John James Audubon Bridge
Cable-Stayed Main Span
Over the Mississippi River

Johns Hopkins University
Whiting School of Engineering
September 10, 2008
The Project
## Overall Project Facts

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduled Time to Complete</td>
<td>47 Months (February 2010)</td>
</tr>
<tr>
<td>Estimated Number of Man-Hours</td>
<td>793,000 MH</td>
</tr>
<tr>
<td>Number of Bridges</td>
<td>8</td>
</tr>
<tr>
<td>Concrete</td>
<td>99,000 CY</td>
</tr>
<tr>
<td>Reinforcing Steel</td>
<td>27,900,000 LBS</td>
</tr>
<tr>
<td>Structural Steel</td>
<td>14,500,000 LBS</td>
</tr>
<tr>
<td>Stay Cables</td>
<td>1,834,000 LBS</td>
</tr>
<tr>
<td>Asphalt</td>
<td>95,000 TON</td>
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</tbody>
</table>
Design/Bid/Build

Owner

Design Team

CEI or Construction Manager

Construction Contractor
Design/Build

Owner
Program Manager (Optional)

Design/Builder
(Often a General Contractor)

Construction Team

Quality Control

Designer
The Joint Venture

The $348 million dollar project is being constructed by Audubon Bridge Constructors, a joint venture consisting of:

- Flatiron Constructors (Longmont, CO)
- Granite Construction Company (Watsonville, CA)
- Parsons Transportation Group, Inc. (Washington, DC)
Louisiana Department of Transportation & Development

- LA DOTD is the owner of this bridge and are managing the construction with the Louisiana TIMED Program.
Cable-Stayed Bridge
General Arrangement

- 1583 ft main span
- 1463 ft navigational clearance provided
Towers:

- 500’ high
- 136 cable stays
- Two crossbeams
- Tower top is Elev. 520
- Deck is Elev. 130
Key Design Features

• Light superstructure supported by 136 stay cables
• Minimum loads on foundations
• Durability
  – Beneficial deck compression from stay cables and deck post-tensioning
  – 2 “ LTM overlay
  – 8000psi HPC precast deck panels
  – 50ksi weathering steel protected by deck
Main Span
Dead Load Analysis

• Dead load analysis is non-linear
  – Non-linear cable elements
  – Non-linear beam elements
  – Non-linear soil springs

• Structure is “tuned” for dead loads
  – Towers built tall to compensate for shortening
  – Deck built long to compensate for shortening
  – Cables installed short to compensate for stretch
Stage-by-Stage Analysis

- Structure built one segment at a time
- Precisely captures locked-in effects
- Models time-dependent effects during construction
- Required for tracking bridge geometry during construction
- Performed prior to bridge construction
Wind Loads

- AASHTO static wind load pressures not appropriate for long-span structures
- Three components to wind loads
  - Mean static
  - Background
  - Dynamic (Buffeting)
  - Dynamic component obtained from buffeting analysis provided by wind specialists
Sectional Model Tests
Sectional Model in Wind Tunnel
Buffeting

• Dynamic response of structure from uneven loading due to turbulence in natural wind
• Buffeting induces vibration in the bridge’s natural modes of vibration
• The resulting forces which included dynamic inertial forces can exceed those calculated using simple static wind pressures
Buffeting Analysis

- Determine peak resonant response for each mode of vibration
- Input includes
  - Aerodynamic force coefficients
  - Structure dynamic properties (i.e. stiffness, mass, natural modes of vibration)
  - Structure damping
  - Wind turbulence properties
Buffeting Analysis

• Alternative to aeroelastic testing
• Obtain results faster
• Verify by measured response at limited positions during aeroelastic testing
• Requires modal superposition to determine peak response
### Buffeting Demands

<table>
<thead>
<tr>
<th>Input: Modes</th>
<th>RWDI Output: Scaling Factors</th>
<th>Result: Demands</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Mode 1" /></td>
<td><img src="image2.png" alt="Scaling Factor 1" /></td>
<td><img src="image3.png" alt="Result 1" /></td>
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<tr>
<td><img src="image4.png" alt="Mode 2" /></td>
<td><img src="image5.png" alt="Scaling Factor 2" /></td>
<td><img src="image6.png" alt="Result 2" /></td>
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0.51

0.27
## Buffeting Demands

<table>
<thead>
<tr>
<th>Mode</th>
<th>Force Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,100</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>650</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>n</td>
<td>21</td>
</tr>
</tbody>
</table>

\[
\sqrt{m_1^2 + m_2^2 + \ldots + m_n^2} = 1,350 \text{ (RMS Total)}
\]
## Wind Load Combinations

<table>
<thead>
<tr>
<th>Case</th>
<th>Transverse Wind</th>
<th>Longitudinal Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%</td>
<td>50%</td>
</tr>
<tr>
<td>2</td>
<td>50%</td>
<td>100%</td>
</tr>
<tr>
<td>3</td>
<td>70%</td>
<td>70%</td>
</tr>
</tbody>
</table>

Wind Load = Static + Background + Buffeting
Aeroelastic Model in Wind Tunnel
Aeroelastic Model Details
Construction Stage Modeling
Construction Stage Modeling
**Live Load Analysis**

- HL-93 Live Load per AASHTO LRFD:
  - Truck Load (HS-20, 72 kips)
  - Tandem Load (50 kips)
  - Lane Load (640 plf)

