A PROPOSAL FOR NEW CRITERIA FOR THE DESIGN OF ANCHORING SYSTEMS FOR MERCHANT SHIPS

by

L.Brink, Msc.(TU.Delft)
Naval Architect
Master MN(ret)

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CONTENTS

1 SUMMARY

Proposed are new criteria for the design of anchoring systems for merchant ships. They are based on the holding power of the anchor and the environmental conditions which act on the ship at anchor. The proposed criteria are discussed and supporting calculations for four ships are presented. Also the increase in load in the anchor chain due to surge, heave and pitch is discussed and results of calculations are given. Lastly the impact to which a chain can be subjected when the ship is anchored and during the anchoring manoeuvre is addressed and results of calculations are given.

The result of the study indicates that the design method based on the equipment number must be abandoned in favour of the proposed method which proved to be feasible and safer.

The recommendation is that steps must be undertaken by all classification societies to implement the proposed criteria soonest in order to enhance the safety of ships at anchor.

2 INTRODUCTION

This paper is a continuation of the work done on the design of anchoring systems for merchant ships.[1] In that work it was shown that the present design philosophy, which is based on the "equipment number" omits to take into account the holding power of the anchor and the environmental forces which act on the ship whilst she is anchored. Consequently the ship's master has no insight into the capacity of the anchoring system, which from a safety point of view is unsatisfactory. Therefore a design method based on the holding power of the anchor and the environmental forces which act on the ship at anchor is proposed.

The reason that the ship's master is specifically mentioned originates from the fact that the study started with an evaluation of the methods used by seafarers to determine the required length of chain when anchoring their ships. The methods they used were based on " rules of thumb" which in the past were useful but presently obsolete. Hence it was recommended that the required length of anchor chain cable should be determined by means of catenary equations. It was obvious that the study required a careful investigation into the circumstances where, when and how seafarers use the ground tackle. The result was the above mentioned study.

However it is not good enough to propose that a design method based on the " equipment number" should be abandoned in favour of a method based on the holding power of the anchor and the environmental forces which act on the ship. It must also be shown that this is feasible and safer. Hence this paper.

In order to show the safety and feasibility of the proposal a set of design criteria supported by calculations are required. This paper addresses both subjects. The first part deals with the design proposals, the second part with the outcome of the calculations and the last part with the conclusions and recommendations.

3 DESIGN CRITERIA

Before addressing the proposed design criteria it is important to draw your attention to and to point out that the " equipment number" and the requirements for the anchoring equipment as used by the classification societies are based on a fast amount of experience gained over many years. Hence the proposed design criteria only indicate where modifications are required.

The full text is given in appendix A. This section will only deal with those subjects which need clarification.

3.1 Loading conditions

The proposal considers three loading conditions. The reason being that the transverse and longitudinal area above the waterline and the fore, aft and mean draft change with the loading condition. As change in area and draft influences the wind and current forces a calculation must be performed for the 100 and 50 percent loaded conditions. In particular the ballast condition is important because in addition to the wind and current forces which can act on the ship there must be sufficient length of chain cable available to anchor.

3.2 Design water depth

Because ships sail all over the world it is impossible to specify all the locations in which they anchor. It is therefore proposed to define a design water depth which is 6 times the fully loaded draft. An advantage is that for the so defined or deeper water depth the blockage effect is negligible. The influence of the blockage effect will be addressed later.

3.3 Environmental conditions

It is proposed to define a survival and maximum operational condition as is customary in the off-shore industry.

For the maximum operational condition it is proposed to use the wind velocity of 19 m/s at 10 meters above sea level being force 8 on the scale of Beaufort. This is less than is used by the IACS [2]. The reason being that from discussions with ship's masters it became clear that it must be possible to remain at anchor in wind force 8 in an anchorage where waves also act on the ship.

There are a number of methods which can be used to calculate the relations between the wind force and the sea condition. A method by Ippen ,which will be addressed later, was used for this study.

The soil conditions on which the holding power of the anchor must be based was found in the publications by anchor manufacturers.

3.4 Static and dynamic force calculations

It is proposed that a number of calculations are made for various situations and that the outcome of the calculations are presented in a tabular and graphical form.

This serves two purposes:

- the determination of the dimensions of the chain cable;
- that the ship's master can judge the capacity of the anchoring system under various environmental conditions.

In addition to the design water depth a depth of 1.5 times the draft in various loading conditions is specified. The reason being that due to the blockage effect the holding power of the anchor could be insufficient. To check this possibility an additional calculation for shallow water effects is required.

3.5 The anchor

The calculation of the anchoring system can only successfully be done when proper details of the holding power of the ship's anchor are available. Therefore the proposal explicitly spells out the requirements for the anchor.

The requirements do not seem unreasonable as many manufactures publish these data for anchors used in the offshore industry, so why not for a ship's anchor ?

It is possible that for extreme large ships it may not be feasible to fit the anchor and cable based on the design criteria set out. Reasons could be that the dimensions of the anchor are so extreme that they cannot safely be stowed in the anchor pockets and that stowing the chain in the chain locker will give problems. In that case it is proposed that a suitable anchor with the highest possible holding power is fitted. It is obvious that this will reduce the capacity of the anchoring system and that the ship's staff must be fully aware of the limitations of the fitted system.

3.6 Length and strength of chain cable

As is in the case of the anchor the proposal explicitly spells out a number of requirements for the chain cable. They concern on the one hand the strength and energy contents and on the other the required length of the chain cable.

Because the chain cable is not only subjected to a static load, which only occurs for part of the time in excellent environmental conditions, but also to impact and dynamic forces which occur frequently, it is appropriate to set criteria for all the loading conditions mentioned. Because of their special character impact and dynamic loadings will be fully addressed later.

The length is of special importance because from discussions with seafarers it became clear that for large ships in the ballast condition the available length for anchoring is often insufficient. The main and overriding reason being the distance from the waterline through the hawse pipe over the windlass through the spurling pipe requires a long length of chain for large ships. Also it must be realised that on top of that distance there must be sufficient slack in the chain locker. Hence the required length also depends on the design of the bow and the locations of windlass and chain lockers. Therefore it is far better to determine the required length of cable for each individual ship rather than define a fixed length as is done in the rules.

It is obvious that from a safety point of view and in order to avoid confusion the length of port and starboard chain must be equal.

3.7 Load for anchor and chain cable

It is proposed that the breaking load of the chain is derived from the holding power of the anchor. The division by cos 20^{o} is meant to correct the holding power to a line force.

Because the anchoring system is a dynamic system it is proper to take into account the dynamic force which occurs when the chain is subjected to motions generated by the ship in seaway. Later is will be shown that the dynamic load can exceed 50 % of the breaking load.

3.8 Windlass design

The windlass design criteria are based on the manner in which seafarers use the windlass. Anyone who is familiar with the anchoring manoeuvre in all sorts of weather conditions knows that great care is required for this work. This is especially true for large ships where the mass weight of chain and anchor is heavy.

In order to achieve a safer operation of the anchoring system detailed requirements are proposed for the system.

To accomplish this the main stay of the proposals is a direct relation between the break load of the chain and the loads required for the design of the brake and the windlass. This is a different approach to what is done in the rules.

As mentioned above for large ships the mass weight of chain and anchor is heavy. This calls for specific design criteria to control the winch and the brake system in a static and dynamic mode. This being the reason why particular operations are defined. Also it is important to specify the limitations of the system and to provide the ship's staff with this information.

The criteria given in this section are sufficient guidance for a windlass manufacturers to build a winch in accordance with these proposals. Hence the subject is not further addressed.

3.9 Additional calculations and data

There are two reasons for this proposal.

Firstly it is important to inform the ship's staff on the capacity and limitations of the anchoring system.

Secondly because the design calculation will be done with the aid of computers it is not difficult to include a full set of data with which the ship's master can determine the required length of chain and decide if the environmental conditions are safe to anchor.

This concludes the section 3.0 which highlights some of the reasons which prompted the proposed design criteria.

4 EVALUATION OF THE EQUIPMENT NUMBER

4.1 Introduction

Once the design criteria were written the next step was to calculate the required holding power and chain diameter for a particular ship. With the calculated diameter of the chain it is not difficult to determine from the tables on bower anchors and chain cables an estimated equipment number for that ship. By comparing the estimated number with the calculated number both methods can evaluated. This was done for four ships. The method which was used for the calculation is given in ref[1]. A short summary of the method follows .It is based on the equations for surge, sway and yaw motions of a ship in a horizontal plane by Abkowitz [3]. The principle is shown in figure no.1

It shows a system of axes whose directions are fixed with respect to the surface of the earth and the ship's system. Also is shown the velocity of the ship tangent to the ship's path through the water. If there is no wind or current the velocities u and v are :

$$dx_0 = u \cos\Phi - v \sin\Phi$$
$$dy_0 = u \sin\Phi + v \cos\Phi \qquad (1)$$

In these formulae are:

Φ = course ship in degrees
dx_0 = velocity ship in x_0- direction m/sec
dy_0 = velocity ship in y_0- direction m/sec

Figure no 1 also shows the location of the hawse pipe. To simplify the equations it is assumed that the entrance of the hawse pipe is at the surface of the water. Hence the horizontal chain force F_h acts at that point.

The forces and moment are the following;

$$X = F_x + F_{xw} + F_{xc} + F_{xg} + F_{xh}$$

$$Y = F_y + F_{yw} + F_{yc} + F_{yg} + F_{yh} \qquad (2)$$

$$M = M_{xy} + M_{xyw} + M_{xyc} + M_{xyg} + M_{xyh}$$

The forces and moment F_x F_y and M_{xy} relate to added mass and drag. Discussion of these characteristics is outside the scope of this paper. Formulae are not given because they require advanced calculation methods.

The wind forces F_{xw} and F_{yw} and moment M_{xyw}, the current forces F_{xc} and F_{yc} and Moment M_{xyc} and an estimation of the wave drift forces F_{xg} and F_{yg} and moment M_{xyg} can be calculated.

The anchor line forces F_{xh} and F_{yh} and moment M_{xyh} follow from the horizontal chain force F_h.

$$F_{xh} = F_h * \cos\alpha$$

$$F_{yh} = F_h * \sin\alpha$$

$$M_{xyh} = a * F_h * \sin\alpha - b * F_h * \cos\alpha \qquad (3)$$

In the above equation a and b are the coordinates of the hawse pipe where the horizontal chain force F_h is assumed to act. The angle α in degrees is the angle the chain makes with the course Φ of the ship.

From a design point of view the coordinate b is of interest. Mainly because for large ships the hawse pipes are located far from the centre line of the ship. The moment caused by the location of the entrance of the hawse pipe can therefore not be neglected because of its shearing effect on the ship. The shearing effect tends to introduce the surge sway and yaw motions previously described.

When the ship is in equilibrium and the motions are zero the equations can be simplified to:

$$F_h \times \cos \alpha = - (F_{xw} + F_{xc})$$

$$F_h \times \sin \alpha = - (F_{yw} + F_{yc})$$

$$F_h = \sqrt{[(F_{xw} + F_{xc})^2 + (F_{yw} + F_{yc})^2]}$$

$$\alpha = \text{arctg} \; [(F_{yw} + F_{yc}) / (F_{xw} + F_{xc})] \tag{4}$$

$$M_{kyw} + M_{kyc} + (a \times F_h \times \sin \alpha - b \times F_h \times \cos \alpha = 0$$

By placing the ship in a number of different orientations around the estimated course of the equilibrium position the forces and moment can be calculated. By graphical or interpolation methods the course can be determined where the moment is zero. In this way it is possible to construct a table which gives the horizontal anchor line force for different loading and environmental conditions. With the aid of these data the master can decide if it is safe to anchor.

Because the text of the paper[1] was recently updated it is added in appendix B.

4.2 The calculation of the holding power and chain diameter

As mentioned in section 1 ,to show the feasibility and safety of the proposal a set of design criteria supported by calculations is required.. The design criteria were discussed in the section 3 and details on the outcome of the calculations are given in this section. They were done for four ships. Particulars of the ships are given in table no.1.

The data concerning the Tanker are those of an existing ship . The other three are based on research in various publications.

Before addressing the outcome of the calculations some details concerning the origin of the data used as input for the computer calculations are discussed.

All calculations were performed for the loaded and ballasted conditions of the ship. The ballasted condition for the tanker was reasonable accurate. For the other three ships estimated values had to be used.

Because it was the aim of this study to find the maximum environmental condition in which a ship can reasonably expected to remain anchored the number of calculations were limited to a range between to numbers 6 and 12 on the scale of Beaufort. In some instances the range between the number 0 to 6 was included. The wind values allocated to the numbers on the scale of Beaufort are averages and may slightly differ from those found in other publications.

The sea conditions used were based formulae given by Ippen [4]. These formulae give useful first approximations for short fetches and high wind speeds and therefore seemed sufficiently accurate for this study. The equations are the following:

$$H_s = 0.0169\ \sqrt{(U^2.F)} \qquad T_s = 0.5000\ \sqrt[4]{(U^2.F)} \qquad (5)$$

where

H_s = significant wave height in meters

T_s = significant period in seconds

U = wind speed in knots (1 knot = 0.516 m/s)

F = fetch length in nautical miles (1 n.mile = 1858 m)

Based on the above formulae the table no. 2 of sea states was calculated. A fetch of 130.66 nautical miles was used. This value seemed a reasonable distance for this study. In the table the amplitude which is half the height is used.

The tidal and current velocity is 2.5 m/s for all calculations.

The wind and current coefficients used for the calculations of the wind and current force of the Tanker, Marin Tanker and Bulk carrier are those of OCIMF [5]. For the container ship the wind coefficients from Agerschou [6] and the current coefficients of OCIMF were used.

The coefficients used for the calculations of the wave drift forces are those of Wise and English [7].

The choice for the value of the factor which relates the holding power to the mass weight in air of the anchor was based on research into literature and brochures of anchor manufacturers. Ultimately a value of 6 in good soil conditions was chosen because the indications are that this is about the maximum value which at present can be expected for merchant ships.

The U3 quality chain is used for all calculations as the indications are that this a general acceptable quality.

With these data a series of calculations were done to determine the holding power of the anchor under various environmental conditions and in the specified conditions.

Once the required holding power was known the dimensions of the chain were determined.

From the holding power the anchor mass was determined with the relation:

$$[\text{Factor} * \text{Mass (kg)} * g \ (9.81 \ m/sec^2)]/ \ 1000 = \text{Holding power (kN)} \qquad (6)$$

The computation sequence start by solving the equations (4) for the specified situations. This is done with the aid of computer programs which were written for this purpose.

The table no. 3 shows the results of the holding power computations for the loaded tanker in a water depth of about 6 times the loaded draft. The first three columns give the wind and sea state particulars. In the second three columns some results are given of a sequence in which the wind and current direction is kept constant and the direction of the waves changed. The last three columns refer to a sequence in which the current direction is changed. It is to be expected that the highest loads are found in a situation where the direction of the waves is off the bow. In that respect it must be remembered that the direction of the waves usually lag the direction of the wind. Similar computations were made for all four ships in loaded and ballasted condition and in water depths of 6 times and 1.5 times the draft.

The results concerning the equilibrium condition for each of the four ships in loaded condition, Beaufort 8 and design draft are given in the figures 2,3,4 and 5. Each of these figures show the values of the horizontal component of the chain force and the moment. The location where the moment is zero is the equilibrium position and the corresponding force F_h equals the holding power of the anchor. On the right hand scale the F_h is expressed as a percentage of the break load of the chain. These figures show that the proposed load of the chain allows for a fair amount of yawing around the equilibrium position before 50 % of the breaking load is reached. Although not addressed yet it is pointed out that dynamic loads in the chain due to the vertical motions of the chain can reach 50 % of the breaking load. This means that the total load in equilibrium is about 70 % of the breaking load of the chain.

The influence of the dynamic loads which can occur in the chain will be addressed later.

Once the holding power is known the dimensions of the chain and mass weight of the anchor can be determined. The results are summarised in the tables 4, 5 ,6 and 7. For the purpose of this paper it is sufficient to give the data in the tables for environmental conditions relating to the scale numbers 6, 7, 8 and 9 on the scale of Beaufort.

The break load of the chain was calculated in accordance with the design proposals as:

$$\text{Break load (kN)} = \text{Holding Power(kN)} / (0.20 * \cos 20^{\circ}) \qquad (7)$$

The value of the cosines correction is, as will be shown later, an average value.

For the dimension of the chain was chosen the nearest highest value in the table for bower anchors and chain-cables in the rules.

Inspection of these data shows that the mass weight for the anchor of the Marin Tanker is nearly at the top of the table if wind force 9 is adopted for a design criteria.

Also were entered in the tables 4,5,6 and 7 the range of the equipment numbers which corresponds to the chain diameter and quality.

By calculating the equipment numbers with the rules formula for each ship it was possible to compare the numbers. This was done in table no.8.

The table shows not only the increase in difference of the numbers for each ship but also that the increase depends on the size of the ship. The consequence of the increase is best illustrated in the force excursion diagrams. These diagrams are based on the catenary equations [1]. Before addressing these diagrams the cosines relation in formula 7 is discussed.

Because the dimensions of the chain and the holding power are known the required length of chain can be determined with the aid of catenary equations. In the case the holding power of the anchor is in equilibrium with the environmental forces which act on the ship, the anchor chain resembles a fully developed catenary. This is shown in figure no.6. The figure also shows the cosines relation between the force F_h which represents the resultant of the environmental forces and the line force T_o on which the break load of the chain is based. A series of calculations for various cable dimensions indicates that an angle of 20 degrees is a reasonable average. Table no.9 shows the calculation for the tanker. In this table the dimensions of an existing anchor were chosen. The holding power factor is estimated.

As is explained in [1] the force excursion diagram is based on the distance between the slack and fully developed shapes. The figures 7,8,9 and 10 show the force excursion diagrams for all four ships. The scale on the left gives the forces in kN and the scale on the right the holding power factor. The lower scale relates to the excursion. In addition to the chain excursion the upper horizontal bars which give the numbers on the scale of Beaufort with the equivalent wind velocities in meters per second are included. In this way it is possible to relate the environmental forces to the holding power.

The environmental forces for deep water are shown for the cases with and without the influence of waves and relate to the design conditions. A curve for shallow water can be entered but was not done in order to avoid too many lines in the figure.

By plotting in the diagram a force excursion curve for the calculated chain diameter and one for the diameter in accordance with the rules a justified comparison is possible.

For the anchor mass based on the equipment number the holding power was calculated with a factor 4. The reason being that no guidelines on holding power are issued in the existing rules and that generally a factor 4 in good soil seems possible. In the proposed design criteria a holding power is specified and it is up to the manufacturer to provide an anchor with that holding power. It is envisaged that a factor of 6 is quite possible.

By entering the diagram in the point 8 on the scale of Beaufort and going vertically down to the location where the line intersects with the curves for wind, current and waves and then drawing a horizontal line the required holding power in kN or the Holding power factor is found.

The diagrams illustrate vividly where an anchoring system based on the equipment number fails.

The design proposals require that one or more such diagrams for various environmental conditions are made for the use on board ship.

5 DYNAMIC MOTIONS OF THE ANCHOR CABLE

In the preceding sections reference was made to the dynamic forces which occur in the chain cable when a forced motion such as surge, heave and pitch takes place. In the study given in appendix B [1] this phenomena was described and recommended that further study was needed to determine the value of these forces.

This is now done and reported in the paper "Motions and forces in anchor chain cables for merchant ships" by this author.[8] The paper is added to this report in appendix C. A brief description of the method is given and followed by the results of the computations for the four ships used in this study.

