t\_calculated} = K_{t\_measured}$ is a criterion for the reliability of the formulae. The scatter has been described by a Normal distribution with an average of zero and a certain standard deviation. The number of points used to derive this standard deviation effects the value of σ.

  For permeable structures a σ of 0.060 is obtained, this was based on 313 points. A *90 %* confidence level of $K_t \pm 0.10$ can be obtained in this way.

  For impermeable structures a σ of 0.053, based on 53 points, is obtained, which means a *90 %* confidence level of $K_t \pm 0.087$

- The given *90 %* confidence levels are, of course, only valid for the tested boundaries of the parameters involved. For equation 6.10 these boundaries are:

  $1.57 < \xi < 6.63$
  $0.75 < B/H_{si} < 43.50$

  For equation 6.13 the boundaries are:

  $1.42 < \xi < 8.23$
  $0.94 < B/H_{si} < 8.33$

- The influence of the breaker parameter for (impermeable) caisson breakwaters is not well described by the proposed formula (eq. 6.12). A slightly declining slope for values of ξ going to infinite should be used and not the proposed constant values of *0.80*.

7.2 Recommendations

- As already mentioned in section 6.4 the data used for this investigation are not all very reliable and do show some scatter for the equal input values. To come to a better transmission formula than derived in this report it is useful to obtain new data, from which it is safeguarded that they are all reliable and that the same definition for the crest height is used. So one large investigation in one wave flume is necessary. During these tests the slope angle should be varied between a smooth slope ($\cot\alpha = 3.5$) and a vertical wall. Various armour layers should be tested: from permeable rock armour to more permeable armour layers of Tetrapods, Accropods or even Cubes. Also impermeable slopes should be investigated more thoroughly. Especially the roughness of the slope of an impermeable armour layer, e.g. asphalt, should be varied. The influence of the relative wave height should than become clear. Together with a well considered variation of the hydraulic parameters, wave height and wave period, one should be able to derive a better wave transmission formula, which is applicable in a wider range.

- New tests should be performed on a rather large model scale. The influence of the permeability of the armour layer and the core may then be modelled in a more proper way.

- New investigations should mainly concentrate on finding functions for the proposed constants: *-0.40*, *0.64* and *0.80*.

PART B

Stability of Tetrapods at front, crest and rear of a low-crested breakwater

8. DESCRIPTION OF PARAMETERS INVOLVED

Armour layer stability has already been briefly described in section 2.5. Formulae for the stability of an armour layer of rock and Tetrapods were mentioned. The following sections will deal with the parameters which have influence on the stability of Tetrapods at low-crested structures. These influences described below are all taken from literature. Regarding the influences of the various parameters on data set H2061 (DELFT HYDRAULICS, 1994) these are described in Chapter 10. The following parameters were mostly mentioned in literature:

1. **Hydraulic parameters**
   - Wave height
   - Wave period (and therefore wave steepness)
   - Number of waves (duration of the storm)

2. **Structural parameters**
   - Crest height
   - Nominal diameter of armour stone
   - Density of placement
   - Density of concrete

It is not clear whether the above mentioned parameters have the same influence for an armour layer of rock and an armour layer of Tetrapods, at which interlocking plays an important role. Since not much is known about the stability of concrete, interlocked elements, the influence of the parameters mentioned above will be discussed in a general way.

8.1 HYDRAULIC PARAMETERS

Wave height
The influence of the wave height on the stability and therefore on the damage, is often described by the stability number, N_s, see eq. 2.4. The stability number can be used in various ways. For example by assuming a given wave height, H_{si}, the diameter of the armour can be determined. This diameter is required for the stability with a chosen value of the damage number N_{od}. It is clear that a higher wave height will cause more damage.

Another stability number has been introduced by Ahrens (1987), namely the spectral stability number, N_s^*, see also eq. 2.5. Van der Meer (1993) also used this parameter to describe the stability of an armour layer of a submerged rubble mound breakwater. It should be noted that this parameter was derived to describe the stability of dynamically stable structures (reef type breakwaters), however, Van der Meer also used this parameter to describe the stability of an armour layer of a statically stable submerged breakwater.

Wave period

In general the influence of the wave period is brought into account by using the fictitious wave steepness. A longer wave period means a lower wave steepness, see eq. 2.1. Van der Meer (1988a) stated that if the average period, T_m and not the peak period, T_p, is used the spectrum shape and groupiness of waves have no influence on stability of an armour layer of rock. It is not quite clear whether this statement is also true for an armour layer of Tetrapods. However, the existing stability formulae do make use of the fictitious wave steepness based on the average period, see eq. 2.16 and 2.17. As can be seen from the equations an increase in wave period and therefore a decrease in wave steepness will increase the stability of the Tetrapods. It should be noted that the equations have only been derived for high-crested structures, so only the stability of the front and part of the crest section has been taken into account.

Another way of taking into account the influence of the wave period is by using the surf similarity parameter, which also takes the slope angle into account. This slope angle is almost always *1:1.5* for an armour layer of Tetrapods. However, for a rock structure the slope angle can vary. Van der Meer (1987a, 1988a) derived stability formulae for rock in which a distinction is made between surging and plunging waves, see eq. 2.15a, b and c. For surging waves an increase in wave period increases stability, for plunging waves the opposite occurs. An increase in wave period decreases the stability. Also these formulae have been derived for high-crested structures.

Recently Burger (1995) has re-investigated the stability of an armour layer of rock at low-crested structures. He reported the varying influence of the wave period per segment of the breakwater, front, crest or rear and sometimes even dependent on the crest freeboard, R_c. The shorter wave period causes most damage on the front side, independent of the crest freeboard. For the crest segment the influence of the wave period is dependent on the crest freeboard. For $R_c = 0$ the longest wave period causes most damage, for a positive freeboard the shorter period causes most damage. The longest wave period causes most damage to the rear side, independent of the crest freeboard.

It can be concluded that the influence of the wave period on stability is a difficult phenomenon. So the influence of the wave period on a low-crested structure with an armour layer of Tetrapods can not directly be determined, it should be investigated.

Number of waves

The influence of the storm duration is almost always present in stability formulae. It is clear that the longer the storm, the higher the number of waves, the more damage will be caused to the breakwater. For high-crested structures consisting of rock, Van der Meer (1988a) derived the following relation between the damage, S and the number of waves, N:

$$\frac{S_{N=3000}}{S_{N=1000}} = \sqrt{\frac{3000}{1000}} = 1.73 \tag{8.1}$$

Burger (1995) found a slightly lower value for low-crested structures with an amour layer of rock.

Van der Meer (1988b) found a similar formula, describing the influence of the storm duration, for Tetrapods, namely:

$$\sqrt{\frac{N_{od}}{\sqrt{N}}} = \text{constant} \tag{8.2}$$

It is clear that a longer storm causes more damage. However, which relation exists for low-crested structures with Tetrapods has to be investigated.

8.2 STRUCTURAL PARAMETERS

Crest freeboard

The difference between high-crested and low-crested structures is the difference in crest freeboard, R_c. At high-crested structures hardly any overtopping will occur. The wave energy will therefore only be dissipated by the front and possibly by the crest. Thus the damage will also occur at those parts of the breakwater. At low-crested structures a lot of wave overtopping will occur. The wave energy will be dissipated on all segments of the breakwater, front, crest and rear. The structure will therefore be more stable, as the wave energy can now dissipate on a larger area. Van der Meer (1990b) derived a reduction factor for the required nominal diameter of rock, D_{n50}, dependent on the relative crest freeboard, R_c/H_{si} and the fictitious wave steepness, s_{op}. However, Burger (1995) concluded that this reduction of D_{n50} is not quite correct. The stability of the structure remains the same until a crest height equal to the water level. Only with a crest clearly below the water level a significant reduction of D_{n50} seems allowable.

Nominal diameter

The influence of the nominal diameter is also taken into account by the stability number. It is easy to understand that an armour element with a higher weight can better withstand wave attack. However, a special problem arises for very large, heavy, concrete elements. They can break due to limits in structural strength. Breakwater failure due to rocking plays an important role for these heavy concrete elements. Another difference between rock armour and armour of concrete elements is that for rock the gradation plays an important role. Not all rocks used for the armour layer have the same diameter, for concrete elements such as Tetrapods all elements do have the same diameter.

Burger (1995) concluded that for low-crested structures with an armour layer of rock, a wide gradation ($D_{85}/D_{15} = 2.5$) gives a lower stability for damage $S > 2$, than a uniform gradation ($D_{85}/D_{15} = 1.25$).

Two other properties of rock, which do not vary for concrete elements are angularity and length-width ratio. Burger (1995) concluded that the influence of the angularity of rock is not present up to a damage of $S = 5$, for higher damage levels the round rock shows a more progressive development of damage. The length-width ratio did not show any influence on the stability. A rock type with relatively many elongated/flat rocks is just as stable as a more uniformly shaped rock type, as long as the mass or D_{n50} of the rock remains the same and small damage rates are considered.

Density of placement

Since the 'strength' of Tetrapods is not only its mass but also the interlocking between the elements, the density of placement can play a role in stability. The Shore Protection Manual (1984) gives the following formula for the required density of Tetrapods:

$$N_a = n k_\Delta (1 - n_v) D_n^{-2} \tag{8.3}$$

in which: N_a is the number of Tetrapods per m^2
n is the number of layers, *2* for Tetrapods
k_Δ is layer thickness coefficient, *1.04* for Tetrapods
n_v is the volumetric porosity, *0.5* for Tetrapods

It is to be investigated whether a change in the placing density, N_a and therefore a change of k_Δ, changes the stability of the Tetrapods.

Density of concrete

Since the density of the concrete used for the Tetrapods has influence on the mass of the Tetrapod, it has also influence on the stability of it. The variation in mass density is taken into account in the stability number by the relative buoyant density, Δ, see eq. 2.4 and 2.5.

9. DESCRIPTION OF DATA SETS

In this chapter a short description of the two data sets used for the derivation a new stability formulae, are described. Also a description of some problems with data set H2061 and the solutions for it, are given.

9.1 THE TWO DATA SETS USED

DELFT HYDRAULICS has carried out some model investigations on the stability of Tetrapods at low-crested structures (H2061, 1994). During this investigation the following parameters were varied:

- R_c crest freeboard
- h water depth
- T_m average wave period
- H_{si} wave height
- N number of waves
- D_n nominal diameter of the Tetrapods
- ρ_c mass density of concrete used for the Tetrapods
- N_a density of placement and therefore the layer thickness coefficient: k_Δ

The foreshore had a slope angle of $1{:}50$. The core of the breakwater consisted of rock with $D_{n50} = 0.011$ m and $D_{85}/D_{15} > 1.5$. A filter layer of rock with a diameter of 0.020 - 0.025 m was used. The crest width was held constant, namely 0.20 m. The slope angle of the breakwater was $1{:}1.5$ for the front side as well as the rear side.

Various sizes of Tetrapods were used, namely:

Type	Weight (kg)	Height (m)	D_n (m)	ρ_c (kg/m^3)
A	0.294	0.078	0.050	2350
K	0.202	0.068	0.044	2350
S	0.104	0.055	0.035	2320

Table 9-1 Different Tetrapods used in model tests

Nine test series were performed. Table 9-2 gives an overall view of the performed tests. Table A6.1 in Annex 6 gives all the results. An example of a tested cross section is given is Figure A1.8 in Annex 1.

In 1987 DELFT HYDRAULICS has carried out some model investigations on breakwaters with artificial armour units, namely Cubes, Tetrapods and Accropode®. Report H462-II by Van der Meer (1987b), gives a description of the tested cross section with an armour layer of Tetrapods. Table A6.2 gives the test results. Figure A6.1 gives the tested cross section. The formula describing the stability of Tetrapods at high-crested structures, eq. 2.16, is based on those test results.

During these model tests Tetrapods with a D_n of 0.044 m and a mass density of 2360 kg/m^3 were used (Type K from Table 9-1). The breakwater slope was $1{:}1.5$. The thickness of the armour layer was two nominal diameters. The $0.06\ m$ thick filter layer consisted of stones 0.020 - $0.025\ m$ with an average mass of $0.020\ kg$. A slope of $1:30$ was present in front of the structure. Each complete test consisted of a test run of 1000 waves and another test run of 2000 waves more.

Test	h (m)	R_c (m)	s_{om} (-)	D_n (m)			k_Δ (-)	N (-)
				Front	Crest	Rear		
1a	0.50	-0.05	0.055	0.050	0.050	0.050	1.02	950
1k	0.50	-0.05	0.055	0.044	0.044	0.044	1.02	950
1s	0.50	-0.05	0.055	0.035	0.035	0.035	1.02	950
2	0.50	0.00	0.055	0.050	0.050	0.050	1.02	900
2	0.50	0.00	0.037	0.050	0.050	0.050	1.02	1000
3	0.50	0.10	0.055	0.050	0.050	0.050	1.02	920
4	0.40	0.20	0.036	0.050	0.050	0.050	1.02	1000/3000
5	0.50	0.20	0.035/0.055	0.050	0.050	0.050	1.02	1000/3000
5h	0.50	0.20	0.035/0.055	0.050	0.050	0.035	1.02	1000/3000
62a	0.30	0.20	0.033	0.050	0.050	0.050	1.02	1000
64a	0.30	0.20	0.045	0.050	0.050	0.050	1.02	1000
64s	0.30	0.20	0.053	0.035	0.035	0.035	1.02	900
7	0.50	0.20	0.050	0.050	0.050	0.050	0.95	950
8a	0.50	0.20	0.055	0.050	0.050	0.050	0.88	900
8h	0.50	0.20	0.055	0.050	0.050	0.035	0.88	900
9	0.50	0.30	0.037/0.055	0.050	0.050	0.044	1.02	1000

Table 9-2 Overall view of performed tests conditions, H2061 (1994)

9.2 PROBLEMS WITH DATA SET H2061

A new multi-gauge technique, developed by DELFT HYDRAULICS (Klopman and Van der Meer, 1995) has been used to measure the wave heights near the breakwater. This technique, REFLEC, uses linear wave theory. It can be used to discriminate between incident and reflected waves. Despite the standing wave pattern this technique can be used to determine the incident wave height, H_{moi}, accurately up to very close to the structure.

From test analysis on a breakwater with a foreshore of $1:50$, a local water depth of $0.50\ m$ and a s_{op} of 0.02 and 0.04 (these are exactly the same test conditions as for test H2061) it appeared that the minimum distance between the breakwater and the nearest wave gauge should at least be $0.4\lambda_p$. (With λ_p is the wave length based on the peak period, T_p, in front of the structure.) So the minimum distance depends on the local wave length.

During the performance of the tests H2061 the distance was held constant, which certainly should not have happened. Another error was that the distance between the nearest wave gauge and the structure was far too small. Therefore the measured significant incident wave heights were not reliable at all.

To come up with more reliable wave heights in front of the structure the numerical computer model ENDEC has been used. This program calculates the H_{mo} at each point using H_{mo} and T_p at deep water. It also takes into account shoaling and breaking of waves due to depth limited conditions. The program should be very precise for a foreshore of $1:50$.

Therefore computations were made for all the given test conditions of H2061.

Since ENDEC is an energy propagation program, the calculated significant wave heights are based on energy, so H_{moi} is given. To be able to make a comparison with the stability formula presented by Van der Meer (1987b, 1988b) not the H_{moi} should be known, but the significant wave height based on wave height exceedance curves, for instance $H_{1/3}$ or $H_{2\%}$.

On deep water it appears that the wave heights of individual waves follow a Rayleigh distribution very well. However, in shallow water large deviations from the Rayleigh distribution may occur, especially for the higher waves, due to wave non-linearity's and wave breaking. In order to take into account this shallow water effects the so called Glukhovskiy or modified Glukhovskiy distribution is often used. Klopman and Stive (1989) and Klopman (1996) give a good description of this distribution function. The mathematical formulation of this modified Glukhovskiy distribution, which relates H_{moi} to $H_{1/3i}$ at shallow water, is given in Annex 7.

As to verify the computer program ENDEC and the modified Glukhovskiy distribution model for the given test situation (H2061), wave height measurements on a model with the same foreshore angle and water depths are needed. Such a model investigation has been carried out at DELFT HYDRAULICS by Van Nes (1995).

With this data set plots were created which show for two different water levels, $0.90\ m$ respectively $0.70\ m$ at deep water, the relation between $H_{1/3i}$ at deep- versus shallow water and H_{moi} at deep- versus shallow water. The results are shown in Figures A6.2 till A6.5 in Annex 6. In all figures a distinction has been made for a deep water wave steepness, s_p, of 0.02 respectively 0.04. From Figures A6.2 and A6.4 it can to be seen that for the lower wave steepness more shoaling occurs and that there is a difference between the figures based on $H_{1/3i}$ respectively H_{moi}. From Figures A6.3 and A6.5 the same conclusions can be drawn.

With this data set, Van Nes (1995), one can also verify whether the modified Glukhovskiy distribution can be used. The results are shown in Figures A6.6 and A6.7. For the water level of $0.90\ m$ the model works well for both wave steepnesses. However, for the shallow water condition, $h = 0.50\ m$, the modified Glukhovskiy distribution under-estimates $H_{1/3i}$. So the model is not applicable for this test situation. For the lower water level, $h = 0.70$ at deep water, the same conclusion can be drawn. Therefore it is not correct to use the modified Glukhovskiy distribution to calculate the $H_{1/3i}$ in front of the structure, based on H_{moi} at deep water!

The only method left to produce a reliable $H_{1/3i}$ in front of the structure for H2061 is to produce figures of H_{moi} versus $H_{1/3i}$ in front of the structure based on the test results of Van Nes (1995). Therefore first the reliability of ENDEC has to be checked, since this program has been used to calculate the H_{moi} in front of the structure. Again ENDEC calculations had to be made, but now using H_{moi} and T_p at deep water for the whole test programme of Van Nes (1995). Than plots can be made which show the measured H_{moi} at shallow water versus the calculated H_{moi}. The result is shown in Figure A6.8. The conclusion is that ENDEC overestimates the H_{moi}, this difference can not be neglected. Therefore one should take into account this difference to calculate $H_{1/3i}$ from H_{moi}. It is proposed to lower the calculated H_{moi} from ENDEC with a constant ΔH, dependent on the water level and the wave steepness, s_p. The used ΔH's are given below:

h (m)	s_p	ΔH *(m)*
0.50	0.04	0.011
0.50	0.02	0.005
0.40	0.04	0.008
0.40	0.02	0.003
0.30	0.04	0.005
0.30	0.02	0.000

Table 9-3 Used ΔH to correct ENDEC

In Figures A6.9 and A6.10 the dashed lines present the used relation between H_{moi} and $H_{1/3i}$, both in front of the structure. It should be noted that for the water level of *0.80 m*, which has not been tested by Van Nes, an average of the results for a water level of *0.90* respectively *0.70 m* has been used to produce $H_{1/3i}$ in front of the structure.

It should be noted that for shallow water conditions there is a significant difference between $H_{1/3}$ and H_{mo}, especially for a low deep water wave steepness, s_p.

With above described procedure the author was able to produce more correct wave heights in front of the structure for investigation H2061, than the ones that were wrongly reported.

10. ANALYSIS OF NEW DATA

A short description of the data sets used for this investigation has already been given in Chapter 9. In the following sections the influence of some parameters on the damage for the different sections of the breakwater, front, crest and rear, will be discussed. These parameters are relative crest height, R_c/H_{si} or R_c/D_{n50}, fictitious wave steepness based on T_m, s_{om}, the number of waves, N and the placing density of the Tetrapods expressed by the layer coefficient, k_Δ. This is done using data set H2061.

In Annex 8 figures of stability number, $H_{si}/\Delta D_n$, versus damage number N_{od} are given on all individual tests, see Figures A8.1 till A8.11. All Figures show, of course, that an increasing stability number, thus an increasing wave height, gives more damage. Other information from these Figures can not directly be seen, unless one takes Table A6.1 from Annex 6 and investigates the differences per test. So Figures should be created on all data and the varying parameters should be given in the legend.

10.1 INFLUENCE OF RELATIVE CREST FREEBOARD

The influence of the relative crest freeboard, R_c/H_{si}, is given for the three different breakwater segments in Figures A8.12 till A8.14. Figure A8.12 gives $H_{si}/\Delta D_n$, versus N_{od} for the front segment. It is concluded that a structure with a negative relative crest freeboard is the most stable one. A logical explanation for this is that many waves will pass the structure without causing damage to it. A structure with $R_c/H_{si} = 0$ is somewhat less stable than the one with $R_c/H_{si} = -0.25$, but still not much damage is present at the front segment. For structures with a positive crest freeboard the structure with $R_c/H_{si} = 0.75$ is of course the most stable one. It should be noted that for structures with a positive R_c, much more damage is present than for structures with R_c is zero or negative. This is to be explained as follows: for positive crest freeboard almost all wave energy has to be dissipated by the front slope, this contradicts with lower structures at which a lot of energy will pass over the structure and cause also damage to the crest and the rear side. Finally for higher structures, $R_c/H_{si} = 1.25$, 1.75 or 2.25 not much difference is seen.

For the crest section of the breakwater also the structure with a negative value for R_c/H_{si} is the most stable one. For a structure with a crest height equal to the water level already much more damage is present. For higher structures, at which still some wave overtopping will occur, a lot of damage is found. For even higher structures, $R_c/H_{si} = 1.75$ or 2.25, hardly any wave overtopping occurs and therefore no damage is seen for these structures.

For the rear section the same conclusions as drawn for the crest section can be drawn. The only difference is that for $R_c/H_{si} = 0$ also hardly any damage is present.

Another non-dimensionless parameter to take into account the influence of the crest freeboard is R_c/D_n. Graphs which make use of this parameter are given in Figures A8.15 till A8.17. From these figures the same conclusions are to be drawn as for the figures which make use of R_c/H_{si}.

It can not said directly which dimensionless parameter for the influence of the relative crest freeboard, R_c/H_{si} or R_c/D_n, is the best one to describe the influence of the crest freeboard.

Another way of presenting the influence of the relative crest freeboard is by giving figures of relative crest freeboard, R_c/H_{si} or R_c/D_n, versus the stability number, $H_{si}/\Delta D_n$, for fixed damage levels, N_{od}, with constant fictitious wave steepness, s_{om}. This has been done in Figures A8.18 till A8.23 for R_c/H_{si}. The parameter R_c/D_n has been used in Figures A8.24 till A8.29.

For all these figures a distinction has been made between $s_{om} = 0.035$ and $s_{om} = 0.055$. When one imagines curved lines through points of constant N_{od}, the same graph as obtained by Burger (1995) can be made, see also **Figure 10-1**.

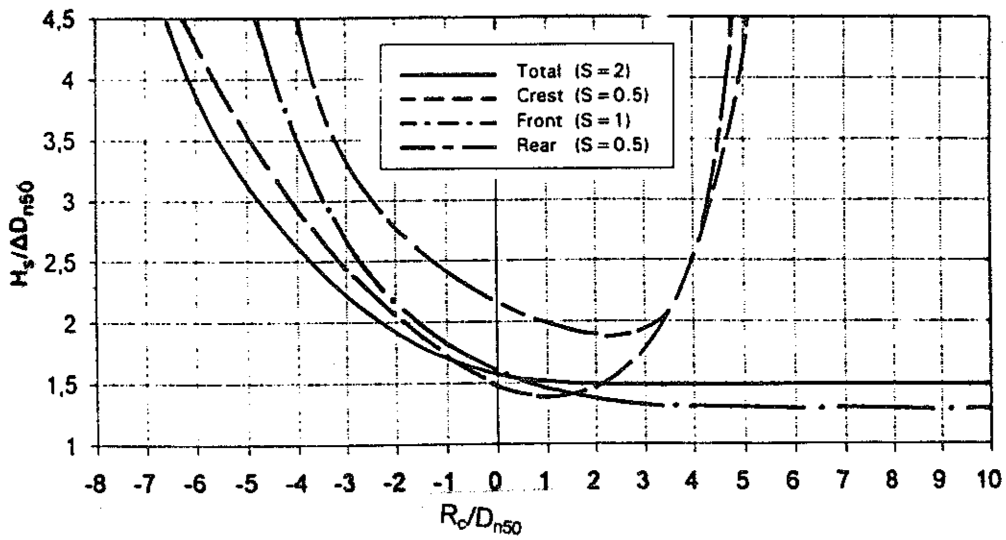

Figure 10-1 Design diagram for start of damage for breakwaters with an armour layer of rock, Burger (1995)

For the front section an increasing R_c/H_{si} or R_c/D_n leads to a lower stability number for the same damage level. For the crest section some sort of parabolic function can be drawn through points of constant N_{od}. The lowest stability is reached for a structure with its crest slightly above the water line. For the rear section the same as for the crest section can be seen. A decreasing stability for increasing crest height (until $R_c/H_{si} = 0.5$ or $R_c/D_n = 2$), hereafter increasing stability for increasing relative crest height, since none or not much wave overtopping occurs for a higher crest freeboard.

Again it is not quite clear which of the two dimensionless parameters is favoured to describe the influence of the crest freeboard. Perhaps one can conclude from a comparison between Figures A8.18 and A8.24 or A8.21 and A8.27 that R_c/D_n is a better parameter to describe the influence of the relative crest freeboard. This because of the fact that the curved lines in Figures A8.18 till A8.23 are probably caused by the 'double use' of parameter H_{si} on both axis. An increasing H_{si} causes a decreasing R_c/H_{si}

and also an increasing $H_{si}/\Delta D_n$. This is exactly what all those figures present.

10.2 INFLUENCE OF WAVE PERIOD

The influence of the wave period on stability of a structure is very often described by the fictitious wave steepness. As was already stated in section 8.1 the influence of wave groupiness and the spectrum shape is not present if the mean wave period, T_m, instead of the wave peak period, T_p, is used in stability formulae.

The influence of the wave period can be seen from test 2, 5, 6 and 9. For these four tests two different wave steepnesses have been tested, namely $s_{om} = 0.035$ and 0.050. The indication '0 or 2' in the legend gives the lower wave steepness, the indication '4' the higher one. It should be noted that damage to the front and crest has been taken together to allow for a comparison with the Van der Meer formula for Tetrapods, equation 2.16. Figures A8.30 till A8.33 show the results.

From a comparison between tests 22 and 24, Figure A8.30, it can be concluded that the lower wave steepness, test 22, gives more damage than the higher wave steepness, for the same wave height. This is not the same conclusion as presented by the Van der Meer formula. However, this formula was based only on fairly low fictitious wave steepnesses, namely $s_{om} < 0.030$. Probably the same influence of s_{om} is present for Tetrapods as for Rock. So a difference in plunging and surging waves might be present. Figure A8.30 shows the same result for the rear segment: an increasing s_{om} leads to an increasing stability.

An explanation for the effect of s_{om} on the front + crest segment is that for these values of wave steepness, $s_{om} > 0.035$, the fast wave run-up after breaking of the wave is decisive for stability. The forces during run-down are relatively small. Since an increasing s_{om} lead to a lower wave run-up, also the damage will be lower.

The explanation for the influence of s_{om} to the rear section is that a decreasing wave steepness leads both to a higher percentage of overtopping waves and to a higher volume of overtopping water. See also section 2.4.2 and De Waal and Van der Meer (1992). Therefore a decreasing s_{om} will lead to an increasing damage number, N_{od}.

Figures A8.31 till A8.33, test 5, 6 and 9, show the same results. Therefore it can be concluded that the influence of s_{om} is not dependent on the crest freeboard, R_c and not dependent on the water depth, h.

10.3 INFLUENCE OF STORM DURATION

The influence of the storm duration and therefore the influence of the number of waves, N, is seen in the figures which show the individual damage curves per test. Examples are Figures A8.4 and A8.5 and A8.6. In these three figures the tests with the index 'a' are tests with $N = 1000$, the index 'b' states that 3000 waves were used.

It can be concluded that the longer the storm duration, a higher value of N, the higher the damage level for the same stability number will be. Which relation exactly exist between N_{od} and N will be investigated lateron, during the investigation of a new stability formula. A relation like the one in eq. 8.2 will probably be used.

10.4 INFLUENCE OF PLACING DENSITY

The placing density, the number of Tetrapods per square metre, has already been briefly described in section 8.2. Since the number of Tetrapods placed per square metre is dependent on the nominal diameter, D_n, of the Tetrapod, it is better to use the layer thickness coefficient, k_Δ (see eq. 8.3), to take into account the density of placement. For two test series a lower k_Δ has been used than during the other tests. For series 7 a layer thickness coefficient $k_\Delta = 0.95$ has been used, for series 8: $k_\Delta = 0.88$. During all the other tests the coefficient was 1.02.

Figures A8.34 till A8.36 show the influence of k_Δ for the different breakwater segments. It should be noted that the structures used for this investigation had the same R_c and that the same fictitious wave steepnesses were tested as well as the same number of waves. (Tests 5a, 7 and 8.)

It is be concluded that the influence of k_Δ is not present for the crest can not be found k_Δ, since at only three tests damage occurred. At the front segment the influence is present. A decreasing k_Δ, which leads to less interlocking between the Tetrapods, leads to an increasing damage number. At the rear segment the same is to be seen.

In DELFT HYDRAULICS report H1872 (1994) a slightly different conclusion is given: *"the looser packing of Tetrapods (implying also a lower crest) seems to affect mainly the rear of the breakwater due to the fact that the wave action can propagate easily through and over the crest. The water coming through and over the crest can push the Tetrapods on the rear out of the layer relatively easy."*

10.5 INFLUENCE OF THE WATER DEPTH

During the model investigation three comparable tests were performed with only different water levels. These tests were: 4, 5 and 6, with a water level of $h = 0.80$, respectively 0.90 respectively $0.70\ m$ at deep water. From Figures A8.37 and A8.38 for $s_{om} = 0.035$ respectively 0.050 it is seen that for damage to the front + crest, as well as for damage to the rear, the points from the different tests are more or less in one line. Therefore it is concluded that, although wave breaking occurs, the wave height H_{si} is a good parameter to describe damage to the breakwater independent of the water depth.

10.6 NORMATIVE PARAMETERS AND SECTIONS

After having studied the development of damage onto the various segments, the influences of the relative crest freeboard and the fictitious wave steepness are known. Table 10-1 shows for the various freeboards at which segment (front, crest or rear) the development of damage starts ($N_{od} = 0.25$). Also the normative segment for a higher damage number, $N_{od} = 1$ has been given is this table. Finally the normative fictitious wave steepness, s_{om}, is mentioned.

	Nod = 0.25		*Nod = 1*	
R_c	**Segment**	s_{om}	**Segment**	s_{om}
Negative	Crest	0.035	Front	-----
Zero	Crest	0.035	Crest	0.035
Positive	Front	0.035	Front	0.035

Table 10-1 Normative segment and s_{om} per crest freeboard

For start of damage the crest segment is normative for negative and zero crest freeboard. For start of damage at positive freeboards and for severe damage for the whole range of freeboards, the front segment is normative. The lowest fictitious wave steepness, $s_{om} = 0.035$, causes most damage, as was already stated in section 10.2.

Table 10-2 shows per segment for both damage levels at which crest freeboard, R_c, the stability is the lowest, again with accompanying wave steepness.

	$N_{od} = 0.25$		$N_{od} = 1$	
Segment	R_c	s_{om}	R_c	s_{om}
Front	+	0.035	+	0.035
Crest	0	0.035	+	0.035
Rear	+	0.035	+	0.035

Table 10-2 Normative parameters per segment

11. DERIVATION OF NEW STABILITY FORMULAE

Since, as was already stated in section 10.2, a different influence of the fictitious wave steepness, s_{om}, is present for the new data set, H2061, it has no use to the Van der Meer formula for Tetrapods, eq. 2.16, to predict the damage of this new data. However, a comparison between the Van der Meer formula, with the data used to derive it, and the new data will show the different influences of s_{op} very well.

New stability formulae will be derived for damage to the front + crest segments together. A reduction factor will be introduced for the influence of the relative crest freeboard, R_c/D_n. For the rear segment a design graph will be created.

11.1 INFLUENCE OF STORM DURATION

As was already stated in section 8.1 a constant relation between N_{od} and N can be assumed, namely:

$$\frac{N_{od}}{\sqrt{N}} = constant = 1.73 \tag{11.1}$$

This relation could be checked for test series 4 and 5. This has been done in two ways, namely by creating figures which predict the damage after *3000* waves by multiplying the damage after *1000* waves by *1.73*. This is shown in Figures A9.1, A9.2 and A9.3. The other way is by calculating the exact relation between N_{od} and $\sqrt{N}$. This is shown in Table A9.1 in Annex 9. From both investigations it can be concluded that the relation as proposed by eq 11.1 predicts the development of damage dependent on the storm duration well. Only for the crest segment this relation is not applicable. What can be seen in these tests is that first damage to the front and to the rear segment takes place, and once there is much damage to those segments, the development of damage to the crest segment develops quickly. During the derivation of the new stability formula, the relation $\frac{N_{od}}{\sqrt{N}}$ will be used.

11.2 DERIVATION OF NEW FORMULA FOR FRONT + CREST

Due to the small random behaviour of damage to breakwaters there is always some scatter present in the data sets. Since it is not easy to derive formulae, when that scatter is present, average damage curves have been drawn for each individual test. For constant damage numbers of: N_{od} = *0.0, 0.2, 0.5, 1.0* and *1.5* the accompanying stability numbers, N_s, were determined. For damage to the front + crest segment these new data points are given in Table A9.2, for damage to the rear segment in Table A9.3. For the data set, which Van der Meer used to derive his formula, H462-II, the data points are given in Table A9.4.

These new data points will from now on be used to derive the new stability formula.

First the influence of the fictitious wave steepness, s_{om}, will be checked. The following power function has been used:

$$\frac{H_{si}}{\Delta D_n} = a_1 \left(s_{om}\right)^{b_1} \tag{11.2}$$

Those tests at which the wave steepness has been varied, were used to determine the power value. The parameter b_1 appeared to have an average value of 0.2.

Since the influence of the storm duration is not present for the no-damage criterion, $N_{od} = 0$, the parameter a_1 can also be determined. From Figures A8.24, A8.25, A8.27 and A8.28 it is concluded that for high values of the relative crest freeboard, $R_c/D_n > 4$, there is a constant influence on the stability to the front and crest segment. The placing density of the Tetrapods has influence on the start of damage, as can be seen in Figure A9.4. Therefore only those tests with $R_c/D_n > 4$ and $k_\Delta = 1.02$ will be used to determine a_1. From tests 5, 6 and 9 it appeared that a_1 has an average value of 4.0. The influence k_Δ of will be taken into account later on.

The influence of the damage level and the storm duration has now to be taken into account. Since equation 11.1 gives the relation between the storm duration, number of waves and the damage number, the following expression will be used to derive a stability formula:

$$\frac{H_{si}}{\Delta D_n} = s_{om}^{0.2}\left(4.0 + a_2\left(\frac{N_{od}}{\sqrt{N}}\right)^{b_2}\right) \tag{11.3}$$

The parameters a_2 and b_2 were determined for all tests with $k_\Delta = 1.02$, since it is expected that the crest freeboard has neither influence on a_2 nor on b_2. From all obtained values the average has been taken. The following values were determined: $a_2 = 8.6$ and $b_2 = 0.5$.

Since a decreasing relative crest freeboard allows more energy to overtop the breakwater and therefore leads to less damage to the front and crest segment, a reduction factor dependent on R_c/D_n should be introduced. As was already concluded in section 10.1 the use of R_c/H_{si} gives more the influence of the wave height than of the crest freeboard. Therefore R_c/D_n will be used.

The following expression for an amplification factor on stability dependent on R_c/D_n is used:

$$A = \frac{\left(\frac{H_{si}}{\Delta D_n}\right)_{measured}}{\left(\frac{H_{si}}{\Delta D_n}\right)_{calculated}} = \frac{\left(\frac{H_{si}}{\Delta D_n}\right)_{measured}}{s_{om}^{0.2}\left(4.0 + 8.6\left(\frac{N_{od}}{\sqrt{N}}\right)^{0.5}\right)} \tag{11.4}$$

The results are shown in Figure A9.5. The proposed function for the amplification factor, A, is:

$$A = 1 + 0.17\, e^{-0.61 \frac{R_c}{D_n}} \tag{11.5}$$

This function represents a slowly declining line with a minimum value of *1.0* for high values of R_c/D_n.

The derived stability formula now becomes:

$$\frac{H_{si}}{\Delta D_n} = s_{om}^{0.2} \left(3.94 + 8.6 \left(\frac{N_{od}}{\sqrt{N}} \right)^{0.5} \right) * \left(1 + 0.17\, e^{-0.61 \frac{R_c}{D_n}} \right) \tag{11.6}$$

From Figure A9.4 it is seen that there is a constant difference in N_s, for constant levels of N_{od}, dependent on the layer coefficient k_Δ. Therefore it is proposed to use a formula dependent on k_Δ instead of the constant value *3.94*. This function appears to be: $2.64\, k_\Delta + 1.25$.

The definite formula, describing stability of the front + crest segment now becomes:

$$\frac{H_{si}}{\Delta D_n} = s_{om}^{0.2} \left((2.64 k_\Delta + 1.25) + 8.6 \left(\frac{N_{od}}{\sqrt{N}} \right)^{0.5} \right) * \left(1 + 0.17\, e^{-0.61 \frac{R_c}{D_n}} \right) \tag{11.7}$$

The data used for this derivation together with above mentioned formula are presented in Figures A9.6, A9.7 and A9.8, for $k_\Delta = 1.02$ respectively *0.95* (Test 7) respectively *0.88* (Test 8). As can be seen the proposed formula describes the given data points very well.

In Figure A9.9 the formula is presented together with the real data points. Also these data points are described very well by the proposed equation, although some scatter is present. Test 4 is not covered too well. An explanation for this might be that during the determination of reliable incoming wave heights, see section 9.2, no data was available for a water depth of *0.80 m*. So perhaps the wave heights were not calculated in a proper way.

It is useful to compare the new proposed formula with the formula derived by Van der Meer. This has been done in Figures A9.10 till A9.13. Each Figure presents the data points derived from fixed damage levels, used to derive the formulae, together with the derived formulae. This has been done to avoid too much scatter between the lines and the data points. The dashed line represents the new formula, eq. 11.7, the other the Van der Meer formula, eq. 2.16. As can be seen from Figures A9.10 till A9.13 the intersection between the two lines depends on the chosen damage number.

For design purpose the transition between the Van der Meer formula and the new stability formula, eq. 11.1, dependent on the fictitious wave steepness, s_{om}, has been given for three damage numbers ($N_{od} = 0$, $N_{od} = 0.5$ and $N_{od} = 1.5$) in Figure A9.14

It is possible to derive a formulae which represents the intersection point between the two formulae. However, when one wants to calculate the stability of a breakwater one can also use both formulae and uses that formula which gives the highest stability number!

Since no data at DELFT HYDRAULICS is available on breakwaters with Tetrapods with the same wave steepness, s_{om}, as used by Van der Meer, it is not possible to check whether the proposed amplification factor, eq. 11.5, is also valid for the Van der Meer formula. However, it is likely that use of the factor on the Van der Meer formula is justified.

11.3 RELIABILITY OF FORMULA FOR FRONT + CREST

In the same way as for the transmission formulae from Part A of this study, see section 6.4, the *90 %* confidence bands will be derived for eq. 11.7. From Figure A9.9 it is seen that the scatter in the graph can be described by using the same formula, but with a different starting point (intersection with horizontal axis).

By changing the starting points in steps of ± 0.05 the percentage of points within that boundary width can be calculated. From this percentage it is possible to calculate the accompanying standard deviation, using a two-sided truncated Normal distribution with mean, μ, is 0 and a standard deviation, σ, of 1, see also Table A5.1. The results are shown in the following table 11-1.

It is noted that for the derivation of σ not all points have been taken into account. Only those points above the horizontal line $\frac{N_{od}}{\sqrt{N}} > 0.005$ are taken into account, as to clearly monitor the trend.

By using the average standard deviation from Table 11-1 the *90 %* confidence level expressed in the starting points is given by: $\pm 1.64 * 0.50 = \pm 0.82$. The formula for data with $k_\Delta = 1.02$ together with the *90 %* confidence level is given in Figure A9.15.

The scatter in the figure around the line, predicting damage, can be due to:

- differences due to random behaviour of the Tetrapods;
- accuracy of measuring wave height and wave period;
- curve fitting.

Boundary width	% within boundary	k	St.dev. σ
0.05	0.1205	0.155	0.323
0.10	0.1687	0.218	0.459
0.15	0.2651	0.338	0.444
0.20	0.3735	0.486	0.412
0.25	0.4217	0.555	0.450
0.30	0.4699	0.628	0.478
0.35	0.5422	0.745	0.470
0.40	0.5783	0.804	0.498
0.45	0.6386	0.912	0.493
0.50	0.6867	1.008	0.496
0.55	0.7590	1.172	0.469
0.60	0.7711	1.206	0.498
0.65	0.7951	1.269	0.512
0.70	0.8072	1.305	0.536
0.75	0.8313	1.375	0.545
0.80	0.8434	1.418	0.564
0.85	0.8916	1.605	0.530
0.90	0.9036	1.664	0.541
0.95	0.9157	1.725	0.551
1.00	0.9157	1.725	0.580
1.05	0.9398	1.880	0.559
1.10	0.9518	1.975	0.557
1.15	0.9639	2.095	0.549
1.20	0.9639	2.095	0.573
1.25	0.9880	2.514	0.497
		Average	**0.503**

Table 11-1 Derivation of standard deviation for eq. 11.7

11.4 DERIVATION OF DESIGN GRAPH FOR REAR SEGMENT

Since not much data is available for the rear segment at which some or severe damage occurred for the whole range of crest freeboard, it is not possible to derive an empirical formula. Therefore a design graph will be created at which as much parameters as possible will be taken into account.

The influence of the fictitious wave steepness, s_{om}, can be derived from tests 2, 5, 6 and 9. However, for tests 2, 6 and 9, only data points with $N_{od} = 0$ are available. Therefore only test 5 has been used to derive a relation between the stability number and the wave steepness. In section 10.2 it has already been mentioned that an increasing wave steepness gives less overtopping waves and therefore less damage to the rear segment.

The same relation as given by equation 11.2 has been used. For the rear segment the average value for parameter b_1 appeared to be: 0.4.

So the following function can be used to describe stability of the rear segment

$$\frac{H_{si}}{\Delta D_n} s_{om}^{-0.4} = f\left(N_{od}, N, k_{\Delta}, \frac{R_c}{D_{n,REAR}} \right) \tag{11.8}$$

The influence of the placing density, expressed by k_{Δ} on damage to the rear is given in Figure A9.16. Theoretically it is expected that a decreasing placing density will give more damage to the breakwater. However, Figure A8.39 does not give a clear relation between damage and k_{Δ}. The placing density can, therefore, not be taken into account.

The influence of the storm duration is given in Table A9.1. As can be seen is the relation between the number of waves, N and the damage caused by is, N_{od}, given by a factor *2*. Since not more than *3000* waves were tested it is not possible to give a function to express the relation between the two parameters. The factor *2* has been used to be able to use the damage points after *3000* waves in comparison with *1000* waves. The damage after *3000* waves has been divided by *2*. In this way new average damage curves could be drawn in order to obtain new data points.

All data points are shown in Figure A9.17, which is a graph of $R_c/D_{n,\ REAR}$ versus $H_{si}/\Delta D_n$, dependent on the damage number. For two damage numbers, namely $N_{od} = 0$ and $N_{od} = 1.0$ the best fit curve has been drawn. The dashed lines can not be proven by data points or by theory, since there is not a formula predicting wave overtopping at structures with an armour layer of Tetrapods. The dashed lines are drawn in accordance with the design graph by Burger (1995) for low-crested structures with an armour layer of rock, see also Figure 10-1. It is clear, that for an increasing freeboard hardly any water will overtop the structure and therefore hardly any damage will occur. A vertical asymptote should therefore be used. At which R_c/D_n this asymptote will occur can not be checked, because of the lack of data points.

It is also seen that for a relative crest freeboard of $R_c/D_{n,\ REAR} = 4$ the development of damage is quickly. Once damage has been initiated the failure of the rear segment of the structure follows very fast. For higher and lower crest freeboards the difference in stability number for the different damage numbers is larger. This phenomenon is also to be seen in the figures for the individual damage curves. For a relative crest freeboard of $R_c/D_{n,\ REAR} = 4$ the curves are very steep.

11.5 COMPARISON BETWEEN FRONT + CREST WITH REAR

In order to find out what the difference is between the derived stability formula for Front + Crest, eq. 11.7, and the above derived design curve for the Rear, Figure A9.14, it is useful to present a graph in which both are given. Therefore, some parameters will have to be taken constant, since they could not be taken into account in the design graph. These parameters are: $s_{om} = 0.055$, $k_\Delta = 1.02$ and $N = 1000$. Figure A9.18 gives for two damage levels, $N_{od} = 0$ and $N_{od} = 1.0$ the design curves. As can be clearly seen from the figure the Front + Crest segments are normative for the whole range of crest freeboard. Except for R_c/D_n around 0.5. At this point the rear is slightly more instable. What else is seen is that for a high positive relative crest freeboard, e.g. $R_c/D_n = 4$, there is a $35\ \%$ difference in the stability numbers. So Tetrapods with a nominal diameter a $0.65 * D_{n,\ FRONT}$ can be used, which means a saving in weight of around $70\ \%$!

12. CONCLUSIONS AND RECOMMENDATIONS

In this Chapter the conclusions and recommendations, which can be drawn from this study (Part B), will be mentioned.

12.1 CONCLUSIONS

- During the investigation and from various literature sources, it became clear that the following parameters describe damage, N_{od}, to a low-crested breakwater with an armour layer of Tetrapods satisfactory:

  Hydraulic parameters:
  - wave height H_{si} (which is defined as $H_{1/3,i}$)
  - mean wave period T_m
  - number of waves N

  Structural parameters:
  - crest height R_c
  - nominal diameter of Tetrapod D_n
  - density of placement, expressed by the layer thickness coefficient k_Δ
  - density of concrete ρ_c

- The variation of the water depth did not affect the development of damage. The wave height $H_{1/3}$ appears to be a good measure for the maximum wave heights causing the damage, for all water depths tested.

- The following non-dimensional parameters were used to take into account above mentioned parameters:

  - relative crest freeboard $\frac{R_c}{D_n}$
  - stability number $\frac{H_{si}}{\Delta D_n}$
  - fictitious wave steepness s_{om}

- Since it was tried to make a comparison between the existing formula by Van der Meer, eq. 2.16, and the new data, the damage for the Front and Crest segment were taken together. The Rear segment has been investigated separately. The Van der Meer formula was derived for fairly low fictitious wave steepnesses up to 0.030. The new data had much higher wave steepnesses. Just like the formulae describing the stability of rock, eq. 2.15 a, b and c, a distinction should be made dependent on the type of wave breaking. For high values of s_{om} an increase of the wave period, T_m, (and therefore a decrease of s_{om}) leads to an increase of the damage number, N_{od}, thus a decrease of the stability number, N_s.

- For the Front + Crest segment the relative crest freeboard, R_c/D_n, has only influence on the stability number for values lower than 2.0. For lower values there is a strong increase in stability for the Front + Crest segment. At the Rear section minimum stability is reached for R_c/D_n between 0.0 and 1.0. For an increasing R_c/D_n the stability of the Rear will strongly increase. For a certain R_c/D_n a vertical asymptote will be present, since no water will overtop the structure and causes damage to it. This asymptote could not be determined, since the range of tested crest freeboards was not large enough. There are also no overtopping formulae found for breakwaters with an armour layer of Tetrapods, so the crest height at which no more water overtops the breakwater could also not be determined.

- The influence of the placing density, expressed by the layer thickness coefficient did have effect on the Front + Crest section. An increasing k_Δ causes an increase in stability. Although it is expected that the same is true for the Rear section, the data did not show considerable difference in stability dependent on this k_Δ.

  The influence of k_Δ has been taken into account in the start of damage ($N_{od} = 0$) by:

$$\frac{H_{si}}{\Delta D_n} s_{om}^{-0.2} = 2.64 k_\Delta + 1.25 \qquad (12.1)$$

- For the Front + Crest segment the existing relation between N_{od} and N was applicable. For the Rear segment the following relation was used:

$$\frac{N_{od}(N = 3000)}{N_{od}(N = 1000)} = 2 \qquad (12.2)$$

- The empirical formulae describing the stability of Tetrapods at low-crested structures with $R_c/D_n > 4$, applicable for damage to the Front + Crest segment is:

$$\frac{H_{si}}{\Delta D_n} = s_{om}^{0.2} \left((2.64 k_\Delta + 1.25) + 8.6 \left(\frac{N_{od}}{\sqrt{N}} \right)^{0.5} \right) \qquad (12.3)$$

- The influence of the relative crest freeboard is present for $R_c/D_n < 4$. An amplification factor on the stability number, dependent on R_c/D_n, has been derived:

$$\text{Amplification factor} = \left(1 + 0.17 e^{-0.61 \frac{R_c}{D_n}} \right) \qquad (11.5)$$

- The final stability for low-crested structures with an armour layer of Tetrapods now becomes:

$$\frac{H_{si}}{\Delta D_n} = s_{om}^{0.2}\left((2.64k_\Delta + 1.25) + 8.6\left(\frac{N_{od}}{\sqrt{N}}\right)^{0.5} \right) * \left(1 + 0.17\, e^{-0.61\frac{R_c}{D_n}} \right) \qquad (11.7)$$

- The *90 %* confidence bands can best be described by taking into account a constant variation of the starting point for damage. The standard deviation appears to have a value of *0.5*.

- For the Rear segment it is not possible to derive an empirical formula. Therefore a design graph is presented, see Figure A9.16.

- For practical design purposes both formulae, the Van der Meer one and the newly derived one, should be taken into account. The formula giving the highest stability number, N_s, is the one that should be used.

- The computer program ENDEC slightly overestimates the wave height based on the energy density spectrum at shallow water, for a foreshore of *1:50*. The difference between laboratory measurements and the program appeared to be dependent on the water depth in front of the structure, h and the deep water wave steepness, s_p.

- The modified Glukhovskiy distribution is not a good model to describe the exceedance curves of the wave height at shallow water. Therefore it is also not a good model to relate H_{moi} to $H_{1/3i}$ at shallow water.

12.2 RECOMMENDATIONS

- The crest with, B, has not been varied during this study. From overtopping formulae it is clear that an increasing crest width causes lower volumes of overtopping water. Therefore, the damage to the Rear as well as to the Crest will be influenced by the crest width.

- As to verify whether the amplification factor A (eq. 11.5) is also applicable on the Van der Meer formula, a new model investigation should be performed. For varying crest heights, R_c, also very low fictitious wave steepnesses, s_{om}, should be tested.

  Since, theoretically, the influence of R_c/D_n in not depending on the fictitious wave steepness, this amplification factor can also be used on the Van der Meer formula.

- Even lower water levels than $h = 0.30\ m$ in front of the structure should be tested to find out whether, for extreme shallow water conditions, the significant wave height $H_{1/3}$ is still a good measure to describe the higher wave heights causing damage to the breakwater.

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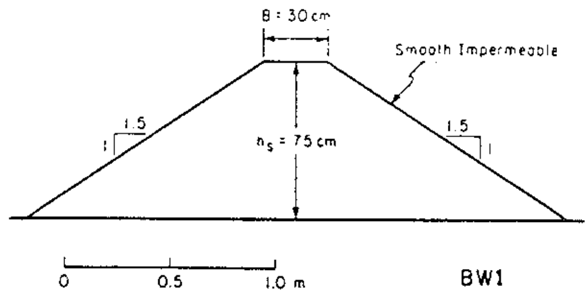
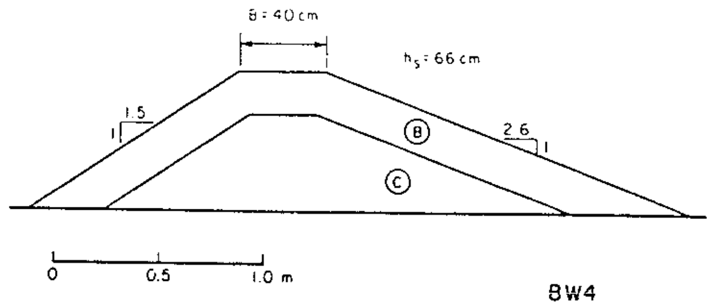
ANNEX 1

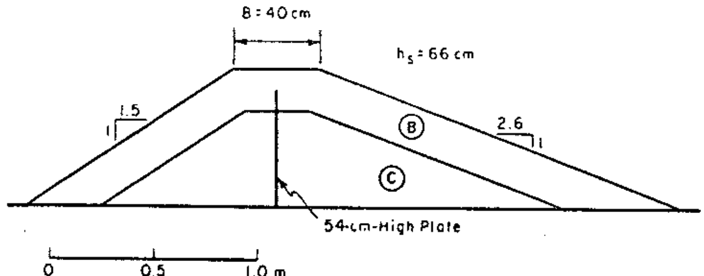
Figures of cross sections of the various data sets



BW1

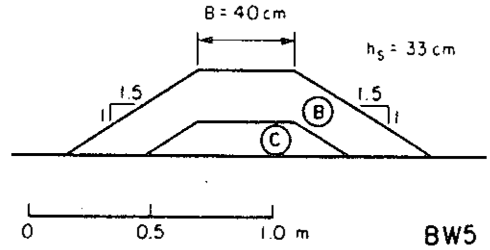


BW4



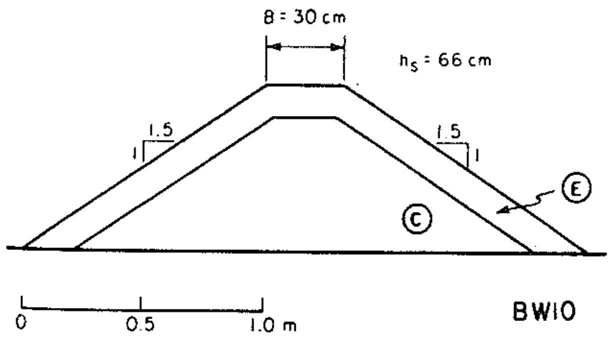
BW4W

BW4W is similar to BW4, but includes a 54–centimeter–high plate in the center of the structure



BW5

BW5 is typical of a breakwater built in relatively shallow water
the armor unit size is large compared to the structure height and the core size relatively small



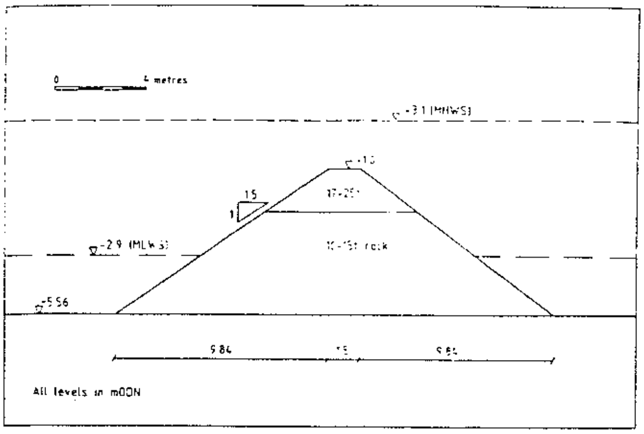
BW10

BW10 was made with an armor one unit thick of well–fitted rectangular rock
the material was placed with one surface parallel to the structure face

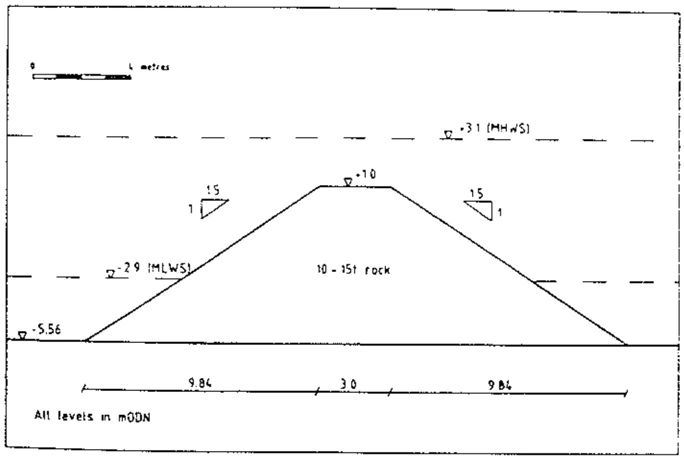
Material characteristics.

Material	Description	W_{85}[1] (g)	W_{50}[2] (g)	W_{15}[3] (g)	d_{50}[4] (cm)
A	Angular stone	2,520	1,530	990	8.3
B	Angular stone	4,680	3,690	2,900	11.1
C	Angular stone	180	68	31	2.9
D	Dolos	405	390	390	----
E	Flat stone	13,200	11,200	8,100	16.1
F	Angular stone	7,600	4,900	2,500	12.2

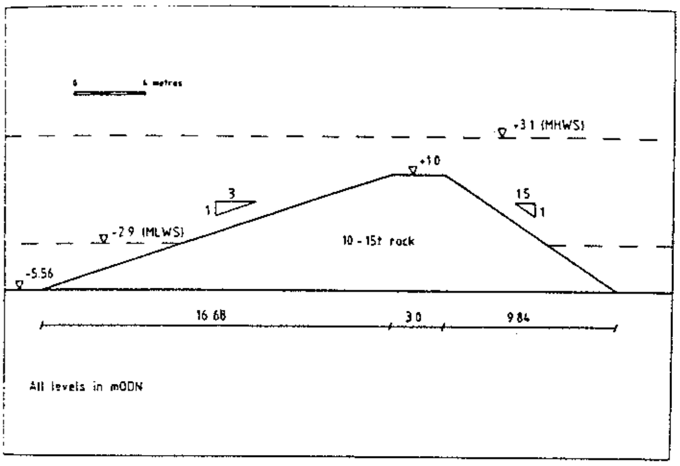
Cross sections of Seelig (1980) **Figure A1.1**



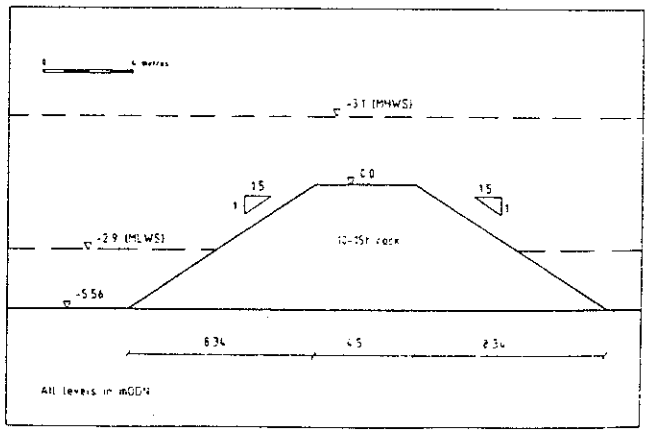
Section III 1 : 1.5 slope, Crest @ +1.0mODN



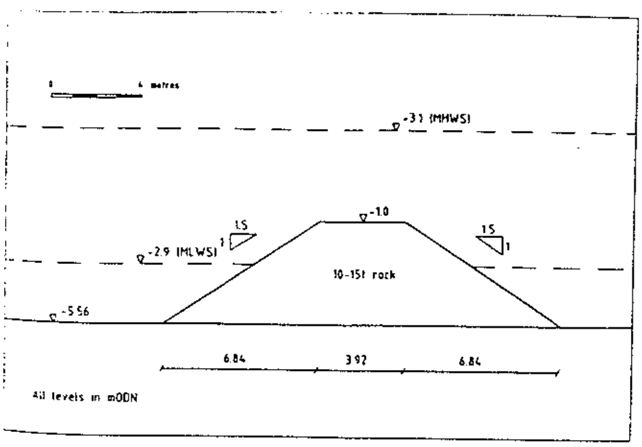
Section II 1:1.5 slope, Crest @ +1.0 mODN



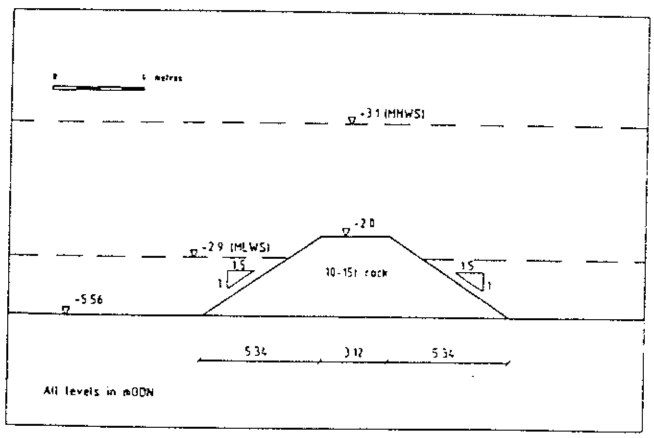
Sections I and IV 1:3 slope, Crest @ +1.0mODN



Section V 1 : 1.5 slope, Crest @ 0.0mODN

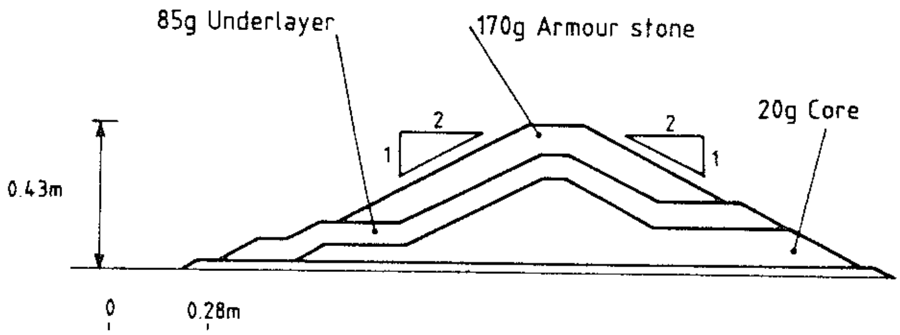


Section VI 1 : 1.5 slope, Crest @ -1.0mODN

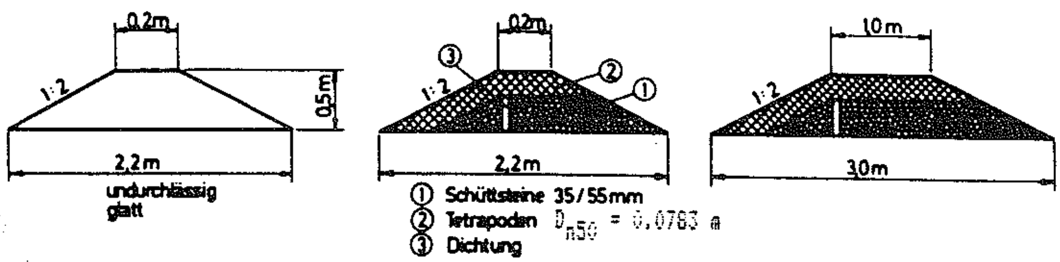


Section VII 1 : 1.5 slope, Crest @ -2.0mODN

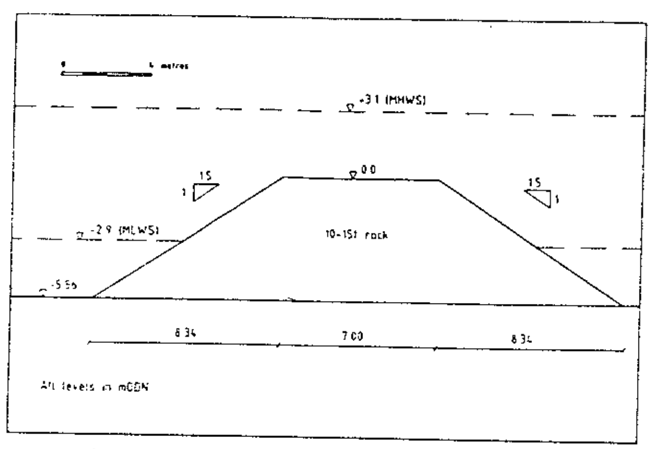
Cross sections of Powell & Allsop (1985) **Figure A1.4**



Cross section of Allsop (1983) **Figure A1.2**

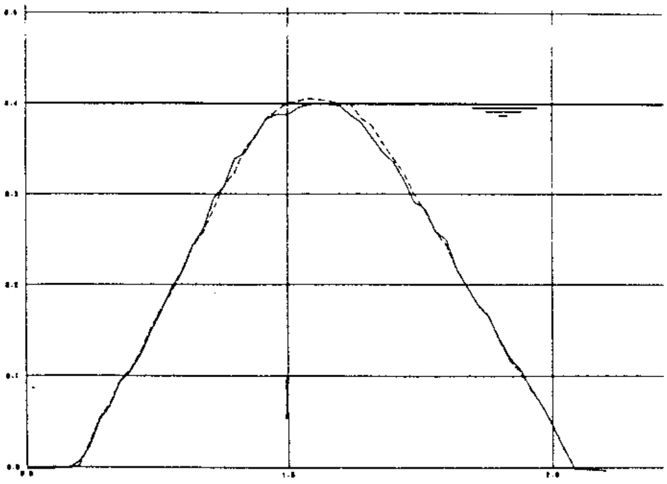


Cross sections of Daemrich & Kahle (1985) **Figure A1.3**

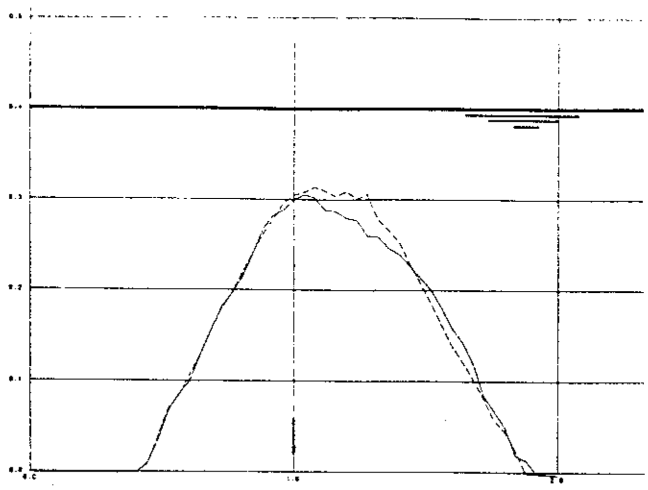


Section VIII 1 : 1.5 slope, Crest @ 0.0mODN

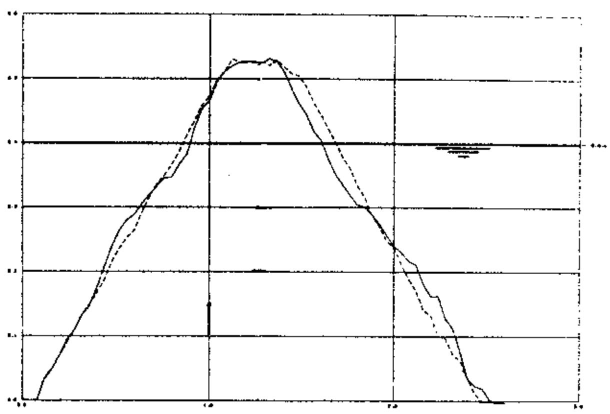
Cross sections of Powell & Allsop (1985) **Figure A1.4**



R_c = 0.0m test 1–11



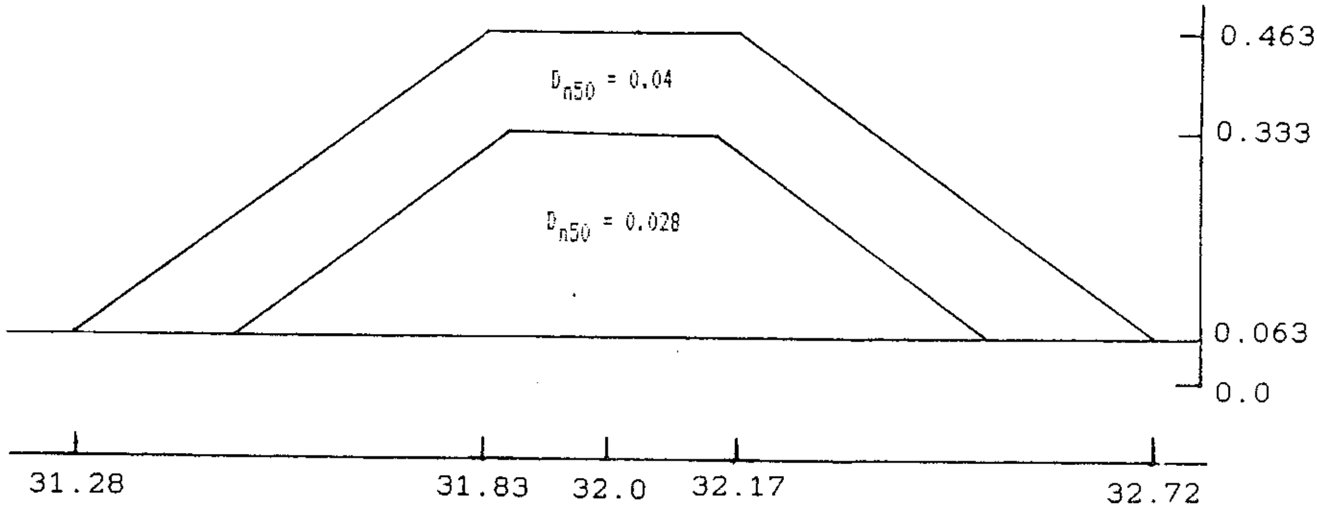
R_c = –0.09m test 21–31



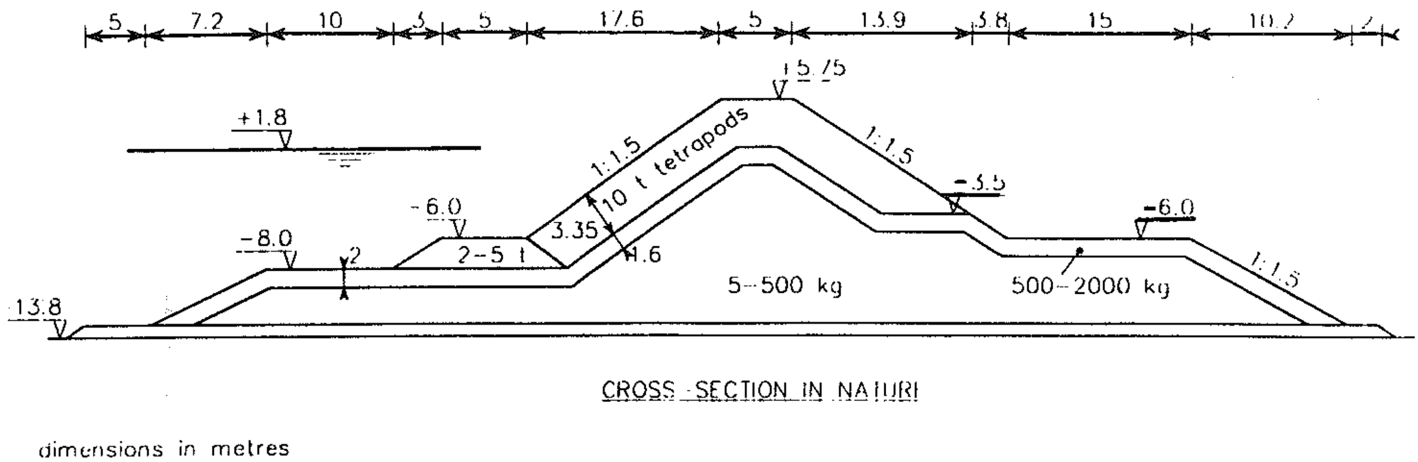
R_c = 0.125m test 12–20

Armour layer	rock
Slope angle	1:2
Diameter armour	D_{n50} = 0.0344 m
Permeability structure	permeable
Width of crest	0.30 m
Slope of foreshore	1:30
Water depth at structure	0.40 m
Water depth in flume	0.80 m

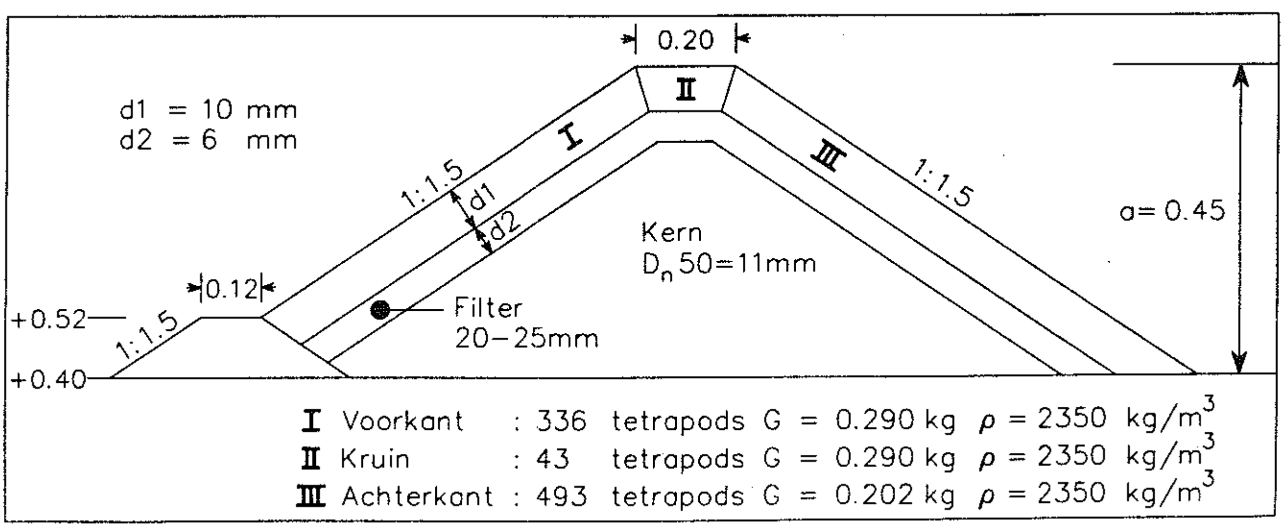
Cross sections of Van de Meer (1988) **Figure A1.5**



Cross section of Daemen (1991) **Figure A1.6**

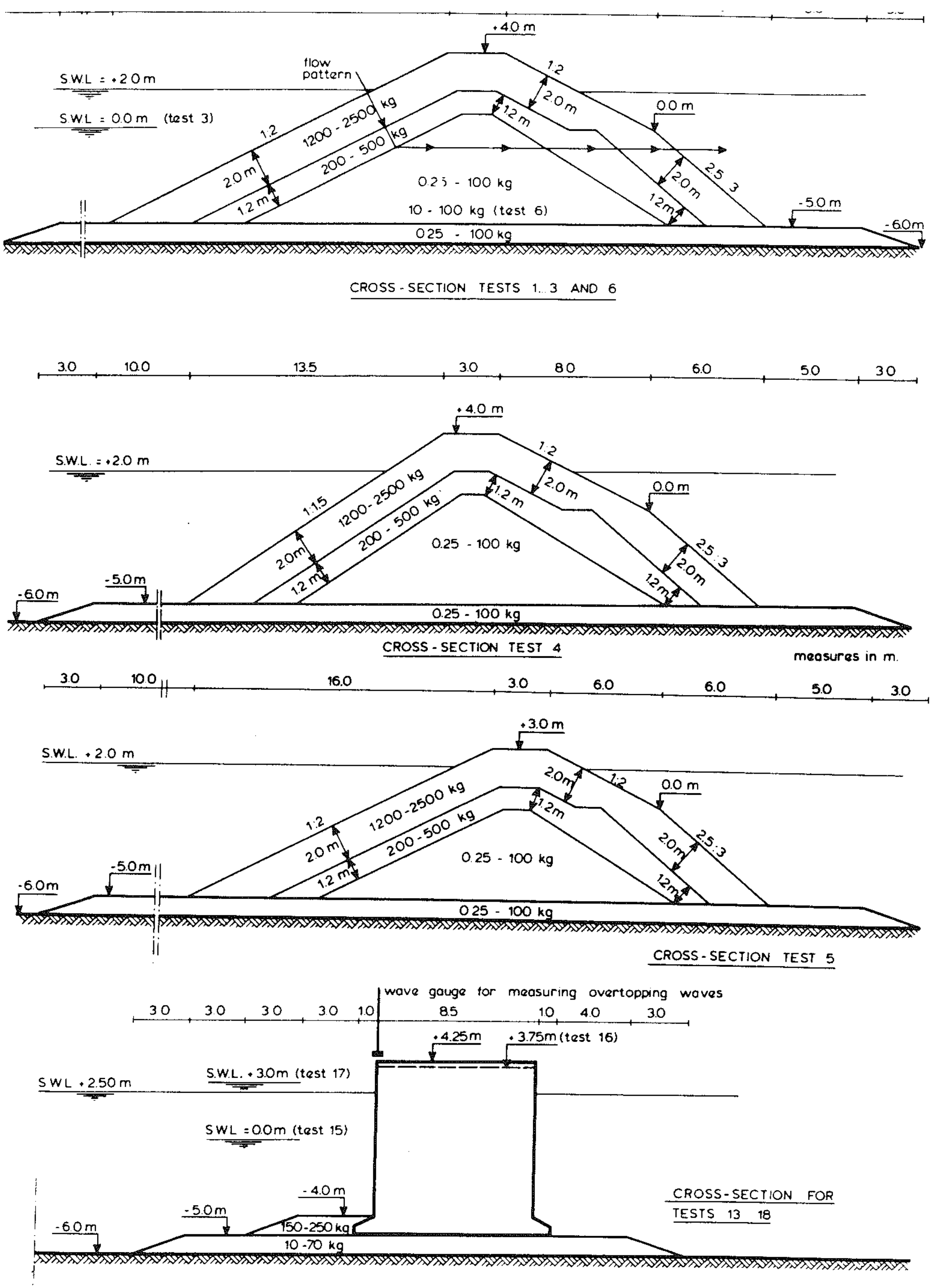


Cross sections of H1872 (1993) **Figure A1.7**

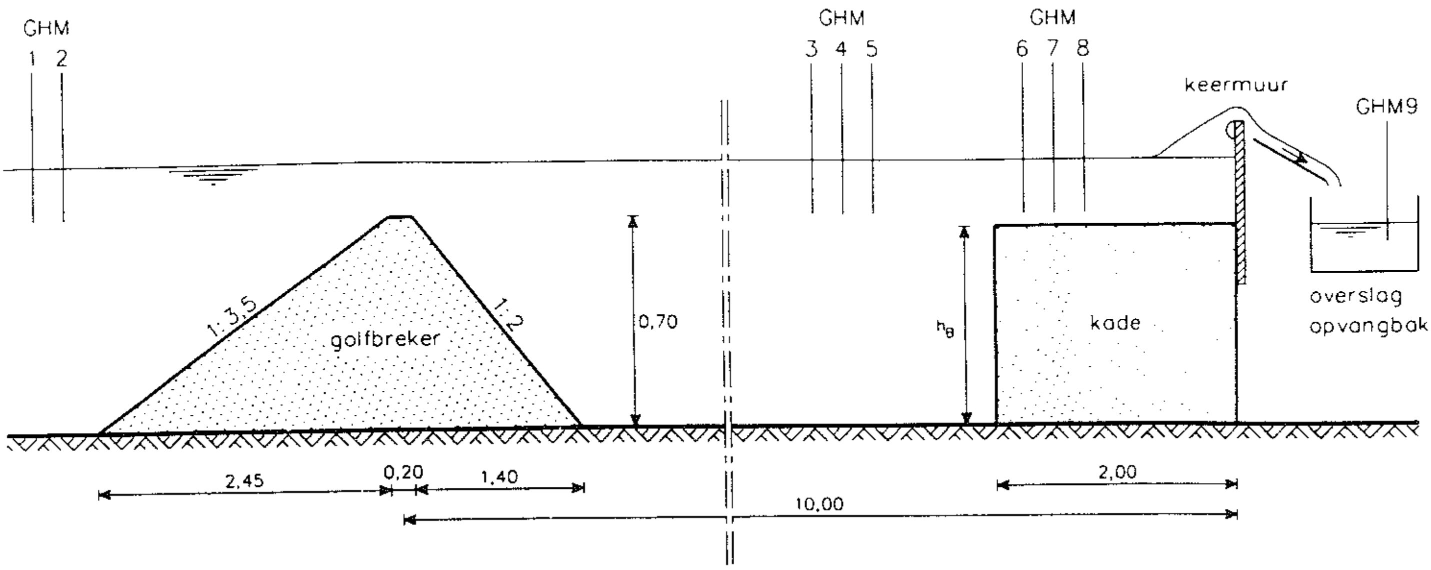


Serie 42a en 42b

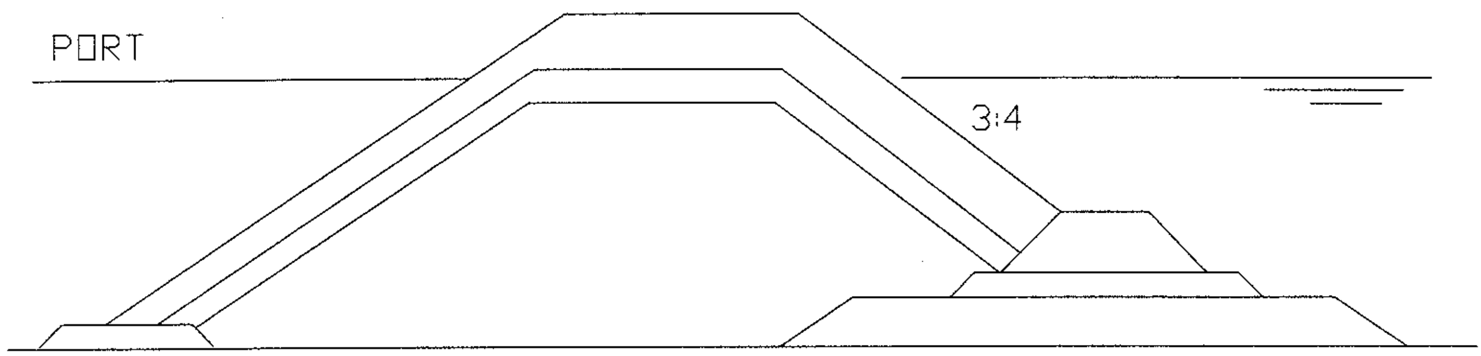
Cross section of H2061 (1994) **Figure A1.8**



