

5.2 BDI STRAIN TRANSDUCER- ST350



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5.2.1 WARRANTY INFORMATION

Bridge Diagnostics, Inc. warrants its products to be free from defects in materials and workmanship under normal use and service for thirty-six (36) months from date of shipment. This warranty shall be void if any products have been subjected to modification, misuse, neglect, accidents of nature, or shipping damage. Batteries have no warranty.

All equipment manufactured by Bridge Diagnostics, Inc. is intended for use by a qualified professional only. Under this warranty Bridge Diagnostics, Inc.'s obligation is limited to repairing or replacing (at Bridge Diagnostics, Inc.'s option) of defective products. In no event shall Bridge Diagnostics, Inc. be liable for punitive, exemplary, special, indirect, incidental, or consequential damages and the customer shall assume all costs of removing, reinstalling, and shipping of defective products. EXCEPT AS STATED HEREIN, BRIDGE DIAGNOSTICS, INC. MAKES NO WARRANTIES, EXPRESSED OR IMPLIED, AND SPECIFICALLY DISCLAIMS ANY IMPLIED WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE OR MERCHANTABILITY.

Before returning any product, Bridge Diagnostics, Inc. technical support must be contacted at 303-494-3230 or stssupport@bridgetest.com. A technician will help determine the nature of the problem and if the problem cannot be resolved authorization will be given to return the item. A return record will be provided to be filled out and shipped with the defective equipment. Bridge Diagnostics, Inc. will not accept shipment of any product without prior authorization as provided herein. Ship all defective equipment to:

Bridge Diagnostics, Inc.
Attn: Technical Support
1965 57th Court North
Suite 106
Boulder, CO 80301-2826

Bridge Diagnostics, Inc. has taken every precaution to ensure accuracy of its manuals, documentation, and software. Bridge Diagnostics, Inc. assumes no responsibility for any errors or omissions that may appear in any manual, documentation or software and in no event shall Bridge Diagnostics be liable for any damages or losses that result from the use of its products in accordance with any manuals, documentation or software.

5.2.2 TYPICAL APPLICATIONS

This transducer is typically used for dynamic or event driven stress in structural members such as bridges or buildings. The ST350 Strain Transducers have been designed for recording Live Load strains only. Hence it is assumed that there will be little to no temperature change during any short time-span testing sequence.

When a transducer is attached to a structure, it is forced to have the same deformation as the structure. However, if a temperature increase (or decrease) occurs, and since the ends of the sensor are "anchored", the transducer will expand between the end blocks and register compression. The same goes for a drop in temperature which will register tension. If the sensor is to be mounted on the structure for a long period of time, it will need to have its "zero" reset periodically as it drifts around with temperature changes.

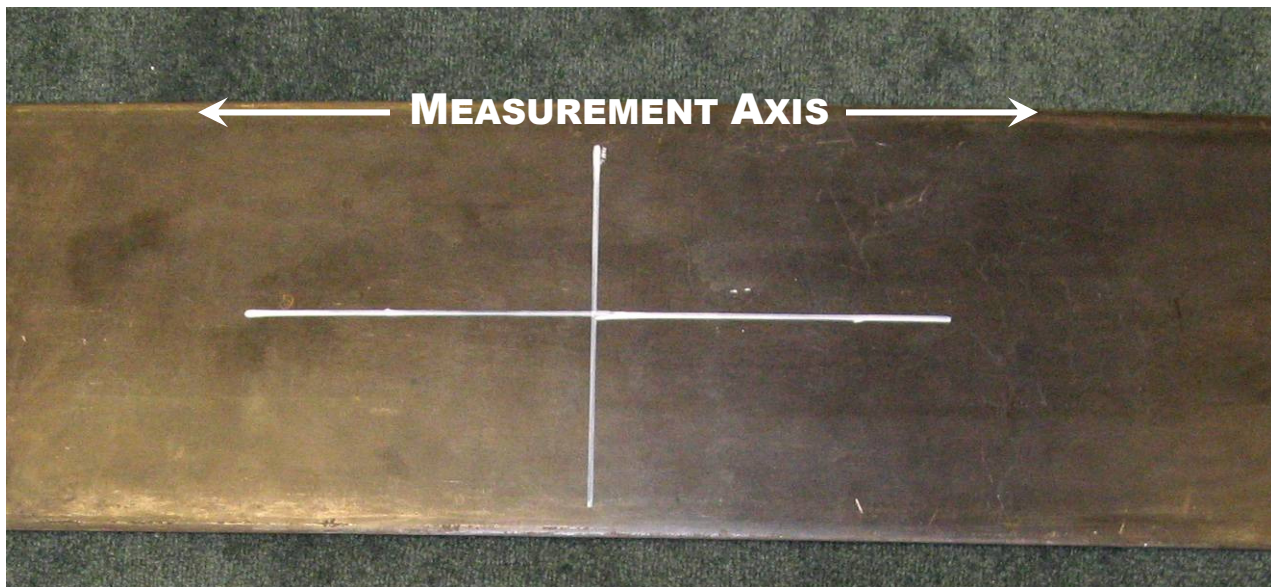
5.2.3 SPECIFICATIONS

Effective gage length:	3.0 in (76.2 mm). Extensions available for use on R/C structures.
Overall Size:	4.375 in x 1.25 in x 0.5 in (111 mm x 32 mm x 13 mm).
Cable Length:	10 ft (3 m) standard, any length available.
Material:	Aluminum
Circuit:	Full wheatstone bridge with four active 350 W foil gages, 4-wire hookup.
Accuracy:	±2%, reading individually calibrated to NIST standards.
Strain Range:	Approximately ±2000 ue.
Force req'd for 1000 µε:	Approximately 17 lbs. (76 N).
Sensitivity:	Approximately 500 ue/mV/V.
Weight:	Approximately 3 oz. (85 g).
Environmental:	Built-in protective cover, also water resistant.
Temperature Range:	-58°F to 185°F (-50°C to 85°C) operation range.
Cable:	BDI RC-187: 22 gage, two individually-shielded pairs w/drain.
Options:	Fully waterproofed, Heavy-duty cable, Special quick-lock connector (available upon request).
Attachment Methods:	C-clamps, threaded mounting tabs & quick-setting adhesive, wood screws, or concrete anchors.

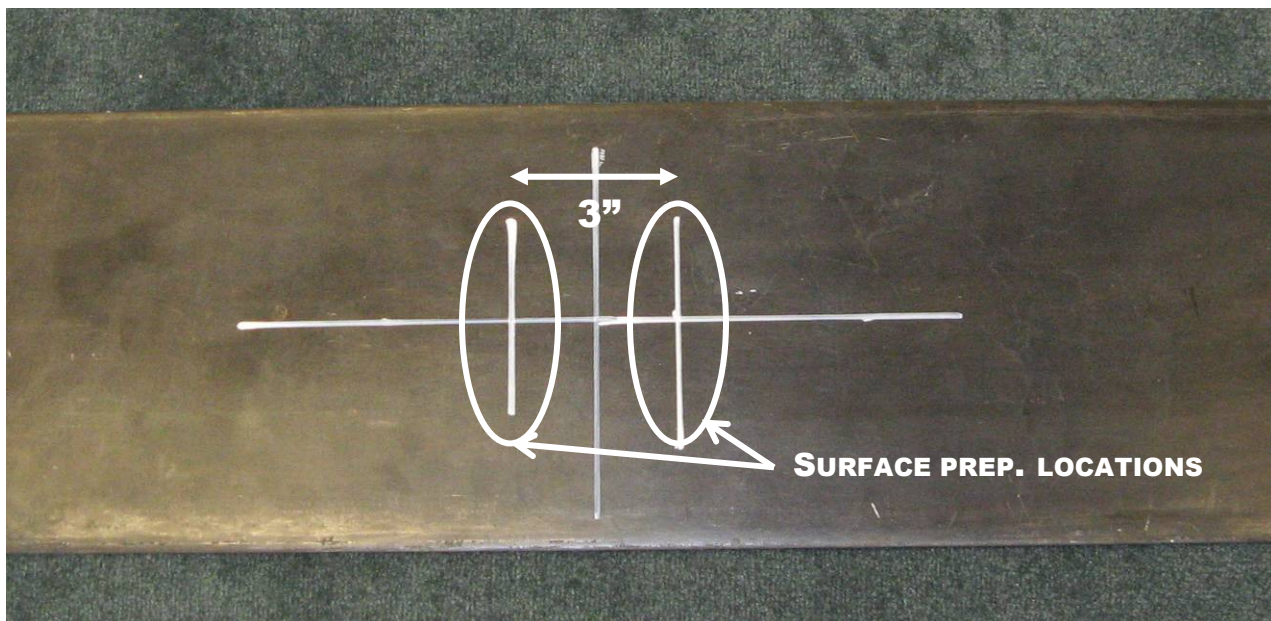
5.2.4 SENSOR ALIGNMENT AND INSTALLATION

5.2.4.1 ALIGNMENT

The BDI ST350 will only measure strain in the axis in which it is aligned with, therefore the more accurate the alignment, the more accurate the measurements will be. The easiest way to align a transducer is to mark a "grid" type pattern for both the proper foot placement and measurement axis. First, locate the center-line of the gaging area in both the longitudinal and transverse directions. For example, if measurements are to be obtained at the mid-span of a joist, locate the midpoint between the supports and the center-line of the joist. The longitudinal mark should be about 8 inches long and the transverse mark about 4 inches long. This will allow the marks to be seen while the transducer is being positioned. This can be seen in the picture below.



