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KINETIC ENERGY OF SQUARE OBJECTS FALLING UNDERWATER

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ABSTRACT

The behaviour of a square object traversing uni-directionally underwater is investigated experimentally. The experiments were conducted up to a Reynolds number of 100,000. The effects of an approaching wall, or the ground, on the velocity and kinetic energy contained in the system are presented. Designers of surface cranage systems involved with lowering submersible packages can make use of the non-dimensional results for a better understanding of the energies involved.

1. INTRODUCTION

One of the principle concepts to become familiar with in studies of underwater forces is that of the 'added mass'. The concept attempts to visualise a bounded region of fluid that accelerates with a solid body and adds to the total mass. Strictly, the fluid particles will accelerate at varying degrees, depending on their location relative to the body and hence the added mass represents the integrated effect of these particles throughout the volume. The added mass can vary for different translation directions depending on the shape. Adding to the complexity of the concept are the dynamic effects of separation and vorticity.

Known added mass values for square type shapes in steady relative motion are given in Newman (1980), Kennard (1967) and Flagg et.al.(1971). The methods of potential flow have been used to construct tables in the aforementioned references. For many situations involving elongated bodies the three-dimensional added mass coefficients can be approximated by a strip theory synthesis using the two-dimensional coefficients of simpler forms.

Added mass is often used in stationary elastic oscillating object cases where noticeable changes in natural frequency are assigned to an additional fluid mass. However, the natural frequencies are shifted by a more complicated fluid dynamic effects, often with vortices that result in pressures in phase with the bodies' acceleration. Understanding the fundamentals of these effects with the concept of an added lumped mass proves fruitless. A more appropriate parameter is the kinetic energy, which is presented in this study.

An experimental approach has been adopted in this study in preference to an analytic or numerical method. A full Navier-Stokes computational solution for each case was deemed to require too much computer resource time, while the likelihood of the flow having a considerable amount of vorticity and unknown separation locations creates problems with potential flow solutions.

The current paper makes use of the following dimensionless terms;

m^* = Mass ratio = Mass of body / mass of fluid displaced.

V^* = Dimensionless velocity = Actual velocity / Terminal velocity.

K^* = Dimensionless kinetic energy = Actual kinetic energy / Terminal kinetic energy.

z^* = Dimensionless height from floor = Height above floor / Width of object parallel to plane of floor.

2. EXPERIMENTAL METHOD

The experimental rig

A submersible testing rig concept was devised. This would enable faster and easier testing by adjusting the testing parameters above water and then submerging for the experimental run. The rig is shown in Figure 2.1