Cross sections of M2090 (1985) **Figure A1.9**



Cross section of H2014 (1994) **Figure A1.10**



Cross section of Accropods **Figure A1.11**

ANNEX 2

Tables of data of various data sets

Test	h	Rc	Hsi	Tp	sop	Hst	Rc/Hsi	Kt	Rc/Dn50	Hsi/Dn50	Dn50	Ir	B/Lo	B/Hsi	Hsi/h
	m	m	m	s	-	m	m	m	-	-	m	-	-	-	
bw1	0.750	0.000	0.156	1.340	0.056	0.050	0.000	0.319				2.826	0.107	1.923	0.208
bw1	0.600	0.147	0.172	1.460	0.052	0.026	0.856	0.151				2.933	0.090	1.744	0.287
bw1	0.750	0.000	0.167	1.450	0.051	0.059	0.000	0.355				2.956	0.091	1.796	0.223
bw1	0.750	0.000	0.133	1.340	0.047	0.041	0.000	0.305				3.061	0.107	2.256	0.177
bw1	0.750	0.000	0.125	1.330	0.045	0.036	0.000	0.291				3.134	0.109	2.400	0.167
bw1	0.750	0.000	0.165	1.560	0.043	0.057	0.000	0.347				3.199	0.079	1.818	0.220
bw1	0.600	0.147	0.169	1.620	0.041	0.030	0.871	0.176				3.283	0.073	1.775	0.282
bw1	0.600	0.147	0.158	1.600	0.040	0.016	0.932	0.103				3.353	0.075	1.899	0.263
bw1	0.600	0.147	0.155	2.020	0.024	0.025	0.950	0.160				4.274	0.047	1.935	0.258
bw1	0.600	0.147	0.128	2.050	0.020	0.009	1.150	0.068				4.773	0.046	2.344	0.213
bw1	0.750	0.000	0.115	2.000	0.018	0.041	0.000	0.356				4.913	0.048	2.609	0.153
bw1	0.600	0.147	0.120	3.320	0.007	0.005	1.227	0.045				7.984	0.017	2.500	0.200
bw1	0.600	0.147	0.113	3.320	0.007	0.004	1.303	0.039				8.227	0.017	2.655	0.188
bw4	0.450	0.204	0.121	2.120	0.017	0.014	1.707	0.113	1.841	1.090	0.111	2.929	0.057	3.306	0.269
bw4	0.450	0.204	0.124	1.700	0.027	0.014	1.665	0.109	1.841	1.117	0.111	2.320	0.089	3.226	0.276
bw4	0.450	0.204	0.124	1.300	0.047	0.009	1.665	0.071	1.841	1.117	0.111	1.774	0.152	3.226	0.276
bw4	0.740	-0.080	0.133	2.120	0.019	0.072	-0.602	0.543	-0.721	1.198	0.111	2.794	0.057	3.008	0.180
bw4	0.600	0.060	0.148	2.230	0.019	0.034	0.405	0.228	0.541	1.333	0.111	2.786	0.052	2.703	0.247
bw4	0.600	0.060	0.150	2.230	0.019	0.035	0.400	0.231	0.541	1.351	0.111	2.767	0.052	2.667	0.250
bw4	0.600	0.060	0.146	2.120	0.021	0.033	0.411	0.229	0.541	1.315	0.111	2.666	0.057	2.740	0.243
bw4	0.600	0.060	0.147	2.120	0.021	0.033	0.408	0.226	0.541	1.324	0.111	2.657	0.057	2.721	0.245
bw4	0.740	-0.080	0.161	2.030	0.025	0.080	-0.497	0.495	-0.721	1.450	0.111	2.431	0.062	2.484	0.218
bw4	0.450	0.204	0.149	1.530	0.041	0.013	1.381	0.084	1.841	1.342	0.111	1.905	0.110	2.685	0.331
bw4	0.600	0.060	0.170	2.030	0.026	0.040	0.353	0.233	0.541	1.532	0.111	2.366	0.062	2.353	0.283
bw4	0.600	0.060	0.150	1.530	0.041	0.029	0.400	0.193	0.541	1.351	0.111	1.899	0.110	2.667	0.250
bw4	0.740	-0.080	0.156	1.530	0.043	0.076	-0.513	0.484	-0.721	1.405	0.111	1.862	0.110	2.564	0.211
bw4	0.740	-0.080	0.146	1.440	0.045	0.073	-0.548	0.501	-0.721	1.315	0.111	1.811	0.124	2.740	0.197
bw4	0.600	0.060	0.146	1.440	0.045	0.027	0.411	0.188	0.541	1.315	0.111	1.811	0.124	2.740	0.243
bw4	0.600	0.060	0.146	1.440	0.045	0.027	0.411	0.187	0.541	1.315	0.111	1.811	0.124	2.740	0.243
bw4	0.450	0.204	0.164	2.350	0.019	0.019	1.252	0.113	1.841	1.477	0.111	2.789	0.046	2.439	0.364
bw4	0.600	0.060	0.154	1.380	0.052	0.032	0.390	0.209	0.541	1.387	0.111	1.690	0.135	2.597	0.257
bw4	0.600	0.060	0.174	1.380	0.059	0.041	0.345	0.237	0.541	1.568	0.111	1.590	0.135	2.299	0.290
bw4w	0.850	-0.184	0.153	1.940	0.026	0.118	-1.214	0.768	-1.661	1.378	0.111	2.384	0.068	2.614	0.180
bw4w	0.850	-0.184	0.170	1.820	0.033	0.130	-1.089	0.766	-1.661	1.532	0.111	2.121	0.077	2.353	0.200
bw4w	0.850	-0.184	0.167	1.530	0.046	0.126	-1.110	0.755	-1.661	1.505	0.111	1.799	0.110	2.395	0.196
bw4w	0.850	-0.184	0.152	1.440	0.047	0.119	-1.222	0.786	-1.661	1.369	0.111	1.775	0.124	2.632	0.179
bw4w	0.800	-0.137	0.174	1.380	0.059	0.114	-0.805	0.658	-1.236	1.568	0.111	1.590	0.135	2.299	0.218
bw4w	0.760	-0.100	0.157	1.300	0.060	0.081	-0.637	0.518	-0.901	1.414	0.111	1.577	0.152	2.548	0.207
bw5	0.600	-0.270	0.134	1.160	0.064	0.089	-2.015	0.663	-2.432	1.207	0.111	2.639	0.191	2.985	0.223
bw5	0.600	-0.270	0.134	1.160	0.064	0.087	-2.015	0.652	-2.432	1.207	0.111	2.639	0.191	2.985	0.223
bw5	0.600	-0.270	0.158	1.260	0.064	0.125	-1.709	0.792	-2.432	1.423	0.111	2.639	0.162	2.532	0.263
bw5	0.750	-0.420	0.178	1.340	0.064	0.160	-2.360	0.898	-3.784	1.604	0.111	2.645	0.143	2.247	0.237
bw5	0.750	-0.420	0.177	1.340	0.063	0.157	-2.373	0.885	-3.784	1.595	0.111	2.652	0.143	2.260	0.236
bw5	0.450	-0.120	0.080	0.910	0.062	0.057	-1.500	0.708	-1.081	0.721	0.111	2.679	0.310	5.000	0.178
bw5	0.450	-0.120	0.122	1.300	0.046	0.087	-0.984	0.710	-1.081	1.099	0.111	3.099	0.152	3.279	0.271
bw5	0.600	-0.270	0.153	1.550	0.041	0.125	-1.765	0.815	-2.432	1.378	0.111	3.300	0.107	2.614	0.255
bw5	0.600	-0.270	0.152	1.550	0.041	0.124	-1.776	0.815	-2.432	1.369	0.111	3.310	0.107	2.632	0.253
bw5	0.450	-0.120	0.148	1.530	0.041	0.098	-0.811	0.662	-1.081	1.333	0.111	3.312	0.110	2.703	0.329
bw5	0.750	-0.420	0.096	1.450	0.029	0.079	-4.375	0.825	-3.784	0.865	0.111	3.897	0.122	4.167	0.128
bw5	0.750	-0.420	0.095	1.450	0.029	0.077	-4.421	0.807	-3.784	0.856	0.111	3.917	0.122	4.211	0.127
bw5	0.600	-0.270	0.171	1.970	0.028	0.139	-1.579	0.810	-2.432	1.541	0.111	3.967	0.066	2.339	0.285
bw5	0.600	-0.270	0.170	1.970	0.028	0.138	-1.588	0.814	-2.432	1.532	0.111	3.978	0.066	2.353	0.283
bw5	0.750	-0.420	0.153	1.880	0.028	0.126	-2.745	0.823	-3.784	1.378	0.111	4.002	0.073	2.614	0.204
bw5	0.750	-0.420	0.153	1.880	0.028	0.126	-2.745	0.826	-3.784	1.378	0.111	4.002	0.073	2.614	0.204
bw5	0.750	-0.420	0.151	1.880	0.027	0.116	-2.781	0.769	-3.784	1.360	0.111	4.028	0.073	2.649	0.201
bw5	0.450	-0.120	0.144	2.230	0.019	0.106	-0.833	0.735	-1.081	1.297	0.111	4.893	0.052	2.778	0.320
bw5	0.450	-0.120	0.158	2.350	0.018	0.108	-0.759	0.685	-1.081	1.423	0.111	4.923	0.046	2.532	0.351

Data of Seelig (1980) **Table A2.1**

Test	h	Rc	Hsi	Tp	sop	Hst	Rc/Hsi	Kt	Rc/Dn50	Hsi/Dn50	Dn50	Ir	B/Lo	B/Hsi	Hsi/h
	m	m	m	s	-	m	m	m	-	-	m	-	-	-	
bw5	0.450	-0.120	0.123	2.120	0.018	0.104	-0.976	0.842	-1.081	1.108	0.111	5.033	0.057	3.252	0.273
bw5	0.450	-0.120	0.122	2.120	0.017	0.097	-0.984	0.798	-1.081	1.099	0.111	5.054	0.057	3.279	0.271
bw5	0.600	-0.270	0.126	2.640	0.012	0.101	-2.143	0.804	-2.432	1.135	0.111	6.193	0.037	3.175	0.210
bw5	0.600	-0.270	0.125	2.640	0.011	0.097	-2.160	0.777	-2.432	1.126	0.111	6.218	0.037	3.200	0.208
bw5	0.750	-0.420	0.098	2.440	0.011	0.079	-4.286	0.803	-3.784	0.883	0.111	6.490	0.043	4.082	0.131
bw5	0.750	-0.420	0.099	2.460	0.010	0.083	-4.242	0.843	-3.784	0.892	0.111	6.510	0.042	4.040	0.132
bw5	0.600	-0.270	0.131	2.840	0.010	0.093	-2.061	0.713	-2.432	1.180	0.111	6.534	0.032	3.053	0.218
bw10	0.600	0.060	0.122	1.140	0.060	0.023	0.492	0.190	0.373	0.758	0.161	2.718	0.148	2.459	0.203
bw10	0.750	-0.090	0.160	1.340	0.057	0.065	-0.563	0.408	-0.559	0.994	0.161	2.789	0.107	1.875	0.213
bw10	0.450	0.210	0.158	1.360	0.055	0.010	1.329	0.062	1.304	0.981	0.161	2.849	0.104	1.899	0.351
bw10	0.750	-0.090	0.162	1.450	0.049	0.072	-0.556	0.447	-0.559	1.006	0.161	3.000	0.091	1.852	0.216
bw10	0.750	-0.090	0.130	1.340	0.046	0.060	-0.692	0.458	-0.559	0.807	0.161	3.095	0.107	2.308	0.173
bw10	0.600	0.060	0.162	1.510	0.046	0.031	0.370	0.191	0.373	1.006	0.161	3.124	0.084	1.852	0.270
bw10	0.750	-0.090	0.125	1.330	0.045	0.051	-0.720	0.405	-0.559	0.776	0.161	3.132	0.109	2.400	0.167
bw10	0.600	0.060	0.169	1.640	0.040	0.036	0.355	0.215	0.373	1.050	0.161	3.322	0.072	1.775	0.282
bw10	0.600	0.060	0.146	1.540	0.039	0.033	0.411	0.229	0.373	0.907	0.161	3.356	0.081	2.055	0.243
bw10	0.450	0.210	0.161	1.670	0.037	0.013	1.304	0.082	1.304	1.000	0.161	3.466	0.069	1.863	0.358
bw10	0.750	-0.090	0.170	1.720	0.037	0.071	-0.529	0.418	-0.559	1.056	0.161	3.474	0.065	1.765	0.227
bw10	0.450	0.210	0.154	2.210	0.020	0.014	1.364	0.090	1.304	0.957	0.161	4.689	0.039	1.948	0.342
bw10	0.750	-0.090	0.110	2.000	0.018	0.052	-0.818	0.475	-0.559	0.683	0.161	5.021	0.048	2.727	0.147
bw10	0.450	0.210	0.125	2.210	0.016	0.012	1.680	0.098	1.304	0.776	0.161	5.205	0.039	2.400	0.278
bw10	0.750	-0.090	0.103	2.640	0.009	0.057	-0.874	0.552	-0.559	0.640	0.161	6.849	0.028	2.913	0.137
bw10	0.600	0.060	0.144	3.240	0.009	0.041	0.417	0.286	0.373	0.894	0.161	7.109	0.018	2.083	0.240
bw10	0.450	0.210	0.123	3.460	0.007	0.015	1.707	0.126	1.304	0.764	0.161	8.215	0.016	2.439	0.273
bw10	0.600	0.060	0.112	3.320	0.007	0.030	0.536	0.268	0.373	0.696	0.161	8.260	0.017	2.679	0.187

Continued **Table A2.1**

Test	h	Rc	Hsi	Tp	sop	Hst	Rc/Hsi	Kt	Rc/Dn50	Hsi/Dn50	Dn	Ir	B/Lo	B/Hsi	Hsi/h
	m	-	m	s	-		-	-	m	-	-	-	-	-	-
All-short	0.348	0.080	0.163	1.802	0.030	0.062	0.490	0.380	2.000	4.075	0.040	2.876	0.032	0.982	0.468
All-short	0.348	0.080	0.136	1.698	0.030	0.037	0.590	0.270	2.000	3.400	0.040	2.876	0.036	1.176	0.391
All-short	0.348	0.080	0.108	1.513	0.030	0.015	0.740	0.140	2.000	2.700	0.040	2.876	0.045	1.481	0.310
All-short	0.348	0.080	0.081	1.310	0.030	0.010	0.990	0.120	2.000	2.025	0.040	2.876	0.060	1.975	0.233
All-short	0.310	0.121	0.148	1.771	0.030	0.030	0.820	0.200	3.025	3.700	0.040	2.876	0.033	1.081	0.477
All-short	0.310	0.121	0.146	1.759	0.030	0.026	0.830	0.180	3.025	3.650	0.040	2.876	0.033	1.096	0.471
All-short	0.310	0.121	0.127	1.641	0.030	0.015	0.950	0.120	3.025	3.175	0.040	2.876	0.038	1.260	0.410
All-short	0.310	0.121	0.127	1.641	0.030	0.014	0.950	0.110	3.025	3.175	0.040	2.876	0.038	1.260	0.410
All-short	0.310	0.121	0.095	1.419	0.030	0.009	1.270	0.090	3.025	2.375	0.040	2.876	0.051	1.684	0.306
All-short	0.310	0.121	0.099	1.449	0.030	0.007	1.220	0.075	3.025	2.475	0.040	2.876	0.049	1.616	0.319
All-short	0.310	0.121	0.073	1.244	0.030	0.005	1.660	0.070	3.025	1.825	0.040	2.876	0.066	2.192	0.235
All-short	0.310	0.121	0.049	1.019	0.030	0.003	2.450	0.070	3.025	1.225	0.040	2.876	0.099	3.265	0.158
All-short	0.275	0.154	0.132	1.673	0.030	0.013	1.170	0.100	3.025	2.593	0.051	2.876	0.037	1.212	0.480
All-short	0.275	0.154	0.117	1.575	0.030	0.018	1.320	0.150	3.025	2.298	0.051	2.876	0.041	1.368	0.425
All-short	0.275	0.154	0.097	1.434	0.030	0.005	1.580	0.055	3.025	1.905	0.051	2.876	0.050	1.649	0.353
All-short	0.275	0.154	0.067	1.192	0.030	0.003	2.300	0.050	3.025	1.316	0.051	2.876	0.072	2.388	0.244
All-short	0.275	0.154	0.049	1.019	0.030	0.002	3.150	0.050	3.025	0.963	0.051	2.876	0.099	3.265	0.178
All-long	0.310	0.121	0.130	3.170	0.008	0.029	0.930	0.220	3.025	3.250	0.040	5.493	0.010	1.231	0.419
All-long	0.310	0.121	0.123	3.170	0.008	0.023	0.980	0.190	3.025	3.075	0.040	5.647	0.010	1.301	0.397
All-long	0.274	0.156	0.115	3.170	0.007	0.013	1.360	0.115	3.900	2.875	0.040	5.840	0.010	1.391	0.420
All-long	0.274	0.156	0.111	3.170	0.007	0.013	1.410	0.120	3.900	2.775	0.040	5.944	0.010	1.441	0.405

Data of Allsop (1983) **Table A2.2**

Test	h	Rc	Hsi	Tp	sop	Hst	Rc/Hsi	Kt	Rc/Dn	Hsi/Dn	Dn	Ir	B/Lo	B/Hsi	Hs/h
	m	m	m	s	-	m	-	-	-	-	m	-	-	-	-
DaKa-Imp.	0.700	-0.200	0.061	1.230	0.026	0.054	-3.279	0.885				3.111	0.085	3.279	0.087
DaKa-Imp.	0.700	-0.200	0.104	1.630	0.025	0.083	-1.923	0.800				3.158	0.048	1.923	0.149
DaKa-Imp.	0.500	-0.200	0.160	2.040	0.025	0.129	-1.250	0.805				3.186	0.031	1.250	0.320
DaKa-Imp.	0.500	0.000	0.100	1.630	0.024	0.057	0.000	0.570				3.220	0.048	2.000	0.200
DaKa-Imp.	0.600	-0.100	0.099	1.630	0.024	0.070	-1.010	0.708				3.237	0.048	2.020	0.165
DaKa-Imp.	0.500	0.000	0.155	2.040	0.024	0.101	0.000	0.653				3.237	0.031	1.290	0.310
DaKa-Imp.	0.600	-0.100	0.155	2.040	0.024	0.124	-0.645	0.801				3.237	0.031	1.290	0.258
DaKa-Imp.	0.500	0.000	0.097	1.630	0.023	0.055	0.000	0.563				3.270	0.048	2.062	0.194
DaKa-Imp.	0.500	0.000	0.055	1.230	0.023	0.024	0.000	0.437				3.277	0.085	3.636	0.110
DaKa-Imp.	0.600	-0.100	0.055	1.230	0.023	0.042	-1.818	0.772				3.277	0.085	3.636	0.092
DaKa-Imp.	0.500	-0.200	0.206	2.450	0.022	0.174	-0.971	0.846				3.372	0.021	0.971	0.412
DaKa-Imp.	0.500	-0.200	0.205	2.450	0.022	0.158	-0.976	0.772				3.381	0.021	0.976	0.410
DaKa-Imp.	0.600	-0.100	0.196	2.450	0.021	0.164	-0.510	0.835				3.457	0.021	1.020	0.327
DaKa-Imp.	0.500	0.000	0.194	2.450	0.021	0.139	0.000	0.715				3.475	0.021	1.031	0.388
DaKa-Imp.	0.600	-0.100	0.132	2.040	0.020	0.105	-0.758	0.793				3.508	0.031	1.515	0.220
DaKa-Imp.	0.500	-0.200	0.129	2.040	0.020	0.097	-1.550	0.749				3.549	0.031	1.550	0.258
DaKa-Imp.	0.700	-0.200	0.078	1.630	0.019	0.061	-2.564	0.782				3.646	0.048	2.564	0.111
DaKa-Imp.	0.500	0.000	0.121	2.040	0.019	0.075	0.000	0.616				3.664	0.031	1.653	0.242
DaKa-Imp.	0.500	0.000	0.168	2.450	0.018	0.114	0.000	0.680				3.734	0.021	1.190	0.336
DaKa-Imp.	0.600	-0.100	0.071	1.630	0.017	0.051	-1.408	0.713				3.822	0.048	2.817	0.118
DaKa-Imp.	0.600	-0.100	0.160	2.450	0.017	0.129	-0.625	0.809				3.827	0.021	1.250	0.267
DaKa-Imp.	0.600	-0.100	0.212	2.860	0.017	0.175	-0.472	0.825				3.881	0.016	0.943	0.353
DaKa-Imp.	0.500	0.000	0.068	1.630	0.016	0.034	0.000	0.494				3.905	0.048	2.941	0.136
DaKa-Imp.	0.600	-0.100	0.101	2.040	0.016	0.076	-0.990	0.752				4.010	0.031	1.980	0.168
DaKa-Imp.	0.600	-0.100	0.197	2.860	0.015	0.150	-0.508	0.763				4.026	0.016	1.015	0.328
DaKa-Imp.	0.500	-0.200	0.099	2.040	0.015	0.074	-2.020	0.749				4.051	0.031	2.020	0.198
DaKa-Imp.	0.500	0.000	0.192	2.860	0.015	0.143	0.000	0.747				4.078	0.016	1.042	0.384
DaKa-Imp.	0.500	0.000	0.174	2.860	0.014	0.124	0.000	0.713				4.284	0.016	1.149	0.348
DaKa-Imp.	0.500	0.000	0.082	2.040	0.013	0.045	0.000	0.552				4.451	0.031	2.439	0.164
DaKa-Imp.	0.500	0.000	0.118	2.450	0.013	0.073	0.000	0.621				4.456	0.021	1.695	0.236
DaKa-Imp.	0.600	-0.100	0.160	2.860	0.013	0.129	-0.625	0.805				4.467	0.016	1.250	0.267
DaKa-Imp.	0.600	-0.100	0.116	2.450	0.012	0.091	-0.862	0.782				4.494	0.021	1.724	0.193
DaKa-Imp.	0.600	-0.100	0.206	3.270	0.012	0.171	-0.485	0.828				4.501	0.012	0.971	0.343
DaKa-Imp.	0.700	-0.200	0.051	1.630	0.012	0.042	-3.922	0.825				4.509	0.048	3.922	0.073
DaKa-Imp.	0.500	0.000	0.204	3.270	0.012	0.148	0.000	0.724				4.523	0.012	0.980	0.408
DaKa-Imp.	0.500	0.000	0.194	3.270	0.012	0.140	0.000	0.724				4.638	0.012	1.031	0.388
DaKa-Imp.	0.500	0.000	0.027	1.230	0.011	0.011	0.000	0.414				4.677	0.085	7.407	0.054
DaKa-Imp.	0.600	-0.100	0.188	3.270	0.011	0.125	-0.532	0.664				4.712	0.012	1.064	0.313
DaKa-Imp.	0.600	-0.100	0.044	1.630	0.011	0.032	-2.273	0.731				4.855	0.048	4.545	0.073
DaKa-Imp.	0.500	0.000	0.177	3.270	0.011	0.123	0.000	0.694				4.856	0.012	1.130	0.354
DaKa-Imp.	0.700	-0.200	0.025	1.230	0.011	0.023	-8.000	0.917				4.860	0.085	8.000	0.036
DaKa-Imp.	0.500	0.000	0.131	2.860	0.010	0.087	0.000	0.667				4.937	0.016	1.527	0.262
DaKa-Imp.	0.600	-0.100	0.024	1.230	0.010	0.020	-4.167	0.837				4.960	0.085	8.333	0.040
DaKa-Imp.	0.700	-0.200	0.065	2.040	0.010	0.050	-3.077	0.763				4.999	0.031	3.077	0.093
DaKa-Imp.	0.600	-0.100	0.128	3.270	0.008	0.102	-0.781	0.793				5.710	0.012	1.563	0.213

Data of Daemrich & Kahle (1985) Impermeable **Table A2.3a**

Test	h	Rc	Hsi	Tp	sop	Hst	Rc/Hsi	Kt	Rc/Dn	Hsi/Dn	Dn	Ir	B/Lo	B/Hsi	Hsi/h
	m	m	m	s	-	m	-	-	-	-	m	-	-	-	-
DaKa 0.2	0.700	-0.200	0.023	1.230	0.010	0.021	-8.696	0.897	-2.564	0.295	0.078	5.067	0.085	8.696	0.033
DaKa 0.2	0.700	-0.200	0.039	1.630	0.009	0.031	-5.128	0.800	-2.564	0.500	0.078	5.157	0.048	5.128	0.056
DaKa 0.2	0.600	-0.100	0.025	1.230	0.011	0.019	-4.000	0.763	-1.282	0.321	0.078	4.860	0.085	8.000	0.042
DaKa 0.2	0.700	-0.200	0.051	1.230	0.022	0.042	-3.922	0.832	-2.564	0.654	0.078	3.403	0.085	3.922	0.073
DaKa 0.2	0.700	-0.200	0.070	1.630	0.017	0.053	-2.857	0.752	-2.564	0.897	0.078	3.849	0.048	2.857	0.100
DaKa 0.2	0.600	-0.100	0.037	1.630	0.009	0.026	-2.703	0.690	-1.282	0.474	0.078	5.294	0.048	5.405	0.062
DaKa 0.2	0.700	-0.200	0.093	2.040	0.014	0.067	-2.151	0.722	-2.564	1.192	0.078	4.179	0.031	2.151	0.133
DaKa 0.2	0.700	-0.200	0.097	1.630	0.023	0.072	-2.062	0.745	-2.564	1.244	0.078	3.270	0.048	2.062	0.139
DaKa 0.2	0.700	-0.200	0.101	2.860	0.008	0.074	-1.980	0.736	-2.564	1.295	0.078	5.622	0.016	1.980	0.144
DaKa 0.2	0.600	-0.100	0.051	1.230	0.022	0.039	-1.961	0.766	-1.282	0.654	0.078	3.403	0.085	3.922	0.085
DaKa 0.2	0.700	-0.200	0.112	2.450	0.012	0.081	-1.786	0.726	-2.564	1.436	0.078	4.574	0.021	1.786	0.160
DaKa 0.2	0.700	-0.200	0.123	2.040	0.019	0.090	-1.626	0.729	-2.564	1.577	0.078	3.634	0.031	1.626	0.176
DaKa 0.2	0.500	0.000	0.024	1.230	0.010	0.010	0.000	0.416	0.000	0.308	0.078	4.960	0.085	8.333	0.048
DaKa 0.2	0.500	0.000	0.040	1.630	0.010	0.014	0.000	0.361	0.000	0.513	0.078	5.092	0.048	5.000	0.080
DaKa 0.2	0.500	0.000	0.055	1.230	0.023	0.020	0.000	0.372	0.000	0.705	0.078	3.277	0.085	3.636	0.110
DaKa 0.2	0.600	-0.100	0.068	1.630	0.016	0.046	-1.471	0.676	-1.282	0.872	0.078	3.905	0.048	2.941	0.113
DaKa 0.2	0.500	0.000	0.072	1.630	0.017	0.026	0.000	0.366	0.000	0.923	0.078	3.795	0.048	2.778	0.144
DaKa 0.2	0.600	-0.100	0.096	2.040	0.015	0.064	-1.042	0.671	-1.282	1.231	0.078	4.113	0.031	2.083	0.160
DaKa 0.2	0.600	-0.100	0.097	1.630	0.023	0.068	-1.031	0.703	-1.282	1.244	0.078	3.270	0.048	2.062	0.162
DaKa 0.2	0.500	0.000	0.098	2.860	0.008	0.047	0.000	0.481	0.000	1.256	0.078	5.708	0.016	2.041	0.196
DaKa 0.2	0.500	0.000	0.098	2.040	0.015	0.039	0.000	0.400	0.000	1.256	0.078	4.071	0.031	2.041	0.196
DaKa 0.2	0.600	-0.100	0.099	2.860	0.008	0.066	-1.010	0.667	-1.282	1.269	0.078	5.679	0.016	2.020	0.165
DaKa 0.2	0.500	0.000	0.100	1.630	0.024	0.039	0.000	0.391	0.000	1.282	0.078	3.220	0.048	2.000	0.200
DaKa 0.2	0.500	0.000	0.118	2.450	0.013	0.055	0.000	0.462	0.000	1.513	0.078	4.456	0.021	1.695	0.236
DaKa 0.2	0.600	-0.100	0.127	2.040	0.020	0.088	-0.787	0.690	-1.282	1.628	0.078	3.576	0.031	1.575	0.212
DaKa 0.2	0.500	0.000	0.127	3.270	0.008	0.065	0.000	0.508	0.000	1.628	0.078	5.733	0.012	1.575	0.254
DaKa 0.2	0.500	0.000	0.128	2.040	0.020	0.057	0.000	0.444	0.000	1.641	0.078	3.562	0.031	1.563	0.256
DaKa 0.2	0.700	-0.200	0.129	3.270	0.008	0.096	-1.550	0.747	-2.564	1.654	0.078	5.688	0.012	1.550	0.184
DaKa 0.2	0.600	-0.100	0.137	3.270	0.008	0.093	-0.730	0.678	-1.282	1.756	0.078	5.520	0.012	1.460	0.228
DaKa 0.2	0.600	-0.100	0.143	2.450	0.015	0.096	-0.699	0.669	-1.282	1.833	0.078	4.048	0.021	1.399	0.238
DaKa 0.2	0.700	-0.200	0.153	2.040	0.024	0.114	-1.307	0.747	-2.564	1.962	0.078	3.258	0.031	1.307	0.219
DaKa 0.2	0.500	0.000	0.154	2.040	0.024	0.074	0.000	0.483	0.000	1.974	0.078	3.248	0.031	1.299	0.308
DaKa 0.2	0.600	-0.100	0.155	2.040	0.024	0.112	-0.645	0.722	-1.282	1.987	0.078	3.237	0.031	1.290	0.258
DaKa 0.2	0.700	-0.200	0.157	2.450	0.017	0.122	-1.274	0.779	-2.564	2.013	0.078	3.863	0.021	1.274	0.224
DaKa 0.2	0.600	-0.100	0.158	2.860	0.012	0.117	-0.633	0.738	-1.282	2.026	0.078	4.495	0.016	1.266	0.263
DaKa 0.2	0.600	-0.100	0.158	2.450	0.017	0.116	-0.633	0.735	-1.282	2.026	0.078	3.851	0.021	1.266	0.263
DaKa 0.2	0.500	0.000	0.160	2.860	0.013	0.091	0.000	0.570	0.000	2.051	0.078	4.467	0.016	1.250	0.320
DaKa 0.2	0.500	0.000	0.161	2.450	0.017	0.081	0.000	0.506	0.000	2.064	0.078	3.815	0.021	1.242	0.322
DaKa 0.2	0.500	0.000	0.164	3.270	0.010	0.091	0.000	0.552	0.000	2.103	0.078	5.045	0.012	1.220	0.328
DaKa 0.2	0.700	-0.200	0.165	3.270	0.010	0.133	-1.212	0.807	-2.564	2.115	0.078	5.029	0.012	1.212	0.236
DaKa 0.2	0.700	-0.200	0.169	2.860	0.013	0.133	-1.183	0.786	-2.564	2.167	0.078	4.346	0.016	1.183	0.241
DaKa 0.2	0.600	-0.100	0.176	3.270	0.011	0.131	-0.568	0.745	-1.282	2.256	0.078	4.870	0.012	1.136	0.293
DaKa 0.2	0.600	-0.100	0.187	2.450	0.020	0.147	-0.535	0.784	-1.282	2.397	0.078	3.540	0.021	1.070	0.312
DaKa 0.2	0.500	0.000	0.188	2.450	0.020	0.098	0.000	0.522	0.000	2.410	0.078	3.530	0.021	1.064	0.376
DaKa 0.2	0.500	0.000	0.189	3.270	0.011	0.109	0.000	0.575	0.000	2.423	0.078	4.699	0.012	1.058	0.378
DaKa 0.2	0.500	0.000	0.192	2.860	0.015	0.115	0.000	0.598	0.000	2.462	0.078	4.078	0.016	1.042	0.384
DaKa 0.2	0.700	-0.200	0.196	2.450	0.021	0.159	-1.020	0.809	-2.564	2.513	0.078	3.457	0.021	1.020	0.280
DaKa 0.2	0.700	-0.200	0.205	3.270	0.012	0.164	-0.976	0.800	-2.564	2.628	0.078	4.512	0.012	0.976	0.293
DaKa 0.2	0.600	-0.100	0.210	3.270	0.013	0.155	-0.476	0.736	-1.282	2.692	0.078	4.458	0.012	0.952	0.350
DaKa 0.2	0.600	-0.100	0.212	2.860	0.017	0.159	-0.472	0.752	-1.282	2.718	0.078	3.881	0.016	0.943	0.353
DaKa 0.2	0.700	-0.200	0.225	2.860	0.018	0.189	-0.889	0.841	-2.564	2.885	0.078	3.767	0.016	0.889	0.321

Data of Daemrich & Kahle (1985) B=0.20 m **Table A2.3b**

Test	h	Rc	Hsi	Tp	sop	Hst	Rc/Hsi	Kt	Rc/Dn	Hsi/Dn	Dn	Ir	B/Lo	B/Hsi	Hsi/h
	m	m	m	s	-	m	-	-	-	-	m	-	-	-	-
Daka 1.0	0.700	-0.200	0.024	1.230	0.010	0.021	-8.333	0.855	-2.554	0.307	0.078	4.960	0.424	41.67	0.034
Daka 1.0	0.700	-0.200	0.041	1.630	0.010	0.029	-4.878	0.706	-2.554	0.524	0.078	5.029	0.241	24.39	0.059
Daka 1.0	0.600	-0.100	0.024	1.230	0.010	0.016	-4.167	0.646	-1.277	0.307	0.078	4.960	0.424	41.67	0.040
Daka 1.0	0.700	-0.200	0.055	1.230	0.023	0.044	-3.636	0.800	-2.554	0.702	0.078	3.277	0.424	18.18	0.079
Daka 1.0	0.700	-0.200	0.074	1.630	0.018	0.050	-2.703	0.671	-2.554	0.945	0.078	3.744	0.241	13.51	0.106
Daka 1.0	0.700	-0.200	0.097	2.040	0.015	0.062	-2.062	0.635	-2.554	1.239	0.078	4.092	0.154	10.31	0.139
Daka 1.0	0.700	-0.200	0.097	2.86	0.008	0.061	-2.062	0.632	-2.554	1.239	0.078	5.737	0.078	10.31	0.139
Daka 1.0	0.500	0.000	0.023	1.230	0.010	0.006	0.000	0.251	0.000	0.294	0.078	5.067	0.424	43.48	0.046
Daka 1.0	0.500	0.000	0.040	1.630	0.010	0.008	0.000	0.209	0.000	0.511	0.078	5.092	0.241	25.00	0.080
Daka 1.0	0.500	0.000	0.051	1.230	0.022	0.008	0.000	0.161	0.000	0.651	0.078	3.403	0.424	19.61	0.102
Daka 1.0	0.600	-0.100	0.055	1.230	0.023	0.035	-1.818	0.632	-1.277	0.702	0.078	3.277	0.424	18.18	0.092
Daka 1.0	0.500	0.000	0.070	1.630	0.017	0.010	0.000	0.138	0.000	0.894	0.078	3.849	0.241	14.29	0.140
Daka 1.0	0.600	-0.100	0.071	1.630	0.017	0.039	-1.408	0.554	-1.277	0.907	0.078	3.822	0.241	14.08	0.118
Daka 1.0	0.500	0.000	0.095	2.040	0.015	0.016	0.000	0.166	0.000	1.213	0.078	4.135	0.154	10.53	0.190
Daka 1.0	0.500	0.000	0.095	2.860	0.007	0.026	0.000	0.276	0.000	1.213	0.078	5.797	0.078	10.53	0.190
Daka 1.0	0.500	0.000	0.097	1.630	0.023	0.014	0.000	0.149	0.000	1.239	0.078	3.270	0.241	10.31	0.194
Daka 1.0	0.600	-0.100	0.098	2.040	0.015	0.048	-1.020	0.485	-1.277	1.252	0.078	4.071	0.154	10.20	0.163
Daka 1.0	0.600	-0.100	0.099	1.630	0.024	0.054	-1.010	0.549	-1.277	1.264	0.078	3.237	0.241	10.10	0.165
Daka 1.0	0.700	-0.200	0.104	1.630	0.025	0.069	-1.923	0.662	-2.554	1.328	0.078	3.158	0.241	9.62	0.149
Daka 1.0	0.500	0.000	0.115	2.450	0.012	0.032	0.000	0.276	0.000	1.469	0.078	4.514	0.107	8.70	0.230
Daka 1.0	0.600	-0.100	0.116	2.450	0.012	0.061	-0.862	0.529	-1.277	1.481	0.078	4.494	0.107	8.62	0.193
Daka 1.0	0.700	-0.200	0.118	2.450	0.013	0.076	-1.695	0.641	-2.554	1.507	0.078	4.456	0.107	8.47	0.169
Daka 1.0	0.500	0.000	0.124	2.040	0.019	0.027	0.000	0.218	0.000	1.584	0.078	3.619	0.154	8.06	0.248
Daka 1.0	0.500	0.000	0.125	3.270	0.007	0.041	0.000	0.324	0.000	1.596	0.078	5.778	0.060	8.00	0.250
Daka 1.0	0.600	-0.100	0.128	2.040	0.020	0.067	-0.781	0.520	-1.277	1.635	0.078	3.562	0.154	7.81	0.213
Daka 1.0	0.600	-0.100	0.129	3.270	0.008	0.075	-0.775	0.582	-1.277	1.648	0.078	5.688	0.060	7.75	0.215
Daka 1.0	0.700	-0.200	0.130	2.86	0.010	0.086	-1.538	0.658	-2.554	1.660	0.078	4.956	0.078	7.69	0.186
Daka 1.0	0.700	-0.200	0.130	3.27	0.008	0.087	-1.538	0.669	-2.554	1.660	0.078	5.666	0.060	7.69	0.186
Daka 1.0	0.500	0.000	0.151	2.040	0.023	0.039	0.000	0.260	0.000	1.928	0.078	3.280	0.154	6.62	0.302
Daka 1.0	0.700	-0.200	0.158	2.040	0.024	0.131	-1.266	0.830	-2.554	2.018	0.078	3.206	0.154	6.33	0.226
Daka 1.0	0.600	-0.100	0.158	2.040	0.024	0.089	-0.633	0.566	-1.277	2.018	0.078	3.206	0.154	6.33	0.263
Daka 1.0	0.600	-0.100	0.160	2.450	0.017	0.093	-0.625	0.582	-1.277	2.043	0.078	3.827	0.107	6.25	0.267
Daka 1.0	0.600	-0.100	0.160	2.860	0.013	0.097	-0.625	0.609	-1.277	2.043	0.078	4.467	0.078	6.25	0.267
Daka 1.0	0.700	-0.200	0.161	2.86	0.013	0.113	-1.242	0.703	-2.554	2.056	0.078	4.453	0.078	6.21	0.230
Daka 1.0	0.700	-0.200	0.162	2.450	0.017	0.114	-1.235	0.703	-2.554	2.069	0.078	3.803	0.107	6.17	0.231
Daka 1.0	0.600	-0.100	0.171	3.270	0.010	0.110	-0.585	0.641	-1.277	2.184	0.078	4.940	0.060	5.85	0.285
Daka 1.0	0.700	-0.200	0.173	3.27	0.010	0.123	-1.156	0.713	-2.554	2.209	0.078	4.912	0.060	5.78	0.247
Daka 1.0	0.500	0.000	0.182	3.270	0.011	0.070	0.000	0.386	0.000	2.324	0.078	4.789	0.060	5.49	0.364
Daka 1.0	0.500	0.000	0.186	2.860	0.015	0.078	0.000	0.418	0.000	2.375	0.078	4.143	0.078	5.38	0.372
Daka 1.0	0.600	-0.100	0.197	2.450	0.021	0.125	-0.508	0.634	-1.277	2.516	0.078	3.449	0.107	5.08	0.328
Daka 1.0	0.700	-0.200	0.205	2.450	0.022	0.153	-0.976	0.745	-2.554	2.618	0.078	3.381	0.107	4.88	0.293
Daka 1.0	0.600	-0.100	0.216	2.860	0.017	0.142	-0.463	0.658	-1.277	2.759	0.078	3.845	0.078	4.63	0.360
Daka 1.0	0.700	-0.200	0.217	3.27	0.013	0.159	-0.922	0.731	-2.554	2.771	0.078	4.386	0.060	4.61	0.310
Daka 1.0	0.700	-0.200	0.218	2.86	0.017	0.162	-0.917	0.745	-2.554	2.784	0.078	3.827	0.078	4.59	0.311

Data of Daemrich & Kahle (1985) B=1.0 m **Table A2.3c**

Test	h	Rc	Hs	Tp	sop	Ht	Rc/Hs	Kt	Rc/Dn50	Hsi/Dn50	Dn50	Ir	B/Lo	B/Hsi	Hsi/h
		m	m	s	-	m	-	-	-	-	m	-	-	-	-
PoAL-2	0.439	-0.141	0.184	2.160	0.025	0.139	-0.767	0.755	-1.854	2.416	0.076	4.199	0.019	0.741	0.418
PoAL-2	0.439	-0.141	0.117	1.640	0.028	0.094	-1.202	0.802	-1.854	1.543	0.076	3.989	0.032	1.160	0.267
PoAL-2	0.298	0.000	0.115	1.640	0.027	0.060	0.000	0.520	0.000	1.507	0.076	4.037	0.032	1.187	0.384
PoAL-2	0.219	0.079	0.118	1.640	0.028	0.030	0.665	0.254	1.035	1.555	0.076	3.974	0.032	1.151	0.540
PoAl-3	0.439	-0.141	0.184	2.160	0.025	0.139	-0.767	0.755	-1.566	2.040	0.090	4.199	0.009	0.370	0.418
PoAl-3	0.439	-0.141	0.117	1.640	0.028	0.101	-1.202	0.864	-1.566	1.303	0.090	3.989	0.016	0.580	0.267
PoAl-3	0.298	0.000	0.115	1.640	0.027	0.064	0.000	0.556	0.000	1.273	0.090	4.037	0.016	0.594	0.384
PoAl-3	0.219	0.079	0.118	1.640	0.028	0.039	0.665	0.327	0.874	1.313	0.090	3.974	0.016	0.575	0.540
PoAl-4	0.439	-0.141	0.184	2.160	0.025	0.134	-0.767	0.730	-1.854	2.416	0.076	2.099	0.019	0.741	0.418
PoAl-4	0.439	-0.141	0.117	1.640	0.028	0.103	-1.202	0.876	-1.854	1.543	0.076	1.995	0.032	1.160	0.267
PoAl-4	0.298	0.000	0.115	1.640	0.027	0.059	0.000	0.512	0.000	1.507	0.076	2.018	0.032	1.187	0.384
PoAl-4	0.219	0.079	0.118	1.640	0.028	0.028	0.665	0.235	1.035	1.555	0.076	1.987	0.032	1.151	0.540
PoAl-5	0.439	-0.186	0.184	2.160	0.025	0.142	-1.015	0.775	-2.452	2.416	0.076	4.199	0.028	1.111	0.418
PoAl-5	0.439	-0.186	0.117	1.640	0.028	0.100	-1.589	0.857	-2.452	1.543	0.076	3.989	0.049	1.740	0.267
PoAl-5	0.298	-0.045	0.115	1.640	0.027	0.068	-0.397	0.595	-0.598	1.507	0.076	4.037	0.049	1.781	0.384
PoAl-5	0.219	0.033	0.118	1.640	0.028	0.042	0.281	0.358	0.437	1.555	0.076	3.974	0.049	1.726	0.540
PoAl-5final	0.439	-0.186	0.143	1.860	0.027	0.122	-1.302	0.851	-2.452	1.884	0.076	4.095	0.038	1.425	0.326
PoAl-5final	0.439	-0.186	0.222	2.300	0.027	0.164	-0.838	0.738	-2.452	2.925	0.076	4.064	0.025	0.918	0.506
PoAl-5final	0.439	-0.186	0.197	2.160	0.027	0.152	-0.945	0.770	-2.452	2.596	0.076	4.051	0.028	1.034	0.449
PoAl-5final	0.403	-0.150	0.151	1.860	0.028	0.123	-0.994	0.813	-1.974	1.986	0.076	3.988	0.038	1.352	0.374
PoAl-5final	0.298	-0.045	0.147	1.860	0.027	0.092	-0.309	0.627	-0.598	1.938	0.076	4.037	0.038	1.385	0.494
PoAl-6	0.439	-0.232	0.184	2.160	0.025	0.152	-1.262	0.829	-3.050	2.416	0.076	4.199	0.024	0.969	0.418
PoAl-6	0.439	-0.232	0.117	1.640	0.028	0.105	-1.977	0.891	-3.050	1.543	0.076	3.989	0.042	1.518	0.267
PoAl-6	0.298	-0.091	0.115	1.640	0.027	0.078	-0.794	0.679	-1.196	1.507	0.076	4.037	0.042	1.554	0.384
PoAl-6	0.219	-0.012	0.118	1.640	0.028	0.049	-0.104	0.412	-0.161	1.555	0.076	3.974	0.042	1.506	0.540
PoAl-7	0.439	-0.277	0.184	2.160	0.025	0.161	-1.510	0.879	-3.648	2.416	0.076	4.199	0.020	0.773	0.418
PoAl-7	0.439	-0.277	0.117	1.640	0.028	0.111	-2.364	0.946	-3.648	1.543	0.076	3.989	0.034	1.211	0.267
PoAl-7	0.298	-0.136	0.115	1.640	0.027	0.093	-1.190	0.813	-1.794	1.507	0.076	4.037	0.034	1.240	0.384
PoAl-7	0.219	-0.058	0.118	1.640	0.028	0.075	-0.488	0.631	-0.760	1.555	0.076	3.974	0.034	1.202	0.540
PoAl-8	0.403	-0.150	0.095	1.390	0.031	0.082	-1.587	0.870	-1.974	1.244	0.076	3.766	0.106	3.363	0.235
PoAl-8	0.439	-0.186	0.092	1.390	0.031	0.090	-2.020	0.980	-2.452	1.214	0.076	3.812	0.106	3.446	0.210
PoAl-8	0.298	-0.045	0.091	1.390	0.030	0.050	-0.500	0.545	-0.598	1.196	0.076	3.840	0.106	3.498	0.305
PoAl-8	0.219	0.033	0.090	1.390	0.030	0.027	0.367	0.302	0.437	1.190	0.076	3.850	0.106	3.516	0.413
PoAl-8	0.403	-0.150	0.120	1.640	0.029	0.092	-1.245	0.766	-1.974	1.585	0.076	3.936	0.076	2.640	0.299
PoAl-8	0.403	-0.150	0.154	1.860	0.029	0.107	-0.973	0.693	-1.974	2.028	0.076	3.947	0.059	2.064	0.382
PoAl-8	0.219	0.033	0.118	1.640	0.028	0.040	0.281	0.338	0.437	1.555	0.076	3.974	0.076	2.691	0.540
PoAl-8	0.298	-0.045	0.151	1.860	0.028	0.073	-0.301	0.482	-0.598	1.986	0.076	3.988	0.059	2.107	0.506
PoAl-8	0.439	-0.186	0.117	1.640	0.028	0.098	-1.589	0.837	-2.452	1.543	0.076	3.989	0.076	2.712	0.267
PoAl-8	0.403	-0.150	0.203	2.160	0.028	0.132	-0.738	0.649	-1.973	2.673	0.076	3.992	0.044	1.565	0.504
PoAl-8	0.439	-0.186	0.150	1.860	0.028	0.112	-1.239	0.743	-2.453	1.980	0.076	3.995	0.059	2.114	0.343
PoAl-8	0.298	-0.045	0.115	1.640	0.027	0.061	-0.397	0.536	-0.598	1.507	0.076	4.037	0.076	2.776	0.384
PoAl-8	0.439	-0.186	0.184	2.160	0.025	0.134	-1.015	0.728	-2.452	2.416	0.076	4.199	0.044	1.732	0.418

Data of Powell & Allsop (1985) **Table A2.4**

Test	h	Rc	Hmoi	Tp	sop	Hst	Rc/Hmoi	Kt	Rc/Dn50	Hsi/Dn50	Dn50	Ir	B/Lo	B/Hsi	Hsi/h
	m	m	m	s	-	m	-	-	-	-	m	-	-	-	-
Meer	0.400	0.003	0.075	2.530	0.008	0.032	0.040	0.424	0.087	2.180	0.034	5.772	0.030	3.987	0.188
Meer	0.400	0.128	0.076	2.500	0.008	0.007	1.684	0.087	3.721	2.209	0.034	5.666	0.031	3.934	0.190
Meer	0.400	-0.088	0.099	2.560	0.010	0.080	-0.889	0.810	-2.558	2.878	0.034	5.083	0.029	3.020	0.248
Meer	0.400	0.007	0.100	2.560	0.010	0.044	0.070	0.442	0.203	2.907	0.034	5.058	0.029	2.990	0.250
Meer	0.400	0.123	0.100	2.560	0.010	0.008	1.230	0.078	3.576	2.907	0.034	5.058	0.029	2.990	0.250
Meer	0.400	0.132	0.119	2.600	0.011	0.010	1.109	0.082	3.837	3.459	0.034	4.709	0.028	2.513	0.298
Meer	0.400	0.011	0.118	2.560	0.012	0.054	0.093	0.459	0.320	3.430	0.034	4.656	0.029	2.534	0.295
Meer	0.400	-0.090	0.118	2.560	0.012	0.091	-0.763	0.770	-2.616	3.430	0.034	4.656	0.029	2.534	0.295
Meer	0.400	0.131	0.127	2.560	0.012	0.012	1.031	0.093	3.808	3.692	0.034	4.488	0.029	2.354	0.318
Meer	0.400	0.128	0.140	2.600	0.013	0.015	0.914	0.106	3.721	4.070	0.034	4.341	0.028	2.136	0.350
Meer	0.400	0.014	0.137	2.560	0.013	0.064	0.102	0.464	0.407	3.983	0.034	4.321	0.029	2.182	0.343
Meer	0.400	0.014	0.082	1.960	0.014	0.031	0.171	0.379	0.407	2.384	0.034	4.276	0.050	3.646	0.205
Meer	0.400	-0.090	0.137	2.530	0.014	0.101	-0.657	0.737	-2.616	3.983	0.034	4.270	0.030	2.182	0.343
Meer	0.400	0.125	0.081	1.940	0.014	0.005	1.543	0.059	3.634	2.355	0.034	4.259	0.051	3.691	0.203
Meer	0.400	0.000	0.151	2.560	0.015	0.075	0.000	0.497	0.000	4.390	0.034	4.116	0.029	1.980	0.378
Meer	0.400	0.000	0.171	2.560	0.017	0.078	0.000	0.459	0.000	4.971	0.034	3.868	0.029	1.749	0.428
Meer	0.400	0.006	0.101	1.960	0.017	0.038	0.059	0.375	0.174	2.936	0.034	3.853	0.050	2.960	0.253
Meer	0.400	0.126	0.102	1.960	0.017	0.005	1.235	0.050	3.663	2.965	0.034	3.834	0.050	2.931	0.255
Meer	0.400	-0.095	0.192	2.600	0.018	0.127	-0.495	0.660	-2.762	5.581	0.034	3.707	0.028	1.557	0.480
Meer	0.400	-0.094	0.112	1.960	0.019	0.083	-0.839	0.737	-2.733	3.256	0.034	3.659	0.050	2.670	0.280
Meer	0.400	0.006	0.121	1.960	0.020	0.047	0.050	0.390	0.174	3.517	0.034	3.520	0.050	2.471	0.303
Meer	0.400	0.125	0.122	1.940	0.021	0.006	1.025	0.052	3.634	3.547	0.034	3.470	0.051	2.451	0.305
Meer	0.400	0.003	0.139	1.980	0.023	0.056	0.022	0.401	0.087	4.041	0.034	3.318	0.049	2.151	0.348
Meer	0.400	-0.088	0.141	1.960	0.024	0.096	-0.624	0.682	-2.558	4.099	0.034	3.261	0.050	2.121	0.353
Meer	0.400	0.126	0.142	1.940	0.024	0.009	0.887	0.060	3.663	4.128	0.034	3.216	0.051	2.106	0.355
Meer	0.400	-0.092	0.157	1.940	0.027	0.104	-0.586	0.664	-2.674	4.564	0.034	3.059	0.051	1.904	0.393
Meer	0.400	-0.087	0.166	1.980	0.027	0.113	-0.524	0.678	-2.529	4.826	0.034	3.036	0.049	1.801	0.415
Meer	0.400	-0.092	0.167	1.960	0.028	0.106	-0.551	0.635	-2.674	4.855	0.034	2.996	0.050	1.790	0.418
Meer	0.400	0.005	0.170	1.960	0.028	0.069	0.029	0.407	0.145	4.942	0.034	2.970	0.050	1.759	0.425
Meer	0.400	-0.095	0.199	1.940	0.034	0.113	-0.477	0.567	-2.762	5.785	0.034	2.717	0.051	1.503	0.498

Data of Van de Meer (1988) **Table A2.5**

Test	h	Rc	Hmoi	Tp	sop	Hmot	Rc/Hmoi	Kt	Rc/Dn50	Hmoi/Dn50	Dn50	Ir	B/Lo	B/Hsi	Hs/h
	m	m	m	s	-	m	-	-	-	-	m	-	-	-	-
Daemen	0.453	0.010	0.032	0.990	0.021	0.005	0.313	0.148	0.250	0.800	0.040	4.610	0.222	10.625	0.071
Daemen	0.433	0.030	0.052	1.317	0.019	0.010	0.577	0.189	0.750	1.272	0.040	4.810	0.126	6.538	0.120
Daemen	0.453	0.010	0.060	1.410	0.019	0.016	0.167	0.258	0.250	1.472	0.040	4.795	0.110	5.667	0.132
Daemen	0.433	0.030	0.060	0.980	0.040	0.006	0.500	0.106	0.750	1.472	0.040	3.333	0.227	5.667	0.139
Daemen	0.453	0.010	0.061	0.990	0.040	0.012	0.164	0.189	0.250	1.497	0.040	3.339	0.222	5.574	0.135
Daemen	0.503	-0.040	0.061	1.394	0.020	0.039	-0.652	0.628	-1.000	1.505	0.040	4.690	0.112	5.543	0.122
Daemen	0.503	-0.040	0.064	0.990	0.042	0.032	-0.625	0.500	0.000	1.572	0.040	3.260	0.222	5.313	0.127
Daemen	0.433	0.030	0.067	1.446	0.021	0.013	0.446	0.193	0.750	1.655	0.040	4.642	0.104	5.050	0.156
Daemen	0.503	-0.040	0.083	1.549	0.022	0.048	-0.484	0.581	-1.000	2.067	0.040	4.488	0.091	4.113	0.164
Daemen	0.453	0.010	0.088	1.740	0.019	0.030	0.114	0.341	0.250	2.200	0.040	4.886	0.072	3.864	0.194
Daemen	0.413	0.050	0.088	1.740	0.019	0.016	0.568	0.182	1.222	2.200	0.040	4.886	0.072	3.864	0.213
Daemen	0.433	0.030	0.089	1.575	0.023	0.022	0.338	0.248	0.750	2.217	0.040	4.406	0.088	3.835	0.205
Daemen	0.433	0.030	0.096	1.704	0.021	0.028	0.313	0.292	0.750	2.400	0.040	4.582	0.075	3.542	0.222
Daemen	0.503	-0.040	0.103	1.833	0.020	0.059	-0.390	0.575	-1.000	2.567	0.040	4.766	0.065	3.312	0.204
Daemen	0.433	0.030	0.112	1.859	0.021	0.038	0.268	0.339	0.750	2.800	0.040	4.627	0.063	3.036	0.259
Daemen	0.503	-0.040	0.114	1.859	0.021	0.063	-0.351	0.548	-1.000	2.850	0.040	4.587	0.063	2.982	0.227
Daemen	0.433	0.030	0.115	1.440	0.036	0.026	0.261	0.222	0.750	2.875	0.040	3.537	0.105	2.957	0.266
Daemen	0.503	-0.040	0.117	1.440	0.036	0.053	-0.342	0.453	0.000	2.925	0.040	3.507	0.105	2.906	0.233
Daemen	0.503	-0.040	0.117	1.440	0.036	0.053	-0.342	0.453	0.000	2.925	0.040	3.507	0.105	2.906	0.233
Daemen	0.413	0.050	0.117	2.050	0.018	0.028	0.427	0.235	1.222	2.925	0.040	4.992	0.052	2.906	0.283
Daemen	0.413	0.050	0.117	1.460	0.035	0.017	0.427	0.145	1.222	2.925	0.040	3.556	0.102	2.906	0.283
Daemen	0.453	0.010	0.118	2.050	0.018	0.043	0.085	0.364	0.250	2.950	0.040	4.971	0.052	2.881	0.260
Daemen	0.453	0.010	0.118	1.460	0.035	0.037	0.085	0.309	0.250	2.950	0.040	3.541	0.102	2.881	0.260
Daemen	0.503	-0.040	0.119	1.460	0.036	0.055	-0.336	0.458	0.000	2.975	0.040	3.526	0.102	2.857	0.237
Daemen	0.503	-0.040	0.135	1.988	0.022	0.072	-0.296	0.528	-1.000	3.383	0.040	4.502	0.055	2.512	0.269
Daemen	0.413	0.050	0.141	2.280	0.017	0.038	0.355	0.266	1.222	3.525	0.040	5.058	0.042	2.411	0.341
Daemen	0.433	0.030	0.143	2.280	0.018	0.048	0.210	0.332	0.750	3.575	0.040	5.023	0.042	2.378	0.330
Daemen	0.413	0.050	0.143	2.880	0.011	0.039	0.350	0.273	1.222	3.575	0.040	6.344	0.026	2.378	0.346
Daemen	0.453	0.010	0.148	2.280	0.018	0.057	0.068	0.385	0.250	3.700	0.040	4.937	0.042	2.297	0.327
Daemen	0.367	0.096	0.131	2.880	0.010	0.017	0.733	0.130	2.400	3.275	0.040	6.628	0.026	2.595	0.357
Daemen	0.413	0.050	0.061	0.990	0.040	0.005	0.820	0.084	1.222	1.497	0.040	3.339	0.222	5.574	0.148
Daemen	0.413	0.050	0.059	1.440	0.018	0.010	0.847	0.164	1.222	1.447	0.040	4.938	0.105	5.763	0.143
Daemen	0.367	0.096	0.110	1.440	0.034	0.010	0.873	0.086	2.400	2.750	0.040	3.617	0.105	3.091	0.300
Daemen	0.367	0.096	0.109	1.859	0.020	0.014	0.878	0.128	2.400	2.733	0.040	4.683	0.063	3.110	0.298
Daemen	0.433	0.030	0.032	0.980	0.021	0.004	0.938	0.130	0.750	0.800	0.040	4.564	0.227	10.625	0.074
Daemen	0.367	0.096	0.093	1.704	0.020	0.012	1.036	0.124	2.400	2.317	0.040	4.663	0.075	3.669	0.252
Daemen	0.367	0.096	0.087	1.575	0.023	0.010	1.099	0.119	2.400	2.183	0.040	4.440	0.088	3.893	0.238
Daemen	0.367	0.096	0.067	1.436	0.021	0.009	1.440	0.131	2.400	1.639	0.040	4.632	0.106	5.100	0.182
Daemen	0.413	0.050	0.033	1.010	0.021	0.004	1.515	0.117	1.222	0.825	0.040	4.631	0.214	10.303	0.080
Daemen	0.367	0.096	0.058	1.010	0.036	0.003	1.655	0.049	2.400	1.422	0.040	3.493	0.214	5.862	0.158
Daemen	0.367	0.096	0.051	1.317	0.019	0.007	1.895	0.133	2.400	1.239	0.040	4.873	0.126	6.711	0.138
Daemen	0.267	0.196	0.103	1.820	0.020	0.011	1.909	0.107	4.900	2.567	0.040	4.732	0.066	3.312	0.385
Daemen	0.267	0.196	0.093	1.704	0.020	0.010	2.115	0.107	4.900	2.317	0.040	4.663	0.075	3.669	0.347
Daemen	0.267	0.196	0.086	1.575	0.022	0.009	2.279	0.105	4.900	2.150	0.040	4.474	0.088	3.953	0.322
Daemen	0.367	0.096	0.033	0.990	0.022	0.002	2.909	0.064	2.400	0.825	0.040	4.540	0.222	10.303	0.090
Daemen	0.267	0.196	0.065	1.461	0.019	0.008	3.031	0.117	4.900	1.589	0.040	4.787	0.102	5.258	0.242
Daemen	0.267	0.196	0.049	1.291	0.019	0.006	4.027	0.118	4.900	1.189	0.040	4.875	0.131	6.986	0.182
Daemen	0.473	-0.010	0.083	1.575	0.022	0.040	-0.120	0.474	-0.161	1.338	0.061	4.545	0.088	4.080	0.176
Daemen	0.473	-0.010	0.115	1.820	0.022	0.056	-0.087	0.488	-0.161	1.823	0.061	4.478	0.066	2.965	0.242
Daemen	0.503	-0.040	0.119	1.859	0.022	0.067	-0.337	0.565	-0.656	1.889	0.061	4.495	0.063	2.865	0.236
Daemen	0.503	-0.040	0.126	1.911	0.022	0.071	-0.317	0.560	-0.656	2.066	0.061	4.484	0.060	2.698	0.250
Daemen	0.520	-0.057	0.127	1.911	0.022	0.075	-0.450	0.592	-0.934	2.077	0.061	4.472	0.060	2.684	0.244
Daemen	0.503	-0.040	0.119	1.460	0.036	0.055	-0.336	0.458	0.000	2.975	0.061	3.526	0.102	2.857	0.237

Test	h	Rc	Hsi	Tp	sop	Hst	Rc/Hsi	Kt	Rc/Dn	Hsi/Dn	Dn	Ir	B/Lo	B/Hsi	Hs/h
	m	m	m	s	-	m	-	-	-	-	m	-	-	-	
H1872-2d-1.1	15.600	3.950	3.610	9.500	0.026	0.390	1.094	0.108	2.455	2.244	1.609	4.134	0.036	1.385	0.231
H1872-2d-1.2	15.600	3.950	4.100	10.600	0.023	0.520	0.963	0.127	2.455	2.548	1.609	4.396	0.029	1.220	0.263
H1872-2d-1.3	15.600	3.950	4.630	11.100	0.024	0.650	0.853	0.140	2.455	2.878	1.609	4.303	0.026	1.080	0.297
H1872-2d-1.4	15.600	3.950	5.020	11.900	0.023	0.740	0.787	0.147	2.455	3.120	1.609	4.396	0.023	0.996	0.322
H1872-2d-1.5	15.600	3.950	5.670	13.100	0.021	1.100	0.697	0.194	2.455	3.524	1.609	4.600	0.019	0.882	0.363
H1872-2d-1.6	12.800	6.750	4.750	11.800	0.022	0.270	1.421	0.057	4.195	2.952	1.609	4.495	0.023	1.053	0.371
H1872-2d-2.1	15.300	4.250	2.560	7.200	0.032	0.160	1.660	0.063	2.641	1.591	1.609	3.727	0.062	1.953	0.167
H1872-2d-2.2	15.300	4.250	3.280	8.300	0.030	0.240	1.296	0.073	2.641	2.039	1.609	3.849	0.047	1.524	0.214
H1872-2d-2.3	15.300	4.250	3.940	9.300	0.029	0.370	1.079	0.094	2.641	2.449	1.609	3.915	0.037	1.269	0.258

Data of H1872 (1993) 2D-tests **Table A2.7a**

Test	h	Rc	Hsi	Tp	sop	Hst	Rc/Hsi	Kt	Rc/Dn	Hsi/Dn	Dn	Ir	B/Lo	B/Hsi	Hs/h
	m	m	m	s	-	m	-	-	-	-	m	-	-	-	-
H1872-3d-I.1	15.300	3.950	3.550	9.400	0.026	0.675	1.113	0.190	2.428	2.182	1.627	4.156	0.036	1.408	0.232
H1872-3d-I.2	15.300	3.950	4.150	10.300	0.025	0.785	0.952	0.189	2.428	2.551	1.627	4.212	0.030	1.205	0.271
H1872-3d-I.3	15.300	3.950	4.680	10.800	0.026	1.240	0.844	0.265	2.428	2.877	1.627	4.159	0.027	1.068	0.306
H1872-3d-I.4	15.300	3.950	5.210	11.600	0.025	1.300	0.758	0.250	2.428	3.202	1.627	4.233	0.024	0.960	0.341
H1872-3d-II.1	15.300	3.950	3.530	9.400	0.026	0.470	1.119	0.133	2.428	2.170	1.627	4.168	0.036	1.416	0.231
H1872-3d-II.2	15.300	3.950	4.070	10.300	0.025	0.690	0.971	0.170	2.428	2.502	1.627	4.253	0.030	1.229	0.266
H1872-3d-II.3	15.300	3.950	4.760	10.800	0.026	0.915	0.830	0.192	2.428	2.926	1.627	4.124	0.027	1.050	0.311
H1872-3d-II.4	15.300	3.950	5.560	11.600	0.026	1.180	0.710	0.212	2.428	3.417	1.627	4.098	0.024	0.899	0.363
H1872-3d-II.5	12.500	6.750	5.430	11.500	0.026	0.330	1.243	0.061	4.149	3.338	1.627	4.111	0.024	0.921	0.434
H1872-3d-II.6	15.300	3.950	6.260	13.000	0.024	1.575	0.631	0.252	2.428	3.848	1.627	4.328	0.019	0.799	0.409
H1872-3d-III.1	15.300	3.950	3.390	9.500	0.024	0.415	1.165	0.122	2.428	2.084	1.627	4.298	0.036	1.475	0.222
H1872-3d-III.2	15.300	3.950	4.030	10.400	0.024	0.585	0.980	0.145	2.428	2.477	1.627	4.316	0.030	1.241	0.263
H1872-3d-III.3	15.300	3.950	4.610	11.000	0.024	0.775	0.857	0.168	2.428	2.834	1.627	4.268	0.026	1.085	0.301
H1872-3d-III.4	15.300	3.950	5.350	11.600	0.025	1.005	0.738	0.188	2.428	3.288	1.627	4.178	0.024	0.935	0.350
H1872-3d-III.5	12.500	6.750	5.190	11.500	0.025	0.290	1.301	0.056	4.149	3.190	1.627	4.205	0.024	0.963	0.415
H1872-3d-III.6	15.300	3.950	6.150	13.000	0.023	1.410	0.642	0.229	2.428	3.780	1.627	4.367	0.019	0.813	0.402
H1872-3d-IX.1	15.000	4.250	2.450	7.200	0.030	0.180	1.735	0.073	2.506	1.445	1.696	3.832	0.062	2.041	0.163
H1872-3d-IX.2	15.000	4.250	2.340	6.100	0.040	0.150	1.816	0.064	2.506	1.380	1.696	3.322	0.086	2.137	0.156
H1872-3d-IX.3	15.000	4.250	2.910	7.700	0.031	0.235	1.460	0.081	2.506	1.716	1.696	3.760	0.054	1.718	0.194
H1872-3d-IX.4	15.000	4.250	3.250	8.200	0.031	0.295	1.308	0.091	2.506	1.917	1.696	3.789	0.048	1.538	0.217
H1872-3d-IX.5	15.000	4.250	3.170	7.400	0.037	0.235	1.341	0.074	2.506	1.869	1.696	3.462	0.059	1.577	0.211
H1872-3d-IX.6	15.000	4.250	3.860	9.200	0.029	0.495	1.101	0.128	2.506	2.276	1.696	3.901	0.038	1.295	0.257
H1872-3d-IX.7	14.500	4.750	3.010	7.700	0.033	0.190	1.578	0.063	2.801	1.775	1.696	3.697	0.054	1.661	0.208
H1872-3d-IX.8	14.500	4.750	3.280	8.200	0.031	0.235	1.448	0.072	2.801	1.934	1.696	3.772	0.048	1.524	0.226
H1872-3d-VIII.1	15.300	3.950	3.490	9.400	0.025	0.500	1.132	0.143	2.329	2.058	1.696	4.191	0.036	1.433	0.228
H1872-3d-VIII.2	15.300	3.950	4.120	10.600	0.023	0.755	0.959	0.183	2.329	2.430	1.696	4.350	0.029	1.214	0.269
H1872-3d-VIII.3	15.300	3.950	4.820	10.900	0.026	0.995	0.820	0.206	2.329	2.842	1.696	4.136	0.027	1.037	0.315
H1872-3d-VIII.4	15.300	3.950	5.340	11.400	0.026	1.265	0.740	0.237	2.329	3.149	1.696	4.109	0.025	0.936	0.349
H1872-3d-VIII.5	12.500	6.750	5.380	11.500	0.026	0.315	1.255	0.059	3.980	3.173	1.696	4.130	0.024	0.929	0.430
H1872-3d-VIII.6	15.300	3.950	6.000	13.200	0.022	1.700	0.658	0.283	2.329	3.538	1.696	4.489	0.018	0.833	0.392

Data of H1872 (1993) 3D-tests **Table A2.7b**

Test	h	Rc	Hsi	Tp	sop	Hst	Rc/Hsi	Kt	Rc/Dn	Hsi/Dn	Dn	Ir	B/Lo	B/Hsi	Hs/h
	m	m	m	s	-	m	-	-	-	-	m	-	-	-	
H2061-141a	0.900	-0.050	0.138	1.611	0.038	0.081	-0.362	0.587	-0.999	2.758	0.050	3.420	0.049	1.449	0.153
H2061-141k	0.900	-0.050	0.144	1.649	0.038	0.087	-0.347	0.604	-1.136	3.271	0.044	3.420	0.047	1.389	0.160
H2061-141s	0.900	-0.050	0.116	1.476	0.039	0.070	-0.431	0.603	-1.428	3.314	0.035	3.376	0.059	1.724	0.129
H2061-142a	0.900	-0.050	0.178	1.823	0.039	0.105	-0.281	0.590	-1.000	3.561	0.050	3.376	0.039	1.124	0.198
H2061-142k	0.900	-0.050	0.183	1.838	0.040	0.109	-0.273	0.596	-1.135	4.156	0.044	3.333	0.038	1.093	0.203
H2061-142s	0.900	-0.050	0.160	1.739	0.039	0.095	-0.313	0.594	-1.431	4.579	0.035	3.376	0.042	1.250	0.178
H2061-143a	0.900	-0.050	0.216	2.161	0.034	0.126	-0.231	0.583	-0.998	4.311	0.050	3.616	0.027	0.926	0.240
H2061-143k	0.900	-0.050	0.215	2.151	0.034	0.123	-0.233	0.572	-1.139	4.896	0.044	3.616	0.028	0.930	0.239
H2061-143s	0.900	-0.050	0.198	2.001	0.037	0.116	-0.253	0.586	-1.431	5.668	0.035	3.466	0.032	1.010	0.220
H2061-144a	0.900	-0.050	0.198	1.960	0.038	0.119	-0.253	0.601	-1.002	3.967	0.050	3.420	0.033	1.010	0.220
H2061-144k	0.900	-0.050	0.197	1.959	0.038	0.118	-0.254	0.599	-1.137	4.481	0.044	3.420	0.033	1.015	0.219
H2061-144s	0.900	-0.050	0.144	1.616	0.040	0.086	-0.347	0.597	-1.428	4.112	0.035	3.333	0.049	1.389	0.160
H2061-145a	0.900	-0.050	0.228	2.109	0.038	0.133	-0.219	0.583	-0.999	4.554	0.050	3.420	0.029	0.877	0.253
H2061-145k	0.900	-0.050	0.227	2.128	0.038	0.130	-0.220	0.573	-1.135	5.153	0.044	3.420	0.028	0.881	0.252
H2061-145s	0.900	-0.050	0.183	1.883	0.038	0.111	-0.273	0.607	-1.427	5.224	0.035	3.420	0.036	1.093	0.203
H2061-146s	0.900	-0.050	0.203	2.038	0.036	0.120	-0.246	0.591	-1.427	5.793	0.035	3.514	0.031	0.985	0.226
H2061-221a	0.900	0.000	0.144	2.105	0.022	0.074	0.000	0.512	0.000	2.880	0.050	4.495	0.029	1.389	0.160
H2061-222a	0.900	0.000	0.188	2.445	0.021	0.099	0.000	0.528	0.000	3.760	0.050	4.600	0.021	1.064	0.209
H2061-223a	0.900	0.000	0.220	2.891	0.018	0.112	0.000	0.504	0.000	4.400	0.050	4.969	0.015	0.909	0.244
H2061-224a	0.900	0.000	0.125	1.944	0.022	0.065	0.000	0.522	0.000	2.500	0.050	4.495	0.034	1.600	0.139
H2061-225a	0.900	0.000	0.163	2.295	0.021	0.087	0.000	0.534	0.000	3.260	0.050	4.600	0.024	1.227	0.181
H2061-226a	0.900	0.000	0.203	2.671	0.019	0.105	0.000	0.517	0.000	4.060	0.050	4.837	0.018	0.985	0.226
H2061-245a	0.900	0.000	0.172	1.847	0.037	0.087	0.000	0.507	0.000	3.440	0.050	3.466	0.038	1.163	0.191
H2061-246a	0.900	0.000	0.214	2.126	0.035	0.109	0.000	0.513	0.000	4.280	0.050	3.563	0.028	0.935	0.238
H2061-641s	0.700	0.200	0.134	1.690	0.036	0.004	1.493	0.031	5.716	3.830	0.035	3.514	0.045	1.493	0.191
H2061-642s	0.700	0.200	0.149	1.844	0.035	0.005	1.342	0.034	5.713	4.256	0.035	3.563	0.038	1.342	0.213
H2061-643s	0.700	0.200	0.081	1.241	0.039	0.002	2.469	0.027	5.714	2.314	0.035	3.376	0.083	2.469	0.116
H2061-644s	0.700	0.200	0.107	1.444	0.037	0.003	1.875	0.030	5.732	3.067	0.035	3.466	0.061	1.869	0.153
H2061-645s	0.700	0.200	0.141	1.701	0.037	0.004	1.417	0.031	5.708	4.024	0.035	3.466	0.044	1.418	0.201
H2061-841h	0.900	0.200	0.159	1.724	0.037	0.006	1.258	0.038	4.000	3.180	0.050	3.466	0.043	1.258	0.177
H2061-842h	0.900	0.200	0.182	1.888	0.036	0.008	1.099	0.044	4.000	3.640	0.050	3.514	0.036	1.099	0.202
H2061-843h	0.900	0.200	0.217	2.095	0.036	0.018	0.922	0.083	4.001	4.342	0.050	3.514	0.029	0.922	0.241

Data of H2061 (1994) **Table A2.8**

Test	h	Rc	Hmoi	Tp	sop	Hst	Rc/Hmoi	Kt	Rc/Dn50	Hsi/Dn50	Dn50	Ir	B/Lo	B/Hsi	Hsi/h
	m	m	m	s	-	m	-	-	-	-	m	-	-	-	-
M2090-12	7.50	1.75	2.50	7.40	0.029	0.34	0.700	0.136					0.100	3.400	0.333
M2090-13	7.50	1.75	1.40	5.80	0.027	0.05	1.250	0.036					0.162	6.071	0.187
M2090-14	7.50	1.75	1.38	7.40	0.016	0.05	1.268	0.036					0.100	6.159	0.184
M2090-15	5.00	4.25	2.56	7.60	0.028	0.13	1.660	0.051					0.094	3.320	0.512
M2090-16	7.50	1.25	1.40	5.80	0.027	0.07	0.893	0.050					0.162	6.071	0.187
M2090-17	8.00	1.25	4.20	10.20	0.026	1.35	0.298	0.321					0.052	2.024	0.525
M2090-18	7.50	1.75	2.57	7.40	0.030	0.32	0.681	0.125					0.100	3.307	0.343
M2090-1a	7.00	2.00	0.90	4.80	0.025	0.08	2.222	0.089	2.299	1.034	0.870	3.160	0.083	3.333	0.129
M2090-1b	7.00	2.00	1.48	6.20	0.025	0.10	1.351	0.068	2.299	1.701	0.870	3.183	0.050	2.027	0.211
M2090-1c	7.00	2.00	2.10	7.00	0.027	0.18	0.952	0.086	2.299	2.414	0.870	3.017	0.039	1.429	0.300
M2090-1d	7.00	2.00	2.52	7.30	0.030	0.28	0.794	0.111	2.299	2.897	0.870	2.872	0.036	1.190	0.360
M2090-1e	7.00	2.00	3.08	7.90	0.032	0.51	0.649	0.166	2.299	3.540	0.870	2.811	0.031	0.974	0.440
M2090-2a	7.00	2.00	1.05	6.70	0.015	0.09	1.905	0.086	2.299	1.207	0.870	4.083	0.043	2.857	0.150
M2090-2b	7.00	2.00	1.42	7.60	0.016	0.16	1.408	0.113	2.299	1.632	0.870	3.983	0.033	2.113	0.203
M2090-2c	7.00	2.00	2.10	9.10	0.016	0.30	0.952	0.143	2.299	2.414	0.870	3.922	0.023	1.429	0.300
M2090-2d	7.00	2.00	2.38	9.20	0.018	0.40	0.840	0.168	2.299	2.736	0.870	3.724	0.023	1.261	0.340
M2090-2e	7.00	2.00	2.86	10.10	0.018	0.56	0.699	0.196	2.299	3.287	0.870	3.730	0.019	1.049	0.409
M2090-3a	5.00	4.00	1.18	4.90	0.032	0.03	3.390	0.025	4.598	1.356	0.870	2.817	0.080	2.542	0.236
M2090-3b	5.00	4.00	1.60	6.10	0.028	0.05	2.500	0.031	4.598	1.839	0.870	3.012	0.052	1.875	0.320
M2090-3c	5.00	4.00	2.20	7.00	0.029	0.08	1.818	0.036	4.598	2.529	0.870	2.947	0.039	1.364	0.440
M2090-3d	5.00	4.00	2.65	7.50	0.030	0.09	1.509	0.034	4.598	3.046	0.870	2.877	0.034	1.132	0.530
M2090-3e	5.00	4.00	3.08	7.60	0.034	0.10	1.299	0.032	4.598	3.540	0.870	2.704	0.033	0.974	0.616
M2090-4a	7.00	2.00	1.03	4.90	0.027	0.09	1.942	0.087	2.299	1.184	0.870	4.020	0.080	2.913	0.147
M2090-4b	7.00	2.00	1.46	6.20	0.024	0.13	1.370	0.089	2.299	1.678	0.870	4.273	0.050	2.055	0.209
M2090-4c	7.00	2.00	2.08	7.10	0.026	0.21	0.962	0.101	2.299	2.391	0.870	4.099	0.038	1.442	0.297
M2090-4d	7.00	2.00	2.46	7.50	0.028	0.29	0.813	0.118	2.299	2.828	0.870	3.982	0.034	1.220	0.351
M2090-4e	7.00	2.00	2.80	7.90	0.029	0.36	0.714	0.129	2.299	3.218	0.870	3.931	0.031	1.071	0.400
M2090-5a	7.00	1.00	1.03	4.90	0.027	0.16	0.971	0.155	1.149	1.184	0.870	3.015	0.080	2.913	0.147
M2090-5b	7.00	1.00	1.46	6.00	0.026	0.27	0.685	0.185	1.149	1.678	0.870	3.101	0.053	2.055	0.209
M2090-5c	7.00	1.00	2.08	6.90	0.028	0.47	0.481	0.226	1.149	2.391	0.870	2.988	0.040	1.442	0.297
M2090-5d	7.00	1.00	2.46	7.60	0.027	0.63	0.407	0.256	1.149	2.828	0.870	3.026	0.033	1.220	0.351
M2090-5e	7.00	1.00	2.80	7.90	0.029	0.76	0.357	0.271	1.149	3.218	0.870	2.948	0.031	1.071	0.400
M2090-6a	7.00	2.00	1.03	4.80	0.029	0.13	1.942	0.126	2.299	1.184	0.870	2.954	0.083	2.913	0.147
M2090-6b	7.00	2.00	1.46	6.20	0.024	0.16	1.370	0.110	2.299	1.678	0.870	3.204	0.050	2.055	0.209
M2090-6c	7.00	2.00	2.08	7.00	0.027	0.25	0.962	0.120	2.299	2.391	0.870	3.031	0.039	1.442	0.297
M2090-6d	7.00	2.00	2.52	7.50	0.029	0.34	0.794	0.135	2.299	2.897	0.870	2.950	0.034	1.190	0.360
M2090-6e	7.00	2.00	2.84	7.90	0.029	0.42	0.704	0.148	2.299	3.264	0.870	2.928	0.031	1.056	0.406
M2090-6f	7.00	2.00	4.00	10.00	0.026	1.05	0.500	0.263	2.299	4.598	0.870	3.122	0.019	0.750	0.571