The method used for the computations is based on a discrete mass model developed by Walton and Polachek [9]. The mathematical model is a ship at anchor and the environmental forces generated by wind, current and waves are in equilibrium with the holding power of the anchor. The length of the cable is determined with the catenary calculations. The so found length is replaced by a series of discrete masses concentrated at a finite number of points along the cable. The masses are then joined together by weightless non-elastic strings. The aim of the model is to calculated the displacement, velocity, accelerations and forces in the points along the cable. Figure no.11 shows the manner in which the cable is divided into segments. The number of segments in the calculations is 30 plus the length of the shaft of the anchor. The anchor pin is defined as a fixed point in space.

The forced motions at the end of the cable at the water surface are simulated by two methods. The first method assumes the impute of a simple and horizontal motion of the hawse pipe and the second is based on the displacement of the hawse pipe by the motions of the ship in waves.

Both methods were used to calculate the dynamic forces and the values of the computations compared.

The tables no.10,11,12 and 13 give the results for both methods. With the results of these table the figures 12,13,14 and 15 were made. In addition the figures 16 and 17 were made. In the last two figures the results of the calculations of the four ships are compared.

Inspection of the figures show that the curves of both methods for each ship differ and that the first method which is based on simple motions indicate higher loads than the second method which is based on the bow motions. It is explained in the paper [9] that the difference can become close as is in the case of the bulk carrier. The reason is that the first method results in a linear and the second method an elliptic track. In some cases the elliptic track can be long and flat and ultimately become linear. In that case there is no difference in the results.

These figures show that the proposed limit of 50 % of the break load for dynamic loads makes sense and that investigation into the dynamic loads is needed during the design stage.

6 IMPACT AND SPEED WHEN ANCHORING

In the preceding sections reference was made to impact which occur in the chain cable when the ship is surging, swaying and yawing. During these motions the ship moves around a certain location and drags the chain along until it is tight. When the chain is tight there is a risk that the chain breaks or the anchor starts to drag. When the anchor holds there will be a sudden arrest in a point of the moving ship which is located in the hawse pipe entrance and the ship will rotate around that point.

It is also possible that impact occurs when anchoring the ship. Hence the speed of anchoring was also addressed. In the study given in appendix B [1] both possibilities were described and it was recommended that further study must be done to determine the value of impact and the speed of anchoring. This was done and is reported in the recent paper by the author[10]. The paper is given in appendix D.

The method used to calculate impact is based on the theoretical treatment of a sudden arrest by a body moving in plane motion and is given by Goldsmith [11].

The average speed when coming to anchor can be found with the aid of the law of conservation of energy.

For all four ships in loaded condition and anchored in the design water depths the impact and impact energy was calculated. The results are shown in the figures 18 up to and including 25. As the impact and impact energy is a function of the velocity, rotation and drift angle two figures were made. One showing the impact and impact energy for a constant drift angle, various rotations and velocities and one for constant rotation and various drift angles and velocities. These figures show how important it is for a ship's master to control his stern speed and if possible the rotation of the bow. To control the bow rotation is only possible for ships fitted with a bow thruster.

In order to assess the impact of these calculations on the design of the anchoring system, knowledge of the energy contents of the anchor chain is required. As is explained in the paper given in appendix B this is the potential energy stored in the elevation of the mass of the catenary above the seabed plus the potential energy stored in stretching the cable. Because the last part is small it is ignored for this calculation. Further more it can be shown that the energy in the chain equals the area of the force excursion diagram. Therefore the energy can also be plotted in that diagram.

For each of the four ships the energy contents were calculated for the fully developed and ultimate taut shapes. This was done for the loaded and ballasted conditions and in water depths corresponding to 6 and 1.5 times the draft. Further more it was done for the chain diameter which was calculated and the diameter based on the equipment number. The results of these calculations are given in the tables 14, 15, 16 and 17. The reason for calculating both the energy contents for the fully and ultimate taut shapes follows from what happens during the anchoring manoeuvre. Generally when a large ship arrives at the anchorage the anchor is walked out to just above seabed and then dropped. During this procedure the ship is slowly eased back following a curved track and yawing to starboard due to propeller action. When a certain amount of chain length is outside the hawse pipe the stern movement is stopped and the brake of the windlass is applied. When the brake is applied the chain becomes tight and impact can occur when the anchor holds.

Because of the risk that impact can occur it is important to include the energy due to impact in the calculation model for anchoring speed.

This can be done by assuming that the amount of energy in the fully developed shape of the chain cable must always be available.

The total amount of energy in the chain cable follows from the Ultimate Taut shape. To this amount can be added the strain energy in Ultimate Taut shape. In the calculation model strain energy is not included. It is further assumed that approximately 50% of the difference between the energy in the taut and fully developed shape is used for impact. By reducing the total amount of energy in the ultimate taut case by the so found difference the potential energy available for anchoring the ship is found. From the impact calculation for the ship the linear and rotational velocity just before impact can be found. These data can then be entered into the calculation model as the end velocities for the anchoring speed. It means that the ship arrives at the location where the shape of the anchor cable is fully developed, overshoots that position and arrives at the ultimate taut location with predetermined velocities. The 50 % difference is arbitrary and any value can be entered into the model.

The following example for the tanker illustrates the philosophy.

Table no.19 gives the distance between the ultimate taut and the fully developed shape as 2.479 m and the difference in energy 4407.686 kNm. So if the ship moves from ultimate slack to the fully developed shape there is 4407.686 kNm energy left in the chain cable over a distance of 2.479 meters. Compared to the length of the ship it is obvious that the amount of 4407.686 kNm is consumed very quickly and then there is insufficient energy left for the impact which can follow when the band brake of the windlass is applied.

Following the philosophy set out above an amount of 2227 kNm ,which is slightly above the difference of 50%, is allowed for impact energy when the chain is ultimate taut.

Table no.18 shows that an amount of impact energy of 2227 kNm allows for an end linear velocity of 0.20 m/sec and a rotational velocity of 15 degrees per minute. A drift angle of 190 degrees is assumed.

Further it is assumed that the resultant environmental force which acts on the ship is 40 kN. This is just over windforce 5 on the scale of Beaufort and a current of about 0.3 m/sec.

The result of the calculation which is given in table no.20.shows that the end velocities are reached with a starting velocity v_o of 0.51 m/ sec ground speed.

From the table no.18 it also follows that the impact which goes with the impact energy of is 15988 kNsec. When the brake of the windlass is applied the brake must be able to cope with that impact. The chain used for these calculations has a break load of 4500 Kn which gives 3.55 seconds impact time. So from table no.18 it is possible to determine first an impact and lastly with the aid of the impact energy the anchoring speed.

An investigation into the effects of water depth and displacement on the maximum ground speed was made for four ships.The water depths were based on 6 and 1.5 times the draft of the ships. For each ship two chains were determined. The lightest chain was based on the equipment number and the heaviest on the force method. The results of the investigation are set out in table no.21 and used to define the proposed design criteria.

Hence by defining a minimum of stern speed of 0.2 m/sec over the ground when anchoring and specifying that Impact in Knsec divided by the breaking load in Kn must be a minimum of 4 sec the safety of the anchoring procedure can be enhanced.

7 CONCLUSIONS AND RECOMMENDATIONS

In the introduction it was stated:

"it is not good enough to propose that a design method based on the " equipment number" should be abandoned in favour of a method based on the holding power of the anchor and the environmental forces which act on the ship. It must also be shown that this is feasible."

In this paper a proposal for design criteria based on a method which takes into account the holding power of the anchor and the environmental forces which act on the ship is presented. Next it is shown that the calculations required in this method with the aid of a personal computer are quite feasible. Lastly the results of the computations for four ships indicate that the requirements for the anchoring system for ships designed in accordance with the equipment number lack in a number of important aspects. The significant results in this paper also confirm the conclusions given in the papers which are attached in appendices B,C and D. This means that the intention of the paper given above is accomplished.

Hence the overall conclusion is that the design method based on the equipment number must be abandoned in favour of the proposed method which proved to be feasible and safer.

The recommendation is that steps must be undertaken by all classification societies to implement the proposed criteria soonest in order to enhance the safety of ships at anchor.

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9 TABLES

9.1 Table no.1, Ship's particulars

SHIP'S PARTICULARS

		Tanker	Marin tanker	Bulk carrier	Container ship
L_{pp}	m	164,00	310,00	250,00	285,00
Depth	m	16,60	29,70	18,20	21,00
B	m	32,24	47,17	33,00	32,30
Loaded Draft	m	11,62	18,90	12,80	13,00
Hawse pipe: X coordinate	m	77,00	152,00	125,00	135,00
Y coordinate	m	8,00	10,00	8,25	10,00
Displacement (1 ton is 1000 kg)	ton	50.000	246.868	87.320	48.837

9.2 Table no.2, Table Sea States

TABLE SEA STATES

Beaufort	Amplitude	T_s
12	6,18	13,52
11	5,75	13,04
10	4,97	12,13
9	4,25	11,21
8	3,57	10,20
7	2,95	9,34
6	2,36	8,37
5	1,84	7,37
4	1,30	6,21
3	0,82	4,93

Fetch : 130.66 nm.

9.3 Table no.3, Holding power loaded tanker

LOADED TANKER								
Draft : 11.62				HOLDING POWER			Water depth : 70 m	
Wind		Waves	Cur: 180° 2.5 m/s	Cur: 180° 2.5 m/s	Cur: 180° 2.5 m/s	Cur: 170° 2.5 m/s	Cur: 160° 2.5 m/s	Cur: 130° 2.5 m/s
Beaufort	North		Waves: 0°	Waves: 10°	Waves: 20°	Waves 10°	Waves 10°	Waves 10°
	m/sec	ζ (m)	kN	kN	kN	kN	kN	kN
9	26.4	4.25	948	1000	968	934	973	774
8	22.6	3.57	805	840	803	790	832	682
7	19.0	2.95	700	717	680	680	718	617
6	12.6	2.36	619	630	—	—	—	—

9.4 Table no.4, Estimated equipment number Tanker

TANKER								
Estimated equipment number based on chain diameter								
Wind		Waves	Current	Anchor holding power	Chain type U3		Anchor mass	Est. number
Beaufort	North	10°	180°		Break load	dia	Mass	Range
	m/sec	ζ (m)	m/sec	kN	kN	mm	Kg	
9	26.4	4.25	2.5	1000	5320	87	16989	4000-4400
8	22.6	3.57	2.5	840	4470	78	14271	3210-3400
7	19.0	2.95	2.5	717	3815	73	12181	2870-3040
6	12.6	2.36	2.5	630	3352	66	10703	2380-2530

9.5 Table no.5, Estimated equipment number Tanker

MARIN TANKER								
Estimated equipment number based on chain diameter								
Wind		Waves	Current	Anchor holding power	Chain type U3		Anchor mass	Est. number
Beaufort	North	10°	180°		Break load	dia	Mass	Range
	m/sec	ζ (m)	m/sec	kN	kN	mm	Kg	
9	26.4	4.25	2.5	2582	13738	147	43866	11500-12400
8	22.6	3.57	2.5	2210	11759	137	37546	8900-10000
7	19.0	2.95	2.5	1937	10307	124	32908	7400-8400
6	12.6	2.36	2.5	1740	9258	117	29561	6900-7400

9.6 Table no.6, Estimated equipment number Bulk Carrier

BULK CARRIER								
Estimated equipment number based on chain diameter								
Wind		Waves	Current	Anchor holding power	Chain type U3		Anchor mass	Est. number
Beaufort	North	10°	180°		Break load	dia	Mass	Range
	m/sec	ζ (m)	m/sec	kN	kN	mm	Kg	
9	26.4	4.25	2.5	1537	8178	111	26113	6500-6900
8	22.6	3.57	2.5	1330	7076	100	22596	5500-5800
7	19.0	2.95	2.5	1110	5906	92	18858	4600-4800
6	12.6	2.36	2.5	988	5257	87	16786	4000-4400

9.7 Table no.7, estimated equipment number Container ship

CONTAINER SHIP Estimated equipment number based on chain diameter								
Wind		Waves	Current	Anchor holding power	Chain type U3		Anchor mass	Est. number
Beaufort	North	10°	180°		Break load	dia	Mass	Range
	m/sec	ζ (m)	m/sec	kN	kN	mm	Kg	
9	26.4	4.25	2.5	1650	8779	114	28033	6900-7400
8	22.6	3.57	2.5	1436	7641	105	24397	5800-6500
7	19.0	2.95	2.5	1260	6704	98	21407	5200-5500
6	12.6	2.36	2.5	1118	5949	92	18994	4600-4800

9.8 Table no.8, Comparison equipment number

EQUIPMENT NUMBER BASED ON RULES FORMULA AND FORCE METHOD				
Type ship	L_{pp}.B.H.T	Displacement	Range equipment number based on	
	m	ton (1000 kg)	Rules formula	Force method
Tanker	164.00 32.24 16.60 11.62	50.000	2870-3040	3210-3400
Marin Tanker	310.00 47.17 29.70 18.90	246.868	6900-7400	8900-10000
Bulk Carrier	250.00 33.00 18.20 12.80	87.320	3800-4000	5500-5800
Container ship	285.00 32.30 21.00 13.00	48.837	3400-3600	5800-6500

9.9 Table no.9., required length of anchor chain Tanker

Type ship is Loaded Tanker

Required length of Anchor chain

Equipment number	3100	
Type Anchor	Unknown	
Mass Anchor	15000.00	kg.
HP factor	6	
Holding power anchor	882.90	kN.
Grade chain	U3	
Dimension chain	78.00	mm.
Mass chain	139.20	kg/m.
Density chain mat	7850.00	kg/m3.
Density water	1025.00	kg/m3.

Depth	Distance	Length	Fh	Fv	Fr	Theta
m	m	m	kN	kN	kN	degrees
0.00	0.00	0.00	882.90	0.00	882.90	0.00
10.00	121.82	122.36	882.90	145.28	894.77	9.34
20.00	172.09	173.63	882.90	206.14	906.64	13.14
30.00	210.53	213.35	882.90	253.30	918.52	16.01
40.00	242.83	247.17	882.90	293.45	930.39	18.39
50.00	271.19	277.25	882.90	329.16	942.26	20.45
60.00	296.75	304.69	882.90	361.75	954.13	22.28
70.00	320.18	330.17	882.90	391.99	966.01	23.94
80.00	341.92	354.10	882.90	420.40	977.88	25.46
90.00	362.27	376.77	882.90	447.32	989.75	26.87
100.00	381.46	398.41	882.90	473.01	1001.62	28.18

9.10 Table no.10, dynamic loads anchor cable tanker

<table>
<tr><td colspan="6">DYNAMIC LOADS ANCHOR CABLE TANKER</td></tr>
<tr><td colspan="2">Break Load (B.L)
chain : 4470 kN</td><td colspan="2">Water depth:
70 meter</td><td colspan="2">Holding Power (H.P)
Anchor : 882 kN</td></tr>
<tr><td colspan="2">Regular wave
T: 10.2 sec
amp: 3.57 m</td><td colspan="2">Method Bow motions</td><td colspan="2">Current
2.5 m/sec</td></tr>
<tr><td colspan="2">Surge</td><td colspan="2">Station waterline</td><td colspan="2">Station Anchor</td></tr>
<tr><td>Period
sec</td><td>amp
m</td><td>F
kN</td><td>% B.L.</td><td>F
kN</td><td>Increase
H.P. %</td></tr>
<tr><td>10.2</td><td>0</td><td>1324</td><td>29.6</td><td>1252</td><td>41.9</td></tr>
<tr><td></td><td>2</td><td>1104</td><td>24.7</td><td>1033</td><td>17.1</td></tr>
<tr><td></td><td>4</td><td>1223</td><td>27.4</td><td>1163</td><td>31.9</td></tr>
<tr><td></td><td>6</td><td>1387</td><td>31.3</td><td>1323</td><td>50.0</td></tr>
<tr><td></td><td>8</td><td>1579</td><td>35.3</td><td>1509</td><td>71.0</td></tr>
<tr><td></td><td>10</td><td>1670</td><td>37.3</td><td>1592</td><td>80.5</td></tr>
<tr><td colspan="2">Trochoidal
T: 10.2 sec
amp: 3.57 m</td><td colspan="2">Method Simple motions</td><td colspan="2">Current
2.5 m/sec</td></tr>
<tr><td>10.2</td><td>0</td><td>1146</td><td>25.6</td><td>1070</td><td>21.3</td></tr>
<tr><td></td><td>2</td><td>1514</td><td>33.9</td><td>1447</td><td>64.0</td></tr>
<tr><td></td><td>4</td><td>1914</td><td>42.8</td><td>1842</td><td>108.8</td></tr>
<tr><td></td><td>6</td><td>2440</td><td>54.5</td><td>2378</td><td>169.6</td></tr>
<tr><td></td><td>8</td><td>2903</td><td>64.9</td><td>2836</td><td>221.5</td></tr>
<tr><td></td><td>10</td><td>3217</td><td>72.0</td><td>3152</td><td>257.3</td></tr>
</table>

9.11 Table no.11, dynamic loads anchor cable Marin Tanker

DYNAMIC LOADS ANCHOR CABLE MARIN TANKER

Break Load (B.L) chain : 12160 kN
Water depth: 113.46 meter
Holding Power (H.P) Anchor : 2253 kN

Regular wave
T: 10.2 sec
amp: 3.57 m
Method Bow motions
Current
2.5 m/sec

Surge		Station waterline		Station Anchor	
Period sec	amp m	F kN	% B.L.	F kN	Increase H.P. %
10.2	0	2860	23.5	2459	9.1
	2	2992	24.6	2612	15.9
	4	3406	28.0	3036	34.8
	6	3879	31.8	3526	56.5
	8	4394	36.1	4073	80.8
	10	4890	40.2	4548	101.9
Trochoidal T: 10.2 sec amp: 3.57 m		Method Simple motions		Current 2.5 m/sec	
10.2	0	3025	24.9	2631	16.8
	2	3427	28.2	3050	35.8
	4	3968	32.6	3600	59.8
	6	4710	38.7	4348	92.0
	8	5238	43.1	4900	117.4
	10	6149	50.6	5786	156.8

9.12 Table no.12, dynamic loads anchor cable Bulk Carrier

DYNAMIC LOADS ANCHOR CABLE BULK CARRIER					
Break Load (B.L) chain : 7060 kN		Water depth: 76.80 meter		Holding Power (H.P) Anchor : 1328 kN	
Regular wave T: 10.2 sec amp: 3.57 m		Method Bow motions		Current 2.5 m/sec	
Surge		Station waterline		Station Anchor	
Period sec	amp m	F kN	% B.L.	F kN	Increase H.P. %
10.2	0	1514	21.8	1372	-
	2	1739	24.6	1601	20.6
	4	2230	31.6	2113	59.1
	6	2596	36.7	2477	86.5
	8	3066	43.4	2950	122.0
	10	3660	51.8	3544	166.0
Trochoidal T: 10.2 sec amp: 3.57 m		Method Simple motions		Current 2.5 m/sec	
10.2	0	1688	23.9	1550	14.3
	2	2058	29.2	1928	45.1
	4	2490	35.2	2378	79.0
	6	3111	44.0	2985	124.7
	8	3773	53.4	3653	175.0
	10	4212	59.7	4084	207.5

