Bridge dolphins subjected to impact

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Bridge Dolphins Subjected to Impact

Protection de pont soumis à des chocs

Aufprall gegen Brückenabweiser

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Professor Heins received his BSCE from Drexel University, M.S. from Lehigh University, and PH.D. from the University of Maryland. He has been a Visiting Professor to Japan, the People's Republic of China, Syria, Saudi Arabia, Turkey and Korea. Professor Heins has done research on bridge structures and pier protection, and has written a book on the subject. Professor Heins was killed on December 24, 1982, in an airplane accident in China.

This paper was submitted by Professor Heins in October 1982, following a special invitation from members of the Scientific Committee to contribute to this colloquium. When the news of his untimely death reached us during the editorial process, the University of Maryland and his family agreed to our proposal to publish his paper in the Preliminary Report as a posthumous contribution.

SUMMARY
The dynamic response of a circular mooring dolphin is predicted considering soil-structure interaction. A study of the response has resulted in a series of simplified design equations for direct application.

RÉSUMÉ
La réaction dynamique d'une protection circulaire est fonction de l'interaction sol- structure. L'étude aboutit à une série d'équations simplifiées permettant des applications directes.

ZUSAMMENFASSUNG
Die dynamische Reaktion eines runden Anlegeabweisers wird unter Berücksichtigung der Wechselwirkung zwischen Boden und Bauteil vorhergesagt. Eine Untersuchung der Reaktion hat zu einer Reihe vereinfachter Konstruktionsgleichungen zur direkte Anwendung geführt.

1. THEORY

1.1 GENERAL

The dynamic response of a dolphin, supported by a soil medium, requires consideration of the following conditions:

(1) Structure - Soil Interaction

(2) Structure - Fender (shock absorber) Interaction

(3) Failure Criteria

(4) Energy Requirements

All of these conditions were considered in developing the computer mode. The solution of such a system results in the evalution of the dynamic forces applied to the dolphin at any time interval. This force is then applied to the actual dolphin model, which is represented as a cantilever beam on an elastic foundation. The analysis of this beam gives the resulting deformations, shears, moments, and stresses in the dolphin.

1.2 MODEL

The dynamic response of a single degree of freedom (SDOF) system or linear spring system can readily be determined (3). The maximum effects imposed on this spring mass system, when subjected to an initial velocity v , is:

$$a_{max} = -v_0 \lambda \qquad (1)$$

$$y_{man} = v_0 / \lambda \qquad (2)$$

$$\rho_{max} = v_0 \{km\}^{\frac{1}{2}} \qquad (3)$$

where:

a = acceleration
y = displacement
ρ = force
m = mass
k = spring constant
$\lambda = \{k/m\}^{\frac{1}{2}}$

In evaluating the dolphin-vessel impact response, it will be assumed that the SDOF system can simulate such interaction. The spring mass (m) will represent the ship weight, and the spring constant (k), will represent the dolphin stiffness. The initial velocity (v_0) of the spring mass respresents the impact velocity of the ship, which has a mass (m). The spring constant (k) represents the stiffness of the dolphin-soil system.

In order however to determine the initial acceleration and deformation of such a system, a preditor-corrector scheme is utilized (1). Utilization of such a method permits rapid determination of the initial deformations and accelerations during initial impact.

The spring constant is determined by applying a unit load to the dolphin-soil system, which gives:

$$k = 1/\Delta$$

This constant is then used to determine λ, and then the resulting acceleration, displacement and force can be determined. The process is then repeated for subsequent time intervals.

Finally the end force ρ max is applied to the end of the elastically supported dolphin. Resulting internal moments and shears are then determined.

The entire scheme has been computerized, in order to expedite the analysis. This computer program was then used to determine the general response of various dolphins. The parameters of these dolphins will now be described.

2. PARAMETRIC STUDY

2.1 TYPE OF DOLPHIN

The type of dolphin to be considered in this study consists of a single steel cell, filled with gravel and earth, as shown in Figure 1. The range in parameters that were considered are as follows:

2.2 PARAMETERS

Single Cell Dolphin

D - Diameter (m); 6.1, 9.1, 12.2, 15.2
t - Thickness (cm); 2.54, 5.08
+M.L. - Length of dolphin above mud line (m); 6.1, 12.2, 18.3
-M.L. - Length of dolphin below mud line (m); 6.1, 12.2, 18.3
R = (-M.L.)/(+M.L.); 1.0, 1.5, 2.0
k_s = Soil Modulus (N/cm^3); 27.1, 54.3, 135.7. 271.5

The soil modulus (k_s) has been selected (4) such that the soil type represents soft clay (k_s = 27.1 N/cm^3) to dense sandy gravel (k_s = 271.5 N/cm^3), as given in Table 1.

