Journal of Physics Special Topics
An undergraduate physics journal

P4 5 Heads Up!

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December 11, 2023

Abstract

In this paper, we calculated that a golf ball hit at an angle of 30° at a speed of 75.1 ms^{-1} would break 7 glass panes of dimensions 1 m ×1 m ×2 mm, on an inclined plane, under these circumstances. On the other hand, in this scenario, it would definitely not be possible to break tempered glass, since the force required to shatter it is 196 kN, hence if you are golfing near a building, tempered glass would be ideal to use.

Introduction

A golf ball is fairly small (diameter 42.7 mm[1]), and incredibly light (45.9 g[2]), but given enough of a boost, you could cause some damage. For this scenario, a golf ball is placed 0.5 m from a 10° inclined plane with glass panes are equally spaced with 0.3 m between each one. The golfer has hit the ball off the tee at a speed of 75.1 ms^{-1}[3] at an angle of 30°, which is illustrated in Figure 1 below:

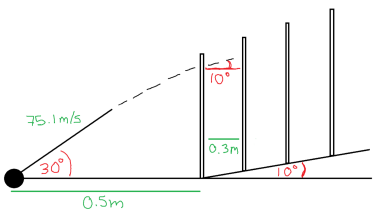

Figure 1: Layout of the golf ball and glass panes

It should be noted that the force required to break a normal untempered glass pane is 100 N[4].

Theory

To determine the time taken (Δt_1 and Δt_2) for the golf ball to hit the glass pane, we can use:

$$\Delta t_1 = \frac{d}{v_0 cos\theta_1} \quad \text{and} \quad \Delta t_2 = \frac{d}{v' cos\theta_2} \tag{1}$$

where d is the distance travelled to the glass pane, v_0 is the initial golf ball speed and θ_1 is the angle the ball is travelling at at the start, v' is the velocity of the ball after breaking through the glass pane and θ_2 is the angle the ball is travelling after breaking through the glass.

Following from this, the momentum of the golf ball can be determined using:

$$p_0 = m_b v_0 \quad \text{and} \quad p' = (m_b + n m_g) v' \tag{2}$$

where p_0 is the initial momentum and p' is momentum after breaking the glass panes with ball mass m_b and glass mass m_g carried through. The factor of n indicates that this is the glass pane number. Throughout the calculations, after the ball has broken through the first glass pane, only Equations (1) (right) and (2) (right) are considered, where the new v' replaces the previous v' as the ball slows down.

We can calculate the force (F) required to break through a glass pane using the change in momentum Δp

$$F = \frac{\Delta p}{\Delta t} \tag{3}$$

The golf ball goes through inelastic collision where velocity would be lost through the glass breaking, hence

$$v' = \frac{m_b + (n-1)m_g}{m_b + nm_g} v_0 \tag{4}$$

The basis of the equation is inelastic velocity, but altered so the numerator includes the number of panes broken, and the denominator includes the glass pane to be broken. Each new v' uses the previous velocity (v_0 before the first pane breaking and then v' after each glass breaking).

If we know the pressure, P, required to break the glass and the surface area of the ball, A, we can determine the force to break the glass with:

$$P = \frac{F}{A} \quad \text{where} \quad A = \pi r^2 \tag{5}$$

where r is the radius of the golf ball.

Results

The glass panes dimensions are 1 m $\times$1 m $\times$2 mm with density of 2500 kgm^{-3}[5], hence the mass of a single glass pane is 5 kg. As the glass breaks, we assume that 1% of the glass travels with the ball for each glass pane (0.05 kg), consequently slowing the ball down, which is seen in Table 1. If we make a comparison with how much force is required to break a sheet of tempered glass, provided that the dimension are the same, it is about 196 kN, using equation 5, from a breaking pressure of 138 MPa[6], and the circular area of golf ball is 1.43×10^{-3} m^2.

Pane no. (n)	v' (ms^{-1})	Δt ($\times 10^{-3}$ s)	F (N)
1	35.9	7.69	448
2	23.6	8.47	407
3	17.6	12.9	267
4	14.0	17.3	199
5	11.65	21.7	159
6	9.97	26.2	132
7	8.71	30.6	113
8	7.73	35.0	98.5

Table 1: Speed, time and force that the golf ball hit the panes of glass.

Conclusion

From the data obtained in Table 1, the number of glass panes broken is 7, in comparison to no glass panes broken if it is tempered. That is due to tempered glass being manufactured differently since it is slowly cooled creating a barrier where the inner layer is under tension and the outer surfaces are under compression. This requires a much larger force to break, so from the above scenario, there is definitely no destruction, but there might be small cracks on the surface instead.

References

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