SALDANHA BAY ORE JETTY: A STUDY OF BERTHING IMPACTS

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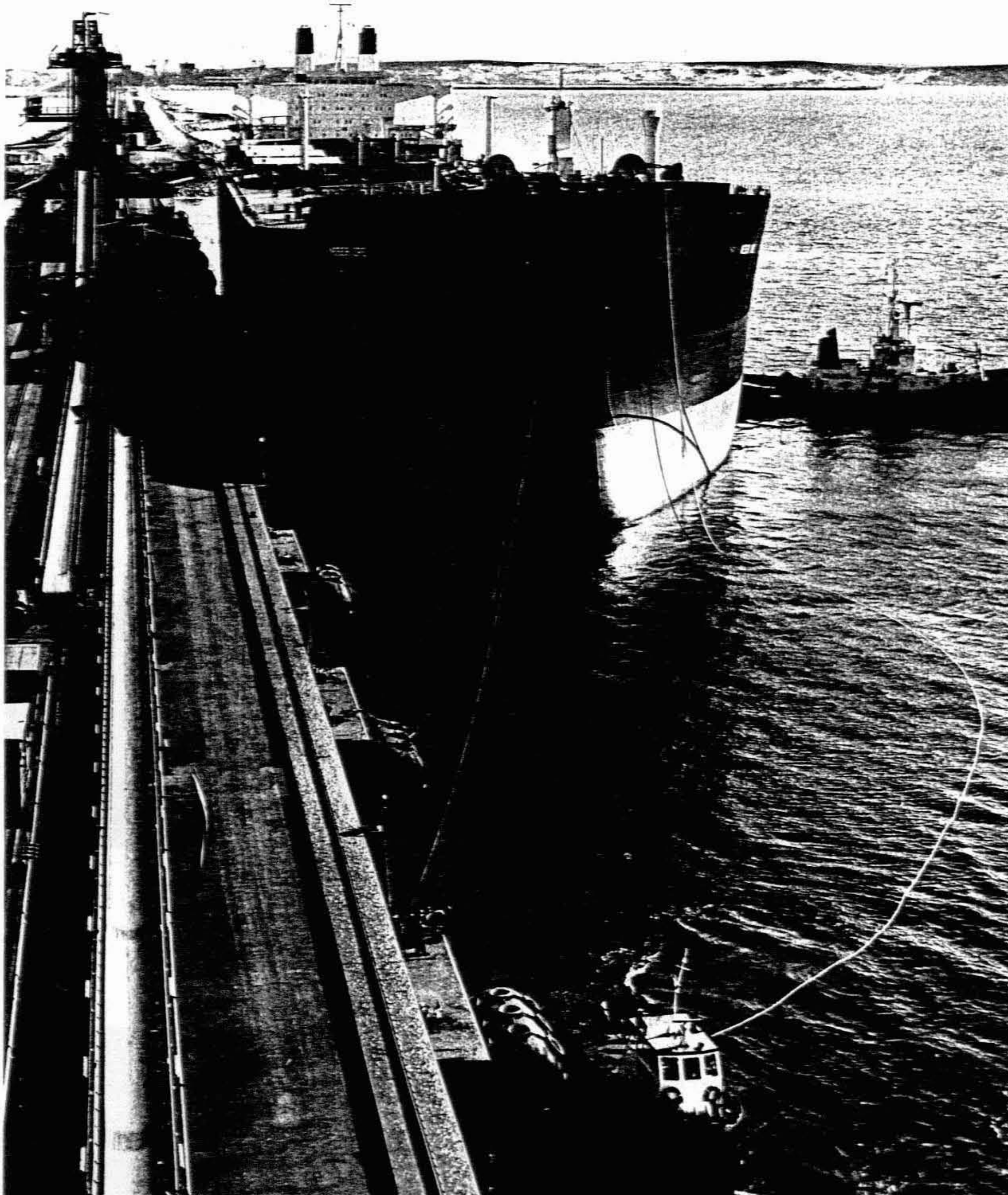





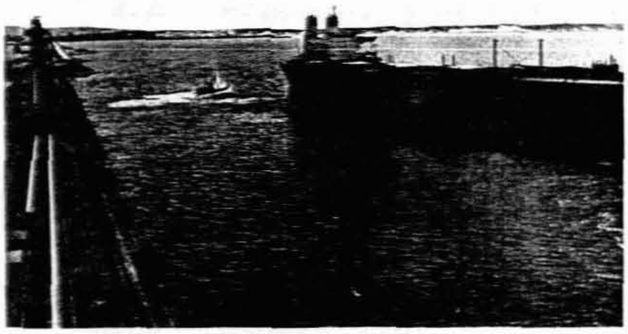
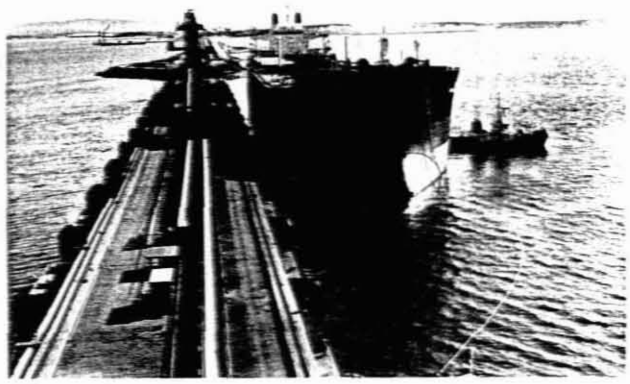

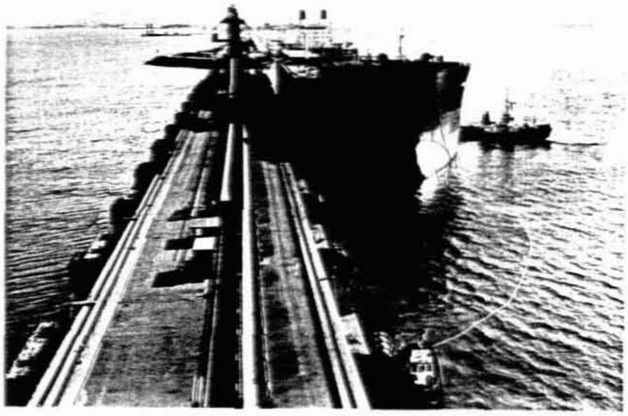

CONTENTS

SYNOPSIS

Between December 1982 and January 1984 the berthing impacts of 50 ore carriers were monitored at the Saldanha Bay ore-jetty. The actual displacement of the monitored vessels ranged between 60 and 263 kilotonnes. Only 50% of the monitoring runs yielded complete sets of data.

Approach velocities recorded were high and the design limits were exceeded several times resulting in fenders being deflated on four occasions.

The added mass coefficient for each impact was calculated. The actual values of C_M varied between 1 and 7. This agrees with values found in literature.

Some of the high values could be attributed to inaccuracies in the measurement techniques.

From the values obtained for added mass it seems that the value used in the design was very low and that a unitary value for C_M is not very satisfactory.

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LIST OF SYMBOLS AND DEFINITIONS

A	Position of fender where the impact occurs.
Alpha(a)	Angle between V_{cg} and R (rad).
App-Ang(b)	Angle of approach relative to the jettty (rad) or (degrees).
B	Breadth of ship (m).
BDT	Time between BTY1 and BTY2 (s).
BIX	Position of impact.
BTX	Position of bow-transducer at time of impact relative to chainage zero on jetty.
BTY1	Distance from fenderboard to ship at bow transducer (m).
BTY2	Distance from fenderboard to ship at bow transducer just before impact (m).
BTY3	Distance from fenderboard to ship at bow transducer at maximum deflection (m).
BX	Position of bow at time of impact relative to chainage zero on jetty (m).
C_C	Construction coefficient.
C_D	Deformation coefficient.
C_E	Eccentricity coefficient of ship at point of impact.
C_F	Diversity coefficient.
C_G	Geometric coefficient.
CG	Centre of gravity of ship relative to midship (m).
CL	Centre line of ship midway between perpendiculars.
C_M	Added mass coefficient of ship.

C_s	Softness coefficient.
D	Actual draft of ship (m).
D(max)	Maximum summer draught of ship (m).
DPL(act)	Actual displacement (tonnes).
DPL(max)	Maximum displacement (tonnes).
DWT	Dead weight tonnage (tonnes).
E	Energy absorbed by the fenders from point of impact until maximum deflection (kN.m)
E_s	Ships energy (kN.m).
Fr	Froude number.
g	Acceleration due to gravity (m/s^2).
J	Radius of gyration of the CG (m).
LOA	Length overall of ship (m).
LPP	Length between perpendiculars of ship (m).
M	Mass of ship (tonnes).
M_T	Mass of ship including the effect of added mass (tonnes).
P	Density of sea water ($tonnes/m^3$).
R	Distance from CG to the the point of impact (m).
SDT	Time between STY1 and STY2 (s).
STX	Position of stern transducer at impact relative to chainage zero on jetty (m).
STY1	Distance from fenderboard to ship at stern transducer at the same time as BTY1 (m).
STY2	Distance from fenderboard to ship at stern transducer at the same time as BTY2 (m).
STY3	Distance from fenderboard to ship at stern transducer at the same time as BTY3 (m).
SX	Position of stern at impact relative to chainage

	zero on jetty (m).
T	Water depth (m).
V	General ship velocity. (m/s).
V^1_A	Representative velocity at point of impact (m/s).
V_A	Representative velocity at point of impact for a=90° (m/s).
V_B	Velocity on impact at bow transducer normal to jetty (m/s).
V_{CG}	Velocity on impact of CG normal to jetty (m/s).
V_S	Velocity on impact at stern transducer normal to jetty (m/s).
W_{CG}	Rotational velocity at CG (rad/s).

LIST OF FIGURES AND APPENDICES

SALDANHA BAY ORE JETTY : A STUDY OF BERTHING IMPACTS

CHAPTER 1

INTRODUCTION

Saldanha Bay is a natural Port on the West Coast of South Africa. It is situated approximately 130 km North of Cape Town.

The Port was built by the South African Iron and Steel Corporation in 1976 mainly to export iron-ore which is mined at Sishen, 860 km North-East of Saldanha.

The jetty is a double caisson construction at the end of a 3 km man-made rubble mole. The caissons are 40 m apart forming a semi- open berth.

There are two 600 m ore berths, one on each side of the ore-jetty.

The entrance channel is dredged to a maximum depth of -23,7 m chart datum to accommodate vessels with a draught of 21 m and a deadweight tonnage of about 280 kilotonnes.

The harbour is protected by a 2 km sand fill breakwater running from Hoedjieskop to Marcus Island. The layout of the harbour is shown on fig 1.1 and a cross- section of the ore jetty on fig 1.2.

Most of the vessels entering Saldanha Bay are in ballast with a draught ranging from 8 to 13 m. Occasionally partly laden

ore carriers enter Saldanha to be topped up.
The entry draught of these vessels can be up to 18 m.

The object of this thesis is to investigate the berthing of ships at the Saldanha Bay Ore Jetty with special emphasis on the following :-

1.1 Measurement of actual berthing energies.

1.2 Measurement of actual berthing velocities.

1.3 Gathering of the following data: environmental conditions, ship dimensions, loading conditions, ships position at impact relative to the jetty.

1.4 Establishment of the "added mass coefficient" for the conditions at Saldanha.

1.5 Comparing the results with those recommended in literature and used in the design of the Saldanha Bay jetty and fenders.

1.6 Evaluation of the existing pneumatic fenders in terms of performance under actual berthing impacts.

CHAPTER 2

WORK PROGRAMME

This chapter describes the different stages of the project. A progress chart depicting the different stages is attached (annexure 2.1).

2.1 LITERATURE STUDY

From July 1982 a literature study was conducted to become acquainted with the subject and to establish how much of this type of work had been done elsewhere. Although most of the literature study was conducted in the initial period this was continually updated. From the literature study it was established that prototype data of berthing impacts is much in demand, because relatively little has been done in this field. It thus seemed to be a worthwhile subject to investigate.

2.2 APPROVAL OF PROJECT

After approval was obtained from the S.A.Transport Services the project description was submitted to the Cape Technikon for approval. This was given in July 1983.

2.3 MONITORING STAGE 1

Because of the fact that the equipment used for monitoring had already been installed for other research work,it was not necessary to devise any instrumentation or install any equipment. The same data that was needed for this project was being gathered for another project although for different reasons.

The first prototype run was completed on 1982:08:08 with the arrival of ship code 001.

All the data eg. berthing velocities,distance off the jetty and fender pressures were recorded on data cassettes and sent to the C.S.I.R. at Stellenbosch for processing.
During the first year approximately 15 runs were completed although only 3 provided any useful data.

The reason for this was that it required some experience to lock the sonar docking device on the ship in the case of a ship approaching the jetty. Therefore the sonar docking data was not recorded correctly. This only became evident after the first data was analysed. Also the calibration of the sonar docking device (used to measure speed of approach and distance off the jetty) presented some problems. Furthermore the pressure sensors and fitted to the fenders were damaged frequently.

Near the end of 1983 it was realised that the papertrace of the sonar docking sytem would have to be used for most of the information that was needed. Until then it was only used to check whether the docking system was operational.

2.4 MONITORING STAGE 2

The only significant difference between the two monitoring stages is that in the second stage the echo traces of the docking system were accurately calibrated and time marked.

During this period of 15 months a further 35 ships were monitored with a much higher success rate.

2.5 COMPUTATION OF CALCULATION-SHEETS

Except for the processing of the echo traces, all the calculations were performed on a IBM-PC. The software used was Lotus 123, which is a spreadsheet and database program. During the second half of 1984 the calculation procedures and spreadsheets were prepared.

2.6 PROCESSING THE ECHO-TRACES

As mentioned before the echo- traces became the main source of data. The distance off the jetty at the bow and at the stern had to be scaled off the paper trace. This was time consuming and took 3 months to complete.

2.7 PROCESSING ON COMPUTER

This part of the work entailed the transferring of data from the data sheets into the computer as well as processing it in graphical, statistical and tabular form.

This work commenced in November 1984 and was completed in

June 1985.

8. <u>WRITING OF REPORT</u>

Although certain sections of the report were written at an earlier stage, it was commenced in earnest during April of 1985 and was completed in November of 1986.

CHAPTER 3

LITERATURE STUDY

The aim of this literature study was to ascertain how much work has been done in the study of berthing impacts with special emphasis on the concept of "added mass" and to critically evaluate them.

Berthing impacts have been studied for several decades since it is of paramount importance that a designer of a quay or jetty structure knows how much force is transmitted from a ship during berthing to the quay structure.

A synopsis of the literature study now follows:

3.1 In 1965 Vasco Costa (21) published his now famous "Analytic study of the problem of berthing" where he analysed the mechanics of a berthing manoeuvre. The same equations will be used in chapter 4 to derive the "added mass" formula. A few interesting comments are made about the concept of "added mass".

3.1.1 He suggests that a certain amount of mass around the ship behaves as if integral with the ship and it moves with the ship. This extra mass he calls "added mass".

3.1.2 For lateral ship movement a simple expression for the "added mass" coefficient is:-

$$C_M = 1 + 2D/B$$

$$C_M = \text{virtual mass / actual mass}$$

virtual mass = actual mass + added mass

D = draught (m)

B = width (m)

3.1.3 Work by Grim (10) and Kilner (12) is discussed The values they obtained for C_M in model tests were several times the mass of the ship. Vasco Costa suggests that the values be reduced until the concept of added mass is studied further. Some relationships are plotted in Figure 3.1.

COMMENTS

It is interesting to note that higher added mass values have become acceptable and that the definition has also changed considerably. Considerations such as keel clearance, currents, ship rotation, approach velocities etc. are now all taken into account.

3.2 Also during 1965 Saurin (19) presented a paper on his laboratory tests and full scale observations at Finnart oil terminal in Scotland.

3.2.1 The energy equation used is

$$E = C_M . C_S . C_E . (1/2.MV^2)$$

where $C_E = \dfrac{J^2}{J^2 + R^2}$

C_S = softness coefficient which is dependant on the tipe of fender used and the rigidity of the hull.

$V = V_{CG} + R.W_{CG}$

$C_M = 1,3$

$J = (0,2 - 0,22)$ LOA

R = Distance from centre of gravity to point of impact.

For the model test a 1/60 linear scale model of a 32 000 DWT tanker was used with a 11 m draft with approach speeds in the range 0,075 m/s to 0,45 m/s. Underkeel clearances varied from 0,30 m to 15 m. (3 to 136% of the ship's draught)

The results were that the added mass factor was found to range between 2 and 3 with a basic value of 2 (see fig 3.2,top).

3.2.3 Full scale observations indicated a reasonable average for C_M is 1,3 (see fig 3.2,bottom).

(a) Echo sounders were used to measure approach velocities.

(b) Displacement gauges measured compression at impact.

(c) 70 ships were monitored between 16 000 and 50 000 DWT.

(d) Impacts energies were slight; 300 to 400 (tonf-inch) with only 2 exceeding 1000 (tonf-inch).

(e) Normal impact speed 0,075 m/s to 0,125 m/s with one of 0,33 m/s.

(f) Open jetty structure with soft fenders.

(g) Angle of approach 3,5° to 9°.

(g) No correlation was found between berthing impact and any sensible parameter.

COMMENTS

Actual C_M values are very low and it seems as though experimental values were doubted because they were relatively high.

Approach velocities were low taking into account the relatively small size of ship.

3.3 Lee (14) conducted a full scale investigation into berthing impacts in order to evaluate a hydraulic pneumatic floating fender in 1965.

Berthings were monitored involving ships from 1 400 t to 17 600 t displacement.

Ships velocity, berthing force, position of impact and energy absorption by the fenders were measured.

Interestingly enough, pressure transducers were used to establish the berthing energy.

3.3.1 The general kinetic energy equations were used.

$$E = C_E.C_B.C_D.C_C.C_M(1/2.MV^2)$$

(a) Geometric coefficient C_G, depends on the geometric configuration of ship at moment of impact.

C_G = 0,85 for an increasing convex curvature of the hull side.

C_G = 1,0 for parallel berthing

C_G = 1,25 for concave curvature

(b) Construction coefficient C_C depends on the berth type.

C_C = 0,8 for a closed berth

C_C = 0,9 for a semi closed berth

C_C = 1,0 for an open berth

(c) Deformation coefficient C_D allows for deformation of the ship's hull.

C_D = 0,5 for wooden log fender

C_D = 1,0 for a soft fender

(d) To compute C_M the Vasco Costa formula was used

$C_M = 1 + 2D/B$

(e) The eccentricity coefficient $C_E = \frac{J^2}{J^2 + R^2}$

J = 0,24 LOA was used

3.3.2 Berthing velocities V_{CB} varied from 0,03 m/s to 0,12 m/s with one extreme case of 0,3 m/s.

3.3.3 Maximum berthing impacts occurred during high wharf-on winds.

3.3.4 Lee recommends that the effect of C_M be studied further.

COMMENTS

For small ships the approach velocities were reasonably low.

From the report it seems that the berthing manoeuvre was studied very thoroughly but very little was done to evaluate C_M more thoroughly.

3.4 Vasco Costa (22) at Wallingford has the following to say on "added mass"

(a) He disputes the high values obtained by Grim (10) and Kilner (12) in their model tests.

(b) A simple formula is suggested.

$$C_M = 1 + 2.D/B$$

(c) It is mentioned that the ship's shape, depth of water, rate of change in velocity and the past history of the motion of the ship affect the added mass factor.

The following acceptable approach velocities were suggested:-

up to	20 000 t	0,2 to 0,3 m/s
20 000 to	50 000 t	0,14 to 0,25 m/s
50 000 to	100 000 t	0,1 to 0,2 m/s
100 000 to	200 000 t	0,1 to 0,2 m/s
Over	200 000 t	0,05 to 0,1 m/s

COMMENT

In 1973 values for added mass were still somewhat uncertain and high values were not readily accepted.

3.5 At the same conference Goulsten (9) evaluated some of the berthing energy data from the BP terminal at Finnart.

He compares the actual energies measured with the calculated energies using a C_M value of 1,3.

(a) The range of error even if the extremes are ignored is of the order 80%.

(b) Actual C_M values varied between 0,43 and 2,25.

(c) He suggests that it is impossible to select an average added mass coefficient for all cases because C_M is affected by many variable factors such as:-

1. Current
2. Underkeel clearance
3. Configuration of the berthing structure
4. Positive or negative acceleration

3.6 Between 1971 and 1973 berthing impacts were measured for 50 tankers of 200 000 DWT at oil terminals in Japan. They were evaluated by Otari, Horii and Ueda(18).

To obtain the kinetic energy of the ship the elastic deflection of the berthing structure plus the deflection of the fenders was measured. The impact was treated as a dynamical model acting like a system of springs.

To compute added mass the following formula was used:-

$$\text{added mass} = \frac{\pi}{4} . D^2 . LOA . \rho$$

<u>Some of the results were:-</u>

(a) Approach velocities were greater than 0,06 m/s, with a maximum of 0,1 m/s. (sum of translational and rotational velocities). (See Fig. 3.3)

(b) Rotation accompanies the berthing operations of any large tanker.

(c) Measured energies were larger than calculated ones by a ratio of 2,02 on first impact and 2,77 on second impact. This is ascribed to the uncertainty in the estimate of the "added mass" constant.

<u>COMMENTS</u>

(a) Approach velocities are very low, perhaps because pilots are cautious when handling large oil tankers.

(b) It seems as though the old established formula for C_M was being doubted.

(c) The importance of the rotational velocity is highlighted.

3.7 In 1977 Wirsbitzki and Lackner (24) presented a paper in Leningrad on the "Criteria for economical design of fender systems".

The berthing energy formula they mention as being generally used for fender design is:-

$$E = C_M . C_E . C_D (1/2.MV^2)$$

C_D = 1 for smaller ships and soft fenders

= 0,95 for large ships and relatively hard fenders

= 0,9 for crude carriers larger than 250 000 DWT.

$$C_E = \frac{0{,}04}{0{,}04 + (R/LOA)^2}$$

$$= \frac{(0{,}2.LOA)^2}{(0{,}2.LOA)^2 + R^2}$$

$$= \frac{J^2}{J^2 + R^2} \qquad \text{where } J = 0{,}2.LOA$$

$$C_M = 1 + 2D/B$$

They maintain that:- "The actual magnitude of the above mentioned individual variables may of course be a subject of dispute. However, as far as energy absorption capacity of the fender is concerned, everything depends on their total, which, despite differing factors, normally leads to identical or at least comparable results."

The significance of prototype berthing data for different types of jetties and quays is mentioned.

COMMENT.

If the value of C_M should prove not to be as low as has been believed, it will have a very marked influence on fender design.

3.8 Brolsma, Hirs and Langeveld (6) evaluated berthing velocities made at Europort, Rotterdam in 1977. Ultrasonic berthing aids were used. 150 berthing measurements were evaluated.

Their findings were as follows:-

1. Wind forces did have a significant effect on the recorded velocities.
2. Approach velocities for ships in the 265 000 DWT tend to be lower than for the 125 000 DWT group. Probability curves for berthing velocities were constructed (see Figure 3.4).
3. For 3 000 berthings a maximum expected velocity for 265 000 DWT ships was 0,1 m/s and for 12 000 DWT ships 0,16 m/s.
4. The design velocity for a 250 000 DWT ship at a Europoort or Finnart type terminal would be 0,1 m/sec although some of the berths are designed for 0,16 m/s impacts.
5. Added mass factor should be taken into account when deciding on an approach velocity for a berth. C_M

is affected by:-

(a) Underwater shape of ship.

(b) Stiffness of the fender system and its natural frequency.

(c) Underkeel clearance and shape of berthing structure.

6. A single value for C_M for all conditions seems impossible to determine.

In addition, the soft fenders at Curacao, an oil jetty which can handle 62 0000 t displacement tankers were also evaluated.

To establish the energy to be absorbed by the Yokohama fender the following constants were used.

C_M = 1,75 (conservative assumption)

C_B = 1,0 (in view of soft fender)

V = 0,14 m/s

C_E = 0,78

where $C_E = \dfrac{J^2 + R^2 \cos^2 a}{J^2 + R^2}$

Approach Angle = 1:8 or 7,1°

COMMENT

To choose a uniform value for C_M seems to be an oversimplification of the matter.

3.9 Mettam (16) presented a paper at Leningrad in 1977 on the fender design criteria used to design three berths at Sines, Portugal.

3.9.1 Design berthing velocities used were:-

Berth	1	2	3
DWT	500 000	250 000	100 000
V_{CB} m/s	0,1to 0,15	0,15to 0,20	0,15to 0,25

These velocities are high because of the exposed nature of the berths.

3.9.2 Energy equation:-

$$E = C_M.C_B.C_E.(1/2.MV^2) \quad \text{was used}$$

$$C_E = \frac{J^2}{R^2 + J^2} \qquad (J = 0{,}21\ LOA)$$

$$C_B = 0{,}9 \qquad \text{(Yokohama Fenders)}$$

$$C_M = 1 + 2D/B$$

For the abovementioned size ships C_M varied between 1,74 and 1,85 with an average of 1,8. This was then averaged out with the following:-

Vasco Costa	1,80
Saurin	1,30
French Studies(Mean)	1,35
Sommet (Mean)	1,35
Ave	1,45

A value of 1,5 was then used by Mettam.

COMMENT

The C_M value that was used for this size of vessel seems low, but then the design approach velocities are reasonably high.

3.10 Girgrah (8) presented a paper at Leningrad in 1977 where he suggests a simpler design criterion, based on the displacement of the ship, for designing fender requirements.

3.10.1 His suggested energy equation is:-

$$E = \frac{DPL(act)}{120 + DPL(act)} \quad (tonf.m)$$

This is for end fenders.

For interior fenders the value of E should be reduced by a factor of 0,5 overall.

This equation would yield the following energy values.

DISPLACEMENT (tonnes)	E (tonf.m)
500 000	605
300 000	449
150 000	296
50 000	146
20 000	77
5 000	26
500	4

3.10.2 He then uses these values to determine permissible values for V by using the basic energy equation with the following constants.

$C_M = 1,5$

$C_C = 1$

DISPLACEMENT (tonnes)	V (m/s)
500000	0,13
300000	0,14
150000	0,16
50000	0,20
20000	0,22
5000	0,26
500	0,30

COMMENT

This seems to be an oversimplication of the matter, although values for E and V seem to agree with literature up to 1977.

3.11 Balfour, Feben and Martin (1) in 1980 analysed the berthing energy records from BP Jetties at Rotterdam. They showed that logarithmic transformation of these records yield a distribution that can be extrapolated to predict extreme probability values.

3.11.1 The berths were equipped with Raykin fenders and fender deflection was measured by a rod and slider device fixed between the front impact panel and the jetty deck.

3.11.2 Energy records were reduced to a "Unit Energy" defined as energy (tonf.inch) divided by displacement (1 000 t).

3.11.3 It was assumed that the maximum impact to be resisted will be once in a typical life time of a jetty. The base case was 100 berthings/year. If the lifetime of a jetty is taken as 30 years the probability is thus 1:3000

3.11.4 Approximately 3000 records were available for vessels from 10 000 to 280 000 t displacement. These were analysed in displacement groups.

3.11.3 For 230 000 to 250 000 t displacement ships the 1:3000 prediction was 1 tf.m / 1 000 t displacement. (see fig 3.5) For 90 000 to 115 000 t displacement) ships the 1:3000 prediction was 1,5 tf.m / 1 000 t displacement. (see fig 3.5)

3.11.5 They conclude that the design energy can be predicted by this statistical method at low risk levels. A summary of these values are depicted on fig 3.6.

COMMENT

The fact that so many berthing impacts were analysed must be of significance. The method will definately become more accurate as more prototype data becomes available. It should then become attractive to use the results in determining design berthing energies.

3.12 Bela Koman (5) in 1980 analysed fender systems at open sea berths. In his article he describes three berthing approaches which have different berthing impacts due to their eccentricities.

(a) Quarterpoint contact (mostly)

(b) Broadside contact (frequently)

(c) Midship impact (very rarely)

3.12.1 He describes how both translation and rotation have an effect when calculating the berthing impact.

3.12.2 The virtual mass of the ship is described as the displacement mass (M) plus the mass of water adjacent (M_2) which moves with the ship.

$$M_2 = LOA.D^2.\frac{\pi}{4}$$

COMMENT

"Added mass" is very much oversimplified.

3.13 In 1981 Barratt (4) performed model tests for a selection of ships to find values for the "added mass" of berthing ships.

His findings were:-

(a) The added mass coefficient is approximately 2 in deep water and rises sharply as the underkeel clearance becomes small compared with the ships draught. The added mass could be several times the ship's inherent mass at a depth/draught ratio of 1.1. (see fig 3.7)

(b) The added mass in sway is not a constant but varies with the rate of change in velocity. This variation is small in deep water but is significant for depth/draught ratios that apply generally in a berthing operation.

(c) A solid quay face increases the added mass but this is cancelled by the cushioning effect of the trapped water between ship and quay.

(d) Test results compared favourably with theoretical results.

COMMENT

It is interesting to see that the model tests show up values for C_M that are much higher than previously used.

3.14 Svendson (20) in 1981 at Edinburgh discusses the statistical approach to the calculation of fender systems. Prototype measurements are used to determine the design value of the berthing impact.

3.14.1 Because this method is based on measurements of the energies actually absorbed by the fenders it includes the effect of impact velocity, eccentricity , added mass etc.

3.14.2 One big problem with this approach is to predict energies for a new berth.

3.14.3 The analysis concentrates on the variation of impact energies with the two most important parameters namely displacement and current conditions at the terminal.

3.14 4 Hundreds of measurements of different European ports were used for the analysis. The harbours were classified in three groups according to their degree of exposure to wind wave and current forces

3.14.5 Berthing data for each type of berth is marked and plotted to show the probability of exceedance of 50% and 5% on a logarithmic normal plot. This is used to determine the frequency distribution for low frequencies of occurrence.

3.14.6 Measured impact energies E are transformed into ship energies Es by

$$Es = E\ (1 + R^2/J^2)$$

$$= E\ \left(\frac{J^2 + R^2}{J^2}\right)$$

$$= E.C_E$$

This is to account for different fender spacing and eccentricity of the fender impact.

3.14.7 From this, graphs are drawn with Es against M with 5% and 50% exceedance lines on them. (see fig 3.8)

COMMENT

This method of choosing relevant berthing energy values for a new berth does not seem to be much different from selecting the approach velocity in the analytical method.

3.15 Ball (2) discussed the concept of added mass in the "Dock and Harbour Authority" of March 1982. He suggested the following:-

3.15.1 Added mass is not a body of water moving with the ship causing surging forces but that surging forces arise from an im-balance between the rate of displacement flow forward by the ship, and the rate of return flow around and under the ship.

3.15.2 "Added mass" is a function of time and the surging force is a function of time.

3.15.3 Generally a ship will produce more fender energy if it has been slowed down just prior to impact, than if it has been accelerated before impact.

3.15.4 A closed berth presents two opposing effects:-

(a) When the ship closes in on the berth the reflected pressure wave raises the water which causes a cushioning effect.

(b) When the ship slows down the inertia of the underkeel flow lowers the level of the water between quay and ship which accelerates the ship towards the quay.

It is not apparent which of the two effects will dominate. See fig 3.9 for a schematic representation of the theory.

3.15.5 As underkeel clearances are reduced, fender energies would be expected to rise because smaller clearances will give higher underkeel velocities and the diminishing of the underkeel flow to zero will take longer. Thus the surge force, which is related to "added mass" will take longer to diminish and increase the "added mass".

3.15.6 "With the problems inherent in definition and quantification and the dangers of over-simplification, perhaps the time has come to critically examine the use of "added mass" as a parameter in data analyses and in design".

COMMENT

This has been a most understandable and sensible analysis of the concept of "added mass".

3.16 Ball and Hall (3) in October 1983 published a review of methods used to derive berthing forces.
In chapter 4 a few reports on added mass are discussed.

3.16.1 Fontijn (7) analysed the hydrodynamic effects by means of model tests and his analyses suggest that the effect of C_M is less dependent on the ship's dimensions and more on underkeel clearance and fender stiffness.
A decrease in underkeel clearance would result in higher coefficients. A typical graph of C_M is depicted on fig. (3.10)

3.16.2 Middendorp (17) analyses the flow of water around the ship approaching the quay. He suggests that the surging force causing the added mass phenomenon is only due to the difference in water level on both sides of the ship when it is decelerated by the fender. He presents curves of added mass according to underkeel clearance, and fender stiffness, see fig. (3.11)

Values for C_M are constant for consecutive berthings for the same conditions because it is related to fender stiffness and underkeel clearance.

3.16.3 Hayashi and Shirai (11) when determining C_M concentrate on the importance of underkeel clearance and the inertia of the body of water under the ship.

They prepared graphs for C_M against T/D (depth / draught) for different ship Froude No's (See fig. 3.12).

Froude number $Fr = V/(gT)^{1/2}$

V = approach velocity before fender impact.

T = water depth.

C_M is therefore dependent on underkeel clearance and approach velocity which is expressed in the Froude Number.

3.16.4 Ball and Hall (3) evaluated prototype berthing data and the values they obtained for C_M varied between 2 and 20. The high values were ascribed to inaccuracies in measuring techniques.

The ships that were monitored varied in size from

80 000 to 160 000 DWT.

(a) Approach velocities 0,1 m/s (max.)

(b) Max E = 203 tf.m

(c) Average approach angle = 0 +/- 1°

Maximum approach angle = 4,5°

Using the above conditions they then calculated C_M values according to:-

(a) Fontijn C_M = 3,5

(b) Middendorp C_M = 1,7 to 2,2

(c) Hayashi C_M = 3,8 to 7,3

COMMENT

It is interesting to note that the values of added mass have considerably changed and that the maximum values have risen to multiples of one.

3.16 Vredestein (23) Use the following method to calculate berthing energies.

3.16.1 Berthing speed is chosen from a graph which shows speeds for various sizes of ships and different types of berths. The values are based on data from literature and practice. See fig. 3.13

3.16.2 Berthing Energy

$C_M = 1,3$ {Saurin (19)}

$$C_E = \frac{J^2}{J^2 + R^2}$$

$J = 0,2$ LOA for a large tanker

$C_E = 0,5$ (aver.)