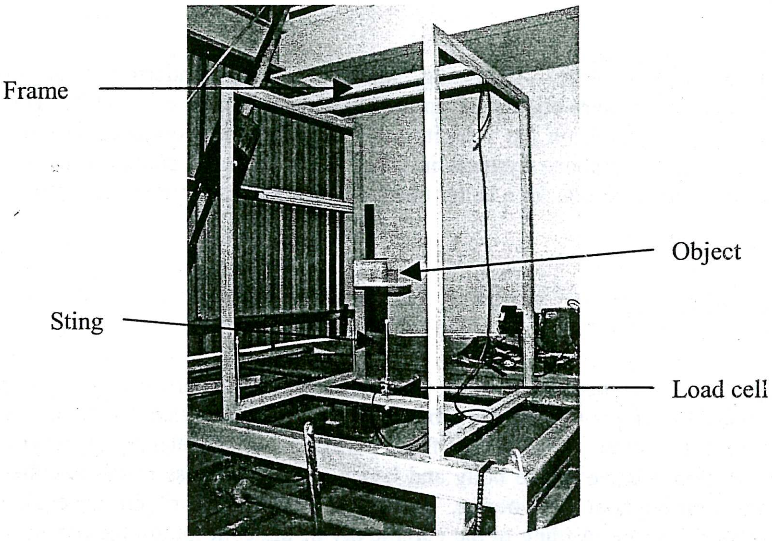

Figure 2.1 The experimental rig set-up for the added mass tests

The rig consists of a frame with two vertical wires to guide a falling object. A false floor is then positioned over a sting (steel rod that acts to decelerate the object) and can be set at different heights relative to the top of the sting by the use of threaded rods at each corner. At each side of the object, there is two times the width of the object in clearance to avoid frame interference effects. A rubber tip is installed on top of a sting. The tip acts to slow the object to rest over a distance of about 3mm, rather than several orders of magnitude less for a steel tip, in which case the forces through the load cell and frame would be very large.

An underwater video camera recorded images on a SVHS Video Cassette Recorder. Successive images of the dropped object were observed beside an underwater measuring stick to record terminal velocity.

A commercially available 500lb max rating load cell was waterproofed and connected to a 3V excitation strain bridge. Voltage signals were then logged onto a Pentium I computer with a Data-Translation data acquisition board. The signals were logged through GLOBAL LAB and then post processed through EXCEL.

Data Processing Procedure

The force-time history recording made by the load cell doubles as a displacement-time history due to the load cell and sting acting as a linear spring. One can calculate the impulse of an object decelerated with the measured force-time history by calculating the area under the force-time curve. The maximum deflection of the load cell indicates the elastic energy stored within the load cell, sting and rubber tip on a proportionality basis. If all the elastic energy is assumed to have originally been the kinetic energy of the falling object then it is possible to calculate the total mass of the falling object.

By setting the sting at different distances from an approaching boundary, the velocity, energy, impulse and mass statistics were determined for the falling object as it approached the boundary. The velocity of the object was calculated from the impulse and kinetic energy values, while terminal velocity measurements were observed from the video.

3. RESULTS AND DISCUSSION

Falling object approaching floor

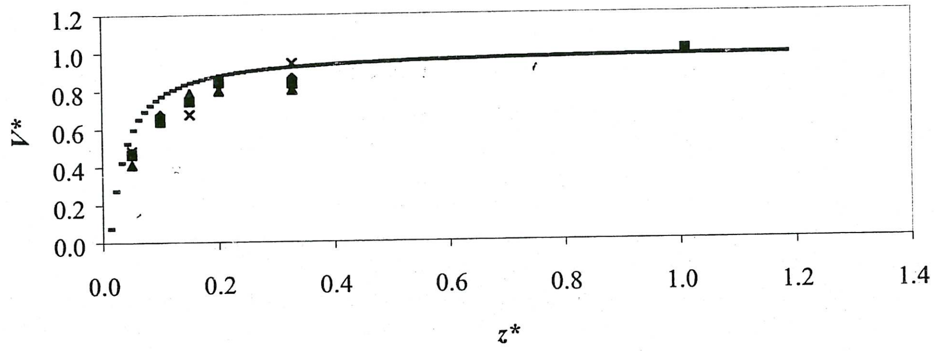

Figure 3.2 V^* as a function of z^* for a falling 200 x 200 x 100mm object approaching an underwater floor (100mm dimension is normal to the floor). Object mass ratios are ◆ = 1.22, ■ = 1.30, ▲ = 1.45, × = 1.67. Theoretical line, -, is for m^* = 1.22.

Figure 3.2 shows the velocity of an object as it approaches an underwater floor. For each m^*, results were obtained from six tests with the sting set at different heights.

A theoretical prediction of the velocity slope has also been presented in figure 3.2. (see Eqn 1).

$$\dot{z} = \dot{z}_o e^{-k/z} \qquad \text{(Eqn 1.)}$$

Where $k = \dfrac{\rho l^4}{32 m_{total}}$, l is the side length of the object, m_{total} is the total associated mass of the object.

The theory is based on the following hypothesis: As the object drops vertically under the influence of gravity, it causes the water in front of it to be ejected horizontally. The energy gain by the horizontally accelerated fluid is equated to the kinetic energy lost by the falling object.

