

## DYNA Force<sup>®</sup> Elasto-Magnetic Sensor Force Monitoring of Post-Tensioned Steel Elements





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## Benefits and Usage of the DYNA Force® System

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### **DYNA Force® Sensors have been successfully used in the following areas:**

- Cable stayed bridges
- Post-tensioning tendons in bridges and buildings
- Ground anchors
- Tie-back and tie-down anchors
- Air traffic control towers
- Wind energy towers
- Repair of various post-tensioned structures

### **The DYNA Force® System offers numerous benefits for health monitoring of the structure and is also suitable for other applications:**

- For Owners:**
  - Lifetime monitoring of the post-tensioning performance in structures
- For Engineers:**
  - Knowledge that their post-tensioning design is working as intended. The system permits posterior analysis and potential adjustment at any time in the future
  - Monitoring of tendon forces at any time
  - Quality and support from the industry leading supplier
- For Contractors:**
  - Typically, no extra work or interference with post-tensioning installation
  - No large load cell at anchorages and no increased pocket depth
  - Load check during stressing
  - Construction site safety

DSI supplied 240 DYNA Force® Sensors for **Penobscot Narrows Bridge, Maine, USA**. Each cable had six sensors, allowing the cable forces at each stage of construction to be monitored. Periodic lift-off operations were additionally carried out on the strands with sensors, and a good correlation was observed. The bridge is now open to traffic, and the forces in all cables can be monitored anytime using DYNA Force® Sensors without any disruption to traffic.



DYNA Force® in Cable Stay Anchorage, Penobscot Narrows Bridge, Maine, USA

## General

There is a large demand for implementing health monitoring of bridges, buildings and underground structures. Post-tensioning is a key element to the performance and durability of these structures. On many occasions during the construction and service life of the structure, it is useful to know the force in the post-tensioning system. Although there are many methods to measure the tendon force, most of them are cumbersome, expensive, and the accuracy varies depending on the method used. DSI is actively involved in the development, testing and utilization of the DYNA Force® System for measuring the force in post-tensioning tendons.\*

DYNA Force® Sensors are based on the magneto-elastic properties of ferrous material. The permeability of steel in a magnetic field changes with the stress level in the steel. By measuring the change in permeability, the stress in the steel element can be determined.

The sensor does not alter the characteristics of the tendon other than its magnetization where the sensor is installed. A readout unit is designed to magnetically energize the steel through the sensor and measure the response of the steel to the process. The readout unit then converts the response into a direct force reading. The sensor has an embedded thermistor which allows for temperature compensation. 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.

The accuracy of the force measurement is within 1.5% for strand and within 3% for bar. The DYNA Force® System allows the user to regularly monitor the forces in the post-tensioning system in minutes as a part of the inspection procedures without the need for lift-off equipment or other special expensive techniques.

The system avoids the inaccuracies and risks associated with lift-off readings.

The DYNA Force® Sensor is robust, requires no maintenance, has no moving parts and is not subject to any load. It is expected to have a similar service life to that of the surrounding structure.

DYNA Force® Sensors are cylindrical in shape and are installed over strand/bar prior to stressing. They can be used for bare, epoxy-coated, galvanized and greased-sheathed steel in the bonded, un-bonded, grouted or ungrouted length of the tendon.

The DYNA Force® System is known for accuracy, its performance, ease of installation, durability, and cost effectiveness.

## DYNA Force® Dimensions

Strand Size		Strand Grade		Sensor I.D.		Sensor O.D.		Sensor Length	
[in]	[mm]	[ksi]	[MPa]	[in]	[mm]	[in]	[mm]	[in]	[mm]
0.5"-0.62"	12.7-15.7	270	1860	0.79	20.0	1.42	36.0	5.2	132.0