$C_B = 0,9$

$C_M.C_E.C_B = 0,6$ (aver.)

COMMENTS

Values used for V seem to be the generally accepted values.

Fender companies generally seem to regard C_M as a constant.

3.17 Lievense (15) In the design of the ore jetty at Saldanha used the following energy equation and factors.

1. The general equation for berthing energies is used, using the Vasco Costa (21) method.
2. Maximum allowable angle of approach is 1:20 = 2,9°
3. Point of contact is assumed to be at 1/4 LOA
4. Radius of gyration of ship $J = 0,2$ LOA
5. $C_M = 1,3$
6. $C_B = 0,9$
7. $C_F = 0,8$ (C_F = diversity factor).

   Only in a certain percentage of berthings will V_A exceed the normal accepted velocity.
8. Approach velocities

DWT	V_A(normal)(m/s)	V_A(allowable)(m/s)	
150 000	0,10	0,12	Small Fender
150 000	0,13	0,15	Large Fender
250 000	0,10	0,12	Large Fender
350 000	0,08	0,10	Large Fender

9. Required energy absorption

DWT	V_A(Allow)(m/s)	E(tf.m)	REQ. E(tf.m)
150 000	0,12	91	182
250 000	0,12	151	302
350 000	0,10	147	294

3.18 Kleber Industrie (13) in their fender selection guide have adopted the following method to calculate berthing impacts.

3.18.1 The energy formula used is:-

$$E = C_M.C_E.C_C.C_D(1/2.MV^2)$$

3.18.2 Added Mass C_M is described as the volume of water carried along with the ship:-

$$C_M = \frac{\pi}{4}.D^2.LOA$$

3.18.3 $$C_E = \frac{J^2 + R^2.\cos^2 a}{J^2 + R^2}$$

where J = 0,25 LOA

3.18.4 C_C takes into account the dampening effect that the water trapped between the ship and the berth has on the berthing impact.

C_C = 0,8 (solid berth)

C_C = 0,9 (semi-open berth)

C_C = 1 (open berth)

3.18.5 $C_D = 0,9$ (flexible hulls)

$C_D = 1$ (rigid hulls)

<u>COMMENT</u>

The definition of C_M is out of date.

3.19 <u>SUMMARY</u>

3.19.1 From the literature surveyed it can be seen that there are three methods for obtaining design berthing impact values.

(a) <u>Analytical Method</u>

An estimate of the ships berthing energy is made by analysing the ships motion when berthing. <u>Vasco Costa</u> (21)

The following are analysed:-

(i) Kinetic energy of ship in sway and yaw

(ii) The eccentricity at impact

(iii) Effect of added mass

(iv) Effect of ship and fender elasticity

This method is the most frequently used by engineers although it is extremely difficult to assess appropriate approach velocities and values for the coefficients.

This method was used in the design of the Saldanha Bay Ore Jetty.

(b) Empirical Method

Recordings of ship berthings are interpreted to provide simple rules for directly determining the required fender energy absorption capacity. Saurin (19) The fender energy absorption is related to the deadweight tonnage of ships that use the berth.

(c) Statistical Method

Prototype data of berthing energies are analysed and statistically represented Svendson (20). It is assumed that if enough data is available an estimate can be made of the probability of a stated fender energy being exceeded. This data automatically includes the effect of approach velocities, eccentricity at impact and hydrodynamic effects.

3.19.2 Added Mass

The definition of added mass has drastically changed over the years from a simple "volume of water flowing with a ship" to a sophisticated analyses of particle flow and surging forces around the ship.

Although it is now common knowledge that C_M cannot be expressed by a constant value and a lot of research work has been done to show that many factors like underkeel clearance, fender stiffness, approach velocities etc. have an influence on C_M the old formulae and constants are still used extensively by designers.

CHAPTER 4

COMPUTATION OF ADDED MASS COEFFICIENT OF A BERTHING SHIP

The kinetic energy of a body in linear motion can be expressed by:-

$$E = 1/2.M.V^2 \tag{4.1}$$

The motion of a berthing ship is normally more complex than is implied in Eqn.4.1 because both translational and rotational velocities are involved. Translational velocity is taken as a sway motion perpendicular to the berthing line. The parallel components are usually negligible because friction between ship and fender does not permit much motion parallel to the berth. The dynamics of a berthing ship has been analysed by many authors. Vasco Costa (21) has presented this very concisely.

Using annexure 4.1 as reference we first of all look at the momentum of the ship. The momentum of the ship just before contact with the fender, at time T_1 is equal to the momentum of the ship at maximum fender deflection, time T_2.

B_1 = Momentum at T_1

B_2 = Momentum at T_2

Just before contact (at T_1) for point A:

$$B_1 = M_T.V_{CG}.R.\sin a + M_T.J^2.W_{CG} \qquad (4.2)$$

At maximum fender deflection at T_2 for point A

$$B_2 = M_T.R^2.W_A + M_T.J^2.W_A$$

$$= M_T(R^2 + J^2).W_A \qquad (4.3)$$

Where W_A = angular speed of rotation of CG relative to A at T_2.

If no other forces are present, then

$$M_T.V_{CG}.R.\sin a + M_T.J^2.W_{CG} = M_T(R^2+J^2)W_A$$

$$W_A = \frac{V_{CG}.R.\sin a + J^2.W_{CG}}{R^2 + J^2} \qquad (4.4)$$

The loss of kinetic energy of the ship between T1 and T2 is equal to the energy absorbed by the fender.

Energy just before contact:

$$E_1 = 1/2.M_T.V_{CG}^2 + 1/2.M_T.J^2.W_{CG}^2 \qquad (4.5)$$

Energy at maximum fender deflection:

$$E_2 = 1/2.M_T.R^2.W_A^2 + 1/2.M_T.J^2.W_A^2$$

$$= 1/2.M_T(R^2 + J^2)W_A^2 \qquad (4.6)$$

Energy loss $DE = E_1 - E_2$, thus

$$DE = 1/2.M_T(V_{CG}^2+J^2.W_{CG}^2)$$
$$-1/2.M_T(R^2+J^2)W_A^2 \qquad (4.7)$$

From equation 4.4

$$(R^2 + J^2)W_A^2 = \frac{(V_{CG}R.\sin a + J^2W_{CG})^2}{R^2+ J^2}$$

$$DE = 1/2.M_T \ (V_{CG}^2+J^2W_{CG}^2) - \frac{(V_{CG}.R.\sin a + J^2W_{CG})^2}{R^2 + J^2}$$

$$= 1/2.M_T\{J^2/(R^2+ J^2)\}\{V_{CG}^2(R^2+ J^2)/J^2+$$
$$W_{CG}^2(R^2+ J^2)-(V_{CG}.R.\sin a+J^2.W_{CG})^2/J^2\}$$

$$= 1/2.M_TC_E \ (V_{CG}R^2/J^2)+$$
$$V_{CG}^2+W_{CG}^2.R^2+W_{CG}^2J^2-$$
$$\frac{(V_{CG}^2R^2\sin^2a+J^4W_{CG}^2+2V_{CG}R\sin aJ^2W_{CG})}{J^2}$$

$$= 1/2.M_T.C_E\{(V_{CG}^2R^2/J^2)(1-\sin^2a)+V_{CG}^2+$$
$$W_{CG}^2.R^2-2V_{CG}.R.\sin a.W_{CG}\}$$

$$= 1/2.M_T.C_E\{V_{CG}^2 - 2V_{CG}R.W_{CG}\sin a + W_{CG}^2.R^2 + [(V_{CG}.R.\cos a)/J]^2\} \quad (4.8)$$

V_A^1 = is defined as the representative velocity at point of impact at time T_1.

$$(V_A^1)^2 = V_{CG}^2(1 + R^2\cos^2 a/J^2) - 2V_{CG}.R.W_{CG}.\sin a + (W_{CG}.R)^2 \quad (4.9)$$

Equation 4.9 takes into account the rotational and translational components of the impact velocity.

Then: $DE = 1/2.M_T.C_E.(V_A^1)^2$ (4.10)

For $a = 90^\circ$: $V_A^1 = V_{CG} - W_{CG}^2$ (4.11)

The Eccentricity Coefficient $C_E = \dfrac{J^2}{R^2 + J^2}$ (4.12)

C_M = the virtual mass of the ship. It is equal to the mass of the ship M plus the hydrodynamic inertia or added mass M_A.

The added mass coefficient $C_M = \dfrac{M + M_A}{M}$

$$= \frac{M_T}{M}$$

$$M_T = C_M . M \qquad (4.13)$$

If it is assumed that no energy is lost due to friction between the ship's hull and the fender, the ship's hull deformation, and additional generated turbulence, then DE is equal to the energy absorbed by the fender which can be calculated from the actual deflection at impact.

Therefore, if the energy absorbed, the representative approach velocity, the mass and the eccentricity coefficient of the ship are known, equation 4.10 can be used to compute the effect of added mass C_M.

$$C_M = \frac{2.DE}{M(V_A{}^1)^2 . C_E} \qquad (4.14)$$

Equation 4.14 was used to calculate values for C_M

It was assumed that $C_S=C_D=C_B=1$. The effect of deviations of these coefficients from unity will, therefore, be incorporated in C_M.

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CHAPTER 5

INSTRUMENTATION

At the outset of the project it was intended to use certain available instruments to measure approach velocities, distances off the jetty and the energy absorbed by the fenders. As discussed briefly in chapter 2 some of the instruments proved unreliable and alternative plans had to be made to obtain reliable data. In this chapter the instruments will be described as well as their operating accuracies and techniques used to calibrate the instruments.

5.1 Instrumentation Used To Measure Approach Velocities And Distances Off The Jetty

After completion of the ore jetty a sonar docking system was installed to assist the pilots during berthing manoeuvres. The system, a "Elac pier sounder", consists of two echo sounders that are housed in a room in caisson 14 of the Ore Jetty. The echo sounder transducers are mounted horizontally under water 118,56 m apart at caisson 8 and 11. For the position of equipment see fig 5.1 and for detail of echo sounder units see fig 5.4.

During a berthing manoeuvre the echo sounder had to be switched on and the pilot could then, on a portable receiver, read the distances off the jetty at bow and stern and the approach velocities forward and aft. Due to the difficulty in activating the echo sounders and the scepticism with which the local pilots regard berthing aids the system was never used.

Calibration

When the N.R.I.O. at Stellenbosch commenced with their investigation into moored ship problems during 1982 the equipment was checked and calibrated.

The vertical scales of the echo sounders were electronically checked by simulating distances and measuring them then on the papar-trace by hand for the different scales.

Because the transducers are mounted behind the quay line the horizontal offset had to be measured. This was done by suspending a shotline down the front face of the fender board and having divers measure the distance from the shot line to the face of the transducer.

This distance differed slightly from bow to stern, but with these measurements the zero line could be established at the front of the fender board.

The horizontal time scales were calculated by running the machine for 30 minutes and then measuring the distance that the paper transported in a given time.

The calibration results are summarised in appendix 5.3

Operating Accuracies

According to the manufacturer's specification the accuracy of the distance measured is +/- 5 cm and of the velocity +/- 1 cm/s.

These inherent inaccuracies are only due to the instrumentation.

5.2 Instrumentation To Measure The Absorbed Fender Energy

The jetty is equipped with Yokohama inflatable fenders (see fig 5.1). As part of the C.S.I.R. Moored Ship Monitoring Project fenders from Caisson 6 to 12 were equipped with pressure transducers.

The pressure inside is measured, transformed into an frequency signal and relayed by cable to a recorder in Caisson 14.

The fender characteristics are known including the pressure - energy absorption relation (see appendix 5.2) Therefore, if the pressure inside the fender at any time is known the energy absorption can be derived.

Operating Accuracies

The pressure transducers are calibrated in the factory over their full range of up to 300 kPa and show an accuracy of better than 1%.

It is important that the unloaded pressure inside the fender remains constant at the design value.

Regular fender inspections are carried out to maintain constant operating pressures.

The fender data provided by the manufacturers of the fenders is also only accurate to +/- 10%.

5.3 Data Acquisition System

The C.S.I.R. data acquisition system is located in caisson 14 on the jetty together with the sonar docking system (see fig 5.5).

The data from both the echo sounders and the fender force transducers are recorded on magnetic tape. The instruments are activated and controlled by a central computer. The signals are monitored every 2 seconds and stored on tape. The data is then processed on a main frame computer at the C.S.I.R. in Stellenbosch where the events are plotted on time graphs.

5.4 Summary

The system as described would have been ideal to gather all the information required. Unfortunately the fender pressure transducers and the data acquisition system did not work as well as had been envisaged and the paper traces of the echo sounders had to be used to obtain the required information on the ship's distances, velocities of approach as well as maximum deflection of the fenders to obtain the berthing energies.

CHAPTER 6

EXAMPLE MONITORING RUN RH34

In this chapter the monitoring procedure is explained in detail. Monitoring run RH34, the arrival of ship code 026 on 1984-06-08 is used as an example.

The chapter is devided into 3 sections:-

(a) section 1 - field work procedure

(b) section 2 - processing of echo-traces

(c) section 3 - computation of data

6.1 Fieldwork

The following data was obtained during the monitoring run RH34 and filled in on a standard form (see appendix 6.1)

6.1.1 Environmental Data

(a) The wind speed and direction was obtained from an anemometer at the Port Control centre situated 2 km West of the Ore Jetty.

The position of Port Control is shown on fig 1.1

(b) The maximum wave height was obtained from a Waverider buoy which is positioned on the East side of the main entrance channel between the entrance channel buoys.

According to the designers of the jetty the wave height at the Ore Jetty is reduced to less than 20 % of the wave height in the channel

(c) The tide levels were obtained from a tide level recorder which is positioned at the South end of the Ore Jetty.

6.1.2 Loading Conditions

All the data pertaining to the loading condition on arrival was obtained from the S.A. Iron and Steel Corporation (ISCOR) at Saldanha. ISCOR control the ore loading operation and they are also responsible for the draught surveys.

(a) Draught

Draught measurements are taken on the port and starboard side at the bow, midships and stern of the ship. At least 2 people are used to make the visual observations. The average value is then rounded off to 0,01 m. The mean of the 6 draught readings is used for the loading calculations.

(b) Displacement And Deadweight Tonnages

Arrival displacement and deadweight tonnages are calculated from draughts surveyed and the ship's loading tables and given to 1 t.

According to the ISCOR personnel the accuracy of the calculated values is within 0,5 %.

(c) Centre Of Gravity

The position of the centre of gravity is not readily available because it changes with each type of loading condition. Initially it was assumed that the centre of flotation , which is readily available, is close to the position of the center of gravity. This was then used in the berthing impact calculations. After the completion of the monitoring runs the matter was again investigated and it was found that there is no correlation between the two centres. For the purpose of this study it will be assumed that the centre of gravity is at midship.

6.1.3. The Sonar Docking System

The sonar docking system situated in caisson 14 of the Ore Jetty was activated before every monitoring run. It was reasonably difficult to activate the system because it was very susceptible to aeration in the water.

The bow and stern echo traces were time marked at the start and the end of the monitoring run.

6.1.4 The Central Computer

After the sonar docking system was activated the computer had to be set up. The time and the name of the ship was entered and then the data cassettes for the sonar docking units and for the fender force transducers were activated.

At the end of the run the computer was switched off and the cassettes were sent to the C.S.I.R at

Stellenbosch for processing.

As was explained in chapter 2 the data thus obtained was of very little value.

6.1.5 Visual Observations

The following visual observations were made:-

(a) Position of ship relative to jetty at impact

The time and the position of the bow relative to the caissons upon impact was visually observed with the aid of an optical square. The distance to the nearest caisson corner was then measured. The accuracy thus obtained was +/-1 m.

The position of the shoulders of the ship relative to the fenders were also noted

(b) Fenders deflected on impact

The size and position of the fender deflected on impact was noted. On a few occasions the fenders were deflated on impact. This was very valuable information and was also noted.

6.2 Processing Of Echo-traces

The sonar docking paper-traces were used to ascertain the following:-

(a) Bow - distance off the jetty at impact.

(b) Bow - approach velocity

(c) Stern - distance off the jetty at impact.

(d) Stern - approach velocity.

All the distances were scaled off. Because all the scales were not standard a program was written for the HP-11C programmable calculator to convert scales and to convert horizontal distances into actual time and vice-versa. Appendix 6.2 contains a copy of the program.

Figure 6.3 is a copy of the echo-traces of run RH34

The following points were marked on the traces at the same real time.

(a) Where the fender line intersects the echo-line is the first point of contact (point 2). Because it was a bow first approach the bow transducer trace was used first.

Both the time and distance off the fender board were measured for point 2.

The point corresponding with the time of point 2 was then marked on the stern trace and the distance off the fenderboard was scaled off.

(b) The point of maximum deflection then marked on the bow trace (point 3).

The corresponding point was also marked on the stern trace.

Distances to the fender board were then scaled off.

(c) To calculate the approach velocities just before impact the gradient of point 2 was established.

A gradient line was drawn through point 2 on both the bow and stern traces and a suitable point 1 was chosen. The time and distance off the fender board was then scaled off for point 1.

The above mentioned procedure could be used when the impact occurred at the caisson where the echo sounder was situated, as was the case with run RH34.

Where the first impact occurred at a point one caisson away, the point of first impact had to be established using geometry. See appendix 6.4 and fig 6.4.

6.3 Computation Of Berthing Energies And Added Mass

All the information was then transferred to a IBM-PC computer to be processed further . The software used was Lotus 1-2-3 which is a spreadsheet program with data-processing, statistical and graph-drawing capabilities.

In this section the processing of the data on the computer will be discussed.

6.3.1 Berthing Energies

The maximum deflection values obtained from the echo-traces were divided by the diameter of the fenders to calculate the % deflection. Using the manufacturers' performance tables the energy absorption could thus be obtained.(fender performances are tabled in appendix 5.2)

The angle of approach was then used to ascertain whether any other fender was deflected on impact and the deflection and energy absorption was calculated as explained.

In the cases where the fenders were deflated on impact the 55 % deflection energy absorption figures given in the tables were used. This was the case for the first impact of Run RH34.

6.3.2 Approach Velocities

The approach velocities of both bow and stern on impact were calculated by dividing the distance between points 1 and 2 on the echo-traces by the time taken from point 1 to 2.

6.3.3 Angle Of Approach

The angle of approach is the angle that the ship forms with the line of the fenders just before impact.

This angle (b) is equal to the arctan of the difference in distances between bow and stern of point 2 divided by the distance between the bow and stern transducers.

Approach velocities towards the quay are positive and those away from the quay are negative.

6.3.4 Rotational Velocity Of The Ship At Point Of Impact

The rotational velocity W_{CG} is equal to the arctan of the difference in approach velocities at the bow and stern transducers divided by the distance between the two transducers.

For the bow first impact the anti clockwise rotational velocity is assumed to be positive.

For the stern first impact the clockwise rotational velocity is assumed to be positive.

6.3.5 Radius Of Gyration Of Yaw Relative To The Centre Of Gravity

From the literature survey it became clear that the generally accepted equation used was 0,2 times the length overall of the ship.

6.3.6 Distance Between CG And Point Of Impact

The distance between the centre of gravity and the point of impact (R) as well as the angle that the approach velocity through the centre of gravity (V_{CG}) forms with the point of impact is derived in Appendix 6.5.

6.3.7 The Eccentricity Coefficient

The eccentricity coefficient (C_E) accounts for the fact that the point of impact is not at the centre of gravity and therefore the fender is not required to absorb all the ship's energy.

$$C_E = \frac{J^2}{R^2 + J^2}$$

6.3.8 Approach Velocity Of The CG

From the approach velocities at the bow and stern transducers the approach velocity of the centre of gravity was calculated. The way in which this was done is shown in appendix 6.6.

6.3.9 Representative Velocity Component At The Point Of Impact

The representative velocity component (V_A^1) includes the effect of translation and rotation at the point of impact and is derived in chapter 4, Eq. (4.9).

6.3.10 Added Mass Coefficient

The equation for the added mass coefficient is also derived in chapter 4 and is given in equation 4.14 Because all the variables in equation 4.14 are available the value for C_M can be calculated.

The actual values obtained for the first bow impact of run RH34 and the formula used in the spreadsheet are given in appendix 6.7.

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CHAPTER 7

ANALYSES OF DATA

This chapter contains all the data that was gathered and a discussion of the results that were obtained.

50 Ships were monitored, but only 25 yielded complete sets of data.

7.1. Loading Conditions

The loading conditions on arrival of the monitored ships are listed in appendix 7.1. The following conclusions can be drawn from the available data.

(a) Displacement Tonnages

From the arrival-displacement distribution given in appendix 7.2 it can be seen that 30% of the ships monitored had arrival displacements of between 100 000 to 120 000 t. 80% of the vessels arrived with displacement tonnages of 60 000 to 160 000 t. These vessels all arrived in ballast.

The remaining 20% of the ships arrived partially loaded with displacements ranging between 160 000 to 263 000 t. Ship code 007, Run RH7, arrived partially loaded with the largest displacement of 263 063 t.

The arrival draughts ranged between 7,9 to 18,42 m.

(b) Deadweight Tonnages

A comparison is made between arrival- and maximum deadweight tonnages in appendix 7.3.

Thirty-eight percent of the ships arriving had a actual dwt of 60 000 to 80 000 t. Sixty- four percent of the ships had a maximum DWT of between 100 000 and 160 000 t.

(c) Draughts

Appendix 7.4 compares the maximum and arrival draughts of the monitored ships.The arrival draught of six ships was over 16 m. Ship code 027, run RH37, had the deepest arrival draught of 18,42 m.

The arrival draughts mainly ranged from 8 to 11 m.

7.2 Weather And Sea Conditions

The weather and sea conditions that prevailed during the monitoring runs are listed in appendix 7.5.

(a) Wind

The windrose (fig. 7.6) depicts the prevailing winds for Saldanha.

The orientation of the jetty is N.N.E/S.S.W, therefore only the prevailing S.E and S.S.E winds will blow a ship towards the jetty. The N.N.W - W.S.W winds will have the opposite effect of keeping a ship away from the jetty.

To establish the magnitude of the wind force acting on a large ship the Standard Building Regulations code of practice for assessing wind loads on buildings was used. This equation is described in appendix 7.7 where it is also used to determine the wind forces acting on run RH36, ship code 027 which accounted for the worst case.

The lateral force thus obtained was 108 tf. This is a significant force and must have a direct influence on the berthing impact forces. For the purpose of this research this was not taken into account. It can be noted that although no complete set of data is available for this run a bow approach velocity of 0,2 m/s was measured, which is very high.

The wind therefore could have had an influence on this berthing manoeuvre.

(b) Swell

The highest swell reading recorded was 4 m. This condition prevailed on 1983-08-06 with the arrival of the ship code 013. Alongside the jetty the swell is less than 20% of that recorded in the entrance channel. Because the swell runs parallel to the jetty it should not influence the berthing force directly. The swell does have an influence on the handling of the ship and therefore indirectly effects the berthing operation.

(c) Currents

The C.S.I.R have measured the currents running perpendicular to the jetty, but no significant values have been recorded. Currents should therefore not have any influence on the berthing manoeuvre.

7.3 Other External Forces Acting On a Ship

(a) Tug Forces

Voith-Schneider tugs with a bollard pull of 43 t are used to assist with the berthing of vessels at Saldanha. The arrival draught determines the number of tugs to be used.

Arrival draught	up to 15 m	2 tugs
Arrival draught	15 m to 18 m	3 tugs
Arrival draught	18 m and deeper	4 tugs

Although 4 tugs may be used for the berthing manoeuvre only two are used to push the ship alongside.The other one or two are used to restrain the lateral movement of the ship.

The maximum force that two tugs can exert on the ship is 86 t but the influence on the berthing force through the ship is complex and was not studied in this report.

(b) Mooring Line Forces

At Saldanha mooring lines are not used to pull the ship towards the jetty. The first impact was therefore not influenced by the mooring lines.

7.4 Pilots

The name of the pilot responsible for the berthing operation was recorded for every monitoring run. Their names are coded and appear in appendix 7.5.

Appendix 7.8 is a plot of the approach velocities versus pilots.

Comments

(a) On four occasions fenders were deflated on impact. These are also depicted on the graph. On two of these occasions the pilot(3) was very experienced and on the other two they were not experienced.

It can be seen that the approach velocities on three of the occasions were in the region of 0,2 m/s which is very high. The arrival displacements in the above mentioned instances were less than 110 000 t. It seems therefore that the lighter ships are not handled as carefully as the bigger ships. This is dangerous because a light ship with a high approach velocity can induce large berthing forces.

(b) *From the graph it can be noticed that no single pilot* is responsible for high approach velocities.

7.4 Berthing Data

The berthing data of the first bow impact is listed in appendix 7.9 and 7.10.

7.4.1 Angle Of Approach

The approach angles are depicted on appendix 7.11

The angle of approach used in the design calculations of the jetty was 2,9º. This was exceeded on three occasions and on three occasions it came within 15% of the design limits.

With run RH42 the approach angle was 7,9º. With the angle being so large the ship came very close to the fender board at caisson 12.

The impact deflated the large fender at caisson 12. The impact energy was 3167 kN.m which was the largest that was recorded.

It is interesting to note that the pilot on that occasion was an experienced person.

The second largest approach angle also resulted in a high berthing impact.

(a) Approach Angle Versus Berthing Energy

Appendix 7.12 depicts a graph of approach angles versus energy absorption. The correlation coefficient of the regression line is 0,3 and the trend is positive. The equation of the regression line is:-

$$y = 0{,}00041x + 0{,}925.$$

Normality was assumed because 80% of the data falls in the interval of 1 standard deviation from the average. The regression line can be accepted at 5% level of confidence.

Comments.

The results seem to indicate that berthing energies will increase with the increase in approach angles.

Pilots should therefore be very careful when

of

approaching the jetty with large approach angles because they tend to increase the berthing impact and because there is a good chance of hitting the jetty especially when the impact is not on the shoulder of the ship. In the case of run RH42 the impact was on the shoulder of the ship which may have prevented an accident.

7.4.2 Approach Velocities

(a) Comparison Between Translation And Rotation

The approach velocity has two main components namely translation and rotation.

In appendix 7.13 the approach velocity $V_{CG} - W_{CG}.R$ is plotted against the translational velocity of the centre of gravity V_{CG}.

From the graph the following is evident:

(1) Approximately 75% of the points plotted lie above the 45° datum which means that the translational velocity in those cases are enhanced by the effect of the rotational velocity.

(2) Where the rotational velocity reinforces the translational velocity it does so by up to 144%.

From the results obtained it seems that tugs deliberately push on the bow end of the ship to ensure firm contact with the fender at first impact. In these cases the effect of rotational velocity is to reinforce the translational velocity.

Comment

It has been suggested that in order to reduce approach velocities the first fender impact should be made in such a way that the effect of the rotational velocity is to oppose the translational velocity.

(b) Approach Velocity Versus Displacement

Appendix 7.14 depicts the relationship between approach velocities and the displacement of the ship.

The correlation coefficient is 0.46 and there is a negative trend. The equation of the regression line is:-

$$Y = -0{,}00047X + 0{,}182$$

Normality was assumed because 70% of the data falls within the interval of 1 standard deviation of the average. The regression line can be accepted at a 5% level of confidence.

It can be assumed that the approach velocity decreases with the increase in displacement. This agrees with the general trend found for design approach velocities in literature.

Comment

Some of the berthing velocities of the lighter ships were dangerously high. Pilots should take more care when berthing light ships.

(c) Approach Velocity Versus Fender Energy

In appendix 7.15 approach velocities are plotted against the energy absorbed by the fenders on impact. The correlation coefficient was 0,54 and the regression line shows a positive trend. The equation of the regression line is:-

$$Y = 0{,}0000476X + 0{,}069$$

Normality was assumed because 80% of the data falls within 1 standard deviation of the average. The regression line can be accepted at 2,5% level of confidence.

The trend indicates that for an increase in approach velocity there is an increase in fender energy.

Comment

If one examines the energy equation one would have expected that the gradient of the curve should have been steeper because the square of the approach velocity is used to determine the energy. The reason for this trend could be that pilots tend to be more careful when handling larger vessels.

(d) Approach Velocity Versus The Added Mass Constant

In appendix 7.16 approach velocities are plotted against the added mass coefficients. The regression line indicates a negative trend with a correlation coefficient of -0,47. The equation of the regression line is:- $Y = -0{,}0139X + 0{,}175$

Normality was assumed because 72% of the data falls in the interval of 1 standard deviation of the average. The regression line can be accepted at 5% level of confidence.

The graph suggests that the added mass coefficient decreases with an increase in approach velocity.

Comments

It is not clear whether there is any significance in this result.

(e) Design Versus Actual Approach Velocities

In appendix 7.17 the actual approach velocities are compared with the allowable design approach velocities. The approach velocities used are a combination of translation and rotation at the point of impact.

The design velocities are different for small and large fenders and this was taken into account. The size of the fender that was deflected on first impact was noted.

The graph shows that 32% of the approach velocities exceeded the allowable design velocities.

Comments

The fact that such a large percentage of the recorded approaches exceeded the design limits is alarming.

7.4.3 Berthing Energies

The actual deflection of the fenders on impact were calculated from the sonar docking readings and the energy absorbed was obtained from the manufacturer's fender performance tables.

(a) Actual Versus Design Berthing Energies

In appendix 7.19 the actual berthing energies were compared with the design energies. The design energies were obtained by using the following equation:

$$E = 0,042 * DWT * V^2 \qquad \text{Lievense (15)}$$

The actual approach velocities and deadweight tonnages were used.

In a large number of impacts the actual impact energies exceed the design energies.

On 4 occasions fenders were deflated on impact. In three instances the fenders were small and once a large fender was deflated.

Comments

From the graph it can be noted that some of the berthing energies are very high. The method that was used to calculate the fender energies was not very accurate and therefore the values obtained may be inaccurate. In the cases where the fenders were deflated the values obtained should be within the manufacturers performance table limits.

(b) Comparison With Statistical Approach Values

Svendsen (20) statistically analysed the berthing energies recorded at several ports in Europe and classified them in three groups with varying degrees of exposure to currents.

In appendix 7.18 the berthing energy results obtained at Saldanha are compared with the design values given by Svendsen for a type C berth. This type berth was chosen because it constituted the highest degree of exposure.

The fender energies were transformed into ship energies by means of the following equation.

$$Es = Ef * 1/C_E$$

Es = Ship energy and Ef = fender energy.

The energies thus derived were very high. More than 50% of the points plotted were above the 5% exceedance limit line.

Comments

From the results it seems that the values obtained in Europe do not compare well with those obtained at Saldanha. The first reason could be that the degree of exposure is not the same. Saldanha is regarded as an exposed port and therefore not really the same as Svendsens' classification of a type C port.

Secondly it could be that some of the values obtained at Saldanha are too high due to the inaccuracies in the measuring technique.

7.4.4 The Added Mass Constant

(a) Actual Versus Design Values

In appendix 7.20 and 7.21 the most popular formula for added mass were used and compared with the actual results obtained at Saldanha.

As the standard formula are related to ship dimensions they do not vary much but only range between 1 and 2. However the C_M values obtained at Saldanha ranged between 1 and 8 with one extreme value of 16.

The maximum value of 16.27 was obtained with run RH42. The berthing energy was 3167 kN.m, also the highest recorded. (A large fender was deflated on impact). The approach velocity was also near the design limits. Because the C_M value for run RH42 was so much higher than the other values obtained it was not included in the graphs.

The values obtained for Saldanha were very high, but they compare well with prototype data obtained by Ball and Hall(3).

(b) Added Mass Versus Displacement

In appendix 7.22 the added mass coefficients were plotted against the displacements of the vessels. The regression line depicts a positive trend with a correlation coefficient of 0.49. The equation of the regression line is:-

$$Y = 0{,}017X + 1{,}57$$

Normality was assumed because 72% of the data falls in the interval of 1 standard deviation from average. The regression line can be accepted at 5% level of confidence.

From the graph it seems that the value of the added mass coefficient increases with an increase of the displacement.

(c) Added Mass Versus Berthing Energy

In appendix 7.23 the added mass coefficients were plotted against the berthing energies recorded.

The trend of the regression line was positive with a correlation coefficient of 0,3

The equation of the regression line is:-

$$Y = 0{,}00082X + 2{,}94$$

Normality was assumed because 69% of the data falls in the interval of 1 standard deviation of the average. The regression line can be accepted at 0,5% level of confidence.

The graph indicates that the added mass coefficient increases with the increase in berthing energy.

(d) Underkeel Clearance Versus Added Mass

In appendix 7.24 the underkeel clearance is plotted against the added mass coefficient.

The trend of the regression line was negative with a correlation coefficient of -0,54

The equation of the regression line is:-

$$Y = -2{,}12X + 8{,}69$$

Normality was assumed because 85% of the data falls in the the interval of 1 standard deviation from average. The regression line can be accepted at a 5% level of confidence.

The trend of the graph indicates that for a increase in underkeel clearance there is an decrease in added mass. The tendency agrees with some of the results obtained in literature.

The research done by both Middendorp (17) and Hayashi and Shirai(11) indicates that the values for added mass increases with the decrease in underkeel clearance. Their results indicate especially large increases in added mass for values of water depth / draught ranging between 1 and 1.3.

Unfortunately the results obtained in Saldanha for water depth / draught only begin at 1.3.

Comments

It is interesting to notice that the trend of the graph agrees with that found in literature even though underkeel clearance is not such an important factor in Saldanha because most of the ships arrive in ballast.

CHAPTER 8

EVALUATION OF YOKOHAMA FENDERS

The Ore-Jetty was originally designed for Yokohama inflatable fenders.

The main advantages of the pneumatic fenders are as follows:-

(a) High energy absorption and small reaction force.

(b) Low surface pressure.

(c) Suitable for inclined berthing. The performance of the fender is not impaired.

(d) The fender floats and therefore the contact of ship and fender is always on the water line.

(e) The fenders are relatively easy to install.

(f) Reliability. Even if the 55% deflection limit is exceeded and the release valve starts releasing air the fender will still continue absorbing energy.

