Bounce of a Basketball in a Puddle: Depth of Water and Coefficient of Restitution

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Abstract

A basketball was dropped into puddles with depths of water ranging from zero to 4 mm from a height of 1.1 m to investigate the relationship between the depth of water in a puddle and the coefficient of restitution with measurements of the drop height and bounce height. It is shown that the coefficient of restitution has a square root relationship with the depth of the puddle. A "puddle constant" is defined and found for this drop height and this ball to be 830 kgm/s^2.

Keywords: basketball, water depth, coefficient of restitution

I. INTRODUCTION

When people play basketball, the coefficient of restitution influences their performance. The International Basketball Federation states that a regulation basketball must bounce to a height between 1.2 and 1.4 m when released from 1.8 m onto the playing floor. The coefficient of restitution must range from 0.82 to 0.88.[1] When people play basketball on an outdoor court after it has rained, the presence of small puddles significantly reduces the bounce height of the ball. This investigation focuses on the relationship between the depth of a puddle and the coefficient of restitution of a regulation basketball.

The coefficient of restitution (COR) is the ratio of the difference in speeds of colliding objects after collision, to that before collision: it measures how well an object bounces off a floor. With the assumption of negligible air resistance the COR can be found with the following relationship,

$$COR = \sqrt{\frac{h_f}{h_i}} \quad (1)$$

where h_f is the final height after the first bounce, and h_i is the initial drop height of the basketball.[2]

There have been numerous investigations of the behavior of a bouncing ball. Rod Cross investigated the oblique rebound of a spinning tennis ball in normal incidence with a racquet.[3] Dolev Illouz examined the relationship between the angular velocity of a ball after impact and the angle of incidence with a racquet.[4] JuWon Kim and Chanhyeok Yim studied the dependence of COR on the air pressure in a handball.[5] But, the behavior of a basketball bouncing in a puddle has not been investigated or theoretically modeled.

In order to qualitatively observe and analyze the phenomenon, the bounce of the basketball in a puddle was recorded at 600 fps. Figure 1 shows selected frames of the video.

As shown in frames 2 and 3 of figure 1 when the ball collides with water, it splashes a small amount of water at high ejection speed in all directions at a small angle with the horizontal. Then when it bounces up, (frame 4) it pulls a column of water along with it. The subsequent splash is shown in frames 5 and 6. Accordingly there are two main components by which the ball loses its energy during the bounce in a puddle.

A simple model can be developed based upon three assumptions. First, the impact speed of the ball with the floor is similar at different depths as the water in the puddle is relatively shallow. Second, the average ejection speed of the water is similar at all puddle depths. Third, the mass of water ejected at high

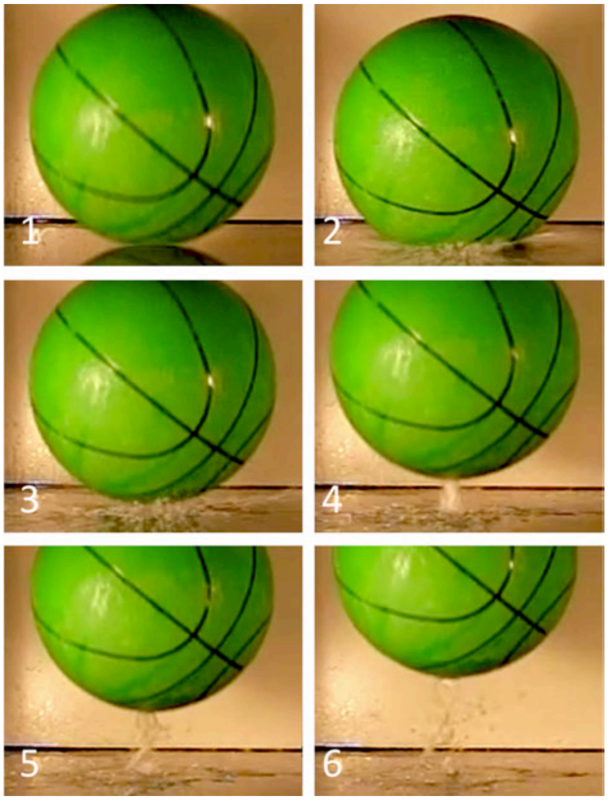

Figure 1. These frames show a basketball bouncing in a shallow puddle: just before hitting the water surface, the instant it reaches maximum compression during the impact with the floor and subsequent bounce upward, respectively.

speed and the mass of water column created are proportional to the depth of water. Hence the energy lost from bouncing in a puddle is proportional to the depth of the puddle,

$$\Delta E = \Delta E_0 + kd \tag{2}$$

where ΔE is the total energy loss after bouncing, ΔE_0 is the energy loss from colliding with a dry floor, k is a constant defined as the puddle constant and d is the depth of water.

