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NINTH BIENNIAL SYMPOSIUM
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STRAIN GAGE MONITORING FOR LOWER CHORD REPLACEMENT AT MARINE PARKWAY BRIDGE

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PERFORMANCE/CONSTRUCTION/MAINTENANCE

Introduction

The Marine Parkway Bridge, built circa 1936, is a tower drive vertical lift bridge that provides vehicular access between Brooklyn and Queens across Rockaway Inlet. The combined length of the lift span and the approach spans is 4022 ft. Recent rehabilitation work included the replacement of 32 approach span bottom chords over a 16 month period. Stafford Bandlow Engineering, Inc. (SBE) used strain gages as part of a process to monitor loads during removal of existing chords and the installation of replacement chords.

Figure 1: View of Marine Parkway Bridge across Rockaway Inlet.

Use of strain gages to compare load in removed and replaced members is a departure from the more common use of strain gage technology in the movable bridge industry as a tool to identify the balance condition of a bridge. This paper describes the use of strain gage technology as part of a process to replace deficient bottom chord truss members at the Marine Parkway Bridge. Discussion is centered on the technical aspects of the strain gage work and includes a discussion of significant results.

Methodology

Inspection of the Marine Parkway Bridge structure identified 32 approach span bottom chords as being deteriorated to an extent necessitating replacement. The bottom chords are comprised of two channels stiffened by backing plates and connected by lacing bars. The deteriorated chords exhibited severe corrosive deterioration and pack rust See Figure 2. The following steps outline the methodology for the bottom chord replacement:

1. Perform a structural analysis of the deck truss to identify the theoretical axial loads in the bottom chords.
2. For each member to be replaced, determine jacking pressures to achieve loads determined through structural analysis.
3. Install jacking frame to remove load from the deficient chords.
4. Load jacking frame, and unload bottom chord, by increasing jacking pressure to the values determined in step 2.
5. Remove the chord.

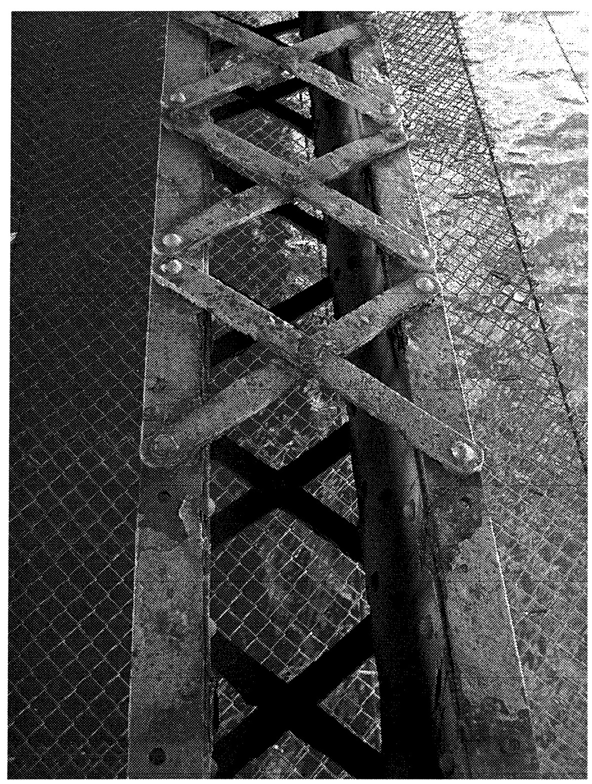

Figure 2: Typical Condition of Lower Chords, Before Replacement

6. Install a new chord.
7. Relieve the load in the jacks, transferring the load from the jacking frame to the new member.
8. Reset jacking frame at next deficient bottom chord location.

Testing

Due to the nature of the rehabilitation work, it was recognized ahead of time that existing conditions might adversely impact the theoretical loading predictions. Therefore the loading and unloading of the bottom chord members during replacement operations was verified in three ways:

- Pressure gages were used to monitor jacking force. The jacking pressures used to load / unload the chords were monitored to verify the axial load changes in the member.
- Strain gages were used to monitor the actual axial force in the member. Strain gage readings were taken to verify that the axial force was being relieved / imparted into the members as indicated by the jacking force readings.
- Connection bolts were monitored as a final check. The connection bolts were checked to ensure that they were loose or tight as was appropriate at the completion of jacking.

