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THESIS

OSCILLATING FLOW ABOUT PERFORATED CYLINDERS

by

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September 2000

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OSCILLATING FLOW ABOUT PERFORATED CYLINDERS

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ABSTRACT

Circular cylinders of various sizes and perforations were subjected to sinusoidally-oscillating flow in a large U-shaped water tunnel. The force-transfer coefficients (drag and inertia) were determined in the range of Keulegan-Carpenter numbers (K) from about 1 to 40. The results have shown that the effect of the perforations is to decrease the inertia coefficient and to increase the drag coefficient. Thus, perforated cylinders are very efficient dampers and could be used in increasing the damping of cables and large structures in the ocean environment.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS

Cd	drag coefficient
Cm	inertia coefficient
D	diameter of the test cylinder
D_h	diameter of holes
F	force
K	Keulegan-Carpenter number, $= UmT/D$
Re	Reynolds number, $= UmD/\nu$
t	time (sec)
T	Period of flow oscillation
U	Velocity of oscillating flow
Um	Maximum velocity in a cycle
β	Porosity, = open area/total area
ν	kinematic viscosity of water
ρ	density of water

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I would like to thank my wife for the long hours of absence she endured while I was working on this project. Her constant support, encouragement, and patience always inspired me. I would also like to thank my family whose blessings have always been with me.

I. INTRODUCTION

The unsteady motion is of great interest in the solution of many applied technical problems in fluid mechanics, such as the motion of bodies through fluids, fluid motion in or about bodies, free surface flow phenomena, and the motion of fluids inside machinery. The complexities of unsteady non-equilibrium turbulence with or without separation under a variety of time-dependent flow conditions (periodic flows, transverse or bidirectional dynamic response of bodies) are far from understood.

There are an infinite number of time-dependent flows, and one can describe only a few that are caused by some well-defined time-dependence of the ambient flow and/or the fluid/structure interaction (e.g., change of freestream velocity; large-amplitude, time-dependent oscillations of the mean flow; the impulsive start from rest; change of angle of attack; motion of helicopter blades, and the dynamic response of a cable).

The theory of sinusoidally oscillating flow about bodies or the sinusoidal oscillation of a body in a viscous fluid otherwise at rest has long been of special interest to fluid dynamists. In steady flow, the position of the separation points is nearly stationary, except for small excursions about ±3 degrees (on a circular cylinder). Furthermore, the interference between the vortices and the body is confined mostly to the aft-body region. There is no obvious relation between the measured lift and drag coefficients and the excursion of the separation points. For example, while the separation angle remains nearly constant at about 80 degrees in the range of Reynolds numbers Re from about 2000 to 20,000, the drag coefficient increases from about 0.8 to, 1.2 and the mean peak value of the lift coefficient varies anywhere from zero to 0.6 (see e.g., Sarpkaya and Isaacson 1981).

Numerical Simulation) and LES (Large Eddy Simulation) techniques are not likely to provide anything more than occasional samples for comparison with experiments at relatively low Reynolds numbers, at great expense even for two-dimensional flows. The most reliable recourse, at least at present, seems to be carefully conducted laboratory experiments. In this effort, flow visualization can serve as an excellent tool, not merely as an aid to understanding the physics of the flow but also as a means to acquire data and to guide the numerical calculations.

The experimental studies of Morison *et al* (1950) on forces on piles due to the action of progressive waves have provided a useful and somewhat heuristic approximation. The forces are divided into two parts, one due to the drag, as in the case of flow at constant velocity, and the other due to acceleration or deceleration of the fluid. This concept necessitates the introduction of a drag coefficient C_d and inertia coefficient C_m in the expression for the in-line force (Keulegan & Carpenter, 1958). Morison's equation does not deal with the transverse force or lift force. If F is the force per unit length experienced by a cylinder, then one has

$$F = \frac{1}{2}\rho C_d D|U|U + \rho C_m \frac{\pi D^2}{4}\frac{dU}{dt} \quad (1)$$

where U and dU/dt represent the undisturbed velocity and the acceleration of the fluid, respectively. A detailed discussion of this equation is given by

Sarpkaya and Isaacson (1981) and will not be repeated here. Suffice it to note that the most comprehensive data on smooth and sand-roughened circular rigid cylinders are given by Sarpkaya (1977, 1986).

