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5950 West Touhy Avenue   Niles, IL 60714-4610   (847) 677-4730

FAX: (847) 647-2047

e-mail: infoserv@triodyne.com

Bungee Cord Danger Analysis*

by Dennis B. Brickman[1], Ralph L. Barnett[2], and Harry R. Smith[3]

ABSTRACT

The utility of bungee cords is so persistently attractive that they continue to gain in popularity. Unfortunately, one of the characteristics of bungee cords is the sudden release of stored energy which results from opening of hooks, failure of the bungee cord and hook connection, inadvertent release of the bungee cord during application, and failure of the structure receiving the hook. Each of these failure modes allows the free end of the bungee cord to attain high speeds which produce injuries through impact. The design of personal protection equipment and the evaluation of the danger level related to a released bungee cord require information on hook speed. This paper presents a first order analysis of the maximum attainable speed.

INTRODUCTION

The popularity of bungee cords for restraining light loads has been observed in applications where they:

1. Hold down trunk lids when cargo bulk is excessive.
2. Hold down tarps which protect boats, campers, pickup trucks, and lading on flat bed trucks.
3. Restrain cargo.
4. Hold items in place temporarily.
5. Apply temporary clamping force (e.g., adhesive applications).
6. Act as barriers.

The utility of the bungee cords is particularly attractive since the hooks act as an extremely versatile connector which can be easily applied with one hand.

The sudden release of stored energy associated with the bungee cord leads to a high speed flailing hazard in the following failure modes:

1. Hook pulls out of user's hand in stretching phase.
2. Hook becomes disengaged from attachment point.
3. Attachment structure fails.
4. Hook straightens out.
5. Cord breaks.
6. Hook detaches from cord.

Injuries associated with the bungee cord have been documented by the U.S. Consumer Product Safety Commission (CPSC) through the National Electronic Injury Surveillance System (NEISS) [1]. Additional information may be found in the medical and safety literature [2-7].

The selection of personal protection equipment and the danger assessment related to a released bungee cord require information on the maximum speed at which one can be hit by the hook. This paper presents a first order analysis of the maximum hook speed of a released bungee cord. A test fixture has been designed and constructed to measure the maximum hook speed.

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[1] Senior Mechanical Engineer, Triodyne Inc., Niles, IL.

[2] Professor, Mechanical and Aerospace Engineering, Illinois Institute of Technology, Chicago, and Chairman of the Board, Triodyne Inc., Niles, IL.

[3] Director of Laboratory Sciences, Triodyne Inc., Niles, IL.

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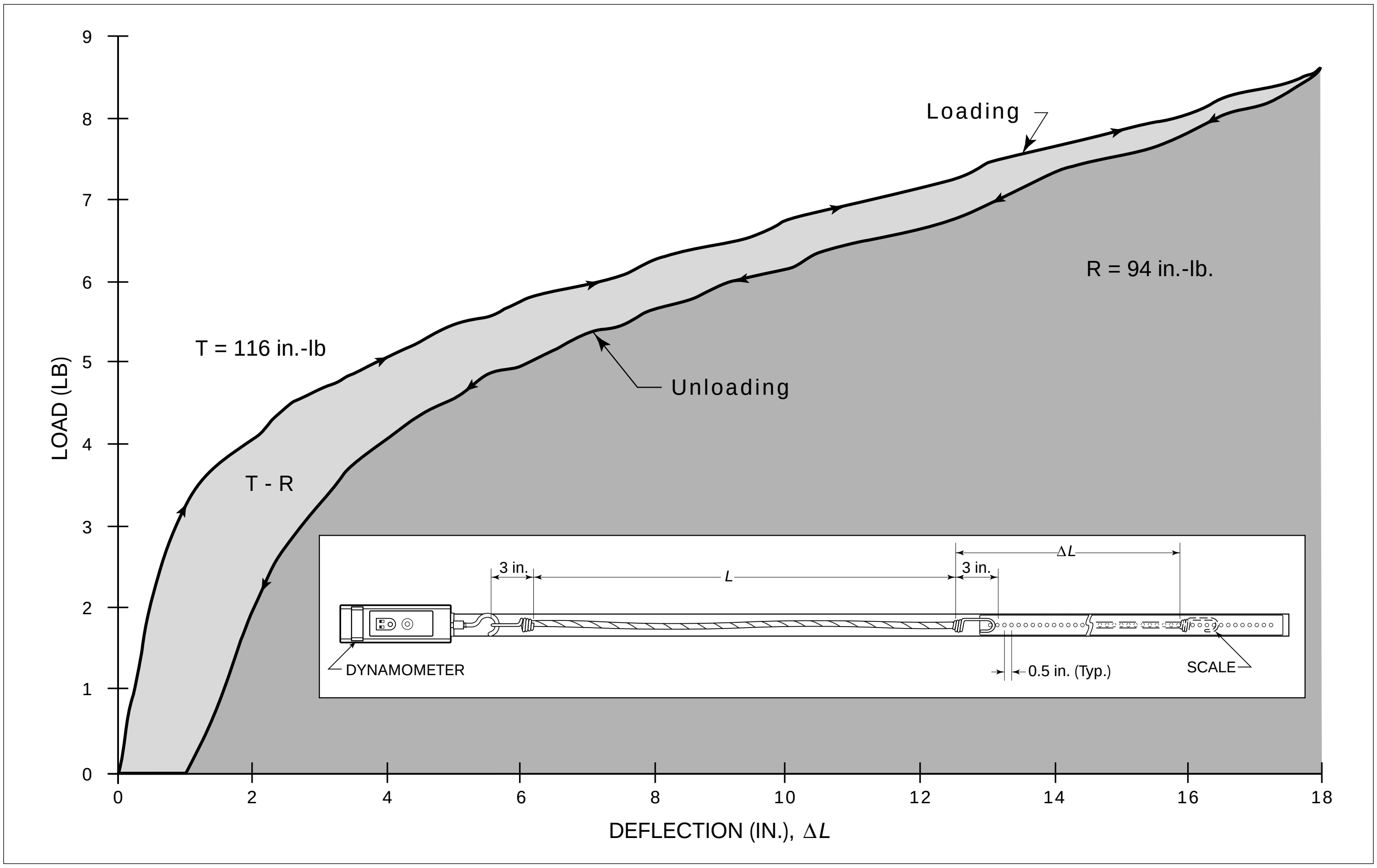