All three steps were intended to work in conjunction with each other. No step was intended for use as a sole basis for determining the load in the member.

Test Preparation

Jacking System

Replacing bottom chords required a means of removing load from existing chords and a way to reload replacement bottom chords. The geometry of the truss was such that the bottom chords marked for replacement included both tension and compression members. As such, one jacking frame was created to accommodate bottom chords in tension, and another frame was created for those in compression.

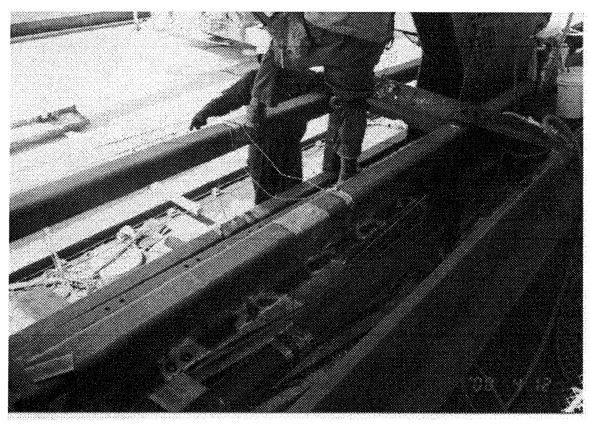

Figure 3: Compression Jacking Frame Testing

Both types of frames used hydraulic jacks to transfer the load from / to the bottom chord. Two high strength threaded rods supported the load transferred from chords in tension. Compression frames used four square steel tubes to support the load from chords in compression. Each frame attached to the truss members surrounding the deficient chord.

The use of the jacking frames was validated at the outset of the project through strain gage testing. Strain gages were installed on the square tubes of the compression frame (see Figure 3), and axial strains were monitored as a function of jacking pressure throughout the jacking cycle. The forces in the compression frame members determined from the axial strain measurements corresponded very well with the jacking force calculated from the jacking pressures. This test validated the theoretical relationship between axial strain and applied force and between jacking pressure and jacking force. Additionally, the test confirmed that the jacking force transferred through the frame and was therefore applied to the truss at the frame connection points.

Strain Gage Configuration and Test Equipment

The strain gage installation used to monitor axial loads in the lower chords replacement is known as a "full Poisson bridge" arrangement. This configuration uses a longitudinal gage parallel to the loading and a transverse gage on both the top and bottom surfaces (see Figure 4). This installation differs from the use of a full Poisson bridge arrangement (to measure torque in a shaft) for analyzing the balance condition of a bridge, where both gages are installed at an angle of +/- 45° from the shaft's neutral axis.

If desired, a half bridge configuration can be used to measure axial loading. The presence of resistors ε_4 and ε_2, shown in Figure 4, is what distinguishes the full Poisson bridge from the half bridge configuration, where only the two longitudinal gages are installed. A full bridge arrangement is preferred because it cancels bending strains of equal magnitudes and opposite signs. Therefore, the recorded strain is due to axial force only. Additionally, the full bridge configuration provides better temperature compensation because a gage is present in every leg of the bridge.

