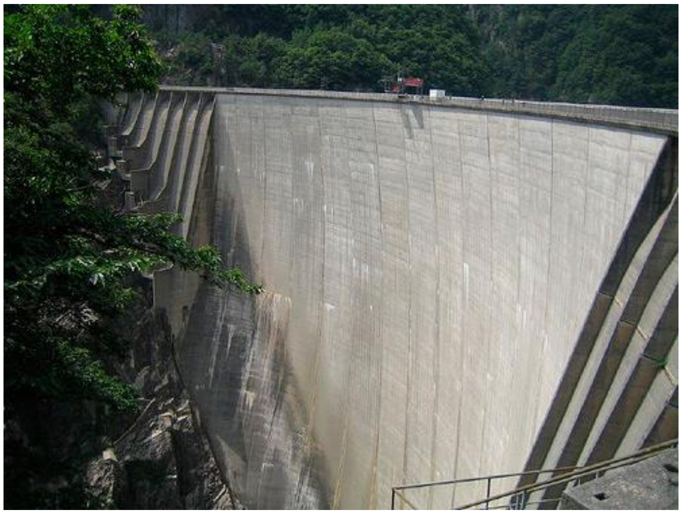
Dam Jumpers



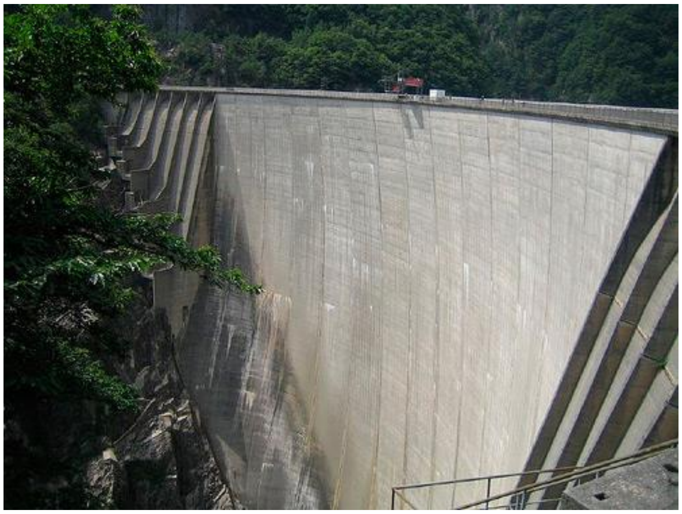

In 1995, one of the most famous stunt scenes ever was filmed for the opening sequence of GoldenEye. In the film, James Bond jumps from the top of a 220m dam, and anchors himself to the ground at the maximum stretch of the rope.

The stunt was performed by Pierce Brosnan's stunt double, Wayne Michaels, on the Verzasca dam in Switzerland, and set a record for the highest bungee jump from a fixed structure.

Wayne Michaels weighed 75kg at the time. Assuming the bungee rope to have a modulus of elasticity 2000N, calculate the (unstretched) length of rope required for Wayne to reach maximum stretch at exactly 220m.

At the maximum extent of the bungee cord, our hero shoots a grapple into the ground and uses it to stop himself bouncing back upwards. Calculate the tension in the grapple wire.

Dam Jumpers Solutions

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$$Initial\ Energy = GPE$$
$$GPE = 220 \times 75 \times 9.8 = 161700J$$

$$Final\ Energy = EPE$$
$$EPE = \frac{\lambda e^2}{2l} = \frac{2000(220-l)^2}{2l}$$

$$E_{initial} = E_{final} \quad \Longrightarrow \quad 161700 = \frac{2000(220-l)^2}{2l} \quad \Longrightarrow \quad 161.7 = \frac{(220-l)^2}{l}$$

$$\Longrightarrow \quad 161.7l = 48400 - 440l + l^2 \quad \Longrightarrow \quad l^2 - 601.7l + 48400 = 0$$

$$\Longrightarrow \quad l = 506.05 \ldots \quad or \quad l = 95.64 \ldots \qquad l < 220 \quad \Longrightarrow \quad \boldsymbol{l = 95.6m\ to\ 3\ s.f.}$$

