EXHIBIT A – SCOPE OF SERVICE

Project Title: **BRIDGE DECK WITH LINK-SLAB**
For FPID: 435390-1-52-01: US 41 from Midway Blvd to Enterprise
Contract Number: BDV34 986-02
Deliverable 2 - TASK 2 – RECOMMENDATIONS FOR BRIDGE INSTRUMENTATIONS AND MONITORING OF LINK-SLAB

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Deliverable 2 - TASK 2 – RECOMMENDATIONS FOR BRIDGE

INSTRUMENTATIONS AND MONITORING OF LINK-SLAB

1. INTRODUCTION

The aim of deliverable 2 of task 2 is to provide recommendations for the instrumentations of the link-slabs, a suggested monitoring plan, and instrumentation system to monitor the temperature, strain, rotation, and elongation of different link-slabs. The research team identified appropriate instrumentation and locations for monitoring the BFRP-RC link-slab on Bridge No. 019003 over Morning Star Waterway. In this deliverable report, the team suggests a monitoring plan and an instrumentation system to monitor the temperature, strain, rotation, and elongation of link-slabs. During construction, the research team will inspect the instrument and sensor locations. The proposed link-slab is designed with enough BFRP reinforcement to withstand the loads placed on the bridge superstructure. Also, it is desired that the link-slab does not crack excessively under typical service loads. For the BFRP-RC link-slab, special measures should be considered to anchor the FRP reinforcement to the existing bridge deck during the installation of a link-slab in the existing deck. In general, the behavior and design of the link-slab are influenced by several variables such as span length and arrangement, bearing type, beam end rotation under load, bridge skew, and relative flexural stiffness of the beam and slab. For the investigated bridge link-slab in this study, it is required to measure and monitor the strains, deformations, and cracks in the link-slab, and rotation of beam ends. The monitoring of the tested bridge with the recorded data under long-term effects as well as live loads will investigate the link-slab behavior and the ability of the continuity detail to transfer forces from one girder to the adjacent girder across the joint over the bent cap.

2. PROPOSED INSTRUMENTATION PLAN

The research team identified appropriate instrumentation and locations for sensors for the BFRP-RC link-slab on Bridge No. 019003 over Morning Star Waterway. The team also suggested a monitoring plan and instrumentation system to monitor the temperature, strain, rotation, and elongation of link-slabs. The bridge link-slab monitoring system will include three main components, (1) sensors, (2) data acquisition system, and (3) cabling and conduit. Sensor locations are shown on the figures. Details of the components of the monitoring system are also provided. The research team will inspect the instrumentations and sensor locations during construction.

3. BRIDGE MONITORING SYSTEM INSTALLATION AND INSTRUMENTATION

I. The system installation activities will be coordinated between involved parties (FDOT technical team, Contractor and other subcontractors, the project manager, and the research team) to establish the installation schedule of both the embedded and surface-mounted sensors. The monitoring system including sensors will be installed as construction on the bridge proceeds and the contractor shall provide a preliminary schedule for installation activities to FDOT. Once the preliminary schedule is approved, the contractor shall develop a detailed installation schedule that will be linked to the project schedule.

II. The following describes the phases required for complete installation of the monitoring system:

Phase 1. During Link-Slab Construction

Investigated elements: Deck - Link-slab connecting spans 1 and 2.

Embedded sensors in the reinforced concrete deck shall be installed at the time of placing reinforcing bars of BFRP at the bridge site as per the plans. Initial readings shall be recorded at time of installation prior to, during, and after concrete casting. Parameters to be measured during this phase are:
a) Strains in structural elements
b) Temperatures at sensor locations
c) Ambient temperature and relative humidity (To be determined from local weather forecasting reports).

Phase 2. After Deck Pouring
Investigated elements & spans: Bridge superstructure/beams and link-slab connecting spans 1 and 2. Once casting the concrete deck is complete, surface-mounted sensors shall be installed as shown in the figures. Initial readings shall be recorded. Parameters to be measured during this phase are:
a) Strains and deformations in structural elements
b) Crack propagation once developed in the link-slab
c) Temperatures at sensor locations
d) Relative movement between adjacent beams (using Vibrating Wire- Crackmeter Model 4420 for example) and beams' rotation
e) Ambient temperature and relative humidity (To be determined from local weather forecasting reports).

Phase 3. Initial Bridge Condition upon Completion of Construction
Once the bridge construction is completed, the contractor shall conduct a series of baseline tests so that the FDOT technical team can assess the performance of the monitoring system and quantify the initial condition of the link-slab and the bridge superstructure. The data collected during the baseline tests will represent the initial link-slab condition. A live load test with predetermined truck weight will be conducted by FDOT technical team or its representatives after completion of construction and prior to opening to traffic.

Parameters to be measured during this phase are:
a) Strains and deformations in structural elements
b) Crack propagation once developed in the link-slab
c) Temperatures at sensor locations
d) Relative movement between adjacent beams and beam end rotation
e) Ambient temperature and relative humidity (To be determined from local weather forecasting reports).

III. The structural engineer inspector shall document any early shrinkage cracking that may take place in the deck, link-slab, or the prestressed concrete girders.

IV. Extreme caution should be taken to protect all instrumentation during construction.

4. SYSTEM DETAILS

The link-slab monitoring system shall include three main components, (1) sensors, (2) data acquisition system, and (3) cabling and conduits. Sensor locations are shown on the change order plans. Details of each component of the system component are given next:

4.1 SENSORS

The bridge link-slab and exterior beams will be equipped with sensors designed to measure the following:

a) Strains and deformations in the link-slab
b) Crack propagation once developed in the link-slab
c) Temperature at sensor locations
d) Relative movement between adjacent beams ends and rotation of beams ends
e) Ambient temperature and relative humidity will not be measured on location with sensors (to be determined from local weather reports).

The various types and quantity of each type are presented. Two types of sensors will be installed; an embedded type and a surface-mounted type. The embedded sensors are vibrating wire sisterbars and strandmeters. Surface mounted sensors are vibrating wire gap-meters and tiltmeters. All vibrating wire gages shall have an integral thermistor for determining temperature at the sensor location, at the time of measurement.

EMBEDDED SENSORS:

The embedded sensors are for measuring strains within and across the link-slab. This will be composed of a 3x3 array of Strandmeters and Sisterbar paired to each other, for a total of 18 (9 pairs) embedded sensors. The Strandmeter measures strain in the BFRP link-slab reinforcement (Geokon model 4410 Strandmeter). The adjacent “Sisterbar” (Geokon model 4911 Rebar Strainmeter) will measure strain in the link-slab concrete at approximately the same location. It is recommended by BDI Inc. that the sisterbar be tied off to its paired strandmeter via loose wire during installation.

Placement of the 3x3 array is a roughly symmetrical location of the 9 pairs of embedded sensors. From the southwest side of the bridge the first three pairs of sensors (labeled as row “A”) will be located on the fourth BFRP rebar from the southwest side of the link-slab. The second row of three sensor pairs (labeled as row “B”) is located on the twelfth BFRP rebar from the southwest side of the link-slab. The third row of three sensor pairs (labeled as row “C”) is located on the twenty-first BFRP rebar from the southwest side of the link slab. Each pair of sensors in a row is identified by its relative compass position. For example, the northernmost pair of embedded sensors is identified as the “NW-C” location (northwest side, row-C) and the other two pairs within that row are in the “Mid-C” and “SE-C” locations. This layout is shown in the following, *Figure 1, Location Labels of Embedded Sensor Array, Top View of Link-Slab* and *Figure 2, Detail of Embedded Sensors, Top View*. Note the orientation of a Sisterbar relative to its corresponding BFRP rebar is always toward the centerline of the bridge, while the accompanying strandmeter sets on the opposite side of the BFRP rebar.

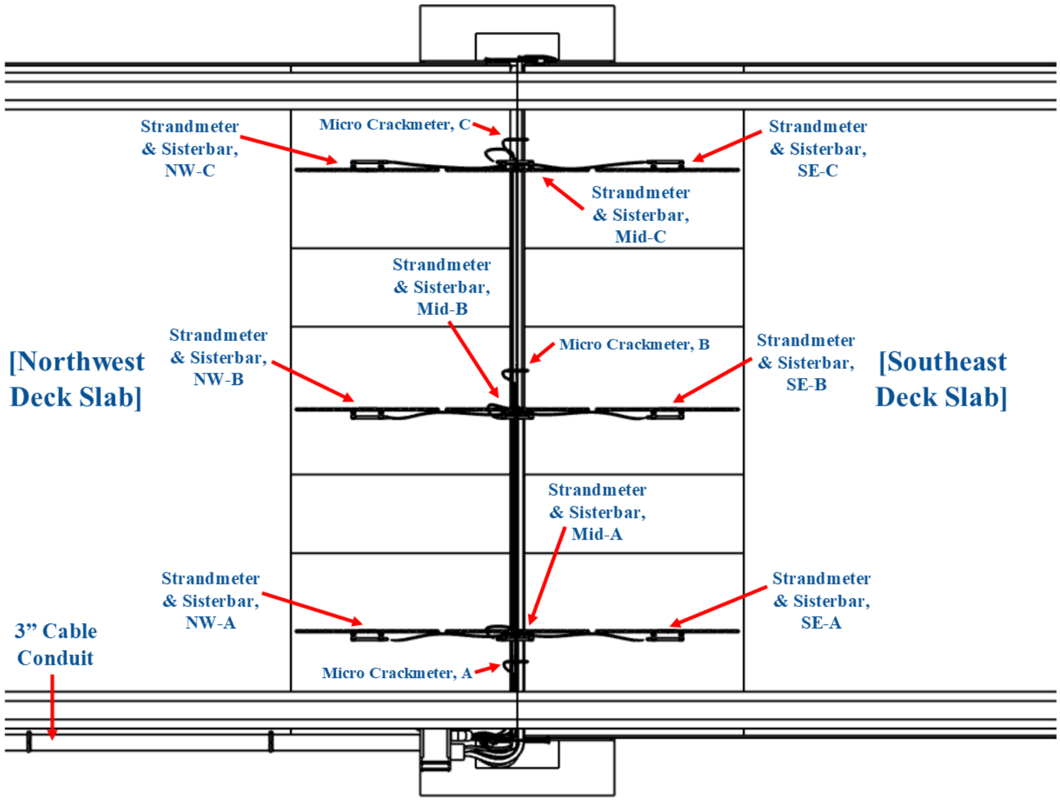


Figure 1, Location Labels of Embedded Sensor Array, Top View of Link-Slab

Strandmeter (model 4410, Geokon): These strain sensors will be clamped to the link-slab reinforcement (BFRP rebars inside cast-in-place link-slab) at the specified locations. Special treatment per the product manual dictates surrounding sensor with grease prior to encasing inside concrete. BDI has expressed that the strandmeter sensor (model 4410) is preferable in this application because it is readily attached to a rounded surface (i.e. the reinforcement bars) and is more appropriate for embedment in concrete than the model 4151 alternative. ***Number of sensors: 9***

Sisterbar (model 4911, Geokon): These strain sensors are fabricated on a #4 steel reinforcing bar. The standard stock length is 36 inches. For this link-slab, all the sisterbars will be an overall length of 31 inches, with the transducer centered on the sensor. The sisterbar sensors can be ordered from Geokon or BDI Inc. already custom cut to this length, or standard length sisterbars may be cut on-site. One sisterbar is paired with each strandmeter (BFRP gauge) and placed adjacent to it in order to measure strain in the concrete surrounding reinforcement bars. BDI suggests loosely tying each sisterbar to its accompanying strandmeter-mounted reinforcement bar with wire. ***Number of sensors: 9***

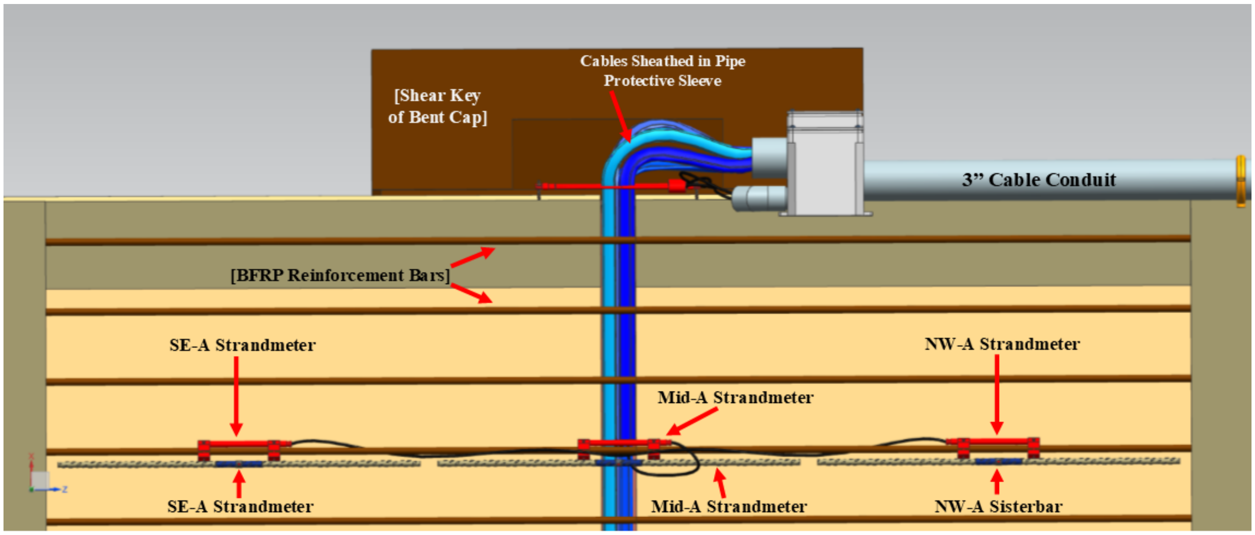


Figure 2, Detail of Embedded Sensors, Top View

SURFACE-MOUNTED SENSORS:

Surface mounted sensors shall be installed after cast-in-place slab and deck components have been set. These sensors are mounted using groutable type anchors, supplied by Geokon (and/or through BDI Inc). To mount a sensor, an appropriately sized hole will be drilled into the deck or slab component to which it is mounting. The hole shall then be filled with an appropriate construction grade epoxy, and the groutable anchor inserted to a depth which allows the sensor to be securely mounted at its dictated position.

Micro Crackmeters (model 4422, Geokon): These are displacement gauges mounted on the top deck surface of the link-slab. Micro Crackmeters are intended to measure crack growth in the link-slab and will be pre-emptively installed across the transverse midline. The location labels of the Micro Crackmeters correspond to the row labels of the Embedded Sensor Array, as shown in *Figure 3, Micro Crackmeters Location Labels*, below. For example, the Micro Crackmeter nearest the southwest side of the link-slab is identified as "Micro Crackmeter A", while the furthest is identified as "Micro Crackmeter C".
Number of sensors: 3

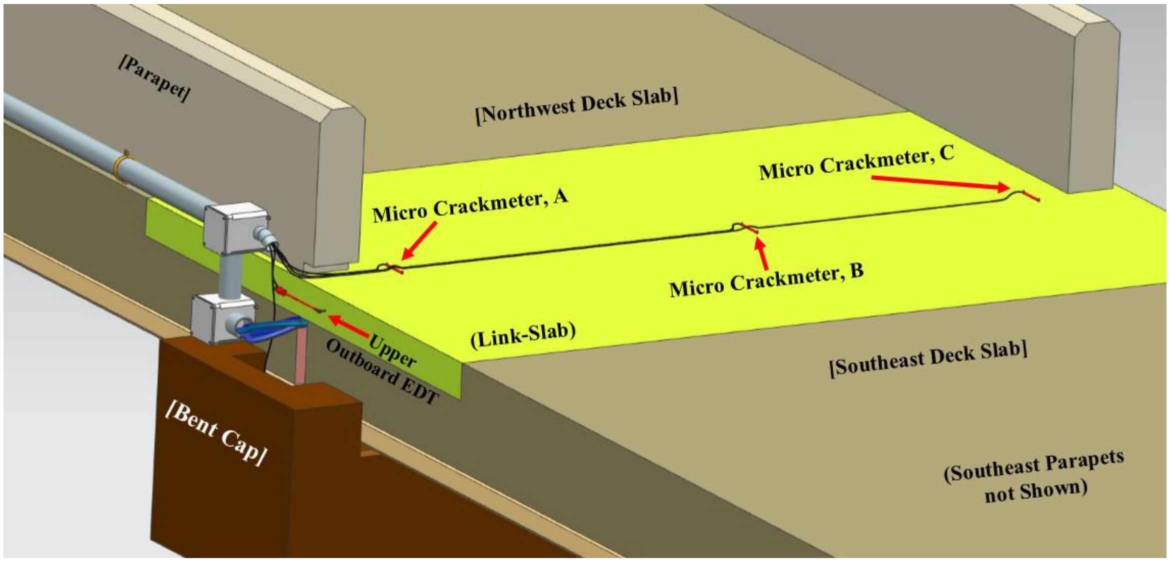


Figure 3, Micro Crackmeters Location Labels

Tiltmeters (model 6350, Geokon): These sensors will be installed to measure rotational deflection of FSB beam ends (within the vertical-longitudinal plane), on both sides of the bent cap supporting the link-slab being monitored. Tiltmeters are to be mounted on the undersides of the bridge span, with the mounting anchor's centerline located 2 inches away from the bent cap (on both side of the bent cap). The anchors which hold the tiltmeter mounting brackets will be placed in the CIP Joint Gap, between the northeastern and centerline FSB beams, on both sides of the bent cap. For illustration, refer to *Figure 4, Relative Location of Tiltmeters*. The mounting anchors used shall be a custom ordered length from Geokon; Overall length of the groutable anchor is 7 inches, to allow for the anchor to reach solid concrete poured for the deck slab. The diameter of the groutable anchor is not to exceed 0.5 inches, as this is the minimum gap size between adjacent FSBs. Additionally, the material in the CIP Joint Gap should be excavated out to 1 inch on either side of the anchors, to ensure that thermal expansion does not cause a bending force to be exerted on the anchor and lead to false readings from the instrument. The sensors shall hang in a vertical orientation, made possible with two additional holes custom drilled into the mounting bracket. ***Number of sensors: 2***

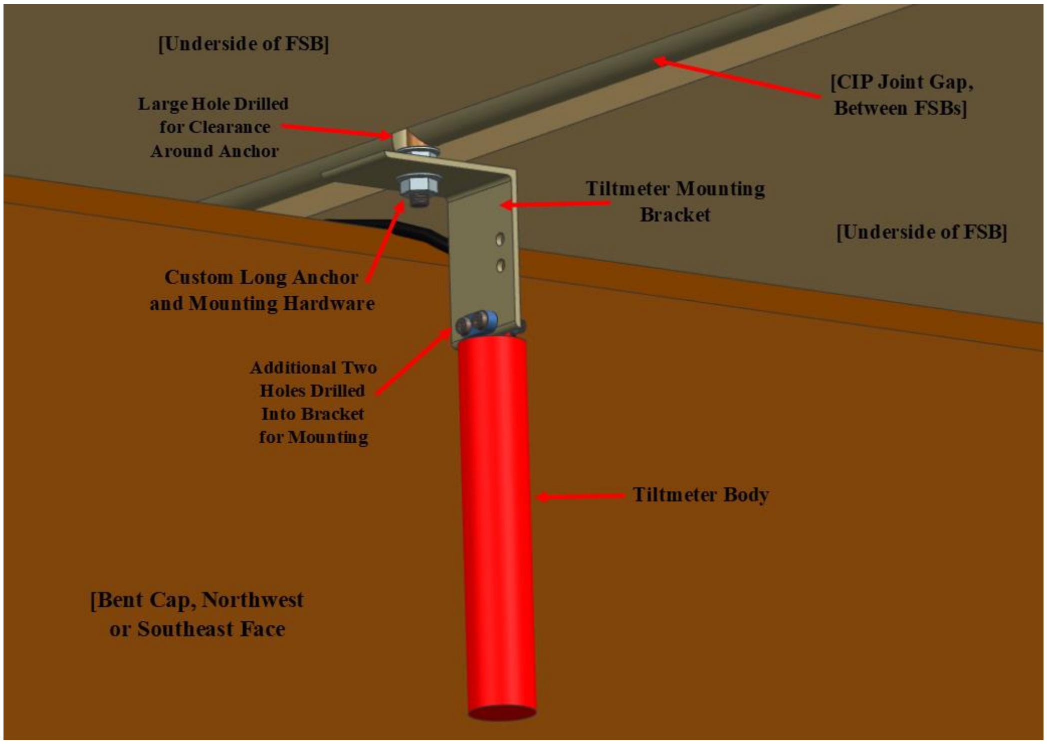


Figure 4, Relative Location of Tiltmeters

Crackmeters (model 4420-25, Geokon): Model 4420 style Crackmeters from Geokon will be used for measuring displacements along the outboard sides of the link-slab (at the link-slab midline), displacements between collinear outboard FSB beams, and displacements between FSBs and the bent cap. Sensors monitoring these external displacements are from here forth referred to as "External Displacement Transducers" or "EDTs". In total, there are three pairs of EDTs. The two "outboard EDTs" are located on the northeast and southwest sides of the bridge. These outboard EDT pairs consist of an upper outboard EDT mounted at a level 3 inches from the top of the link-slab (middle of the link-slab) and a lower outboard EDT mounted at a level 2 inches below the top of the outermost FSB flange (middle of the FSB flange). The lower outboard EDTs necessitate a cutout modification on the shear key of the bent cap. The length of the cut-out is 18 inches and the width is 6 inches. The bottom of the cut-out sloped from an outermost depth of 7 inches to an innermost depth (toward the bridge slabs) of 8 inches. For illustrations, see the following, *Figure 5, Southwest Outboard EDTs* and *Figure 6, Northeast Outboard EDTs*.

