Crevasse Rescue and Trigonometry TEACHER GUIDE

Polar Literacy and Crevasse Safety
Begin with the slideshow on ice in polar landscapes and how that influences polar research and safety. You can then follow up with a video on crevasses

A **crevasse** is a crack that forms in a glacier. These pose a significant safety risk for polar researchers. Rescuing a victim of a crevasse fall is challenging as it requires going against gravity to get a person up and out of the crevasse. This work also needs to be done quickly due to the threat of hypothermia. Researchers (and mountaineers) travel across glaciers roped together so that if someone falls into a crevasse their fall is mitigated by the rope and they can then be pulled out of the crevasse.

Through the use of PreCalculus and physics, we can learn about how to set up a rope system that is more effective for crevasse rescue!

An important early step in building the rope system is to create an anchor and a backup anchor. We need to figure out how to orient these in respect to each other.

Physical demonstration of how angle between two ropes affects distribution of weight

Have two students volunteer to hold the ends of the rope to support the weight or, if supplies allow, break students up into small groups of two or more. Each group needs a weight tied to a rope. Each student can pick up the weight individually before beginning to get an idea of how heavy it is. To start, have both students pull up on the weight, standing close to each other trying to hold the rope as close to vertical as possible (Fig. 1).

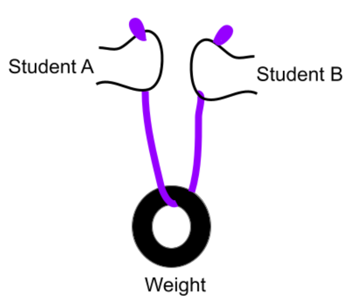


Figure 1: Both students holding the rope vertically

The two students should then walk away from each other, attempting to hold the rope as horizontally as possible while keeping it taut (Fig 2).

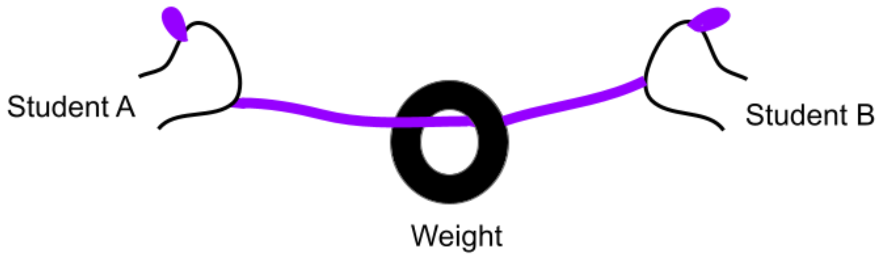
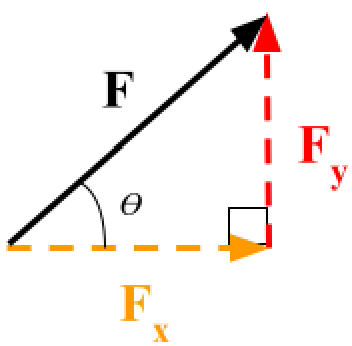


Figure 2: Students should attempt to hold the rope as close to horizontal as possible

Have students record their observations and share them aloud. Observations should generally include: the weight felt progressively heavier as the angle between the two rope ends got wider, the weight felt lighter when two people were holding the rope ends vertically than when one person was holding the weight, and it seemed impossible to hold the rope perfectly horizontal.

Mathematical analysis of angles and forces

If the magnitude (**F**) and angle (Θ) of a force are known, they can be broken into horizontal ($\mathbf{F_x}$) and vertical ($\mathbf{F_y}$) components.



We've made a right triangle! Our tool for relating sides and angles of right triangles is trigonometry.

