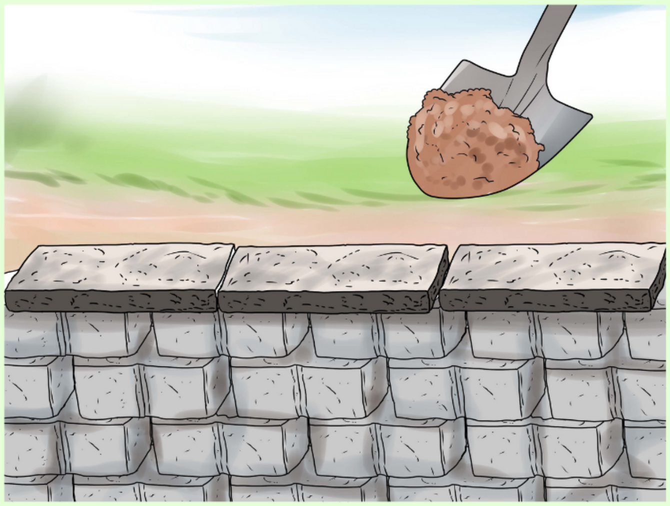

Project 2 Report

CSCE-155N

Computer Science I: Engineering and Science Focus

Retaining Wall Model System

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I. Model Details

In project one we discussed how the University of Nebraska-Lincoln needed to design a soil retaining wall to prevent soil from spreading to the sidewalk. The wall needed to be 2 meters tall, 5 meters wide, and .5 meters thick. We did not know what materials were strong enough to withstand the forces of the soil, and we had no budget set in place to proceed with the building of the project. So we established that there needs to be a comparison of cost and material strength. In Project two, we will be comparing and discussing data that was created using MATLAB to display the minimum Young's Modulus and the lowest cost of certain materials for budgeting. In addition to this, we will also display the minimum Young Modulus to describe the heights and Poisson's ratios the material can withstand. This information will help UNL in the design of walls in the future (see ***Results and Discussion***)

Within the scope of this project are several assumptions. These assumptions are used to simplify the problem or focus attention on the most significant properties. These assumptions are of the following:

Data Values

I. The soil was decided to have a Poisson's ratio of 0.4 and a density of 3000 kg/m^3. These values were chosen because they are assumed to be the upper limits of the coarse soil that can be found on the UNL campus. The wall is 2 meters tall, .5 meters thick, and 5 meters wide.