9.13 Table no.13, dynamic loads anchor cable container ship

DYNAMIC LOADS ANCHOR CABLE CONTAINER SHIP					
Break Load (B.L) chain : 7700 kN		Water depth: 78.0 meter		Holding Power (H.P) Anchor : 1436 kN	
Regular wave T: 10.2 sec amp: 3.57 m		Method Bow motions		Current 2.5 m/sec	
Surge		Station waterline		Station Anchor	
Period sec	amp m	F kN	% B.L.	F kN	Increase H.P. %
10.2	0	1637	21.3	1477	2.8
	2	1741	22.6	1590	10.7
	4	2139	27.8	1997	39.0
	6	2547	33.1	2407	67.6
	8	2992	38.9	2853	98.6
	10	3443	44.7	3326	131.6
Trochoidal T: 10.2 sec amp: 3.57 m		Method Simple motions		Current 2.5 m/sec	
10.2	0	1818	23.6	1663	15.8
	2	2187	28.4	2040	42.0
	4	2658	34.5	2529	76.1
	6	3296	42.8	3158	119.9
	8	4010	52.1	3874	169.7
	10	4235	55.0	4145	188.6

9.14 Table no.14, Energy contents chain cable Tanker

TANKER							
Equipment number	Dis- placement	Depth	Chain	FD Catenary		Taut	
	ton (1000 kg)		dia	energy	excur- sion	energy	excur- sion
		m	mm	kNm	m	kNm	m
2870-3100 Rule formula	50.000	10.00	73	238	09.20	380	09.41
		17.43	73	516	15.62	842	16.01
		30.00	73	1080	25.92	1842	26.94
		70.00	73	3246	55.71	5813	59.24
3210-3400 Force method		10.00	78	426	09.45	666	09.59
		17.43	78	941	16.17	1493	16.48
		30.00	78	2016	27.17	3262	27.88
		70.00	78	6396	60.02	10799	62.49

9.15 Table no.15, energy contents chain cable Marin Tanker

MARIN TANKER							
Equipment number	Dis- placement	Depth	Chain	FD Catenary		Taut	
	ton (1000 kg)		dia	energy	excur- sion	energy	excur- sion
		m	mm	kNm	m	kNm	m
6900-7400 Rule formula	246.868	11.25	114	856	10.46	1358	10.65
		28.35	114	3110	25.19	5107	25.19
		45.36	114	5872	38.99	9893	40.58
		113.40	114	19115	88.73	34705	94.80
8900- 10000 Force method		11.25	137	1396	10.53	2202	10.71
		28.35	137	5124	25.50	8333	26.21
		45.36	137	9742	39.62	16210	41.04
		113.40	137	32339	91.07	57505	96.57

9.16 Table no.16, energy contents chain cable Bulk Carrier

BULK CARRIER							
Equipment number	Dis-placement	Depth	Chain	FD Catenary		Taut	
	ton (1000 kg)		dia	energy	excur-sion	energy	excur-sion
		m	mm	kNm	m	kNm	m
3800-4000 Rule formula	87.320	11.25	84	366	10.28	588	10.52
		19.20	84	768	17.04	1262	17.58
		45.00	84	2394	37.36	4146	39.25
		76.80	84	4711	55.99	8566	64.12
5500-5800 Force method		11.25	100	788	10.57	1240	10.74
		19.20	100	1684	17.68	2689	18.07
		45.00	100	5481	39.60	9067	40.95
		76.80	100	11203	64.84	19144	67.81

9.17 Table no.17 ,energy contenst anchor cable Container ship

CONTAINER SHIP							
Equipment number	Dis-placement	Depth	Chain	FD Catenary		Taut	
	ton (1000 kg)		dia	energy	excur-sion	energy	excur-sion
		m	mm	kNm	m	kNm	m
3400-3600 Rule formula	48.837	19.50	78	694	17.34	1139	17.88
		78.00	78	4274	61.12	7751	65.27
5800-6500 Force method		19.50	105	1876	17.94	3000	18.33
		78.00	105	12438	65.64	21310	68.70

9.18 Table no.18, Impact and impact energy results Tanker

IMPACT AND IMPACT ENERGY RESULTS

Type ship is	Loaded tanker	
Displaced mass is	50000000.0	kg.
Length b.p.p. is	164.00	m.
Beam is	32.24	m.
Draft is	11.62	m.
x coord H pipe is	77.00	m.
y coord H pipe is	8.00	m.
Radius gyration is	0.24	-.
Density water is	1025.00	kg/m3.
Water depth is	70.00	m.

beta degr	V m/sec	rb degr/m	ra Degr/m	delta p kNsec	Ei kNm
190.0	0.00	0.00	0.00	0.0	0.0
190.0	0.00	5.00	0.95	2260.1	139.6
190.0	0.00	10.00	1.90	4520.1	558.4
190.0	0.00	15.00	2.85	6780.2	1256.4
190.0	0.00	20.00	3.80	9040.3	2233.5
190.0	0.00	25.00	4.74	11300.3	3489.9
190.0	0.10	0.00	0.44	5879.7	266.8
190.0	0.10	5.00	1.39	7181.4	390.4
190.0	0.10	10.00	2.34	8876.4	793.1
190.0	0.10	15.00	3.29	10780.7	1475.0
190.0	0.10	20.00	4.24	12801.3	2436.1
190.0	0.10	25.00	5.19	14890.8	3676.4
190.0	0.20	0.00	0.89	11759.4	1067.4
190.0	0.20	5.00	1.83	12929.7	1174.8
190.0	0.20	10.00	2.78	14362.8	1561.4
190.0	0.20	15.00	3.73	15988.0	2227.3
190.0	0.20	20.00	4.68	17752.7	3172.3
190.0	0.20	25.00	5.63	19619.3	4396.5
190.0	0.30	0.00	1.33	17639.0	2401.6
190.0	0.30	5.00	2.28	18759.7	2493.0
190.0	0.30	10.00	3.23	20073.1	2863.5
190.0	0.30	15.00	4.18	21544.2	3513.3
190.0	0.30	20.00	5.12	23142.8	4442.2
190.0	0.30	25.00	6.07	24844.3	5650.3
190.0	0.40	0.00	1.77	23518.7	4269.5
190.0	0.40	5.00	2.72	24613.3	4344.8
190.0	0.40	10.00	3.67	25859.5	4699.3
190.0	0.40	15.00	4.62	27236.5	5332.9
190.0	0.40	20.00	5.57	28725.5	6245.8
190.0	0.40	25.00	6.52	30310.1	7437.8

9.19 Table.no 19, force/energy excursion loaded Tanker

Type ship is Loaded Tanker

Force/Energy excursion of Anchor chain

Equipment number	0	
Type Anchor	AC	
Mass Anchor	15000.00	kg.
Correction mass Anchor	1.00	
HP factor	6	
Holding power anchor	882.90	kN.
Grade chain	U3	
Dimension chain	78.00	mm.
Mass chain	139.20	kg/m.
Density chain mat	7850.00	kg/m3.
Density water	1025.00	kg/m3.
Water depth	70.00	m.

ForceH kN	Energy kNm	Excursion m
0.000	0.000	0.000
50.000	532.625	34.95199
100.000	1110.214	43.00686
150.000	1628.094	47.22171
200.000	2096.754	49.92419
250.000	2526.883	51.84664
300.000	2926.266	53.30449
350.000	3300.510	54.45920
400.000	3653.752	55.40315
450.000	3989.128	56.19356
500.000	4309.074	56.86802
550.000	4615.524	57.45237
600.000	4910.044	57.96504
650.000	5193.919	58.41959
700.000	5468.221	58.82623
750.000	5733.854	59.19283
800.000	5991.587	59.52556
850.000	6242.085	59.82933
882.900	6403.248	60.01537

Ultimate Taut Case

Excursion 62.494 m.
Energy 10810.964 kNm.

9.20 Table no.20, Maximum speed when anchoring Tanker

```
                    MAXIMUM SPEED WHILST ANCHORING

       Type ship is                  Loaded Tanker
       Displaced mass is                  50000000  kg.
       Length b.p.p. is                     164.00  m.
       Beam is                               32.24  m.
       Draft is                              11.62  m.
       x coord H pipe is                     77.00  m.
       y coord H pipe is                      8.00  m.
       Radius gyration is                     0.24   -.
       Density water is                    1025.00  kg/m3.
       Water depth is                        70.00  m.
       Chain energy Ult Taut              10810.00  kNm.
       Chain energy is                     6403.00  kNm
       Impact energy is                    2227.00  kNm
       Resultant envir.force is              40.00  kN
       Excursion is                          62.49  m.
```

beta degr	Ve m/sec	re degr/m	Vs m/sec	Vs knots
190.0	0.00	0.00	0.48	0.9
190.0	0.00	2.00	0.48	0.9
190.0	0.00	4.00	0.48	0.9
190.0	0.00	6.00	0.49	0.9
190.0	0.00	8.00	0.49	1.0
190.0	0.00	10.00	0.49	1.0
190.0	0.05	0.00	0.48	0.9
190.0	0.05	2.00	0.48	0.9
190.0	0.05	4.00	0.48	0.9
190.0	0.05	6.00	0.49	0.9
190.0	0.05	8.00	0.49	1.0
190.0	0.05	10.00	0.49	1.0
190.0	0.10	0.00	0.49	0.9
190.0	0.10	2.00	0.49	0.9
190.0	0.10	4.00	0.49	1.0
190.0	0.10	6.00	0.49	1.0
190.0	0.10	8.00	0.49	1.0
190.0	0.10	10.00	0.50	1.0
190.0	0.15	0.00	0.49	1.0
190.0	0.15	2.00	0.49	1.0
190.0	0.15	4.00	0.50	1.0
190.0	0.15	6.00	0.50	1.0
190.0	0.15	8.00	0.50	1.0
190.0	0.15	10.00	0.51	1.0
190.0	0.20	0.00	0.50	1.0
190.0	0.20	2.00	0.50	1.0
190.0	0.20	4.00	0.50	1.0
190.0	0.20	6.00	0.51	1.0
190.0	0.20	8.00	0.51	1.0
190.0	0.20	10.00	0.51	1.0

9.21 Table no.21, Impact and impact load comparison

Type ship	Water depth	Displ	Maximum speed	Maximum speed	Chain dia	Chain break load	Impact	Imp/ brk load
	m	$k=10^3$ kg	m/sec	knots	mm	kN	kNs	sec
Tanker	17.43	50k	0.09 0.11	0.2 0.2	73 78	3990 4500	2260 7181	0.57 1.60
-.-	70.00	50k	0.32 0.53	0.6 1.0	73 78	3990 4500	14362 15988	3.60 3.55
Tanker 2	28.35	235k	0.14 0.21	0.3 0.4	114 137	8900 12160	32813 20193	3.68 1.66
-.-	113.4	235k	0.42 0.59	0.8 1.1	114 137	8900 12160	67038 97522	7.53 8.02
Bulk carr	19.20	87k	0.14 0.20	0.3 0.4	84 100	5160 7060	3584 5974	0.70 0.85
-.-	76.80	87k	0.31 0.56	0.6 1.1	84 100	5160 7060	22105 33653	4.28 4.77
Container	19.50	49k	0.12 0.28	0.2 0.6	78 105	4500 7700	2200 6651	0.49 0.86
-.-	78.00	49k	0.37 0.79	0.7 1.5	78 105	4500 7700	23888 38871	5.30 5.05

10 FIGURES

11 APPENDICES

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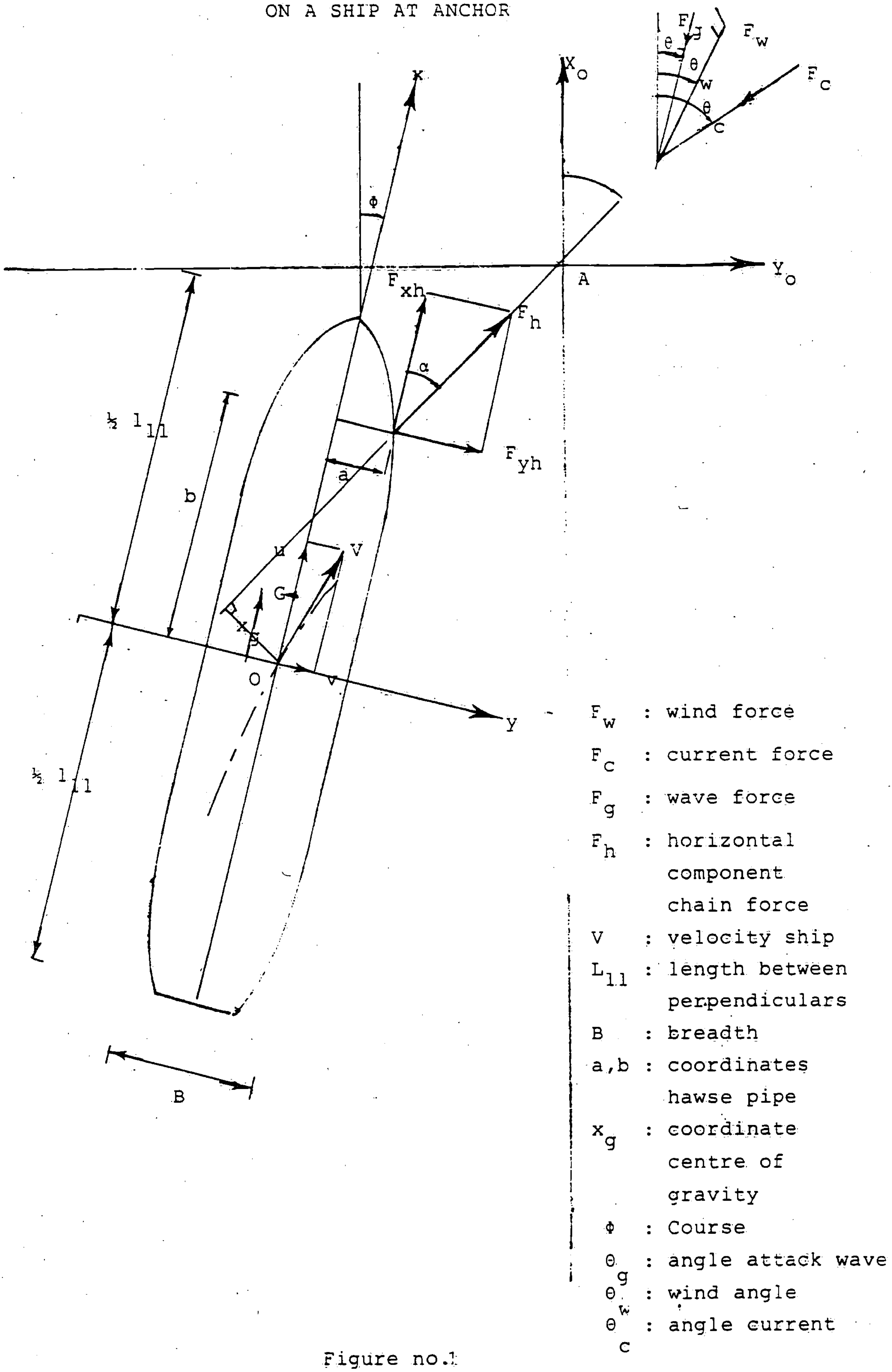
WIND-,CURRENT-,WAVE- AND HORIZONTAL CHAINFORCE ON A SHIP AT ANCHOR