At the maximum extent of the bungee cord, our hero shoots a grapple into the ground and uses it to stop himself bouncing back upwards. Calculate the tension in the grapple wire.

$$Tension\ in\ rope: \quad T = \frac{\lambda x}{l} = \frac{2000 \times (220 - 95.6)}{95.6} = 2600.53 \ldots \quad Weight: \quad mg = 75 \times 9.8 = 735$$

$$Tension\ in\ wire = T - mg = \boldsymbol{1870N\ to\ 3\ s.f.}$$

Bungee Jump: *Phases of motion*

Figures shown are approximate, and based loosely on the Verzasca dam bungee jump from GoldenEye, ignoring loss of energy from the system due to air resistance, heat, transverse motion (in reality bungee jumpers end up swinging sideways, which reduces vertical speed).
Note: Displacement, velocity and acceleration values are given as positive in the downwards direction.

Beginning:

Displacement	*Velocity*	*Acceleration*	***GPE***	***KE***	***EPE***
$0m$ (min) increasing	$0ms^{-1}$ increasing	$9.8ms^{-2}$ constant	$160kJ$ **(max)** **decreasing**	$0kJ$ **(min)** **increasing**	$0kJ$ **(min)** **constant**

Phase 1 - Freefall: At the start, the jumper is stationary, and the cord is slack, so all energy is in the form of gravitational potential. The only force acting is his own weight, hence his acceleration is simply that due to gravity. During this phase, GPE is being converted directly to KE.

Cord becomes taut:

Displacement	*Velocity*	*Acceleration*	***GPE***	***KE***	***EPE***
$95m$ increasing	$43ms^{-1}$ increasing	$9.8ms^{-2}$ decreasing	$90kJ$ **decreasing**	$70kJ$ **increasing**	$0kJ$ **(min)** **increasing**

Phase 2 – Cord taut, still accelerating: At the instant the cord becomes taut, nearly halfway down, the jumper is travelling at around $90mph$, but he is still accelerating (albeit not as rapidly as when in freefall). Nearly half of the GPE has now been converted into KE, but during this phase GPE will go increasingly into EPE, meaning KE will not increase as fast as before. The resultant force will still be downwards, as the tension is not as great as the weight.

Max speed:

Displacement	*Velocity*	*Acceleration*	***GPE***	***KE***	***EPE***
$130m$ increasing	$47ms^{-1}$ (max) decreasing	$0ms^{-2}$ decreasing	$65kJ$ **decreasing**	$80kJ$ **(max)** **decreasing**	$15kJ$ **increasing**

Phase 3 – Slowing down: Eventually the upward force of tension will exceed the weight, and his downward speed will begin to drop at last. From now on, energy is being transferred from both GPE and KE to EPE due to the increased tension in the bungee cord.

Lowest point:

Displacement	*Velocity*	*Acceleration*	***GPE***	***KE***	***EPE***
$220m$ (max) decreasing	$0ms^{-1}$ decreasing	$-25ms^{-2}$ (min) Increasing	$0kJ$ **(min)** **increasing**	$0kJ$ **(min)** **Increasing**	$160kJ$ **(max)** **decreasing**

Phase 4 – Bouncing back:
At the lowest point, all GPE and KE has been transferred to EPE. Since the cord is at maximum extension, the acceleration is now the greatest it will be at any point during the jump, but it is still acting in the upwards direction. However, since the jumper has lost all downward speed by this point, rather than falling downwards more and more slowly, he will begin travelling upwards faster and faster. The reverse journey is identical in all respects except the direction of velocity and acceleration. His maximum speed will be reached once again, for instance, at the same point (where tension equals weight, giving zero acceleration), but this time he will be travelling up instead of down. He should end up exactly back at the starting point with zero speed and a slack rope.

Note that due to the inefficiency of this system in real life (see disclaimer at the top!) a jumper won't quite reach their original height.