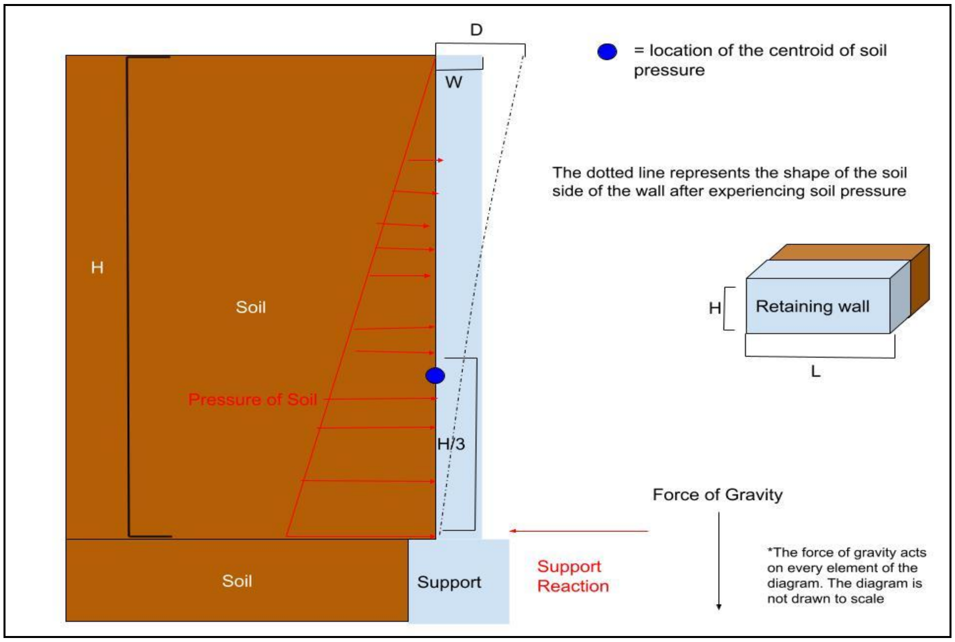

Figure 1: Wall System Model

Mechanics

I. The support foundation the wall is attached to (Figure 1) can provide an equal and opposite reaction to the force of gravity and soil pressure so the wall will not move; the net force on the wall is considered to be zero, but the net torque (twist or bend) on the wall is not zero.

II. The wall is considered to be internally stable, the wall will not snap where it connects to the support. The design is the one described and does not change from material to material. This is assumed to reduce the scope of the primary function of the retaining wall.

III. Pressure is uniform across the surface area of the wall. Soil has variations within itself in composition as it varies in depth. It is assumed those differences are negligible.

IV. Pressure is uniform across time. It is assumed that variations in pressure caused by changes in density over time are negligible. This reduces complexity.

Limits

I. The lower pressure limit at the top of the wall is considered zero Pa. In practice, air pressure exerts a force on the wall, but it is equally canceled out by pressure on the other side of the wall.

II. The maximum allowable deformation is H/240 m, and over-deformation will not cause damage to other objects, theoretically. This matches the American Concrete Institutes' allowable deformation limits for deformation that does not pose risk to other objects.

Analytical Model

In this section, we calculated the minimum Young's Modulus to determine viable materials, comment on the significance of this calculation, recommend materials, and suggest costs to factor into a budget. This was also calculated in the Project 1 report.

Young's Modulus Calculation

Table 1. List of variables, significance, and derivation.

Variable	Significance	Derivation/Input
D	Deformation	H/240
K	Coefficient of Earth Pressure	U/(1-U)
H	Height of the wall above below the soil surface	Input
L	Length of the wall	Input
W	Thickness of the wall	Input
Y	Density of Soil	Input
U	Poisson's Ratio of Soil	Input
M	Moment of Inertia	$1/12*L*W^3$
Z	Young's Modulus	Output

1. Load= (.5 x K x Y x H^2 x L)

Equivalent Load x 2= Load x 2/3

2. Equivalent Load= Load/3
3. Deformation= (Equivalent Load x $Height^3$)/(3*Young's Modulus x Moment of Inertia)

Rearrange by dividing by Deformation and Multiplying by Young's Modulus

4. Young's Modulus= (Equivalent Load*$Height^3$/(3 x Deformation x Moment of Inertia)

Substitute

5. Z= (.5 x K x Y x H^2 x L)/3 x H^3/(3 x D x M)

Simplify

6. Z=160 x Y x H^4 x U/ (W^3-W^3 x U)
7. Volume of a Rectangular Prism= H*L*W
8. Cost= H*L*W*Cost of Material with Lowest Young's Modulus per unit volume
9. Cost= H*L*W*Density of Material*Cost of material per kg

Figure 3. Mathematical relationship defining, simplifying, and rearranging.

Mathematically, the necessary and sufficient conditions for the two systems of forces to be equivalent are

Conditions for equivalent systems of forces

$$\Sigma \mathbf{F} = \Sigma \mathbf{F}' \quad \text{and} \quad \Sigma \mathbf{M}_O = \Sigma \mathbf{M}'_O$$

Figure 4. Rule of equivalent systems. The moments of both systems around a point must be equivalent.

The model begins with equations found in Figure 3. The formula for the deflection of a wall with a load at one free end is described by Equation 3. The load caused by soil is defined by Equation 1, which states pressure is directly related to the height and density of soil. Using the rule of equivalent systems in Figure 4, the equivalent load at the free end of the wall can be derived.