Recall:

$$sin(\theta) = \frac{opposite}{hypotenuse}$$

$$cos(\theta) = \frac{adjacent}{hypotenuse}$$

$$tan(\theta) = \frac{opposite}{adjacent}$$

The force makes up the hypotenuse of the triangle, so filling in the details we get:

$$sin(\theta) = \frac{F_y}{F}$$

$$cos(\theta) = \frac{F_x}{F}$$

We can isolate what we'd like to solve for:

$F * sin(\theta) = F_y$

$F * cos(\theta) = F_x$

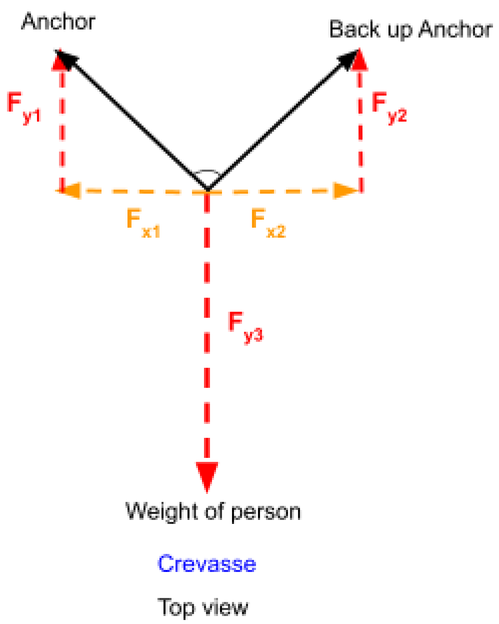
These can be rearranged differently if we need to solve for the original force!

Assessing Anchor Configurations

When building anchors, rescuers need to understand how different configurations affect the forces on the anchors in order to establish safe rescue systems. Students will be assessing the tension on the anchor and backup anchor for three different scenarios. Lowest tension is the goal! NOTE: the length of the rope does not change the tension in these scenarios (this can be demonstrated to students by having them do the weight exercise with longer and shorter ropes).

Important things to know:

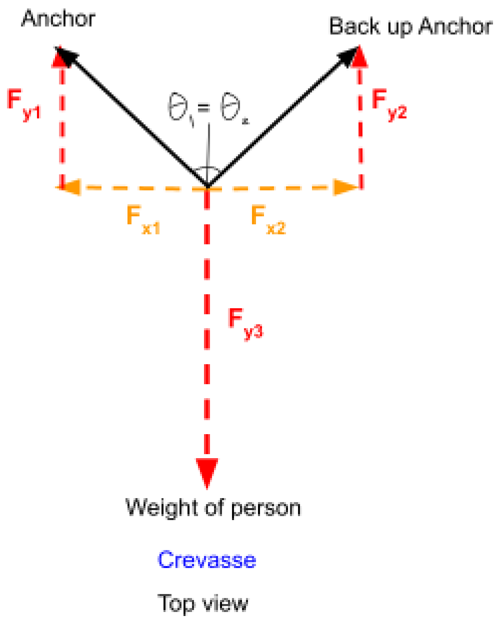
1. These systems are in **equilibrium**, meaning the forces in the x-direction sum to zero and the forces in the y-direction sum to zero. There are 3 forces in the y-direction: one at each anchor and the weight of the fall victim. The crevasse victim's weight is in the negative y-direction, as it is pulling down and acting in the opposite direction of the anchor forces. The x-direction forces are equal in magnitude, but are in opposite directions.



$\sum F_x = 0 = F_{x1} + F_{x2}$

$\sum F_y = 0 = F_{y1} + F_{y2} + F_{y3}$

2. The anchor and backup anchor are **equalized**, meaning that the weight of the fallen person is bisecting the angle between the ropes attached to the anchors. Note that equalizing the anchors is an important safety goal, but calculations can be done when the angles are not equal to each other.



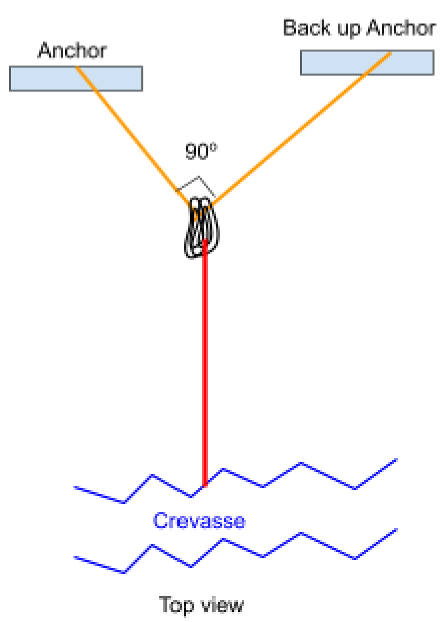
$F_{y1} = F_{y2}$

Students can start building an understanding of these systems by calculating the forces on the anchors in these scenarios. You can have students vote for which they think will prove to be the best option!

