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Ship Impact in Ferry Berths

Choc de navire dans les bassins de mouillage

Schiffsstoß in Fährbetten

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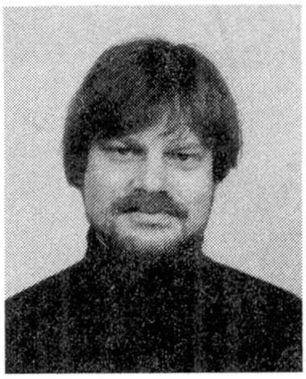


Jesper Larsen, born 1950, holds M. Sc. and Ph. Degrees from the Technical University of Denmark. For six years he has been a consultant in applied mathematical modelling. For DSB he has been involved in the design of ferry berths.

SUMMARY
The paper reports on the computation of reaction forces from ship impact in ferry berths. Actual berthing records and computed results are presented.

RÉSUMÉ
L'article présente le calcul de force de réaction dans les bassins de mouillage par suite de choc de navire. Les forces réelles lors d'accostage et les résultats de calcul sont présentés.

ZUSAMMENFASSUNG
Der Artikel behandelt die Berechnung von Reaktionslasten nach einem Schiffsstoß in Fährbetten. Theoretische und tatsächliche Lasten beim Anlegen werden angegeben.

1. INTRODUCTION

Since the time required for the berthing of a ferry often is a substantial part of the total operational time of the ferry, considerable gains can be obtained by reducing this time as far as possible. For that purpose many ferry berths consist of two lead-in jetties which guide the ferry to its final position in the berth. The lead jetties are constructed of a rigid, movable part which is separated from a fixed quay wall by elastic elements. The fender construction is made of panels linked by loose joints in order to limit the bending moments in the construction and to activate only a rather limited number of elastic elements and accordingly limit the stiffness of the total system and hence the resulting force. To assure sufficient mobility of the system the joints are constructed with play.

In the present paper we analyse the problem of designing these constructions. From the horizontal motion of the ship we estimate the impact energy which is stored in the elastic elements at maximum compression. The ship - structure interaction is sufficiently complex to warrant the development of a computer program for the evaluation of the forces and the deformations involved in the impact. The computer program is based on conservation equations for energy, forces and moments on the structure at maximum compression.

In the next section we analyse ship manoeuvres in ferry berths from simulated data and actual measurements. The impact energy is considered next. In the the last two sections the computer program is described and an example of a computation is presented.

2. FERRY MANOEUVRES

In order to possibly improve the navigation in the danish ferry harbours Nyborg and Korsør a series of manoeuvring simulations has been carried out by the Danish Ship Research Laboratory. The simulations are carried out with a navigation program simulating in real time the combined effect of propeller, rudder, wind and current forces on the ship. The navigator controls the propellers and the rudder. Due to the large surface area of the ferry, which are exposed to the wind, a considerable drift can be observed in storms.

In parallel with the simulations a series of actual measurements of ferry arrivals and departures was conducted. With two optical laser instruments the horizontal angle and the distance to two prisms, attached to the ferry some distance apart, are recorded every two seconds. From the data the ferry position and horizontal velocity components can be tracked throughout the berthing procedure. Two trackings are shown in Fig. 1. In Fig. 1a the ferry enters the berth with a fairly high velocity (5 knots) but is slowed down to 3.3 knots at the time of impact. The ship has no sway and only little yaw motion. In Fig. 1b the ferry enters the berth with a slower speed, but now it has considerable sway and yaw motions. The positions are shown every 10 seconds.

3. IMPACT ENERGY

A definition sketch of the impact situation is shown in Fig. 2. We consider only the horizontal degrees of freedom, i.e. the surge,

