John A. Roebling and the Design of Suspension Bridges

1. Methods of stiffening suspension bridges
2. Evolution of form in Roebling's suspension bridges
3. Wind and dangerous oscillations in suspension bridges
4. Ambiguity of form vs. structural redundancy in suspension bridges
5. Artistic representations of the Brooklyn Bridge
Eiffel

PONT DE GARABIT
Designed by Eiffel the engineer.

THE ENGINEER'S AESTHETIC AND ARCHITECTURE

Brunel
Load Paths in Suspension Bridges

Weight of Bridge Deck

Shape of cable?
Parabola
Load Paths in Suspension Bridges

Vehicle on Bridge Deck

Bending
Stiffness
Resistance to Deformation

1. Cables have Stiffness
2. Force Follows Stiffness
Load Paths in Suspension Bridges

Vehicle on Bridge Deck

Bending
The Historical Record

Severely Damaged by Wind
Excessive Wind-Induced Motion

Longest Span
Severely Damaged by Wind
Excessive Wind-Induced Motion
Local unstiffened suspension bridge example
Patapsco Valley State Park “Swinging Bridge” (Early 1800’s)
Union Bridge (1820)  
Samuel Brown  
449 ft [137m] span  
England
Brighton Chain Pier (1823)  
Samuel Brown  
England  
225 ft [69 m] spans
Severely Damaged by Wind
Excessive Wind-Induced Motion

Longest Span

- Severeley Damaged by Wind
- Excessive Wind-Induced Motion

Year
1800 1820 1840 1860 1880 1900 1920 1940
Main Span (ft)
0 1000 2000 3000 4000 5000
Menai Straits Bridge (1826)
Thomas Telford

580 ft [177 m] span
Wales
C.L.M.H. Navier

Cable Stiffness: Deformation $\propto \frac{1}{\text{Weight}}$
Severely Damaged by Wind
Excessive Wind-Induced Motion

Longest Span

- Green dots: Severely Damaged by Wind
- Yellow dots: Excessive Wind-Induced Motion
Wheeling Bridge (1849)  
Charles Ellett  
West Virginia  
1010 ft [308 m] span
Niagara Railroad Bridge (1849)  
John A. Roebling  

822 ft [250 m] span  
Niagara River
Severely Damaged by Wind
Excessive Wind-Induced Motion

Longest Span
- Green dots: Severely Damaged by Wind
- Yellow squares: Excessive Wind-Induced Motion

Main Span (ft)

Year
John Augustus Roebling
1806-1869
“The means employed are: Weight, Girders, Trusses, and Stays. With these any degree of stiffness can be insured, to resist either the action of trains or the violence of storm . . .”

J.A. Roebling, *Final Report*, Niagara Bridge

Niagara Railroad Bridge (1849)  822 ft [250 m] span  
John A. Roebling  
Niagara River
Load Paths in Suspension Bridges

Vehicle on Bridge Deck

1. Suspension Cables
2. 
3. 
Load Paths in Suspension Bridges

Vehicle on Bridge Deck

1. Suspension Cables
2. Bridge Deck
3.
Load Paths in Roebling’s Bridges

Vehicle on Bridge Deck

1. Suspension Cables
2. Bridge Deck
3. Diagonal Stays
“The means employed are: **Weight, Girders, Trusses, and Stays.**
With these any degree of stiffness can be insured, to resist either the action of trains or the violence of storm . . .”

J.A. Roebling, *Final Report, Niagara Bridge*

**Niagara Railroad Bridge (1849)**  
822 ft [250 m] span  
John A. Roebling  
Niagara River
John Scott Russell (1839)

2nd Dryburgh Abbey Bridge (1818) 260 ft span
Second Montrose Bridge (1840) 432 ft [132 m] span
Deck is so stiff you don’t need the cables anymore. Efficiency?

Britannia Bridge (1850)                                        460 ft [140 m] span
Robert Stephenson                                                                      Wales
<table>
<thead>
<tr>
<th></th>
<th>Niagara</th>
<th>Britannia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span Length</td>
<td>821 ft</td>
<td>460 ft</td>
</tr>
<tr>
<td>Total Length</td>
<td>821 ft</td>
<td>2 @ 1400 ft</td>
</tr>
<tr>
<td>Weight</td>
<td>2400 lb/ft</td>
<td>7000 lb/ft</td>
</tr>
<tr>
<td>Cost</td>
<td>£ 100 /ft</td>
<td>£ 215 /ft</td>
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<tr>
<td>Relative Stiffness</td>
<td>1.5</td>
<td>1</td>
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John Augustus Roebling 1806-1869
John Roebling’s Suspension Bridges

1844 Allegheny aqueduct at Pittsburgh
1845 Smithfield Street Bridge
1849 Delaware and Hudson aqueducts
1855 Niagara suspension bridge
1856 Ohio river bridge at Cincinnati
1860 Sixth Street Bridge
1883 Brooklyn Bridge
Niagara suspension bridge - 1855
Smithfield Street Bridge (1846)  
John A. Roebling  
188 ft [57 m] spans  
Pittsburgh
Sixth Street Bridge (1860)                     344 ft [105 m] spans
John A. Roebling                             Pittsburgh
The original idea upon which the plan has been perfected, was to form a wooden trunk, strong enough to support its own weight, and stiff enough for an aqueduct or bridge, and to combine this structure with wire cables of a sufficient strength to bear safely the great weight of water.

