Comparative Field Qualification of ACM and ACSM Systems at Sycamore, IL

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Introduction

The purpose of this comparative field qualification is to demonstrate the new Kelunji EchoPro hybrid ACSM system and its performance relative to the eDAQ and eko Motes systems. These three systems are installed at a test site in Sycamore, IL, adjacent to an active quarry. Data for this report was collected during a period between March 7, 2011 and May 13, 2011. The analysis includes a comparison of the long-term results for all three systems and a comparison of the dynamic results and noise levels for the eDAQ and the Kelunji EchoPro systems.

Figure 1 is an aerial view of the site, and Figure 2 is a view of the exterior of the house with the exterior walls annotated. These photographs, along with the floor plan in Figure 6, will give a basic understanding of the site and test house layout. Figure 3 through Figure 5 illustrate the sensor locations throughout the house. The comparable sensors include the three crack sensors on the first floor shear crack and the second floor ceiling crack and the two crack sensors on the first floor seam crack. Also, dynamic data from the internal and exterior geophones will be compared.

This report is organized into five major sections. The first section is a comparison of the three systems. The second section is the dynamic results from a blast event. The third section is the long term results of the systems over the period. The fourth section is a comparison of the noise levels on the eDAQ and EchoPro. The last section contains three appendices, one for each of the deployed systems.

Figure 1: Aerial View of Site with Annotations

Figure 2: Exterior View of Floit Hoise with Annotations

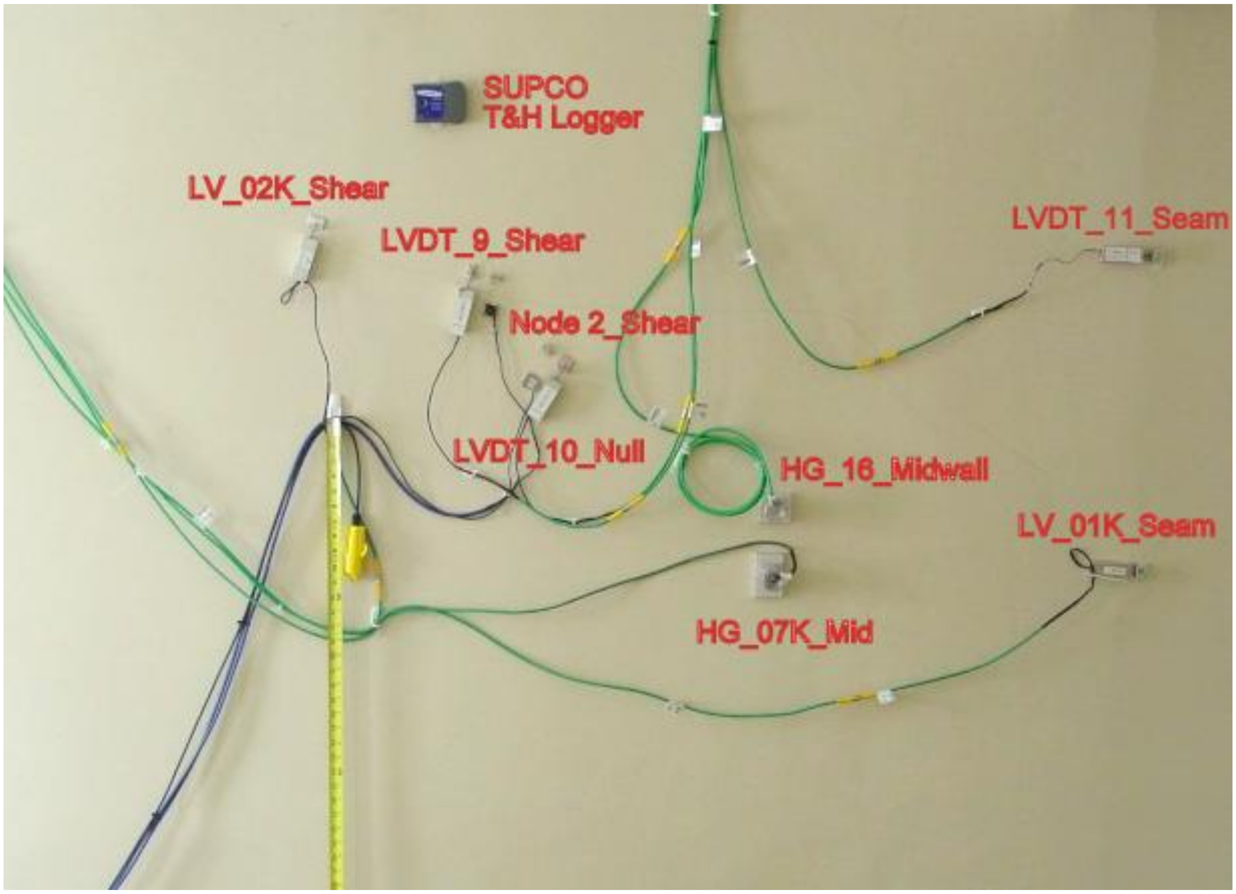


Figure 3: South Exterior Wall with Sensors

Figure 4: Ceiling Crack Bedroom with Sensors

Figure 5: Ceiling Crack Bedroom with KEP sensors

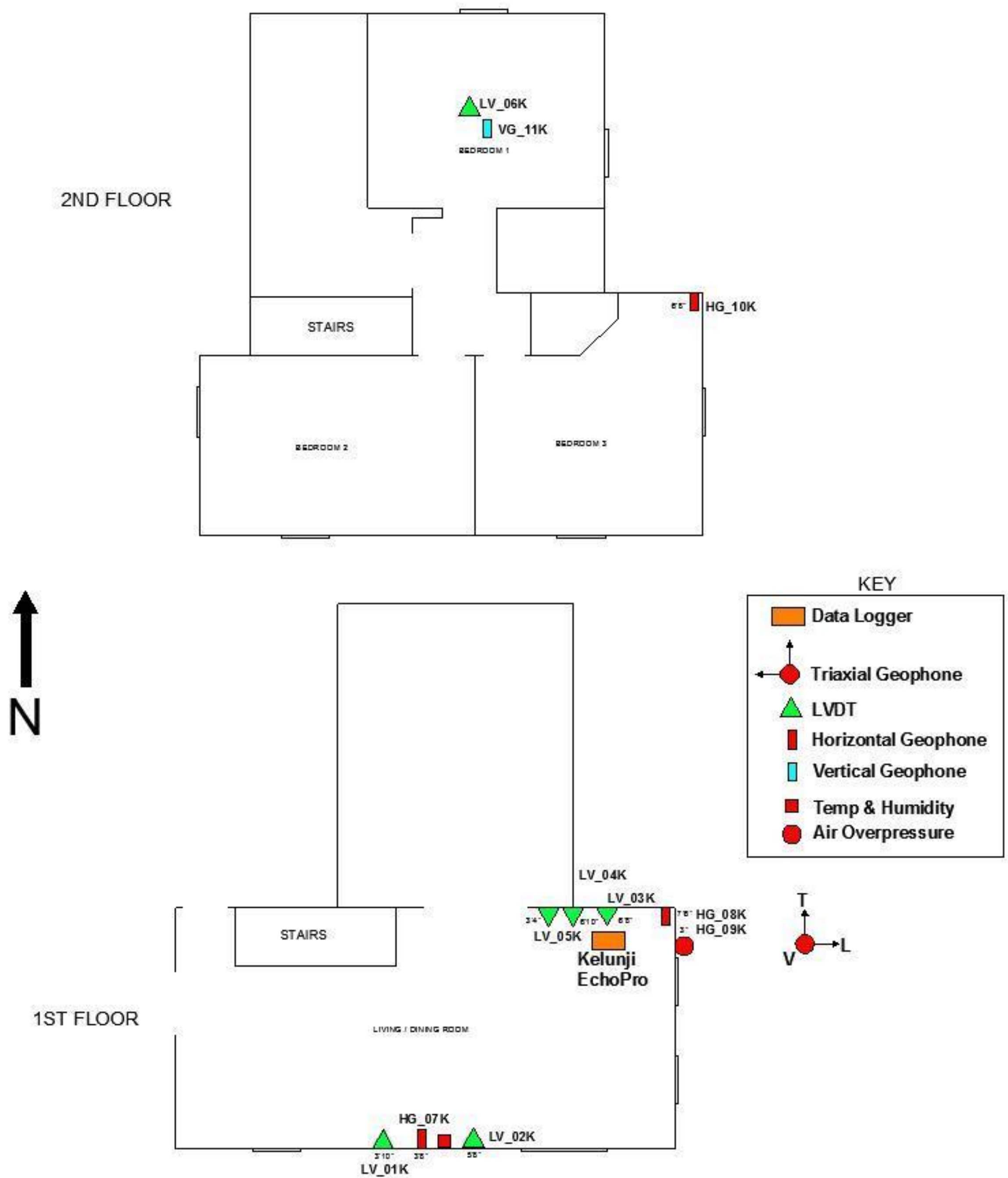


Figure 6: Floit House Floor Plan and Kelunji EchoPro System Layout

System Comparison

Objective

This section will provide important background details about the Kelunji EchoPro ACSM hybrid system, the eDAQ ACSM system, and the ēKo Motes system deployed at the test house at Sycamore, IL. In addition, comparisons of the three systems with regard to system properties and sensors will begin to demonstrate the advantages and disadvantages of the different systems and their independent capabilities.

Comparative Matrices

The tables below help summarize the key capabilities of each system in an attempt to highlight their similarities and differences. Table 1 shows system properties and Table 2 shows sensor and recording properties.