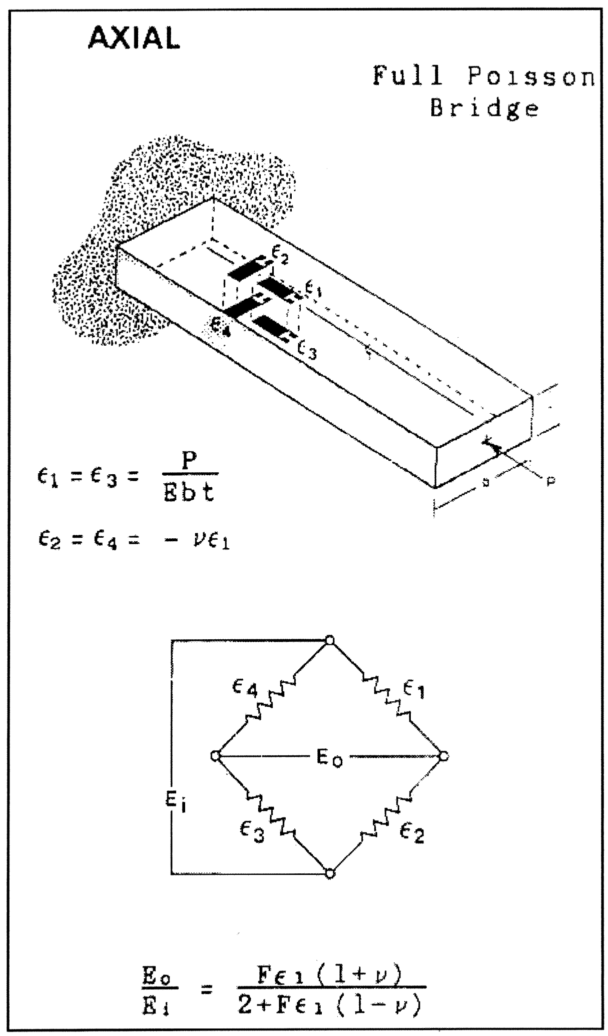

Figure 4: Strain Gage Installation Configuration

The bottom chords of the Marine Parkway deck truss are comprised of two channels aligned back-to-back, connected with cross bracing. Each channel is stiffened by a plate that is riveted to the web on the side opposite the flange.

The replacement methodology called for the channels that comprise the existing bottom chords to be unloaded as a pair. Therefore the chord was treated as a unit and gages were installed to the inboard and outboard faces of the channels and connected as a single full bridge. The two sets of rosettes were wired to form the full Poisson bridge described above. This installation results in a reading of the average of the loads in the two channel / backing plate assemblies that comprised the chord. Figure 5 describes the location for gage installation at the existing chords.

The replacement methodology called for the new bottom chords to be installed one channel at a time. Therefore each channel was treated independently. A pair of rosettes was installed on the inboard and outboard face of each channel / backing plate assembly. The rosettes were then wired together to form a full Poisson bridge. Figure 6 describes the location for gage installation for new chords.

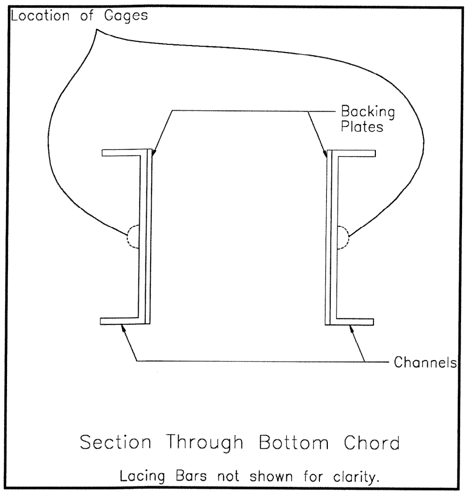

Figure 5: Strain Gage Installation Location at Existing Chords

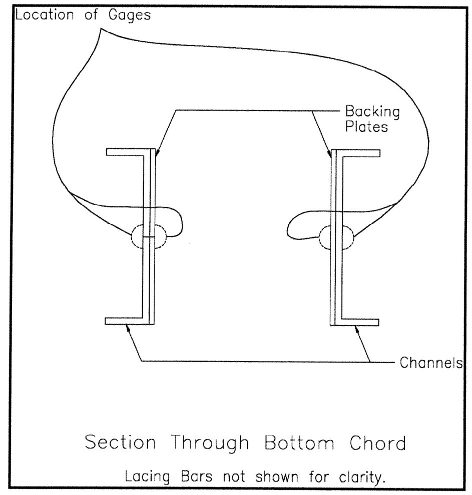

Figure 6: Strain Gage Installation Location at New Chords

After the gages had been installed, they were hard wired via shielded cable to an eight channel IOtech DBK43A strain gage module and Daqbook/112 PC based data acquisition system (DAQ unit). This unit induces a voltage through the full bridge circuit, and was calibrated to establish the unit change in strain in the member for each millivolt change in voltage across the full bridge.

Test Procedure

With the jacking frame installed at a specific location, and with the existing strain gage installment hard wired to the DAQ unit, the test procedure was as follows:

1. Zeroed the DAQ unit equipment. Began recording strain gage data.
2. Used the hydraulic jacks to transfer load from the existing lower chord to the jacking frame while recording strain gage data and jacking pressure. Jacking pressure was incrementally raised to the pressure necessary to remove the theoretical axial load in the chord, as determined by the structural analysis.
3. Checked for loose bolts at connections to verify that chord was unloaded. If bolts still holding load, jack pressure was incrementally increased until the bolted connections were loose.

