MOORING FORCES INDUCED BY PASSING SHIPS
- MEASUREMENTS IN PROTOTYPE -

by

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ABSTRACT

In the present study the mooring systems of four bulk carriers which were moored at a jetty located parallel to a navigable water were investigated with special regard to forces due to passing ships. The objective of this study was to verify in praxi the present knowledge of moored vessels berthed at more protected sites and to prove proposed models of forcing functions by passing ships as well as numerical models for the computation of ship mooring systems. For that purpose the mooring forces and also those data which characterized the properties of the mooring systems were recorded. On the basis of the also recorded wind and current data and the data of the passing ships with which the external forces could be estimated the mooring forces were computed. These computed forces are compared with the measured mooring forces.

1. INTRODUCTION

In recent years ship mooring problems arose at existing or projected berths located not only in exposed areas but also at comparatively protected sites. Among the more protected facilities also jetties rank which are located in close proximity and parallel to much frequented navigable waters (Laucht, 1976). For ships moored at these jetties in general not only forces due to wind and current and possibly due to waves have to be taken into account but also forces which are induced by passing ships. These forces can be of considerable significance when the passing distances of the ships are small or the velocities which are generally limited to a certain minimum to ensure sufficient manoeuvrability increase largely.

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The forces on moored ships due to wind and current can be estimated with sufficient accuracy, for instance with the data given by the Oil Companies International Marine Forum (1977) or by Remery and van Oortmerssen (1975), just as the behavior of moored ships in regular and irregular seas as well as in long waves (van Oortmerssen, 1976). Compared with this, the knowledge about those forces which are induced by passing ships is incomplete till now. One of the few theoretical works to this subject which provides more extensive results is that of Wang (1975), who replaces both vessels by idealised bodies with semicircular cross sections and a parabolic sectional-area distribution. Results of model investigations as well as of theoretical work are given by Remery (1974) and Muga and Fang (1975). Field investigations to this complex however are rare up to now. In 1972 measurements were carried out in Rotterdam at the Kalandkanal Quay by the Gemeendewerken Rotterdam and in 1976 the author performed measurements at the Kiel Canal (Haffke, 1976).

The behavior of moored ships can be described in general by a set of six simultaneous second order differential equations

$$\{M\}\ \{x\} + \{F_h\} + \{F_b\} + \{F_l\} + \{F_f\} + \{F_r\} = \{F_w\} + \{F_a\} + \{F_c\} + \{F_p\} \quad \ldots (1)$$

in which the mass forces $\{F_m\} = [M]\{x\}$, the hydrodynamic forces $\{F_h\}$, the hydrostatic forces $\{F_b\}$, the restoring forces due to the mooring and the fender system $\{F_l\}$ and $\{F_f\}$ and the fender friction forces $\{F_r\}$ face the external forces due to waves, wind, current and passing ships $\{F_w\}$, $\{F_a\}$, $\{F_c\}$ and $\{F_p\}$.

A comprehensive mathematical model of the non-linear oscillating system in which the hydrodynamic forces are frequency dependent functions of the accelerations and velocities in the six modes of motion was given by van Oortmerssen (1976) who investigated a moored ship in a quay-side position for various quai-distances and underkeel clearances due to wave excitation. In a similar manner Cuthbert and Seidl (1976) analysed the design layout of an offshore terminal mooring system. The time domain solution they used was, for the study of ship motions, originally formulated by Cummins (1962) and is based on the well known impulse response function technique.

Although a derivation of this technique is beyond the scope of this paper, some of the expressions may be given. Here for example the hydrodynamic force $F_{h,\ kj}$, the force in the k-th mode due to motion in the j-th mode

$$F_{h,kj} = m_{kj} x_j + \int_{-\infty}^{t} K_{kj}\ (t - \tau)\ x_j(\tau)\ d\tau \qquad \ldots\ldots\ldots (2)$$

where: $$K_{kj}(t) = \frac{2}{\pi} \int_{0}^{\infty} b_{kj}(\omega)\ \cos\omega t\ \ d\omega \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

with m_{kj} = a high frequency asymptotic value of the added mass

and b_{kj} = the frequency dependent damping coefficient

Substituting the hydrostatic forces as linear forces, equation (1) can be written

$$\sum_{j=1}^{6} (M_{kj} + m_{kj})\ \ddot{x}_j + c_{kj}\ x_j + \int_{-\infty}^{t} K_{kj}\ (t - \tau)\ \dot{x}_j(\tau)\ d\tau$$

$$+ F_{l,k} + F_{f,k} + F_{r,k} = F_{w,k} + F_{a,k} + F_{c,k} + F_{p,k} \qquad \ldots\ldots\ldots (4)$$

$k = 1,2,\ \ldots\ 6$

where the wave forces may also include drift forces. These equations can then be solved by a time stepping procedure. In those cases where the forces due to wind and current, which in a practical engineering approach can be considered as quasi-static forces, dominate or at locations where ship oscillations are not allowed a pure static analysis of the problem is sufficient.