Table 1: Comparison of System Properties of deployed ACM and ACSM systems

System	Battery Type	Battery Life	A/D Converter	Wiring	Internet Communication	Long Term Monitoring	Dynamic Monitoring	Cost
EchoPro	12 V DC or regulated power supply	--	24 bit	SoMat cables	Yes	Yes	Yes	
eDAQ	--	--		SoMat cables	Yes	Yes	Yes	
ēKo Motes	**Base station:** 110 AC power **Motes:** Self powered	5 years (with sunlight) for Motes	10 bit	None	Yes	Yes	No	

Table 2: Comparison of Sensor Properties of deployed ACM and ACSM systems

Sensors	Sampling	Channels	Type(s)	Trigger	Power
EchoPro	**12 channels:** up to 1000 Hz **6 channels:** up to 2000 Hz	12	**Displacement**: Single Pole LVDTs **Velocity**: Geophones	External or Internal	Powers sensors directly
eDAQ	Up to 1000 Hz	16	**Displacement**: any **Velocity**: any **Temperature & Humidity**: any	Internal	Separate power source required
ēKo Motes	Every 15 minutes		**Crack**: any **Temperature & Humidity**: any	Internal	Separate power source required

Dynamic (Burst Event) Comparison

Objective

This section will investigate the crack and structural response of the test house at Sycamore, IL for a specific blast event from May 11, 2011. Triggered data was collected for the event on both the Kelunji EchoPro hybrid ACSM system and the eDAQ ACSM system. Plots of the data for corresponding sensors on each system will help graphically compare the two systems.

Results

The blast event on May 11, 2011 at 11:05 AM triggered the dynamic recording of both systems. Table 3 below summarizes the event from the Kelunji EchoPro system of sensors. The largest structural response was .57 inches per second on the first floor exterior mid-wall geophone. The ground motion excitation had a maximum of .64 inches per second in the radial direction and about .5 inches per second in both the transverse and vertical directions. From this raw data, the displacement results were obtained by integrating the velocity data with the 1 milli-second time step. The relative displacement is the difference between the top and bottom first floor geophones.

Figure 7 and Figure 8 show the time histories of the comparable first floor cracks, the relative displacement, the displacement of the first floor corner geophones, and the transverse ground motion for the eDAQ and EchoPro systems respectively. The two systems perform similarly. They both record similar structural velocity and displacement response, and they both record similar crack responses. Similarities in the magnitude of the responses are seen by the comparison of the responses in Table 3 and Table 4. The maximum and minimum values are the absolute max and min during the duration of the time history, even if there is a step shift.

There is a difference between the shape of each systems response across the seam. The KEP LVDT returned a step response and the the eDAQ LVDT did not. This difference may be a result of different locations on the crack or installation differences such as the parallelism of the LVDT body and target.

Table 3: Summary Table of the Kelunji EchoPro ACSM System for the May 11, 2011 Blast Event

Externally Triggered Dynamic Event - EchoPro May 11, 2011 11:05 AM		Blast Event at Floit test house near quarry in Sycamore, IL		
Kelunji EchoPro				
Channel	Description	Maximum	Minimum	Unit
1	Crack Response – LV_01K_Seam	38	-140	μ-in
2	Crack Response – LV_02K_Shear	16	-66	μ-in
3	Crack Response – LV_03K_Null	9	-8	μ-in
4	Crack Response – LV_04K_IntHor	31	-29	μ-in
5	Crack Response – LV_05K_IntVert	45	-48	μ-in
6	Crack Response – LV_06K_Ceil	25	-120	μ-in
7	Structural Response – HG_07K_Mid	0.47	-0.57	in/s
8	Structural Response - HG_08K_1FUp	0.21	-0.23	in/s
9	Structural Response - HG_09K_1FDwn	0.16	-0.22	in/s
10	Structural Response – HG_10K_2FUp	0.28	-0.36	in/s
11	Structural Response – VG_11K_2FCeil	0.00	0.00	in/s
12	Trigger Signal – LC_12K_Trig	5.05	0.00	Volts
LARCOR Seismograph				
Channel	Description	Maximum	Minimum	Unit
A	Air Blast	0.02	0.02	Millibars
R	Radial Ground Motion	0.62	-0.64	in/s
V	Vertical Ground Motion	0.52	-0.42	in/s
T	Transverse Ground Motion	0.54	-0.5	in/s
Displacement				
Channel	Description	Maximum	Minimum	Unit
7	Absolute Displacement - Channel 7	0.064	-0.061	milli-in
8	Absolute Displacement - Channel 8	0.019	-0.019	milli-in
9	Absolute Displacement - Channel 9	0.025	-0.030	milli-in
10	Absolute Displacement - Channel 10	0.017	-0.017	milli-in
11	Absolute Displacement - Channel 11	0.000	0.000	milli-in
Ch9 - Ch8	Relative Displacement (Ch 9 - Ch8)	0.031	-0.035	milli-in

Table 4: Summary Table of the eDAQ ACSM System for the May 11, 2011 Blast Event

Externally Triggered Dynamic Event - eDAQ 5/11/2011 11:05		Blast Event at Floit test house near quarry in Sycamore, IL		
eDAQ - Crack and Velocity Sensors				
Channel	Description	Maximum	Minimum	Unit
9	Crack Response - LVDT_9_Shear	63	-121	µ-in
10	Crack Response - LVDT_10_Null	26	-33	µ-in
11	Crack Response - LVDT_11_Seam	84	-80	µ-in
12	Crack Response - LVDT_12_Ceil	122	-249	µ-in
13	Structural Response - HG_13_Bottom1	0.23	-0.18	in/s
14	Structural Response - HG_14_Top1	0.24	-0.25	in/s
15	Structural Response - HG_15_Top2	0.41	-0.31	in/s
16	Structural Response - HG_16_Midwall	0.53	-0.63	in/s
eDAQ - External Sensors				
Channel	Description	Maximum	Minimum	Unit
1	Radial Ground Motion	0.177933485	-0.200018911	in/s
2	Vertical Ground Motion	0.167359581	-0.191971283	in/s
3	Transverse Ground Motion	0.197665746	-0.148249314	in/s
4	Air Blast	0.00269782	-0.001940944	Millibars
Displacement				
Channel	Description	Maximum	Minimum	Unit
13	Absolute Displacement - Channel 13	0.035	-0.037	milli-in
14	Absolute Displacement - Channel 14	0.022	-0.020	milli-in
15	Absolute Displacement - Channel 15	0.022	-0.022	milli-in
16	Absolute Displacement - Channel 16	0.073	-0.079	milli-in
Ch14 - Ch13	Relative Displacement (Ch 14 - Ch13)	0.042	-0.038	milli-in

The relative displacement for the eDAQ is slightly larger than the EchoPro. This is likely due to the EchoPro monitoring geophones at the corners of an interior wall and the eDAQ monitoring geophones at the corners of an exterior wall. Looking at the displacement results, it is clear that the top displacement for the eDAQ is greater than the one for the EchoPro. This is the probable source of the difference between the relative displacements.

The transverse ground motion for the eDAQ tri-axial geophone is about 50 percent of the ground motion measured by the LARCOR compliance seismograph that is part of the EchoPro hybrid system. While there are likely many sources of variation, including soil types, sensor depth and location, and sensor type, the large magnitude of the difference creates the possibility of an issue with the different systems, sensor calibration, or other sources of error.