The third pair of EDTs is referred to as the "lower centerline EDTs". One of these is mounted on both sides of the bent cap, oriented in-line with the length of the bridge. A vertical anchor connects to the end of the lower centerline EDT which is furthest from the bent cap via a swivel ball-joint (Heim joint). This vertical anchor is a custom length 9 inch groutable anchor set into the CIP Joint Gap between the southwestern and center FSB beams. This mounting is in similar fashion to the Tiltmeters, explained above. The end of the lower centerline EDT closest to the bent cap is connected to an inline groutable anchor, via a universal joint. These inline groutable anchors set into the northwest and southeast faces of the bent cap, at a level 2 inches below the bent cap's bed surface (surface supporting the FSB beams). Like the Tiltmeters, the material in the CIP Joint Gap should be excavated out to 1 inch from both sides of the vertical anchor. For illustrations refer to the following, *Figure 7, Lower Centerline EDT, Example 1* and

Figure 8, Lower Centerline EDT, Example 2. Note, the gauge length of all model 4420-25 Crackmeters shall be mid-length, which corresponds to a length of approximately 13.5 inches from mounting point to mounting point. (See Crackmeter drafts in Appendix B).

Number of Crackmeter sensors: 6

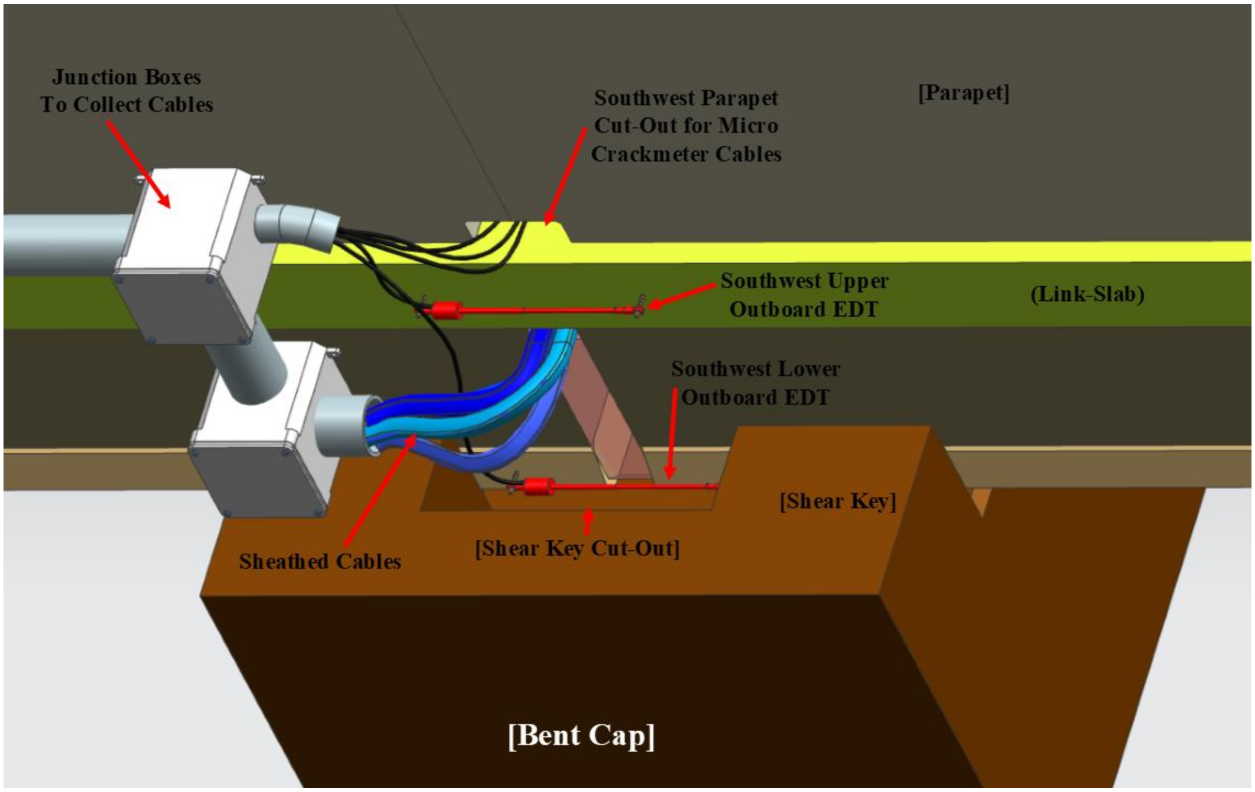


Figure 5, Southwest Outboard EDTs

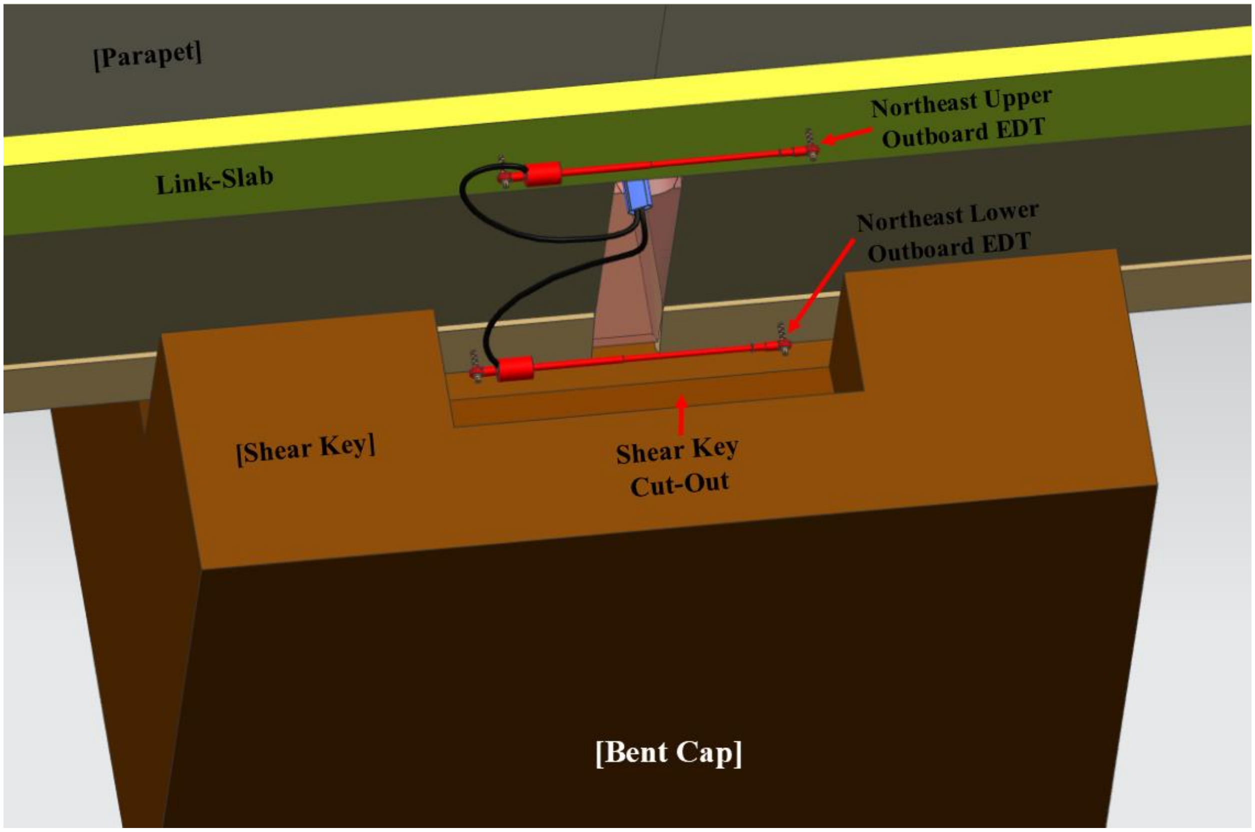


Figure 6, Northeast Outboard EDTs

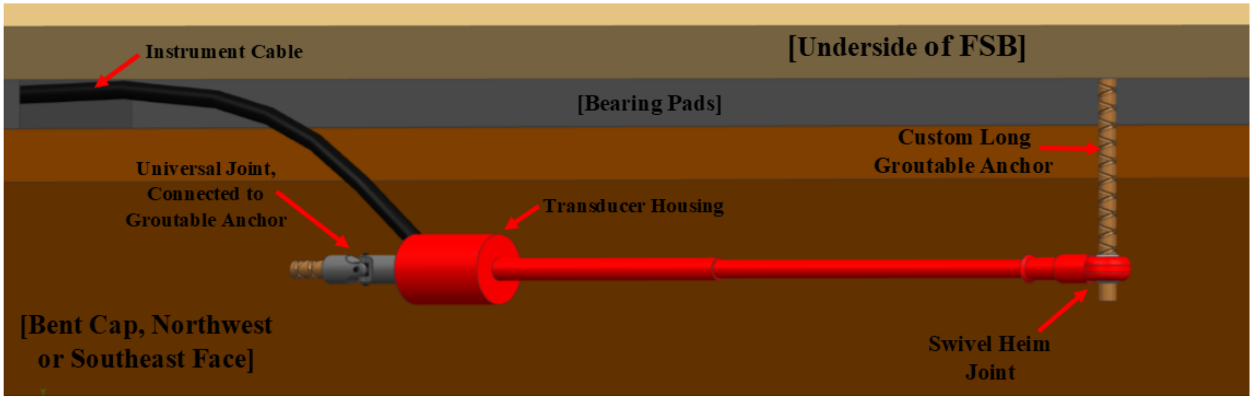


Figure 7, Lower Centerline EDT, Example 1

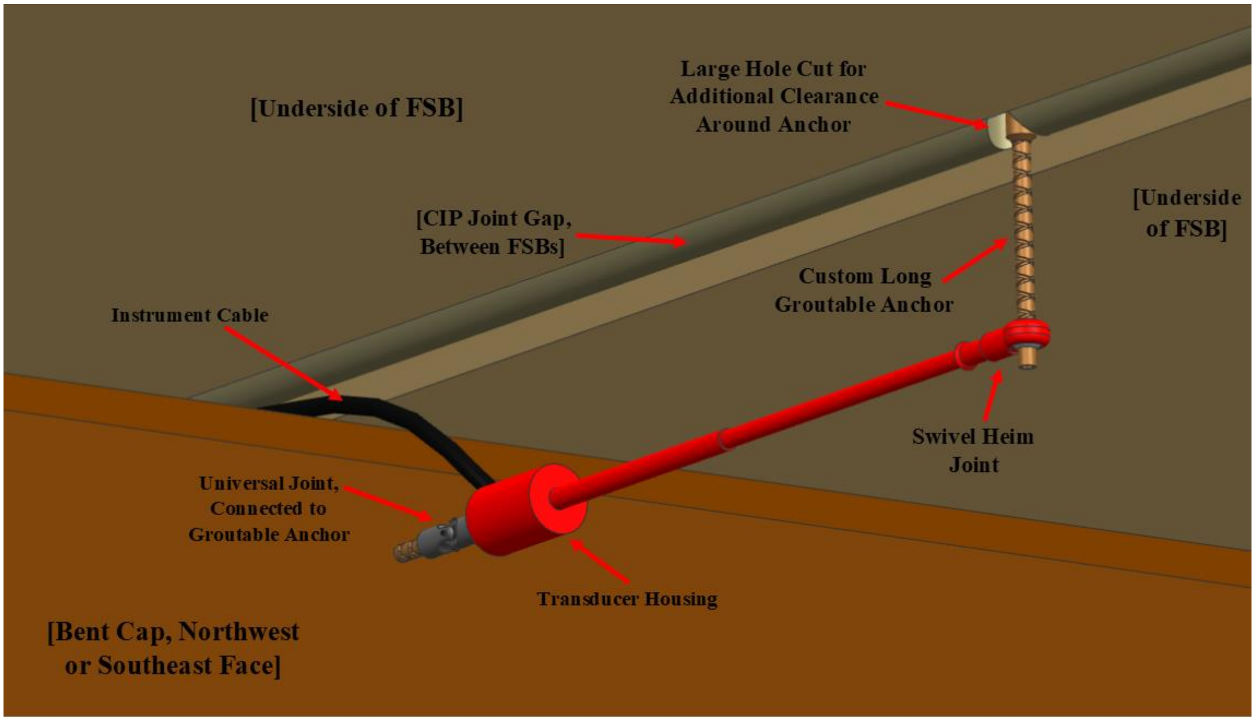


Figure 8, Lower Centerline EDT, Example 2

Total number of sensors to be deployed: 29

All sensors are of commercial-grade quality vibrating wire devices and shall be installed in accordance with manufacturers' recommendations. Sensor specifications are shown in *Table 1, Sensor Models and Specs* below. Manufacturer's data sheets and manuals along with images/illustrations are provided in Appendix C.

Group #	Sensor Objective	Gauge Type/Model & Source	Sensor Resolution	Sensor Accuracy	Sensor Measuring Range	Sensor Dimensions
1	Strain in BFRP; clamps sized to fit 0.625" dia.	*Strandmeter (4410, Geokon)*	<5 με	(+/-) 0.003 mm	3 mm (15000 με)	8" Long x 1.77" Wide Clamps
2	Strain in Concrete Link Slab	*Sisterbar (4911, Geokon)*	0.4 με	(+/-) 7.5 με	3000 με	36" Length, #4 Size Rebar
3	Crack Width in Link Slab	*Micro Crackmeter (4422, Geokon)*	.001 mm	(+/-) 0.004 mm	4 mm	4.725" Long x 0.315" Diameter
4	Outboard EDTs	*Crackmeter (4420-25, Geokon)*	.00625 mm	(+/-) 0.025 mm	25 mm	Length: 13.5", Dia:1"
5	Lower Centerline EDTs	*Crackmeter (4420-25, Geokon)*	.00625 mm	(+/-) 0.025 mm	25 mm	Length: 13.5", Dia:1"
6	Rotation of Beam Ends	*Tiltmeter (6350, Geokon)*	(+/-) 10 arc seconds	(+/-) 0.01°	(+/-) 10°	Length: 5.47", Diameter: 1.26"
7	Datalogging	*Datalogger (LC-2, Geokon)*	1 part in 20,000; Thermistor: 0.1 deg C	(+/-) 0.05% F.S. (450 to 4000 Hz); Thermistor: (+/-) 2.0% F.S.	450 to 4000 Hz; Thermistor: -30 deg C to 50 deg C	(LxWxH): 13.46" x 11.85" x 6.3"

Table 1, Sensor Models and Specs

4.2 Sensor Wiring:

<u>A. Sensor Cables</u>

Connections between the sensors and data acquisition system is accomplished via a “Vibrating Wire” cable (abbreviated as VW cable). VW cable consists of five conducting elements: 2 twisted wire pairs (red/black & white/green), and a 24AWG stranded copper drain wire for grounding. A 0.0625-inch diameter blue PVC jacket protects the cable. An estimated total of 1770 feet of cable will be used in routing between sensors and the data acquisition system. See *Table 2, Total Estimated Cable Length for Sensors* below for breakdown of cable length estimate.

All cables will be routed through a 3-inch PVC conduit pipe from the dataloggers toward the northeast side of the link-slab. From this point, cables will diverge in bundles to their respective sensor locations. Most of these cables must partly or fully cross along the transverse midline of the link-slab and will do so within channels of the Expanded Poly-Styrene Gap Filler (EPS Gap Filler) between the northwest and southeast FSBs and Deck Slabs. This is explained in greater detail in section 4.2.B, Cable Routing. Cables of the 3x3 Embedded Sensor Array will be routed along their respective BFRP rebar toward the transverse midline of the link-slab, held close and securely to the rebar with zip-ties. At the midline, these cables will then exit through the link-slab bottom into their corresponding channels within the EPS Gap Filler.

Sensors shall be delivered with pre-attached heavy-duty VW cables. Special care shall be taken to protect the cables, especially at exit points for embedded sensors’ cables and around sharp edges. Protective containers should be provided at exit points with enough room to store cable ends for protection against damage and accidental cutting during concrete casting, curing, transportation and erection. High quality cable tags shall be used at multiple points along each cable in order to positively identify each cable and its associated sensor. This is especially important for embedded sensors/cables. The contractor installing sensors and cables may find it necessary to cut cables to facilitate installation of sensors and erection of bridge components. In this case, each new end created from cutting a cable should be clearly labeled with a heavy-duty cable tag. Cut points should be in places easily accessible later for splicing. All splices should implement a heavy-duty water/chemical/heat-resistant shrink wrap to protect previously cut cables (For example: 6" Thin Wall Heat Shrink Tubing - Flexible Polyolefin - Shrink Ratio 3:1).

Cables running from the surface mounted Micro Crackmeters (Group #3) shall be held down with cable clips screwed down onto the link-slab. These cables should also be protected with heavy duty cable runners. These will be laid transversely across the midline and lead the cables through the bottom of the concrete parapet, toward the main conduit line where the cables will be collected.

Cable Length Requirements		
Group #	**Sensor**	**Cable Length for Instrument (feet), Plus 10%**
1 & 2	**3x3 Embedded Array, (Strandmeters and Sisterbars)**	
	NW-A, Strandmeter	62.5
	NW-A, Sisterbar	62.5
	Mid-A, Strandmeter	59.0
	Mid-A, Sisterbar	59.0

	SE-A, Strandmeter	62.5
	SE-A, Sisterbar	62.5
	NW-B, Strandmeter	66.5
	NW-B, Sisterbar	66.5
	Mid-B, Strandmeter	63.5
	Mid-B, Sisterbar	63.5
	SE-B, Strandmeter	66.5
	SE-B, Sisterbar	66.5
	NW-C, Strandmeter	71.5
	NW-C, Sisterbar	71.5
	Mid-C, Strandmeter	68.0
	Mid-C, Sisterbar	68.0
	SE-C, Strandmeter	71.5
	SE-C, Sisterbar	71.5
3	**Micro Crackmeters**	
	A	58.5
	B	64.5
	C	69.0
4	**Lower Centerline EDTs**	
	Northwest Slab	67.0
	Southeast Slab	67.0
5	**Outboard EDTS**	
	Southwest Side, Upper	56.5
	Southwest Side, Lower	58.0
	Northeast Side, Upper	72.5
	Northeast Side, Lower	73.0
6	**Tiltmeters**	
	Northwest Slab	72.0
	Southeast Slab	72.0
	Total (ft):	1770 feet

Table 2, Total Estimated Cable Length for Sensors

B. Cable Routing

All cables will be led from the dataloggers at the northwest end of the bridge, (along the outside of the southwest parapet), inside a 3-inch diameter PVC electrical conduit pipe. At the southwest shear key of the bent cap this conduit leads into two 6x6x6-inch PVC junction boxes, located atop one another. It is recommended the terminal ends of conduits leading cables from the junction boxes toward sensors are covered with a flexible rubber caps, in which holes are cut just large enough for the bundles of cables to exit through. Exiting the top junction box are five bare VW cables which lead directly to the southwest side Outboard EDTs and the Micro Crackmeters. Exiting the lower junction box are bundles of cables leading to all other instruments via small channels carved into the EPS Gap Filler. These cables are gathered into four tracts, with each tract contained inside a 1-inch diameter polyethylene Pipe Protection Sleeve (Ex: Oatey brand's Pipe Guard). To accommodate these tracts the EPS Gap Filler has a top surface carved out just deep enough for these four bundles to lay into while staying underneath the debonding material layer set between the deck slab ends and link-slab. Additionally, the EPS Gap Filler features two smaller vertical channels cut through the interior and located within the planes of the Lower Centerline EDTs and Tiltmeters. For illustrations, see the following: *Figure 9, Cable Routes Through EPS*; *Figure 10, Carved Topside of EPS*; and *Figure 11, Detail Embedded Sensor Routing, Side View*.