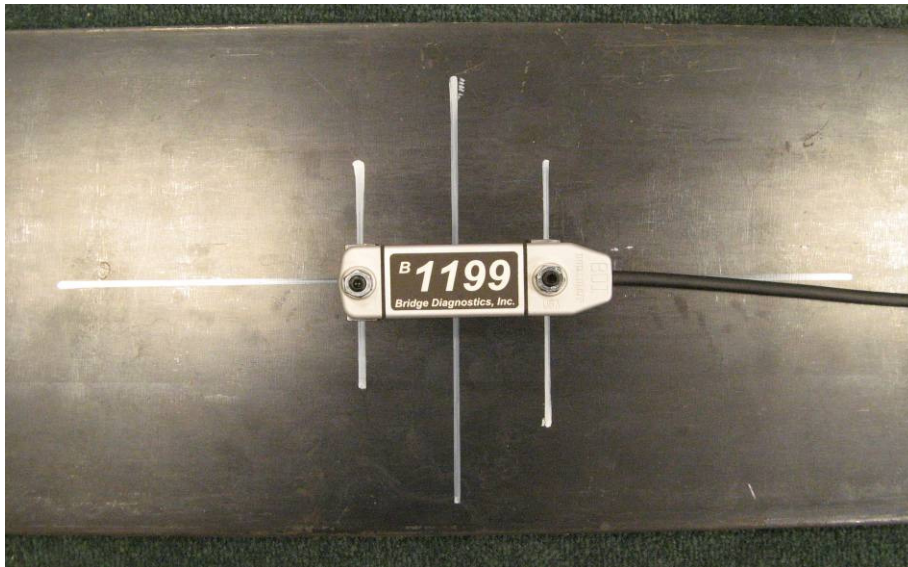
From the transverse mark, make two additional marks at 1.5 inches on either side of the centering mark (see below photo). The areas circled below are the portions of the cross-section that the necessary surface preparations must be performed. Surface preparation techniques are explained in Section 5.2.7.



5.2.4.2 INSTALLATION

Once surface preparation is complete, the transducer can be installed using the selected mounting technique (see Sections 5- Mounting of Sensors to Various Surfaces). The two marks 1.5 inches from the center-line are used to locate the transducer longitudinally; align these marks with the center of the transducer feet. Notice that the front of the transducer (end opposite of the cable) as been machined to a slight point. This point, along with the cable exit on the rear of the transducer, should be aligned with the measurement axis line to ensure that strain is being measured parallel to the measurement axis. An installed transducer can be seen in the picture below. Note that if an R/C extension is used, the longitudinal mark will need to be 30 inches long

in order to be seen behind the transducer/ extension combination. It is important that this line is drawn carefully as the strains are inherently more susceptible to error due to misalignment as the gage length increases.



5.2.5 ADJUSTING EXCESSIVE TRANSDUCER OFFSET

If it is determined that zeroing cannot be accomplished with the Wheatstone Bridge circuit, then it is possible that the transducer has either been damaged or deformed slightly. In many cases the deformation is caused by a thermal change in the gage due to weather changes, such as location of the sun. In this case, the offset can be adjusted by simply loosening one nut and allowing it to return to a “zero-stress” state. Once the nut is loose, rebalance the bridge and ensure the gage can be zeroed. Retighten the nut and again, rebalance and ensure the gage is zeroed. If the transducer still cannot be zeroed, ensure that the mounting surface is flat. In many mounting situations, especially on timber and aged concrete, additional surface preparation will need to be performed to obtain a flat mounting surface. If it has been determined neither of the above are causing the excessive offset proceed with the following steps:

1. Determine which direction the offset is in.
2. If the gage is too far in compression, loosen the free end of the gage (the end opposite of where the cable exits).

NOTE

Sensor is in compliance if offset is within \pm mV/V excitation (approximately 1000 microstrain).

3. Pull on this end of the transducer gently and re-tighten the nut or C-clamp.
4. If enough force cannot be applied with the gage attached to the structure, remove the gage and pull it from both ends. Hopefully, while watching the gage in “Monitor” mode, the gage will come closer to zero.
5. If the offset is in the opposite direction (i.e. too far offset in tension) perform steps two through four, except push on the transducer rather than pull.

If this initial offset cannot be removed, please return the transducer to BDI for evaluation.

Remember!

The transducers are high-quality, precision sensors and are therefore quite sensitive, so be very careful while handling them!

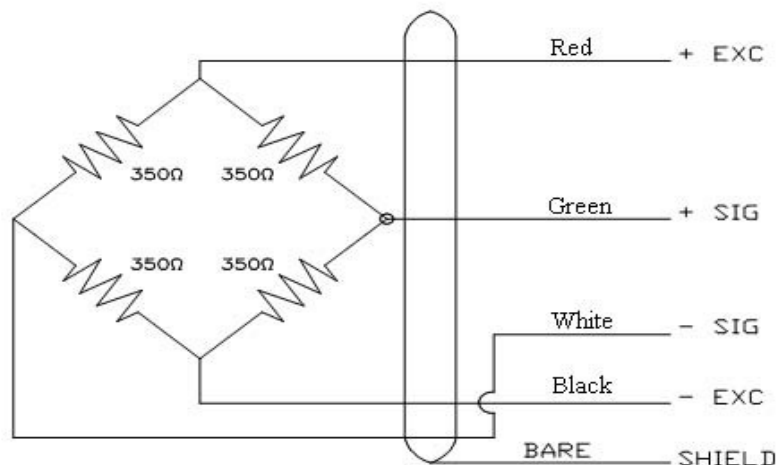
5.2.6 WIRING

This section outlines the wiring of a ST350 Strain Transducer. Generally when using the Strain Transducers with the STS-WiFi equipment you will not have to worry about wiring the sensor since it is pre-wired with the intelligent plug.

5.2.6.1 INITIAL CHECK-OUT

Upon receiving new transducers, it is important to check that they are in proper working order. Using an ohmmeter, read the resistances between the black and red wires and then the green and white wires, both readings should be very close to 350 Ω . If they are not, the unit may be unusable and should be returned to BDI either for repair or replacement. This test should be performed on a periodic basis, especially if the transducer has been dropped or otherwise mishandled.

The ST350 Strain Transducer has four active arms consisting of 350 Ω strain gages. This configuration provides approximately 3 to 3-1/2 times the output of a standard 1/4-arm foil gage installation for a given strain level. The connection sequence is shown in the following figure.



When testing the ST350 Strain Transducer with the intelligent plug the pin out is as follows:

Intelligent Plug Pin	ST350 Wires	ST350 Signal
G	Red	+ Excitation
C	Green	+ Signal
J	White	- Signal
K	Black	- Excitation (Ground)
K	Bare	Shield Wire

Note

Output = V_{diff} is defined as $[(+ Sig) - (- Sig)]$

Therefore, [+ Output = Member in Tension] and [- Output = Member in Compression]

5.2.6.2 EXCITATION VOLTAGE

The recommended excitation voltage is generally between 2.5 and 5 volts DC. The STS-WiFi Nodes provide an excitation of precisely 5.0 volts DC.

Once the transducer has been connected to the data acquisition system, the user should verify output by monitoring the signal in real time while gently placing the transducer in tension and compression by hand. This will ensure that tension provides a positive output signal and compression a negative signal. If a tension force provides a negative signal (and vice-versa), the user should either switch the signal leads or make appropriate adjustments to the signal conditioning.

Please see Section 5.2.11 for information regarding verifying the accuracy of the ST350. There are some very common problems that are encountered when trying to verify the calibration.

5.2.7 MOUNTING ST350 TO VARIOUS SURFACES

5.2.7.1 GENERAL INSTALLATION INFORMATION

In most situations, other than reinforced concrete, the most efficient method of mounting a transducer is using the tab/glue method. This method is the least invasive and is truly a “non-destructive testing” technique. Below is an outline for implementing the glue/tab technique. Tips and alternative mounting techniques for different mounting surfaces can be found in the following sections.