Some of the disadvantages are:-

(a) The fenders do not dissipate a lot of energy and therefore the ship on impact is bounced off the jetty resulting in more impacts.

(b) Relatively high maintenance costs. The annual cost to maintain one fender is in the order of R3000. In addition the fender pressure has to be checked regularly.

Performance of fenders on the jetty.

Since the fenders were installed on the jetty some 9 years ago they have performed extremely well.

The jetty has not yet been damaged due to a berthing impact and only once was a fender destroyed on impact. From an eye-witness account the only conclusion that could be arrived at was that the approach velocity was too high. The release valve on the fender opened but because the berthing force was too great for the small fender it exploded. Fortunately the adjacent fenders absorped the remaining energy and the the jetty structure was not damaged.

The layout of the fenders on the east side of the jetty is depicted on fig 5.1.

During the research project the position and size of the fender that was deflected, as well as instances where fenders were deflated on first impact were recorded.

Because of the fact that a large number of impacts occurred on the small fender at caisson 11 and because it was deflated twice, the fender was changed with the large fender at caisson 13 during August 1984.

Four fenders were deflated during the time of monitoring.

These cases will now be discussed:-

(a) Run RH34

Ship code 026 arrived on 1984-06-08 with a diplacement of 108 367 t. The resultant approach velocity on impact was 0,23 m/s. The small fender at caisson 11 can according to the manufacturer's design tables accommodate a 150 000 t ship with an approach velocity of 0,15 m/s.

The approach velocity is used as V^2 in the energy formula and therefore the effect of the increase in approach velocity is severe on the berthing energy.

From the above it can be seen that the fender deflated because the approach velocity was very high resulting in a high berthing force, E = 1 643 kN.m.

(b) <u>Run RH39</u>

Ship code 028 arrived on 1984-08-03 with a displacement of 99 262 t. The representative approach velocity on impact was 0,29 m/s.

As was the case with run RH34 the fender at caisson 11 was deflated, E = 1 942 kN.m.

The reason was the same. The approach velocity was much higher than the allowable.

(c) <u>Run RH42</u>

Ship code 030 arrived on 84-08-20 with a displacement of 100869 t. The resultant approach velocity on impact was 0,14 m/s and the angle of approach was 7,86°.

The large fender at caisson 12 was deflated on impact, E = 3 167 kN.m.

The approach velocity was slightly higher than the allowable but the angle of approach was very much larger than allowable.

The added mass calculated for this run was also the highest during the study. It is not very clear why the impact was so great, but possibly there was a forward velocity component which could not be brought into the calculations but which could have had an influence on the impact.

(d) Run RH47

Ship code 032 arrived on 1984-11-08 with a displacement of 78 529 t. The bow transducer velocity on impact was 0,20 m/s. The first impact was out of position on the small fender at caisson 13.

The approach velocity was again more than the allowable and this caused the large impact, E = 1 555 kN.m.

It should be noted that had the impact occurred at caisson 11 or 12 the large fender there would in all probability not have been deflated.

Conclusions

In the above four cases the fenders were severely tested but no fender was damaged. The effectiveness of the pneumatic fender over several years has definitely been proven.

From some of the fender literature that was surveyed it does not seem as though any fenders are available which could replace the pneumatic fenders installed at Saldanha.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

This chapter contains a summary of the conclusions that can be drawn from the analyses of the data in the preceeding chapters as well as some recommendations.

9.1 Conclusions

9.1.1 Loading Conditions

(a) Displacement

The majority of vessels using the Ore-Jetty arrive in ballast and 80% of the monitored ships' displacements ranged between 60 and 160 kt. Although 20% of the monitored ships were partly laden with displacements ranging between 160 and 263 kt, this tendency has changed over the past year . More lighter ships are now coming into Saldanha. Because the mass of the ship has a big influence on the berthing energies the maximum design limits are very seldom tested.

(b) Draught

From literature it is apparent that underkeel clearance greatly affects the added mass of a berthing ship. Because of the shallow arrival draughts small underkeel clearances are not a major factor at Saldanha.

9.1.2 Weather conditions

(a) Wind

The effect of wind force was only analysed for the worst case (run RH36). The resultant wind force acting on the ship on that occassion was 108 tf. The bow approach velocity was 0,2 m/s which is high.
The wind forces acting on a ship can be significant and must be taken into account by the pilot during a berthing manoeuvre.

(b) Swell

The swell at the jetty runs parallel to it and therefore does not directly influence the berthing force. The wave height is greatly reduced by the time it reaches the jetty but because it still contains a large amount of energy it does have an effect on the handling of the ship.

9.1.3 Other External Forces Acting On The Ship

(a) Tug forces

The maximum force that can be excerted on a berthing ship by tugs at Saldanha is 86 tf. This is a significant force and must have an effect on the berthing energy but it was not studied in this report.

(b) Berthing line forces

The berthing lines are not used to pull the ship towards the jetty on first impact and therefore have no influence on the berthing impact.

9.1.4 Pilots

No evidence was found to believe that only certain pilots are responsible for high berthing impacts.

The results show that the average approach velocities are very much the same and that both experienced and in-experienced pilots are responsible for high berthing impacts (appendix 7.8)

There seems to be a tendency for pilots to handle small ships less carefully than large ships. This is very dangerous because a small ship with a high approach velocity can result in a large berthing impact.

9.1.5 Berthing Data

(a) Angle of approach

The design approach angle was only exceeded on three occasions (appendix 7.12).

The largest approach angle resulted in the highest berthing energy. On that occasion a large fender was deflated.

The available data indicates that the approach velocity increases with an increase in the angle of approach.

From the above it can be seen that it very important not to exceed the design limits.

(b) Approach velocities

1. Rotation and translation

A comparison between translational and rotational velocities of the centre of gravity indicates that in approximately 75% of the runs the translational component was enhanced by the rotational component (appendix 7.12).

It is therefore important that the rotational component be included in the berthing impact calculations.

2. Approach velocity versus displacement

The data indicates that the approach velocity decreases with the increase in displacement (appendix 7.13). This would support the theory that larger vessels are handled more carefully than smaller vessels.

3. Approach velocity versus fender energy

The trend of the graph indicates that for an increase in approach velocity there is an increase in fender energy (appendix 7.15).

4. Approach velocity versus added mass

The graph indicates that the added mass coefficient decreases with an increase in approach velocity (appendix 7.16). No conclusions can be drawn from this result.

5. Design versus actual approach velocities

Thirty percent of the measured approach velocities exceeded the design limits (appendix 7.17).

This is an alarming tendency.

(c)

Berthing Energies

A comparison of actual and design berthing energies shows that 32% of the monitored berthing energies exceeds the design energies. On four occasions fenders were deflated on impact (appendix 7.18).

(d) The Added Mass Coeficient

1. Actual versus design values

The values obtained at Saldanha ranged from 1 to 8. In 76% of the runs the value calculated exceeded the value used by the designers of the jetty. Although some of the values obtained were very high it still looks as though a constant of 1,3 is far too low (appendix 7.21).

2. Added mass versus displacement

The results indicate that the added mass coefficient increases with an increase in the displacement of the ship (appendix 7.22).

3. Added mass versus berthing energy

The results indicate that the added mass coefficient will increase when the berthing energy increases (appendix 7.23).

4. Added mass versus underkeel clearance

The trend of the graph indicates that for a decrease in underkeel clearance there is an increase in added mass (appendix 7.24).

This result is in agreement with trends found in literature.

9.2 Recommendations

9.2.1 Measurement Techniques

(a) Ultrasonic berthing aids seem to be adequate to measure distances off the jetty and approach velocities. The problems encountered at Saldanha were mainly due to the age of the equipment.

Processing the echo trace by hand is not very practical and very time consuming. Digitising the echo trace is a solution to the problem. Such a facility has been developed by the C.S.I.R at Stellenbosch.

(b) It is important to measure the actual impact energy. For a pneumatic fender a pressure sensor as described in chapter 5 is a very accurate way to measure the impact. Unfortunately this was not functioning at the time of the project.

(c) Ideally the fender energies and the berthing aid data should be recorded by a central processing unit as was described in chapter 5. The different parameters are then recorded on the same time scale and can be easily studied.

(d) The position of the centre of gravity is not readily available because it has to be calculated for each loading condition. If a ship is fully laden this is not such a problem because the centre of gravity is very close to midships but when the ship is in ballast and out of trim as is often the case at Saldanha, *it makes quite a differance. It is* therefore important to obtain the position of the centre of gravity.

9.2.2 The Berthing Manoeuvre

Approach velocities were generally high. This increases the berthing energies that have to be absorbed by the fenders on impact.

The results indicate that smaller ships are not handled as carefully as the larger ships. Pilots should take care that the design approach velocities are not exceeded even for smaller ships.

The results clearly indicate that larger approach angles result in larger approach velocities. Pilots should therefore take care not to exceed the design approach angle.

The results indicate that it would be safer if the first impact was against a large fender. Care must be taken that the ship is not berthed out of position which may result in a small fender being deflated.

9.2.3 Added Mass Coefficient

Added mass could not be clearly related to any known parameter although certain trends were established. No specific formula or fixed value for C_M could be established for Saldanha. It seems as though the design value of 1,3 is very low if one compares it with the results. The results seem to indicate that the value used for C_M should be increased but it is not clear how or by how much.

From the literature surveyed it is clear that research work indicates that larger values should be used for C_M.

Until this can be proved adequately designers will probably continue using the old established values and formulae.

9.2.4 Fendering

The jetty was designed for pneumatic fenders and from the literature surveyed it does not seem as though any other type fender could replace the existing fenders.

9.2.5 Further Research

It would definitely be of benefit to do some more prototype measurements at Saldanha with the recommended improvements in measurement techniques as described in 9.2.1

Statistically and in terms of accuracy one would then be in a better position to try and establish values or a formula for added mass.

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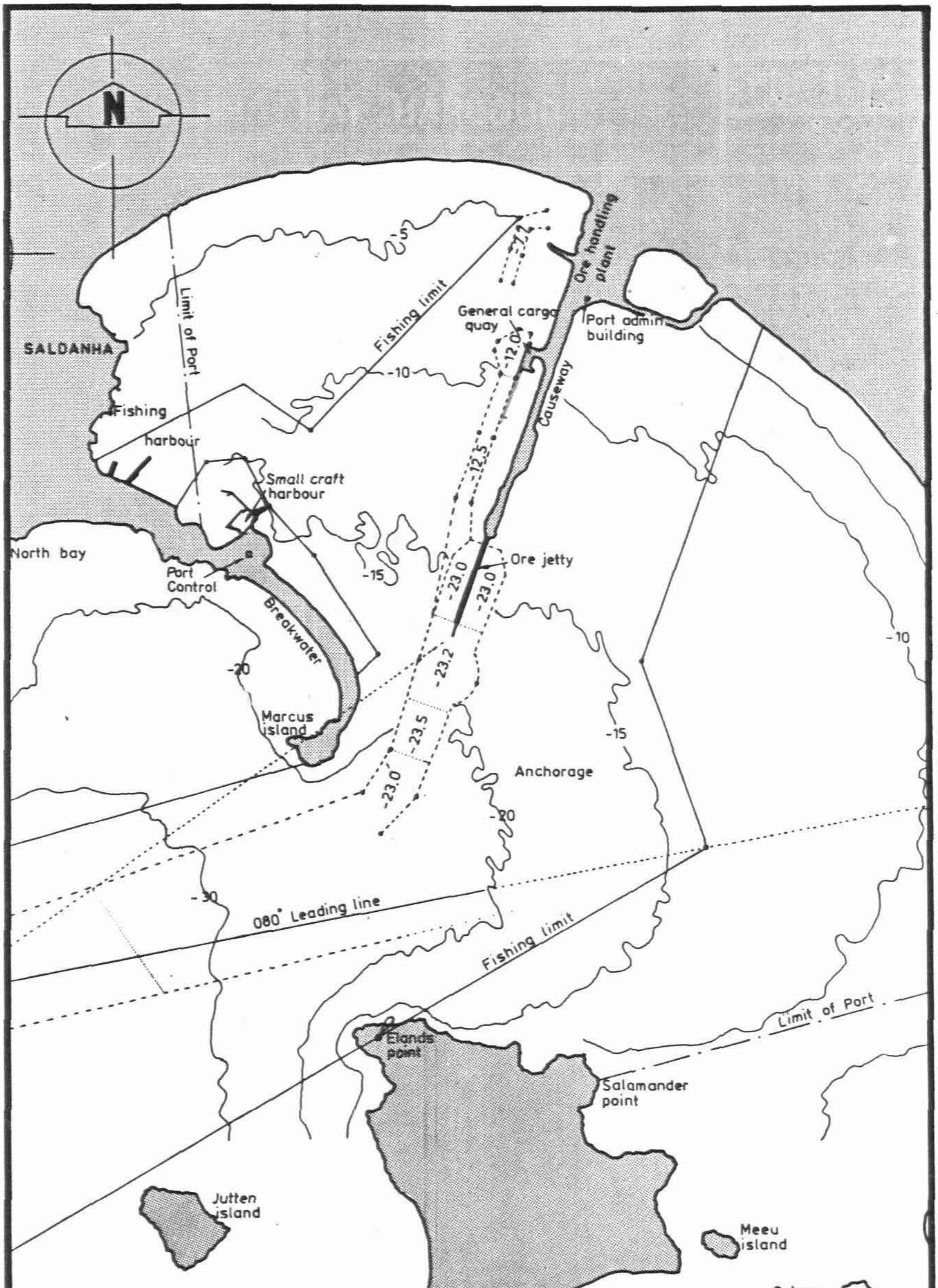
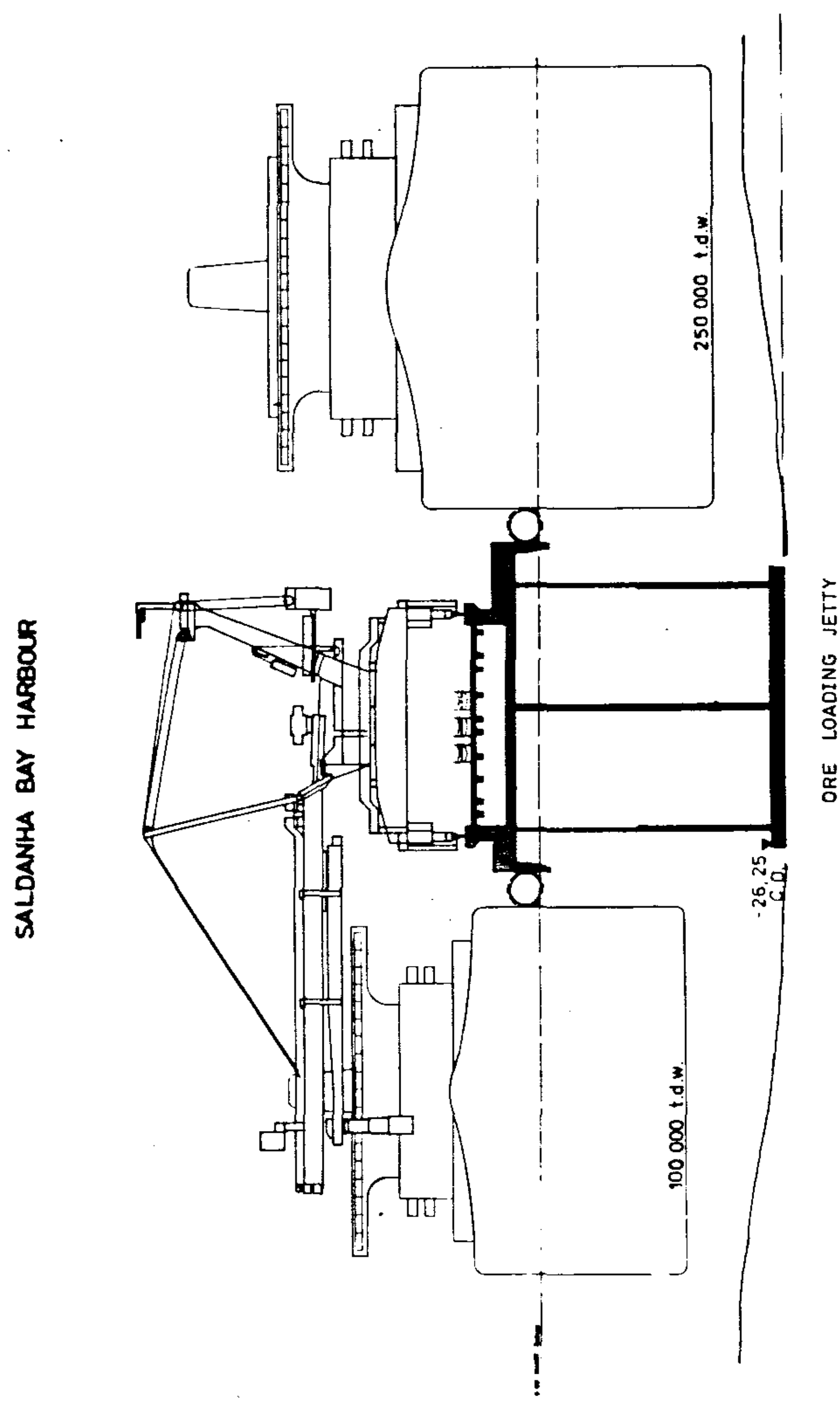


SALDANHA BAY HARBOUR

Fig 1.1



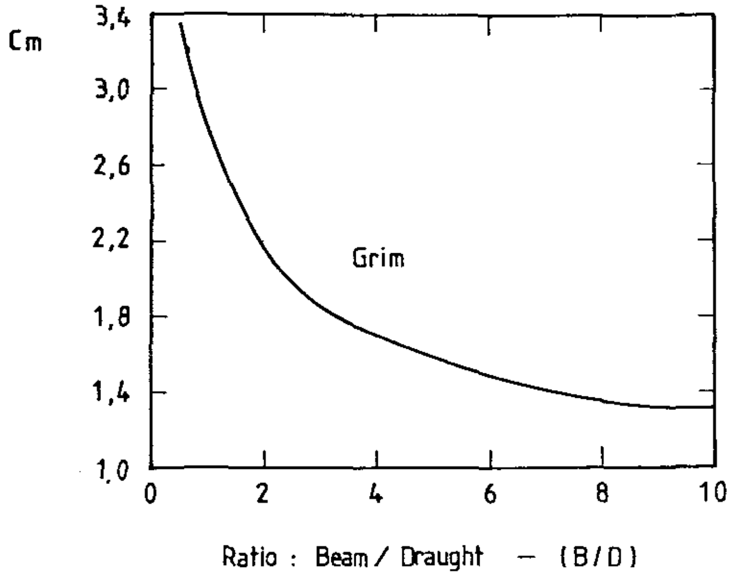
CROSS - SECTION SALDANHA JETTY

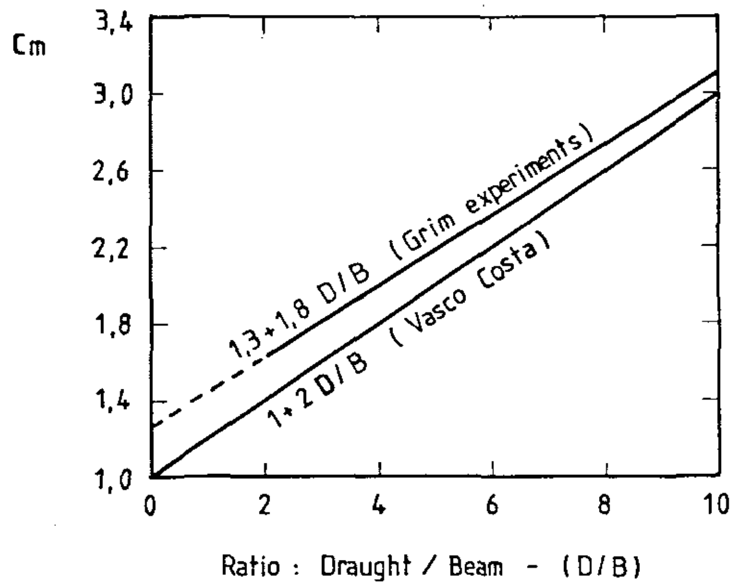
Fig 1.2

(Appendix 2.1)

WORK PROGRAMME.

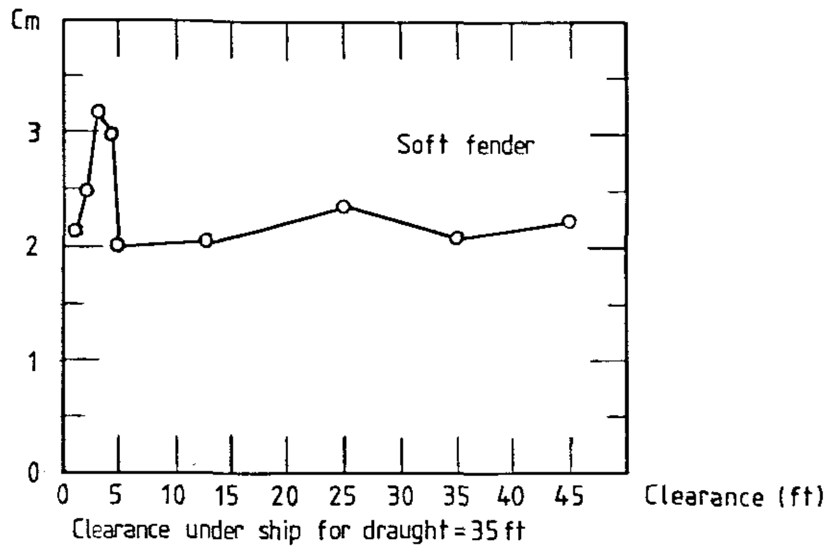
	DESCRIPTION	1982	1983	1984	1985	1986
1	Literature study	*****	**			
2	Approval of project		*****			
3	Monitoring stage 1	*	*******			
4	Monitoring stage 2		**	**********	*	
5	Design of calc sheets			*****		
6	Processing echo trace			**		
7	Processing on computer			**	*****	
8	Writing of report				******	********



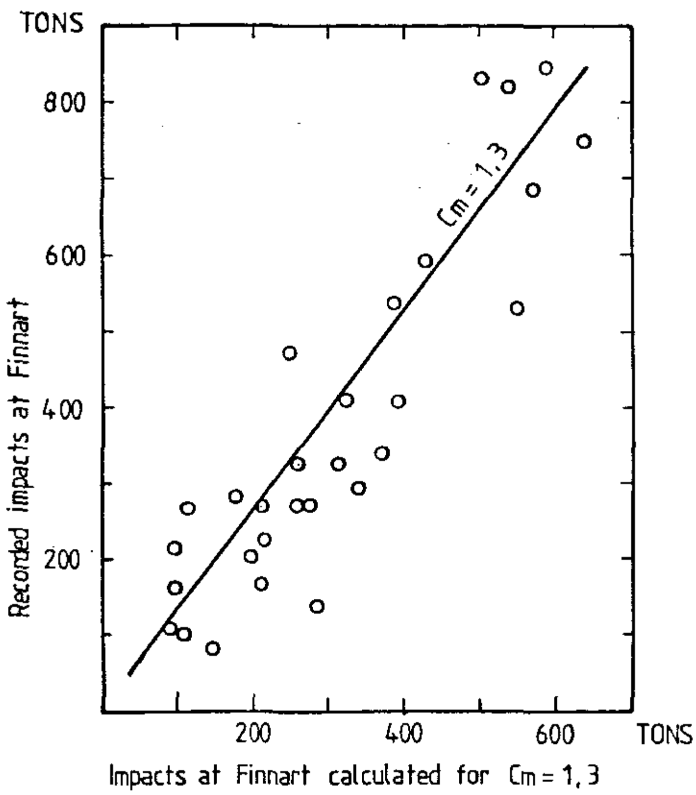


Cm ACCORDING TO COSTA, GRIM

Fig 3.1

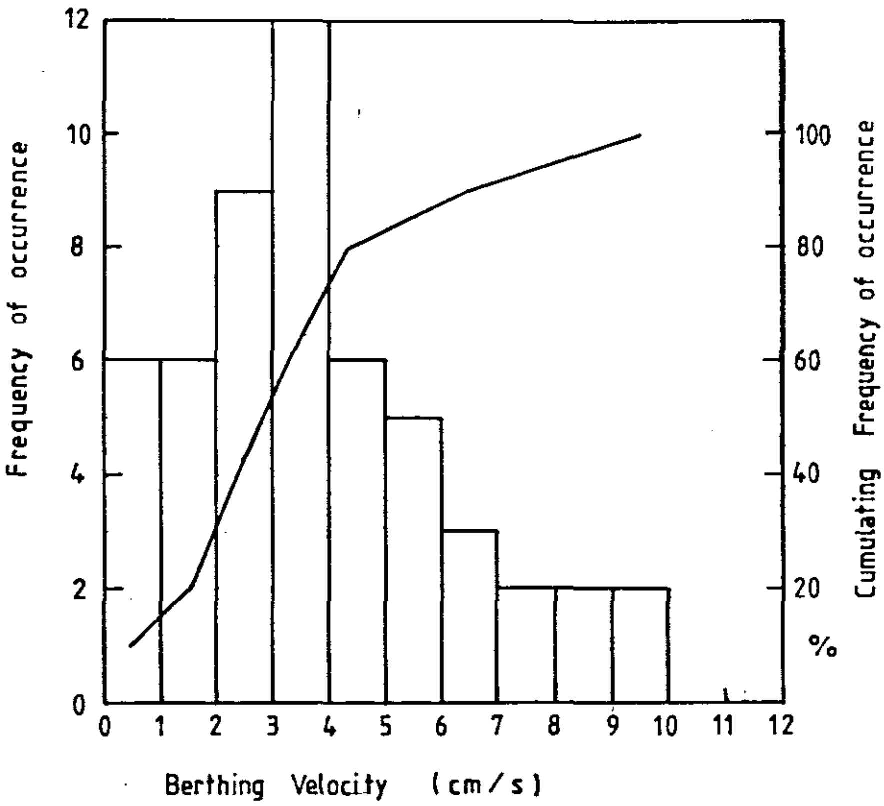


SAURIN (19) MODEL TESTS



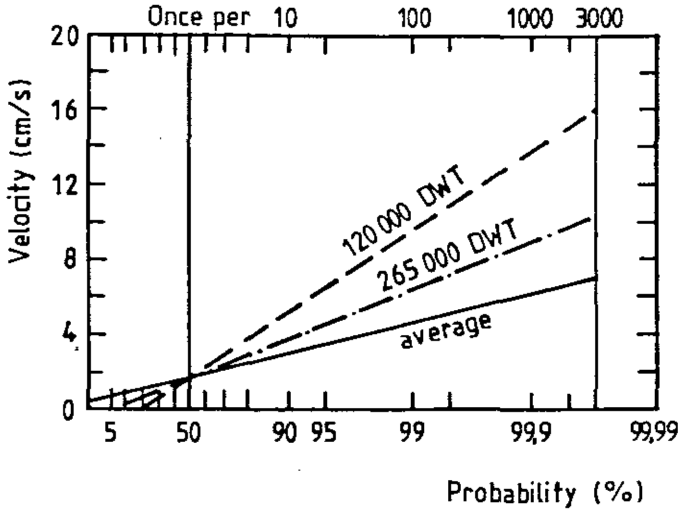
PROTOTYPE OBSERVATIONS AT FINNART

Cm ACCORDING TO SAURIN	**Fig 3.2**

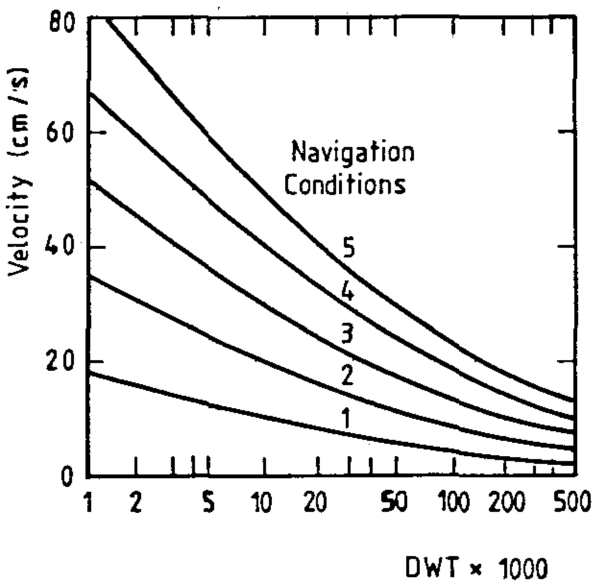


BERTHING VELOCITIES - JAPAN 1972

Fig 3.3



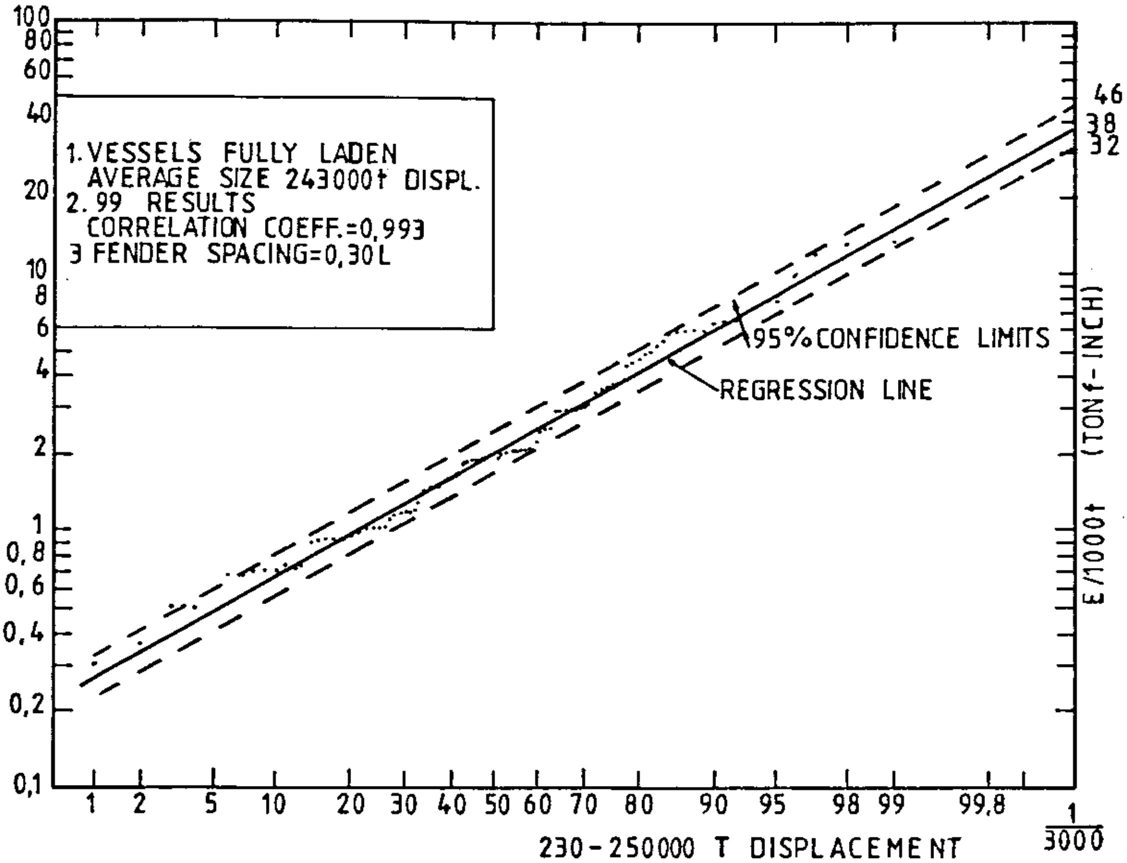
Probability of berthing velocity as function of size of tanker

