Force Monitoring of Pre-Stressing Steel in Structures

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DSI

POST-TENSIONING INSTITUTE ®
Stressing the Stronger Concrete Solution

OUTLINE

- Introduction
- Theory
- 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 sensors to measure the force in tendon/stay

THEORY

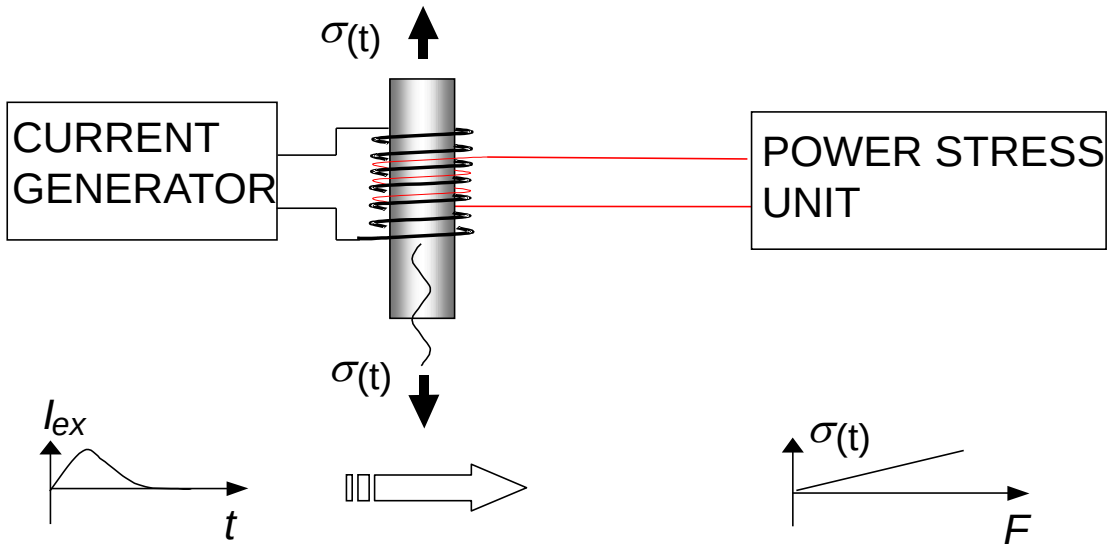
Sensors are manufactured based on the magneto-elastic properties of ferrous material.

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

$$\varepsilon = -\frac{d}{dt}(\phi_B)$$

$\varepsilon =$ ELECTROMOTIVE FORCE

$\phi_B =$ MAGNETIC FLUX



THEORY Cont'd

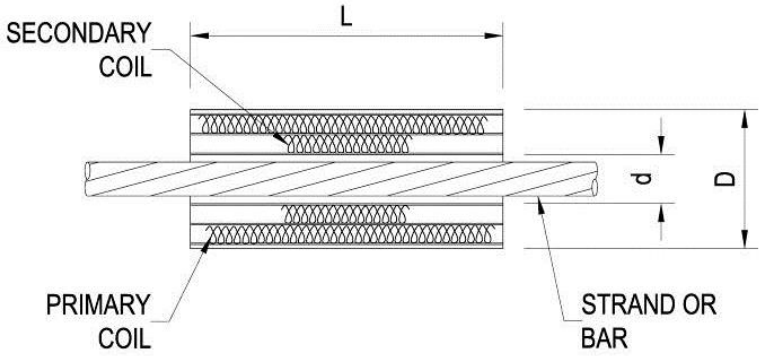
Sensor is composed of a primary coil and a secondary coil

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

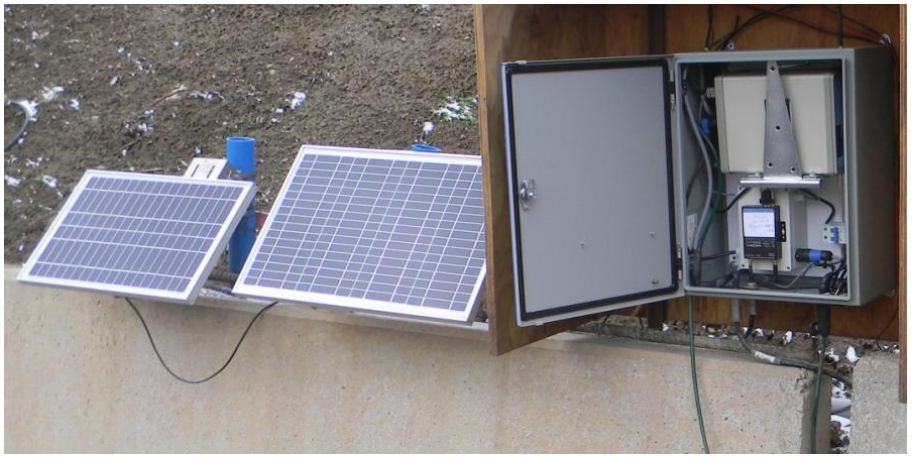


SYSTEMS

DYNA Force System consists of mainly sensor and readout unit

The force can be measured by:

- Manual reading
- Local data storage
- Remote access



Sensor

Readout Unit

Multiplexer

SYSTEMS- Cont'd

Table: DYNA Force Dimensions

Strand Size	Strand Grade	Sensor Dimensions [in]		
[in]	[KSI]	ID	OD	Length
0.5" - 0.62"	270	0.79	1.42	5.2
THREADBAR Size	Bar Grade	Sensor Dimensions [in]		
[in]	[KSI]	ID	OD	Length
#7 - #11	75-97	1.69	3.15	7.09
#14	75-97	2.09	3.90	7.87
#18 / #20	75-97	2.87	5.71	12.20
#24	75-97	3.35	6.10	12.99
1" - 1-3/8"	150	1.69	3.15	7.09
1-3/4"	150	2.09	3.90	7.87
2-1/2"	150	2.87	5.71	12.20
3"	150	3.35	6.10	12.99