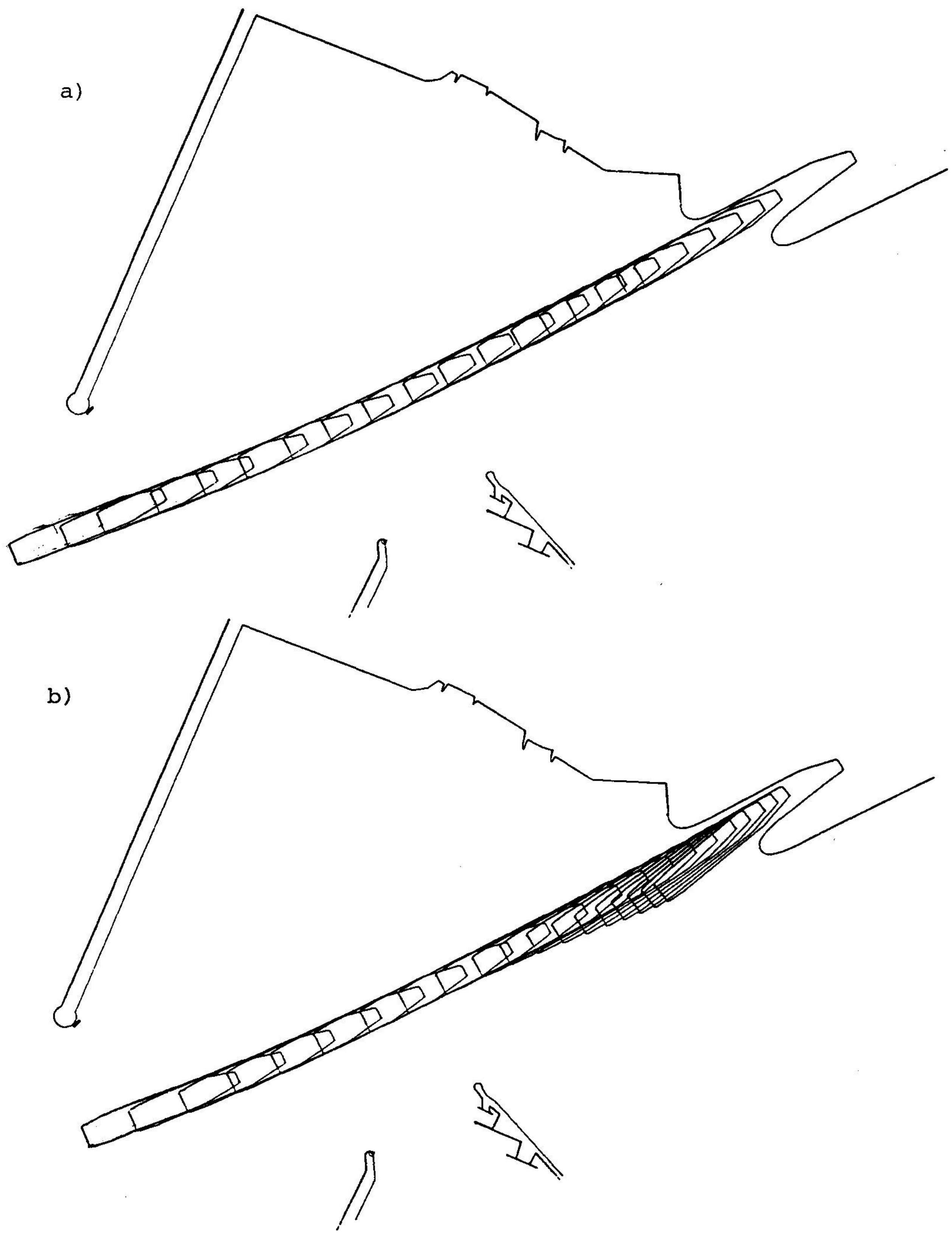


Fig.1 Actual ship manoeuvres in Korsør ferry harbour. 1a) normal berthing. 1b) berthing with considerable sway and yaw motion.

sway and yaw motions and we denote the corresponding velocities u, v and ω, respectively. The distance between the center of gravity and the point of impact is a. We include here a derivation of an expression for the impact energy, since existing formulas [1] and [2] are either too simple or inadequate.

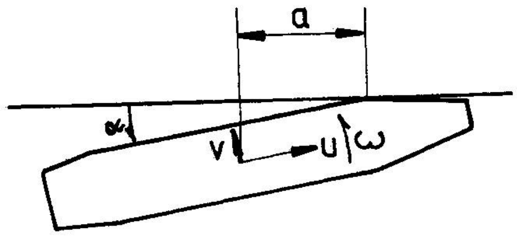


Fig.2 Definition sketch.

