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The Drunk, the Child and the Soldier – My, How They Fall.

by Ralph L. Barnett[1]

ABSTRACT

It's better to collapse than to topple over, it's better to be short than tall and it's best not to fall at all. The head strikes the ground at "killer" speeds. Toppling produces greater impact speeds than free fall and for certain limiting shaped objects, infinite speeds are attained.

INTRODUCTION

Erect stationary objects have potential energy which they shed when they fall over. This energy is converted to kinetic energy, the energy of motion, just before striking the ground. The law of conservation of energy requires that the kinetic and potential energies be equal and this enables one to simply compute the striking speed of any known object. This relationship is applied to some very elementary shapes and models that nevertheless provide insights into the nature of falling.

HEAD STRIKING SPEEDS

1. The Collapsing Drunk

Drunks collapse in the fashion of a dangling chain that is suddenly released. Referring to Fig. 1 the speed v_0 of the top link (or head) when it falls through a height h is given by the classic formula for free-fall:

$$v_0 = \sqrt{2gh} \qquad \text{Eq. 1}$$

where g is the gravitational constant, 32.2 ft / sec^2. For a six foot drunk,

$$v_0 = \sqrt{2\left(32.2\right)6} = 19.66 \text{ ft / sec.} = 13.4 \text{ mph}$$

(6 foot drunk)

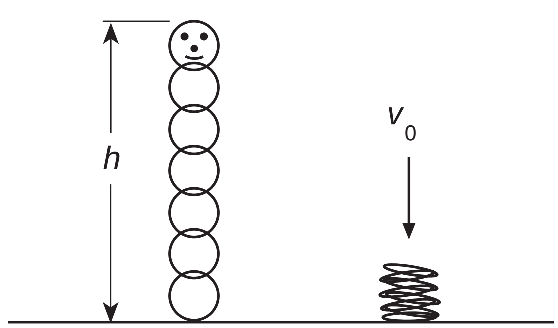

FIGURE 1 COLLAPSING DRUNK MODEL

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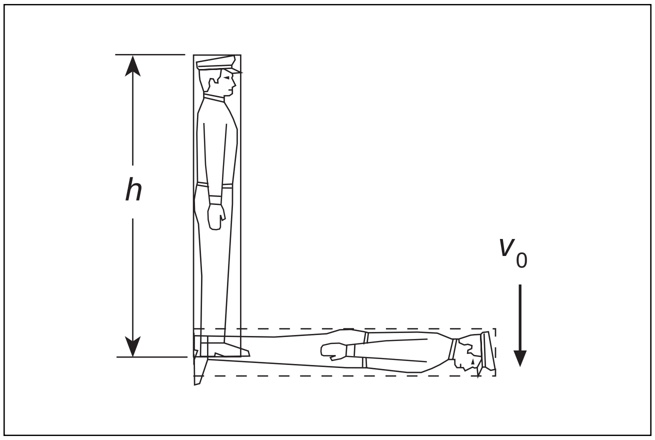

FIGURE 2 - RIGID SOLDIER MODEL

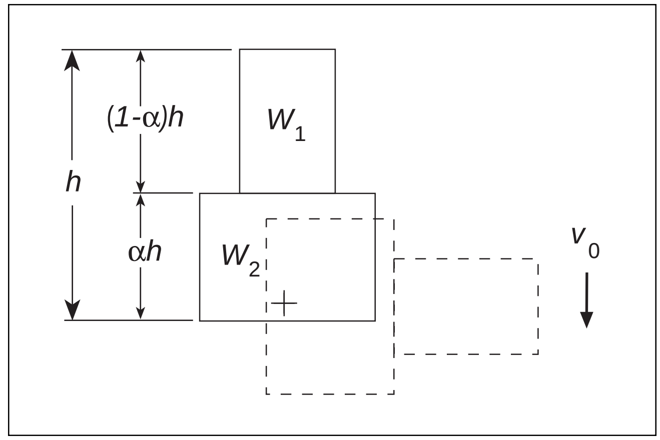

FIGURE 3 - CRANE TOPPLING MODEL

2. The Collapsing Child

When a three foot tall child collapses, Eq. 1 provides the head speed just before impact:

$$v_0 = \sqrt{2\left(32.2\right)3} = 13.9 \text{ ft / sec.} = 9.48 \text{ mph}$$

(3 foot child)

Observe that this speed is 29.3% slower than the drunk's. Although half the size, the speed is not half of the drunk's speed; the speed is proportional to $\sqrt{h}$ not h.

3. The Toppling Soldier

A rigid solder flopping or toppling over is modelled in Fig. 2 where engineers will characterize the problem as "rotation of a rigid body about a fixed axis." Using this prismatic representation of the soldier, the head impact speed v_0 is given by:

$$v_0 = \sqrt{3gh} \qquad \text{Eq. 2}$$

We observe that the number three replaces the number two in the free-fall or collapse Equation 1. Consequently, toppling always produces a head impact speed that is 22.5% greater than the collapse mode speed. For a six foot soldier the head impact speed is:

$$v_0 = \sqrt{3\left(32.2\right)6} = 24.1 \text{ ft / sec.} = 16.4 \text{ mph}$$

(6 foot soldier)

Most of us in our youth could not exceed a running speed of 15 mph. If you ran flat out and smashed your head into a low slung reinforced concrete beam, would you expect to survive? Toppling into the ground at 16.4 mph helps explain why falls are always the number one or number two killer when compared to other accident categories.

4. Striking Speeds of Machinery

A slightly more sophisticated model for toppling is shown in Fig. 3 where W_1 and W_2 represent the weights of each section of the model. The tip speed of the object is given by:

Equation 3:

$$v_0 = \sqrt{3gh}\left[\frac{W_1\left(1-\alpha^2\right)+W_2\,\alpha\left(1-\alpha\right)}{W_1\left(1-\alpha^3\right)+W_2\,\alpha^2\left(1-\alpha\right)}\right]^{\frac{1}{2}}$$

The quantity in brackets acts to magnify the prismatic toppling speed $\sqrt{3gh}$. For example, taking a large lattice boom crane with a boom weight W_1 that is a twentieth of the crane weight, i.e. $W_1 = W_2 \div 20$, and taking the boom height to be thirty times the height of the crane body, $\alpha = 1/30$, we obtain:

$$v_0 = \sqrt{3gh}\left[\frac{\frac{W_2}{20}\left(1-\frac{1}{30^2}\right)+W_2\,\frac{1}{30}\left(1-\frac{1}{30}\right)}{\frac{W_2}{20}\left(1-\frac{1}{30^3}\right)+W_2\,\frac{1}{30^2}\left(1-\frac{1}{30}\right)}\right]^{\frac{1}{2}}$$

$$= \sqrt{3gh}\left(1.27\right)$$

The boom point hits the ground at a speed that is 56% greater than free-fall.

It is of engineering interest that the speed v_0 becomes infinite when $W_1 \to 0$ and $\alpha \to 0$, e.g., a weightless antenna on top of a flat slab.