An extensive literature search has shown that there are no studies of oscillating flow about perforated cylinders in spite of the fact that they are used in various industrial applications, though mostly for filtering purposes. In the course of search for realistic solutions to the flow-induced oscillations of cables and bodies immersed in the ocean environment it became clear that perforated cylinders can be ideally suited for the damping of undesirable oscillations. Thus, an extensive investigation has been undertaken through the use of a number of carefully selected perforated pipes immersed in a large U-shaped oscillating flow tunnel.

II. PRESENTATION AND DISCUSSION OF RESULTS

Each perforated cylinder was subjected to a sinusoidally oscillating flow in a large U-shaped water tunnel (10 m wide and 7.5 m high). The tunnel and the force-acquisition system have been designed and constructed in 1974 and described a number of times since then (see, e.g., Sarpkaya 1977). These will not be repeated here.

The perforated cylinders were constructed of perforated metal sheets in such a manner that they have retained their perfectly circular shape throughout the measurements. We will refer to them here by their numbers. Perforated cylinder No. 1 had a diameter of 127-mm, a hole size of 0.406 m m and a porosity of 30%. Perforated cylinder No. 2 had a diameter of 127 mm, a hole size of 0.83 mm and a porosity of 28%. Perforated cylinder No. 3 had a diameter of 152 mm, a hole size of 0.50 mm and a porosity of 30%. Perforated cylinder No. 4 had a diameter of 127 mm, a hole size of 1.60 mm and a porosity of 30%. Perforated cylinder No. 5 had a diameter of 127 mm, a hole size of 1.59 mm and a porosity of 23%. Finally, Perforated cylinder No. 6 had a diameter of 127 mm, a hole size of 2.50 mm and a porosity of 51%.

Figures 1 through 6 show the drag and inertia coefficients for the above-perforated cylinders. It evident from a careful perusal of these figures that the magnitudes of the two force-transfer coefficients are dictated primarily by the porosity. Screen No. 1 through No. 5 yield essentially similar drag and inertia coefficients because of the fact that they have nearly identical porosities. On the other hand, the cylinder number No. 6 yields considerably smaller drag and inertia coefficients. This is in conformity with the expectations that the larger the porosity, the larger the flow through the cylinder. Consequently, not only the normal pressures on the cylinder but also the flow about the cylinder are reduced. The consequence of this reduction is that the region of separation and vortex shedding is considerably decreased relative to perforated cylinders of smaller porosity. However, the most remarkable feature of the results is the variation of the inertia coefficients. It is a well-established fact (Sarpkaya 1977, 1986) that the inertia coefficient for K smaller than about 4 is nearly constant at a value slightly larger than 2. In the case of perforated cylinders, the inertia coefficient in the said region is always smaller than 2. For the cylinder No. 6, the inertia coefficient is indeed very small.

Figure 7 shows the drag and inertia coefficients for a non-porous (solid) cylinder of 127-mm diameter. It is clear from a comparison of Figs. 1 through 6 with Fig. 7 that the drag coefficients of porous cylinders are about an order of magnitude larger than those of solid cylinders. This is a consequence of the dissipation of large amounts of energy in the vortices generated on both sides of the perforations. It is this remarkable feature of the porosity that makes perforated cylinders ideally suited for damping of cables and structures undergoing hydro-elastic oscillations.

The investigation is currently underway with cylinders oscillating in a fluid otherwise at rest and the results will be reported at a later date.

III. CONCLUSIONS

Circular cylinders of various sizes and perforations were subjected to sinusoidally oscillating flow in a large U-shaped water tunnel. The force-transfer coefficients (drag and inertia) were determined in the range of Keulegan-Carpenter numbers (K) from about 1 to 40. The results have shown that the effect of the perforations is to decrease the inertia coefficient and to increase the drag coefficient. Thus, perforated cylinders are indeed very efficient dampers and could be used in increasing the damping of cables and large floating structures in the ocean environment, thereby reducing considerably the vortex-induced oscillations and hydroacoustic noise.