THREADBAR® Size		Bar Grade		Sensor I.D.		Sensor O.D.		Sensor Length	
[in]	[mm]	[ksi]	[MPa]	[in]	[mm]	[in]	[mm]	[in]	[mm]
#7-#11	16-35	75-97	515-670	1.69	43.0	3.15	80.0	7.09	180.0
#14	43	75-97	515-670	2.09	53.0	3.90	99.0	7.87	200.0
#18/#20	57/63	75-97	515-670	2.87	73.0	5.71	145.0	12.20	310.0
#24	75	75-97	515-670	3.35	85.0	6.10	155.0	12.99	330.0
1"-1-3/8"	26-36	150	1050	1.69	43.0	3.15	80.0	7.09	180.0
1-3/4"	40/46	150	1050	2.09	53.0	3.90	99.0	7.87	200.0
2-1/2"	66	150	1050	2.87	73.0	5.71	145.0	12.20	310.0
3"	75	150	1050	3.35	85.0	6.10	155.0	12.99	330.0

DYNA Force® over the entire tendon is custom made, and dimensions will be provided on request



Readout unit



DYNA Force® Sensor for strand or bar



Multiplexer

\* The DYNA Force® System was developed in partnership with the supplies of the PowerEM® System: Intelligent Instrument System, Inc. 

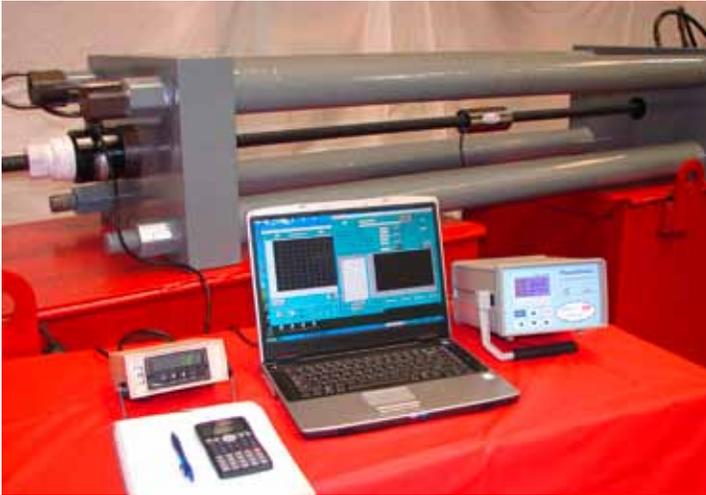
## Quality Assurance

All DYNA Force® Sensors are manufactured and assembled in a quality controlled facility. Furthermore, each sensor is calibrated, individually packed and labeled at a DSI facility prior to shipping to site. Both hardware and software associated with manual and remote reading are also pretested.

Although many tests were carried out during the development of the DYNA Force® System, DSI conducted special tests to determine the impact of surrounding steel elements on the accuracy of the sensors. In these tests, DYNA Force® Sensors were placed near the center and on the outside of the strand bundle. The loads were applied using a typical stressing jack, and the force was monitored using a very accurate load cell.

The load cell readings were compared to the results from the readout unit, and excellent correlations were obtained.

When applying DYNA Force® Sensors in a bond zone of an earth anchor, the sensors are typically installed at a DSI facility during tendon fabrication rather than in the field. DSI offers full technical field support for training the user in the proper assembly/installation and operation.