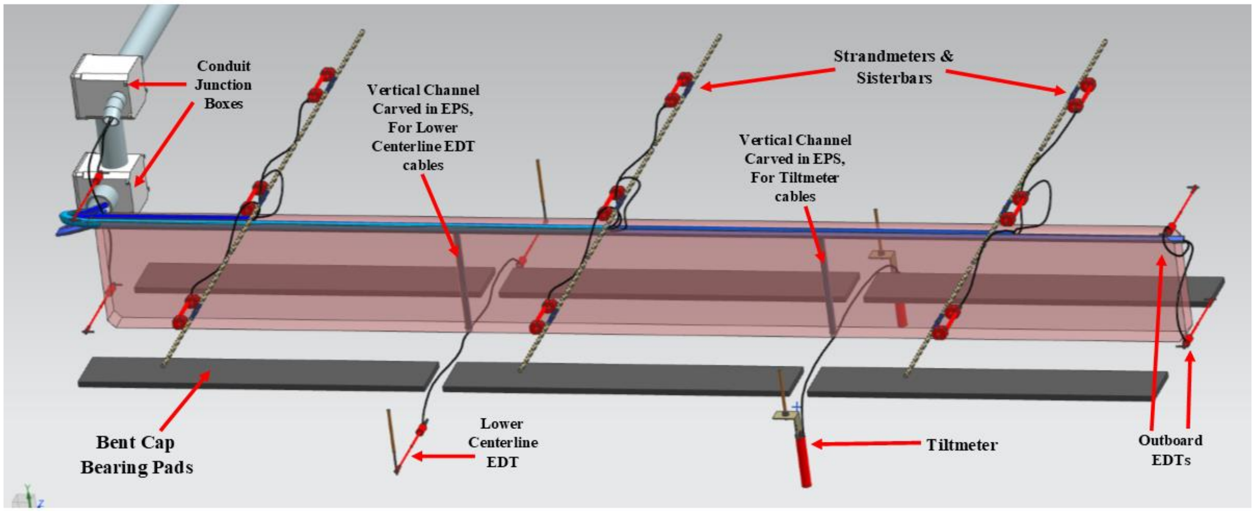


Figure 9, Cable Routes Through EPS

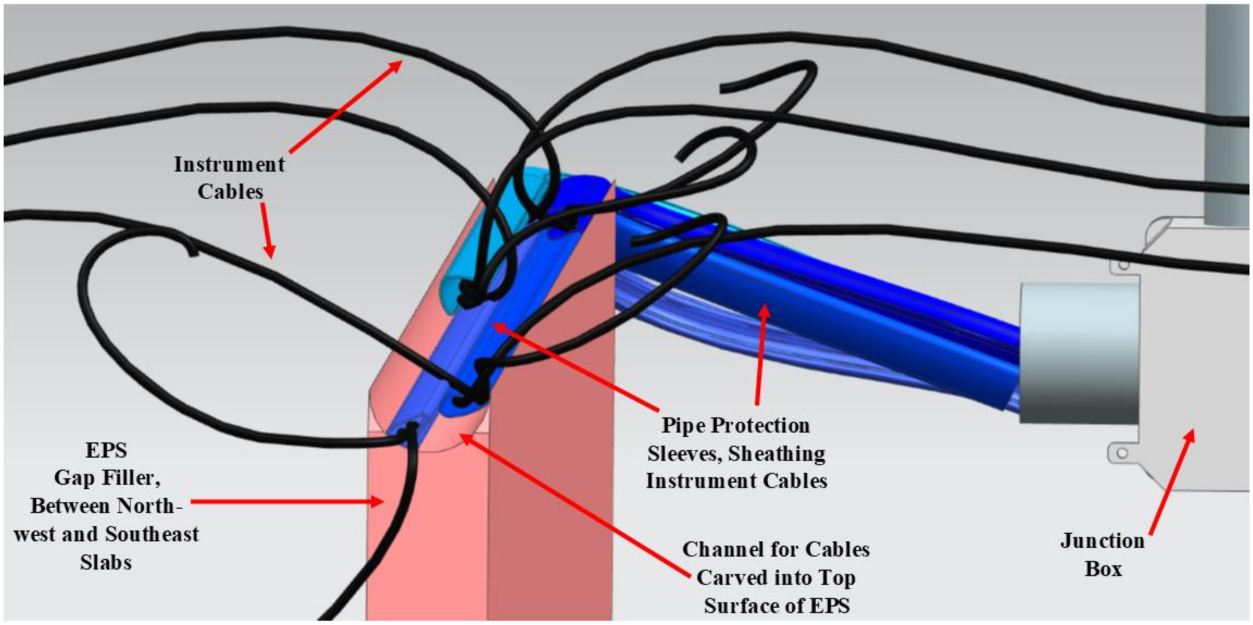


Figure 10, Carved Topside of EPS

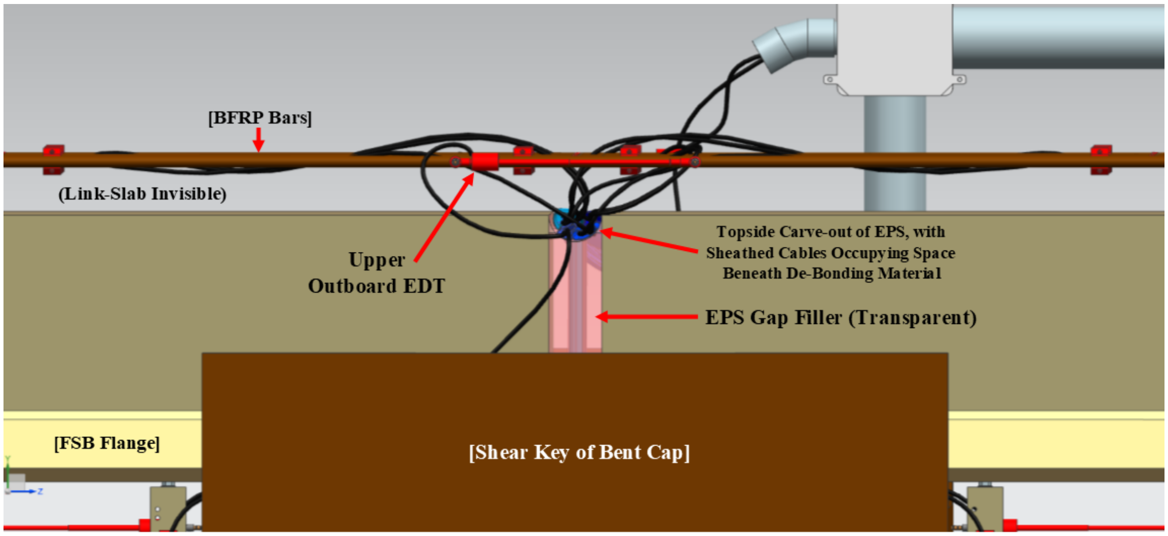


Figure 11, Detail Embedded Sensor Routing, Side View

The four tracts/bundles of cables contained by pipe protection sleeves are labeled according their overall reach and contain the cables of specific instruments. Tract No. 1 is the shortest and contains cables supplying Strandmeters and Sisterbars NW-A, Mid-A, and SE-A. Tract No. 2 contains cables supplying Strandmeters and Sisterbars NW-B, Mid-B, and SE-B. Tract No. 3 contains cables supplying Strandmeters and Sisterbars NW-C, Mid-C, and SE-C. Tract No.4 is the longest and also features branching sleeves which run through the vertical channels carved into the EPS. Tract No. 4 contains the cables supplying the Lower Centerline EDTs, Tiltmeters, and the northeast side Outboard EDTs. The separate tracts are laid out in the following illustrations, *Figure 12, Tract No. 1 of Bundled Cables*, *Figure 13, Tract No. 2 of Bundled Cables*, *Figure 14, Tract No. 3 of Bundled Cables*, and *Figure 15, Tract No. 4 of Bundled Cables*.

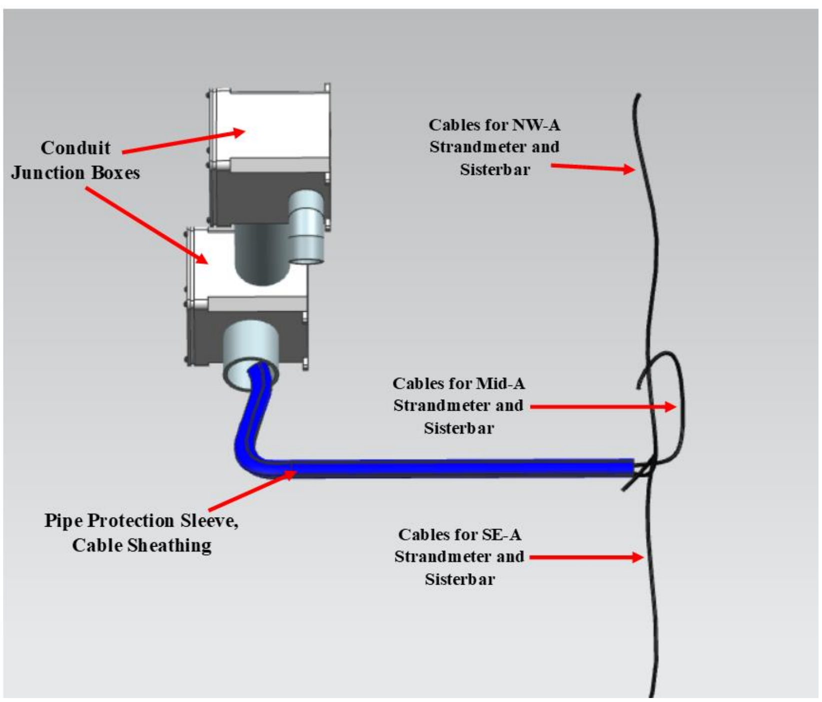


Figure 12, Tract No. 1 of Bundled Cables

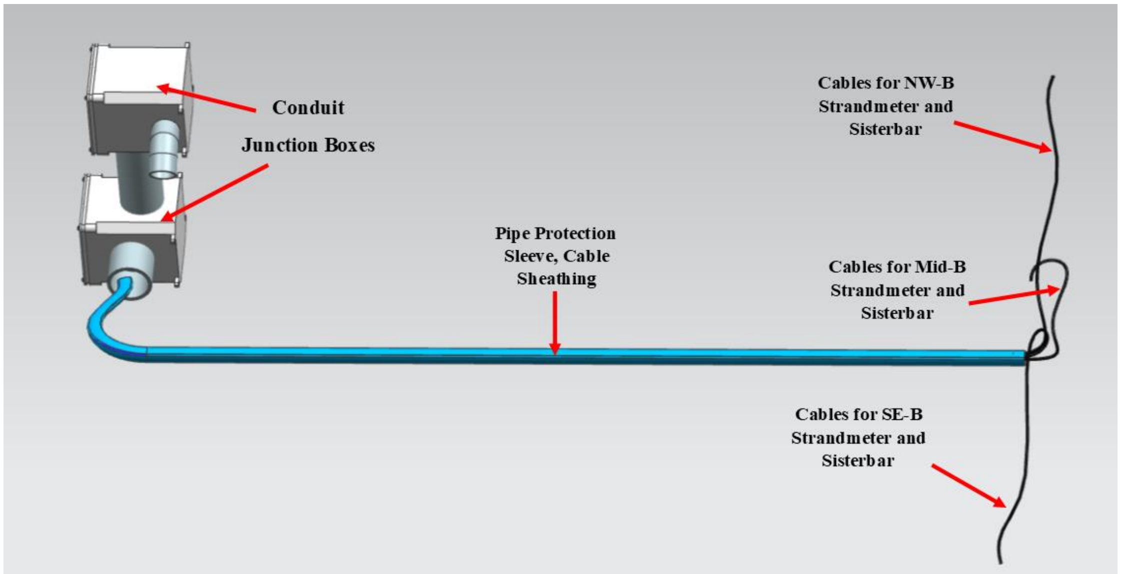


Figure 13, Tract No. 2 of Bundled Cables

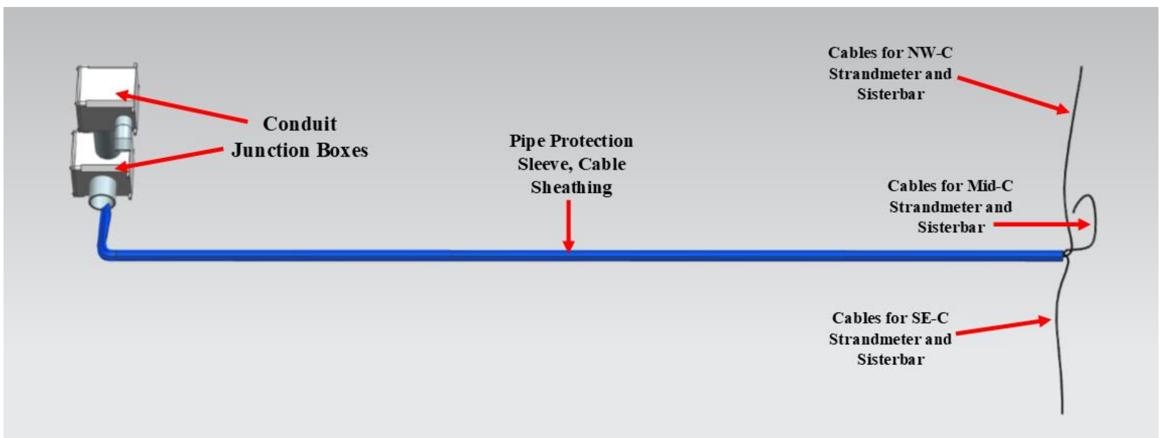


Figure 14, Tract No. 3 of Bundled Cables

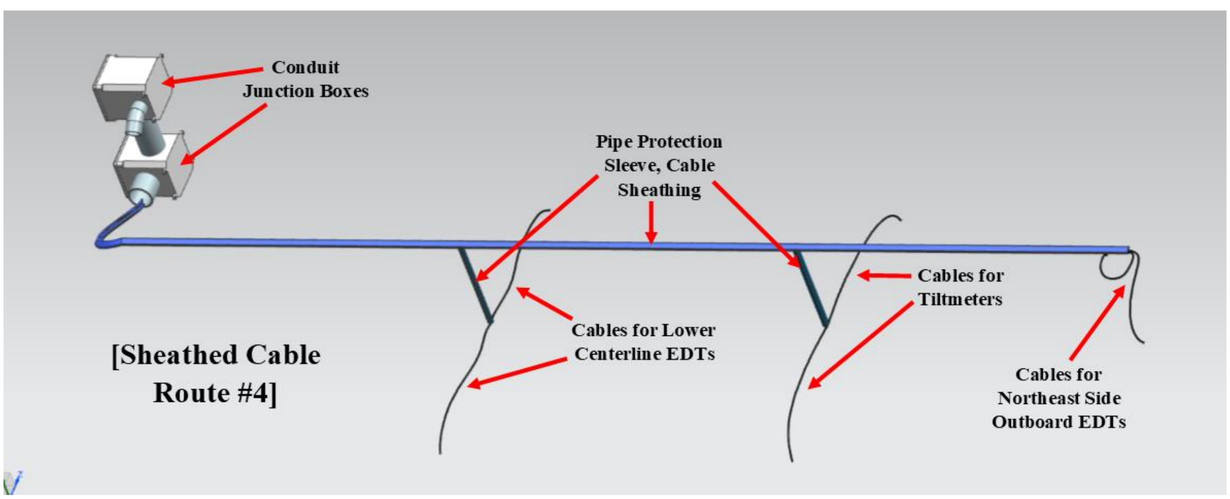


Figure 15, Tract No. 4 of Bundled Cables

4.3 DATA ACQUISITION:

Data acquisition will be accomplished by two Geokon brand, model 8002-16-1 dataloggers, also referred to as LC-2x16 datalogger units (also abbreviated as LC-2). Each of these units is capable of monitoring input from up to 16 VW cables for a total of 32 possible inputs, of which only 29 are planned for use. Storage capacity of the dataloggers is 320 KB of EEPROM type memory (data not lost upon de-energizing system), which provides storage for up to 3,555 readings from all 32 possible VW inputs. At an instrument reading rate of once per hour, this provides a maximum window of 148 days or approximately 5 months to retrieve data before capacity is reached and data points are compromised. Datalogger internal power is supplied by either four alkaline D-cell batteries or a 12-volt external grid supply. Recorded sensor data shall be accessed by direct retrieval on a periodic basis within the data capacity window. Interfacing with the LC-2 units will be accomplished either through an RS-232 Serial Interface or a USB 2.0 port, using LogView software.

The data acquisition system will be located on the outboard side of the southwest facing parapet, on the northwest end of the bridge. It shall be ten feet from the absolute end of the bridge structure, where the bridge slab ends, and the approach slab begins. LC-2 Datalogger units come housed inside fiberglass NEMA 4X weatherproof enclosures. For security, these datalogger units will also be set inside a single large lockable aluminum enclosure. This enclosure will be custom fabricated and large enough to allow the NEMA 4X boxes to be opened and easily accessed (prospective dimensions shown on drafts in Appendix B).

5. ADDITIONAL NOTES ON INSTRUMENTATION SETUP

Highlighted points on the proposed instrumentation setup:

1) Installing the EDTs on the outside of the bridge is acceptable. However, having the 27 inch-concrete parapets (barrier wall) right on top of these locations could provide additional stiffness that affects the readings in these locations. That behavior of the exterior beams (stiffened with the parapet) may be different than the behavior of the middle beam. Upper outboard EDTs are to be located 3 inches from top of link-slab deck (middle of 6-inch link-slab).

2) In order to provide clearance for installation of and access to the lower outboard EDTs, the shear keys of the bent cap supporting the link-slab must be modified. A cutout on the top surface is to be formed, centered to the midline and against the interior facing side of the shear key. The foot print of the cutout is to be 18 inches long and 6 inches wide. The bottom will slope from a depth of 7 inches on the outboard side, to a depth of 8 inches on the inboard side (equal to the height of the shear key). Lower outboard EDTs are to be located at a height of 2 inch measured from the top of the FSB beam flange (mid-height of the 4-inch thick flange).

3) Displacement between adjacent FSB beams along the middle of the bridge structure is monitored by the Lower Centerline EDTs. These are Crackmeters anchored into the bottom surface of the span with vertical anchors, and into the northwest/southeast faces of the bent cap with horizontal anchors. This will allow measurement of the adjacent beam displacement, relative to the bent cap location.

4) To accurately detect and measure the force in the link-slab, the strandmeter (4410, Geokon) is recommended to be clamped onto the reinforcement bars (BFRP). Geokon, the manufacturer, recommends these gauges be encased with grease after mounting to reinforcement, before pouring of surrounding concrete to prevent the adhesion of concrete and immobilization of the instrument. Various size strandmeter clamps are available from Geokon; the BFRP reinforcement bars used in the link slab have a diameter of approximately 0.625 inches and clamps will be sized accordingly. Gauges that are clamped to reinforcement bars are needed since the gauges embedded in concrete will be greatly affected by concrete cracking that could result in wrong readings or no reading at all. Those gauges on BFRP reinforcement are in addition to the embedded gauges in concrete.

5) It is recommended to install two Tiltmeter gauges to measure angular deflection (in the vertical-longitudinal plane) of FSB beam ends at the midline junction. They are to be located on the underside of the bridge on both sides of the bent cap supporting the link-slab, with the anchors mounted 2 inches away from the bent cap. Since Florida regulation dictates that holes may not be drilled into the bottom surface of FSB beams, the anchors are to be set into the CIP Joint Gap between the northeastern and middle FSBs. The mounting brackets provided with the sensors will need two additional holes drilled to allow vertical hanging of the sensors from a horizontal surface. The anchor used will need to be custom ordered 9-inch groutable Tiltmeter anchor, from Geokon.

6. Estimated Cost

The total estimated cost of the sensor package is $14,931 before taxes or potential shipping costs. NOTE: This estimate considers that FDOT already possesses and will provide four model 4420-25 Crackmeters and two LC-2x16 datalogging units. This estimate only includes the required sensors; data acquisition system; cabling between the sensors and data acquisition system; conduit to house and protect cabling; and some various installation hardware. The selected sensors and hardware are shown in the charts below along with their prospective application, technical specifications, and costs.

Group #	Sensor Objective	Gauge Type/Model & Source	Number of Units	Unit Price (USD)	Part Total (USD)
1	Strain in BFRP; clamps sized to fit 0.625" dia. rebars	*Strandmeter (4410, Geokon)*	9	345.00	3105.00
2	Strain in Concrete Link Slab	*Sisterbar (4911, Geokon)*	9	345.00	3105.00
3	Crack Width in Link Slab	*Micro Crackmeter (4422, Geokon)*	3	445.00	1335.00
4	Outboard EDTs	*Crackmeter (4420-25, Geokon)*	4	0.00	0.00
5	Lower Centerline EDTs	*Crackmeter (4420-25, Geokon)*	2	335.00	670.00
6	Rotation of Beam Ends	*Tiltmeter (6350, Geokon)*	2	530.00	1060.00
7	Datalogging	*LC-2x16 Datalogger (8002-16-1, Geokon)*	2	0.00	0.00
8	Custom 9" Groutable Anchors for (Group #5), Pair	*Custom from Geokon*	2	76.00	152.00
9	Custom 7" Groutable Anchors for Tiltmeters	*Custom from Geokon*	2	50.00	100.00
10	Protective Covers for EDTS (Group #4 & #5)	*Aluminum Crackmeter Cover (SPC-4420-01, BDI/Geokon)*	6	125.00	750.00
11	Tiltmeter Uni-Axial Mounting Bracket, Includes: 3⁄8" Rawl	*Tiltmeter Bracket (MNT-6350-01,*	2	95.00	190.00

	drop-in anchor, (2) 3⁄8-16 nuts, (2) flat washers and (1) lock washer	*BDI/Geokon)*			
12	Tiltmeter Cover, Aluminum	*Protective Cover, Tiltmeter (SPC-6350-01, BDI/Geokon)*	2	145.00	290.00
13	Hardware for Group #5, U-Joint	*U-joint for Axial Anchor, (A4400-26-1, Geokon)*		22.00	0.00
14	Hardware for Group #5, Set Screw	*Set Screw for Axial Anchor, (HRD-A1670, Geokon)*		0.50	0.00
15	Hardware for Group #5, O-Ring	*O-Ring for Axial Anchor, (ORB-008, Geokon)*		0.10	0.00
16	Groutable Anchors for Model 4420 Crackmeters, Pair	*(MNT 4420-02, BDI/Geokon)*	4	46.00	184.00
17	Protective Tube for Micro Crackmeter	*4422 Al Housing (SPC-4422-01, BDI/Geokon)*	3	75.00	225.00
18	Groutable Anchors for Micro Crackmeters, Sold as Pair.	*Micro Crackmeter Anchors (MNT-4420-02, BDI/Geokon)*	3	48.00	144.00
19	Conduit to House Cables and Hardware	***See Conduit Costs Below***			569.44
20	Blue PVC Jacketed Vibrating Wire Cable	*VW cable (IC-02-250, BDI/Geokon), unit price/ft.*	1770 feet	0.92	1628.43
21	Various Hardware	***See Miscellaneous Costs Below***			1423.13
		Package Pre-Tax & Shipping Total (USD):	**$14,931.00**	**Plus Tax (7%) Total:**	**$15,976.17**

Table 3, Estimated Total Cost of Sensor Plan

Miscellaneous and Conduit Costs Continued on Next Page

Conduit Parts and Hardware:	Price per Unit	# of Units	Cost (USD)	Source
3 in. Hinged Split Ring Pipe Hanger in Galvanized Malleable Iron (5-Pack)	63.99	2	127.98	HDX/Lowes
Wedge-All 7/8 in. x 6 in. Zinc-Plated Expansion Anchor (5-Pack), for 3" Pipe Hangers	34.99	2	69.98	HDX/Lowes
Schedule 40 PVC Conduit with Bell End, Trade Size: 3", Nominal Length: 10 ft.	43.73	5	218.65	Grainger (grainger.com)
Schedule 40 PVC Conduit with Bell End, Trade Size: 1-1/2", Nominal Length: 10 ft.	16.16	1	16.16	Grainger (grainger.com)
3 in. x 3 in. PVC Mechanical Flexible Expansion Coupling	9.25	2	18.50	HDX/Lowes
1 1/2" Schedule 40 PVC 30-degree Elbow Socket	0.99	1	0.99	HDX/Lowes
6x6x6 (Trade Size) Conduit Junction Box	30.00	2	60.00	various suppliers
3" (Trade Size) Box Adapter, (Case of 5)	17.10	1	17.10	HDX/Lowes
1.5" (Trade Size) Box Adapter, (Case of 8)	8.16	1	8.16	HDX/Lowes
Conduit/PVC Glue, Oatey Gray PVC Cement	11.71	2	23.42	HDX/Lowes
1.5" Flexible Rubber Pipe Cap	3.50	1	3.50	HDX/Lowes
3" Flexible Rubber Pipe Cap	5.00	1	5.00	HDX/Lowes
	Subtotal Conduit:			**$ 569.44**

Table 4, Conduit Component & Hardware Costs

Miscellaneous Items	Price per Unit	# of Units	Cost (USD)	Source
15' of rubber HD cord cover/runner (for containing Micro Crackmeter cables)	100.00	1	100.00	Cabletiesandmore.com
Various Concrete Anchors & Other Hardware	50.00	1	50.00	Various suppliers
6" Thin Wall Heat Shrink Tubing, Flexible Polyolefin, Shrink Ratio 3:1, 10 per pkg, Part# 30N545, For Splicing Cut VW Cable	21.33	5	106.65	Grainger (grainger.com)
Strong-Tie SET-3G22-N - 22 Oz. Epoxy Anchor w/ Nozzle, Pkg 1	42.99	2	85.98	Fastenersplus.com
Pipe Protection Sleeve, for 1" piping (for cables passing across midline of bridge), Box of 200 linear feet	30.00	1	30.00	walmart/various
Datalogger Weather & Intrusion-Proof Box	300.00	1	300.00	Custom Aluminum Fabricator
Cabe Clamps/Clips, to Hold Down Micro Crackmeter Cables (Group 3)	1.50	15	22.50	HDX/Lowes
1/2" x 8-foot Copper Grounding Rod	12.00	1	12.00	HDX/Lowes
1/2" Ground Rod Clamps	2.50	2	5.00	HDX/Lowes
Estimate Flex Factor (5% of Subtotal of Entire Estimate)	711.00	1	711.00	
	Subtotal Miscellaneous:			**$ 1,423.13**
	Total for Miscellaneous & Conduit Expenses:			**$ 1,992.57**

Table 5, Miscellaneous Costs

7. Brief Summary

The team will investigate the concrete simple-span beams that are made continuous by pouring a continuity link-slab between the beam ends. The bridge will be instrumented with embedded and surface-mounted sensors and will be monitored for at least 2 years to evaluate the performance of the new continuity detail.