APPENDIX: FIGURES

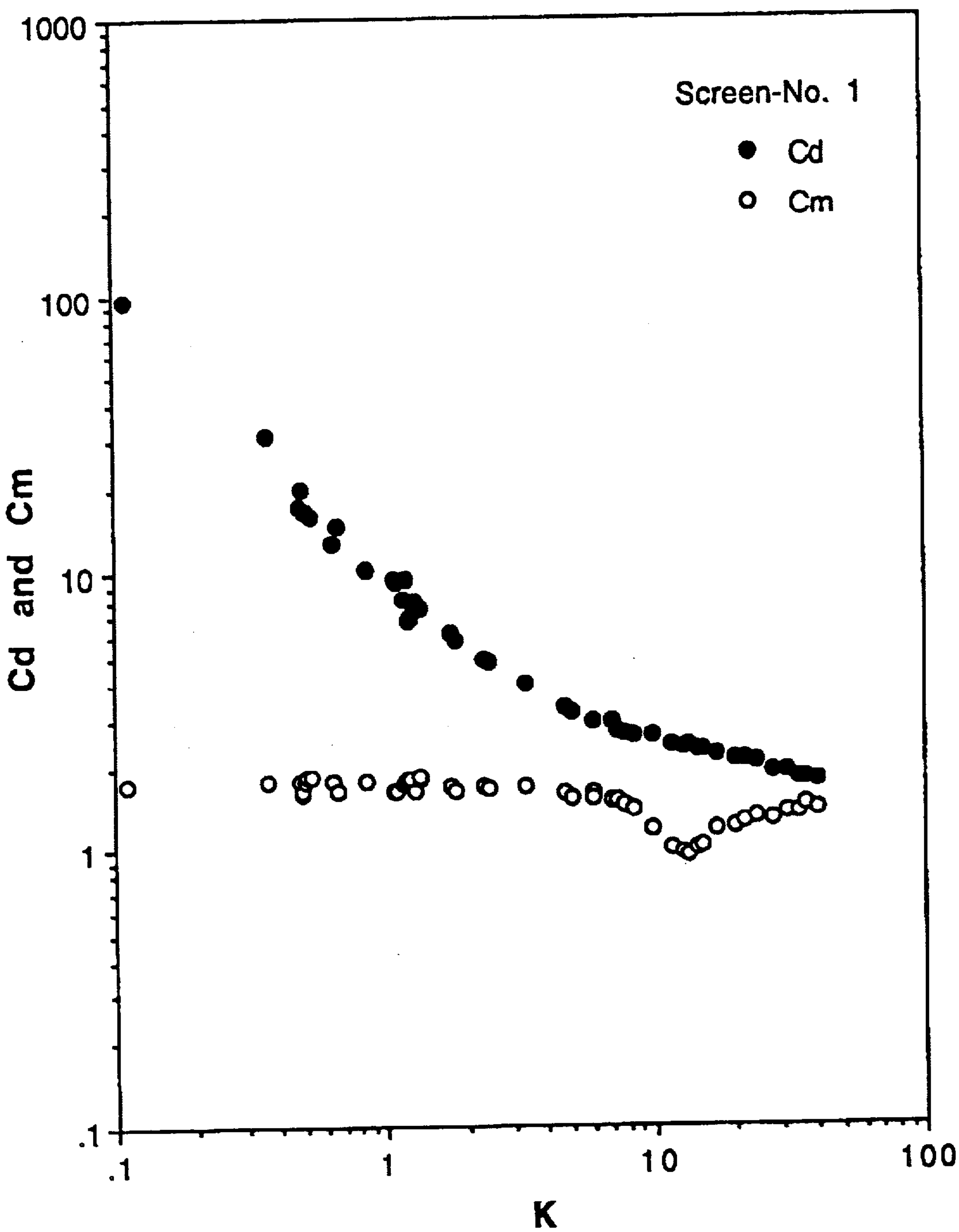

Figure 1. Cd and Cm versus K for screen No. 1.