The impact energy is estimated as

$$\Delta E = \tfrac{1}{2}M(w^2-w_m^2) + \tfrac{1}{2}I(\omega^2-\omega_m^2). \tag{1}$$

Here

$$w = u\cdot\sin\alpha + v\cdot\cos\alpha \tag{2}$$

is the velocity of the ferry perpendicular to the fender construction at the time of impact. The subscript m refers to the corresponding quantities at maximal compression of the fender construction. The mass M and the moment of inertia I include the induced hydrodynamic inertia. The friction of the fender construction is neglected, hence the contributions from the velocity along the quay cancel. At maximal compression the velocity perpendicular to the fender construction at the point of impact is zero. Thus

$$w_m = -a\cdot\omega_m. \tag{3}$$

From conservation of angular momentum about a vertical axis through the point of impact we find

$$I(\omega-\omega_m) = aM(w_m-w). \tag{4}$$

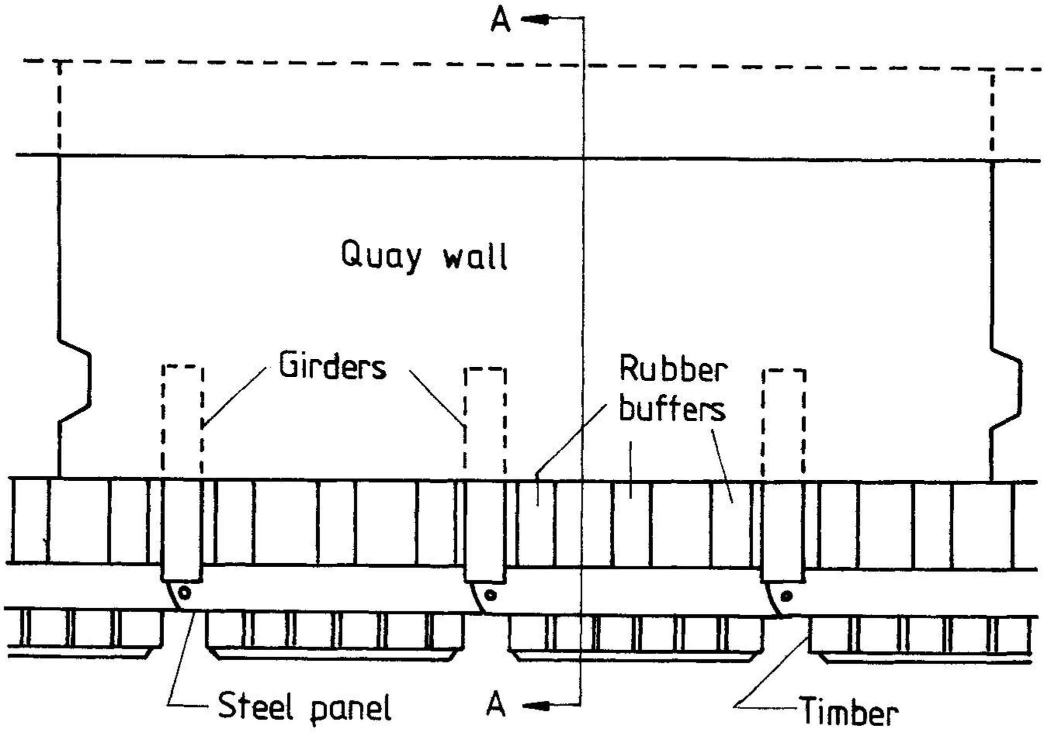
Elimination of ω_m and w_m between (1), (3) and (4) yields

$$\Delta E = \tfrac{1}{2}M(w+a\omega)^2/(1+a^2/k^2), \tag{5}$$

where $k = (I/M)^{\frac{1}{2}}$ is the radius of gyration. The energy estimate in (5) is conservative since friction losses are neglected. A considerable uncertainty in the estimate is the determination of the added mass coefficient (c.f. [3]). The ferry shown in Fig. 1 has a displacement of about 12,000 m^3. With an added mass coefficient of 1.5 and $a \simeq k \simeq 40$m we find $\Delta E = 0.4$ MJ and $\Delta E = 1.3$ MJ for the situations shown in Fig. 1a and 1b, respectively. But considerably higher energies have been recorded.