Several types of sensors will be used, and a data acquisition system will record strain/loads a regular time interval. The preferred sensor types for this application are vibrating wire sensors with integrated thermistors (per FDOT request). Sensors are strategically located on both sides of the midline to capture important measures with the greatest influence on the continuity, such as strains in BFRP bars, strains in the continuity concrete, the gap between adjacent beams' ends, and the rotation of beam ends.

All measurements should be corrected for temperature changes per recommendations of the gauge manufacturer. Data can be collected during field tests and service. The data acquisition system should be able to keep record when certain strains are reached in the BFRP reinforcement.

A live load test using a weighted truck will be conducted on the monitored link-slab, prior to opening for traffic. The performance of the link-slab continuity will be tested in nine static loading conditions, using the embedded and external sensor data and inspections to assess the bridge and continuity detail's integrity. The weight of the truck used for load testing will be determined after testing to ensure the measurement is conservative regarding weight lost by fuel use.

APPENDIX A
IMAGES AND ILLUSTRATIONS OF BRIDGE AND SENSOR LAYOUT

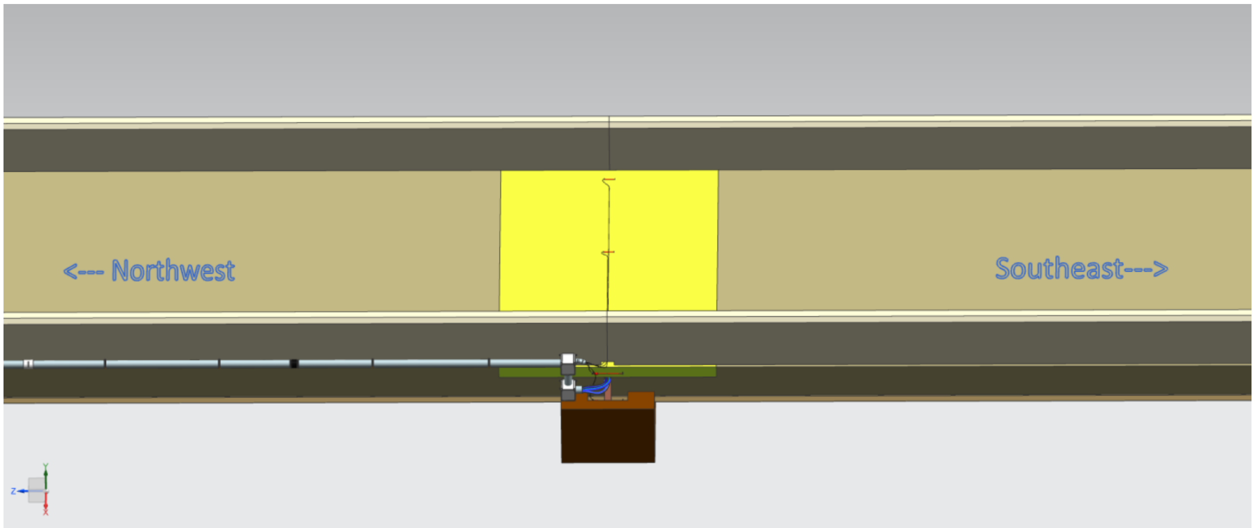


Figure 16, Side View

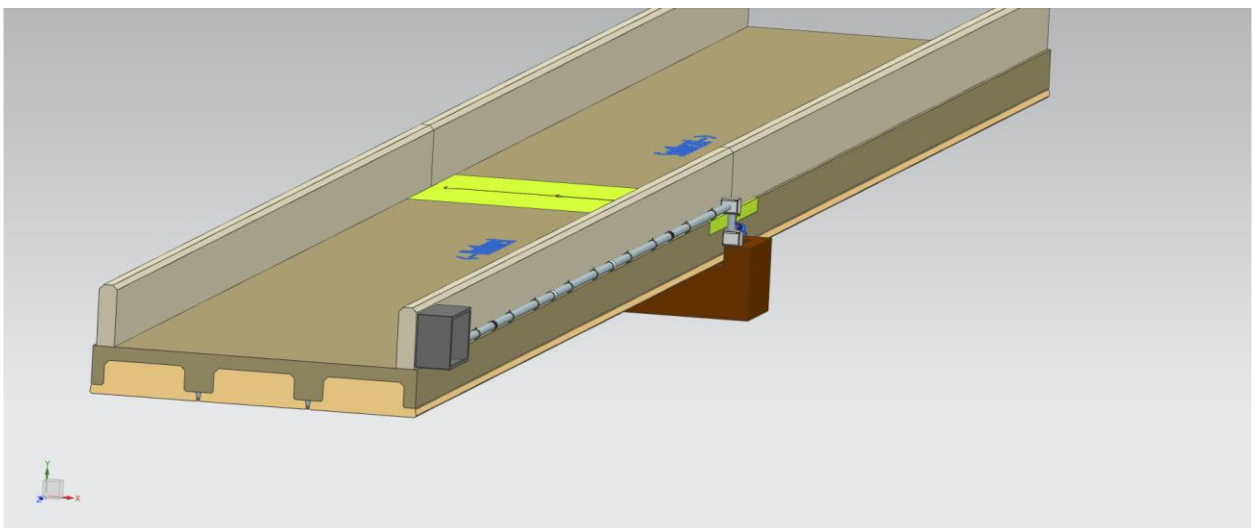


Figure 17, Angled View

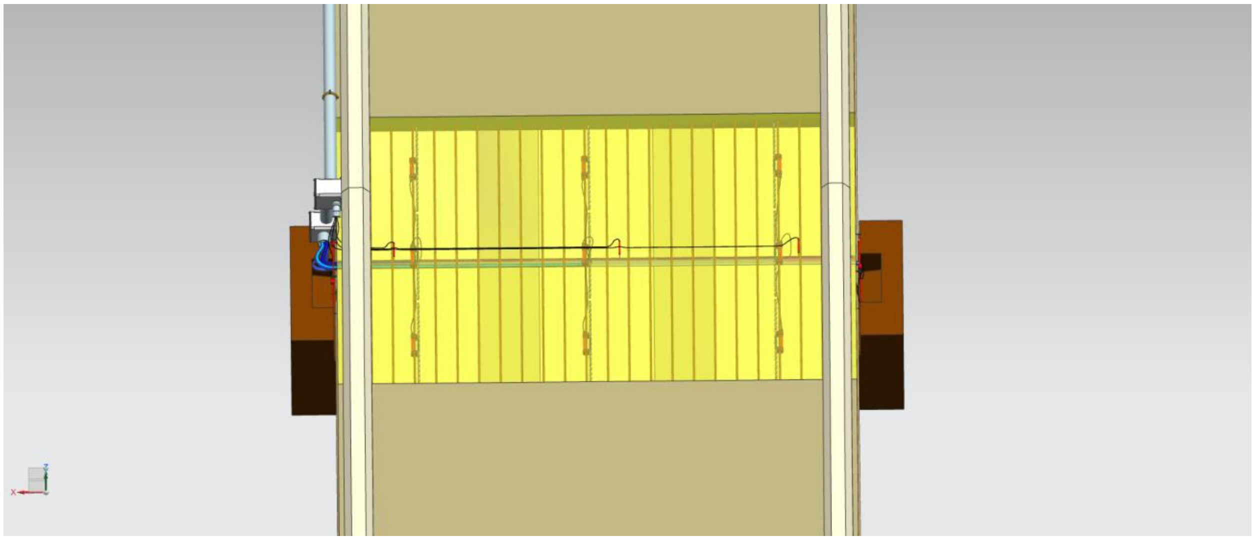


Figure 18, Top View

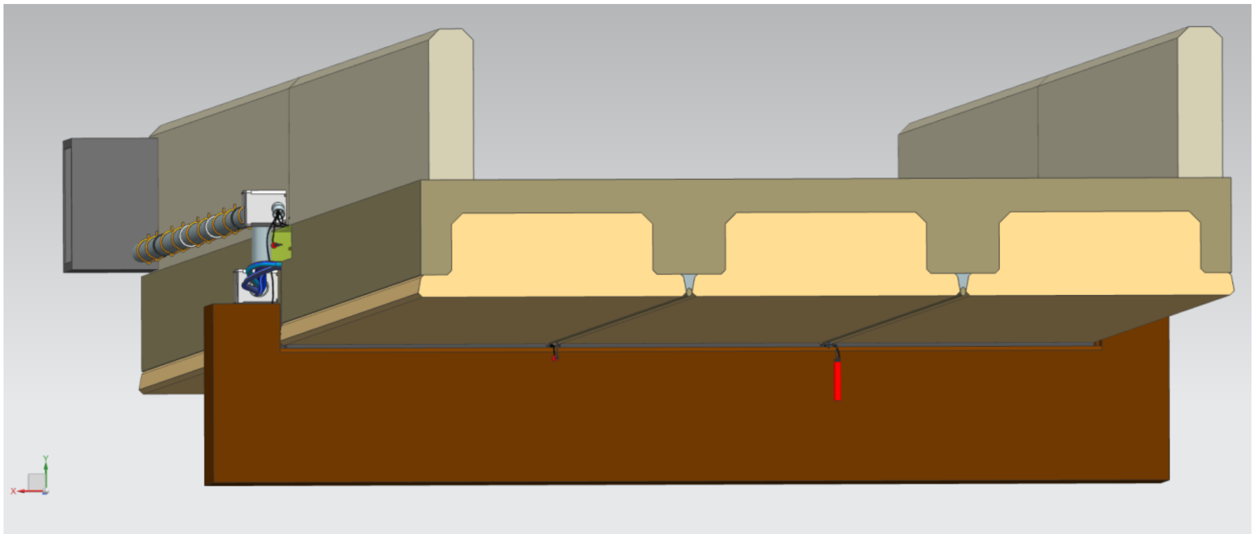


Figure 19, End View

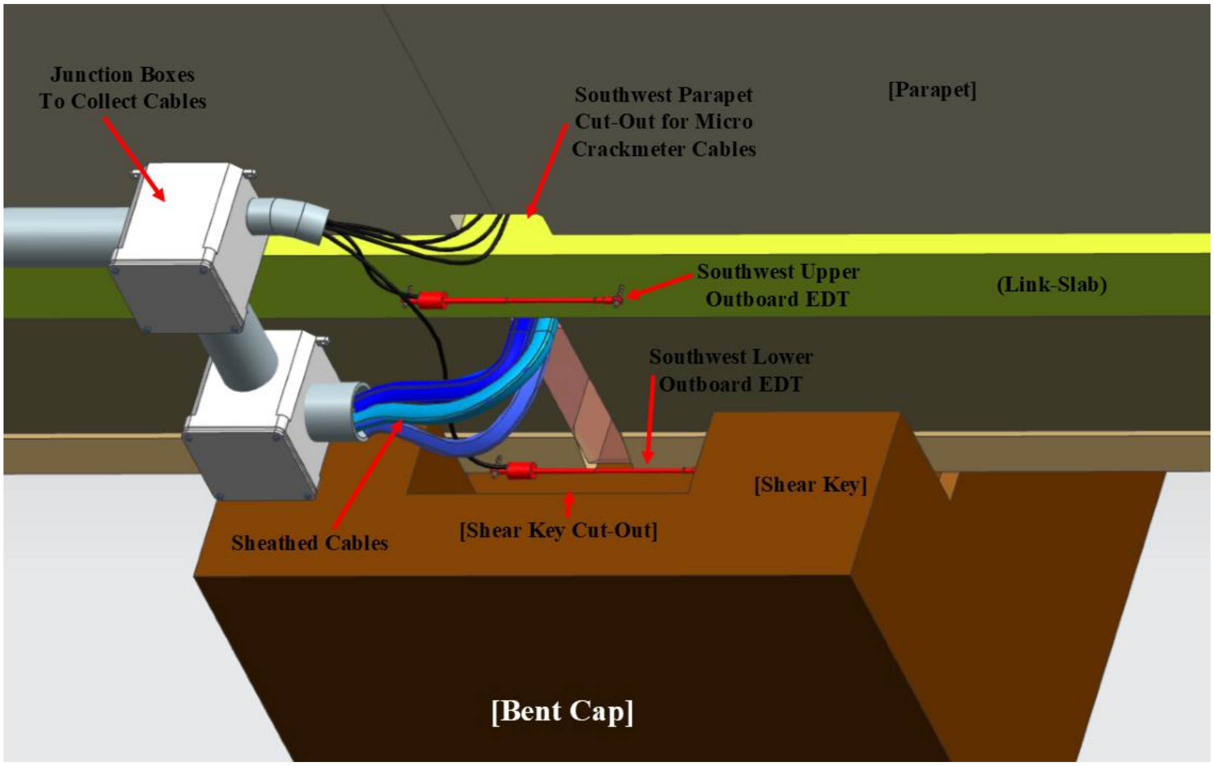


Figure 20, Top View of Southwest Shear Key

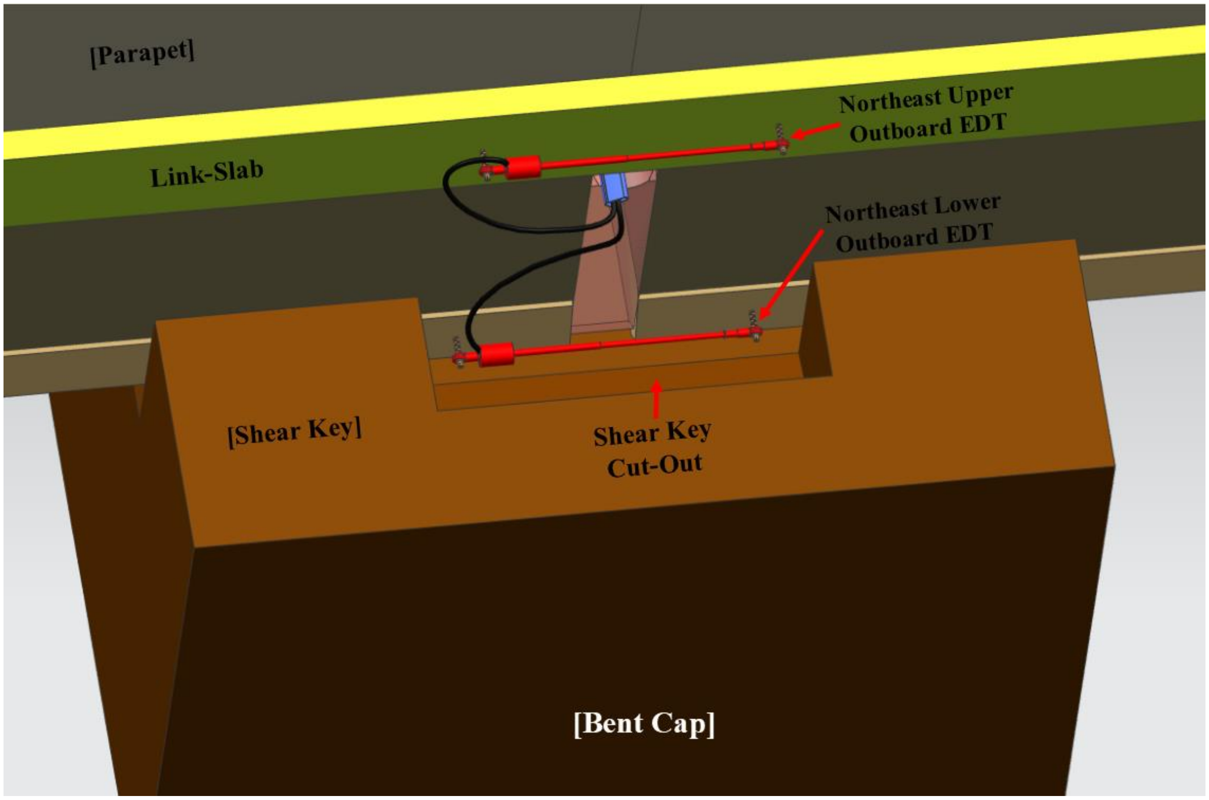


Figure 21, Top View of Northeast Shear Key

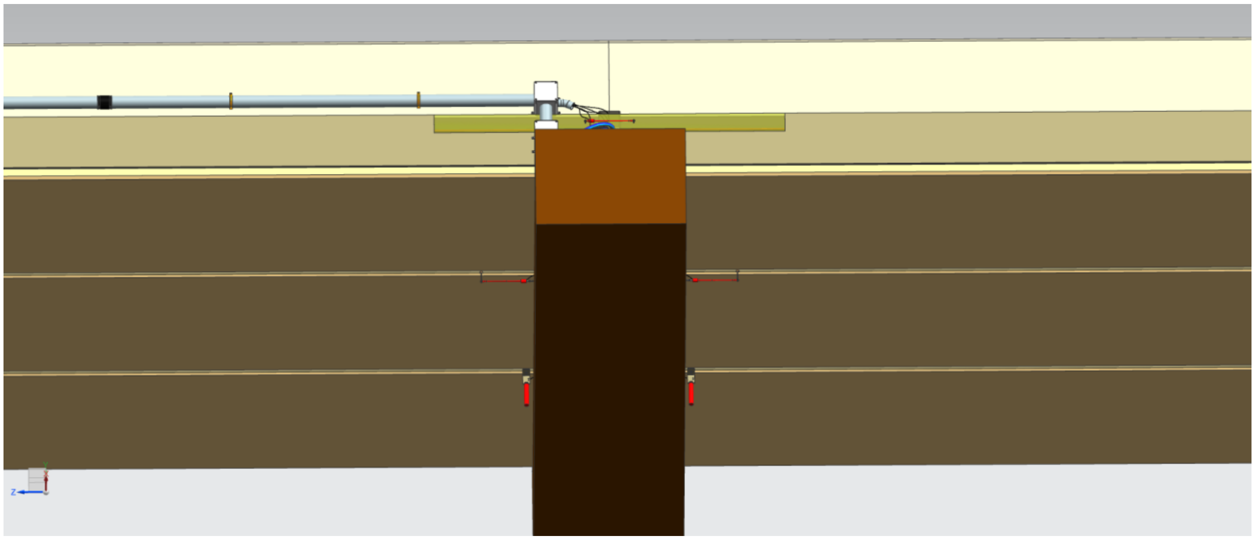


Figure 22, Bottom View from Southwest