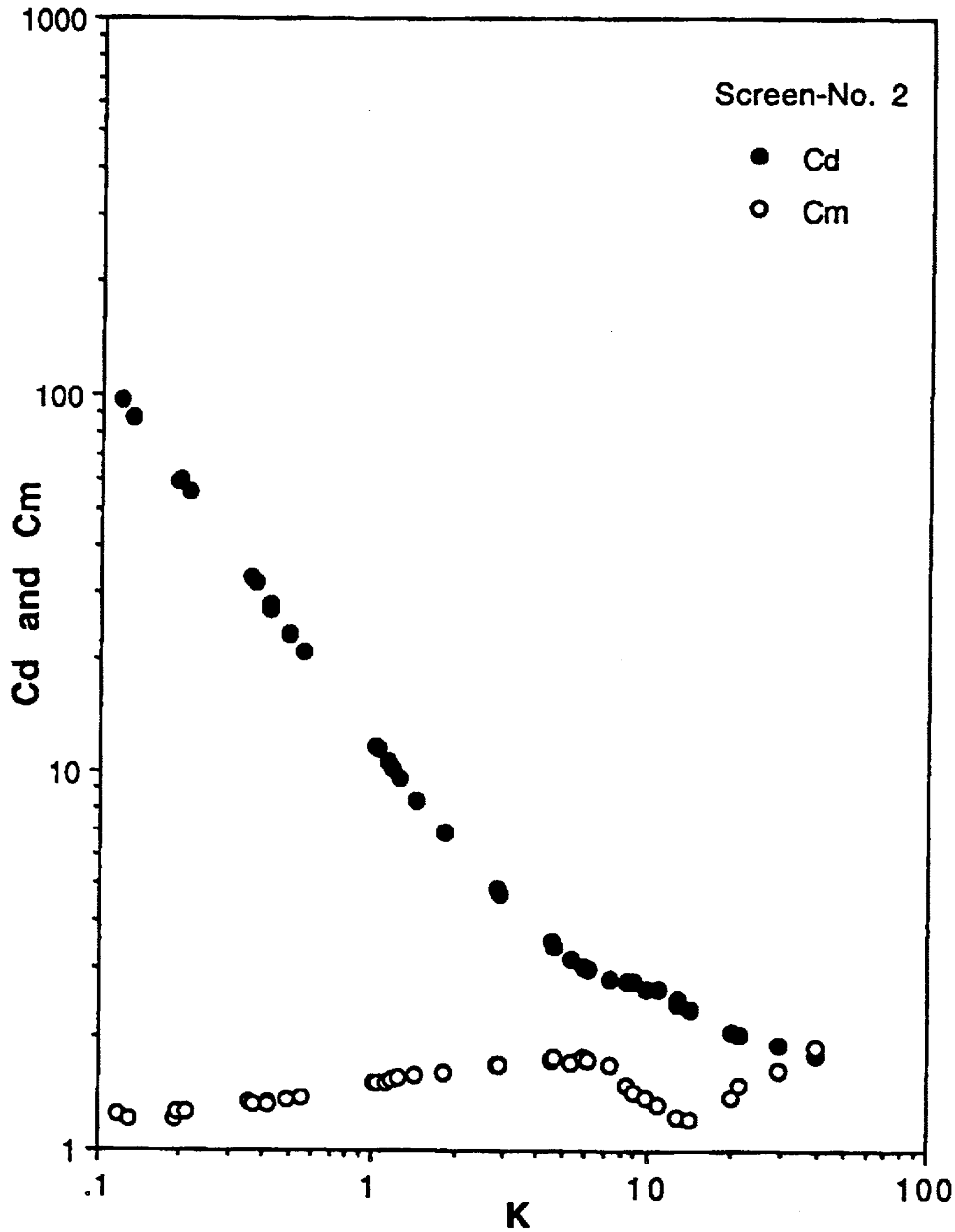

Figure 2. Cd and Cm versus K for screen No. 2.