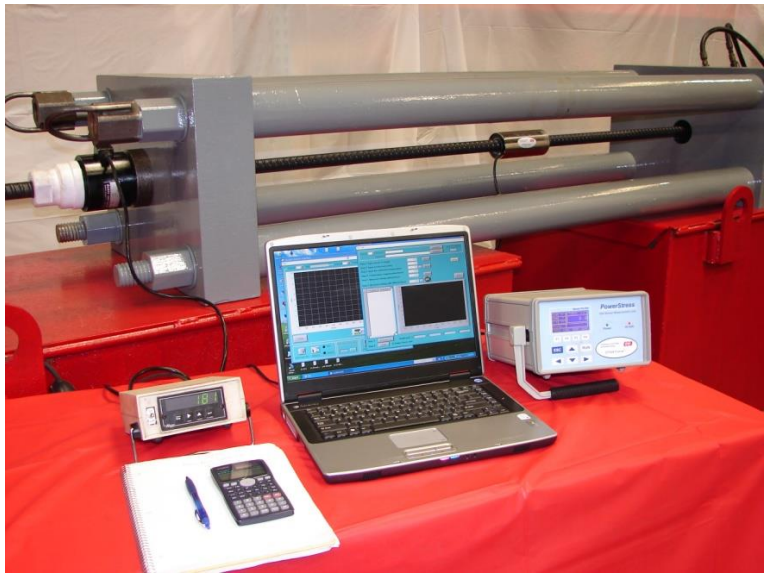
DYNA Force over the tendon x-section is custom made and dimensions will be provided upon request

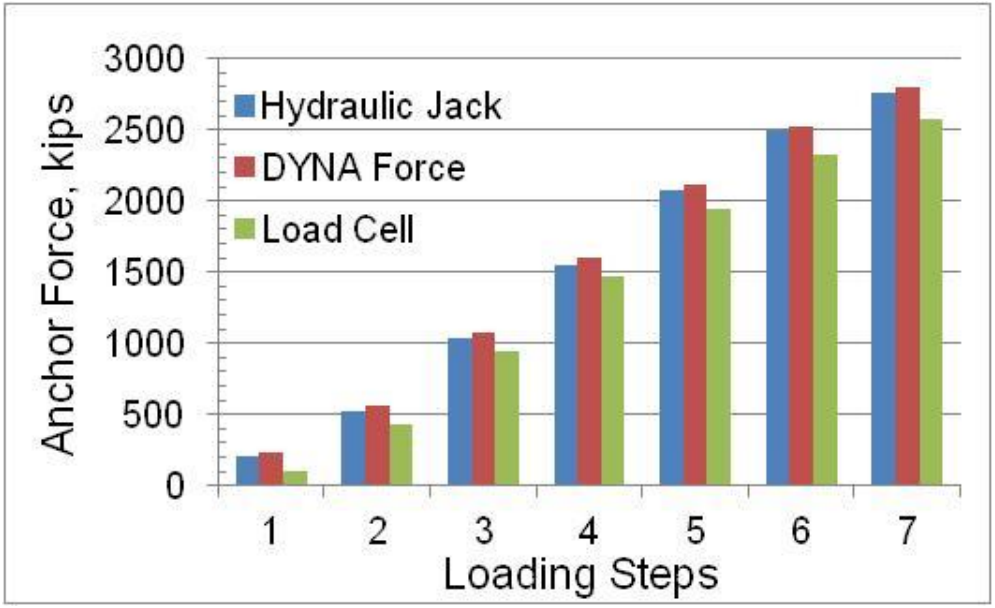
ACCURACY

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 the sensor

Take a zero reading before applying any force

Apply PT/stay force

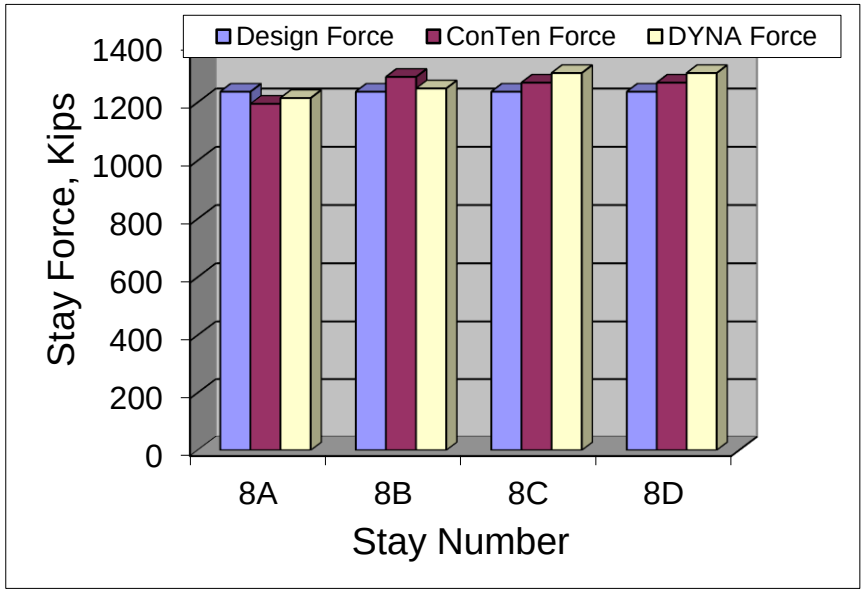
Measure the force in tendon/anchor anytime from anywhere