Fig. 1 Test Set-Up and Load-Deflection Diagram

FIRST ORDER ANALYSIS

The static behavior of tension members, and specifically bungee cords, may be characterized by their load-deflection diagrams. Figure 1 illustrates a typical load-deflection relationship during the loading and unloading phases of the bungee cord. The area under the top (loading) curve represents the total energy required to stretch the cord from its unloaded length to the final elongation of interest; this is called toughness and will be designated as T. The area under the lower (unloading) curve represents recoverable or elastic energy obtained when the cord is completely unloaded; this is called resilience and will be designated as R. In this paper, T and R will be measured in in.-lb. The positive difference between these two areas, $T - R$, will be termed hysteresis and represents the energy lost to heat during the load/unload cycle.

An elongated bungee cord is a two-force member; the two hooks are being pulled together along a straight line between the attachment points. When one hook is released, it will be accelerated toward the fixed hook until it achieves its unstretched length where the pull force drops to zero. At this point it is assumed that all of the recoverable energy R will be used to produce kinetic energy in the cord. This energy may be approximated as

$$\text{Kinetic Energy} \doteq \frac{1}{2g}\left(W_h + \frac{W_c}{3}\right)v_h^2 \qquad \text{Eq. (1)}$$

where W_h is the weight of the hook and any attachment devices such as knots and clips, W_c is the weight of that portion of the bungee cord that lies between the hooks, v_h is the hook speed, and g is the acceleration due to gravity (386.4 in./sec^2). It should be noted that the contribution of the cord weight to the kinetic energy is taken as one third of its actual weight. This classic relationship is discussed by Timoshenko [8] where it is assumed that the velocity of any cross-section of the cord at a distance c from the fixed end is the same as in the case of a massless cord, i.e.,

$$\frac{c}{L}v_h$$

where L is the unstretched length of the cord between the hooks. The factor follows immediately from this assumption.

Equating the kinetic energy to the resilience R gives:

$$v_h = \sqrt{\frac{2gR}{W_h + \frac{W_c}{3}}} \qquad \text{Eq. (2)}$$

Real cords use up energy through air resistance, stress waves, and dissipation in the release mechanism. Consequently, Eq. 2 may be regarded as an upper bound on the achievable hook speed.

RESILIENCE

When bungee cords are used, they are typically stretched and fastened between two fixed points. This implies that the elongation of the cord is an independent variable and that the resulting resistance to this stretching is a dependent variable. The associated load-deflection curves are the type normally obtained using universal testing machines. Because of the considerable stretching associated with bungee cords, testing often proceeds by elongating the cord horizontally and measuring the resistance; this method was employed in the paper using the test set-up shown in Fig. 1. Ten nominally identical three foot bungee cords with a 0.375 in. diameter were tested using an 18 in. elongation

(50% of the total cord length including the two hooks). Each cord was prestretched five times to an 18 in. elongation. The associated values of T and R are tabulated in Table 1 together with their hysteresis.

