Measuring Displacement of Piers During Construction of the Jeremiah Morrow Bridge

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Overview of this Presentation

1. Ohio’s tallest bridge; 25th highest in the nation
2. ODOT sensitive to geometry control issues
3. Horizontal jacking issues – need to verify displacements
4. Reliable, cost-effective method to measure in real-time
5. Useful extensions
Construction in the Clouds

Tallest Bridge in Ohio
Pier height from 60 to 220 ft
Piers 1-4 monolithic, Pier 5 on bearings
Twin Walls

• Twin walls are 65’-0” tall
• “Fuse” mitigates creep and shrinkage-induced forces as well as thermal movements
• Provide capacity for all other external loads
Cantilever Construction
Geometry Control Program

Implement quality control and assurance procedures to check

- Cantilever tips are in alignment
- Final profile grade conforms to established elevation
- Measured deflection reasonably agrees with estimations from modeling
Longitudinal Jacking & Closure Pours
Estimated Final Deformations

Longitudinal contraction and shortening due to shrinkage, concrete creep, and secondary moments, primarily due to the high axial forces from post-tensioning.

- As-generated from computer modeling, shown at 600% magnification
- Deformations add considerable moment to the pier columns/twin walls
Sequentially jack apart the open cantilevers before casting the center closure.

Contract Plans indicated a jacking force to produce a longitudinal deflection equal to a portion of the long-term deformation.
Deflection Monitoring System

Implementation Stages

- Phase 1
  1. Noise floor measurement at the Deck level of Pier 2
  2. Wireless Coverage Test
  3. Tilt Meter Installation on Pier 2
  4. Temperature Coefficient Calibration
  5. Website development
  6. Tilt Meter Installation on Pier 3
  7. Website development

- Phase 2
  1. Pier 4 Sensor Installation
  2. Pier 1 Sensor Installation
  3. Average Method added to the website
  4. Monitoring the Jacking Events (High Speed)
Deflection Monitoring System (Hardware Development)
Deflection Monitoring System
(Data Flow)

UCII

Web Server

Data Processing

Every 30 minutes

JM Bridge

Different wireless gateways on the bridge

Realtime Monitoring

Database

Datalogger

Modem
Deflection Monitoring System (Sensor Plan; Phase 2)

Pier 4 (13 Gages)
Deflection Monitoring System (Sensor Plan; Phase 2)

Pier 1 (11 Gages)

Added

EL 894.5

48.5ft

EL 846

EL 806

EL 781

* ELEVATION
* ELEVATIONS ARE NOT SHOWN FOR CLARITY
Deflection Monitoring System
(Number of Sensors)

Gage Accuracy:
+/- 0.01 degrees or 1.75e-4 rad

Desired accuracy in deflection at the deck level ¼”

<table>
<thead>
<tr>
<th>Elevation</th>
<th>Accuracy of calculated deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>715 ft.</td>
<td>0.08” (One gage is used)</td>
</tr>
<tr>
<td>755 ft.</td>
<td>0.12” (Two gages are used)</td>
</tr>
<tr>
<td>795 ft.</td>
<td>0.15” (Three gages are used)</td>
</tr>
<tr>
<td>835 ft.</td>
<td>0.17” (Four gages are used)</td>
</tr>
<tr>
<td>893 ft.</td>
<td>0.21” (Five gages are used)</td>
</tr>
</tbody>
</table>
Deflection Monitoring System (Installation)
Gages were installed on the same bracket = Should read the same
• Please be advised that data is already adjusted for polarity; one gage values are multiplied by -1
**Data Processing – Thermal Effect Correction**

\[ \theta_{loc} = \theta_{locu} + K(T - T_R) \]

*Initial K Selection*

- Investigate the daily standard deviation
  - Daily Standard Deviation is acceptable? (No → Change K)
  - Daily swing is consistent with neighbors (No → Record the K Value)

**Tilt Meter Data (Temperature Effect Corrected; Modified Temp. Coeff.)**

Elevation 680ft North

*(Comparison of two gages with opposite polarities installed on the same bracket)*

*Gages were installed on the same bracket - Should read the same*

*Please be advised that data is already adjusted for polarity - gage values are multiplied by -1*
Data Processing – Implemented Website

Pier 2

Plot Options

Start Date: 04/23/2013
End Date: 05/23/2013
Last Update: 2013-05-23 08:00
Avg Temp: 54.97°F

Sensors:
- EL800SouthP
- EL800NorthP
- EL760SouthP
- EL760NorthP
- EL720SouthP
- EL720NorthP
- EL680SouthP
- EL680NorthP
- EL682BaseP

Selected:

Plot Type:
- Tilt Method 1
- Tilt Method 2
- Tilt Method 3
- Longitudinal Deflection
- Temperature

Clear List

Units: english

Plot Type Descriptions:
- **Tilt Method 1**
  Uses the manufacturer’s specified calculation for temperature correction.
- **Tilt Method 2**
  Same as Method 1 with gage readings zeroed.
- **Tilt Method 3**
  Same as Method 2 with additional temperature correction based on UCI findings.

[1] **Longitudinal Deflection**
Total deflection accumulated vertically based on data from Tilt Method 3. [1]

**Note:** Tilt and deflection polarities are positive to the north.
**Note:** Times are reported in Eastern Standard Time (not Daylight Savings).

Reference:
[1] Project Proposal (click Documents link on the left hand side)
[2] Pier 2 Instrumentation (click Documents link on the left hand side)
Classical survey methods vs. tiltmeter measurement

• Total Station provides Cartesian coordinate readings; secondary processing is required for longitudinal displacement.
• Frequency of readings during the jacking procedure necessitates repetitive algorithms best suited for automated calculation.
• Tiltmeter data acquisition completely automated with graphic support capability.
• Quick evaluation of data was needed to avoid impeding contractor’s progress.

Decision to provide companion manual survey readings to validate tiltmeter monitoring.
Real-time Monitoring during Longitudinal Jacking

Improved in Phase 2
Real-time Monitoring during Longitudinal Jacking

<table>
<thead>
<tr>
<th>Force</th>
<th>0%</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Axial Force (kips)</td>
<td>0.0</td>
<td>9.5</td>
<td>57.1</td>
<td>36.0</td>
<td>43.1</td>
<td>43.8</td>
</tr>
<tr>
<td>Applied Moment (k-in)</td>
<td>0.0</td>
<td>-11016.2</td>
<td>558503.6</td>
<td>687192.4</td>
<td>2067373.6</td>
<td>2770907.3</td>
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Summary Measurements

- Tiltmeter monitoring provided quick data for easy evaluation.
- Comparison of measured & predicted closure opening spread and pier movement indicated systemic force loss that was addressed by the contractor.
- Decision to continue monitoring program for the twin Northbound structure, capturing movements at Piers 1 and 4.
Special Findings (Case1; Bearings)

Out of four P5 Bearings, two are unidirectional. The unidirectional bearings were actually placed transversely (Not longitudinally).
Movement of both travelers to one side of the pier caused unexpected large rotation; (Travelers weigh approximately 195 kips, similar to what half a segment weighs.)
Long term Monitoring During Winter

Deflection versus Temperature

Outlier

Moving Window
Valuable Tool During Construction

- Relatively inexpensive tilmeter system is accurate for this type of application.
- Real-time data collection allowed for instantaneous evaluation during key construction procedures.
- Automated system with web-based information site provides bridge response data for monitoring.
Thank you for your time!

Questions?