It should be noted that the moment of inertia is based on planar rotation on the cross-section with dimensions W by L. The maximum deflection D is assumed to be L/240 to match the American Concrete Institute's (ACI) standard for deflections that will not cause critical damage to other structural elements.

After substitution and simplification, Equation 6 describes the minimum Young's modulus using the model. The next step is to begin substituting values. For this model, we have set U = 0.4 and Y = 3000 kg per cubic meter. After Equation 6 has been substituted with values, we can solve for Z, the minimum Young's modulus. The required modulus is approximately 41 megapascals.

Comparing this information with common building materials, it becomes clear that a 41 MPa Young's modulus is very low. Most materials have Young's modulus in the GPa range, about 1000 higher than our required minimum. Having such a low limit means that almost every material used for building on the market would be a viable option.

Another thing we can extrapolate from this calculation is that the reason the wall failed most likely did not occur because the material itself could not hold up the soil. It is more likely that the wall had degraded over time, the support had collapsed, or the joint between the wall and the support collapsed. Taking this into consideration, we recommend that the landscaping department invest in stronger support and join systems along with our material recommendation.

Cost Calculations

Researching materials and their costs per unit volume as well as Equations 8 and 9 from Figure 3, we have created a table of possible material candidates. The materials listed are common, easily sourceable construction materials, but other materials may still meet the requirements of this model. As shown in Table 2, the cheapest viable construction material is concrete. We recommend considering at least 300$ to cover the cost of materials.

Matlab Implementation

To begin our Matlab implementation, the first step was to create a function that could output the minimum Young's Modulus according to ordered inputs. Figure 3, Equation 6, was written in Matlab. The first output, the minimum Young's Modulus, was outputted simply by calling the function with the variables presented. The function uses the "fprintf" function, which prints the minimum Young's Modulus if the user enters a single number (a scalar).

The second output was a graph of Young's Modulus for various heights and Poisson's ratios. This was done by using the plot function. A row matrix was chosen to represent the horizontal axis (values increasing from 1 to 10 or 0 to 1), and that row matrix was entered in the function created earlier. The resultant row vector was then plotted against the vector that represented the horizontal axis. To add perspective, flat lines were added in to represent the Young's Modulus of various materials. This was done by making a filler row matrix equal to the horizontal axis matrix. After the filler matrix is set, all the values were replaced by a Young's Modulus of some material. When the filler and horizontal rows are plotted, the result is a flat line. The filler matrix was plotted against the horizontal matrix with new Young's Modulus to generate five flat lines. Each flat line corresponds to a certain material listed in Table 2.

The last output, a bar graph comparing costs, was generated using the bar graph and reorder function in Matlab. The reorder function will order the names under each bar of the bar graph in a specific order, resulting in a bar graph that matches the values found in Table 2.

All three graphs were generated along with the figure function in Matlab, which assigns a graph to a new window on the computer. Each figure has its own labels. Functions x-label was used to label the horizontal axis, y-label was used to label the Y axis, legend was used to create a legend, and title was used to create a title. The "clf" function was used on all graphs so that each time the script is run, the graph will not write on top of the previous run. Overall, no more additional assumptions were needed to implement Matlab.

Table 2. Viable construction materials.

Material	Cost per cubic meter ($\$/m^3$)	Cost to build ($)
Pine Wood (Z= 10 GPa)	265$	1324$
Oak Wood (Z= 9 GPa)	2000$	10000$
Spruce Wood (Z= 7 GPa)	500$	2500$
Concrete (Z= 50 GPa)	60$	300$
Brick (Z= 6 GPa)	470$	1410$

II. *Solution Details*

After running the code with the variables of wall height, soil density, soil Poisson ratio, and wall width, several graphs and numbers have been generated. The code stated in the command window "The minimum Young's modulus is 40960000.000000 Pascals". It generated two graphs of different independent variables while controlling the others to match the problem provided by UNL landscaping (For example, in Figure 5, H varies, but U=.4, Y=3000 kg/m^3, and W=.5m).

