UNDERSTANDING SHOCK LOADS
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When most people think of the cause of a line (chain, wire, or fiber rope) failing, they think of the load exceeding the tensile breaking strength of the line. While this situation can certainly cause the line to fail, there is another possible cause—the dynamic load (or shock load) exerted on the line is greater than the line's energy-absorbing capacity.

A shock load is the force that results when an object suddenly accelerates or decelerates, but we most often associate it with the abrupt stopping of a falling object. Remember the old adage: “It is not the fall that kills you, it is the sudden stop at the end.” A shock load force is exerted on both the object and whatever stops the object’s fall. While this force is momentary, it can be tremendous.

Three factors determine the magnitude of the shock load: the weight of the object, the speed that the object is traveling before it starts to decelerate, and the rate of deceleration (the stopping distance).

With a free-falling object, the stopping distance (or time it takes for the object to stop falling) is critically important in determining shock loads, and the amount of stretch/elasticity in the material stopping the fall determines this distance. The more a material stretches, the more energy it absorbs. Bungee cord (a.k.a. shock cord) has a great deal of elasticity and is an excellent shock absorber. Therefore, falls on bungee cord typically result in relatively low shock loads. On the other hand, steel cable, and especially chain, has very little elasticity, and falls involving these materials usually result in extremely high shock loads.

The tensile breaking strength of a line is not related to its energy-absorbing capacity. In fact, many lines with very high tensile strengths that allow them to hold extremely heavy loads have very low energy-absorbing capacities and can break easily when subjected to dynamic shock load.

A common situation where we might want to calculate a shock load relates to fall protection. How much shock load results when a technician falls a specified distance, is caught by his harness and lanyard, and stops over a specified distance as the lanyard stretches or the shock absorber on the lanyard expands?

The equation for solving this problem is:

\[
\text{Force} = \text{Weight} \times \left( \frac{\text{Free Fall Distance}}{\text{Stopping Distance} + 1} \right)
\]

Note: The “1” represents the weight of the falling object. Without it there would be no load on the line after the initial shock occurs, so do not forget to include it. If both the free fall distance and the stopping distance are zero (there is no fall and therefore no shock load), then these two zeros cancel each other out, and Force = Weight \times 1 or just the weight of the object. If the stopping distance is zero, and the free fall distance is greater than zero, then force would be infinite, which is not possible. So, the stopping distance must be greater than zero.
EXAMPLE: A 200-pound man wearing a safety harness and lanyard falls 6 feet. As he stops, the harness and lanyard stretch 6 inches (or .5 feet). What is the force on him and the rigging that supports him?

Note: Remember to keep all measurements in feet.

Force = 200 × \(\frac{6}{0.5} + 1\)

Force = 200 × (12 + 1)

Force = 200 × 13

Force = 2,600 pounds

If this number seems large to you, it is; but it is also correct. It would also probably be fatal. Shock loads can be huge; that is why you want to avoid them at all costs.

SHOCK LOAD ON WIRE ROPE

The equation used above to calculate the force of a falling object is straightforward, and it is easy to see how most of the numbers were derived. But, where did the stopping distance come from? To be honest, that number in the example, half a foot, was made up. The actual stopping distance is determined by the elasticity of the material stopping the fall. The equation for calculating the shock load when a wire rope stops a falling object, taking into account the elasticity of wire rope, is:

\[
\text{Shock Load} = \text{Load} \times \left(1 + \sqrt{\frac{2 \times \text{FD} \times \text{Area} \times E}{\text{Load} \times \text{Length} \times 12}}\right)
\]

where . . .

Load is the weight of the falling object in pounds;
Falling Distance (FD) is in inches;
Length of wire rope is in feet;
Modulus of Elasticity (E) is in pounds per square inch (psi).

Note: The modulus of elasticity for wire rope that has the structural stretch removed, either through pre-stretching or through use is, 15,000,000 psi. New wire rope has a modulus of elasticity of 11,500,000 psi.