1. Place two tabs in mounting jig (if available, if not simply hold with vice grips). Place transducer over mounts and tighten the 1/4-20 nuts until tight. Be sure that the transducer calibration number is facing up. This procedure allows the tabs to be mounted without putting stress on the transducer itself.
2. Mark the centerline of the transducer location on the structure. Place marks 1-1/2 inch on both sides of the centerline and using a grinder, remove paint or scale from these areas. For steel structures, a power grinder is recommended for the initial cleaning. If available, use a portable grinder (a Makita Model 9500D battery-powered grinder with a 46-grit wheel works very well) to “touch up” the newly-cleaned surface. If attaching to concrete, lightly grind the surface with the portable grinder to remove any scale and remove dust with a shop rag or paint brush.
3. Using the portable grinder, very lightly grind the bottom of the transducer tabs to remove any oxidation and/or other contaminants. Before mounting, set the transducer in the location it is to be attached, and ensure that the tabs seat uniformly on the member and that the transducer doesn’t “rock”. This is important for a good bond.
4. Apply a thin line of adhesive to the bottom of each transducer tab (**Loctite 410 Black Toughened Adhesive, Part # 41045 in 0.7oz containers**) about 1/4” wide. If bonding to concrete, slightly more adhesive is necessary to allow some to flow out and around the tabs. Mount the transducer in the marked location, and then pull it away. This action will apply adhesive to the structural member at the tab locations.
5. Spray each adhesive contact area on the structural member (just one “light shot”) with the adhesive accelerator (**Loctite Tak Pak 7452, Part # 18637 in 0.7oz aerosol spray container**).

Note

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6. Very quickly, mount transducer in its proper location and apply a light force to the top of the tabs (not the center of the transducer) for approximately 15-20 seconds.

If the above steps are followed, it should be possible to mount each transducer in approximately five minutes.

Once testing is complete, **CAREFULLY** loosen the 1/4-20 nuts from the tabs and remove transducer. If one is not careful, the tab will pop loose from the structure (particularly when testing concrete structures) and the transducer may be damaged. Use vice grips to remove the tabs from the structure. If the tabs remain with the transducer during removal, use vice grips to hold the bottom of the tab while loosening the nut. **DO NOT** try to loosen the nut without keeping the tab from twisting as the transducer can be damaged! The tabs can be re-used by soaking them in acetone for 30-40 minutes to remove the hardened adhesive. Be sure to cover the container since the acetone will evaporate quickly and is very flammable!

5.2.7.2 MOUNTING TO STEEL

1. Examples:

Bridges, building components (columns, joists, floor systems, etc), large mechanical equipment (tower cranes, mobile cranes, cooling towers, etc.), liquid tanks, piles.

2. Methods for attaching the ST350 to steel:

- a. Tab/Glue: See above.
- b. C-clamps: Place transducer on specimen surface and tighten a C-clamp over each raised bolt hole.
- c. Threaded stud: Drill 1/4" holes in specimen at correct foot locations, insert proper sized bolt, and tighten nut on each raised bolt hole.

3. Installation method for best measurements: All methods are sufficient

4. Pitfalls to avoid during installation:

If the mounting surface is rough due to pitting or thick paint, smooth the surface using acceptable methods.

If the mounting surface is not flat, a transducer can be installed in some situations. Proceed with caution, ensuring not to distort the transducer as damage may occur.

If the mounting surface is hot to the touch and/or the humidity level is high, the glue may not stick as well as in other conditions. Although the bonding strength is more than sufficient for taking measurements, when loosening the nuts during the removal process, take extra care as the mounting tab may pop off the member and the strain transducer can be bent.

5.2.7.3 MOUNTING TO REINFORCED CONCRETE

Note

See Section 5.2.10 for extension attachment instructions and important information regarding the use of transducer extensions.

1. Examples:

Bridges, buildings components (columns, joists, floor systems, etc.), foundations, piles.

2. Methods for attaching the ST350 Strain Transducer to reinforced concrete:

a. Tab/Glue: See above.

b. Tab/Glue + Threaded Stud (1/4"-20 x 3-1/4" Powers Fasteners Power-Stud or similar).

- i. Locate the gauging point on the structure and make two marks approximately 2 feet apart along the axis of where the transducer/extension assembly is to be mounted. It can sometimes be difficult to align the marks on the bottom of concrete slab structures, particularly if the structure is skewed. Often, a series of marks are laid out on the bottom of the slab and a chalk line is used to lay out a grid, making gage alignment very easy. Another alternative is to use a laser chalk line to temporarily create a line while the gage is installed.
- ii. Temporarily hold the transducer/extension assembly up to where it is to be mounted to ensure that there are no obstructions along the length of the unit. Make small marks at the two mounting points, one for the transducer end and one for the selected gage length on the extension end (6-24inches).
- iii. Using a concrete drill, drill a 1/4" hole at the extension end mark about 1.75" deep. For the tab end, it is possible that the concrete surface will need to be smoothed slightly with a grinder to ensure that the tab is making good contact with the structure. Once smooth, use the edge of the grinder as a cutting wheel and cut two or three grooves at a 45° angle to the direction of gage. Be sure to wipe all grinder dust clear from the location using a rag or paint brush. If possible, use compressed air (available in cans) blow the area clean.
- iv. Place two to three washers on the stud and thread on a bolt about 1/2 of the way down its length. These washers will act as spacers to account for the height of the tab on the transducer end. Slide a 3/8" deep wall socket over the stud and hold it against the nut. Drive the stud into the concrete by pounding on the end of the socket; this will help prevent bending the stud.
- v. Tighten the washers against the concrete by twisting the nut with an open-end wrench. It is important to set the stud before attaching the extension to prevent damaging the gage. Once secure, leave the nut on the bolt to hold the washers in place.
- vi. Apply adhesive to the tab and push unit to mounting location. Pull back tab, leaving a patch of adhesive on the structure.

- vii. Apply accelerator to the adhesive, and quickly put assembly in place. Hold the tab end of the unit in place by hand for several seconds until the adhesive has hardened.
 - viii. While holding the transducer assembly in place, screw a nut on the stud and tighten with an open-end wrench.
- c. Threaded Studs Both Ends (1/4"-20 x 3-1/4" Powers Fasteners Power-Stud or similar).

Note

When using this method it is very important that the drilling of the holes is accurate to + 1/8" in order to align properly with the transducer mounting holes. To help drill holes accurately, a steel drilling guide made for the particular extension length can be fabricated.

- i. Locate the gauging point on the structure and make two marks approximately 2 feet apart along the axis of where the transducer/extension assembly is to be mounted. It can sometimes be difficult to align the marks on the bottom of concrete slab structures, particularly if the structure is skewed. Often, a series of lines are laid out on the bottom of the slab using a chalk line, making gage alignment very easy. Another alternative is to use a laser chalk line to temporarily create a line while the gage is installed.
- ii. Temporarily hold the transducer/extension assembly up to where it is to be mounted to ensure that there are no obstructions along the length of the unit. Make small marks at the two mounting points, one for the transducer end and one for the selected gage length on the extension end (6-24inches).
- iii. Using a concrete drill, drill the first of two 1/4" hole about 1.75" deep.
- iv. Place two to three washers on the stud and thread on a bolt about 1/2 of the way down the stud. Slide a 3/8" deep wall socket over the stud and hold it against the nut. Drive the stud into the concrete by pounding on the end of the socket; this will help prevent bending the stud.
- v. Tighten the washers against the concrete by twisting the nut with an open end wrench. It is important to set the studs before attaching the extension to prevent damaging the gage. Once secure, leave the nut on the bolt to hold the washers in place.
- vi. Slide the drilling jig over the stud and align it with the second hole location.
- vii. Drill the second 1/4" hole and follow the previous steps for securing the second concrete anchor.
- viii. Remove the washers and nut from this stud.
- ix. Slide the transducer end over the stud without washers and the extension end over the one with washers.

- x. While holding the transducer assembly in place, screw nuts on the studs and tighten with an open-end wrench.
3. Installation method for best measurements:

The method of gluing both tabs has been used for many years with very few problems. The main concern is having a clean, dust free surface for the glue to stick to. Occasionally the bottom of a slab may be wet or excessively rough, or the sensors must stay in place for over a couple of days, necessitating the use of mounting studs. Another consideration is if the structure has automobile or other traffic below it, it is always a good idea to use the studs on at least one end.