Data of M2090 (1985) **Table A2.9**

Test	h	Rc	Hsi	Tp	sop	Hst	Rc/Hsi	Kt	Rc/Dn	Hsi/Dn	Dn	Ir	B/Lo	B/Hsi	Hs/h
	m	m	m	s	-	m	-	-		-	m	-	-	-	-
3101	0.620	0.080	0.194	1.840	0.037	0.052	0.412	0.268				1.491	0.038	1.031	0.313
3102	0.700	0.000	0.146	2.130	0.021	0.059	0.000	0.404				1.989	0.028	1.370	0.209
3103	0.700	0.000	0.199	1.830	0.038	0.071	0.000	0.357				1.464	0.038	1.005	0.284
3104	0.780	-0.080	0.205	1.830	0.039	0.091	-0.390	0.444				1.442	0.038	0.976	0.263
3105	0.860	-0.160	0.161	2.160	0.022	0.115	-0.994	0.714				1.921	0.027	1.242	0.187
3106	0.860	-0.160	0.205	1.800	0.041	0.130	-0.780	0.634				1.419	0.040	0.976	0.238
3141	0.780	-0.080	0.206	1.830	0.039	0.092	-0.388	0.447				1.439	0.038	0.971	0.264
3142	0.860	-0.160	0.160	2.160	0.022	0.114	-1.000	0.713				1.927	0.027	1.250	0.186
3151	0.700	0.000	0.144	2.140	0.020	0.060	0.000	0.417				2.012	0.028	1.389	0.206
3152	0.700	0.000	0.195	1.820	0.038	0.071	0.000	0.364				1.471	0.039	1.026	0.279
3153	0.780	-0.080	0.205	1.810	0.040	0.092	-0.390	0.449				1.427	0.039	0.976	0.263

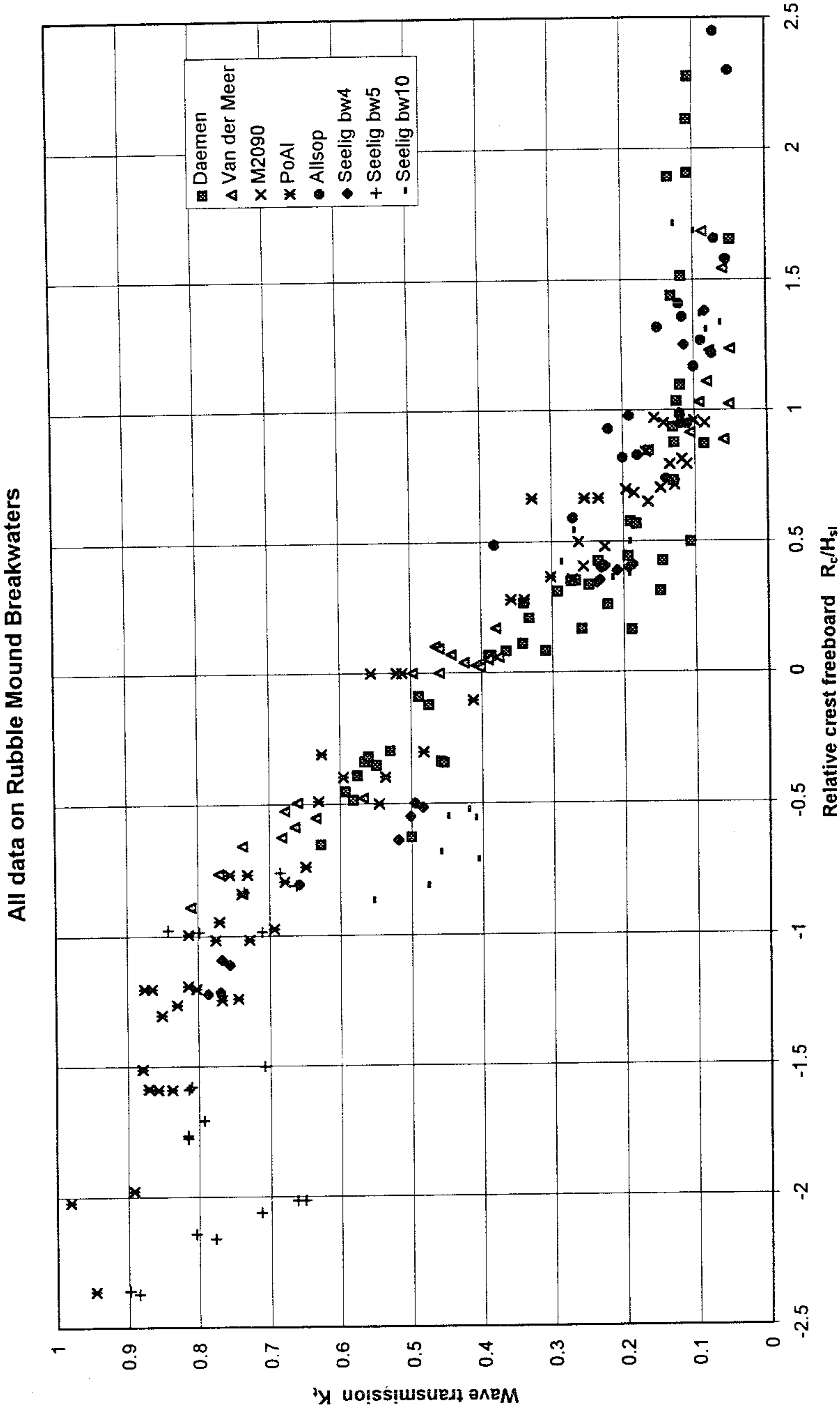
Data of H2014 (1994) **Table A2.10**

Test	h	Rc	Hsi	Tp	sop	Hst	Rc/Hsi	Kt	Rc/Dn50	Hsi/Dn50	Dn50	Ir	B/Lo	B/Hsi	Hsi/h
	m	m	m	s	-	m	m	m	-	-	m	-	-	-	-
H1974	12.7	3.7	4.03	9.4	0.029	0.390	0.918	0.097	2.002	2.181	1.848	4.386	0.092	3.161	0.317
H1974	12.7	3.7	6.4	12.3	0.027	0.990	0.578	0.155	2.002	3.463	1.848	4.554	0.054	1.991	0.504
H1974	12.7	3.7	6.8	14.1	0.022	1.200	0.544	0.176	2.002	3.680	1.848	5.065	0.041	1.874	0.535
H1974	11.1	5.3	3.3	9.5	0.023	0.180	1.606	0.055	2.868	1.786	1.848	4.899	0.090	3.861	0.297
H1974	11.1	5.3	5.7	11.6	0.027	0.410	0.930	0.072	2.868	3.084	1.848	4.551	0.061	2.235	0.514
H1974	11.1	5.3	5.9	12.5	0.024	0.520	0.898	0.088	2.868	3.193	1.848	4.821	0.052	2.159	0.532
H1974	11.1	5.3	6.1	14.7	0.018	0.630	0.869	0.103	2.868	3.301	1.848	5.575	0.038	2.089	0.550
H1974	12.7	3.7	4.7	10.2	0.029	0.610	0.787	0.130	2.002	2.543	1.848	4.407	0.078	2.711	0.370
H1974	12.7	3.7	5.7	11.3	0.029	0.830	0.649	0.146	2.002	3.084	1.848	4.434	0.064	2.235	0.449
H1974	12.7	3.7	6.4	12.2	0.028	1.030	0.578	0.161	2.002	3.463	1.848	4.517	0.055	1.991	0.504

Data of H1974 (1995) **Table A2.11**

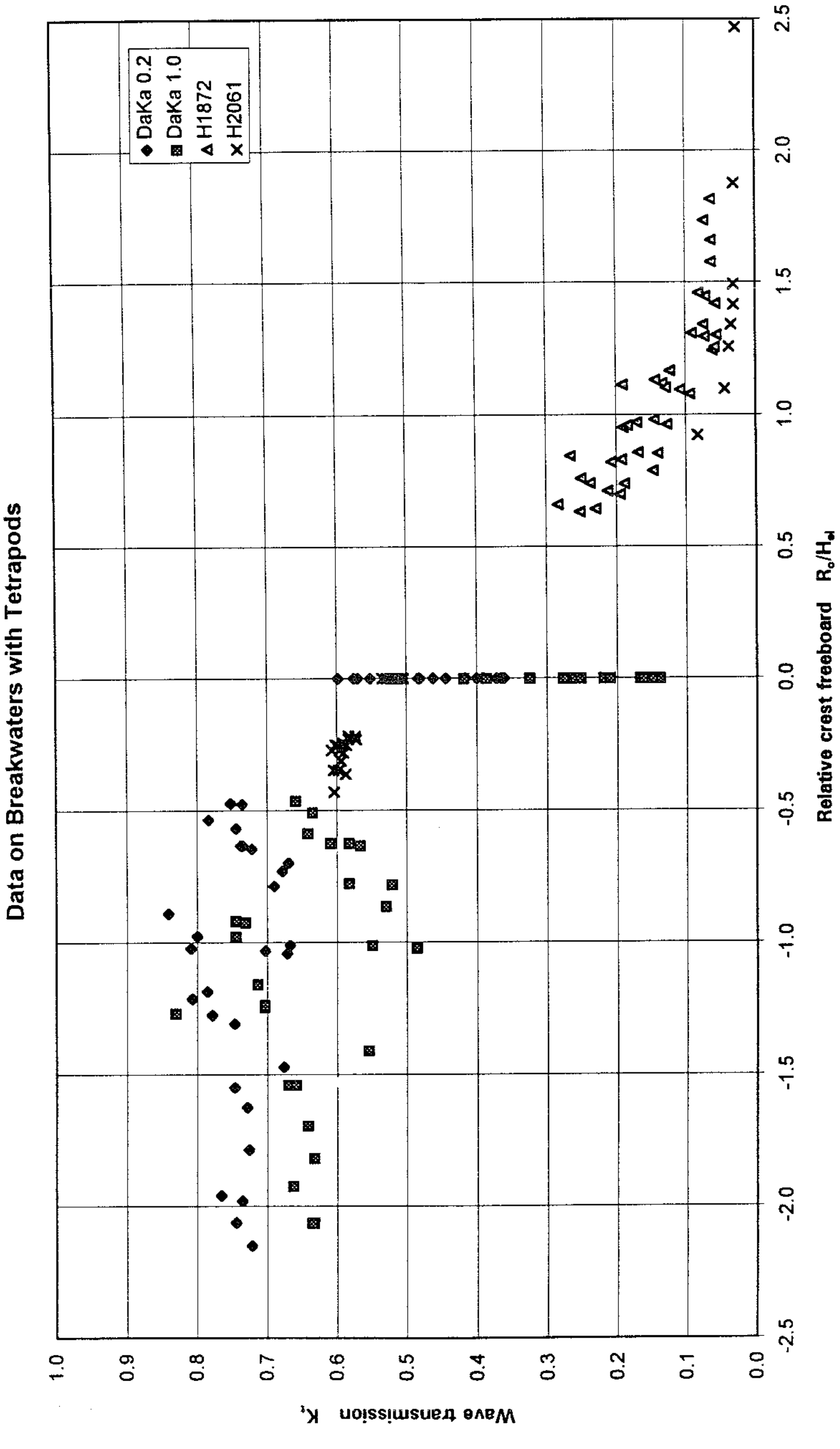
ANNEX 3

Figures for Chapter 5

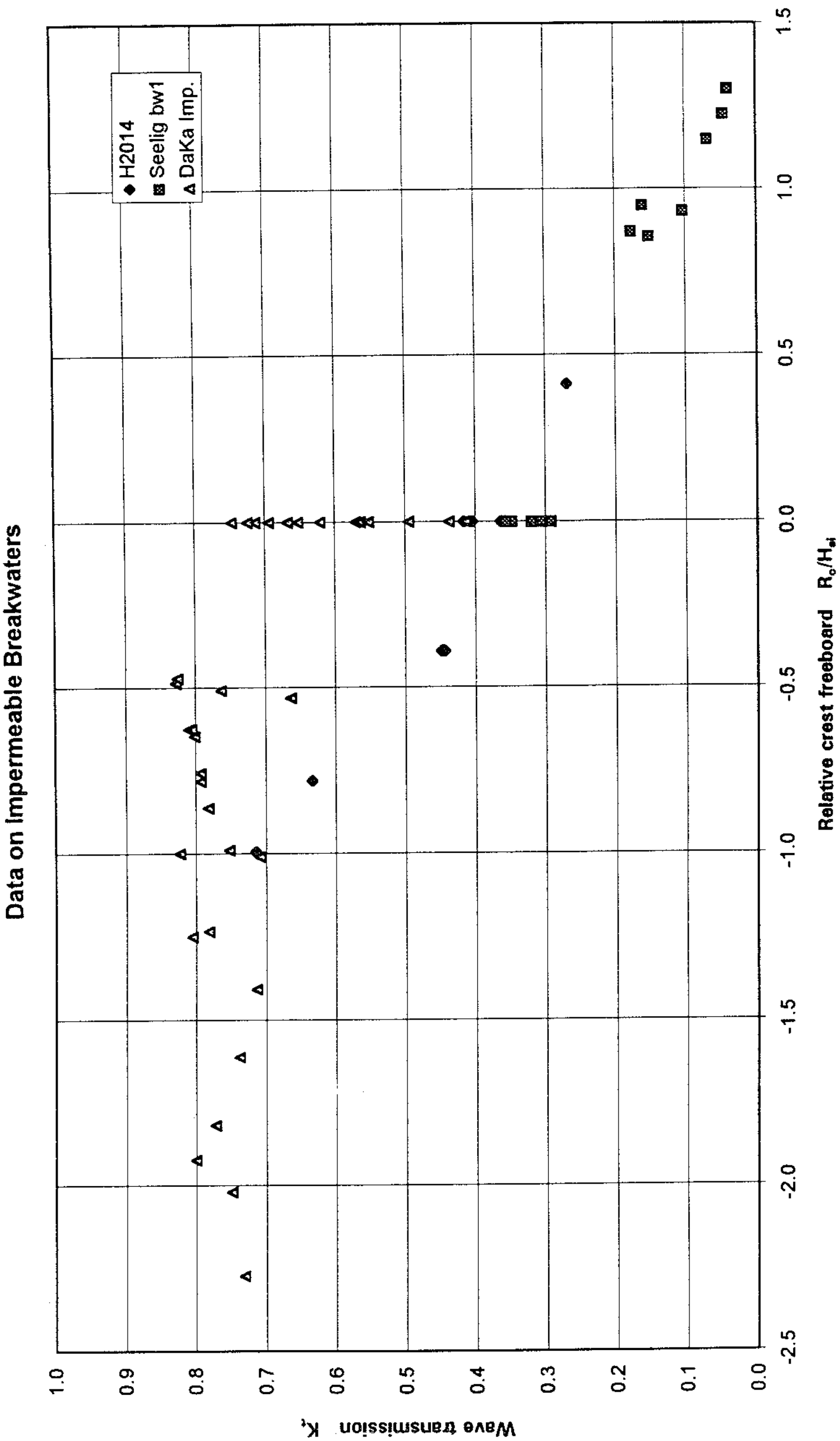


Rubble Mound breakwaters, K_t vs. R_c/H_{si}

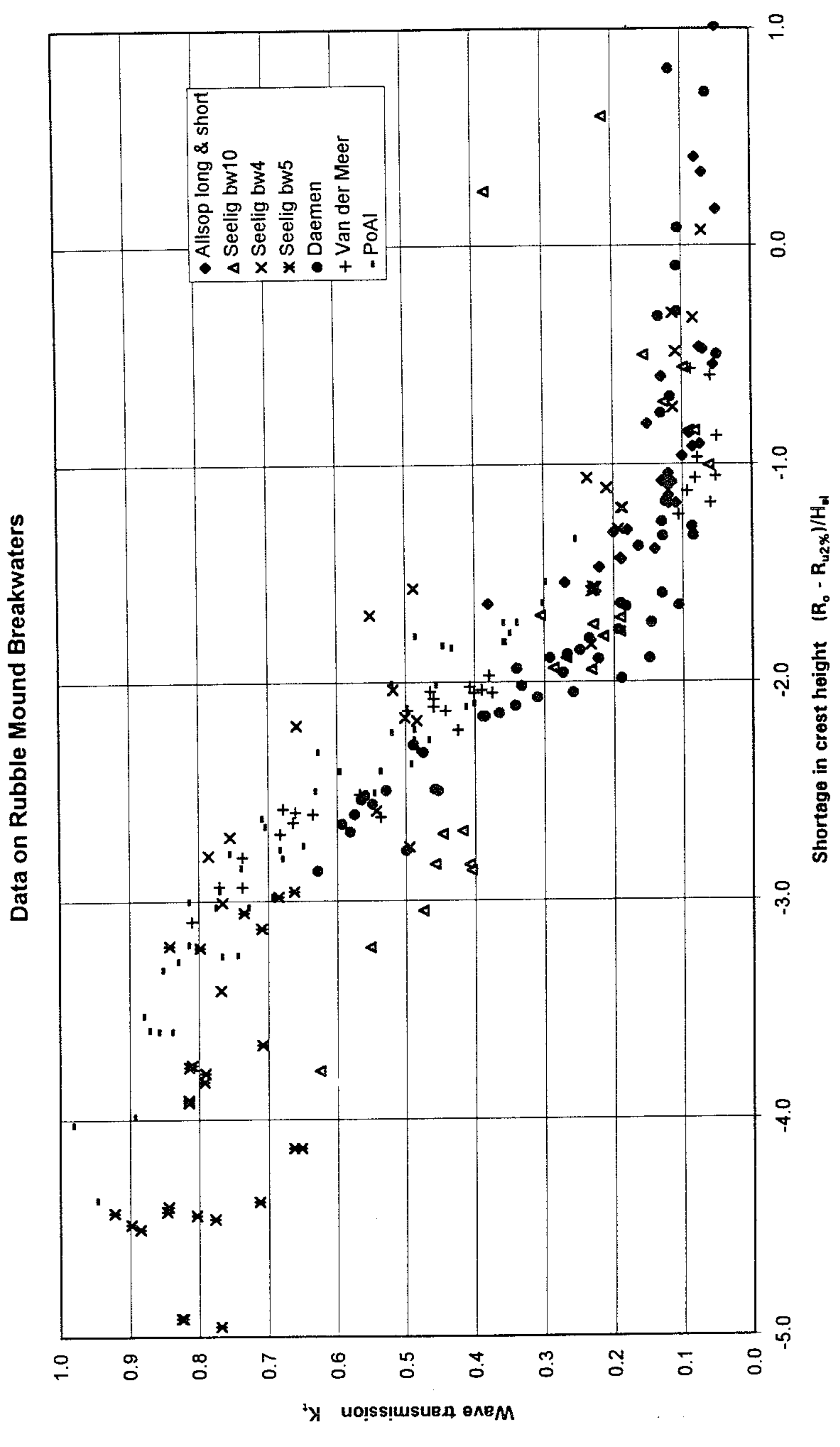
Figure A3.1



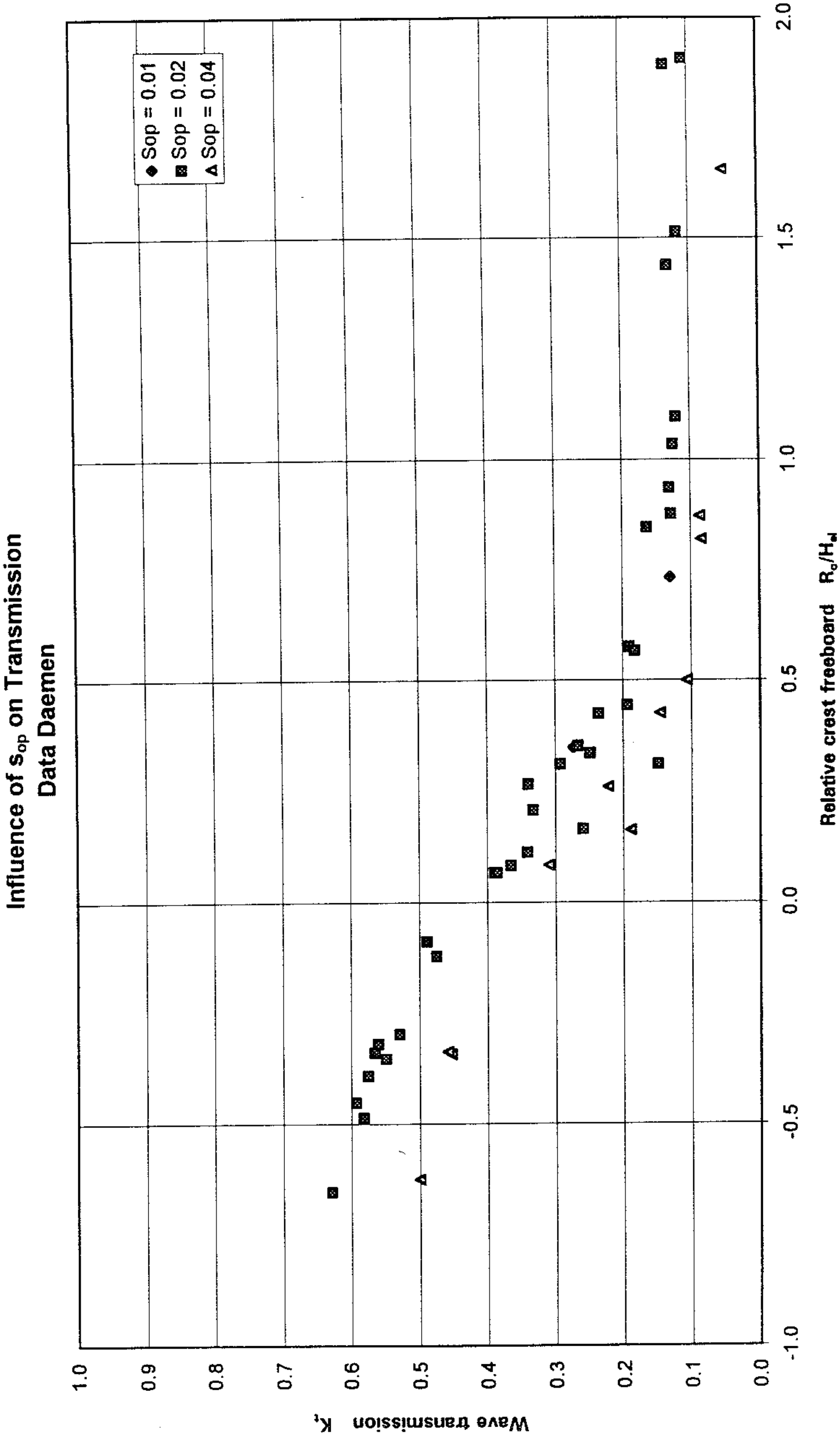
Breakwaters with Tetrapods, K_t vs. R_c/H_{si} **Figure A3.2**



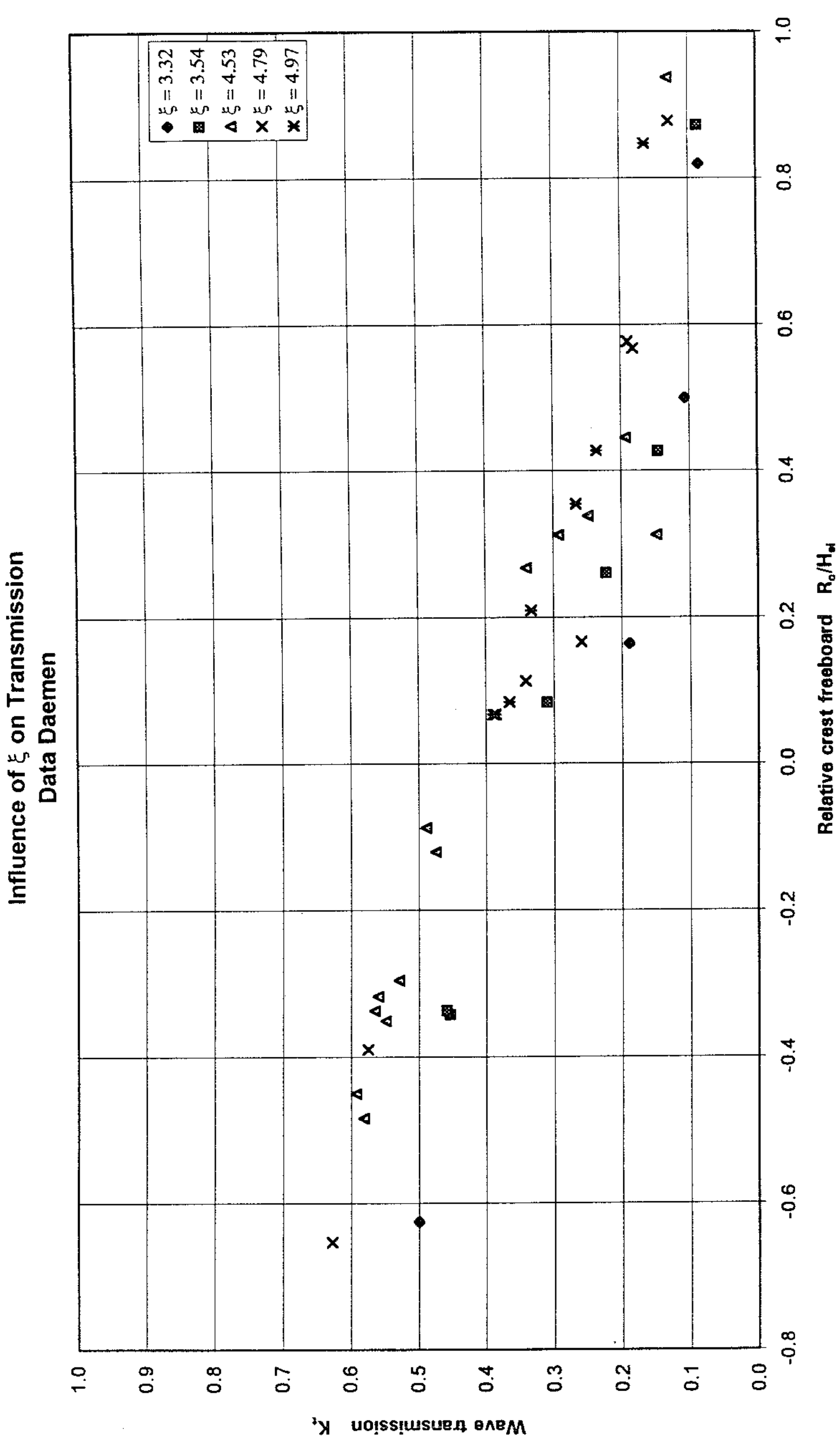
Impermeable breakwaters, K_t vs. R_c/H_{si} **Figure A3.3**



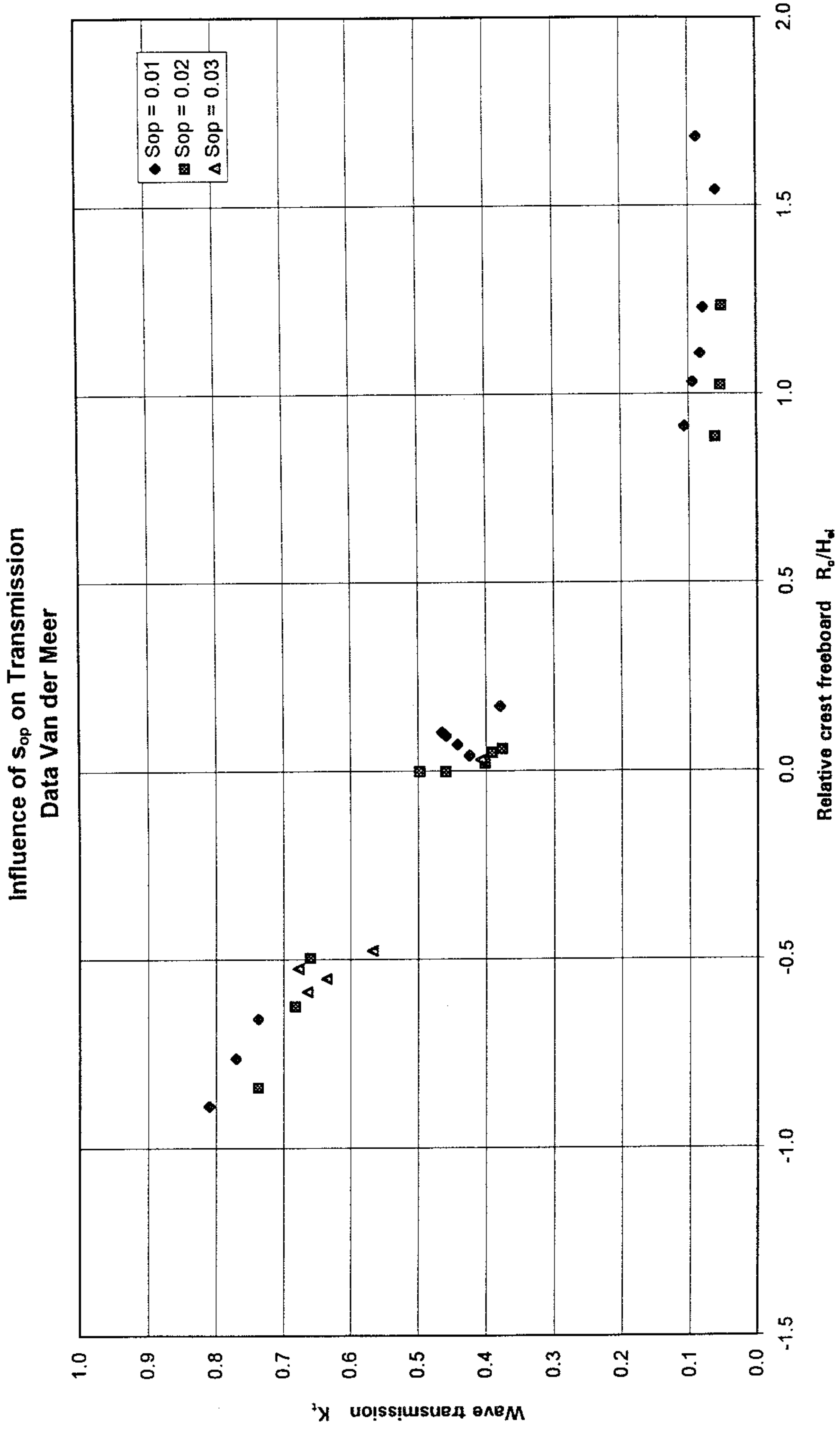
Rubble Mound breakwaters, K_t vs. $(R_c - R_{u2\%})/H_{si}$ **Figure A3.4**



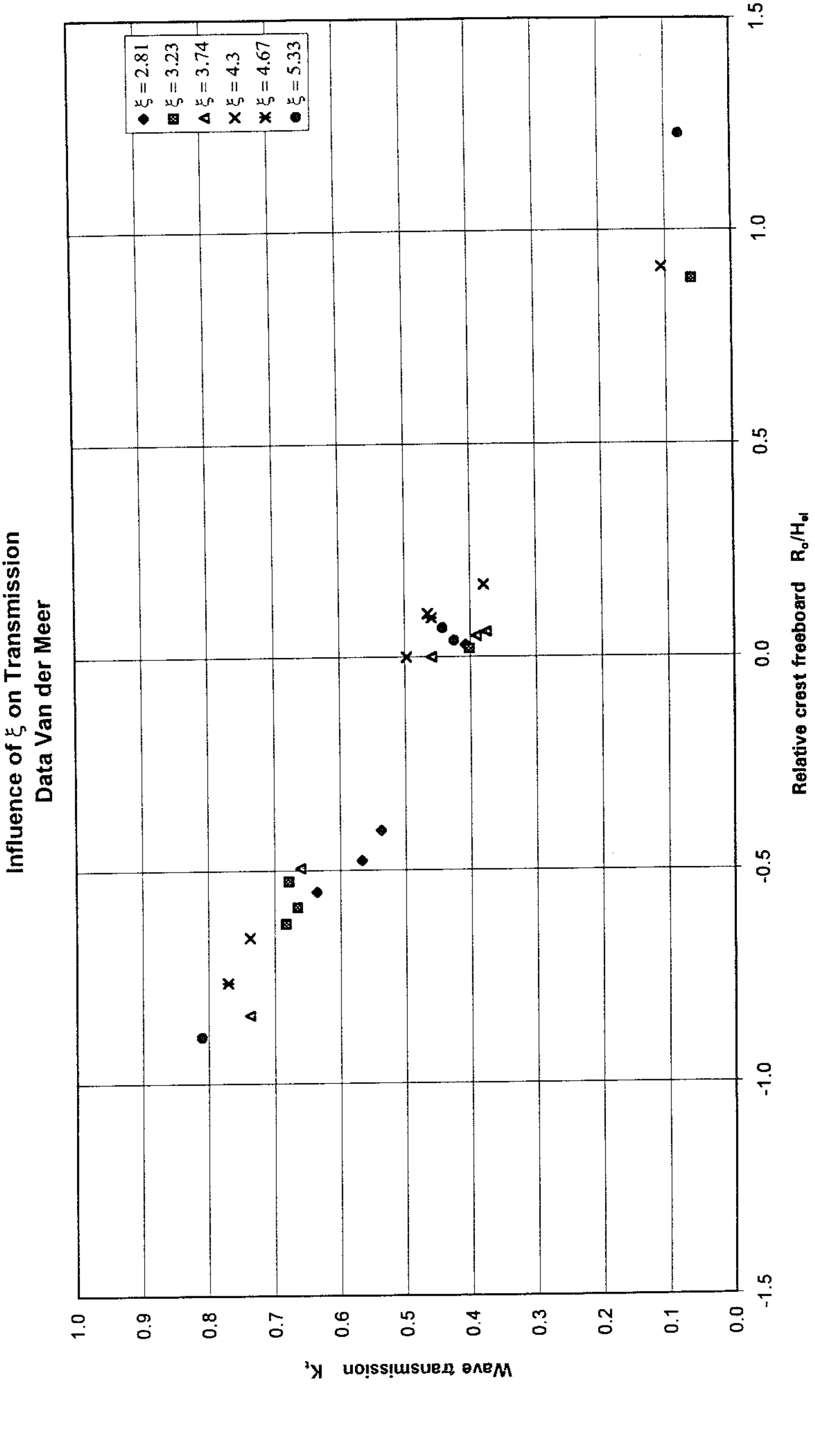
Influence on wave steepness, Data of Daemen **Figure A3.5a**



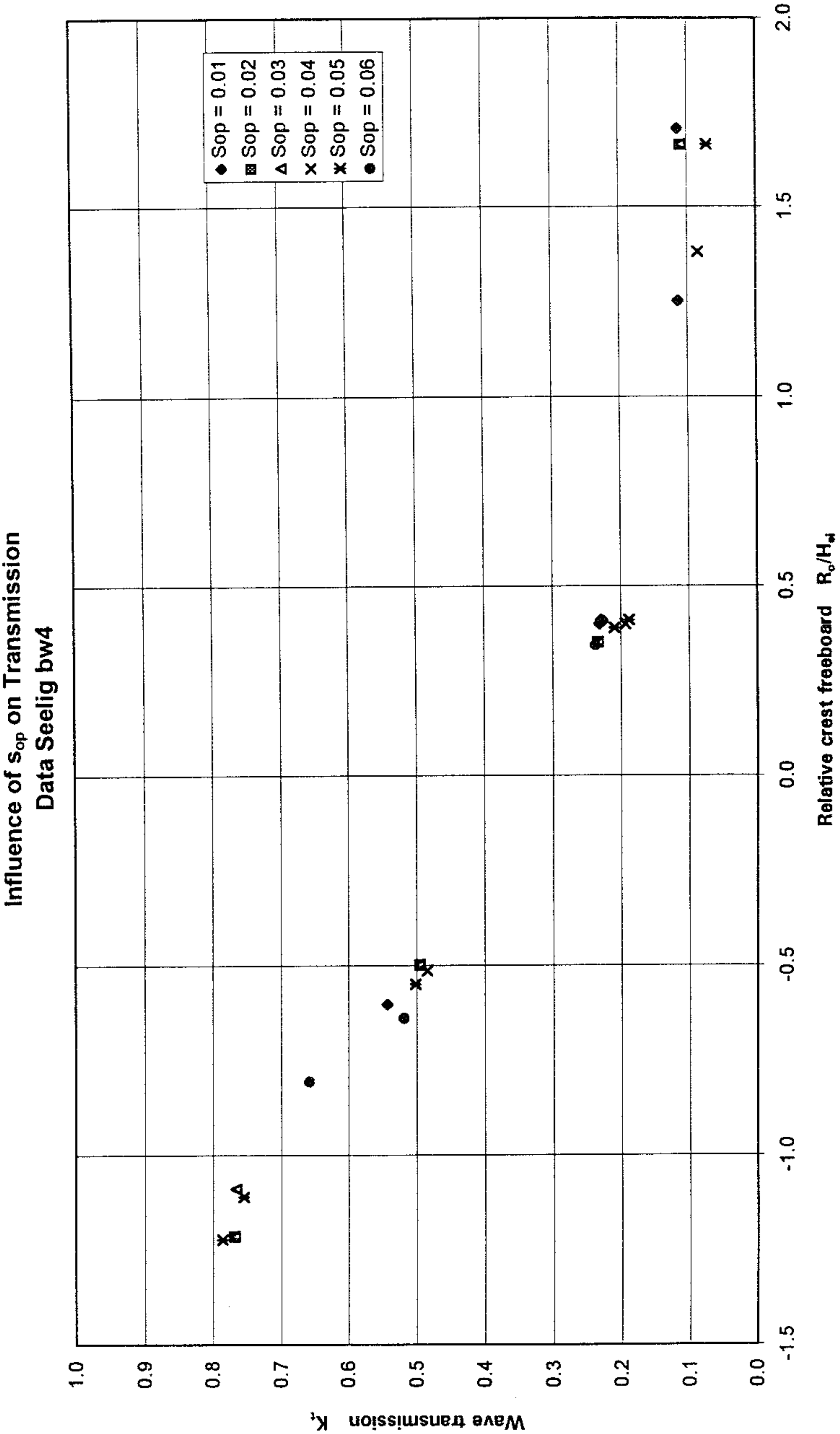
Influence of breakerparameter, Data of Daemen **Figure A3.5b**



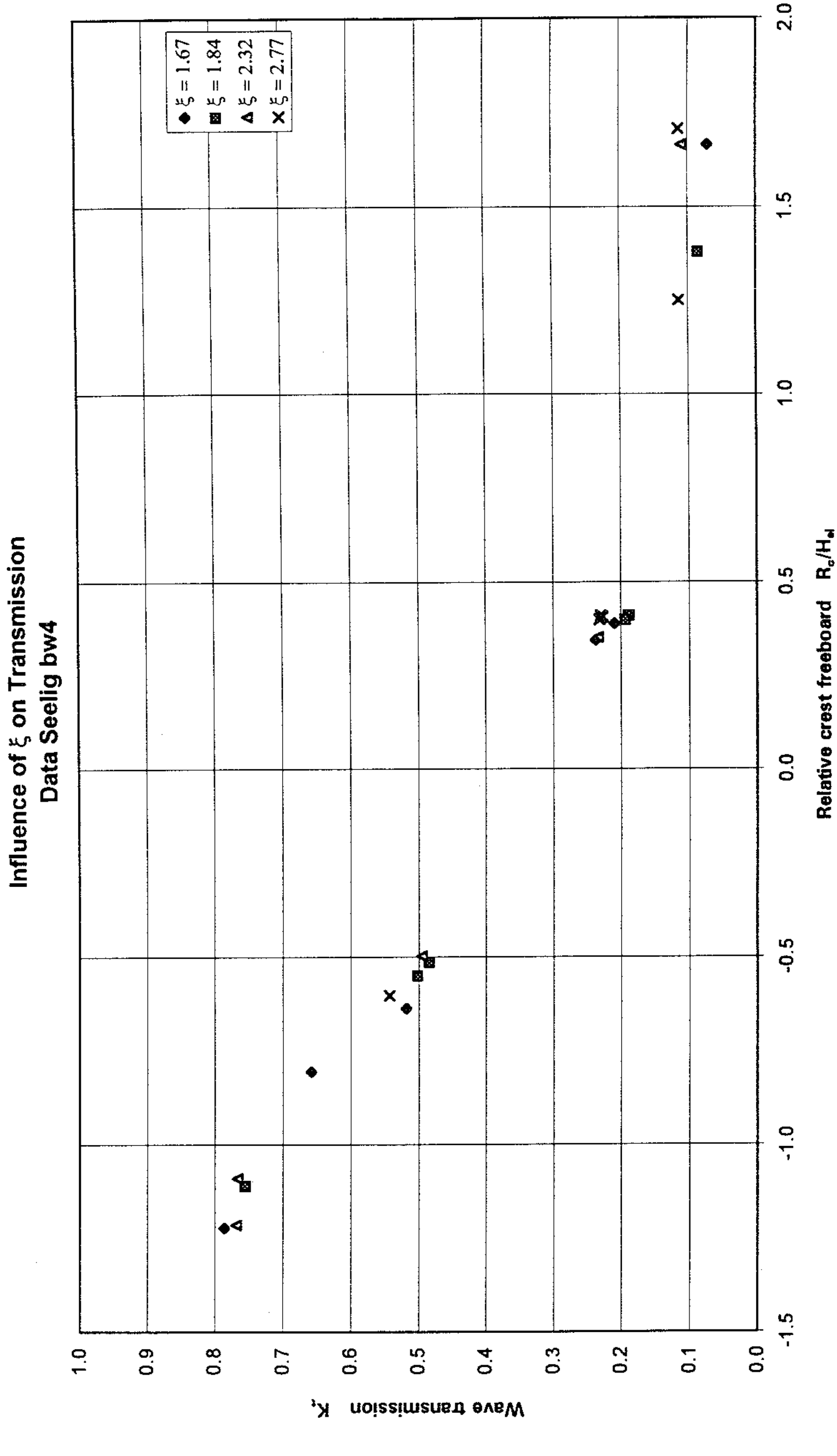
Influence on wave steepness, Data of Van der Meer **Figure A3.6a**



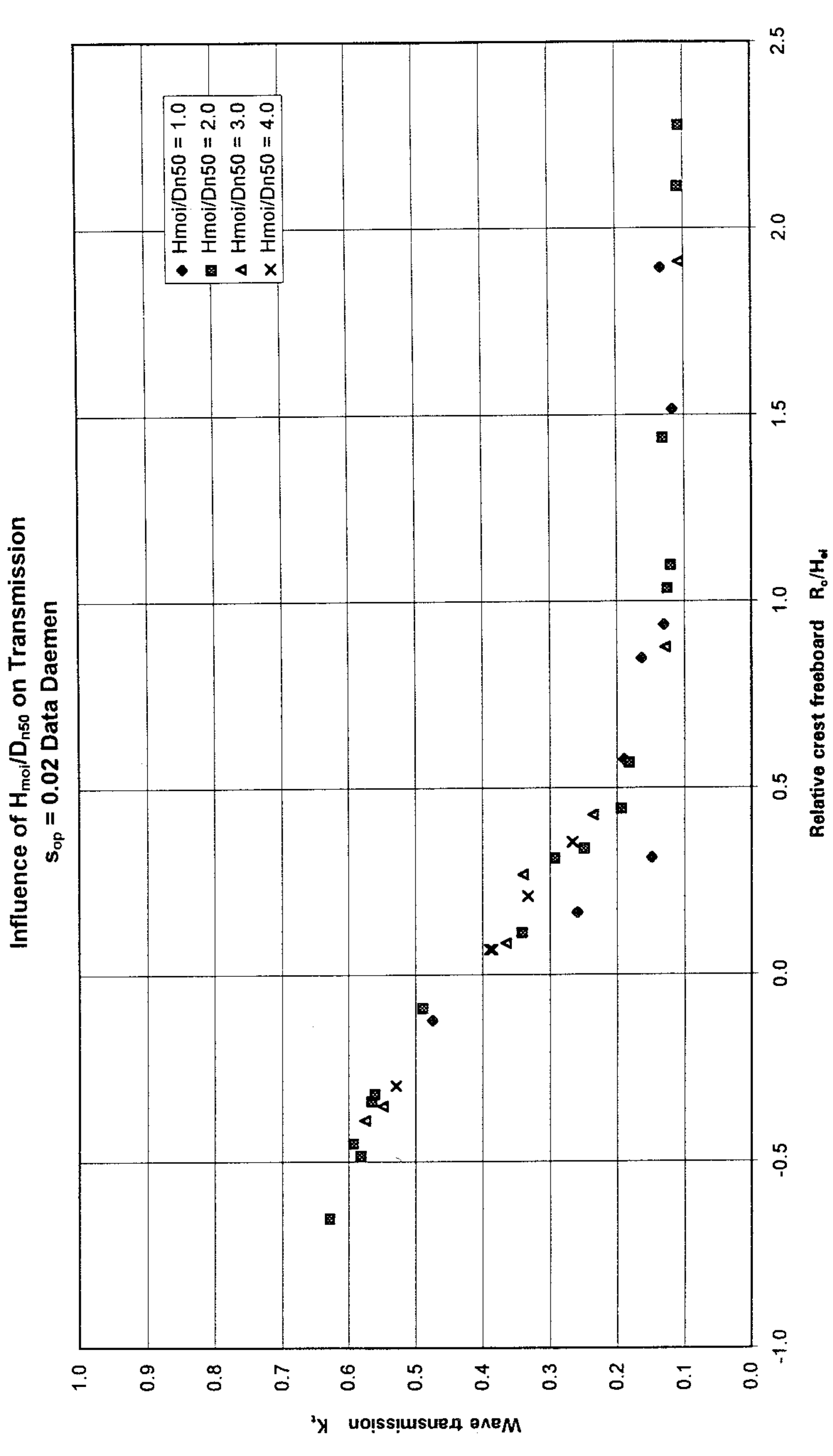
Influence of breakerparameter, Data of Van der Meer **Figure A3.6b**



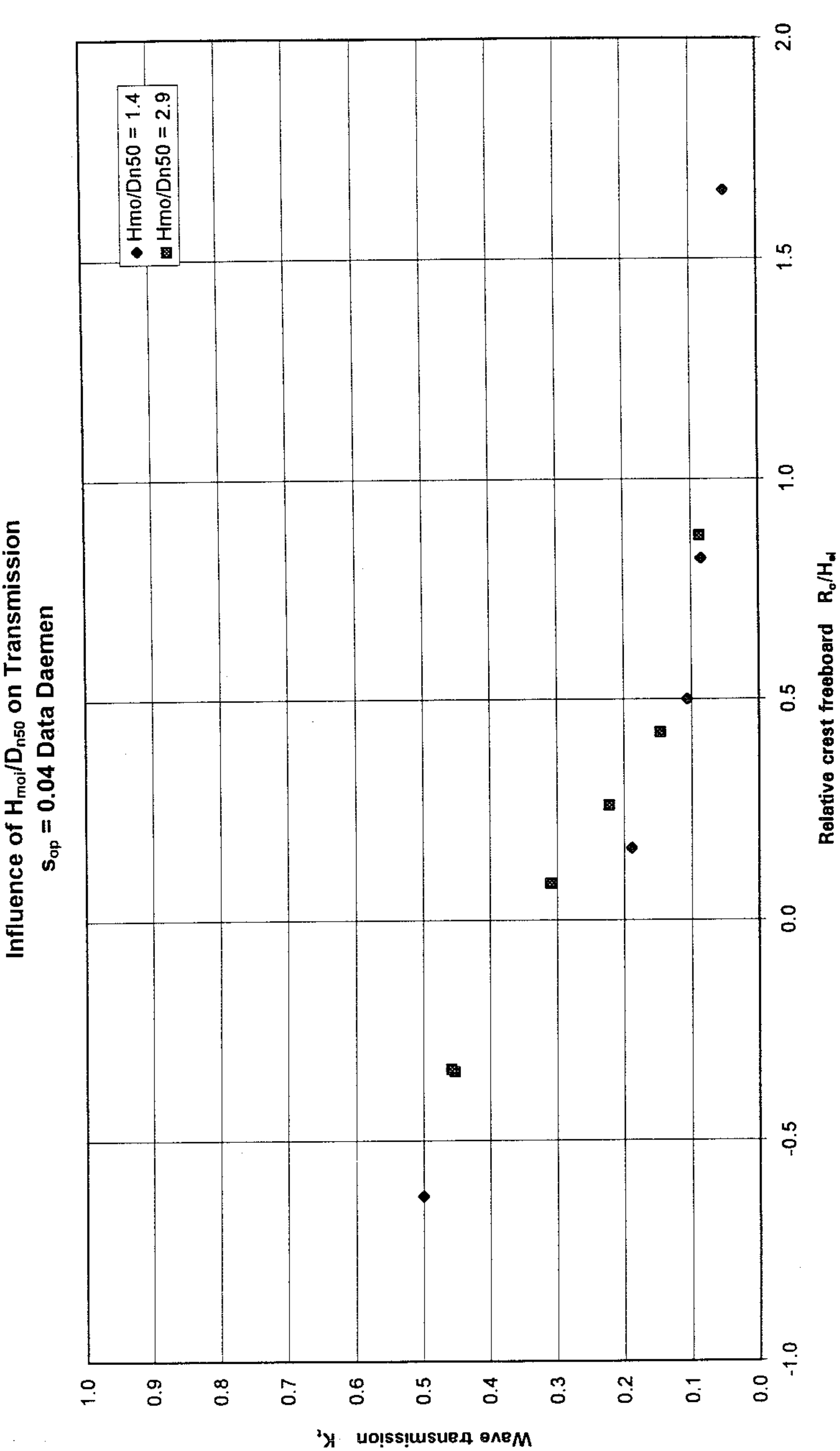
Influence on wave steepness, Data of Seelig bw4 **Figure A3.7a**



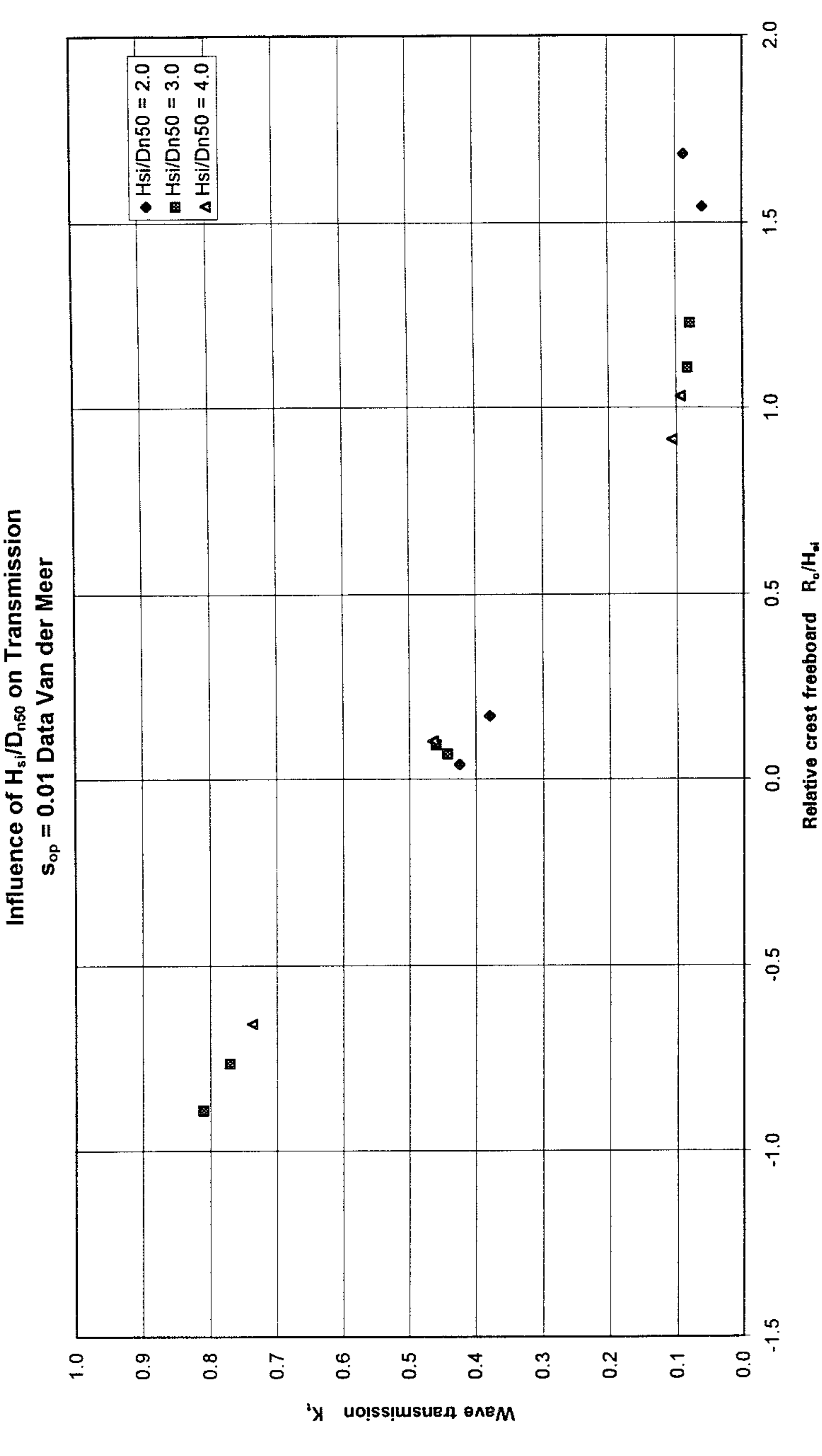
Influence of breakerparameter, Data of Seelig bw4 **Figure A3.7b**



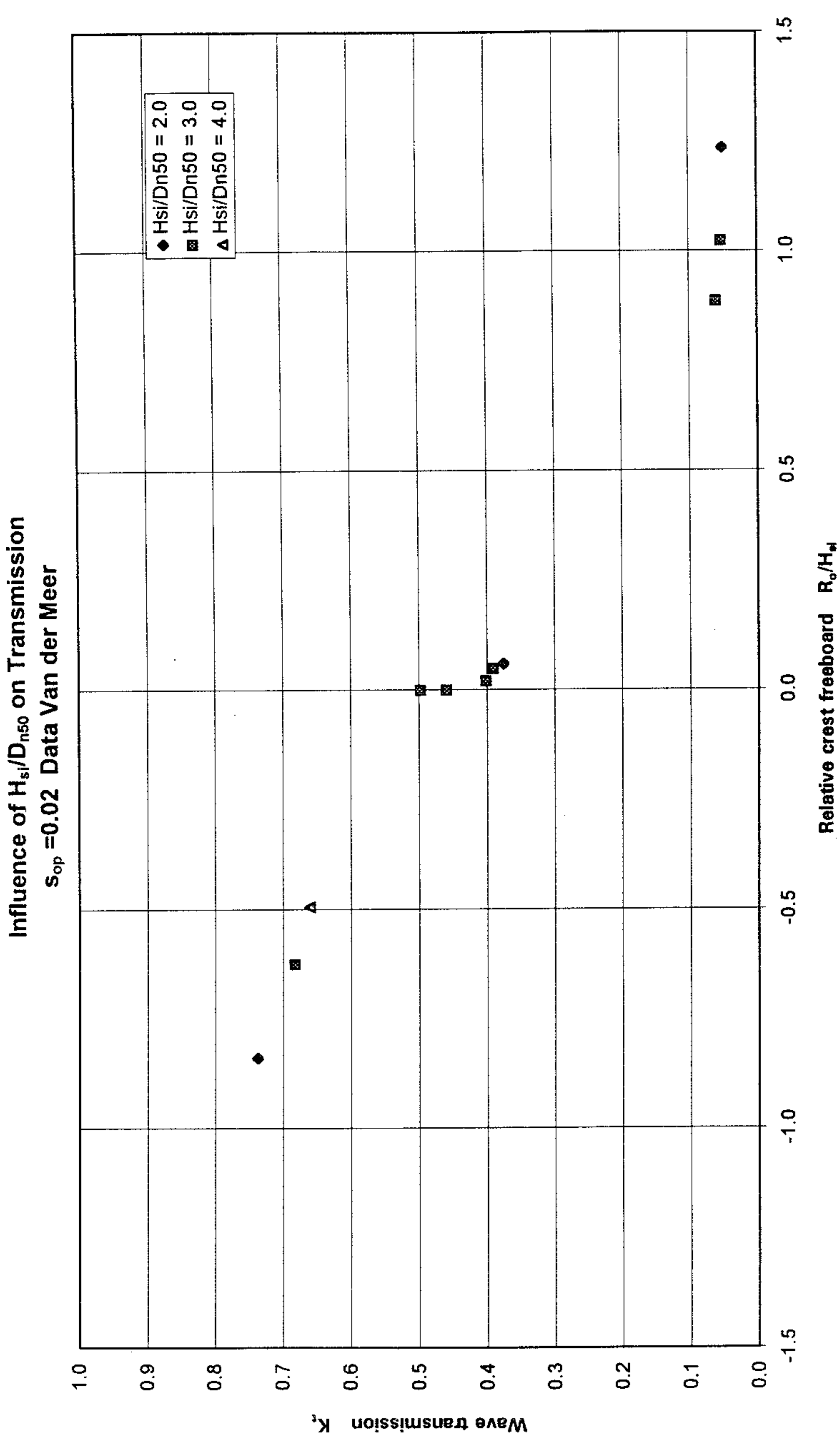
Influence of H_{moi}/D_{n50} for $s_{op} = 0.02$, Data of Daemen **Figure A3.8a**



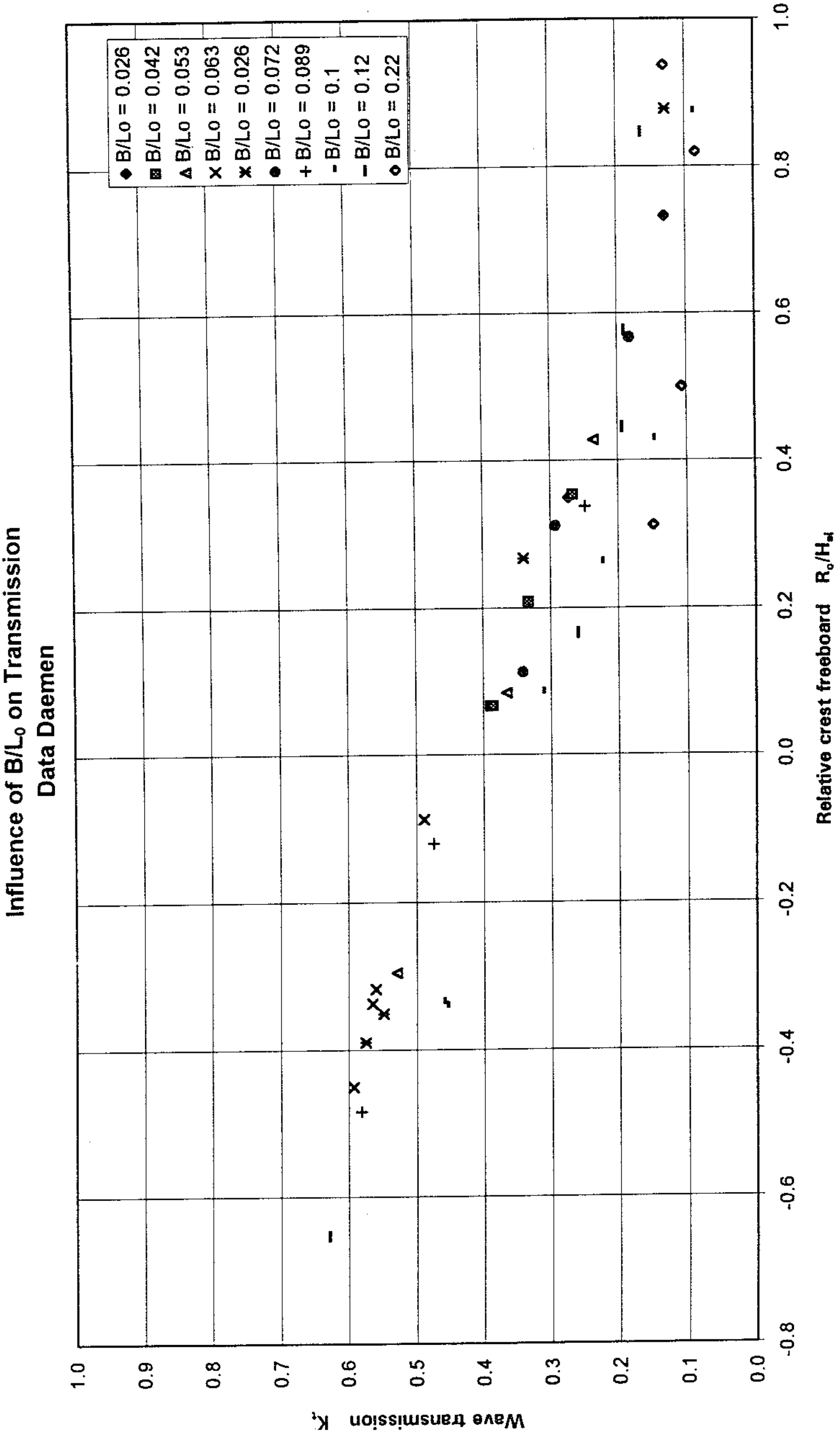
Influence of H_{moi}/D_{n50} for $s_{op} = 0.04$, Data of Daemen **Figure A3.8b**



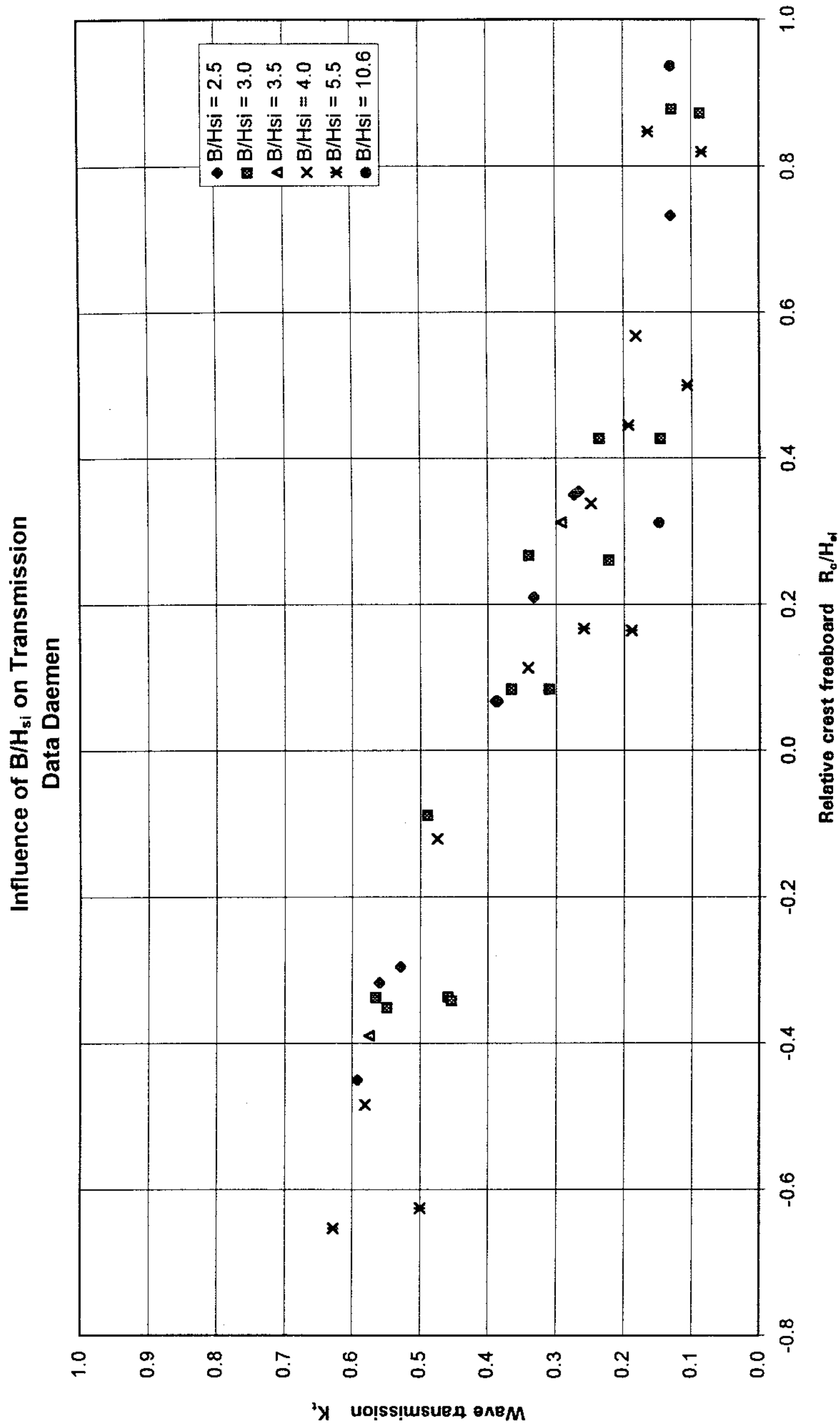
Influence of H_{moi}/D_{n50} for $s_{op} = 0.01$, Data of Van der Meer **Figure A3.9a**



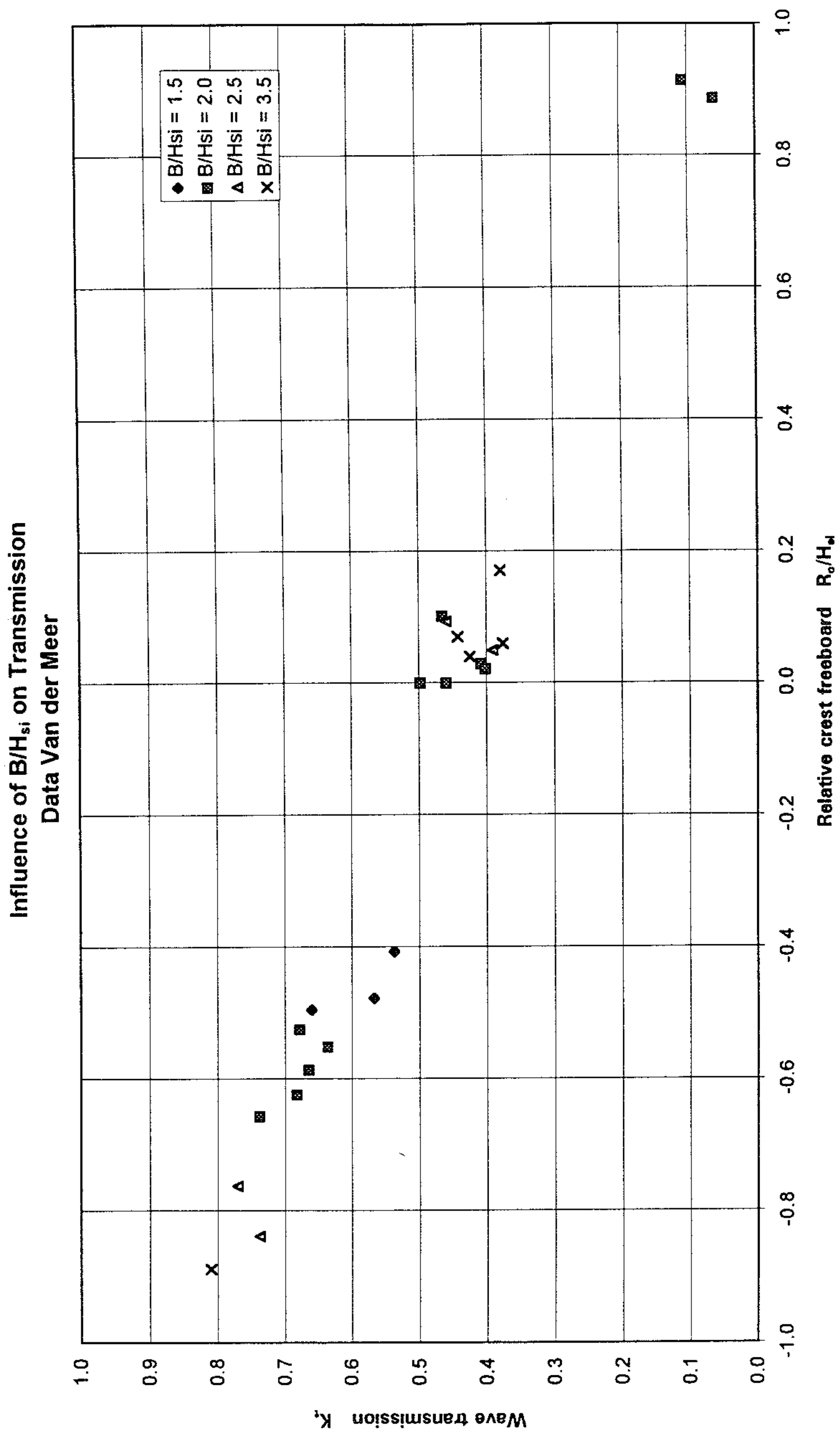
Influence of H_{moi}/D_{n50} for $s_{op} = 0.02$, Data of Van der Meer **Figure A3.9b**



Influence of relative crest width (B/L_0), Data of Daemen **Figure A3.10a**



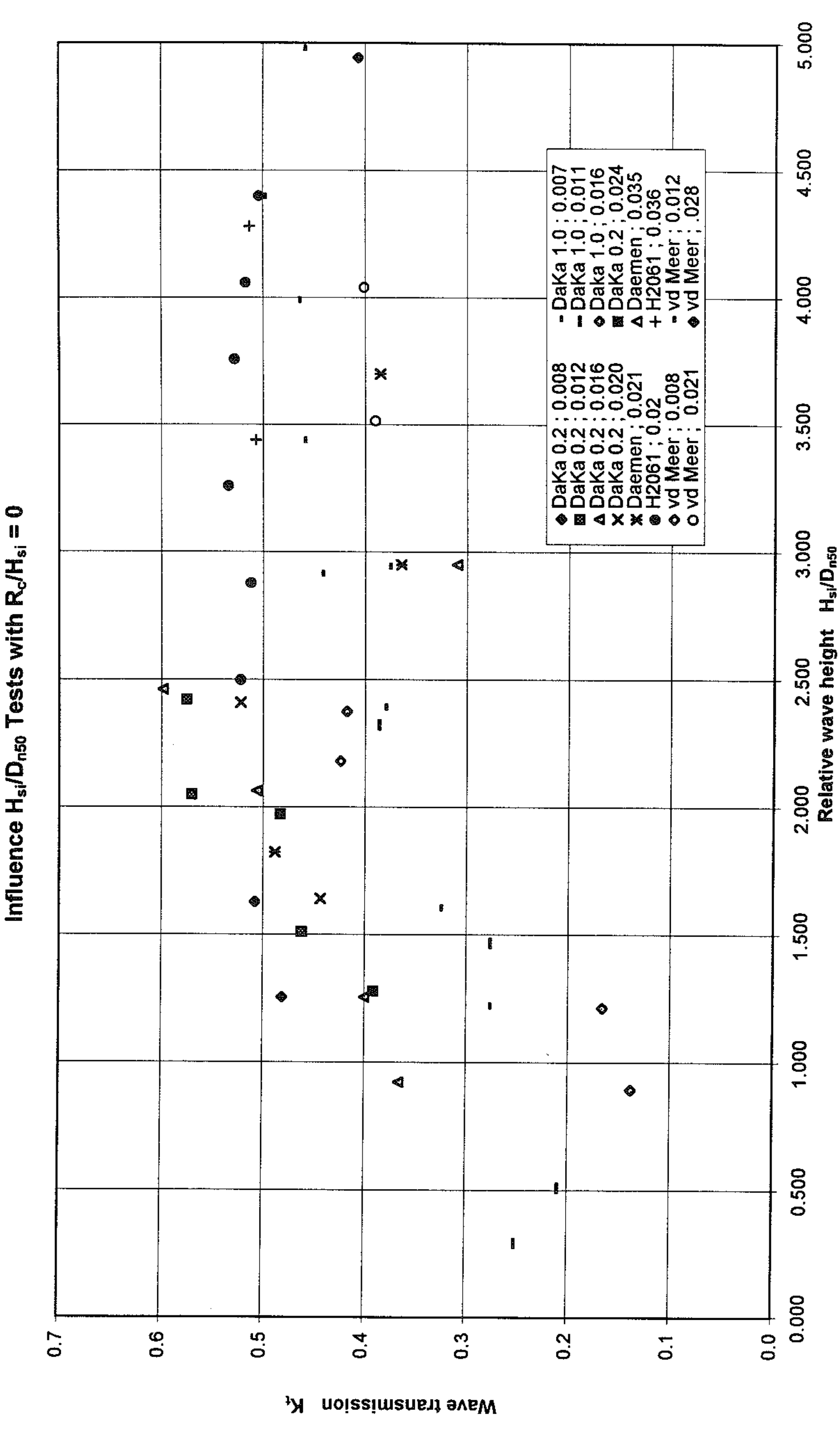
Influence of relative crest width (B/H_{si}), Data of Daemen **Figure A3.10b**



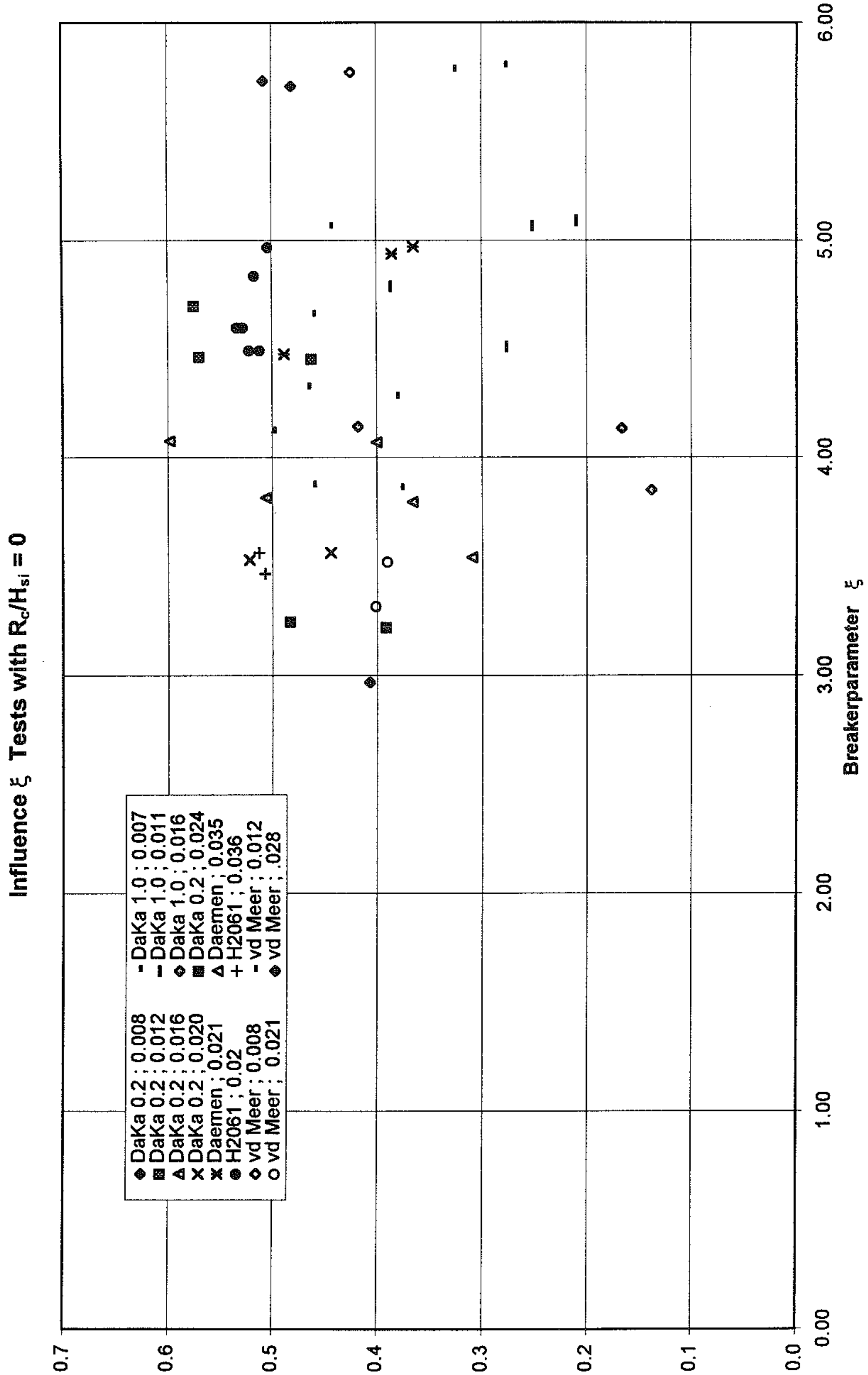
Influence of relative crest width (B/H_{si}), Data Van der Meer **Figure A3.11b**

ANNEX 4

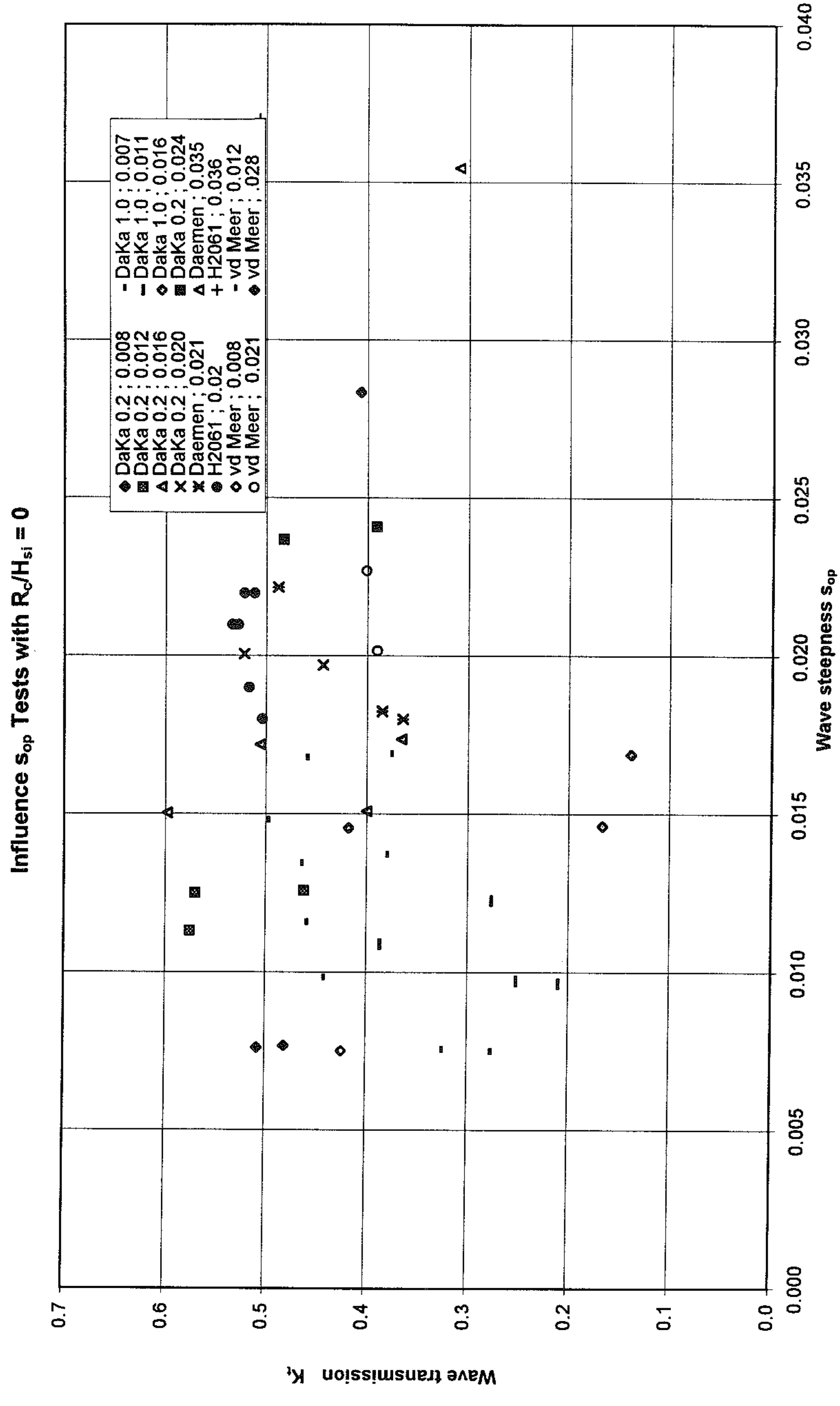
Figures for Chapter 6



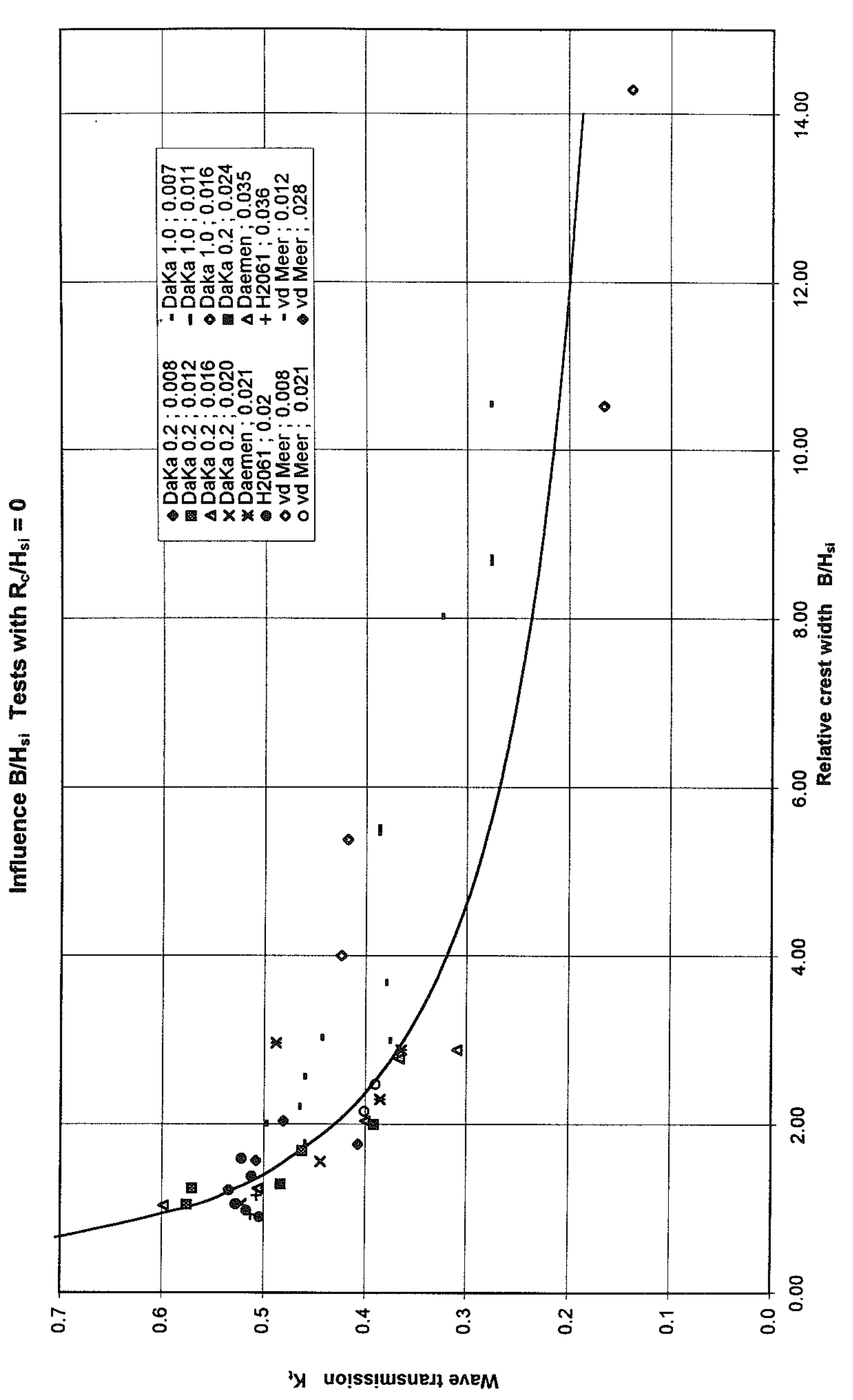
Influence of H_{si}/D_{n50} for $R_c/H_{si} = 0$, Rubble Mound breakwaters **Figure A4.1**