The forces due to a passing ship are in general functions of the geometric properties of both ships and the waterway, the velocity and the distance of the passing ship and the properties of the fluid and may be described as follows

$$\frac{1}{\rho\,(v-u)^2}\left\{\frac{F_{p,1}}{B_1T_1},\ \frac{F_{p,2}}{L_1T_1},\ \frac{F_{p,3}}{L_1B_1},\ \frac{F_{p,4}}{L_1T_1^{2}},\ \frac{F_{p,5}}{L_1^{2}B_1},\ \frac{F_{p,6}}{L_1^{2}T_1},\right\}$$

$$= \phi\left[\frac{B_1T_1}{L_1^{2}},\ \frac{B_1}{L_1},\ \Gamma_1,\ \frac{L_2}{L_1},\ \frac{B_2T_2}{L_2^{2}},\ \frac{B_2}{L_2},\ \Gamma_2,\right.$$

$$\left.\frac{v}{v-u},\ Fn,\ Rn,\ \frac{a}{B_1},\ \frac{b}{L_1},\ \frac{d}{L_1},\ \frac{2c}{L_1+L_2}\right] \quad \ldots\ldots\ldots \ (5)$$

where $F_{p,1}$, $F_{p,2}$ ... $F_{p,6}$ denote the forces and moments in the six modes of motion: surge, sway, heave, roll, pitch, yaw and L_1, B_1, T_1 and L_2, B_2, T_2 denote the length, the beam and the draught of the moored and the passing ship respectively. Further in this simplifying scheme the form parameter of both hulls are summarized by Γ_1 and Γ_2, v denotes the velocity of the passing ship, u a characteristic current velocity in the navigable water, b the passing distance, c the distance of the transverse centerlines, a the distance from a vertical quay and d the water depth.

In nearly all practical cases the Froude numbers based on length of the passing ship are so small that the effect of the Kelvin-type wave pattern can be neglected and hence the influence of the Froude number too. A larger influence however is due to viscous effects especially cross-flow separation forces. Nevertheless approaches based on potential theory give good results when the geometric properties can be well approximated. Forces and moments i. e. their Euler numbers are therefore essentially functions of the geometric boundary conditions given by the ships and the navigable water. For engineering purposes simpler geometric models are possible.

For practical approaches the forces in surge, sway and yaw are the important ones. Due to the mostly large hydrostatic restoring forces and the small restoring forces of the mooring and the fender system in heave, roll and pitch the forces in these modes which are in a similar manner nearly even or odd functions of the normalized distance of the transverse centerlines of the ships can usually be ignored.

In the present study the mooring systems of four ships were investigated with special regard to forces induced by passing ships. The objective of this study was to verify and complete in praxi the present knowledge of moored vessels berthed at more protected sites and their mooring systems and to prove models of forcing functions by passing ships as well as numerical models for the computation of ship mooring systems.

2. FIELD INVESTIGATIONS

The investigations were performed at the "Asbestos Anleger" Nordenham, a jetty located in close proximity and parallel to the navigable water of the Weser near Bremerhaven (Figure 1). The structure has vertical quay walls and is equipped with mooring dolphins on both sides; the depth of the navigable water is SKN - 9,50 m. At this location forces due to passing ships, wind forces and distinct current forces have to be considered; due to the comparatively protected site wave forces have no influence.

Subject of the investigations were the mooring systems of four bulk carriers of conventional form and design which needed at this berth on an average six days to discharge their cargo (asbestos). The three ships of the first, the third and the fourth measuring period, the "Ouivendrecht", the "Deltadrecht" and the "Oordrecht" are sister ships with a loading capacity of 42 550 tdw (L = 187,00 m, B = 29,00 m, T = 11,90 m) the ship of the second measuring period, the "Scherpendrecht", has a loading capacity of 65 350 tdw (L = 224,00 m, B = 32,30 m, T = 13,60 m).