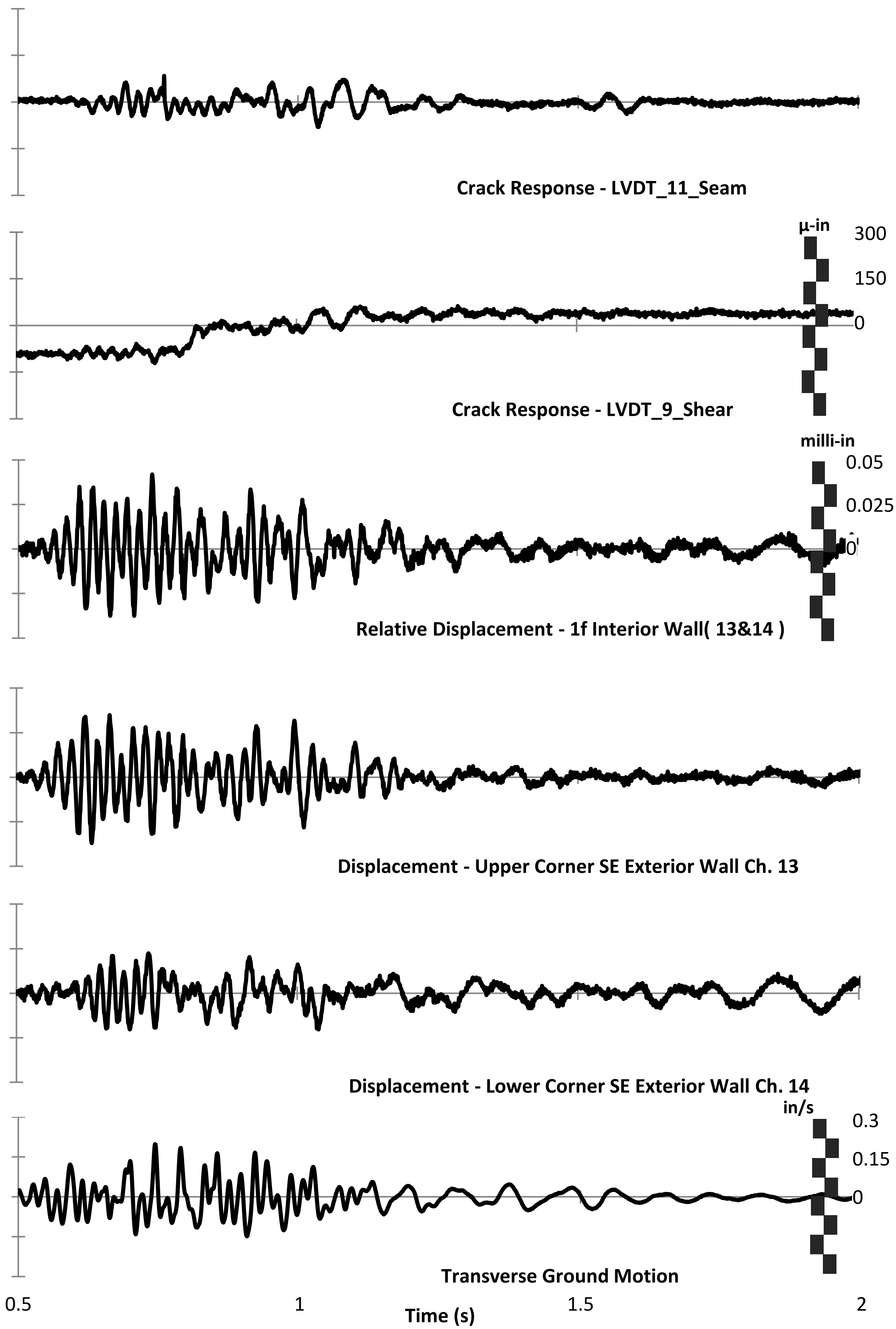


Figure 7: May 11, 2011 1105 Dynamic Event - eDAQ

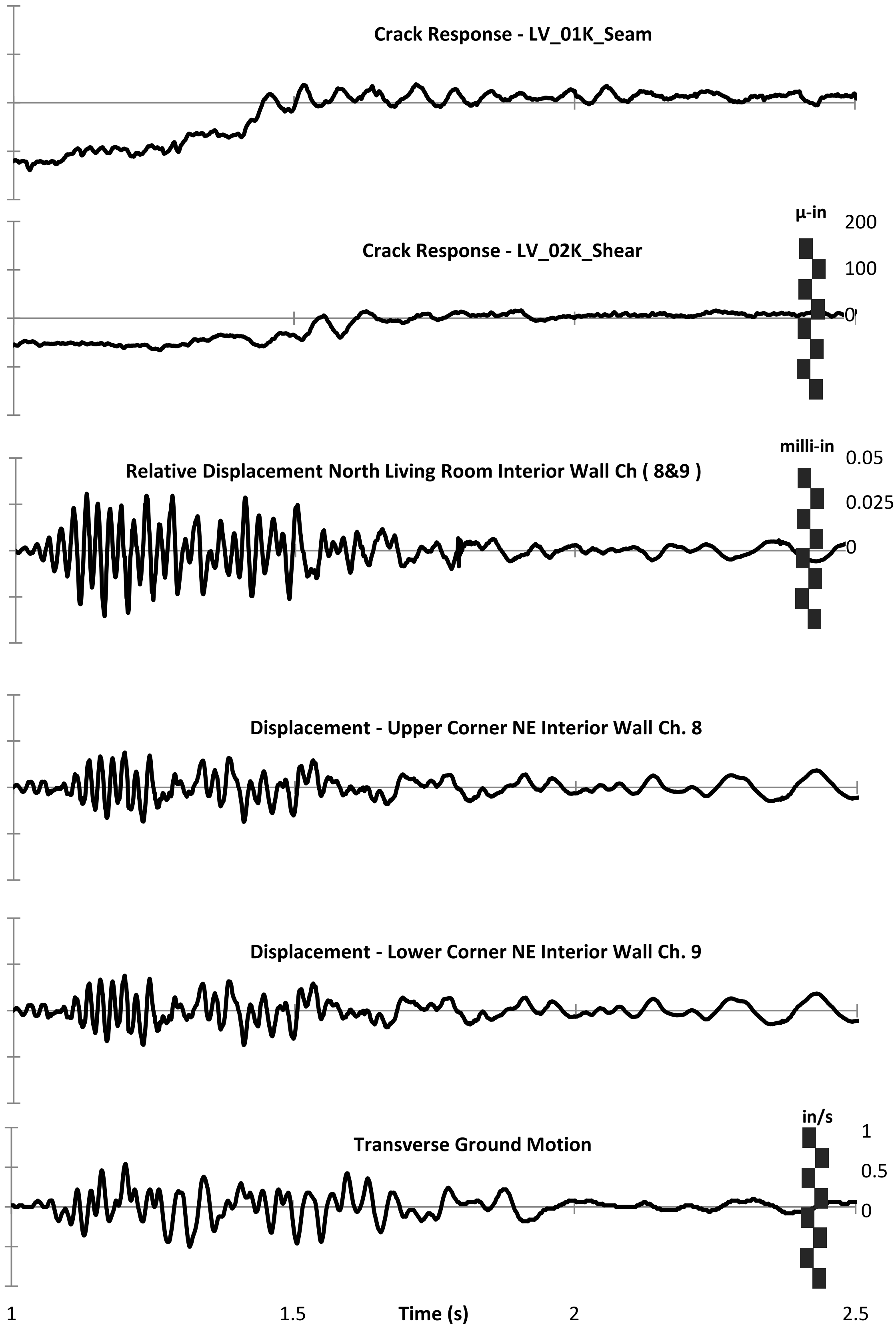


Figure 8: May 11, 2011 1105 Dynamic Event - EchoPro

Figure 9 illustrates the crack response of each system to the ceiling crack on the second floor bedroom and the velocity response from the vertical geophone. The response of the crack sensors is similar across the two systems. However, the vertical geophone is not responding at the magnitude expected for the event. This is likely an issue inherent to the sensor or its preparation and installation because the raw data showcases the same problem.

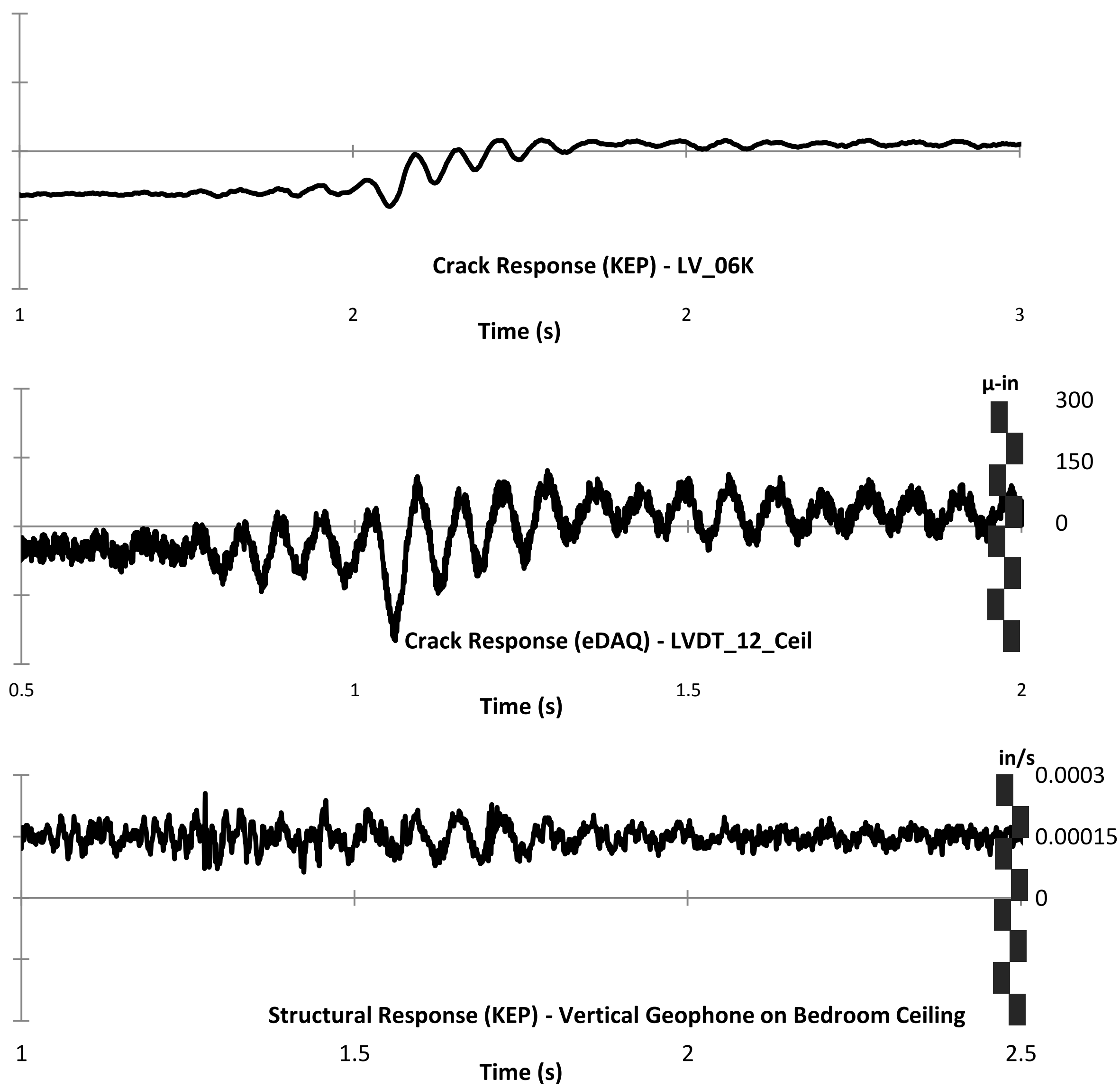


Figure 9: May 11, 2011 1105 Dynamic Event - Second Floor Response (Both Systems)

Long Term Crack Monitoring Comparison

Objective

The following section will describe the crack movements and environmental data for the period between March 7, 2011 and May 13, 2011 for the three systems (Kelunji EchoPro, eDAQ, eko Motes) present at the Sycamore, IL test house. The purpose of this is to graphically compare the long term results from the systems and attempt to describe any discrepancies. Additionally, a dynamic event from May 11, 2011 will serve as a sample event for comparison of dynamic and long term crack response.