The ship parameters consisted of velocity v_0 and weight (w). The velocity was held constant at 1.0 knots. The ship weight (tons) was then increased accordingly until failure was instituted in the system, in order to find the maximum strength of the system.

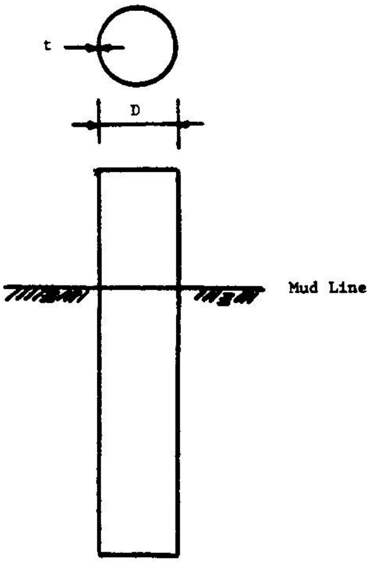

Fig. 1 Single steel cell dolphin

Soil	k_s
Sense sandy gravel	219.9 - 393.6
Medium dense coarse sand	157.5 - 314.9
Medium sand	111.3 - 282.3
Fine or silty, fine sand	78.7 - 187.3
Stiff clay (wet)	54.3 - 219.9
Stiff clay (saturated)	27.1 - 111.3
Medium clay (wet)	38.0 - 141.2
Medium clay (saturated)	10.9 - 81.4
Soft clay	1.6 - 38.0

Table 1 Soil modulus k_s (N/cm^3)

2.3 RESULTS

Typical results for the dolphin response are given in Figures 2 through 7. These results are all for a constant ship velocity of $v_0 = 1$ knot. Figures 2 and 3 show the resulting dolphin spring constant k_d as a function of dolphin parameters. These figures are useful in design, as they indicate the magnitude of k_d, which is required in the simplified design approach.

Figures 4 through 7 show the relationships between the ship weight (tons) and the soil modulus k_s. The parameter k_f represents the stiffness of a fender or shock absorber which may be attached to the dolphin. The unsafe region of these curves indicates that soil failure will occur. These failure curves are valid for all the cell parameters given previously.