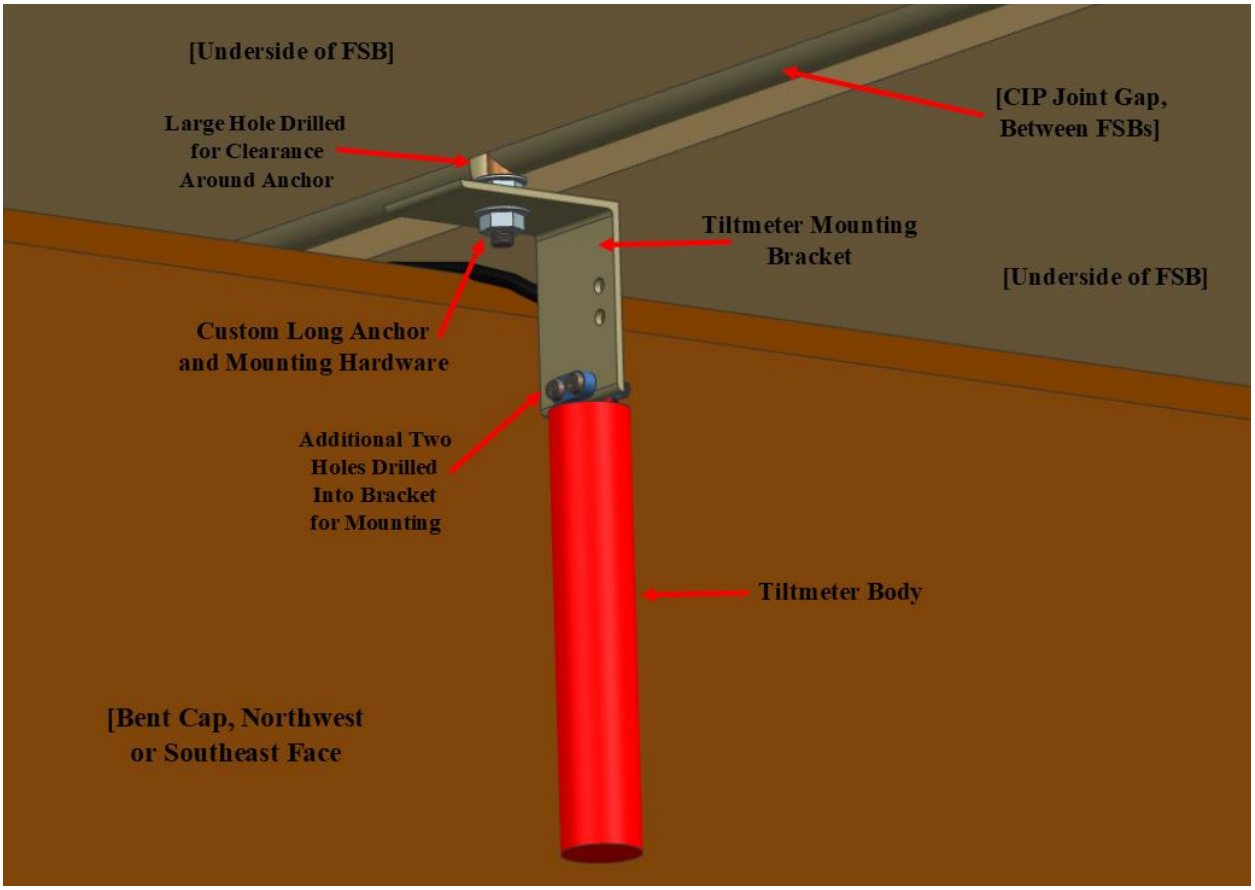


Figure 23, Detail of Tiltmeter

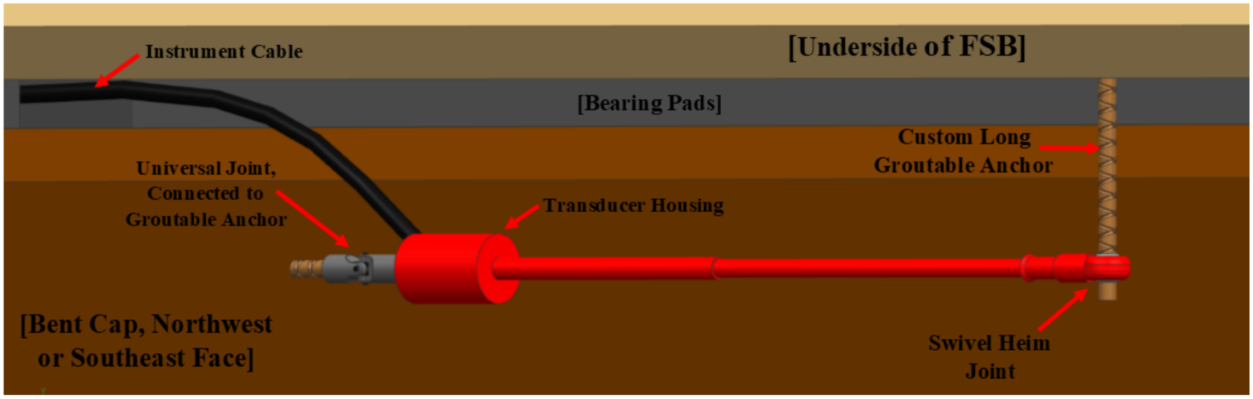


Figure 24, Detail No.1 of Lower Centerline EDT

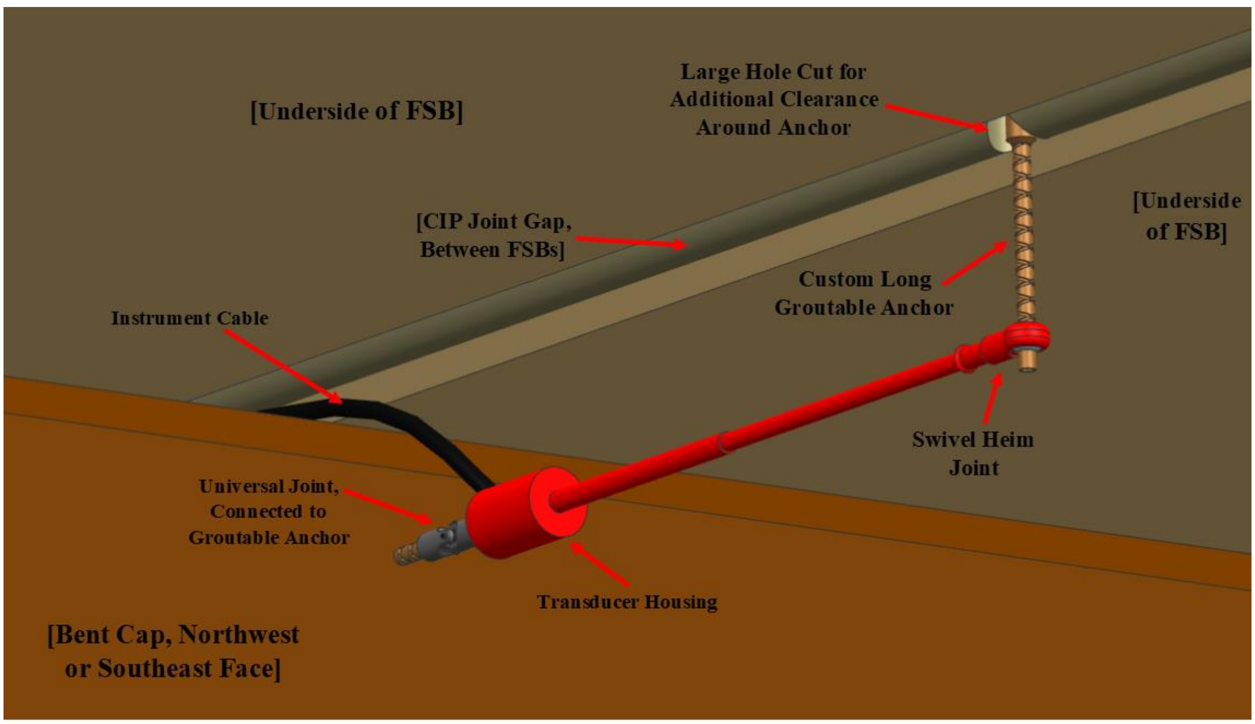


Figure 25, Detail No.2 of Lower Centerline EDT

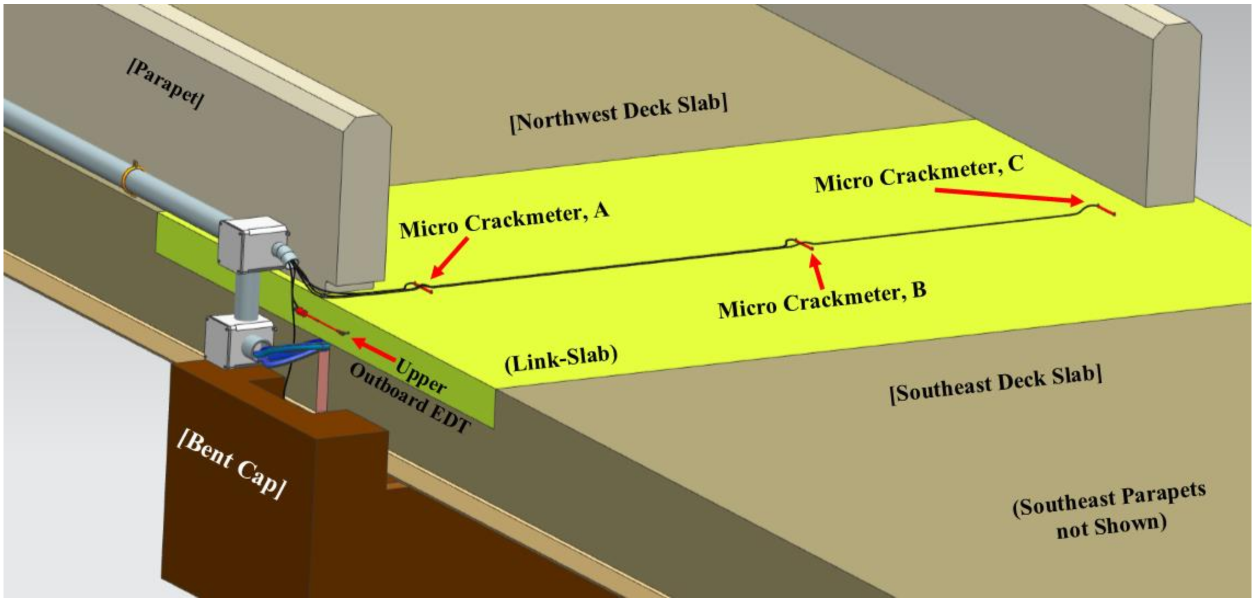


Figure 26, Side View, Exposed

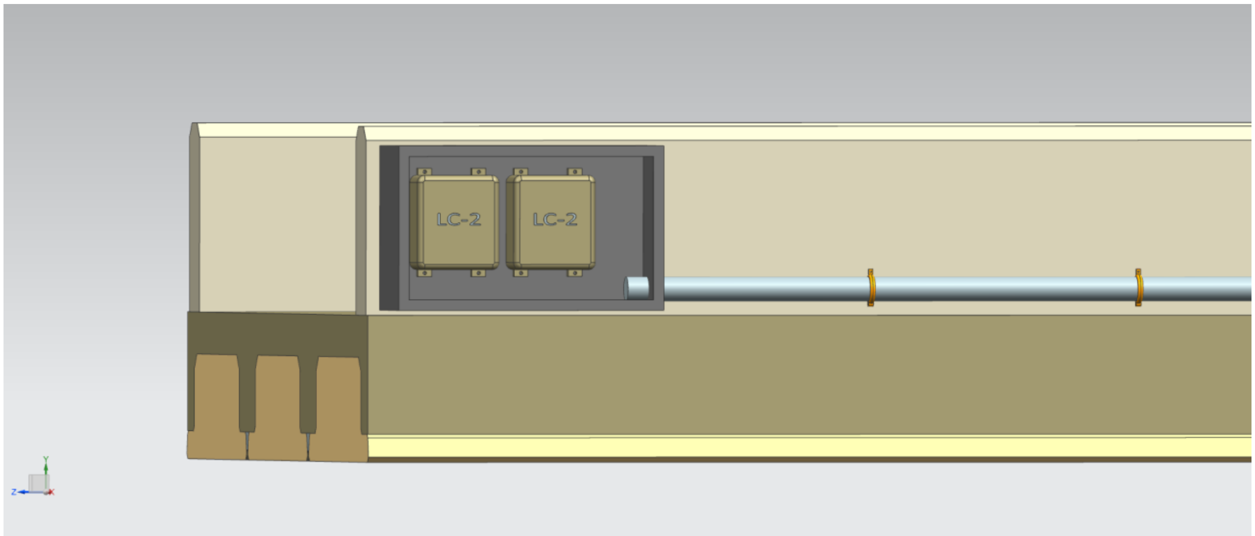


Figure 27, Detail Data Acquisition

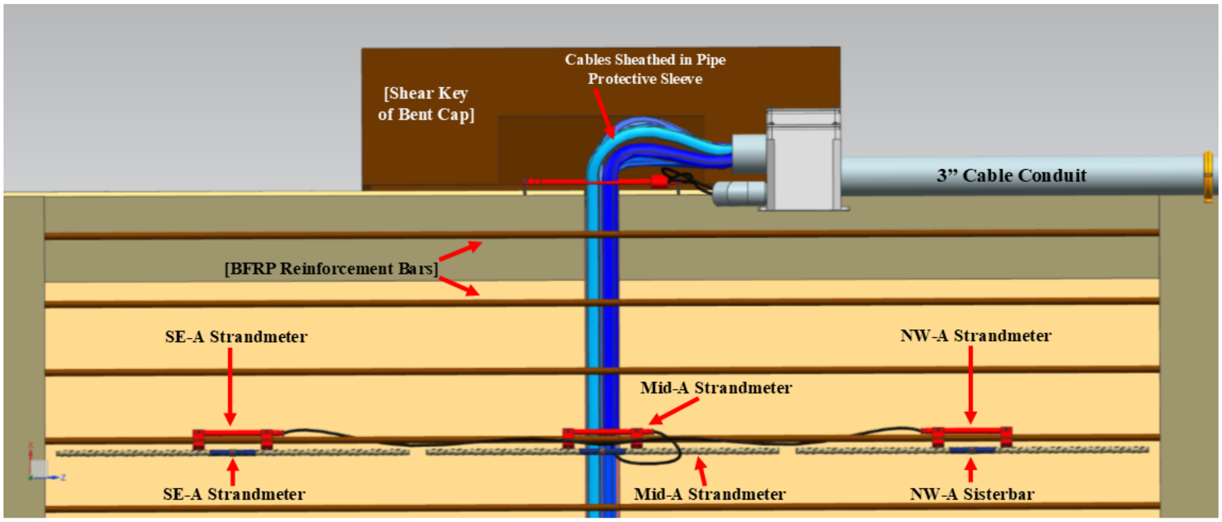


Figure 28, Detail Link-Slab, Top View

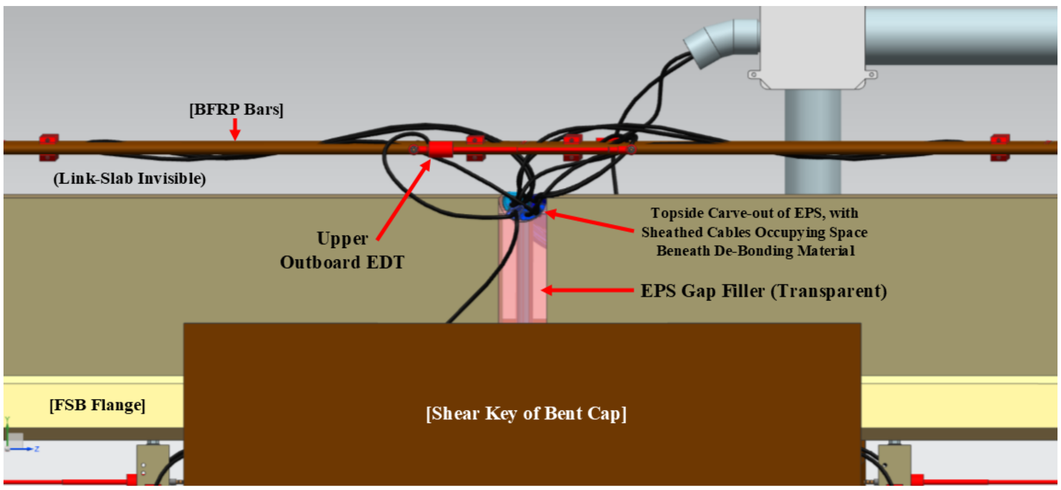


Figure 29, Side View of Exposed Embedded Sensors and BFRP rebars

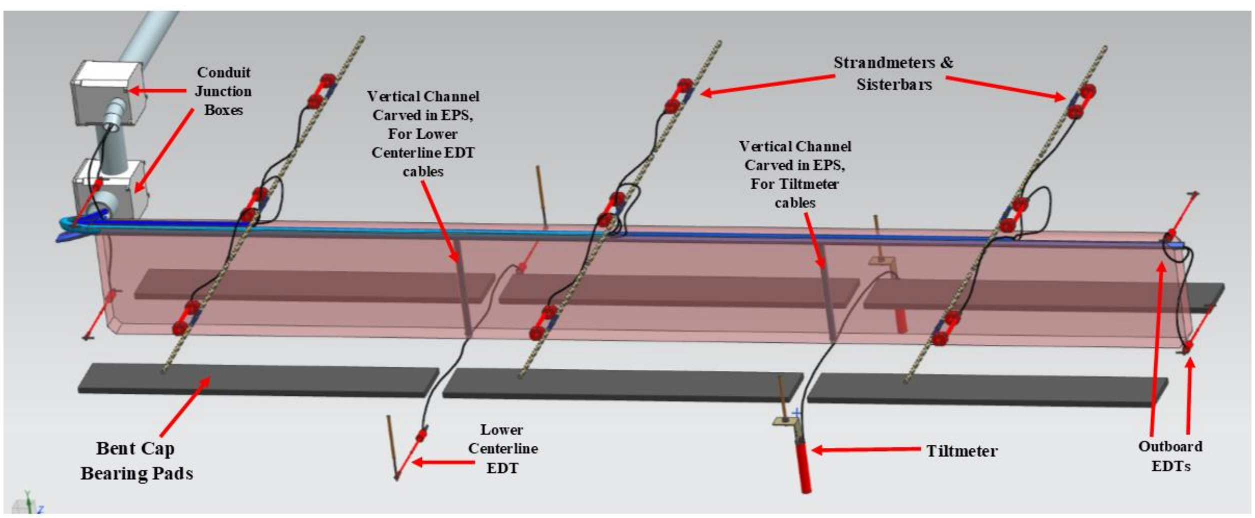


Figure 30, Exposed View of Cable Routing (EPS is Translucent)

APPENDIX B

DIMENSIONED DRAWINGS OF SENSOR LAYOUT

Group #	Gauge Type/Model & Source	Resolution	Accuracy	Measuring Range	Dimensions	# of Units
1	*Strandmeter (4410, Geokon)*	<5 με	(+/-) 0.003 mm	3 mm (15000 με)	8" Long x 1.77" Wide Clamps	9
2	*Sisterbar (4911, Geokon)*	0.4 με	(+/-) 7.5 με	3000 με	36" Length, #4 Size Rebar	9
3	*Micro Crackmeter (4422, Geokon)*	.001 mm	(+/-) 0.004 mm	4 mm	4.725" Long x 0.315" Diameter	3
4	*Crackmeter (4420-25, Geokon)*	.00625 mm	(+/-) 0.025 mm	25 mm	Gauge Length: 13.5", Dia:1"	4
5	*Crackmeter (4420-25, Geokon)*	.00625 mm	(+/-) 0.025 mm	25 mm	Gauge Length: 13.5", Dia:1"	2
6	*Tiltmeter (6350, Geokon)*	(+/-) 10 arc seconds	(+/-) 0.01°	(+/-) 10°	Length: 5.47", Diameter: 1.26"	2
7	*Datalogger (LC-2, Geokon)*	1 part in 20,000; Thermistor: 0.1 deg C	(+/-) 0.05% F.S. (450 to 4000 Hz); Thermistor: (+/-) 2.0% F.S.	450 to 4000 Hz; Thermistor: -30 deg C to 50 deg C	(LxWxH): 13.46" x 11.85" x 6.3"	2

Table 6, Instrument Groups

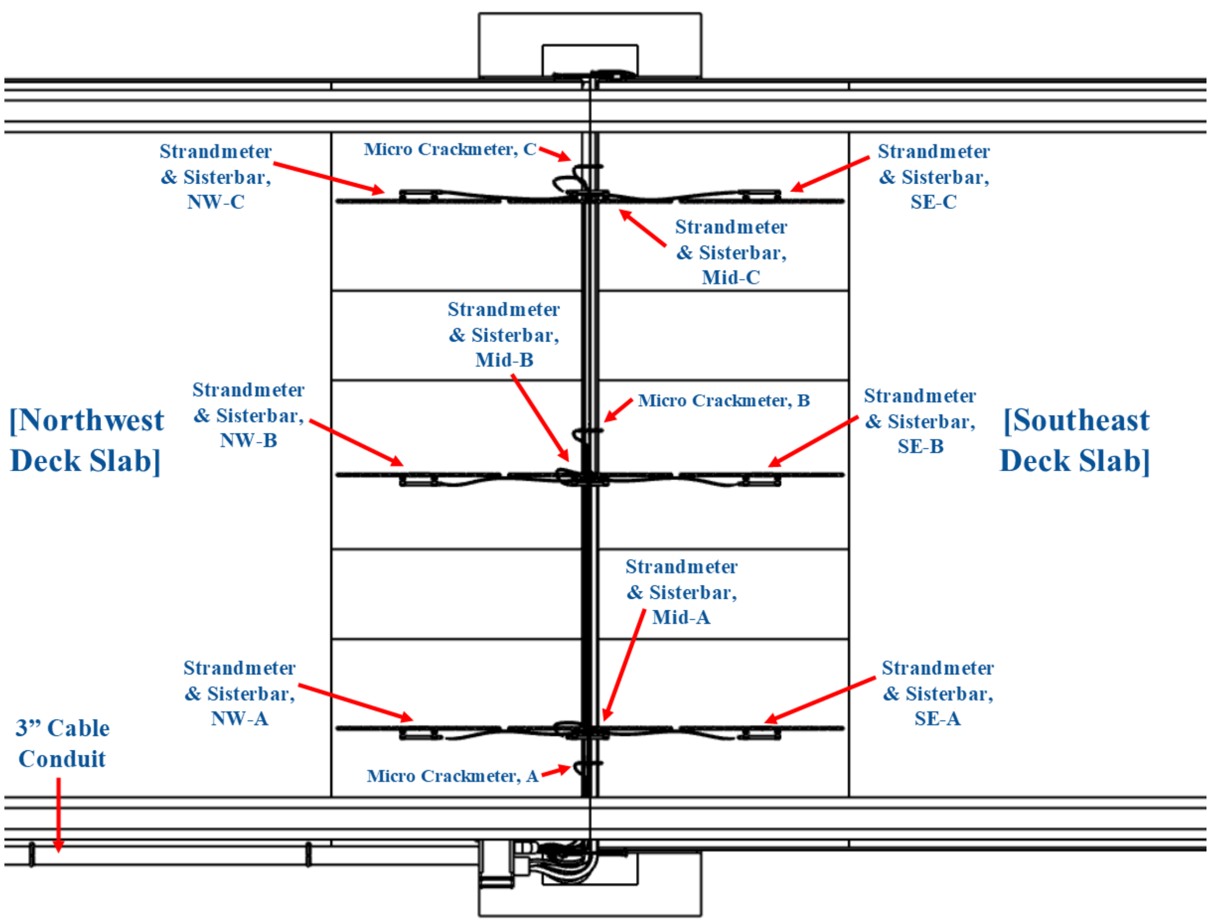


Figure 31, Drawing, Labels of Embedded Array and Micro Crackmeters

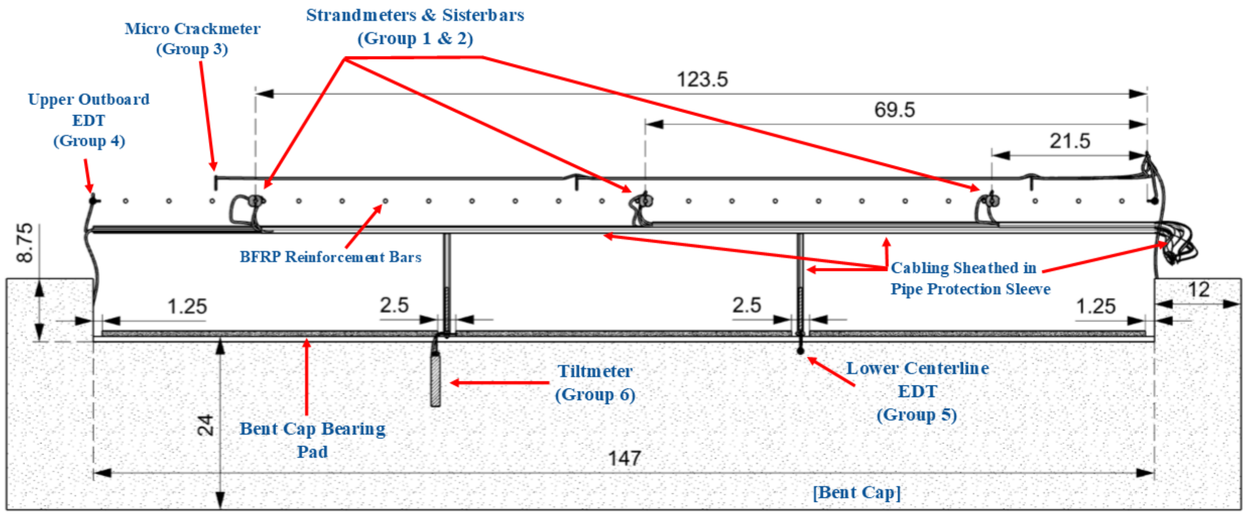


Figure 32, Drawing, Bent Cap End View (Slabs, Beams, and Parapets not Shown)