Long Term Results

Long term response monitoring shows crack movements that occur due to long term environmental factors such as temperature and humidity. For the best results, sensors must be continuously monitored over long period of time and return reasonable data. Figure 10 shows the crack response of all three systems over the entire collection period, and Figure 11 shows the interior and exterior environmental variations over the same time. Figure 9 and Figure 10 show the response of each individual system for the exterior shear crack and the bedroom ceiling crack.

The trend that can be extracted from the figures is that as the average temperature increases, the cracks decrease in size. This makes sense as thermal expansion of the wall material with increased temperature would serve to reduce the size of the cracks. However, it is important to note that humidity fluctuations also have a large impact on crack response, though it is difficult to discern a trend from the figures due to the rapid variation of the exterior humidity response.

For the most part, the crack sensors measure very similar responses and show peaks and troughs at the same points in time. However, there are observable deviations between the sensors at the beginning and end of the shear crack time history and the end of the seam crack time history. There are several possible explanations for these differences. First, human error in installation and sensor error in responding to crack movements can the different magnitudes.

Second, the crack gauges monitor different locations on the crack. Therefore, the long term environmental factors could create strain localizations that vary the impacts at the various positions of the sensors. Further study could involve multiple LVDT’s on a single system and crack to help determine what factors influence differences in long term crack response between sensor locations.

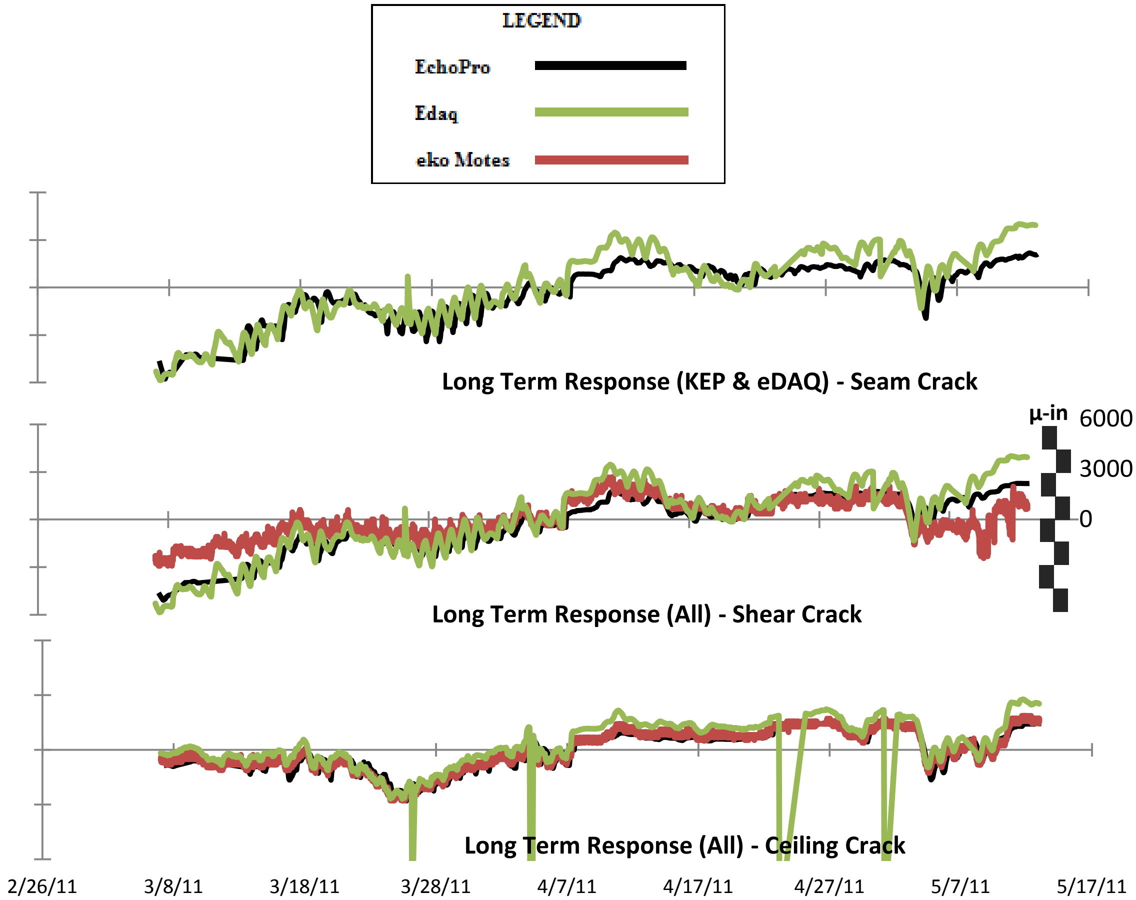


Figure 10: Long Term Crack Response for Multiple Systems to Highlight Differences in Response Patterns