- a. Using two threaded studs is the most secure way to attach a transducer to an R/C structure, but it is considerably more time-consuming and the accuracy of the marking and hole drilling is significantly more important. If the area is difficult to access, the transducers are going to be installed for an extended period of time, or it is imperative that the measurements be taken at a specific time, using two threaded studs is highly recommended.
 - b. If the transducers are only going to be used for one day tab/glue is likely sufficient. If the transducer is going to be installed for two to four days the tab/glue + threaded stud is likely acceptable, but depends on the climate and concrete condition. In areas of high humidity the concrete tends to have higher moisture content. This moisture builds up behind the glue tab and in some cases can cause the tab to “pop” off.
4. Pitfalls to avoid during installation:
 - a. If the Tab/Glue method is being used, ensure that the area is clean of dust before installing the gage. A can of compressed air or an air compressor is a great way to ensure a dust-free gluing area.
 - b. If two threaded studs are going to be used, a drilling jig should be fabricated to properly locate the hole positions. The transducer does have an oval hole to help compensate for a hole being miss-drilled, but as the gage length increases, the variability in the alignment increases too.
 - c. If the mounting surface is not flat or there are obstructions in the way of the extension, the obstruction may have to be chipped/ground or the mounting surface may need to be flattened with a grinder.
 - d. When a transducer is attached to an extension it is significantly more vulnerable to damage. A five gallon bucket is a good way to transport multiple gages while extensions are installed. Put the extension downward into the bucket and loop the cable over the transducer to help prevent cable tangles.

5.2.7.4 MOUNTING TO PRE-STRESSED/POST-TENSIONED CONCRETE

1. Examples:

Bridges, building components (columns, joists, floor systems, etc), foundations, piles.
2. Methods for attaching ST350:
 - a. Tab/ Glue: See above.

- b. Threaded Studs: 1/4"-20 x 3-1/4" Powers Fasteners Power-Stud or similar
 - i. Locate the installation point on the structure.
 - ii. Using a concrete drill, drill 1/4" holes about 1.00" deep; ensure to not drill into pre-stressing tendons.
 - iii. Place two to three washers on the studs and thread on a bolt about half way down the stud. These washers will act as spacers to account for the height of the tab on the transducer end. Slide a 3/8" deep wall socket over the stud and hold it against the nut. Pound in the stud by hitting the end of the socket; this will help prevent bending the stud.
 - iv. Remove the washers and nut from the stud.
 - v. Slide the transducer end over studs.
 - vi. While holding the transducer assembly in place, screw nuts on the studs and tighten with an end wrench.
3. Installation method for best measurements:

Glue is sufficient for transducers that are only going to be installed for a day or two. If the transducers are going to be left in place for an extended period of time, threaded studs are required.
4. Pitfalls to avoid during installation:
 - a. Know the locations of the pre-stressing strands. Locate the drilled holes between the strands to prevent damage to the strand.
 - b. If the Tab/Glue method is being used ensure that the area is clean of dust before installing the gage. A can of compressed air or an air compressor is a great way to ensure a dust-free gluing area.

5.2.7.5 MOUNTING TO TIMBER

1. Examples:

Bridges, building components (columns, joists, floor systems, etc), piles.
2. Methods for attached ST350:
 - a. Tab/ Glue: See above.
 - b. Use two self-tapping Phillips-head screws:
 - i. Washers are required to ensure that the head of the screw does not sink into the transducer mounting hole.
 - ii. Use a power screwdriver to drive the screw until it is 1/16" from the surface of the transducer then hand-tightened with a standard Phillips screwdriver.
3. Installation method for best measurements:

Self-tapping screw method.
4. Pitfalls to avoid during installation:

- a. In many situations the timber members that the transducers are going to be mounted to are twisted. This surface must be flattened using appropriate techniques to reduce the chance of damage to the transducer.
- b. If the wood has any sort of glue laminated section or chemically treated, it is recommended that pilot holes be drilled.

5.2.8 CALIBRATION AND VALIDATION

Calibration is performed on each sensor prior to shipping and a Calibration Certificate is shipped with each sensor. This certificate certifies that the sensor is traceable to NIST Standards. If this sensor is out of specification it can be sent to BDI for re-calibration.

Note

For quality control purposes, BDI recommends each transducer be re-calibrated on an annual to bi-annual basis depending on the usage and number of times the transducers have been installed on a structure.

Based upon experience, the ST350 transducers should be re-calibrated after every 15-25 installations depending on the care taken during the installation process. The customer is responsible for any cost associated with the removal of the transducer and shipping to BDI. If the part is under warranty, the transducer will be re-calibrated at no further cost to the customer. If the part is out of warranty, it will be repaired and calibrated for a nominal fee.

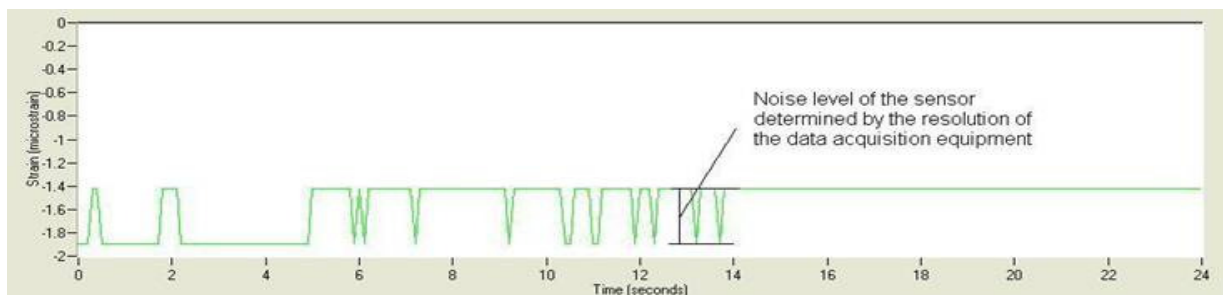
5.2.9 MAINTENANCE, REPLACEMENT PARTS AND REPAIR

5.2.9.1 MAINTENANCE

The ST350 Strain Transducer has been designed to minimize the amount of maintenance required to keep the transducers operational. Before each use it is recommended that every transducer be visually inspected for damage and powered on to ensure it is working properly. This should be done two to three weeks before the testing date in case any repairs are required.

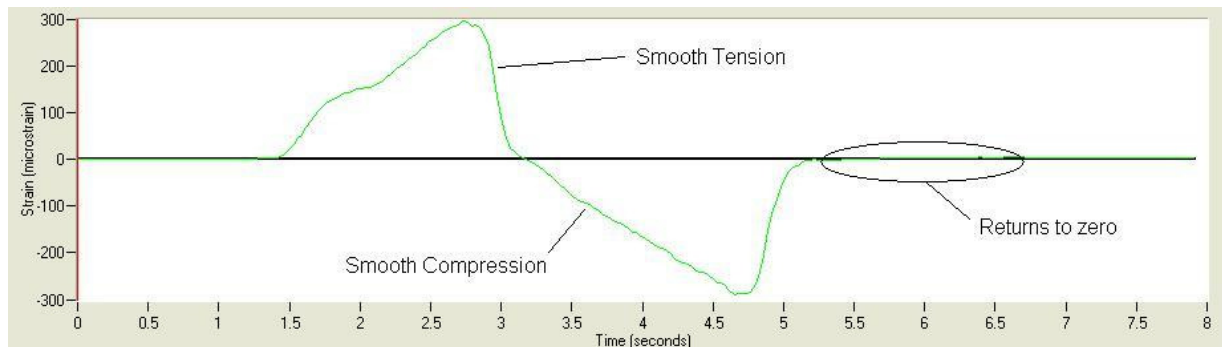
Procedure for verifying ST350 is functioning properly

1. Ensure the Strain Transducer noise is within the specified noise range of the Data Acquisition Equipment. This can be done by running a short test (approximately 15-20 seconds) and allowing the sensors to collect data while not being handled. An example of an output seen for this test can be seen in the figure below.



2. Ensure the Strain Transducer returns a smooth output. Run a test at a sample frequency higher than 30 Hz and apply a smooth tension force (gently pulling one each

end) followed by a smooth compression force (gently pushing each end). The output returned should be a tension spike followed by a compression spike and should not appear “stair-steppy”. An example of this output can be seen below.



3. Using the data from No. 2, ensure the sensor returned to very near zero. In some cases it may not return exactly to zero due to the sensor being heated up from being handled and/or not being placed on the work surface in the same position as it was sitting before being handled. If a significant offset remains after such a test, this can be an indication of possible damage and the unit should be sent back.
4. Also, using the data from No. 2, ensure that the transducer has been connected to the data acquisition system correctly by ensuring that tension was registered as positive and compression as negative.