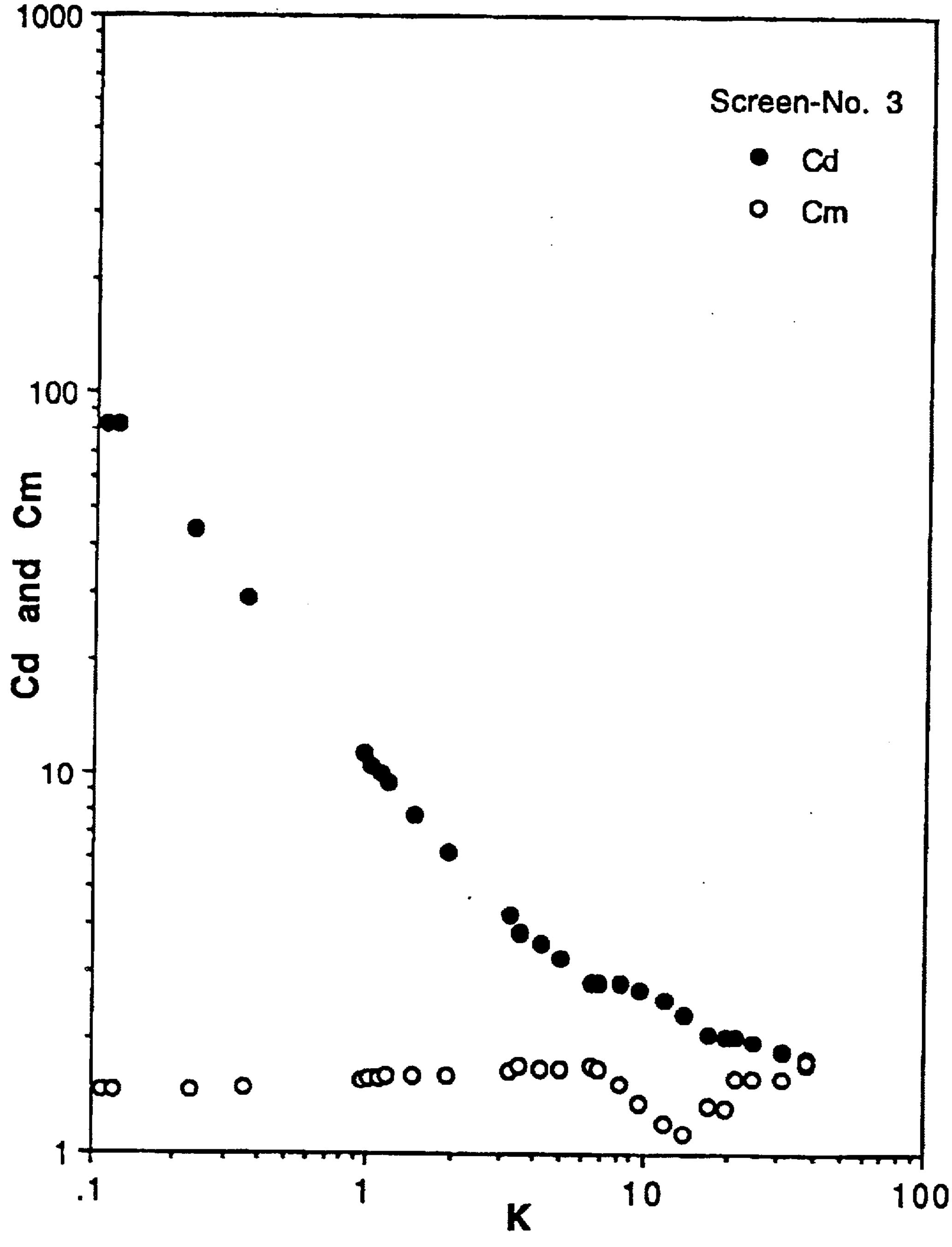

Figure 3. Cd and Cm versus K for screen No. 3.