4. Removed all of the connection bolts and pulled out one of the two existing channel / backing plate assemblies that comprised the existing chord.
5. Installed first channel / backing plate assembly for the new installation into position.
6. Hard wired the gages at the first channel / backing plate assembly to the DAQ unit.
7. Zeroed the DAQ unit equipment for the new installation. Began recording strain gage data.
8. Installed the connection bolts for the new channel / backing plate assembly.
9. Removed the second channel / backing plate assembly from the existing chord.
10. Installed second channel / backing plate assembly for the new installation into position.
11. Hard wired the gages at the new channel / backing plate assembly to the DAQ unit.
12. Zeroed the DAQ unit equipment for the second channel / backing plate assembly. Began recording strain gage data for the second assembly.
13. Installed the connection bolts for the second channel / backing plate assembly.
14. Incrementally reduced the jack pressure, transferring the load from the jacking frame to the new member.

The above procedure was followed with close coordination between Stafford Bandlow Engineering and the contractor in order to minimize any delay to the construction work during the calibration of the equipment or any other test activity.

Calculations Relating Axial Load to Strain Gage Data

The relationship between strain and force is a direct application of Hooke's Law as follows:

$\sigma = \varepsilon \cdot E$ Hooke's Law

$\frac{P}{A} = \varepsilon \cdot E$ By substitution

$P = \varepsilon \cdot E \cdot A$ Determination of force in member

Definitions of variables in above equations:

$\sigma =$ Stress in the member
$\varepsilon =$ Measured strain
$E =$ Modulus of elasticity
$P =$ Force in member
$A =$ Cross sectional area of member *

* Note that chord replacement work was necessitated by the severe deterioration of existing members. Pack rust, corrosion, and resultant section loss existed at those members and detracted from the original section area. Additionally, these factors contribute to stress risers that might have adversely affected the strain measurements.

Results

The following charts present the axial strain and jacking force measurements recorded during the replacement of Span 19, Southeast, Member L22-24. These results are typical for members and form the basis for the ensuing discussion on testing observations.