Testing and calibration of DYNA Force® Sensor

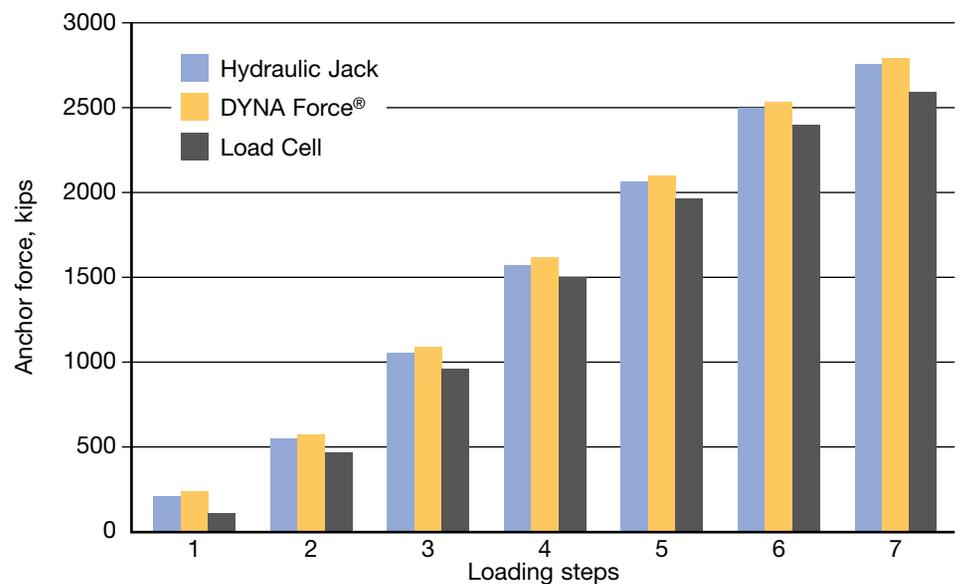


Installation of DYNA Force® Sensor over strand anchor bond length

## Accuracy of the System

DYNA Force® Sensors provide accurate readings. The data obtained from three 59-0.6" (15.2mm) strand ground anchors were analyzed. Each of these anchors was equipped with three DYNA Force® Sensors as well as a load cell. The graph clearly shows that force readings obtained by DYNA Force® Sensors are very similar to the jack readings during the loading stages. Throughout the testing, DYNA Force® Sensors were consistently more accurate than load cells when compared to the actual jacking force.

### DYNA Force® Sensor Readings compared to Jack and Load Cell Readings



# System

## System Option

The DYNA Force® System consists of:

- DYNA Force® Sensor
- A DYNA Force® Readout Unit
- Cable connections as needed
- Multiplexers for automatic reading
- Multiplexers, modem & controller for remote reading

Once a sensor has been installed on the strand or bar, the force can be measured and recorded manually, automatically or remotely.



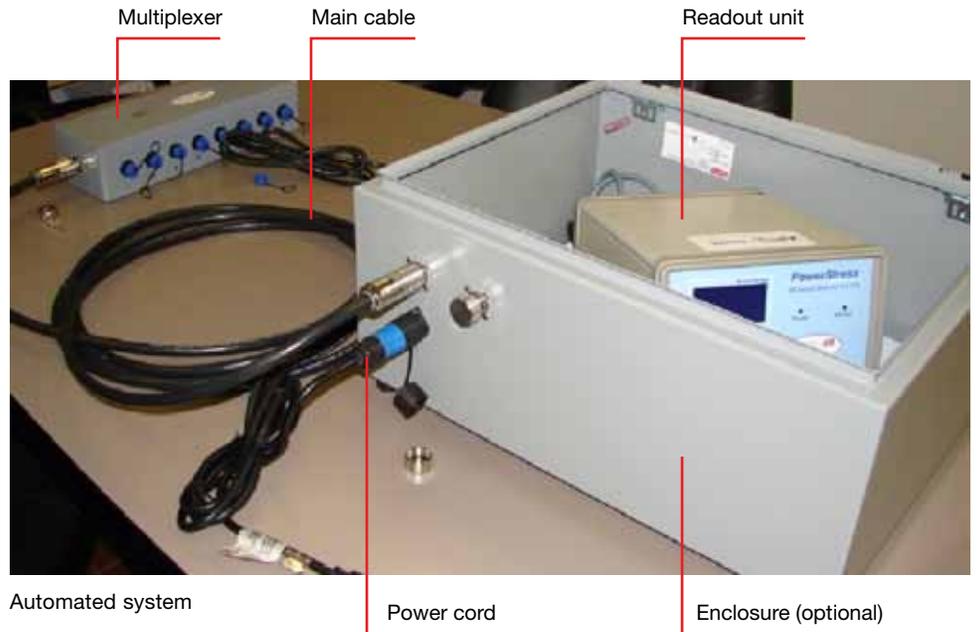
Readout unit with two types of sensors

## Manual Option

In the manual option, each DYNA Force® Sensor is individually connected to the readout unit. By selecting the channel number and corresponding sensor number, the force in the strand or bar can be obtained in 3 seconds and will be displayed on the screen. The reading may then be recorded manually.