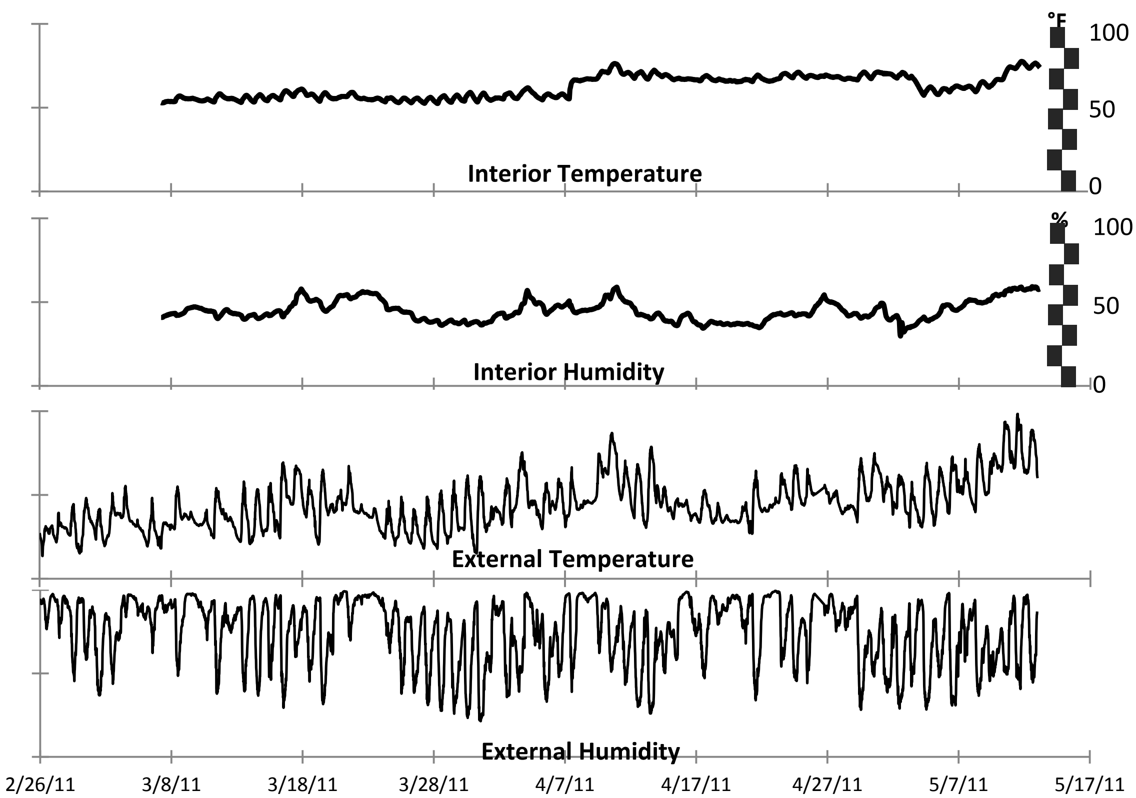


Figure 11: Interior and Exterior Temperature and Humidity Fluctuations

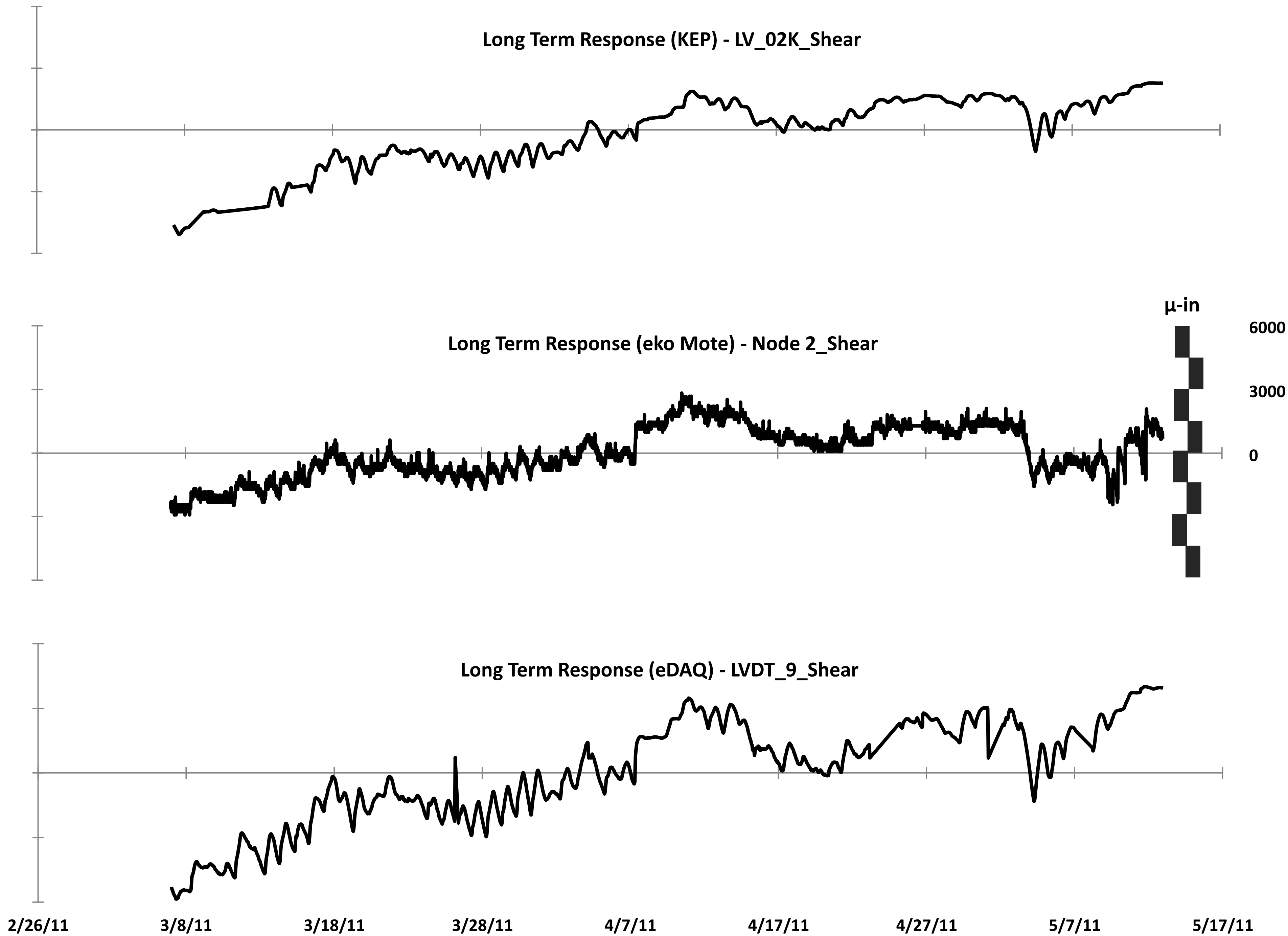


Figure 12: Long Term Crack Response for Exterior Shear Crack

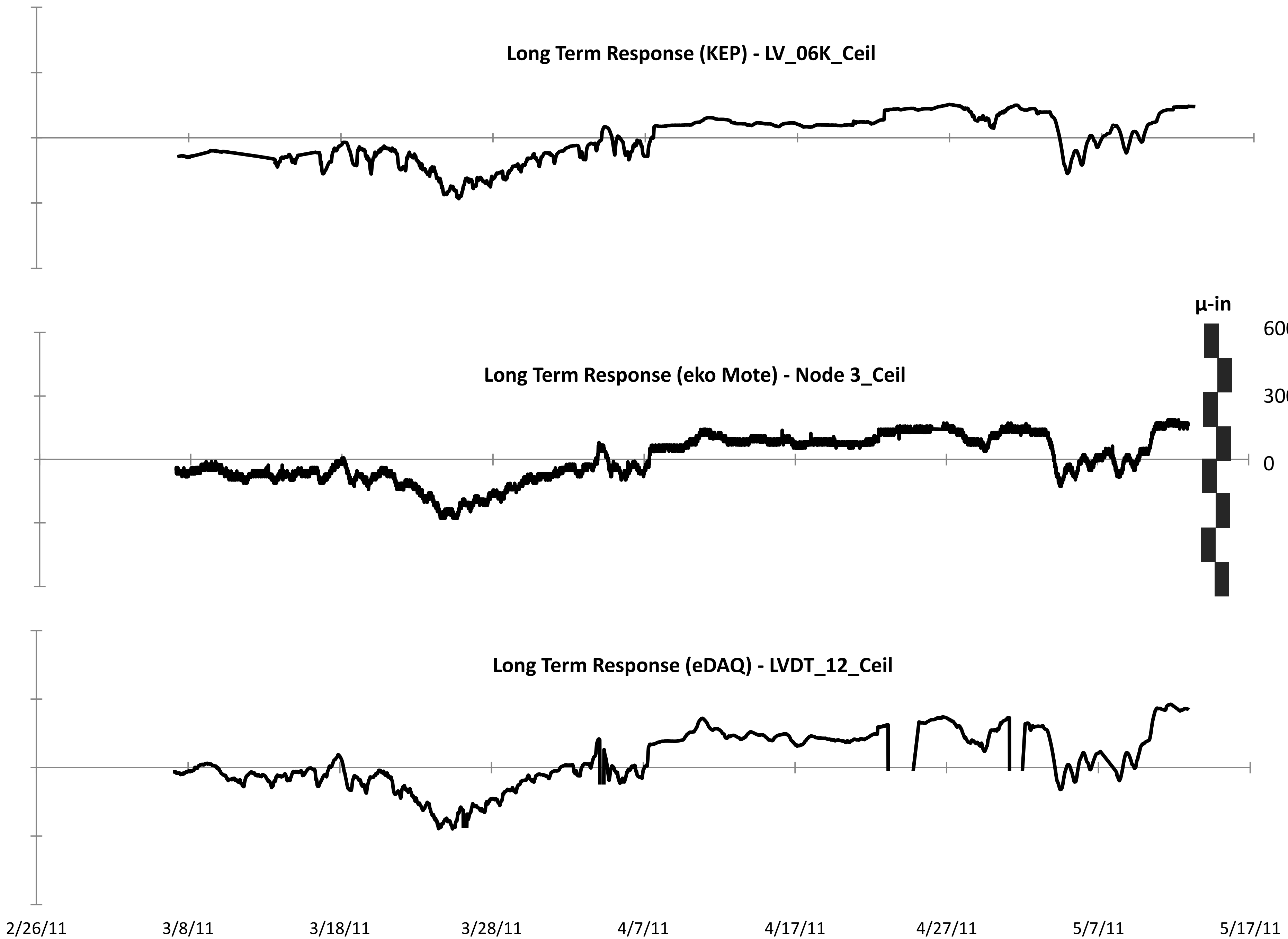


Figure 13: Long Term Crack Response for Bedroom Ceiling Crack

Comparison of Long Term Response with the Sample Blast Event

To compare the magnitude of crack response between the long term environmental variations and the dynamic response from a blast event, it is important to establish a means of visually comparing the two. This is complicated by the large differences in the time scale (long term is in terms of days and months while dynamic response occurs in a matter of seconds).

Figure 14 and Figure 15 shows the long term crack response of the EchoPro and eDAQ systems respectively with the dynamic event period circled in red. These figures show that there is no large change in the long term trend of the crack movement during this period. In order to further demonstrate this, Figure 13 and Figure 14 enlarge the long term response for the three comparable cracks (exterior seam, exterior shear, bedroom ceiling). Also included in these figures is a representation of the dynamic response of these cracks during the May 11, 2011 blast event. These dynamic responses are displayed below the x-axis near the corresponding date and are scaled to about twice their real response magnitude for viewing purposes

More information on the specifics of the blast event can be found in the dynamic analysis section of this report. However, it can be concluded that the event, with an maximum ground motion near .5 or .6 inches per second, does not produce a crack response that is significant when compared to the magnitude of the long term crack variations due to environmental effects.