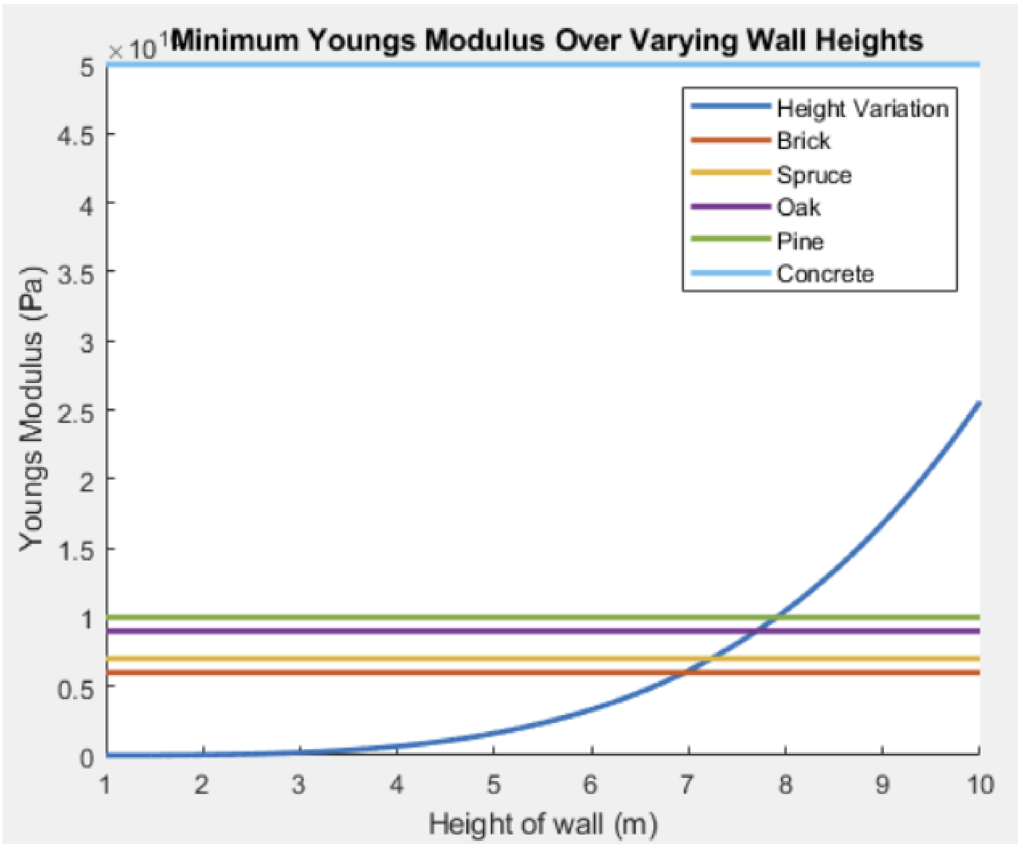

Figure 5. YM across various heights

