Rigid Wall Effects on Softball Coefficient of Restitution Measurements

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Abstract The coefficient of restitution (*COR*) is often measured by impacting a ball against a rigid wall. The ball *COR* is used to regulate performance in many sports. In the case of ball impact sports, such as baseball and softball, the ball *COR* also contributes to bat performance. Understanding the accuracy of the ball *COR* has received greater scrutiny as bat performance tests have been refined and performance limits lowered. The effect of the idealized rigid wall surface was considered in this study by impacting softballs against flat surfaces of controlled stiffness. The ball *COR* was generally observed to decrease as the impact surface stiffness increased. An exception to this observation was found for the thinnest impact plate (6 mm) which provided the lowest *COR* value in this study. Only impact surfaces of relatively large compliance were observed to affect the measured ball *COR*. The affect of the distance of the rigid wall from the speed measurement due to drag was also considered. The common distance of 450 mm was shown to report a ball *COR* that is approximately 0.005 lower than would be obtained by measuring the ball speed at the impact surface.

Introduction

The coefficient of restitution (*COR*) of two colliding objects is defined as the ratio of their relative speed after and before impact, respectively (Beer and Johnston, 1997). The ball *COR*, independent of the object being impacted, is often desired. To this end balls are impacted against a flat rigid wall. Accordingly, the ball *COR* is taken as the ratio of the ball speed after to before impact. The rigid wall ball *COR* is used by a number of governing associations to certify balls and bats for softball and baseball. Little has been done, however, to define or quantify a rigid wall. ASTM 1887 defines a rigid wall “as cinder block or concrete, minimally 20-cm (8-in.) thick.” It is unclear whether this definition is sufficient or unnecessarily conservative.

The motivation to understand the effect of a rigid wall on ball *COR* is two-fold. First, obtaining uniform ball *COR* measurements from laboratory round-robin studies has been surprisingly difficult. It is possible that differences in respective laboratory rigid wall impact surfaces contribute to this problem. Second, most ball and bat manufacturers design their products near the allowed performance limits. Reducing the variation in ball *COR* measurements will allow manufacturers to design their products closer to the allowed limit.

The effect of impact surface stiffness will be examined by impacting plates supported near their edges as a function of plate thickness. Plate displacement and ball *COR* will be examined as a function of thickness.

Experiment

Softballs nominally 300 mm (12 in) in circumference were projected toward a flat impact surface at 27 m/s (60 mph). The balls were delivered using an air cannon as described in ASTM 2219 striking the impact surface without rotation. The balls were impacted sequentially on the four surfaces with the widest distance between the stitches.

The impact plate was nominally 300 mm (12 in) in diameter. Six impact plates were studied ranging in thickness from 13 to 44 mm (0.5 to 1.75 in) in 6 mm (0.25 in) increments. The impact plate was attached to a support structure through 12 equally spaced 19 mm (0.75 in) bolts arranged on a 240 mm (9.5 in) diameter circle. Twelve spacers measuring 32 mm (1.25 in) in diameter were placed between the impact plate and support structure to allow free motion of the center of the impact plate. A 25 mm (1 in) diameter hole was drilled through the support structure which allowed a non-contact laser vibrometer (Polytec OFV-511 Fiber Interferometer with a Polytec OFV-5000 Controller) to measure the surface motion of the impact plate as depicted in Fig. 1.

Numerical Simulation

The effect of impact plate stiffness was studied numerically using a finite element simulation. The model consisted of nearly 30,000 elements and is shown in Fig. 2. The ball was meshed using 8 noded brick elements while the plate was meshed using 4 noded plate elements. Symmetry conditions were applied to the sectioned edges of the model. The round holes in the plate represent the edges of the spacers which were constrained in the direction of the impending ball motion. The ball was modeled as a viscoelastic material whose properties were tuned to match the nominal ball density, COR, and stiffness as described elsewhere (Shenoy, Smith, Axtell 2001).

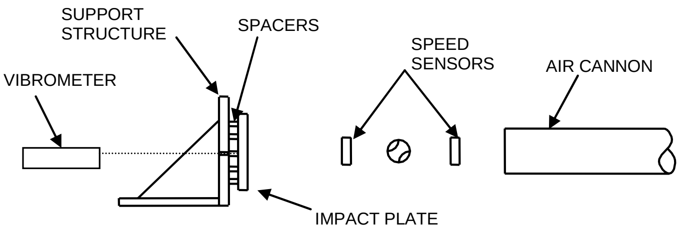

Fig. 1. Schematic of impact plate stiffness study.

Results

The average *COR* was found for 6 softballs impacted 6 times against each of the impact plates, as shown in Fig. 3. (The experiment was repeated with 24 balls with similar results.) The error bars represent the standard deviation of the mean for each thickness. The *COR* was observed to decrease with increasing plate thickness. This trend is analogous to the so-call trampoline effect from which thin walled hollow bats derive their performance. The balls were also impacted against a reinforced concrete wall, labeled “Fixed” in the figure. The results suggest that wall compliance must be relatively large to affect the measured ball *COR*.