APPLICATION- Penobscot Narrows Bridge, Maine, USA

80 stay cable anchors with 3 sensors in each anchor- opened to traffic Dec 2006

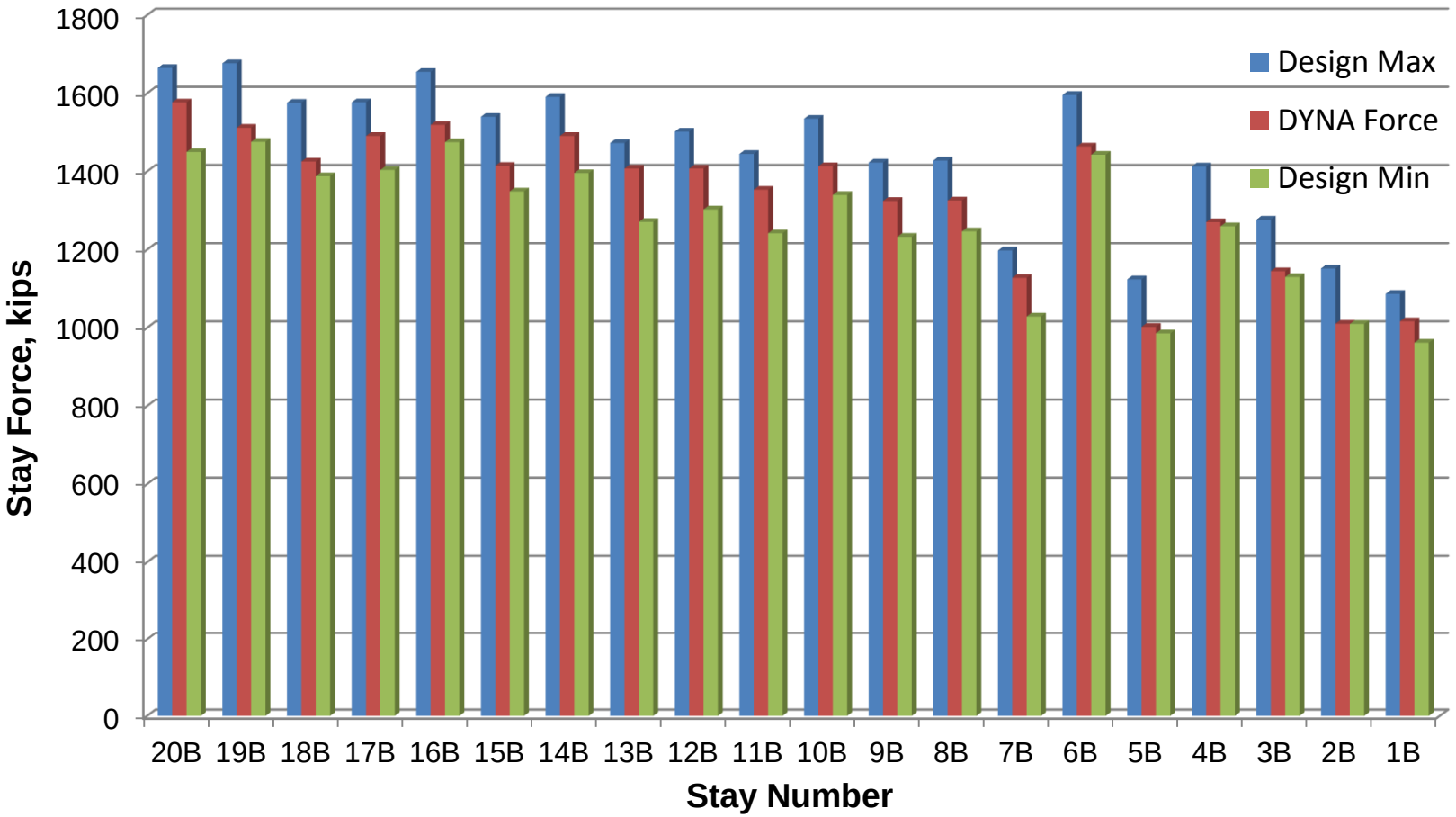
Stay force was monitored during construction

Recent sensor readings Dec 2013



APPLICATION- Penobscot Narrows Bridge, Maine, USA

Data received after the bridge 7 years in service are very consistent

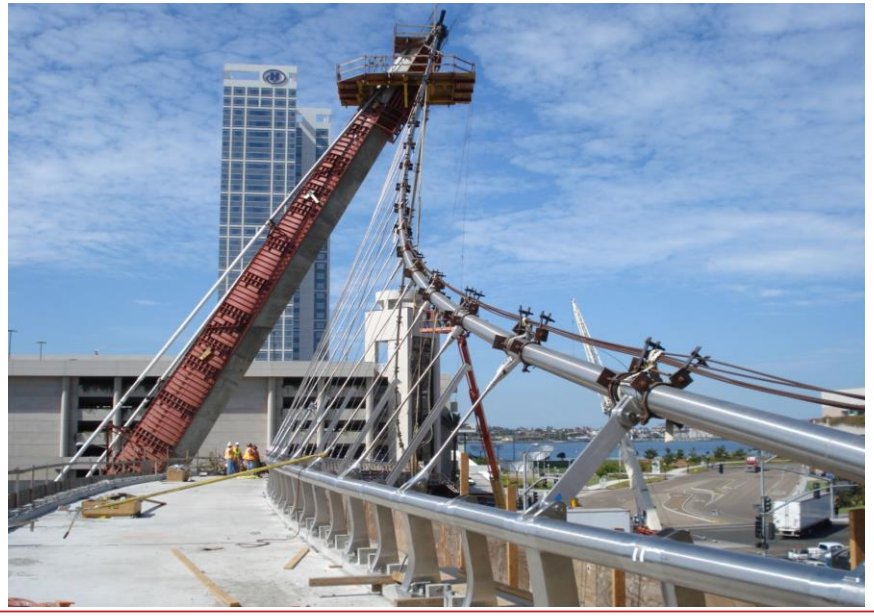


APPLICATION- Harbor Drive Bridge, San Diego, USA

Sensors were installed in two foundation tie-downs, two back stays and two main cables.