- Four design lanes

- Demands obtained through influence surface loading
Live Load Analysis
Tower Foundation, $M_{\text{long}}$
Live Load Analysis

Edge Girder, $M_{\text{long}}$
Cable Loss Analysis

- Extreme limit state
- Cable loss in accordance with PTI Recommendations
- 1.1DC + 1.35 DW + 0.75 LLI + 1.1 Cable Loss
Cable Loss Design Philosophy

• Structural Elements Design to prevent structural instability
  – Prevention of progressive collapse
  – Member yielding and load redistribution permitted
  – Fully plastic behavior permitted
  – Brittle failure mechanisms prohibited
Cable Replacement

- Strength limit state
- In accordance with PTI Recommendations
- 1.2DC+1.4 DW+1.5LLI+Cable Exchange
- Adjust traffic pattern to control live load
- Limit areas where cable replacement governs
Non-Linear Behavior

- Flexible suspended structure (geometric)
- Cable stiffness due to sag
- Material properties at strength and extreme limit states
- Soil properties
Geometric Non-Linearities

- Non-linear beam elements
- 3-D beam elements with stability functions to capture P-delta effects
- Stability functions to account for stiffening and softening of structure under axial load
Non-Linear Performance

- Most significant non-linear performance is under dead load analysis
- Non-linear behavior due to superimposed loads are typically small
Non-Linear Analysis

• Geometric
  – Dead load analysis
  – Live load analysis for verification only

• Geometric and Material
  – Wind load analysis for critical cases
  – Construction stage analysis for critical cases
  – Cable loss analysis
Deck/Tower Articulation

- Longitudinal Fixity
  - Pier 1W & 2W – Fixed Bearing
  - Pier 1E – Lockup Device
  - Pier 2E – Sliding Bearing

- Advantages
  - Maintain flexibility for temperature movements
  - Spread longitudinal shear from wind to both towers
Lock Up Devices

Diagram shows a mechanical system with labeled parts:
- Piston Rod
- Piston Head
- Orifices
- End Clevis, 2 Places
- Cylinder
- Fluid
- Cap and Seal

Graph shows the relationship between Force (kN) and Velocity (mm/s):
- Force: 50 to 16000 kN
- Velocity: 0.05 mm/s to 2 mm/s

Graph divided into:
- Free Movement
- Prevented Movement
Tower Foundations 1W & 1E

- 160’ x 64’ x 15’ Cap
- 7 by 3 pile group – 1 test pile
- 8’-0” diameter shafts
Tower Shafts

- 96” dia permanent casing
- 90” dia drilled shaft
- Pile tip Elev. -175 to -180
- Tip grouting
Tower Cross Section

- Box sections for simple jump forming
- Cable anchorage on inside tower wall
Tower Cable Anchorages

- Steel anchorage trays for upper stays
- Concrete corbels for lower steep cables
- Crossbeams connected clear of anchorage zone
Composite Deck Cross-Section

- Economy, simplicity and constructability
- Durability
- Accessibility
- Low maintenance
Stay System

- 7-Wire parallel strand
- Monostrand Jacking
- State-of-the-Art Corrosion Protection
  - Galvanizing
  - Grease
  - Strand PE
  - Coextruded HDPE Pipe
- Vibration suppression
Counterweight
Bridge Construction
Bridge Construction
Bridge Construction
Bridge Construction
Foundation Construction

Installation of Drilled Shafts
Drilled Shaft Installation

- Set shaft template
- Drive permanent casing using vibro hammer
- Excavation of permanent casing
- Installation of temporary casing by oscillator
- Excavation of temporary casing
- Install reinforcing cage
- Pour tremie concrete while removing temporary casing
Set Shaft Template

- Secondary Template
- Upper Template
- Lower Template
- Spud Pile
Drive Permanent Casing

APE 400B Vibratory Hammer

Paint markings at each foot verify depth of casing as it is being installed.

River bottom EL approx. -40’ East, 5’ West
Drive Temporary Casing

An oscillator works like someone is opening and closing a jar (back and forth).

Speed has been accelerated.
Excavate Temporary Casing

- Bottom of Permanent Casing
- 90” Temporary Casing
- Hammer Grabs

West - 175  East - 180
Install Reinforcing Cage
Pour Tremie Concrete
Footing Cofferdam Structure

Piles and trestle are installed
Install Soffit Panels
Install Bracing Frame

- Install first tier of brace frame
Erect Pre-Cast Wall

- Install pre-cast walls
- Connect to soffit panels and first tier brace frame
Install Jacking System

- Install jacking system with permanent hangers
- Lower structure to facilitate 2\textsuperscript{nd} & 3\textsuperscript{rd} tier bracing installation
Install Additional Brace Frames

- Install 2\textsuperscript{nd} and 3\textsuperscript{rd} tier brace frame.
Install Follower Sheeting

• Install sheet pile
Lower Structure

- Lower structure to final elevation
- Lock off hangers
Pour Concrete Seal

- Install 8 foot concrete seal
Dewater Structure

- Install pump.
- Remove water
Remove Hangers and Cut Casing

- Remove hangers
- Cut casing
Place Reinforced Pile Cap

- Place reinforced pile cap concrete
Place Pedestal Concrete

- Place pedestal reinforcing and concrete lift 1
- Restrut as required
Place Pedestal Concrete Lift 2

• Place pedestal concrete lift 2
Remove Cofferdam

- Remove sheeting
- Remove Bracing
- Patch blockouts