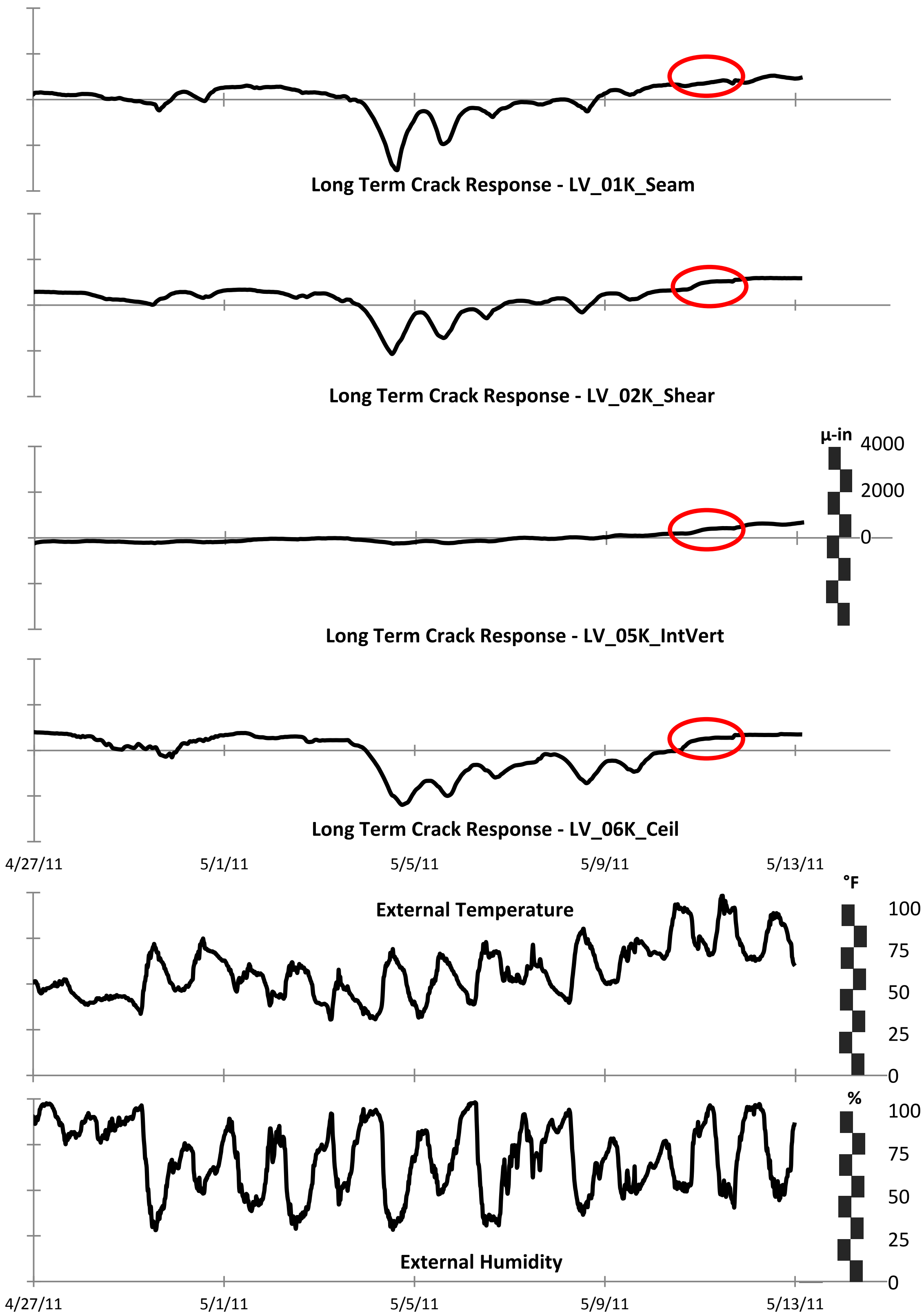


Figure 14: April 27 – May 13th EchoPro Response with Dynamic Event Data Circled

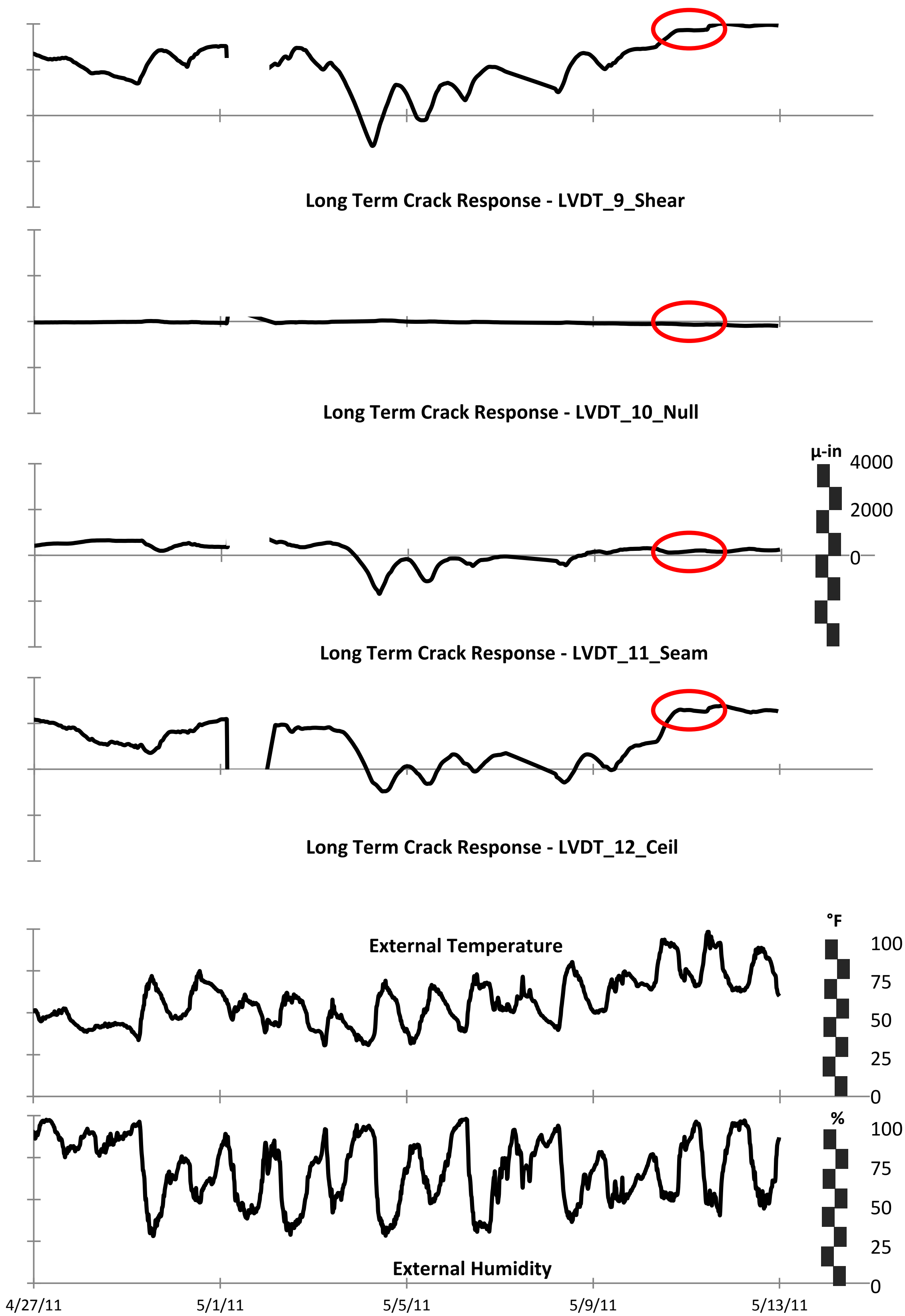


Figure 15: April 27 - May 13th eDAQ Response with Dynamic Event Data Circled:

