Structural Efficiency
Why do engineers design suspension bridges for some locations and girder bridges for others?
Why do engineers design arch bridges for some locations and truss bridges for others?
Why are I-sections used for beams, and angles are not?
Why are some girders haunched over the supports, and others have uniform depth?
Why are some trusses tallest over the supports, and others shallowest over the supports?
Introduction

Why are trusses used for some structures, and beams used for others? Why are suspension bridges used to cross large bodies of water and girder bridges used to cross creeks? To answer these and other questions about structure type, we will look at the following types of structure components:

- trusses,
- arches,
- beams, and
- cables

Each of the structure components listed above can be distinguished by appearance. We will learn to distinguish component types by function also; specifically, by the type of internal forces in the component.

The type and distribution of internal forces in a component also explains other features of the component, such as:

- cross-section shape
- profile (depth vs. member length)

And finally, the continuity across supports of horizontal components (trusses and beams) affects the internal forces in a component, which in turn affect the component’s profile.

Exercises

1. Types of Components. To start, let’s rank the four types of structure component listed above from longest span to shortest span (truss, arch, beam, cable).

   (a) (longest span) _____ cable ______________
   (b) __ arch __________________
   (c) ___ truss ________________
   (d) (shortest span) ___ beam ________________

2. Failure Modes. Assume that component type a) above is composed of fibers (e.g. wood) and is loaded to failure. Draw a sketch (side view) showing the loads acting on the component and showing the appearance of the fibers immediately after failure. Repeat for component types b) through d).

   (a) _____ cable ________________   (b) _____ arch ____________

   ![“fibers” rupture](image)
   ![“fibers” crush](image)
3. **Internal Forces.** Internal forces are frequently represented as force per cross-section unit area or stress. Based on the sketches above, draw a line from each component type on the left to the appropriate stress distribution (immediately before failure) on the right.

**Member Types by Internal Force Distribution**

<table>
<thead>
<tr>
<th>Type of Component</th>
<th>Stress Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) (longest span) <strong>cable</strong></td>
<td>uniform compression</td>
</tr>
<tr>
<td>(b) <strong>arch</strong></td>
<td>linearly varying</td>
</tr>
<tr>
<td>(c) <strong>truss</strong></td>
<td>uniform tension</td>
</tr>
<tr>
<td>(d) (shortest span) <strong>beam</strong></td>
<td>uniform compression &amp; uniform tension</td>
</tr>
</tbody>
</table>
4. Structural Efficiency vs. Internal Force. In long-span structures, the weight of the structure itself dominates the design. Therefore component types associated with longer-span structures weigh less per foot of span and are said to be more structurally efficient.

\[
\text{structural efficiency} = \frac{\text{load supported}}{\text{weight of structure}}
\]

4.1. Describe why component type (a) is more efficient than component type (b). (Hint: what is different between the two stress distributions).

Cables (uniform tension) are more efficient than arches (uniform compression) because compression members can fail by buckling as well as by material failure (rupture or crushing).

4.2. Describe why component type (b) is more efficient than component type (d). (Hint: Do all "fibers" of component type (d) fail simultaneously? Which fail first?)

Arches (uniform compression) are more efficient than beams (max tension & compression in outside fibers, zero in middle fibers) because a uniform stress distribution at failure means that all of the fibers are loaded to full strength, whereas the middle fibers in a beam do not get loaded to full capacity.

5. Structural Efficiency vs. Cross-Section Shape. Based on the reasoning for Exercise 4.2 above, rank the following five beam cross-sections from most efficient (1) to least efficient (5) for bending in the vertical plane. All beams have the same cross-sectional area. Explain.

All cross-sections have the same area

- "tall" rectangular solid
- "flat" rectangular solid
- I-beam
- square solid
- tube

3 5 1 4 2
6. **Structural Efficiency vs. Profile** (member depth along its length).

6.1 Draw the distribution of internal bending moment (the moment diagram) for the simply-supported beam shown below.

![Beam Diagram]

6.2 Indicate the location of the maximum structural demand in the beam of Exercise 6.1 above.

6.3 Which beam profile shown below would be the most efficient for the situation shown in 6.1? Why?

![Beam Profiles]

7. **Span Continuity vs Profile**

7.1 The moment diagrams for two three-span structures are shown below.

![Moment Diagrams]

7.2 Which beam is more efficient? Why?

    The continuous beam is more efficient (max moment = w L^2 / 10) than the simply supported spans (max moment = w L^2 / 8).

7.3 Which beam would be more affected by settlement?

    The continuous beam would be more affected by settlement.
7.4 Which of the two structure profiles above would be more efficient for the continuous-span structure? Why?

The haunched girder would be more efficient because the deepest section occurs where the moment is maximum—over the supports.

7.5 Which of the two structure profiles above would be more efficient for the continuous-span structure? Why?

The cantilever truss would be more efficient because the deepest section occurs where the moment is maximum—over the supports.

7.6 When looking at a multi-span bridge from the side, how can you tell if it has simple spans or continuous spans?

If the deepest section of the bridge occurs over the supports, then the bridge is likely continuous.