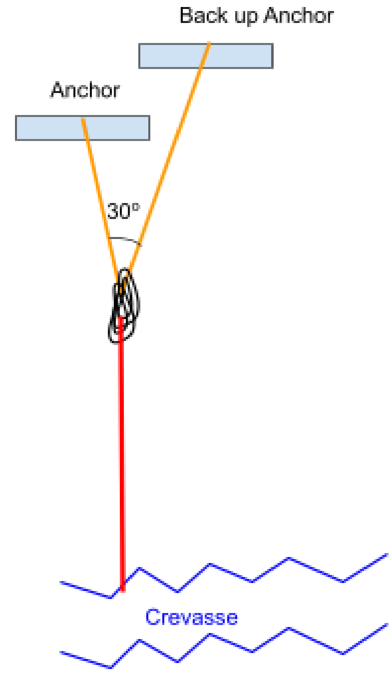
You can select a weight for the person (and their equipment) in the crevasse, or you can use a weight of 180 lbs (the solution guide uses 180 lbs.)

Anchor Scenarios:

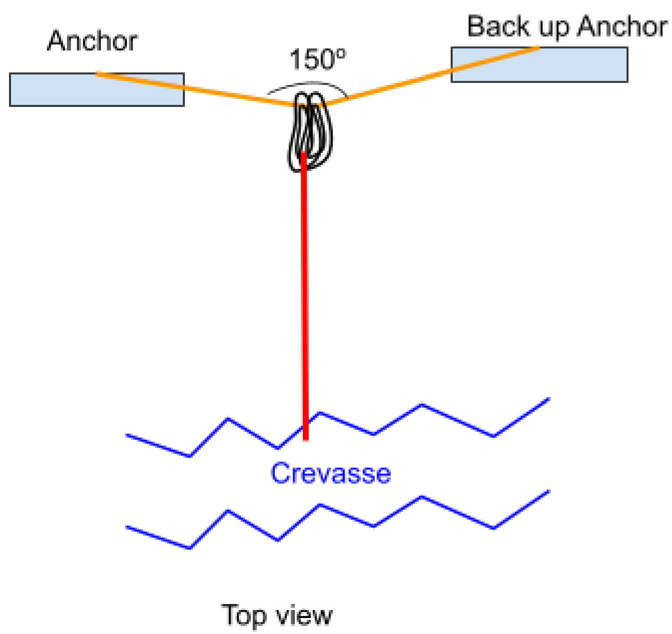
Angle between anchor ropes is 90 degrees:



Angle between anchor ropes is 30 degrees:

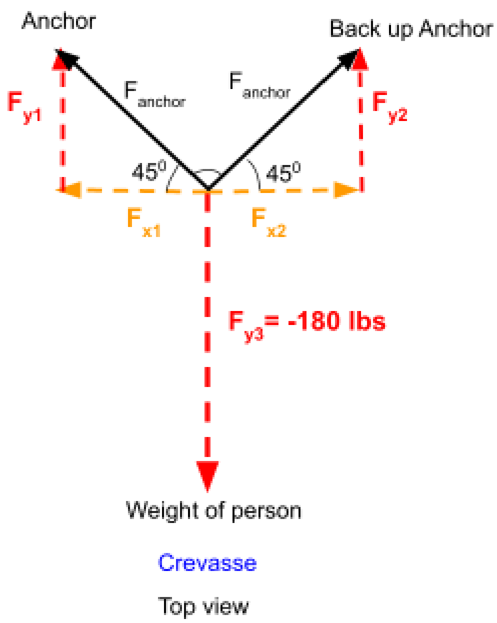


Angle between anchor ropes is 150 degrees:



Solutions

Angle between anchor ropes is 90 degrees:



We need to solve for the force on the anchors, the hypotenuse of the triangles!