Equation 2 can be combined with Equation 1 and rearranged to give,

$$COR = \sqrt{(COR_0)^2 - \frac{k}{E_i}d} \tag{3}$$

where COR_0 is coefficient of restitution with no water and E_i is the gravitational potential energy of the ball at its dropping height above floor. Hence the COR^2 is expected to decrease linearly as the depth of water increases. This model is expected to be applicable only to shallow water depths.

II. METHODS

A Vernier Motion Detector, with sample rate of 30 Hz, was set up directly above the puddle, which was confined by sealing a retaining ring onto the floor. The diameter of the ring was 39.5±0.8 cm. A basketball with pressure of 0.56±0.02 bar, a circumference of 75.30±0.05 cm and a mass of 598.7±0.1 g was used. The temperature of the room was constant at 24.5±0.7 ˚C.

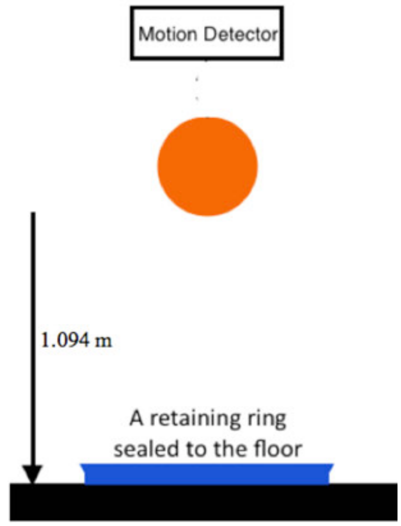

Figure 2. The position of the ball was recorded as it was dropped into puddles of varying depth.

As shown in figure 2 the ball was first dropped from the controlled drop height of 1.094±0.003 m with no water inside the retaining ring. Approximately 100 mL of water was poured into the retaining ring ensuring that the entire surface of the floor inside the container was covered. After each trial with water, the floor and the ball were dried. This was repeated with six different volumes of water with three trials each with 0, 100, 200, 300, 400, and 500 mL of water so that the puddles ranged in depth from 0 mm to 4.1±0.2 mm. Rebounds from deeper puddles were not investigated because people would not play basketball in these conditions.

III. RESULTS AND DISCUSSION

As shown in figure 3, the relationship between COR^2 and depth of water is,

$$COR^2 = 0.56 - (130\text{m}^{-1})d \tag{4}$$

where d is the depth of water in meters.

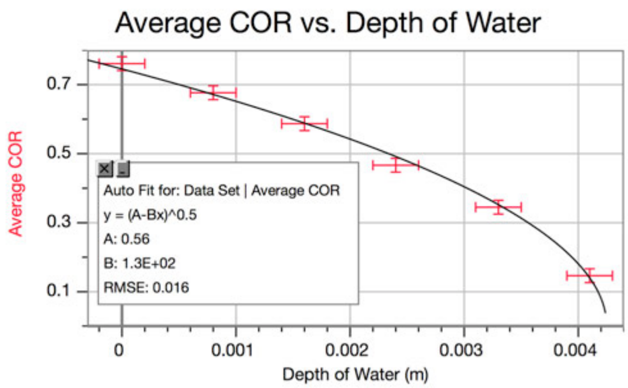

Figure 3. Average COR shows a root relation with Depth of Water, as proposed in equation 3.

Equation 4 may only be applied to shallow water. The x-intercept, 0.0043 m, is not significant because the proposed model assumes a basketball bounce in a shallow puddle. Therefore when the depth of water increases to a certain level where the ball effectively does not bounce, the model cannot be applied.

Equation 4 is rearranged following the form of equation 3,

$$COR = \sqrt{0.75^2 - \frac{830\text{kg}\cdot\text{m/s}^2}{6.42\text{J}}d} \quad (5)$$

According to Equation 5, the puddle constant of the particular situation investigated is 830kg·m/s^2. The higher the puddle constant, the greater the energy loss from displacing water per unit increase in the depth of the puddle. It is presumed that numerous factors influence the puddle constant such as impact speed, size of the ball, air pressure inside the ball as well as the density and viscosity of the liquid.

Further research is suggested investigating the effect of different impact velocities on the COR at a constant depth of water along with the puddle constant found for typical impact velocities when playing the game. A method to measure the mass and velocity of the two types of displaced water using high-speed and high-resolution video could be developed for a more detailed model of the phenomenon. More studies could be done to determine the ranges of different variables for which the puddle constant stays constant to determine the relative importance of the many possible factors on its value.

IV. CONCLUSION

When a basketball bounces in a shallow water puddle, the coefficient of restitution has been shown to have a square root relationship with the depth of water in the puddle. The puddle constant, defined as the slope of the relationship between the total energy loss of the rebounding ball and the depth of the puddle, has been found for specific conditions of this investigation to be 830 kg·m/s^2. It is important to note that this conclusion is limited to the dropping of a regulation basketball from approximately one meter into puddles of depths up to 4 mm.

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