Debris and glue removal from foam areas between transducer body and lid:

1. This area should be cleared of any debris or glue. The easiest way to remove any sort of obstruction from the foam area is by using a dental pick. Glue can be chipped away and debris, such as sand, can be pulled to the surface and wiped away. Extra care should be taken when removing glue as it is easy to slip and damage the gage or cut your hand.

Note

If the foam is damaged during the cleaning process, it cannot be repaired or replaced!

Debris and glue removal from mounting feet:

1. This area should also be inspected and cleared of any debris and glue. To remove glue from the feet, use the tip of a shop rag wetted with acetone. Wipe the glue until it dissolves. A shop rag with mild soapy water can be used to remove other debris from the mounting feet.

Mounting tab inspection:

1. These tabs have been design to be reusable by simply dissolving the glue with acetone. Acetone can be reused multiple times, but if it becomes too saturated with glue it will start leaving a thin layer of glue in the threads of the mounting tabs. Also, sometimes when the mounting tabs are removed from a structure the top threads can be chipped. If it becomes hard to thread nuts onto the mounting tab stud, run a 1/4-20 tap down the threads to remove the chips and glue from the threaded stud.

As stated in the previous sections, it is recommended each transducer be re-calibrated on an annual to bi-annual basis or every 15-25 installations depending on the care taken during the installation process.

5.2.9.2 REPLACEMENT PARTS

In order to optimize the weather proofing of the transducer, it has been designed to be completely sealed. Due to this design the only replacement part available for the transducer is the cable. For the cable to be replaced, the transducer must have at least a one foot cable exiting the transducer body. This cable can be spliced to a new cable of the proper length.

If a transducer is damaged beyond repair, the transducer will be replaced at a discounted price.

Please contact Bridge Diagnostics, Inc. to obtain authorization for return of the unit.

5.2.10 SPECIAL INSTRUCTIONS FOR UNSING ST350

5.2.10.1 INSTRUCTIONS FOR USING TRANSDUCER EXTENSIONS ON R/C STRUCTURES

Special gage-lengthening extensions have been designed for use with the ST350 Strain Transducers in order to measure surface strains on reinforced concrete (R/C) structures. The aluminum extensions simply increase the transducer gage length to allow an “averaged” strain value to be recorded in the presence of cracks associated with most R/C structures. These units make available seven additional gage lengths, each one an integer multiple of the original 3-inch (76.2mm) transducer gage length.

There are three items to consider when selecting an appropriate gage length for a particular R/C member. The first is that it must be long enough to minimize the effects of flexural cracks. There are several factors that control crack formation in concrete, primarily the beam depth, steel ratio, concrete strength, and bond strength. While there are no precise methods for determining a minimum crack spacing, it has been determined experimentally that a gage length equal to the member depth (d) is satisfactory for slabs and rectangular beams and 1.5 times d is suitable for T-beams. The second item to consider is that the gage length be short enough that the measured strains are not significantly affected by moment gradients. An upper limit of 1/20th the span length (L) will usually maintain the gradient below 5%. In general, it is desired to obtain as long a gage length as possible without exceeding the upper bound. The following table provides the recommended lower and upper gage length limits for R/C members.

Recommended Lower and Upper Gage Limits		
Member Type	Lower Limit	Upper Limit
Slabs and Rectangular Beams	1.0 x d	$L / 20$
T-Beams	1.5 x d	$L / 20$

The third item is the available strain range of the transducer. As the gage length is progressively increased, the force on the transducer imposed by the extension is increased as well for a given amount of strain. This has the effect of reducing the available strain range for the transducer/extension assembly. The upper limit of the strain range recommended for aluminum transducers is approximately $\pm 4000 \mu\epsilon$. However, to minimize the force in the system and to avoid the mounting tabs from popping off the concrete members during loading, BDI recommends keeping the maximum strain in the transducer to about $1,000 \mu\epsilon$. Therefore, the following table has been developed to indicate the maximum strain ranges for each available gage length. Higher strains can of course be measured. However, special attention should be paid to the gain settings on the data acquisition equipment being used. If the load is going to be very heavy, we recommend that the gain level for the STS be set to 500. It should be noted that in most cases, the live-load strain magnitudes recorded by BDI on reinforced concrete structures have been less than $100 \mu\epsilon$.

Maximum Strain Ranges						
Multiple of	Actual Gage Length w/	Maximum Strain Range	Approx. Conc. Stress	Approx. Conc. Stress	Approx. Conc. Stress	Approx. Steel

Original Length	Extension		for $f''_c = 3,000$ psi	for $f''_c = 4,000$ psi	for $f''_c = 5,000$ psi	Re-bar Stress
1	3 in (76.2 mm)	$\pm 1000 \mu\epsilon$.	3.1 ksi	3.6 ksi	4.0 ksi	30 ksi
2	6 in (152.4 mm)	$\pm 500 \mu\epsilon$.	1.6 ksi	1.8 ksi	2.0 ksi	15 ksi
3	9 in (228.6 mm)	$\pm 330 \mu\epsilon$.	1.0 ksi	1.2 ksi	1.3 ksi	9.9 ksi
4	12 in (304.8 mm)	$\pm 250 \mu\epsilon$.	780 psi	900 psi	1.0 ksi	7.5 ksi
5	15 in (381.0 mm)	$\pm 200 \mu\epsilon$.	625 psi	720 psi	800 psi	6.0 ksi
6	18 in (457.2 mm)	$\pm 160 \mu\epsilon$.	500 psi	575 psi	650 psi	4.8 ksi
7	21 in (533.4 mm)	$\pm 140 \mu\epsilon$.	440 psi	500 psi	560 psi	4.2 ksi
8	24 in (609.6 mm)	$\pm 125 \mu\epsilon$.	390 psi	450 psi	500 psi	3.8 ksi

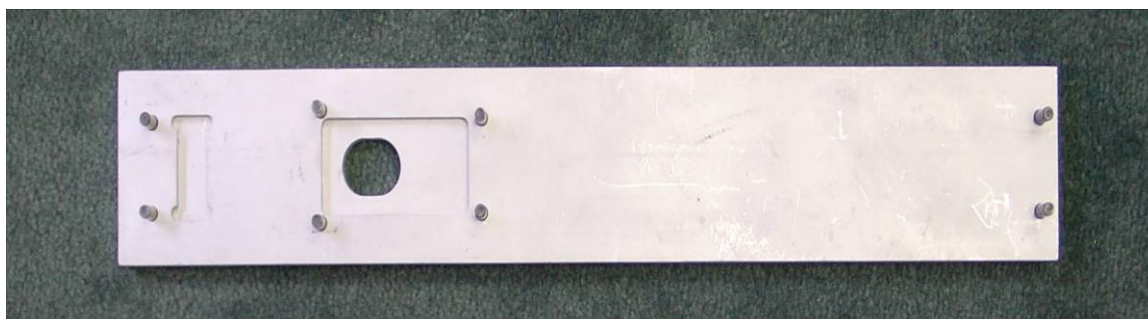
5.2.10.2 ATTACHING THE CONCRETE EXTENSION TO THE ST350

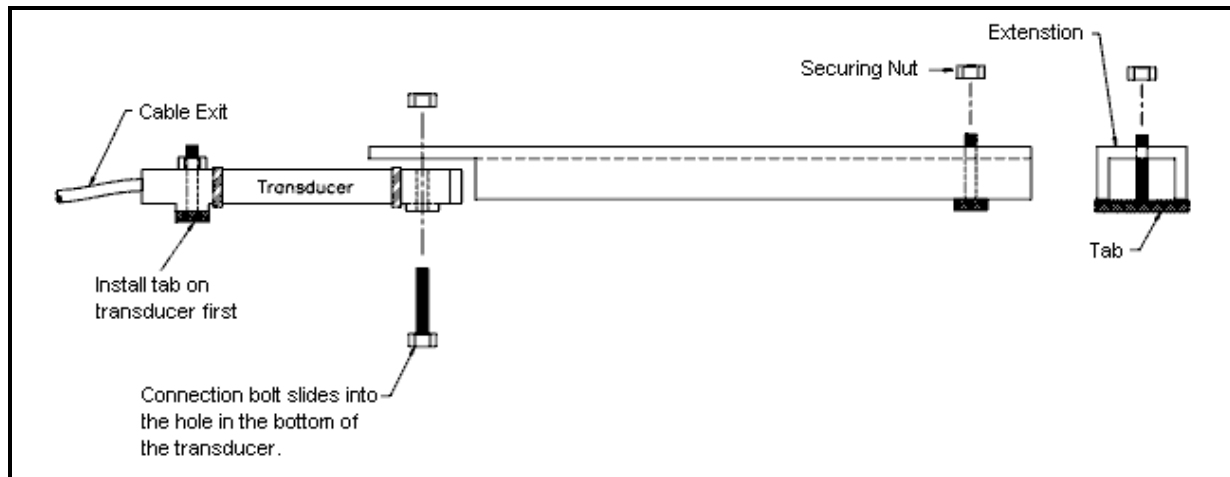
Once a gage length has been determined, there are three possible scenarios for mounting the transducer/extension assemblies to the structure:

1. Adhesive/tabs on both ends. If conditions are dry, the concrete surfaces relatively smooth, and testing will not last more than a day, the tab/adhesive system will usually work fine as described below.
2. Adhesive/tab on transducer end and a masonry anchor on the extension end. This is the preferred method of BDI. Again, if conditions are dry, then the adhesive/tab system on one end will be sufficient for a couple of day's worth of testing, as long as the other end is securely mounted with a mechanical anchor. It is highly recommended to use masonry screws such as 1/4-20 x 3.25" concrete studs or another type of masonry anchor (readily available at most hardware stores) to install transducer/extension assembly due to the additional weight of the extension.
3. Anchor/masonry anchor on both ends. Use this approach only when the structure is wet and/or very rough.