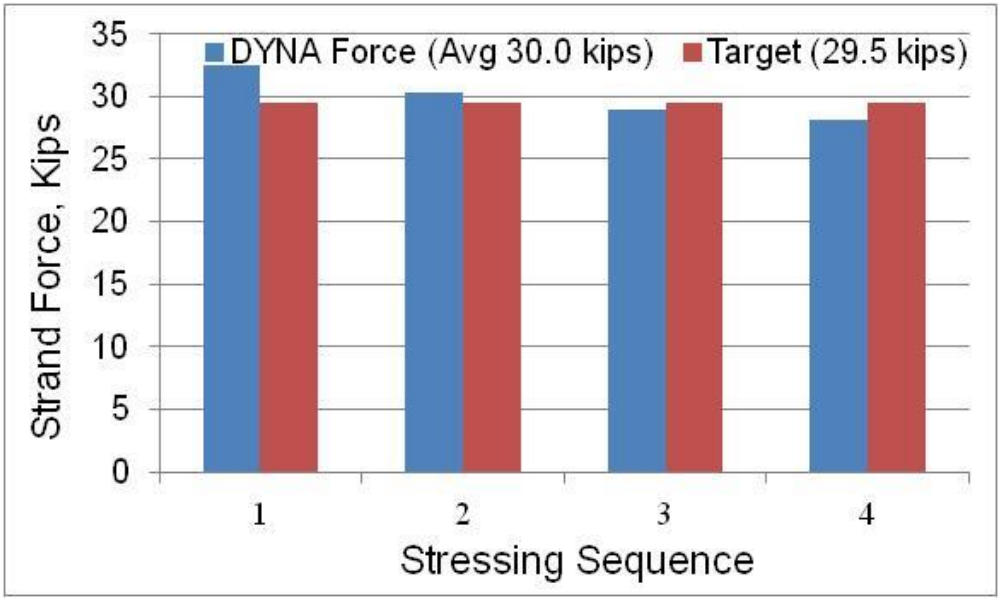
Sensors enabled verification of friction assumptions and permitted adjustment to jacking forces to achieve the target force at the pylon tip.

Lock-off forces in the tie-down anchors were also adjusted based on the sensor readings.



APPLICATION- Wacker Drive Bridge, Chicago, USA

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



APPLICATION- Wade Bridge (I-81), Pennsylvania, USA

Twelve sensors were installed to monitor forces in 1-3/4” DCP external tendons in Pier Caps
Good correlation was observed

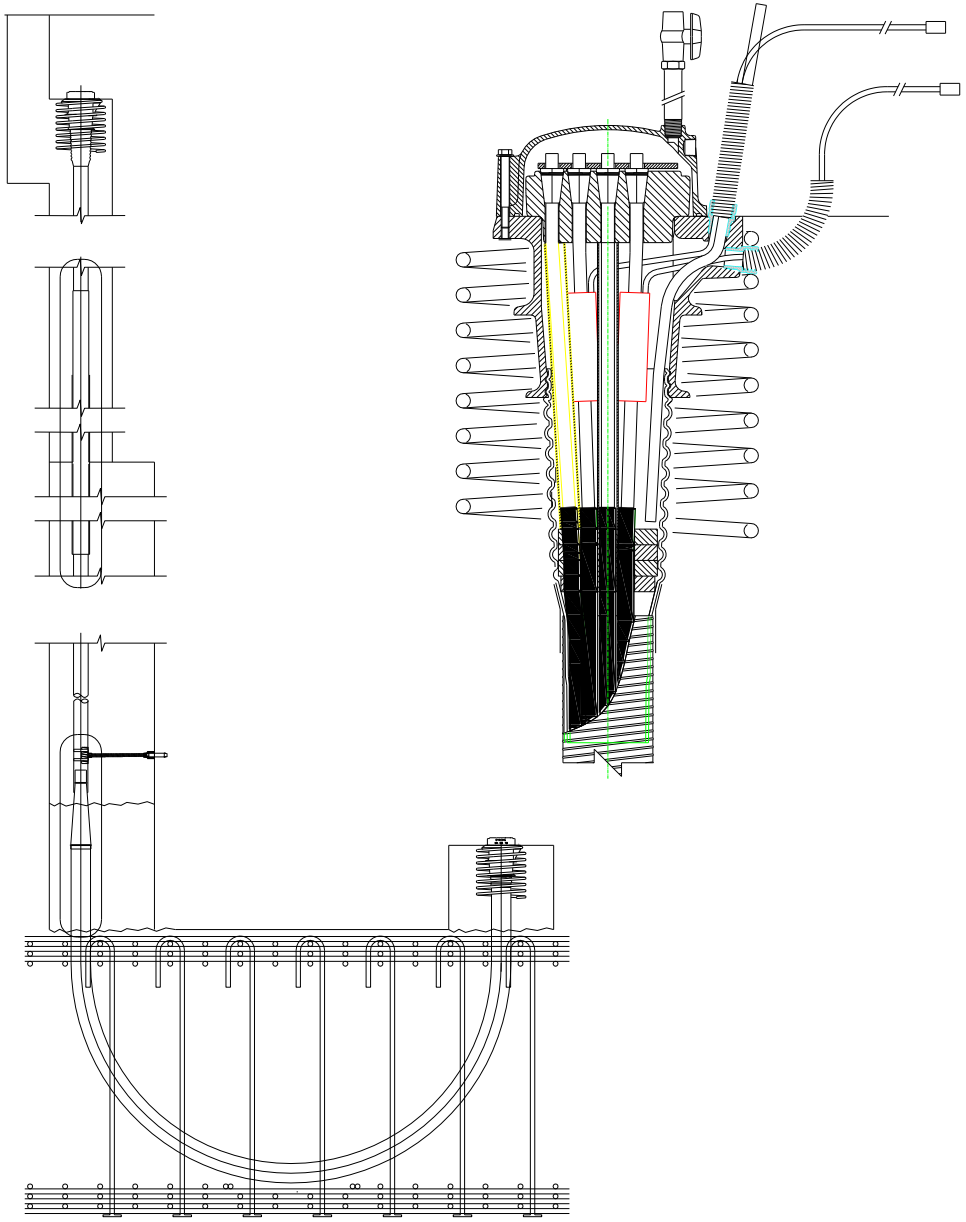
APPLICATION- Pont Champlain Bridge, Montreal, Canada