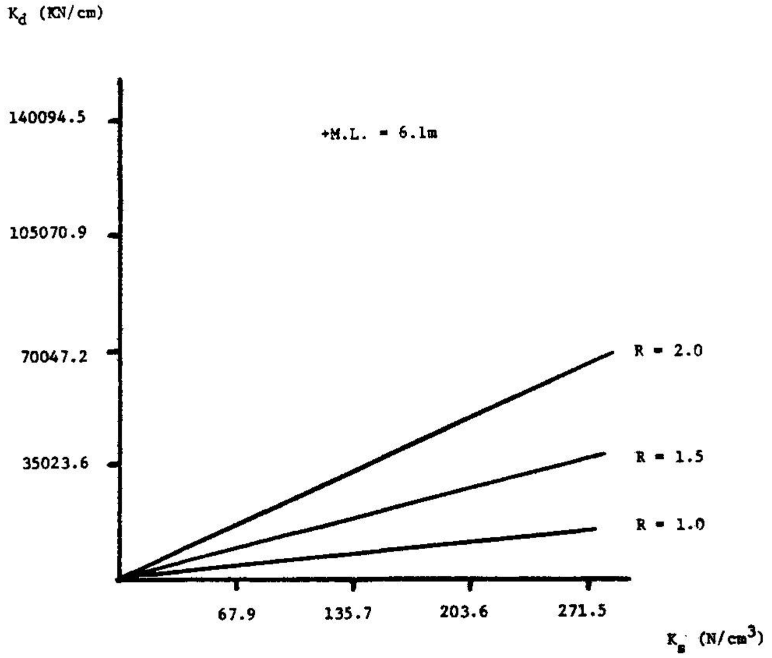

Fig. 2

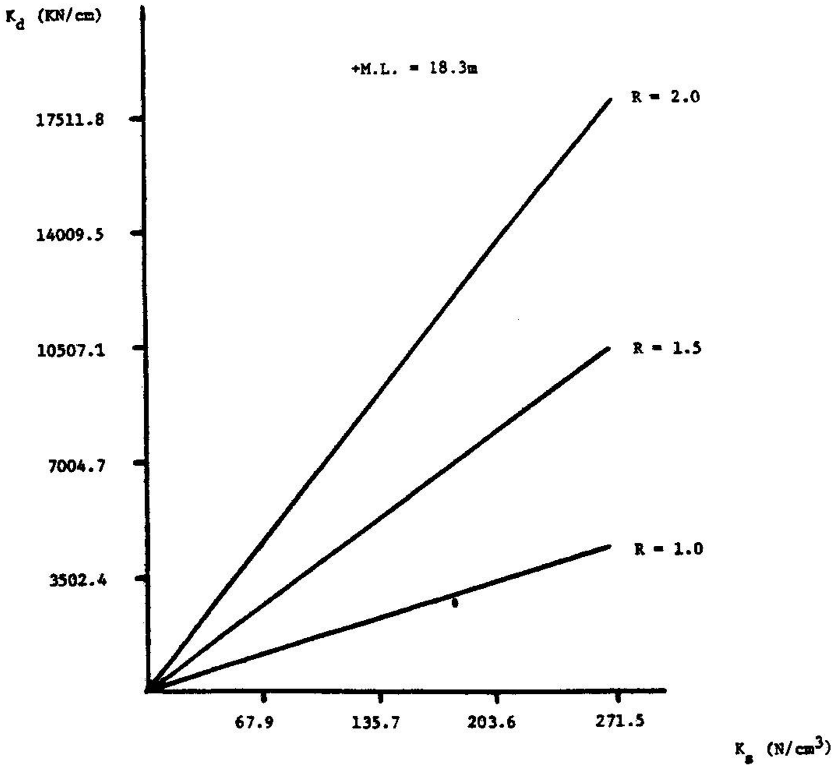

Fig. 3

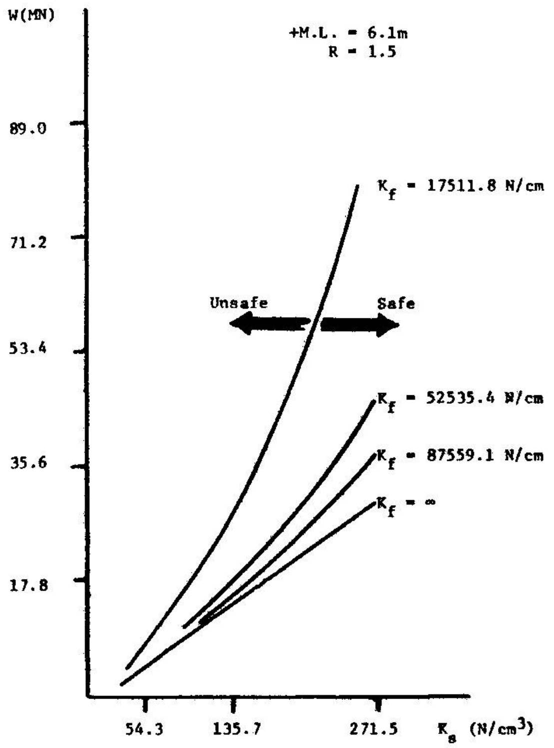

Fig. 4

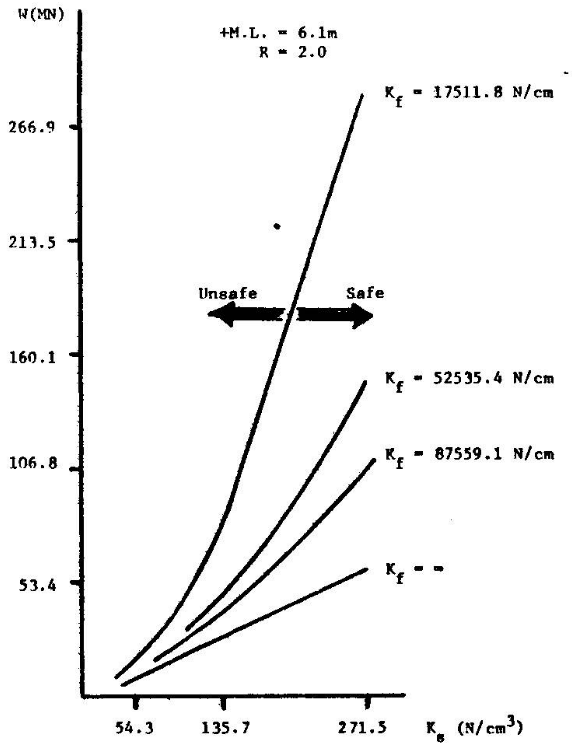

Fig. 5

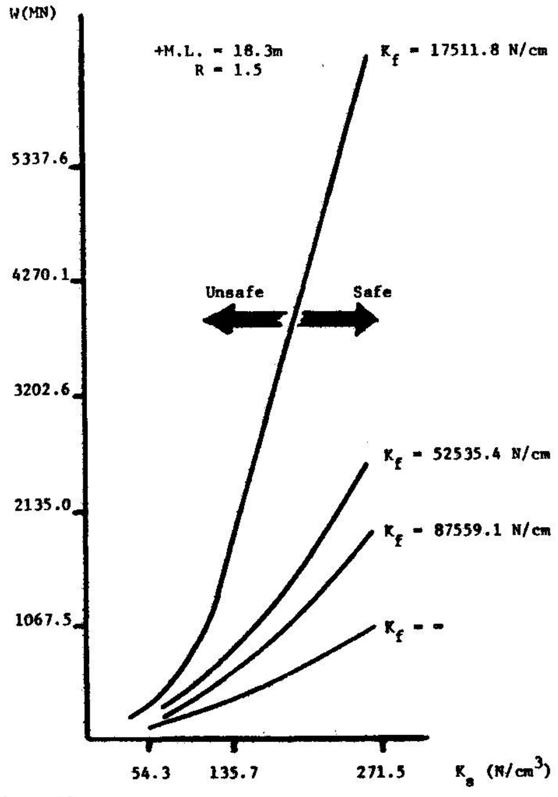

Fig. 6

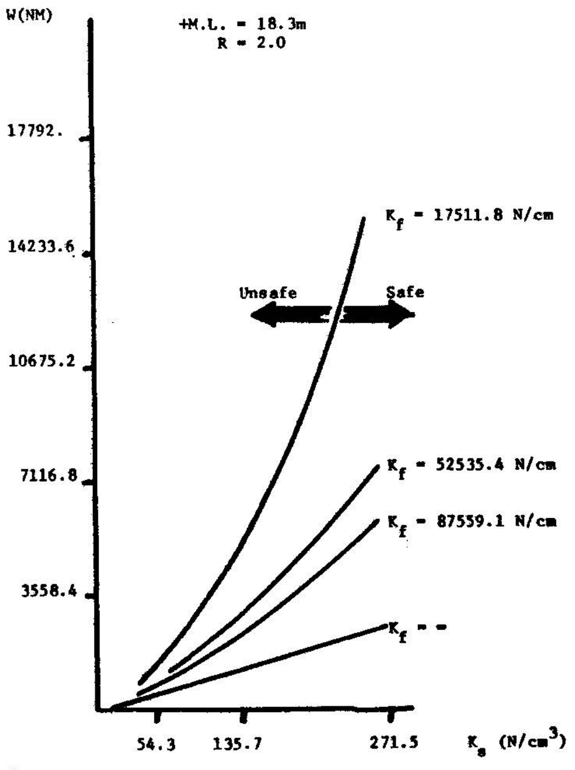

Fig. 7

3. DESIGN CRITERIA

The maximum load or ship weight that can be applied to the dolphin is governed by the strength of the soil or strength of the cell. The soil will fail when the strain of the soil reaches a maximum. The cell will fail either due to development of a maximum bending or shear stress or a combination. Examination of the failure mode of either the cell dolphins or clusters, indicates that the bending mode will not govern and therefore only soil or cell shear failure will be examined (1).

3.1 CELL DOLPHIN

As given previously by Eqn. (3); $\rho = v_0 (km)^{\frac{1}{2}}$, however the maximum shear V developed in the cell is equal to ρ therefore;

$$V = v_0 (km)^{\frac{1}{2}} \qquad (5)$$

however the shear stress is governed by

$$\tau = VQ/It \qquad (6)$$

where:

$I = D^3t$, $Q = D^2t$. Therefore,

$$\tau = V/Dt \qquad (7)$$

and substituting in Equation (5) gives;