Area (Equivalent Metallic Area in square inches) = Diameter of wire rope (in inches) × Diameter of wire rope (in inches) × Area Factor.

Note: Area factors of commonly used wire ropes are listed in the table on the next page.
**EXAMPLE:** A 200-pound object is connected to a 10-foot length of 7x19 GAC, 1/4 inch in diameter and free-falls 1 foot (12 inches). What is the shock load on the wire rope and the beam to which it is attached?

First, calculate the area of the wire rope using the area factor for 7x19 GAC in the table.

\[
\text{Area} = 0.25 \times 0.25 \times 0.472 = 0.0295 \text{ square inches}
\]

Next, plug the other variables into the shock load equation.

\[
\text{Shock Load} = \text{Load} \times \left(1 + \frac{10,620,000}{\sqrt{200 \times 10 \times 12}}\right)
\]

\[
\text{Shock Load} = \text{Load} \times (1 + \sqrt{442.5})
\]

\[
\text{Shock Load} = \text{Load} \times (1 + 21.059)
\]

\[
\text{Shock Load} = 200 \times 22.059
\]

\[
\text{Shock load} = 4,411.88 \text{ pounds}
\]

### SHOCK LOADS ON FIBER ROPE

Accurately calculating the shock load of fiber ropes can be more difficult than calculating the shock load on wire rope for three reasons: 1) because humidity can change the ability of some materials to stretch, and some natural fibers lose elasticity with age; 2) because there are many different blends of materials; and 3) because different manufacturers of rope supply different data about the energy-absorbing capacities of their ropes. Despite this, it is possible to get a good idea of the shock load of a falling object being caught by a fiber rope.

As stated earlier, different companies supply different data on the elasticity of their ropes. We will look at the data provided by two rope companies, New England Ropes and Yale Cordage, and show how to calculate shock loads on each.

**Method #1:** Ron Reese, an arborist in Chattanooga, Tennessee, developed the first method we will look at. His equation is:

\[
\text{Shock Load} = \frac{-B + \sqrt{B^2 - (4 \times A \times C)}}{4 \times A}
\]

- **A** = \((0.005 \times \text{Rope Stretch} \times \text{Rope Length})/ \text{Rope Load}\)
- **B** = \(-2 \times A \times \text{Load}\)
- **C** = \(-\text{Load} \times \text{Fall Distance} \text{ (in feet)}\)

**Rope stretch** is a percentage specified by the manufacturer. For example, New England Ropes KMIII 7/16” rope stretches 5.1 percent. Use “5.1” in the equation for calculating A above.

**Rope length** is the distance, in feet, between the load and the termination point.

**Rope load** is the force, in pounds, required to achieve the manufacturer’s rope stretch. For example, the rope stretch of New England Ropes KMIII is 5.1 percent at 10 percent of the minimum breaking strength (MBS). The MBS is 7,083 pounds, so the rope load = 0.1 \times 7,083 pounds = 708 pounds.

**Load** is weight of object that falls.

**Fall** is the distance, in feet, that the load free falls.

Let’s use the same load, rope length, and fall distance we used in our example calculation for wire rope. We’ll use 1/2-inch Multiline II, a fairly stretchy rope, instead of 1/4-inch 7x9 GAC.

**EXAMPLE:** A 200-pound object is connected to a 10-foot length of 1/2-inch diameter Multiline II and free-falls 1 foot. What is the shock load on the rope and the beam to which it is attached?