The ships were moored in the usual way with up to twenty mooring lines wire ropes with polyamid tails as well as fibre ropes, and in some cases the tension winch equipment was used. Figure 2 shows the bow mooring of the "Dordrecht" and Figure 3 the mooring at the stern.

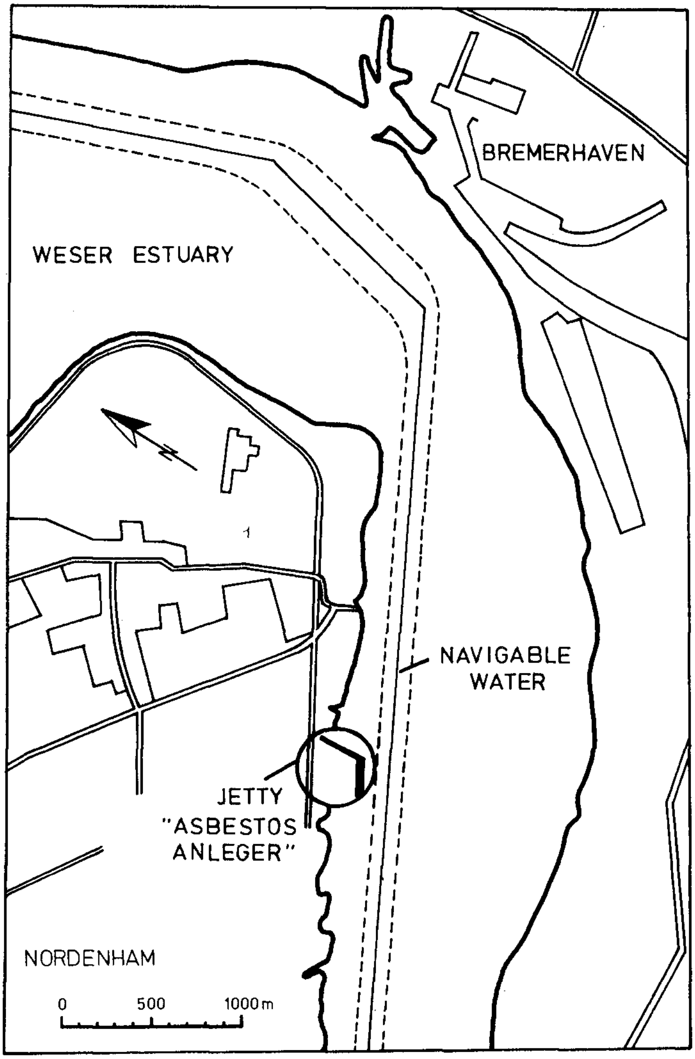


Fig. 1: Location of the "Asbestos Anleger"

Fig. 2: Bow mooring of the "Dordrecht" .

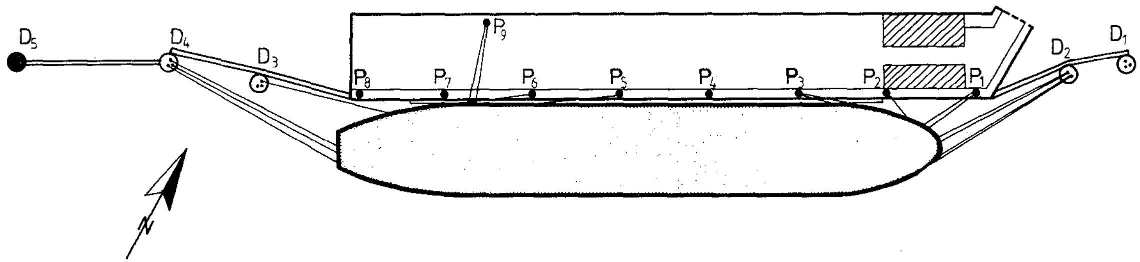
Fig. 3: "Dordrecht"-mooring at the stern

The mooring forces were measured by means of a special measuring equipment, strain gauge force transducers with a capacity of 750 kN which were connected to the mooring lines during the whole berthing time of each ship. In cases in which the number of mooring lines exceeded the number of transducers being available those lines were not connected which ran over mooring winches or which as reserve lines remained without effect. Consequently also in these cases, apart from some failures, the complete response of the mooring systems could be recorded since the forces adjusted at the tension winches were known. An example of a mooring line layout is given with Figure 4 with again the "Dordrecht". The mooring forces were recorded during the passage of ships just as in fixed intervals without a passing ship; in addition permanent measurements were performed in the first and in the second measuring period. For measurements only those passing ships were chosen by which larger forces could be expected. Velocity and distance of these ships whose main dimensions were known were recorded separately. Furthermore the geometric properties of the mooring systems, the draught of the moored ships and the waterlevel fluctuations were recorded as well as wind and current velocities at selected points. An example of a mooring force record is given in Figures 5 and 6.