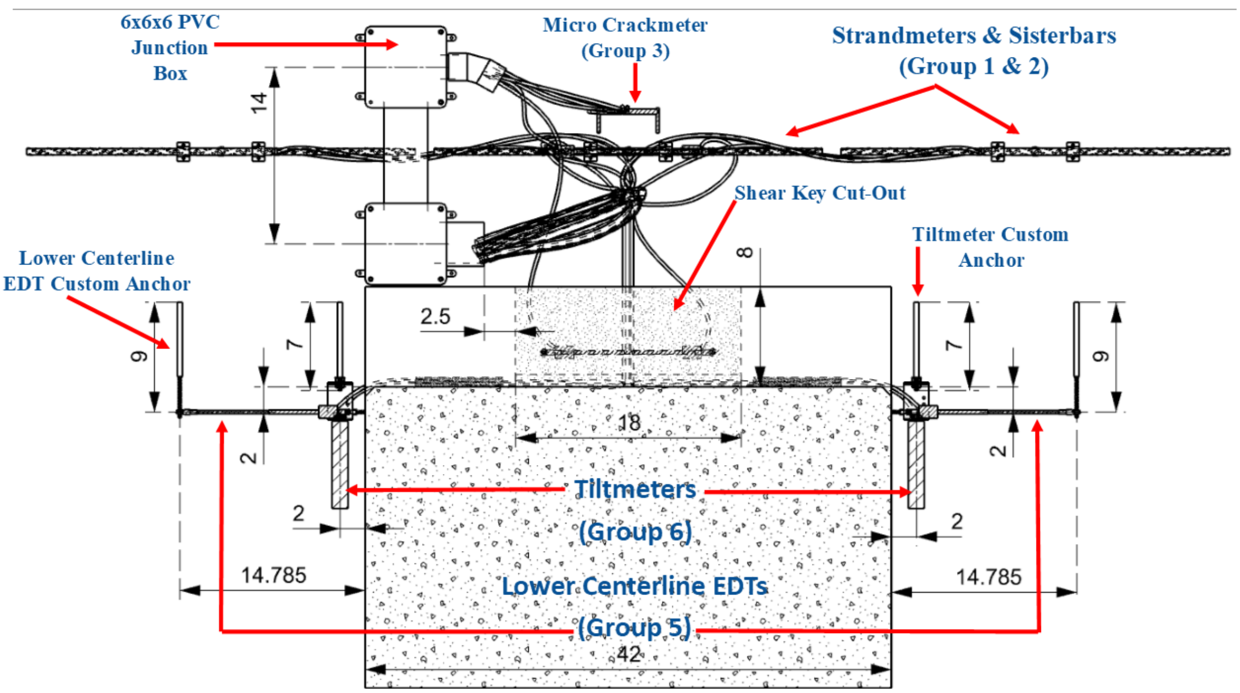


Figure 33, Drawing, Bent Cap Side View (Slabs, Beams, and Parapets not Shown)

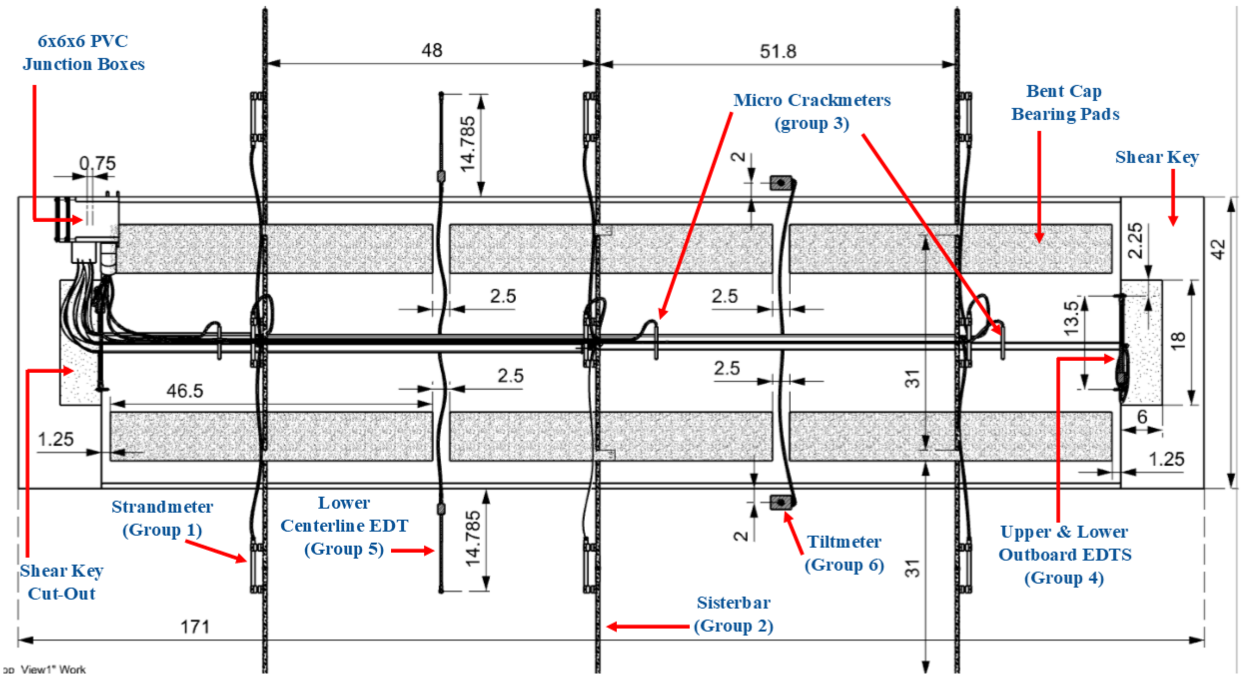


Figure 34, Drawing, Bent Cap Top View (Slabs, Beams, and Parapets not Shown)

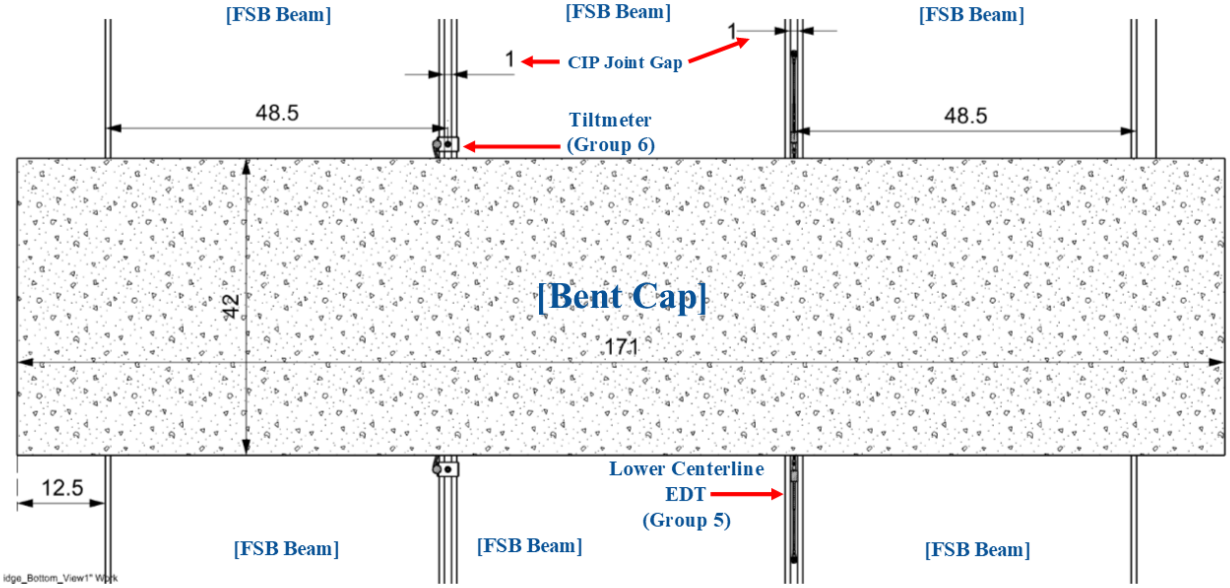


Figure 35, Drawing Bridge Bottom View

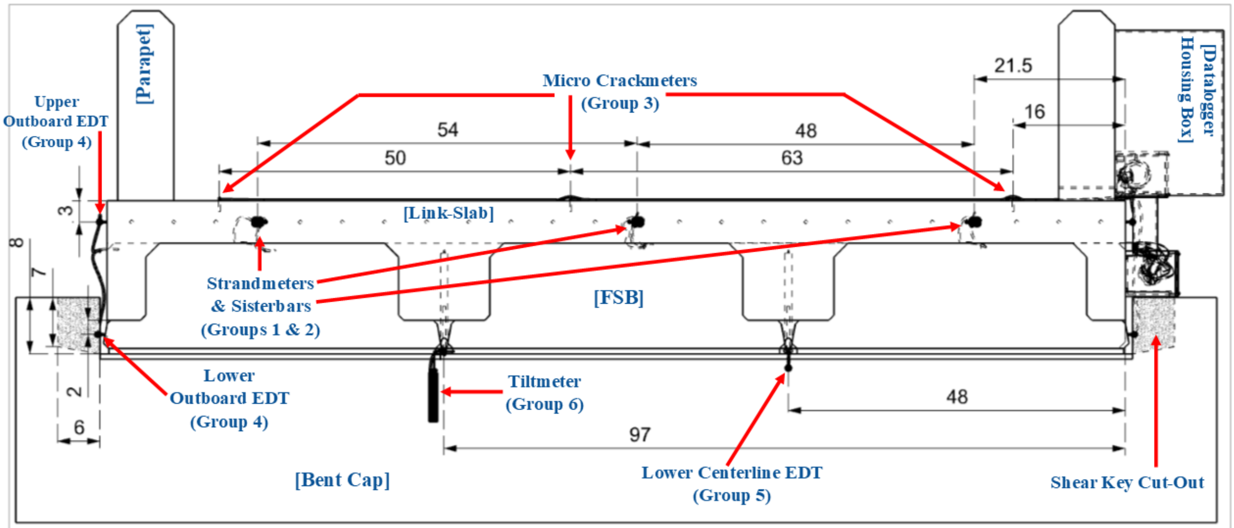


Figure 36, Drawing, Bridge End View No.1 (from Northwest Perspective)

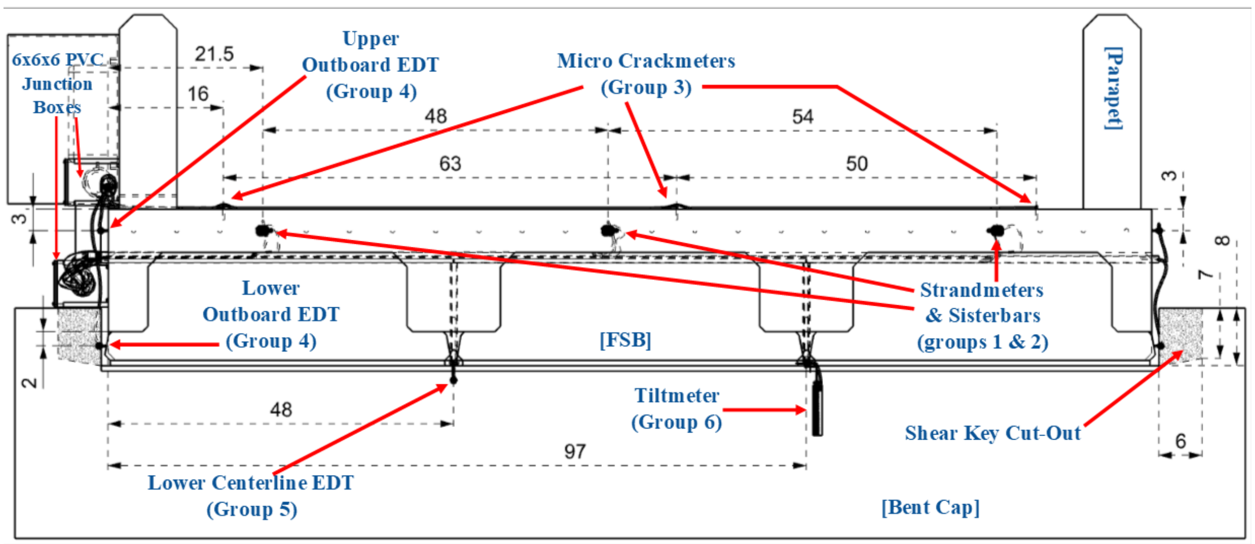


Figure 37, Drawing, Bridge End View No.2 (from Southeast Perspective)

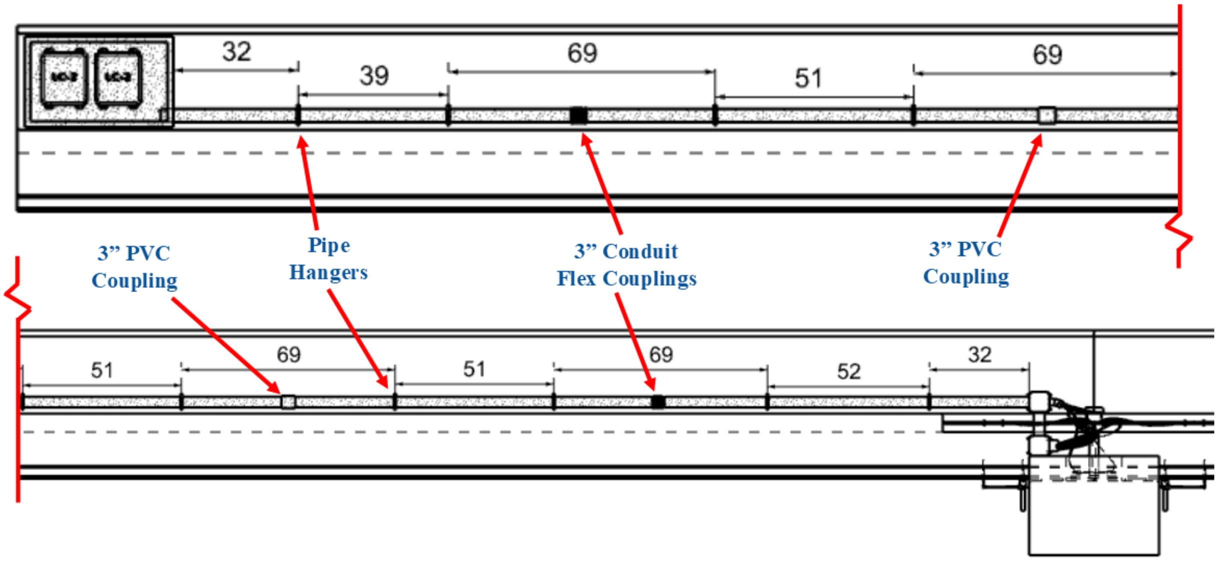


Figure 38, Drawing, Bridge Side View No.1 (Wide)

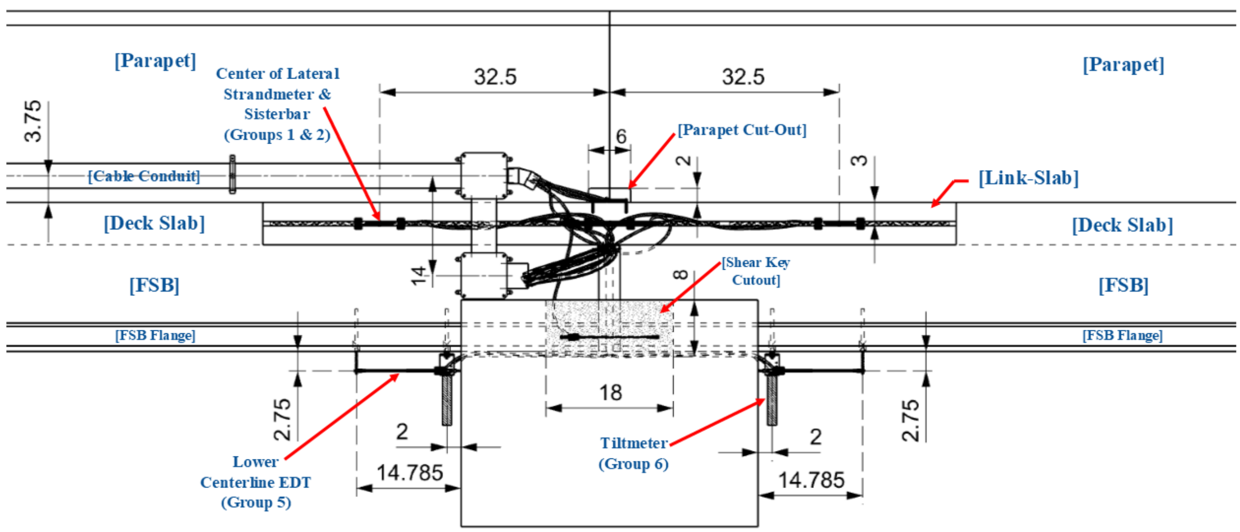


Figure 39, Drawing, Bridge Side View No.2 (Detail of Link-Slab)

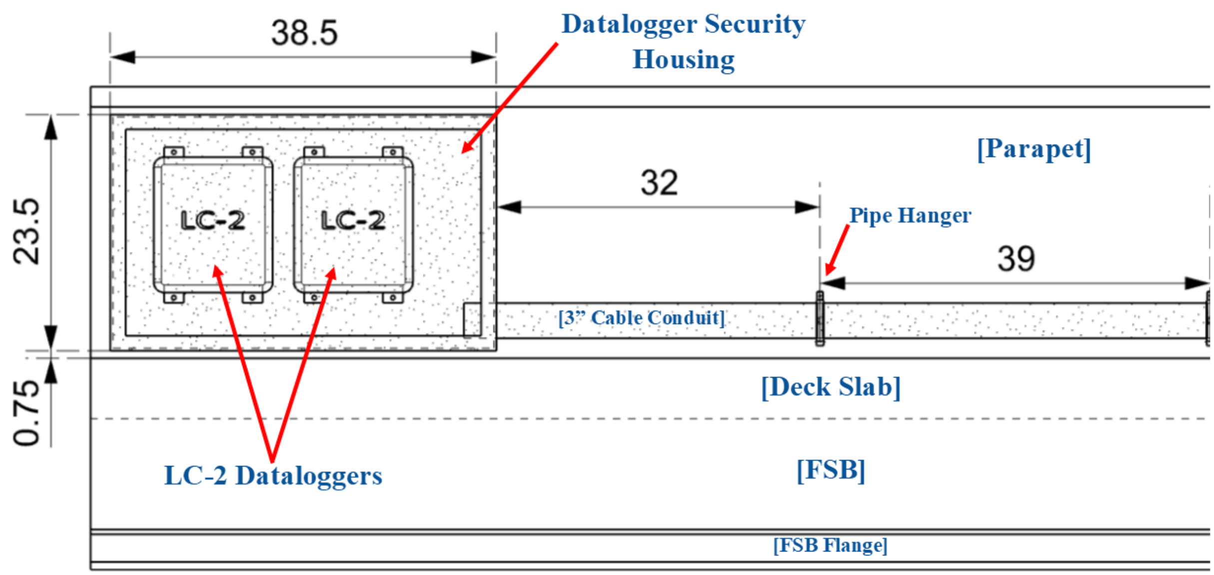


Figure 40, Drawing, Bridge Side View No.3 (Detail of Data Acquisition)

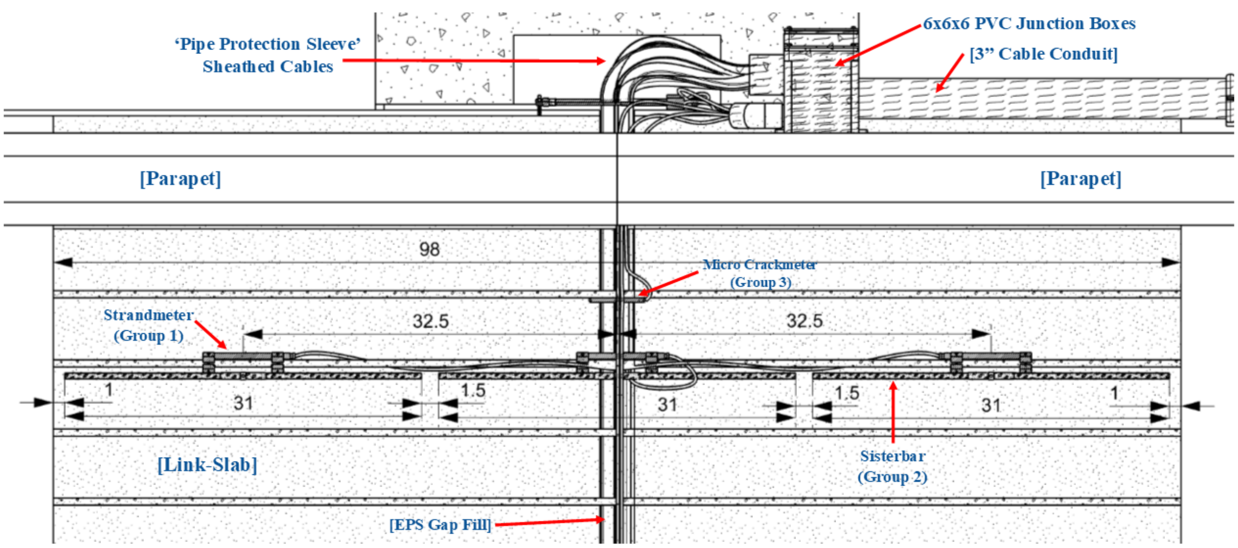


Figure 41, Drawing, Top View Detail of Link-Slab (Southwest Side)