The velocity seems quite well behaved globally as the data collapses reasonably well onto one line when each case is non-dimensionalised with its terminal velocity far away from the floor. The experimental results have some variations at intermediate values which may be a Reynolds number effect. The theory only takes into account the fluid dynamics of the leading edge of the object approaching the wall and not trailing edge effects. Discrepancies between the theory and the experimental results are hence ascribed to trailing edge effects and the dynamics of shedding vortices.

Flow visualisation

Arrays of wool tuffs on wire were positioned vertically in the water adjacent to the path of the falling object. Another set of wool tuffs was positioned on top of the moving object on stiff wires to study the trailing edge effects. Flow patterns revealed that as the object decelerates near the floor, a narrow jet of the trailing wake shoots out from just above the trailing edge. Also observed was that still water, initially to the side of the object, is firstly accelerated away from the object as the leading edge approaches, then sucked back into the far wake after the trailing edge passes.

The trailing wake escaping as a narrow jet upon deceleration of the object is a characteristic that would be important enough to cause the theoretical prediction to differ from the experimental results.

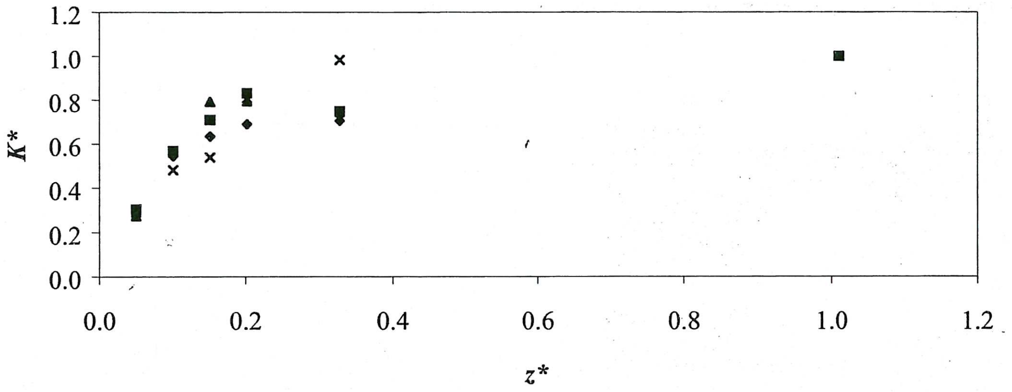

Figure 3.3 K^* as a function of z^* for a falling 200 x 200 x 100mm object approaching an underwater floor (100mm dimension is normal to the floor). Object mass ratios are ◆ = 1.22, ■ = 1.30, ▲ = 1.45, × = 1.67.

Figure 3.3 shows the behaviour of the kinetic energy of an object as it approaches an underwater floor. The dimensionless energy appears predictable for high and low values above the floor. At intermediate heights, where the floor is beginning to have a deceleration effect on the object, the behaviour appears to be more complex. As kinetic energy is proportional to velocity squared, the apparent larger variations in energy than velocity, can be attributed to the velocity squared effect.

Understanding the behaviour at intermediate ranges may not be necessary for Engineers. Designing for stresses during sub-sea mating operations or collisions should only require the close proximity data.

CONCLUSION

We have seen that by using a sting and measuring the impulse, load cell extension and velocity of an underwater falling object, instantaneous mass and kinetic energy can be calculated.

When an object approaches an underwater floor and a deceleration effect takes place, the velocity and kinetic energy of the system is predictable in the early and late stages of deceleration ($z^* < 0.1$, $z^* > 1.0$). Simple flow visualisation was performed to discover any effects in the intermediate range of z^* so as to be able to explain the difference between the theoretical prediction and the experimental results. An effect was discovered in which the trailing wake escapes in a narrow jet just above the trailing edge. Further detailed flow visualisation or computational techniques would be required to fully reveal the characteristics of the phenomenon and explain its effects on the falling object.

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