In the first and second measuring period 56 passing ships were recorded, the number of ships recorded in the third and fourth measuring period was 51. The permanent measurements had a total length of 60 hours.

3. COMPUTATIONS

In the first stage of the study the described dynamic model was assigned for the computation of the mooring systems. In view of the relatively inaccurate hydrodynamic data being available for both ships however this model wasn't used since in all cases the oscillations of the ships and with that the mass and damping forces were negligible. Hence a static model was applied which includes also the reaction of tension winches, hydrostatic forces and fender friction forces which were approximated with a dynamical approach.



MOORING LINE No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
BOLLARD No.	D2	D2	D2	D2	P1	P1	P2	P3	P3	P6	P5	P9	P9	D3	D4	D4	D4
HAWSE No.	201	201	101	101	104	105	107	108	110	112	113	116	118	119	121	122	221
FIXING AT THE SHIP T = TENSION WINCH- B = SHIP BOLLARD	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
MATERIAL PP = POLYPROPYLENE S = STEEL WIRE CIRCUMFERENCE [INS.] DIAMETER [mm]	PP 7	PP 7	PP 7	PP 7	PP 7	S 26	S 26	PP 7	S 26	PP 7	S 26	S 26	S 26	PP 7	PP 7	PP 7	PP 7
FORCE TRANSDUCER No.	5	2	6	4	3	10	8	9	7	—	T	1	S	K	G	R	B