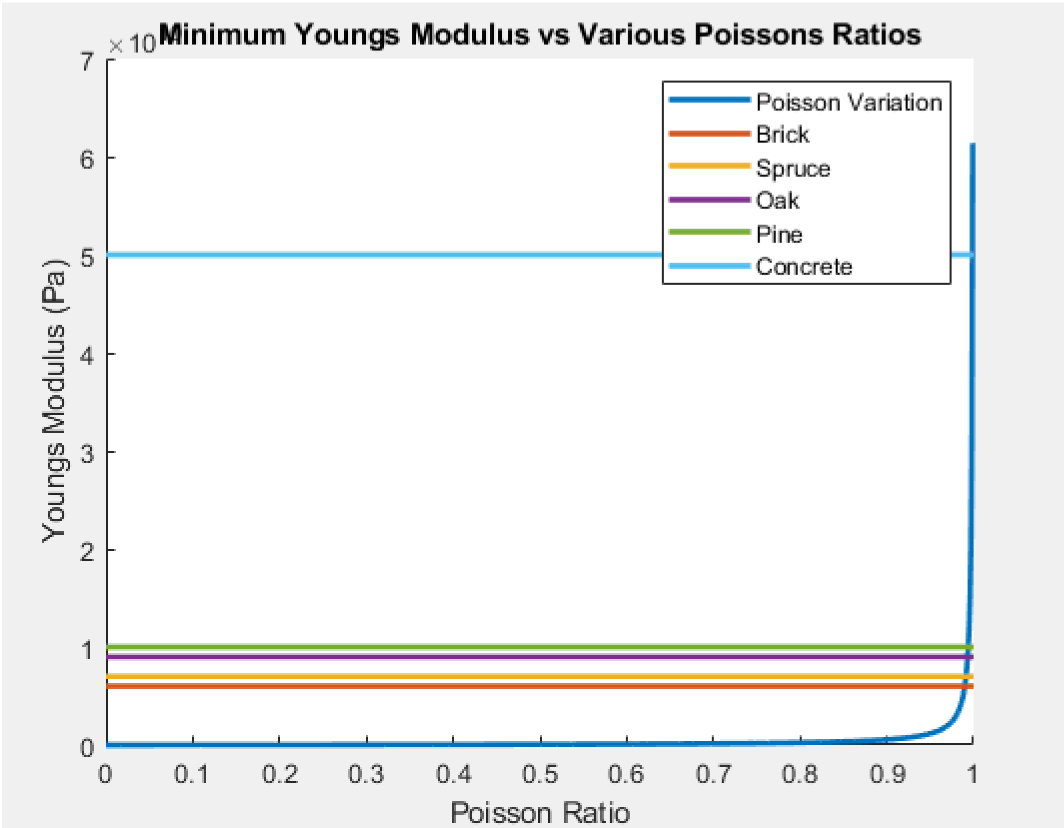

Figure 6. Minimum YM across various Poisson's ratios.