F_w : wind force

F_c : current force

F_g : wave force

F_h : horizontal component chain force

V : velocity ship

L_{11} : length between perpendiculars

B : breadth

a,b : coordinates hawse pipe

x_g : coordinate centre of gravity

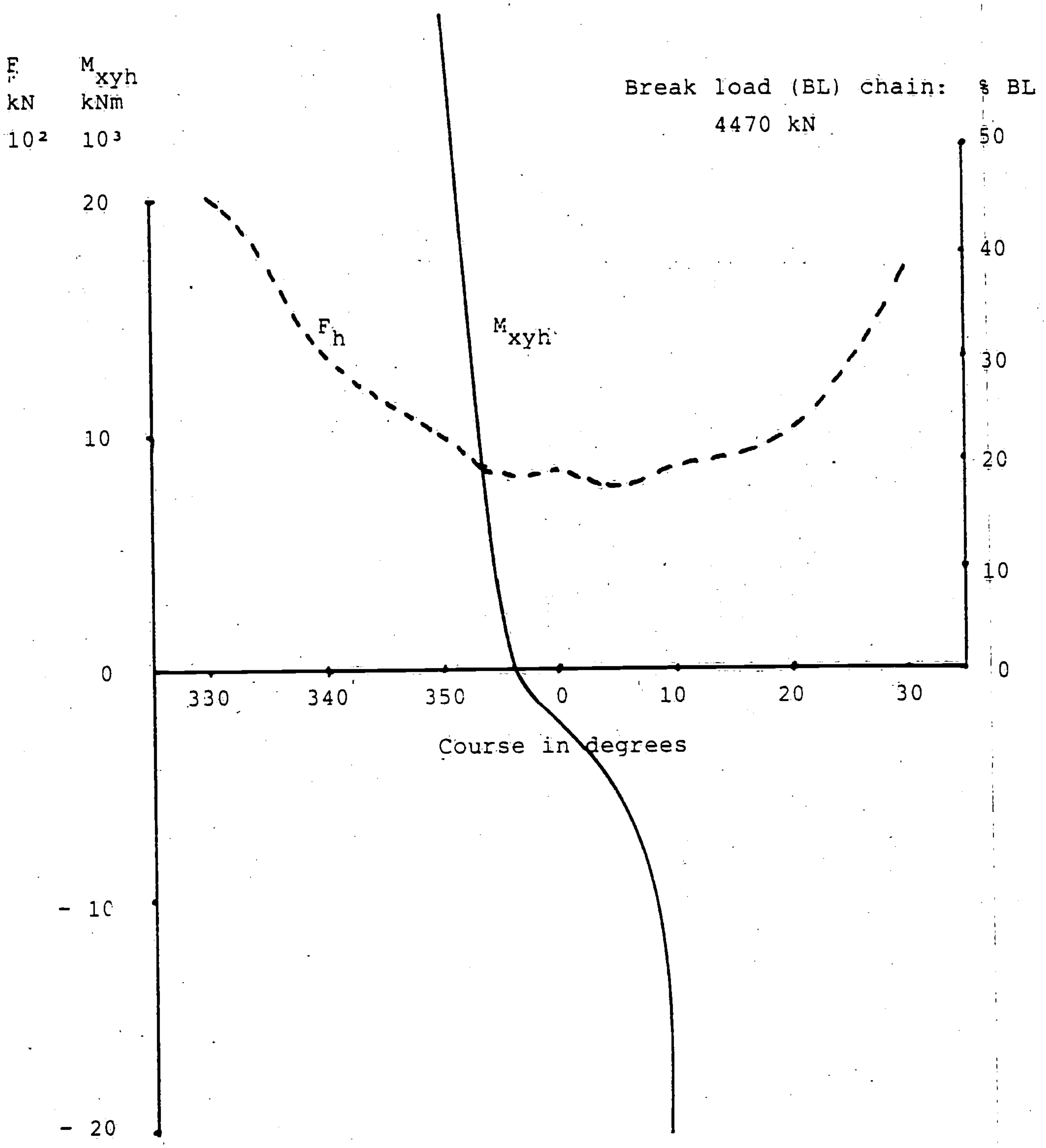
Φ : Course

θ_g : angle attack wave

θ_w : wind angle

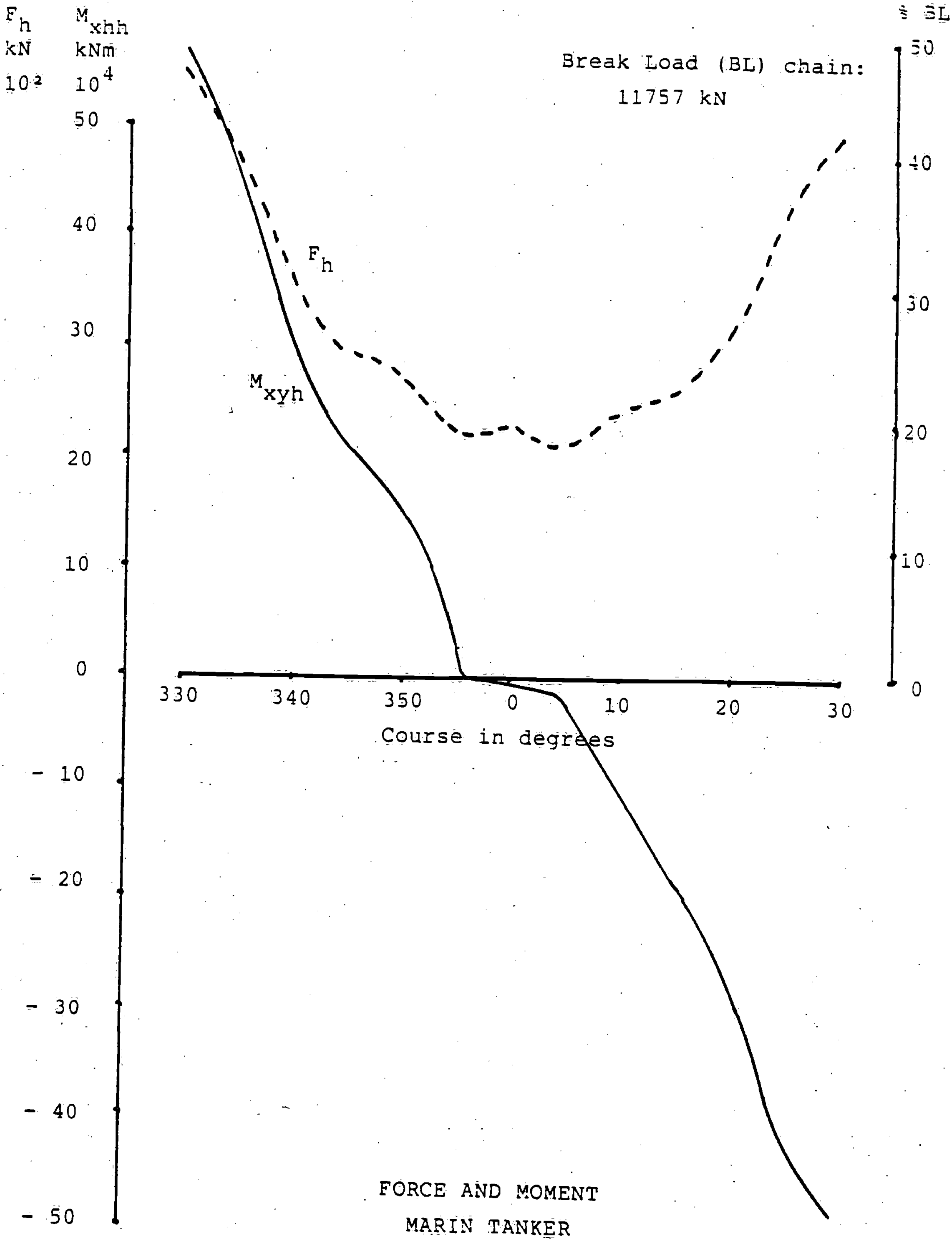
θ_c : angle current

Figure no.1



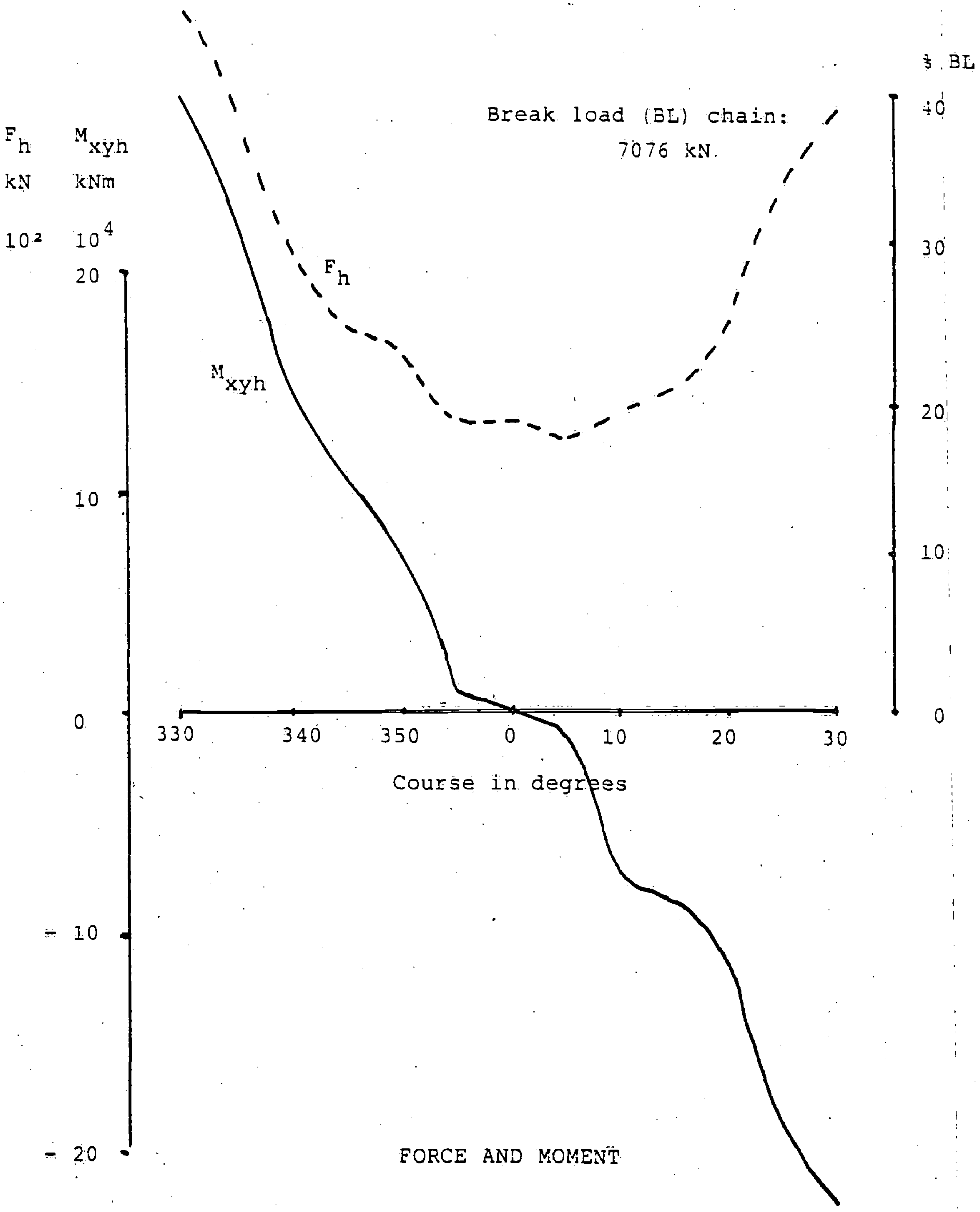
FORCE AND MOMENT
TANKER

figure no.2



FORCE AND MOMENT
MARIN TANKER

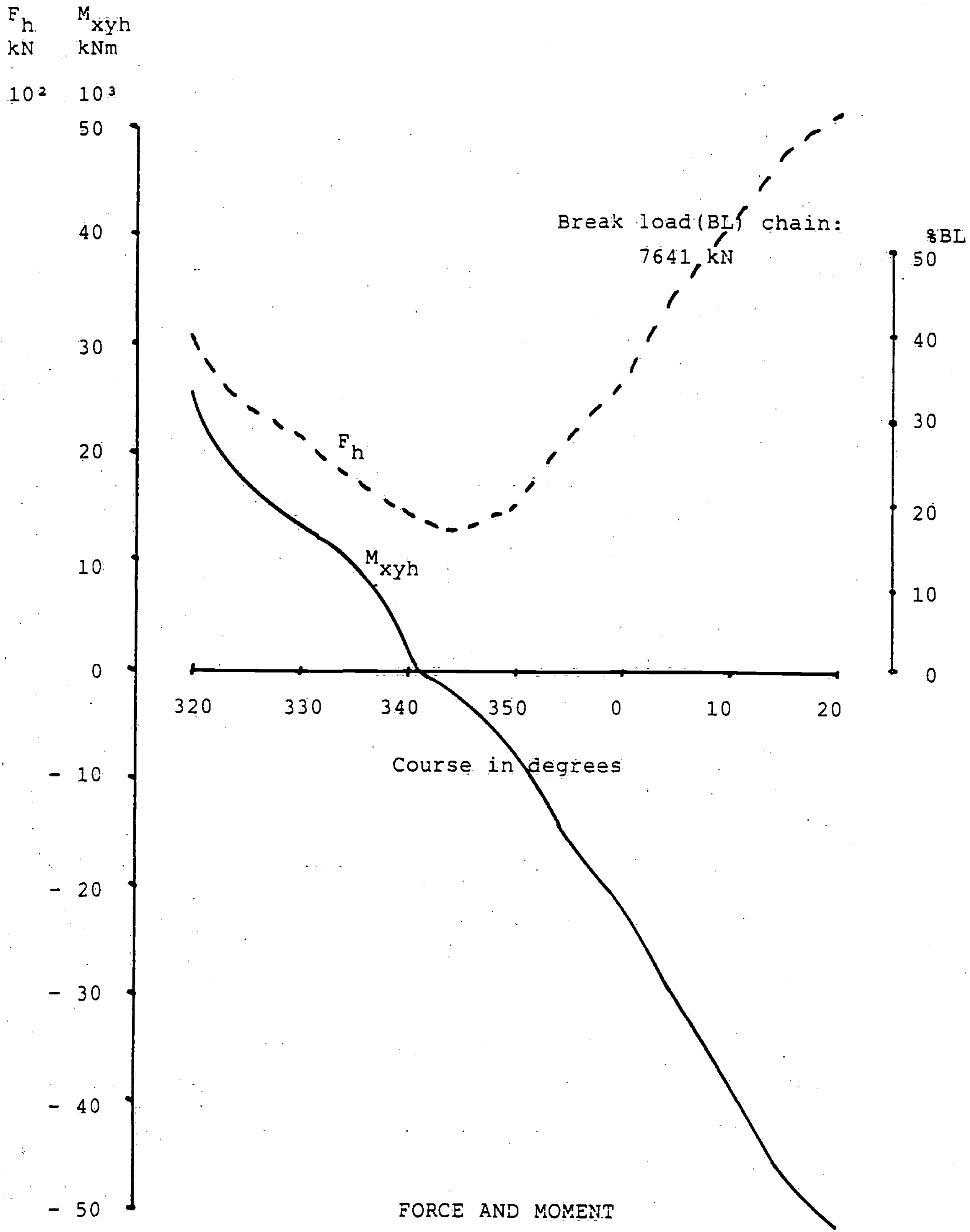
Figure no.3



FORCE AND MOMENT

BULK CARRIER

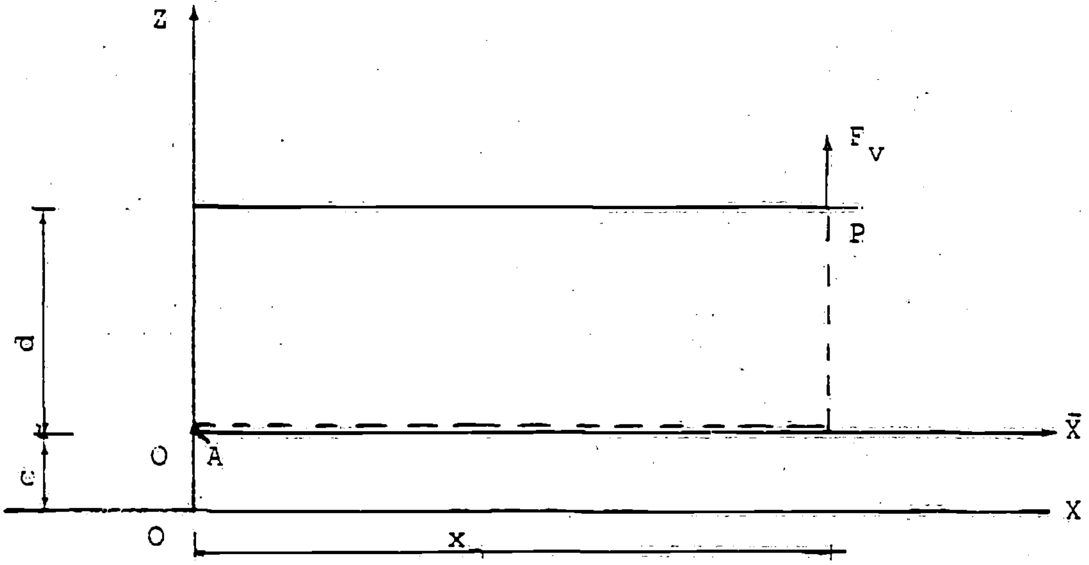
Figure no.4



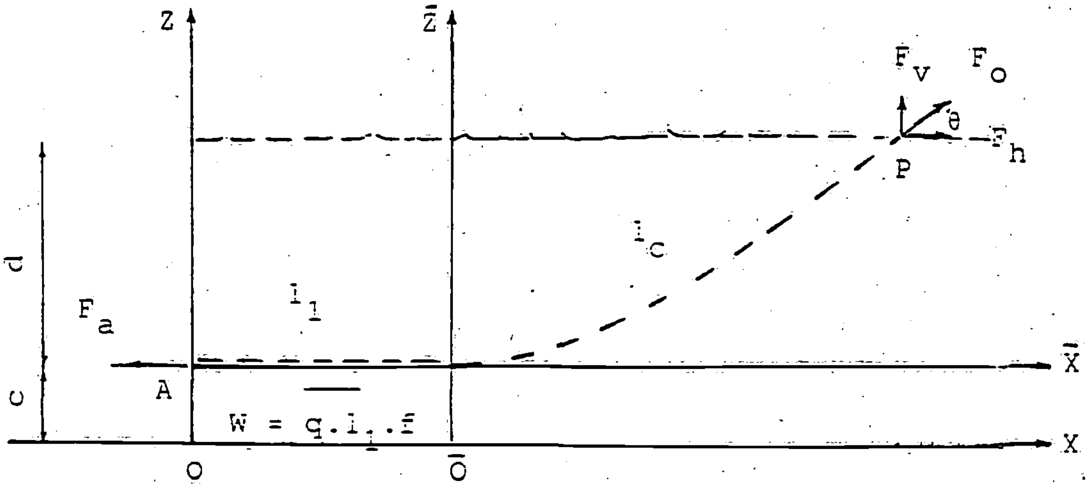
FORCE AND MOMENT