MOORING OF THE
„DORDRECHT"
MEASURING PERIOD 41
FROM 30.09.1978 / 20.30
TO 03.10.1978 / 23.00

Fig. 4: Mooring line layout in measuring period 41

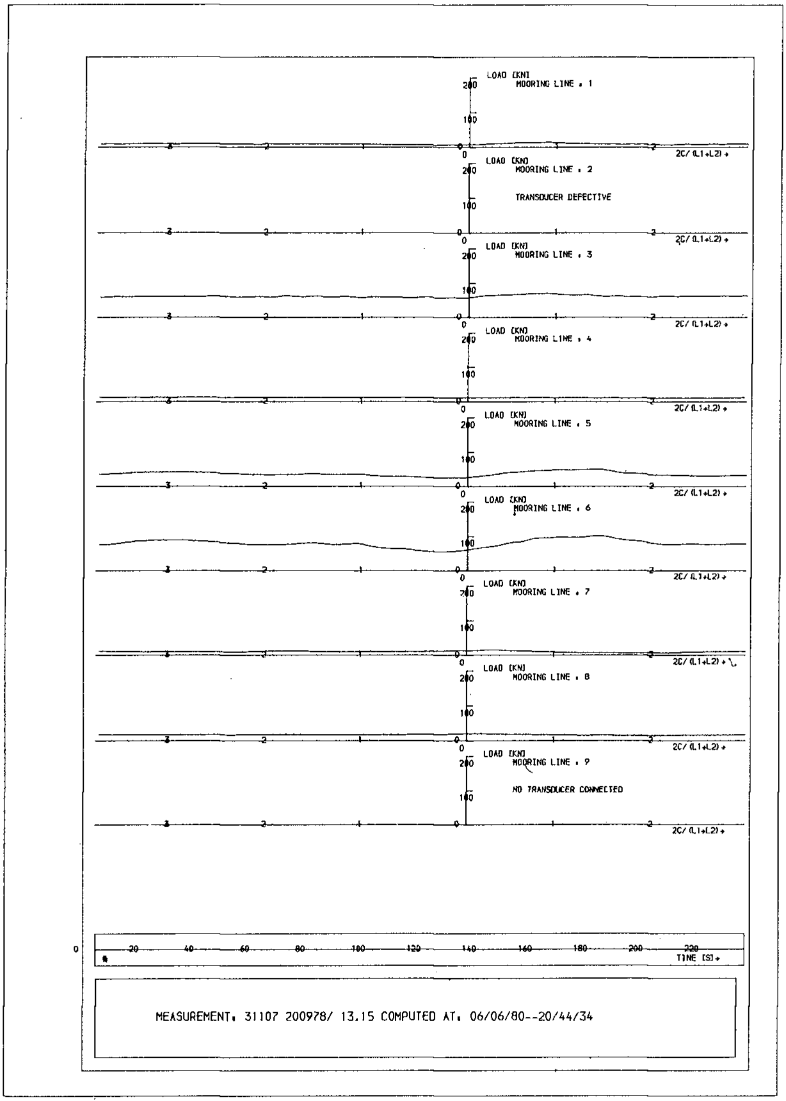


Fig. 5: Mooring forces - measurement No. 31107

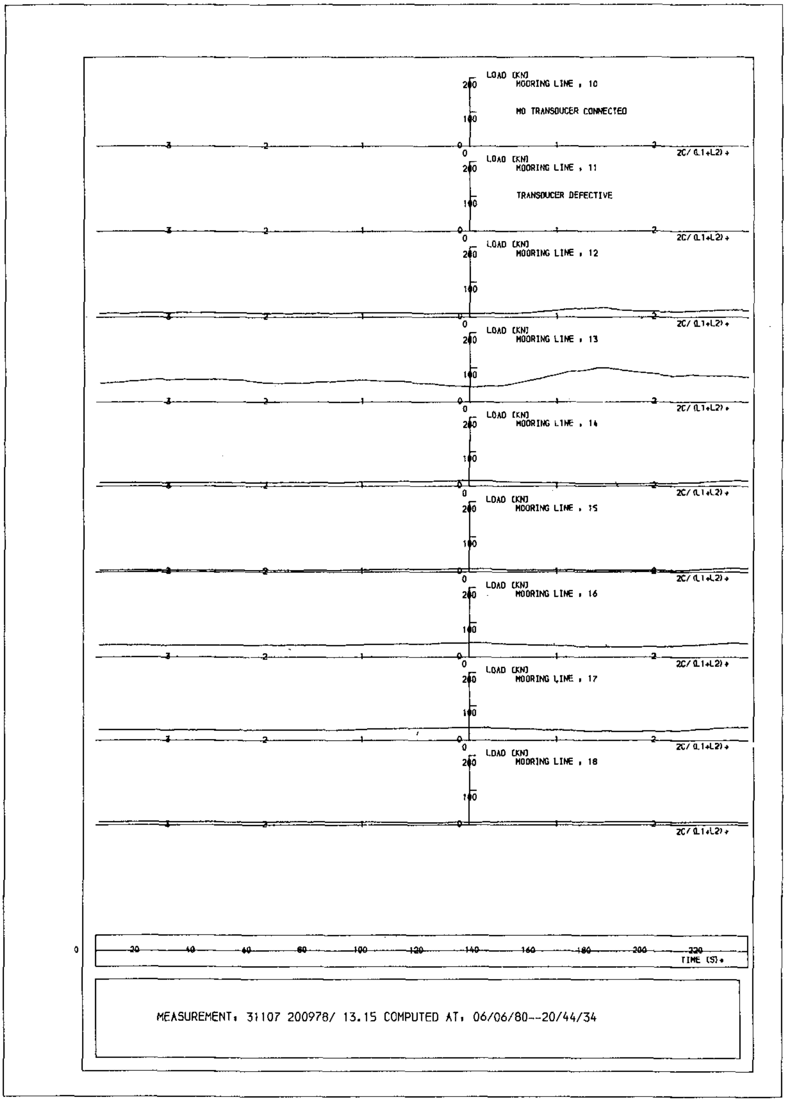


Fig. 6: Mooring forces - measurement No. 31107

For the determination of the forces due to passing ships only the data collection of Wang (1975) was used since these data provided the best approach with regard to the water depth - draught relation. In nearly all cases however it was also necessary here to extrapolate the data, since the given range of passing distances and water depths wasn't sufficient. The computations were performed for the overlapping position in which the force in sway reaches its maximum and the forces in surge and yaw become negligible. The wind and current forces were estimated with the data given by Remery and van Oortmerssen (1973).

The load-deflection curve of the installed tire fendering, a so called "Schweden Typ", which as well as the load-elongation characteristic of the mooring lines served as an input for the computations is shown in Figure 7. An other input of the computations was the initial static state of the mooring systems. This initial static state was estimated for each measuring period by some measurements at slack water and low wind velocities. Figure 8 and 12 give examples of such measurements.