## Automated Option

In the automated option, all DYNA Force® Sensors are connected to the readout unit using extension cables, multiplexers and main cables. The readout unit is programmed to record the temperature and force reading of all sensors at a specified time interval. It can record up to a maximum of 2,400 sets of data. The recorded data may be downloaded to a laptop using a RS232 port attached to the unit. The data is in Txt or ASCII format and can be imported to other programs and analyzed.

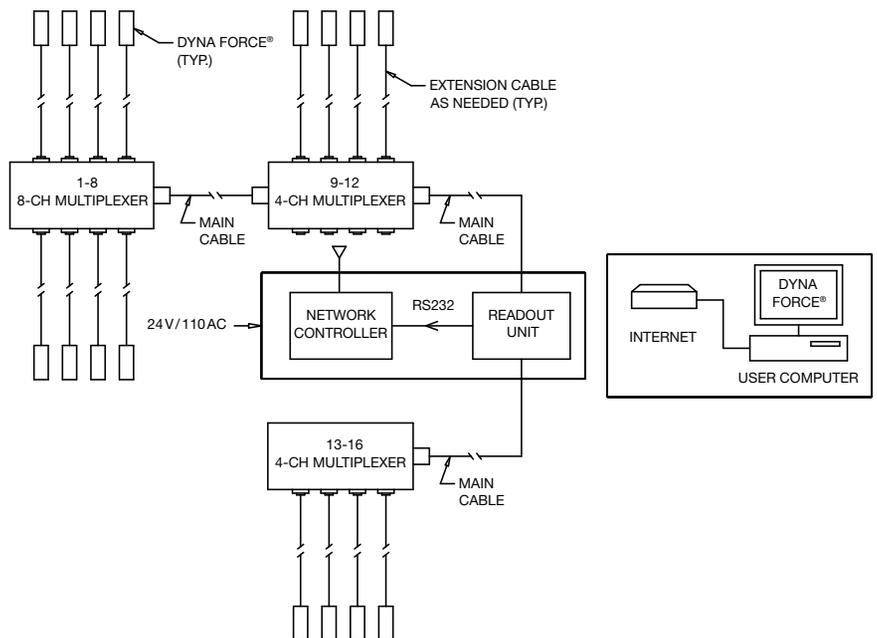


Automated system

## Remote Option

In the remote option, all DYNA Force® Sensors are connected to the readout unit using extension cables, multiplexers and main cables. A modem and a controller are also attached to the unit. A cellular SIM card with a data plan is installed to communicate from a remote computer with a static IP address. Software is provided to collect data from the readout unit through a RS232 port. It can either take readings from a remote computer as needed or can get data stored at specified intervals in the readout unit positioned at the point of use. The output from the readout unit may be incorporated into other data acquisition systems as well. Data in Txt or ASCII format can also be imported to other programs and analyzed.

## Remote System



## Technical Information

### Power Requirement

Operation of the DYNA Force® System requires either 110 or 220 Volt electricity during readings. Alternatively, a 24 Volt battery can be used. If a battery is used, the use of recommended solar panels is to keep the battery charged continuously.

### Operating Temperature

The operating temperature for the DYNA Force® Readout Unit is from 32 to 150°F (0 to 66°C). When operated in winter, it is important to take precautions to keep the unit warm (preferably higher than 42°F (6°C)). The cable temperature range is from -4°F to 176°F (-20°C to 80°C).

### Handling of DYNA Force® Sensors

Care should be exercised during the transportation, installation and handling of DYNA Force® Sensors. Even though DYNA Force® Sensors are robust and durable, careful handling is required to avoid damage to the lead wire.

### Cable Length Effect

In many occasions, extension cables and main cables are used to connect DYNA Force® Sensors to the Multiplexers and readout units. Tests have demonstrated that there is no significant loss of accuracy on the force readings due to the cable length of up to 655ft (200m).

### Temperature Compatibility

DYNA Force® Sensors are equipped with a temperature thermistor to record the temperature of the steel. This information is used for the correction in permeability measurement. When a sensor is installed for a strand or bar that has been in place for a while, wait for two hours after the sensor has been installed before taking any reading. This will accurately measure the temperature of the strand or bar and will accurately compensate for temperature.