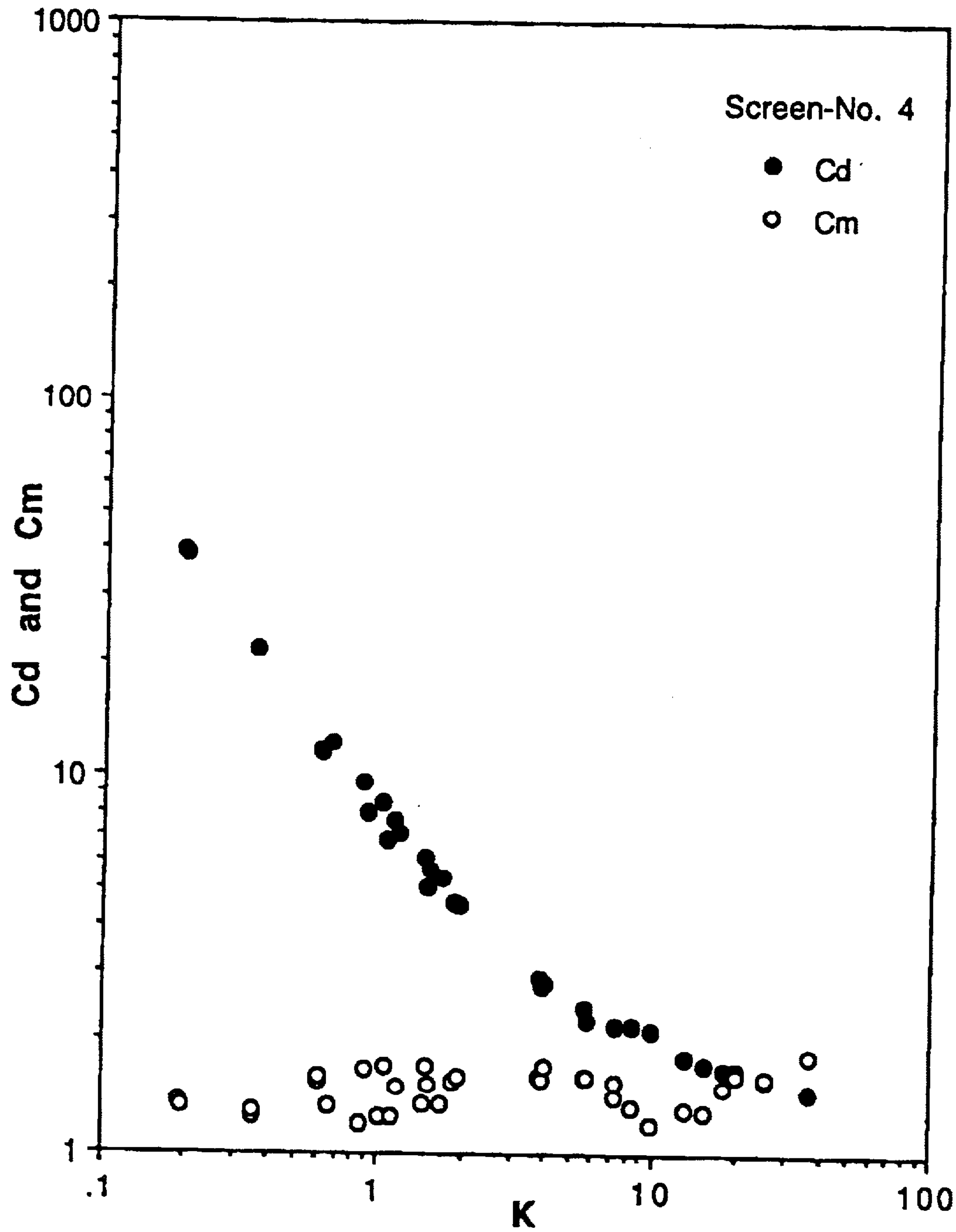

Figure 4. Cd and Cm versus K for screen No. 4.