CONTAINER SHIP

Figure no.5

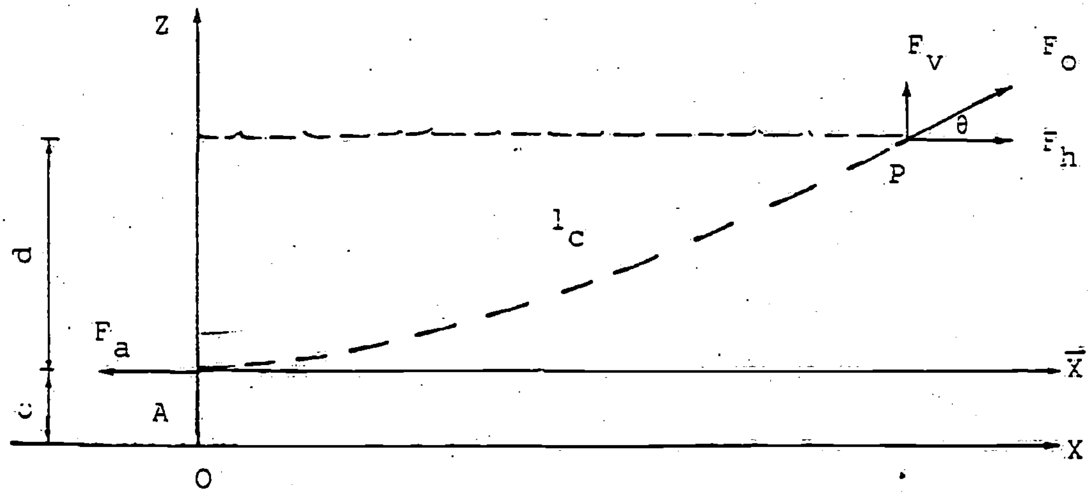
ANCHORLINE SHAPES



Ultimate slack



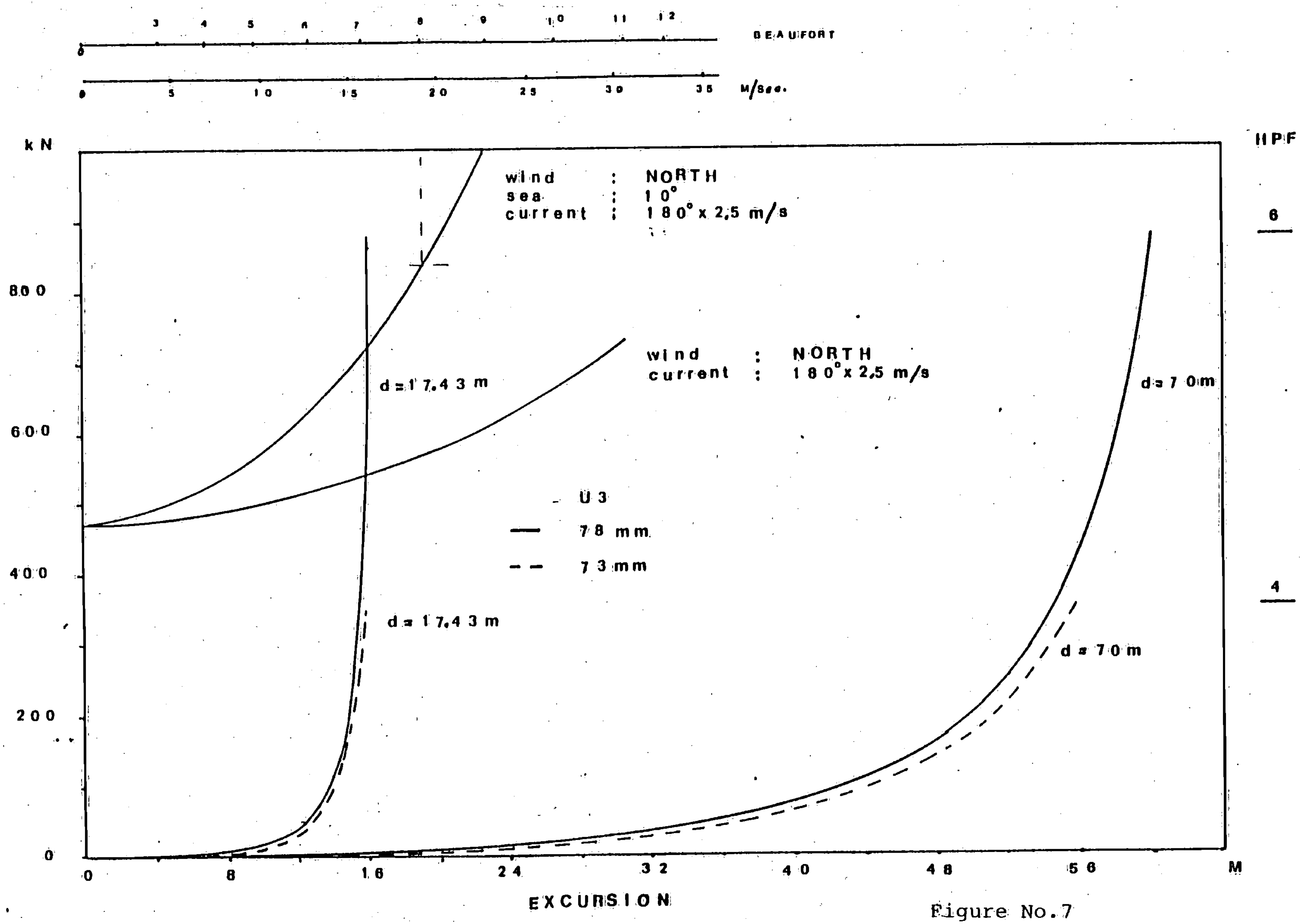
Slack



Fully developed

Figure no.8

LOADED TANKER



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LOADED ARIN TANKER

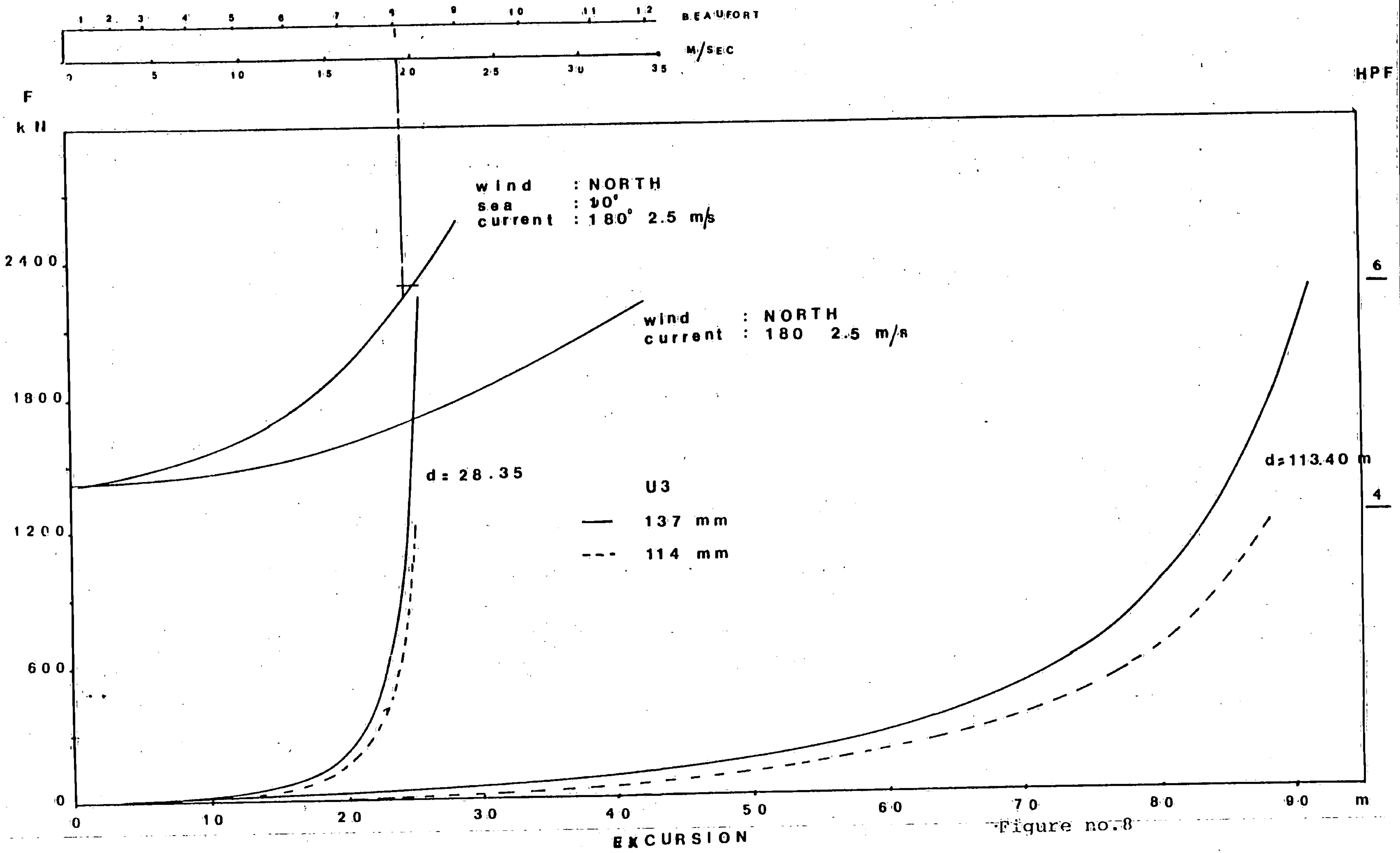
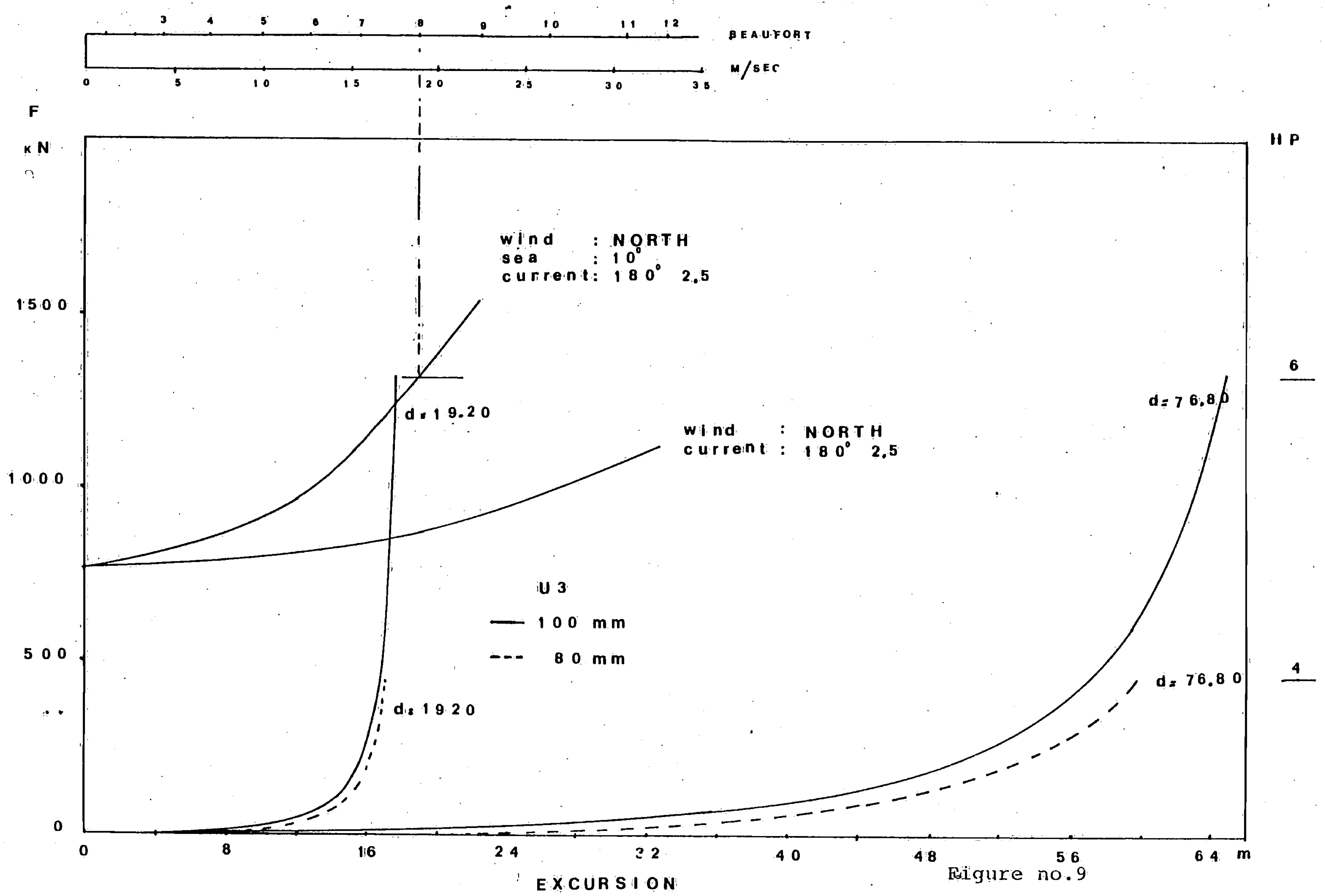


Figure no.8

LOADED BULK CARRIER



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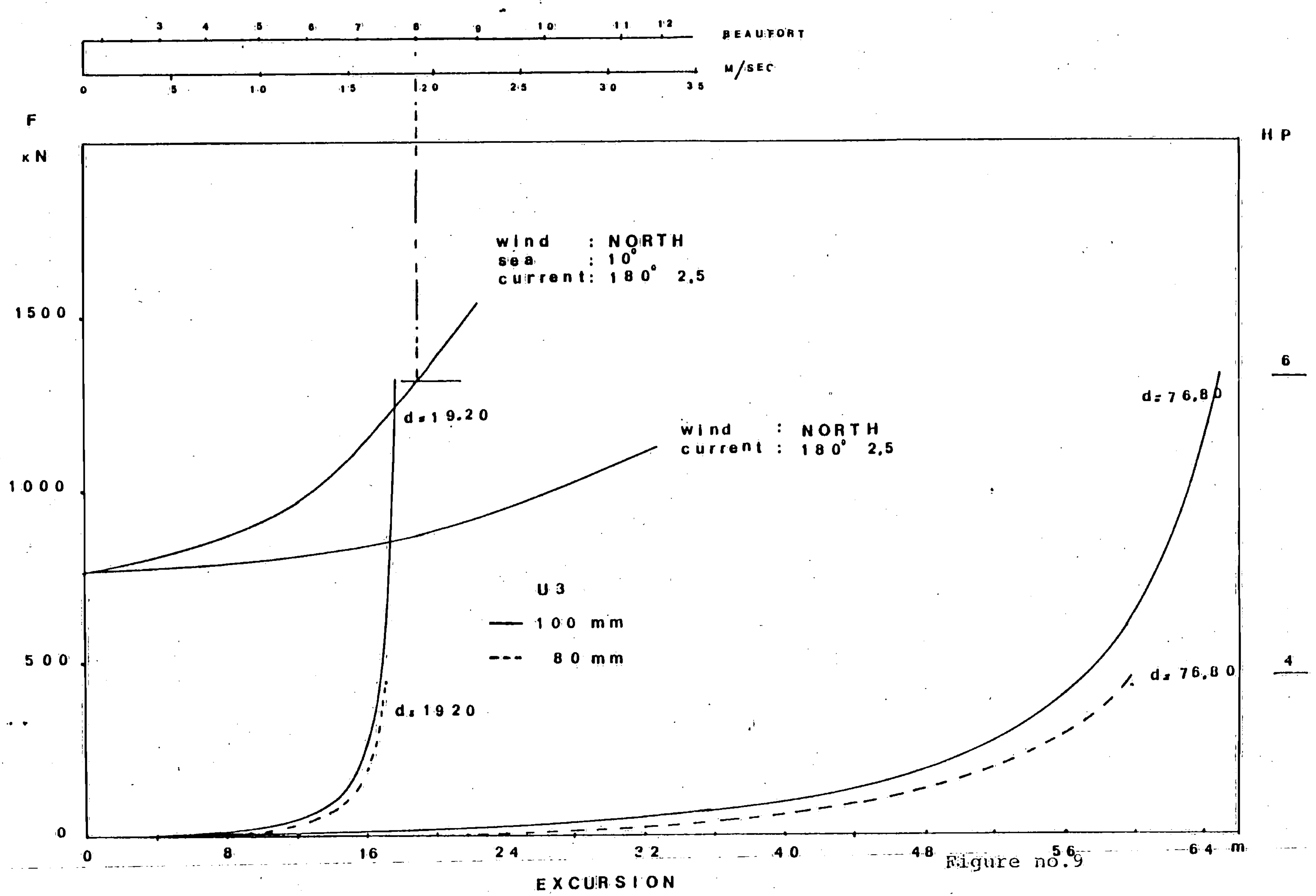

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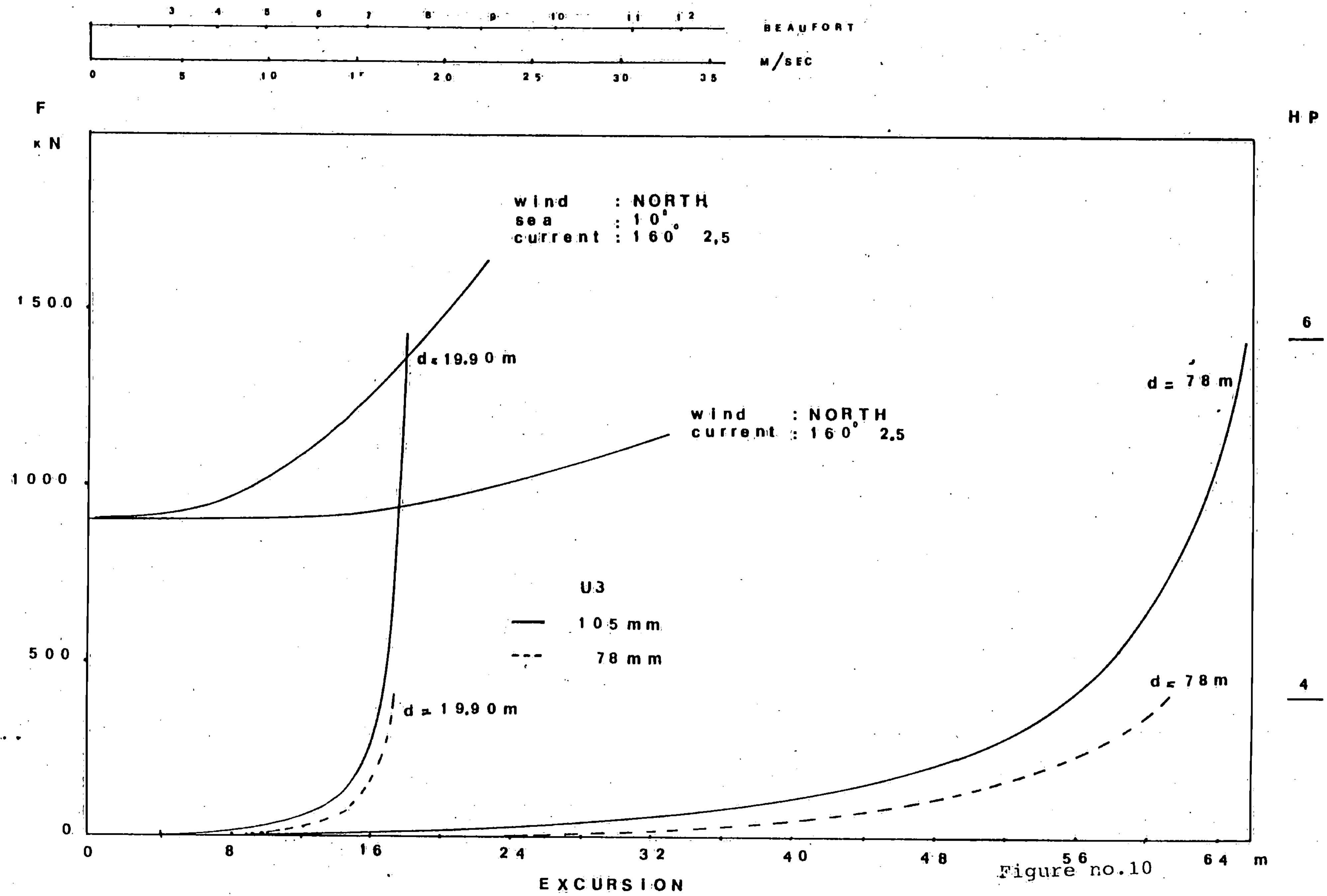


Figure no.10

LOADED CONTAINER SHIP

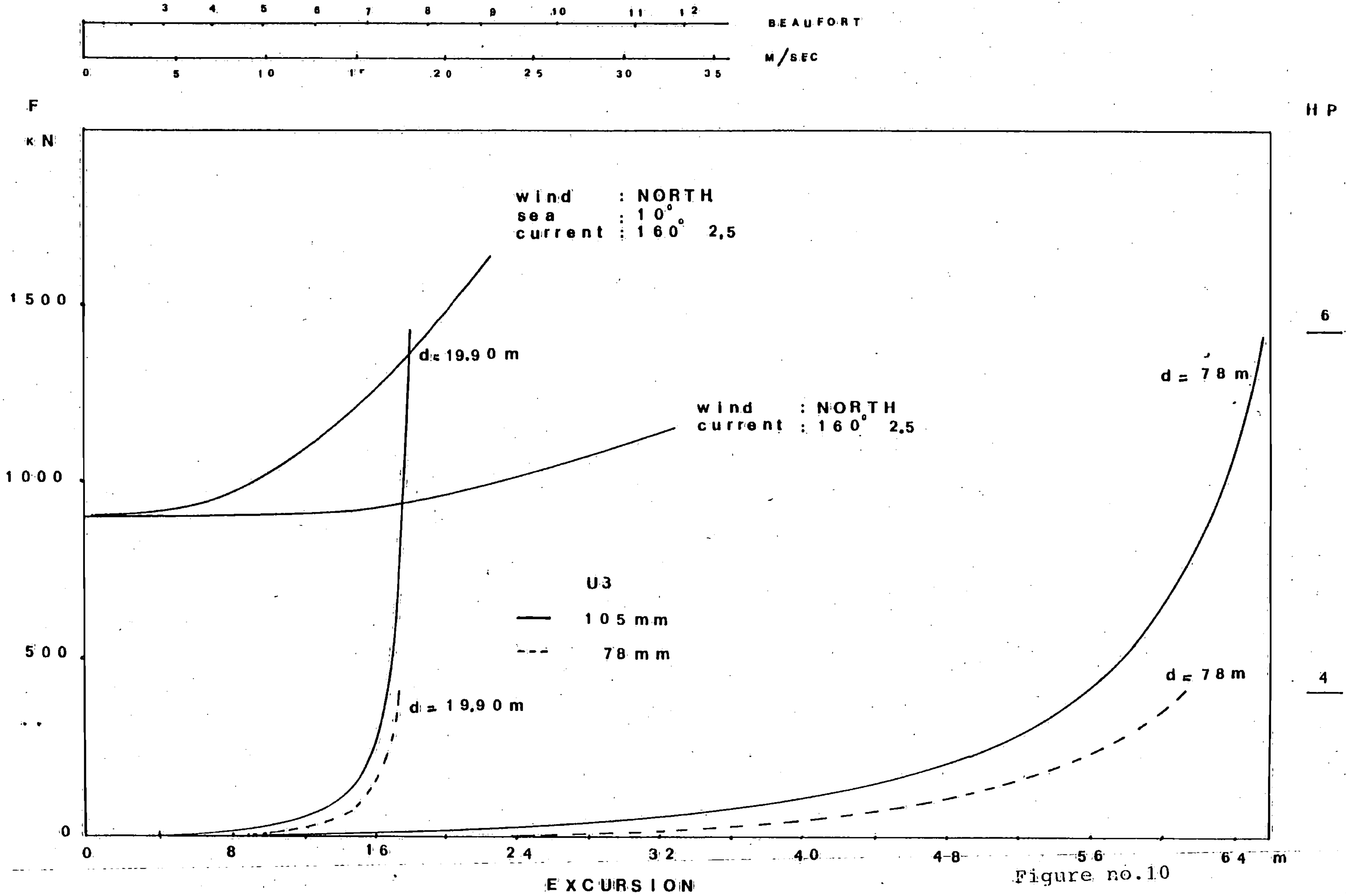
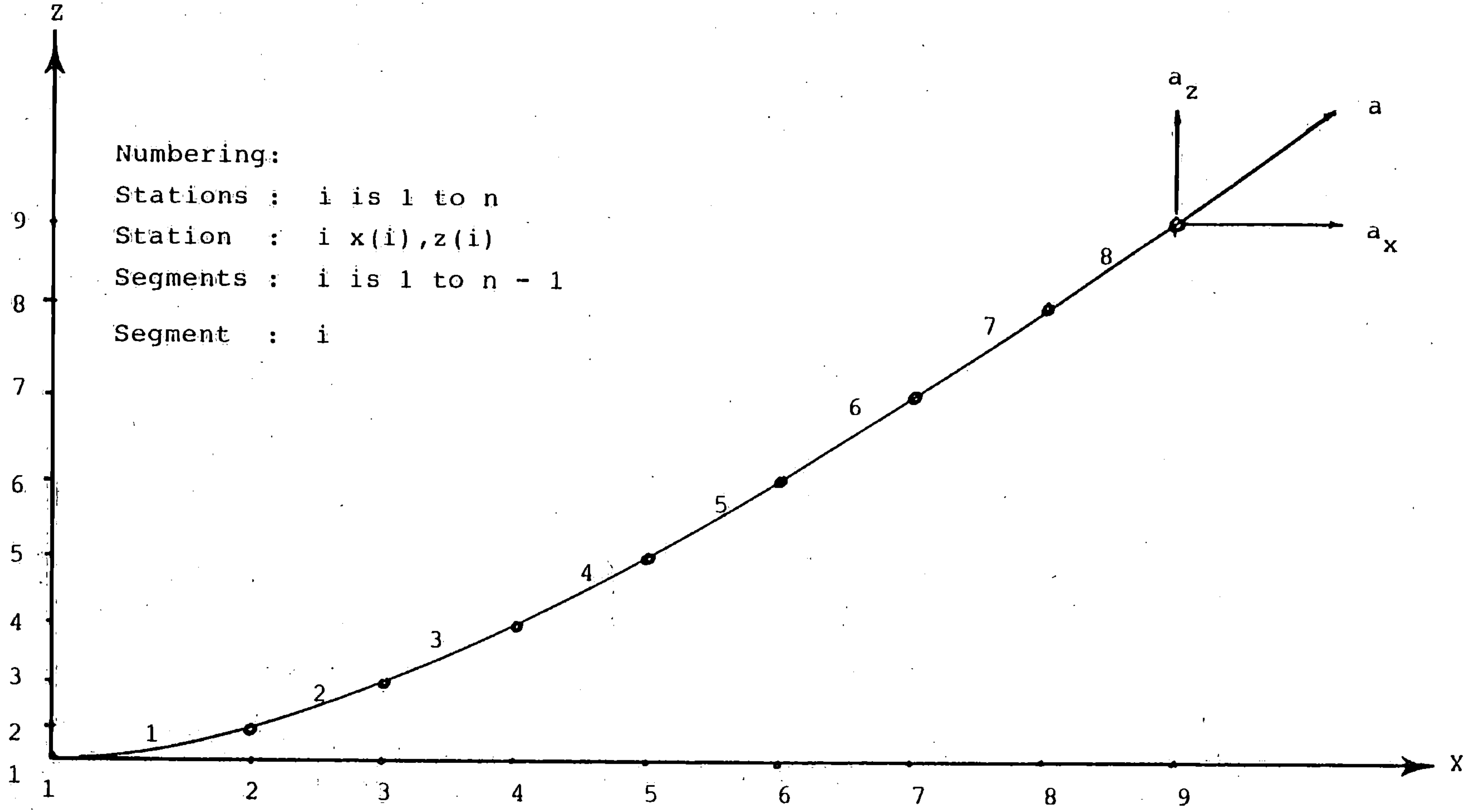