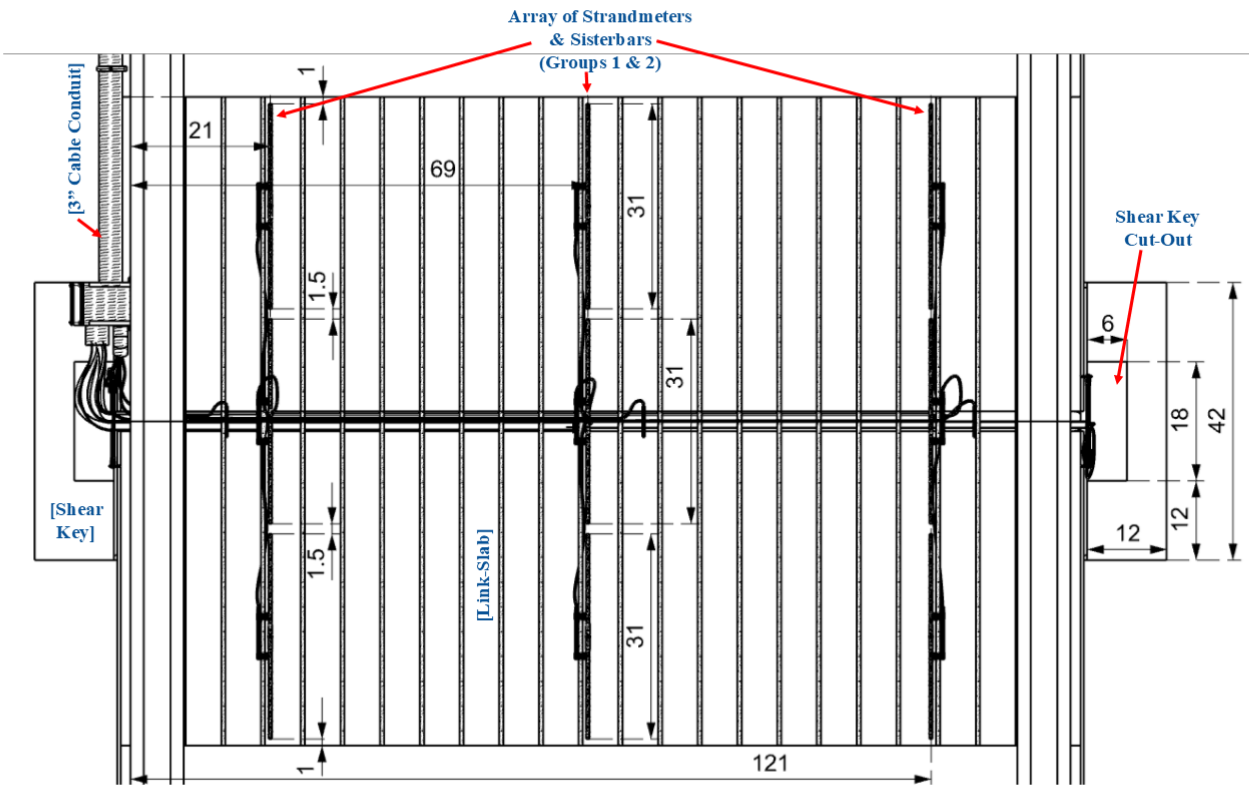


Figure 42, Drawing, Top View of Whole Link-Slab

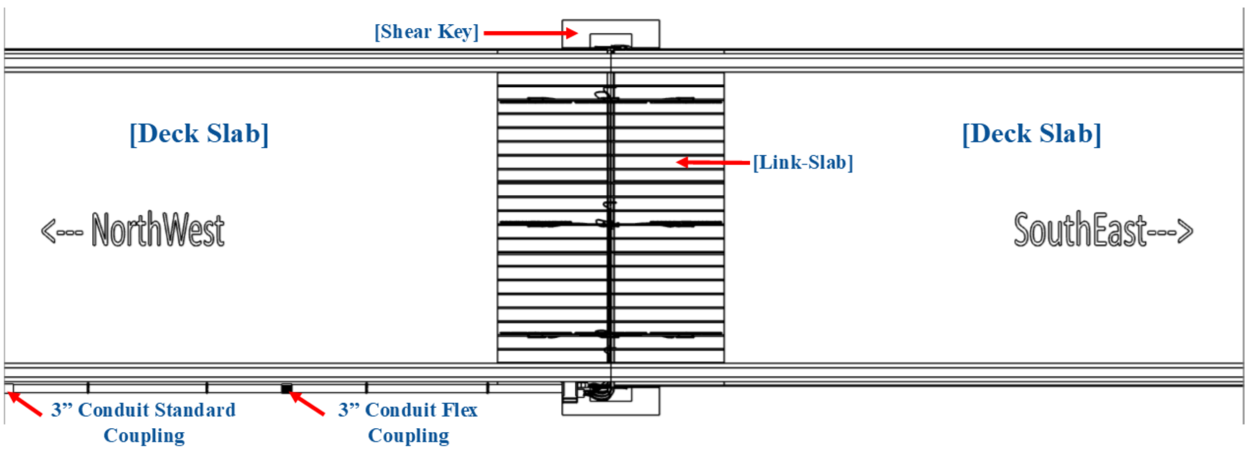


Figure 43, Drawing, Top View of Bridge (Wide)

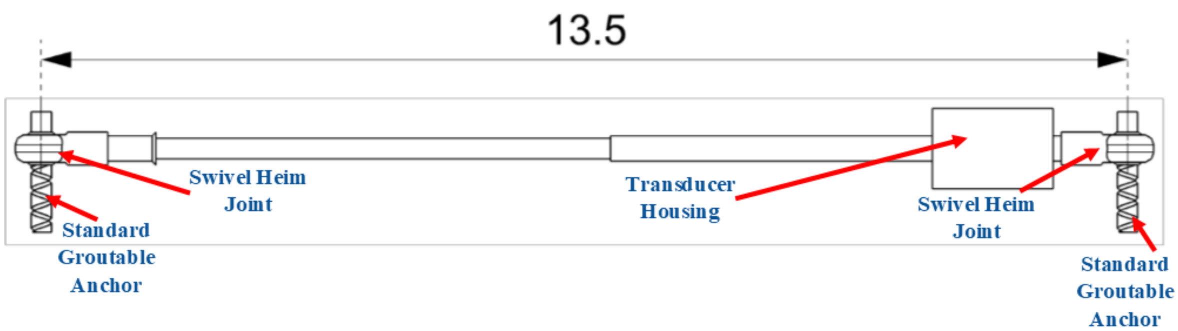


Figure 44, Drawing, Detail of Crackmeter for Outboard EDTs

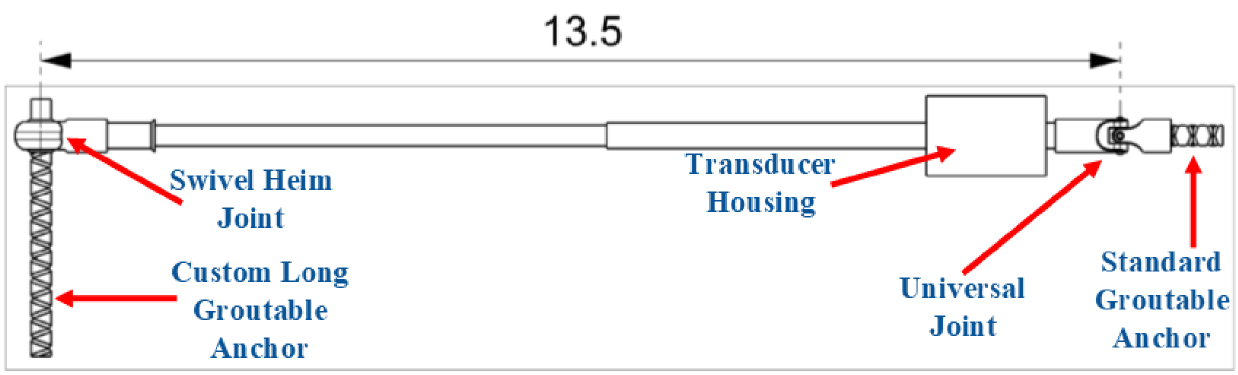


Figure 45, Drawing, Detail of Crackmeter for Lower Centerline EDTs

APPENDIX C

MANUFACTURER'S INSTRUMENT DATASHEETS

(Credit: Geokon)

4400 Series

Vibrating Wire Displacement Transducers

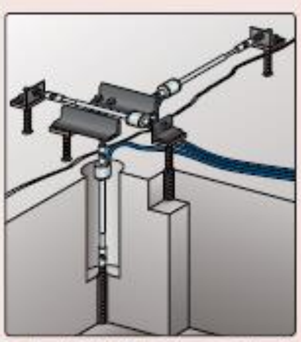
Applications

The 4400 Series are designed to measure or monitor the...

- **Expansion or contraction of a joint**
- **Strains in tendons and steel cables**
- **Movement across surface cracks and joints**
- **Closures in underground excavations, tunnels, etc.**
- **Displacements associated with landslides**
- **Movement of boulders, snow, etc. on unstable slopes**

• *Model 4410 Strandmeter (front), Model 4400 Embedment Jointmeter (center) and Model 4420 Crackmeter (rear).*

• *Model 4420 Crackmeter installation.*



• *Three Model 4420 Crackmeters configured as a single 3-D Crackmeter.*

Operating Principle

Geokon vibrating wire displacement transducers are designed to measure displacements across joints and cracks in concrete, rock, soil and structural members.

In essence, the transducer consists of a vibrating wire in series with a tension spring. Displacements are accommodated by a stretching of the tension spring, which produces a commensurate increase in wire tension.

The wire and spring are connected to a free-sliding rod which protrudes from, and is free to slide inside, a protective outer tube. An o-ring seal prevents water from entering.

The frequency signal is transmitted through the cable to the readout location, conditioned, and displayed on portable readouts or dataloggers.

Advantages and Limitations

The 4400 Series Displacement Transducers are fabricated entirely from stainless steel and are waterproof to 1.75 MPa, which, coupled with their excellent long-term stability, guarantees reliability and performance in even the harshest environments.

An advantage of vibrating wire displacement transducers over more conventional linear potentiometers (or LVDT's) lies mainly in the use of a frequency, rather than a voltage, as the output signal. Frequencies may be transmitted over long lengths of electrical cable without appreciable degradation caused by variations in cable resistance or leakage to ground. This allows for a readout location that may be over a thousand meters from the transducer.

Thermistors are provided with all transducers for temperature measurement.

Model 4400 Embedment Jointmeter

• *Model 4400 Embedment Jointmeter shown with socket removed.*

The Model 4400 is designed for use in construction joints; e.g. between lifts in concrete dams. In use, a socket is placed in the first lift of concrete and, when the forms are removed, a protective plug is pulled from the socket. The gage is then screwed into the socket, extended slightly and then concreted into the next lift. Any opening of the joint is then measured by the gage which is firmly anchored in each lift. The sensing gage itself, is smaller than the protective housing, and a degree of shearing motion is allowed for by the use of ball-joint connections on the gage.

A tripolar plasma surge arrestor is located inside the housing and provides protection from electrical transients such as those that may be induced by lightning.

Model 4410 Strandmeter

• *Model 4410 Strandmeter.*

The Model 4410 Strandmeter is designed to measure strains in tendons and steel cables, including bridge tendons, cable stays, ground anchors, tiebacks, etc. Two clamps at each end of the strandmeter hold it firmly onto the cable. Various size clamps are available.

Model 4420 Crackmeter

• *Model 4420 Crackmeter.*

The Model 4420 Crackmeters are designed to measure movement across joints such as construction joints in buildings, bridges, pipelines, dams, etc.; tension cracks and joints in rock and concrete.

The ends of the sensor are attached to anchors (with ball joints) that have been grouted, bolted, welded or bonded on opposite sides of the crack or fissure to be monitored. 3-D mounting brackets, which allow measurement of displacements in three orthogonal directions, and special clamps for attachment to a variety of earth reinforcements and geogrids, are also available.

Special versions are offered for underwater use, where water pressures exceed 1.7 MPa, and for use in cryogenic or elevated temperature regimes.

Model 4422 Micro Crackmeter

• *Model 4422 Micro Crackmeter.*

The Model 4422 is a miniature crackmeter intended to measure displacements across surface cracks and joints. It has been specially designed for applications where access is limited and/or where monitoring instrumentation is to be as unobtrusive as possible (e.g. on historical structures or buildings).

Model 4425 Convergence Meter

• *Model 4425 Convergence Meter.*

The Model 4425 Convergence Meter is designed to detect deformation in tunnels and underground caverns by measuring the contraction (or elongation) between 2 anchor points fixed in the walls of the tunnel or cavern.

The Model 4425 consists of a spring-tensioned vibrating wire transducer assembly, turnbuckle, 6 mm diameter connecting rods (stainless steel, fiberglass or graphite), rod clamp, and a pair of anchor points. Changes in distance between the 2 anchors are conveyed by the connecting rods and measured by the transducer.

The Model 4425 can operate in horizontal, inclined or vertical orientations. In areas where construction traffic is expected or where the instrument may be left in an exposed location, some form of protective housing should be considered.

Model 4427 Long-Range Displacement Meter

• *Model 4427 Long-Range Displacement Meter.*

The Model 4427 Long-Range Displacement Meter is ideally suited for the measurement of large displacements associated with landslides. The Model 4427 can also be used for monitoring the movement of boulders, snow, etc., on unstable slopes.

The Model 4427 consists of a vibrating wire displacement transducer coupled to a spring motor drive by means of a lead screw. As the cable is pulled, the motor drum rotates and advances the lead screw. Thus the rotation is converted into a linear displacement which is measured by the vibrating wire displacement transducer.

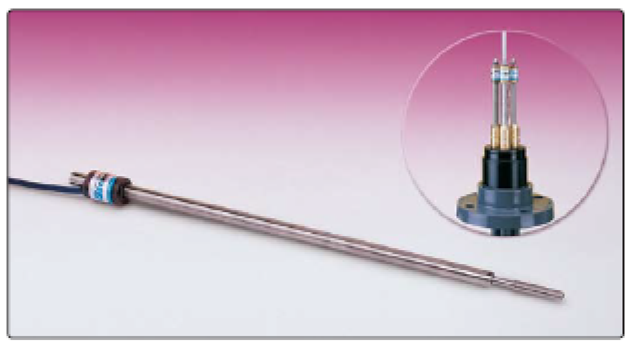
Model 4430 Deformation Meter

• *Model 4430 Deformation Meter.*

The Model 4430 Deformation Meter is designed to measure axial strains or deformations in boreholes in rock, concrete or soil. It can also be embedded in soils in embankments such as earth dams and highway fills. The Model 4430 can be installed in series to give a total deformation profile along a particular axis. Base lengths of the gage can vary from a minimum of 1 meter to over 25 meters.

When used in rock in horizontal or inclined downward boreholes, grouting is the most common method of installation. In vertical boreholes, a special grouting apparatus and hydraulic or snap-ring anchors are required. Direct placement or pre-wiring to a rebar cage allows use in concrete.

Model 4450 Displacement Transducer



• *Model 4450 Displacement Transducer and Extensometer Head Assembly (inset).*

The Model 4450 Displacement Transducer provides remote readout capability for Borehole Extensometers (see the Geokon Model A-3, A-4, A-5, A-6 Rod-Type Borehole Extensometers data sheet for more information). They are particularly useful where other types of vibrating wire sensors are used and/or for installations where long cable runs are required.

The Model 4450 can also be installed between borehole anchors, in conjunction with the requisite length connecting rod, to provide a permanent, in-place incremental extensometer (contact Geokon for details).

Technical Specifications

Model	Standard Ranges[1]	Resolution	Accuracy	Nonlinearity	Temperature Range[1]	Dimensions
4400 Embedment Jointmeter	12.5, 25, 50, 100 mm	0.025% F.S.	±0.1% F.S.	<0.5% F.S.	−20°C to +80°C	*Length:* 406 mm *Flange Diameter:* 51 mm
4410 Strandmeter	20,000 με	<5 με	±0.1% F.S.	<0.5% F.S.	−20°C to +80°C	*Length:* 203 mm *Clamp Width:* 45 mm
4420 Crackmeter	12.5, 25, 50, 100, 150 mm	0.025% F.S.	±0.1% F.S.	<0.5% F.S.	−20°C to +80°C	*Lengths:* 318, 362, 527 mm *Coil Diameter:* 25 mm
4422 Micro Crackmeter	3 mm (±1.5 mm)	0.001 mm	±0.1% F.S.	<0.5% F.S.	−20°C to +80°C	*Length:* 120 mm *Diameter:* 7.9 mm
4425 Convergence Meter	25, 50, 100, 150 mm	0.025% F.S.	±0.1% F.S.	<0.5% F.S.	−20°C to +80°C	*Transducer Lengths:* 356, 508, 838 mm *Transducer Diameter:* 25 mm
4427 Long-Range Displacement Meter	1, 2 m (without resetting)	0.025% F.S.	±1.0% F.S.	—	−30°C to +60°C	*Enclosure (L × W × H):* 610 × 152 × 152 mm
4430 Deformation Meter	25, 50, 100 mm	0.02% F.S.	±0.1% F.S.	<0.5% F.S.	−20°C to +80°C	*Length:* varies *Flange Diameter:* 50 mm
4450 Displacement Transducer	12.5, 50, 100, 150, 300 mm	0.02% F.S.	±0.1% F.S.	<0.5% F.S.	−20°C to +80°C	*Lengths:* 210, 212, 270, 410 mm *Coil Diameter:* 19 mm

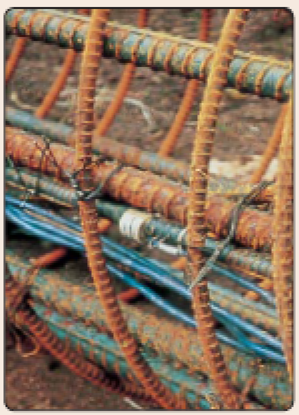
[1] *Other ranges available on request.*

Rebar Strainmeters and "Sister Bars"

Applications

Rebar Strainmeters are commonly used for measuring strains in...

- Concrete piles & caissons
- Slurry walls
- Cast-in-place concrete piles
- Concrete foundation slabs and footings
- Osterberg pile tests
- All concrete structures



• Close-up of Model 4911 shown as installed in concrete pile reinforcing cage.

• Model 4911A Rebar Strainmeter (front) and the Model 4911 "Sister Bar" (rear).

Operating Principle

Rebar Strainmeters and "Sister Bars" are designed to be embedded in concrete for the purpose of measuring concrete strains due to imposed loads. The Rebar Strainmeter is designed to be welded into, and become an integral part of, the existing rebar cage, while the "Sister Bar" is installed by tying it alongside an existing length of rebar in the rebar cage.

The rebar extensions on either side of the central strain-gauged area are long enough to ensure adequate contact with the surrounding concrete so that the measured strains inside the steel are equal to the strains in the surrounding concrete.

In use, Rebar Strainmeters and "Sister Bars" are usually installed in pairs on either side of the neutral axis of the structural member being investigated. This is done so that bending moments may be analyzed in addition to axial loads.

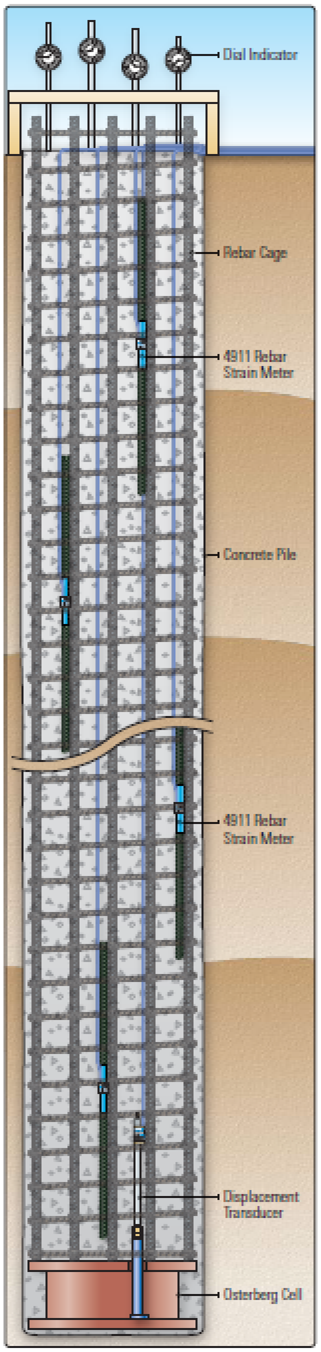
A built-in thermistor enables the measurement of temperatures and aids in the evaluation of thermally induced strains.

Advantages and Limitations

The main advantage of the Rebar Strainmeters and "Sister Bars" lies in their ruggedness. They are fully waterproof and virtually indestructible so that, if the cable is adequately protected, they are safe from damage during the concrete placement.

Each Rebar Strainmeter and "Sister Bar" is individually calibrated and tested for weld strength. The Rebar Strainmeter requires the services of an experienced welder who can guarantee full-strength welds, whereas the "Sister Bar" is very easy to install.

The single vibrating wire strain sensor, located along the axis of the strainmeter, is not affected by the bending of the strainmeter itself. It also has the advantage of all vibrating wire sensors, namely: long-term stability, it can be used with long cables and it's relatively unaffected by moisture intrusion into the cables.



Installation of the Model 4911 in an Osterberg Cell pile test. (For more information regarding Osterberg Cell pile testing, please contact Loadtest, Inc. — www.loadtest.com).