4. RESULTS

As a result of the initial conditions, the fluctuating waterlevel and the varying draught and trim of the ships the pretension of the mooring systems differed widely between the measuring periods (see Figures 8 and 12) and within these periods between the various measurements too. In most cases the pretensions were moderate but in some however (periods 20, 21 and 22) they also reached considerable large values, corresponding to the magnitude of pretension fender friction forces gained importance.

During these measurements the spectrum of the passing ships was essentially determined by ships smaller than the moored ones; in most cases the velocities of the ships were in the upper part of the range characterising navigation in restricted waters. Due to the mostly large passing distances, which were not expected in this magnitude, however in most cases the response of the mooring systems was comparatively small.

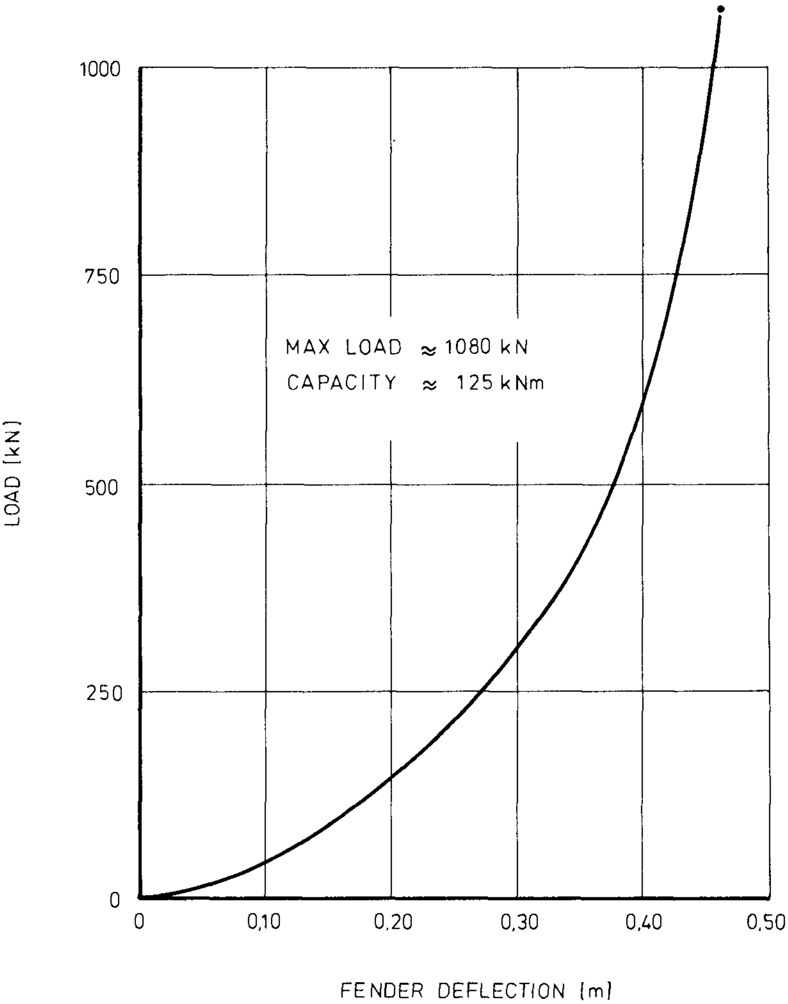


Fig. 7: load-deflection characteristic of the installed tire fendering

In figures 9, 10, 11 and 13 the results of some measurements are compared with computed data. These figures show, representative of all investigations: 1. that the mooring forces due to wind and current action computed with the fore mentioned data agree pretty well with the measured forces and 2. that the computed response due to passing ships determined with the data given by Wang differ widely from the measured forces at which in most cases the computed forces exceed the measured ones. The good agreement between measured and computed forces in those cases in which only wind and current forces appeared is certainly the result of the only small external loads but also shows that the applied static model is quite useful in this special case. The large difference between the measured and computed response in measurements with passing ships however seems in the main to be the result of an inaccurate estimation of those forces which were induced by passing ships. Consequently these investigations with their restrictions by the given range of passing vessels, velocities and passing distances can not verify the used data given by Wang.

Moreover these investigations showed the difficulties involved in handling, measuring and computation of soft mooring systems which like here in most cases are used at more protected sites such as jetties located at navigable waters and harbors.