Figure no.10

DIVISION INTO SEGMENTS



Numbering:

Stations : i is 1 to n

Station : i x(i),z(i)

Segments : i is 1 to n - 1

Segment : i

Figure No. 11

DYNAMIC EFFECTS ANCHOR CHAIN TANKER

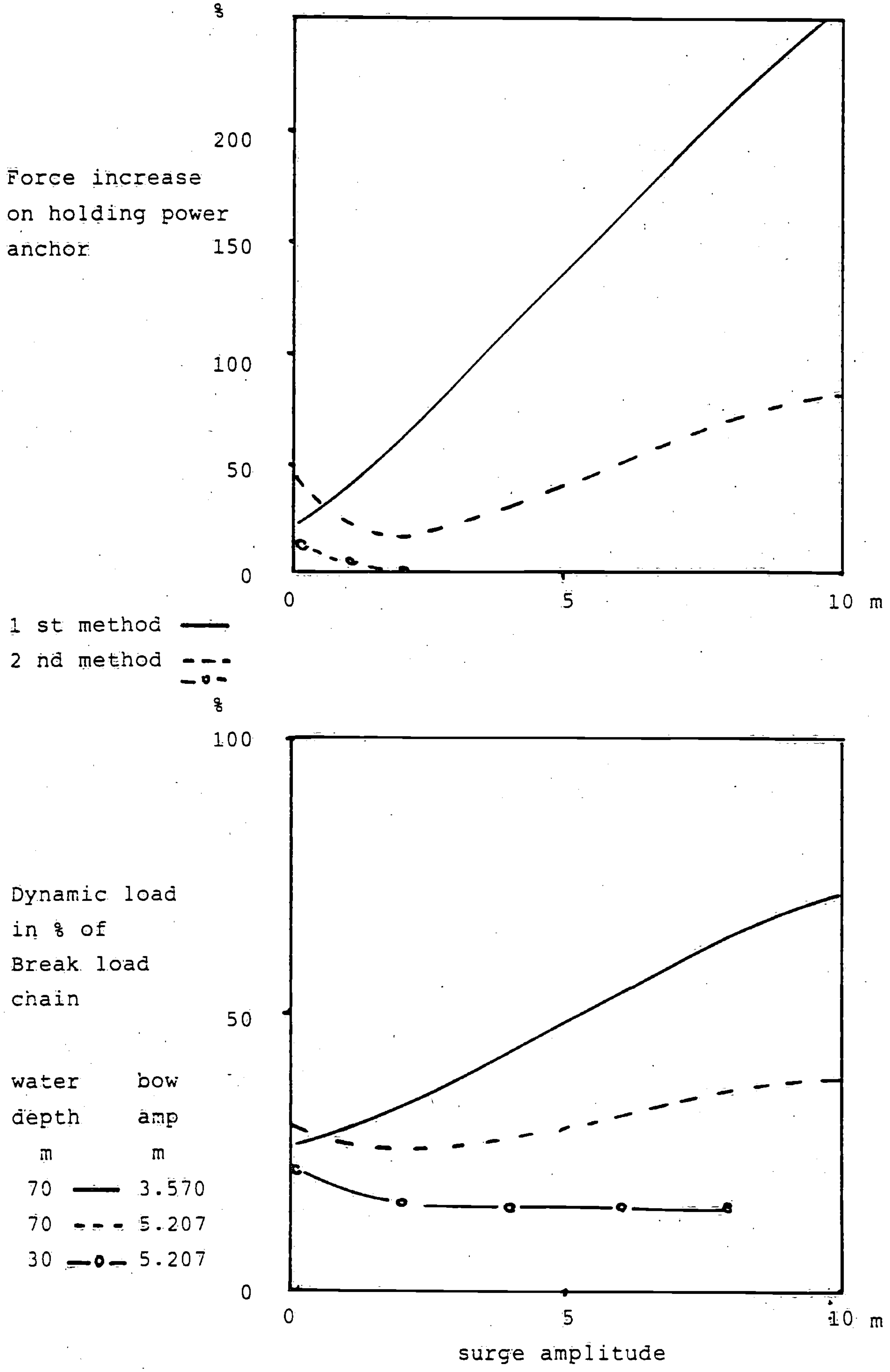


Figure no.12

DYNAMIC EFFECTS ANCHOR CHAIN CABLE MARIN TANKER

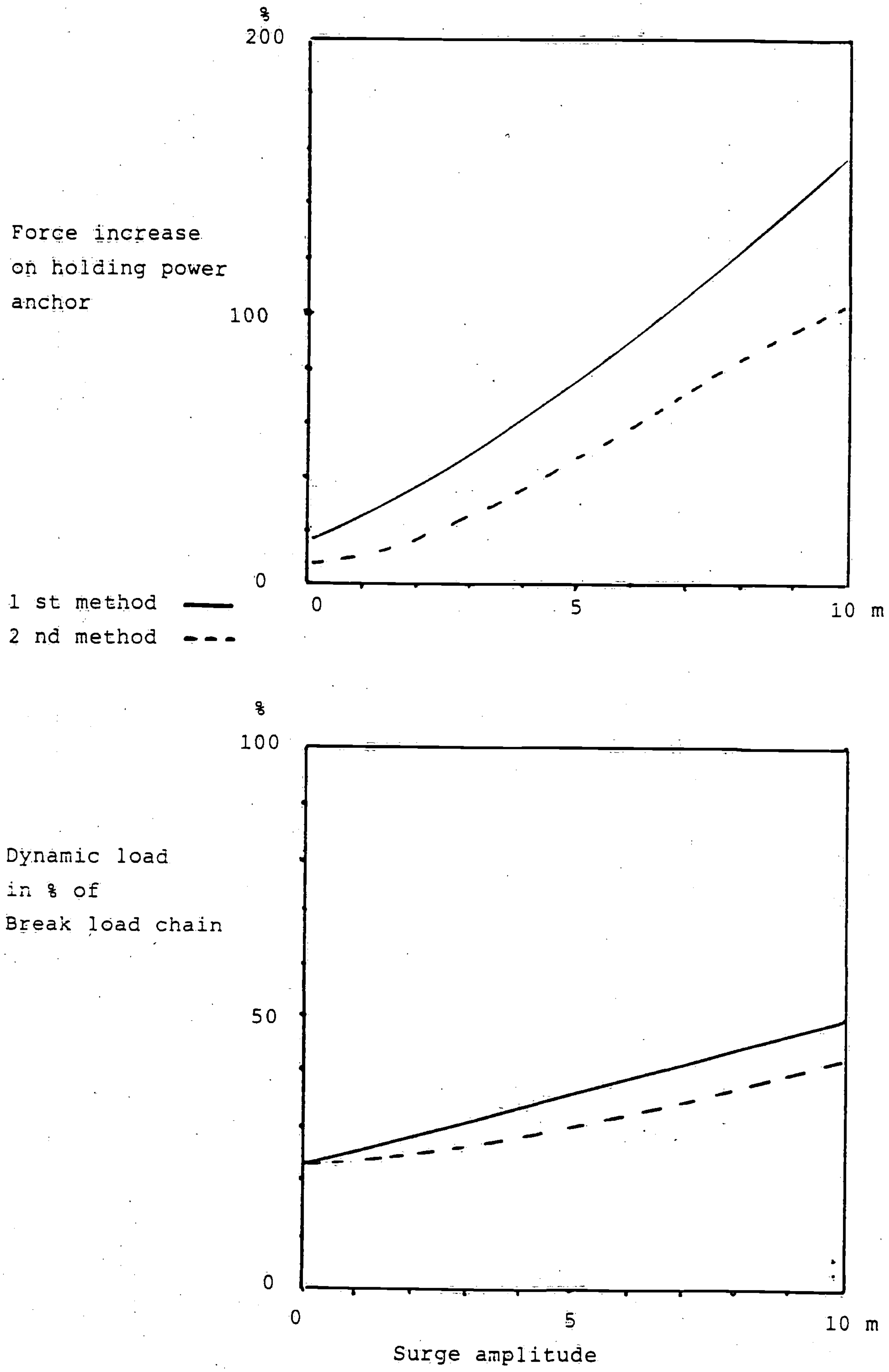


Figure no.13

DYNAMIC EFFECTS ANCHOR CHAIN CABLE BULK CARRIER

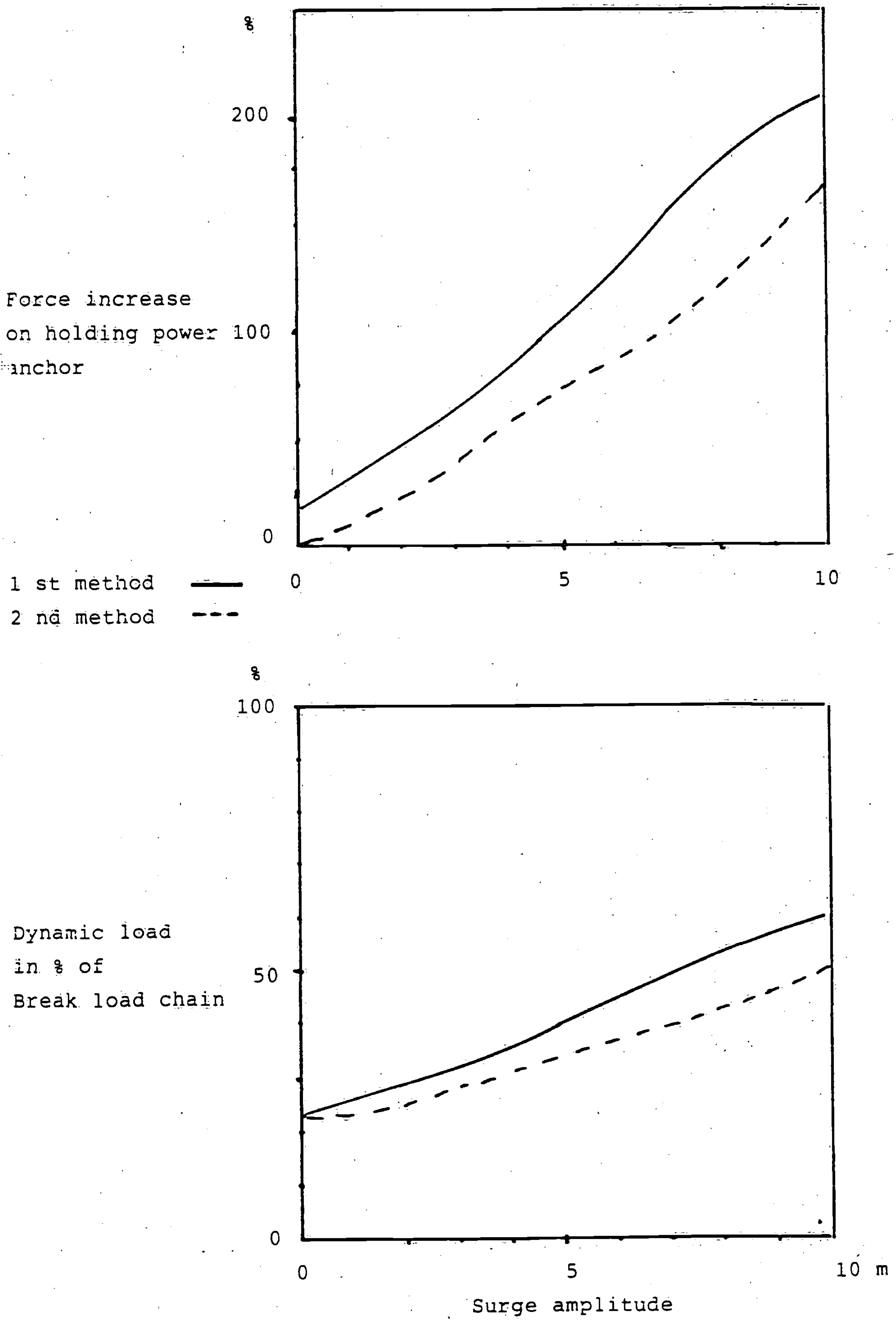


Figure no.14

DYNAMIC EFFECTS ANCHOR CHAIN CABLE CONTAINER SHIP

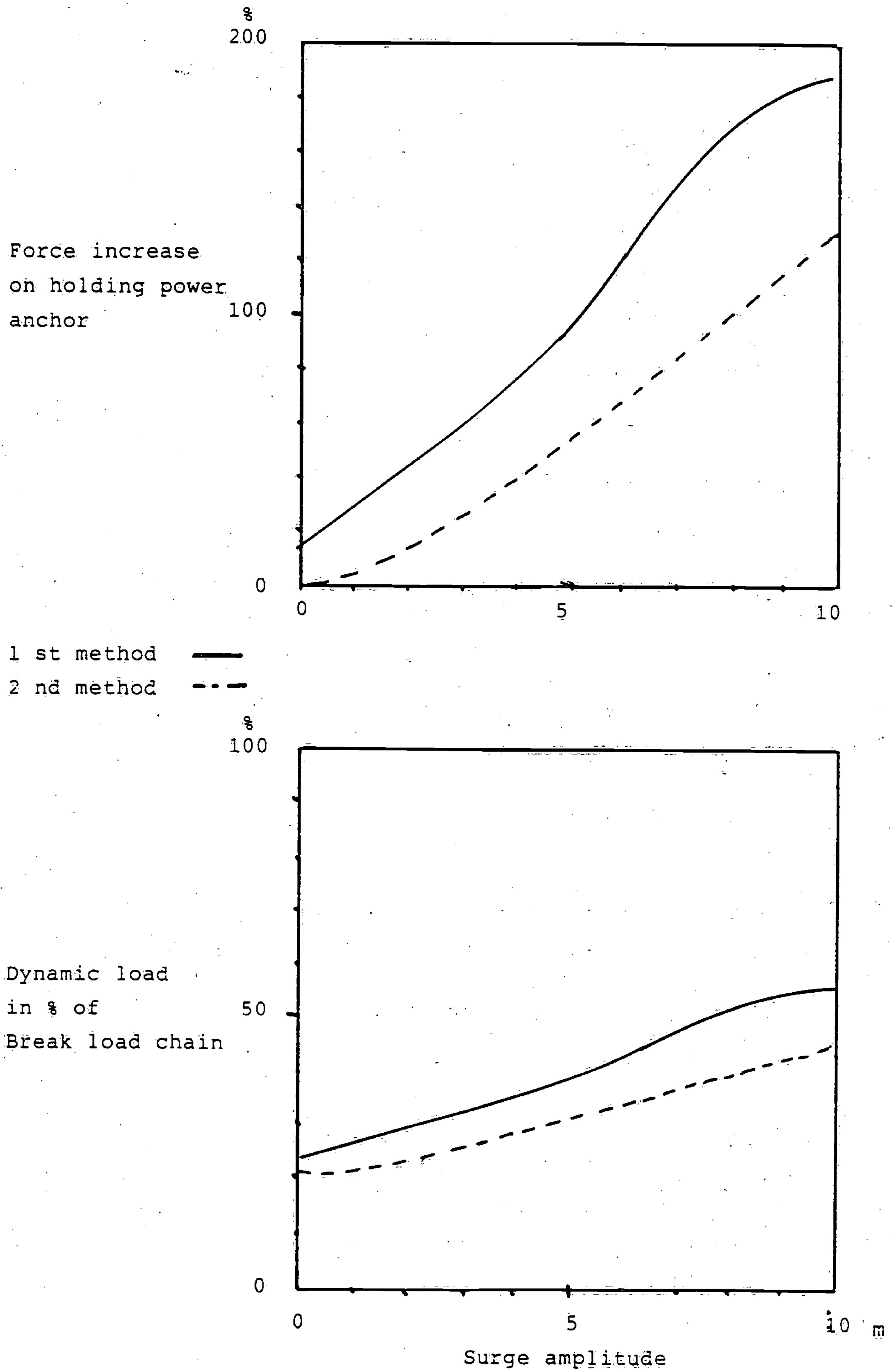
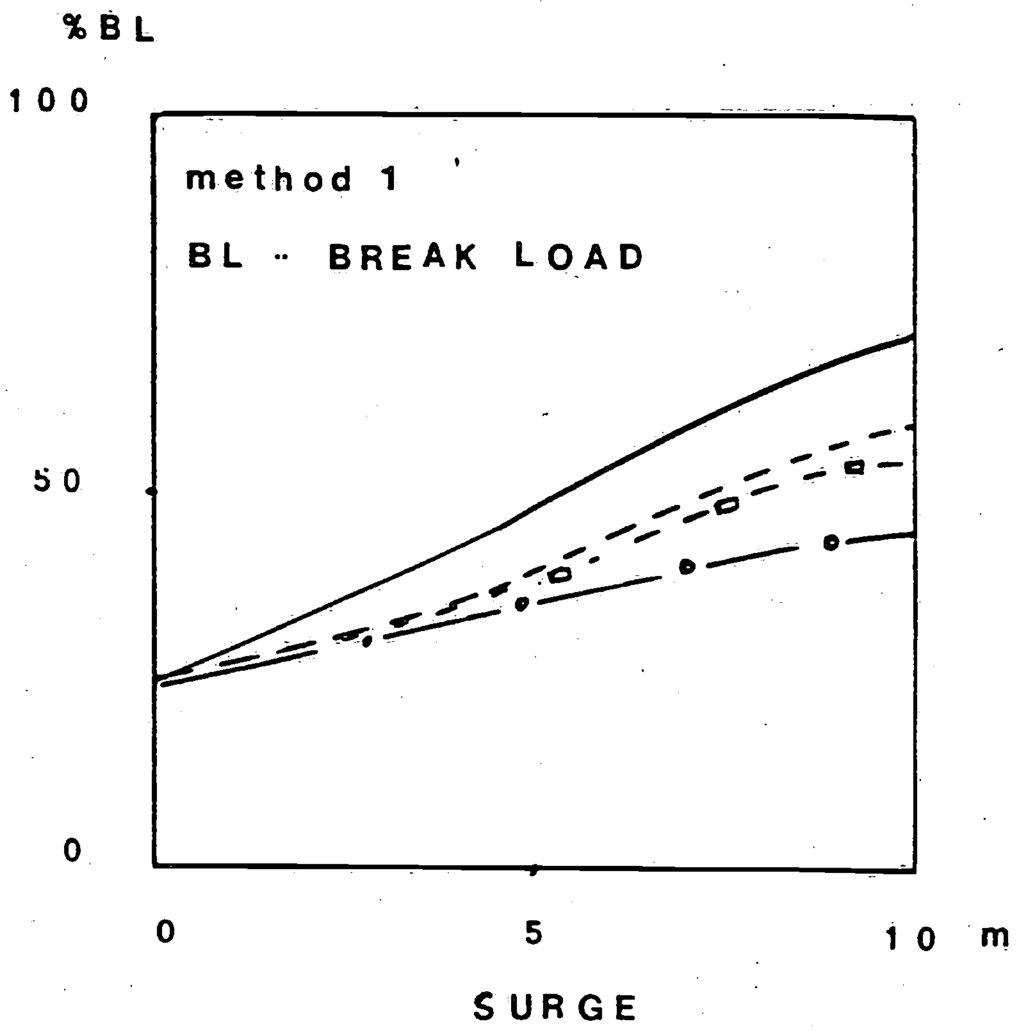