To solve for the hypotenuse, we need to know another side, in addition the angle inside the triangle

We know that the vertical forces sum to zero, so:

$\mathbf{F_{y1}} + \mathbf{F_{y2}} - 180 = 0$

We also know that $\mathbf{F_{y1}} = \mathbf{F_{y2}}$

So $2\mathbf{F_{y1}} - 180 = 0$

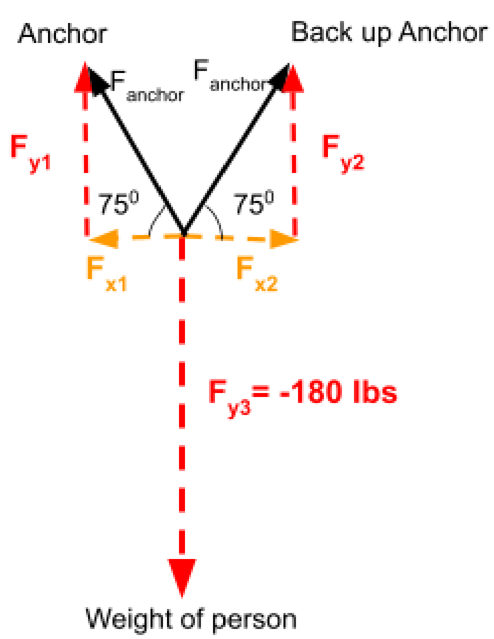
$\mathbf{F_{y1}} = \frac{180}{2} = 90\text{lbs}$

Now to solve for the hypotenuse: $sin(45) = \frac{90}{F_{anchor}}$

$F_{anchor} = \frac{90}{sin(45)} \approx 127\text{lbs}$

The force on each anchor is approx 127 lbs

Angle between anchor ropes is 30 degrees:



F_{y1} and F_{y2} remain the same (because the weight hasn't changed), but we still need to solve for the hypotenuse of our different triangle

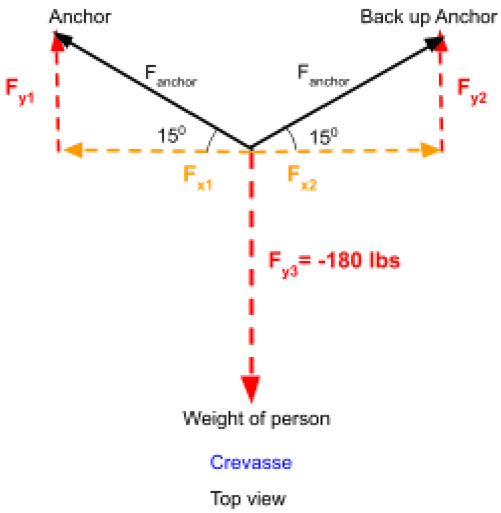
$\mathbf{F_{y1}} = \frac{180}{2} = 90\text{lbs}$

Now to solve for the hypotenuse: $sin(75) = \frac{90}{F_{anchor}}$

$F_{anchor} = \frac{90}{sin(75)} \approx 93\text{ lbs}$

The force on each anchor is approx 93 lbs

Angle between anchor ropes is 150 degrees:



Again, F_{y1} and F_{y2} remain the same (because the weight hasn't changed), but we still need to solve for the hypotenuse of our different triangle

$$F_{y1} = \frac{180}{2} = 90\text{lbs}$$

Now to solve for the hypotenuse: $sin(15) = \frac{90}{F_{anchor}}$

$$F_{anchor} = \frac{90}{sin(15)} \approx 348 \text{ lbs}$$

The force on each anchor is approx **348 lbs**

30 degrees is the best option because the tension is the lowest on the anchors, so failure is the least likely. This can be asked as a question to the students and have them justify their answers.

EXTENSIONS:

- Have students calculate the percent of the weight loaded on each anchor in each scenario

  Example: $\frac{348}{180} * 100 \approx 193$ % of the weight is on each anchor

- Have students calculate the tensions for a scenario where the anchors aren't equalized (theta 1 does not = theta 2)
- Have students write and graph the F on each anchor as a function of angle between anchors. Then have students describe the end behavior of the graph