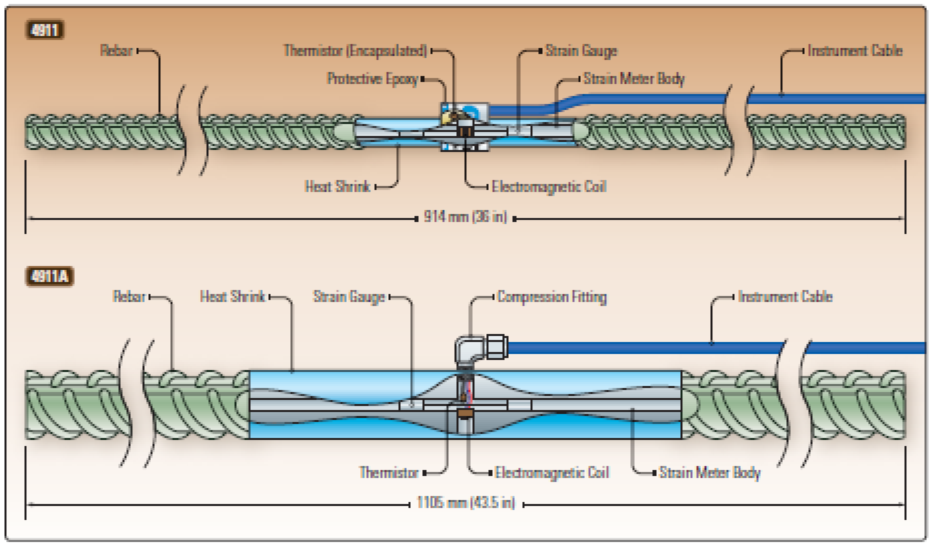


Illustration of the Model 4911 "Sister Bar" and Model 4911A Rebar Strainmeters and their various components.

System Components

A vibrating wire strain gauge sensor is fixed axially inside a short, central length of round steel bar. This central section is de-bonded from the surrounding concrete by means of a plastic coating, and is extended by welding a length of rebar to each end. The Model 4911A Rebar Strainmeter is available in various sizes to match the size of the rebar cage into which it is to be welded, whereas the Model 4911 "Sister Bar" comes in one size only (#4 rebar, at approximately 12.7 mm in diameter).

A thermistor to measure temperature changes can be included in the 4911 and 4911A sensors.

Readouts and Cables

The 4911 Series Rebar Strainmeters are read using the Model GK-404 or GK-405 Readouts. Alternatively, the LC-2 Series or 8600 Series Dataloggers can be used.

The 4911 Series Rebar Strainmeters use the Model 02-250V6 4 pair, 22 AWG cable.

Technical Specifications

	4911	4911A
Standard Range	3000 με	3000 με
Resolution	0.4 με	0.4 με
Accuracy[1]	±0.25% F.S.	±0.25% F.S.
Nonlinearity	< 0.5% F.S.	< 0.5% F.S.
Temperature Range[2]	−20°C to +80°C	−20°C to +80°C
Rebar Sizes	#4 (Sister Bar)	#6, 7, 8, 9, 10, 11, 14
Length	914 mm	1105 mm

[1]*Accuracy established under laboratory conditions.*
[2]*Other ranges available on request.*

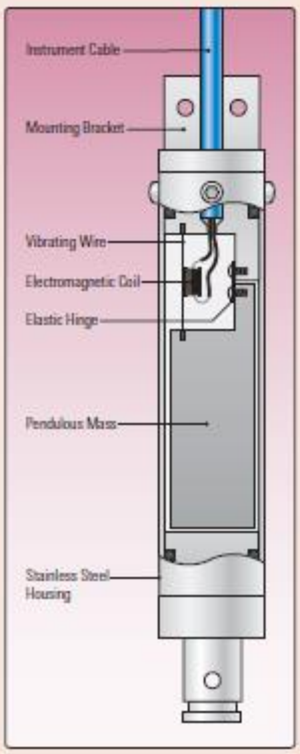
Model 6350

Vibrating Wire Tiltmeter

Applications

The Model 6350 Vibrating Wire Tiltmeter is designed to measure tilt in structures including...

- **Buildings**
- **Dams**
- **Embankments**
- **Slopes**
- **Excavation walls**
- **Open pits**



• *Vibrating wire tilt sensor construction.*

• *Model 6350 Vibrating Wire Tiltmeter shown with mounting bracket assembly.*

Operating Principle

The Model 6350 Tiltmeter is designed for attachment to structures, on either a vertical or horizontal surface by means of an adjustable bracket, and for the subsequent measurement of any tilting that may occur.

When at rest, in a vertical configuration, a pendulous mass inside the sensor, under the force of gravity, attempts to swing beneath the elastic hinge on which it is supported but is restrained by the vibrating wire. As the tilt increases or decreases the mass attempts to rotate beneath the hinge point and the tension in the vibrating wire changes, altering its vibrational frequency. This frequency is measured using the Geokon Model GK-401, GK-403 or GK-404 Readout Box, or the Model 8020 Micro-10 Datalogger, and is then converted into an angular displacement by means of calibration constants supplied with the sensor.

Advantages and Limitations

Vibrating wire tiltmeters combine a high range with high sensitivity, and very high calibration accuracy. They have excellent long-term stability and their temperature dependence is close to zero.

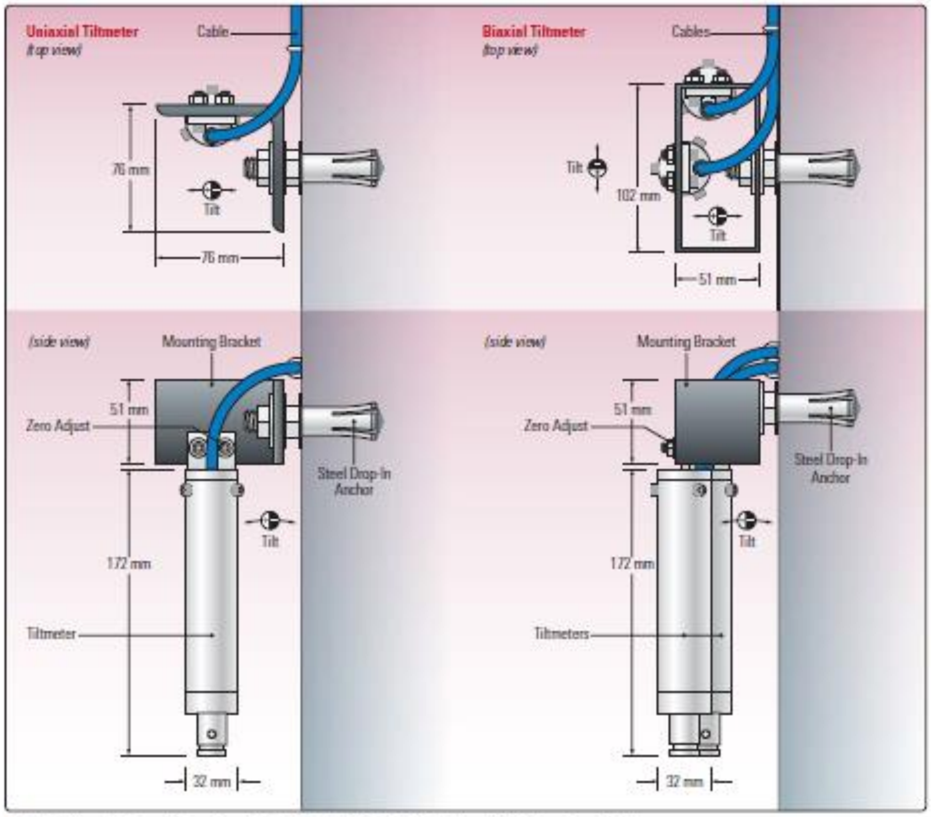
The sensor output is a frequency, which can be transmitted over long cables, and renders the sensors less susceptible to the effects of moisture intrusion.

Biaxial measurements can be achieved by mounting the sensors in pairs, each member oriented at 90 degrees to the other.

Damping fluid may be added to the sensor to counteract the effect of any vibrations of the structure.

In-built shock absorbers protect the sensor from shock loading.

• Model 6350 installation using a custom mounting bracket designed for concrete face rock fill dam applications (shown with protective cover removed).



• Installation details and dimensions for the Model 6350 Uniaxial (left) and Biaxial versions (right).

System Components

The basic transducer is mounted inside a stainless steel housing equipped with a lug for mounting the sensor to an adjustable bracket. The bracket is bolted to the structure using hardware supplied with the sensor, which includes a 3/8-inch drop-in anchor. Special biaxial mounting brackets and protective enclosures are also available.

A thermistor mounted inside the sensor housing permits the measurement of temperatures.

Readout is accomplished using a Geokon Model GK-401, GK-403 or GK-404 Readout Box.

Technical Specifications

Standard Range[1]	±10°
Resolution	±10 arc seconds (±0.05 mm/m)
Accuracy[2]	±0.1% F.S.
Temperature Range	−20°C to +50°C
Shock Survival	50 g
Length × Diameter[3]	139 × 32 mm

[1] Other ranges available on request.
[2] Established under laboratory conditions.
[3] Transducer only.

LC-2 Series Dataloggers

Applications

The LC-2 Series Dataloggers are used to read all GEOKON® vibrating wire instruments. Sensors that can be read and monitored include...

- **Piezometers**
- **Precision water level sensors**
- **Crackmeters**
- **Settlement systems**
- **Temperature sensors**

• *Model 8002-WP-2 (LC-2WP) Waterproof Single-Channel Datalogger.*

• *Model 8002-16-1 (LC-2×16) 16-Channel, Model 8002-4-1 (LC-2×4) 4-Channel and Model 8002-1-1 (LC-2) Single-Channel Dataloggers.*

Operating Principle

The Model 8002 LC-2 Series Dataloggers are designed to read both the vibrating wire element and the integral thermistor of any **GEOKON** vibrating wire sensor.

The LC-2 (internal hard wired transducer connection), LC-2A (10-pin transducer connector option) and LC-2WP (waterproof option) are designed to be standalone, single-channel dataloggers, which makes them especially useful for the remote and continuous monitoring of isolated sensors.

The LC-2×4 is a self-contained, 4-channel version (vibrating wire with thermistor) of the LC-2, and the LC-2×16 is a 16-channel (vibrating wire with thermistor) version.

The LC-2, LC-2×4 and LC-2×16 are housed inside Fiberglass NEMA 4X enclosures, which makes them very robust, weather-proof and particularly well-suited to operation in harsh environments. The LC-2WP is a waterproof version housed inside a rugged PVC enclosure. Low power consumption provides long battery life and the condition of the main batteries is reported as an element in the data array.

Data memory consists of 320K bytes of EEPROM. This translates into a memory storage capacity of 16,000 arrays for the LC-2 and LC-2A, 10,666 arrays for the LC-2×4 and 3,555 arrays for the LC-2×16. Each array consists of the datalogger ID, day (Julian or month/day format), time (HHMM), seconds, main battery voltage, datalogger temperature, vibrating wire sensor reading (in engineering units), the sensor temperature and array number. The array transmission is in comma delineated ASCII text, for easy importation into popular spreadsheet programs.

Up to 6 intervals may be specified from a logarithmic table, with a maximum of 255 iterations. The programmed intervals can be started or stopped once at preset times of the day.

Power

The Model 8002 LC-2 Series Dataloggers are powered by easily accessible alkaline or lithium (optional) D cells. Additional power options, including internal and external 12 V batteries and solar panels, are available (please contact **GEOKON** for more information).

Communications

The Model 8002 LC-2 Series Dataloggers are available with an RS-232 Serial Interface or with a direct USB 2.0 connection; patch cords are supplied for this purpose.

Technical Specifications

	Single-Channel	4-Channel	16-Channel
	LC-2, LC-2A, LC-2WP*	**LC-2x4, LC-2x4A**	**LC-2x16**
Measurement Accuracy	±0.05% F.S. (450–4000 Hz)	±0.05% F.S. (450–4000 Hz)	±0.05% F.S. (450–4000 Hz)
Measurement Resolution	1 part in 20,000	1 part in 20,000	1 part in 20,000
Program Memory	24K FLASH	24K FLASH	24K FLASH
Data Memory	320K EEPROM	320K EEPROM	320K EEPROM
Data Connection	RS-232, USB or RS-485	RS-232, USB or RS-485	RS-232, USB or RS-485
Storage Capacity (Arrays)	16,000[1]	10,666	3,555
Temperature Range	−30°C to +50°C	−30°C to +50°C	−30°C to +50°C
Temperature Measurement	*(accuracy)* 2.0% F.S. *(resolution)* 0.1 °C	*(accuracy)* 2.0% F.S. *(resolution)* 0.1 °C	*(accuracy)* 2.0% F.S. *(resolution)* 0.1 °C
Communication Speed	9600 bps	9600 bps	9600 bps
Communication Parameters	8 data bits, no parity, 1 stop bit	8 data bits, no parity, 1 stop bit	8 data bits, no parity, 1 stop bit
Power Supply	3 VDC (2 Alkaline 'D' cells)	3 VDC (2 Alkaline 'D' cells)	3 VDC (4 Alkaline 'D' cells)
Communication Current	< 100 mA	< 100 mA	< 100 mA
Measurement Current	< 250 mA	< 250 mA	< 250 mA
Quiescent Current	< 500 µA	< 500 µA	< 500 µA
Scan Interval	3 - 86,400 seconds (24 hours)	10 - 86,400 seconds (24 hours)	30 - 86,400 seconds (24 hours)
Operating Time (20°C)	3 days - 3 years, depending on scan interval	8 days - 2 years, depending on scan interval	8 days - 2 years, depending on scan interval
Sensor Connection	*(LC-2, LC-2WP*)* Hard wired *(LC-2A)* 10-pin Connector	*(LC-2×4)* Hard wired *(LC-2×4A)* 10-pin Connector	*(LC-2×16)* Hard wired *(LC-2×16A)* 10-pin Connector
L × W × H H × Ø	*(LC-2, LC-2A)* 122 × 120 × 91 mm *(LC-2WP*)* 211 × 168 mm	260 × 160 × 91 mm	342 × 301 × 160 mm[2]

[1] 8,000 arrays when used with LogWare software. [2] Does not include mounting feet.

Ordering Information

	Single-Channel	4-Channel	16-Channel
Data Connection	**LC-2, LC-2A, LC-2WP***	**LC-2x4**	**LC-2x16**
RS-232	8002-1-1, 8002-1A-1	8002-4-1, 8002-4A-1	8002-16-1, 8002-16A-1
USB	8002-1-2, 8002-1A-2, 8002-WP-2*	8002-4-2, 8002-4A-2	8002-16-2, 8002-16A-2
RS-485	8002-1-3, 8002-1A-3	8002-4-3	8002-16-3

Software

LogView Software simplifies the task of configuration, communication, monitoring, data collection and data reduction using the Model 8002 (LC-2) Series Dataloggers.

LogView is compatible with **Windows®** 2000, XP, XP Pro, Vista and 7.

Please see the Model 8001-3 LogView Software data sheet for more information.

PLEASE NOTE: THE MODEL 8002-WP-2 (LC-2WP) WATERPROOF SINGLE-CHANNEL DATALOGGER IS NOT CE APPROVED.

Instrumentation Cables

Applications

GEOKON® cables are of the highest quality materials and construction. They are designed to be matched with the appropriate instrument for a variety of geotechnical and hydrological applications. Standard and specialized cables are available for…

- **Typical applications**
- **High temperature environments**
- **Extra abrasion resistance**
- **Heavy duty use**

*The Model 4500HT High Temperature Piezometer depicts a **Teflon®** cable threaded inside stainless steel tubing.*

Standard GEOKON cables.

Cable Design

GEOKON cables are made from individual stranded copper conductors encased in an insulation material. Individual, insulated conductors are twisted into pairs, bundled inside a conductive Mylar-type shielding material and then covered by an outer jacket made from the most suitable material. In addition, cables may be water blocked, armored, or may contain steel or **Kevlar®** cables for additional strength, or plastic tubes for circulation fluids, or for venting to atmosphere.

Cable Conductors

In general, the number of conductors in a cable is determined by the number of sensors to be connected to the cable, and the number of conductors required by each sensor.

The type of conductor normally used is stranded, 22 AWG tinned copper. Stranded conductors are more flexible than solid conductors, which makes the cable easier to handle during installation.

Cable Shielding and Insulation

Shielding provides protection from electromagnetic radiation coming from nearby electrical equipment, lightning strikes and fields surrounding power lines, transformers, etc. **GEOKON** multi-conductor cables are individually shielded and twisted in pairs, which helps minimize common mode interference. Drain wires connected electrically to Mylar-type shields provide a simple means of connecting all the shields to a common ground. For applications with very high levels of EMI, such as in pumping wells, a special cable with a braided shield can be provided.

Plastic insulation is typically used on the individual copper conductors. Polyethylene or polypropylene insulation is used at normal temperatures and **Teflon** is most often used for high temperature.

Outer Jackets

GEOKON cable jackets are thicker than regular commercial types, and pressure extruded, which produces cables that are rounder, firmer and easier to grip and seal at the point of entry on the sensor. A wide variety of outer jacket materials is available depending on the end use:

Neoprene: A synthetic rubber compound commonly used for outdoor applications, with good resistance to gasoline, oils etc. Ordinary rubber should never be used.

PVC: A common choice for its good electrical properties and for being waterproof. It should not be used at low temperatures where it becomes brittle.

Polyurethane: This material is very resistant to cuts and abrasions making it useful for cables that are subject to repeated rough handling. It is not as water resistant as PVC but has better low temperature capabilities.

High Density Polyethylene: An excellent material that is highly resistant to environmental attack and exhibits excellent low temperature characteristics. Unfortunately, like **Teflon**, the material is so slippery that splicing and potting compounds will not stick to it.

Teflon: This material is essential wherever sensors and cables are subject to high temperature. It has outstanding resistance to environmental attack and has excellent low temperature properties. However, splicing and potting compounds will not adhere to it.

Other compounds such as **Kevlar** or **Kapton**® etc. may be required where there is a need for low smoke emissions, flame retardant, or resistance to nuclear radiation.

Armor

Armored cables are most often needed for sensors installed in earth embankments or landfills where large forces are exerted on the cable by compaction equipment and earth moving vehicles, and by settlement, "weaving," and sideways spreading of the embankment as it is built. Armored cables should not be connected directly to strain gauges or crackmeters because the stiffness of the cable would pull on the gauge and alter the readings. Armored cable is not necessary in concrete. The armor usually takes the form of a helically laid layer of steel wire. In very severe situations, regular cable may be put inside stainless steel tubing.

Vented Cables

Special cables are available which contain plastic tubes inside of them as well as the usual conductors. These tubes can be used to transport air or other fluids. This kind of cable is required for vented piezometers, where a single vent tube allows the inside of the pressure sensor to be connected to the ambient atmosphere to provide automatic barometric compensation.

Cable Splices

Cable splicing is best done using commercially available splicing kits containing butt splice connectors and epoxy potting compounds. These help provide a waterproof and mechanically strong splice. Armored cables are difficult to splice if the mechanical strength is to be maintained; special mechanical connections need to be fabricated which will grip the armor firmly.

Technical Specifications

Model	Conductors	Conductor Insulation	Drain Wire	Cable Jacket[1]	Nominal O.D.	Temp. Range
02-187P6	4-conductor, 2 twisted pairs, 22 AWG 7/30	8 mil HDPP	24 AWG	Blue PU	4.75 mm (±0.25 mm)	−20 °C to +80 °C
02-187V3	4-conductor, 2 twisted pairs, 22 AWG 7/30	8 mil HDPP	24 AWG	Red PVC	4.75 mm (±0.25 mm)	−20 °C to +80 °C
02-250P4	4-conductor, 2 twisted pairs, 22 AWG 7/30	8 mil HDPP	24 AWG	Green PU	6.35 mm (±0.25 mm)	−20 °C to +80 °C
02-250T	4-conductor, 2 twisted pairs, 22 AWG 19/34	10 mil FEP	24 AWG	White **Teflon** with aluminum polyester foil shielding	5.20 mm (±0.25 mm)	−80 °C to +200 °C
02-250V6	4-conductor, 2 twisted pairs, 22 AWG 7/30	10 mil HDPP	24 AWG	Blue PVC	6.35 mm (±0.25 mm)	−20 °C to +80 °C
02-313PI	4-conductor, 2 twisted pairs, 22 AWG 7/30	10 mil HDPP	24 AWG	Black PU with integral stranded steel wire	7.95 mm (±0.38 mm)	−20 °C to +80 °C
02-335VT8	4-conductor, 2 twisted pairs, 24 AWG 7/32	10 mil HDPP	24 AWG	Yellow PU with integral 0.125" Ø PE vent tube	8.50 mm (±0.38 mm)	−20 °C to +80 °C
02-500PE1A	4-conductor, 2 twisted pairs, 22 AWG 7/30	10 mil HDPP	24 AWG	Black PVC inner; Black MDPE outer, with served armor	12.70 mm (±0.38 mm)	−20 °C to +80 °C
03-250V0	6-conductor, 3 twisted pairs, 24 AWG 7/32	10 mil HDPP	24 AWG	Black PVC	6.35 mm (±0.38 mm)	−20 °C to +80 °C
04-375V9	8-conductor, 4 twisted pairs, 22 AWG 7/30	10 mil HDPP	22 AWG	Violet PVC	9.50 mm (±0.38 mm)	−20 °C to +80 °C
04-500VT10	8-conductor, 4 twisted pairs, 22 AWG 7/30	10 mil HDPP	22 AWG	Gray PVC with integral 0.125" Ø PE vent tube	12.70 mm (±0.38 mm)	−20 °C to +80 °C
05-375V12	10-conductor, 5 twisted pairs, 22 AWG 7/30	10 mil HDPP	22 AWG	Tan PVC	9.50 mm (±0.38 mm)	−20 °C to +80 °C
06-312V0	12-conductor, 6 twisted pairs, 24 AWG 7/32	10 mil HDPP	24 AWG	Black PVC	7.95 mm (±0.38 mm)	−20 °C to +80 °C
06-500V7	12-conductor, 6 twisted pairs, 22 AWG 7/30	10 mil HDPP	22 AWG	Orange PVC	12.70 mm (±0.38 mm)	−20 °C to +80 °C
12-625V5	24-conductor, 12 twisted pairs, 22 AWG 7/30	10 mil HDPP	22 AWG	Brown PVC	15.90 mm (±0.38 mm)	−20 °C to +80 °C

[1]All outer cable jackets are pressure extruded. In addition, other cable jackets are available for special applications.
*FEP = Fluorinated Ethylene Propylene (**Teflon**) | HDPP = High Density Polypropylene | MDPE = Medium Density Polyethylene | PE = Polyethylene | PP = Polypropylene | PU = Polyurethane | PVC = Polyvinylchloride*

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