Allegheny River Aqueduct (18xx)
John A. Roebling
188 ft [57 m] spans
Pittsburgh
Delaware and Hudson Canal Aqueducts (1847-1850)
114 ft to 170 ft [35 m to 52 m] spans
Pennsylvania & New York
Ohio River Bridge (1856)                                      1057 ft [322 m] span
John A. Roebling                                                                     Cincinnati
LONG AND SHORT SPAN

RAILWAY BRIDGES.

BY

JOHN A. ROEBLING,

CIVIL ENGINEER.

The greatest economy in Bridging can only be obtained by a judicious
application of the Parabolic Truss.

NEW YORK:
D. VAN NOSTRAND, PUBLISHER,
25 MURRAY STREET & 17 WARREN STREET.
1866.
What is one method for imparting stiffness to a suspension bridge?

What are the aesthetic implications of this method?

Draw a quick sketch of such a proposal
Flood tide below me! I see you face to face!
Clouds of the west – sun there half an hour high –
    I see you also face to face

Crowds of men and women attired in the usual costumes,
    how curious you are to me!
On the ferry-boats the hundreds and hundreds that cross, returning home,
    are more curious to me than you suppose,
And you that shall cross from shore to shore years hence are more to me,
    and more in my meditations, than you might suppose

-Crossing Brooklyn Ferry
Walt Whitman (1856)
JOHN ROEBLING'S DREAM—ORIGINAL DESIGN OF THE BROOKLYN BRIDGE
The contemplated work, when constructed in accordance with my designs, will not only be the greatest Bridge in existence, but it will be the great engineering work of this continent, and of the age. Its most conspicuous features, the great towers, will serve as landmarks to the adjoining cities, and they will be entitled to be ranked as national monuments. As a great work of art, and as a successful specimen of advanced Bridge engineering, this structure will forever testify to the energy, enterprise and wealth of that community, which shall secure its erection.

Respectfully submitted,

JOHN A. ROEBLING.

TRENTON, N. J., Sept. 1st, 1867.
Brooklyn Bridge (1883) 1595.5 ft [486 m] main span
John and Washington Roebling  New York
extensive system of stays forms the third. The stays are arranged in four distinct planes, connected by the floor. The latter in connection with the stays will support itself without the assistance of the cables. If the structure is viewed...
The Brooklyn Bridge was politically and economically significant because it joined the cities of New York and Brooklyn.

Can you think of other civil works that have had similar political and economic meanings?

Are there places you would propose such a construction?

Were the results positive, negative, mixed?
Again the traffic lights that skim thy swift
Unfractioned idiom, immaculate sigh of stars,
Beading thy path--condense eternity:
And we have seen night lifted in thine arms.

“The Bridge”
Hart Crane (1930)
Washington Roebling’s response to the corrupt Mr. Hewitt. In response to Hewitt’s request for discussing the Brooklyn Bridge as a symbol of man’s progress. (McCullogh, *The Great Bridge*, p. 522)

To build his pyramid Cheops packed some pounds of rice into the stomachs of innumerable Egyptians and Israelites. We today would pack some pounds of coal inside steam boilers to do the same thing, and this might be cited as an instance of the superiority of modern civilization over ancient brute force. But when referred to the sun, our true standard of reference, the comparison is naught, because to produce these few pounds of coal required a thousand times more solar energy than to produce the few pounds of rice. We are simply taking advantage of an accidental circumstance.

It took Cheops twenty years to build his pyramid, but if he had had a lot of Trustees, contractors, and newspaper reporters to worry him, he might not have finished it by that time. The advantages of modern engineering are in many ways over balanced by the disadvantages of modern civilization.
Brooklyn Bridge

Scientific
- Innovative structural system of cables, stays and truss
- Longest span in the world

Social
- Construction amidst political corruption
- Transforms city of New York (connects the city)
- Bridge itself is a unique experience

Symbolic
- Inspires numerous works of art
- The image of New York City
Suspension Bridge Statics
Load Path

All forces or loads must eventually get to the ground. Can we trace the path of tension of compression?
How does Roebling’s introduction of diagonal stays introduce ambiguity to the load path?
Free Body Diagrams

A sketch of all or part of a structure, detached from its support

Cable tension

Gravity

Tower base reaction

Cable tension
Equilibrium

\[ \Sigma M_A = 0 \]
Equilibrium

\[ \Sigma M_A = 0, \quad Hd - wL^2/8 = 0, \quad H = wL^2/8d \]
Cable tension

\[ H = \frac{wL^2}{8d} \]

\[ R = \frac{L}{d} \]

\[ H = \frac{wLR}{8} \]

\( R, L \) transform \( w \) into \( H \)

\( w = \text{load} \)

\( L = \text{size} \)

\( R = \text{form} \)

\( H = \text{function} \)
\[ R = 10, \ H = 2 \times 10^5 \]

\[ R = 6, \ H = 1.3 \times 10^5 \]

Compression

Tension

Compression