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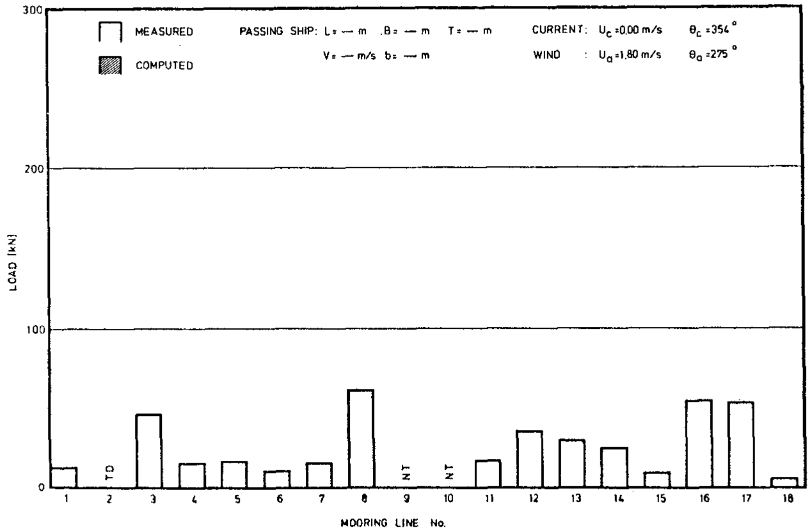