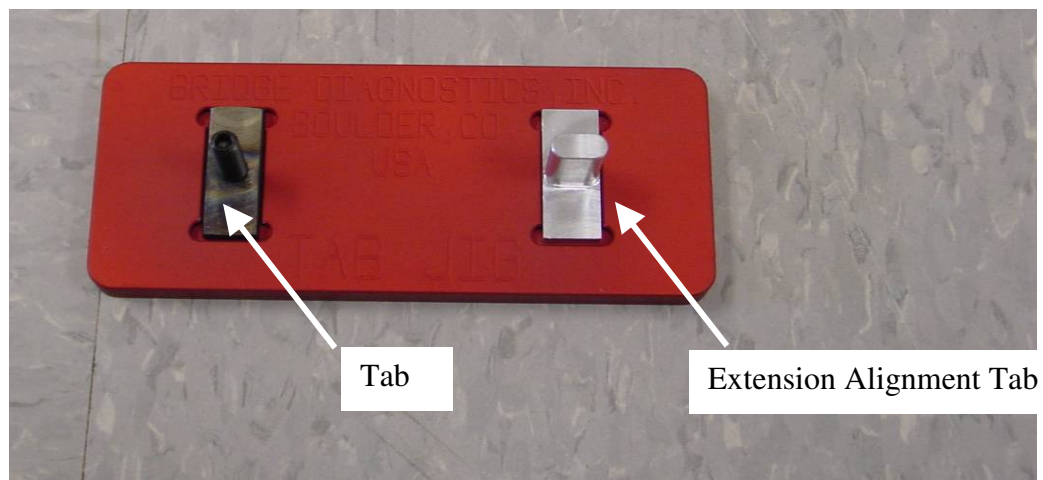
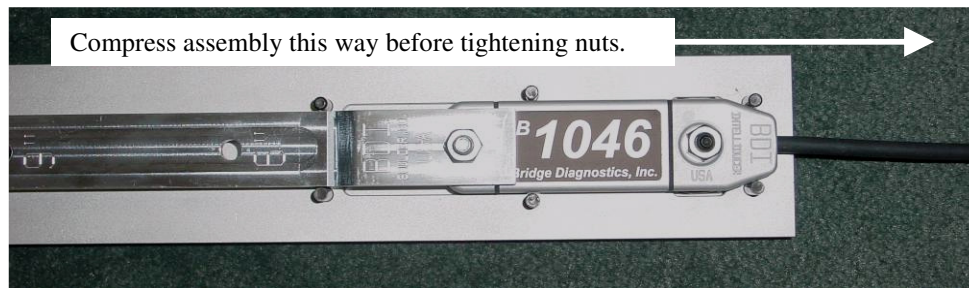
In either of the above scenarios, the steps below should be followed for mounting the extensions to the transducers. The extension jig is used to ensure that the transducer is aligned properly with the extension. If using the anchor mounting on both ends, then omit the mounting tabs described below.

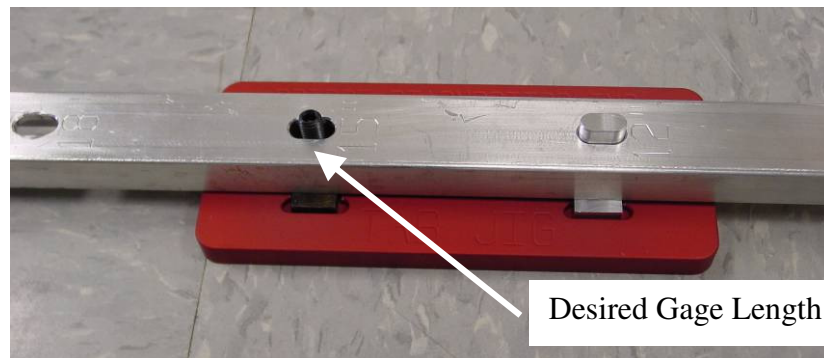
4. Using an extension jig as seen in the picture below, insert a tab into slot. Set the transducer over the tab into the transducer hole closest to the cable exit and *loosely* thread on a nut.





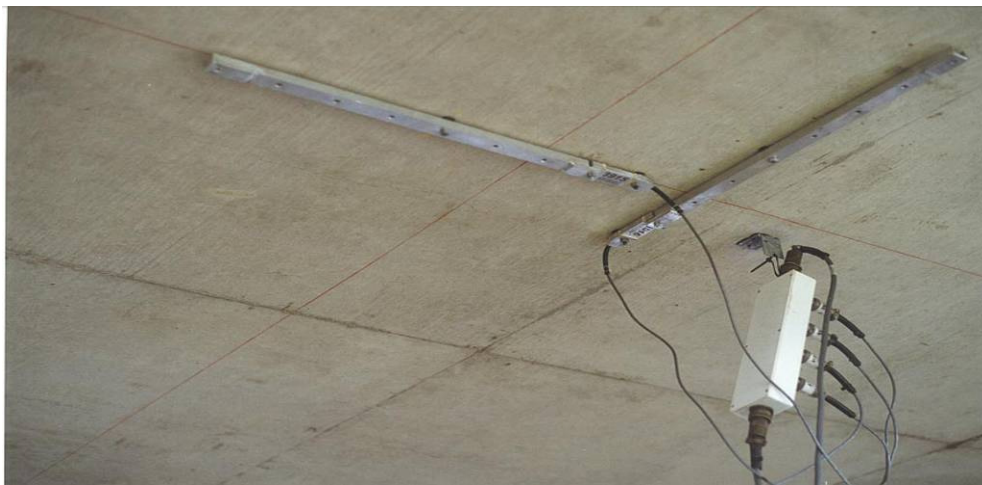
- There is a machined hole in the non-cabled end of the transducer that will capture a standard $\frac{1}{4}$ 20 hex head bolt (see picture below). Simply insert the bolt through the bottom of the transducer and twist until the bolt head drops into the hole. There is a relief cut in the back of the extension to accept the protrusion on top of the gage. This will ensure that the gage is positioned correctly.





Important!

Once the extensions have been installed, the transducers are much more susceptible to damage during handling due to the large extension “lever”. To minimize possible damage, place the transducer/extension assemblies in a plastic five-gallon bucket with the extension ends down. This will allow for many assemblies to be carried at once and still be relatively protected.



It may be noted during testing that there is significantly drift due to ambient temperature changes once the extensions are installed. This is due to the relatively low thermal inertia of the transducer/extension assembly compared to that of the concrete structure. The best solution is to run the tests on a day when the temperature is remaining constant. This is not always possible, therefore, the drift can be minimized, particularly for assemblies that receive direct sunlight (on top of the deck, on the parapet, etc.), by covering the gage and extension with an insulating material. Often, a temporary cover of foam or cloth attached with duct tape can protect them from wind and direct sunlight. Alternatively, BDI can provide custom gage covers that can be mounted temporarily.

After the test has been completed, extreme care must be taken in removing the securing nuts from the tabs, as often tabs will have a tendency to “twist off” at the glue line, particularly if the concrete is slightly rough. Do not attempt to remove the extension from the transducer while the assembly is still mounted to the structure. Also, before the assemblies are removed, double-check that the gage length used for each transducer is recorded. If this is not done, the data will be useless!

Back off the securing nut between the transducer and extension by holding the extension only. If the tabs are still attached to the transducer or extension after removal from the structure, use vice grips to hold the bottom of the tab while the securing nut on top is removed. Again, never use the transducer as a lever!