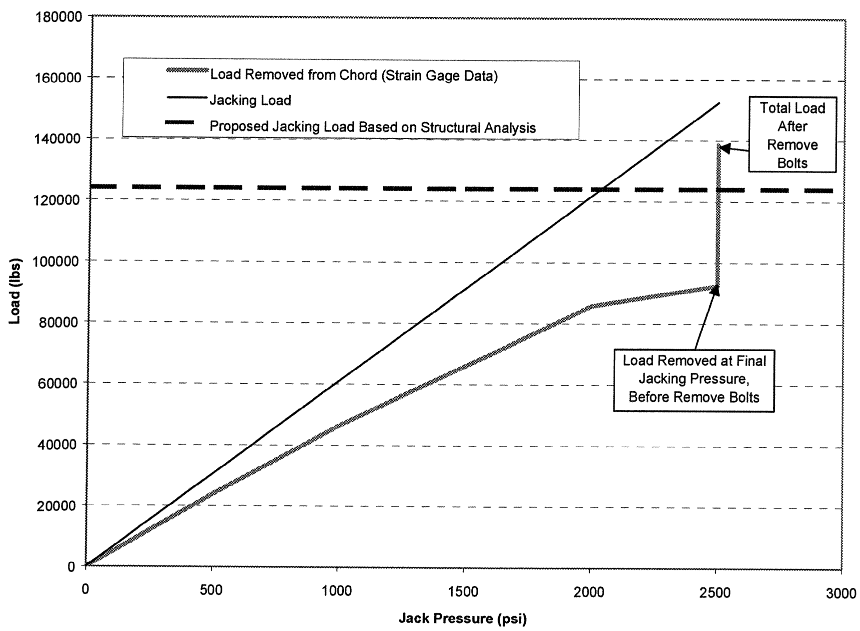

Figure 7: Unloading of Existing Bottom Chord

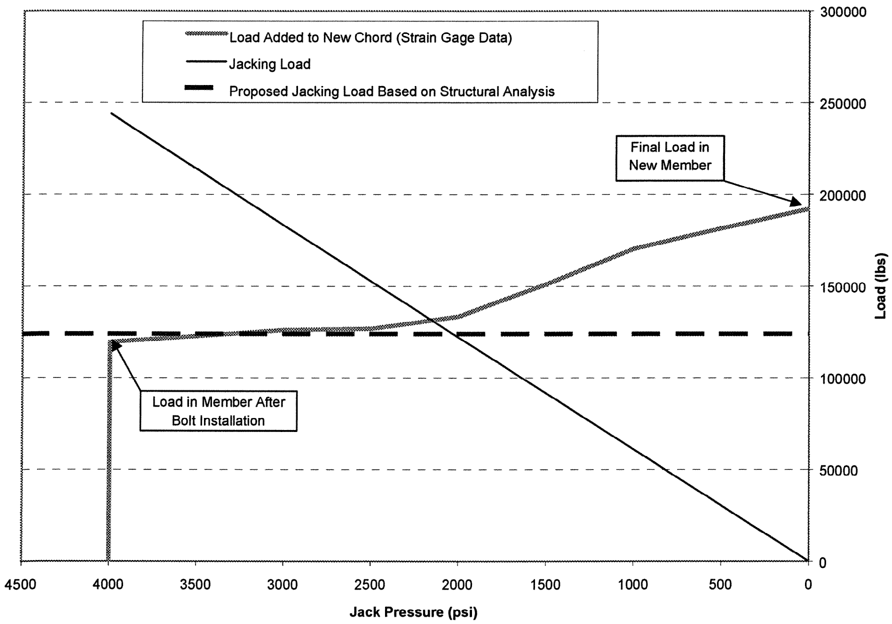

Figure 8: Loading of New Bottom Chord

Observations

Analysis of the strain gage testing results for the bottom chord replacement at Marine Parkway Bridge yielded the following significant observations:

- The theoretical jacking loads for the deficient bottom chords, as determined through structural analysis, were generally lower than the total jacking loads necessary to remove the existing chords.

  This discrepancy underlines the fact that rehabilitation work yields inconsistencies between theoretical predictions and actual results.

- The removal of bolts at existing deteriorated chords resulted in a significant load change in the chord. This indicates that the full load of the existing chord was not removed by jacking.

  Per the test procedure, existing chords were to be jacked to the theoretical pressure that would remove the entire load from the chords and result in loose bolt connections. During the actual implementation of this procedure in the field, this condition was not achieved. While some bolts were loose, others still held load and these fasteners had to be forced out. In Figure 7 the remaining effect of driving out the tight bolts on chord load is illustrated by the vertical spike in "Load Removed from Chord" after the jacking pressure had been finalized.

- The final measured load in the existing lower chords was consistently lower than the load provided by the jacks. See Figure 7.

  This discrepancy is attributed to the fact that some portion of the jacking load was dispersed among the additional truss members at the chord termination points.

- The installation of bolts for replacement chords resulted in a significant load increase in the chord.

  During installation of new chords, misalignment of bolt holes or small differences in length of the new chord compared with the existing chord necessitated the forceful installation of some bolts. The effect of this process is shown in Figure 8, with the spike in "Load Added to Chord" at the start of the new installation, before any load was transferred from the jacking frame to the new chord.

- The total measured load imparted to the replacement chord varied considerably from the total measured load in the deficient chord that was extracted.

  The strain gage testing performed on the jacking frame at the outset of the project confirmed that the loads indicated by the jacking pressures and the strain readings were in fact real loads. Therefore this discrepancy in loading from the existing to the new chords must be attributed to the permanent shift of some amount of load between the bottom chords and the surrounding truss members that feed into the bottom chord connections.

Conclusions

The bottom chord strain gage analysis at Marine Parkway Bridge demonstrates that strain gage testing is a valuable resource in the construction environment. Two significant findings were noted during the course of work:

1. The theoretical jacking loads for the deficient bottom chords, as determined through structural analysis, were generally lower than the total measured loads in the existing chords. This discrepancy underlines the fact that rehabilitation work yields inconsistencies between theoretical predictions and actual results.

2. The total measured load imparted to the replacement chord varied considerably from the total measured load in the deficient chord that was extracted. This change in loading at the bottom chords was attributed to the permanent shift of some amount of load between the bottom chords and the surrounding truss members that feed into the chord connections.

These two findings show that the ability to positively establish the loading in structural members was a valuable tool for this work. Strain gage load measurement is potentially a valuable tool in similar environments in the construction industry, where outside factors can sometimes compromise theoretical work.