4. COMPUTATION OF REACTION FORCES

The fender constructions are shown in Fig. 3. Rigid steel panels are separated from the quay wall by elastic rubber cylinders. The panels are connected by loose joints. The play in each joint is 3 cm. Each panel has three degrees of freedom, a translation perpendicular to the quay wall and rotations about a vertical axis and a horizontal axis parallel to the quay wall. When the displacements are given the compression of each cylinder can be found and correspondingly the reaction forces and the energy stored in each



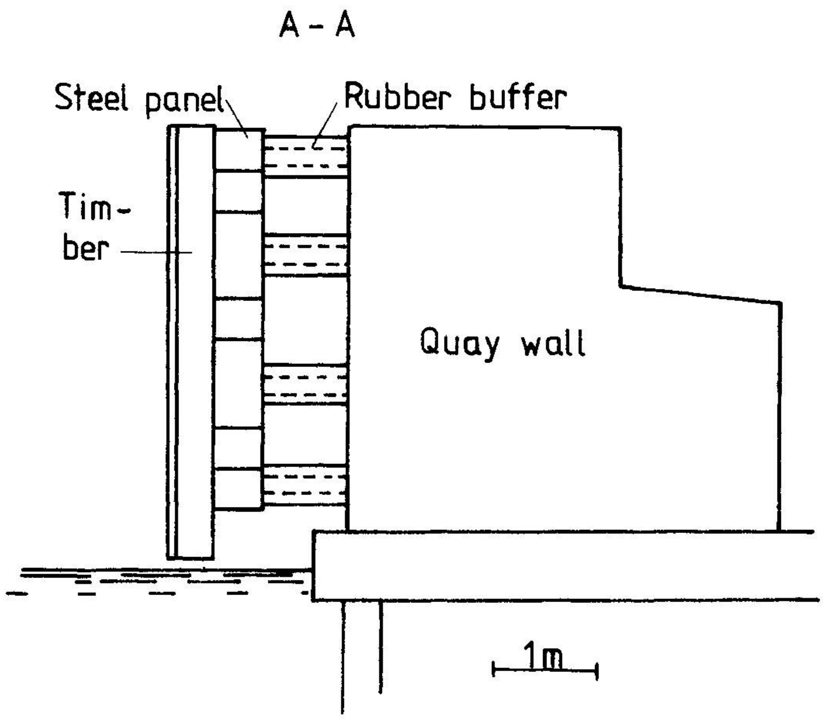
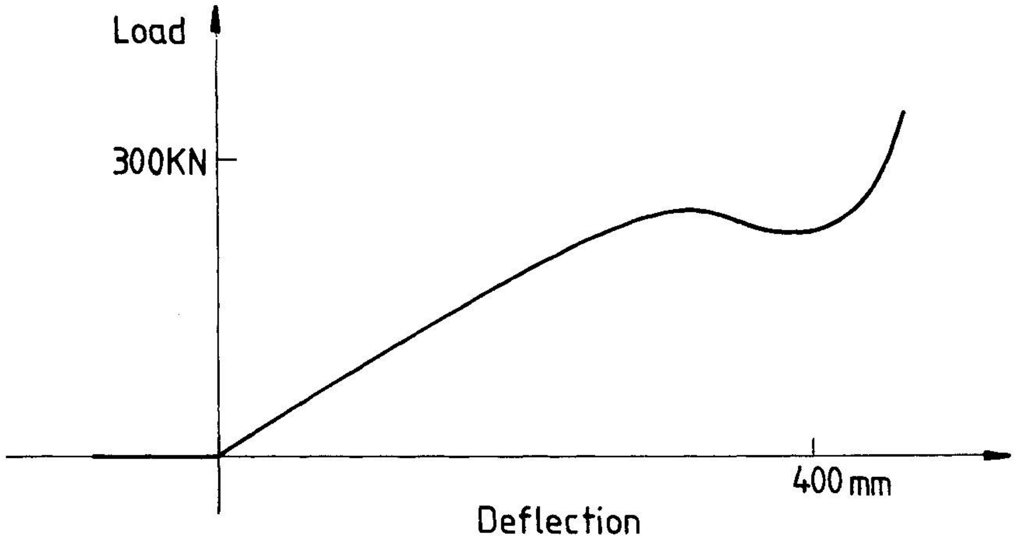


Fig.3 Fender constructions in Korsør ferry harbour.

cylinder can be computed. The panels are suspended in vertical chains and their horizontal motions are limited by horizontal chains. For a section of N panels we have 3N+1 unknowns, viz. the three degrees of freedom per panel and the total impact force. For the determination of these unknowns we have 2(N-1) geometrical constraints at the joints, N moment balance equations about vertical axes through the joints, a moment balance equation about a horizontal axis, a horizontal force balance and an energy balance, in all 3N+1 equations. These non-linear equations are solved by an iterative technique based on a combination of the steepest descent method and Newton's method [4] . In Fig. 4a we have shown a load-deflection curve for the rubber cylinders. This curve is represented by a third-order spline [5] in the program. In Fig 4b we have sketched the force-deformation curve for the horizontal chains which also must be treated as elastic elements, although of very high stiffness, in order to close the system of equations. The energy stored in the rubber cylinders is calculated a)



from the load-deflection curve as

$$E(\delta) = \int_0^{\delta} K(x)dx, \quad (6)$$

where E is the energy stored, δ is the deflection and K is the reaction force as a function of the deflection.