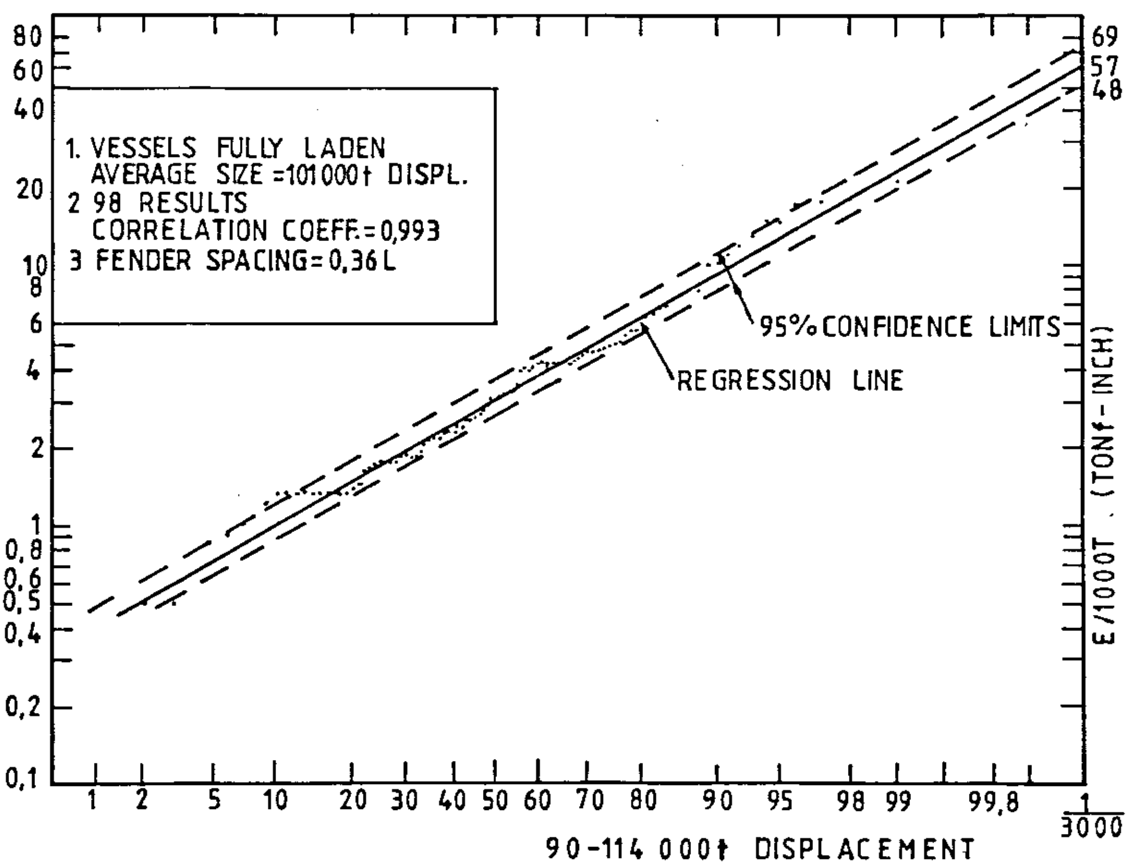


Design berthing velocity as function of navigation conditions and tanker size

BERTHING VELOCITIES - ROTTERDAM

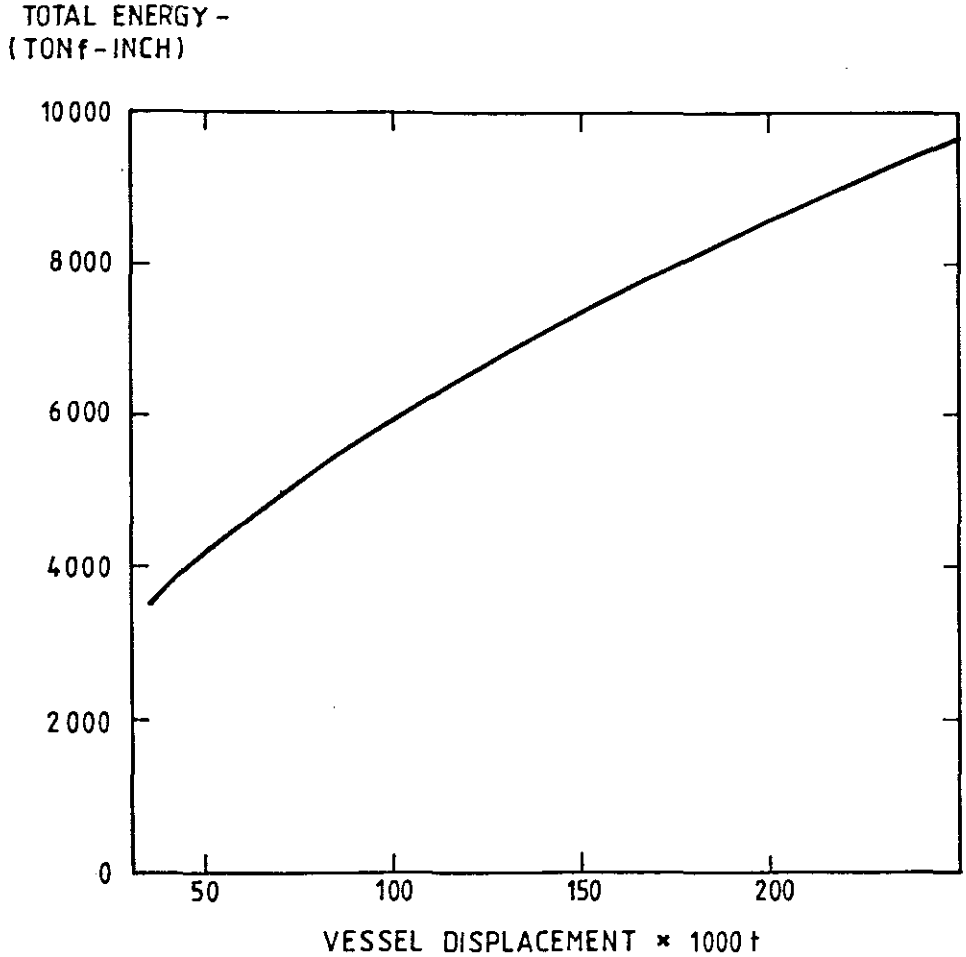
Fig 3.4





BERTHING IMPACTS AT ROTTERDAM

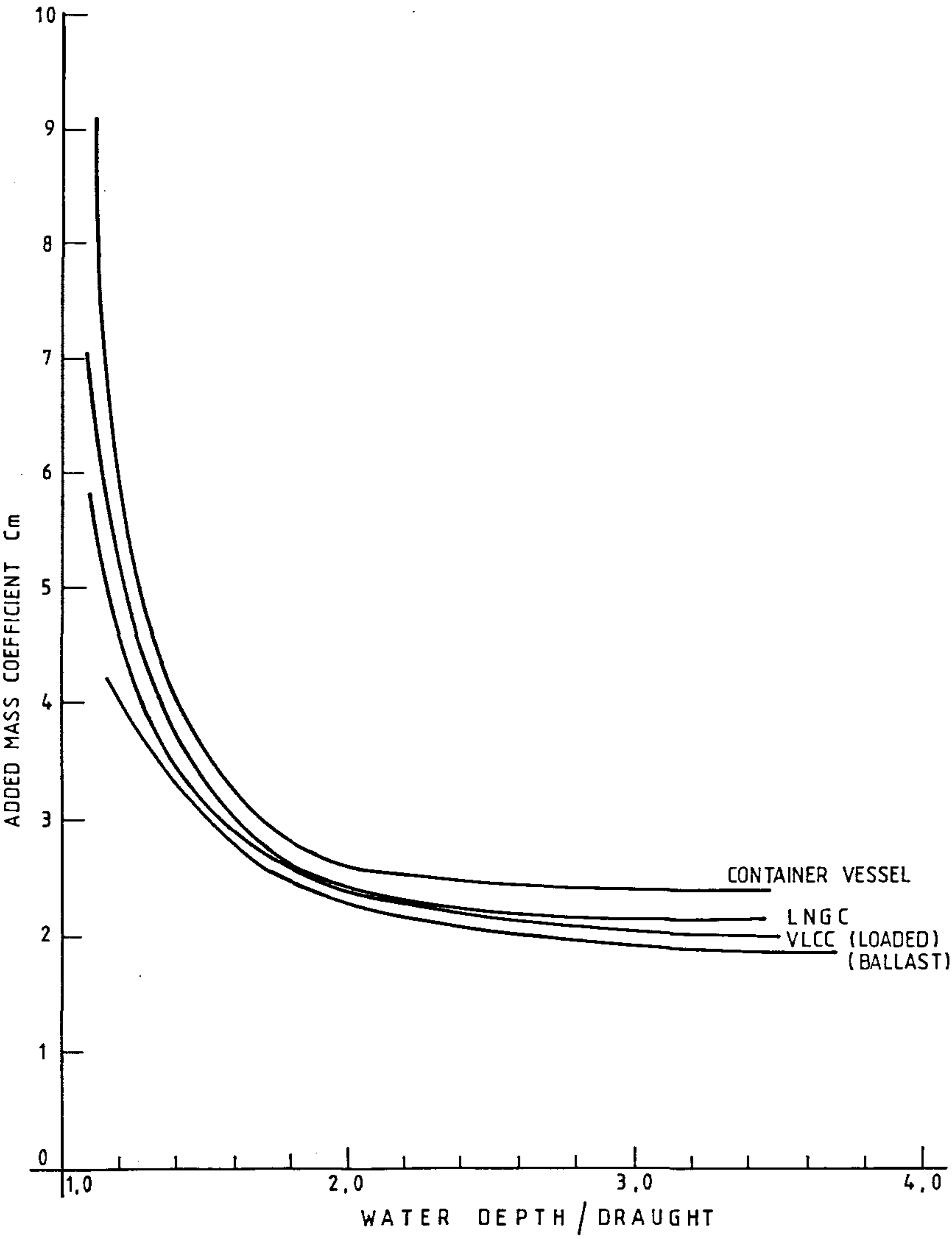
Fig 3.5



DESIGN ENERGY VALUES FOR ENCLOSED HARBOUR

DESIGN ENERGY VALUES (BALFOUR)

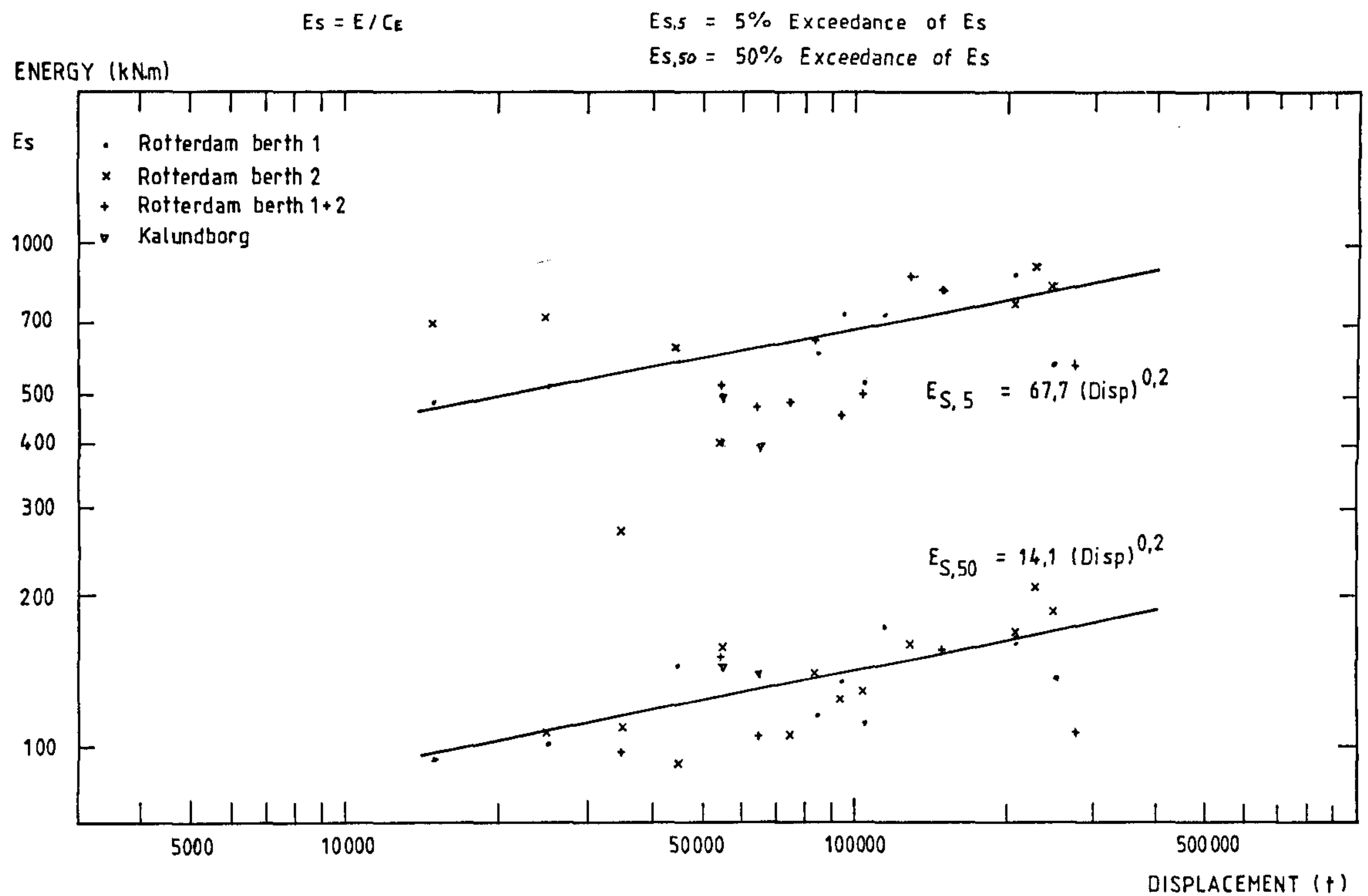
Fig 3.6



ADDED MASS VARIATION WITH WATER DEPTH

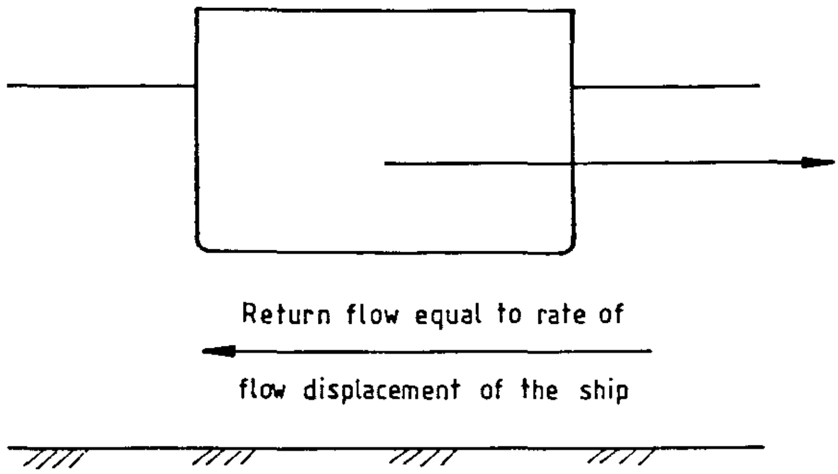
ADDED MASS COEFFICIENT (BARRATT)	**Fig 3.7**

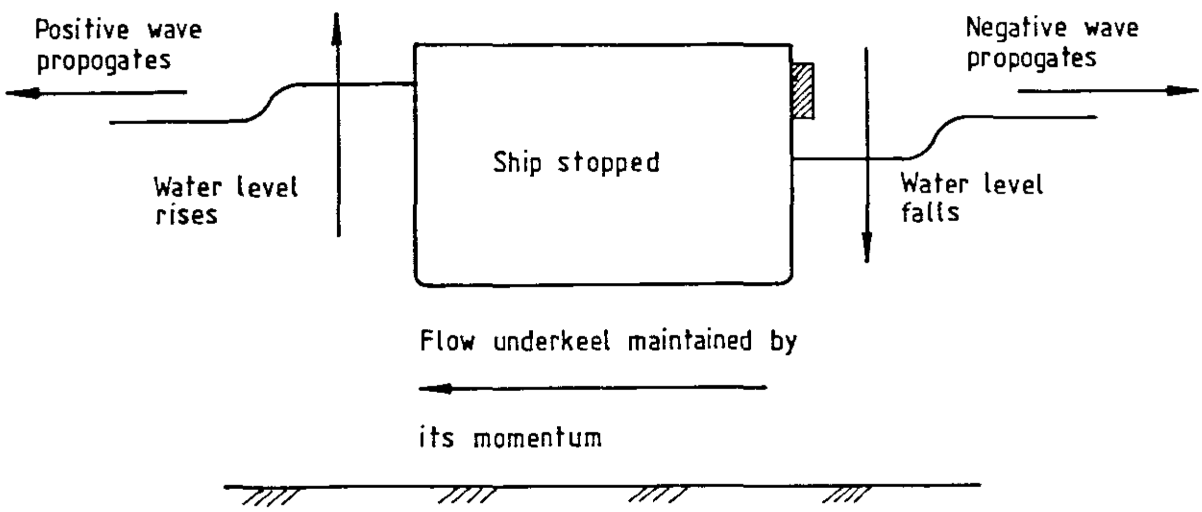
BERTHING ENERGIES (SVENDSEN)



TYPE (A) BERTH

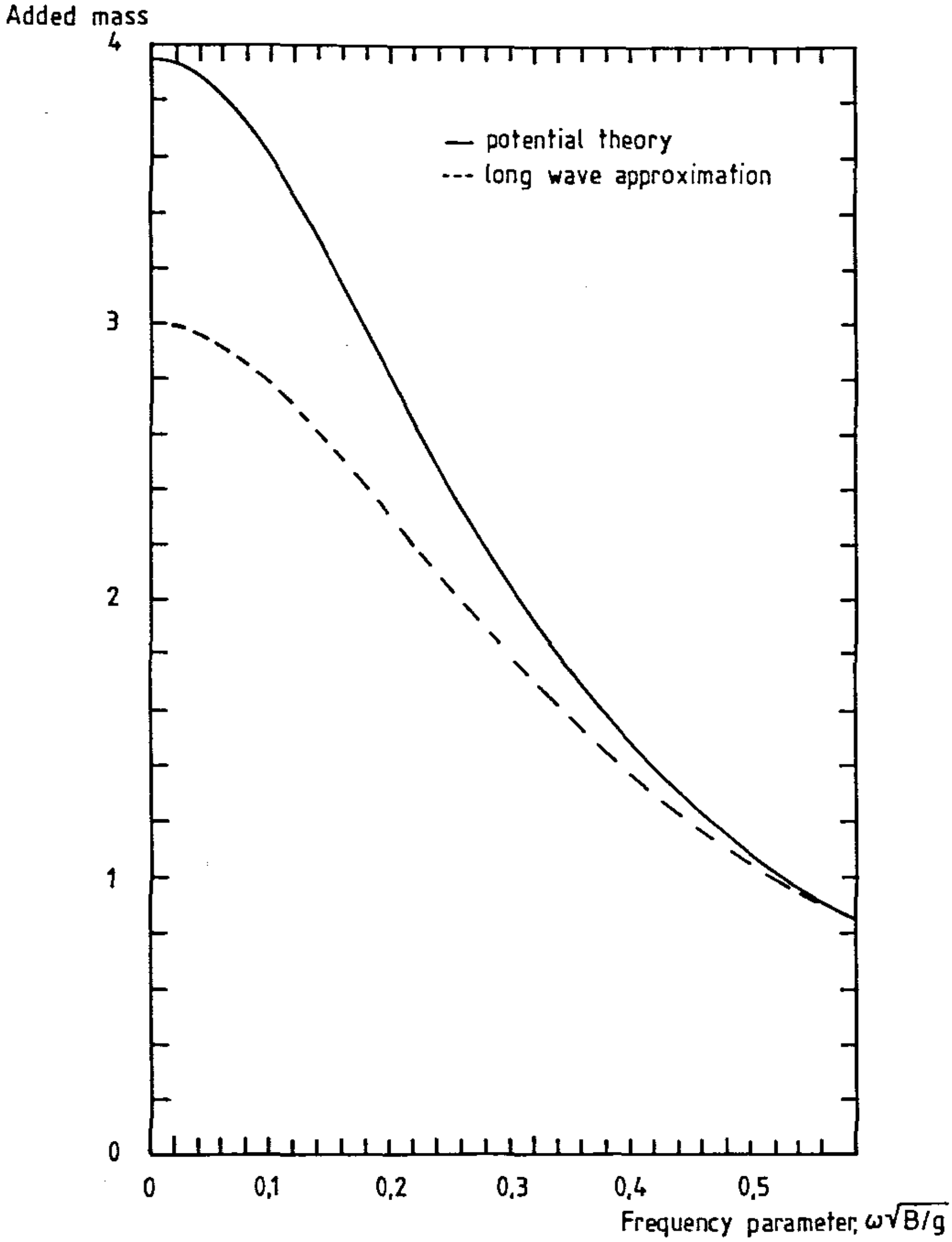
Fig 3.8





ADDED MASS ACCORDING TO BALL

Fig 3.9



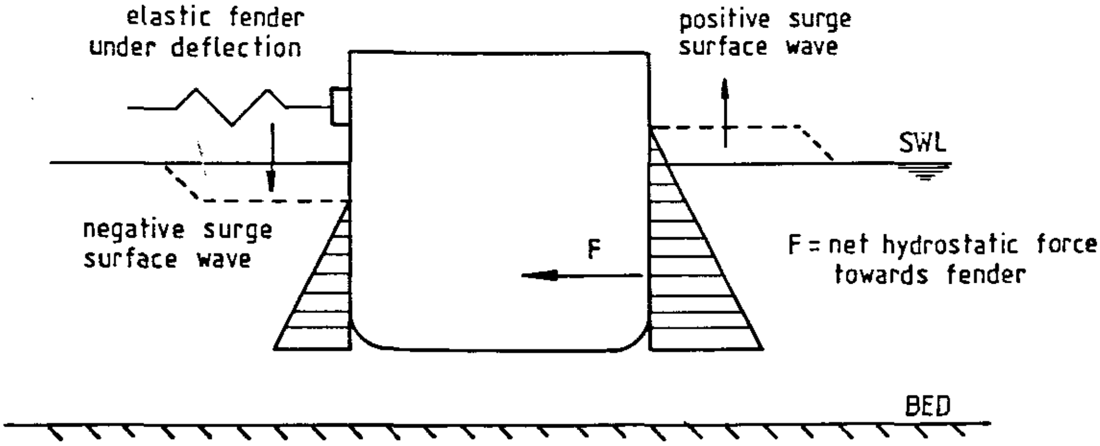
ω = Frequency of berthing oscillation
B = Beam of ship

ADDED MASS FOR SWAYING MOTION

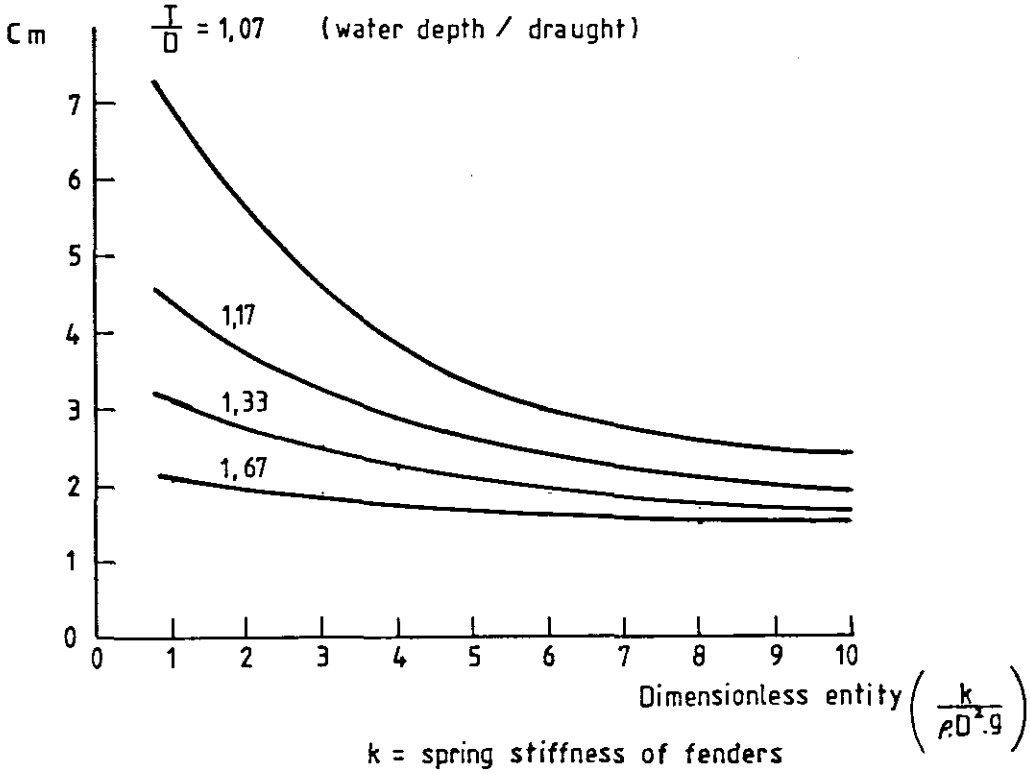
for Depth of water / Draught ratio of 1,333
and Beam / Draught ratio of 2,50

Cm ACCORDING TO FONTIJN

Fig 3.10

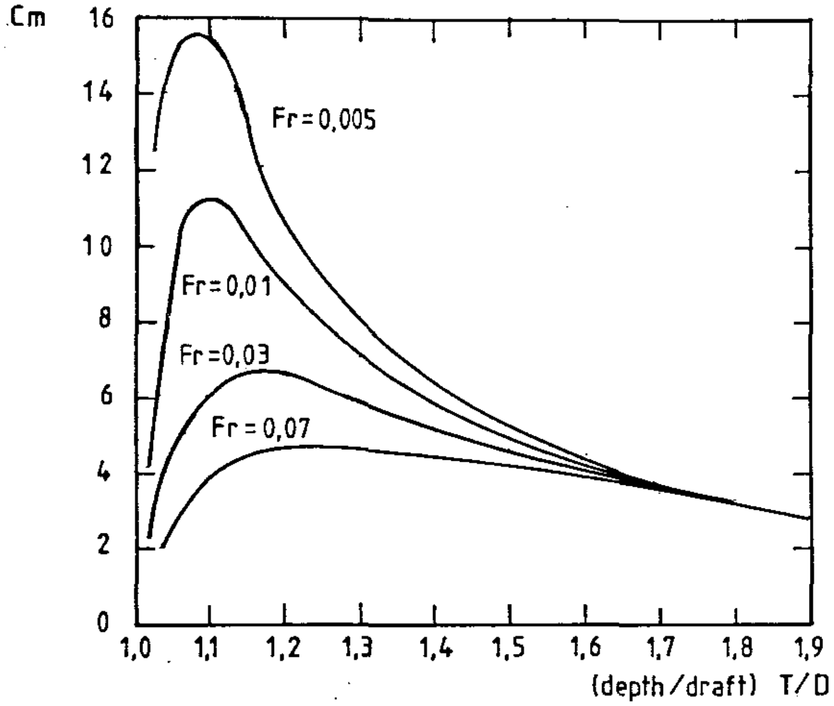


ADDED MASS PHENOMENON ACCORDING TO MIDDENDORP



ADDED MASS VALUES ACCORDING TO MIDDENDORP

Cm ACCORDING TO MIDDENDORP	**Fig 3.11**



ADDED MASS VALUES ACCORDING TO HAYASHI & SHIRAI

$$C_m = 1 + \frac{C(\frac{T}{D} - 1)}{C^2(\frac{T}{D} - 1)^2 + (\frac{2}{3\pi \lambda} . Fr . \frac{T}{D})}$$

C = contraction of flow under ship (suggested value ≈ 0,5)

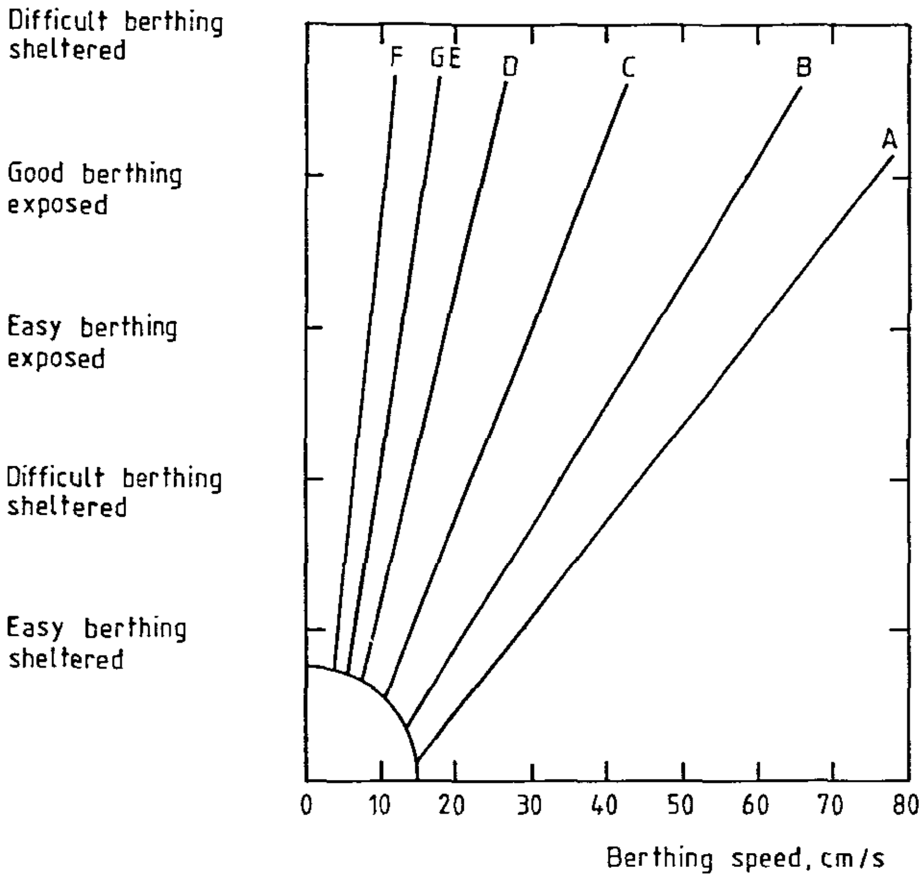
λ = frictional head loss in d'Arcy equation (for underkeel flow ≈ 1)

Fr = ship's Froude number

$= V/\sqrt{g \cdot T}$

Cm ACCORDING TO HAYASHI & SHIRAI

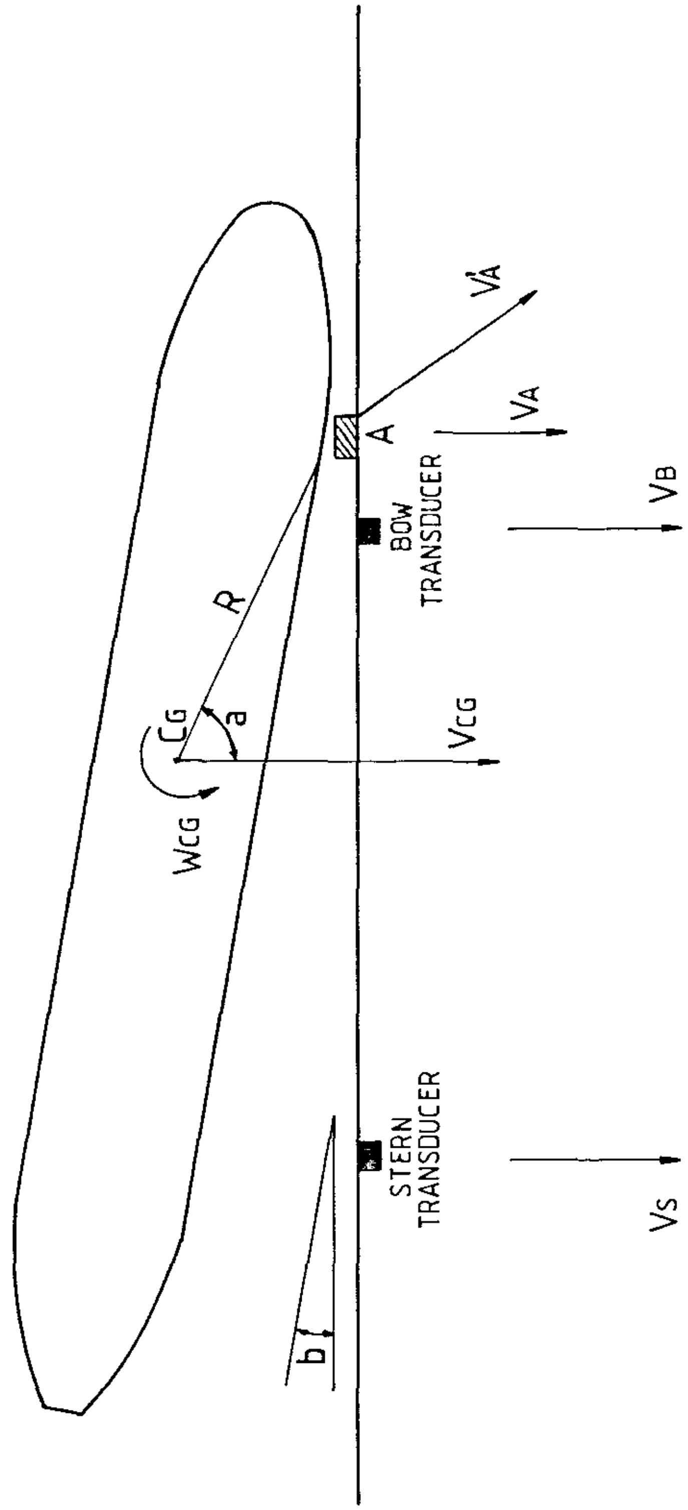
Fig 3.12



A	=	for	vessels	of	about	1 000	t	
B	=	"	"	"	"	5 000	"	
C	=	"	"	"	"	10 000	"	
D	=	"	"	"	"	20 000	"	
E	=	"	"	"	"	30 000	"	
F	=	"	"	"	"	80 000	"	
G	=	"	"	"	"	100 000	t	and larger

BERTHING SPEED – VREDESTEIN

Fig 3.13



SIGN CONVENTION USED

Fig 4.1

GEOMETRY OF THE ORE JETTY

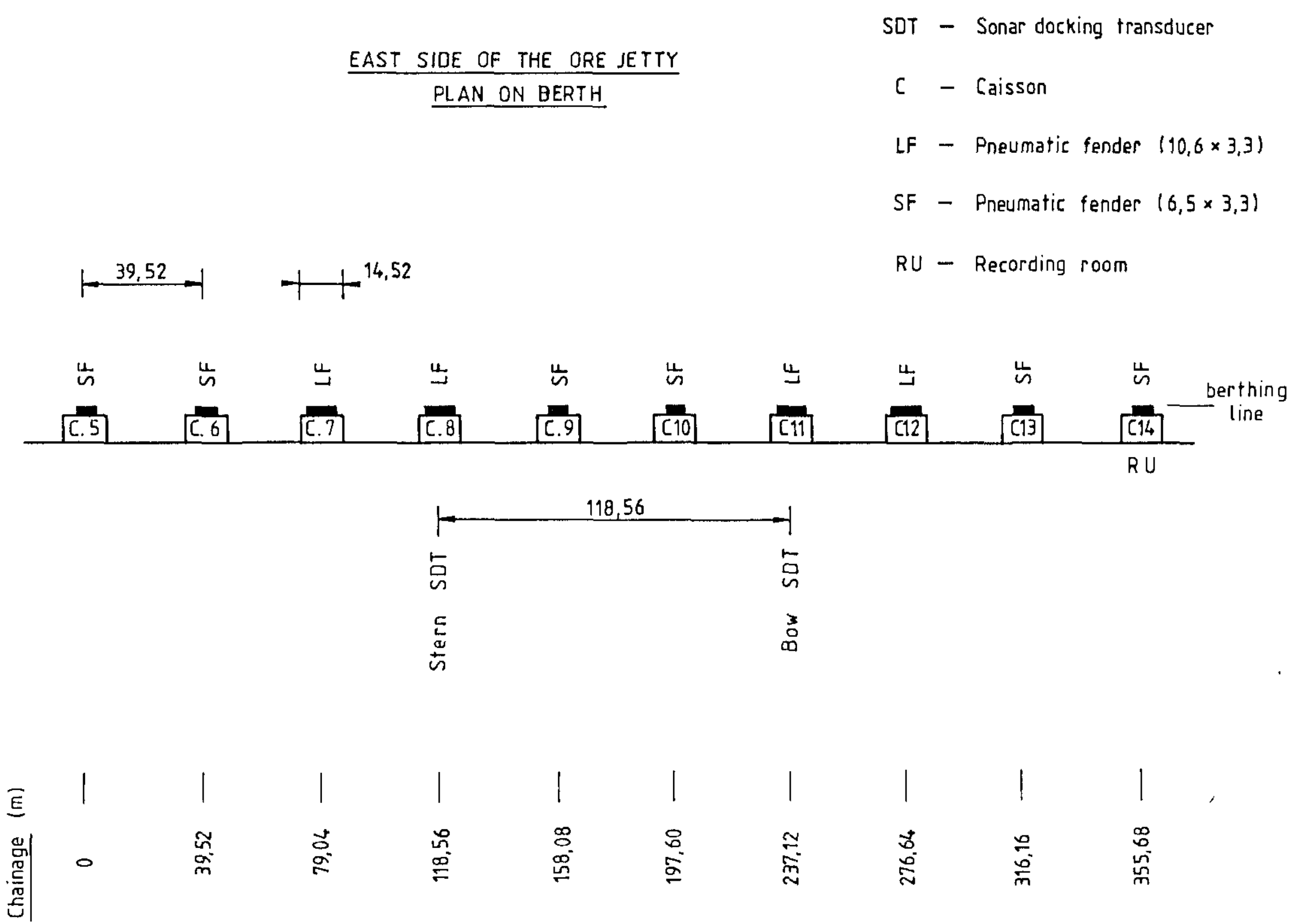


Fig 5.1

PERFORMANCE OF "YOKOHAMA" PNEUMATIC FENDER

Appendix 5.2

FENDER DATA (LARGE FENDER)

