Slide 1

This series of slide shows was prepared for parents and teachers of technology students. It provides a method to introduce students to structural engineering design. Structural considerations for the design and construction of trusses for model bridges is discussed and an example is presented.

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Slide 2

Optimization

The previous show ended with a model that held the load. In fact, it was capable of carrying too much load. Therefore we might be able to reduce the size of some of the members and save some material. Optimization is the process whereby we use the individual members results to increase the overall efficiency of the structure.

We do this in a series of steps. First we optimize the geometry of the truss. Then the size (cross section) of each element (member). Finally we consider material grade by using lighter (Less dense and thus weaker) members where possible.

Printing

We will learn to use the printing features in the program to print patterns that we can build on.

Slide 3

Optimization – The process of designing the best model that satisfies the problem statement.
Usually you want to design the lightest model that can support a given load over a given span.
The most efficient model possible is said to have been fully optimized.

We can break the optimization process down into two main parts.

The **geometry of the structure** and the characteristics of the **individual elements**.

Slide 4

The overall geometry of the structure

What overall form (outline or shape) will the bridge take.

Should it have an overhead or under slung superstructure.

What should the maximum height of the structure be and how should the structure taper (straight or curved) to its support points.

Sometimes the form depends of the skill of the builder. The straight tapers are easier to construct well.

Slide 5

The individual element – Orientation, Grade (density) and cross section.

Orientation - Length and slope of the member.

The quality of the material - amount of wood fiber versus voids.
The amount of summer wood versus winter wood.
The rings in Balsa are not very pronounced.
Could that indicate a mild winter where it's grown?

Cross Section – How chunky is the member.
A large cross section means a stronger member but also heavier.

Slide 6

Let's try optimizing our bridge.

Recall from the last show, we stopped altering the model when we found a solution that could carry the load.

Now let's take a closer look at the forces in each member to determine if we can save some material by altering the overall height of the bridge and the individual member sizes.

Slide 7

The indicated member is only carrying 5.55 pounds of compression force.
It can support 15.6 pounds of compression (at ultimate).

Therefore it is only using (5.55/15.6) *100 about 36% of the members material.
This is not very efficient.

This members has reserve strength to carry more load.

The force in this members is directly effected by the height of the truss.
We could decrease the height of our truss and save material.
Decreasing the height of the truss will increase the amount of force in the top chord members making them more efficient an make the web members (the members between the top and bottom chord) shorter thus lighter.

Slide 8

In order to alter the height of the bridge we must first remove the portal bracing in the end panels.
(Normally we would have optimized the model before adding the sway bracing.)

Select the “Joints|Delete” menu option and delete the intermediate height joints on the main diagonals.

Slide 9

Add back the main diagonals.

Slide 10

Since we placed the origin at the leftmost rear joint, we can use the joint properties dialog to determine the overall height of the bridge. Y=4.

The height of the bridge is given in the Y coordinate (Y=4).

Let’s reduce the height to 3”

Select the “Joint|Properties…” menu option then click on the upper left joint in the near truss.

Slide 11

Enter “3” for the Y coordinate and click “Apply”

Repeat this process until all joints have been lowered to y=3.

Slide 12

Re-analyze.

The critical members are now the two forward main diagonals.
(If you are wondering why the rear to diagonals didn’t fail at the same time, remember that we have some lateral load (Z force) that affects the internal force distribution.)

What can we do to make these failing members stronger?

Slide 13

When a slender member is in compression shortening the member will allow it to carry more load (Ie withstand more internal force).

Let’s move the joint at the top of the diagonal so that we shorten the member – without making the top chord member too long.

Slide 14

Recall how members (in a truss – that are primarily subjected to axial forces) can fail.

Tension members fail by pulling apart.

Compression members fail by either crushing or buckling.

Slide 15

Finish up by adjusting the main diagonals to the right.

Slide 16

Re-analyze.

It works!

Now let's consider material grade to see if we could safe some weight by using lighter members.

Slide 17

What is material grade?

Look at the end of a balsa wood stick.
What do you see? - Wood and voids (holes).
The stick is not solid wood fiber (cellulose).
Some sticks have more fiber and less voids than others (for the same cross sectional area).
The more fiber they have (within a given cross section) the heavier and stronger the stick.

The higher the grade number (ie BalsaD1,BalsaD1.1, BalsaD2…) the greater the strength of the member (for a given cross section).

This means:
You can examine the members results and use a lesser grade and thus lighter member where you have excess members strength.

Slide 18

There are two methods that can be used to determine balsa grade.
Deflection test
Density test

Let’s use the density method:

Number each balsa stick.

Weigh each balsa stick – in grams.

(Record the weight and size of each stick.)

Determine the density of each stick.

Arrange the balsa sticks by weight.

Classify each stick by grade.

Place a grade mark on each stick.

Slide 19

Here is an example

Slide 20

Density = weight/volume

Measure the stick:

1/8”x1/8”x36”

Volume=.125”x.125”x36”= .5625 in^3

Change units

We want units of pounds per cubic foot (lbs/ft^3).

Slide 21

Change the weight of the stick to pounds.

Calculate the density in pounds per cubic foot.

Slide 22

Classify the stick

The density of the stick is less that 18pcf but more that 16.

It is a balsaD1.2

Apply a grade mark to the stick “D1.2”

We know we are only using Balsa.

Slide 23

You can use the exact density of your stick.

(By using the exact density, the program will make a better approximation of the models weight (less glue).

Open the Edit Materials dialog.

Type the density into the Density edit box then click the “Balsa” button.

The program will insert the appropriate material properties for the given density.

(Do not erase any of the values.)

Slide 24

Looking at the member results we can determine which members that have excess strength – low mode ratio numbers.

Let's try to lighten up the interior web members by using a lesser grade for these members.

Select the "Members|Change Default Material and Shape …" menu option.
Set the default member grade to BalsaD1 and click the "OK" button.
Select the "Members|Change Material" menu option.
Change the grade of two diagonals nearest the mid span in both trusses by click on these members.
Also change grade of the interior bracing in the top plane.

Re-analyze
The model works and we saved to weight!

Slide 25

A final analysis. The bridge is OK.

Slide 26

It's time to build the model.
You can use ModelSmart3D to print a layout pattern.
This section explains ModelSmart3D's printing features.

Slide 27

Select the “View|Show All” menu option then press the “F1” key.

The program prints all members within ½” of the GuidePlane.

To print out the near main truss, you must first move the XYGuidePlane forward until it goes through a joint in this part of the model.

Select the “Guides|XY GuidePlane|Move Plane to Joint” menu option.
Then click on the joint shown in the inset above.

The XYGuidePlane now contains the near main truss.

Slide 28

Use the toolbar to hide the XZ and YZ GuidePlanes.

Select the “File|Tile Orientation|Landscape” menu option.
Then select the “File|XY Plane Tiles|Show Tiles” menu option.

Slide 29

To move the tiles slightly, select “File|XY Plane Tiles|MoveTiles” from the menu.
Then click on the XYGuidePlane to locate the lower left corner of the page outlines.

Slide 30

Select “File|Print XY Plane” to print the tiles.
(Do not select landscape from the print dialog properties.)