$$\tau = C \frac{v_0 (km)^{\frac{1}{2}}}{Dt} \qquad (8)$$

where C is a constant, which was determined from the computer analysis. Examination of these analyses has resulted in a value of C = 0.732. Therefore, the final design equation for the cellular dolphin is;

$$\tau = 0.732\ v_0 \frac{(km)^{\frac{1}{2}}}{Dt} \qquad (9)$$

if soil failure does not govern.

4. CONCLUSIONS

Using a computer oriented model, the dynamic response of a series of cellular dolphins have been examined. These results have permitted the development of a series of design equations and charts, which will permit rapid design/analysis of such dolphins when subjected to vessel impact. A complete set of design curves are available in Ref (1).

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NOTATIONS

A	Cross Sectional Area of Dolphin
D	Diameter of Dolphins
I	Moment of Inertia
k	Spring Constant
k_d	Dolphin Stiffness
k_f	Fender Stiffness
k_s	Subgrade Modulus of Soil
R	-M.L./+M.L.
V	Shear
w	Vessel Weight
+M.L.	Pile Length above Mud Line
-M.L.	Pile Length below Mud Line
a	Acceleration
M	Mass
t	Thickness of Cell
v_0	Initial Velocity of Vessel
y	Displacement
λ	Natural Frequency
τ	Shear Stress