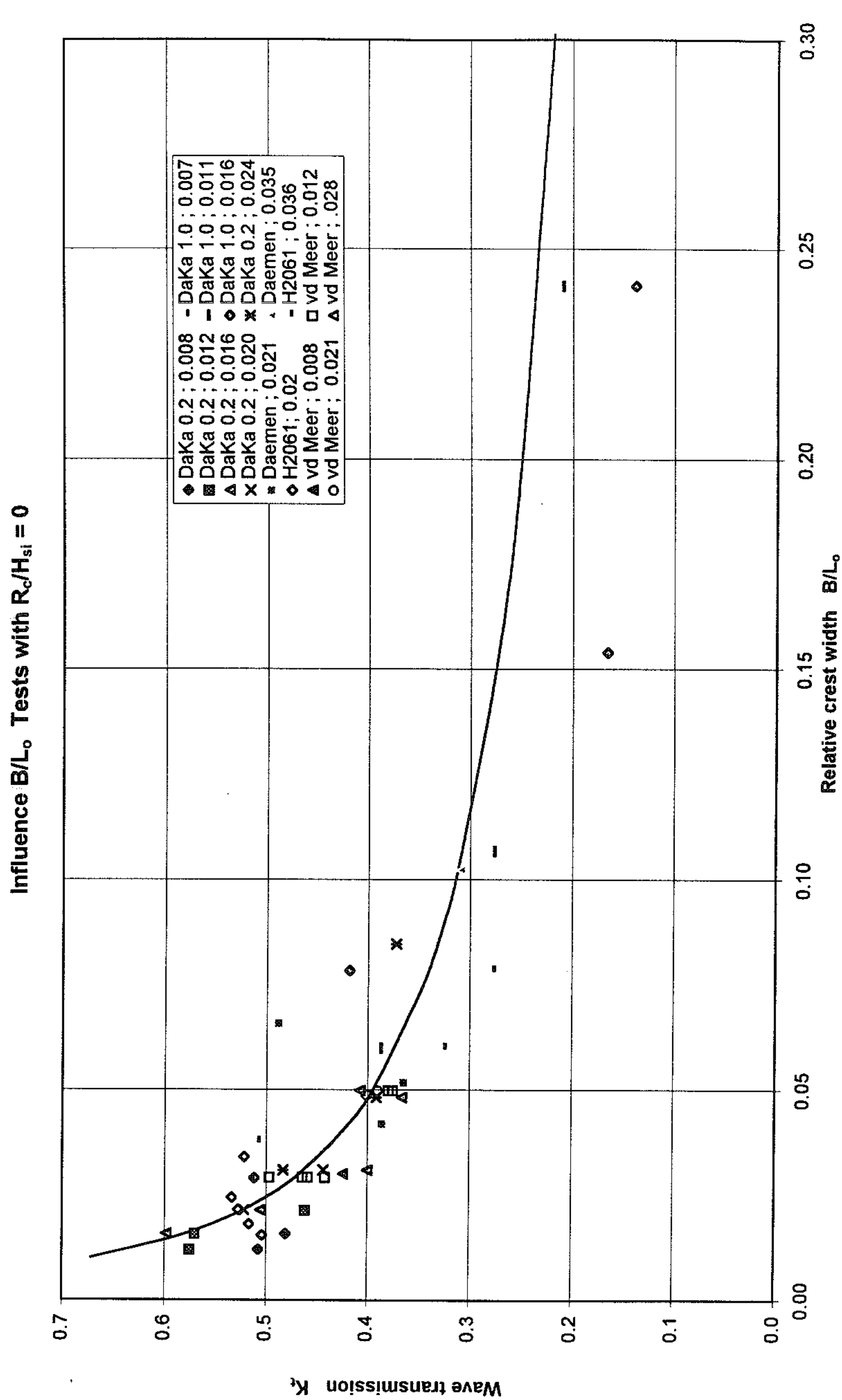
Influence of ξ for $R_c/H_{si} = 0$, Rubble Mound breakwaters **Figure A4.2**



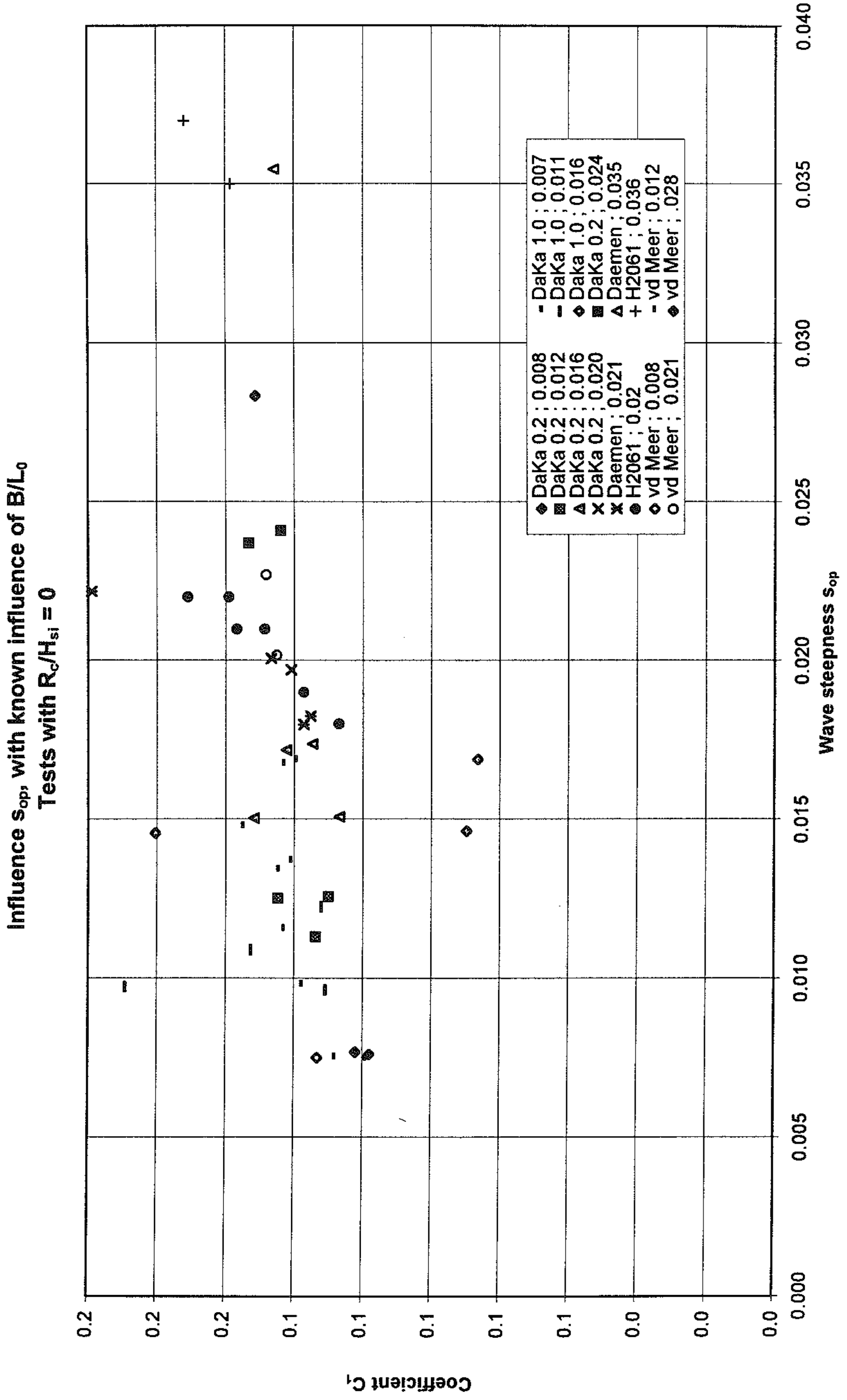
Influence of s_{op} for $R_c/H_{si} = 0$, Rubble Mound breakwaters **Figure A4.3**



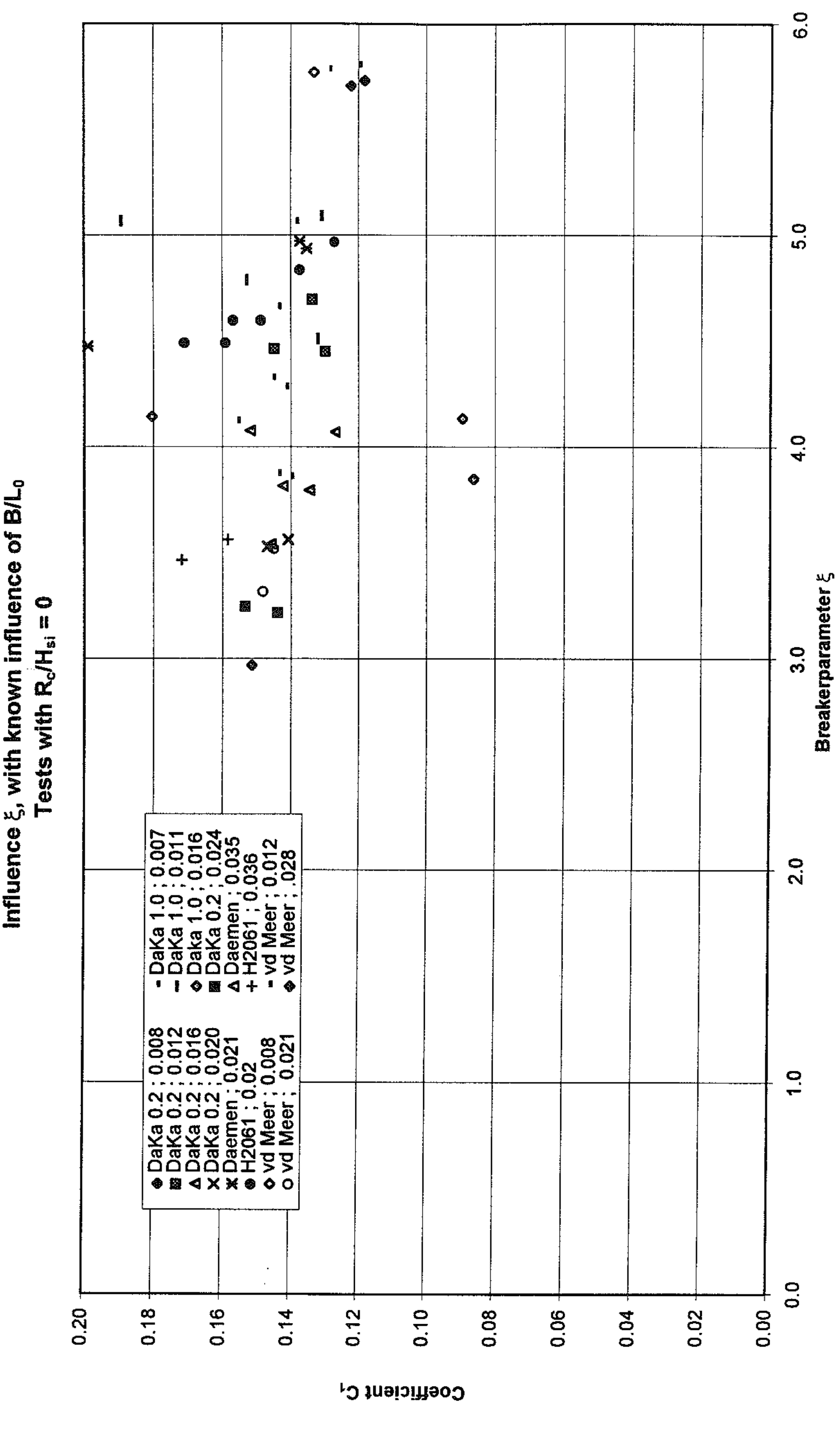
Influence of B/H_{si} for $R_c/H_{si} = 0$, Rubble Mound breakwaters **Figure A4.4**



Influence of B/L_0 for $R_c/H_{si} = 0$, Rubble Mound breakwaters **Figure A4.5**

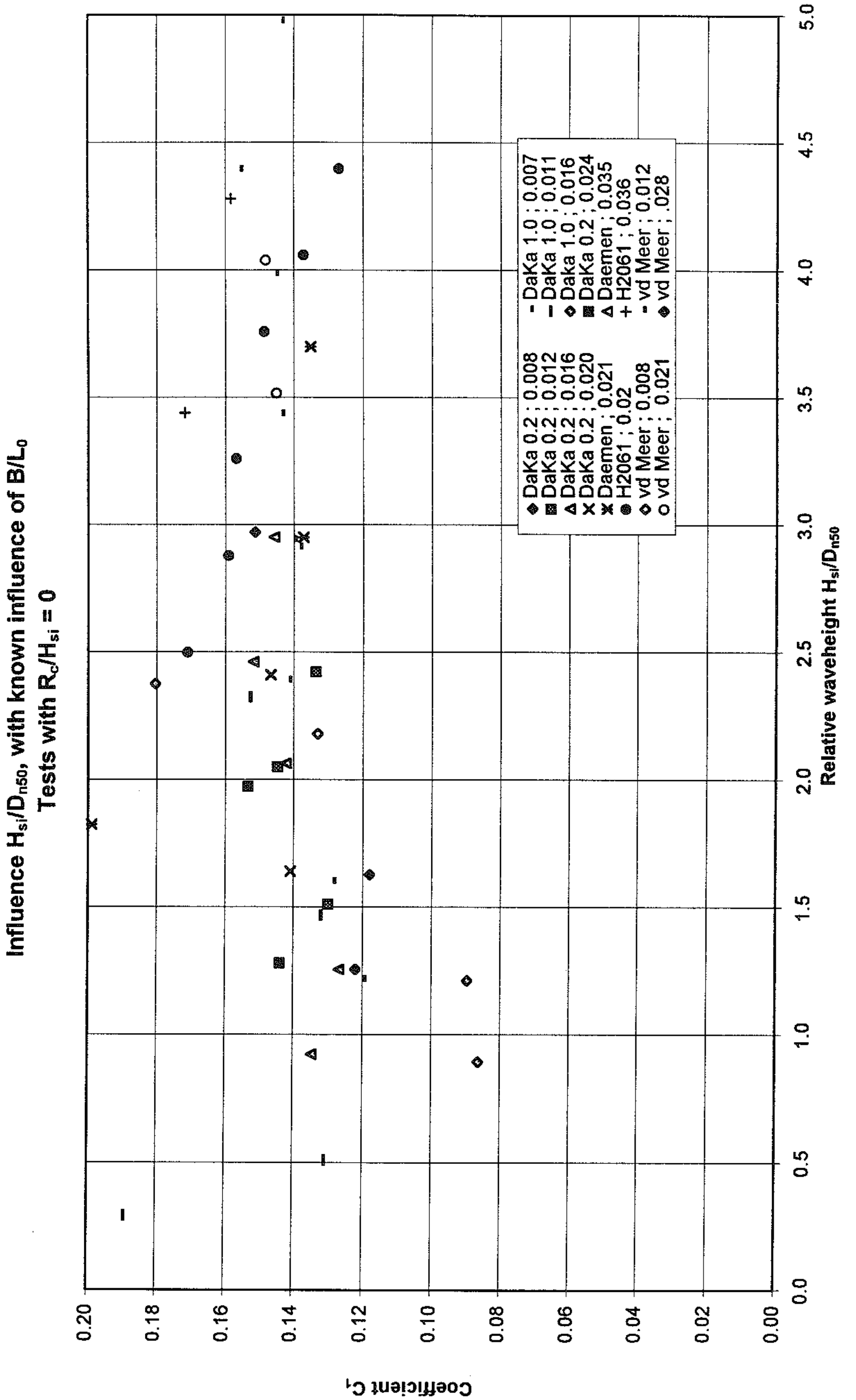


Influence of s_{op}, with known influence of B/L_0, Rubble Mound **Figure A4.6**

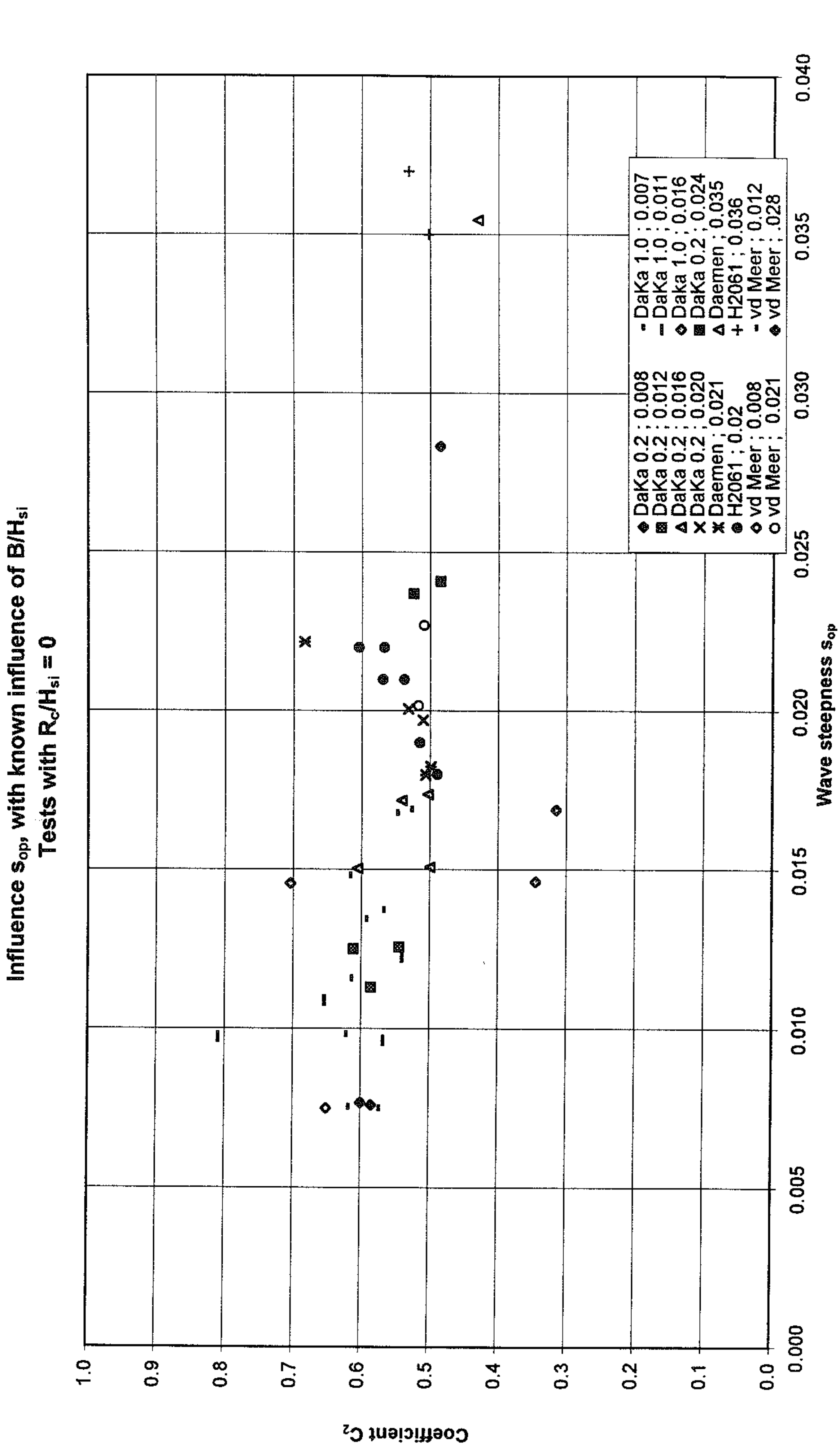


Influence of ξ, with known influence of B/L_0, Rubble Mound

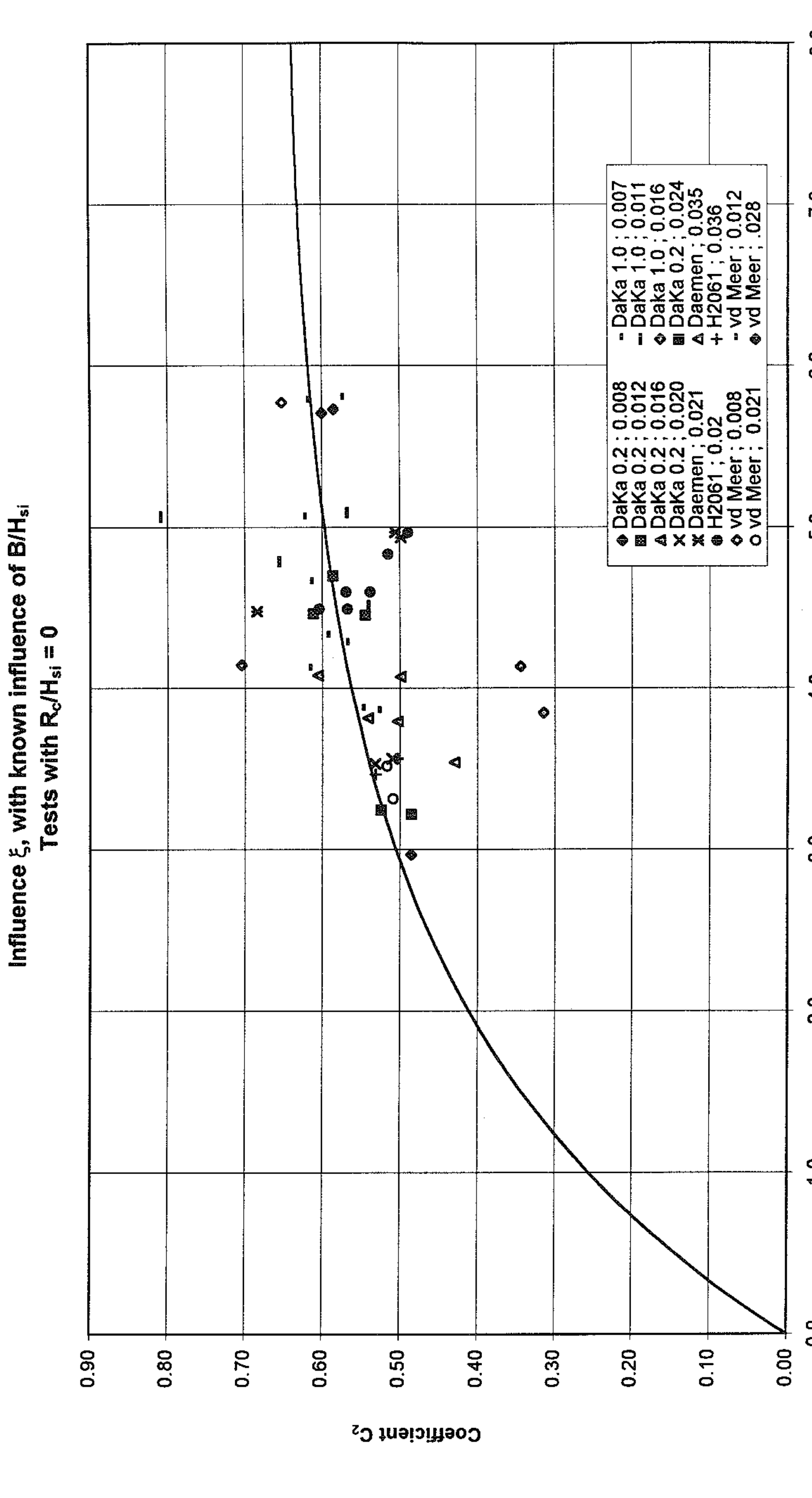
Figure A4.7



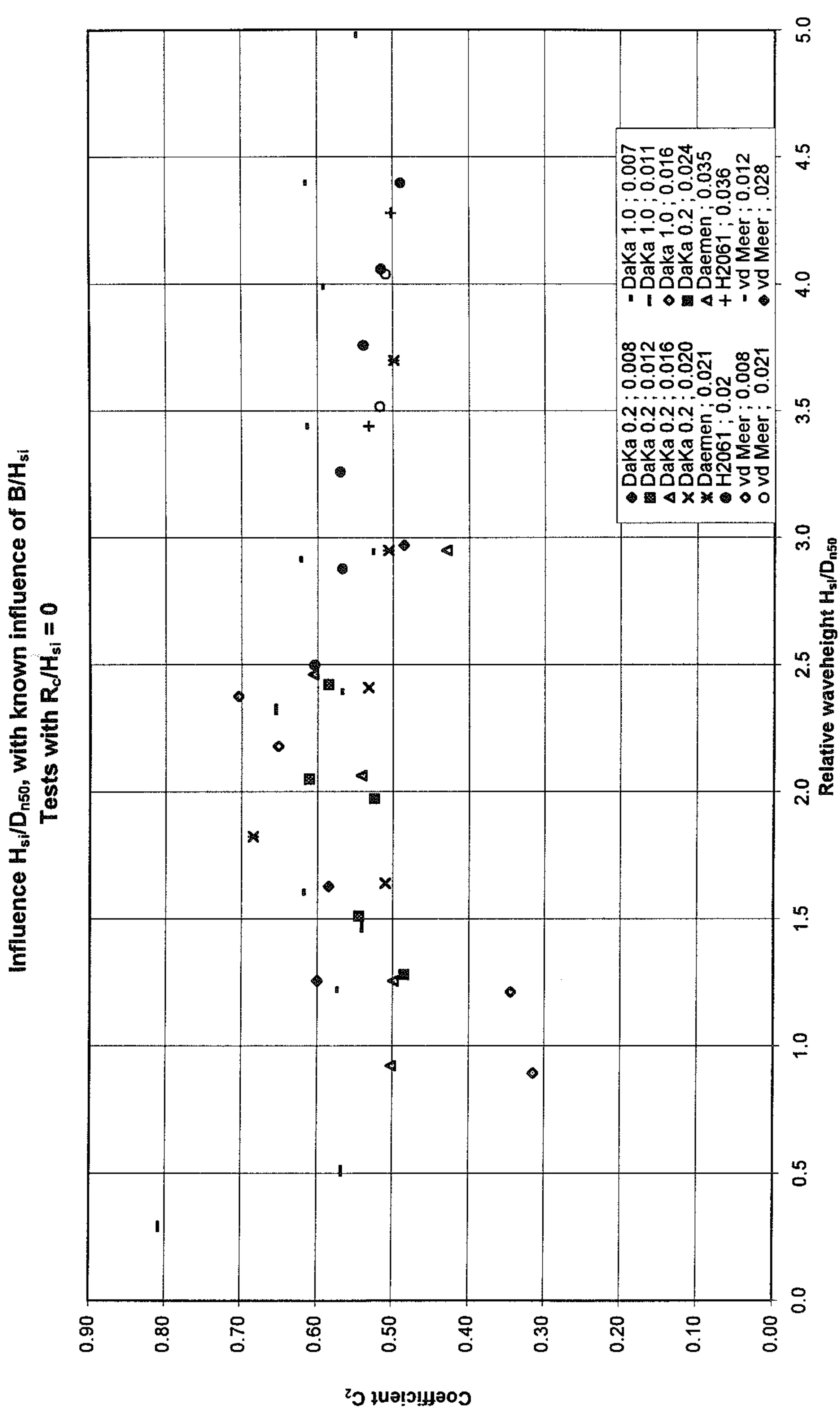
Influence H_{si}/D_{n50}, with known influence of B/L_0, Rubble Mound **Figure A4.8**



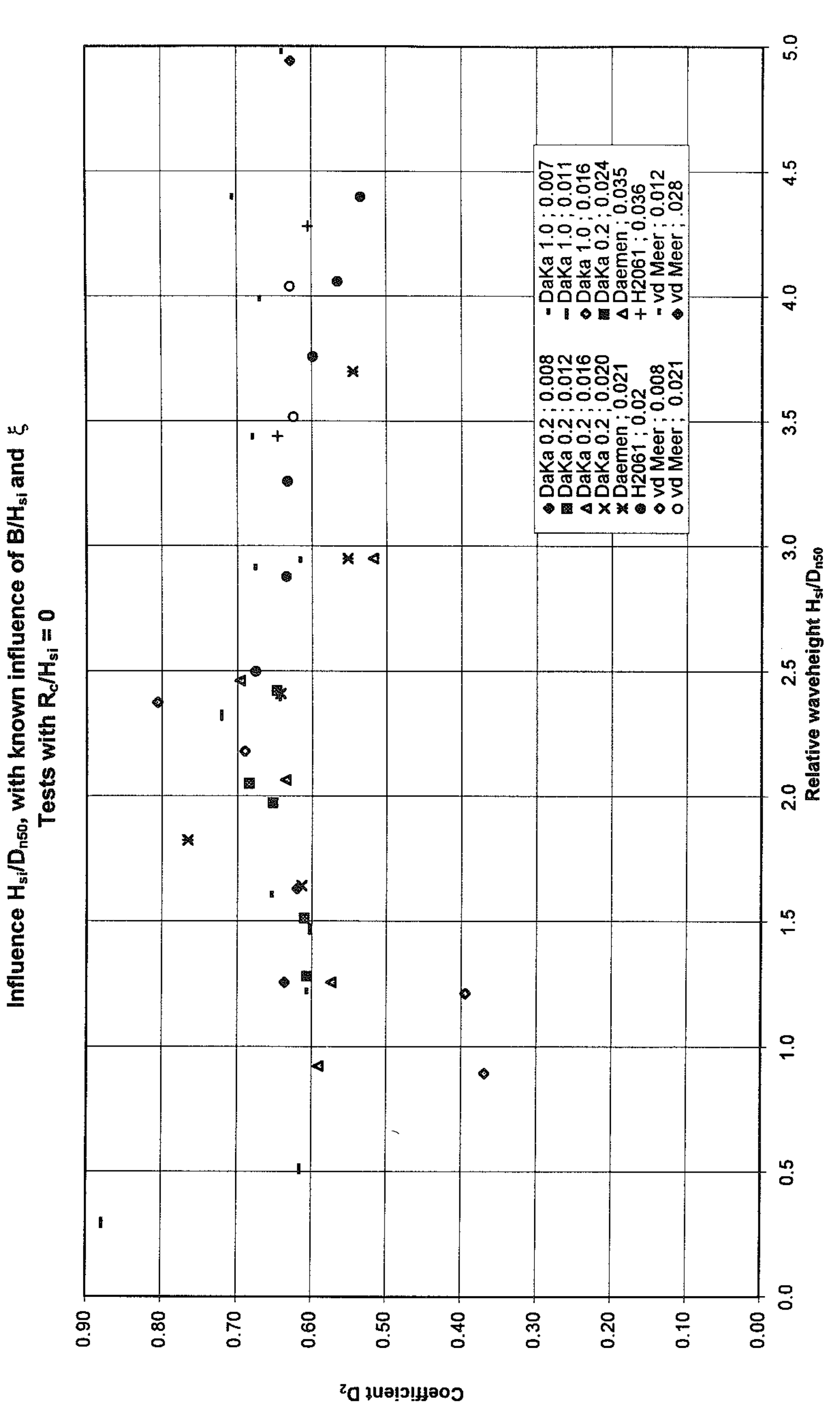
Influence of s_{op}, with known influence of B/H_{si}, Rubble Mound **Figure A4.9**



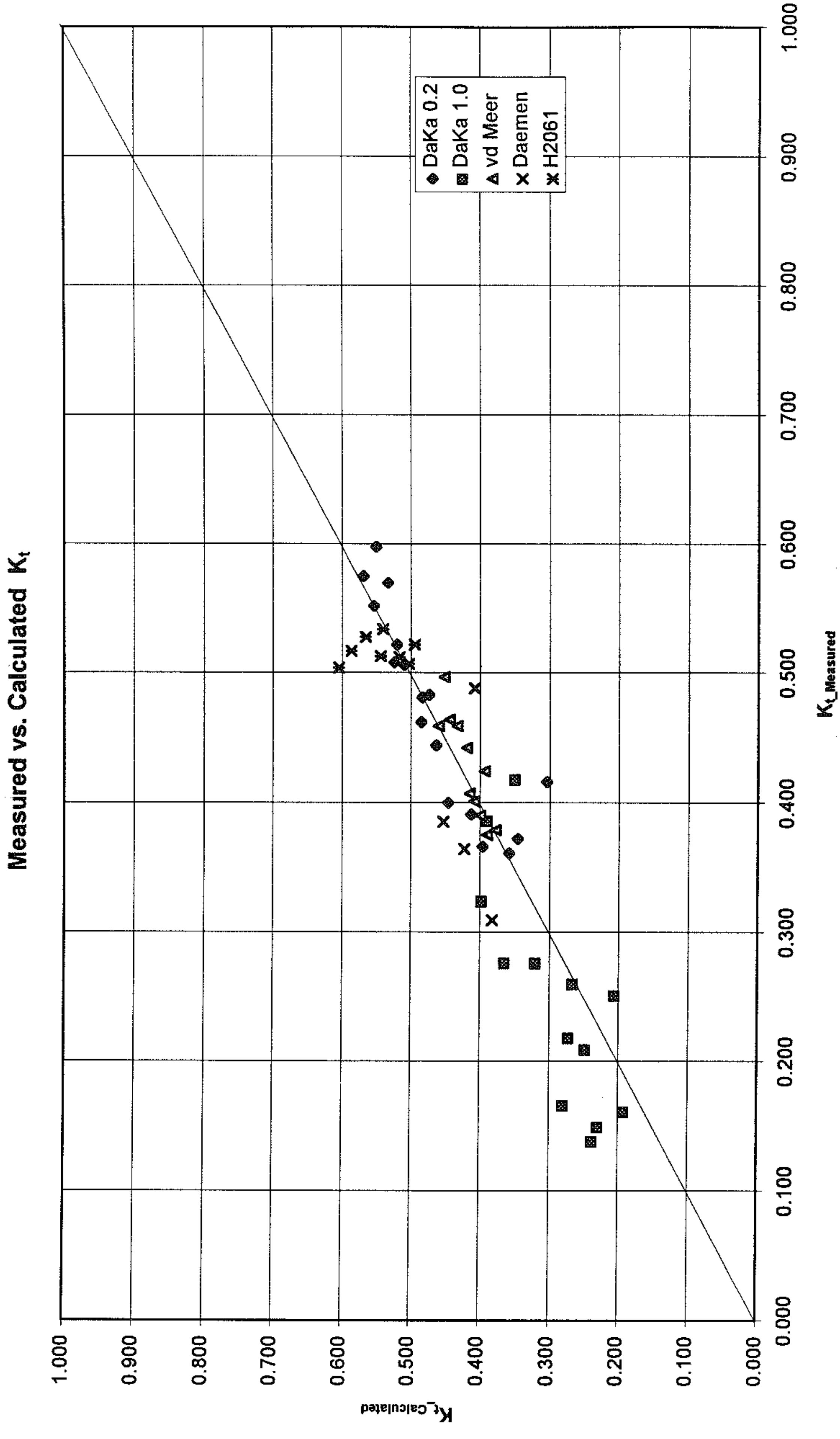
Influence of ξ, with known influence of B/H_{si}, Rubble Mound **Figure A4.10**



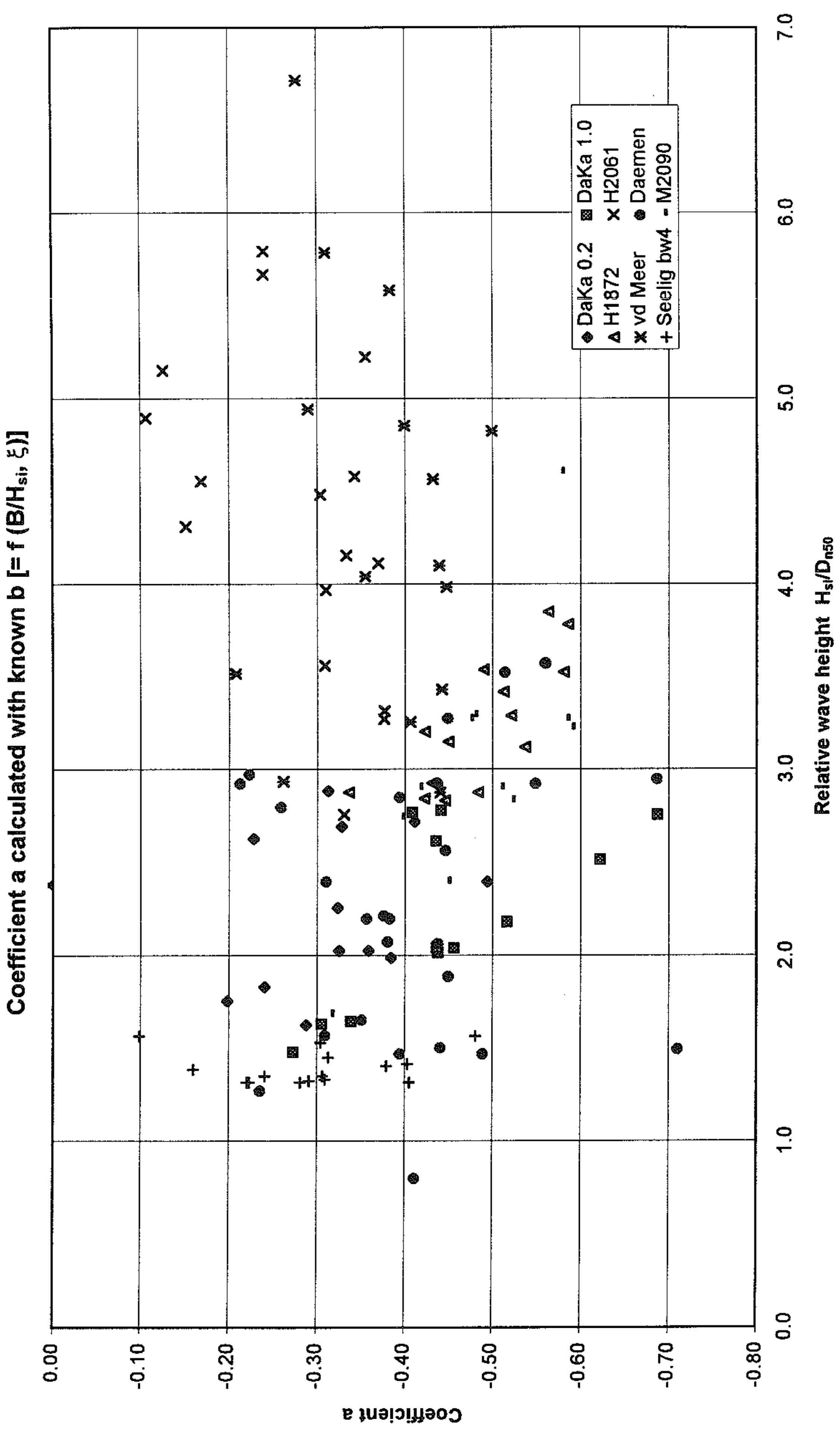
Influence of H_{si}/D_{n50}, with known influence B/H_{si}, Rubble Mound **Figure A4.11**



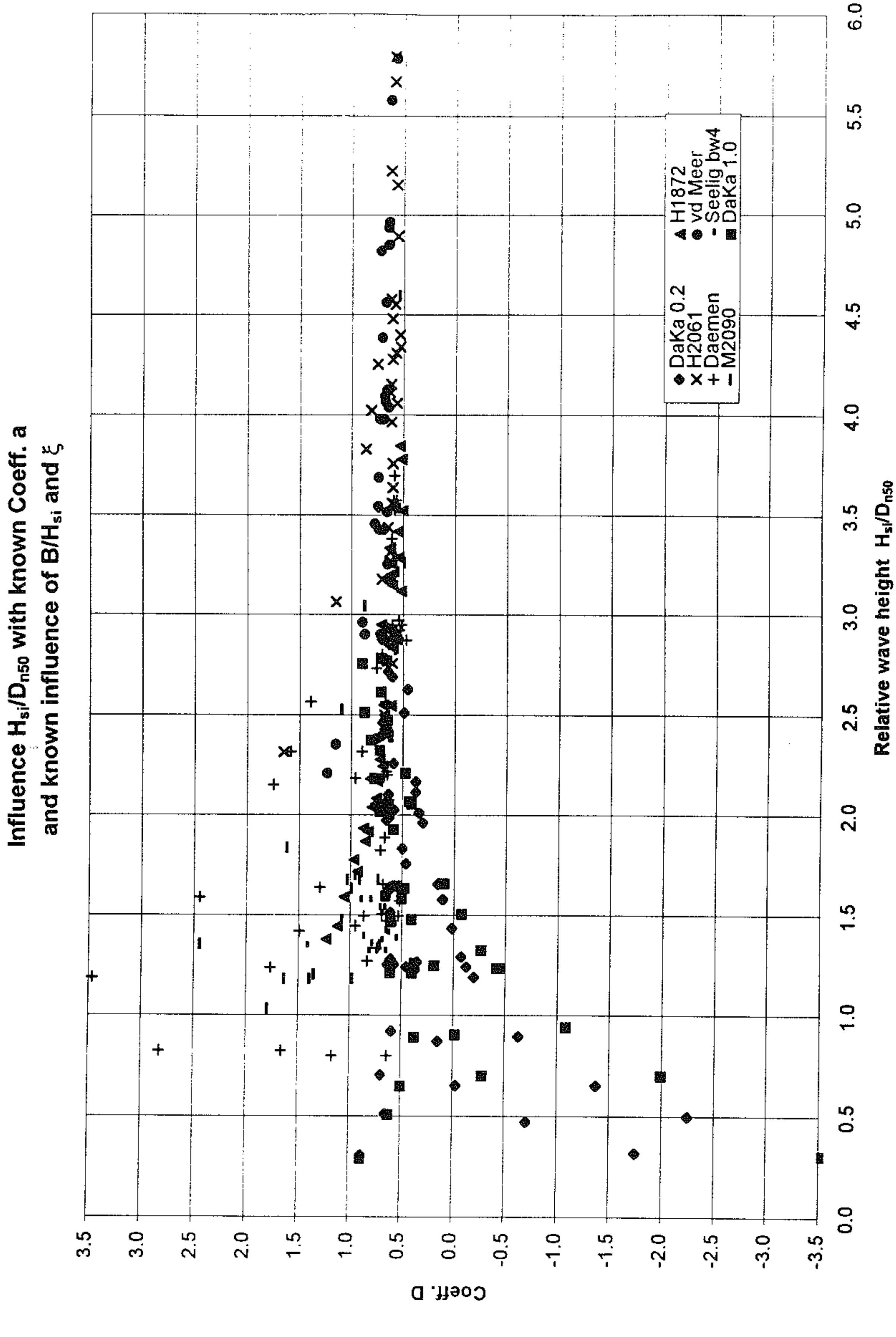
Influence of H_{si}/D_{n50} with known influence of B/H_{si} and ξ **Figure A4.12**



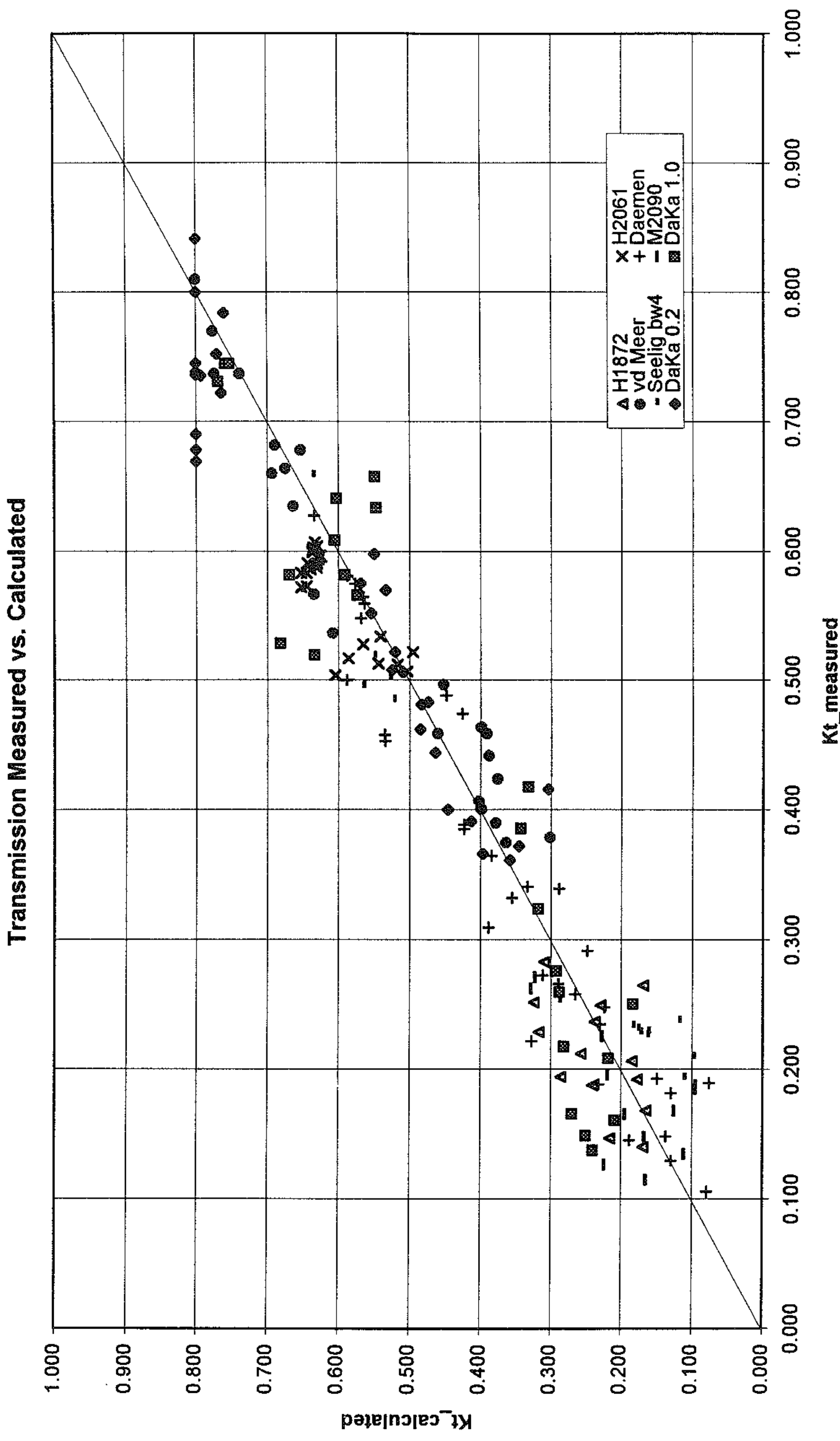
Measured vs. Calculated transmission, $R_c/H_{si} = 0$, Rubble Mound **Figure A4.13**



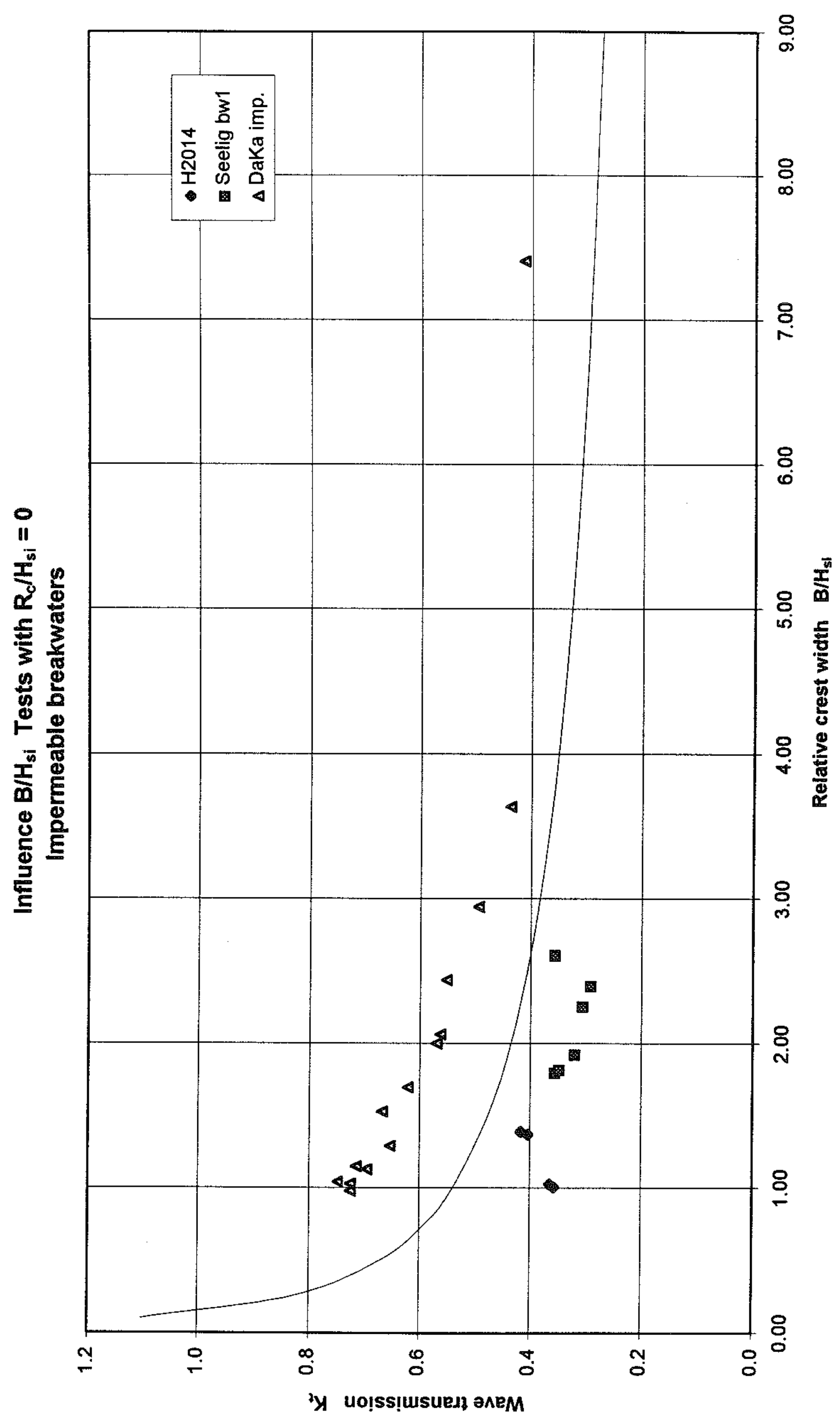
Coefficient a with known coefficient b, Rubble Mound **Figure A4.14**



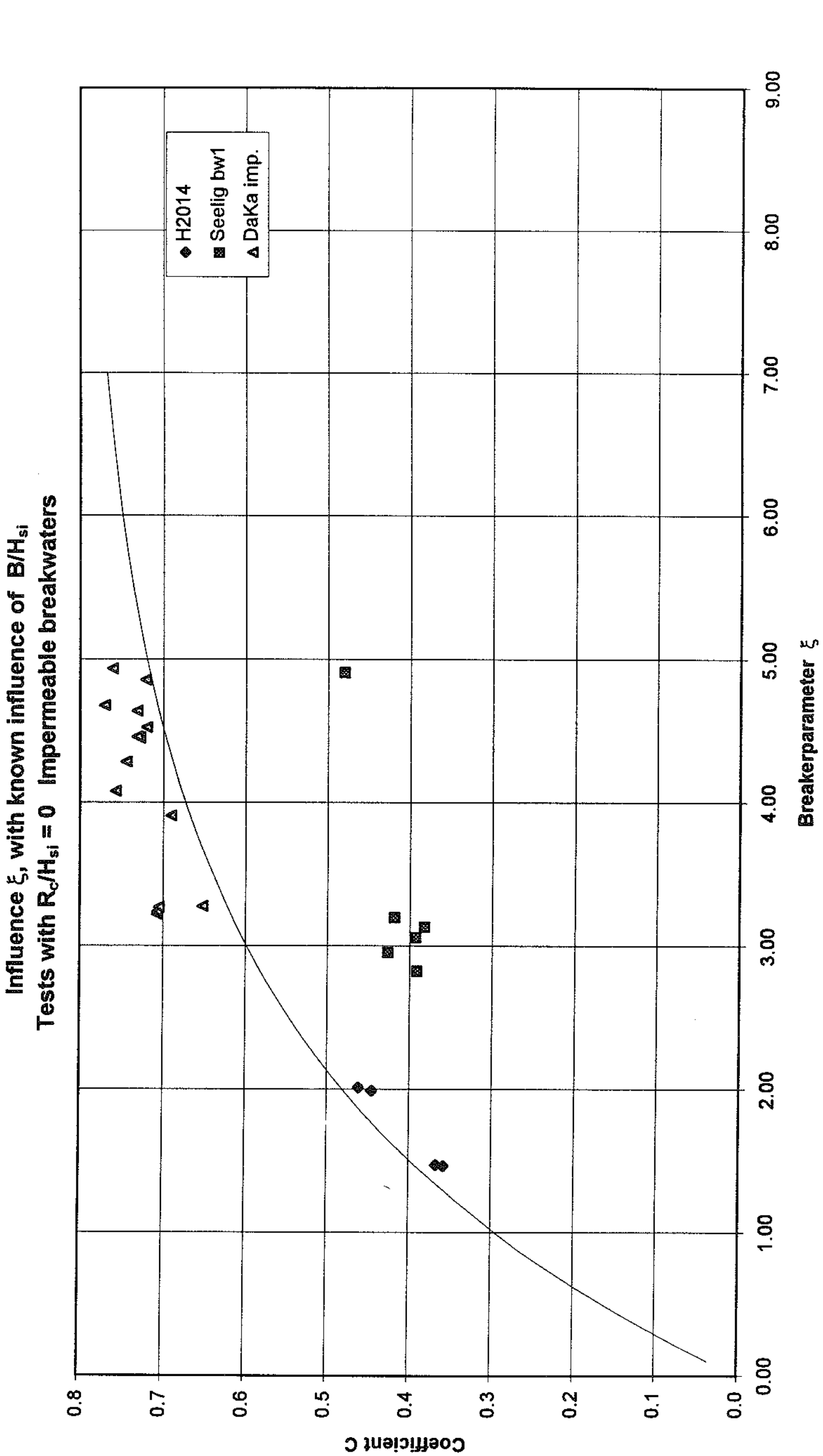
Influence H_{si}/D_{n50}, known Coeff. a and influence of B/H_{si} and ξ **Figure A4.15**



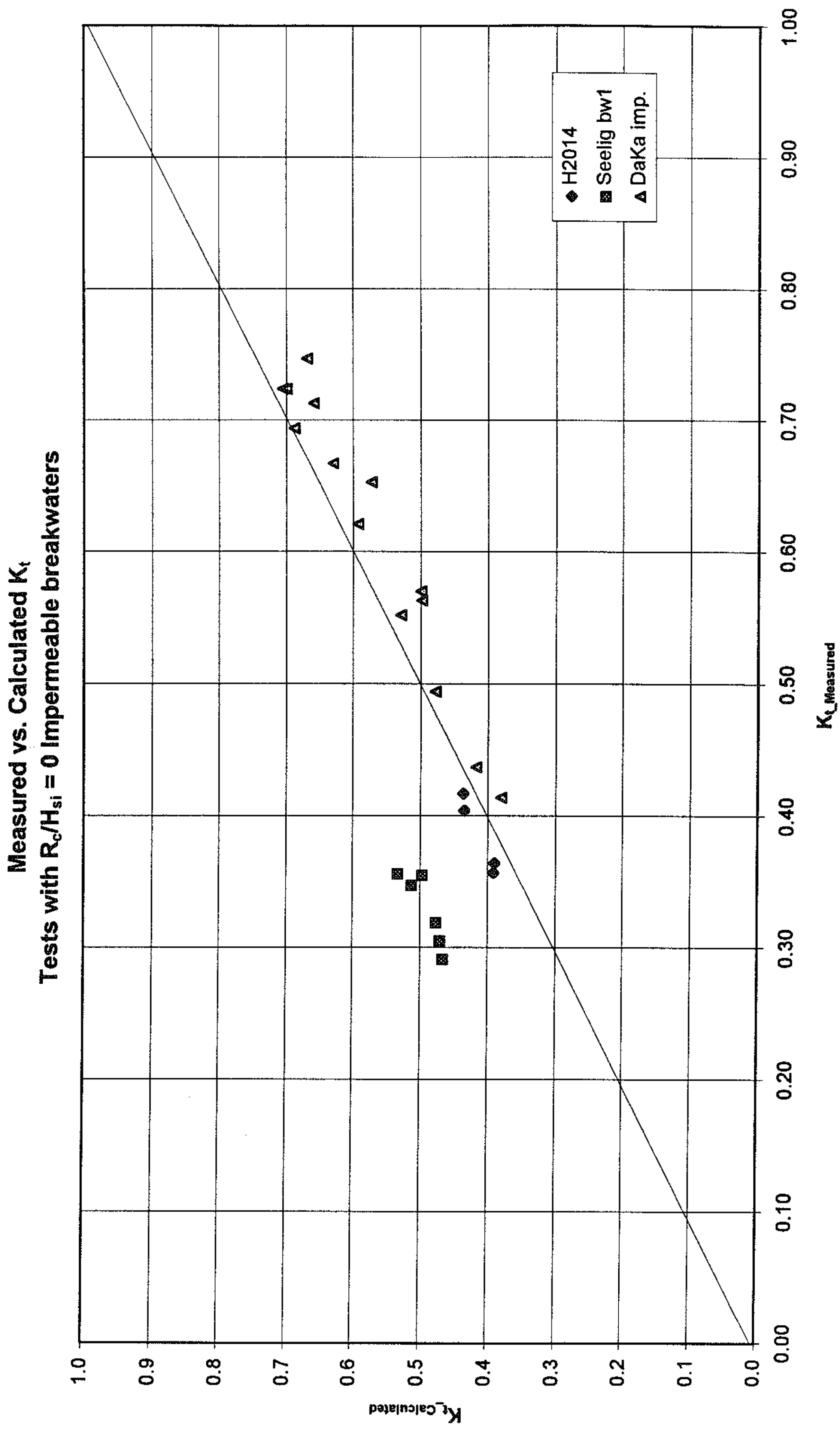
Measured vs. Calculated transmission, Rubble Mound breakwaters **Figure A4.16**



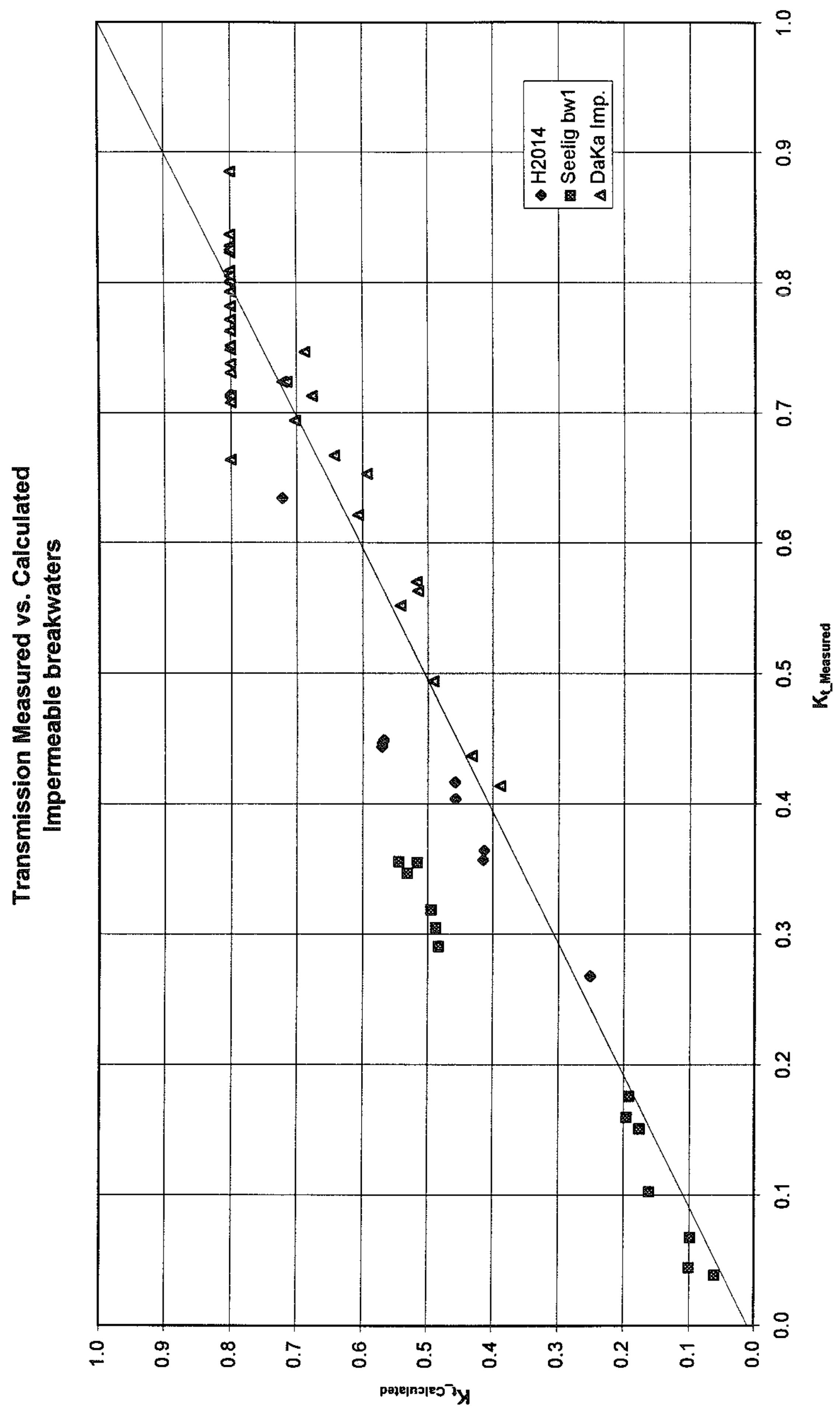
Influence of B/H_{si} for $R_c/H_{si} = 0$, Impermeable breakwaters **Figure A4.17**



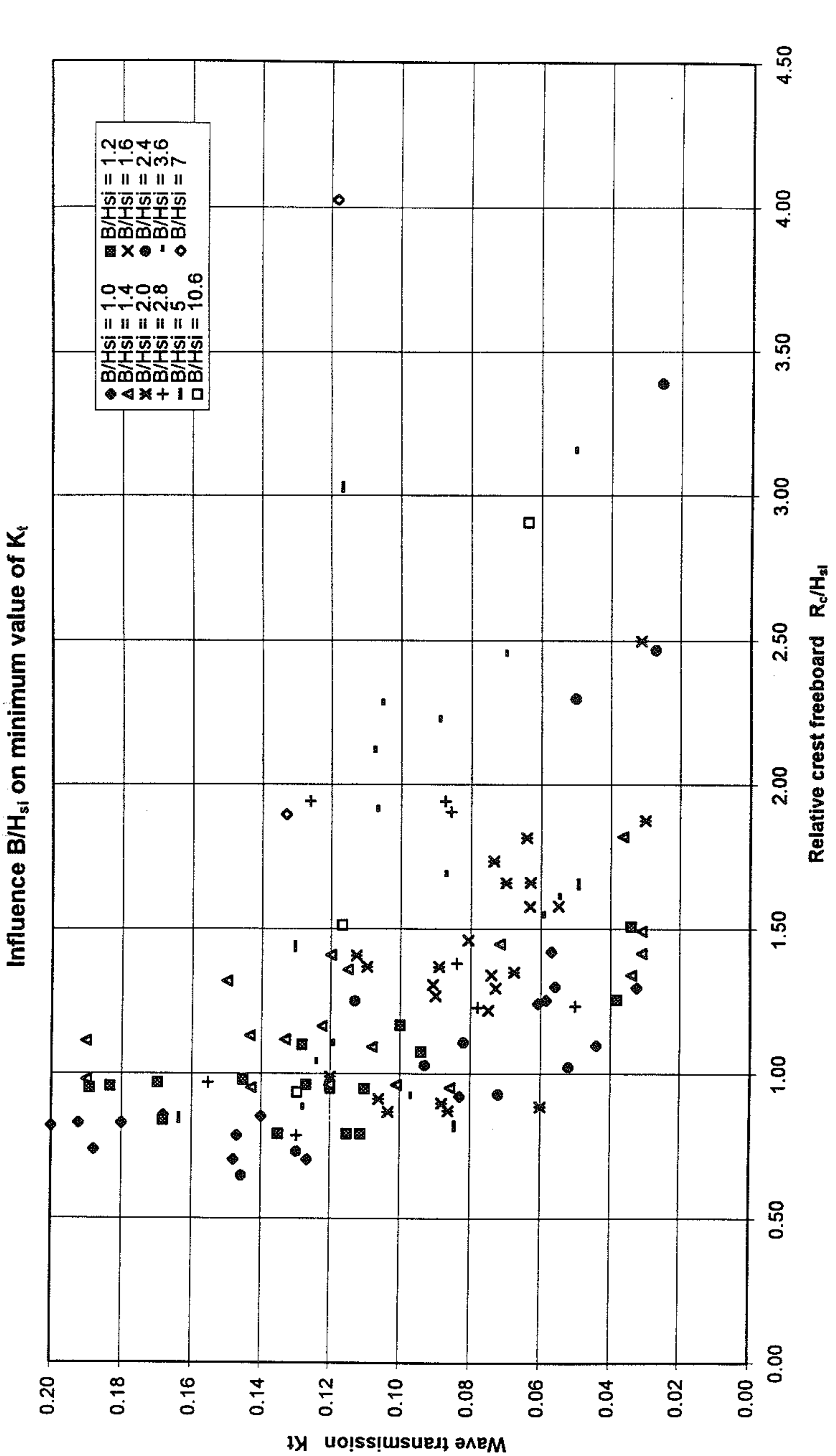
Influence of ξ, with known influence of B/H_{si}, Impermeable **Figure A4.18**



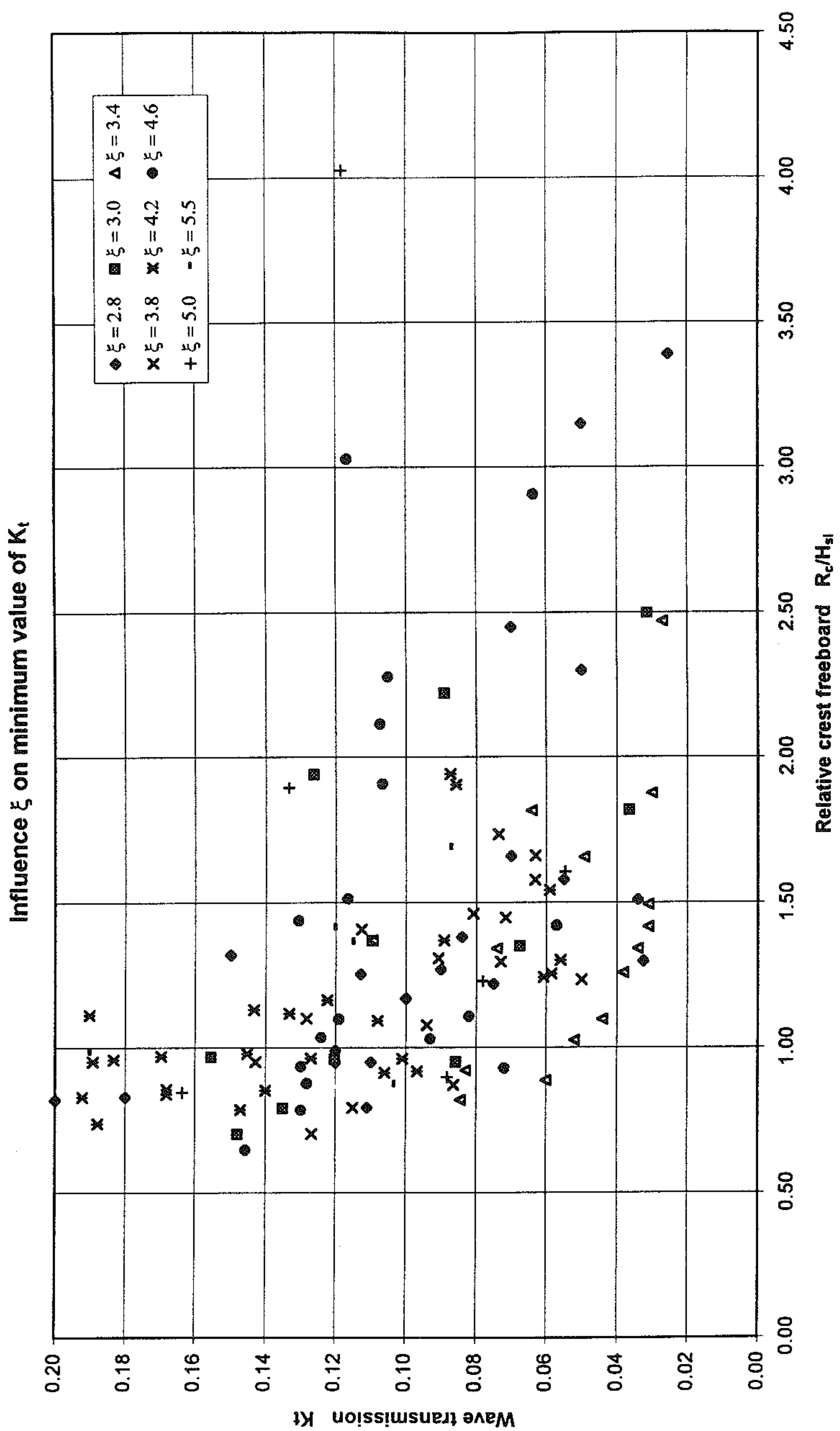
Measured vs. Calculated transmission, $R_c/H_{si} = 0$, Impermeable **Figure A4.19**



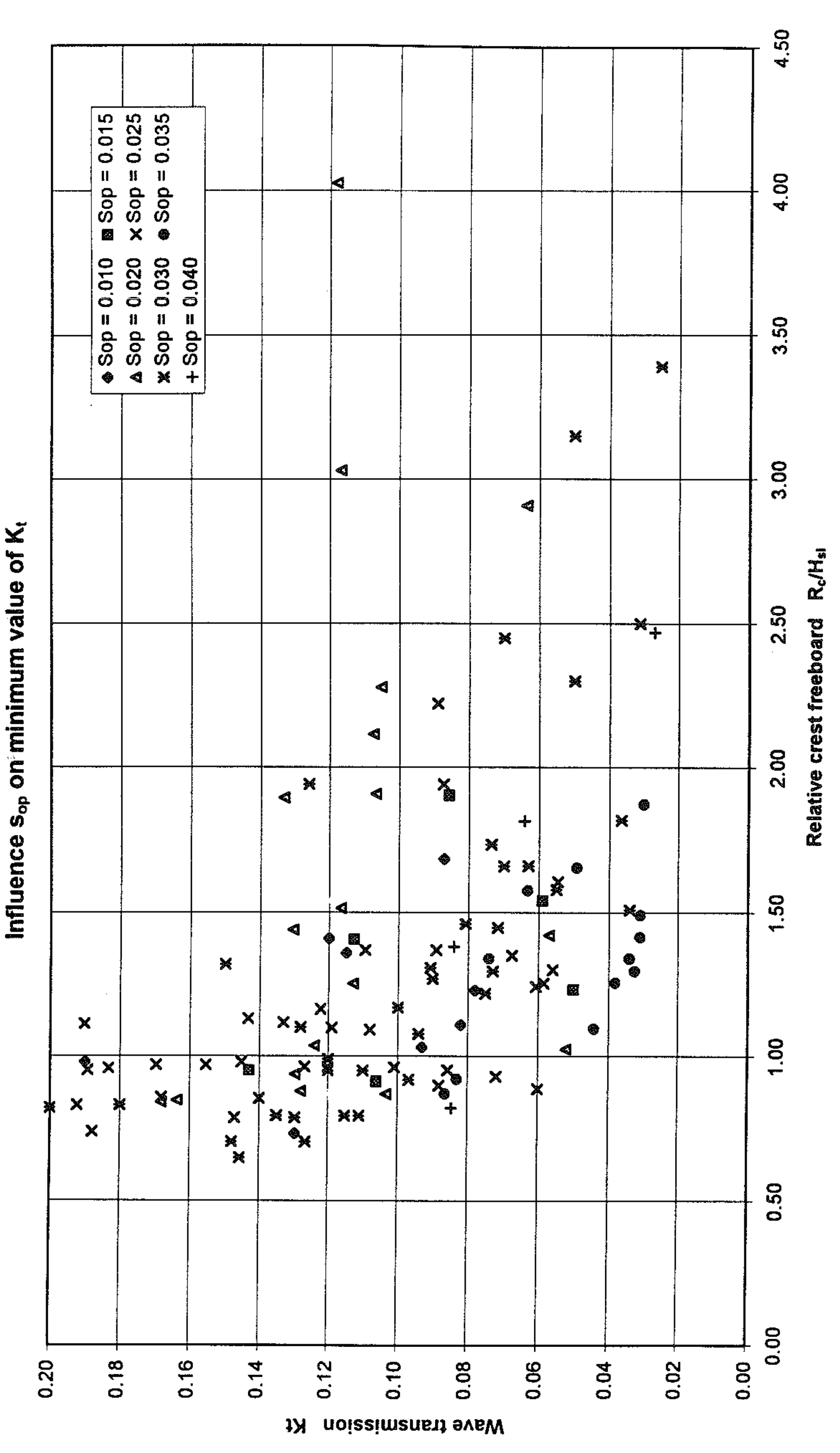
Measured vs. Calculated transmission, Impermeable breakwaters **Figure A4.20**



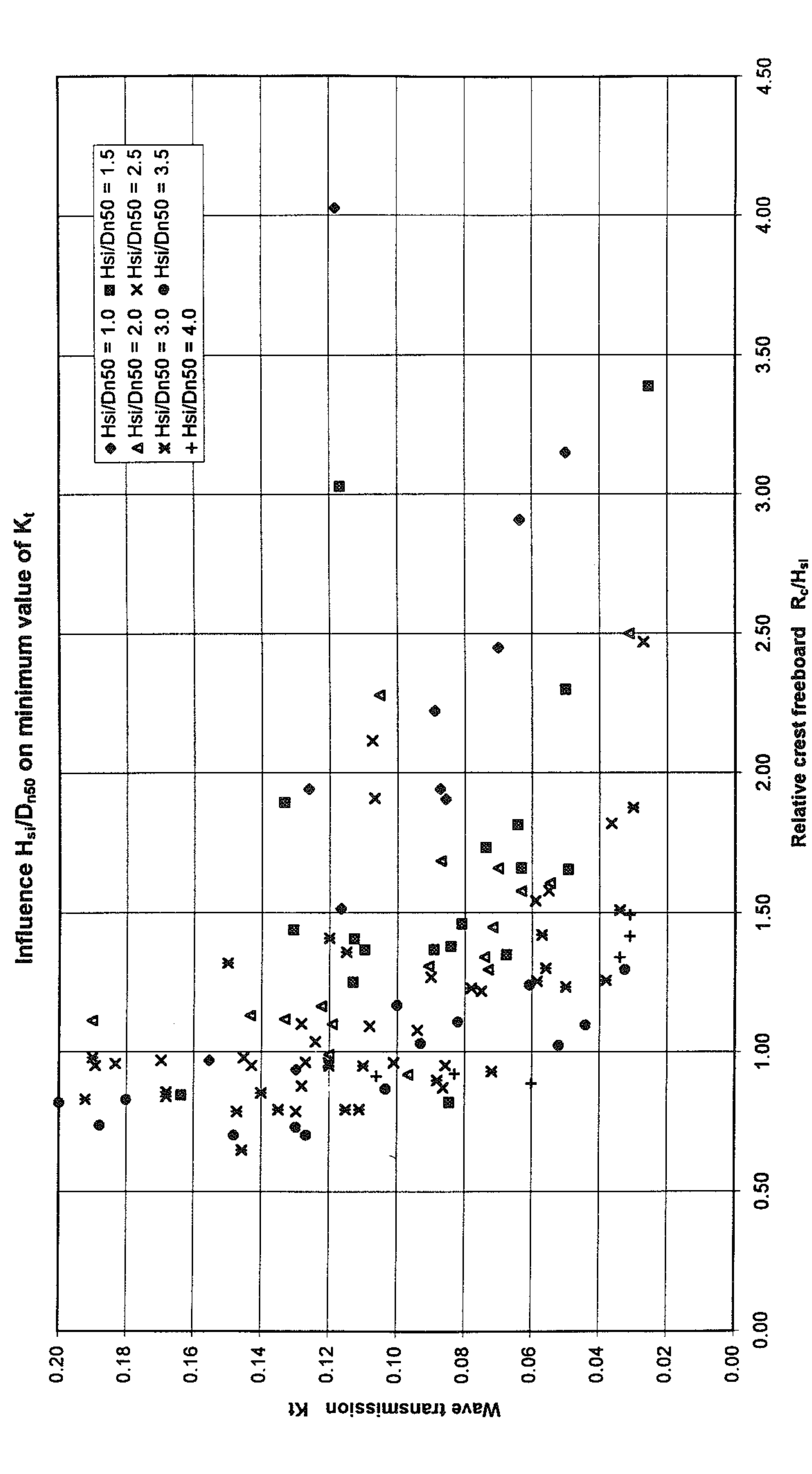
Influence of B/H_{si} on minimum value of K_t, Rubble Mound **Figure A4.21**



