Measurement Activity: Covenant Sculpture

Definition of Measurement: The maximum height of the sculpture will be defined as the highest point that the sculpture reaches from the ground (sidewalk).

Hypothesis #1: It is possible to measure the maximum height of the sculpture using string, a weight, and a measuring tape.

Procedure:

1. Determine the diameter of pipe that makes the sculpture.
   a. Measure the circumference of the pipe at various places on the sculpture.
   b. Take an average of the measurements to determine the average diameter.

2. Measure height.
   a. Place weight on string.
   b. Throw weight over sculpture.
   c. Position string at top of sculpture and mark string at the ground level.
   d. Use a measuring tape to measure the distance of the string.

3. Subtract the diameter from the total length of the string and divide by two.

No observations or measurements were taken because it was almost impossible to have the string positioned at the top of the structure.
Hypothesis #2: It is possible to measure the maximum height of the sculpture using a protractor, a tape measurer, and some sunshine.

Procedure:

1. Measure the distance from the point below the maximum height of the sculpture to the point of a shadow produced by the sculpture. This distance is the adjacent side of a triangle.

2. Using a protractor measure the angle that is made by the adjacent side of the triangle and the hypotenuse of the triangle. The hypotenuse is defined as the highest point of the structure to the shadow.

3. Using trigonometry, calculate the opposite side of the triangle, which is the height of the structure, by using the formula: \( \tan \text{ of angle} = \text{opposite side} / \text{adjacent side} \).

Observations:

- Tangent angle = 65 degrees
- Adjacent side = 28 feet
- Opposite side = 60 feet plus or minus 5 feet = Maximum height of structure

This measurement takes into account some uncertainty. The largest source of error lies in accurate protractor reading. Two-degree variation in either direction will change the end result by five feet. Also, this final measurement is calculated based the following assumptions: the point that was measured under the structure was perpendicular to the maximum height, the protractor and measuring tape were accurate instruments, and we measured with some degree of accuracy.
Rich holds tape measure for a scale measurement.
Chris holds his hand out at five feet for a scale measurement while Rich continues to attempt to get the measuring device over the top of the sculpture.

The team uses their best athletic arms to lob the line over the highest point of the statue.
The line holders shimmy the measuring device towards the peak of the statue.
True teamwork. A human pyramid to retrieve the measuring tool.

Here is the method finally chosen to measure the height of the sculpture. Measured the angle created by the line from the peak of the sculpture to the endpoint of its shadow and the horizontal line from the end of the shadow to the point directly under the peak using a rolled up piece of paper and a protractor. With the distance of the horizontal line it was possible to calculate the maximum height of the statue using trigonometry.
Rich- Contributed to the brainstorming process. Used a practiced softball arm to attempt to throw the string over the sculpture. Wrangled the string at great length to find the top of the sculpture. Brought tennis ball and tape measure.

Ken – Contributed to the brainstorming process. Successfully tossed the string over the sculpture. Scoped the angle of the tangent while lying on the ground. Brought tape measure, 250 foot masonry line. Reporter.

Chris – Contributed to the brainstorming process. Took measurements. Suggested how to calculate the measurements. Supplied the laptop and typed the report.

Isabel – Contributed to the brainstorming process. Provided protractor, 50 feet of rope, camera. Recorded the process with digital photographs. Typed a small part.

**Answers to feedback questions**

- "Was it exactly 60 ft."

As we stated in the observation section, we are confident that the measurement is within plus or minus 5 feet.

- "$\ldots$ need better explanation of actual method used to get the final number."

- "I wonder about the reliability of the shadow measurements."

We will address these two questions together. The use of trigonometry to accurately measure distances is well established, and there are countless examples of where it is used in engineering and physics. For a triangle with a 90 degree angle, the ratios of the lengths of the sides are always the same regardless of the size of the triangle as long as
the corresponding angles are equal. The tangent of an angle equals the length of the side opposite the angle, divided by the length of the side adjacent to the angle. By multiplying the tangent of our angle by the distance from directly beneath the peak of the sculpture to where the shadow of the peak of the sculpture was on the ground, gave us the length of the opposite side of our triangle, which is equal to the height of the sculpture. The reliability of the shadow measurement was very good. We used a measuring tape and the measurement was accurate to within 6 inches. We plugged the maximum distance and the minimum distance into our calculations, and they were well within the range of our stated error, we do not believe it had a significant effect on our estimate. We marked where the peak of the shadow was. The shadow became irrelevant after that. All that was necessary from that point on was to sight the peak from that point. In fact, we did not even necessarily need to use a shadow. We could have sighted the peak from any point and measured from that point to the point directly beneath the sculpture.

- "What was your prediction?"

We never made a formal prediction. Rick eyeballed it at about 60 feet. Our hypothesis was that we could measure it to within plus or minus 5 feet.

- "Curious about how dependable the protractor measurements are."

That topic is covered adequately in the body of our report, and presentation.

- "Once the ball failed, how come you didn't come up with a more reasonable method for direct measurement?"

The sculpture was just too high to safely get a measuring tool to the peak of the sculpture. At least we couldn’t think of one.
"It seems like the tennis ball idea was very weak and the shadow method was a lot more reliable, but how accurately was the highest point determined this way? Did you measure several positions?"

"I probably would not have tried the tennis ball method - seems to have a great deal of error; shadow/angle measurements seem more reliable..."

We will address these comments at the same time. We don’t believe that the tennis ball idea was weak. It was the only way to measure the height directly. If you subtracted the diameter of the pipe from the length of the string, then divided by 2, the measurement would have been accurate to within 1 foot. There would be very little room for error, and that would have been no more than 2% of the actual height. The highest point of the sculpture is very obvious. It makes a peak slightly off center with the sidewalk. We did not measure several positions, but if we were to measure the sculpture again, we would measure from several different positions, as well as making further adjustments to our experimental techniques.