Figure no.15

DYNAMIC LOAD ANCHOR CHAIN CABLE

Wind Beaufort 8	22.6	m/sec.
Regular wave amplitude	3.57	m
Current velocity	2.5	m/sec.

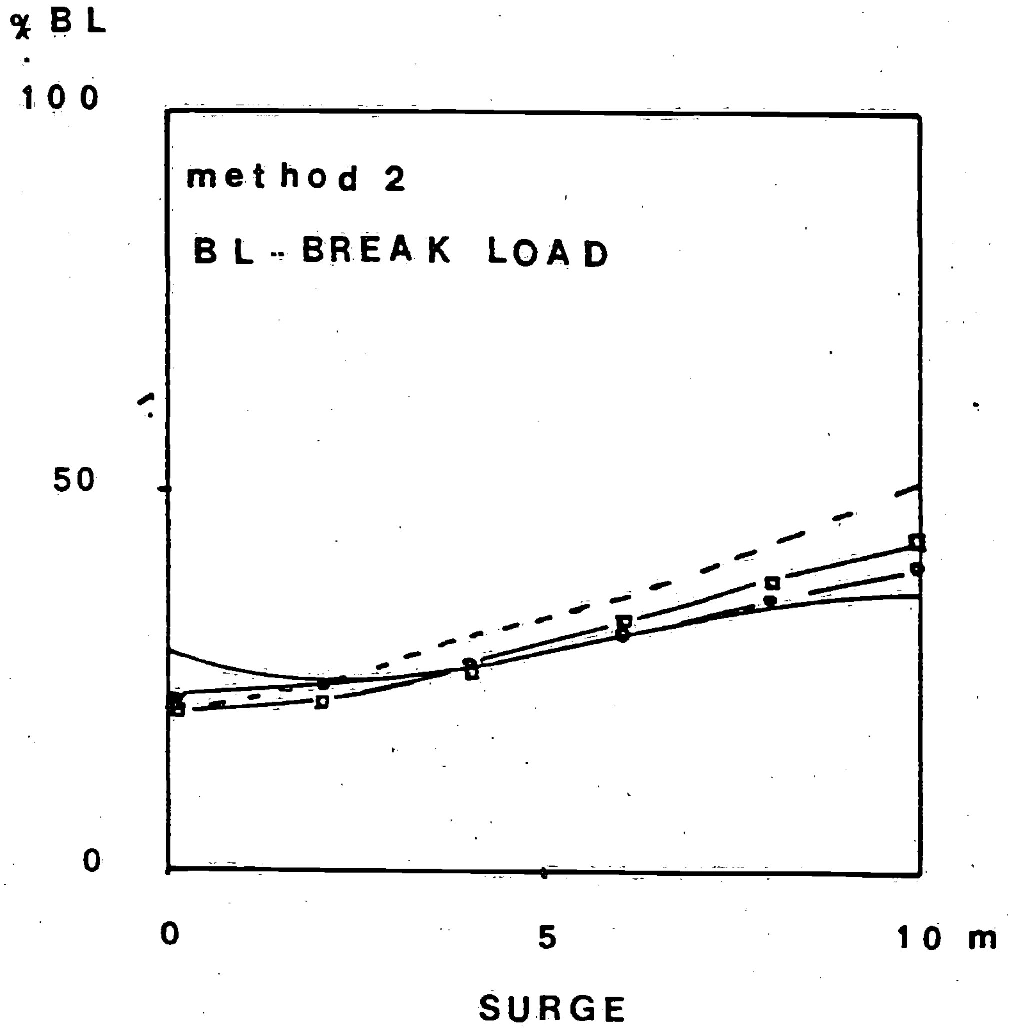


		Displacement	L_{pp}	Chain
——	TANKER	50.000 ton	164.0 m	d = 78 mm
—•—	MARIN TANKER	234.994 ton	310.0 m	d = 137 mm
- - -	BULK CARRIER	87.320 ton	250.0 m	d = 100 mm
—▫—	CONTAINER SHIP	48.837 ton	285.0 m	d = 10[illegible] mm

Figure no.16

DYNAMIC LOAD ANCHOR CHAIN CABLE

Wind Beaufort 8	22.6	m/sec.
Regular wave amplitude	3.57	m
Current velocity	2.5	m/sec.



		Displacement	L_{pp}	Chain
——	TANKER	50.000 ton	164.[illegible] m	d = 78 mm
—•—	MARIN TANKER	234.994 ton	31[illegible] m	d = 137 mm
- - -	BULK CARRIER	87.320 ton	250.[illegible] m	d = 10[illegible] mm
—▫—	CONTAINER SHIP	48.837 ton	285.0 m	d = 10[illegible] mm

Figure no.17

IMPACT AND ENERGY

TANKER

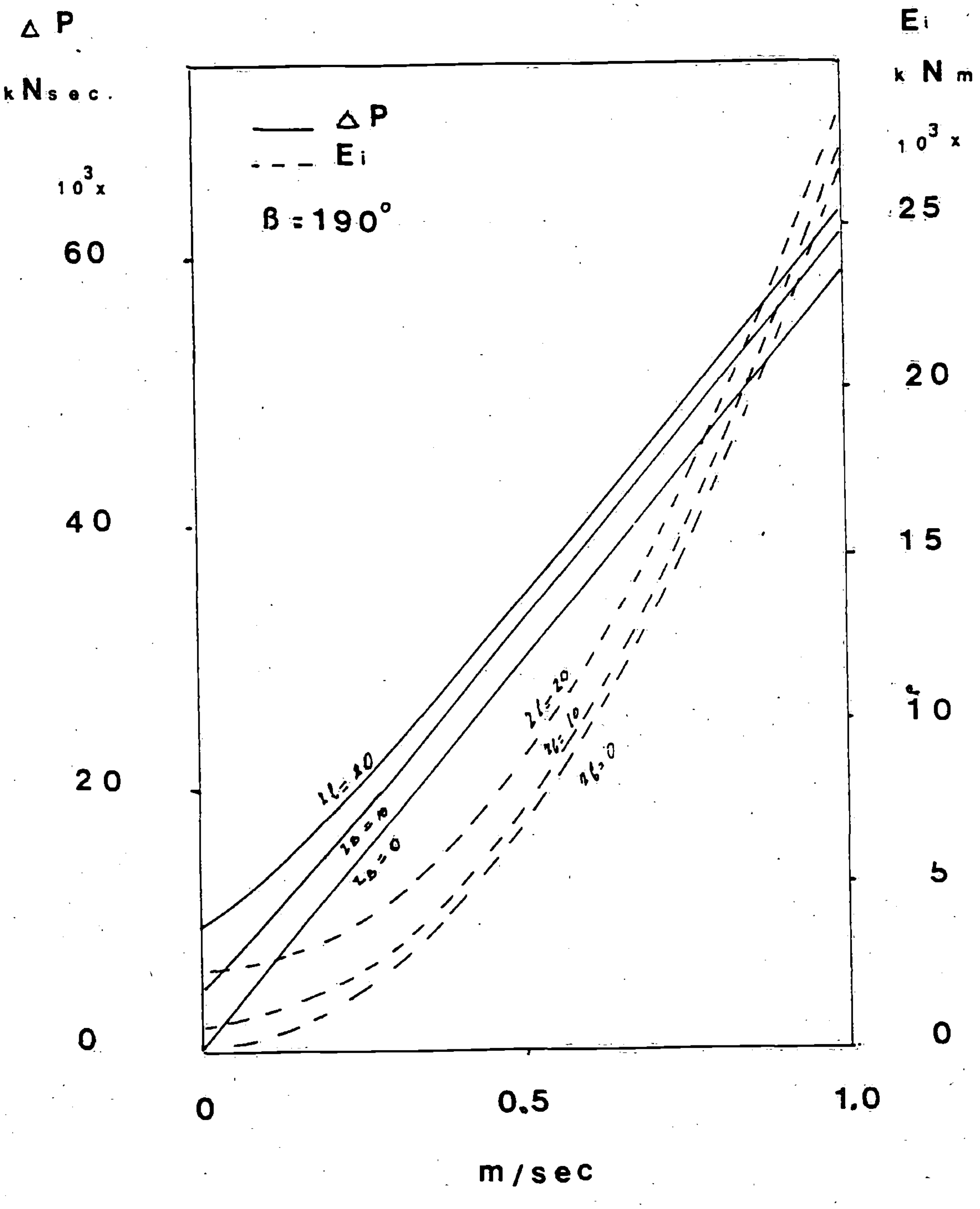


Figure no. 18

IMPACT AND ENERGY

TANKER

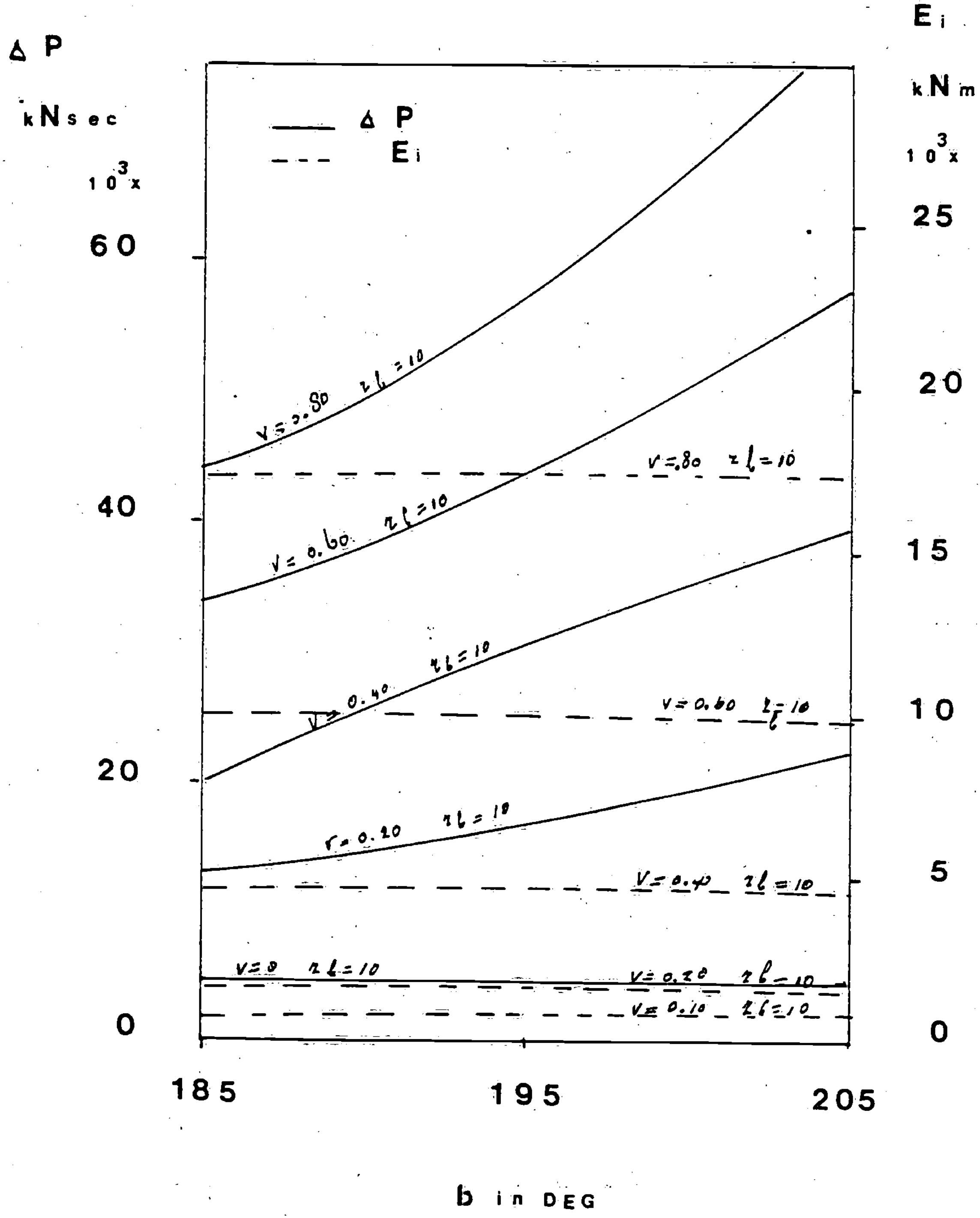


Figure No.19

IMPACT AND ENERGY
MARIN TANKER

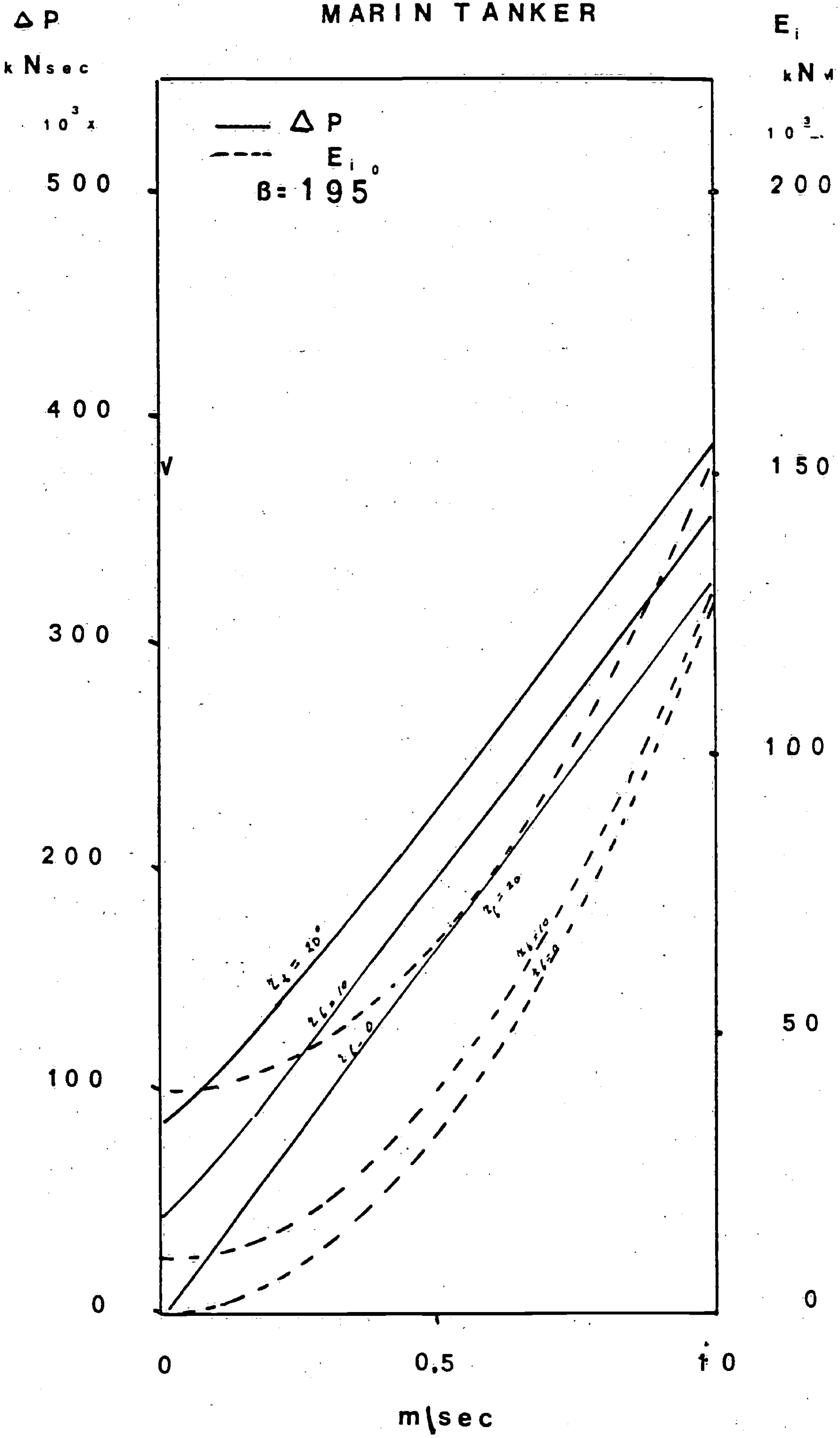
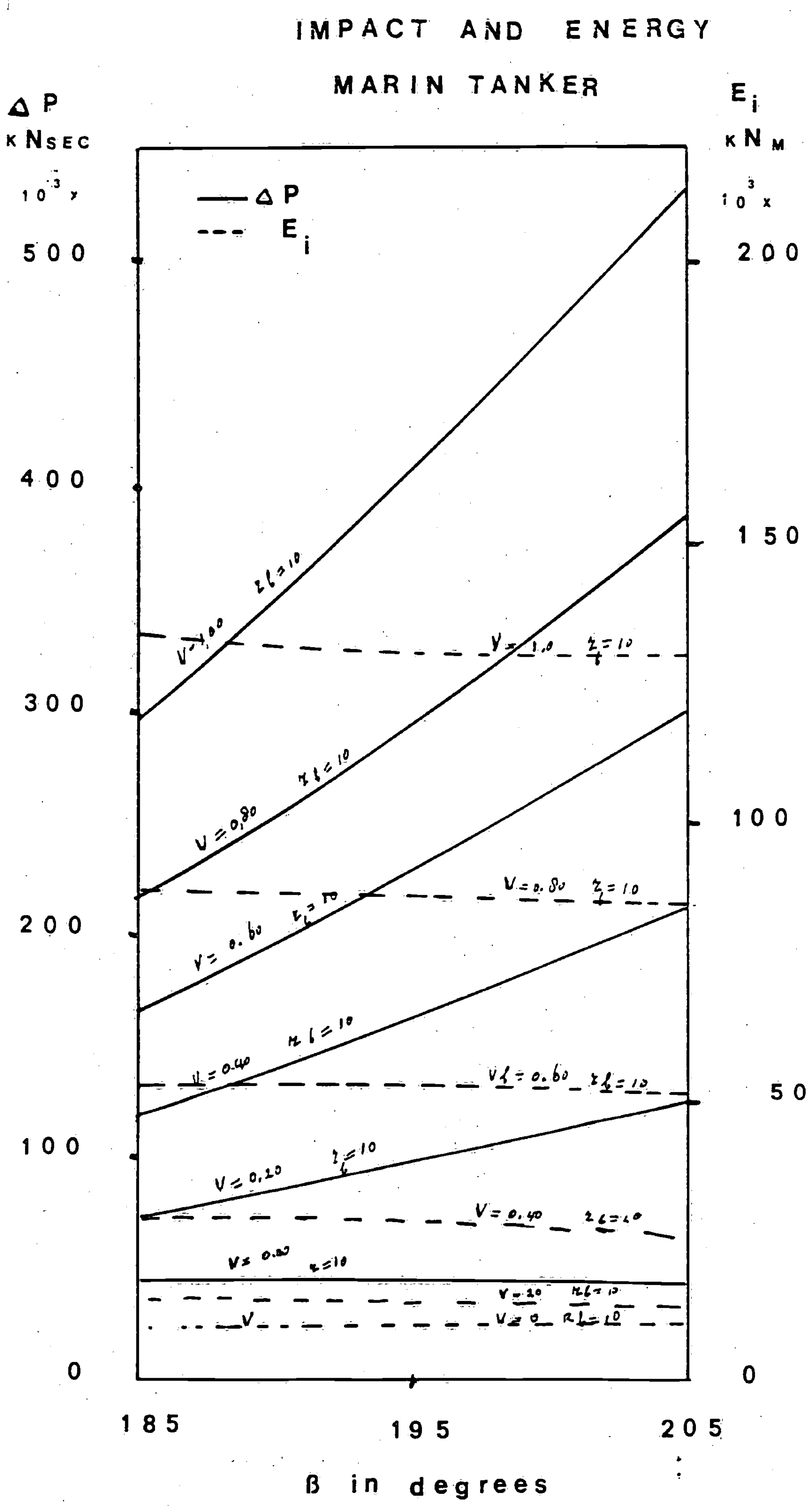