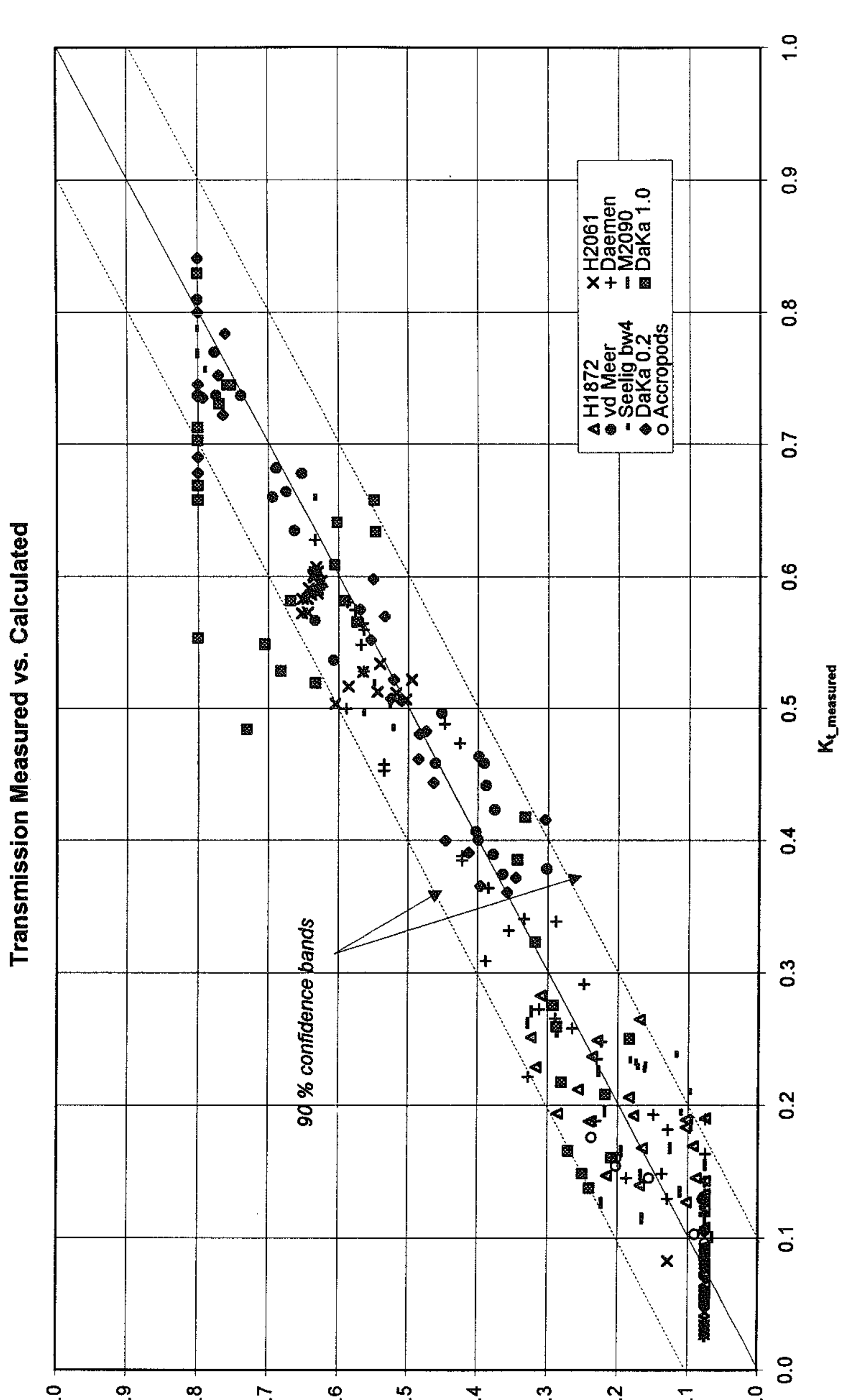
Influence of ξ on minimum value of K_t, Rubble Mound **Figure A4.22**



Infuence of s_{op} on minimum value of K_t, Rubble Mound **Figure A4.23**

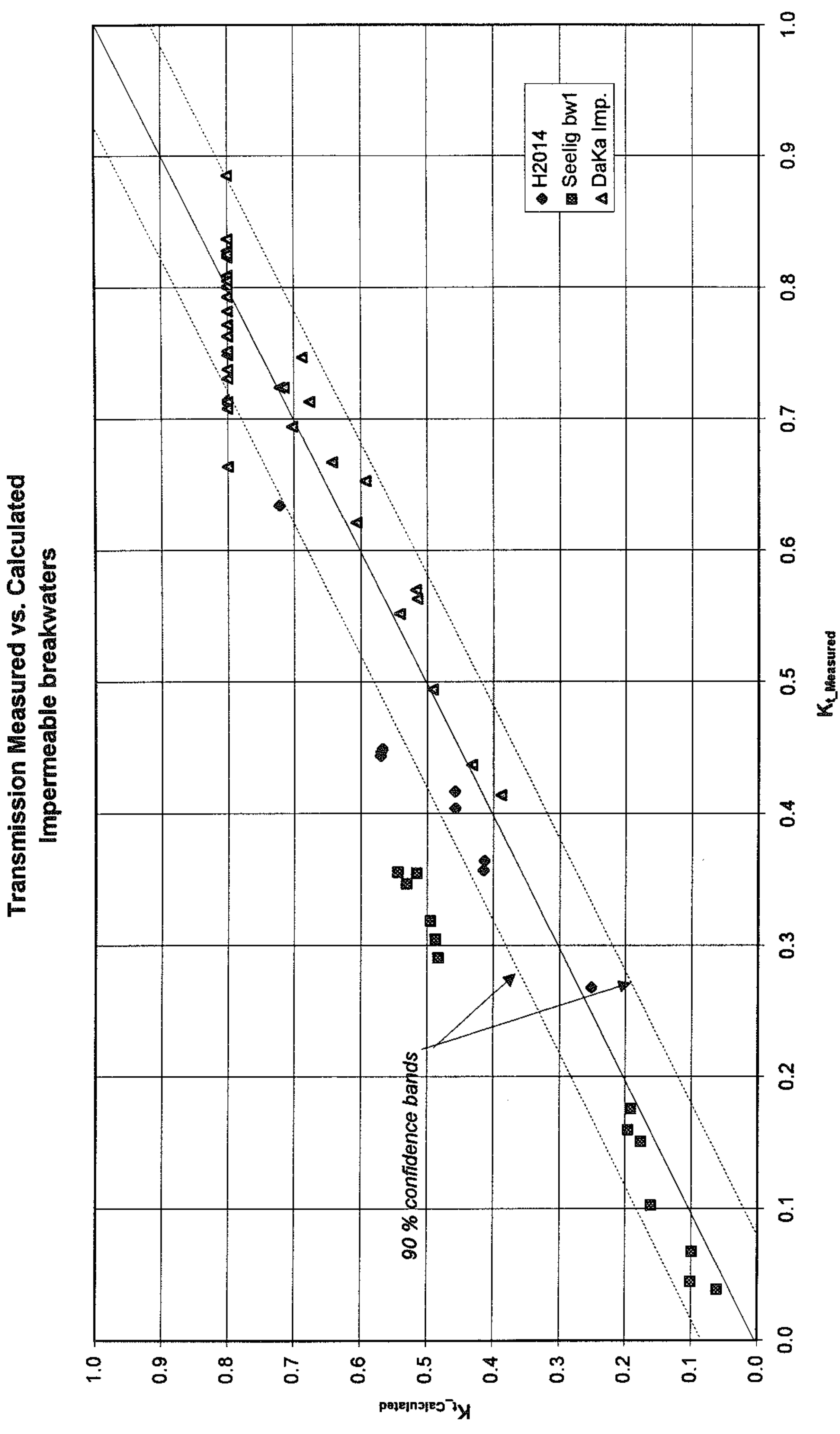


Influence of H_{si}/D_{n50} on minimum value of K_t, Rubble Mound **Figure A4.24**

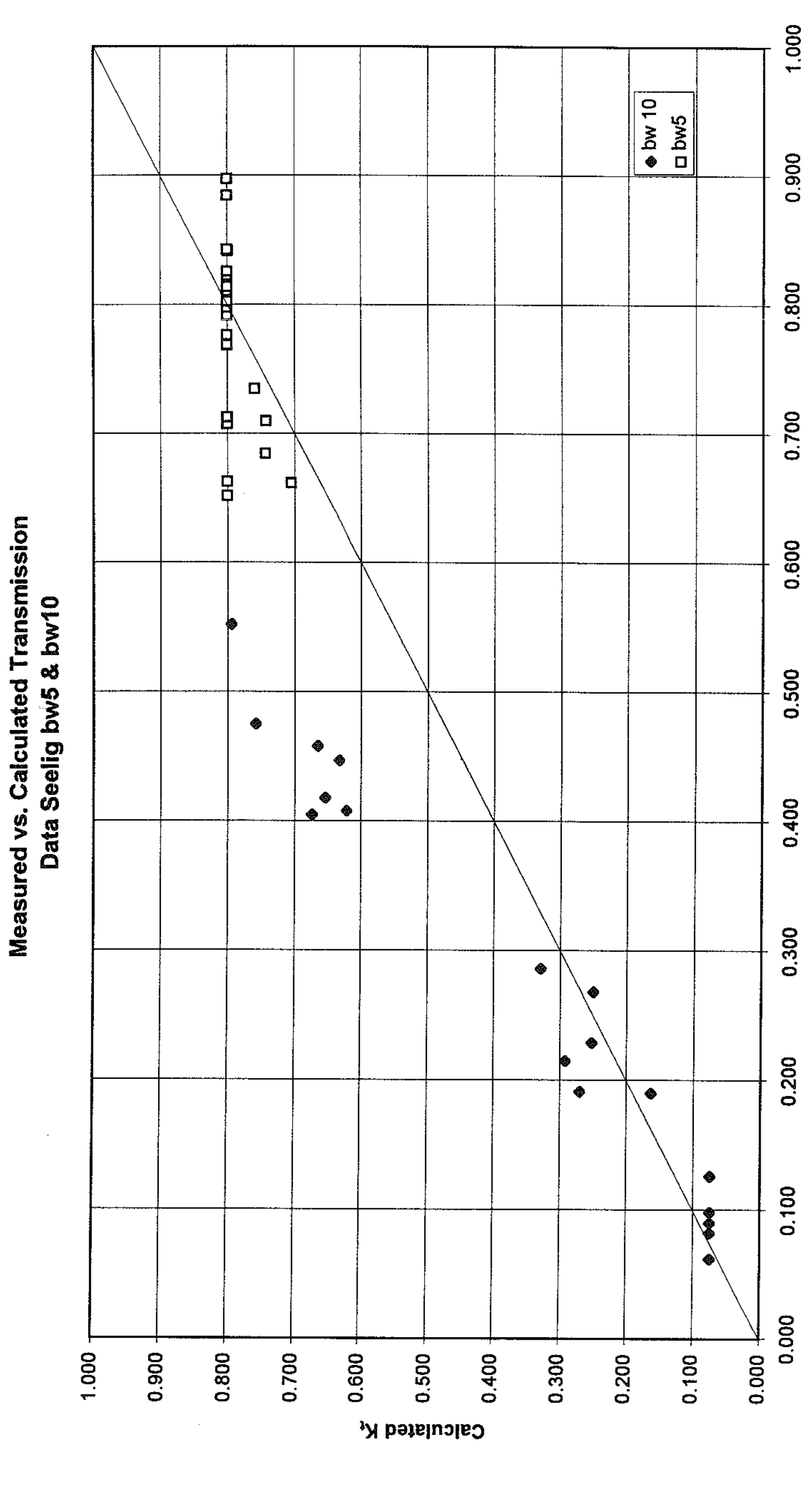


Measured vs. Calculated K_t, including 90 % conficence levels,
Rubble Mound Breakwaters

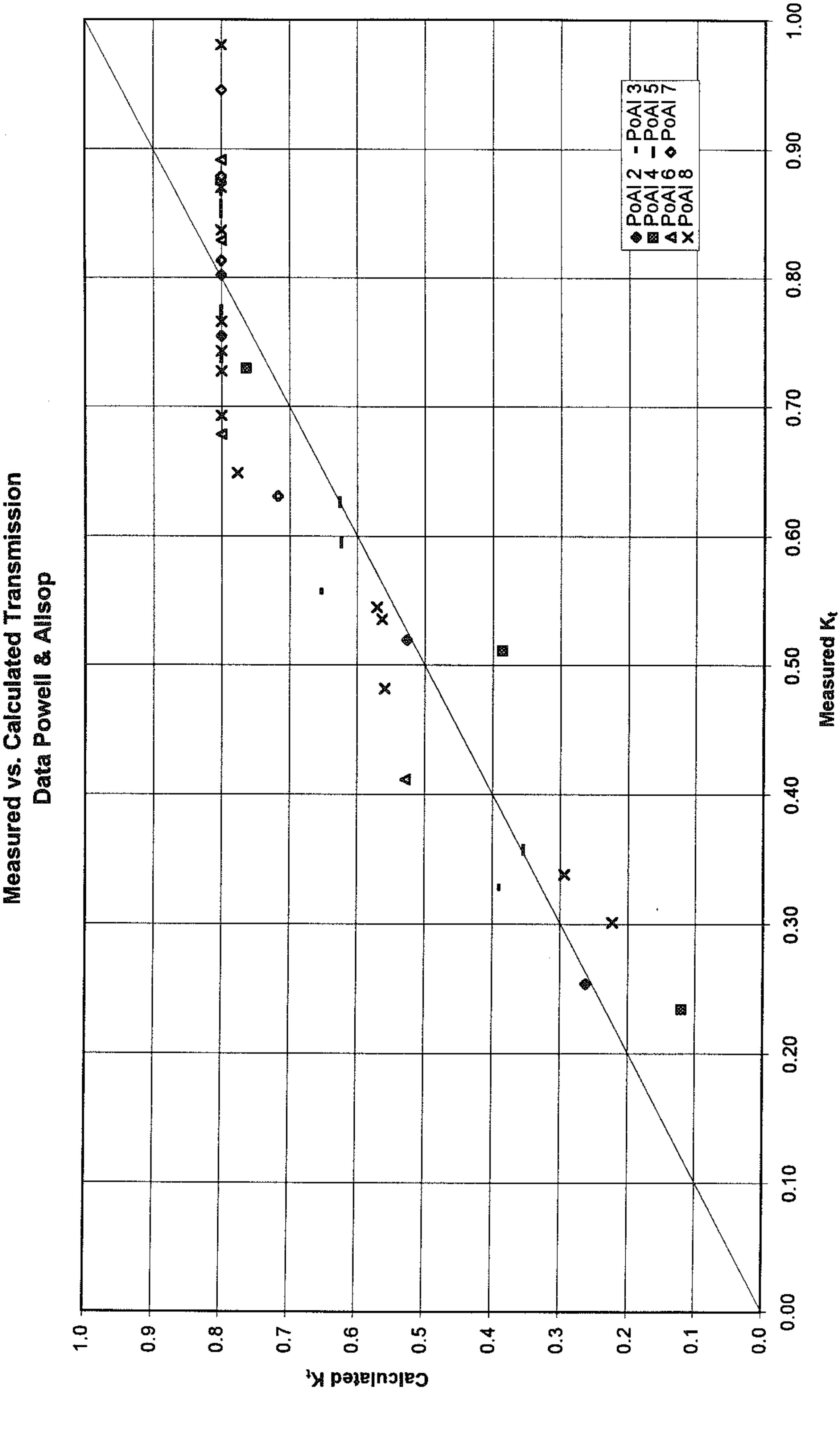
Figure A4.25



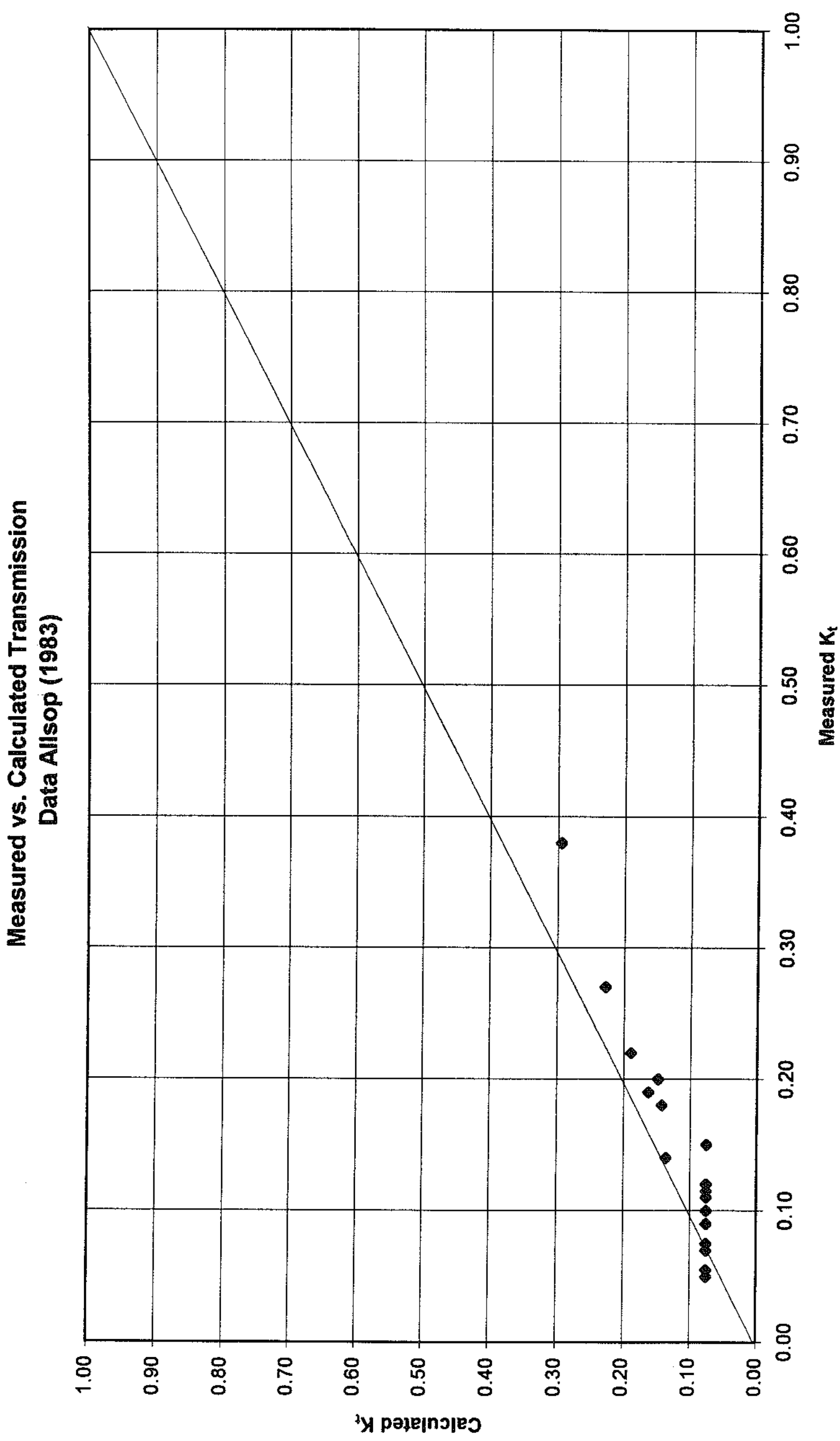
Measured vs. Calculated K_t, including 90 % conficence levels, Impermeable Breakwaters **Figure A4.26**



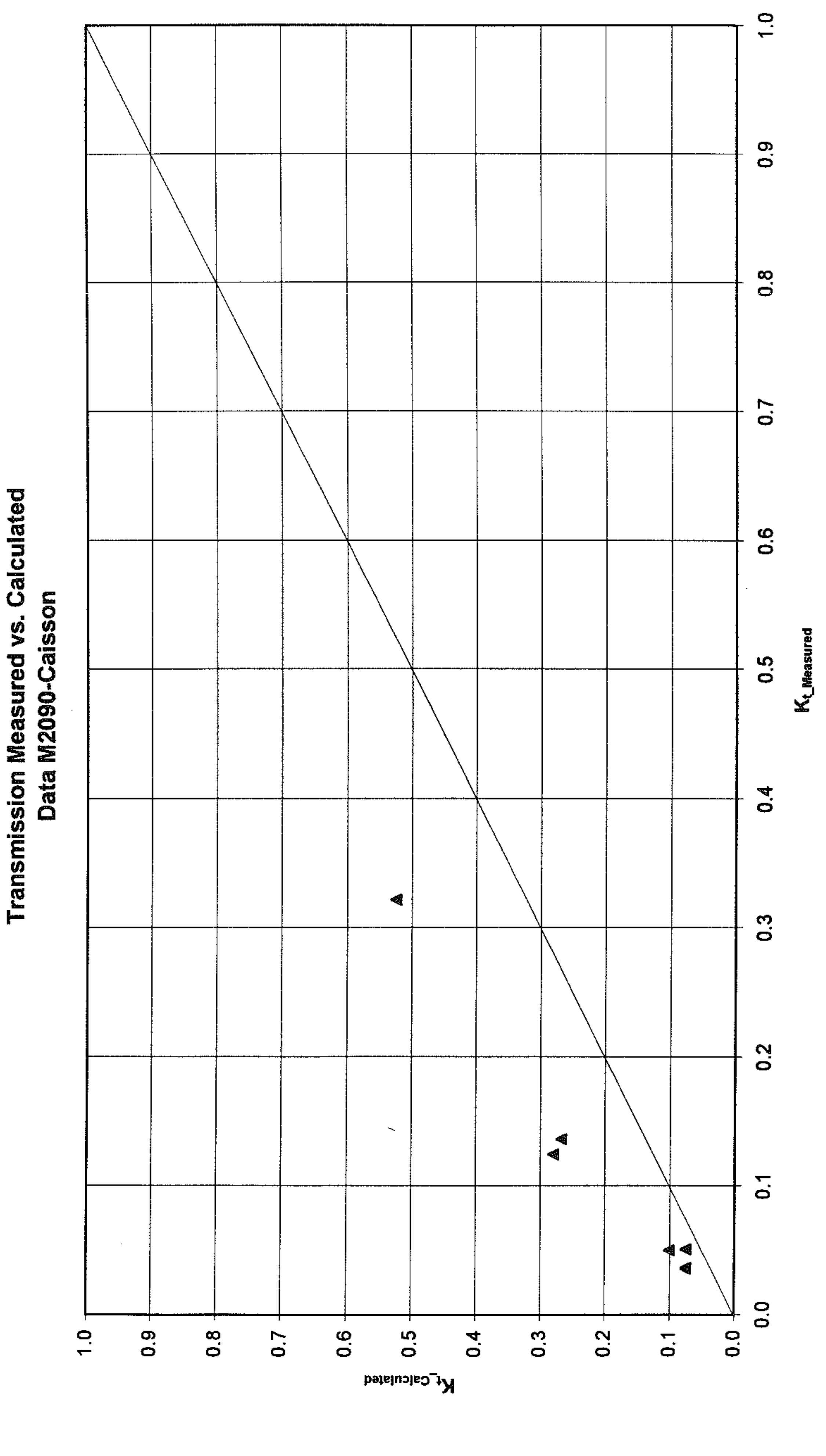
Measured vs. Calculated K_t, Data Seelig bw4 & bw10 **Figure A4.27**



Measured vs. Calculated K_t, Data Powell & Allsop **Figure A4.28**



Measured vs. Calculated K_t, Data Allsop **Figure A4.29**



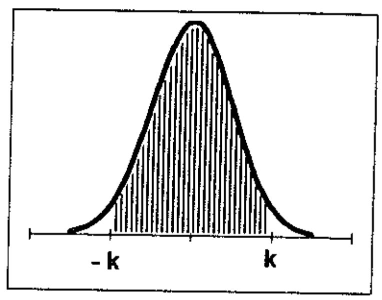
Measured vs. Calculated K_t, Data M2090 - Caisson **Figure A4.30**

ANNEX 5

Table of Normal distribution

k	0	1	2	3	4	5	6	7	8	9
0.0	0.0000	0.0080	0.0160	0.0239	0.0319	0.0399	0.0478	0.0558	0.0638	0.0717
0.1	0.0797	0.0876	0.0955	0.1034	0.1113	0.1192	0.1271	0.1350	0.1428	0.1507
0.2	0.1585	0.1663	0.1741	0.1819	0.1897	0.1974	0.2051	0.2128	0.2205	0.2282
0.3	0.2358	0.2434	0.2510	0.2586	0.2661	0.2737	0.2812	0.2886	0.2961	0.3035
0.4	0.3108	0.3182	0.3255	0.3328	0.3401	0.3473	0.3545	0.3616	0.3688	0.3759
0.5	0.3829	0.3899	0.3969	0.4039	0.4108	0.4177	0.4245	0.4313	0.4381	0.4448
0.6	0.4515	0.4581	0.4647	0.4713	0.4778	0.4843	0.4907	0.4971	0.5035	0.5098
0.7	0.5161	0.5223	0.5285	0.5346	0.5407	0.5467	0.5527	0.5587	0.5646	0.5705
0.8	0.5763	0.5821	0.5878	0.5935	0.5991	0.6047	0.6102	0.6157	0.6211	0.6265
0.9	0.6319	0.6372	0.6424	0.6476	0.6528	0.6579	0.6629	0.6680	0.6729	0.6778
1.0	0.6827	0.6875	0.6923	0.6970	0.7017	0.7063	0.7109	0.7154	0.7199	0.7243
1.1	0.7287	0.7330	0.7373	0.7415	0.7457	0.7499	0.7540	0.7580	0.7620	0.7660
1.2	0.7699	0.7737	0.7775	0.7813	0.7850	0.7887	0.7923	0.7959	0.7995	0.8029
1.3	0.8064	0.8098	0.8132	0.8165	0.8198	0.8230	0.8262	0.8293	0.8324	0.8355
1.4	0.8385	0.8415	0.8444	0.8473	0.8501	0.8529	0.8557	0.8584	0.8611	0.8638
1.5	0.8664	0.8690	0.8715	0.8740	0.8764	0.8789	0.8812	0.8836	0.8859	0.8882
1.6	0.8904	0.8926	0.8948	0.8969	0.8990	0.9011	0.9031	0.9051	0.9070	0.9090
1.7	0.9109	0.9127	0.9146	0.9164	0.9181	0.9199	0.9216	0.9233	0.9249	0.9265
1.8	0.9281	0.9297	0.9312	0.9328	0.9342	0.9357	0.9371	0.9385	0.9399	0.9412
1.9	0.9426	0.9439	0.9451	0.9464	0.9476	0.9488	0.9500	0.9512	0.9523	0.9534
2.0	0.9545	0.9556	0.9566	0.9576	0.9586	0.9596	0.9606	0.9615	0.9625	0.9634
2.1	0.9643	0.9651	0.9660	0.9668	0.9676	0.9684	0.9692	0.9700	0.9707	0.9715
2.2	0.9722	0.9729	0.9736	0.9743	0.9749	0.9756	0.9762	0.9768	0.9774	0.9780
2.3	0.9786	0.9791	0.9797	0.9802	0.9807	0.9812	0.9817	0.9822	0.9827	0.9832
2.4	0.9836	0.9840	0.9845	0.9849	0.9853	0.9857	0.9861	0.9865	0.9869	0.9872
2.5	0.9876	0.9879	0.9883	0.9886	0.9889	0.9892	0.9895	0.9898	0.9901	0.9904
2.6	0.9907	0.9909	0.9912	0.9915	0.9917	0.9920	0.9922	0.9924	0.9926	0.9929
2.7	0.9931	0.9933	0.9935	0.9937	0.9939	0.9940	0.9942	0.9944	0.9946	0.9947
2.8	0.9949	0.9950	0.9952	0.9953	0.9955	0.9956	0.9958	0.9959	0.9960	0.9961
2.9	0.9963	0.9964	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972
3.0	0.9973	0.9974	0.9975	0.9976	0.9976	0.9977	0.9978	0.9979	0.9979	0.9980
3.1	0.9981	0.9981	0.9982	0.9983	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986
3.2	0.9986	0.9987	0.9987	0.9988	0.9988	0.9988	0.9989	0.9989	0.9990	0.9990
3.3	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.4	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995	0.9995

For example: $P\{k \leq 1.64\} = 0.8990$



Two-sided truncated Normal distribution, N(0,1) **Table A5.1**

ANNEX 6

Figures and Tables for Chapter 9

Test	Front		Crest		Rear			h	Tm	Tpd	Hsi (m)	H1/3	sop	som	Hsi/ΔDn	Hsi/ΔDn	Hsi/ΔDn	Rc/Hs	Rc/Dn		N		Nod	Nod	Nod	Nod
	M	Dn	M	Dn	M	Dn	kΔ	m	s	s	deep	toe	-	-	front	crest	rear	toe	front	rear	deep	rear	total	front	crest	rear
141a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.314	1.611	0.155	0.142	0.035	0.053	2.107	2.107	2.107	-0.351	-1.000	-1.000	908	908	0.000	0.000	0.000	0.000
142a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.493	1.823	0.202	0.191	0.037	0.055	2.827	2.827	2.827	-0.262	-1.000	-1.000	925	925	0.000	0.000	0.000	0.000
143a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.679	2.161	0.249	0.248	0.034	0.056	3.680	3.680	3.680	-0.201	-1.000	-1.000	943	943	0.250	0.150	0.100	0.000
144a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.589	1.960	0.228	0.223	0.037	0.057	3.308	3.308	3.308	-0.224	-1.000	-1.000	943	943	0.100	0.050	0.050	0.000
145a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.732	2.109	0.266	0.259	0.037	0.055	3.833	3.833	3.833	-0.193	-1.000	-1.000	957	957	0.550	0.300	0.250	0.000
141k	0.202	0.044	0.202	0.044	0.202	0.044	1.02	0.9	1.343	1.649	0.162	0.149	0.035	0.053	2.513	2.513	2.513	-0.335	-1.136	-1.136	915	915	0.000	0.000	0.000	0.000
142k	0.202	0.044	0.202	0.044	0.202	0.044	1.02	0.9	1.513	1.838	0.211	0.203	0.038	0.057	3.411	3.411	3.411	-0.247	-1.136	-1.136	944	944	0.044	0.044	0.000	0.000
143k	0.202	0.044	0.202	0.044	0.202	0.044	1.02	0.9	1.673	2.151	0.248	0.247	0.034	0.057	4.157	4.157	4.157	-0.202	-1.136	-1.136	947	947	0.352	0.220	0.132	0.000
144k	0.202	0.044	0.202	0.044	0.202	0.044	1.02	0.9	1.587	1.959	0.227	0.223	0.037	0.057	3.759	3.759	3.759	-0.224	-1.136	-1.136	944	944	0.088	0.044	0.044	0.000
145k	0.202	0.044	0.202	0.044	0.202	0.044	1.02	0.9	1.733	2.128	0.266	0.259	0.037	0.055	4.356	4.356	4.356	-0.193	-1.136	-1.136	957	957	0.308	0.132	0.176	0.000
141s	0.104	0.035	0.104	0.035	0.104	0.035	1.02	0.9	1.204	1.476	0.132	0.117	0.034	0.052	2.538	2.538	2.538	-0.426	-1.429	-1.429	913	913	0.105	0.070	0.035	0.000
142s	0.104	0.035	0.104	0.035	0.104	0.035	1.02	0.9	1.413	1.739	0.182	0.171	0.036	0.055	3.707	3.707	3.707	-0.292	-1.429	-1.429	926	926	0.560	0.385	0.175	0.000
143s	0.104	0.035	0.104	0.035	0.104	0.035	1.02	0.9	1.571	2.001	0.229	0.226	0.036	0.059	4.897	4.897	4.897	-0.221	-1.429	-1.429	941	941	2.450	1.365	0.945	0.140
144s	0.104	0.035	0.104	0.035	0.104	0.035	1.02	0.9	1.334	1.616	0.163	0.149	0.037	0.054	3.231	3.231	3.231	-0.335	-1.429	-1.429	921	921	0.420	0.315	0.105	0.000
145s	0.104	0.035	0.104	0.035	0.104	0.035	1.02	0.9	1.504	1.883	0.210	0.203	0.037	0.057	4.386	4.386	4.386	-0.247	-1.429	-1.429	949	949	1.330	1.015	0.315	0.000
146s	0.104	0.035	0.104	0.035	0.104	0.035	1.02	0.9	1.614	2.038	0.234	0.232	0.036	0.057	5.025	5.025	5.025	-0.215	-1.429	-1.429	427	427	4.270	2.730	1.505	0.035
241a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.219	1.515	0.132	0.119	0.033	0.051	1.767	1.767	1.767	0.000	0.000	0.000	901	820	0.000	0.000	0.000	0.000
242a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.440	1.732	0.183	0.170	0.036	0.053	2.522	2.522	2.522	0.000	0.000	0.000	909	810	0.050	0.050	0.000	0.000
243a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.587	2.008	0.227	0.225	0.036	0.057	3.330	3.330	3.330	0.000	0.000	0.000	944	890	0.250	0.200	0.050	0.000
244a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.648	2.062	0.241	0.238	0.036	0.056	3.527	3.527	3.527	0.000	0.000	0.000	940	858	0.700	0.400	0.300	0.000
245a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.452	1.847	0.196	0.185	0.035	0.056	2.739	2.739	2.739	0.000	0.000	0.000	943	874	0.250	0.050	0.150	0.050
246a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.679	2.126	0.248	0.247	0.035	0.056	3.658	3.658	3.658	0.000	0.000	0.000	941	852	1.150	0.450	0.600	0.100
221a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.612	2.105	0.152	0.153	0.022	0.038	2.267	2.267	2.267	0.000	0.000	0.000	1016	873	0.150	0.000	0.100	0.050
222a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.905	2.445	0.198	0.200	0.021	0.035	2.969	2.969	2.969	0.000	0.000	0.000	991	927	0.350	0.050	0.250	0.050
223a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	2.107	2.891	0.239	0.243	0.019	0.035	3.604	3.604	3.604	0.000	0.000	0.000	1005	885	1.800	0.800	0.850	0.150
224a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.479	1.944	0.133	0.132	0.022	0.039	1.956	1.956	1.956	0.000	0.000	0.000	1020	920	0.000	0.000	0.000	0.000
225a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.740	2.295	0.172	0.175	0.021	0.037	2.593	2.593	2.593	0.000	0.000	0.000	993	940	0.150	0.100	0.000	0.050
226a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	2.011	2.671	0.217	0.223	0.020	0.035	3.308	3.308	3.308	0.000	0.000	0.000	993	910	0.800	0.250	0.400	0.150
341a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.218	1.514	0.133	0.119	0.033	0.052	1.767	1.767	1.767	0.839	2.000	2.000	902	73	0.000	0.000	0.000	0.000
342a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.443	1.745	0.183	0.171	0.036	0.053	2.537	2.537	2.537	0.584	2.000	2.000	907	294	0.500	0.050	0.100	0.350
343a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.603	2.021	0.229	0.228	0.036	0.057	3.374	3.374	3.374	0.439	2.000	2.000	935	512	2.800	0.500	0.900	1.400
344a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.303	1.617	0.155	0.142	0.035	0.054	2.107	2.107	2.107	0.703	2.000	2.000	916	205	0.050	0.050	0.000	0.000
345a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.528	1.902	0.212	0.206	0.036	0.056	3.046	3.046	3.046	0.486	2.000	2.000	935	498	0.950	0.850	0.000	0.100
346a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.330	1.644	0.165	0.152	0.036	0.055	2.256	2.256	2.256	0.657	2.000	2.000	924	291	0.100	0.100	0.000	0.000
347a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.494	1.882	0.203	0.195	0.035	0.056	2.892	2.892	2.892	0.512	2.000	2.000	922	461	0.500	0.300	0.050	0.150
401a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	1.509	2.017	0.132	0.137	0.022	0.038	2.022	2.022	2.298	1.465	4.000	4.532	994	7	0.000	0.000	0.000	0.000
402a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	1.655	2.242	0.161	0.167	0.021	0.039	2.475	2.475	2.812	1.197	4.000	4.532	1026	70	0.050	0.050	0.000	0.000
403a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	1.837	2.437	0.188	0.189	0.020	0.036	2.801	2.801	3.183	1.058	4.000	4.532	995	193	0.277	0.100	0.000	0.177
404a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	2.043	2.825	0.229	0.210	0.017	0.032	3.110	3.110	3.535	0.953	4.000	4.532	1028	417	2.827	0.650	0.500	1.677
405a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	1.947	2.572	0.205	0.199	0.019	0.034	2.947	2.947	3.349	1.005	4.000	4.532	987	268	1.089	0.250	0.000	0.839
406a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	2.053	2.846	0.231	0.211	0.017	0.032	3.127	3.127	3.553	0.948	4.000	4.532	1023	432	3.321	0.800	0.050	2.471

Data of H2061 (1994)

Table A6.1

Test	Front		Crest		Rear			h	Tm	Tpd	Hsi (m)	H1/3	sop	som	Hsi/ΔDn	Hsi/ΔDn	Hsi/ΔDn	Rc/Hs	Rc/Dn		N		Nod	Nod	Nod	Nod
	M	Dn	M	Dn	M	Dn	kΔ	m	s	s	deep	toe	-	-	front	crest	rear	toe	front	rear	deep	rear	total	front	crest	rear
401b	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	1.507	1.998	0.131	0.137	0.022	0.039	2.022	2.022	2.298	1.465	4.000	4.532	2985	21	0.000	0.000	0.000	0.000
402b	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	1.656	2.240	0.161	0.167	0.021	0.039	2.475	2.475	2.812	1.197	4.000	4.532	3076	211	0.094	0.050	0.000	0.044
403b	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	1.834	2.450	0.188	0.189	0.020	0.036	2.801	2.801	3.183	1.058	4.000	4.532	2990	563	0.459	0.150	0.000	0.309
404b	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	2.057	2.756	0.228	0.210	0.018	0.032	3.110	3.110	3.535	0.953	4.000	4.532	1702	690	9.367	2.050	2.551	4.766
405b	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	1.933	2.573	0.203	0.199	0.019	0.034	2.947	2.947	3.349	1.005	4.000	4.532	2973	804	2.109	0.300	0.000	1.809
406b	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.8	2.045	2.831	0.229	0.211	0.017	0.032	3.127	3.127	3.553	0.948	4.000	4.532	2291	967	9.141	0.950	2.101	6.090
501a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.649	2.275	0.164	0.167	0.021	0.039	2.474	2.474	2.474	1.198	4.000	4.000	1029	63	0.150	0.150	0.000	0.000
502a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.823	2.456	0.192	0.195	0.021	0.038	2.889	2.889	2.889	1.026	4.000	4.000	1002	191	0.800	0.550	0.000	0.250
503a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.972	2.715	0.220	0.221	0.019	0.036	3.272	3.272	3.272	0.906	4.000	4.000	1014	297	4.850	1.250	0.200	3.400
504a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.606	2.137	0.153	0.156	0.022	0.039	2.311	2.311	2.311	1.282	4.000	4.000	1020	48	0.100	0.100	0.000	0.000
505a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.882	2.546	0.202	0.203	0.020	0.037	3.007	3.007	3.007	0.985	4.000	4.000	1003	257	2.350	0.800	0.050	1.500
501b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.658	2.275	0.164	0.167	0.021	0.039	2.474	2.474	2.474	1.198	4.000	4.000	3078	189	0.400	0.400	0.000	0.000
502b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.821	2.475	0.192	0.195	0.020	0.038	2.889	2.889	2.889	1.026	4.000	4.000	3011	573	1.350	0.800	0.000	0.550
503b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.981	2.649	0.219	0.221	0.020	0.036	3.272	3.272	3.272	0.906	4.000	4.000	2808	822	11.150	2.650	2.300	6.200
504b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.605	2.133	0.153	0.156	0.022	0.039	2.311	2.311	2.311	1.282	4.000	4.000	3062	144	0.200	0.200	0.000	0.000
505b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.884	2.539	0.201	0.203	0.020	0.037	3.007	3.007	3.007	0.985	4.000	4.000	3008	771	5.200	1.100	1.400	2.700
541a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.220	1.515	0.133	0.119	0.033	0.051	1.767	1.767	1.767	1.677	4.000	4.000	901	2	0.000	0.000	0.000	0.000
542a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.433	1.741	0.183	0.171	0.036	0.053	2.537	2.537	2.537	1.168	4.000	4.000	914	66	0.200	0.200	0.000	0.000
543a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.524	1.896	0.211	0.191	0.034	0.053	2.827	2.827	2.827	1.048	4.000	4.000	936	171	0.200	0.100	0.000	0.100
544a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.342	1.666	0.165	0.152	0.035	0.054	2.256	2.256	2.256	1.314	4.000	4.000	916	24	0.150	0.150	0.000	0.000
545a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.454	1.875	0.199	0.189	0.035	0.057	2.805	2.805	2.805	1.056	4.000	4.000	941	118	0.350	0.350	0.000	0.000
546a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.587	2.022	0.230	0.228	0.036	0.058	3.374	3.374	3.374	0.878	4.000	4.000	944	261	1.400	1.250	0.000	0.150
547a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.645	2.056	0.245	0.243	0.037	0.057	3.593	3.593	3.593	0.825	4.000	4.000	942	293	2.350	2.000	0.000	0.350
541b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.218	1.516	0.133	0.119	0.033	0.052	1.767	1.767	1.767	1.677	4.000	4.000	2706	6	0.000	0.000	0.000	0.000
542b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.440	1.762	0.184	0.172	0.036	0.053	2.552	2.552	2.552	1.161	4.000	4.000	2734	198	0.700	0.700	0.000	0.000
543b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.524	1.888	0.211	0.191	0.034	0.053	2.827	2.827	2.827	1.048	4.000	4.000	2814	523	1.800	1.600	0.100	0.100
544b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.340	1.664	0.165	0.152	0.035	0.054	2.256	2.256	2.256	1.314	4.000	4.000	2751	72	0.200	0.200	0.000	0.000
545b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.459	1.871	0.199	0.189	0.035	0.057	2.805	2.805	2.805	1.056	4.000	4.000	2818	354	0.800	0.800	0.000	0.000
546b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.602	2.025	0.229	0.228	0.036	0.057	3.374	3.374	3.374	0.878	4.000	4.000	2816	783	2.500	2.250	0.100	0.150
547b	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.9	1.639	2.039	0.243	0.240	0.037	0.057	3.549	3.549	3.549	0.835	4.000	4.000	2647	823	6.500	3.900	1.500	1.100
541h	0.294	0.050	0.294	0.050	0.104	0.035	1.02	0.9	1.386	1.758	0.175	0.164	0.034	0.055	2.433	2.433	2.433	1.218	4.000	5.714	928		0.150	0.150	0.000	0.000
542h	0.294	0.050	0.294	0.050	0.104	0.035	1.02	0.9	1.510	1.853	0.214	0.206	0.038	0.058	3.046	3.046	3.046	0.973	4.000	5.714	946		1.095	0.850	0.000	0.245
543h	0.294	0.050	0.294	0.050	0.104	0.035	1.02	0.9	1.624	1.927	0.239	0.232	0.040	0.056	3.439	3.439	3.439	0.861	4.000	5.714	682		11.280	1.550	1.750	7.980
544h	0.294	0.050	0.294	0.050	0.104	0.035	1.02	0.9	1.457	1.772	0.194	0.181	0.037	0.055	2.685	2.685	2.685	1.103	4.000	5.714	925		0.500	0.500	0.000	0.000
545h	0.294	0.050	0.294	0.050	0.104	0.035	1.02	0.9	1.574	2.017	0.227	0.225	0.035	0.058	3.330	3.330	3.330	0.890	4.000	5.714	939		1.930	0.900	0.050	0.980
621a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.567	2.059	0.139	0.157	0.024	0.041	2.322	2.322	2.322	1.276	4.000	4.000	995	42	0.050	0.050	0.000	0.000
622a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.868	2.439	0.186	0.179	0.019	0.033	2.653	2.653	2.653	1.117	4.000	4.000	979	231	0.200	0.200	0.000	0.000
623a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	2.100	2.934	0.230	0.188	0.014	0.027	2.784	2.784	2.784	1.064	4.000	4.000	1009	432	0.400	0.250	0.100	0.050
624a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.679	2.198	0.159	0.169	0.022	0.038	2.504	2.504	2.504	1.183	4.000	4.000	1012	91	0.000	0.000	0.000	0.000
625a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.990	2.748	0.212	0.192	0.016	0.031	2.843	2.843	2.843	1.042	4.000	4.000	1004	330	0.600	0.050	0.050	0.500
626a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.749	2.288	0.169	0.173	0.021	0.036	2.566	2.566	2.566	1.155	4.000	4.000	988	144	0.000	0.000	0.000	0.000
627a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.994	2.733	0.212	0.185	0.016	0.030	2.746	2.746	2.746	1.079	4.000	4.000	1002	344	0.200	0.000	0.000	0.200
628a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	2.133	2.984	0.237	0.189	0.014	0.027	2.796	2.796	2.796	1.060	4.000	4.000	1016	436	1.550	0.100	0.100	1.350

Data of H2061 (1994), Continued

Table A6.1

Test	Front		Crest		Rear			h	Tm	Tpd	Hsi (m)	H1/3	sop	som	Hsi/ΔDn	Hsi/ΔDn	Hsi/ΔDn	Rc/Hs	Rc/Dn		N		Nod	Nod	Nod	Nod
	M	Dn	M	Dn	M	Dn	kΔ	m	s	s	deep	toe	-	-	front	crest	rear	toe	front	rear	deep	rear	total	front	crest	rear
641a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.265	1.543	0.136	0.139	0.037	0.056	2.053	2.053	2.053	1.443	4.000	4.000	917	4	0.050	0.050	0.000	0.000
642a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.490	1.775	0.186	0.172	0.035	0.050	2.545	2.545	2.545	1.164	4.000	4.000	912	69	0.050	0.050	0.000	0.000
643a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.661	2.035	0.223	0.184	0.029	0.043	2.728	2.728	2.728	1.086	4.000	4.000	920	202	0.150	0.150	0.000	0.000
644a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.757	2.105	0.235	0.187	0.027	0.039	2.767	2.767	2.767	1.071	4.000	4.000	899	276	0.250	0.250	0.000	0.000
646a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.587	1.936	0.210	0.181	0.031	0.046	2.675	2.675	2.675	1.108	4.000	4.000	925	118	0.000	0.000	0.000	0.000
647a	0.294	0.050	0.294	0.050	0.294	0.050	1.02	0.7	1.812	2.190	0.248	0.189	0.025	0.037	2.804	2.804	2.804	1.057	4.000	4.000	899	291	0.050	0.050	0.000	0.000
641s	0.104	0.035	0.104	0.035	0.104	0.035	1.02	0.7	1.362	1.690	0.160	0.160	0.036	0.055	3.459	3.459	3.459	1.252	5.714	5.714	913	16	1.421	1.421	0.000	0.000
642s	0.104	0.035	0.104	0.035	0.104	0.035	1.02	0.7	1.484	1.844	0.185	0.173	0.033	0.050	3.740	3.740	3.740	1.157	5.714	5.714	916	59	3.625	3.589	0.036	
643s	0.104	0.035	0.104	0.035	0.104	0.035	1.02	0.7	1.036	1.241	0.093	0.089	0.037	0.053	1.926	1.926	1.926	2.247	5.714	5.714	897		0.107	0.107	0.000	0.000
644s	0.104	0.035	0.104	0.035	0.104	0.035	1.02	0.7	1.179	1.444	0.121	0.120	0.037	0.055	2.601	2.601	2.601	1.665	5.714	5.714	915		0.355	0.355	0.000	0.000
645s	0.104	0.035	0.104	0.035	0.104	0.035	1.02	0.7	1.390	1.701	0.168	0.163	0.036	0.054	3.532	3.532	3.532	1.226	5.714	5.714	924	51	1.812	1.812	0.000	0.000
741a	0.294	0.050	0.294	0.050	0.294	0.050	0.95	0.9	1.209	1.514	0.134	0.119	0.033	0.052	1.767	1.767	1.767	1.677	4.000	4.000	908	4	0.000	0.000	0.000	0.000
742a	0.294	0.050	0.294	0.050	0.294	0.050	0.95	0.9	1.431	1.741	0.183	0.171	0.036	0.054	2.537	2.537	2.537	1.168	4.000	4.000	915	50	0.100	0.100	0.000	0.000
743a	0.294	0.050	0.294	0.050	0.294	0.050	0.95	0.9	1.519	1.890	0.212	0.206	0.037	0.057	3.046	3.046	3.046	0.973	4.000	4.000	940	143	0.200	0.200	0.000	0.000
744a	0.294	0.050	0.294	0.050	0.294	0.050	0.95	0.9	1.597	2.027	0.230	0.228	0.036	0.057	3.374	3.374	3.374	0.878	4.000	4.000	939	224	1.250	1.150	0.050	0.050
745a	0.294	0.050	0.294	0.050	0.294	0.050	0.95	0.9	1.337	1.677	0.165	0.153	0.035	0.055	2.270	2.270	2.270	1.305	4.000	4.000	919	46	0.300	0.300	0.000	0.000
746a	0.294	0.050	0.294	0.050	0.294	0.050	0.95	0.9	1.567	1.974	0.222	0.219	0.036	0.057	3.243	3.243	3.243	0.914	4.000	4.000	937	187	1.900	1.850	0.000	0.050
747a	0.294	0.050	0.294	0.050	0.294	0.050	0.95	0.9	1.645	2.108	0.246	0.244	0.035	0.058	3.615	3.615	3.615	0.820	4.000	4.000	941	227	3.400	2.700	0.350	0.350
841a	0.294	0.050	0.294	0.050	0.294	0.050	0.88	0.9	1.213	1.514	0.134	0.119	0.033	0.052	1.767	1.767	1.767	1.677	4.000	4.000	906	14	0.050	0.050	0.000	0.000
842a	0.294	0.050	0.294	0.050	0.294	0.050	0.88	0.9	1.440	1.767	0.184	0.172	0.035	0.053	2.552	2.552	2.552	1.161	4.000	4.000	909	89	0.650	0.650	0.000	0.000
843a	0.294	0.050	0.294	0.050	0.294	0.050	0.88	0.9	1.508	1.913	0.212	0.206	0.036	0.058	3.046	3.046	3.046	0.973	4.000	4.000	948	132	1.050	1.050	0.000	0.000
844a	0.294	0.050	0.294	0.050	0.294	0.050	0.88	0.9	1.598	2.025	0.231	0.228	0.036	0.057	3.374	3.374	3.374	0.878	4.000	4.000	936	224	1.950	1.300	0.000	0.650
845a	0.294	0.050	0.294	0.050	0.294	0.050	0.88	0.9	1.308	1.618	0.156	0.142	0.035	0.053	2.107	2.107	2.107	1.406	4.000	4.000	913	14	0.400	0.400	0.000	0.000
846a	0.294	0.050	0.294	0.050	0.294	0.050	0.88	0.9	1.463	1.837	0.200	0.194	0.037	0.058	2.870	2.870	2.870	1.032	4.000	4.000	941	151	1.950	1.950	0.000	0.000
848a	0.294	0.050	0.294	0.050	0.294	0.050	0.88	0.9	1.254	1.584	0.144	0.131	0.034	0.054	1.944	1.944	1.944	1.524	4.000	4.000	923	13	0.000	0.000	0.000	0.000
849a	0.294	0.050	0.294	0.050	0.294	0.050	0.88	0.9	1.433	1.754	0.184	0.171	0.036	0.053	2.537	2.537	2.537	1.168	4.000	4.000	914	71	0.350	0.350	0.000	0.000
850a	0.294	0.050	0.294	0.050	0.294	0.050	0.88	0.9	1.599	2.022	0.230	0.228	0.036	0.057	3.374	3.374	3.374	0.878	4.000	4.000	937	251	1.300	0.600	0.300	0.400
841h	0.294	0.050	0.294	0.050	0.104	0.035	0.88	0.9	1.391	1.724	0.173	0.161	0.035	0.053	2.389	2.389	3.490	1.240	4.000	5.714	923	26	0.300	0.300	0.000	0.000
842h	0.294	0.050	0.294	0.050	0.104	0.035	0.88	0.9	1.478	1.888	0.202	0.191	0.034	0.056	2.827	2.827	4.130	1.048	4.000	5.714	932	86	1.610	0.650	0.050	0.910
843h	0.294	0.050	0.294	0.050	0.104	0.035	0.88	0.9	1.692	2.095	0.247	0.245	0.036	0.055	3.636	3.636	5.313	0.815	4.000	5.714	498	146	35.900	1.800	3.300	30.800
921a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.610	2.130	0.154	0.150	0.021	0.037	2.226	2.226	2.529	1.997	6.000	6.818	1018	2	0.200	0.200	0.000	0.000
922a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.875	2.528	0.203	0.207	0.021	0.038	3.067	3.067	3.486	1.449	6.000	6.818	1007	51	0.650	0.650	0.000	0.000
923a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	2.051	2.825	0.238	0.244	0.020	0.037	3.615	3.615	4.107	1.230	6.000	6.818	1023	176	4.146	3.550	0.200	0.396
924a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.485	1.965	0.132	0.125	0.021	0.036	1.856	1.856	2.109	2.395	6.000	6.818	1015		0.050	0.050	0.000	0.000
925a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.968	2.693	0.221	0.228	0.020	0.038	3.374	3.374	3.834	1.317	6.000	6.818	1016	128	3.000	3.000	0.000	0.000
926a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.719	2.339	0.174	0.171	0.020	0.037	2.537	2.537	2.883	1.752	6.000	6.818	1005	20	0.350	0.350	0.000	0.000
927a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.944	2.652	0.211	0.216	0.020	0.037	3.199	3.199	3.635	1.389	6.000	6.818	995	106	2.450	2.400	0.050	0.000
941a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.215	1.515	0.132	0.119	0.033	0.052	1.767	1.767	2.008	2.516	6.000	6.818	904		0.050	0.050	0.000	0.000
942a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.429	1.751	0.183	0.171	0.036	0.054	2.537	2.537	2.883	1.752	6.000	6.818	916	9	0.150	0.150	0.000	0.000
943a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.601	2.022	0.230	0.228	0.036	0.057	3.374	3.374	3.834	1.317	6.000	6.818	936	64	2.450	2.300	0.150	0.000
944a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.342	1.668	0.164	0.152	0.035	0.054	2.256	2.256	2.563	1.970	6.000	6.818	916	2	0.100	0.100	0.000	0.000

Data of H2061 (1994), Continued

Table A6.1

Test	Front		Crest		Rear			h	Tm	Tpd	Hsi (m)	H1/3	sop	som	Hsi/ΔDn	Hsi/ΔDn	Hsi/ΔDn	Rc/Hs	Rc/Dn		N		Nod	Nod	Nod	Nod
	M	Dn	M	Dn	M	Dn	kΔ	m	s	s	deep	toe	-	-	front	crest	rear	toe	front	rear	deep	rear	total	front	crest	rear
945a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.527	1.905	0.231	0.223	0.039	0.061	3.308	3.308	3.759	1.343	6.000	6.818	938	38	2.000	1.950	0.050	0.000
946a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.255	1.584	0.144	0.131	0.034	0.053	1.944	1.944	2.210	2.286	6.000	6.818	924		0.100	0.100	0.000	0.000
947a	0.294	0.050	0.294	0.050	0.202	0.044	1.02	0.9	1.467	1.859	0.199	0.189	0.035	0.056	2.805	2.805	3.187	1.585	6.000	6.818	933	12	2.100	2.100	0.000	0.000

Explanation of numbering of test numbers:

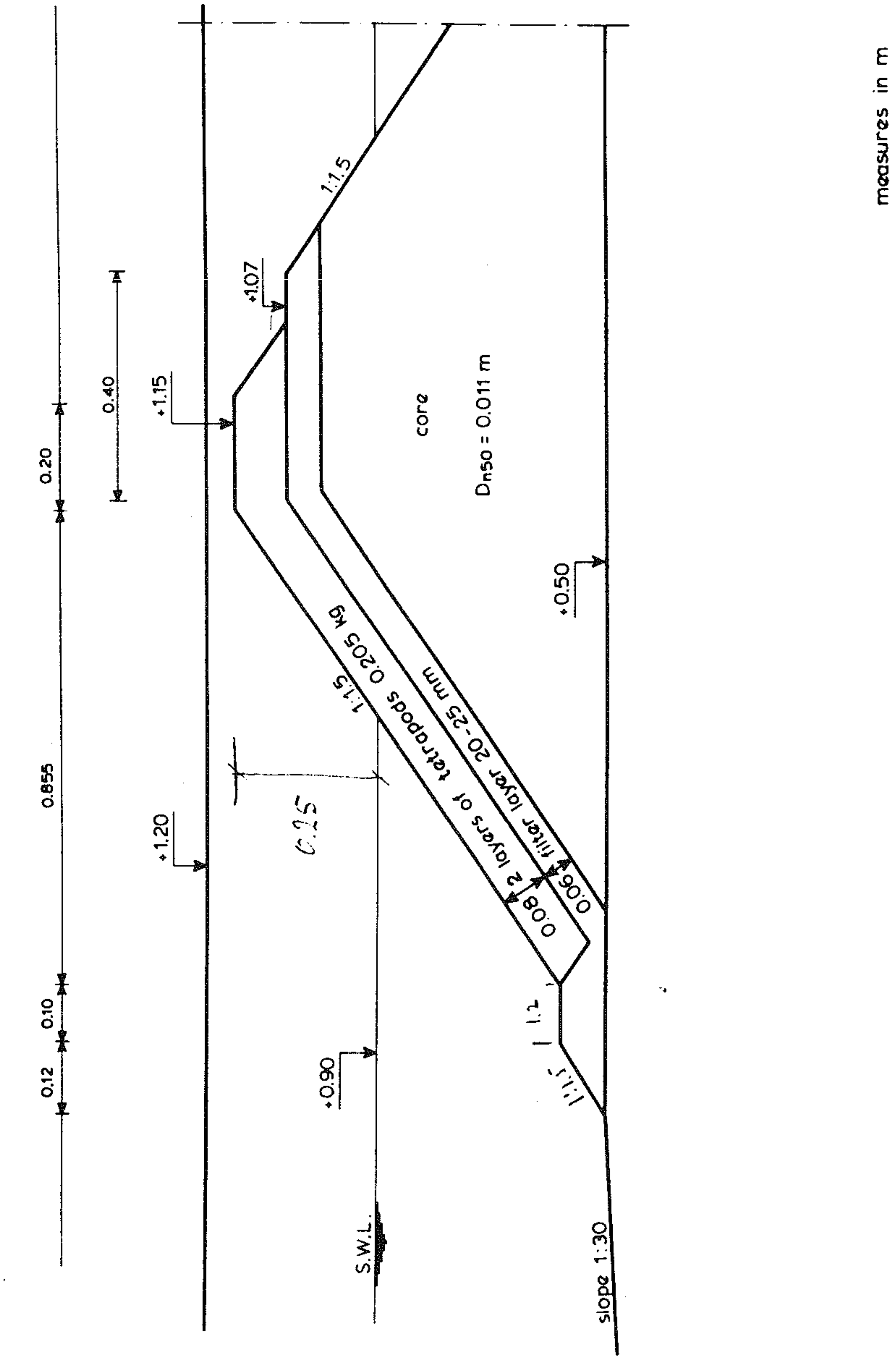
First number	Test series
Second number	Deep water wave steepness:
	0 or 2 $s_p = 0.02$
	4 $s_p = 0.04$
Third number	Test number
Letter indication	**a** Tetrapod type A or *1000* waves tested
	b *3000* waves tested
	h Test has been repeated
	k Tetrapod type K
	s Tetrapod type S

Example: **141a** Test serie 1
Deep water wave steepness: $s_p = 0.04$
First test
Tetrapods type A has been used

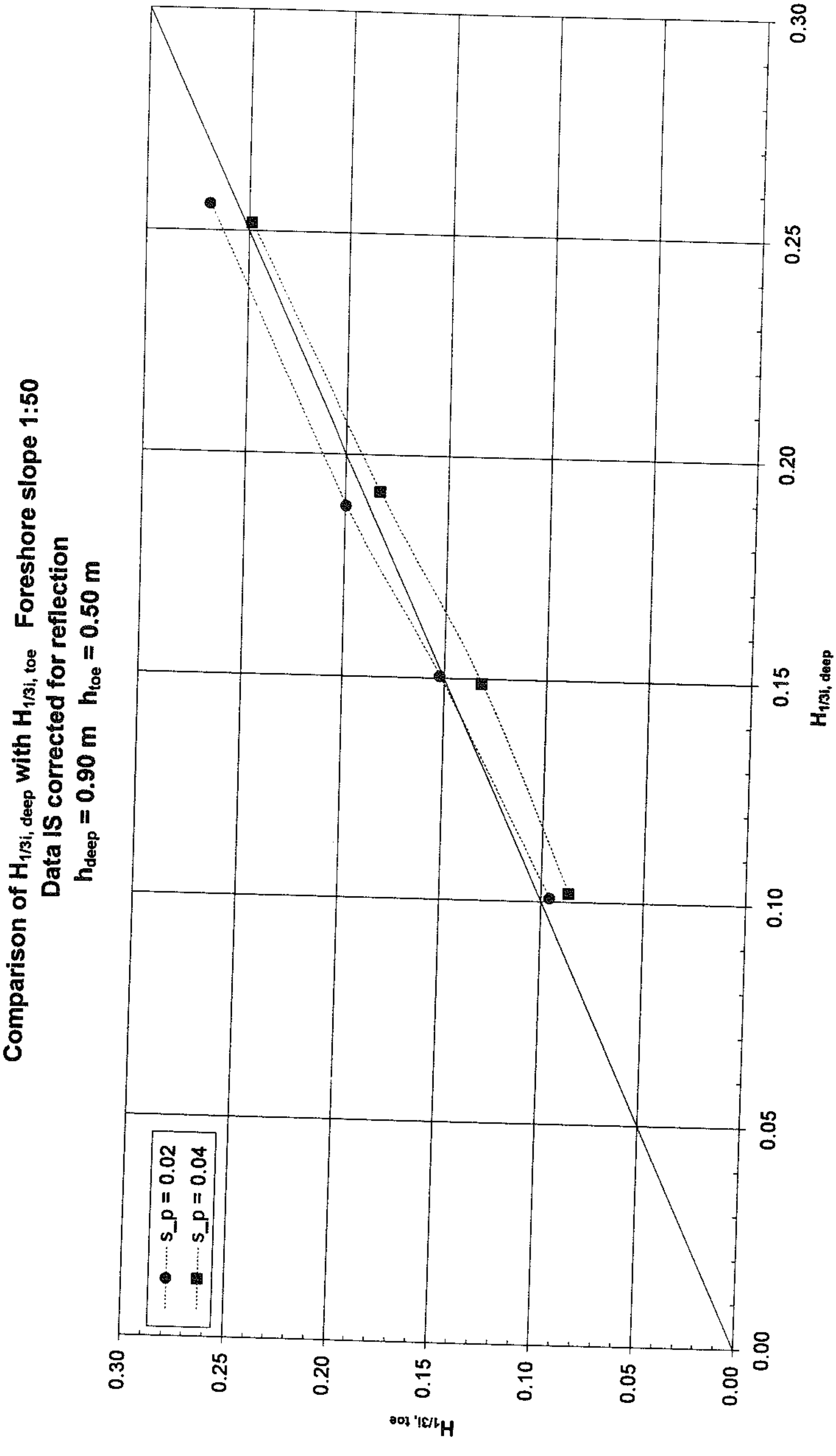
Data of H2061 (1994), Continued **Table A6.1**

Test	Hs	Tm	Hs/ΔDn	Som	Rc/Hsi	Nod (1000)	Nod (3000)
1	0.20	2.19	3.32	0.027	1.25	0.93	1.77
2	0.17	2.21	2.81	0.022	1.48	0.27	0.62
3	0.14	2.19	2.32	0.019	1.79	0.04	0.04
4	0.15	2.19	2.56	0.021	1.62	0.04	0.18
5	0.19	2.20	3.09	0.025	1.34	0.84	1.42
6	0.16	1.70	2.59	0.035	1.60	0.53	0.97
7	0.13	1.69	2.12	0.029	1.95	0.22	0.31
8	0.11	1.68	1.83	0.025	2.27	0.04	0.04
9	0.18	1.72	3.02	0.039	1.37	0.89	1.68
10	0.13	1.35	2.16	0.046	1.92	0.22	0.31
11	0.16	1.40	2.66	0.052	1.56	0.13	0.44
12	0.18	1.45	3.04	0.056	1.37	0.53	1.15
13	0.15	1.37	2.46	0.051	1.69	0.49	0.93
14	0.11	1.34	1.76	0.038	2.36	0.04	0.04
15	0.16	2.98	2.71	0.012	1.53	0.18	0.31
16	0.19	2.91	3.20	0.015	1.30	0.27	0.93
17	0.15	2.99	2.41	0.010	1.72	0.09	0.22
18	0.13	2.99	2.19	0.009	1.89	0.04	0.04
19	0.21	2.90	3.54	0.016	1.17	1.42	3.68

Data of H462-II (1987) **Table A6.2**

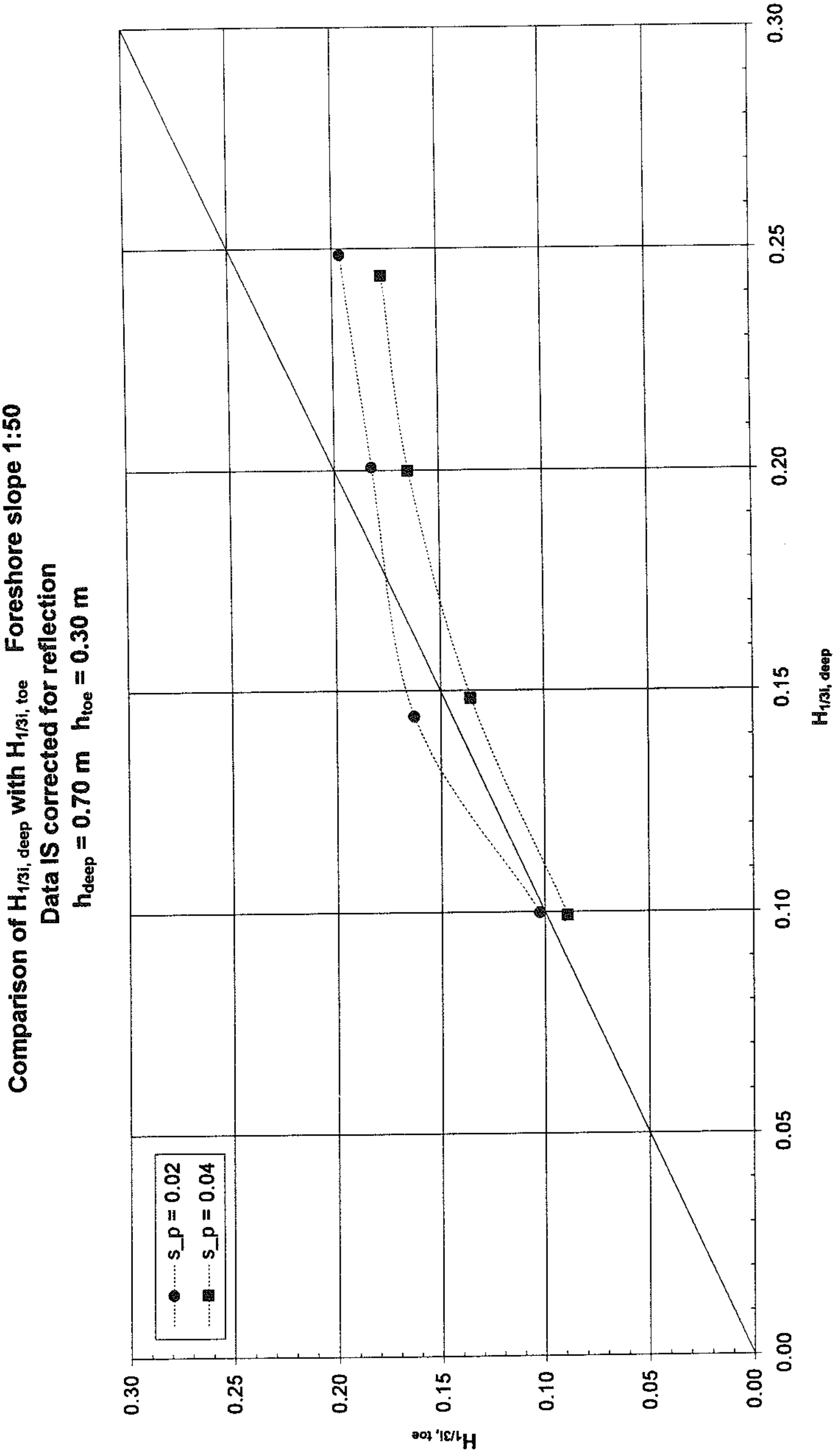


Cross section Breakwater Test H462-II (1987) **Figure A6.1**

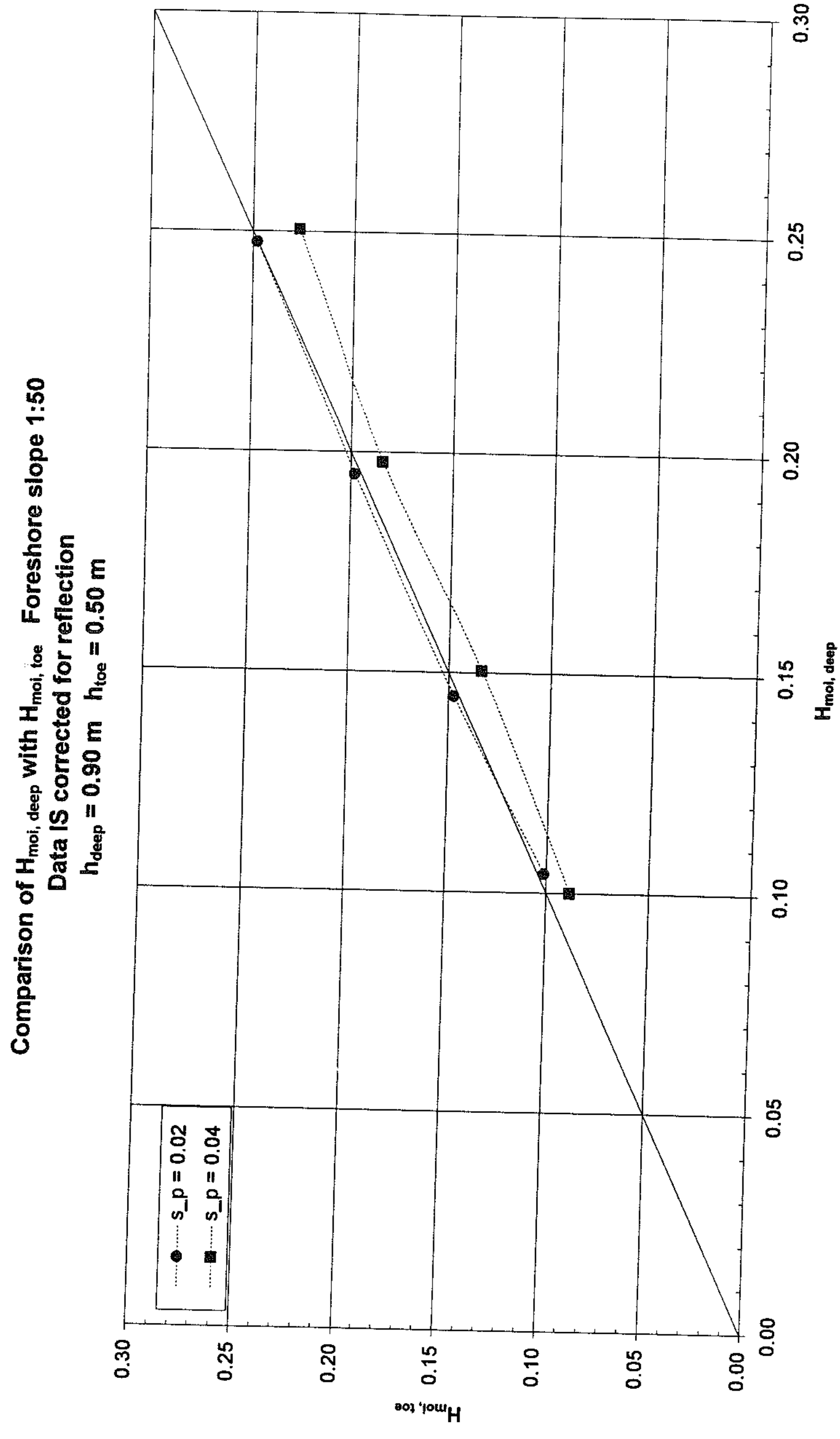


Comparison of $H_{1/3i,\,deep}$ with $H_{1/3i,\,toe}$, $h_{deep} = 0.90\ m$

Figure A6.2

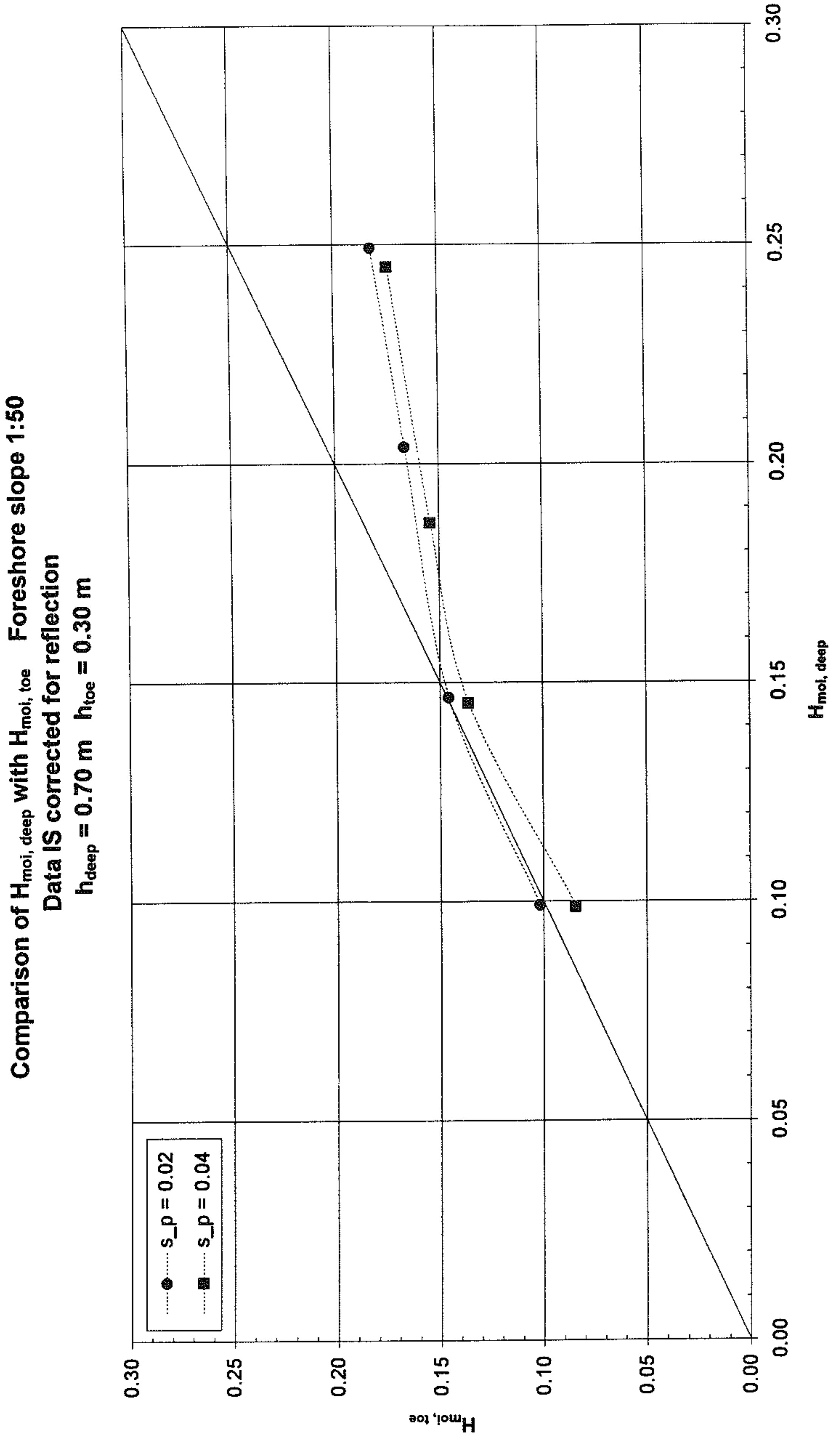


Comparison of $H_{1/3i,\ deep}$ with $H_{1/3i,\ toe}$, $h_{deep} = 0.70\ m$ **Figure A6.3**

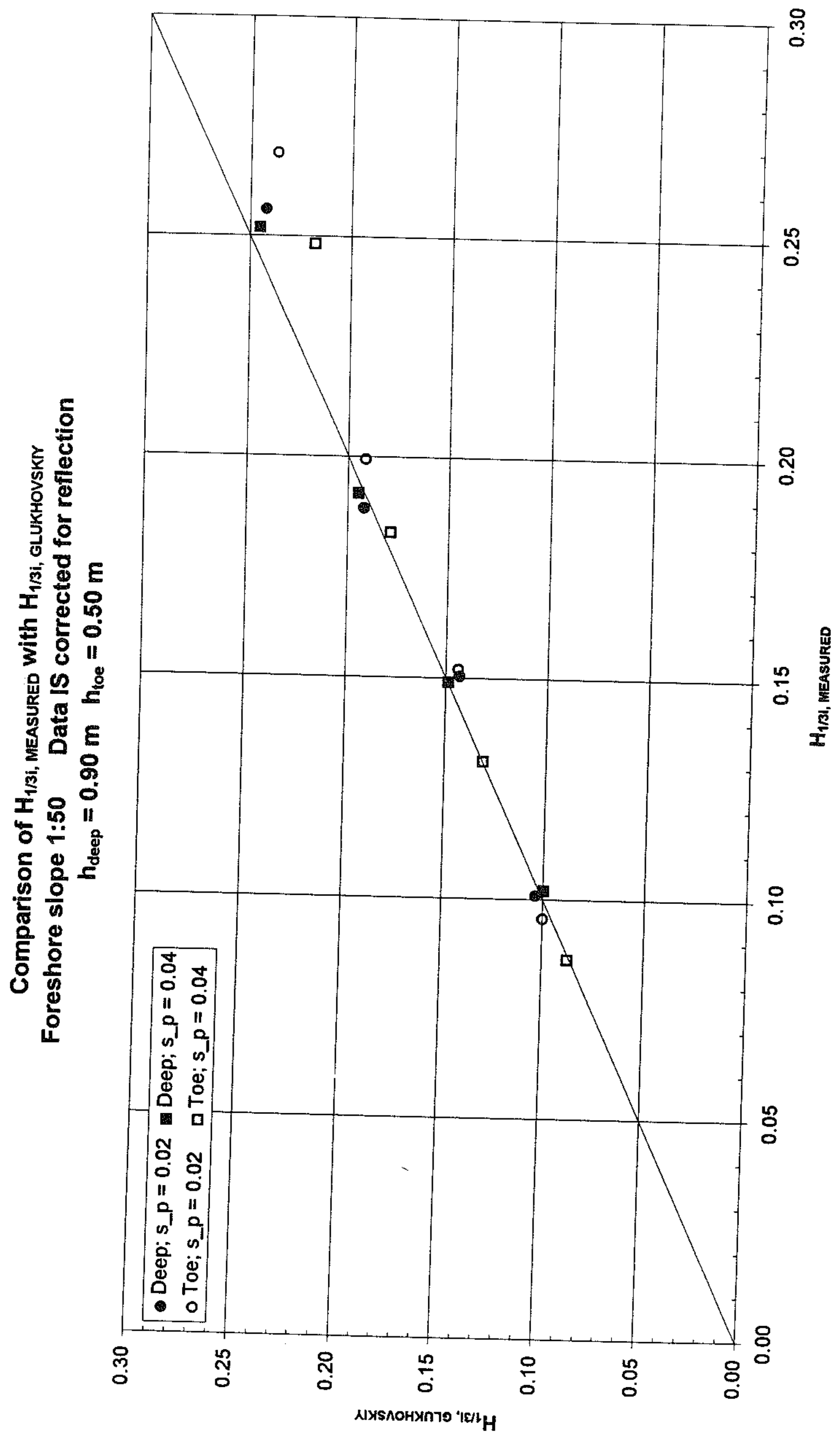


Comparison of $H_{moi, deep}$ with $H_{moi, toe}$, $h_{deep} = 0.90\ m$

Figure A6.4

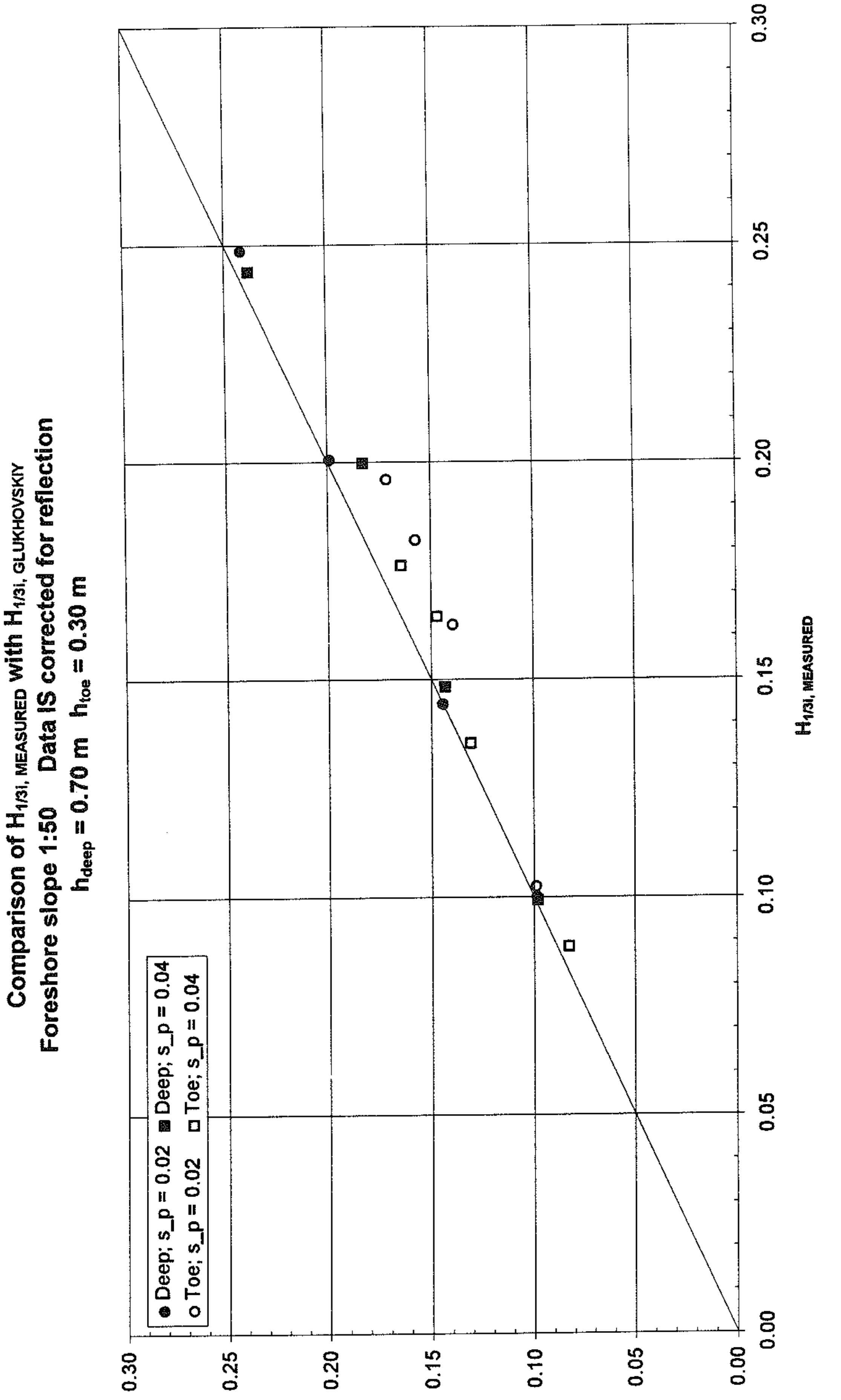


Comparison of $H_{moi,\ deep}$ with $H_{moi,\ toe}$, $h_{deep} = 0.70\ m$ **Figure A6.5**