Sensors were installed to monitor forces in 0.6” dia strands used to retrofit the exterior girders

Sensors readings provided valuable Information to the designer

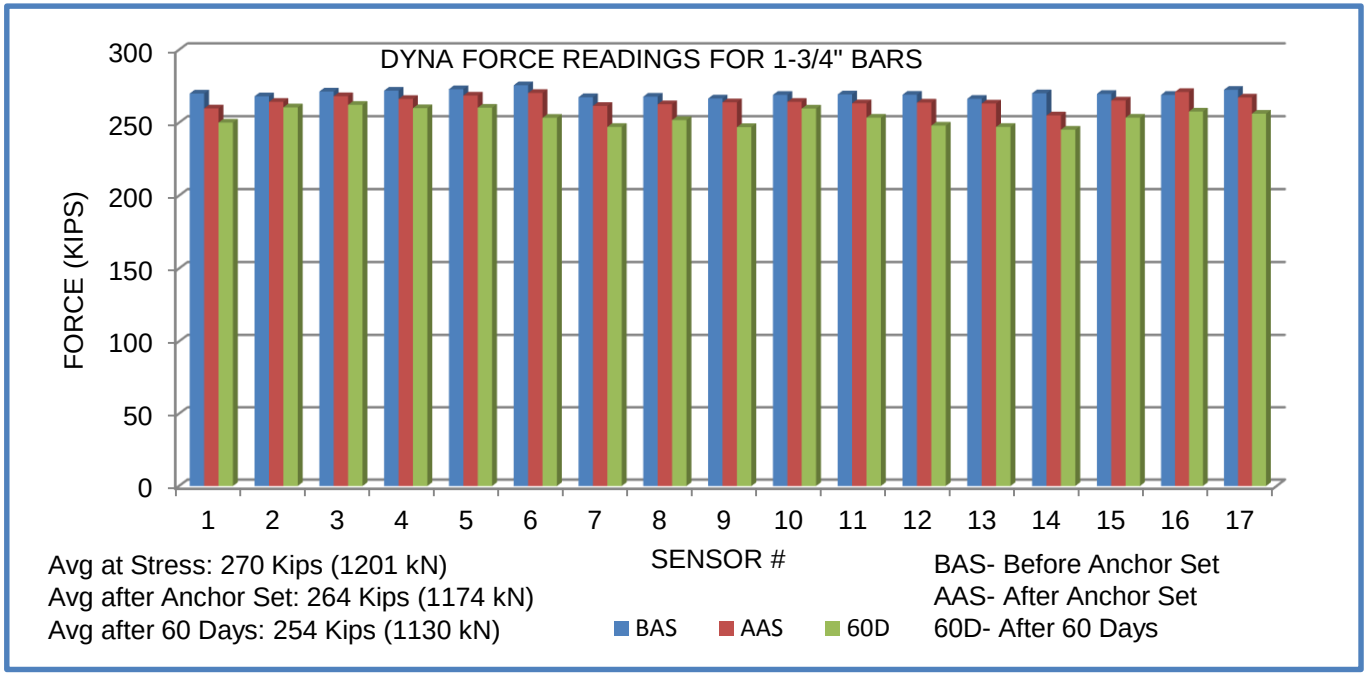
APPLICATION- SFO Tower

Fifty-two DF sensors were installed in 19-06 tendons (2 per anchor). All sensors were monitored during construction and will be monitored after any seismic event. Sensor readings were very consistent with jacking force.



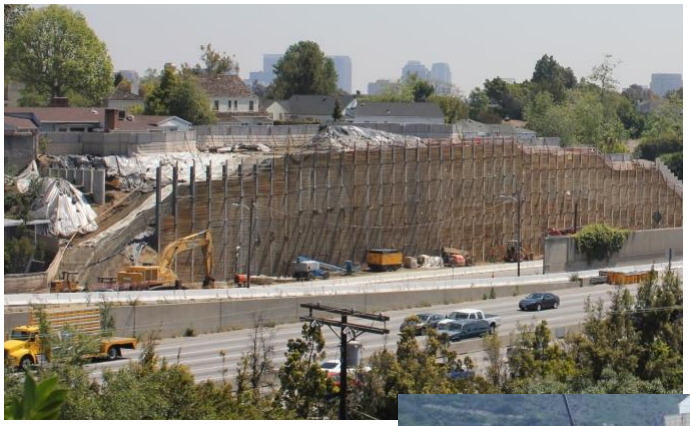
APPLICATION- Wind Technology Testing Center-Boston, USA