Fig. 8: Initial static state of the system - measurement No. 31116

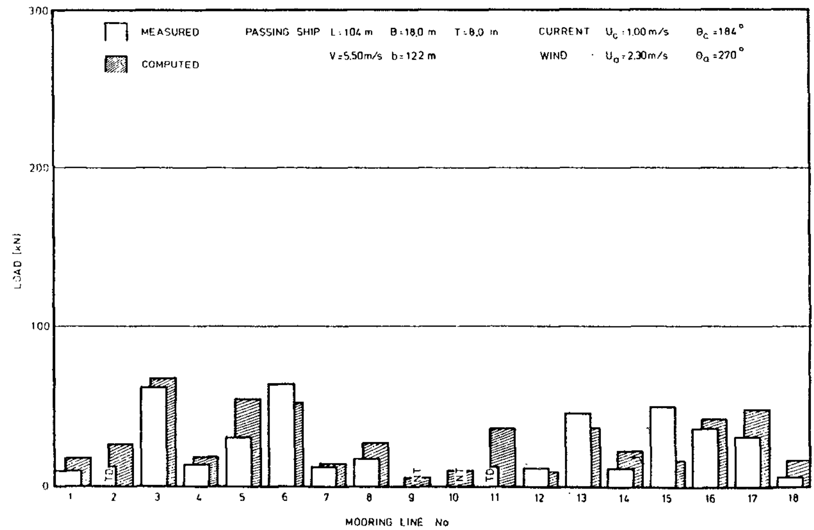

Fig. 9: Measured and computed forces - measurement No. 31106

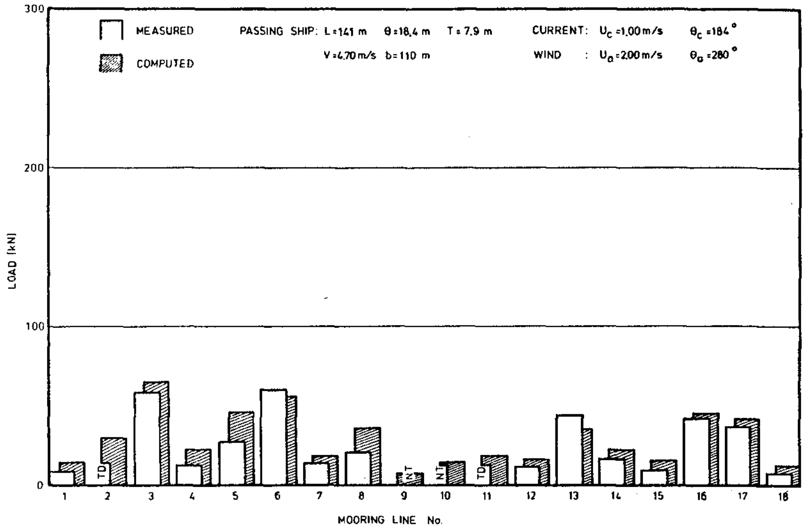

Fig. 10: Measured and computed forces - measurement No. 31107

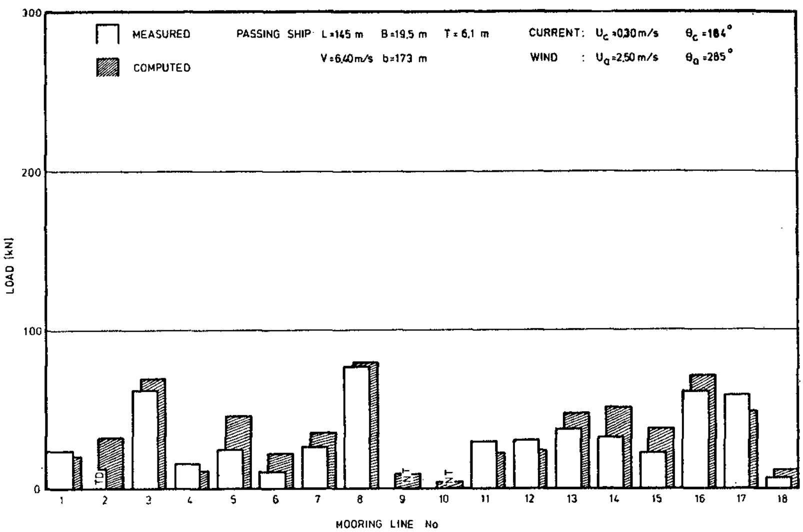

Fig. 11: Measured and computed forces - measurement No. 31115

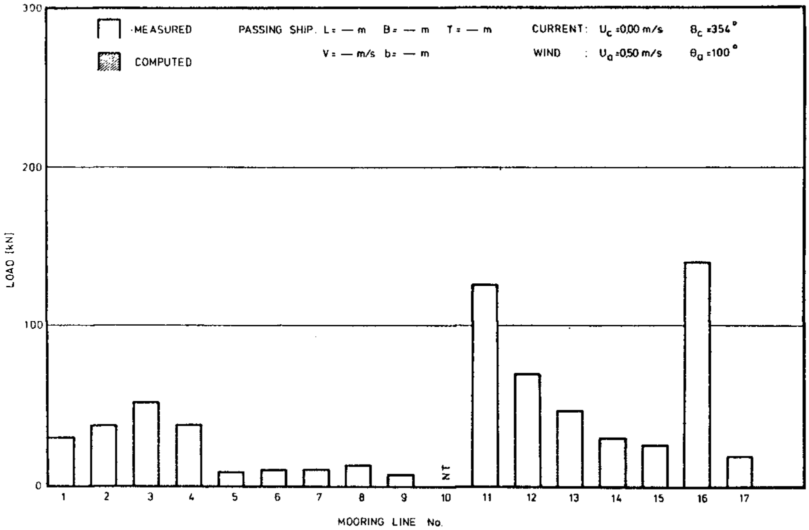

Fig. 12: Initial static state of the system - measurement No. 41206

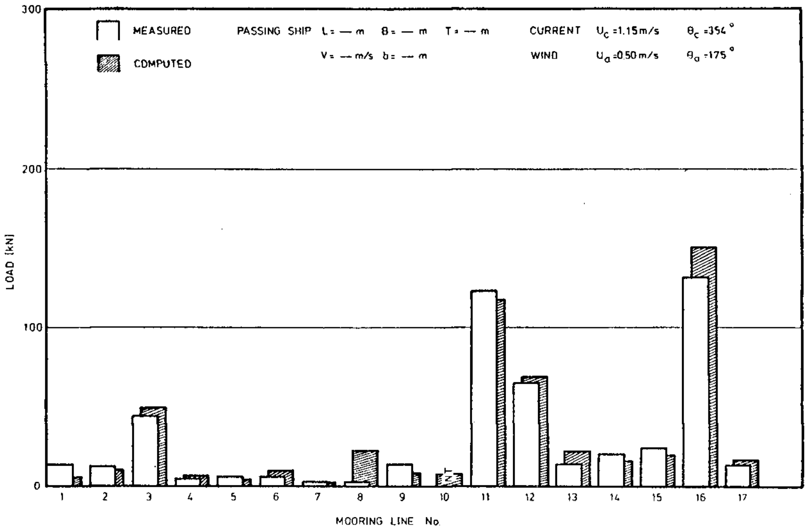

Fig. 13: Measured and computed forces - measurement No. 41209

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ACKNOWLEDGEMENTS

The present investigation was supported by the German Science Foundation. The author wishes to thank the Wasser- und Schiffahrtsamt Bremerhaven and the Asbestos Corporation GmbH, Nordenham for their generous aid during the field measurements.