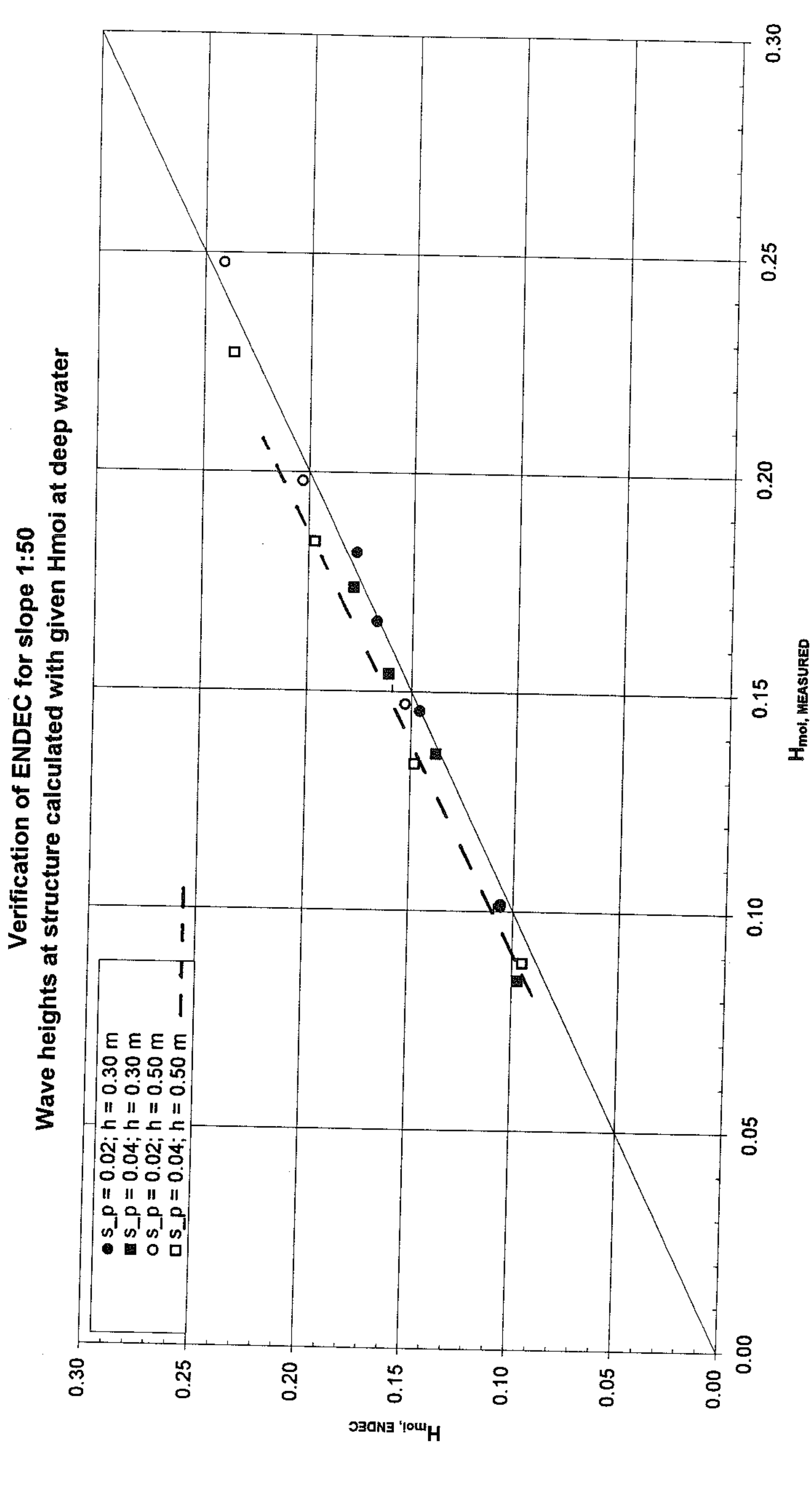


Comparison of $H_{1/3i,\ MEASURED}$ with $H_{1/3i,\ GLUKHOVSKIY}$, $h_{deep} = 0.90\ m$

Figure A6.6

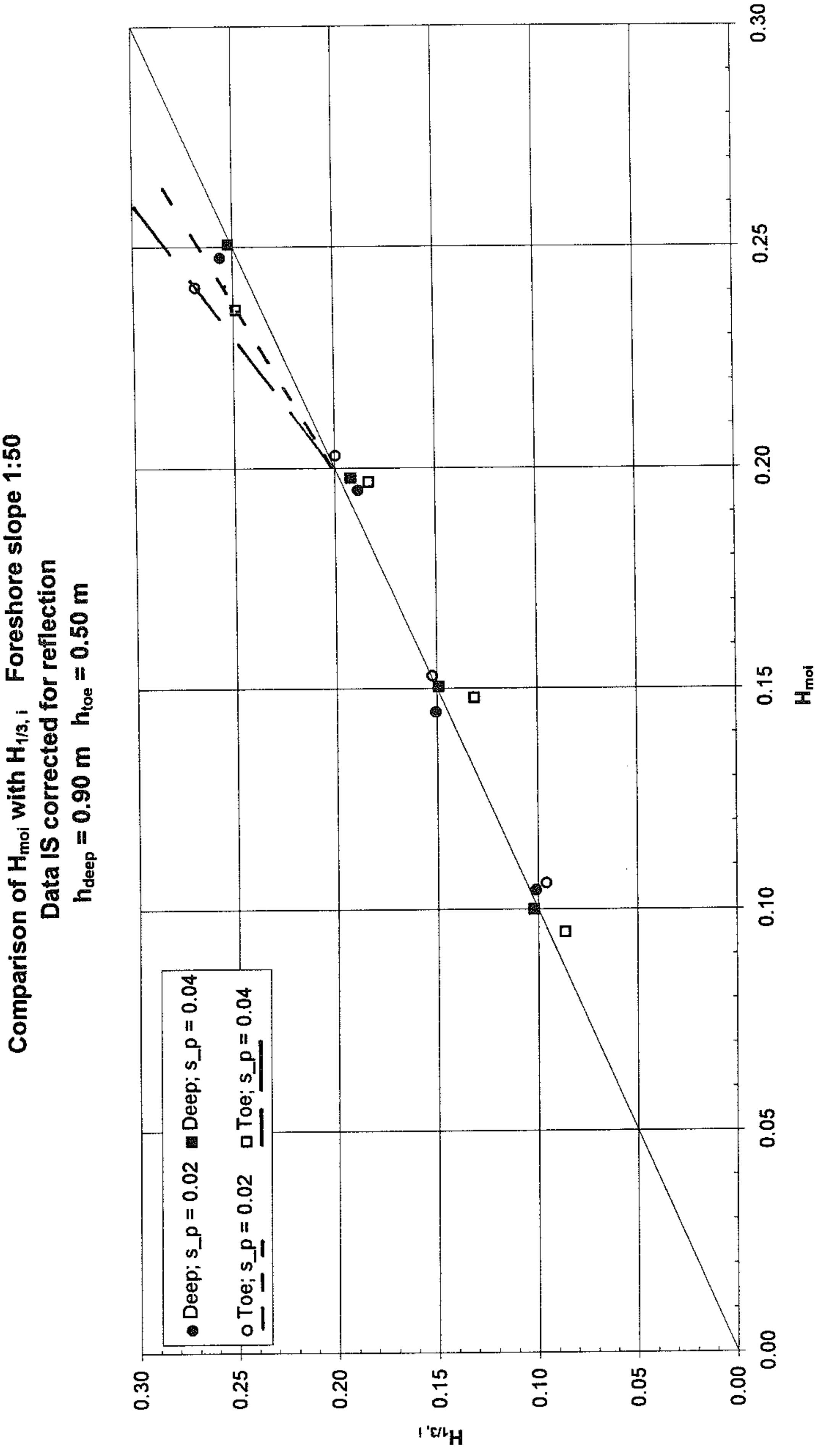


Comparison of $H_{1/3i,\ MEASURED}$ with $H_{1/3i,\ GLUKHOVSKIY}$, $h_{deep} = 0.70\ m$ **Figure A6.7**

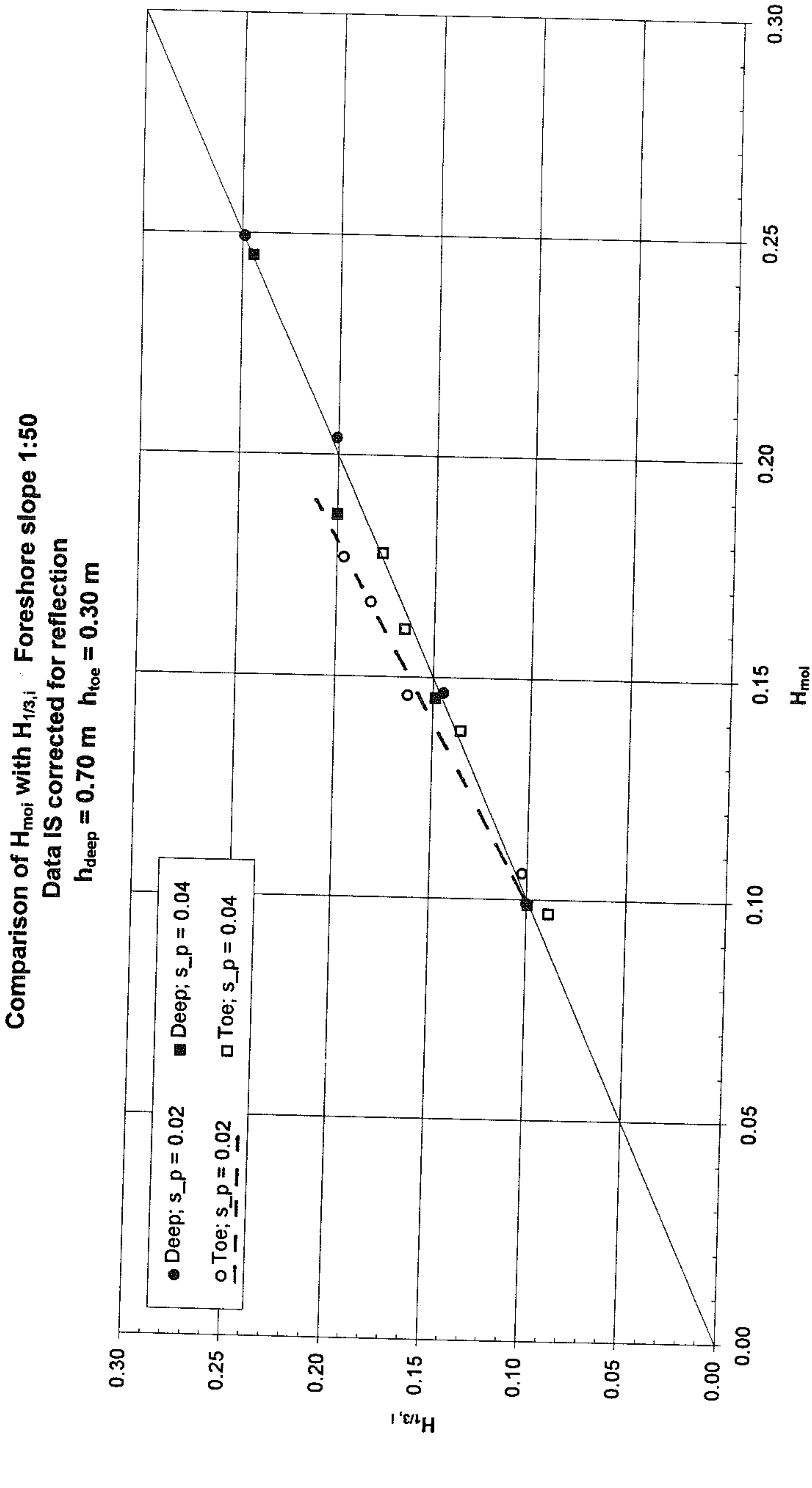


Verification of ENDEC for slope *1:50*

Figure A6.8



Comparison of H_{moi} with $H_{1/3i}$, h_{deep} = 0.90 m **Figure A6.9**



Comparison of H_{moi} with $H_{1/3i}$, $h_{deep} = 0.70\ m$

Figure A6.10

ANNEX 7

Mathematical formulation of modified Glukhovskiy distribution

MODIFIED GLUKHOVSKIY DISTRIBUTION

Klopman (1996) has used the modified Glukhovskiy distribution to relate the H_{mo} to $H_{1/3}$ for extreme wave heights in shallow water. The following lines give an outline of the mathematical formulation of this relation.

It is assumed that the extreme wave heights are distributed according to a Weibull probability distribution, with the exceedance probability of the wave height H given by:

$$P(H) = Prob\{\underline{H} > H\} = \exp\left[-B\left(\frac{H}{H_{rms}}\right)^{\kappa^*}\right] \quad \text{(A7.1)}$$

The exponent κ^* is assumed to be a function of the relative wave height parameter d^*:

$$d^* = \frac{H_{rms}}{d} \quad \text{(A7.2)}$$

The parameterisation of κ^* is very much the same as for the Glukhovskiy distribution:

$$\kappa^* = \frac{2}{1-\beta d^*} \quad \text{(A7.3)}$$

The nth moment M_n of the Weibull distribution is equal to:

$$M_n = H_{rms}^n \, B^{-\frac{n}{\kappa^*}} \Gamma\left(\frac{n}{\kappa^*}+1\right) \quad \text{(A7.4)}$$

with $\Gamma(x)$ is the gamma function of x.

In order to have a consistent probability distribution M_2 has to be equal to H^2_{rms} giving the following expression for B:

$$B = \left[\Gamma\left(\frac{2}{\kappa^*}+1\right)\right]^{\frac{\kappa^*}{2}} \quad \text{(A7.5)}$$

Now the following relationships between several characteristic wave heights can be formulated:

$$\frac{H_N}{H_{rms}} = \left(\frac{\ln(N)}{B}\right)^{\frac{1}{\kappa^*}} \quad \text{(A7.6)}$$

$$\frac{H_{1/3}}{H_{rms}} = 3\frac{\Gamma\left[\frac{1}{\kappa^*}+1, \ln(3)\right]}{\sqrt{\Gamma\left(\frac{2}{\kappa^*}+1\right)}} \quad \text{(A7.7)}$$

with H_N is the wave having an exceedance probability of $P(H_N) = 1/N$
$H_{1/3}$ the significant wave height (mean of the waves higher than H_3)
and $\Gamma(a, x)$ is the incomplete gamma function.

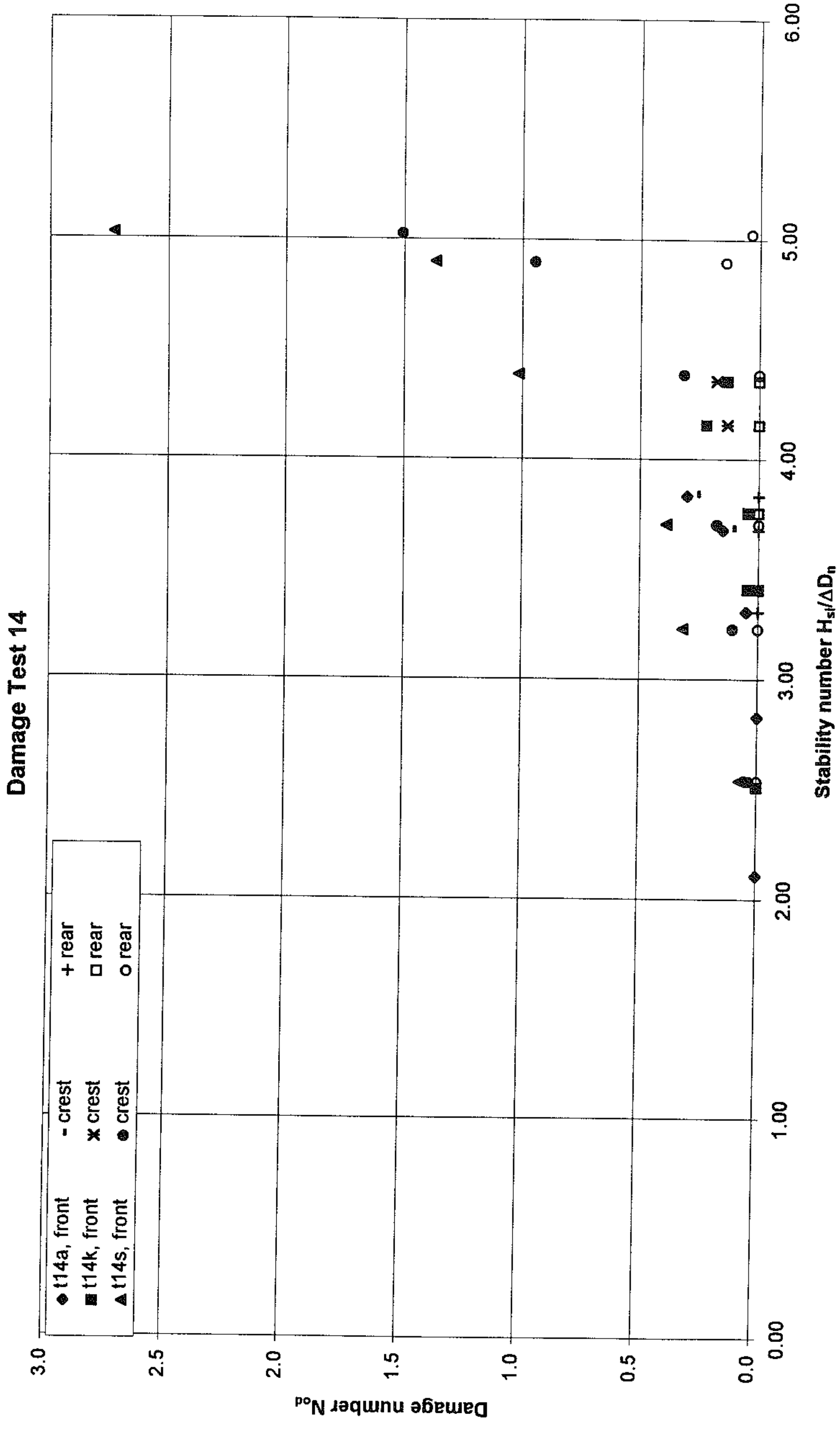
In order to be able to use the results of wave energy propagation models, like ENDEC, H_{rms} has to be related to the model output. This wave height is assumed to be directly related to the surface elevation variance m_0 in the same way as for the Rayleigh distribution of a narrow-banded Gaussian process:

$$H_{m_0} = 4\sqrt{m_0} = \sqrt{2}\, H_{rms} \quad \text{(A7.8)}$$

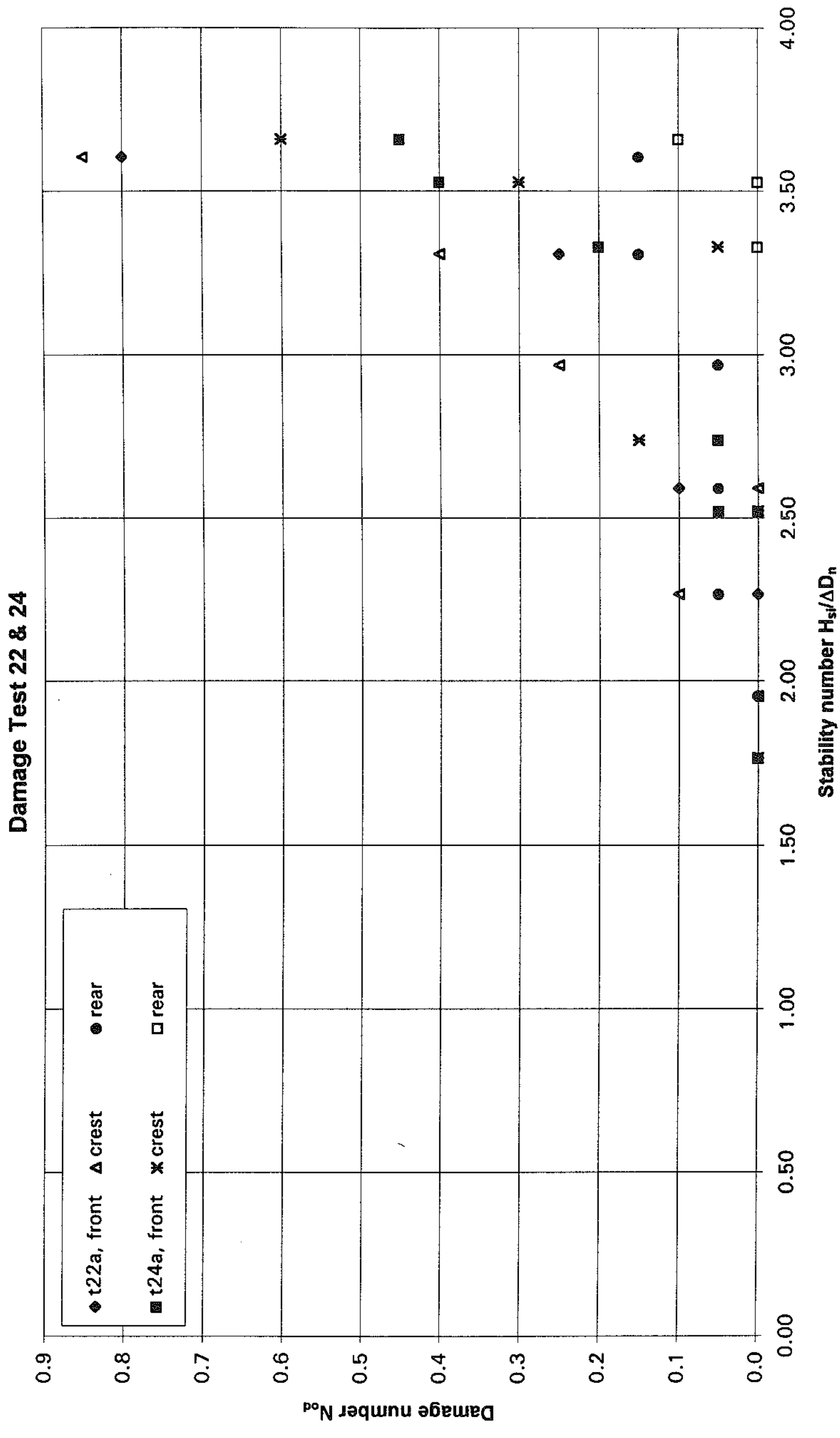
The factor β has been set to a value of 0.7, which has been derived using laboratory data.

ANNEX 8

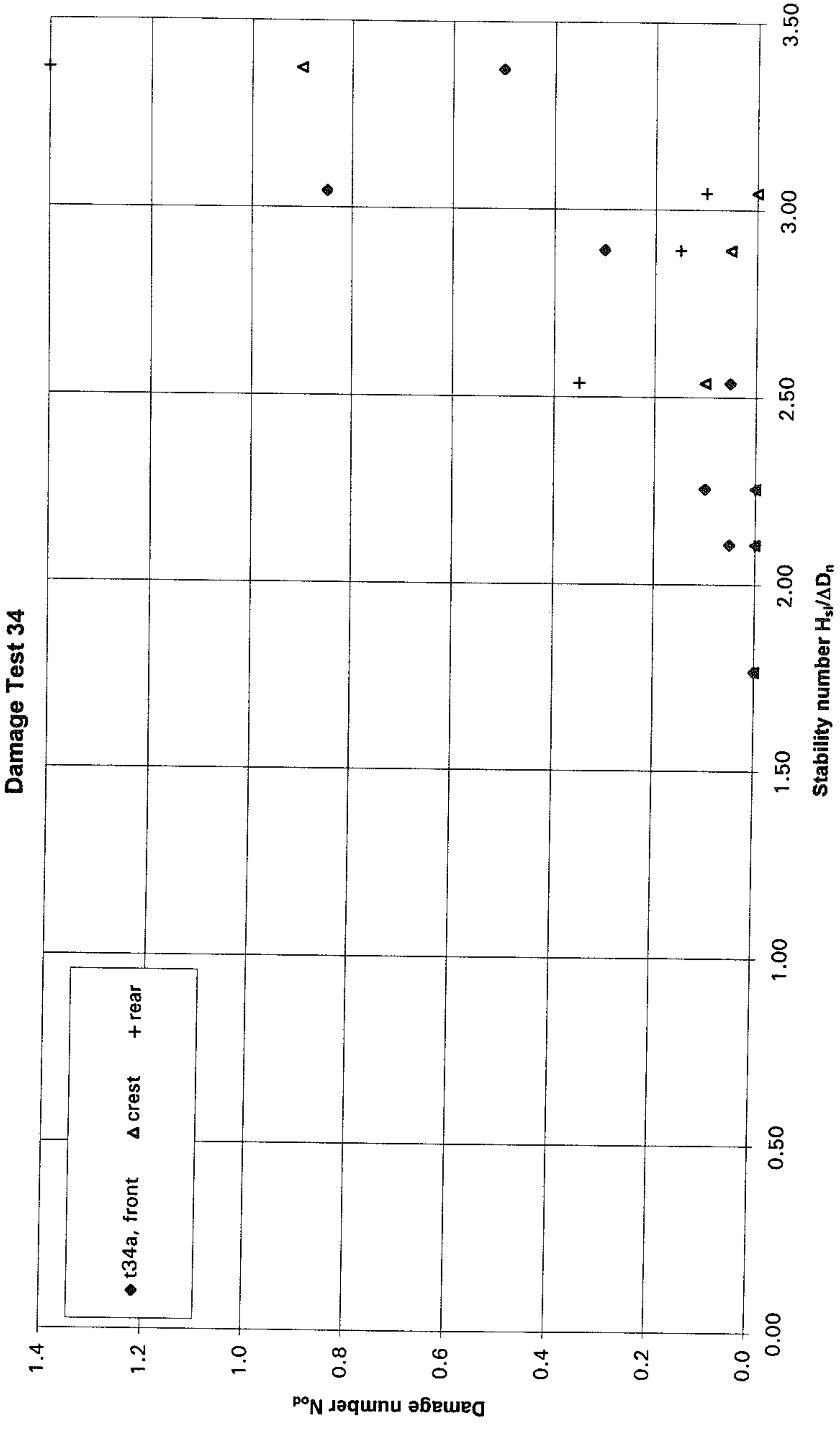
Figures for Chapter 10



Individual damage curves for Test 14 **Figure A8.1**

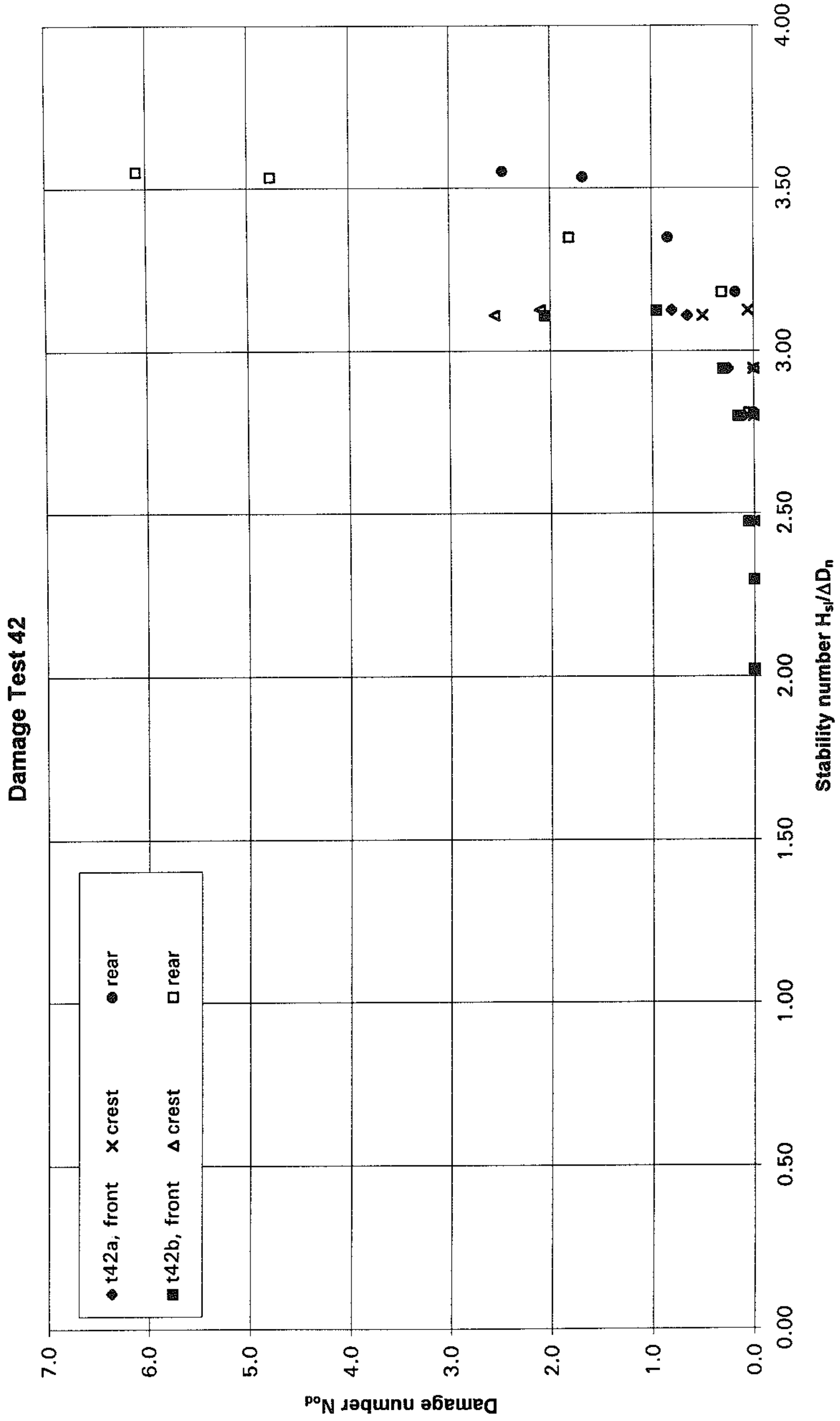


Individual damage curves for Test 22 and 24 **Figure A8.2**

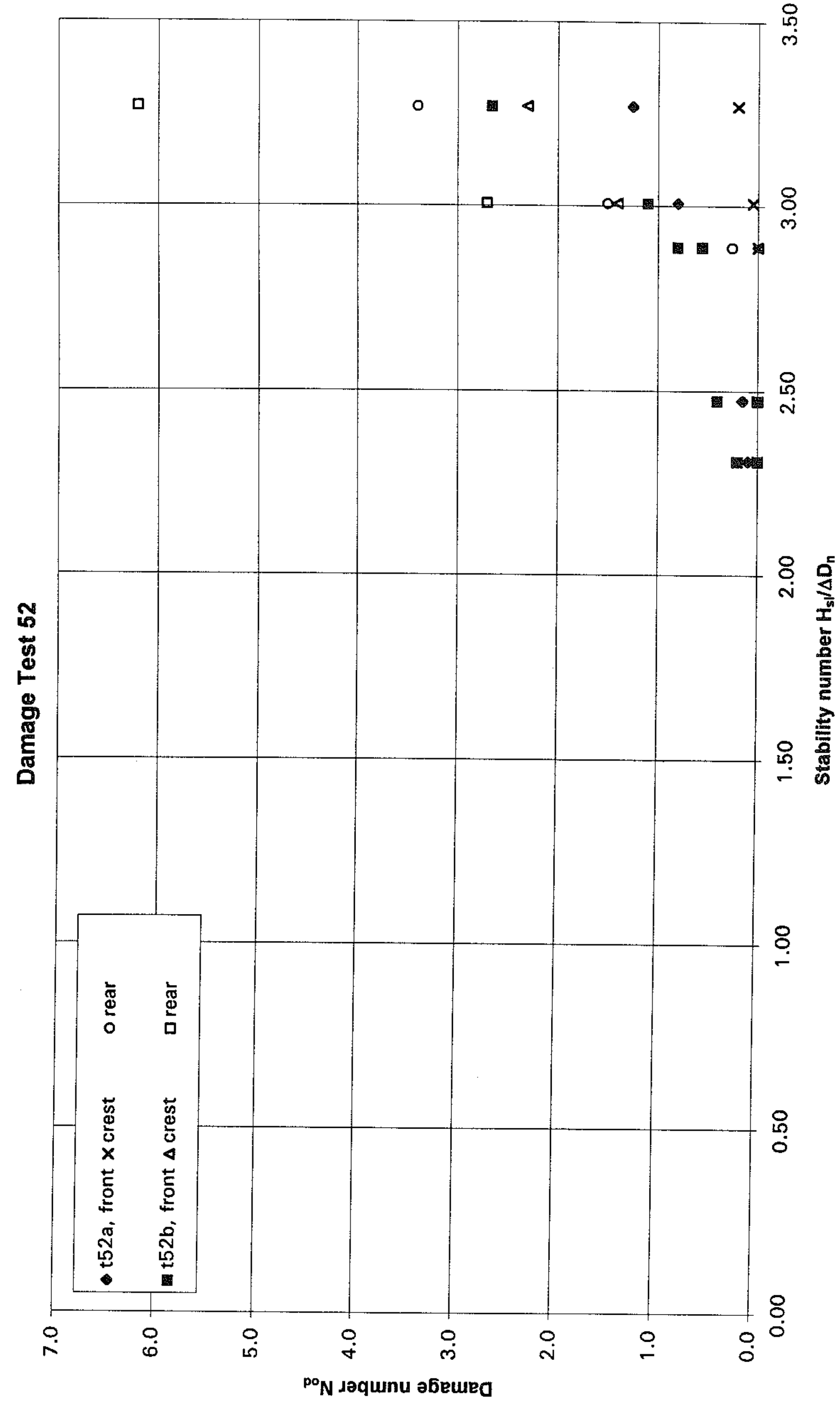


Individual damage curves for Test 34

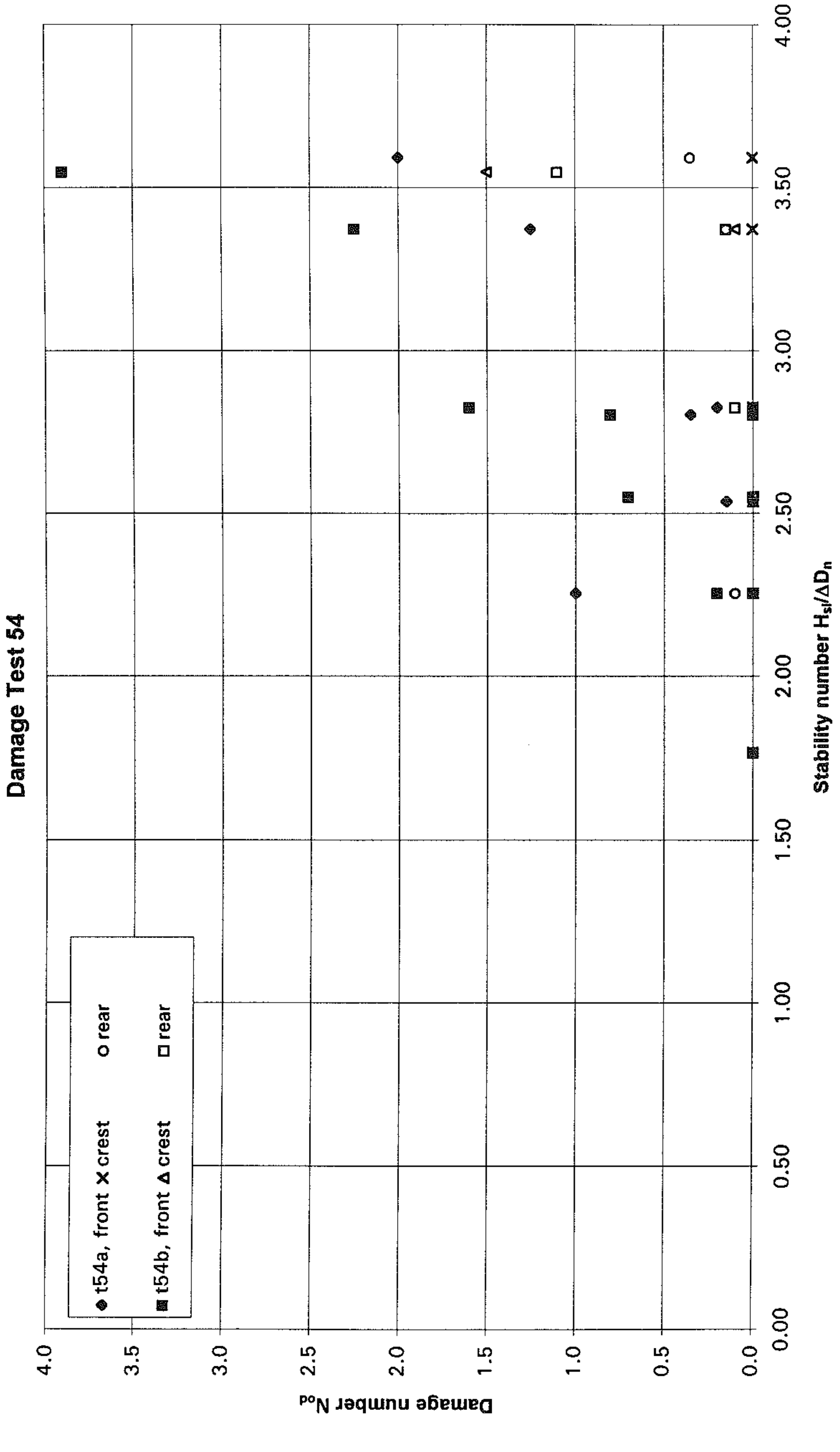
Figure A8.3



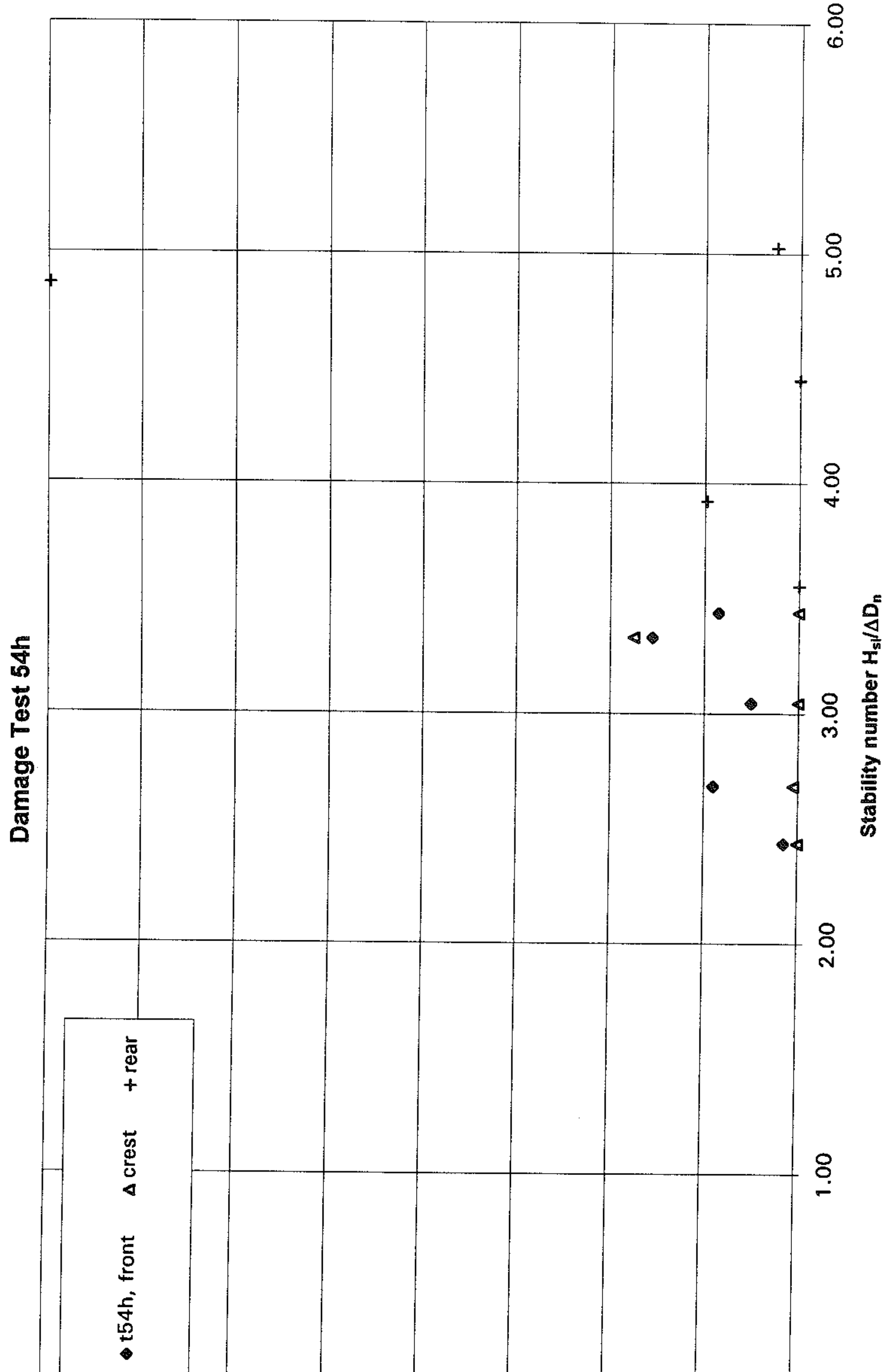
Individual damage curves for Test 42 **Figure A8.4**



Individual damage curves for Test 52 **Figure A8.5**

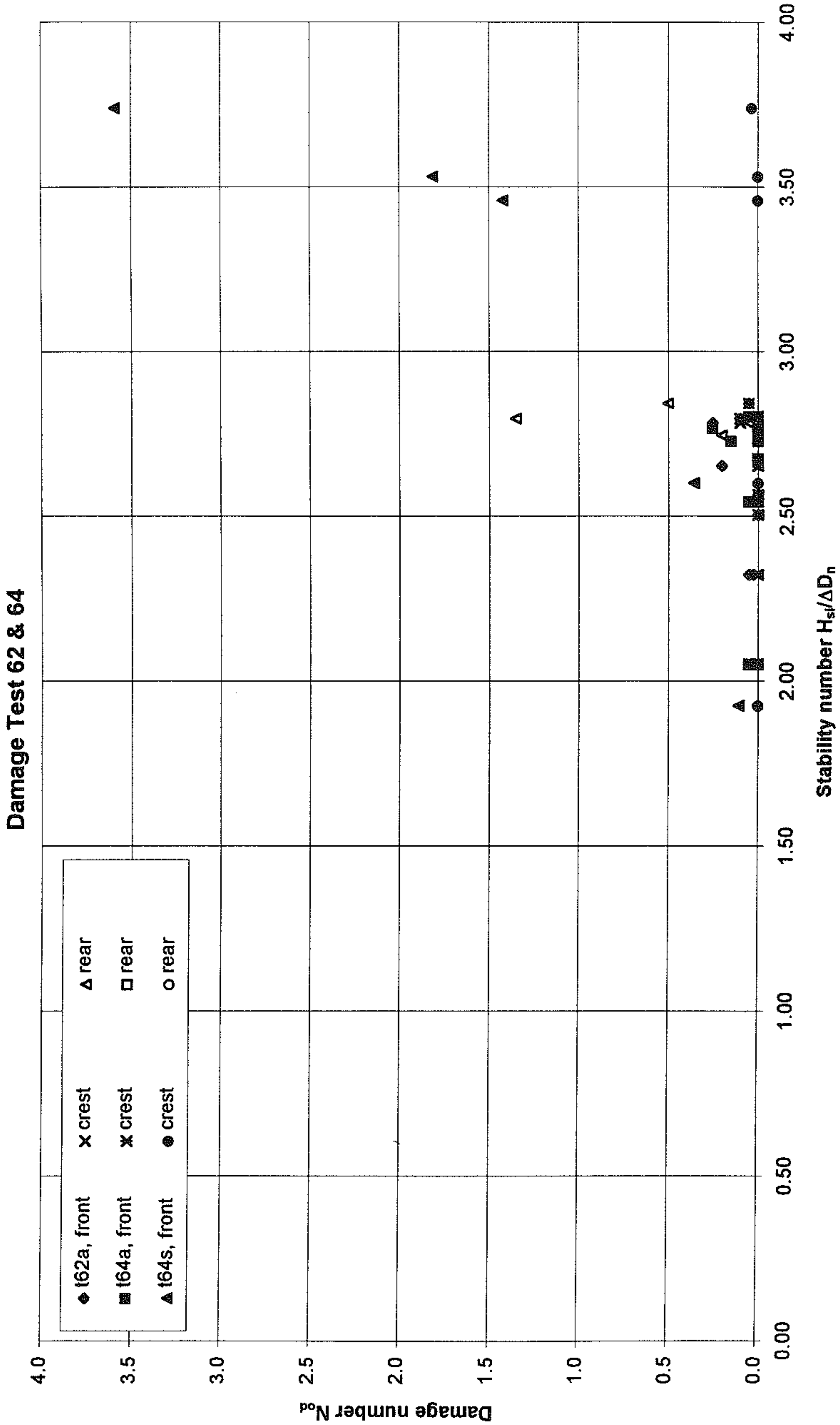


Individual damage curves for Test 54 **Figure A8.6**



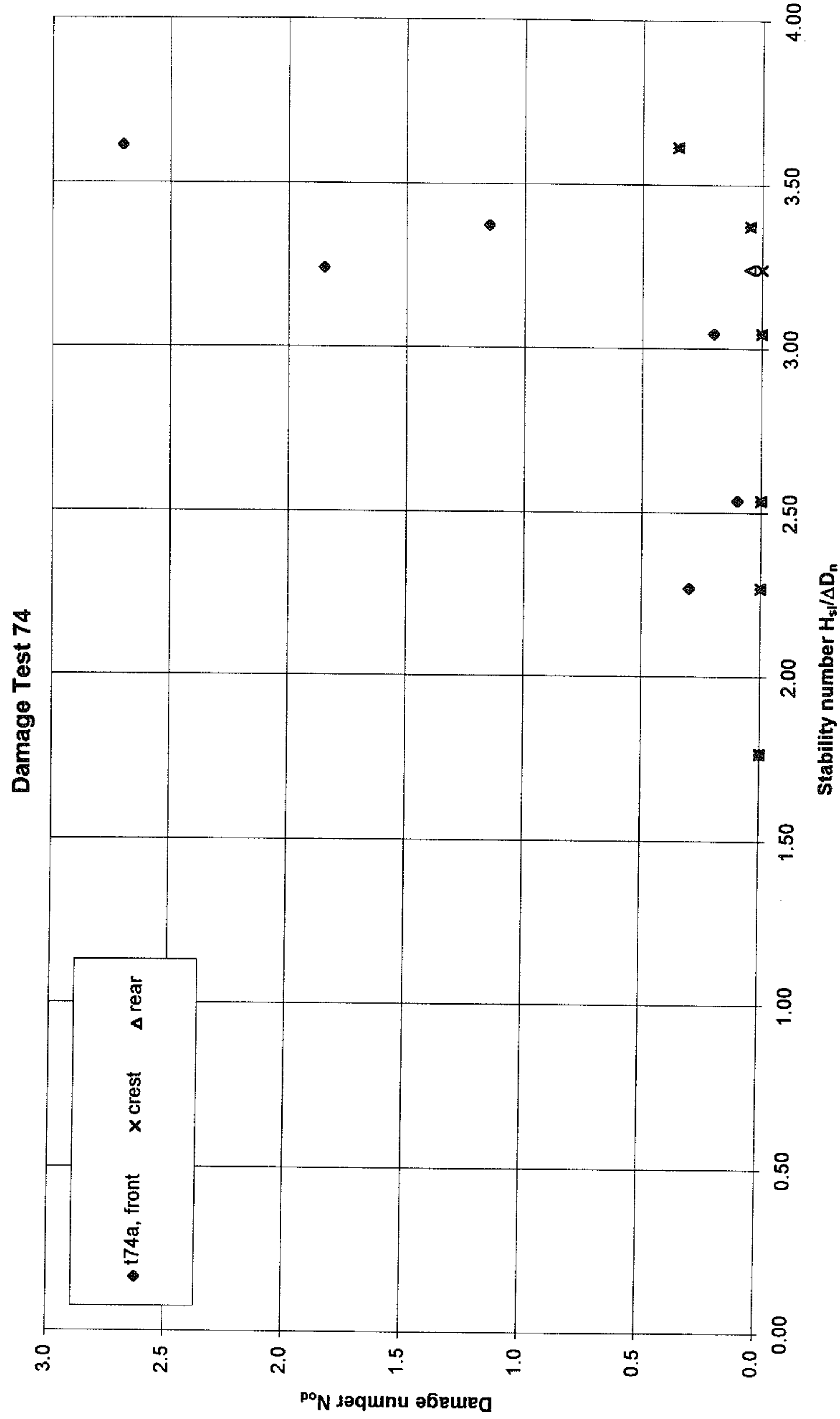
Individual damage curves for Test 54h

Figure A8.7

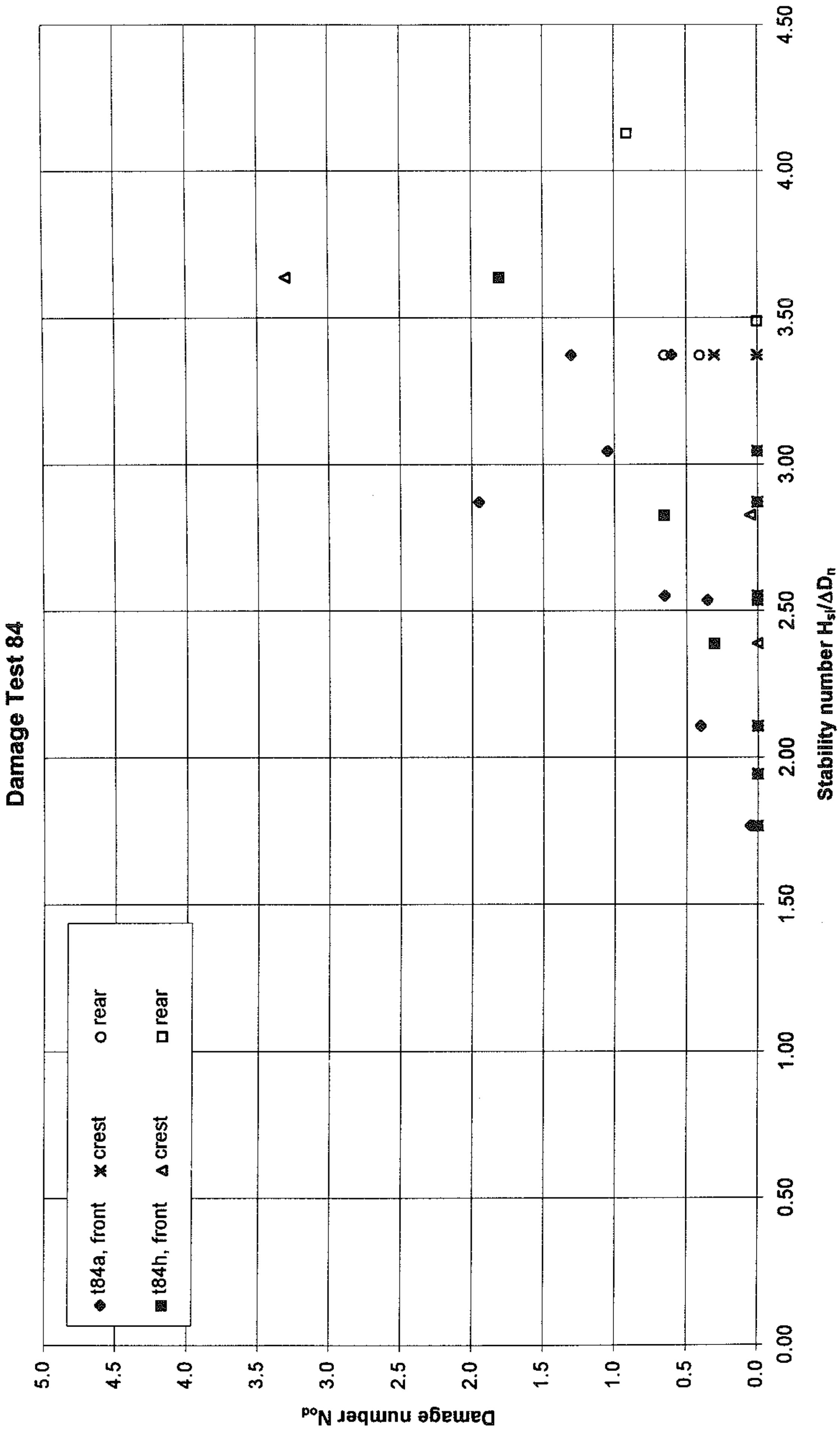


Individual damage curves for Test 62 and 64

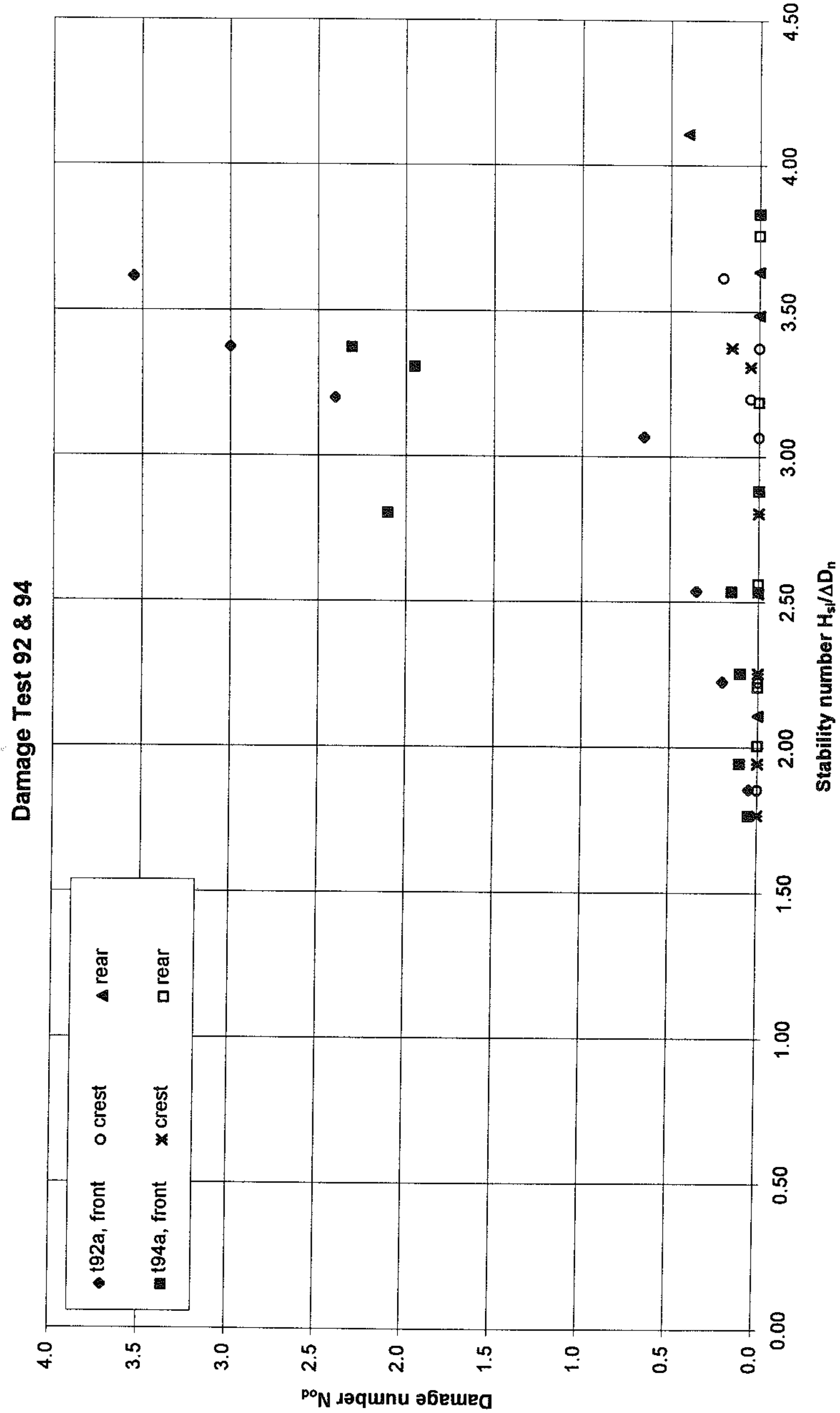
Figure A8.8



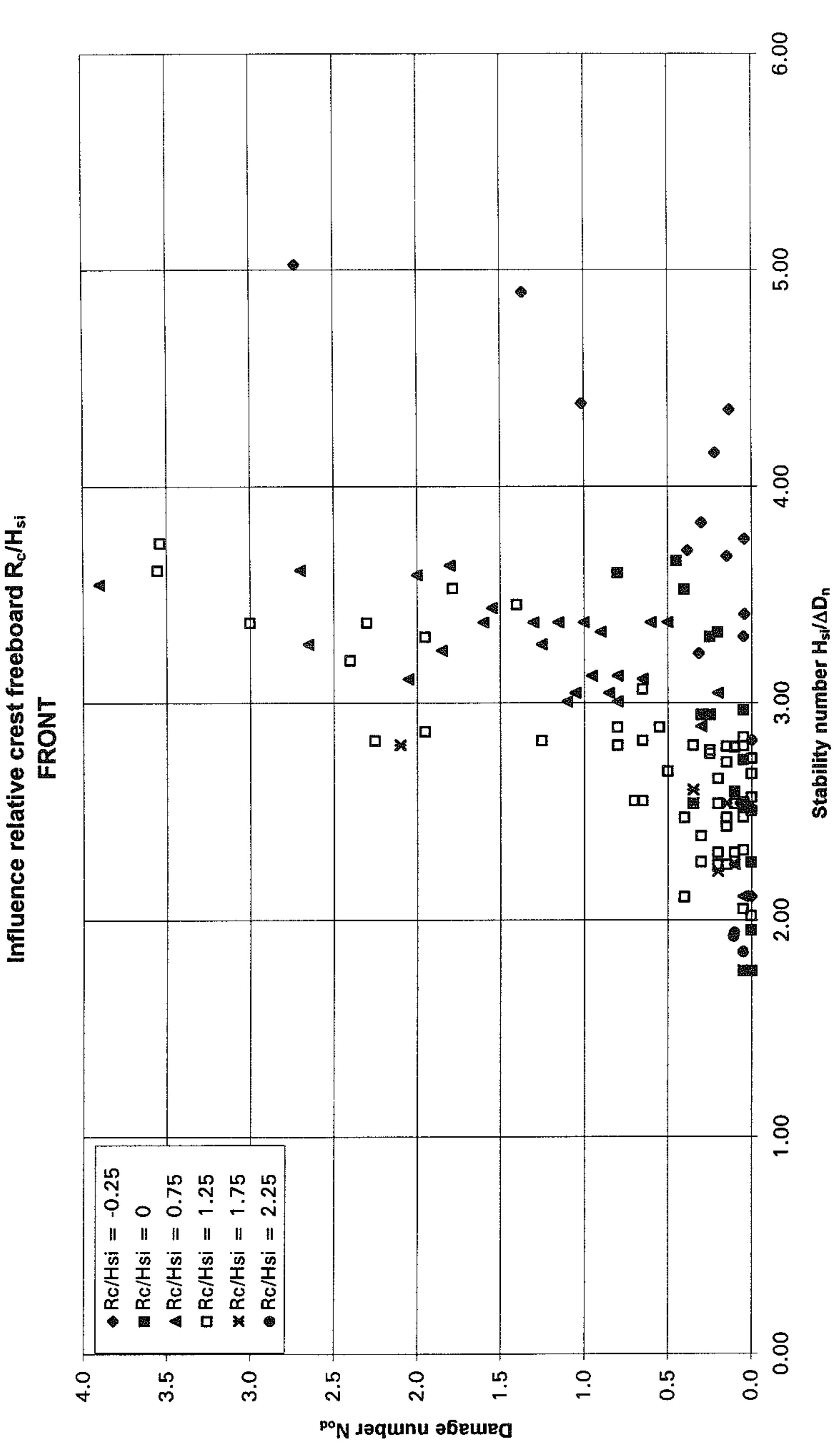
Individual damage curves for Test 74 **Figure A8.9**



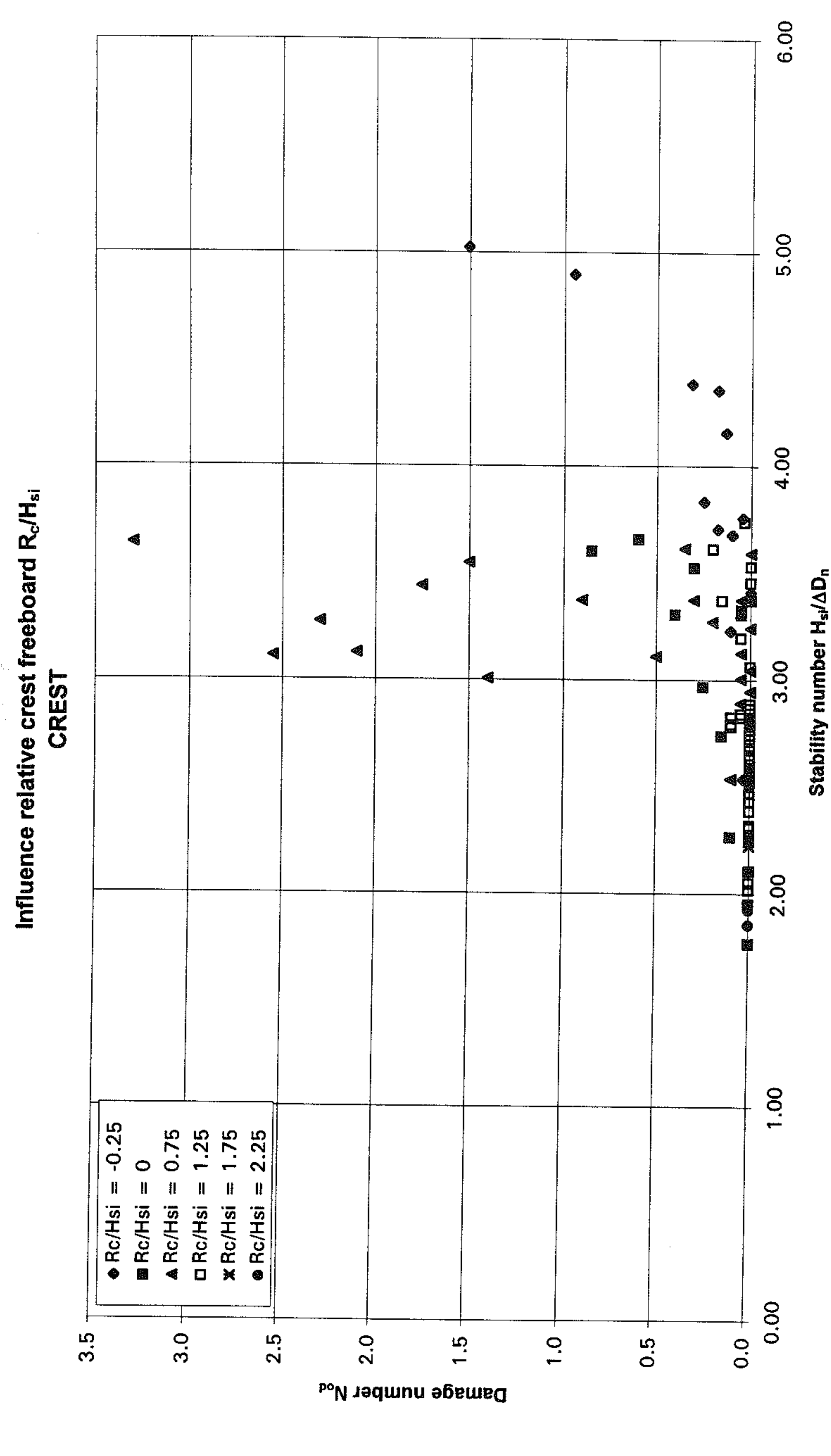
Individual damage curves for Test 84 **Figure A8.10**



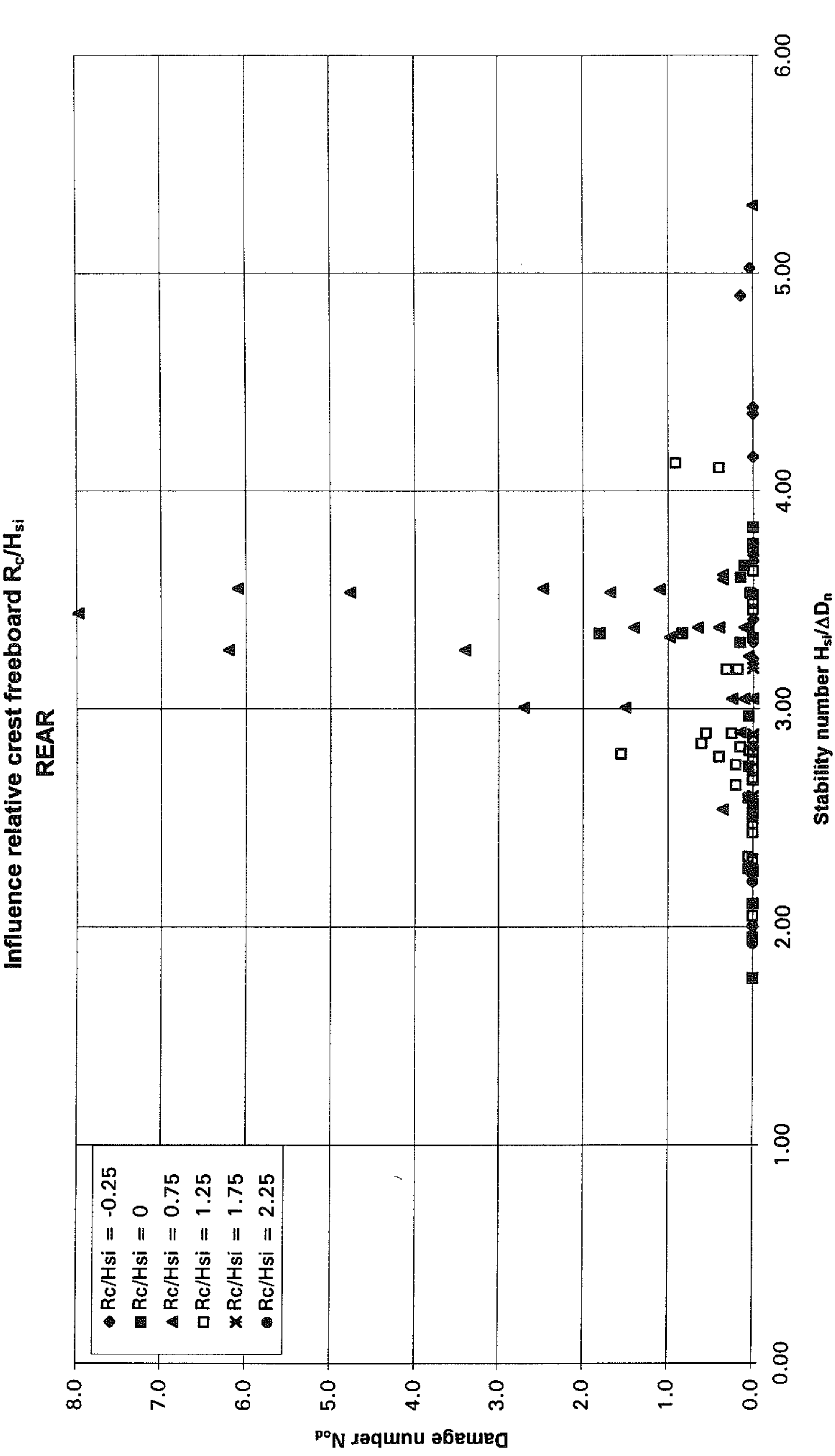
Individual damage curves for Test 92 and 94 **Figure A8.11**



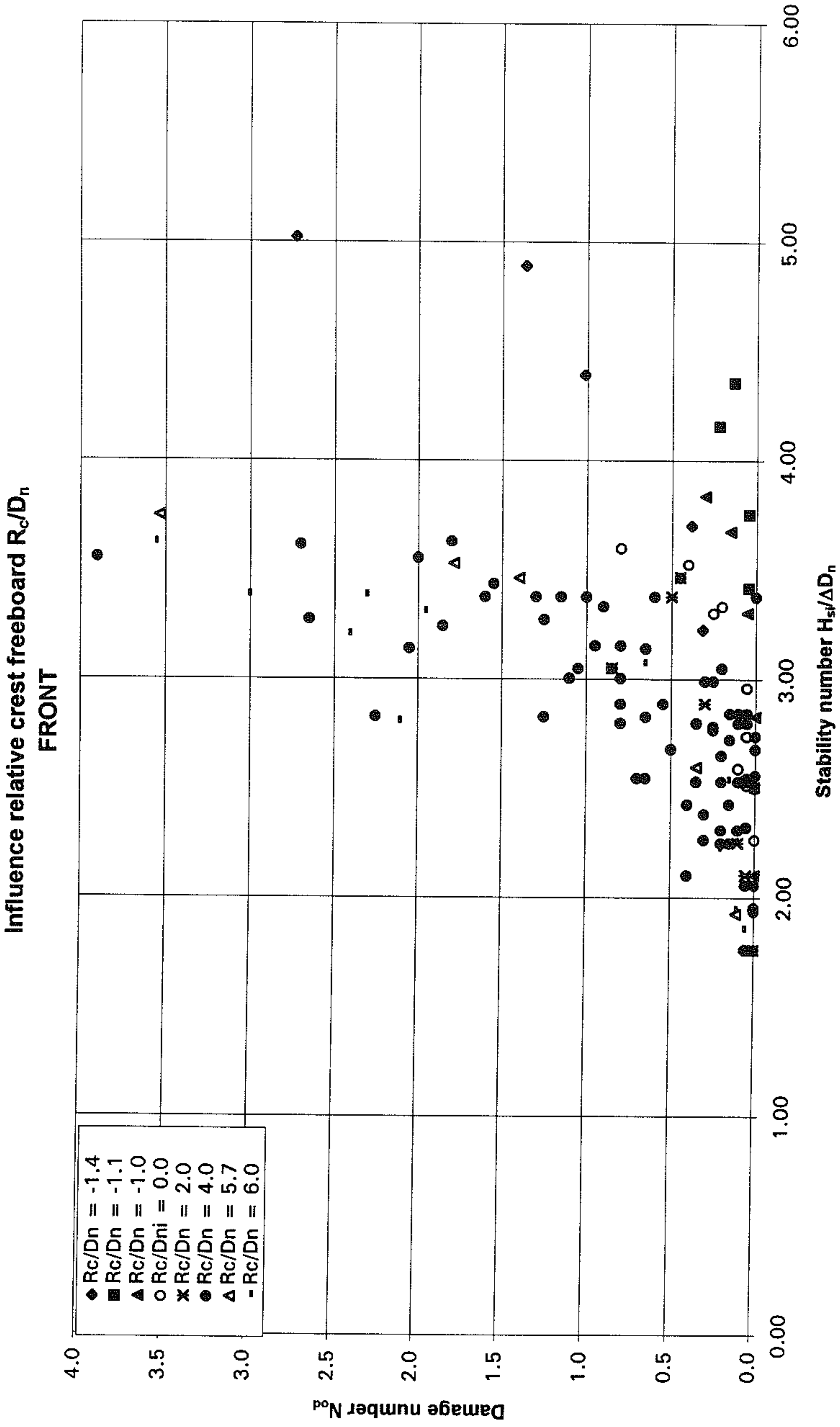
Influence of relative crest freeboard R_c/H_{si}, Front segment **Figure A8.12**



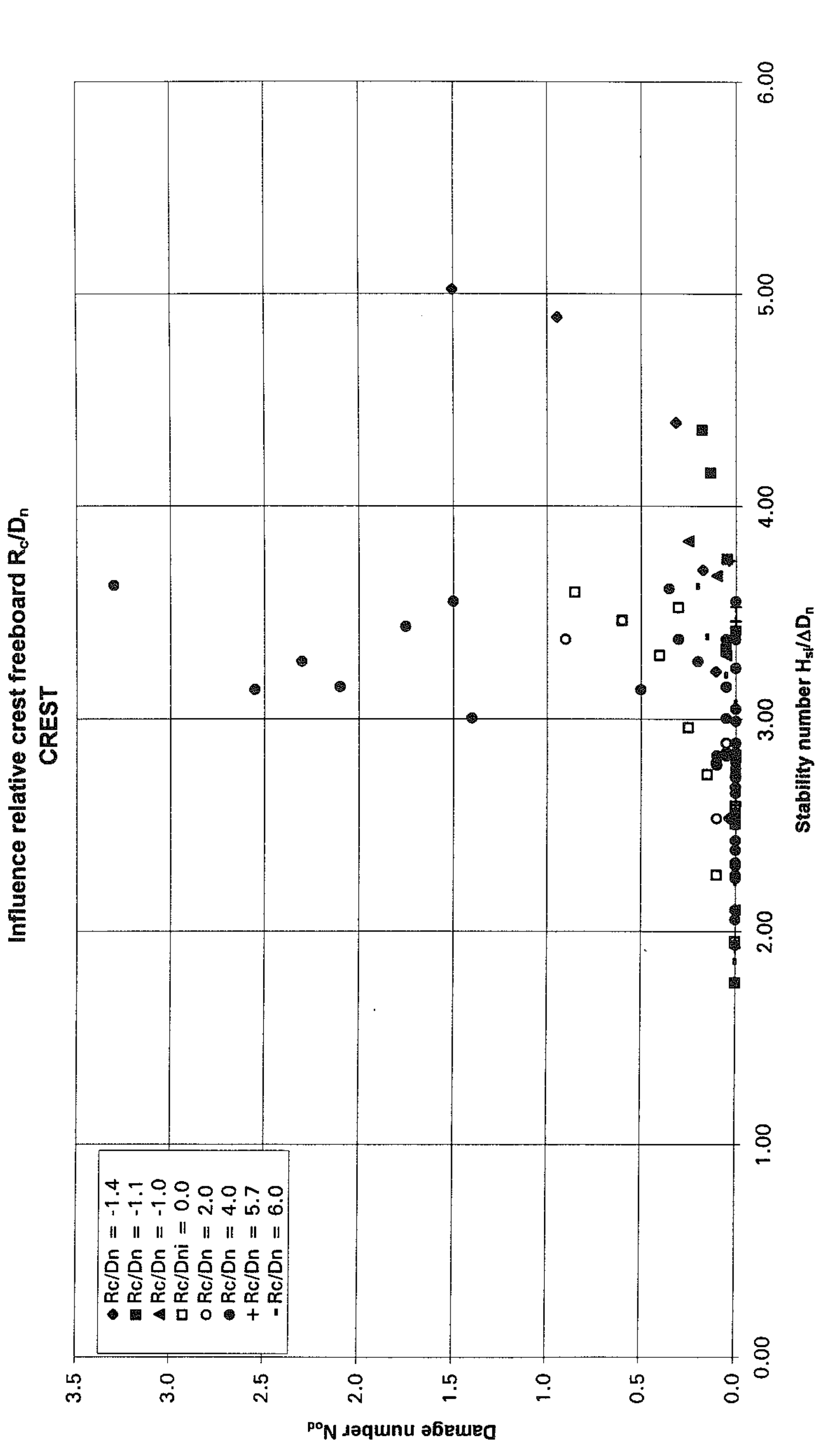
Influence of relative crest freeboard R_c/H_{si}, Crest segment **Figure A8.13**



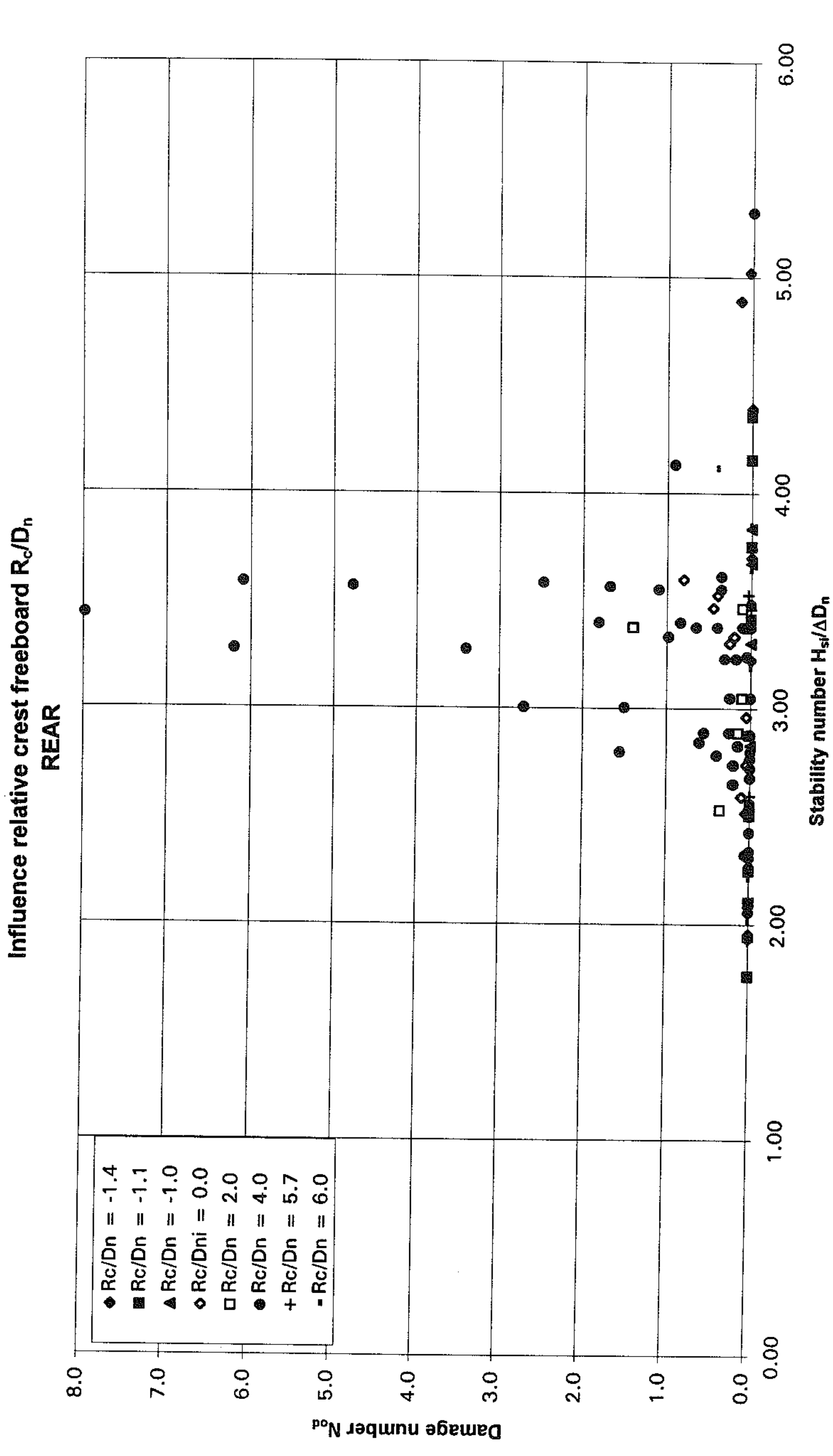
Influence of relative crest freeboard R_c/H_{si}, Rear segment **Figure A8.14**