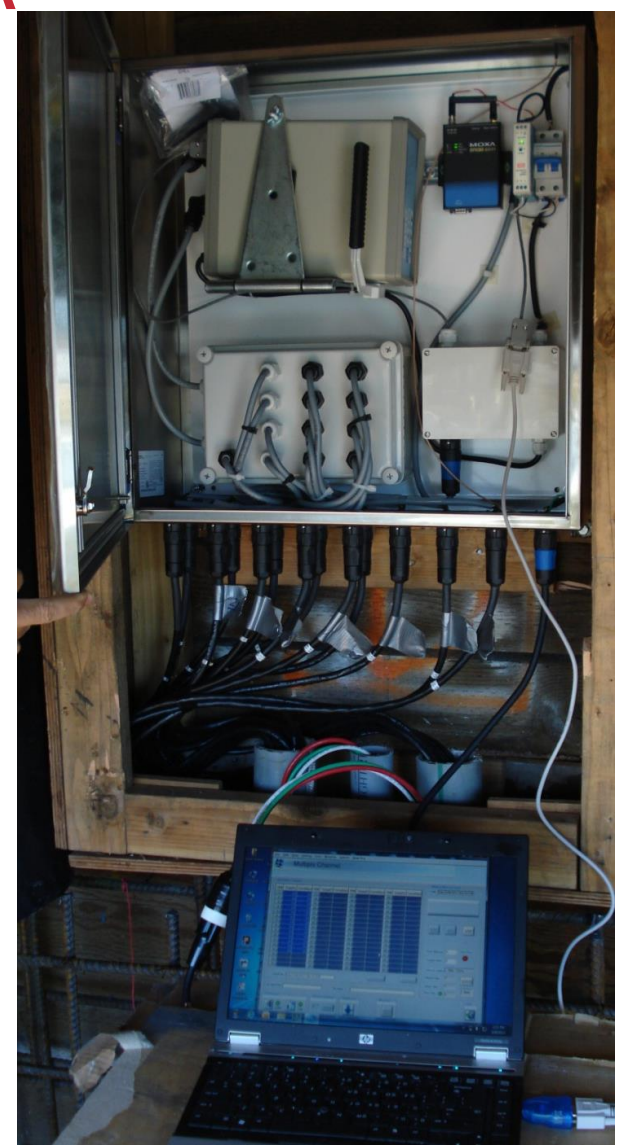
Sensors were utilized to monitor the force in 1-3/4”-Gr. 150 ksi post-tension bars in the vertical wall. Forces were monitored during construction and two months after stressing. Force will be measured after Dynamic Testing is completed.



APPLICATION- Retaining Wall- Rt 405, CA

48 DYNA Force sensors were installed on tie back anchors to monitor the performance of the retaining wall. Automated readout units were installed to record the force at every 4 hrs.





APPLICATION- Sellwood Bridge Abutment, Oregon, USA

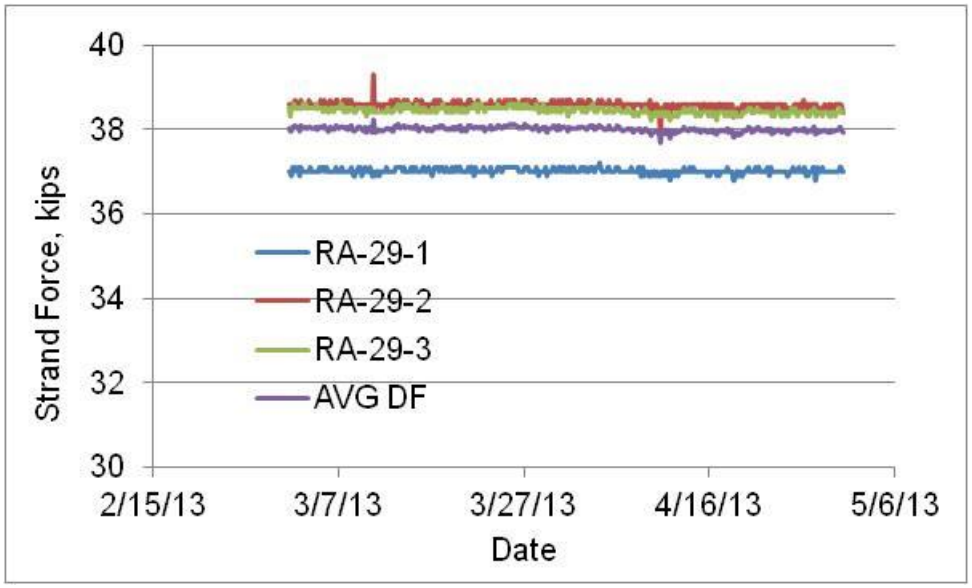
56 sensors were supplied to monitor the slope stability in front of the bridge abutment. Automated readout units were installed to record the force readings at every 4 hours.

APPLICATION- Willow Island Hydroelectric Project, WV, USA

To monitor the forces in the anchors during excavation of rocks, three sensors were installed in each of 28 anchors (59-0.6”).