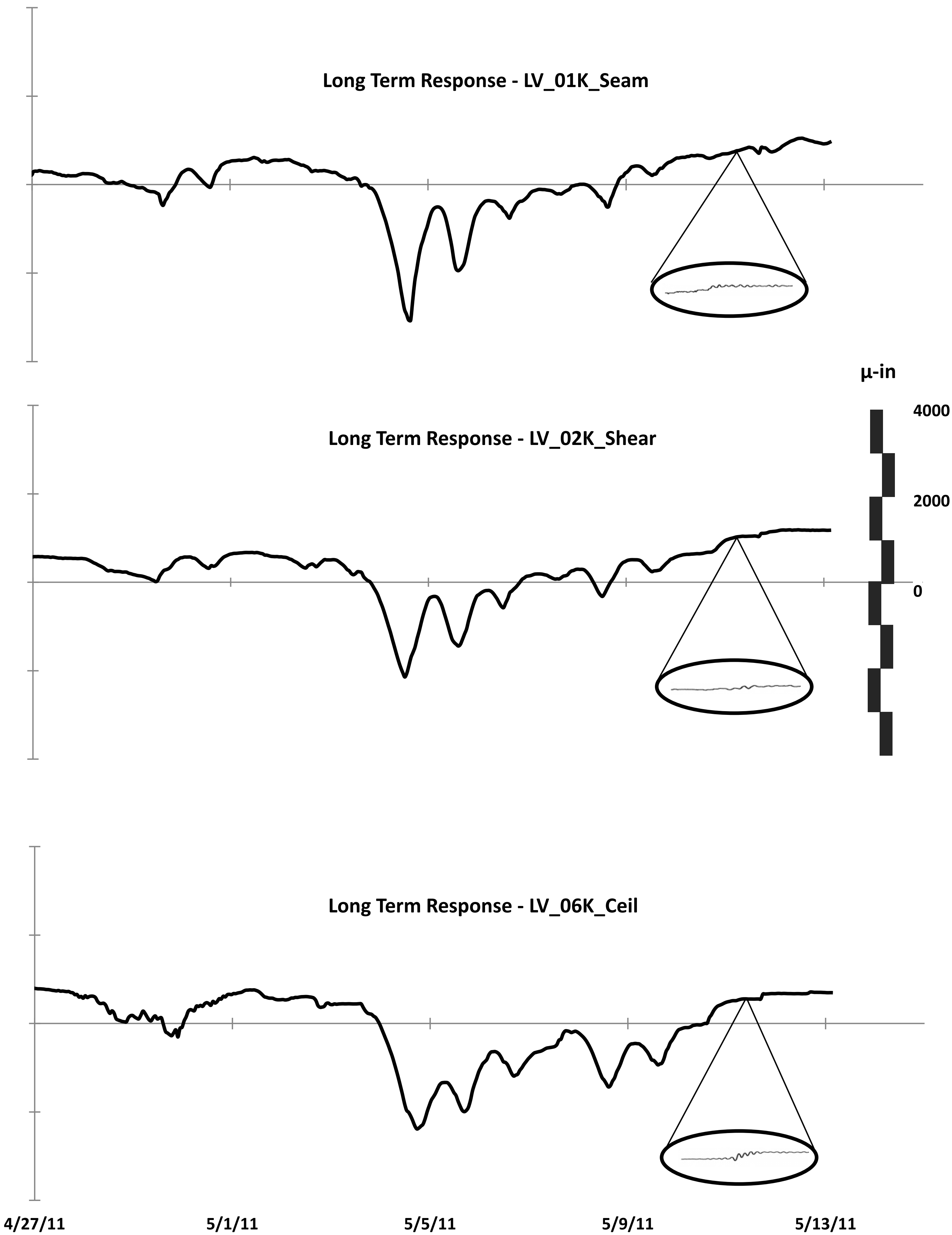


Figure 16: Visual Comparison of Long Term and Dynamic Crack Movements on EchoPro

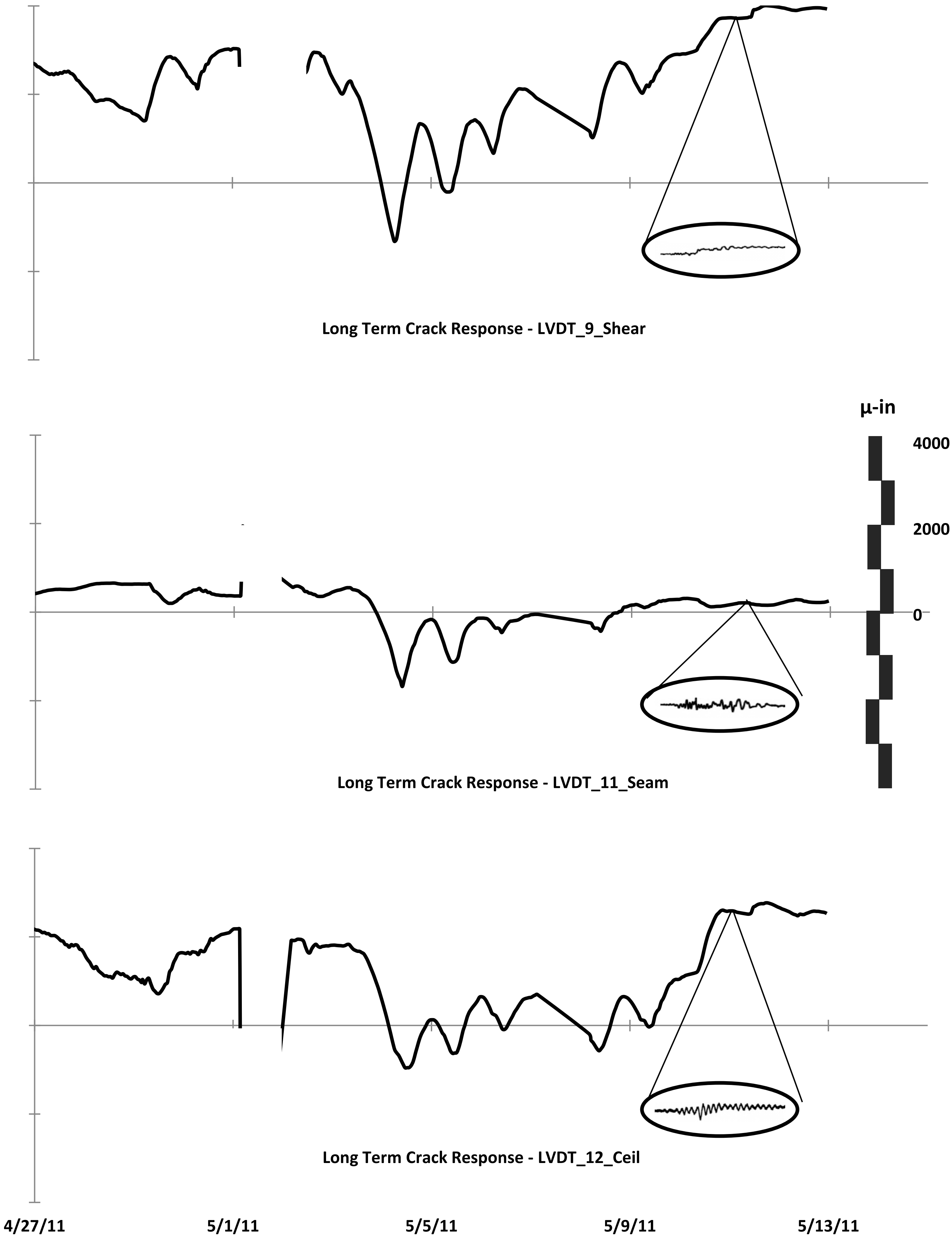


Figure 17: Visual Comparison of Long Term and Dynamic Crack Movements on eDAQ

Noise Analysis

Objective

This section will attempt to compare the noise levels for the Kelunji EchoPro and EDAQ crack monitoring systems based on data obtained from the test house in Sycamore, Illinois. Visual resolution of a crack monitoring system is constrained by the noise level. Simply put, the lower the noise level relative to the sensor sensitivity, the higher the resolution of the output. Higher resolution allows smaller crack movements to be detected, improving the value and performance of the system. For the purpose of this comparison, the noise levels of the Kelunji crack sensors (LVDTs) and the EDAQ crack sensors (LVDTs) will be determined from the data.

Results

The results shown in

Table 5 and Table 6 were derived from two events that were recorded on the EchoPro and eDAQ systems. The noise calculations took four to six random 1-second peak to peak difference samples for each crack sensor channel from each time history (in the range after the event response) and determined the average peak to peak noise for a given channel across both events. A standard deviation is included to show the variation in the noise across samples. Visual estimates were included to ensure that peak to peak noise estimates were not being distorted by data outliers.

The tables illustrate the noise difference between the EchoPro and eDAQ by grouping the corresponding sensors with the same color. The results show that the EchoPro, monitoring the same cracks, has at the very least a 50 percent reduction in the noise level from the eDAQ. The large levels of noise on eDAQ channel LVDT_12_Ceil is likely due to a sensor problem, as these levels of noise are not typical for the other sensor channels on the system and does not represent the typical sensor resolution.

Table 5: Noise Level Comparison for EchoPro and eDAQ ACSM systems

System	Channel	Type	Peak to Peak Average Noise	Standard Deviation of Average Noise	Visual Estimate	unit
EchoPro	LV_01K_Seam	crack	11.39	1.21	10	µ-inches
eDAQ	LVDT_11_Seam	crack	26.66	2.46	20	µ-inches
EchoPro	LV_02K	crack	10.63	1.54	10	µ-inches
eDAQ	LVDT_9_Shear	crack	35.28	3.14	25	µ-inches
EchoPro	LV_06K	crack	8.54	1.31	8	µ-inches
eDAQ	LVDT_12_Ceil	crack	83.68	3.28	70	µ-inches

Table 6: Noise Level Reduction from eDAQ to EchoPro

System	Channel	Reduction Peak to Peak (%)	Reduction Visual Estimate (%)
EchoPro eDAQ	LV_01K LVDT_11_Seam	57.26825034	50.00
EchoPro EDAQ	LV_02K LVDT_9_Shear	69.87387511	60.00
EchoPro EDAQ	LV_06K LVDT_12_Ceil	89.78928096	88.57

Figure 18 and Figure 19 illustrate two-second time histories for the EchoPro and eDAQ systems respectively. They visually demonstrate the increased resolution of the Kelunji system relative to the eDAQ due to lower noise levels of the recorded data. Figure 20 shows the full EchoPro time history and the two second time window from which the first two figures were developed.

With both visual inspection and data analysis methods, it is clear that a significant noise reduction is achieved by using the Kelunji EchoPro ACSM system. This allows monitoring of smaller crack movements relative to the eDAQ system. Further studies of noise could include additional crack sensor types and additional crack monitoring systems.