D = DIAMETER = 3300 (mm)
L = OVERALL LENGTH = 10600 (mm)
PO = INITIAL PRESSURE = 75 (kPa)

ABBREVIATIONS

(P) = PERCENTAGE DEFLECTION
(mm) = DEFLECTION IN MILLIMETRES
R = REACTION FORCE
E = TOTAL ENERGY ABSORBTION
P = INITIAL PRESSURE
S = SURFACE AREA

DEFLECTION		R	E	P	S
(P)%	(mm)	(tf)	(tf.m)	(kPa)	(sq.m)
0	0	0	0	0	0
1	33	3.24	0.05	75	0.43
2	66	6.51	0.21	75.1	0.87
3	99	9.83	0.48	75.2	1.31
4	132	13.2	0.86	75.4	1.75
5	165	16.63	1.36	75.6	2.2
6	198	20.15	1.96	75.9	2.65
7	231	23.69	2.69	76.2	3.11
8	264	27.33	3.53	76.6	3.57
9	297	31.07	4.49	77	4.03
10	330	34.89	5.58	77.5	4.5
11	369	38.83	6.8	78	4.98
12	396	42.87	8.14	78.6	5.46
13	429	47.04	9.63	79.2	5.94
14	462	51.33	11.25	79.8	6.42
15	495	55.77	13.02	80.7	6.91
16	528	60.36	14.93	81.5	7.41
17	561	65.1	17	82.3	7.91
18	594	70.02	19.23	83.3	8.41
19	627	75.13	21.63	84.2	8.29
20	660	80.43	24.19	85.3	9.43
21	693	85.93	26.94	86.4	9.95
22	726	91.66	29.87	87.6	10.47
23	759	97.62	32.99	88.8	10.99
24	792	103.84	36.32	90.2	11.52
25	825	110.32	39.85	91.5	12.05
26	858	117.08	43.6	93	12.59
27	891	124.15	47.58	94.6	13.13
28	924	131.55	51.8	96.2	13.67
29	957	139.25	56.27	97.9	14.22
30	990	147.33	61	99.7	14.78
31	1023	155.79	66	101.6	15.34
32	1056	164.66	71.29	103.6	15.9
33	1089	173.95	76.87	105.7	16.46
34	1122	183.7	82.78	107.8	17.03
35	1155	193.94	89.01	110.1	17.61
36	1188	204.68	95.58	112.5	18.19
37	1221	215.98	102.52	115.1	18.77
38	1254	227.86	109.85	117.7	19.36
39	1287	240.36	117.57	120.5	19.95
40	1320	253.51	125.72	123.4	20.55

DEFLECTION (P)%	(mm)	R (tf)	E (tf.m)	P (kPa)	S (sq.m)
41	1353	267.37	134.32	126.4	21.15
42	1386	281.97	143.38	129.6	21.75
43	1419	297.38	152.94	133	22.36
44	1452	313.63	163.02	136.5	22.97
45	1485	330.79	173.65	140.2	23.59
46	1518	346.9	184.87	144.1	24.21
47	1551	368.1	196.7	148.2	24.84
48	1584	388.38	209.18	152.5	25.47
49	1617	409.85	222.35	157	26.1
50	1650	432.61	236.25	161.8	26.74
51	1683	453.19	250.87	166.8	27.17
52	1716	474.94	266.18	172.1	27.6
53	1749	496.96	282.24	177.7	28.03
54	1782	522.35	299.07	183.6	28.46
55	1815	548.2	316.74	189.8	28.89

PERFORMANCE OF "YOKOHAMA" PNEUMATIC FENDER

FENDER DATA (SMALL FENDER)

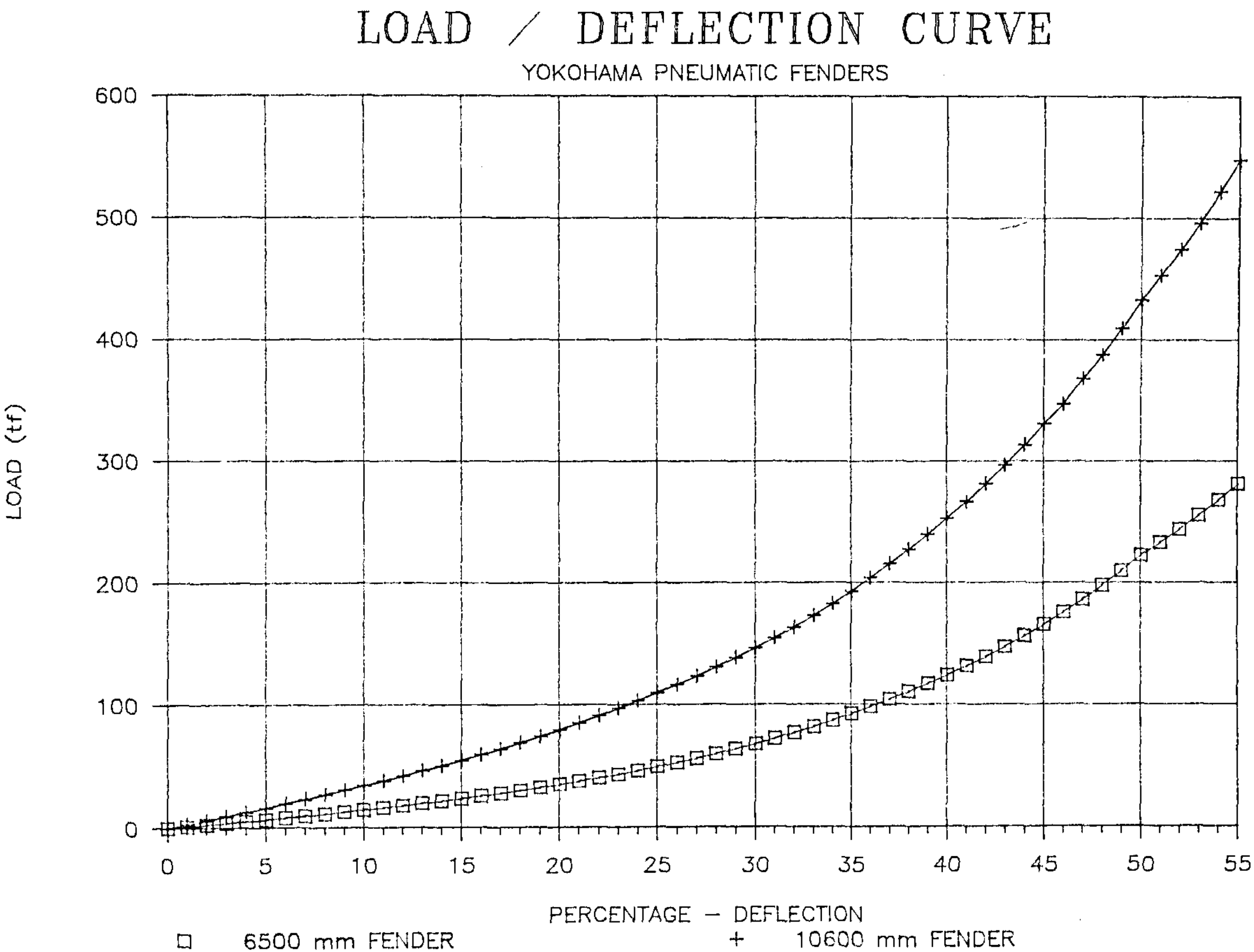
D = DIAMETER = 3300 (mm)
L = OVERALL LENGTH = 6500 (mm)
PO = INITIAL PRESSURE = 0.60 (kPa)

ABBREVIATIONS

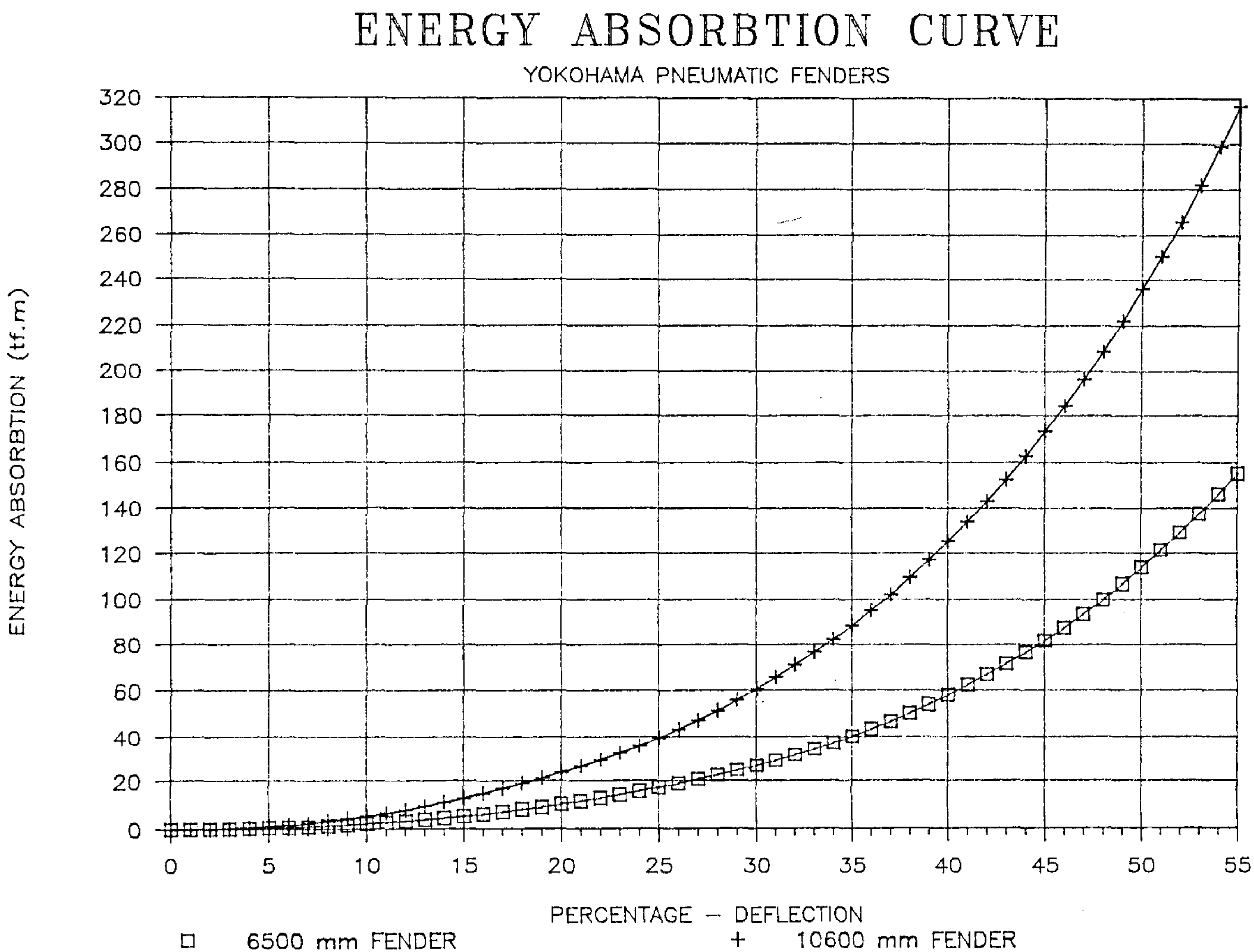
(P) = PERCENTAGE DEFLECTION
(mm) = DEFLECTION IN MILLIMETRES
R = REACTION FORCE
E = TOTAL ENERGY ABSORBTION
P = INITIAL PRESSURE
S = SURFACE AREA

DEFLECTION (P)%	DEFLECTION (mm)	R (tf)	E (tf.m)	P (kPa)	S (sq.m)
0	0	0	0	0	0
1	33	1.3	0.02	60	0.22
2	66	2.63	0.09	60.1	0.44
3	99	3.99	0.2	60.2	0.66
4	132	5.39	0.35	60.4	0.89
5	165	6.82	0.55	60.6	1.13
6	198	8.29	0.8	60.8	1.36
7	231	9.81	1.1	61.1	1.61
8	264	11.38	1.45	61.4	1.85
9	297	13	1.85	61.8	2.1
10	330	14.68	2.31	62.3	2.36
11	363	16.42	2.82	62.8	2.62
12	396	18.22	3.39	63.3	2.88
13	429	20.1	4.03	63.9	3.15
14	462	22.05	4.72	64.5	3.42
15	495	24.08	5.48	65.2	3.69
16	528	26.2	6.31	65.9	3.97
17	561	28.41	7.21	66.7	4.26
18	594	30.72	8.19	67.6	4.55
19	627	33.13	9.24	68.5	4.84
20	660	35.65	10.38	69.4	5.14
21	693	38.3	11.6	70.4	5.44
22	726	41.07	12.91	71.5	5.74
23	759	43.97	14.31	72.6	6.05
24	792	47.02	15.81	73.9	6.37
25	825	50.22	17.42	75.1	6.68
26	858	53.58	19.13	76.5	7.01
27	891	57.12	20.95	77.9	7.33
28	924	60.83	22.9	79.4	7.66
29	957	64.74	24.97	80.9	8
30	990	68.86	27.18	82.6	8.34
31	1023	73.2	29.52	84.3	8.68
32	1056	77.76	32.01	86.1	9.03
33	1089	82.58	34.66	88	9.38
34	1122	87.66	37.47	90	9.74
35	1155	93.02	40.45	92.1	10.1
36	1188	98.67	43.61	94.3	10.46
37	1221	104.65	46.97	96.6	10.83
38	1254	110.96	50.52	99	11.2
39	1287	117.63	54.29	101.6	11.58
40	1320	124.68	58.29	104.2	11.96

DEFLECTION (P)%	(mm)	R (tf)	E (tf.m)	P (kPa)	S (sq.m)
41	1353	132.15	62.53	107	12.35
42	1386	140.05	67.02	110	12.74
43	1419	148.41	71.78	113	13.13
44	1452	157.28	76.73	116.2	13.53
45	1485	166.67	82.17	119.6	13.93
46	1518	176.64	87.84	123.2	14.34
47	1551	187.22	93.84	126.9	14.75
48	1584	198.45	100.2	130.9	15.16
49	1617	210.38	106.95	135	15.58
50	1650	223.07	114.1	139.4	16.01
51	1683	233.5	121.63	143.9	16.22
52	1716	244.53	129.52	148.8	16.44
53	1749	256.22	137.78	153.9	16.65
54	1782	268.6	146.44	159.3	16.87
55	1815	281.74	155.52	164.9	17.08


LOAD / DEFLECTION CURVE
YOKOHAMA PNEUMATIC FENDERS
LOAD (tf)
0
100
200
300
400
500
600
0 5 10 15 20 25 30 35 40 45 50 55
PERCENTAGE – DEFLECTION
□ 6500 mm FENDER
+ 10600 mm FENDER

Appendix 5.2


ENERGY ABSORBTION CURVE
YOKOHAMA PNEUMATIC FENDERS
ENERGY ABSORBTION (tf.m)
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45
50
55
PERCENTAGE – DEFLECTION
□ 6500 mm FENDER
+ 10600 mm FENDER

Appendix 5.2

CALIBRATION RESULTS OF SONAR DOCKING SYSTEM

BOW - TRANSDUCER

1. Distance of echo-eye to fender board = 4,3 m

2. Paperspeed
   - sp 1 : 1 mm = 7,65 sec
   - sp 2 : 1 mm = 3,89 sec
   - sp 3 : 1 mm = 1,94 sec

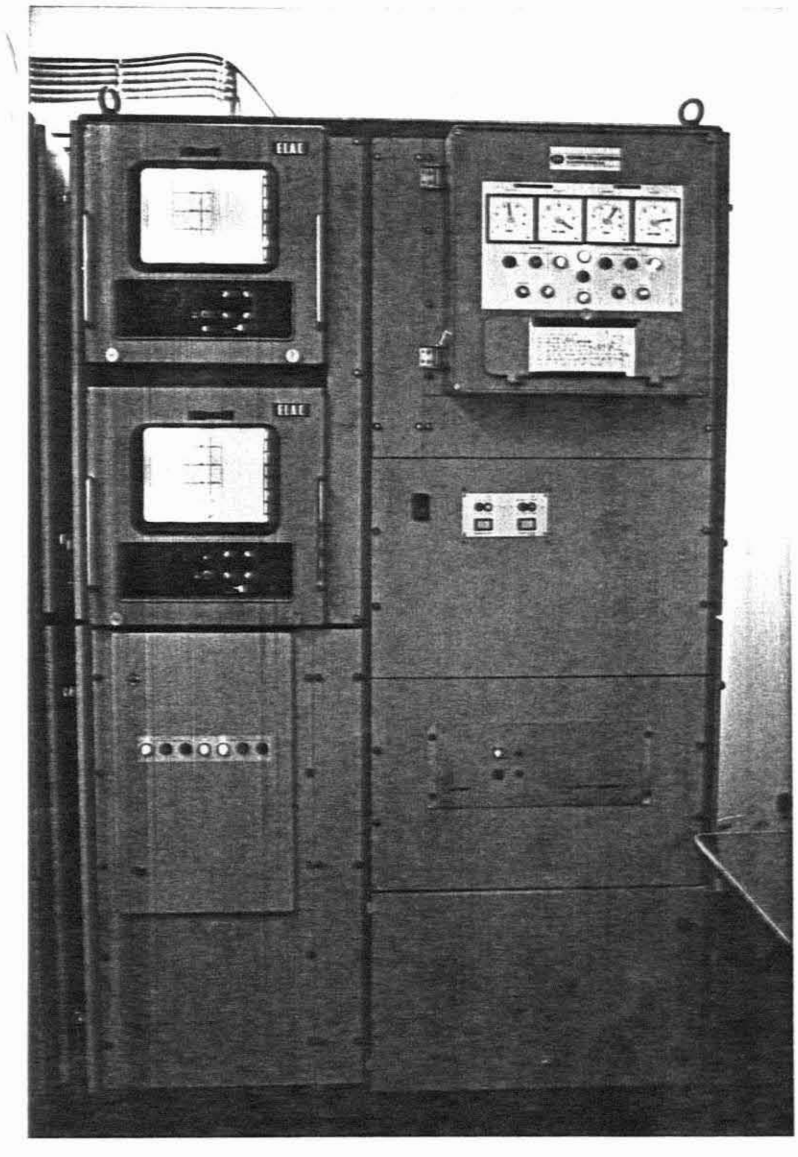
3. Vertical scale
   - 0-48 m 1 mm = 0,269 m
   - 0-96 m 1 mm = 0,538 m

STERN - TRANSDUCER

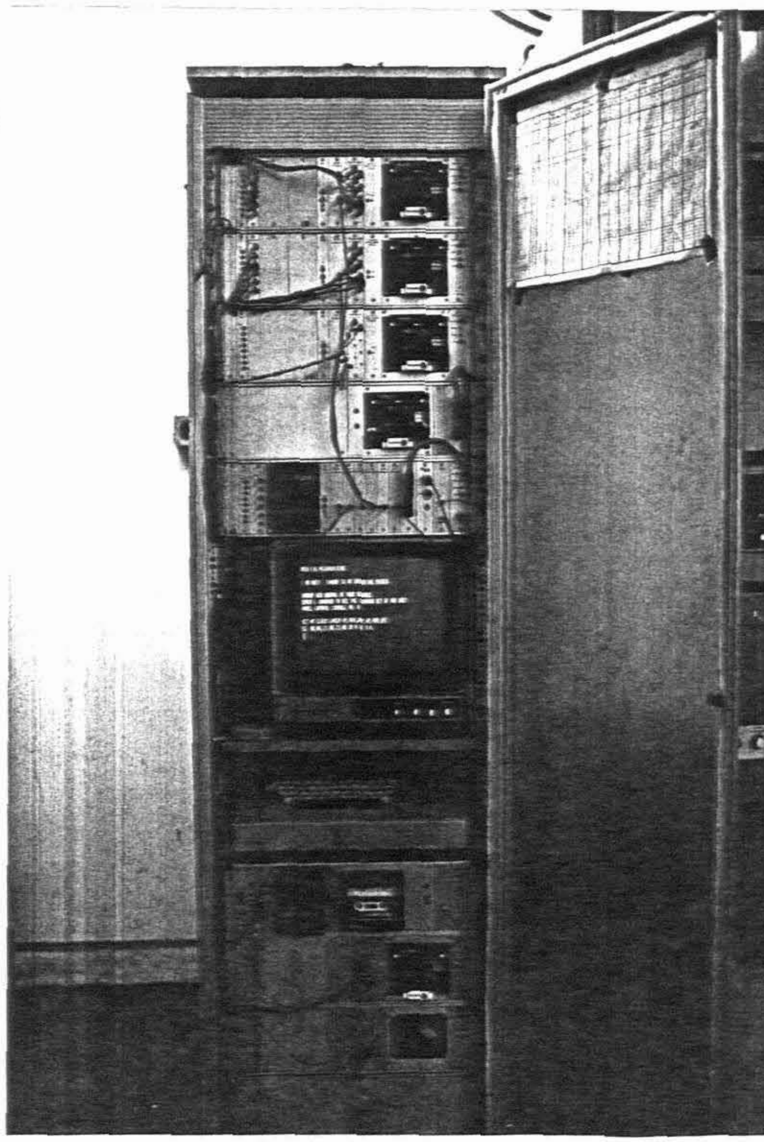
1. Distance of echo-eye to fender board = 4,4 m

2. Paperspeed
   - sp 1 : 1 mm = 7,85 sec
   - sp 2 : 1 mm = 3,94 sec
   - sp 3 : 1 mm = 1,97 sec

3. Vertical scale
   - 0-48 m 1 mm = 0,265 m
   - 0-96 m 1 mm = 0,534 m



SONAR DOCKING SYSTEM



DATA ACQUISITION SYSTEM

SALDANHA BAY HARBOUR
MONITORING OF BERTHING IMPACTS

RUN Nº: RH 34	NAME OF VESSEL:	ANDROS ANTARES		DATE 84 06 08
PILOT:	PILOT 5			
ARRIVAL DRAUGHT	FORWARD 7,61 m/~~ft~~		AFT 10,10	m/~~ft~~
L.O.A	323,6	m/~~ft~~	C. flotation ~~C.G~~ (from midship)	10,80 forw. m/~~ft~~
L.P.P.	315	m/~~ft~~	DWT (max)	227 481 mt/~~lt~~
BREADTH	48,15	m/~~ft~~	DWT. (arrival)	71 532 mt/~~lt~~
DESIGN DRAUGHT	20,49	m/~~ft~~	DISPLACEMENT (arrival)	108 369 mt/~~lt~~

POSITION OF VESSEL RELATIVE TO JETTY AT IMPACT				FENDER HIT AT IMPACT		
TIME	IMPACT	BOW	STERN	CAISSON	SMALL	LARGE
08 59 16	1.	26m.S.cl. C12		11	√	
09 02 23	2.	23m. S. cl. C12		11	√	
09 02 40	3.	9m. S. cl. C12		11	√	

WIND	SPEED	12 km / hr	DIRECTION	SSE
TIDE (CD)	09 00 - 1,22m	10 00 - 1,40 m		
MAX SWELL	2m in channel			

	CASSETTE NO	TIME ON	TIME OFF
SONAR DOCKING	1011	08 58 25	09 15 35
FENDER PRESSURE	1006	09 00 16	09 08 50

COMMENTS

Ship shoulder south of caisson 11

Fender at C11 slightly deflated on impact

HP-15C PROGRAM SHEET appendix 6.2

TITLE: Berthing Impacts Scale Conversion Calculations

DISPLAY STEP	DISPLAY CODE	KEY	COMMENTS
1	42,21,11	f.LBL.A	Key in time A in HMS
2	43,2	--> H	
3	44,0	STO 0	Time in Hrs
4	31	R/S	Key in time B in HMS
5	43,2	--> H	
6	45,0	RCL 0	
7	30	-	
8		3	
9		6	
10		0	
11		0	
12	20	*	
13	31	R/S	Key in distance A-B in mm (from trace)
14	10	/	
15	44,1	STO 1	Horizontal scale
16	31	R/S	
17	48	0,	
18		2	
19		6	
20		9	
21	44,2	STO 2	
22	43,32	RTN	
23	42,21,12	f.LBL.B	Key in vertical distance in mm (trace)
24	45,2	RCL 2	
25	20	*	
26		4	
27	48	,	
28		4	
29	30	-	
30	43,32	RTN	Distance from fenderboard to ship at bow
31	42,21,13	f.LBL.C	Key in horizontal distance in mm
32	45,1	RCL 1	
33	20	*	
34		3	
35		6	
36		0	
37		0	
38	10	/	
39	45,0	RCL 0	
40	40	+	
41	42,2	--> HMS	
42	42,32	RTN	Time at point X in HMS
43	42,21,14	f LBL D	Key in time of point X
44	43,2	--> H	
45	45,0	RCL 0	
46	30	-	
47		3	
48		6	
49		0	
50		0	

HP-15C PROGRAM SHEET

TITLE: Berthing Impacts Scale Conversion Calculations

DISPLAY STEP	DISPLAY CODE	KEY	COMMENTS
51	20	0	
52	45,1	RCL 1	
53	10	/	STERN
54	43,32	RTN	Distance from start in mm
55	42,21,1	f.LBL.1	Key in time C in HMS
56	43,2	--> H	
57	44,3	STO 3	Time C in HRS
58	31	R/S	Key in time D in HMS
59	43,2	--> H	
60	45,3	RCL 3	
61	30	-	
62		3	
63		6	
64		0	
65		0	
66	20	*	
67	31	R/S	Key in distance C-D in mm
68	10	/	
69	44,4	STO 4	
70	31	R/S	Horizontal scale
71	48	0,	
72		2	
73		6	
74		5	
75	44,5	STO 5	Vertical scale
76	43,32	RTN	
77	42,21,2	f.LBL.2	Key in vertical distance in mm
78	45,5	RCL 5	
79	20	*	
80		4	
81	48	,	
82		6	
83	30	-	
84	43,32	RTN	Distance off the fenderboard
85	42,21,3	f.LBL.3	Key in horizontal distance in mm
86	45,4	RCL 4	
87	20	*	
88		3	
89		6	
90		0	
91		0	
92	10	/	
93	45,3	RCL 3	
94	40	+	
95	42,2	--> HMS	
96	43,32	RTN	Time at point X in HMS
97	42,21,4	f.LBL.4	Key in time at point
98	43,2	--> H	
99	45,3	RCL 3	
100	30	-	

HP-15C PROGRAM SHEET   appendix 6.2

TITLE: Berthing Impacts Scale Conversion Calculations

DISPLAY STEP	DISPLAY CODE	KEY	COMMENTS
101		3	
102		6	
103		0	
104		0	
105	20	*	
106	45,4	RCL.4	
107	10	/	
108	43,32	RTN	Distance from start to point in mm

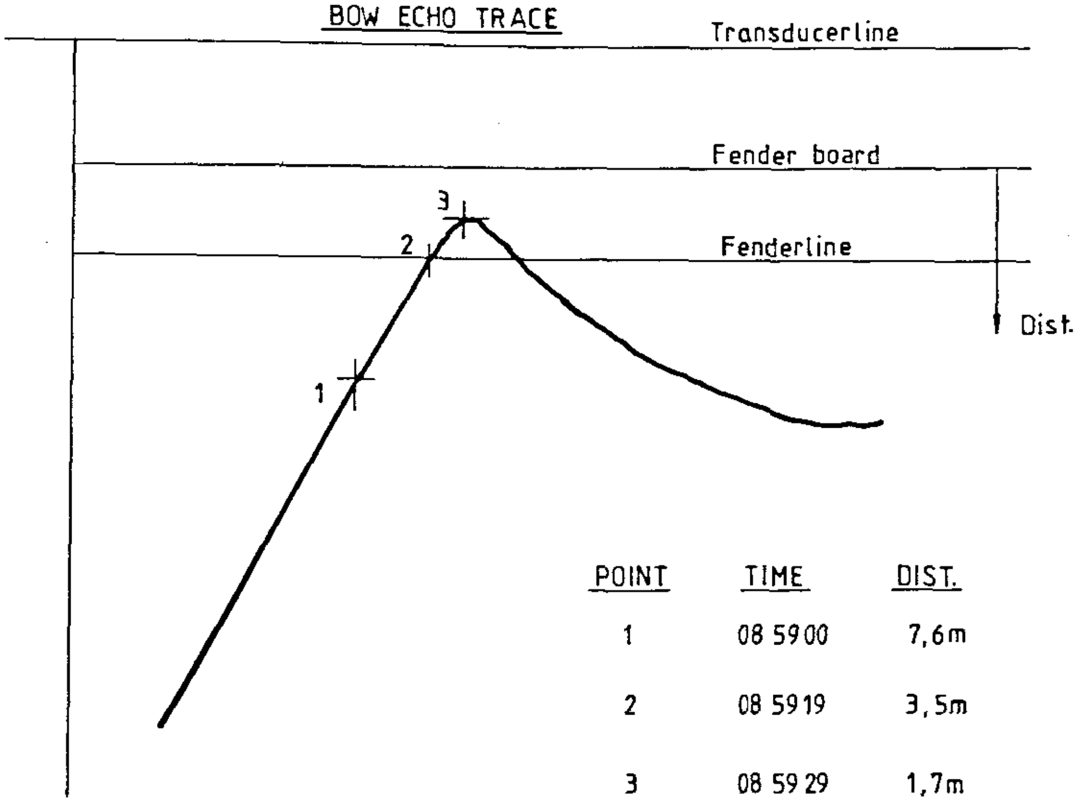
FOR BOW

Enter time A in HMS (start of trace)	Press A
Enter time B in HMS (end of trace)	Press R/S
Enter distance A-B in mm	Press R/S
Output = Horizontal scale 1mm = ? sec	Press R/S
Enter Vertical distance in mm	Press B
Output = Distance from ship to fenderboard in m	
Enter horizontal distance in mm	Press C
Output = Time at distancein HMS	
Enter time at a required point in HMS	Press D
Output = Distance from start to required point (mm)	

FOR STERN

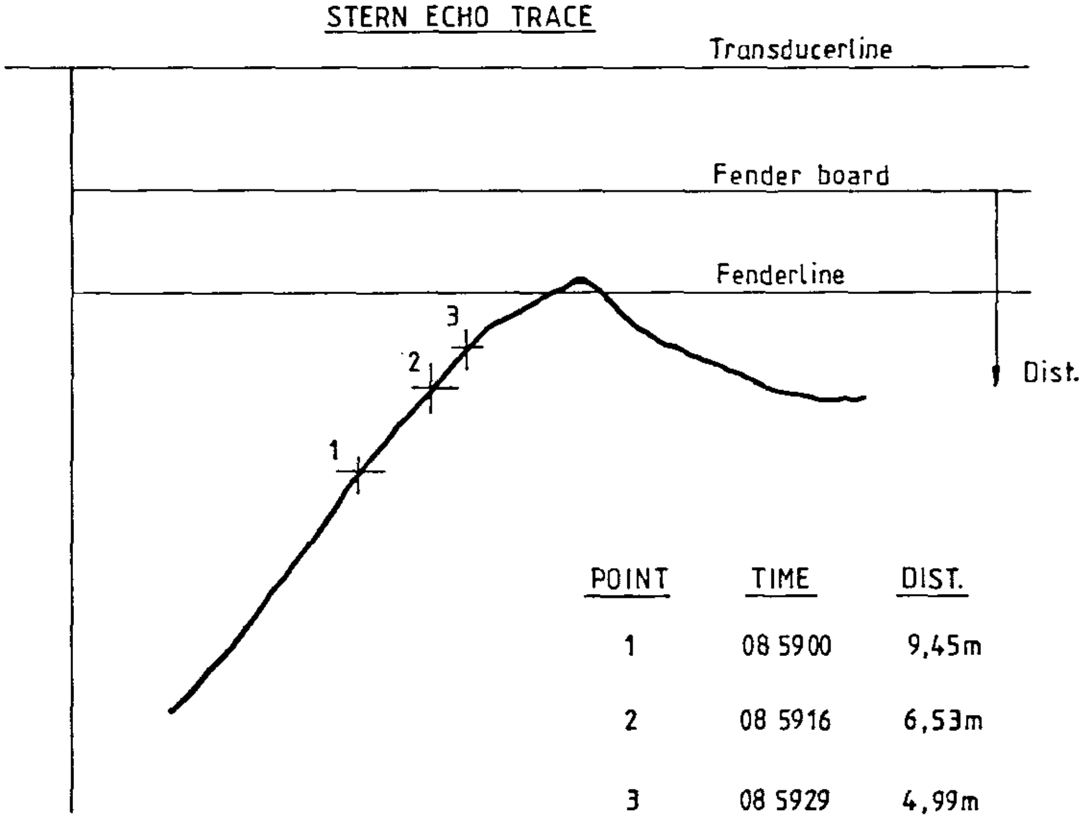
Enter time C in HMS (start of trace)	Press GSB 1
Enter time D in HMS (end of trace)	Press R/S
Enter distance C-D in mm	Press R/S
Output = Horizontal scale 1mm = ? sec	Press R/S
Enter Vertical distance in mm	Press GSB 2
Output = Distance from ship to fenderboard in m	
Enter horizontal distance in mm	Press GSB 3
Output = Time at distance in HMS	
Enter time at a required point in HMS	Press GSB 4
Output = Distance from start to required point (mm)	

BOW ECHO TRACE



POINT	TIME	DIST.
1	08 59 00	7,6m
2	08 59 19	3,5m
3	08 59 29	1,7m

STERN ECHO TRACE



POINT	TIME	DIST.
1	08 59 00	9,45m
2	08 59 16	6,53m
3	08 59 29	4,99m

ECHO TRACES RUN RH34

Fig 6.3

PROCESSING OF ECHO TRACE WHEN IMPACT IS NOT AT POSITION OF TRANSDUCER

If the maximum impact is at caisson 12 in stead of caisson 11 where the sonar docking transducer is situated the distance off the fenderboard at caisson 12 at maximum impact has to be established as well as the position of first impact.
Fig 6.4 depicts the problem.