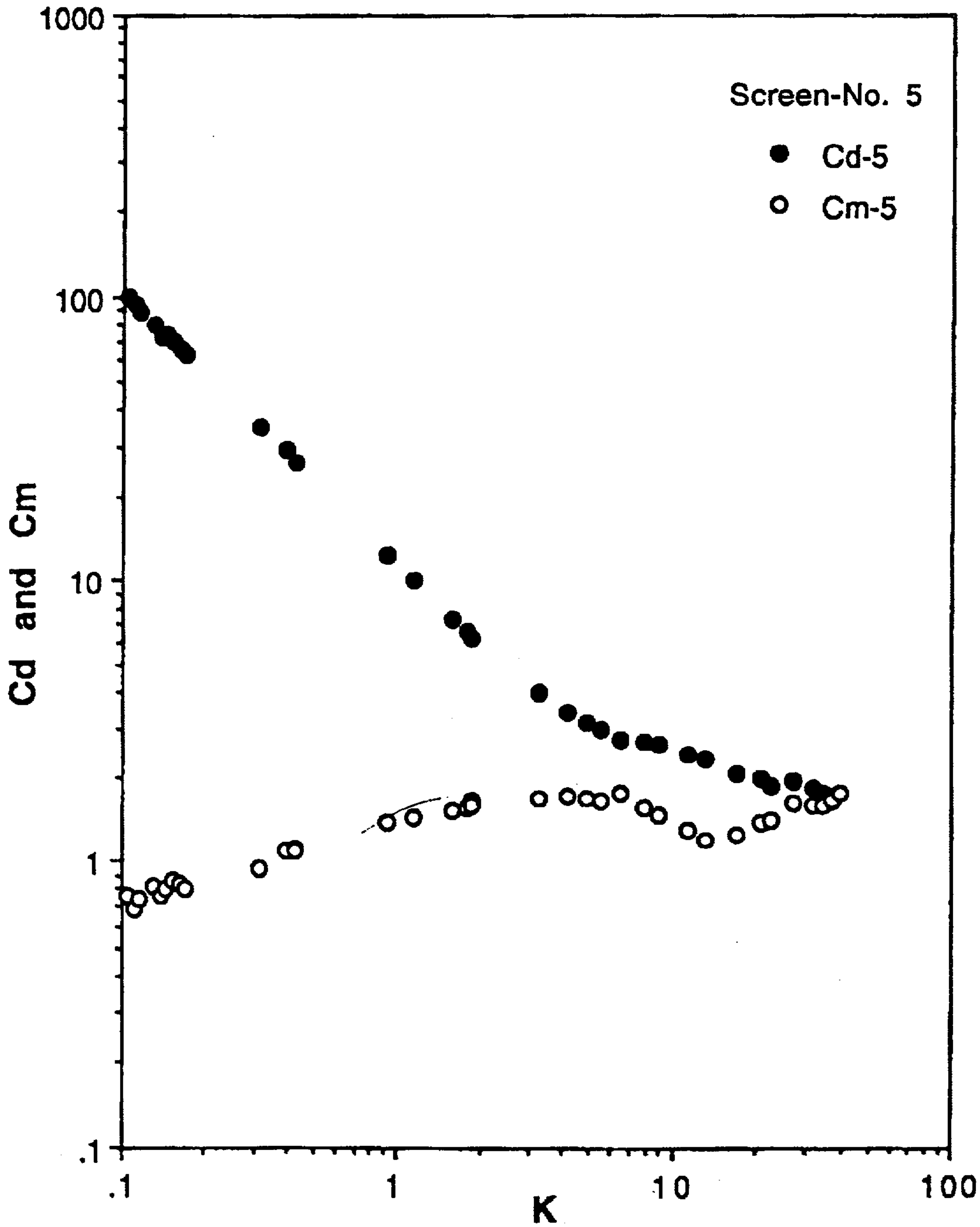

Figure 5. Cd and Cm versus K for screen No. 5.

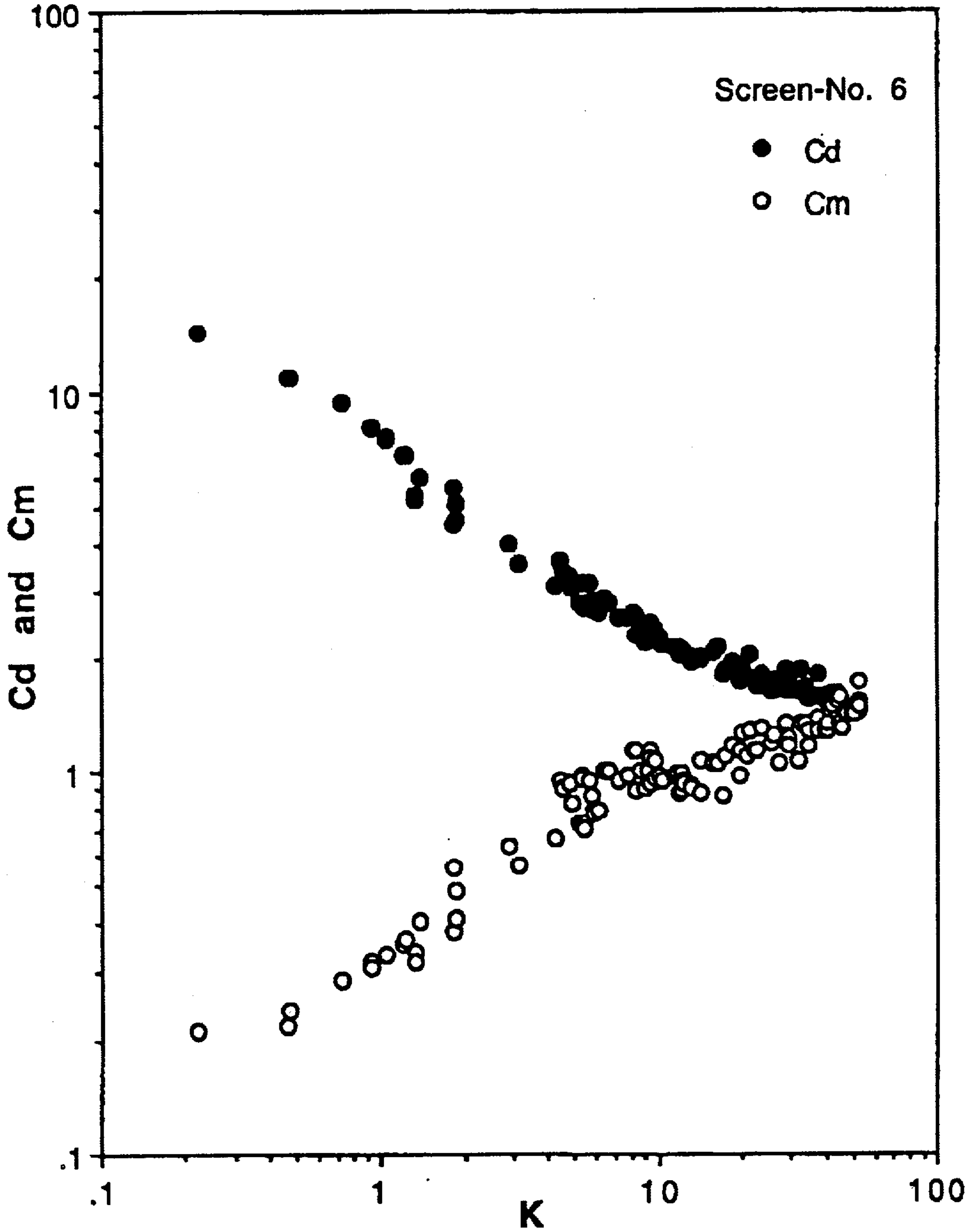

Figure 6. Cd and Cm versus K for screen No. 6.