### System Compatibility

The output from the DYNA Force® Readout Unit is in digital numerical format. The output can be easily incorporated into other conventional data acquisition systems. If the data acquisition system is in analog type, then a digital to analog converter needs to be attached to the readout unit to deliver volt or current output to the analog

data acquisition system. Data can be recorded at fixed intervals and fed into another acquisition system. If required, other acquisition systems can direct the DYNA Force® Readout Unit to take readings as desired and transmit the data into the other system.

### Field Connections

End connectors of DYNA Force® Sensors and extension cables have 6 pins inside

the socket. The main cable connector has 12 pins inside the socket.



6-pin sensor or extension cable connectors

12-pin main cable connectors

### Protection of Lead Wire and End Connector

Always use end caps as shown below. If there is a possibility for the end connector to be submerged in water, seal the end

using heat shrink and seal mastic tape to avoid water penetration into the connectors.



End connectors with cap



Splice of end connectors with heat shrink

## References

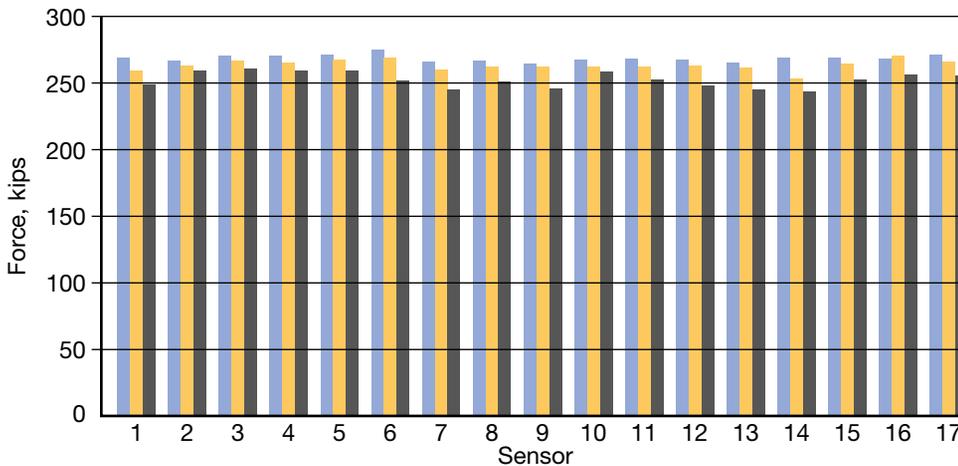
### Project Description: Monitoring of PT Forces in Bars at Wind Technology Testing Center - Boston

DYNA Force® Sensors were utilized to monitor the force in 1- $\frac{3}{4}$ " (46mm) 150ksi (1035MPa) post-tensioning bars in the vertical wall of the Wind Technology Testing Center in Boston, MA, USA. All lead wires with end connectors were routed to the outside of the wall as shown below.

The forces were monitored during construction and then again two months after stressing. The recorded data proved to be valuable information for validating the design. After dynamic testing of the turbine, the force in the post-tensioned bars will be measured using the sensors to ensure structural safety within the facility.



### DYNA Force® Readings for 1- $\frac{3}{4}$ " bars



Avg at stress: 270 kips (1201 kN)

Avg after anchor set: 264 kips (1174 kN)

Avg after 60 days: 254 kips (1130 kN)

■ BAS    BAS- before anchor set  
■ AAS    AAS- after anchor set  
■ 60D    60D- after 60 days

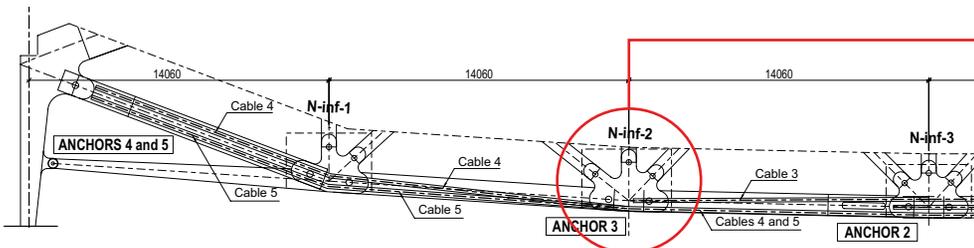


DYNA Force® at Wind Technology Testing Center, Boston, MA, USA

### Project Description: Force Monitoring of Lattice Girders at Lille Stadium, France

DSI supplied 38 DYNA Force® Sensors for Lille Stadium in France. The roof of the stadium is carried by two main lattice girders with a span of approximately 672ft (205m) at a height of 52ft (16m). Two girders were equipped with 19 sensors in each girder to continuously monitor the forces in the tendons.