At maximum impact the distance off the fenderboard at C8 and C11 are known from the echo traces.

$$\text{Angle of approach} \quad b = \arctan\frac{(A_{max} - B_{max})}{118{,}56}$$

$$C_{max} = B_{max} - 39{,}52.\tan(b)$$

$$= 39{,}52.\tan.\arctan\frac{(A_{max} - B_{max})}{118{,}56}$$

$$= B_{max} - \frac{39{,}52\ (A_{max} - B_{max})}{118{,}56}$$

$$= B_{max} - 0{,}333.A_{max} + 0{,}333.B_{max}$$

$$= 1{,}333.B_{max} - 0{,}333.A_{max}$$

The problem now is to find when the point of first impact at C12 occurred. At that point C = 3,5 m. A and B have to be established for C = 3,5m.

From echo trace for B = 5m measure A

$$(b) = \arctan \frac{A-5}{118,56}$$

Use this value for (b) to calculate with C = 3,5 m what the value of B is.

$$B = 3,5 + 39,52.\tan(b)$$

$$= 3,5 + 39,52.\tan.\arctan(A-5)/118,56$$

$$= 3,5 + 39,52.(A-5)/118,56$$

$$= 3,5 + 0,333.A - 1,667$$

$$= 1,833 + 0,333.A$$

Now measure A for B = 1,833 + 0,333.A

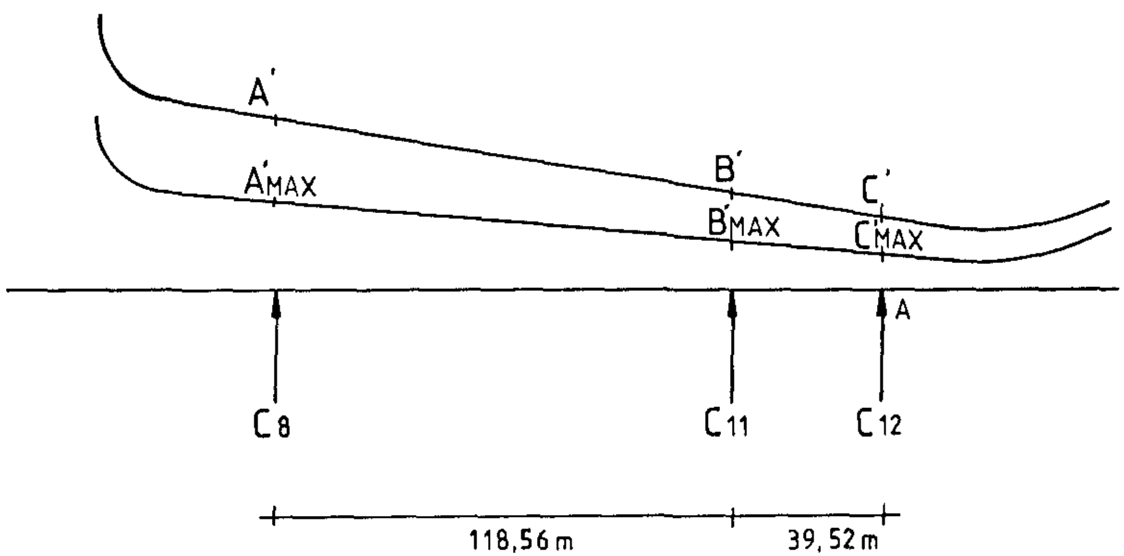
$$C = 1,333.B - 0,333.A$$

Check now how close C is to 3,5m

If not satisfactory repeat the calculation with a different value for B.

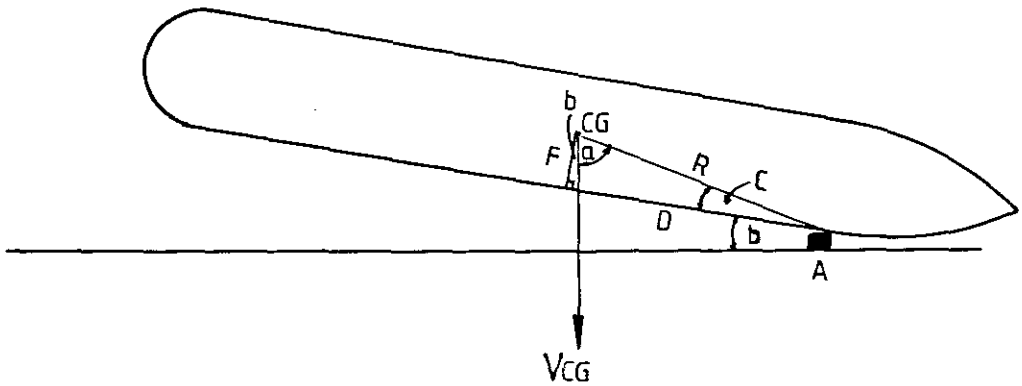
A = POINT OF IMPACT

A', B', C'MAX ARE DISTANCES FROM SHIP TO FENDERBOARD AT MAX. IMPACT



CALCULATION FOR OFFSET IMPACT

Fig 6.4



F = 0,5 × BREADTH OF SHIP

b = ANGLE OF APPROACH AT IMPACT

D = LOA/2 – DISTANCE FROM BOW TO POINT A

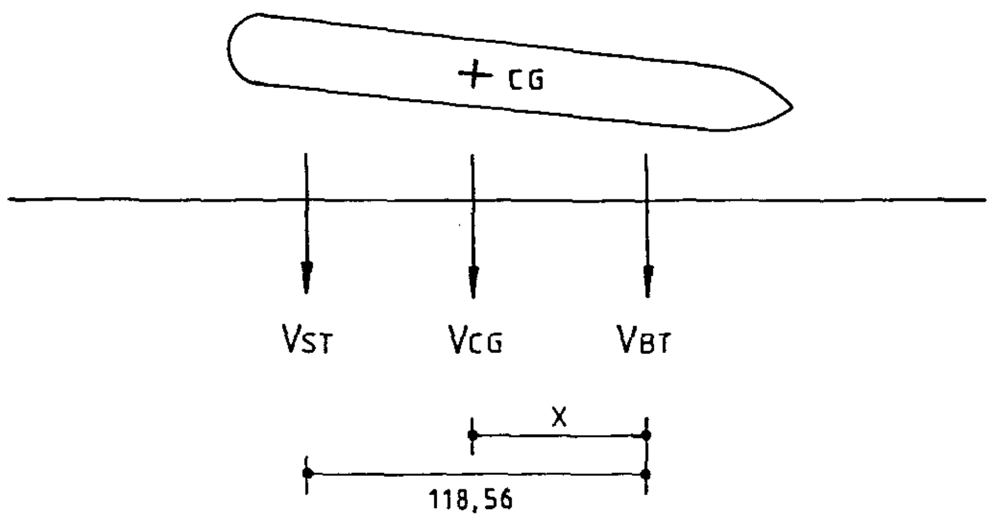
$$R = \sqrt{F^2 + D^2}$$

$$c = \text{ARCTAN } F/D$$

$$a = 90° - c - b$$

COMPUTATION OF 'R' AND 'a'

Fig 6.5



V_{BT} = APPROACH VELOCITY AT BOW TRANSDUCER

V_{ST} = APPROACH VELOCITY AT STERN TRANSDUCER

V_{CG} = APPROACH VELOCITY AT CENTRE OF GRAVITY

X = HORIZONTAL DISTANCE FROM CG TO BOW TRANSDUCER

$$V_{CG} = \frac{X}{118,56} \cdot V_{ST} + \frac{118,56 - X}{118,56} \cdot V_{BT}$$

COMPUTATION OF Vcg

Fig 6.6

APPENDIX 6.7

COMPUTER WORKSHEET: ACTUAL VALUES OBTAINED IN RUN RH34

In this annexure the layout of the main computer spreadsheet used is explained using as an example the actual values obtained *in run* RH34.

1.	RUN	Run number	1
2.	DATE	Date of monitoring run	84-06-08
3.	NAME	Name of ship	Ship Code 026
4.	DWT.MAX	Maximum deadweight tonnage of ship in metric tons.	227481
5.	LOA	Length overall of ship (m)	323,6
6.	WIDTH	Width of ship (m)	48,15
7.	DRAFT.MAX	Maximum draft of ship (m)	20,49
8.	DRAFT.FPP	Draft at forward perpendicular on arrival (m)	7,61
9.	DRAFT.APP	Draft at aft perpendicular on arrival (m)	10,10
10.	DRAFT MN	Mean of forward and aft drafts (m)	8,86
11.	DISPL.T	Displacement tonnage of ship on arrival in metric tons	108369
12.	DWT	Deadweight tonnage of ship on arrival in metric tons	71532
13.	BTY2	Bow transducer distance 2 (m)	3,50
14.	STY2	Stern transducer distance 2 (m)	6,53

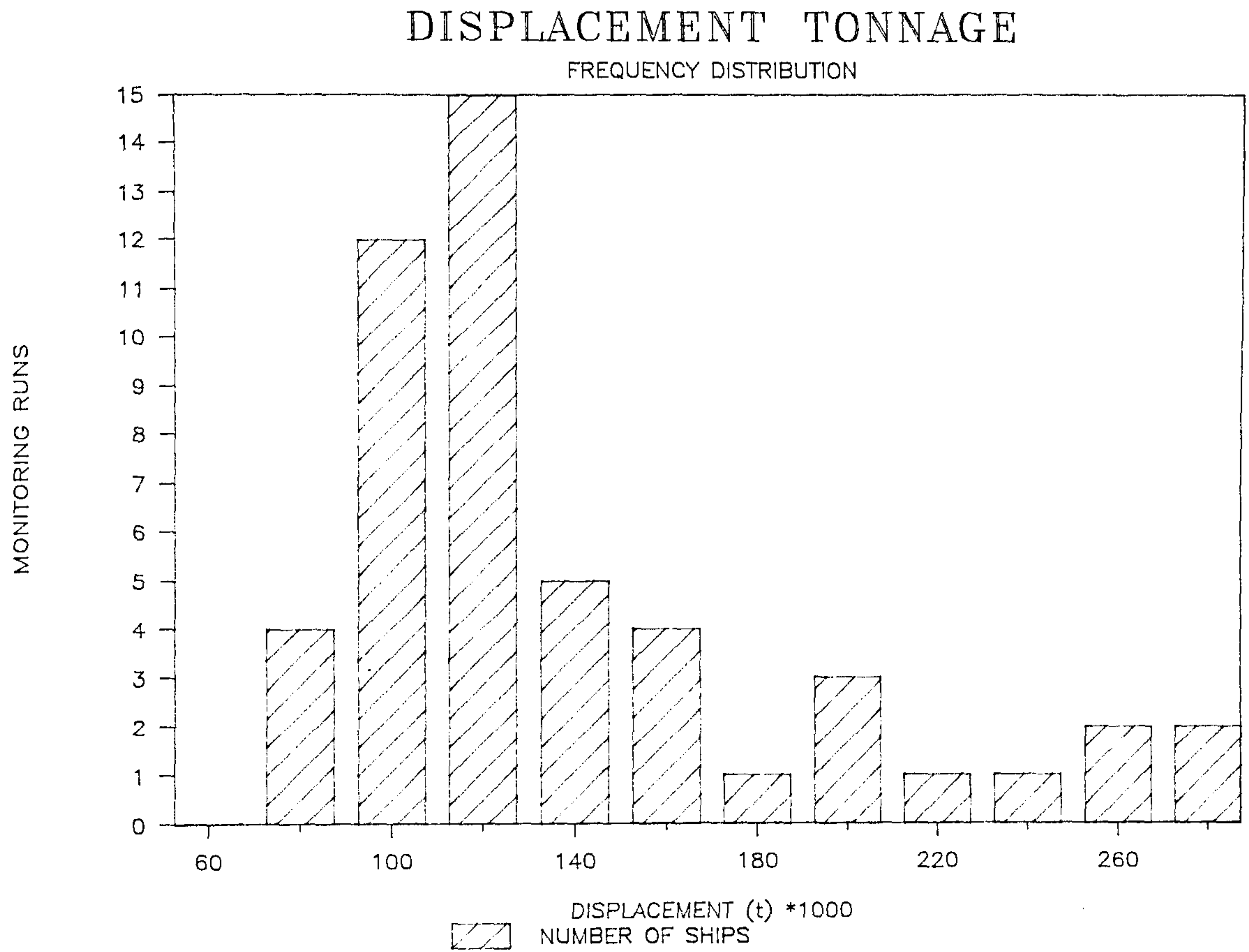
15.	APP.ANGLE RAD	Angle of approach at impact in radians.	0,026
16.	APP.ANGLE DEGR	Angle of approach at impact in degrees.	1,46
17.	BTY1	Bow transducer distance 1	7,61
18.	BDT	Time from BTY2-BTY1 in (s)	19
19.	V_B	Approach velocity at bow transducer $= \frac{BTY1 - BTY2}{BDT}$ in m/s	0,22
20.	STY1	Stern transducer distance 1 (m)	9,45
21.	STDT	Time from STY2 - STY1 in (s)	19
22.	V_S	Approach velocity at stern transducer $= \frac{STY1 - BTY2}{STDT}$ in m/s	0,15
23.	W_{CG}	Velocity of rotation at CG at impact $= \frac{V_S - V_B}{118{,}56}$ in radians/s	-0,000524
24.	J	Radius of gyration of ship = 0,2 * LOA (m)	64,72
25.	BIX-BX	Horizontal distance from bow of ship to point of impact (m)	65,52
26.	CG-BX	Horizontal distance from bow of ship to centre of gravity +/- midships = LOA/2 (m)	161,8
27.	R	Distance from CG to point of impact $= \{(CG-BIX)^2 + (width/2)^2\}^{0,5}$	99,24
28.	ALPHA(a)	Angle between R and perpendicular through CG on quay (radians) = arctan {(CG-BIX)/WIDTH/2}	1,30

29.	C_E	Eccentricity coefficient	
		$= \dfrac{J^2}{J^2 + R^2}$	0,30
30.	$V^1{}_A{}^2$	The square of the representative velocity componant at the point of impact (m/sec) (eq 4.9)	0,0512
31.	$V^1{}_A$	Representative Velocity componant componant at point of impact (m/s)	0,23
32.	V_{CG}	Transverse velocity of CG (m/s)	0.17
33.	DE	Energy absorbed by fenders(kN-m)	1643
34.	C_M	Added mass constant	
		$= 2*DE/(C_E.M.V^1{}_A{}^2)$	1,98

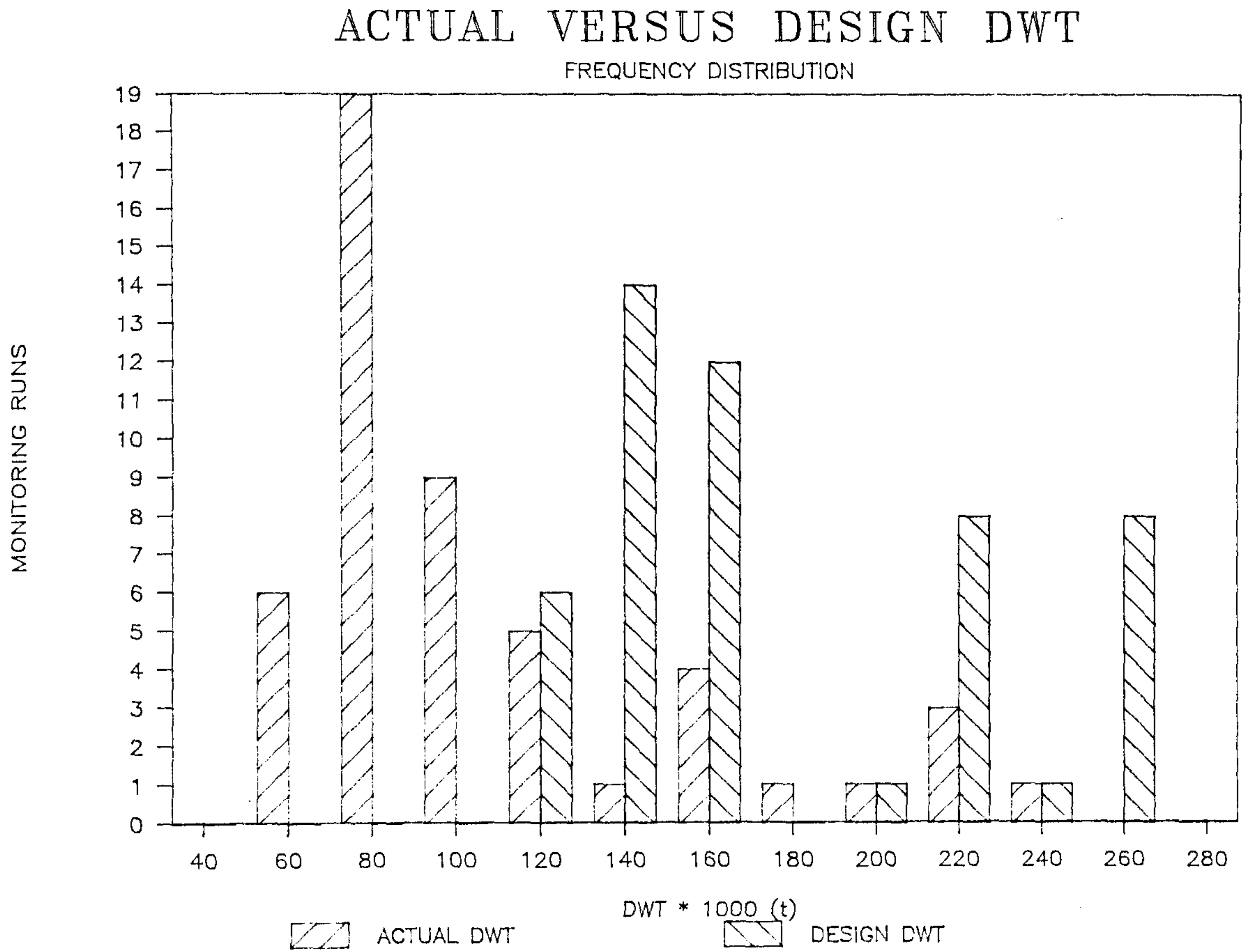
=======================

LOADING CONDITIONS

RUN	DATE	SHIP CODE	DWT MAX (t)	LOA m)	WIDTH (m)	DRAFT MAX.(m)	DRAFT FOR.(m)	DRAFT AFT(m)	DRAFT MEAN(m)	DISPL. (t)	DWT (t)
1	820808	001	169749	296.60	48.00	17.08	6.68	10.76	8.72	93607	67818
2	821115	002	274326	335.00	52.00	22.00	9.72	11.08	10.40	141975	100001
3	821212	003	179618	298.50	47.50	17.73	12.22	13.21	12.72	140293	117385
4	830316	004	172182	300.00	48.00	17.71	15.44	16.56	16.00	180782	149489
5	830325	005	168394	297.50	47.40	17.57	13.88	14.80	14.34	162595	130479
6	830330	006	126509	275.15	42.00	15.72	14.29	14.73	14.51	136251	114001
7	830426	007	264596	335.66	53.60	20.62	17.91	17.71	17.81	263063	219857
8	830523	008	158646	289.00	44.06	17.93	8.96	11.25	10.11	100539	72414
9	830602	009	158118	289.00	44.00	17.90	9.65	10.96	10.31	102644	73824
10	830606	010	224666	315.00	50.00	19.72	8.50	10.76	9.63	110558	82564
11	830616	011	170414	299.25	43.80	18.32	16.45	16.70	16.58	180386	150166
12	830726	008	158646	289.00	44.06	17.93	10.30	11.90	11.10	110095	81970
13	830713	012	142068	270.00	43.00	17.33	11.55	12.46	12.01	110863	89372
14	830806	013	142286	284.15	45.60	16.56	8.80	9.55	9.18	91333	63949
15	830817	002	274326	335.00	52.00	22.00	8.72	11.28	10.00	135020	93046
16	831028	014	131260	260.00	41.60	17.47	11.42	12.06	11.74	98225	78406
17	831029	009	158118	289.00	44.00	17.93	8.15	10.19	9.17	88602	59782
18	831115	015	168404	290.02	47.40	17.61	12.55	13.37	12.96	146124	113957
19	831117	016	154900	291.50	45.10	16.99	10.06	13.21	11.64	121159	92213
20	831124	017	122971	272.30	39.00	16.14	7.90	9.83	8.87	74838	56140
21	831231	009	158118	289.00	44.00	17.93	7.76	10.56	9.16	89384	60564
22	840104	018	227557	314.00	50.00	20.41	9.04	10.30	9.67	119121	82506
23	840106	019	123920	256.98	39.05	17.09	8.66	9.63	9.15	72522	51410
24	840115	020	217453	327.80	50.00	19.16	15.11	17.34	16.23	210388	173313
25	840122	021	161805	291.80	42.80	18.21	7.80	10.23	9.02	86759	59522
26	840229	022	268770	337.00	54.50	21.03	15.82	16.93	16.38	236325	192325
27	840319	002	274326	325.00	52.00	22.00	7.45	9.66	8.56	113213	71239
28	840324	023	169317	294.15	47.40	17.92	8.34	10.50	9.42	100378	70077
29	840427	010	224666	315.00	50.00	19.72	8.48	10.38	9.43	107964	79970
30	840409	012	144348	270.00	43.00	17.33	6.73	9.09	7.91	69242	47758
31	840503	009	158118	289.00	44.00	17.93	8.69	10.74	9.72	95482	158118
32	840518	024	227075	332.77	45.59	20.51	14.78	14.78	14.78	185556	151561
33	840528	025	272326	335.00	52.00	22.00	9.67	11.71	10.69	141950	99976
34	840608	026	227481	323.60	48.15	20.49	7.61	10.10	8.86	108369	71532
35	840610	001	169749	296.60	48.00	17.08	6.92	10.20	8.56	92379	66583
36	840612	018	227557	314.00	50.00	20.41	8.20	9.78	8.99	111147	74532
37	840624	027	234753	327.50	49.00	20.50	18.23	18.61	18.42	242205	205080
38	840729	010	224666	315.00	50.00	19.80	8.52	10.33	9.43	107588	79594
39	840803	028	177754	299.60	47.50	17.58	8.46	9.70	9.08	99262	75078
40	840809	029	125103	260.00	41.60	16.81	12.42	12.24	12.33	103701	83882
41	840812	002	274326	335.00	52.00	22.00	18.13	18.67	18.40	262992	221018
42	840820	030	158153	314.00	44.30	17.13	9.68	10.33	10.01	100869	72198
43	840901	007	264596	335.66	53.60	20.62	16.60	17.27	16.94	249170	205964
44	841006	001	169749	296.60	48.00	17.08	8.72	9.99	9.36	102337	76546
45	841026	031	247924	326.00	52.00	20.49	8.59	11.56	10.08	134527	94940
46	841108	009	158118	278.30	44.00	17.92	8.88	10.60	9.74	95824	67004
47	841206	032	139831	283.17	42.50	17.00	7.92	8.53	8.23	78529	54978
48	850106	033	162466	294.16	44.80	17.87	12.57	13.88	13.23	139342	109092
49	850107	009	158118	289.00	44.00	17.93	8.52	11.23	9.88	96716	67896
50	850129	034	157650	289.00	44.00	17.96	8.78	10.46	9.62	94693	65064

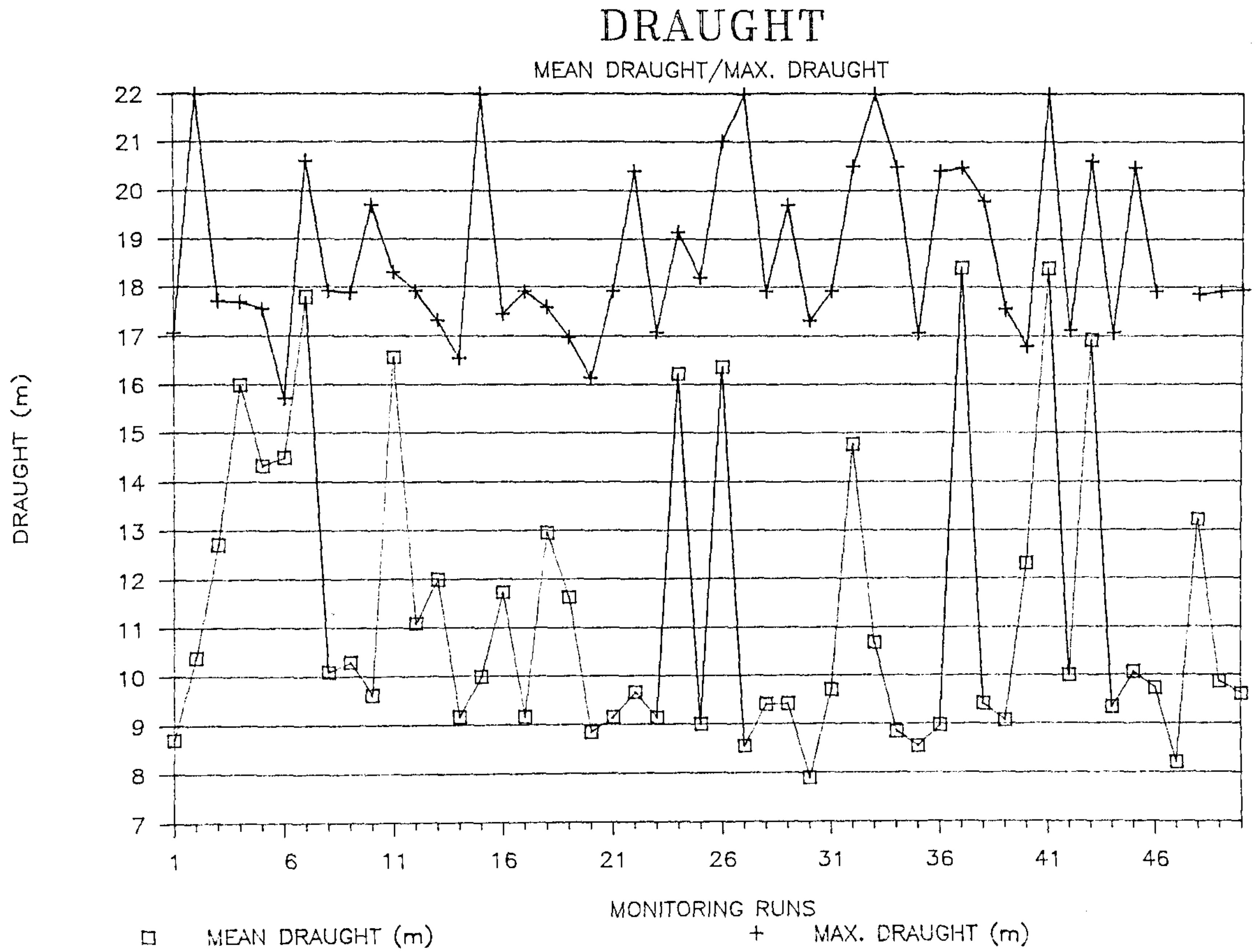

DISPLACEMENT TONNAGE
FREQUENCY DISTRIBUTION
MONITORING RUNS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
60
100
140
180
220
260
DISPLACEMENT (t) *1000
NUMBER OF SHIPS

Appendix 7.2



ACTUAL VERSUS DESIGN DWT
FREQUENCY DISTRIBUTION
MONITORING RUNS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
40
60
80
100
120
140
160
180
200
220
240
260
280
DWT * 1000 (t)
ACTUAL DWT
DESIGN DWT

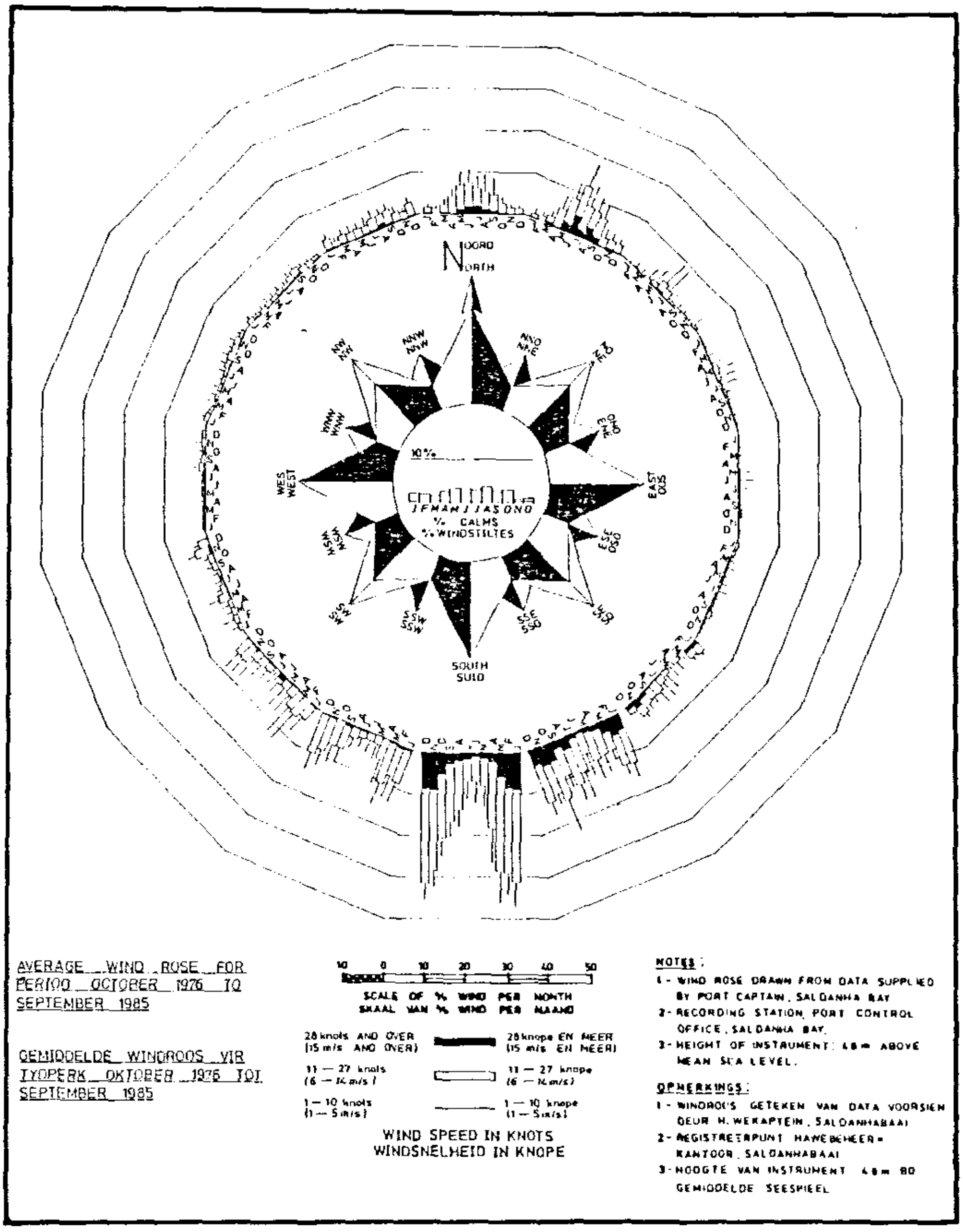
Appendix 7.3


DRAUGHT
MEAN DRAUGHT/MAX. DRAUGHT
DRAUGHT (m)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
1
6
11
16
21
26
31
36
41
46
MONITORING RUNS
MEAN DRAUGHT (m)
MAX. DRAUGHT (m)

Appendix 7.4

WEATHER AND SEA CONDITIONS

RUN	DATE	SHIP CODE	WIND SPD km/hr	WIND DIR	SWELL CHAN. (m)	TIDE CD. (m)	PILOT
1	820808	001	50	N	1.00	0.58	1
2	821115	002	0	-	0.80	1.20	2
3	821212	003	20	WNW	1.00	0.30	1
4	830316	004	0	-	1.50	0.43	1
5	830325	005	40	SSE	2.50	1.40	2
6	830330	006	30	SSW	1.20	0.23	3
7	830426	007	55	NNE	1.50	1.41	4
8	830523	008	40	N	1.30	1.50	3
9	830602	009	40	N	2.00	0.74	3
10	830606	010	40	SSE	2.00	1.03	1
11	830616	011	30	NW	1.50	0.85	3
12	830726	008	36	SSE	0.80	0.92	3
13	830713	012	55	N	2.50	0.57	3
14	830806	013	44	W	4.00	1.00	2
15	830817	002	36	W	1.00	1.06	4
16	831028	014	30	S	1.50	0.94	1
17	831029	009	42	SSW	1.50	1.00	1
18	831115	015	50	S	1.00	1.05	1
19	831117	016	25	SE	0.60	0.70	1
20	831124	017	0	-	2.00	1.26	1
21	831231	009	20	SW	1.20	0.85	3
22	840104	018	0	-	1.20	0.71	1
23	840106	019	30	WNW	2.00	0.75	1
24	840115	020	0	-	1.00	0.87	1
25	840122	021	25	SW	1.20	0.36	1
26	840229	022	40	NNW	2.50	1.58	1
27	840319	002	40	SW	1.20	0.84	4
28	840324	023	20	SW	0.50	1.10	3
29	840427	010	50	S	3.00	0.77	1
30	840409	012	30	S	1.60	0.76	1
31	840503	009	0	-	1.00	0.68	1
32	840518	024	0	-	2.00	0.55	1
33	840528	025	42	SSE	1.20	0.83	1
34	840608	026	12	SSE	2.00	1.30	5
35	840610	001	0	-	2.50	1.55	3
36	840612	018	70	SSE	2.40	0.69	5
37	840624	027	10	E	1.50	1.16	5
38	840729	010	50	SE	0.80	0.38	5
39	840803	028	60	NNW	0.80	1.23	3
40	840809	029	15	NW	2.00	0.74	6
41	840812	002	15	N	1.00	0.42	5
42	840820	030	10	N	1.40	1.30	3
43	840901	007	40	NW	0.50	0.89	1
44	841006	001	20	W	2.50	0.61	5
45	841026	031	10	ENE	1.30	1.41	1
46	841108	009	22	SW	1.30	0.64	6
47	841206	032					7
48	850106	033	50	W	1.30	0.53	1
49	850107	009	20	SSW	3.60	1.69	5
50	850129	034	25	W	0.50	1.04	8



SALDANHA WIND ROSE

Fig 7.6

Wind Force Acting on Run RH36

The Standard Building Regulation's code of practice formula for assessing wind forces on buildings can be used to calculate the wind forces acting on a bulk carrier.