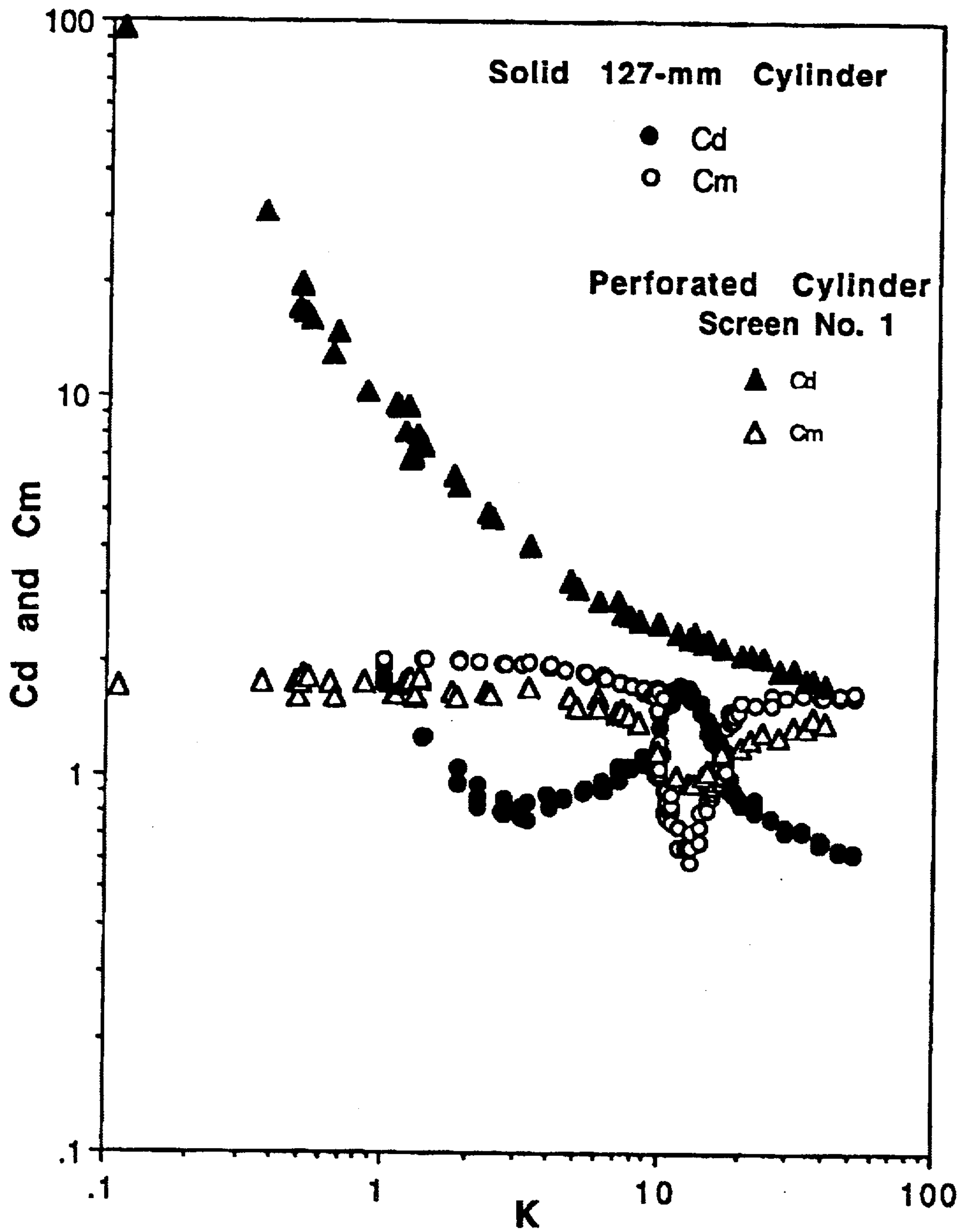

Figure 7. Cd and Cm versus K for a solid and perforated cylinder.

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