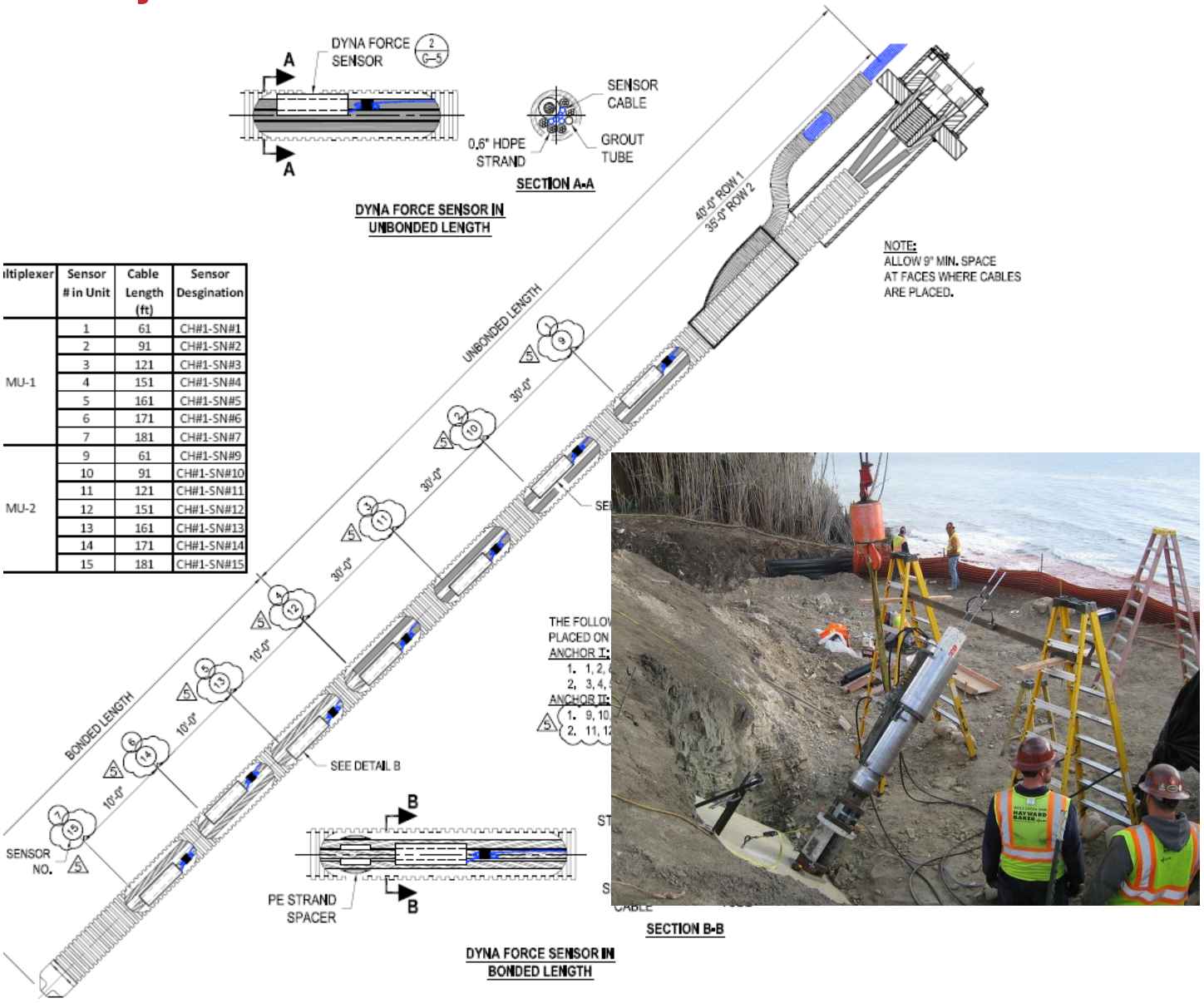
Data from all of the sensors are being taken remotely every 3 hours, analyzed and reported to the owner.

In service since Nov 2012



APPLICATION- Project in LA

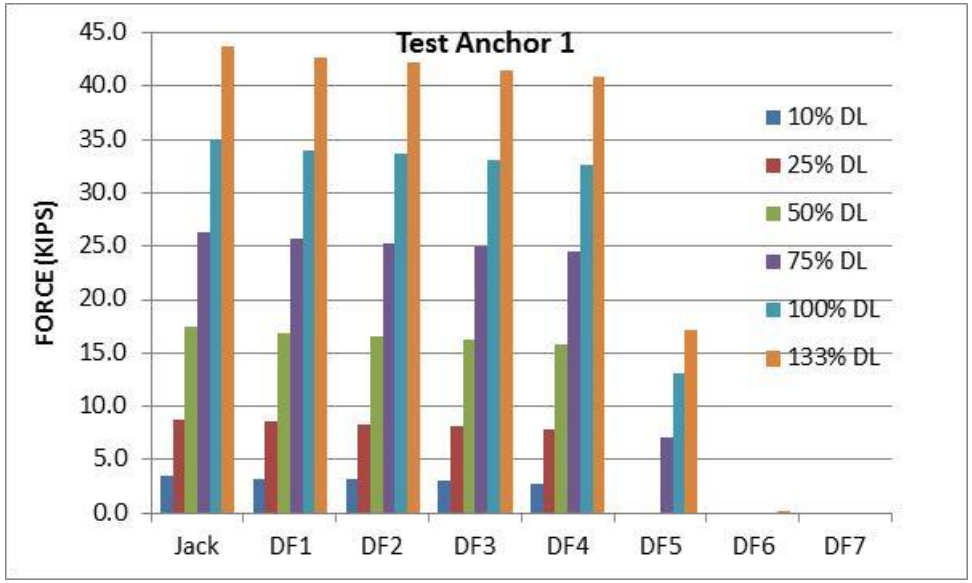
To monitor the forces in the anchors in un-bonded and bonded length of the anchors. Data is taken every 15 days and compared with the target value