The equation is as follows:

$F = q.A$

where $q = 0,613.V_T^2$

and $V_T^2 = V.S_1.S_2$

$F = 0,613.V_T^2.A$

F – wind force acting on ship (kN)

V – basic wind speed (m/s)

S_1 – multiplying factor relating to topology.

S_2 – multiplying factor relating to height above ground of structure.

V_T^2 –Total wind speed. (m/s)

A – area of ship exposed to wind. (m^2)

= {LOA. freeboard + 1000}cos(a)

1000 – allowance for accommodation (m^2)

a – angle at which wind blows on ship. (degr.)

The worst case was run RH36, ship code 018.

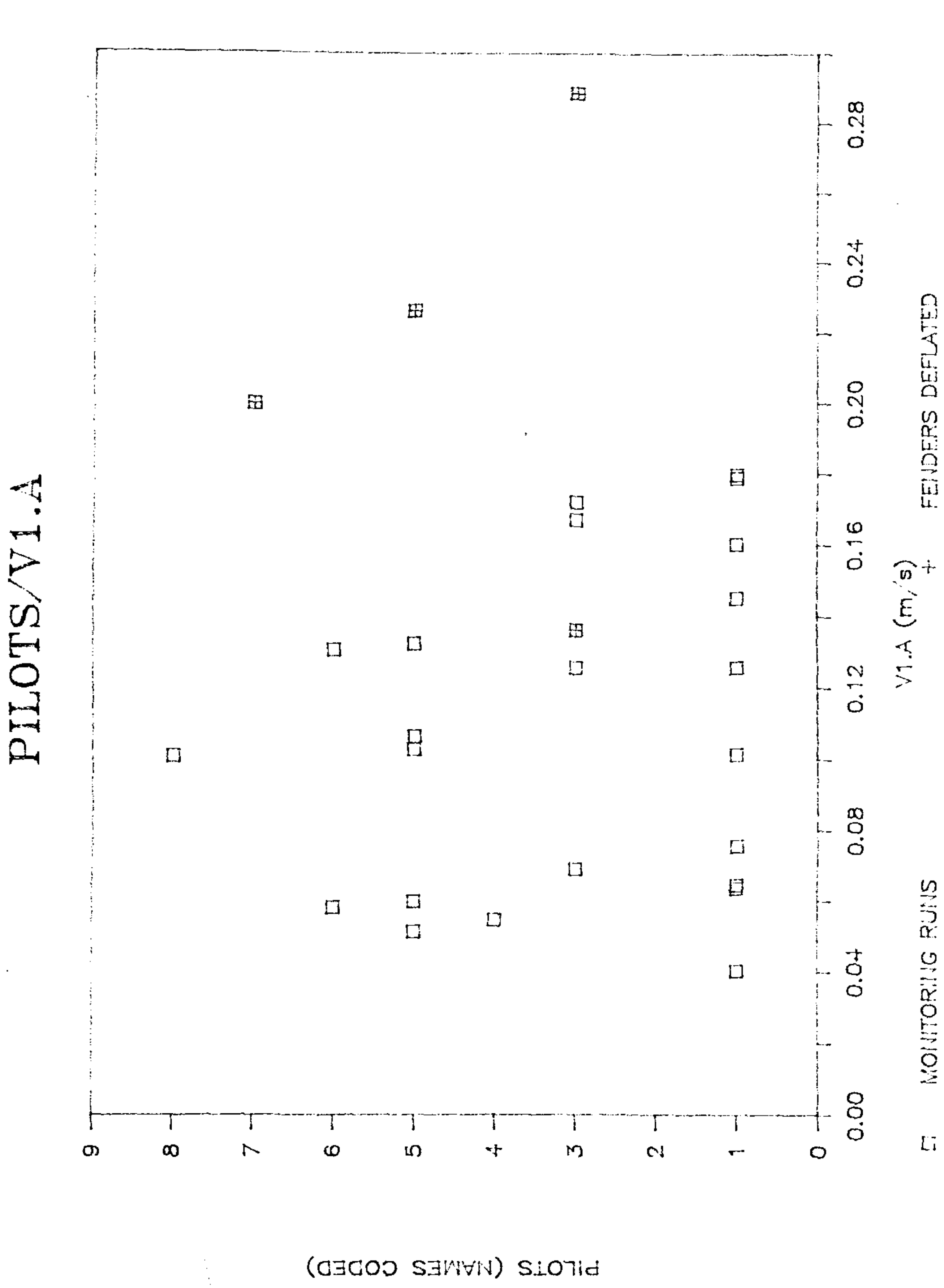
The wind blew S.S.E at 70 km/hr

= 19,44 m/s

$F = 0,613*(19,44*1*1,03)^2*[(314*16 + 1000)\cos 43]$

= 1083 kN

= 108 tf


PILOTS/V1.A
PILOTS (NAMES CODED)
0
1
2
3
4
5
6
7
8
9
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
V1.A (m/s)
□ MONITORING RUNS
+ FENDERS DEFLATED

APPENDIX 7.9

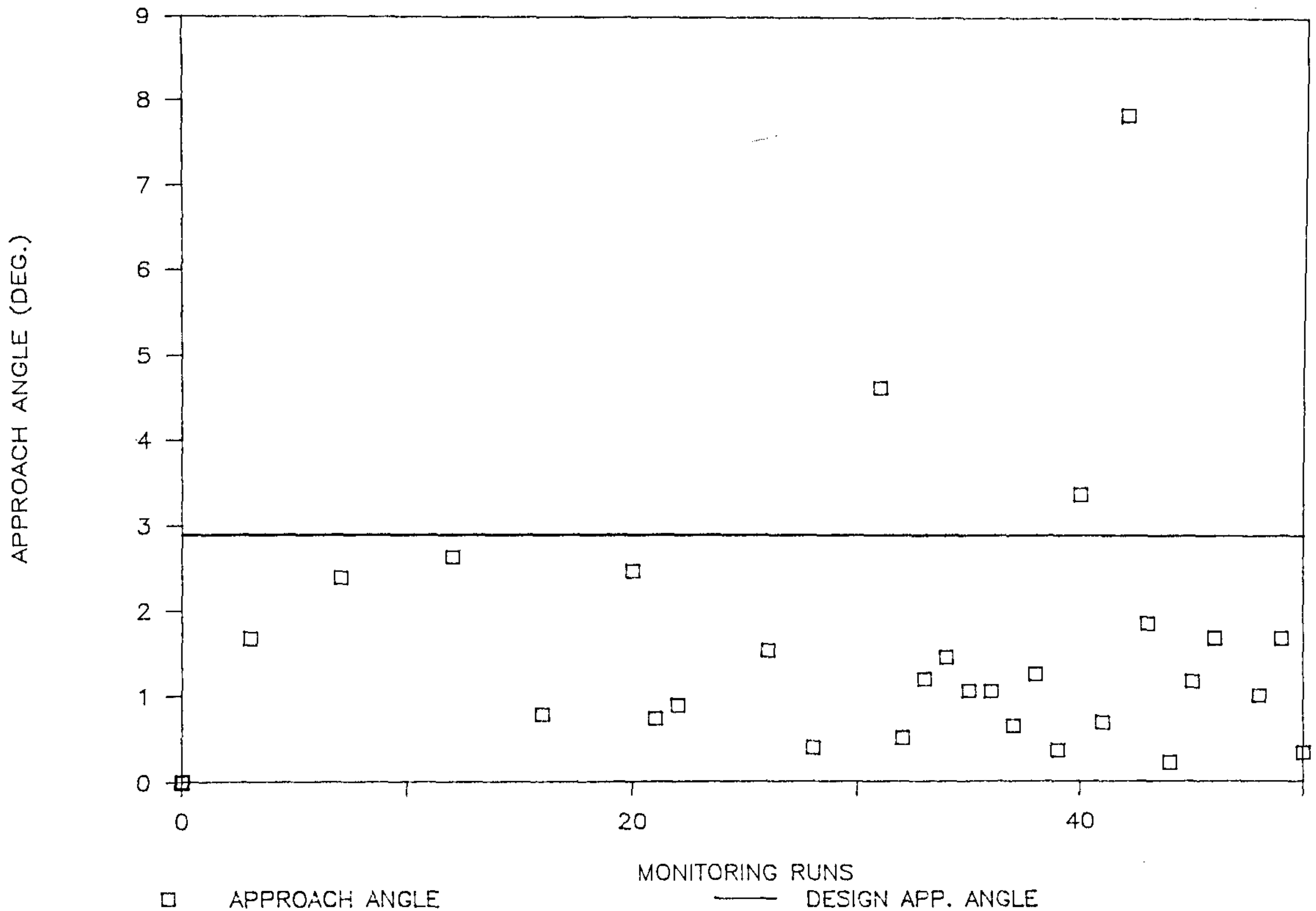
BOW IMPACT

RUN	BTY2 (m)	STY2 (m)	APP-ANGLE (rad)	APP-ANGLE (deg)	BTY1 (m)	BDT (s)	VB (m/s)	STY1 (m)	STDT (s)	VS (m/s)	WCG (rad/s)	J (m)
1												
2							0.20					
3	3.72	7.40	0.029	1.68	11.78	71.00	0.11	9.59	71.00	0.03	-0.000697	59.70
4	3.77				8.88	50.00	0.10					
5	5.38				11.30	50.00	0.12					
6	4.35				6.84	77.00	0.03					
7	3.70	4.95	0.042	2.39	8.64	102.00	0.05	8.41	59.00	0.06	0.000086	67.13
8												
9												
10							0.07					
11												
12	2.80	8.26	0.046	2.64	9.15	39.00	0.16	7.19	39.00	-0.03	-0.001605	57.80
13												
14												
15												
16	3.50	5.13	0.014	0.79	5.93	34.00	0.07	6.87	34.00	0.05	-0.000171	52.00
17												
18												
19	3.67				5.93	29.00	0.08					58.30
20	5.02	10.13	0.043	2.47	12.33	48.00	0.15	14.90	48.00	0.10	-0.000446	54.46
21	3.50	5.03	0.013	0.74	7.49	33.00	0.12	6.76	33.00	0.05	-0.000578	57.80
22	4.10	5.95	0.016	0.89	6.90	27.00	0.10	10.20	27.00	0.16	0.000453	62.80
23												
24												
25												
26	4.50	7.70	0.027	1.55	5.53	29.00	0.04	8.57	29.00	0.03	-0.000047	67.40
27	3.50				10.05	42.00	0.16					65.00
28	3.50	4.33	0.007	0.40	5.53	31.00	0.07	5.66	31.00	0.04	-0.000190	58.83
29	3.72				7.81	31.00	0.13					63.00
30	2.21				16.30	64.00	0.22					54.00
31	4.20	13.80	0.081	4.63	9.32	36.00	0.14	18.60	37.00	0.13	-0.000105	57.80
32	4.20	5.26	0.009	0.51	5.82	25.00	0.06	7.27	25.00	0.08	0.000132	66.55
33	3.50	6.00	0.021	1.21	9.64	37.00	0.17	12.14	37.00	0.17	0.000000	67.00
34	3.50	6.53	0.026	1.46	7.60	19.00	0.22	9.45	19.00	0.15	-0.000524	64.72
35	3.50	5.71	0.019	1.07	13.65	63.00	0.16	13.39	63.00	0.12	-0.000331	59.32
36	4.30	6.50	0.019	1.06	12.57	40.00	0.21					62.80
37	3.80	5.15	0.011	0.65	5.77	39.00	0.05	7.67	39.00	0.06	0.000119	65.50
38	4.30	6.93	0.022	1.27	8.30	31.00	0.13	11.99	31.00	0.16	0.000288	63.00
39	3.40	4.15	0.006	0.36	9.18	21.00	0.28	6.98	21.00	0.13	-0.001185	59.92
40	3.64	10.64	0.059	3.38	14.40	94.00	0.11	20.05	94.00	0.10	-0.000121	52.00
41	3.67	5.10	0.012	0.69	14.00	114.00	0.09	13.20	114.00	0.07	-0.000165	67.00
42	6.44	22.80	0.137	7.86	13.20	62.00	0.11	25.48	62.00	0.04	-0.000555	62.80
43	4.80	8.65	0.032	1.86	6.76	44.00	0.04	8.12	44.00	-0.01	-0.000477	67.13
44	3.50	3.96	0.004	0.22	6.14	26.00	0.10	4.15	26.00	0.01	-0.000795	59.32
45	2.54	5.00	0.021	1.19	6.36	33.00	0.12	8.82	33.00	0.12	0.000000	65.20
46	2.70	6.21	0.030	1.70	7.51	64.00	0.08	13.45	64.00	0.11	0.000320	55.66
47							0.20					
48	3.50	5.60	0.018	1.01	6.66	51.00	0.06	5.60	27.00	0.00	-0.000523	58.83
49	3.50	7.00	0.030	1.69	7.22	65.00	0.06	8.90	65.00	0.03	-0.000236	57.80
50	3.50	4.20	0.006	0.34	5.45	20.00	0.10	4.99	20.00	0.04	-0.000489	57.80

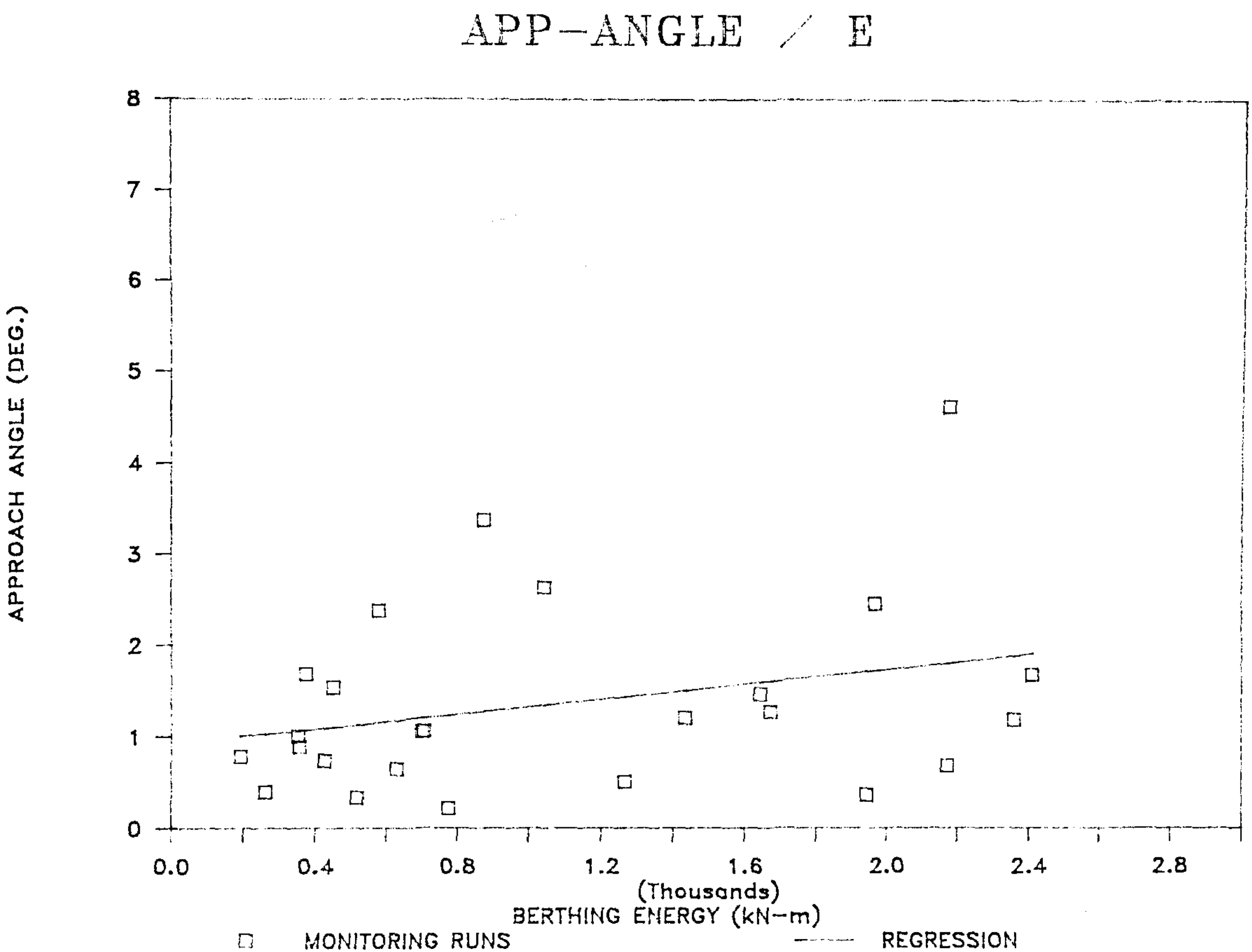
BOW IMPACT

RUN	DISPL. (t)	APP-ANG rad	VST m/s	VBT m/s	V.CG m/s	WCG rad/s	ALFA(a) rad	R (m)	J (m)	CE	V1A^2	V1A m/s	E	CM
1	93607													
2	141975			0.20										
3	140293	0.031	0.03	0.11	0.07	-0.000697	1.313	104.84	59.70	0.24	0.0211	0.15	2410.00	6.66
4	180782			0.10										
5	162595			0.12										
6	136251			0.03										
7	263063	0.011	0.06	0.05	0.06	0.000086	1.200	83.00	67.13	0.40	0.0030	0.05	579.00	3.74
8	100539	0.044	0.06	0.22										
9	102644													
10	110558			0.07										
11	180386													
12	110095	0.046	-0.03	0.16	0.03	-0.001605	1.257	83.32	57.80	0.32	0.0279	0.17	1043.00	2.09
13	110863													
14	91333													
15	135020													
16	98225	0.014	0.05	0.07	0.06	-0.000171	1.289	78.41	52.00	0.31	0.0057	0.08	191.00	2.23
17	88602	0.010	0.09	0.08										
18	146124													
19	121159			0.08										
20	74838	0.043	0.10	0.15	0.13	-0.000446	1.303	87.55	54.46	0.28	0.0320	0.18	1967.00	5.89
21	89384	0.013	0.05	0.12	0.08	-0.000578	1.247	71.95	57.80	0.39	0.0158	0.13	426.00	1.54
22	119121	0.016	0.16	0.10	0.12	0.000453	1.270	88.79	62.80	0.33	0.0103	0.10	355.00	1.74
23	72522													
24	210388													
25	86759													
26	236325	0.027	0.03	0.04	0.03	-0.000047	1.242	91.55	67.40	0.35	0.0016	0.04	450.00	6.72
27	113213			0.16									158.00	
28	100378	0.007	0.04	0.07	0.05	-0.000190	1.229	72.04	58.83	0.40	0.0048	0.07	261.00	2.73
29	107964			0.13										
30	69242			0.22									465.00	
31	95482	0.081	0.13	0.14	0.14	-0.000105	1.166	69.06	57.80	0.41	0.0257	0.16	2177.00	4.31
32	185556	0.009	0.08	0.06	0.07	0.000132	1.256	75.60	66.55	0.44	0.0042	0.06	1266.00	7.53
33	141950	0.021	0.17	0.17	0.17	0.000000	1.273	95.05	67.00	0.33	0.0323	0.18	1433.00	1.88
34	108369	0.026	0.15	0.22	0.17	-0.000524	1.300	99.24	64.72	0.30	0.0512	0.23	1643.00	1.98
35	92379	0.019	0.12	0.16	0.14	-0.000331	1.177	65.55	59.32	0.45	0.0295	0.17	706.00	1.15
36	111147	0.019		0.21									700.00	
37	242205	0.011	0.06	0.05	0.06	0.000119	1.319	102.91	65.50	0.29	0.0026	0.05	630.00	6.88
38	107588	0.022	0.16	0.13	0.14	0.000288	1.247	84.25	63.00	0.36	0.0175	0.13	1672.00	4.95
39	99262	0.006	0.13	0.28	0.20	-0.001185	1.186	64.31	59.92	0.46	0.0833	0.29	1942.00	1.01
40	103701	0.059	0.10	0.11	0.11	-0.000121	1.261	83.82	52.00	0.28	0.0171	0.13	875.00	3.56
41	262992	0.012	0.07	0.09	0.08	-0.000165	1.290	98.01	67.00	0.32	0.0105	0.10	2171.00	4.92
42	100869	0.137	0.04	0.11	0.06	-0.000555	1.252	122.50	62.80	0.21	0.0185	0.14	3167.00	16.27
43	249170													
44	102337	0.004	0.01	0.10	0.06	-0.000795	1.119	55.46	59.32	0.53	0.0113	0.11	775.00	2.51
45	134527	0.021	0.12	0.12	0.12	0.000000	1.250	87.93	65.20	0.35	0.0158	0.13	2360.00	6.25
46	95824	0.030	0.11	0.08	0.08	0.000320	1.297	91.05	55.66	0.27	0.0034	0.06		
47	78529			0.20	ERR								1555.00	
48	139342	0.018	0.00	0.06	0.02	-0.000523	1.271	80.48	58.83	0.35	0.0040	0.06	353.00	3.60
49	96716	0.030	0.03	0.06	0.04	-0.000236	1.235	72.86	57.80	0.39	0.0036	0.06	374.00	5.60
50	94693	0.006	0.04	0.10	0.06	-0.000489	1.275	76.91	57.80	0.36	0.0102	0.10	517.00	2.97