The results from the FEA model are also presented in Fig. 3, and show good agreement with experiment. The plate clamping condition was observed to have a large effect on the numerical results. Pinned supports at the outside edge of the plate, for instance, produced a much larger change in ball *COR* with plate thickness than was observed experimentally; while clamped supports at the fastener holes resulted in a smaller change in ball *COR* with plate thickness than was observed experimentally. For the results presented in Fig. 3, the plate was pinned at the hole circle radius since mechanical fasteners are not able to produce a true clamped boundary condition.

The model also considered a 6 mm (0.25 in.) thick plate. The ball *COR* with this plate decreased sharply (0.291). The FEA model of the plate was linear elastic and did not consider yielding, which would have occurred for a 6 mm plate. The reason for the low *COR* using the 6 mm thick plate is likely related to its high compliance and low natural frequency (~300 Hz). The contact time between the ball and plate is of order 1 ms. The 6 mm thick plate continued to deform while the ball was recoiling. This is an example of an elastic mechanism of impact energy loss, and shows that decreasing rigid wall compliance may not always reduce the measured ball *COR*.

The vibrometer was used to measure the displacement of the impact plates. Unfortunately the results of these measurements did provide a reliable description of the plate motion. The displacement rate of the thinner plates exceeded the capacity of the vibrometer, while the motion of the millbase, used to support the impact plates, affected the displacement of the thicker plates. Although the millbase motion

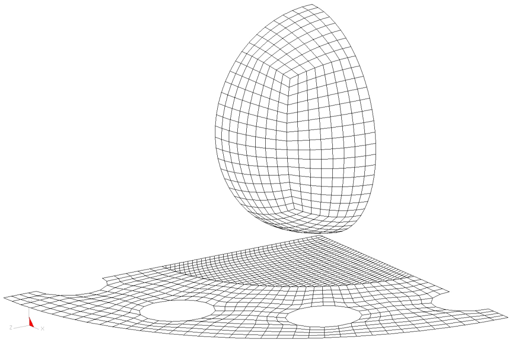

Fig. 2. Mesh of the simulated ball-plate impact.

appeared to be relatively small during the ball contact (~0.01 mm), its contribution was difficult to separate from the plate motion. The results of the numerical simulation were used, therefore, to describe the effect of rigid wall motion on *COR*.

Ball *COR* is shown as a function of the plate displacement in Fig. 4. The ball *COR* appears relatively constant for plate displacements below 0.1 mm. A peak *COR* occurred for plate displacements near 0.3 mm before decreasing sharply with larger plate displacements (i.e. the 6 mm thick plate). It should be noted that displacement magnitude alone may not be sufficient to describe rigid wall compliance. Plate speed may also play a roll if the ball contact duration changes appreciably with plate compliance. For the case at hand the contact duration was relatively constant resulting in comparable speed and displacement trends with *COR*, where the speed ranged from 6 to 0.04 m/s.

The effect of air resistance is often neglected when measuring the ball *COR*. The short flight distance of the ball and a misconception that the effect of drag approximately cancels in the *COR* calculation have been cited to discount drag effects. For a non-rotating sphere (which is the case with the air cannon used for this work) traveling at a speed, V, the drag force, F, may be found from (White 1986)

$$F = \tfrac{1}{2}\rho C_D V^2 A \qquad (1)$$

where C_D, ρ, and A are the drag coefficient, air density, and sphere cross sectional area, respectively. Over the range of speeds common to softball (below 110 mph), C_D falls between 0.5 and 0.3 (Adair, 2002). The ratio of the measured speeds, v_o/v_i, may be found as

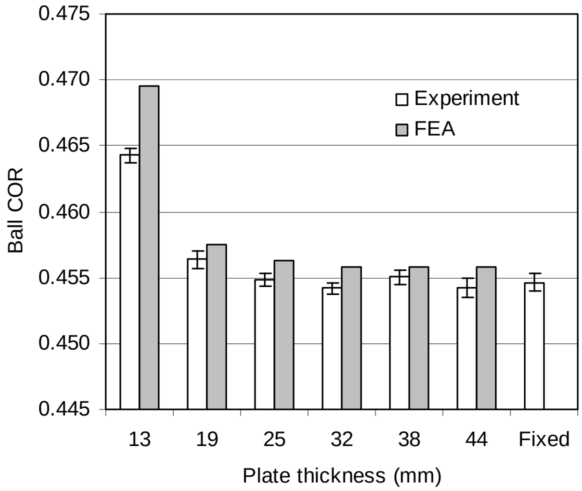

Fig. 3. Average ball *COR* from 6 softballs.

$$\frac{v_o}{v_i} = COR_o\left(e^{-k}\right) \tag{2}$$

where COR_o is measured at the impact plate and

$$k = \frac{\rho C_D A}{m} x \tag{3}$$

where m is the ball mass and x is the distance from the speed sensor to the impact plate.