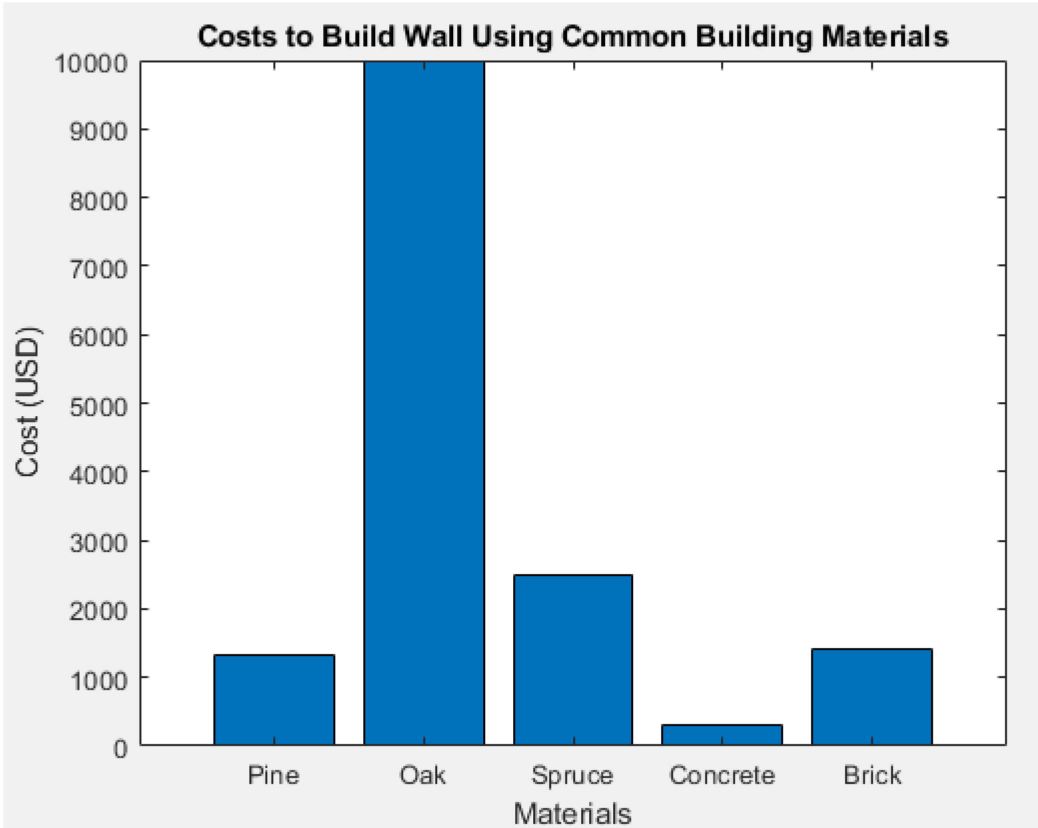

Figure 7. Minimum materials budget to build a wall.

III. Results & Discussions

The results of the code (see Figure 5, 6, and 7) as discussed in ***Solution Details***, are significant in several ways.

The primary goal, to calculate the minimum, find viable materials, and calculate a materials budget, was met. Using the assumptions in ***Data Values***, the minimum Young's Modulus was calculated in Matlab to be about 41 megapascals. Because the minimum is so low(most materials have YMs in the gigapascal range), virtually any modern building material meets the strength requirement to build the wall. Using five easily sourceable building materials, concrete was found to have the lowest cost for this project as demonstrated by Figure 7. The material with the lowest cost was concrete (Z=50 MPa). Concrete materials would cost 300$ for this project.

The secondary goal was to display how modifying wall height and Poisson's ratio may change the required Young's Modulus. From Figure 5 and 6, it is shown that the Young's

Modulus does not become considerable until a wall is 5-6 meters tall. Should UNL landscaping take on similar projects in the future with a similar design and similar soil, it would not be necessary to seriously consider the material of the wall until the wall is greater than 5 meters tall. From both Figure 5 and Figure 3, it can be seen that the minimum YM is directly related to the fourth power of wall height.