According to New England Ropes, Multiline II has an elongation rate of 1.7 percent at 10 percent of its tensile strength. Since the tensile strength of 1/2-inch diameter Multiline II is 6,000 pounds, 10 percent would be 600 pounds.

\[
A = \frac{0.005 \times 1.7 \times 10}{600}
\]

\[
B = -2 \times 0.000141667 \times 200
\]

\[
C = -200 \times 1
\]

Plugging these numbers into the shock load equation for fiber rope, we get:

\[
\text{Shock Load} = \frac{0.056666667 + \sqrt{0.056666667^2 - (4 \times 0.000141667 \times -200)}}{4 \times 0.000141667}
\]

\[
\text{Shock Load} = \frac{0.056666667 + \sqrt{0.003211111 - (-0.1133336)}}{0.000566668}
\]

\[
\text{Shock Load} = \frac{0.056666667 + 0.341386454}{0.000566668}
\]

\[
\text{Shock Load} = \frac{0.398053254}{0.000566668}
\]

\[
\text{Shock load} = 702.45 \text{ pounds}
\]
This is significantly less than the 4,411.88 pounds of shock load that occurred on the same fall using wire rope.

**Method #2:** Yale Cordage does not list the elongation of their ropes in percentages of the breaking strength as New England Rope does, so the equation above will not work. Instead, Yale Cordage provides energy-absorption data that is based on the weight of each rope. For example, Yale Cordage’s Double Esterlon rope, a low-stretch rope, has a “green working energy absorption” of 291 foot-pounds per pound of rope. A 5/8-inch Double Esterlon rope weighs 13.7 pounds per 100 feet (or .137 lbs/ft) and has a recommended working load limit of 3,400 pounds at 20 percent of its breaking strength (a 5:1 design factor). As before, let’s use a 200-pound load falling 1 foot on a 10-foot-long piece of rope.

First, we need to calculate the force of the fall:

\[
\text{Force} = \text{Load} \times \text{Falling Distance}
\]
\[
\text{Force} = 200 \text{ pounds} \times 1 \text{ foot}
\]
\[
\text{Force} = 200 \text{ foot-pounds}
\]

Next we calculate the energy-absorption capacity of our rope using Yale Cordage’s equation:

\[
\text{Energy-Absorption Capacity} = \text{Length of Rope} \times \text{Green Working Energy Absorption} \times \text{Weight of 1 foot of rope}
\]
\[
\text{Energy-Absorption Capacity} = 10 \text{ feet} \times 291 \text{ foot pounds} \times 0.137 \text{ pounds per foot}
\]

Since the force being placed on the rope (200 foot pounds) is less than the Energy-Absorption Capacity (398.67 foot pounds) of the rope, we know that the rope will be able to sustain the shock load without failing. However, to find the actual shock load on the rope, we use the equation

\[
\text{Shock Load} = \frac{\text{Force}}{\text{Energy-Absorbing Capacity}} \times \text{Recommended Working Load}
\]

So, for Yale’s 5/8-inch diameter Double Esterlon rope (which has a working load limit of 3,400 pounds at 5:1), the shock load is:

\[
\text{Shock Load} = \frac{200}{398.67} \times 3,400
\]
\[
\text{Shock load} = 1,705.67 \text{ pounds}
\]

As we can see, Yale Cordage’s 5/8-inch diameter Double Esterlon has less elasticity than New England Ropes Multiline II but a great deal more elasticity than 1/4-inch 7x9 GAC wire rope.

**SHOCK LOADS ON CHAIN**

The steel in an alloy chain has a modulus of elasticity of 30,000,000 psi, so it has even less elasticity than wire rope and, therefore, potentially greater shock loads. This is why the shock load on the beam supporting a load being lifted by a 16-foot per minute (fpm) chain hoist can be 20 to 50...
percent greater than the load being lifted, simply due to the starting and stopping of the hoist. A 64-fpm chain hoist can create a shock load that is 200 percent greater than the load being lifted.

According to Phil Braymen, engineering manager at Laclede Chain Manufacturing Company, “The chain industry does not test, certify, or condone shock loading [of chain].” The National Association of Chain Manufacturers (NACM) states, “Manufacturers do not accept any liability for injury or damage which may result from dynamic or static loads in excess of the working load limit.”