Six balls were impacted against a rigid impact plate at 60 mph six times each. The speed sensors were moved in 125 mm (5 in) increments, where the distance to the impact plate was taken as the center of the speed sensors. The ratio of the after to before impact speeds are presented in Fig. 5 as a function of sensor distance from the impact plate. While the relatively small range of sensor distances considered here have a small effect on the ball *COR*, the effect is measurable and outside the range of experimental scatter. For the case of softball and baseball standardized *COR* measurements, the center of the sensors are 450 mm from the impact plate. This implies that the actual ball *COR* is on average 0.005 higher than the commonly measured value. For comparison Eq. (2) is also plotted in Fig. 5, which appears to support $C_d = 0.5$.

Summary

The foregoing has considered the effect of impact surface compliance and distance in measuring the ball *COR*. The reinforced concrete wall commonly used as a rigid surface provided a similar *COR* measure as suspended plates which much larger

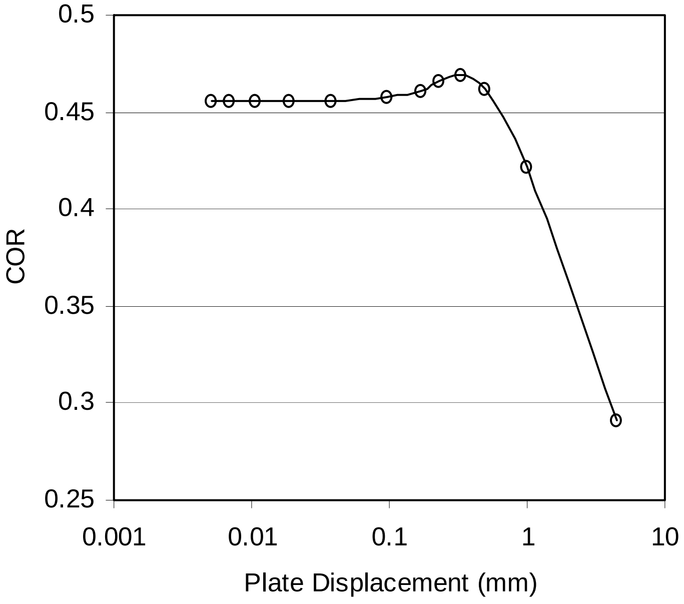

Fig. 4. Ball *COR* as a function of the impact plate displacement from the numerical simulation.

compliances. The results of this work suggest that the current practice of using reinforced concrete provides a good approximation of a rigid impact surface and that more compliant impact surfaces can also provide comparable *COR* values. The distance between the speed sensors and the impact surface was shown to have a small, but measurable effect on the measured ball *COR*. This distance should be controlled and reported when measuring ball *COR*.

Acknowledgements

The authors gratefully acknowledge the American Softball Association and the Sports Science Laboratory at Washington State University whose support made this work possible. The authors also acknowledge the assistance of Nicholas Smith and Ryan Smith whose meticulous experiments greatly benefited this work.

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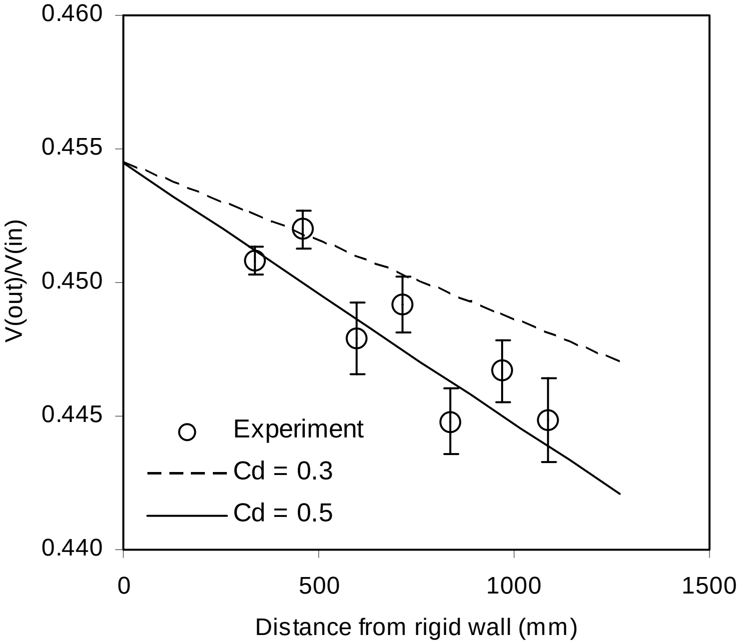

Fig. 5. Ball COR as a function of speed sensor distance from the impact plate.