To reduce the strain data, remember that the recorded strains have been “amplified” by the integer multiple of the gage length. For example, if the longest possible gage length is used (24 in, 58.8cm) this is eight times the standard gage length. Therefore, the data will need to be divided by eight to arrive at the correct “averaged” strain. In addition, a factor of 1.1 will need to be applied to the output to account for the extension effect. The BDI WinGRF Software has a feature to easily handle this operation.

5.2.11 ST350 ACCURACY VERIFICATION

Often, our customers like to verify the accuracy of their new ST350 Strain Transducers, something that we encourage them to do. However, there are several pitfalls that can be made while trying to check these sensors out in the laboratory. Having fielded similar questions from several customers, we have assembled the following explanations to help avoid some of these problems. In almost all of the cases we have seen, the measurements have been proven to be correct, and the assumptions made in the "strain application system" or structural system are either incomplete or incorrect.

Remember that these accurate sensors have been designed to help obtain the structure's overall behavior, rather than at possible stress concentrations like at connections and rivet points. This is because most bridge ratings are controlled by the flexural or shear stresses, rather than localized stresses at a connection. Therefore, it is best to keep the transducers away from stress concentrations or structural non-uniformities. For measuring local strains in tight areas, either a small foil strain gage or an alternative method such as photo-elasticity is required.

5.2.11.1 BACKGROUND

These full-Wheatstone bridge strain transducers were originally developed in about 1970 for use in the driven pile industry. They were designed for recording strains on the side of a pile (steel or concrete) as it was being driven with a pile hammer. This operation applies very high accelerations and requires a very rugged sensor to survive. Over the ensuing years, the transducers have been tested extensively to determine their limitations, often leading to design refinements. Based on the latest design, the Strain Transducers have been modified slightly through the use of a different type of internal strain gage that is better suited for static or "semi-static" structural load testing.

5.2.11.2 FACTORY CALIBRATIONS

These sensors are calibrated by inputting a known excitation voltage and applying a known strain and then recording the output over approximately a 1000 $\mu\epsilon$ range. The manufacturer's calibration that we supply is performed with a **NIST-traceable system** that consists of a small precision slide table and a precision optical displacement sensor. The entire calibration process is always verified by a calibrated precision micrometer. Reproducibility of this system is typically better than one percent and in no case worse than two percent.

In field test applications with linear-elastic structures, we have found repeatedly that we can expect reproducibility of the measurements of approximately $\pm 2.0 \mu\epsilon$. The errors contained in this result included differences in load (truck) placement. Thus, one can expect that every field test can have an error of 2 $\mu\epsilon$. This, of course, is insignificant for quantifying the behavior of a large civil structure.

5.2.11.3 TEMPERATURE EFFECTS

The ST350 Strain Transducers have been designed for recording **Live Load** strains only. Hence it is assumed that there will be little to no temperature change during any short time-span testing sequence. For example, most highway bridge tests (a truck passage at crawl speed) can be completed in less than one minute, usually not enough time for ambient air temperatures to change significantly. If the sensor is to be mounted on the structure for a long period of time, it will need

to have its "zero" reset periodically as it drifts around with temperature changes. The primary reason that these sensors drift with temperature (even a steel transducer on a steel structural member) is due to large difference in thermal inertias. Because of the relatively small mass of the transducer compared to a typical structural member, the rate of temperature change and therefore thermal expansion of the transducer is much greater. When a transducer is attached to a structure, it is forced to have the same deformation as the structure. However, if a temperature increase (or decrease) occurs, and since the ends of the sensor are "anchored", the transducer will expand between the end blocks and register relative compression. The same goes for a drop in temperature which will register tension. It is very difficult to separate the temperature effects on the gage from the actual temperature-induced strains, particularly on statically indeterminate structures.

If the transducers are exposed to direct sunlight during live-load tests, such as on truss members or on top of a concrete slab, significant temperature drift can be experienced during short periods of time due to changing cloud cover. Covering the gages with rags or packing material can usually reduce or eliminate this problem.

5.2.11.4 SPECIMEN TYPE AND SIZE

Often, the first verification test to be performed is either on a bending beam or compression/tension specimen in some kind of laboratory testing machine, with the results compared to the output of a foil strain gage or the theoretical strain value. Some of the items to consider during such tests are listed below.

5.2.11.5 ITEMS FOR CONSIDERATION

1. Remember that these sensors are designed to measure "axial strain". Flexural bending on structural members can be determined via axial strain measurements as long as the applied curvature is relatively small such that the small angle theory is applicable ($\sin \theta = \theta$). This means that if bending stresses are to be measured, it is best to use a beam with a minimum depth of approximately 12" or more, since the transducer will actually be offset from the beam surface slightly due to the thickness of the mounting tabs. However, with the beam depth of 12" or more, this difference is minimal. Another thing to watch out for during a beam bending test; is that it is very difficult to apply the load to the beam without inducing some kind of torsion or lateral bending. This occurs because the beam was not perfectly "straight" or because the end conditions are not perfectly level with one another. To minimize this, the transducers should be mounted with the tab/adhesive technique to the center of the flanges, rather than with C-Clamps on the edge of the flanges.

Trying to measure the strain on a 2" wide strip of metal that is 1/8" thick and mounted as a cantilever beam is not a good verification test for these sensors. The primary problem with a thin bending specimen is that a large degree of curvature is required to obtain a small level of surface strain. In other the words, the transducer will simply be bent rather than elongated. Furthermore, the actual location of the transducer will be relatively far from the neutral axis compared to the surface (aggravated again by the thickness of the tabs if they are used). Therefore, significant errors are induced when comparing surface strains obtained by a foil strain gage and the transducer reading.

For calibration purposes, it is highly recommended that strains be compared at constant moment regions rather than at locations with significant moment gradients. For the "bending beam" type of test, we recommend a beam at least 10 to 12 long, with a shorter beam (4 ft to 6 ft) set on top (with "pins" under each end), and the load cell above that. This "4-point" type of setup will supply a constant moment region at mid-span. Remember, the strain measured from the transducers is averaged over the 3" gage length. Therefore any error in gage placement or in the assumed strain gradient will cause errors in subsequent data comparisons.

2. In almost every case we have seen, a specimen that is supposedly undergoing tension only is actually bending as well. A popular test is to use a "dog bone" with the transducer mounted on one side and then the whole assembly put into tension. It is almost impossible to get pure tension in this setup since the specimen may be slightly bent to begin with and "straightens out" slightly. Also, since the transducers themselves have a small amount of stiffness, they will cause a non-symmetrical system. Another consideration is the distance of the centroid of the transducer to the specimen's neutral axis. Since bending will most likely occur, the output from the transducer may be reduced or amplified since its centroid is about 1/4" away from the foil gage (further from the neutral axis), and this might be the "compression" or "tension" side of the specimen. This phenomenon is very critical on small laboratory specimens, but insignificant on larger structures where the depths of the sections are usually much bigger.

In order for the tension test to be successful, transducers should be mounted on both sides of the specimen (on all four sides if the stiffnesses are similar in two directions) and the output averaged to determine the tension strain. In addition, the specimen should be relatively stiff compared to the transducer.

3. If a compression test is being attempted, then the gages need to be at least two member depths away from the ends, (a criteria for plane strain), with gages mounted on both sides of the specimen and the data averaged. For compression specimens, it may be necessary to place gages on all four sides since it can often be difficult to know the exact orientation of the neutral axis if the stiffness is approximately the same in both directions.
4. Using reinforced concrete as a test specimen material is a poor choice since inaccuracies in the reinforcement locations and variations in the concrete's elastic modulus (often up to 20%) can cause larger errors than the accuracy range of the strain transducers. For example, more aggregate near the surface of one gage will affect the modulus in that area. The way BDI addresses strain measurements on reinforced concrete is to use gage extensions, effectively amplifying the strain over anywhere from two to eight gage lengths, then taking an average. We accept the idea that concrete strains are not as accurate as those taken on steel structures, and attempt to maximize the accuracy with the gage extensions. This approach amplifies the signal, thus also improving the signal to noise ratio. With a gage length that is too short, stress concentrations, micro-cracking, or local effects might have an unusually large effect on the measurements.

For reinforced concrete structures (non pre-stressed or post tensioned), because of the margins of unknowns in concrete modulus, load magnitudes, placement of reinforcement, etc., in general, we prefer not to use measurements where the maximum

strain is less than about $30 \mu\epsilon$ if we are making conclusions based on the magnitude of strain. (Note that $2 \mu\epsilon$ is almost 10% of a $30 \mu\epsilon$ peak). This translates into only about 100 psi in concrete and 1 ksi in steel, which is really quite accurate for analytical modeling and load rating reinforced concrete structures. For these types of structures, numbers that are claimed to be more accurate are probably suspect. Using the transducers on pre-stressed concrete will usually provide excellent measurements, not only because there shouldn't be any cracking, but the concrete modulus usually tends to be more uniform.