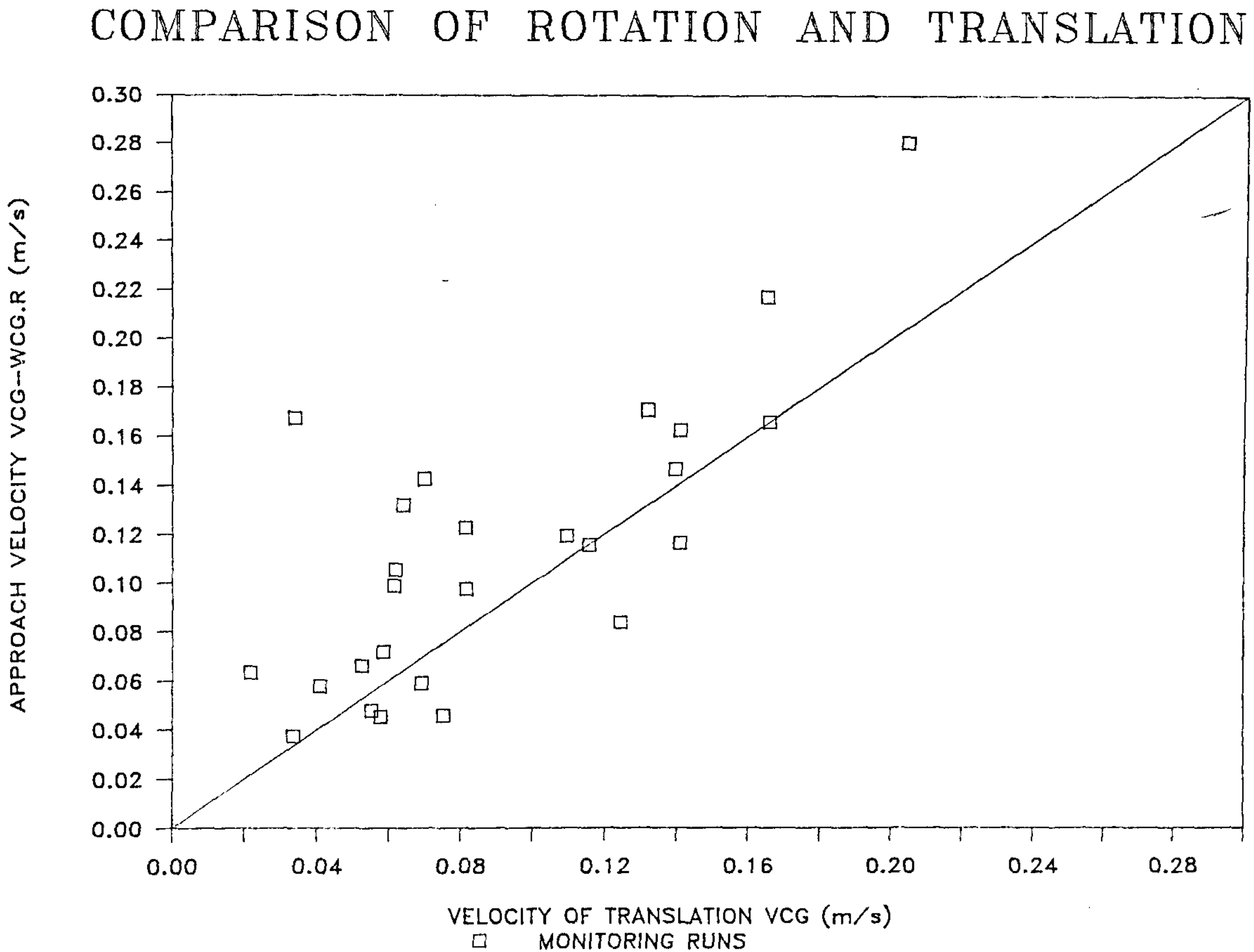
APPROACH ANGLES



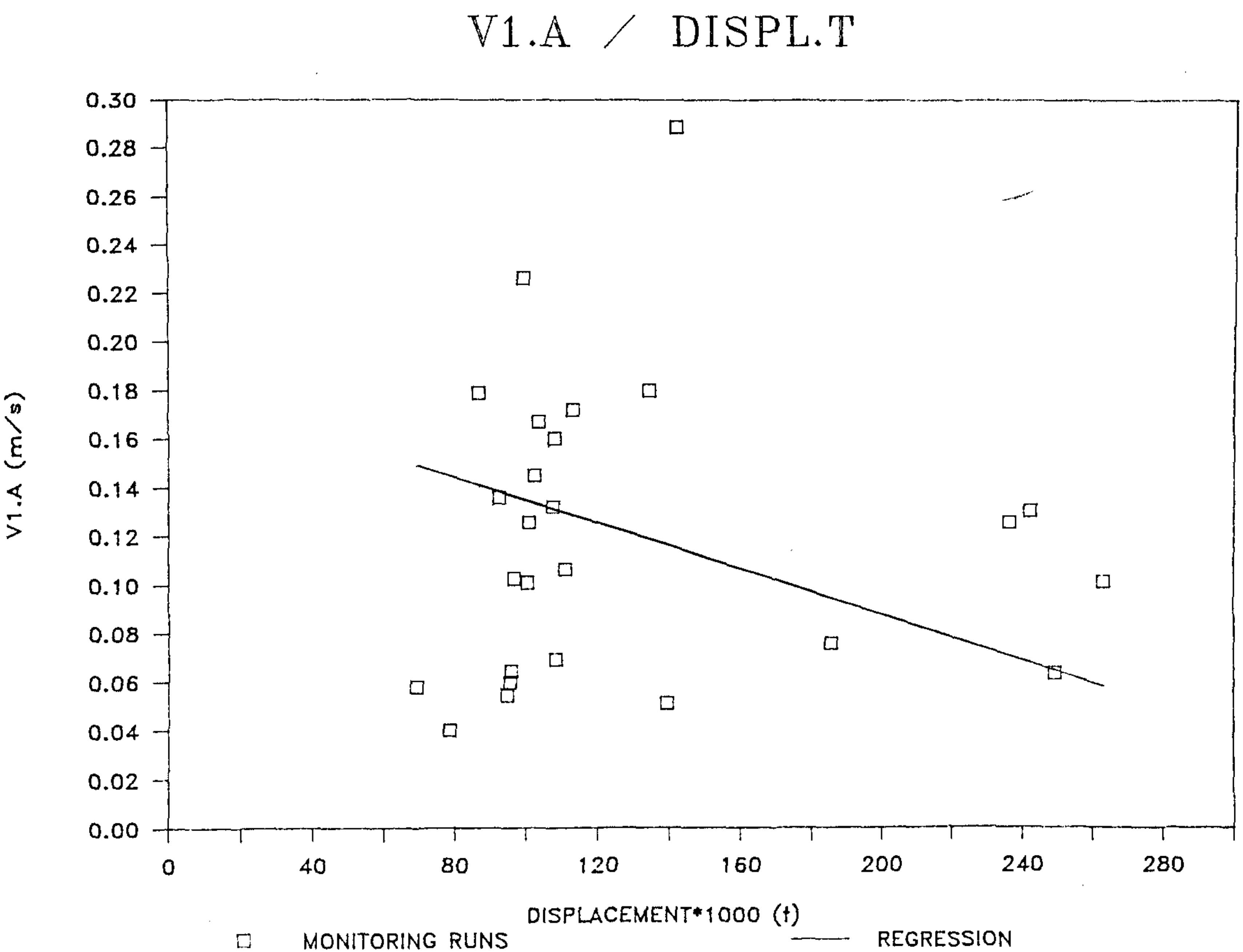
Appendix 7.11



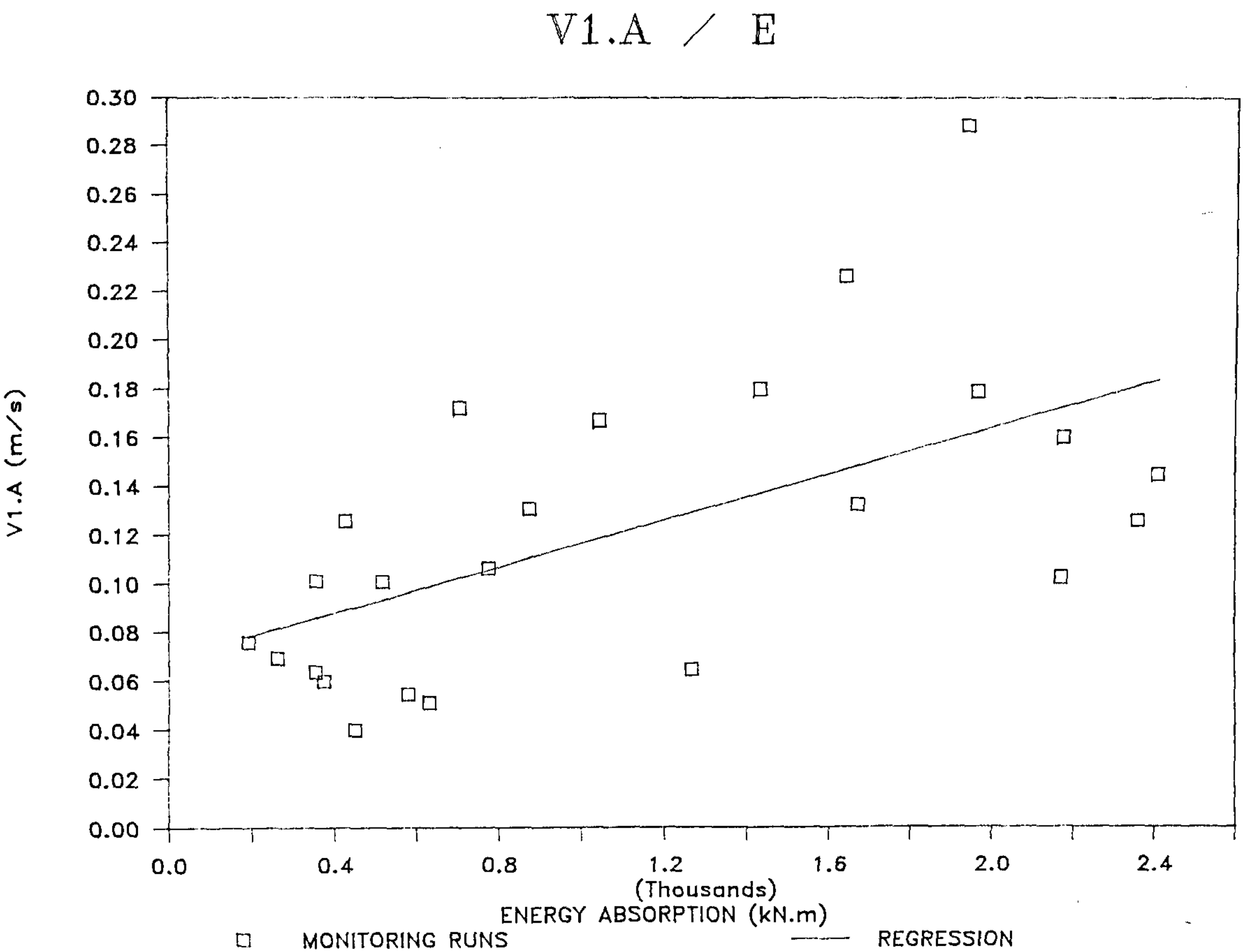
Appendix 7.12



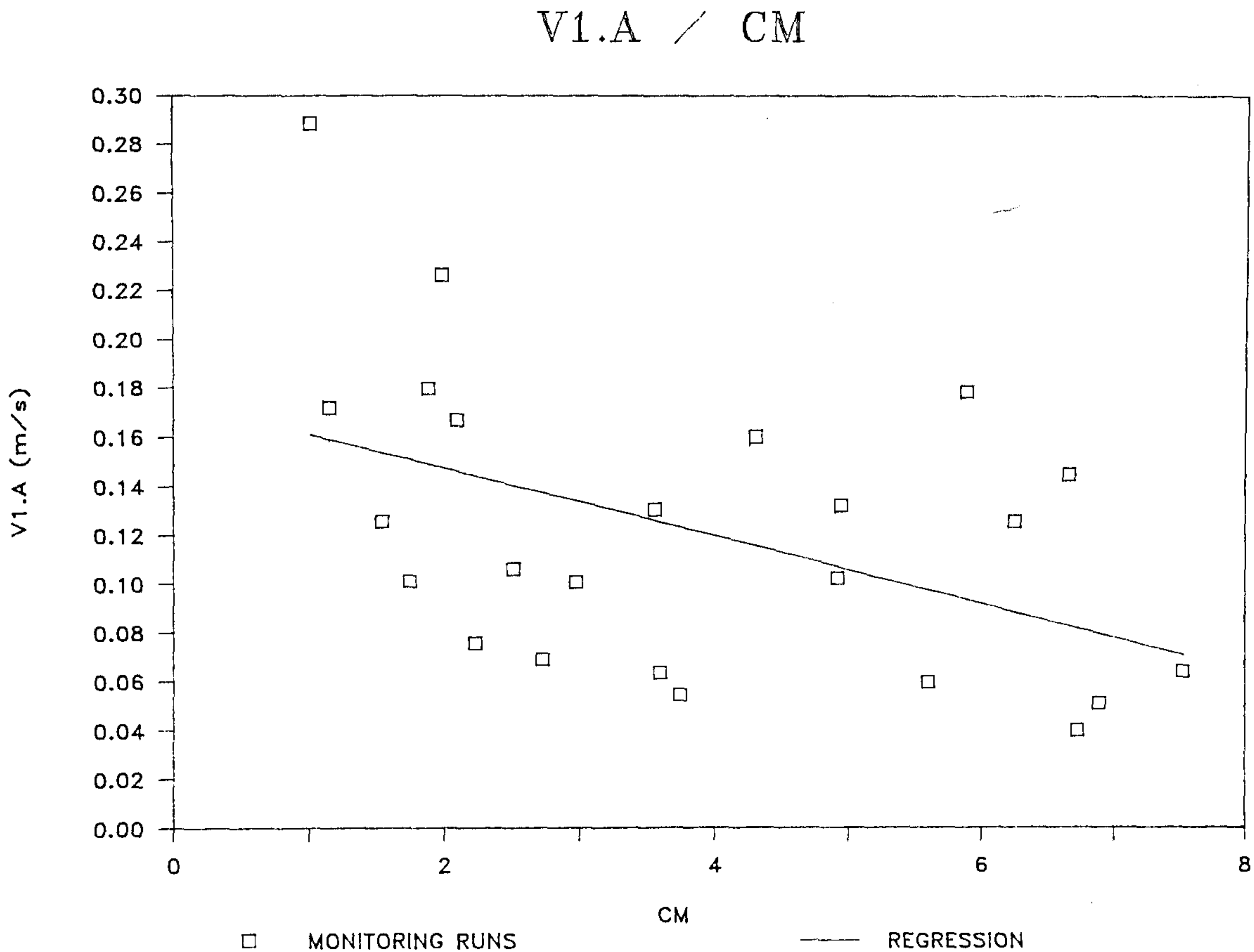
Appendix 7.13



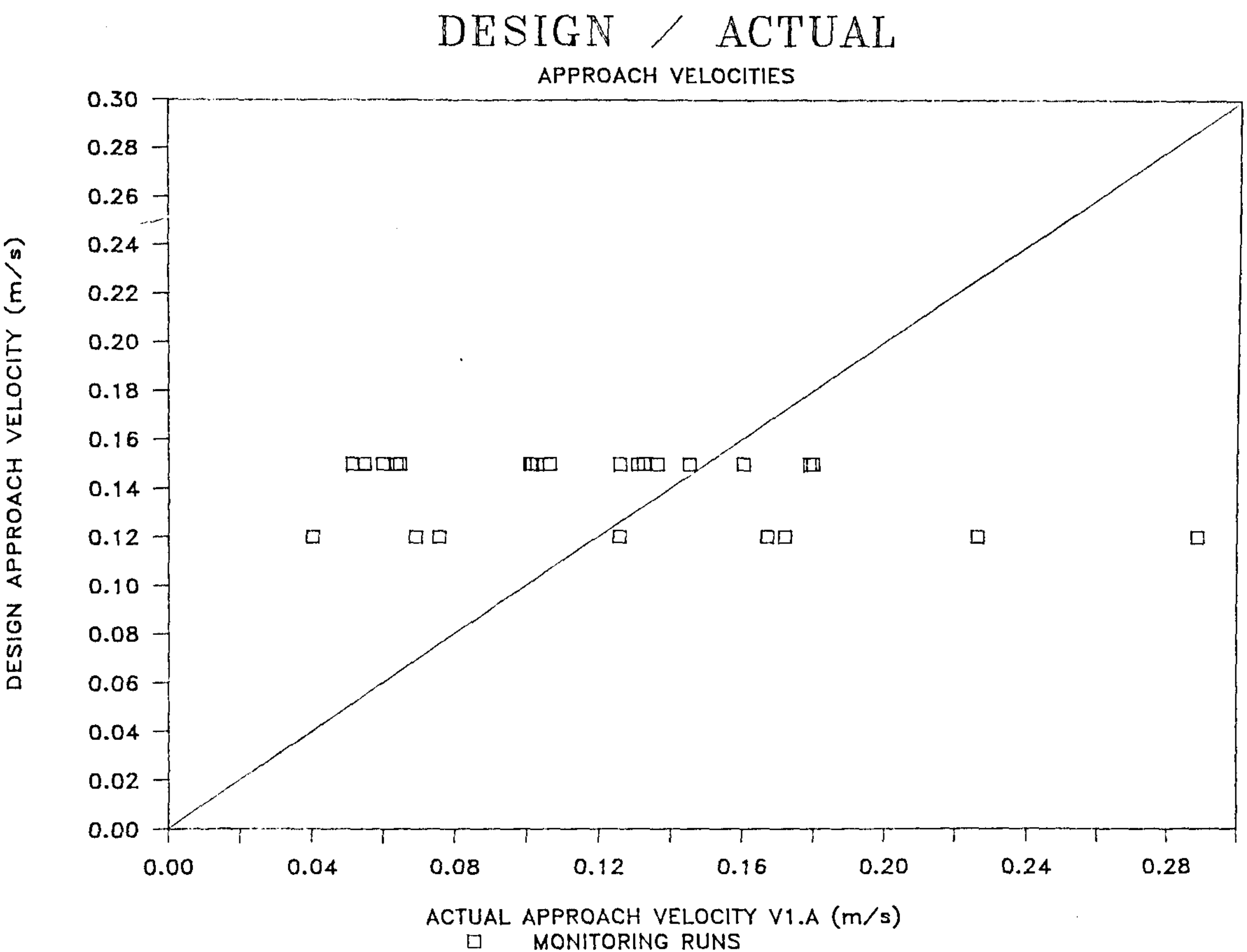
Appendix 7.14



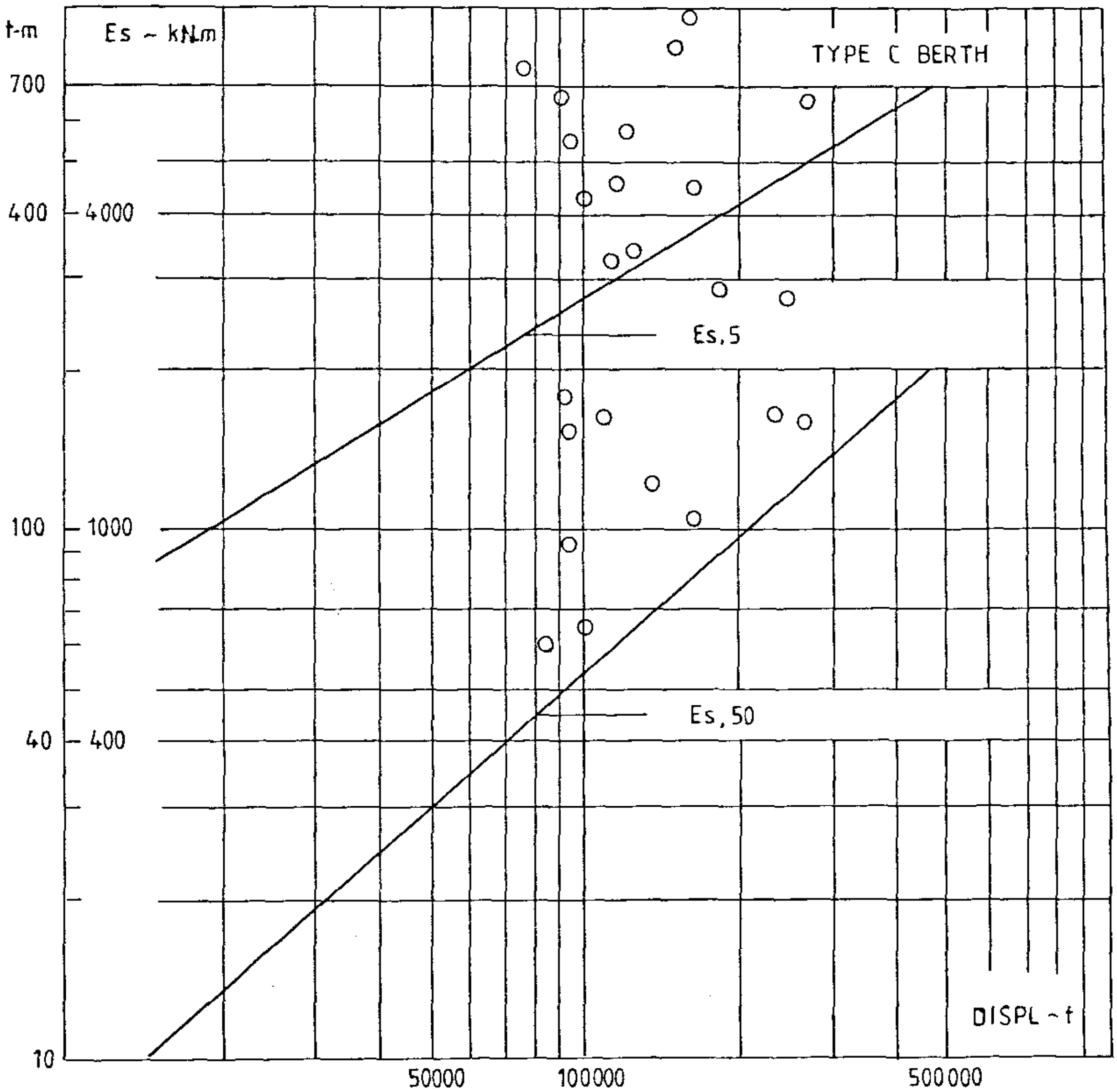
V1.A / E
V1.A (m/s)
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.0
0.4
0.8
1.2
1.6
2.0
2.4
(Thousands)
ENERGY ABSORPTION (kN.m)
MONITORING RUNS
REGRESSION



Appendix 7.16



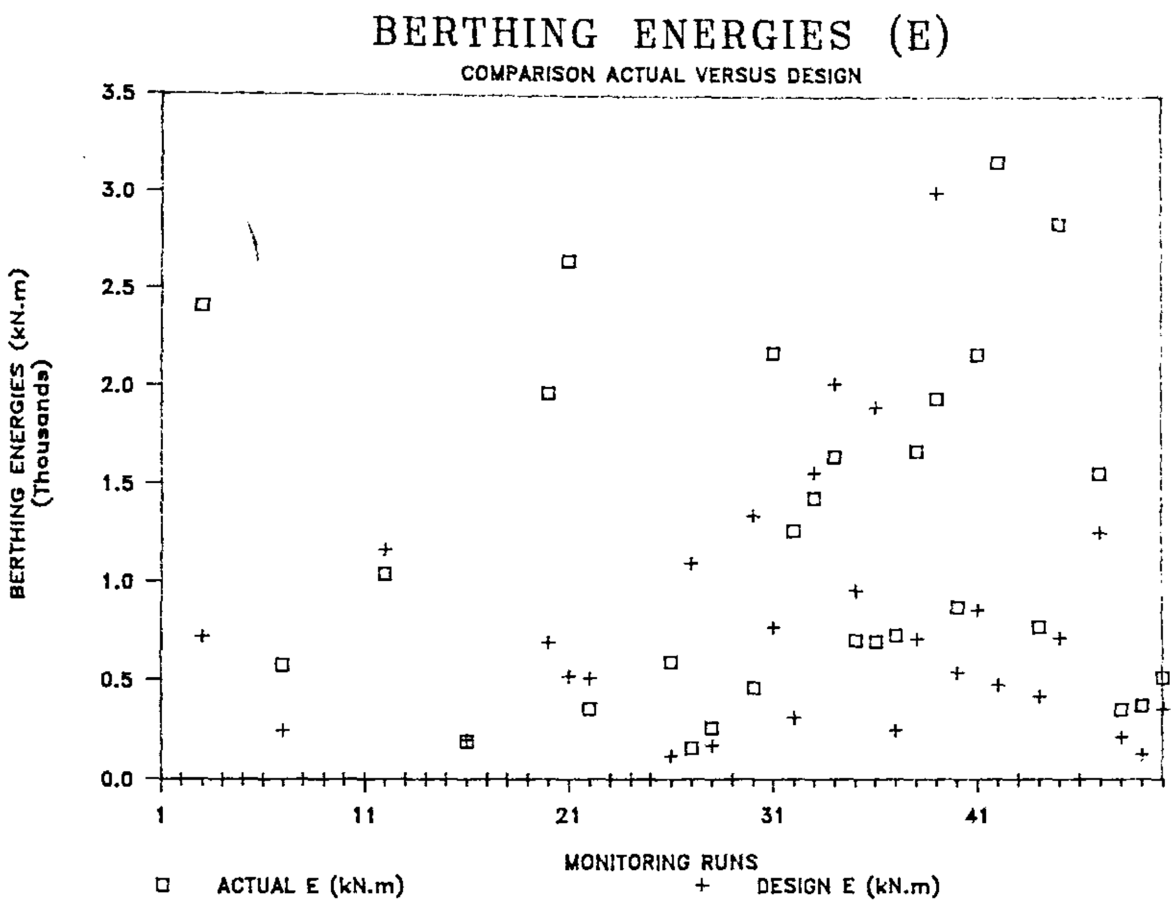
Appendix 7.17

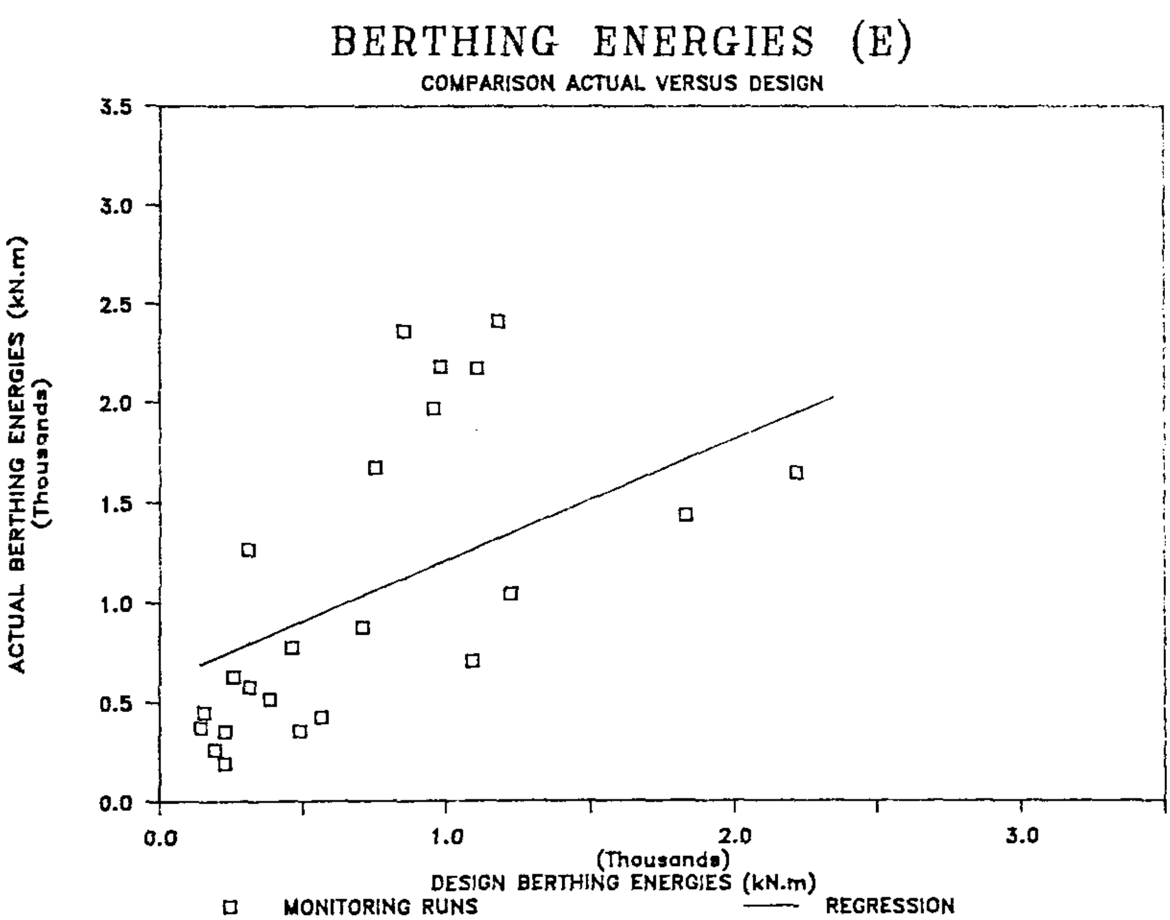


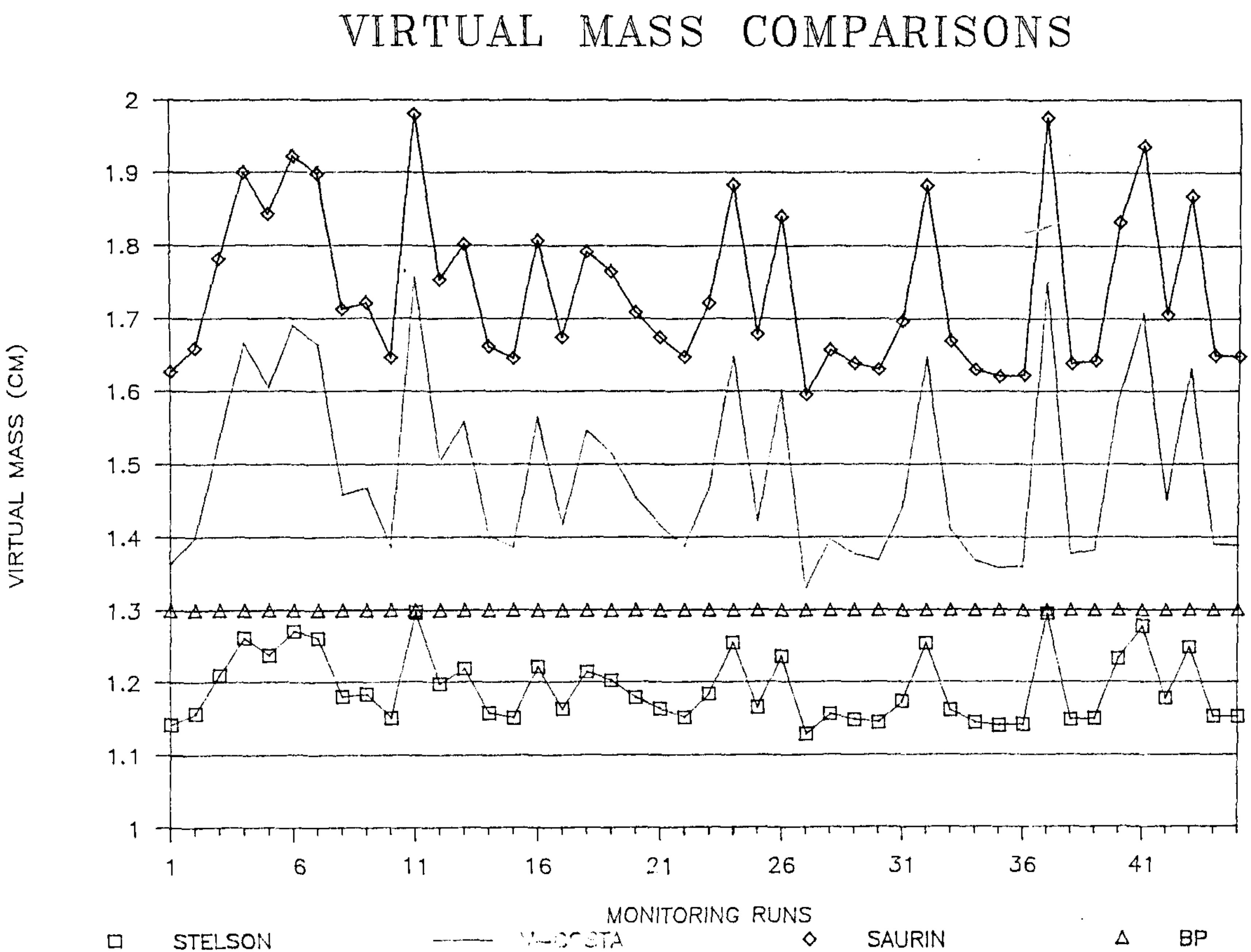
o - SALDANHA

Fig 7.18

STATISTICAL PLOT E - SALDANHA BAY


BERTHING ENERGIES (E)
COMPARISON ACTUAL VERSUS DESIGN
BERTHING ENERGIES (kN.m)
(Thousands)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1
11
21
31
41
MONITORING RUNS
ACTUAL E (kN.m)
DESIGN E (kN.m)


BERTHING ENERGIES (E)
COMPARISON ACTUAL VERSUS DESIGN
ACTUAL BERTHING ENERGIES (kN.m)
(Thousands)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.0
2.0
3.0
(Thousands)
DESIGN BERTHING ENERGIES (kN.m)
MONITORING RUNS
REGRESSION

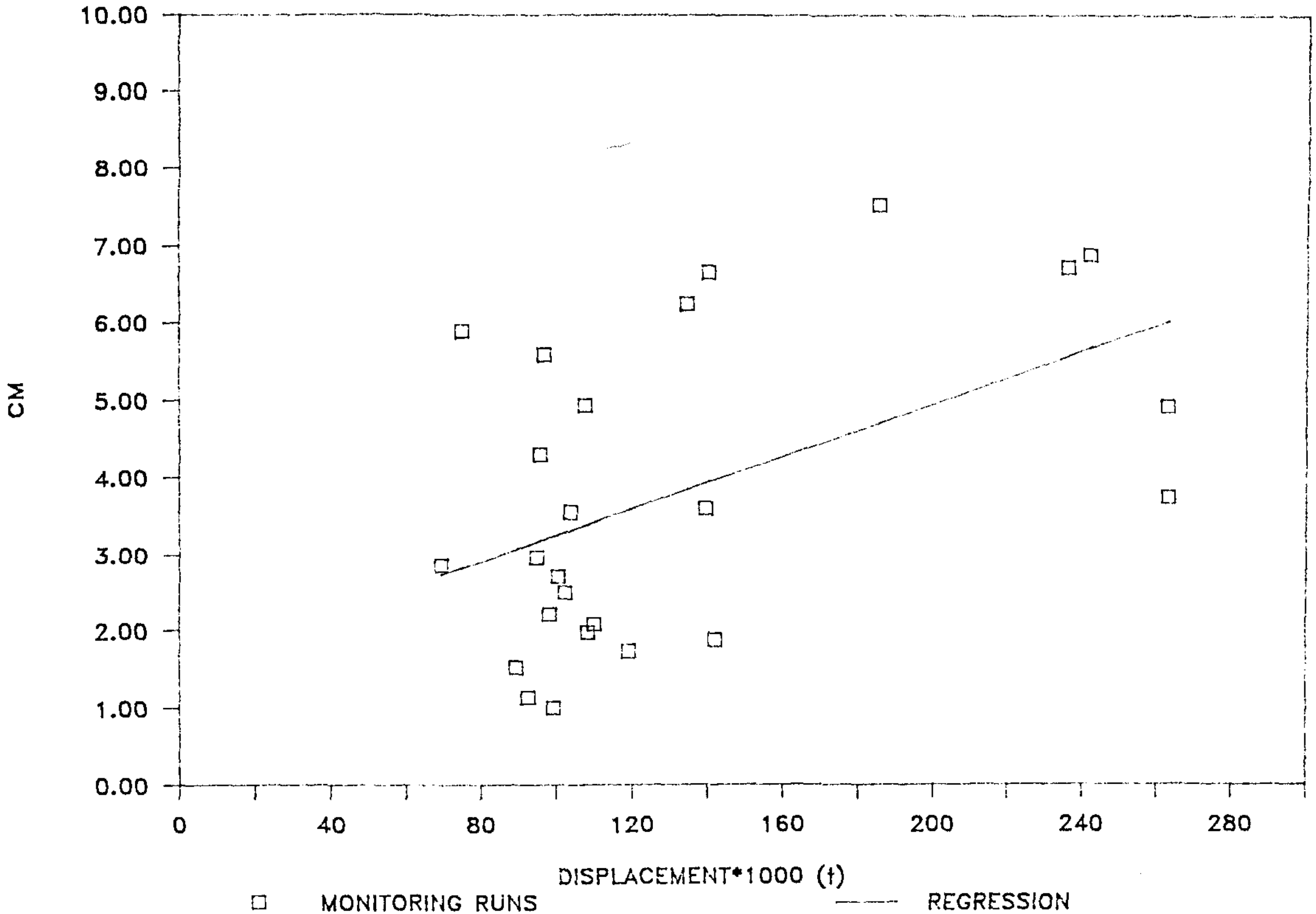

VIRTUAL MASS COMPARISONS
VIRTUAL MASS (CM)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
1
6
11
16
21
26
31
36
41
MONITORING RUNS
STELSON
SAURIN
BP

APPENDIX 7.21

VIRTUAL MASS COMPARISONS

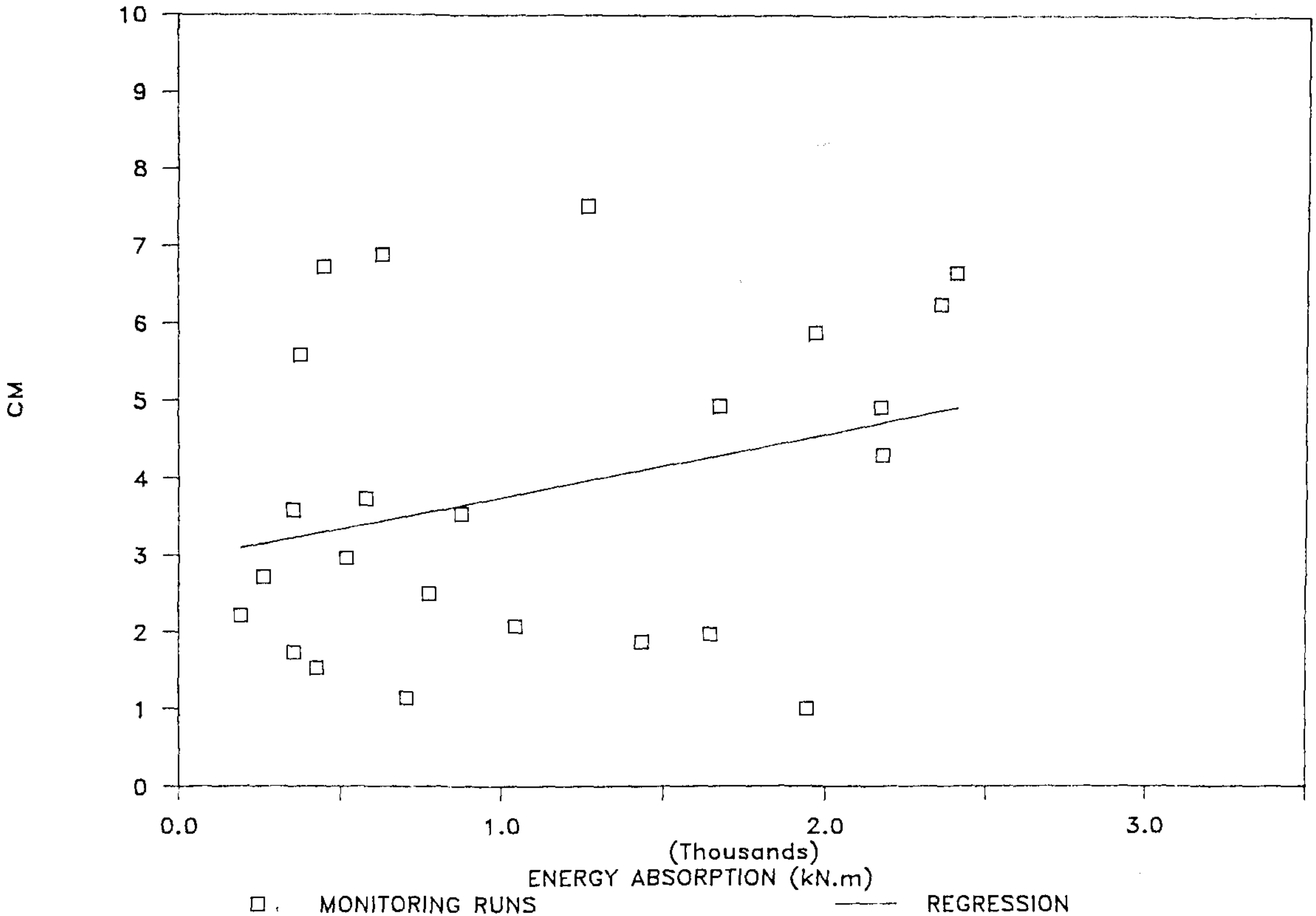
RUN	DATE	SHIP CODE	STELSON PI/4*D/B+1	V-COSTA 2*D/B+1	SAURIN (.3+1.8*D/B)+1	BP	SALDANHA
1	820808	001	1.14	1.36	1.63	1.30	
2	821115	002	1.16	1.40	1.66	1.30	
3	821212	003	1.21	1.54	1.78	1.30	6.66
4	830316	004	1.26	1.67	1.90	1.30	
5	830325	005	1.24	1.61	1.84	1.30	
6	830330	006	1.27	1.69	1.92	1.30	
7	830426	007	1.26	1.66	1.90	1.30	3.74
8	830523	008	1.18	1.46	1.71	1.30	
9	830602	009	1.18	1.47	1.72	1.30	
10	830606	010	1.15	1.39	1.65	1.30	
11	830616	011	1.30	1.76	1.98	1.30	
12	830726	008	1.20	1.50	1.75	1.30	2.09
13	830713	012	1.22	1.56	1.80	1.30	
14	830806	013	1.16	1.40	1.66	1.30	
15	830817	002	1.15	1.38	1.65	1.30	
16	831028	014	1.22	1.56	1.81	1.30	2.23
17	831029	009	1.16	1.42	1.68	1.30	
18	831115	015	1.21	1.55	1.79	1.30	
19	831117	016	1.20	1.52	1.76	1.30	
20	831124	017	1.18	1.45	1.71	1.30	5.89
21	831231	009	1.16	1.42	1.67	1.30	1.54
22	840104	018	1.15	1.39	1.65	1.30	1.74
23	840106	019	1.18	1.47	1.72	1.30	
24	840115	020	1.25	1.65	1.88	1.30	
25	840122	021	1.17	1.42	1.68	1.30	
26	840229	022	1.24	1.60	1.84	1.30	6.72
27	840319	002	1.13	1.33	1.60	1.30	
28	840324	023	1.16	1.40	1.66	1.30	2.73
29	840427	010	1.15	1.38	1.64	1.30	
30	840409	012	1.14	1.37	1.63	1.30	2.32
31	840503	009	1.17	1.44	1.70	1.30	4.31
32	840518	024	1.25	1.65	1.88	1.30	7.53
33	840528	025	1.16	1.41	1.67	1.30	1.88
34	840608	026	1.14	1.37	1.63	1.30	1.98
35	840610	001	1.14	1.36	1.62	1.30	1.15
36	840612	018	1.14	1.36	1.62	1.30	1.58
37	840624	027	1.30	1.75	1.98	1.30	6.88
38	840729	010	1.15	1.38	1.64	1.30	4.95
39	840803	028	1.15	1.38	1.64	1.30	1.01
40	840809	029	1.23	1.59	1.83	1.30	3.56
41	840812	002	1.28	1.71	1.94	1.30	4.92
42	840820	030	1.18	1.45	1.71	1.30	16.27
43	840901	007	1.25	1.63	1.87	1.30	
44	841006	001	1.15	1.39	1.65	1.30	2.51
45	841026	031	1.15	1.39	1.65	1.30	6.25
46	841108	009	1.17	1.44	1.70	1.30	
47	841206	032	1.15	1.39	1.65	1.30	
48	850106	033	1.23	1.59	1.83	1.30	3.60
49	850107	009	1.18	1.45	1.70	1.30	5.60
50	850129	034	1.17	1.44	1.69	1.30	2.97

CM / DISPLACEMENT



Appendix 7.22

CM / E



Appendix 7.23

CM / UNDERKEEL CLEARANCE