FORCE MONITORING OF POST-TENSIONING TENDONS & CABLE STAYS IN BRIDGE STRUCTURES

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OUTLINE

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- Systems
- Accuracy
- Measuring Procedure
- Applications
- Conclusions
INTRODUCTION

Health monitoring system
- Determine the behavior of the structure under various loads and environmental effects
- Know the condition of the structure before it is too late
  - Inspection- non-destructive testing
  - Repair or replacement

Post-tensioning is a key element to the performance and durability of the structures where they are installed

Tendon or stay force
- During construction
- Long-term monitoring
  - Periodic, continuous, remote
INTRODUCTION Cont’d

Tendon embedded or external

Tendon/stay either of strand or high strength bar

Strand/bar can be of bare, coated or grouted

Various methods to measure the tendon/stay force

Most are cumbersome and accuracy differs

DSI involved in development, testing and utilization of DYNA Force (DF) to measure the force in tendon/stay
THEORY

DYNA Force sensors are manufactured based on the magneto-elastic properties of ferrous material.

FARADAY’S LAW: Change in magnetic environment of a coil of wire will cause a voltage to be induced in the coil

\[ \mathcal{E} = - \frac{d}{dt} (\phi_B) \]

\[ \mathcal{E} = \text{ELECTROMOTIVE FORCE} \]

\[ \phi_B = \text{MAGNETIC FLUX} \]
THEORY Cont’d

Sensor is composed of a primary coil and a secondary coil

By passing current through primary coil, ferromagnetic material is magnetized

Sensing coil picks up induced electromotive force that is proportional to change rate of applied magnetic flux and relative permeability

As permeability of core changes, output voltage changes

Output voltage is calibrated to measure force
DYNA Force System consists of mainly sensor and readout unit. The force can be measured by:
- Manual reading
- Local data storage
- Remote access

DF Sensor  Readout Unit  Multiplexer
### Table: DYNA Force Dimensions

<table>
<thead>
<tr>
<th>Strand Size</th>
<th>Strand Grade</th>
<th>Sensor Dimensions [in]</th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>[in]</td>
<td>[KSI]</td>
<td>ID</td>
<td>OD</td>
<td>Length</td>
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<td>0.5&quot; - 0.62&quot;</td>
<td>270</td>
<td>0.79</td>
<td>1.42</td>
<td>5.2</td>
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<table>
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<th>THREADBAR Size</th>
<th>Bar Grade</th>
<th>Sensor Dimensions [in]</th>
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<td>Length</td>
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<td>#7 - #11</td>
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<td>3.15</td>
<td>7.09</td>
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<td>3.90</td>
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<tr>
<td>#18 / #20</td>
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<tr>
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<td>1.69</td>
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DYNA Force over the entire tendon is custom made and dimensions will be provided upon request.
Due to the diversity of the magnetic property of steel, calibration is done for each type of steel allowing the sensors to perform at their highest accuracy.

Three sensors were used in each of three 59-0.6” strand anchors. Sensors were consistently more accurate than load cells when compared to the actual jacking force.
MEASURING PROCEDURE

Sensors supplied are pre calibrated at DSI facility

Install over the strand/bar or tendon during construction

Attach portable readout unit to wire leads from DYNA Force

Take a zero reading before applying any force

Apply PT/stay force

Measure the force in cable/strand anytime
APPLICATION- Penobscot Narrows Bridge, Maine

80 stay cable anchors with 3 DYNA Force in each anchor
Stay force was monitored during construction
APPLICATION- Harbor Drive Bridge, San Diego

Sensors were installed in two foundation tie-downs, two back stays and two main cables. DF enabled verification of friction assumptions and permitted adjustment to jacking forces to achieve the target force at the pylon tip. Lock-off forces in the tie-down anchors were also adjusted based on the DF sensor readings.
APPLICATION- Wacker Drive Bridge, Chicago

Sensors were installed to know:
Force at dead end of 9-06 longitudinal tendons
  Jacking force was revised based on finding
Force at dead end of 4-06 transverse tendons
  Good correlation was observed

![Graph showing strand forces vs stressing sequence]
APPLICATION- Wade Bridge (I-81), Pennsylvania

Twelve sensors were installed to monitor forces in 1-3/4” DCP external tendons in Pier Caps
Good correlation was observed
APPLICATION- Pont Champlain Bridge, Montreal, Canada

Sensors were installed to monitor forces in 0.6” dia strands used to retrofit the exterior girders. DF readings provided valuable information to the designer.
APPLICATION- Stone Cutters Bridge, Hong Kong

32 sensors were installed at the interfaces of steel girders and RC girders to monitor the force in 37-0.62” tendons

Courtesy- IIS
APPLICATION- Hsing-Tung Bridge, Taiwan

EM sensors were installed on all 34 stay cables
Sensors were fabricated in the field by winding process
Each stay force is being monitored

Courtesy- IIS
APPLICATION- Adige Bridge, Italy

EM sensors were used on the existing stays
A total of twelve sensors were installed
Sensors were precalibrated at the laboratory
All sensor reading are accessed remotely

Courtesy- IIS
APPLICATION- Sellwood Bridge Abutment, Oregon

56 DYNA Force sensors were supplied to monitor the slope stability in front of the bridge abutment. Automated readout units were installed to record the force readings at every 4 hours.
APPLICATION - Willow Island Hydroelectric Project, WV

To monitor the forces in the anchors during excavation of rocks, three sensors were installed in each of 28 anchors (59-0.6”). Data from all of the sensors are being taken remotely every 3 hours, analyzed and reported to the owner.

In service since Nov 2012

![Graph showing strand force in kips over time](image)

![Construction site photo](image)
CONCLUSIONS

DYNA Force sensors can be used for:
bare, epoxy-coated, galvanized and greased-sheathed steel in bonded, un-bonded, grouted or un-grouted length of the tendon.

Sensors for existing tendon/stay

Eliminates any lift-offs & possible friction tests

Portable read-out unit

Reading in seconds by a trained person

Owner can regularly monitor forces in PT tendon/stays even from remote access
CONCLUSIONS- Cont’d

Durability

DYNA Force system is robust
Requires no maintenance & has no moving parts
Similar service life to that of bridge or structure

The accuracy of the force measurement is normally within 1.5% for strand and within 3% for bar for preinstalled DF sensors.
THANK YOU FOR YOUR ATTENTION