The sensors were positioned behind the anchorage, mounted on a unique holder. Afterwards, the sensors were connected to the readout unit via 16 and 4 channel multiplexers. These sensors will provide valuable information during the service life of the structure.



DYNA Force® for force monitoring of girder tendons at Lille Stadium, France

## References

### Project Description: Force Monitoring of Ring Tendons at Storage Tank, West Virginia, USA

DSI was contracted to perform repairs on the damaged circumferential tendons in a storage tank in an industrial facility in West Virginia, USA and to supply and install 41 new circumferential external tendons of 0.6" (15.2 mm) diameter strand.

DYNA Force® Sensors were installed on ten strands to monitor the force during construction and during the life of the structure. Sensors were installed on each fourth tendon, and all lead wires were routed through the PVC conduit to the bottom of the silo into the mechanical room. The end connectors were stored inside the enclosure boxes for protection. Forces will be measured on a yearly basis as part of the structure's monitoring and maintenance program.



DYNA Force® for force monitoring of ring tendons at storage tank, West Virginia, USA

### Project Description: Load Monitoring of Anchors at Changuinola Dam, Panama

DSI supplied 48 DYNA Force® Sensors for permanent 12x0.6" strand anchors at Changuinola Dam in Panama. Sensors were installed on the un-bonded lengths to monitor anchor loading during the proof test, during filling of the reservoir as well as during the life of the structure.

All sensors were connected to a 48-channel multiplexer that was connected to the readout unit using a main cable. Force readings obtained from the sensors during the filling of the reservoir were useful to monitor the behavior of the dam and the adequacy of the anchors. The forces in the anchors were monitored on a regular basis as part of the dam monitoring and maintenance program.



DYNA Force® for load monitoring of anchors at Changuinola Dam, Panama

## References

### Project Description: Remote Load Monitoring of Ground Anchors at Willow Island Hydroelectric Project, West Virginia, USA

DSI supplied twenty-eight 59-0.6" strand anchors for the stability and safety of the dam at the Willow Island Hydroelectric project in West Virginia, USA. Rock mass was excavated to allow for the installation of a power generator.

In order to monitor the forces in the anchors during rock excavation, three sensors were installed in each anchor. A total of 84 DYNA Force® Sensors were installed in these permanent rock anchors. All sensors were connected to a multiplexer using extension cables, and all multiplexers were connected to the readout unit via main cable. Modem, controller and Cell SIM card were installed so the data could be accessed from a remote location. Battery and solar panels were used to power the readout unit. The data from all of the sensors are being taken remotely every three hours, analyzed and reported to the owner.



DYNA Force® for rock anchor at Willow Island Hydroelectric Project, West Virginia, USA

### Project Description: Continuous Monitoring of Ground Anchors at Sellwood Bridge, Oregon, USA

DSI supplied 56 DYNA Force® Sensors for both permanent and test ground anchors for Sellwood Bridge in Oregon, USA. The main purpose was to monitor the slope stability in front of the bridge abutment. Six sensors were installed in the bond length and one in the free length of each of the test anchors. Two sensors were installed in each of the permanent anchors, with the number of strands varying from 8 to 24. Fifteen automated readout units were installed to record the force readings of the sensors every four hours. Software was provided so that the engineer could transfer the recorded data to a laptop. DYNA Force® Sensors provided valuable information for both test and permanent anchors.



DYNA Force® for ground anchors at Sellwood Bridge, Oregon, USA

## References

### Project Description: Bond Length Design Based on DYNA Force® Readings at Park Place, Toronto, Canada

DYNA Force® Sensors were installed for 7 x 0.6" strand tie-back anchors for Park Place Condominium in Toronto, Canada.