If a certain impact force F is exceeded, the quay wall will slide on the lower part. A special mechanism, which gives a well defined friction force and which allows for an easy re-establishment of the pertinent quay wall section, has been developed. If the quay wall slides a distance s, an additional energy of F•s is absorbed.

b)

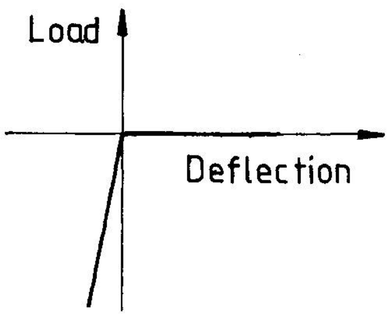


Fig.4 Load-deflection diagrams for rubber cylinders a) and chains b).

5. EXAMPLE

The input to the program comprises the number of panels, the placements of the joints, the specification of the placement and the load-deflection curves of the elastic elements, the point of impact and the energy to be absorbed. The output comprises the total impact force and force in each elastic element. In Fig. 5 the resulting forces on a section of nine panels are shown. The impact energy is 0.9 MJ. Only the results in the three panels closest to the point of impact are shown. We see that although the right hand panel has a smaller displacement than the one in the middle, it is supported by the buffer with the highest reaction force. Thus the nonlinear character of the problem is clearly demonstrated.

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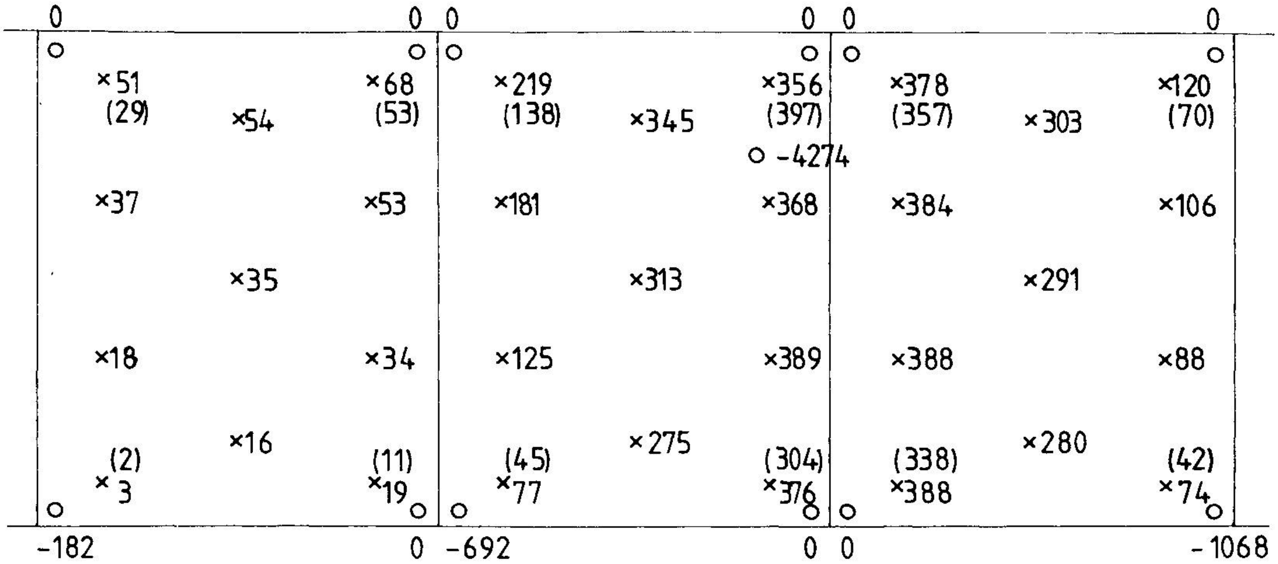

Fig. 5 Resulting forces and deformations of a fender construction shown on a sketch of the construction. Forces are in KN and deformations (shown in parentheses) are in mm. Crosses mark the rubber cylinders and circles mark the chains and the point of impact.

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