To help understand how static loads affect chain, I ran several tensile tests using 1/4-inch Grade 30 proof coil chain. At its working load limit—25 percent of its breaking strength—this chain stretches only about one-half of one percent of its length. At approximately 60 percent of the breaking strength of chain—the yield point of the steel—the chain stretches approximately 1 percent of its length. However, when the force on the mild steel chain reaches the yield point, two things happen: 1) the shape of the links begins to deform, causing the links to get narrower and longer, and 2) the metal enters its “plastic stage,” where the metal stretches significantly under slight increases in force. During this stage, the growing tension on the chain slows dramatically as the deforming and elongating chain absorbs the energy. The tension grows even slower as the tension surpasses 90 percent of the breaking strength of the chain. In the final 40 percent of the breaking strength of the chain, the stretch of the chain is approximately 7.5 times greater than in the first 60 percent. This nearly constant changing of the rate of stretch under different amounts of force makes it nearly impossible to accurately calculate shock loads on chain with a mathematical equation.

The bottom line is that shock loads on chain can be quite high and can very easily exceed the working load limit of the chain, especially given the low design factor used for chain. Shock loading chain should be avoided when possible.

**CHAIN HOISTS AND SHOCK FORCES**

Because most chain hoists start and stop suddenly (very little “ramp up” or “ramp down” to the time), the starting and stopping of a chain hoist can produce a significant amount of shock load. How much? That depends on the acceleration and deceleration speed of the hoist. The starting and stopping of a 16-fpm chain hoist does not produce as much shock load as the starting and stopping of a 64-fpm chain hoist.

As a general rule of thumb, we say that a 16-fpm chain hoist produces a shock load of between 20 and 25 percent of the weight of the load it is lifting when it starts or stops. A 16-fpm chain hoist lifting a 2,000-pound load would produce a shock load between 400 and 500 pounds. So, the total force on the point would be between 2,400 and 2,500 pounds, plus the weight of the hoist and chain. Let’s test this rule of thumb using the dynamic force formula to calculate the force of a 16-fpm chain hoist starting or stopping a 2,000-pound weight. If we assume that the acceleration/deceleration time for the chain hoist is one second and we convert the velocity of the chain into seconds (16 fpm / 60 = 0.266667 fps) we see that the acceleration of the chain is 0.266667 fps². Now we can plug these variables into the dynamic force equation:

$$F = \frac{1}{2} m a$$
Dynamic Force = Weight × Acceleration
Dynamic Force = 2,000 × 0.266667
Dynamic Force = 533.32 pounds

Add this to the 2,000-pound load, and the calculated force is 2,533.32 pounds. This is pretty darn close to the shock load we derived from our rule of thumb.

No matter how you calculate the shock load that results from the starting and stopping of the chain hoist, you need to include this amount into the load being supported by each beam because every time the chain hoist starts or stops the load on the point increases by roughly 533 pounds.

One more thing: “bumping” the hoist multiple times in quick succession (often done when leveling a truss) can compound the shock loads. Pausing a few seconds between bumps will help keep this compounding from occurring.

CONCLUSION
Shock loads are not the same as static loads. The stiffness of the line (elasticity or lack of elasticity) amplifies the static load of a falling object when it decelerates. The less elasticity in the line, the greater the amplification. Technicians must consider the elasticity (energy-absorbing capacity) of lines whenever a shock load is possible. As we have demonstrated, calculating the actual shock load on a wire or fiber rope is possible and can help you understand the results of dynamic forces involved in rigging.

Delbert L. Hall is president of D2 Flying Effects, an ETCP Certified Rigger and Recognized Trainer, and be regularly presents rigging related sessions at the USITT Conference & Stage Expo and at LDI. He is also a professor of theatre and dance at East Tennessee State University and the recipient of United States Institute for Theatre Technology Southeast Regional Section’s Founders Award as the Outstanding Educator in Theatrical Design and Technology for 2001. His rigging app, RigCalc, is available for Android and Apple iOS devices.

Editor’s note: This article is adapted from Delbert Hall’s book Rigging Math Made Simple (Spring Knoll Press, February 4, 2013).