5. Under no circumstances should loads be applied directly to the strain transducer. The transducers are designed with a very flexible geometry. This enables large strains to be measured with little axial load being transmitted through the transducer. Therefore, when testing typical structural members, the stiffness of the transducer is inconsequential. The transducer is intended to provide a measure of strain; it is not a load cell.

5.2.11.6 OTHER CONSIDERATIONS

Excitation Voltages and Electronics:

It is recommended that the Wheatstone bridge excitation voltage stay at or below 10VDC for these sensors. Higher voltage levels can cause drifting and stability problems in the 350Ω foil gages in the transducers. The STS-WiFi Nodes uses 5VDC with very good results. If extension cables are added, remember that these can add a slight amount of offset and possibly some signal attenuation. Allowing the electronics and the gages to warm up for several minutes is also recommended. A small amount of drift will be detected as the gages warm up, but should stabilize in several minutes.

Measuring the Applied Strain or Load:

Often, the output of a strain gage-based load cell is used in a testing machine as the basis for comparisons in tension/compression tests. However, we have found that many of these units may not have been NIST-calibrated for years and may be producing inaccurate results. If a gage is manually read for hydraulic pressure, then the result will be sensitive to jack friction. Also, if stress and strain are being calculated ($\sigma = E\epsilon$, $\sigma = My/I$, etc.), then accurate measurements of the cross-sectional areas are required.

Magnitude of Applied Loads:

Calibration tests should always be run up near the maximum safe linear range of the system. This will give the required confidence that the outputs from the transducers are indeed linear over the range of stresses of interest.

Recording Data:

It is VERY important to record the data continuously, rather than discretely. A qualitative review of the strain history will often be even more important than the actual magnitude because possible electronic noise or other effects will immediately be apparent. Furthermore, the other sensors such as load cells and foil strain gages should all be recorded with the same equipment and at the same sample frequency as the transducer data. This again allows for a qualitative check to be completed.

We are confident that if the above precautions are taken, the ST350 Strain Transducers will provide very accurate and reproducible results. If you have any questions on the above discussion or have a lab testing "pitfall" experience that you would like to have us investigate or think it may help other users, please contact us.

5.2.12 CALIBRATION SHEETS

5.2.12.1 APPLYING CALIBRATION FACTORS TO BDI STRAIN TRANSDUCERS

Each BDI strain transducer is supplied with a general gage factor that has the following format and units:

$$\text{GGF} = (\text{###})\mu\epsilon * V_{\text{exc}}/V_{\text{out}}$$

where:

GGF = General Gage Factor

= factor for particular transducer, usually between 300 and 500.

$\mu\epsilon$ = units of microstrain

V_{exc} = Excitation Voltage in (Volts)

V_{out} = Output Voltage (millivolts)

To calculate the strain level for a given excitation voltage, use the following calibration constant formula:

$$\text{Calibration Constant: } \mu\epsilon = (\text{GGF}/V_{\text{exc}}) * (V_{\text{out}})$$

Also, if a hardware gain is used, the user must divide it out. For the majority of the structural testing BDI has been involved with, a gain of 1000 has been used. However, depending on the A/D limits of the User's data acquisition system and the anticipated strain levels for a particular test, the gain may need to be reduced. As a double-check of the hookup and calibration factor application, it is highly recommended that the User perform a simple calibration experiment to ensure that correct strains are indeed being measured.

BDI Strain Transducers have been calibrated with precision equipment traceable to NIST standards. Although the supplied calibrations are quite reliable (within plus/minus 2%), it is recommended that transducers be re-calibrated periodically. For heavy usage (several field tests per month), calibrations should be performed on a yearly basis. For lighter usage, approximately once every three years is sufficient.

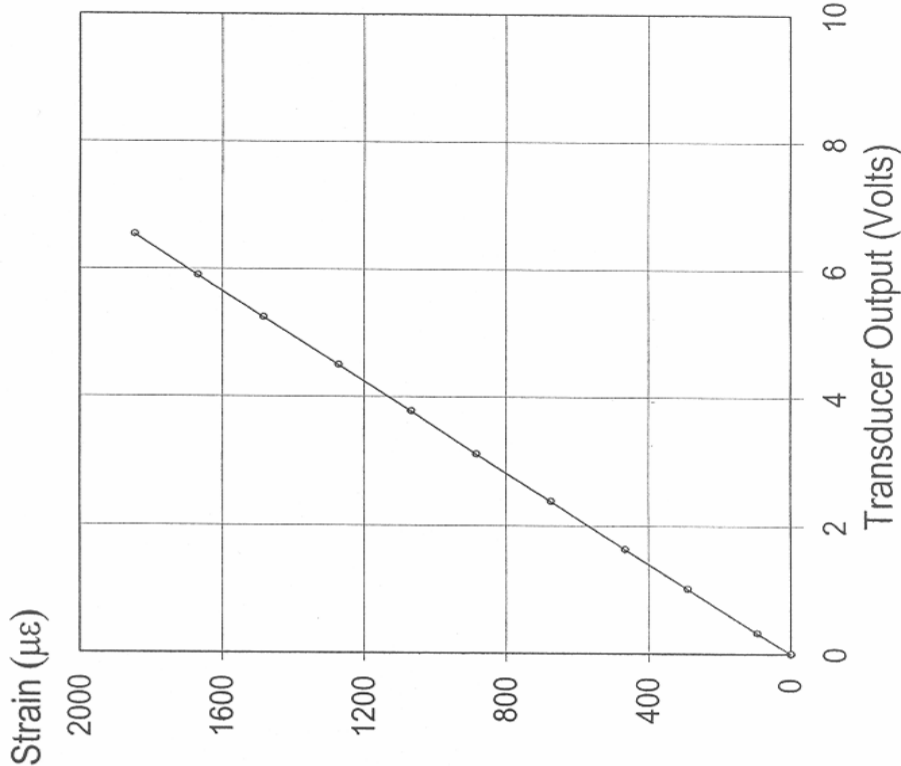
If you are doing your own calibration verification, please refer to our discussion on this topic entitled "Verifying Accuracy of BDI Strain Transducers" available from us and on our website.

5.2.12.2 EXAMPLE CALIBRATION SHEETS

Bridge Diagnostics

Transducer 1207

PDA Cal Factor (5.0 V) 141.3 $\mu\epsilon/V$



Applied Strain ($\mu\epsilon$)	Transducer Output (Volts)
0	0.00
96	0.33
290	1.01
466	1.63
675	2.38
883	3.11
1068	3.77
1275	4.49
1486	5.24
1671	5.90
1848	6.54

Shunt (60.4 K Ω) 2.5 V
 General Factor 490.7 $\mu\epsilon/mV/V$

Traceable to N.I.S.T.

Strain Transducer Calibrator System 2004 Version 1.2

Calibrated by: *[Signature]*
 Calibrated on: 27-Oct-2006

Certificate of Calibration

CUSTOMER:

Company Name: Campbell Scientific, Inc
 Street/City/State: 815 W 1800 N, Logan, UT 84321

CSI Sales No.: 246

Model: BDI Strain Transducer ST350

Serial Number: 1207

Instrument Calibration Condition

New Strain Transducer

Received Condition: Operation failure Mis-aligned (bent) Other

Returned Condition: In tolerance

GENERAL GAGE FACTOR: 490.7 $\mu \epsilon/mV/V$

Recommended Calibration Schedule

If the customer has not requested a calibration interval, a non-mandatory recommended interval is provided. Based on past experience and assumed normal usage, it is recommended that this instrument be calibrated by the due date stated below to insure sustained accuracy and reliable performance.

Re-Calibration Due Date: 27-Oct-2008

Report of Calibration Standards Used

Calibration Procedure: Precision Laser Applied Displacement

<u>Make / Model</u>	<u>SN</u>	<u>Calibration Date</u>	<u>NIST reference</u>
1. PDI Ref Cal	8069	7/8/2005	374.1 $\mu M/V$ (0.01473 in/V)

BDI certifies the above instrument meets or exceeds published specifications and has been calibrated using standards and instruments whose accuracies are traceable to the National Institute of Standards and Technology (NIST), an accepted value of a natural physical constant or a ratio calibration technique. The calibration of this instrument was performed in accordance with the BDI Quality Assurance program. Measurements and information provided on this report are valid at the time of calibration only.

Calibrated By: Claire Vederling

Date: 27 Oct 2006