As seen in Figure 6, the Poisson ratio does not become appreciable until the ratio reaches the .9 threshold. In practice, future projects do not need to seriously consider the Poisson's ratio of soil. This is because most materials Poisson's ratios are less than .7. This is also significant because it also means that if the soil is changed by mixing in sand, mulch, or water, the wall shouldn't collapse. From Figure 3, Equation 6, the most important soil property that should be considered is the density (Y), as it is linearly related to the minimum Young's Modulus. Specifically for the project in question, should UNL need to replace the soil with another, there is no serious concern that the wall may collapse from deformation.

```
clf
%confirm the actual minimum Young's Modulus value
actualvalue = calcZstan(3000,2,.4,.5);
%create row  representing wall heights from 1-10
tall=1:.01:10;
%create row matrix representing Poisson's ratios from 0 to 1
soils=0:.001:1;
%calculate YM's based on tall
tallVar=calcZstan(3000,tall,.4,.5);
%calculate YM's based on soils
soilmod=calcZstan(3000,2,soils,.5);
%the next 3 lines are to make matrixes the same size as tall with every
%value within the matrix equal to c. This is used to generate a flat line
%when plotted
c=6*10^9;
filler=tall;
filler(:,:)=c;
%the next two lines create a figure that graphs YM over various wall heights,
%and clear any figure history to remove
%duplicated legends
figure(1);
clf;
title(' Minimum Youngs Modulus Over Varying Wall Heights');
ylabel('Youngs Modulus (Pa)');
xlabel('Height of wall (m)');
hold on;
%plotting variation, aswell as flat lines that represent YM's of various
%materials
plot(tall,tallVar,'DisplayName','Height Variation',LineWidth=2);
plot(tall,filler,'DisplayName','Brick',LineWidth=2);
c=7*10^9;
filler(:,:)=c;
plot(tall,filler,'DisplayName','Spruce',LineWidth=2);
c=9*10^9;
filler(:,:)=c;
plot(tall,filler,'DisplayName','Oak',LineWidth=2);
c=10*10^9;
filler(:,:)=c;
plot(tall,filler,'DisplayName','Pine',LineWidth=2);
c=50*10^9;
filler(:,:)=c;
plot(tall,filler,'DisplayName','Concrete',LineWidth=2);
legend;
hold off;
%graph of YMs when Poisson's ratio is varied, clearing the legend.
figure(2);
clf;
PoissonGraph=figure(2);
%begin plotting
hold on;
plot(soils,soilmod,'DisplayName','Poisson Variation',LineWidth=2);
%once again, making filler row matrixes of size soils so that
%plot(soils,filler) will produce a flat line at Y=C
filler=soils;
c=6*10^9;
filler(:,:)=c;
plot(soils,filler,'DisplayName','Brick',LineWidth=2);
c=7*10^9;
filler(:,:)=c;
plot(soils,filler,'DisplayName','Spruce',LineWidth=2);
c=9*10^9;
filler(:,:)=c;
plot(soils,filler,'DisplayName','Oak',LineWidth=2);
c=10*10^9;
filler(:,:)=c;
plot(soils,filler,'DisplayName','Pine',LineWidth=2);
c=50*10^9;
filler(:,:)=c;
plot(soils,filler,'DisplayName','Concrete',LineWidth=2);
title('Minimum Youngs Modulus vs Various Poissons Ratios');
ylabel('Youngs Modulus (Pa)');
xlabel('Poisson Ratio');
legend;
figure(3);
%bar graph comparing costs. material names are created and organized into
%the same order that the costs are in so they match an already made
%calculation table
matNames = categorical({'Pine','Oak','Spruce','Concrete', 'Brick'});
matNames = reordercats(matNames,{'Pine','Oak','Spruce','Concrete', 'Brick'});
costs = [1324 10000 2500 300 1410];
bar(matNames,costs);
title('Costs to Build Wall Using Common Building Materials');
xlabel('Materials');
ylabel('Cost (USD)');
%function to determine the Young's Modulus given the density, height
%Poisson ratio, and width of a wall. The function will print out the result
%only if the user asks for a single input-output.
function [Z]=calcZstan(y,h,u,w);
Z= 160.*y.*h.^4.*u./(w.^3-u.*w.^3);
formatSpec = 'The minimum modulus is %f';
if width(Z)==1;
    fprintf(formatSpec,Z);
end
end
```

Script 1: Code for Figure 5, Figure 6, and Figure 7

IV. Conclusion

For this project, we took what we had from project one and placed it into MatLab. In project one we found Young's Modulus which helped calculate what materials were the best to use based on cost, and strength. The calculations in project 1 were done by hand. This will help with a factor into the budget as well. During this part of the project, we took the equations from Project 1 and put them into MatLab using the variables given by UNL landscaping and costs researched by the team. By doing so, we have created three graphs that show us cost of materials, Young's modulus vs height, and Young's modulus vs various Poisson's ratios. According to the graphs, for a retaining wall, concrete would be the most viable material because it has a higher MPa in both the height and Poisson graphs. Not only does concrete have a high Young's Modulus in both of those graphs, but it also costs the least. Concrete would be the best and most viable material for the retaining wall, costing only about 300$ to be used.

Contributions

Luke - helped throughout made a few edits as well as wrote the conclusion for the project.

Conner Rainforth - helped with ideas, editing and grammar, model details, models and references.

Caleb Ginting- helped with ideas, Matlab code development, editing and grammar

Fatima C Pilar-Solis - Helped with Model Details and editing

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