SPEED TESTS

Using the test set-up shown in Fig. 2, a stretched bungee cord was propelled upward through sets of sensors[1] vertically spaced on one inch centers in the neighborhood of the unstretched cord deployment.

Calculations of the hook speed were made for the bungee cord illustrated in Fig. 3. The weight of the cord within the 30 inch length is typically $W_c = 0.06897$ lb; the weight of the hook, knot, staple, and wand shown on the left hook averaged $W_h = 0.06582$ lb. Using this data, Eq. 2 becomes:

$$v_h = \sqrt{\frac{2(386.4)R}{0.06582 + \frac{0.06897}{3}}}$$

For trial one, $R = 94$ in.-lb and $v_h = 51.3$ mph. The predicted or calculated speeds for the ten bungee cords tested are tabulated in Table 1.

CONCLUSIONS

1. Equation 2 represents a first order analysis of hook speed which gives an upper bound and a close estimate. Our findings indicate that predictions are approximately 8.8% too high for 50% elongation stretch. Actual values of hook speed depend on the exact manner of their release and on the load-deflection history of the cord. For these reasons, it does not appear useful to refine the estimate of Eq. 2.

2. Safety eyewear with tempered glass lenses is required by ANSI Z87.1-1989 to survive an impact of a 1 in. diameter steel ball dropped 50 in. [9]. The associated energy level is 7.409 inch pounds which is 8% of the available energy released by a bungee cord under its design environment of 50% stretch.

3. Hook speeds of 45 to 49 mph are developed for three foot bungee cords under design use conditions and it is clear that the eye cannot resist this loading environment. Indeed, the majority of bungee cord accidents involve the eye.

4. Given the high hook speeds and high energy levels, manufacturers should continue to recommend stretching strategies which remove a user's eyes from the hook trajectory. A typical on-product warning is shown in Fig. 4.