Figure no.20


IMPACT AND ENERGY
MARIN TANKER
ΔP
KNSEC
10^{3} x
Ei
KNM
10^{3} x
ΔP
Ei
500
400
300
200
100
0
200
150
100
50
0
V=1,00 ℓ=10
V=1,0 ℓ=10
V=0,80 ℓ=10
V=0.80 ℓ=10
V=0.60 ℓ=10
V=0.40 ℓ=10
Vℓ=0.60 ℓ=10
V=0,20 ℓ=10
V=0.40 ℓ=10
V=0.20 ℓ=10
V=.20 ℓ=10
V
V=0 ℓ=10
185
195
205
ß in degrees

Figuur no.21

IMPACT AND ENERGY
BULK CARRIER

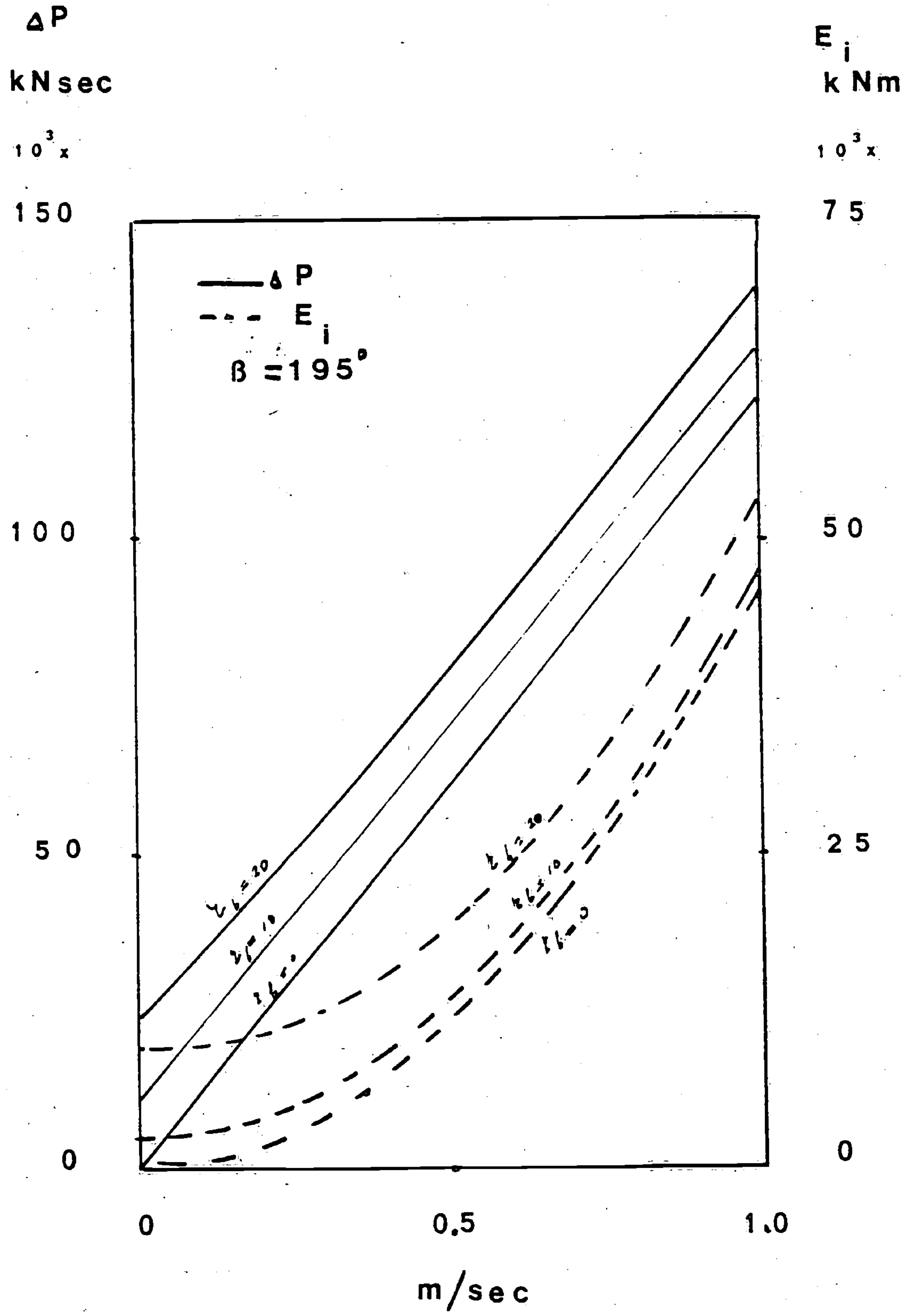


Figure no.22

IMPACT AND ENERGY
BULK CARRIER

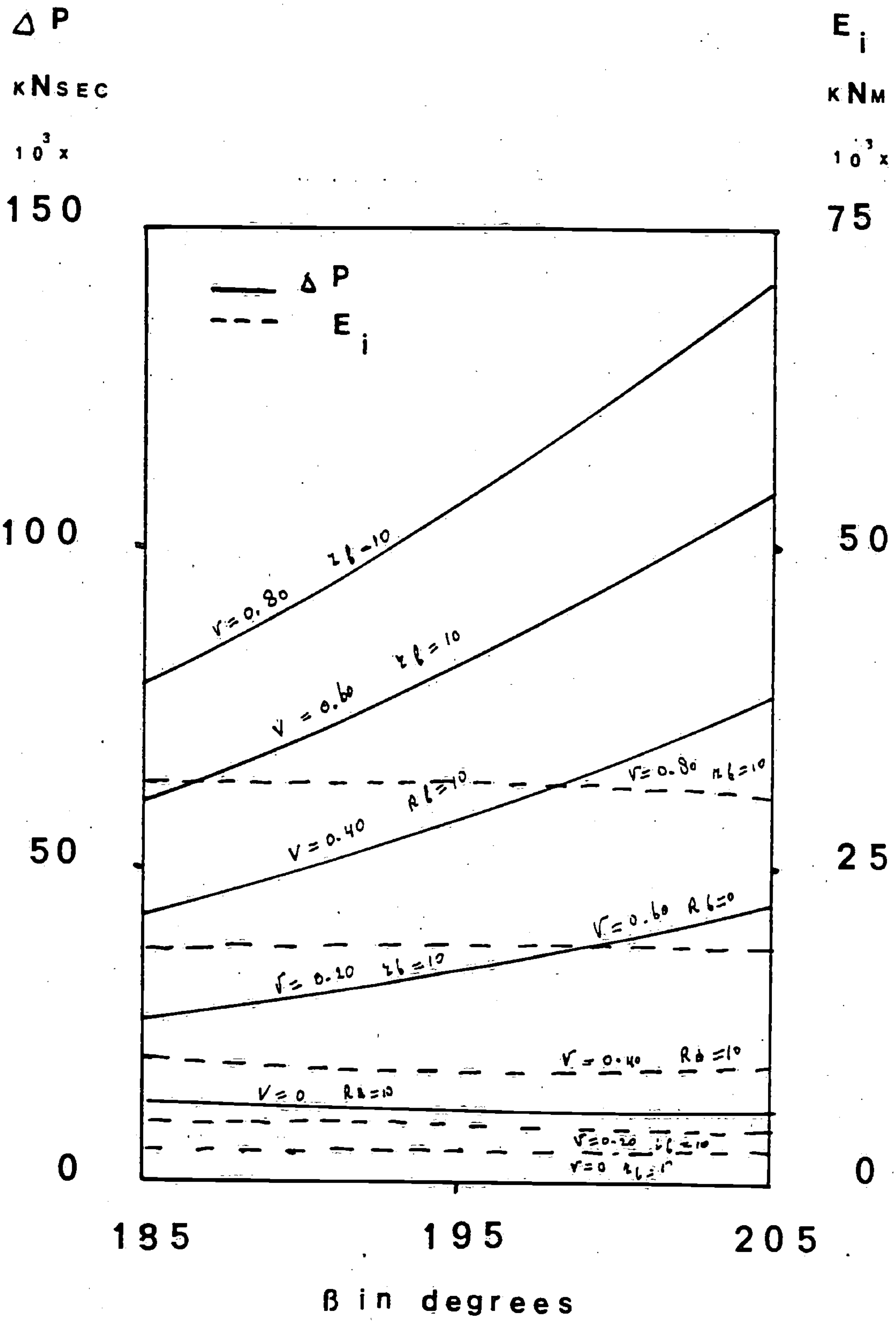


Figure no.23

IMPACT AND ENERGY
CONTAINER SHIP

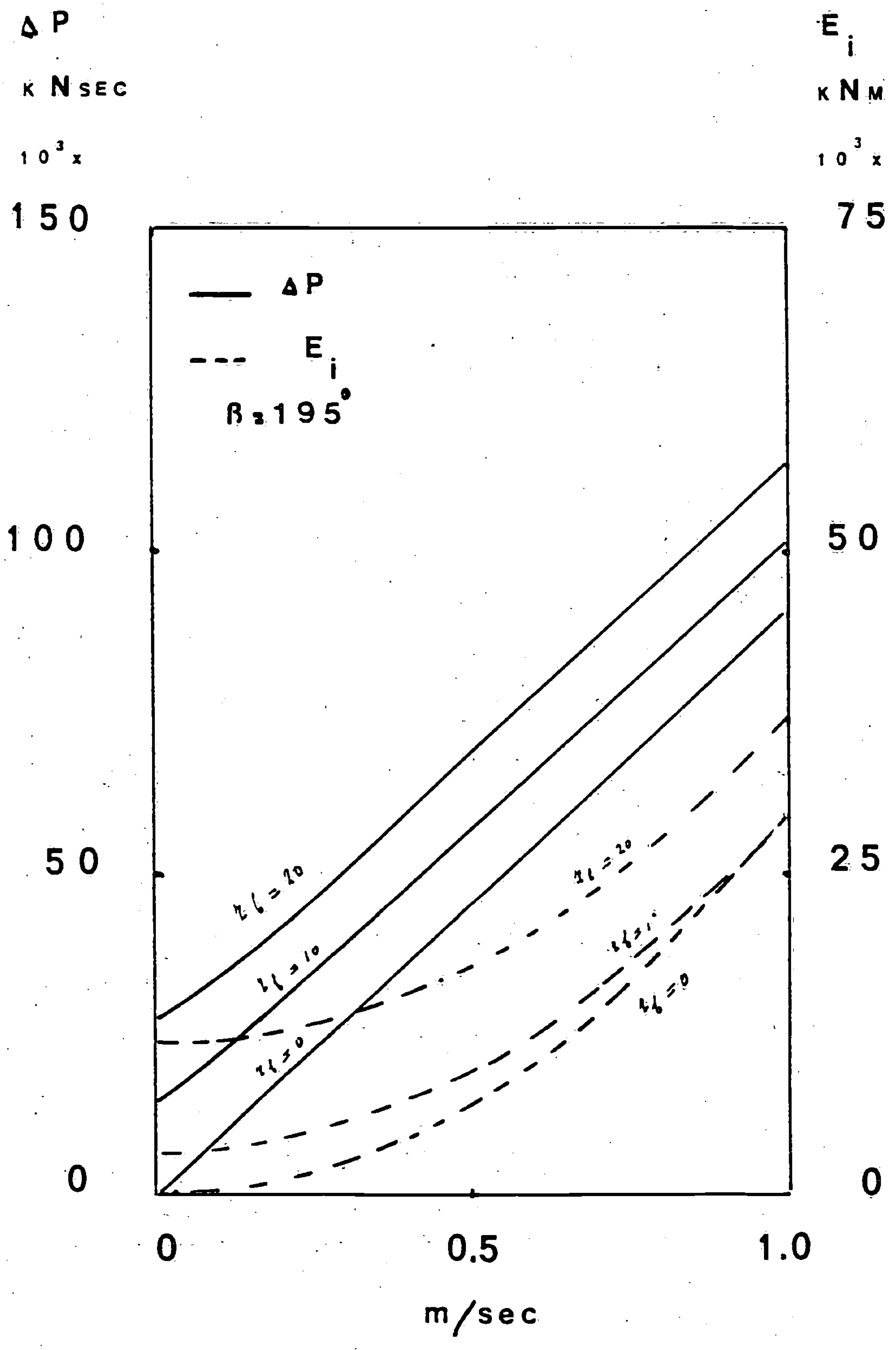
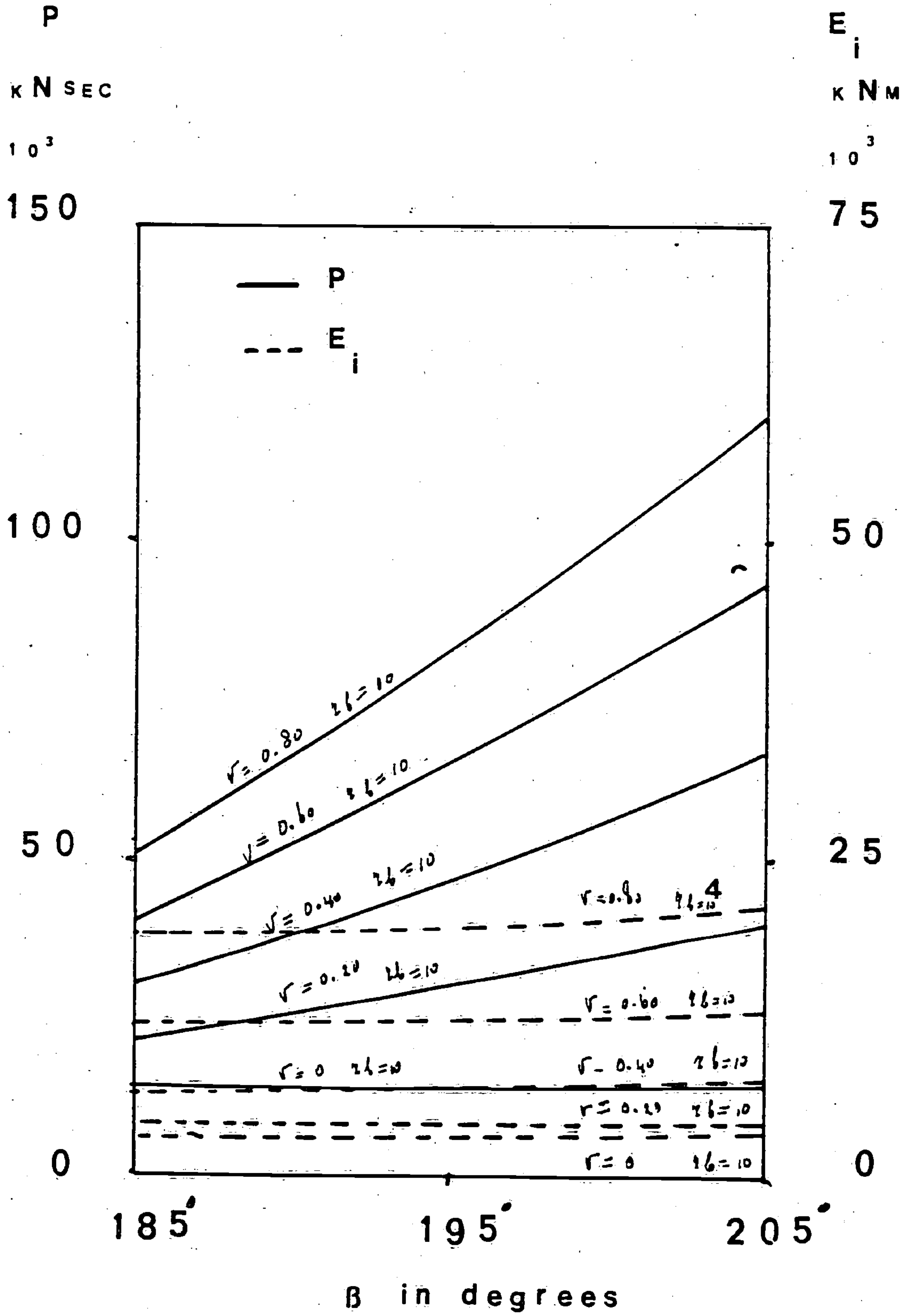


Figure no.24

IMPACT AND ENERGY
CONTAINER SHIP



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