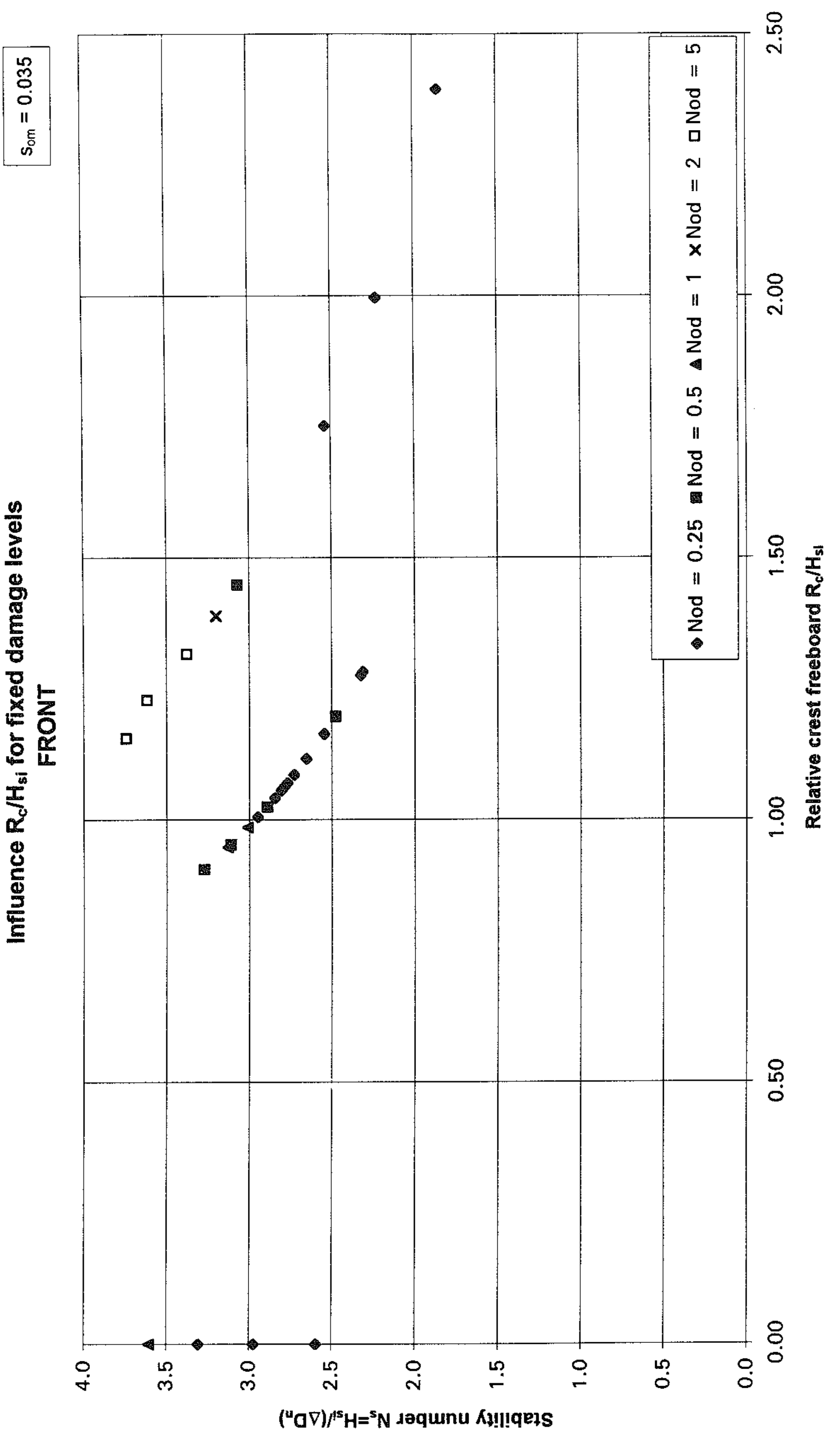
Influence of relative crest freeboard R_c/D_n, Front segment **Figure A8.15**



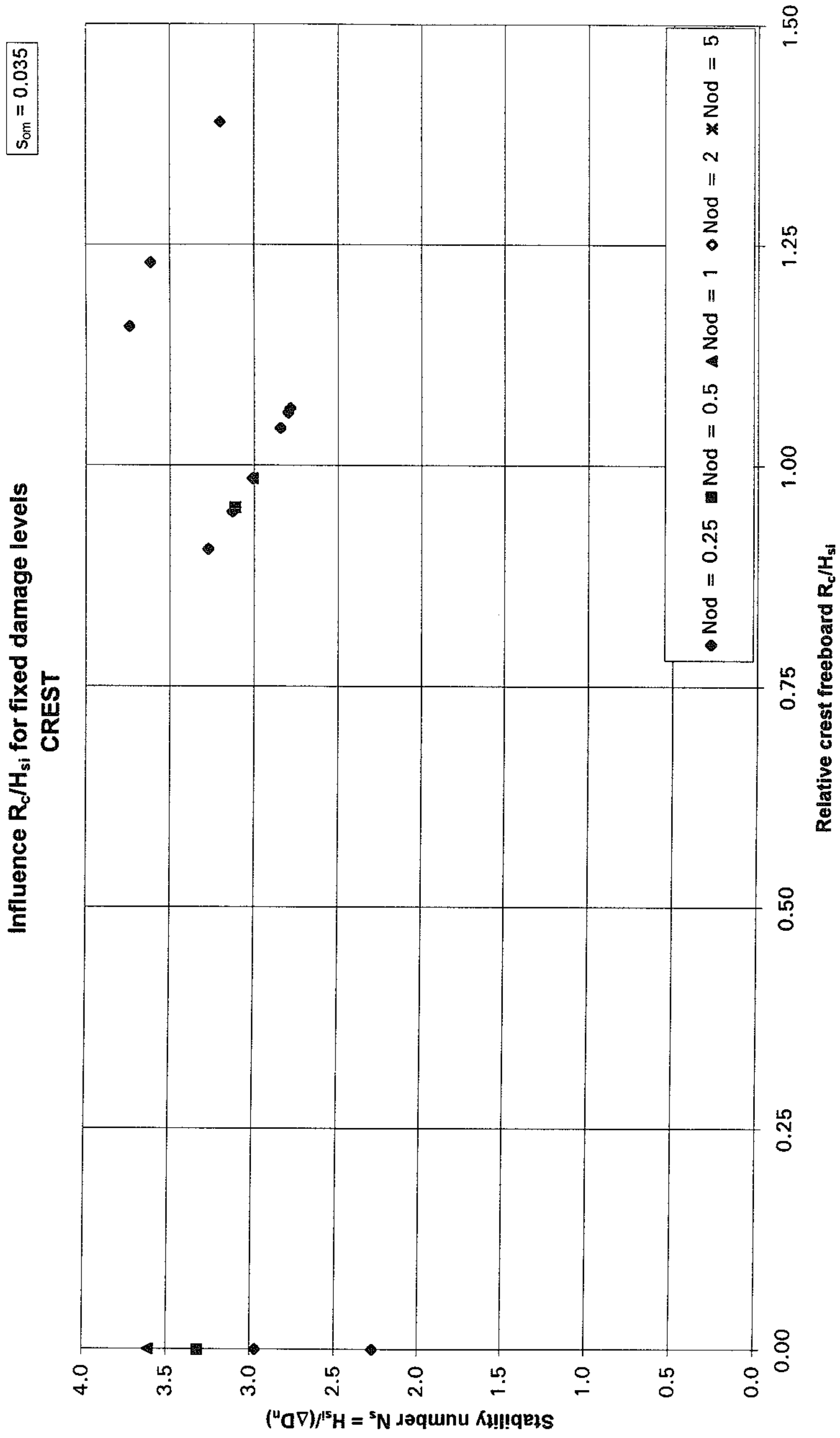
Influence of relative crest freeboard R_c/D_n, Crest segment **Figure A8.16**



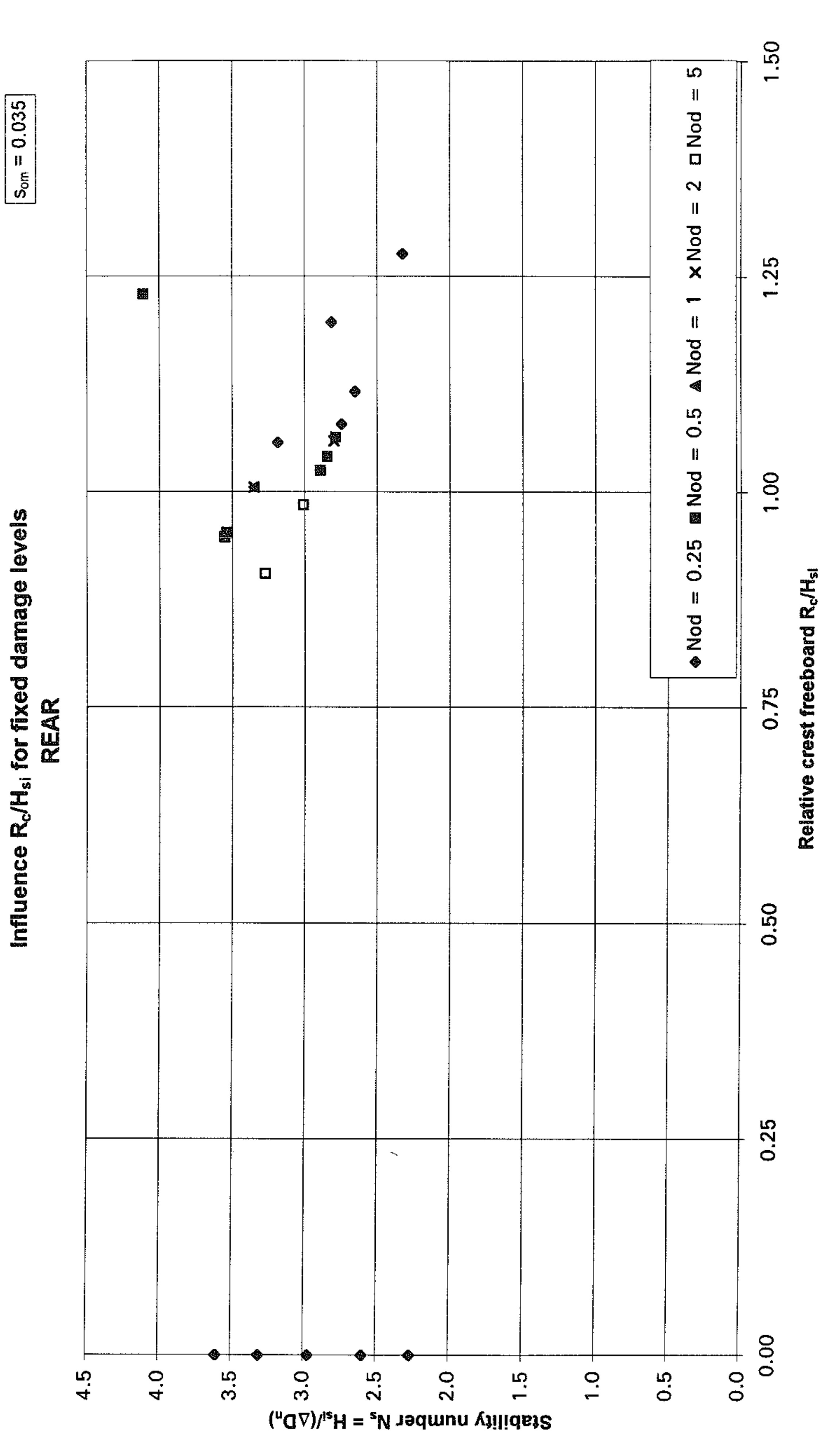
Influence of relative crest freeboard R_c/D_n, Rear segment **Figure A8.17**



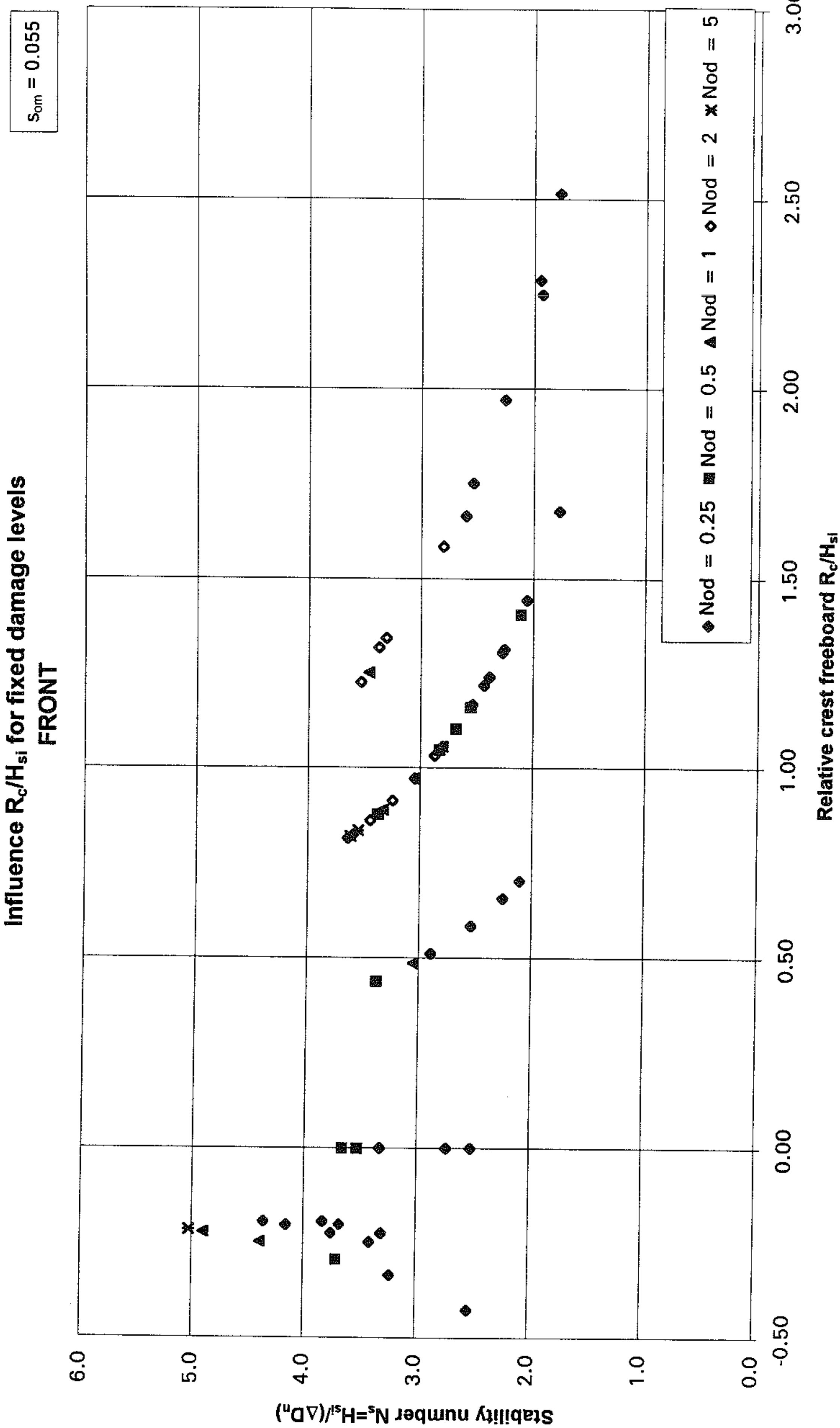
Influence of R_c/H_{si} for fixed damage levels $s_{om} = 0.035$, Front **Figure A8.18**



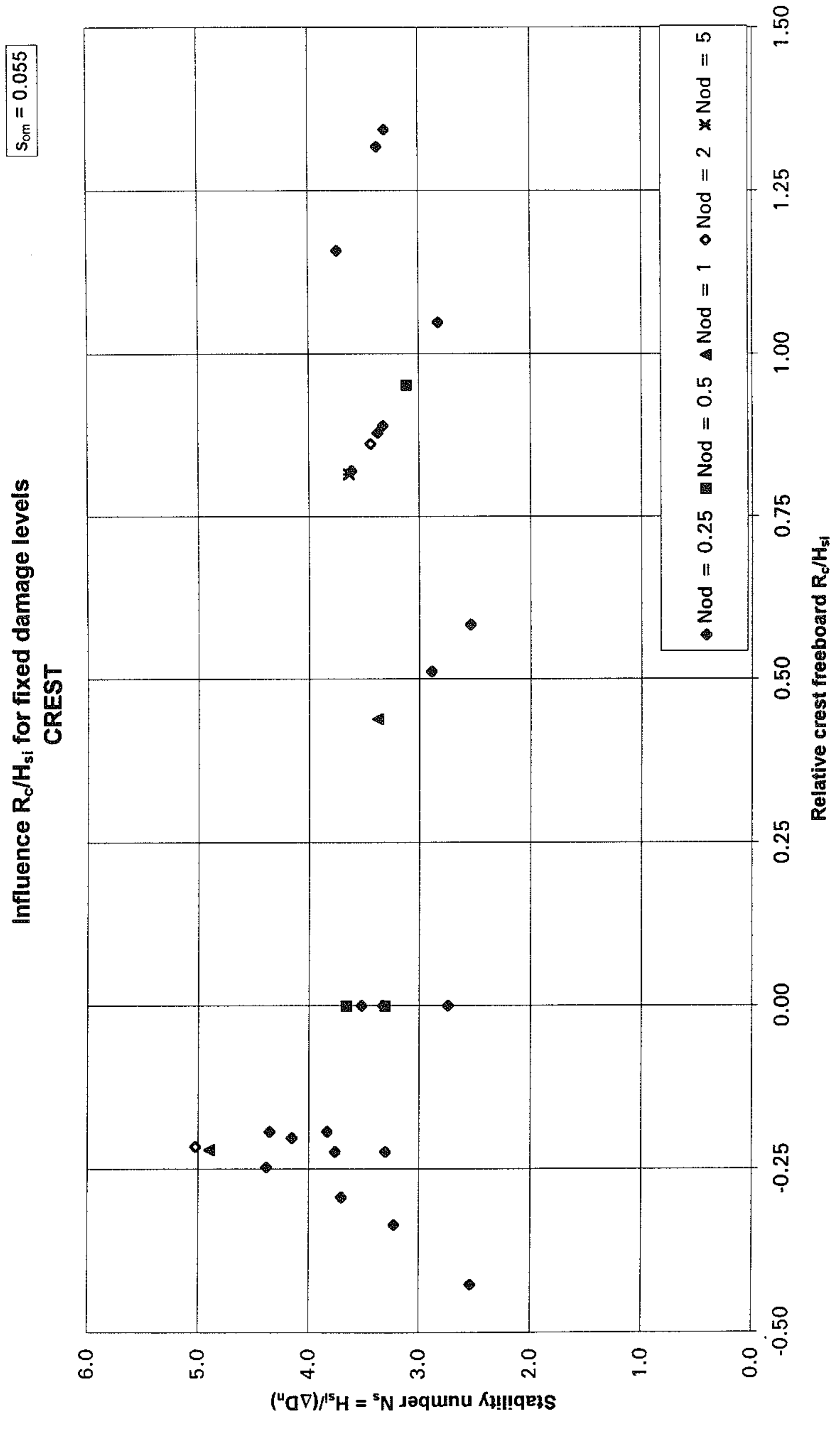
Influence of R_c/H_{si} for fixed damage levels $s_{om} = 0.035$, Crest **Figure A8.19**



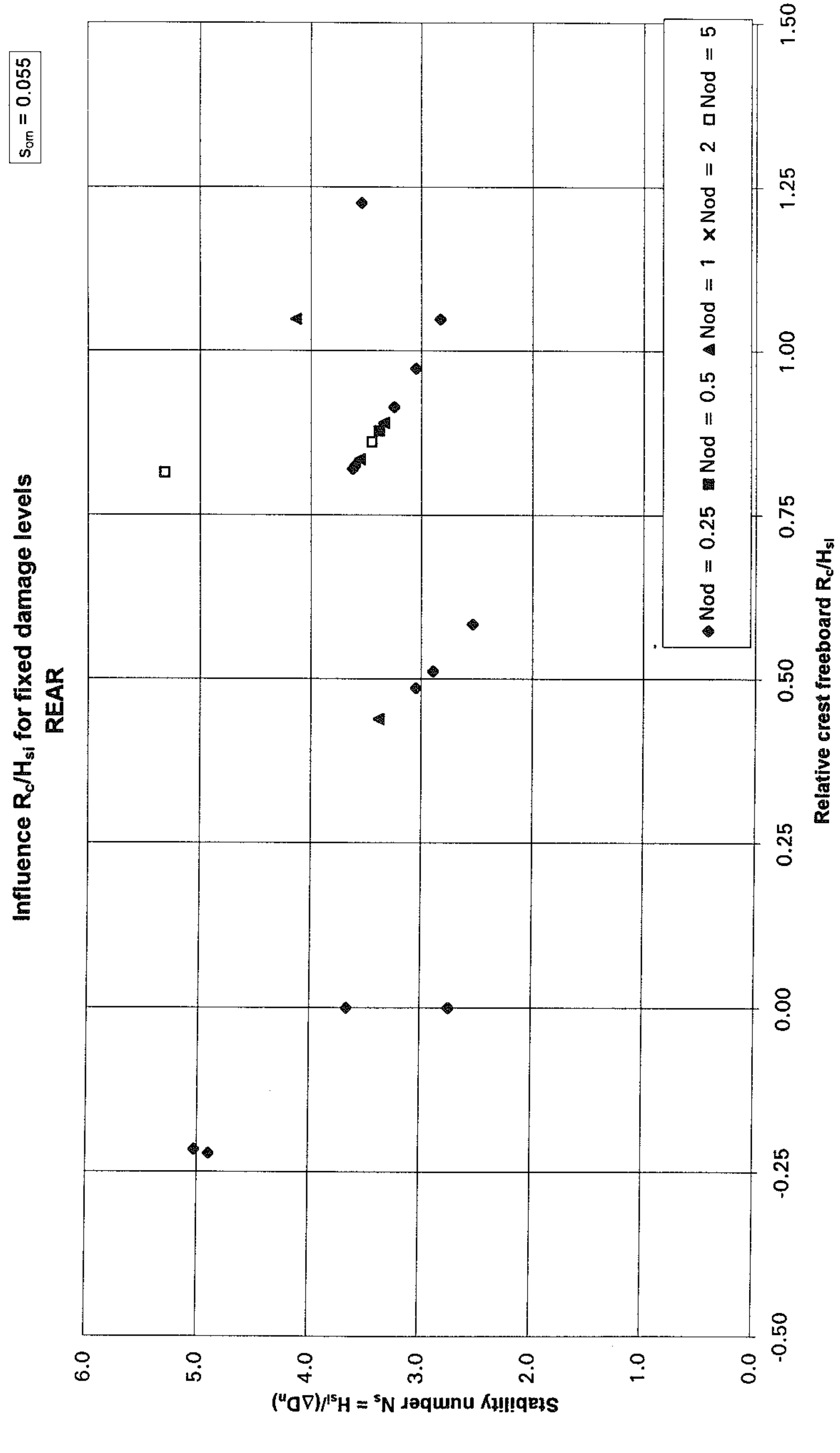
Influence of R_c/H_{si} for fixed damage levels $s_{om} = 0.035$, Rear **Figure A8.20**



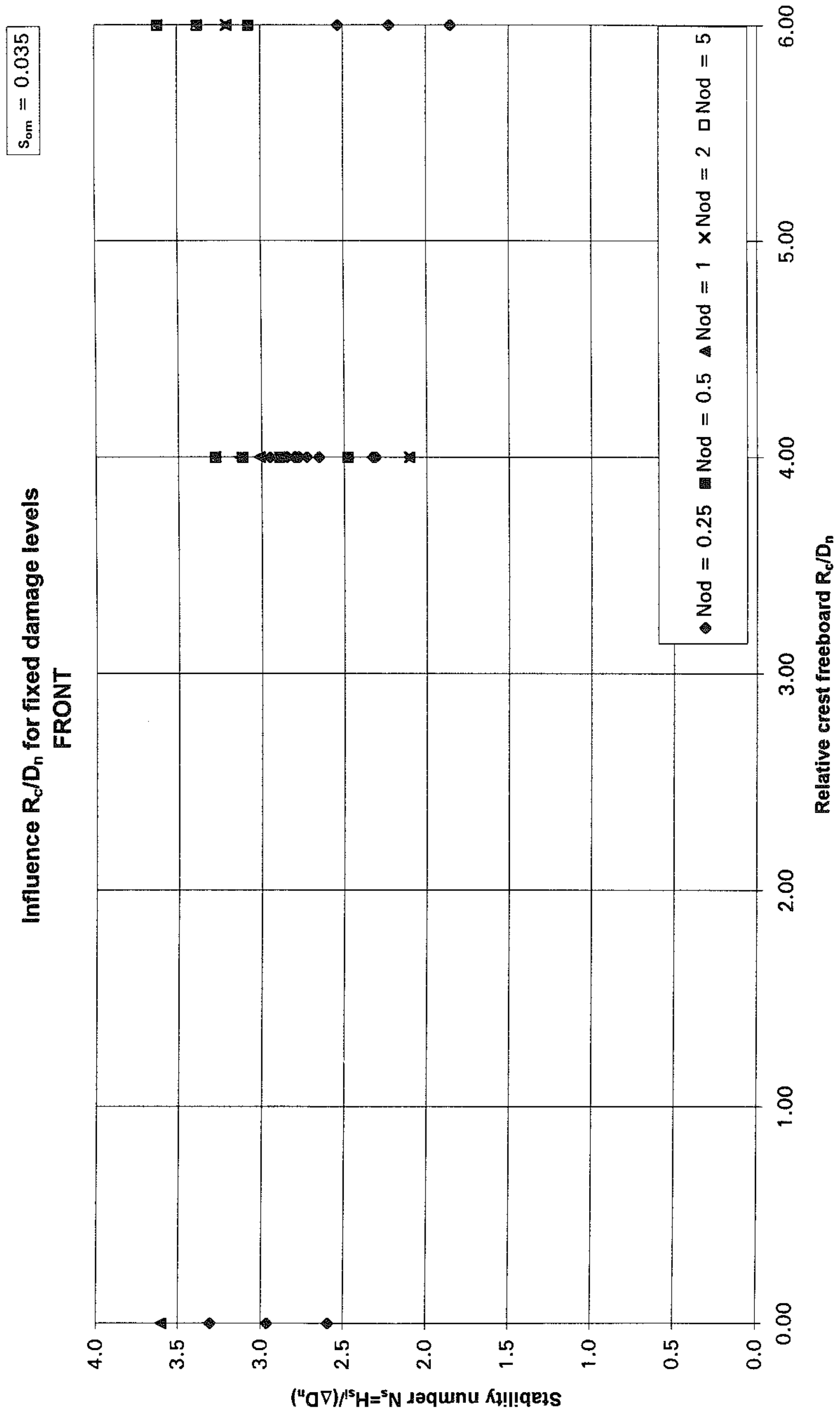
Influence of R_c/H_{si} for fixed damage levels $s_{om} = 0.055$, Front **Figure A8.21**



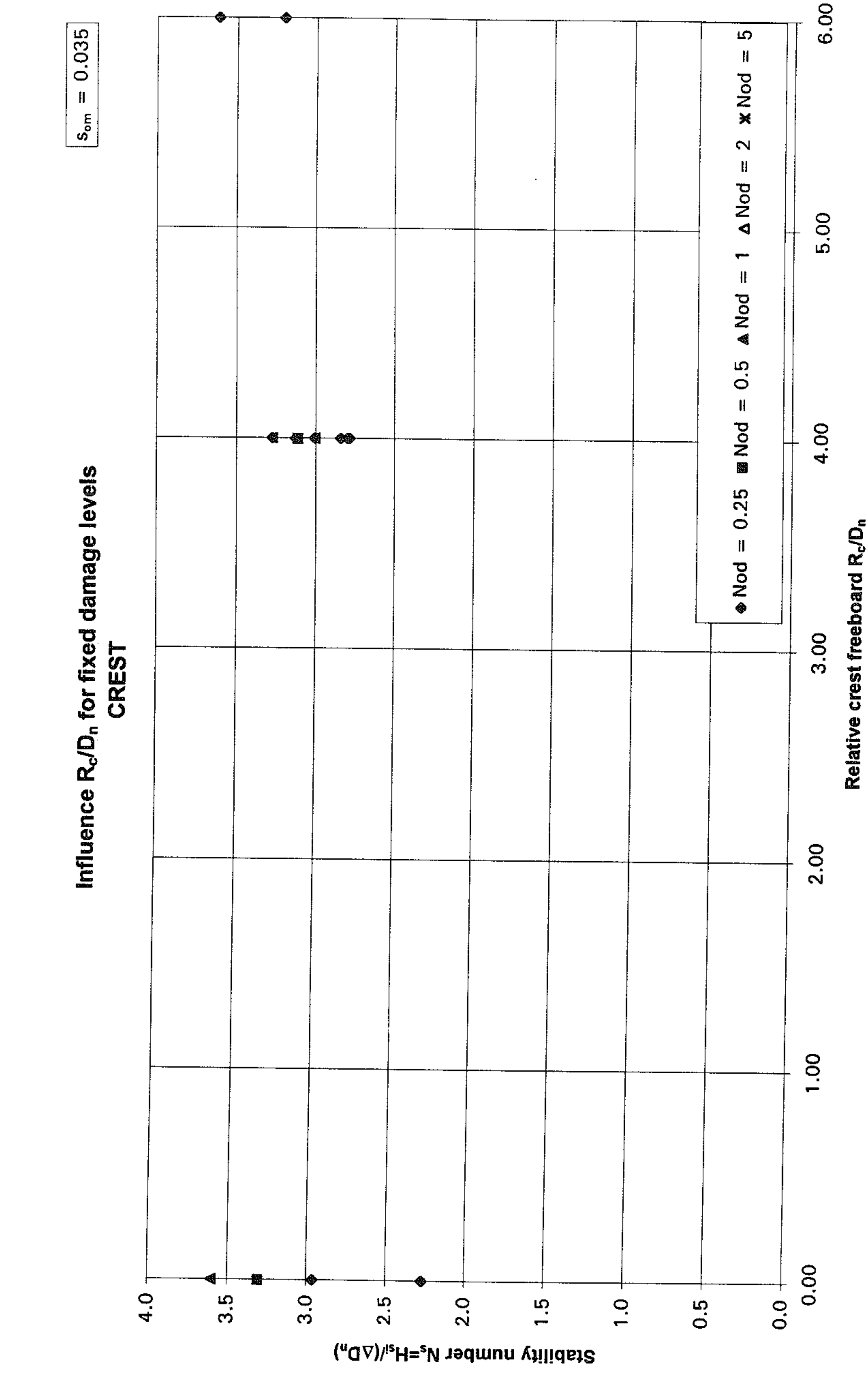
Influence of R_c/H_{si} for fixed damage levels $s_{om} = 0.055$, Crest **Figure A8.22**



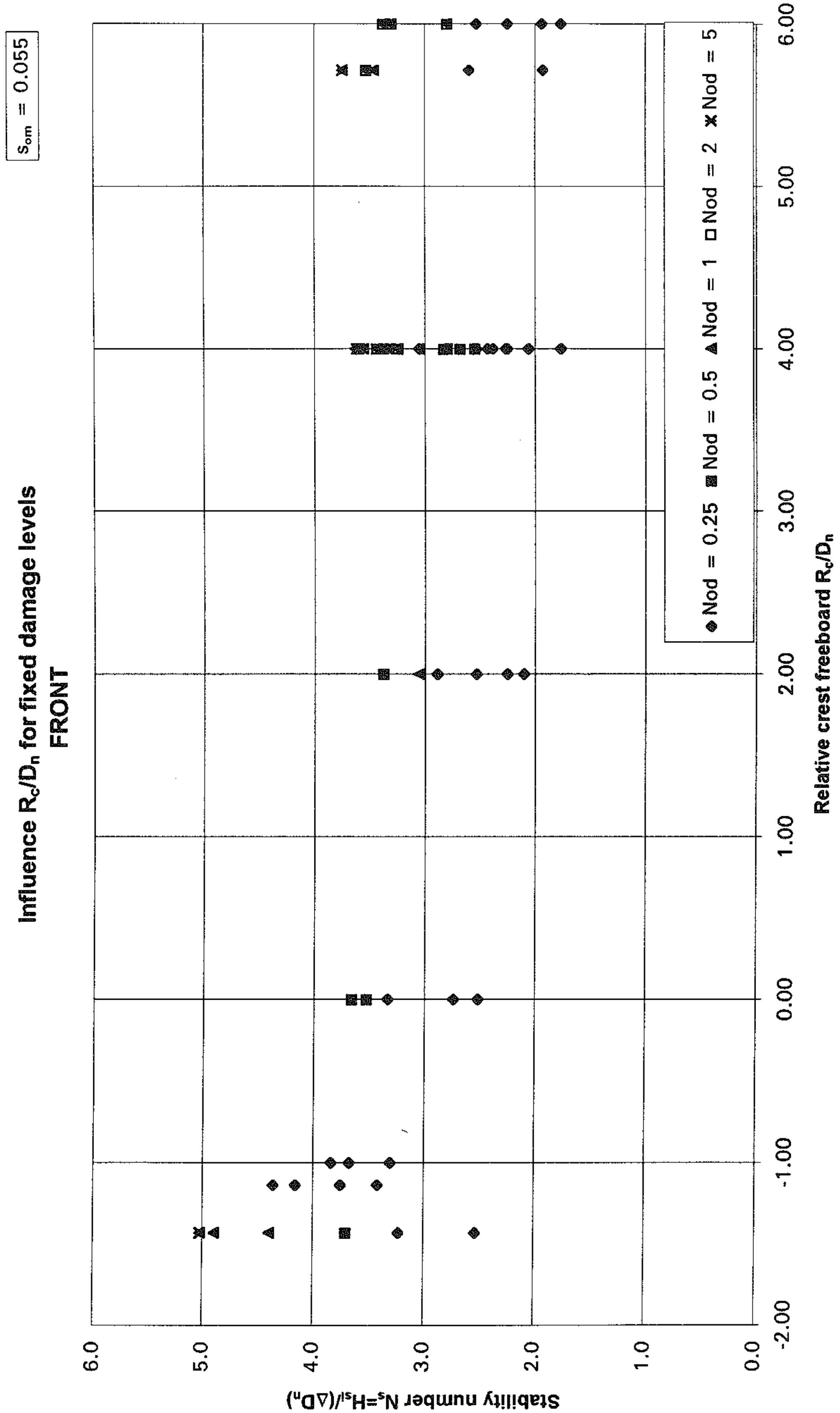
Influence of R_c/H_{si} for fixed damage levels $s_{om} = 0.055$, Rear **Figure A8.23**



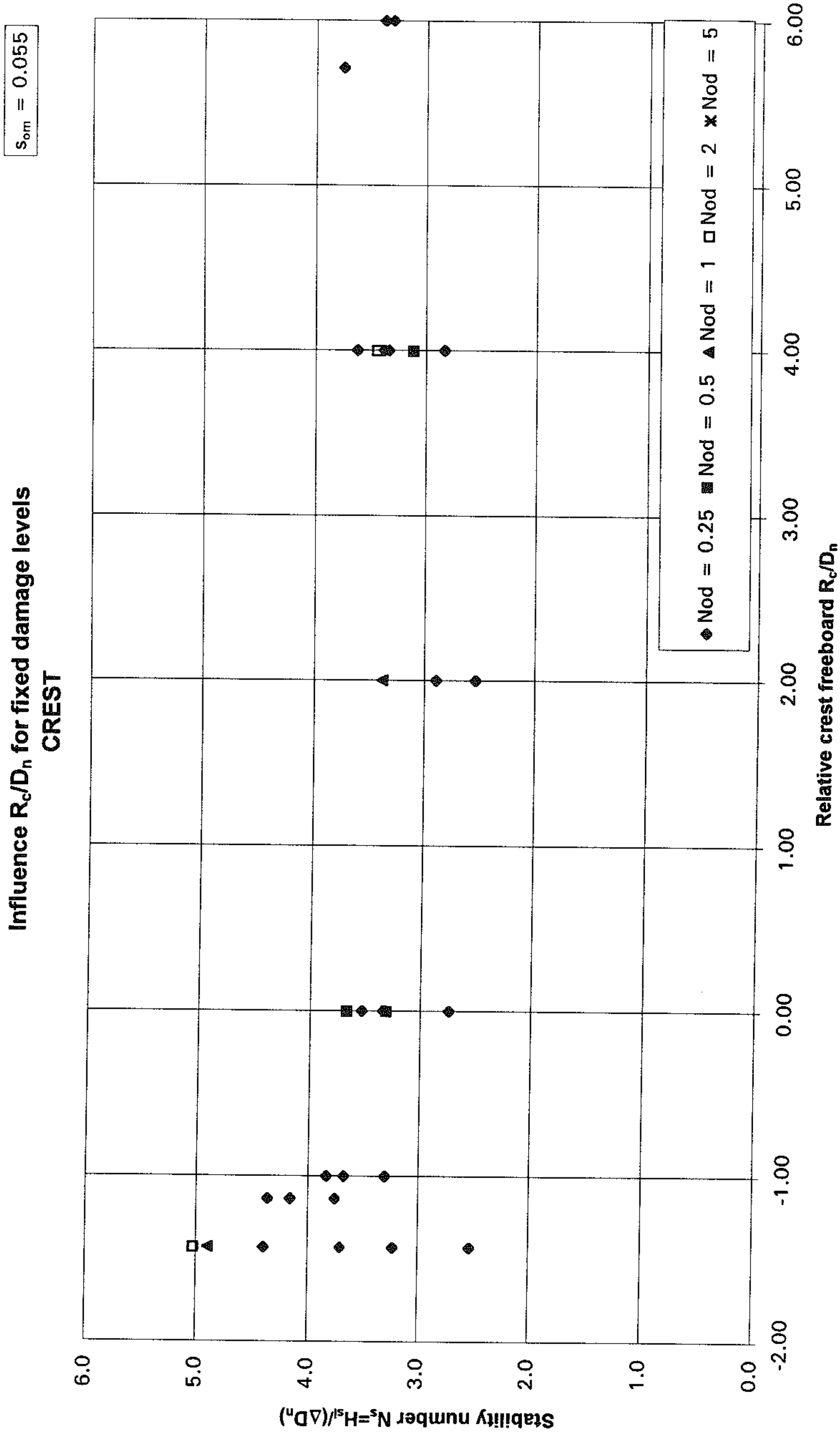
Influence of R_c/D_n for fixed damage levels $s_{om} = 0.035$, Front **Figure A8.24**



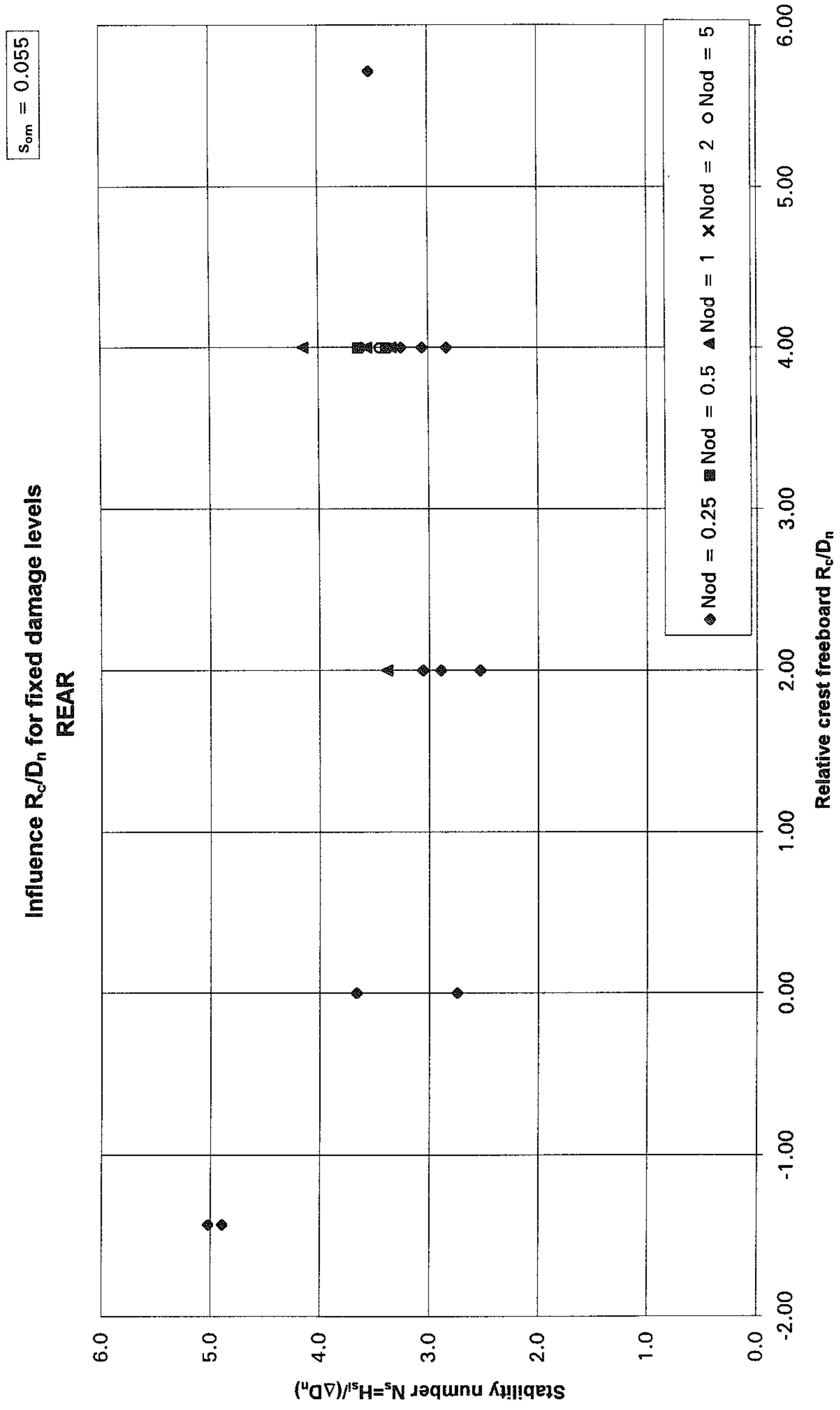
Influence of R_c/D_n for fixed damage levels $s_{om} = 0.035$, Crest **Figure A8.25**



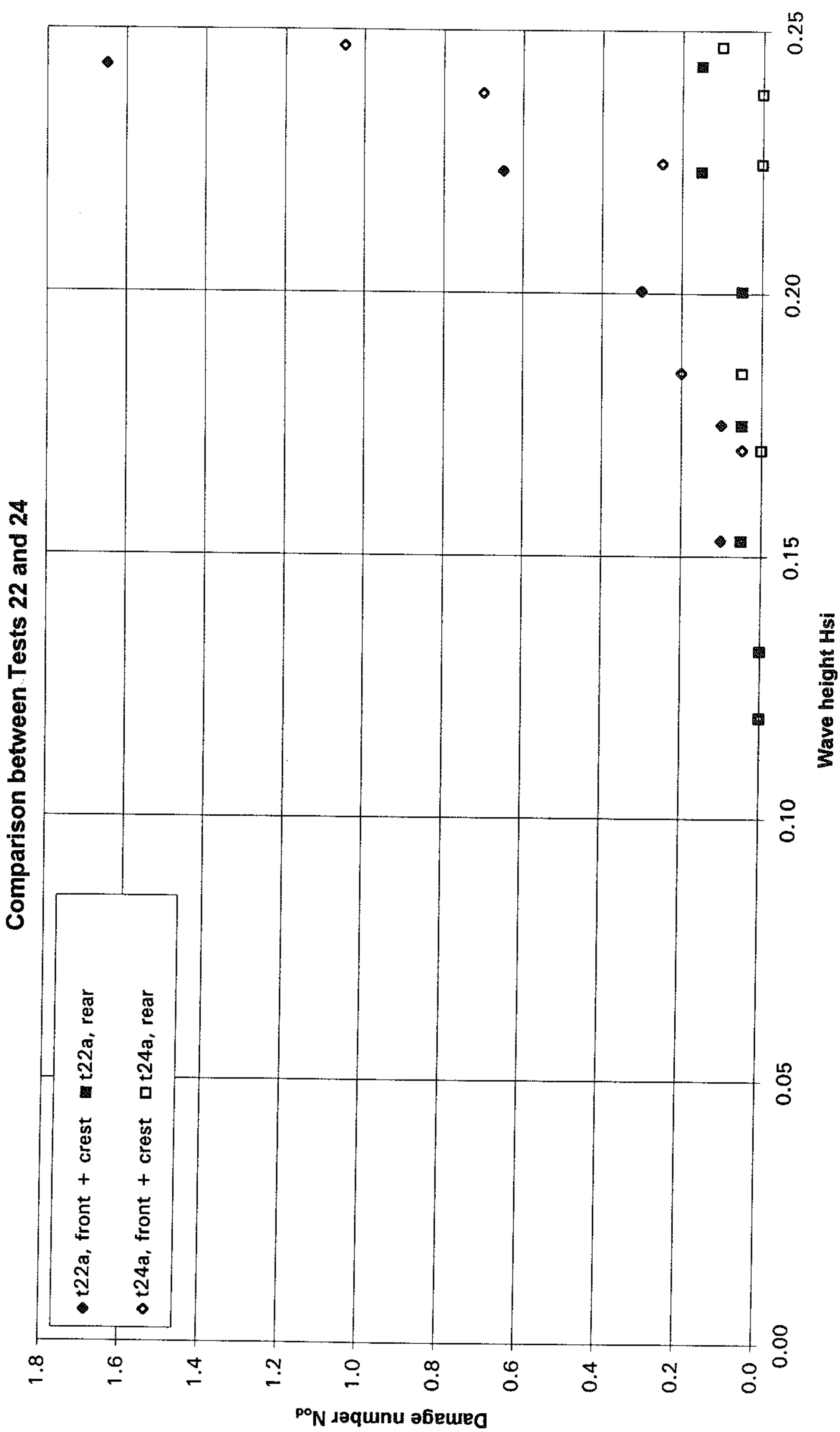
Influence of R_c/D_n for fixed damage levels $s_{om} = 0.055$, Front **Figure A8.27**



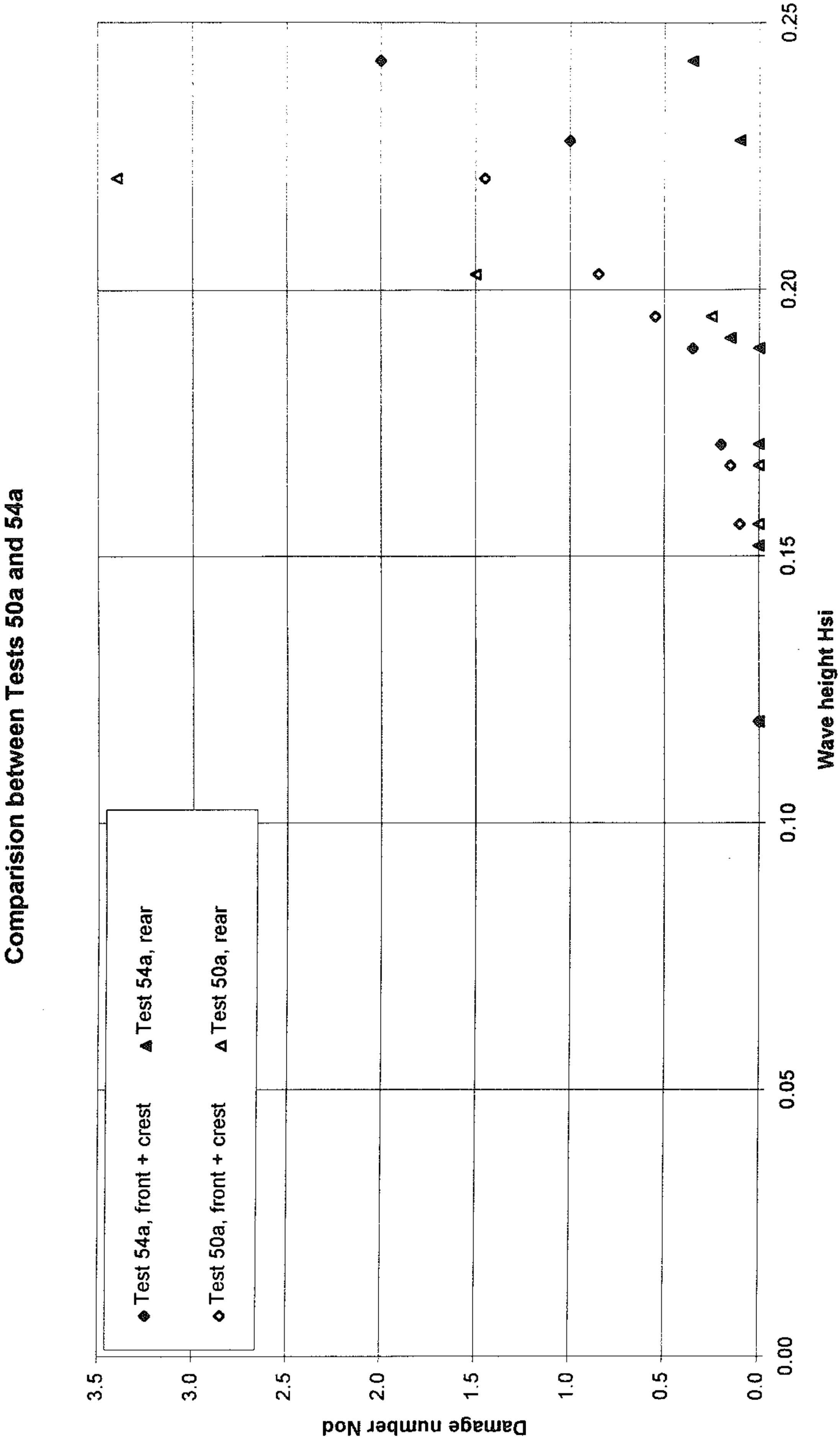
Influence of R_c/D_n for fixed damage levels $s_{om} = 0.055$, Crest **Figure A8.28**



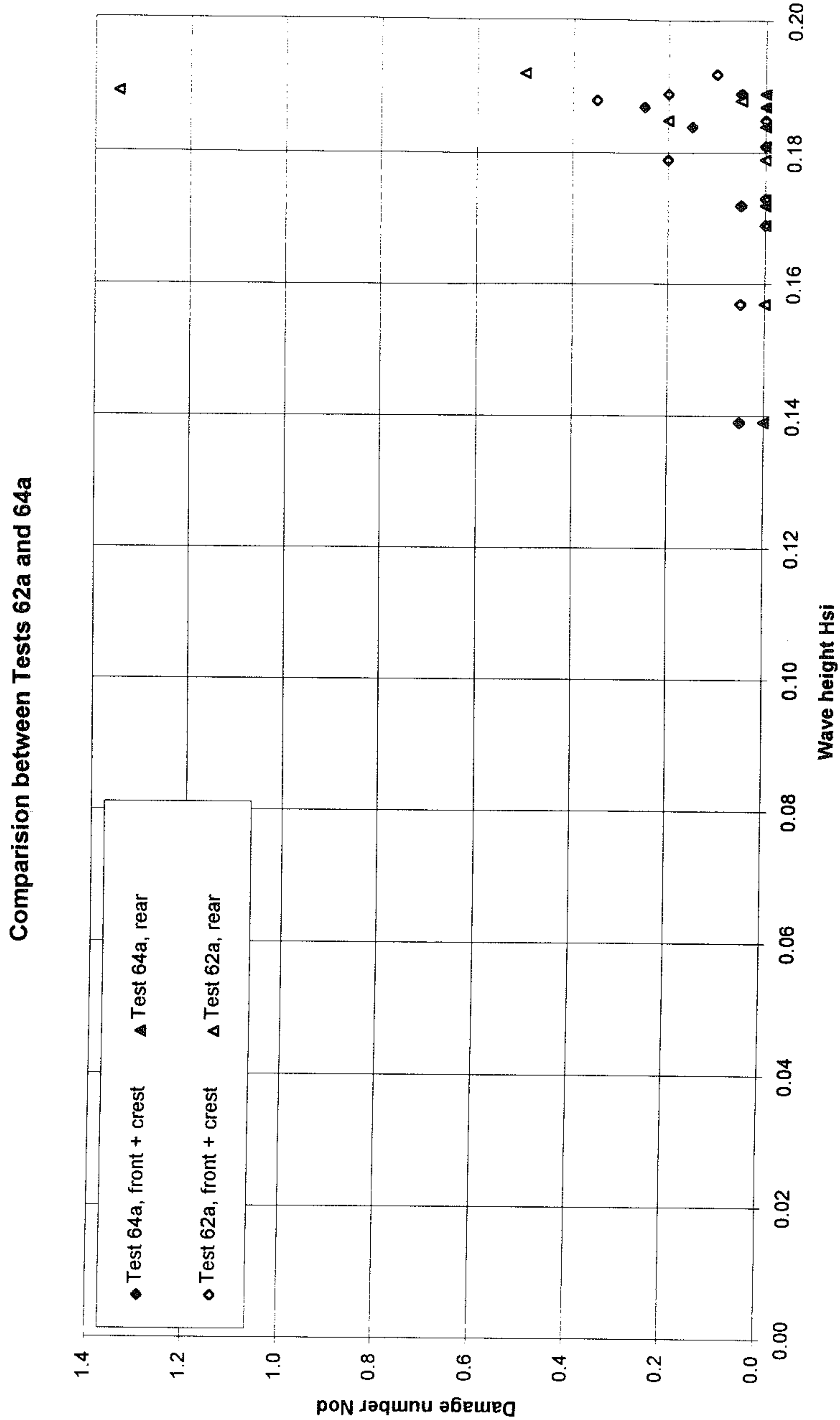
Influence of R_c/D_n for fixed damage levels $s_{om} = 0.055$, Rear **Figure A8.29**



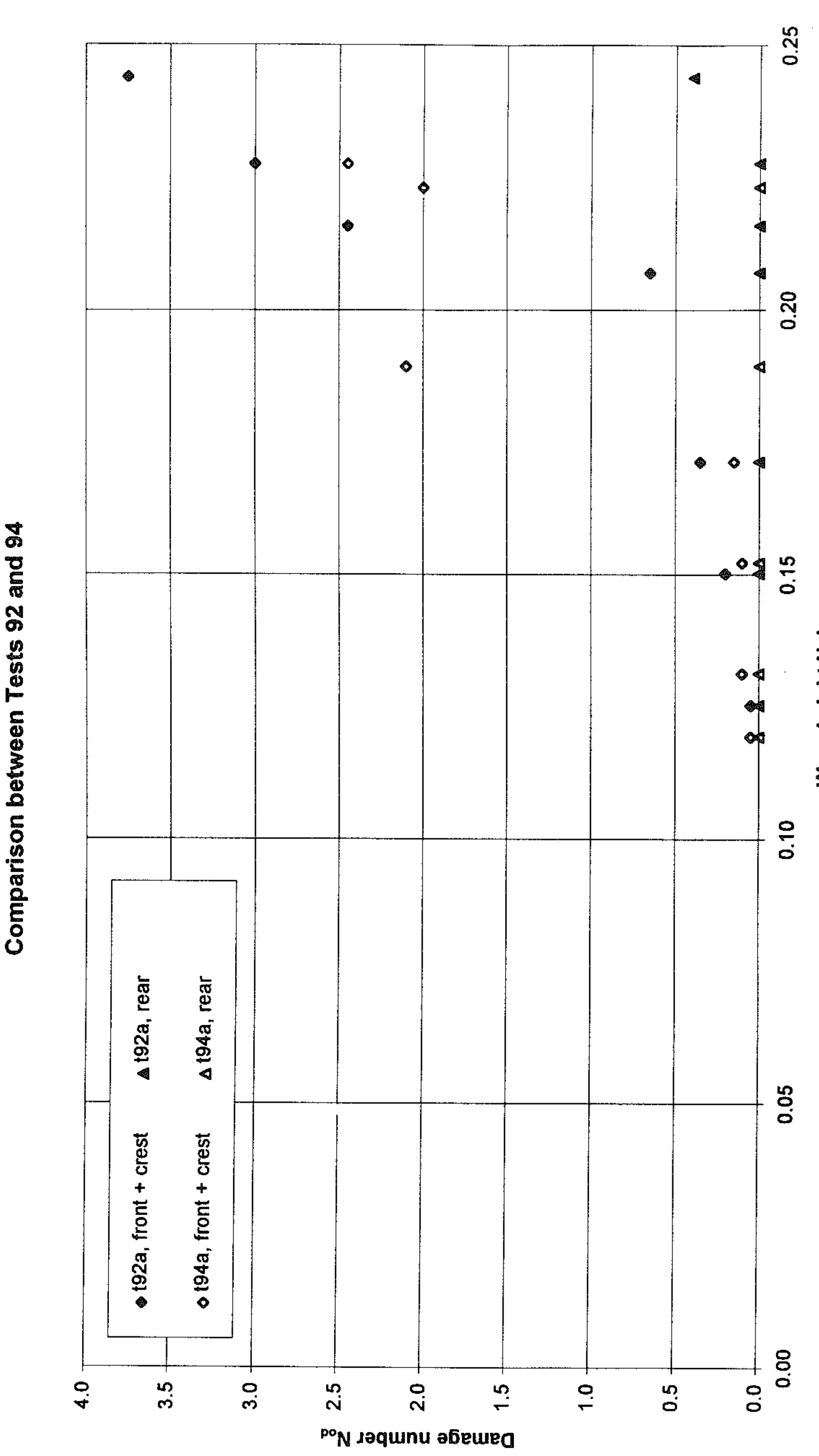
Comparison between Tests 22 and 24 **Figure A8.30**



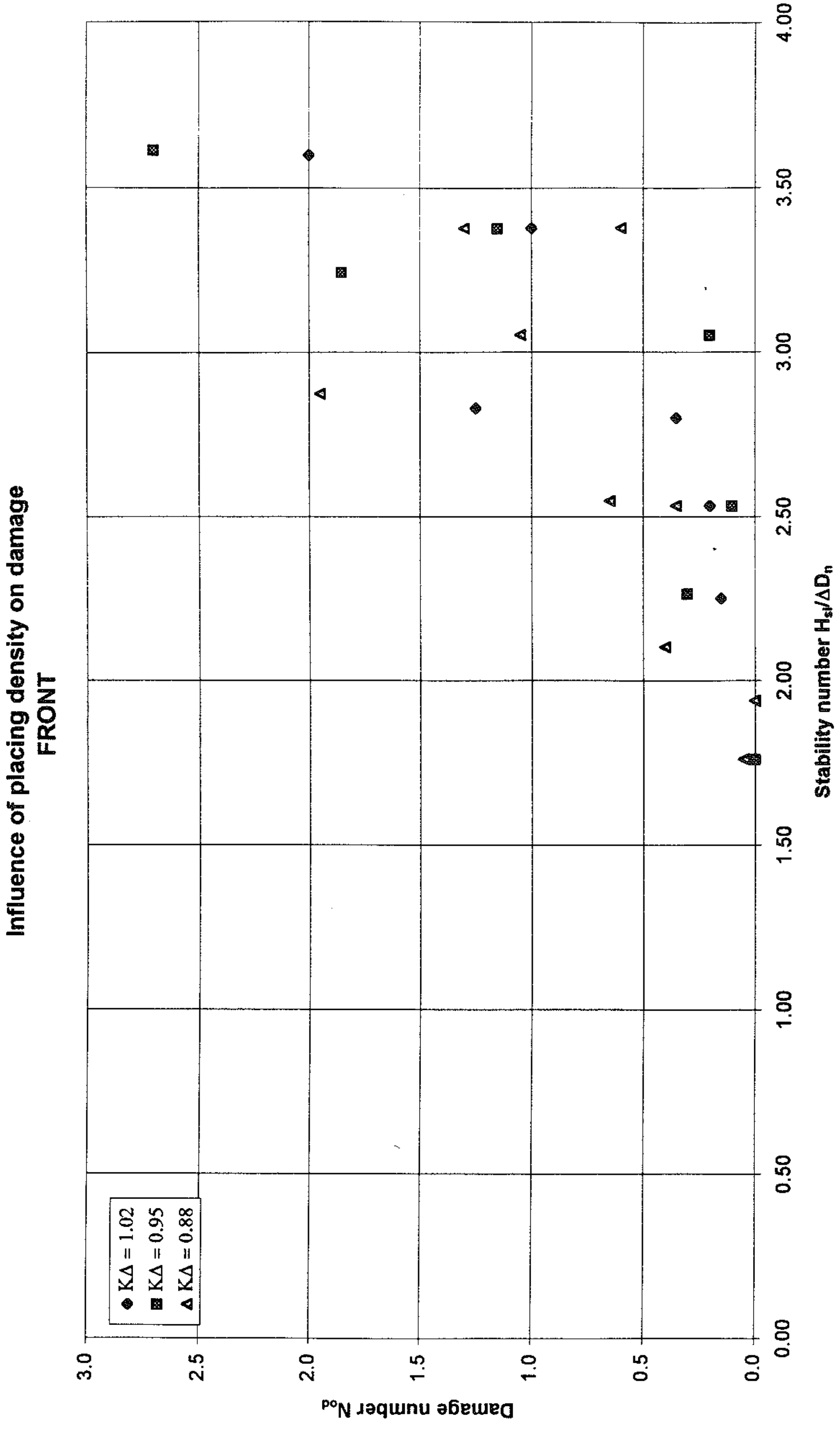
Comparison between Tests 50a and 54a **Figure A8.31**



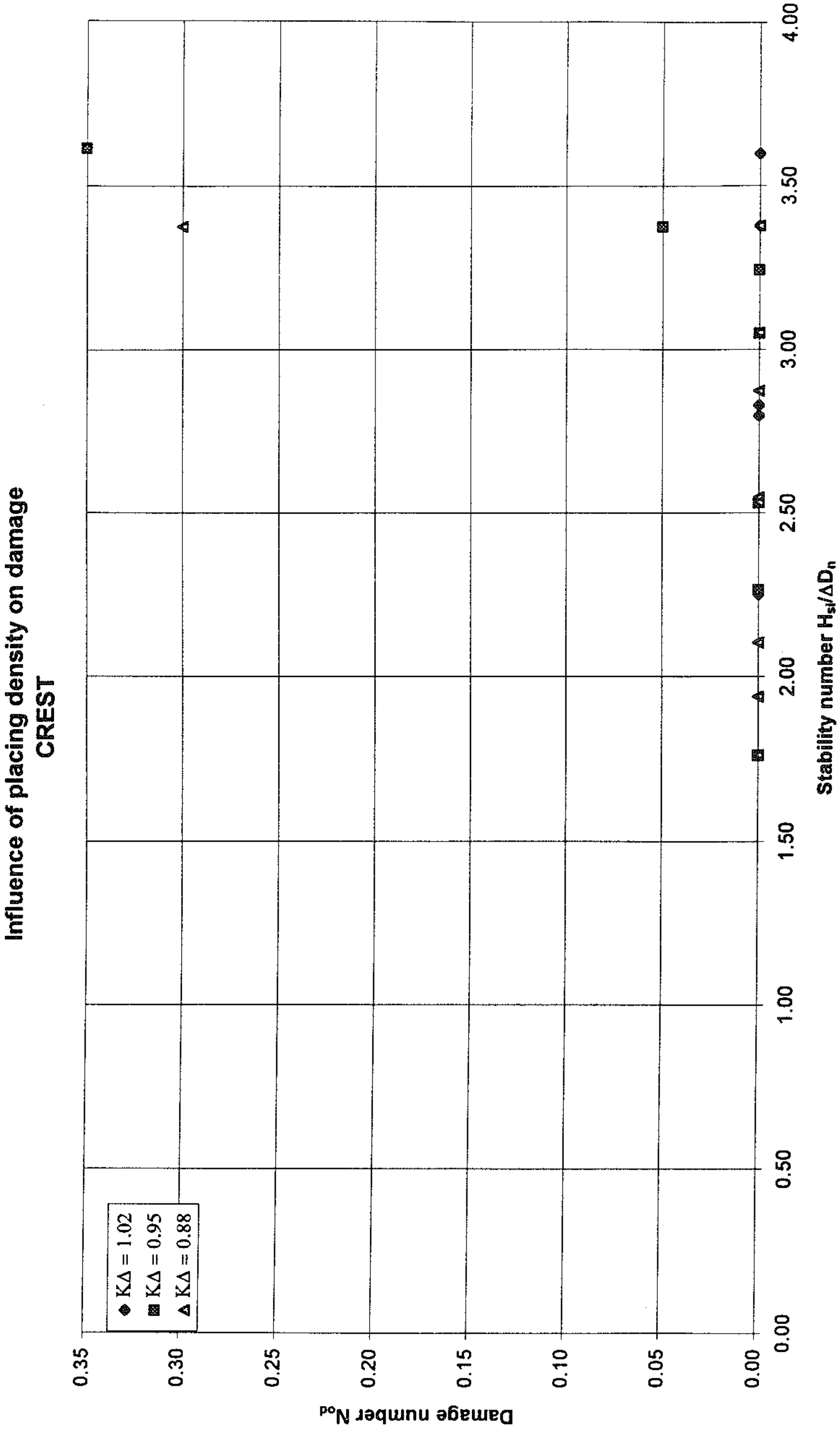
Comparison between Tests 62a and 64a **Figure A8.32**



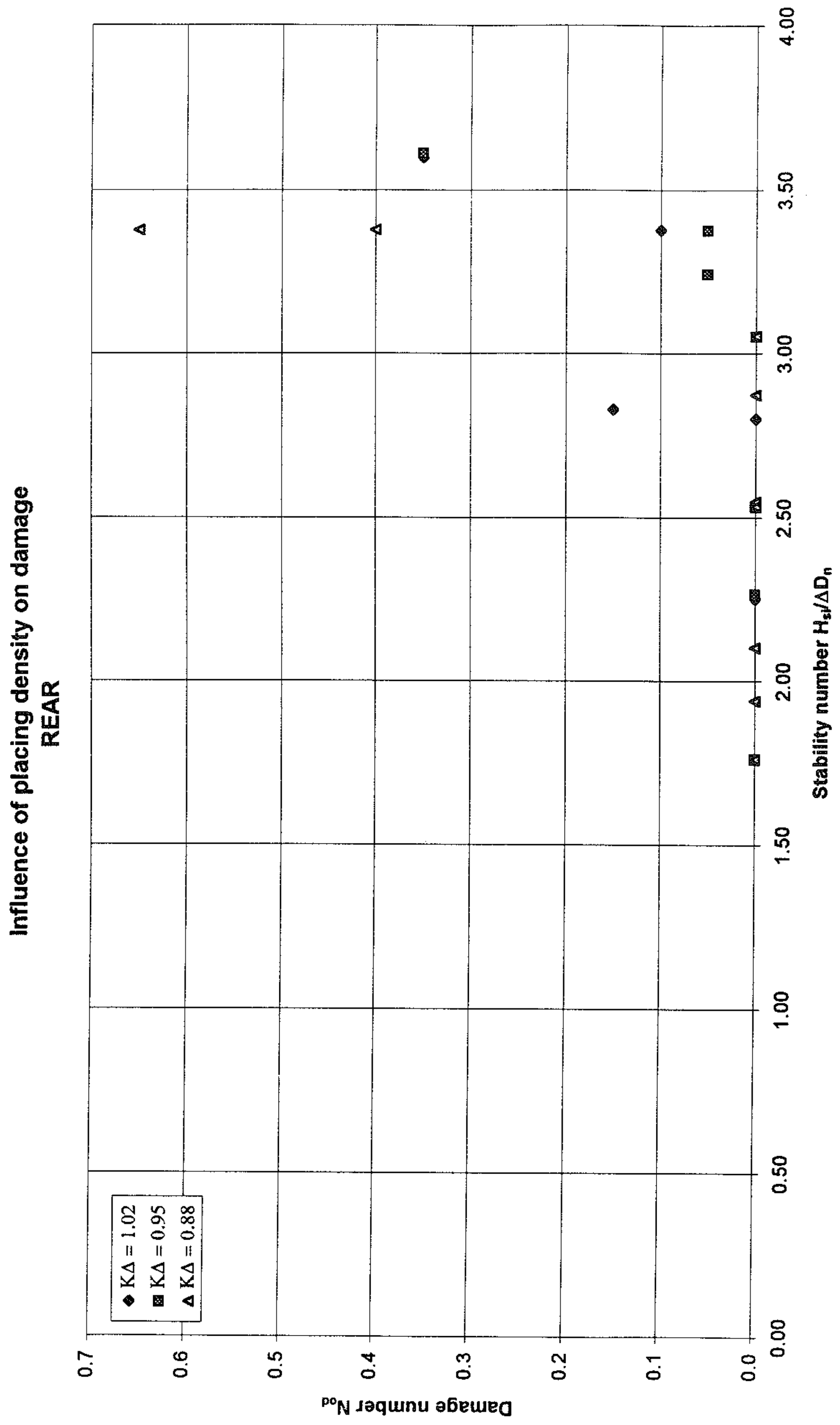
Comparison between Tests 92 and 94 **Figure A8.33**



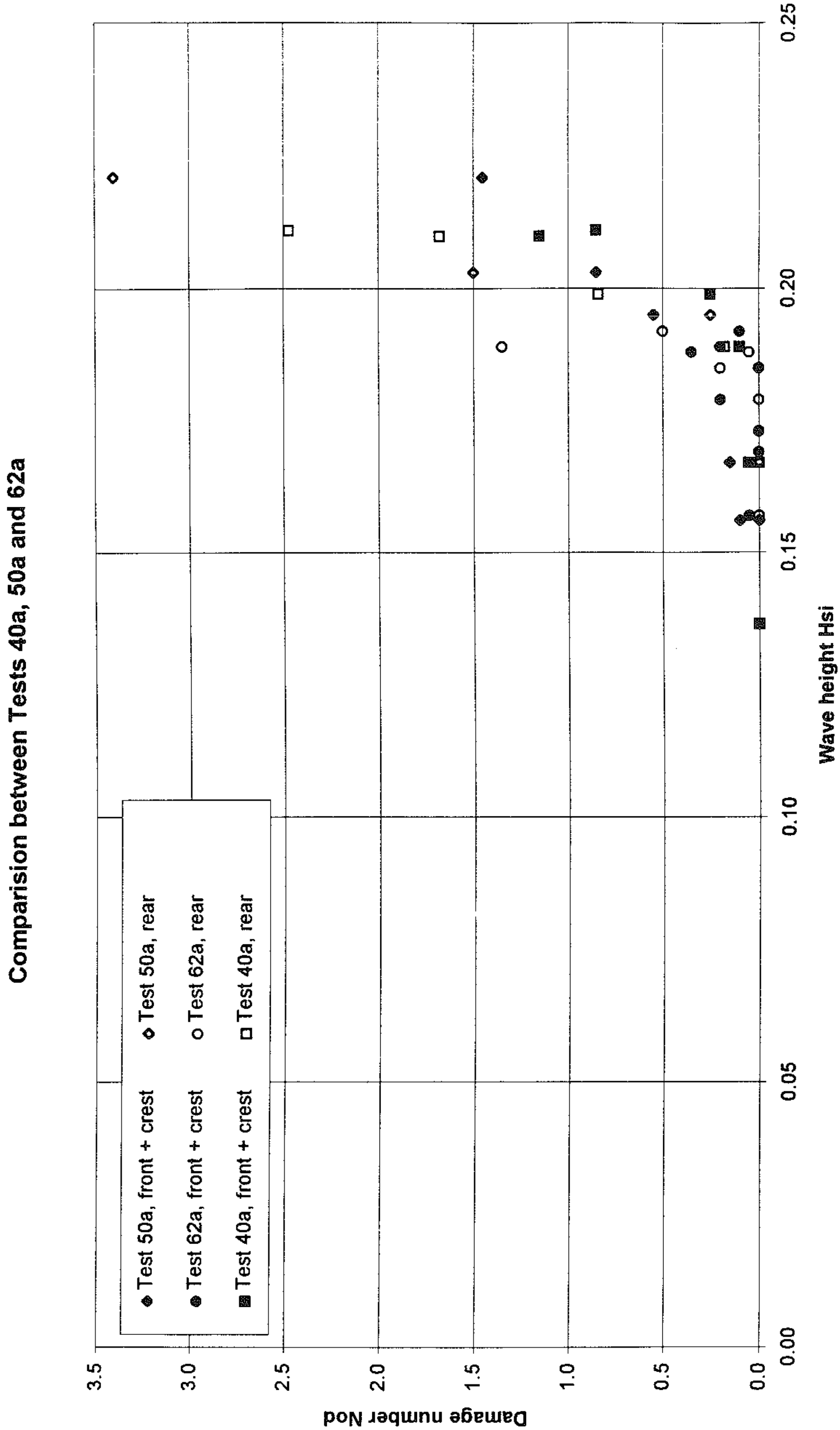
Influence of placing density on damage, Front segment **Figure A8.34**



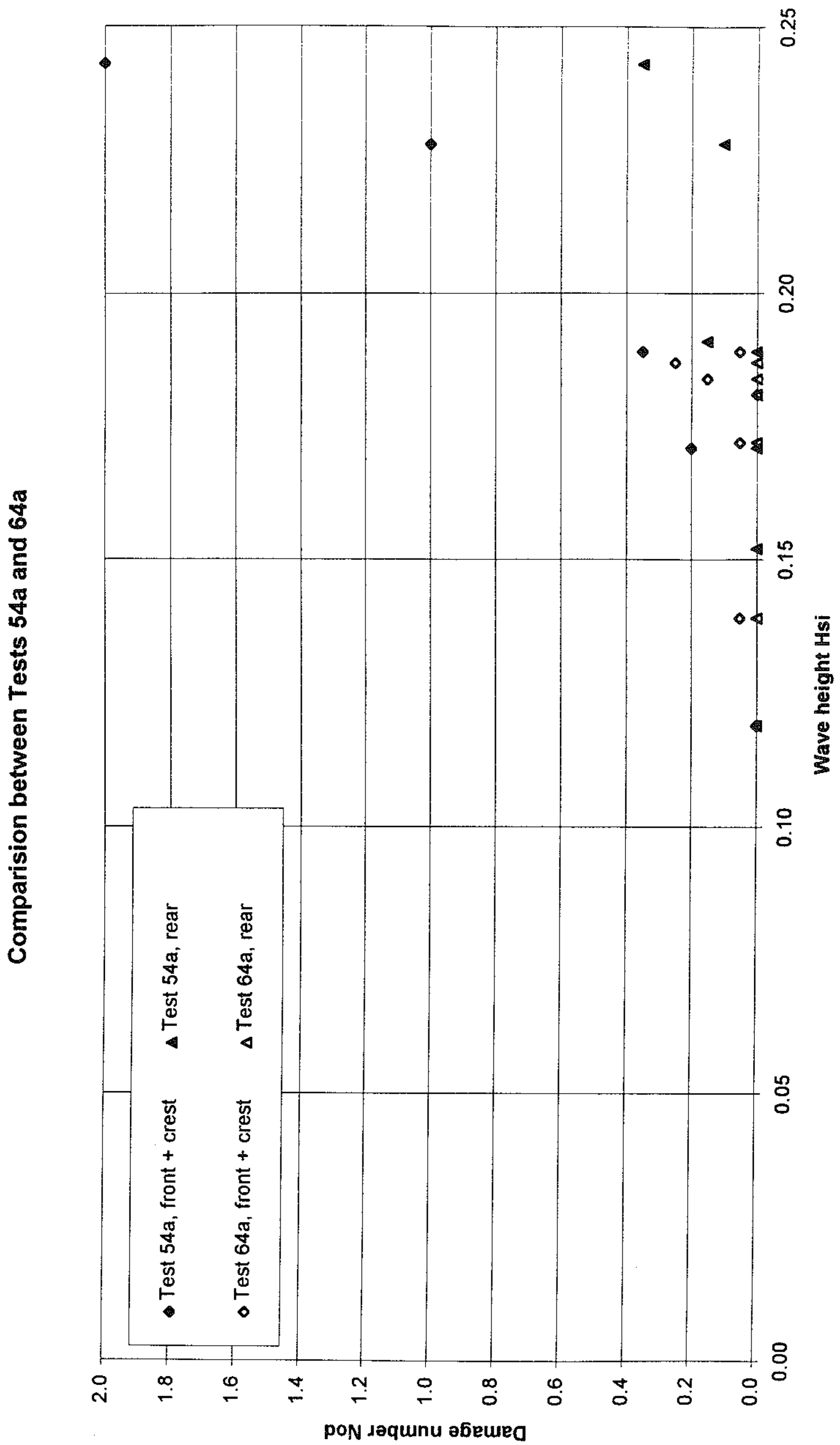
Influence of placing density on damage, Crest segment **Figure A8.35**



Influence of placing density on damage, Rear segment **Figure A8.36**



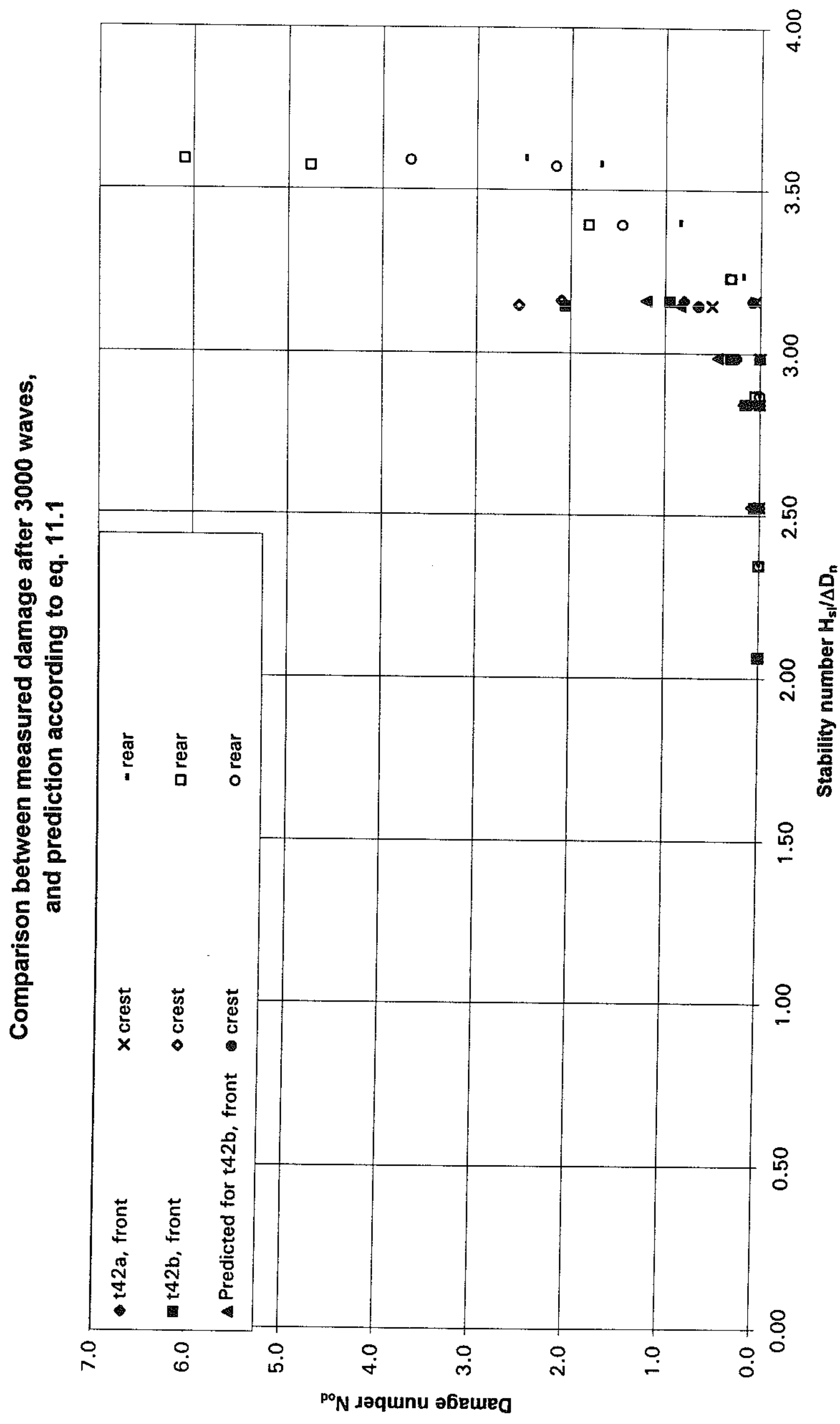
Comparison between Tests 40a, 50a and 62a **Figure A8.37**