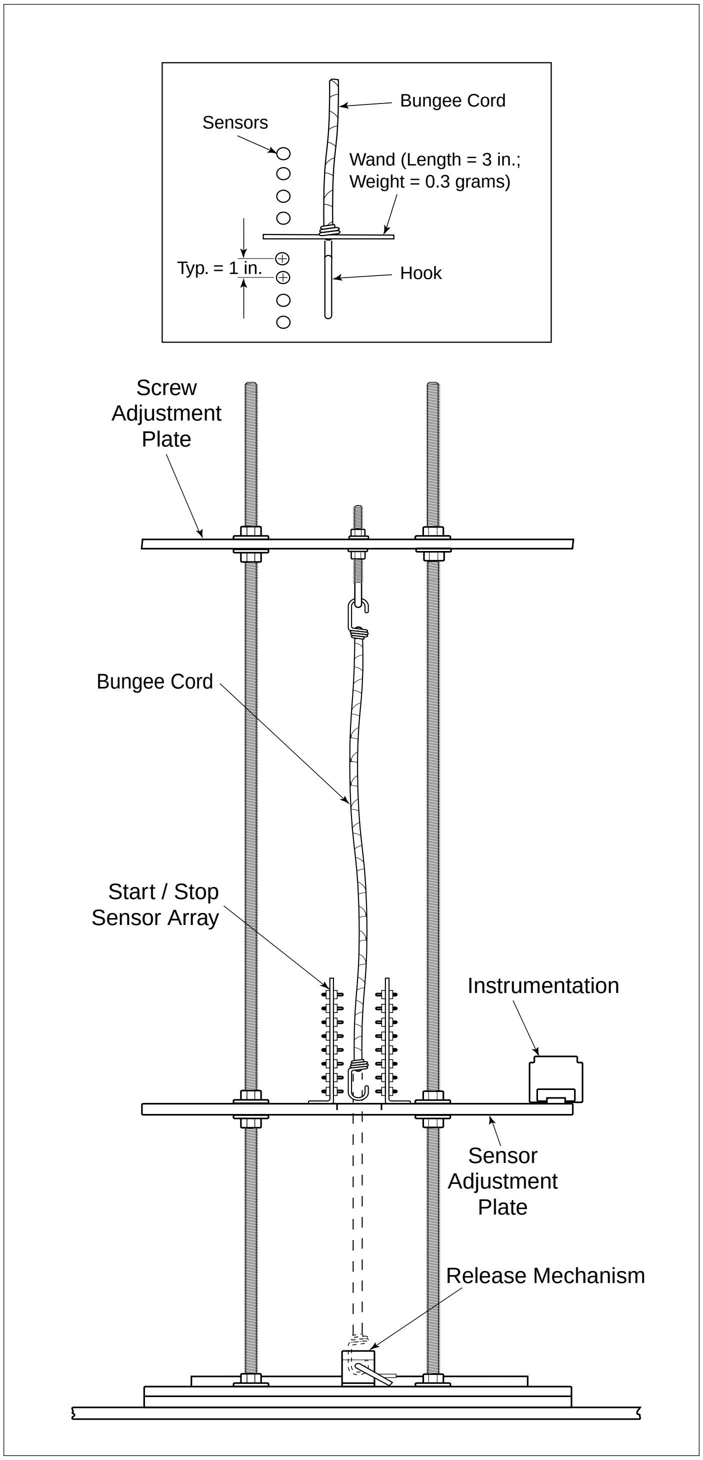

Fig. 2 Speed Test Set-up

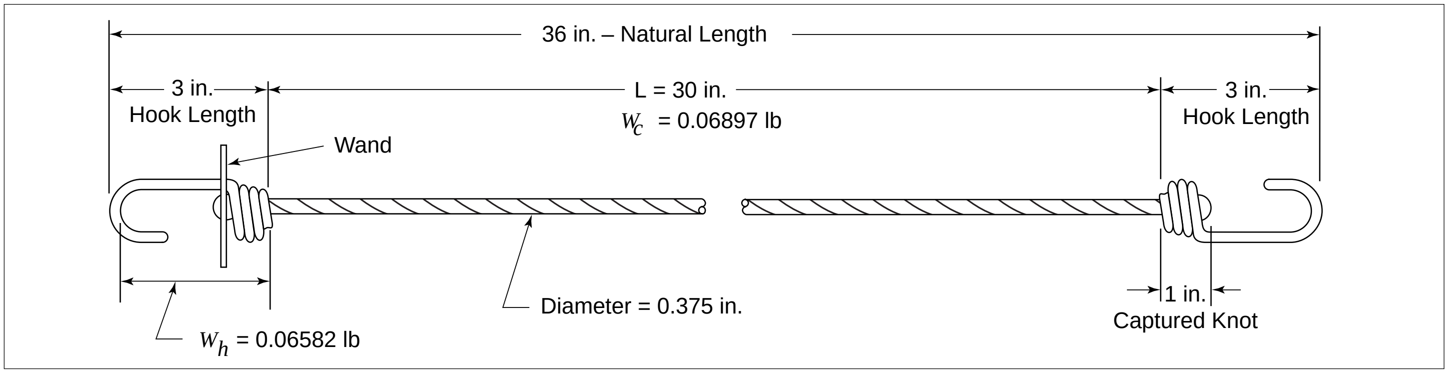

Fig. 3 Typical 3 foot Bungee Cord

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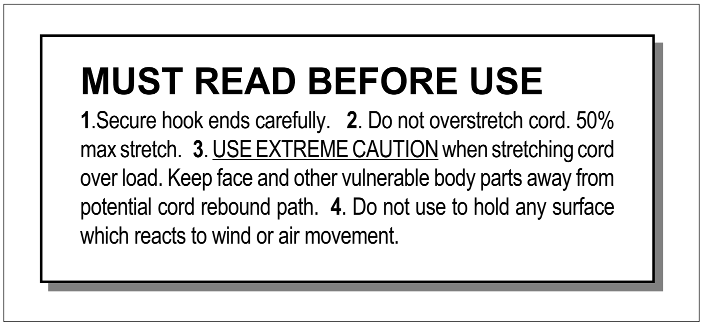
[1] Omron Model E3X-All fiber optic amplifier, Omron Model E32-TC200 fiber optic cable, and Newport Model P5000A timer.

Table 1 Bungee Cord Hook Speed and Strain Energy
(Length = 36 in.; Diameter = 0.375 in.; Elongation = 18 in.)

Trial No.	Toughness T (in.-lb)	Resilience R (in.-lb)	Hysteresis $\frac{T-R}{T}$	Measured Hook Speed v_h (mph)	Calculated Hook Speed v_h (mph)
1	116	94	19.0%	47.3	51.3
2	105	86	18.1%	45.5	49.1
3	114	94	17.5%	48.0	51.3
4	122	100	18.0%	48.9	53.1
5	106	87	17.9%	45.5	49.5
6	112	90	19.6%	45.3	50.4
7	103	84	18.4%	45.1	48.6
8	115	96	16.5%	45.8	51.9
9	110	91	17.3%	47.3	50.7
10	105	86	18.1%	45.3	49.1
Average	111	91	18.0%	46.4	50.5



MUST READ BEFORE USE

1.Secure hook ends carefully. **2**. Do not overstretch cord. 50% max stretch. **3**. USE EXTREME CAUTION when stretching cord over load. Keep face and other vulnerable body parts away from potential cord rebound path. **4**. Do not use to hold any surface which reacts to wind or air movement.

Fig. 4 On-Product Warning Label

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