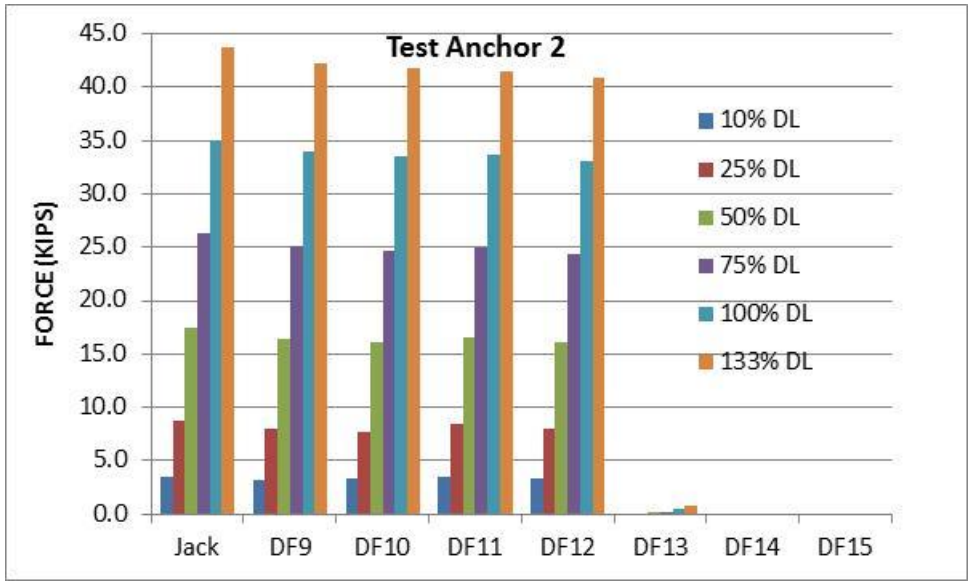


Multiplexer	Sensor # in Unit	Cable Length (ft)	Sensor Desgination
MU-1	1	61	CH#1-SN#1
	2	91	CH#1-SN#2
	3	121	CH#1-SN#3
	4	151	CH#1-SN#4
	5	161	CH#1-SN#5
	6	171	CH#1-SN#6
	7	181	CH#1-SN#7
MU-2	9	61	CH#1-SN#9
	10	91	CH#1-SN#10
	11	121	CH#1-SN#11
	12	151	CH#1-SN#12
	13	161	CH#1-SN#13
	14	171	CH#1-SN#14
	15	181	CH#1-SN#15

APPLICATION- Project in LA

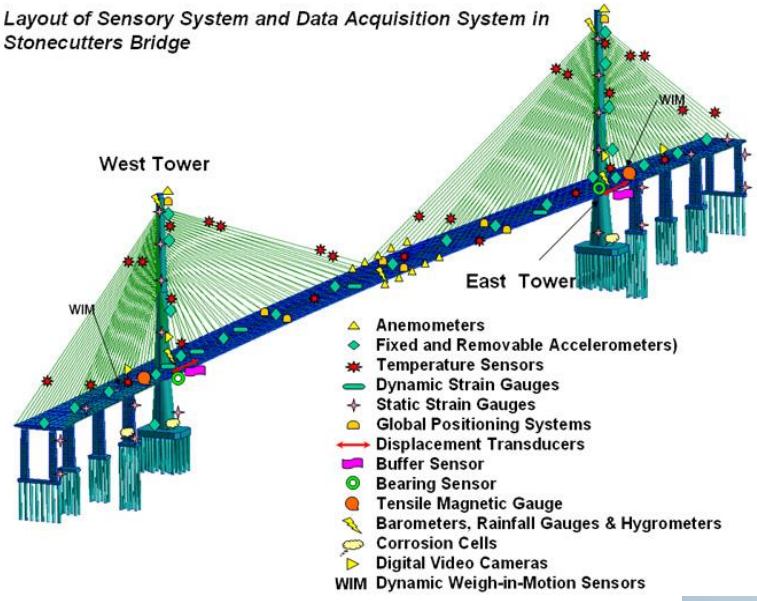
Sensors in bonded and un-bonded length provide valuable data to the engineer.

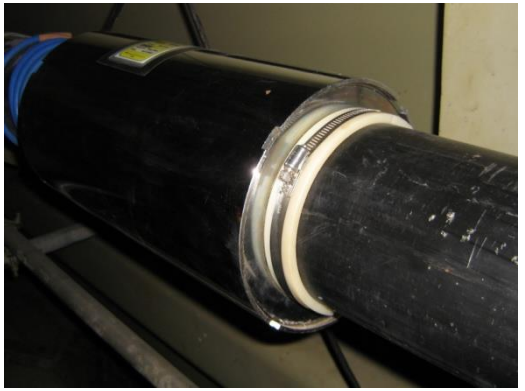




APPLICATION- Stone Cutters Bridge, Hong Kong

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 sensor was installed on stay cable

Sensor was fabricated in the field by winding process

Stay force is being monitored

Courtesy- IIS

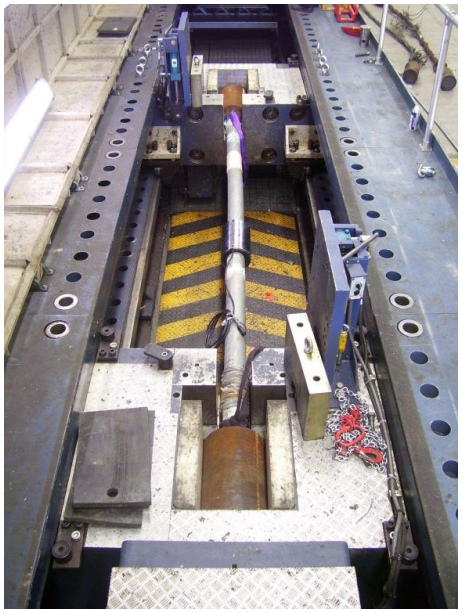
APPLICATION- Adige Bridge, Italy

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

CONCLUSIONS

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 & friction tests

Portable read-out unit

Reading in seconds by a trained person

Owner can regularly monitor forces in PT tendon/stays/anchors even from a 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 sensors.

The accuracy of the in-situ sensor is lower due to some uncertainties during the field winding process and due to non existence of zero stress state.

Sensors have been used in over fifty projects and have proven to be the preferred technique to monitor the forces in steel element in terms of accuracy, its performance, ease in installation, & cost effectiveness.

THANK YOU FOR YOUR ATTENTION