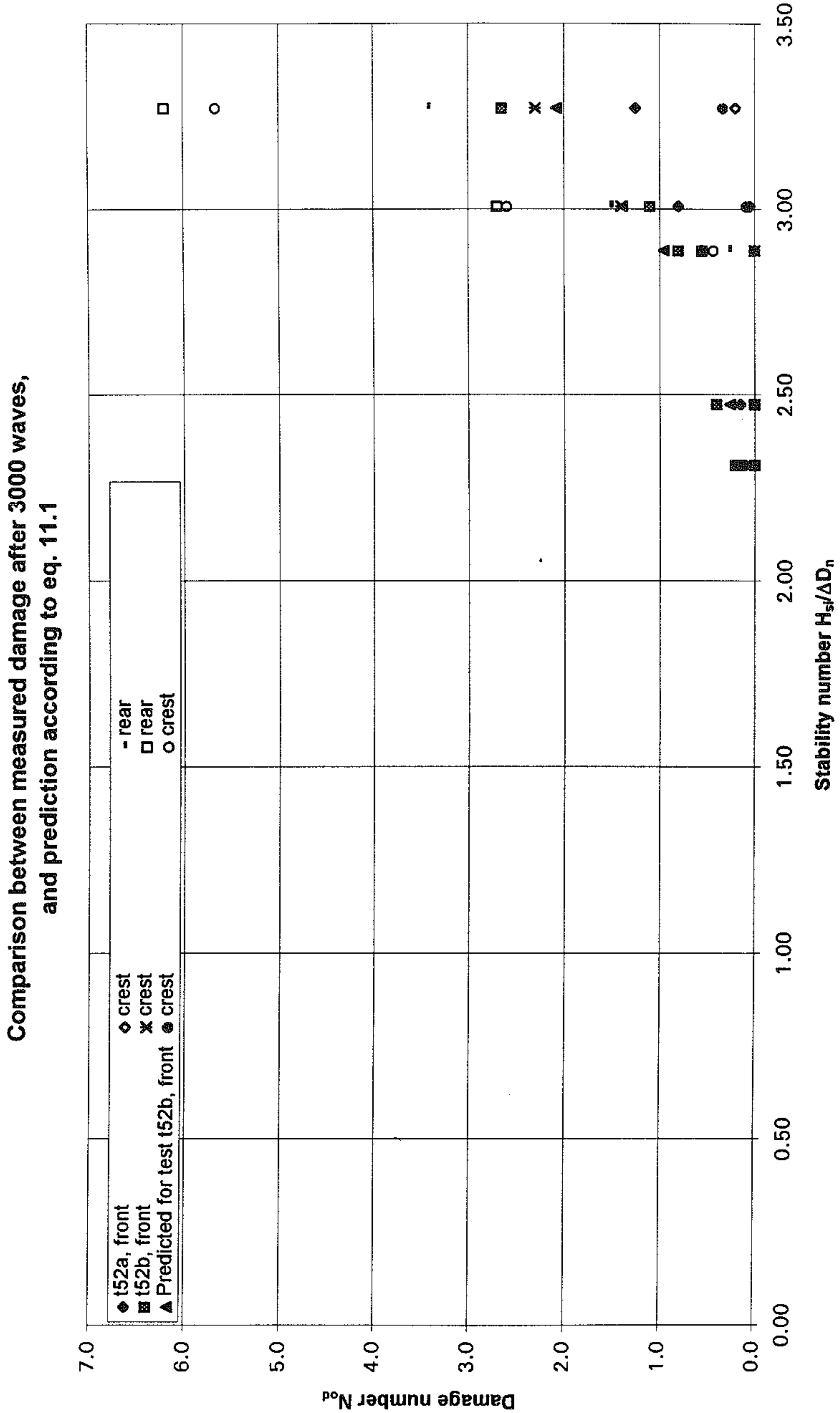
Comparison between Test 54a and 64a **Figure A8.38**

ANNEX 9

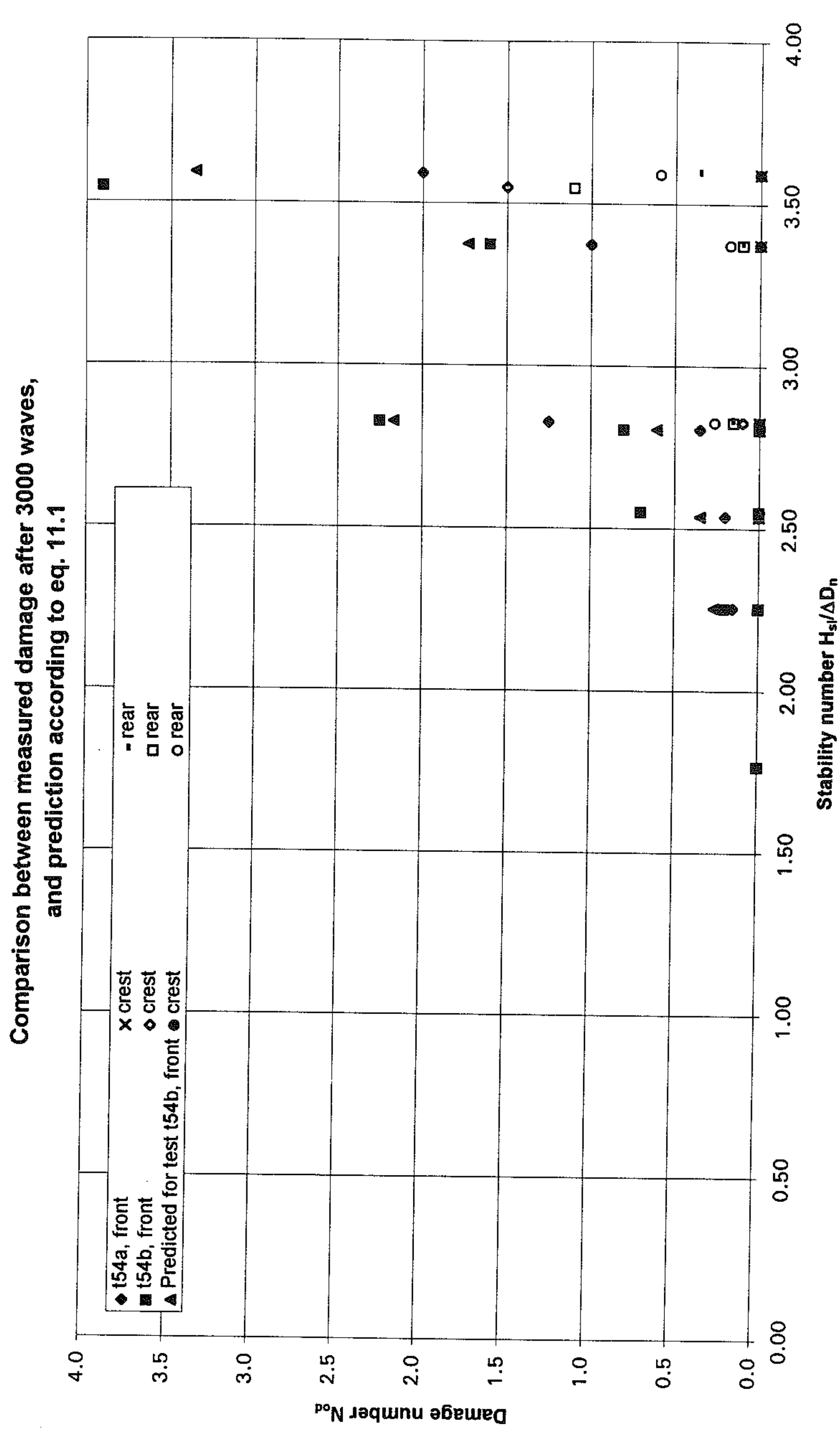
Figures and Tables for Chapter 11



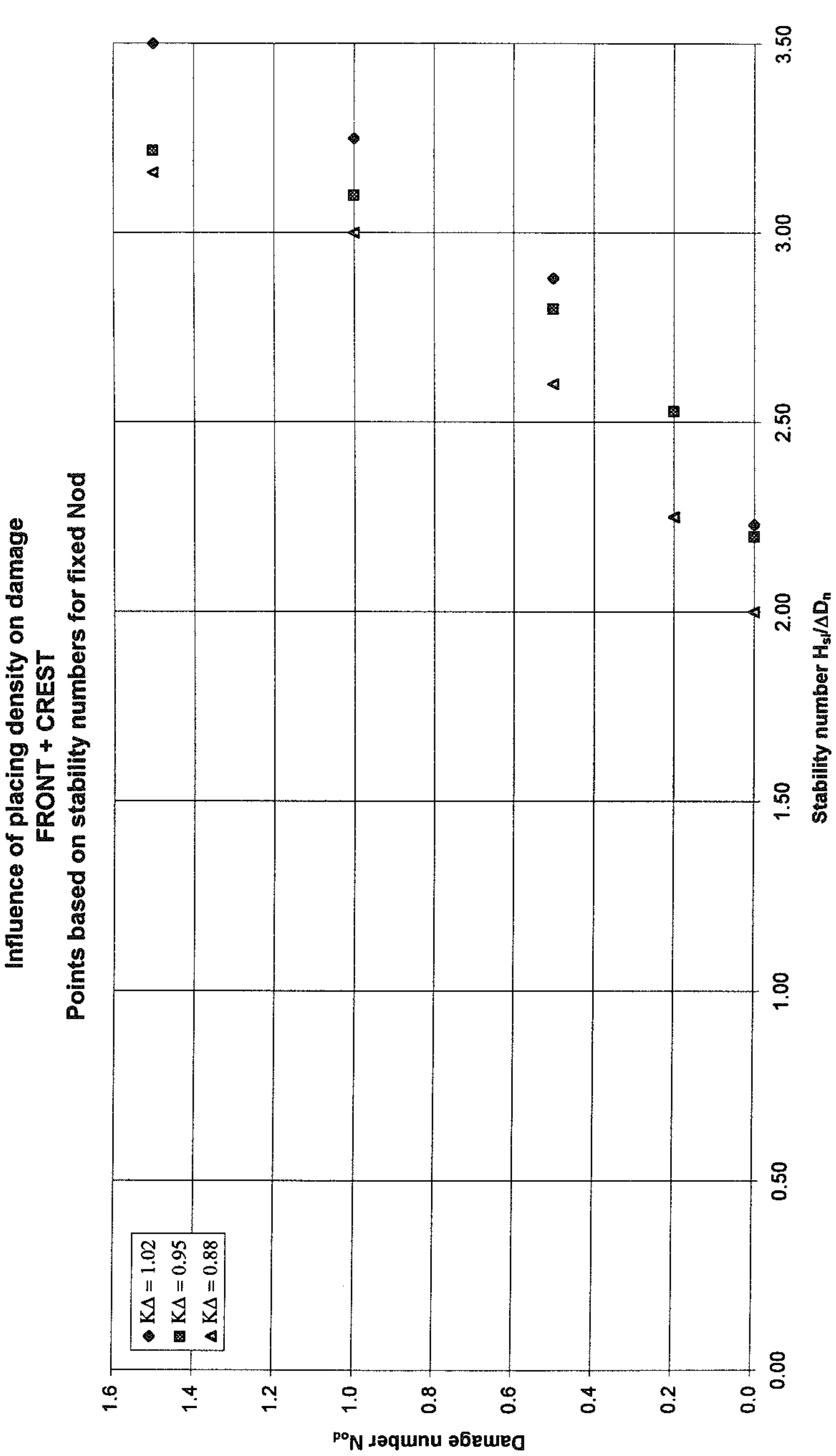
Damage after *3000* waves in comparison with eq. 11.1, Test 4 **Figure A9.1**



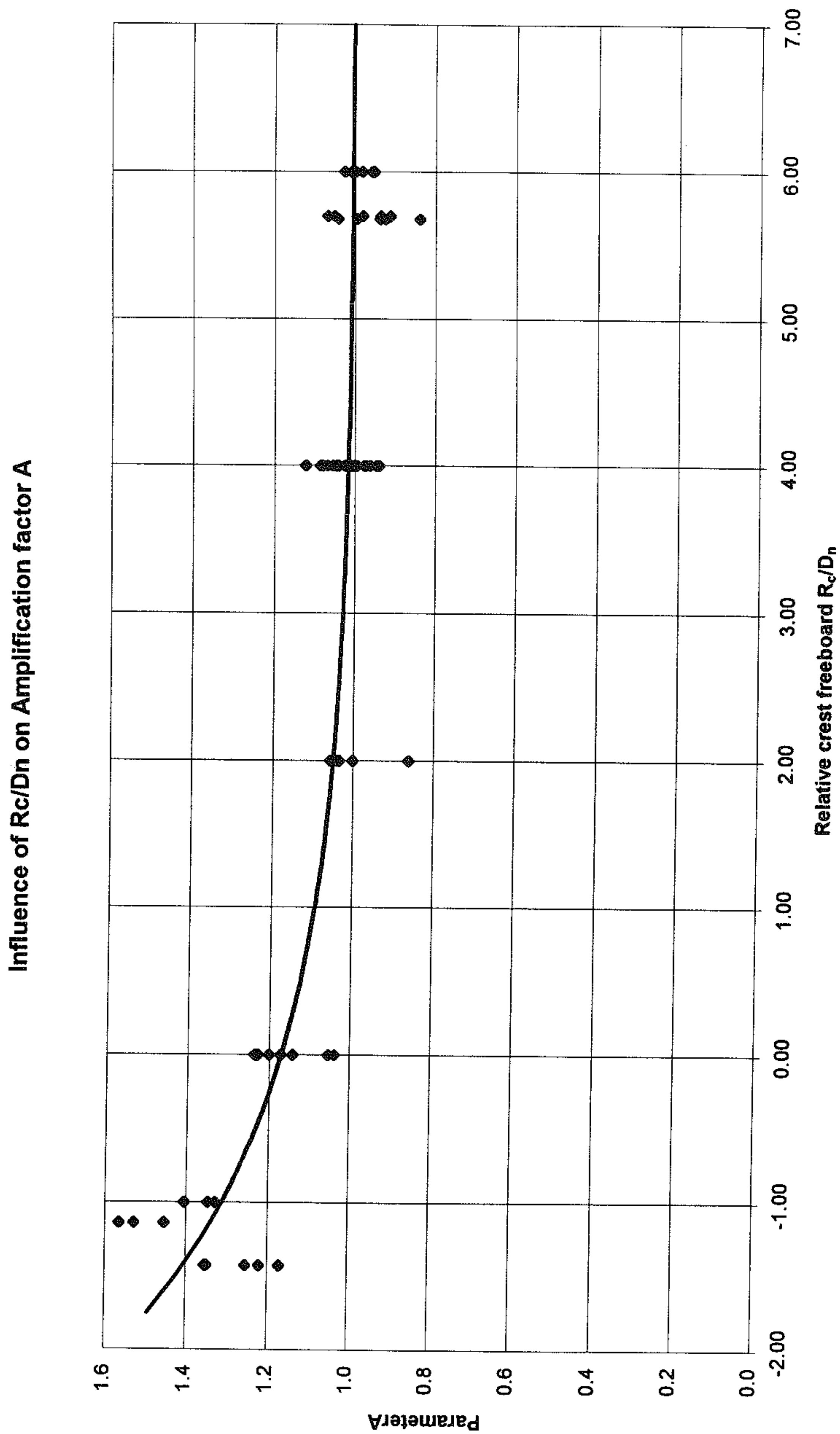
Damage after *3000* waves in comparison with eq. 11.1, Test 50 **Figure A9.2**



Damage after *3000* waves in comparison with eq. 11.1, Test 54 **Figure A9.3**

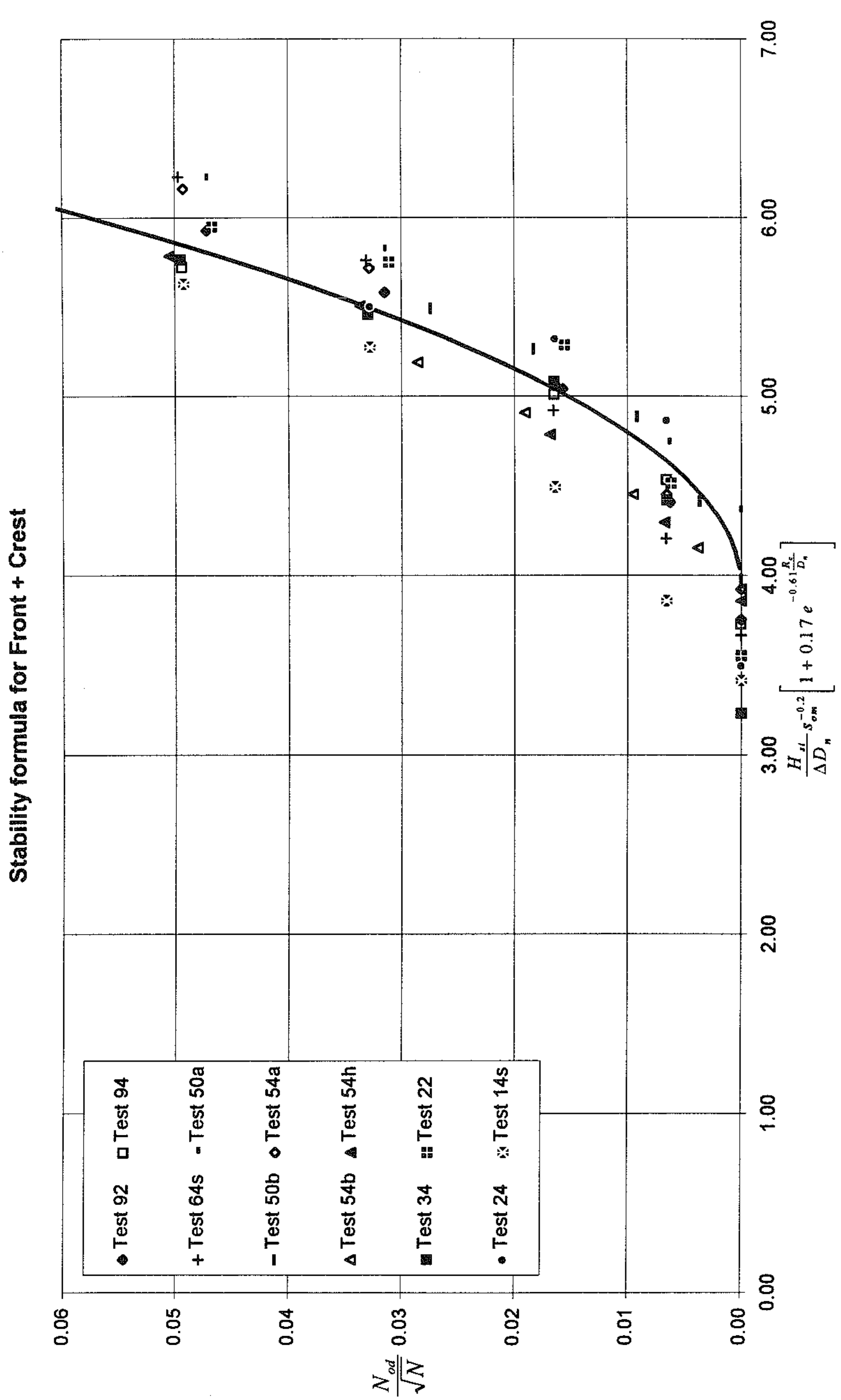


Influence of placing density on damage Front + Crest **Figure A9.4**

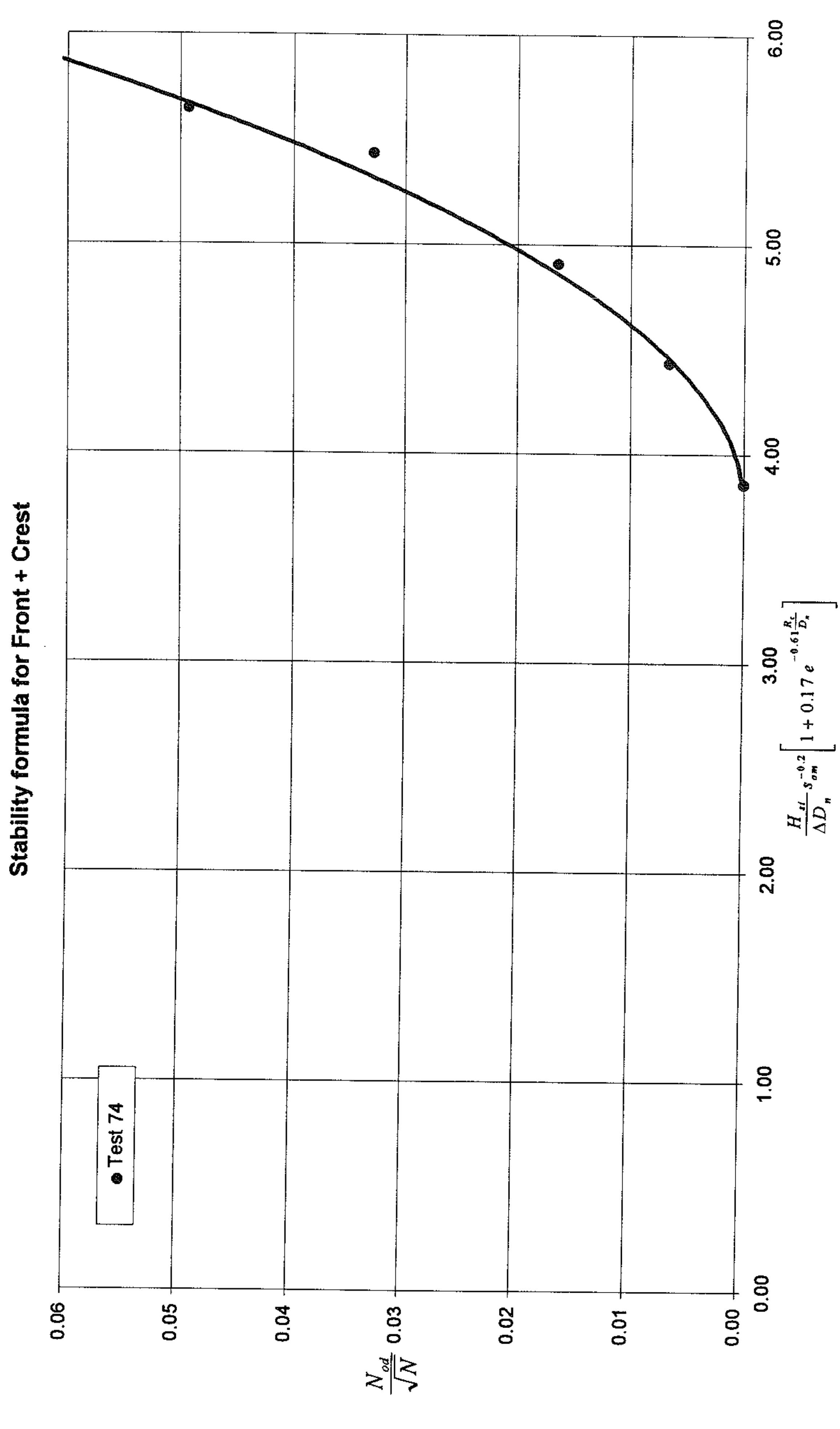


Influence of R_c/D_n on amplification facor A

Figure A9.5

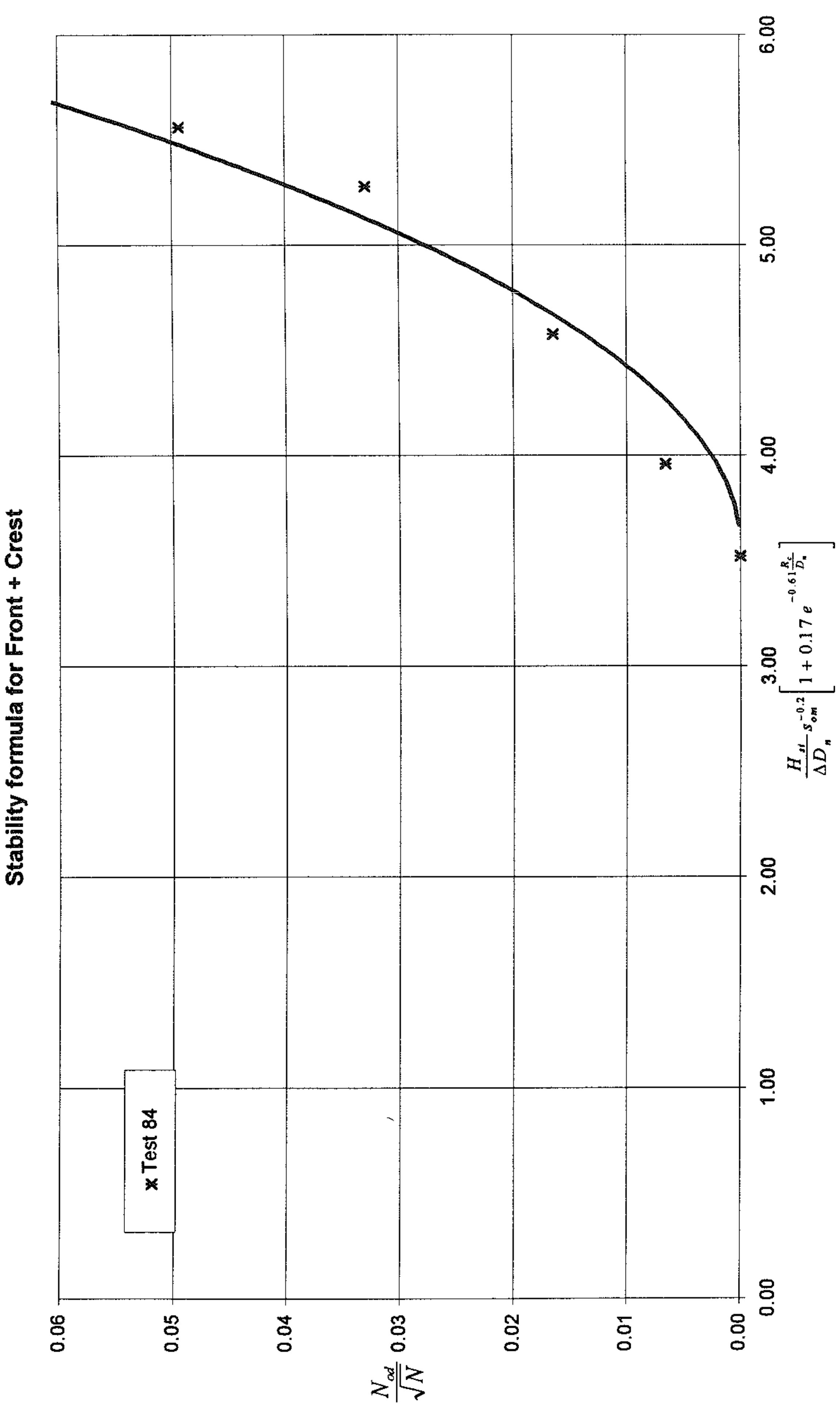


Stability formula for Front + Crest, average data points are used **Figure A9.6**.

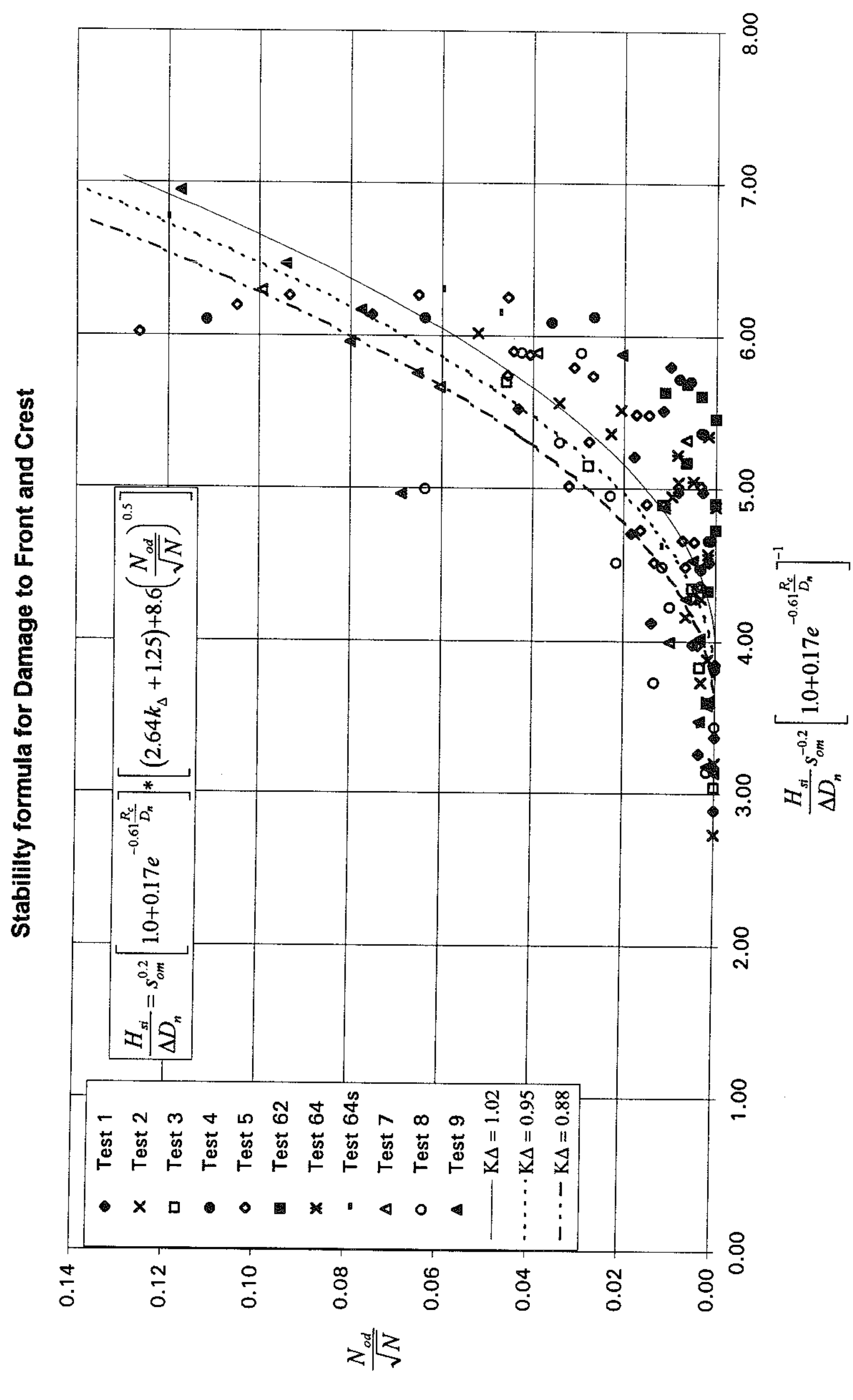


Stability formula for Front + Crest, Test 7

Figure A9.7

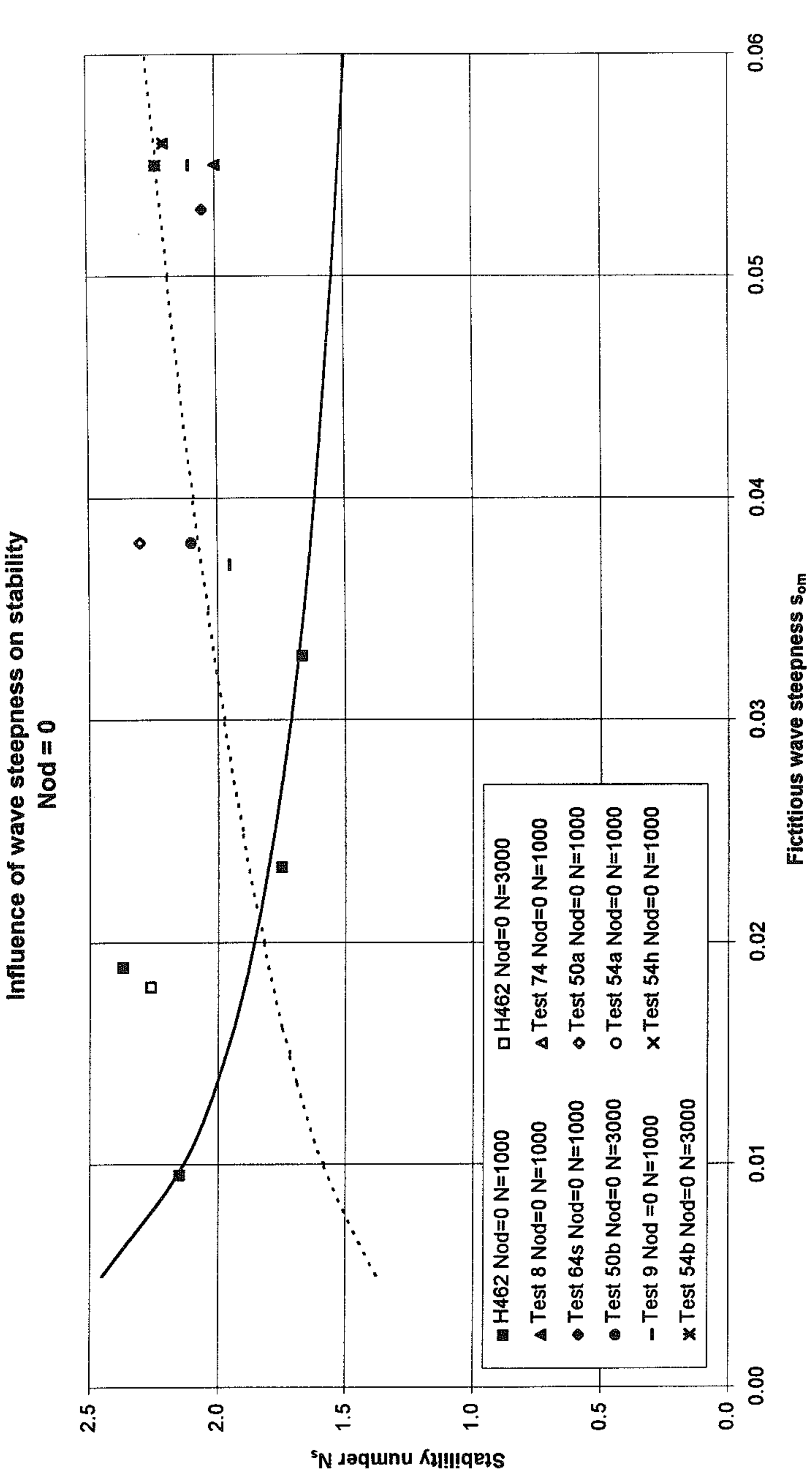


Stability formula for Front + Crest, Test 8 **Figure A9.8**

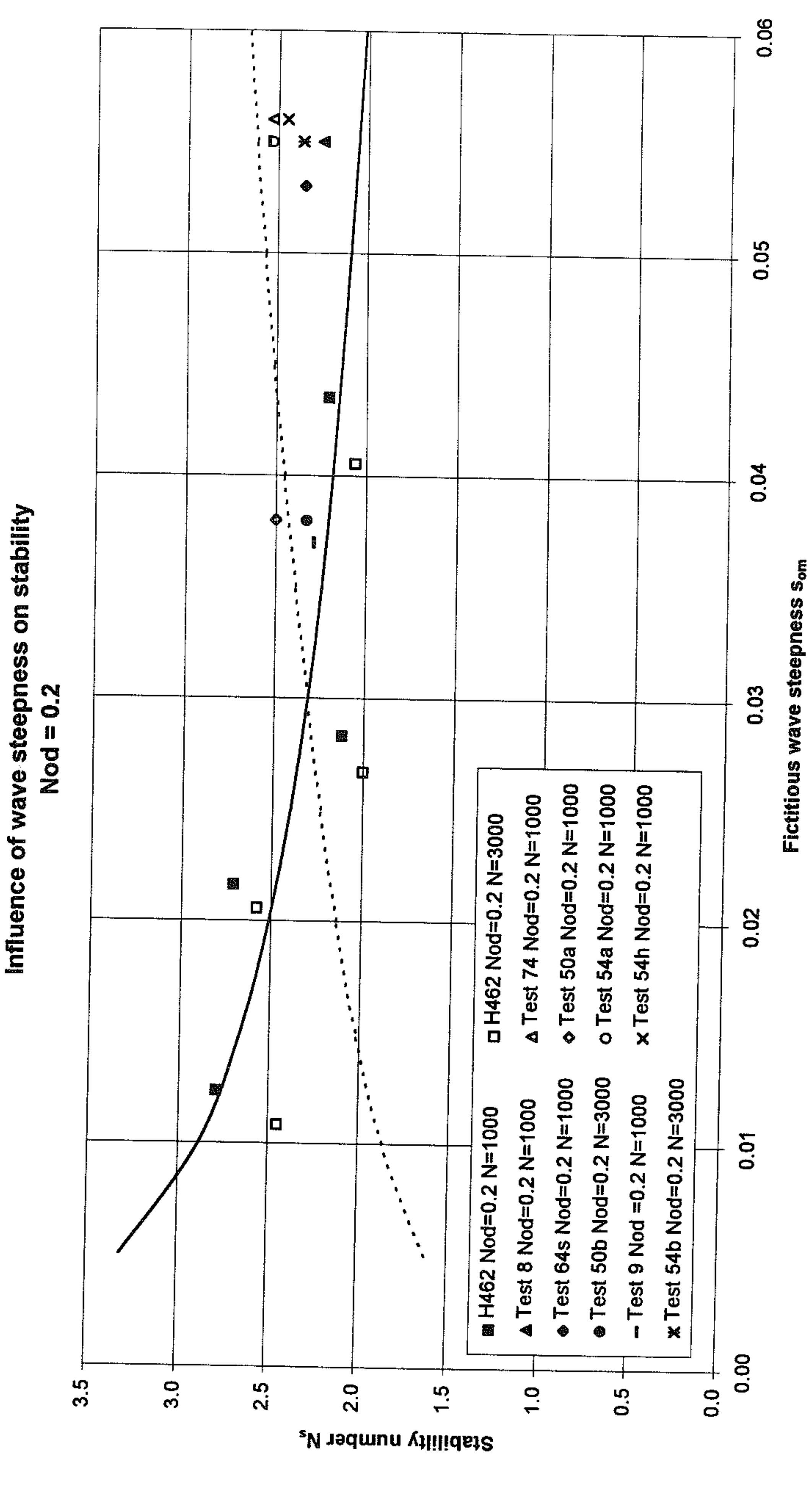


Stability formula for Front + Crest, real data points are used

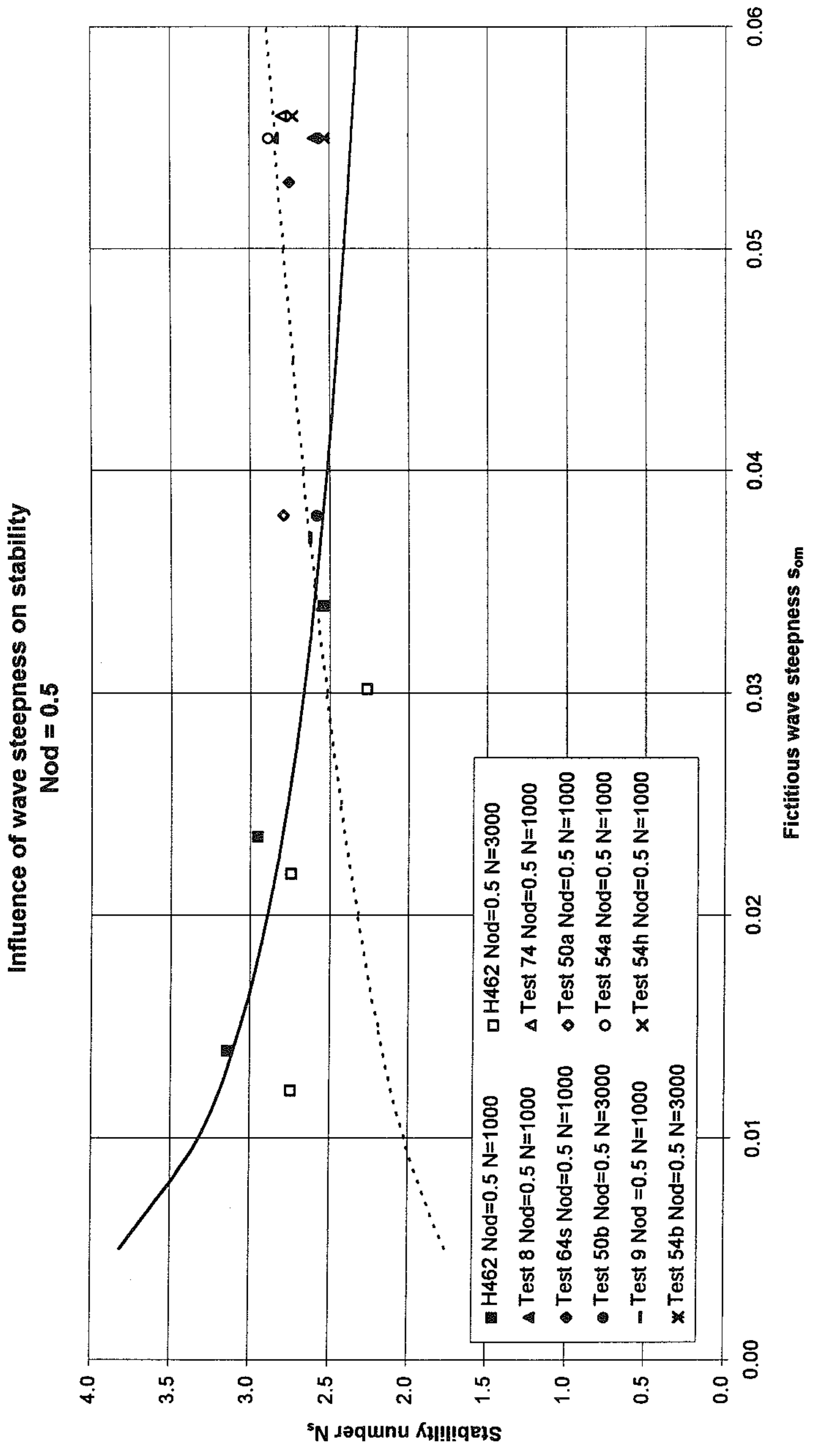
Figure A9.9



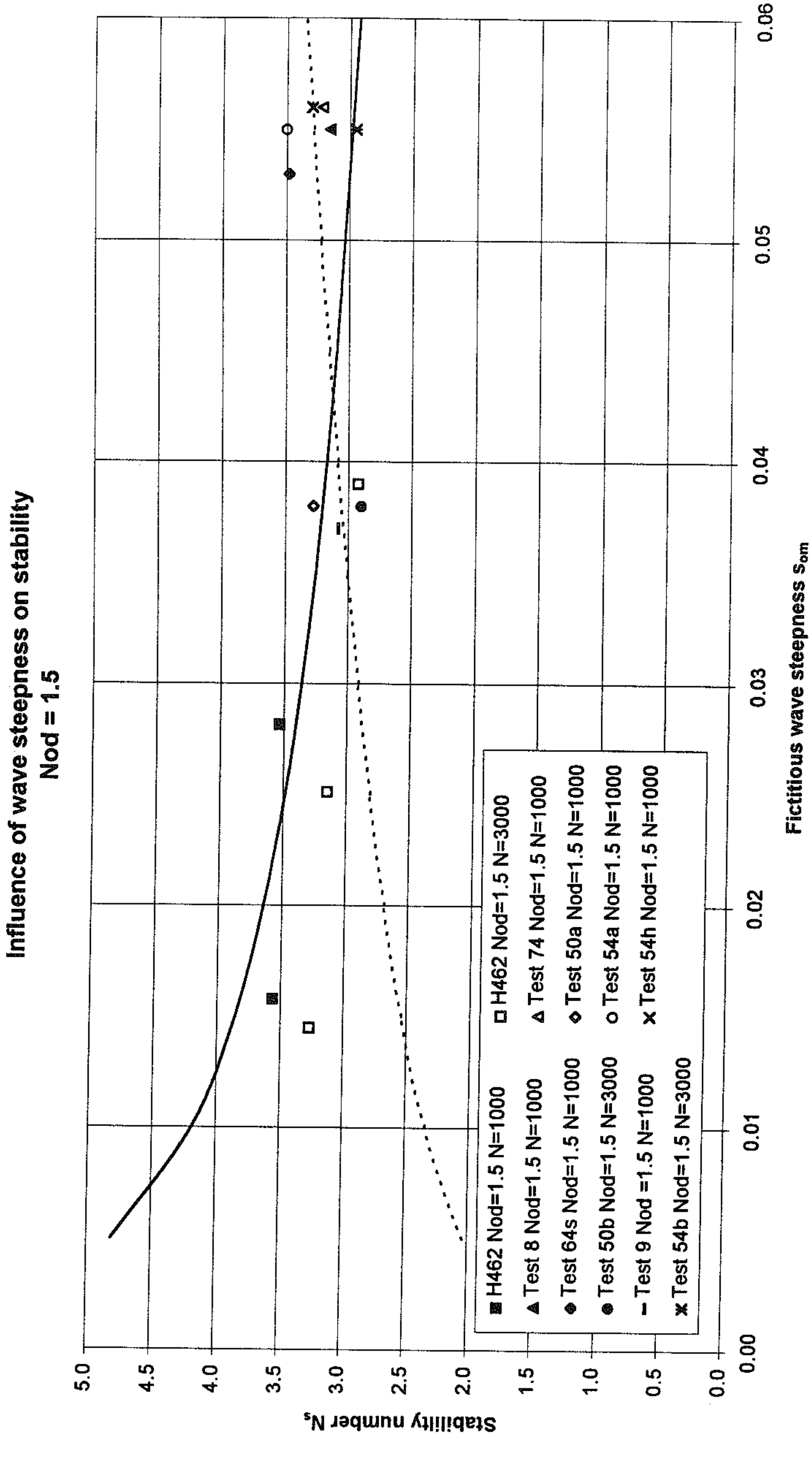
Influence of s_{om} on Van der Meer formula and eq. 11.7, $N_{od} = 0$ **Figure A9.10**



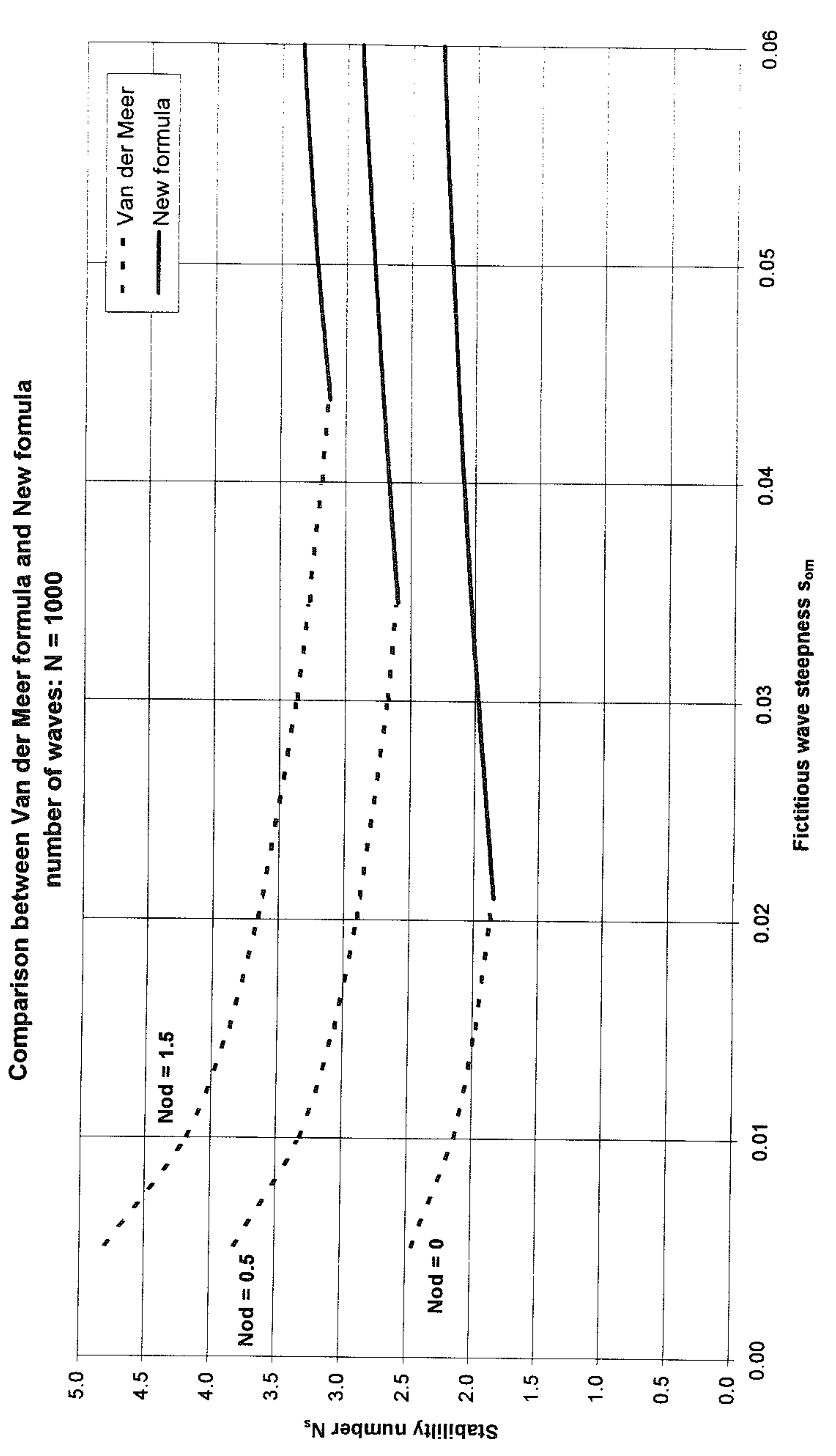
Influence of s_{om} on Van der Meer formula and eq. 11.7, $N_{od} = 0.2$ **Figure A9.11**



Influence of s_{om} on Van der Meer formula and eq. 11.7, $N_{od} = 0.5$ **Figure A9.12**

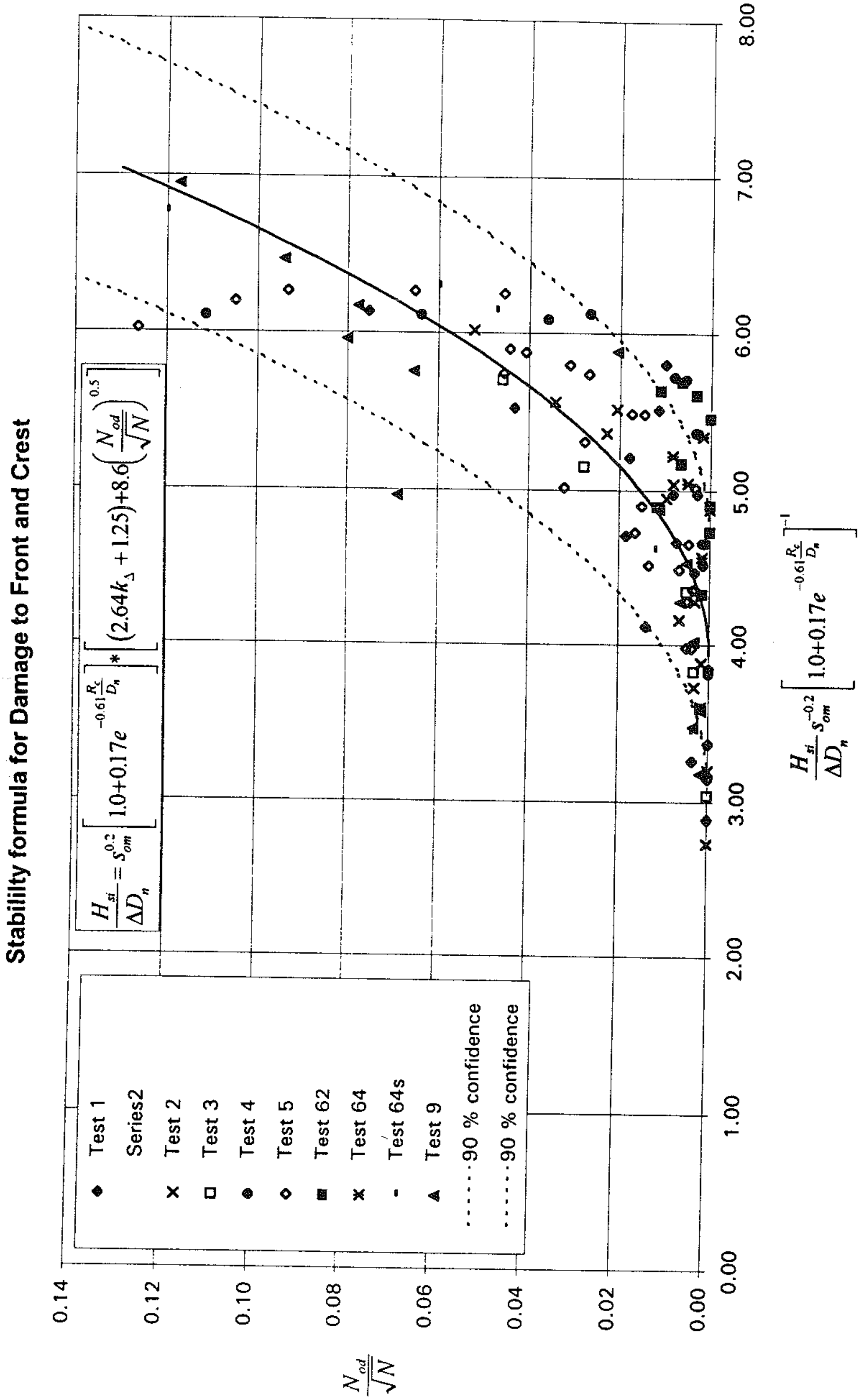


Influence of s_{om} on Van der Meer formula and eq. 11.7, $N_{od} = 1.5$ **Figure A9.13**



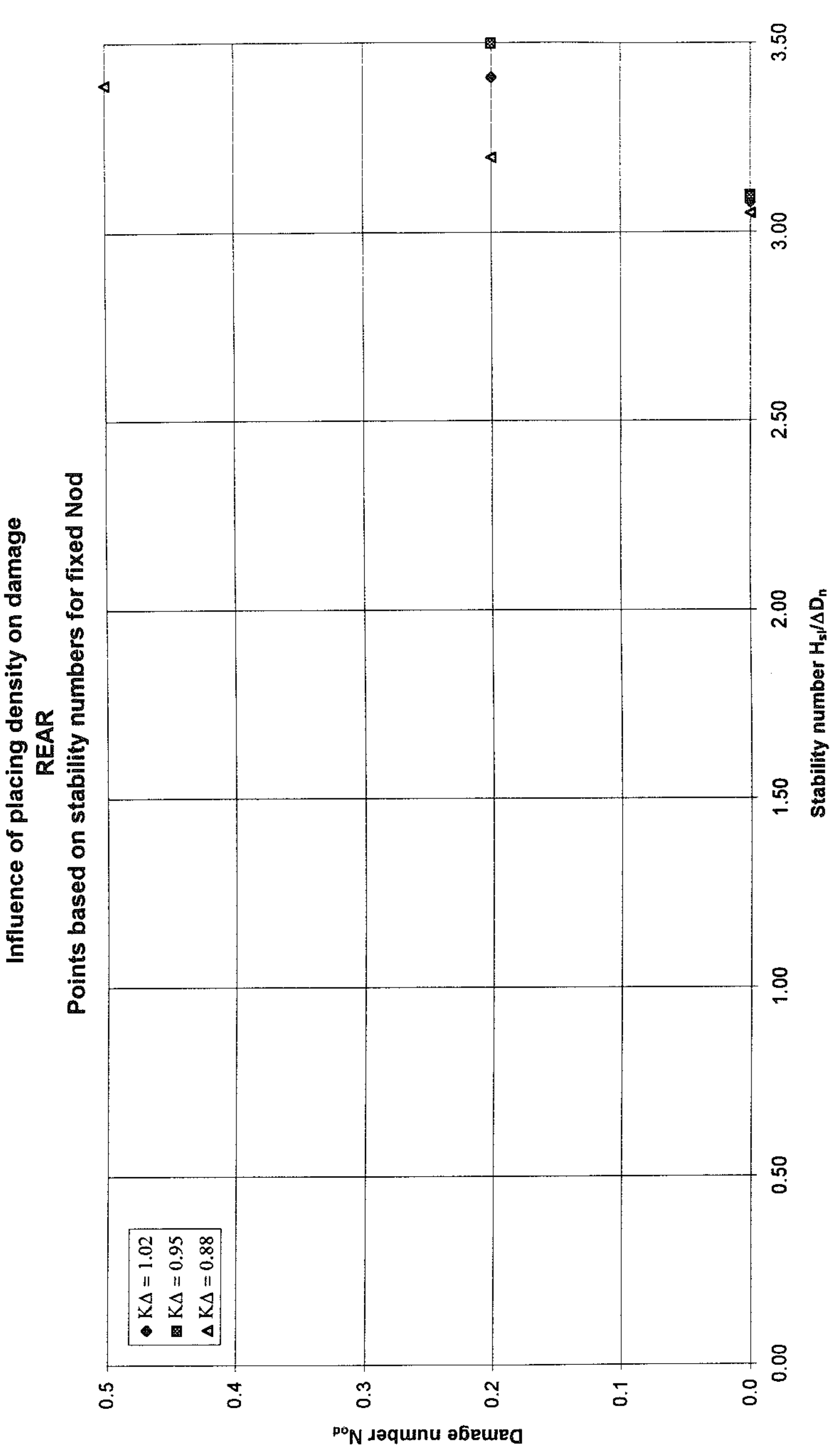
Comparison between Van der Meer formula and eq. 11.7 for three damage levels

Figure A9.14

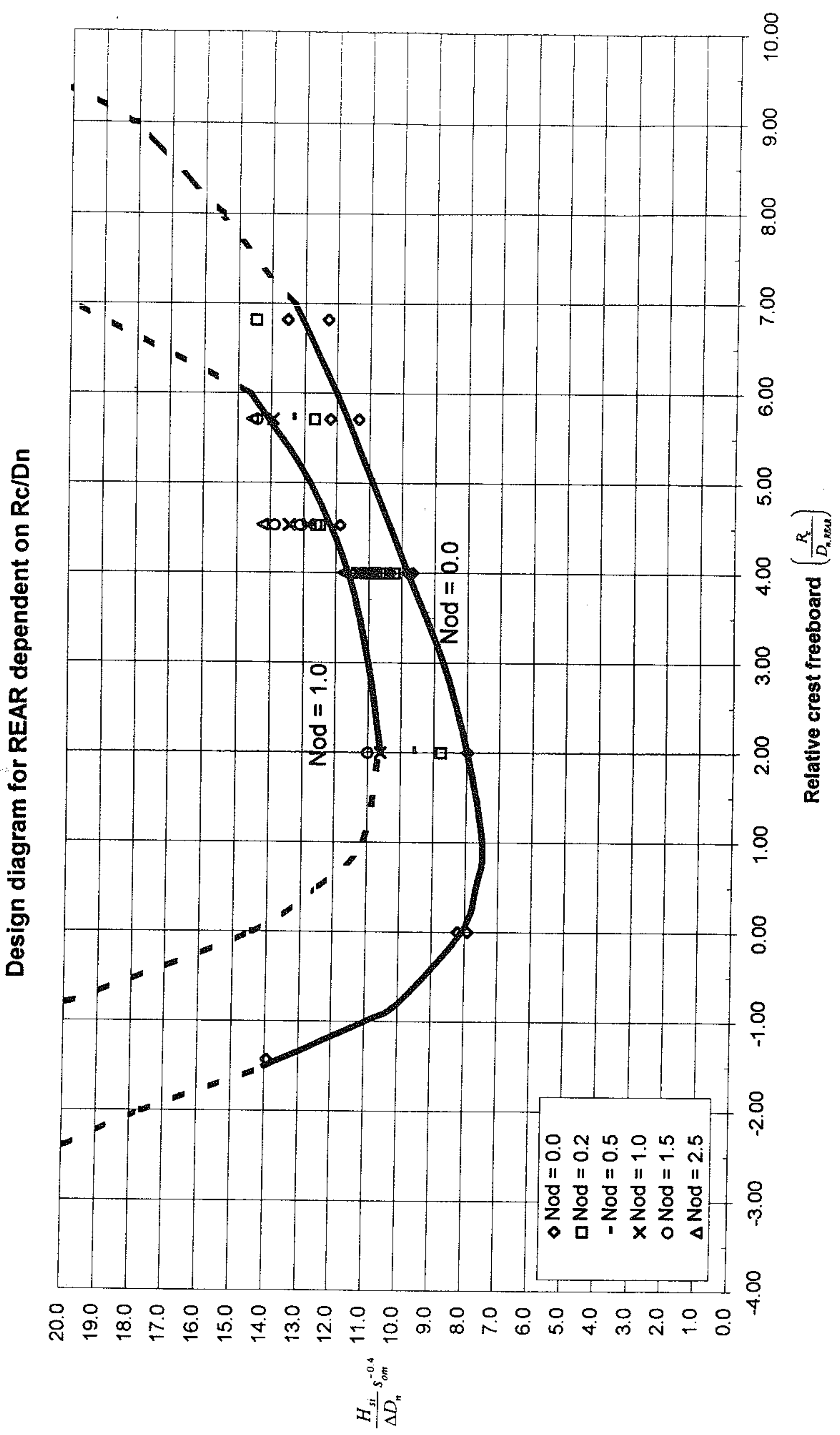


Stability formula, eq. 11.7, with *90 %* confidence levels

Figure A9.15

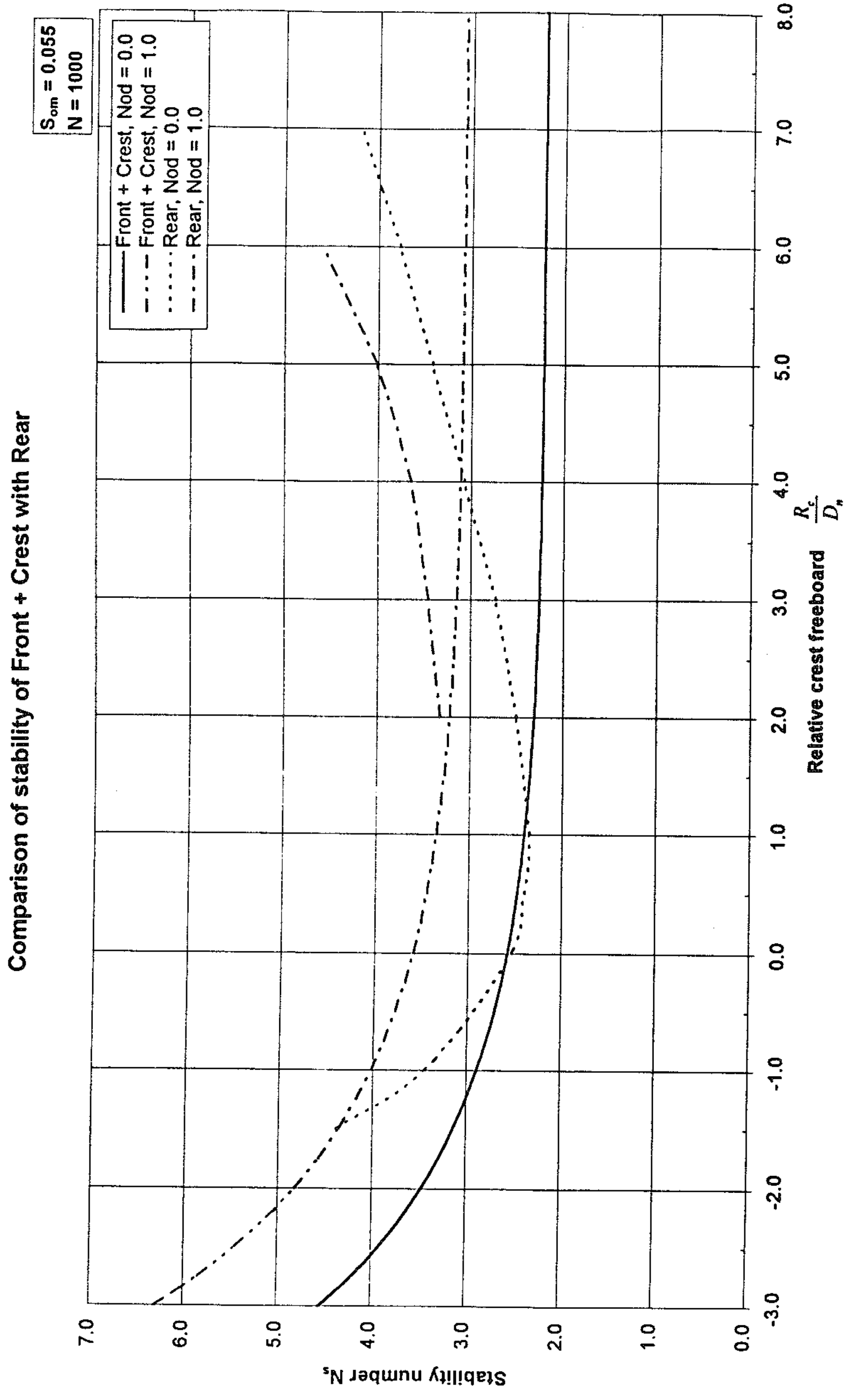


Influence of placing density to Rear **Figure A9.16**



Design diagram for Rear, dependent on R_c/D_n

Figure A9.17



Comparison of stability of Front + Crest with Rear **Figure A9.18**

Test	N deep	Nod front	Nod crest	Nod rear	$\sqrt{\frac{N_{long\,storm}}{N_{short\,storm}}}$	$\frac{N_{od,\,long\,storm}}{N_{od,\,short\,storm}}$ front	$\frac{N_{od,\,long\,storm}}{N_{od,\,short\,storm}}$ crest	$\frac{N_{od,\,long\,storm}}{N_{od,\,short\,storm}}$ rear
401a	994	0.000	0.000	0.000	1.73			
401b	2985	0.000	0.000	0.000				
402a	1026	0.050	0.000	0.000	1.73	1.00		
402b	3076	0.050	0.000	0.044				
403a	995	0.100	0.000	0.177	1.73	1.50		1.75
403b	2990	0.150	0.000	0.309				
404a	1028	0.650	0.500	1.677	1.29	3.16	5.10	2.84
404b	1702	2.051	2.551	4.766				
405a	987	0.250	0.000	0.839	1.74	1.20		2.16
405b	2973	0.300	0.000	1.809				
406a	1023	0.800	0.050	2.471	1.50	1.19	42.02	2.46
406b	2291	0.950	2.101	6.090				
501a	1029	0.150	0.000	0.000	1.73	2.67		
501b	3078	0.400	0.000	1.500				
502a	1022	0.550	0.000	0.250	1.72	1.45		2.20
502b	3011	0.800	0.000	0.550				
503a	1014	1.250	0.200	3.400	1.66	2.12	11.50	1.82
503b	2808	2.650	2.300	6.200				
504a	1020	0.100	0.000	0.000	1.73	2.00		
504b	3062	0.200	0.000	0.000				
505a	1003	0.800	0.050	1.500	1.73	1.38	28.00	1.80
505b	3008	1.100	1.400	2.700				
541a	901	0.000	0.000	0.000	1.73			
541b	2706	0.000	0.000	0.000				
542a	914	0.200	0.000	0.000	1.73	3.50		
542b	2734	0.700	0.000	0.000				
543a	936	1.250	0.000	0.150	1.73	1.80		1.00
543b	2814	2.250	0.100	0.150				
544a	916	0.150	0.000	0.000	1.73	1.33		
544b	2751	0.200	0.000	0.000				
545a	941	0.350	0.000	0.000	1.73	2.29		
545b	2818	0.800	0.000	0.000				
546a	944	1.000	0.000	0.100	1.73	1.60		1.00
546b	2816	1.600	0.000	0.100				
547a	942	2.000	0.000	0.350	1.68	1.95		3.14
547b	2647	3.900	1.500	1.100				
				Average	**1.68**	**1.88**	**21.66**	**2.02**
				St.Dev.	**0.11**	**0.72**	**16.65**	**0.70**

Relation between number of waves, N and damage number, N_{od} **Table A9.1**

Test	Dn		Som	N	Rc/Dn		kΔ	Nod	Ns
	Front	Rear			Front	Rear			
92	0.050	0.044	0.037	1011	6.00	6.82	1.020	0.00	1.95
92	0.050	0.044	0.037	1011	6.00	6.82	1.020	0.20	2.29
92	0.050	0.044	0.037	1011	6.00	6.82	1.020	0.50	2.62
92	0.050	0.044	0.037	1011	6.00	6.82	1.020	1.00	2.90
92	0.050	0.044	0.037	1011	6.00	6.82	1.020	1.50	3.08
94	0.050	0.044	0.055	924	6.00	6.82	1.020	0.00	2.10
94	0.050	0.044	0.055	924	6.00	6.82	1.020	0.20	2.55
94	0.050	0.044	0.055	924	6.00	6.82	1.020	0.50	2.82
94	0.050	0.044	0.055	924	6.00	6.82	1.020	1.00	3.08
94	0.050	0.044	0.055	924	6.00	6.82	1.020	1.50	3.22
84	0.050	0.035	0.055	925	4.00	5.71	0.880	0.00	2.00
84	0.050	0.035	0.055	925	4.00	5.71	0.880	0.20	2.25
84	0.050	0.035	0.055	925	4.00	5.71	0.880	0.50	2.60
84	0.050	0.035	0.055	925	4.00	5.71	0.880	1.00	3.00
84	0.050	0.035	0.055	925	4.00	5.71	0.880	1.50	3.16
74	0.050	0.050	0.056	928	4.00	4.00	0.950	0.00	2.20
74	0.050	0.050	0.056	928	4.00	4.00	0.950	0.20	2.53
74	0.050	0.050	0.056	928	4.00	4.00	0.950	0.50	2.80
74	0.050	0.050	0.056	928	4.00	4.00	0.950	1.00	3.10
74	0.050	0.050	0.056	928	4.00	4.00	0.950	1.50	3.22
62	0.050	0.050	0.033	998	4.00	4.00	1.020	0.00	2.50
64	0.050	0.050	0.045	912	4.00	4.00	1.020	0.00	2.50
64s	0.035	0.035	0.053	913	5.70	5.71	1.020	0.00	2.05
64s	0.035	0.035	0.053	913	5.70	5.71	1.020	0.20	2.35
64s	0.035	0.035	0.053	913	5.70	5.71	1.020	0.50	2.75
64s	0.035	0.035	0.053	913	5.70	5.71	1.020	1.00	3.22
64s	0.035	0.035	0.053	913	5.70	5.71	1.020	1.50	3.48
50a	0.050	0.050	0.038	1014	4.00	4.00	1.020	0.00	2.30
50a	0.050	0.050	0.038	1014	4.00	4.00	1.020	0.20	2.50
50a	0.050	0.050	0.038	1014	4.00	4.00	1.020	0.50	2.79
50a	0.050	0.050	0.038	1014	4.00	4.00	1.020	1.00	3.07
50a	0.050	0.050	0.038	1014	4.00	4.00	1.020	1.50	3.28
50b	0.050	0.050	0.038	2993	4.00	4.00	1.020	0.00	2.10
50b	0.050	0.050	0.038	2993	4.00	4.00	1.020	0.20	2.33
50b	0.050	0.050	0.038	2993	4.00	4.00	1.020	0.50	2.58
50b	0.050	0.050	0.038	2993	4.00	4.00	1.020	1.00	2.78
50b	0.050	0.050	0.038	2993	4.00	4.00	1.020	1.50	2.90
54a	0.050	0.050	0.055	928	4.00	4.00	1.020	0.00	2.23
54a	0.050	0.050	0.055	928	4.00	4.00	1.020	0.20	2.53
54a	0.050	0.050	0.055	928	4.00	4.00	1.020	0.50	2.88
54a	0.050	0.050	0.055	928	4.00	4.00	1.020	1.00	3.25
54a	0.050	0.050	0.055	928	4.00	4.00	1.020	1.50	3.50
54b	0.050	0.050	0.055	2755	4.00	4.00	1.020	0.00	2.23
54b	0.050	0.050	0.055	2755	4.00	4.00	1.020	0.20	2.36
54b	0.050	0.050	0.055	2755	4.00	4.00	1.020	0.50	2.53
54b	0.050	0.050	0.055	2755	4.00	4.00	1.020	1.00	2.79
54b	0.050	0.050	0.055	2755	4.00	4.00	1.020	1.50	2.95
54h	0.050	0.035	0.056	884	4.00	5.71	1.020	0.00	2.20
54h	0.050	0.035	0.056	884	4.00	5.71	1.020	0.20	2.45
54h	0.050	0.035	0.056	884	4.00	5.71	1.020	0.50	2.73
54h	0.050	0.035	0.056	884	4.00	5.71	1.020	1.00	3.14
54h	0.050	0.035	0.056	884	4.00	5.71	1.020	1.50	3.30
40a	0.050	0.044	0.032	1009	4.00	4.55	1.020	0.00	2.70

Average data points for damage to Front + Crest **Table A9.2**

Test	Dn		Som	N	Rc/Dn		kΔ	Nod	Ns
	Front	Rear			Front	Rear			
40a	0.050	0.044	0.032	1009	4.00	4.55	1.020	0.20	2.89
40a	0.050	0.044	0.032	1009	4.00	4.55	1.020	0.50	3.02
40a	0.050	0.044	0.032	1009	4.00	4.55	1.020	1.00	3.13
40b	0.050	0.044	0.032	2670	4.00	4.55	1.020	0.00	2.70
40b	0.050	0.044	0.032	2670	4.00	4.55	1.020	0.20	3.00
40b	0.050	0.044	0.032	2670	4.00	4.55	1.020	0.50	3.00
40b	0.050	0.044	0.032	2670	4.00	4.55	1.020	1.00	3.08
40b	0.050	0.044	0.032	2670	4.00	4.55	1.020	1.50	3.10
34	0.050	0.050	0.055	920	2.00	2.00	1.020	0.00	1.90
34	0.050	0.050	0.055	920	2.00	2.00	1.020	0.20	2.60
34	0.050	0.050	0.055	920	2.00	2.00	1.020	0.50	2.99
34	0.050	0.050	0.055	920	2.00	2.00	1.020	1.00	3.21
34	0.050	0.050	0.055	920	2.00	2.00	1.020	1.50	3.39
22	0.050	0.050	0.037	1033	0.00	0.00	1.020	0.00	2.15
22	0.050	0.050	0.037	1033	0.00	0.00	1.020	0.20	2.73
22	0.050	0.050	0.037	1033	0.00	0.00	1.020	0.50	3.20
22	0.050	0.050	0.037	1033	0.00	0.00	1.020	1.00	3.48
22	0.050	0.050	0.037	1033	0.00	0.00	1.020	1.50	3.60
24	0.050	0.050	0.056	930	0.00	0.00	1.020	0.00	2.30
24	0.050	0.050	0.056	930	0.00	0.00	1.020	0.20	3.20
24	0.050	0.050	0.056	930	0.00	0.00	1.020	0.50	3.50
24	0.050	0.050	0.056	930	0.00	0.00	1.020	1.00	3.62
14a	0.050	0.050	0.055	935	-1.00	-1.00	1.020	0.00	3.10
14a	0.050	0.050	0.055	935	-1.00	-1.00	1.020	0.20	3.45
14a	0.050	0.050	0.055	935	-1.00	-1.00	1.020	0.50	3.80
14k	0.044	0.044	0.056	941	-1.14	-1.14	1.020	0.00	3.22
14k	0.044	0.044	0.056	941	-1.14	-1.14	1.020	0.20	3.98
14k	0.044	0.044	0.056	941	-1.14	-1.14	1.020	0.50	4.43
14s	0.035	0.035	0.056	930	-1.43	-1.43	1.020	0.00	2.70
14s	0.035	0.035	0.056	930	-1.43	-1.43	1.020	0.20	3.05
14s	0.035	0.035	0.056	930	-1.43	-1.43	1.020	0.50	3.55
14s	0.035	0.035	0.056	930	-1.43	-1.43	1.020	1.00	4.17
14s	0.035	0.035	0.056	930	-1.43	-1.43	1.020	1.50	4.45

Continued **Table A9.2**

Test	Dn		Som	N	Rc/Dn		kΔ	Nod	Ns
	Front	Rear			Front	Rear			
92	0.050	0.044	0.037	1011	6.00	6.82	1.020	0.00	3.62
92	0.050	0.044	0.037	1011	6.00	6.82	1.020	0.20	3.87
94	0.050	0.044	0.055	924	6.00	6.82	1.020	0.00	3.85
84	0.050	0.050	0.055	925	4.00	4.00	0.880	0.00	3.05
84	0.050	0.050	0.055	925	4.00	4.00	0.880	0.20	3.20
84	0.050	0.050	0.055	925	4.00	4.00	0.880	0.50	3.39
84h	0.050	0.035	0.055	925	4.00	5.71	0.880	0.00	3.45
84h	0.050	0.035	0.055	925	4.00	5.71	0.880	0.20	3.63
84h	0.050	0.035	0.055	500	4.00	5.71	0.880	0.50	3.82
74	0.050	0.050	0.056	928	4.00	4.00	0.950	0.00	3.10
74	0.050	0.050	0.056	928	4.00	4.00	0.950	0.20	3.50
62	0.050	0.050	0.033	998	4.00	4.00	1.020	0.00	2.65
62	0.050	0.050	0.033	998	4.00	4.00	1.020	0.20	2.78
62	0.050	0.050	0.033	998	4.00	4.00	1.020	0.50	2.85
62	0.050	0.050	0.033	998	4.00	4.00	1.020	1.00	2.90
64	0.050	0.050	0.045	912	4.00	4.00	1.020	0.00	2.80
64s	0.035	0.035	0.053	913	5.71	5.71	1.020	0.00	3.50
50a	0.050	0.050	0.038	1014	4.00	4.00	1.020	0.00	2.80
50a	0.050	0.050	0.038	1014	4.00	4.00	1.020	0.20	2.88
50a	0.050	0.050	0.038	1014	4.00	4.00	1.020	0.50	2.93
50a	0.050	0.050	0.038	1014	4.00	4.00	1.020	1.00	3.00
50a	0.050	0.050	0.038	1014	4.00	4.00	1.020	1.50	3.08
50b	0.050	0.050	0.038	2993	4.00	4.00	1.020	0.00	2.80
50b	0.050	0.050	0.038	2993	4.00	4.00	1.020	0.20	2.83
50b	0.050	0.050	0.038	2993	4.00	4.00	1.020	0.50	2.89
50b	0.050	0.050	0.038	2993	4.00	4.00	1.020	1.00	2.93
50b	0.050	0.050	0.038	2993	4.00	4.00	1.020	1.50	3.00
54a	0.050	0.050	0.055	928	4.00	4.00	1.020	0.00	3.08
54a	0.050	0.050	0.055	928	4.00	4.00	1.020	0.20	3.41
54b	0.050	0.050	0.055	2755	4.00	4.00	1.020	0.00	3.08
54b	0.050	0.050	0.055	2755	4.00	4.00	1.020	0.20	3.20
54b	0.050	0.050	0.055	2755	4.00	4.00	1.020	0.50	3.39
54b	0.050	0.050	0.055	2755	4.00	4.00	1.020	1.00	3.53
54h	0.050	0.035	0.056	884	4.00	5.71	1.020	0.00	3.85
54h	0.050	0.035	0.056	884	4.00	5.71	1.020	0.20	4.00
54h	0.050	0.035	0.056	884	4.00	5.71	1.020	0.50	4.20
54h	0.050	0.035	0.056	884	4.00	5.71	1.020	1.00	4.40
54h	0.050	0.035	0.056	884	4.00	5.71	1.020	1.50	4.55
40a	0.050	0.044	0.032	1009	4.00	4.53	1.020	0.00	3.10
40a	0.050	0.044	0.032	1009	4.00	4.53	1.020	0.20	3.18
40a	0.050	0.044	0.032	1009	4.00	4.53	1.020	0.50	3.28
40a	0.050	0.044	0.032	1009	4.00	4.53	1.020	1.00	3.39
40a	0.050	0.044	0.032	1009	4.00	4.53	1.020	1.50	3.50
40b	0.050	0.044	0.032	2670	4.00	4.53	1.020	0.00	3.10
40b	0.050	0.044	0.032	2670	4.00	4.53	1.020	0.20	3.15
40b	0.050	0.044	0.032	2670	4.00	4.53	1.020	0.50	3.20
40b	0.050	0.044	0.032	2670	4.00	4.53	1.020	1.00	3.25
40b	0.050	0.044	0.032	2670	4.00	4.53	1.020	1.50	3.31
34	0.050	0.050	0.055	920	2.00	2.00	1.020	0.00	2.50
34	0.050	0.050	0.055	920	2.00	2.00	1.020	0.20	2.75
34	0.050	0.050	0.055	920	2.00	2.00	1.020	0.50	3.00
34	0.050	0.050	0.055	920	2.00	2.00	1.020	1.00	3.33
34	0.050	0.050	0.055	920	2.00	2.00	1.020	1.50	3.45
22	0.050	0.050	0.037	1033	0.00	0.00	1.020	0.00	2.20
24	0.050	0.050	0.056	930	0.00	0.00	1.020	0.00	2.50
14s	0.035	0.035	0.056	930	-1.43	-1.43	1.020	0.00	4.40

Average data points for damage to Rear **Table A9.3**

Test	Tm	Nod	Som (N=1000)	Som (N=3000)	Ns (N=1000)	Ns (N=3000)
1	1.40	0.0	0.033	0.033	1.67	1.67
2	1.40	0.5				
3	1.40	1.5				
4	1.70	0.0	0.023	0.023	1.75	1.75
5	1.70	0.5	0.034	0.030	2.54	2.26
6	1.70	1.5		0.039		2.92
7	2.20	0.0	0.019	0.018	2.37	2.26
8	2.20	0.5	0.024	0.022	2.95	2.74
9	2.20	1.5	0.028	0.025	3.53	3.15
10	2.95	0.0	0.010	0.010	2.15	2.15
11	2.95	0.5	0.014	0.012	3.14	2.74
12	2.95	1.5	0.016	0.015	3.56	3.27
13	1.40	0.2	0.044	0.041	2.21	2.06
14	1.70	0.2	0.028	0.027	2.12	2.00
15	2.20	0.2	0.022	0.021	2.71	2.58
16	2.95	0.2	0.012	0.011	2.79	2.45

Average data points Test H462-II (1987) **Table A9.4**