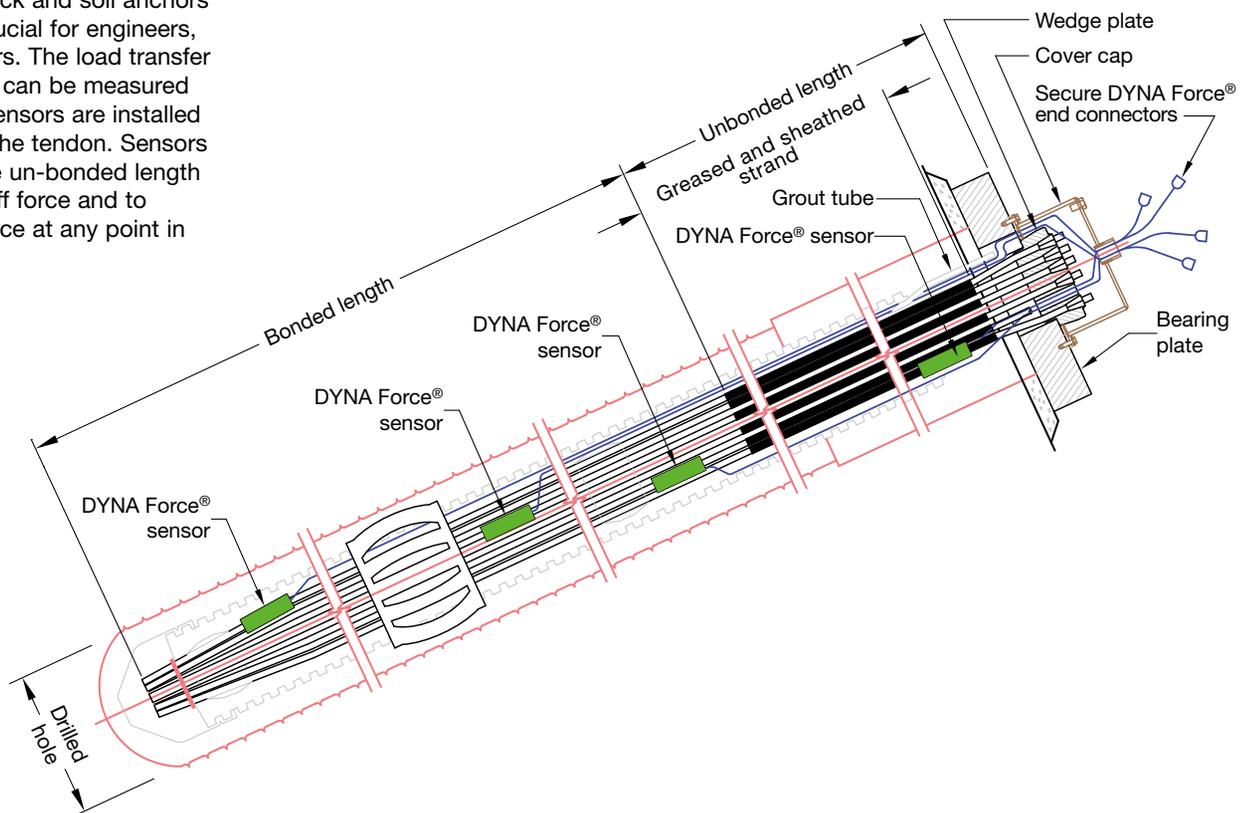
Sensors were installed at various locations along the tendon length in both bond and free length. Based on the observed DYNA Force® Readings, the engineer increased the bond length for the rest of the production anchors. The sensors provided valuable information to the engineer during the decision making process.



DYNA Force® for force monitoring of tie-back anchors at Park Place, Toronto, Canada

### Typical Load Monitoring of Ground Anchors in Bonded and Un-Bonded Zones

The performance of rock and soil anchors in the bond zone is crucial for engineers, contractors and owners. The load transfer along the bond length can be measured when DYNA Force® Sensors are installed in the bond length of the tendon. Sensors may be installed in the un-bonded length to measure the lock-off force and to monitor the anchor force at any point in the future.



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