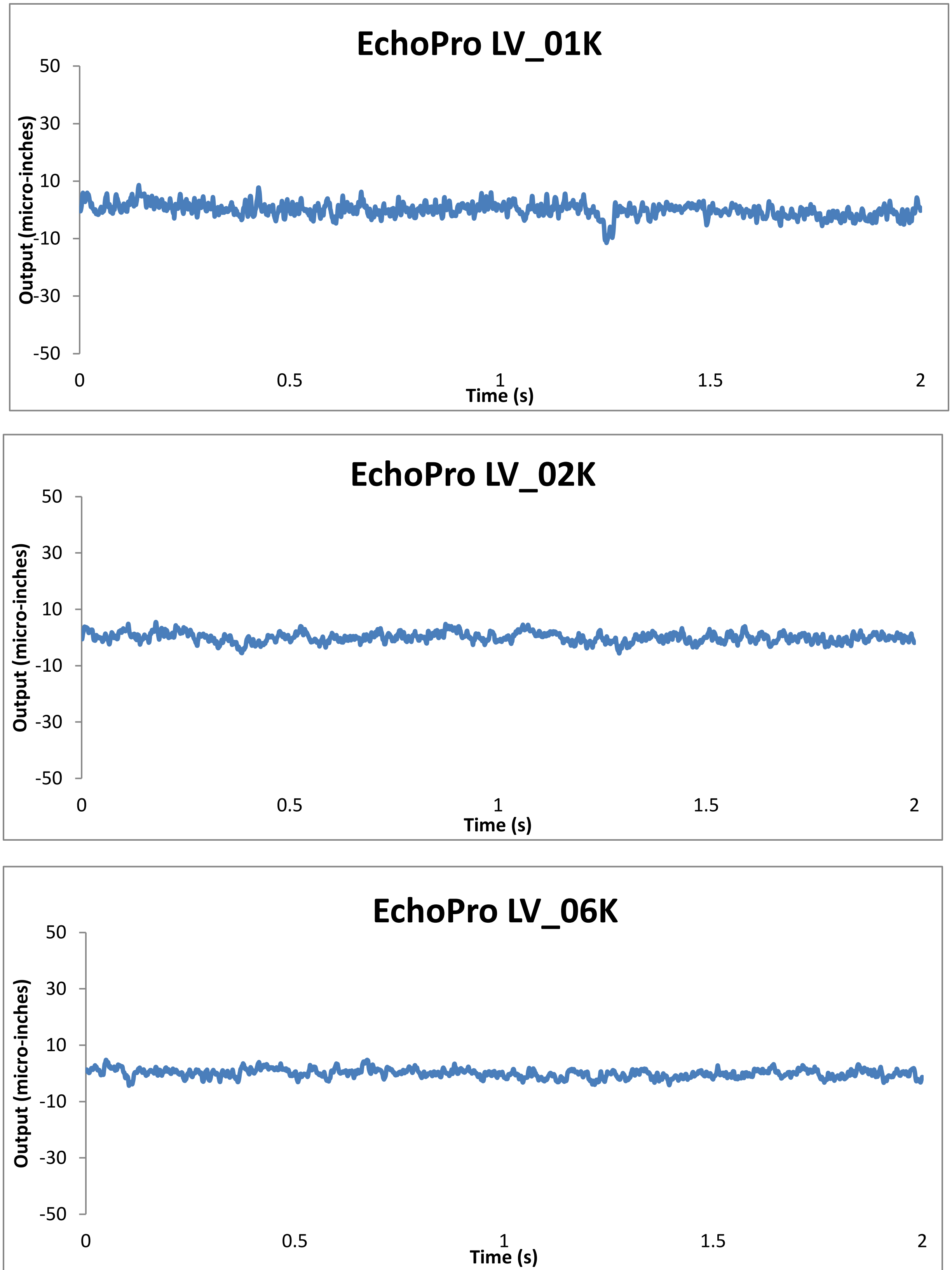


Figure 18: Noise Illustration - EchoPro 2 second Time History

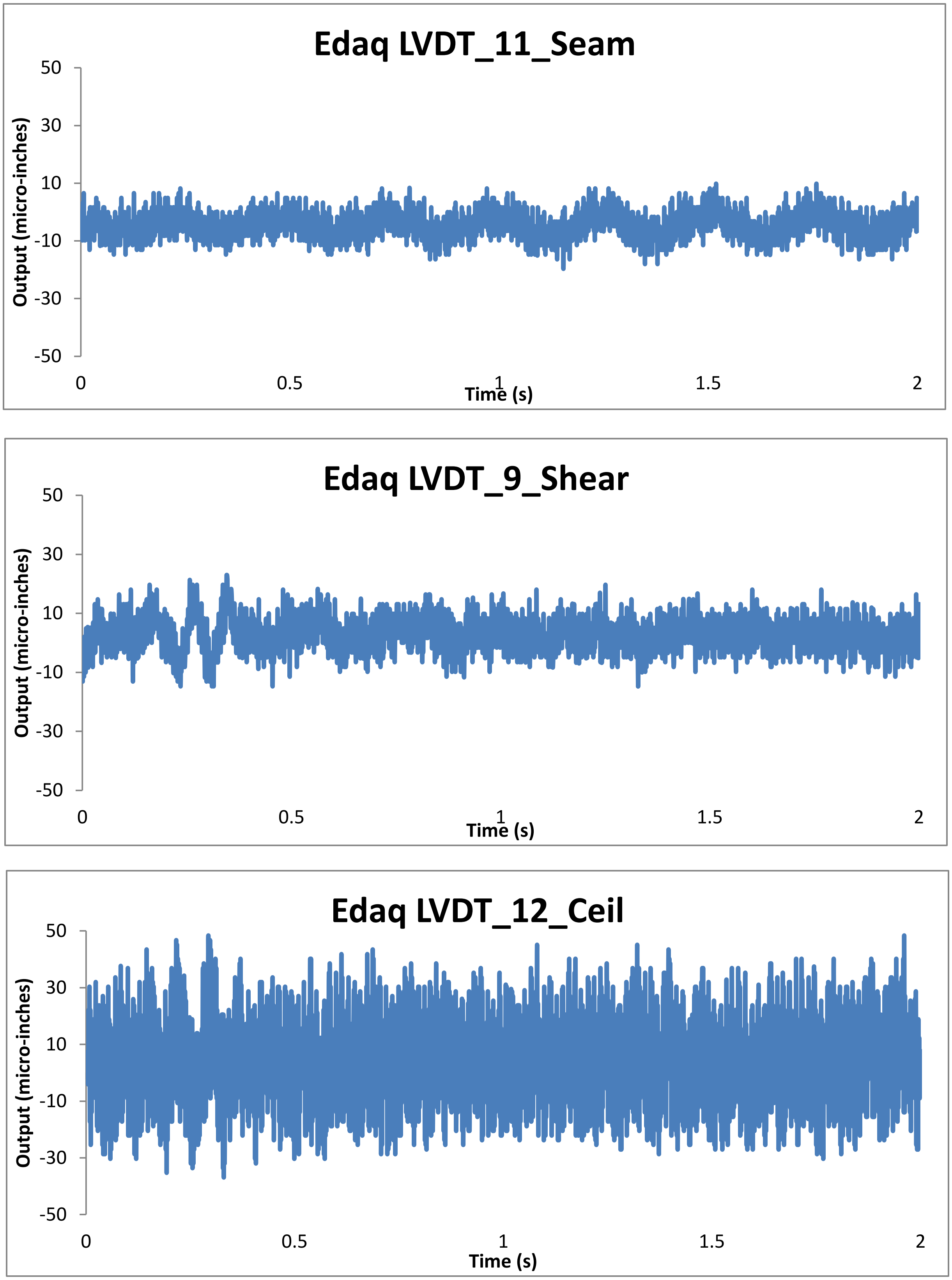


Figure 19: Noise Illustration - eDAQ 2 second Time History

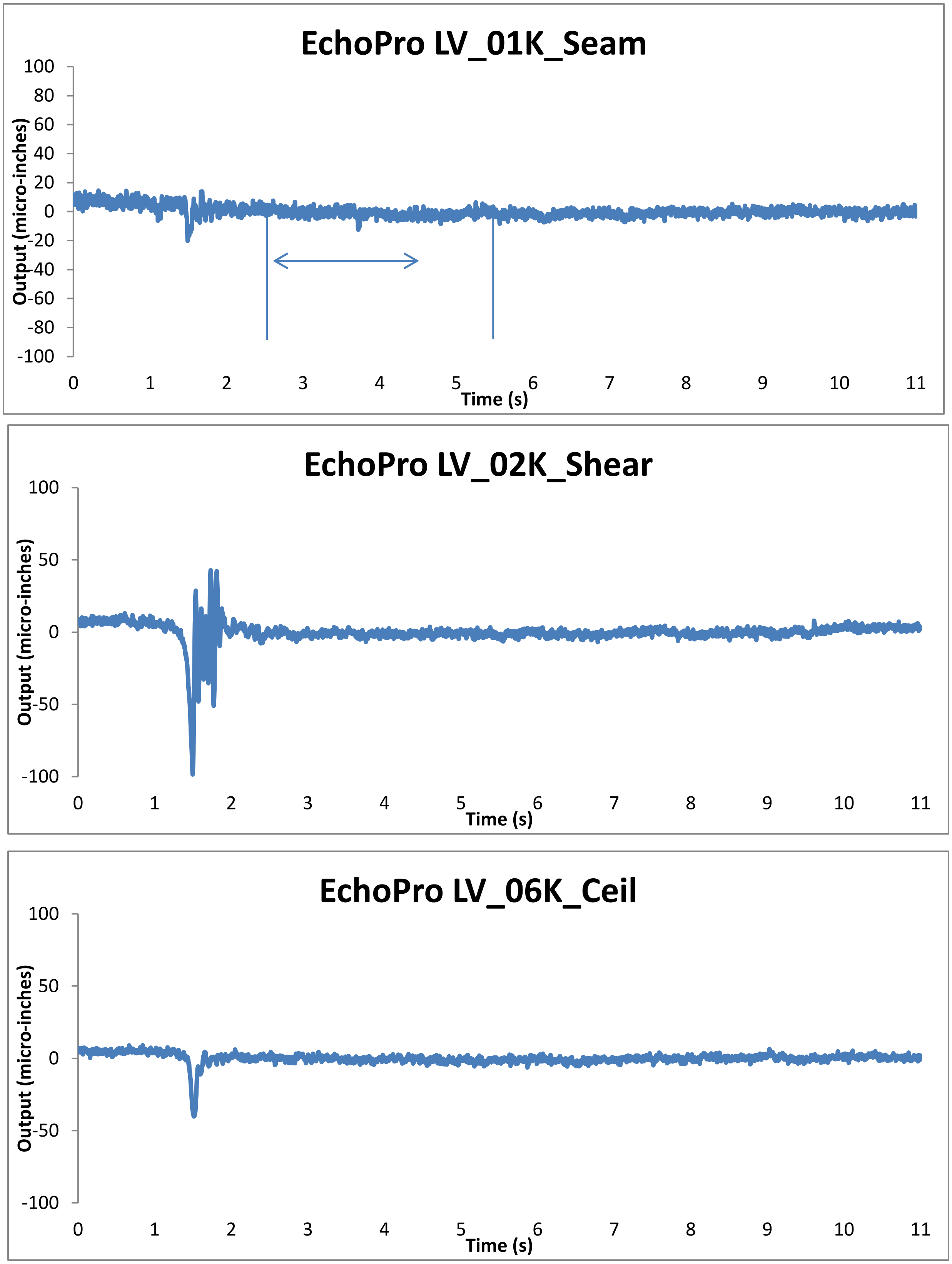


Figure 20: Noise Illustration - EchoPro Full Time History with Annotated 2 Second Window

Appendix A - Kelunji EchoPro Information

-System Summary

The Kelunji EchoPro system is a new hybrid autonomous crack and structural response monitoring (ACSM) system. It is designed as a low cost alternative to the research grade version employing SOMAT's eDAQ data recording system. The concept is to combine a new field portable, 24 bit, 12 channel seismograph with a compliance seismograph. The 24 bit seismograph monitors the crack and structural response, while the compliance seismograph monitors ground motions and air over pressures. As configured the Kelunji EchoPro (KEP) recorder can monitor autonomously monitor crack and structural response in a wide range of field configurations. Cost and simplicity were the main priorities for design of the hybrid system. The full installation, illustrated in Figure 21includes structural response velocity and crack sensors, a LARCOR compliance seismograph with a trigger connection, connector boxes, and the KEP unit. More information on the Kelunji EchoPro recorder can be obtained from the manufacturer's user manual, which can be obtained at (<http://customer.esands.com/index.php?section=45)

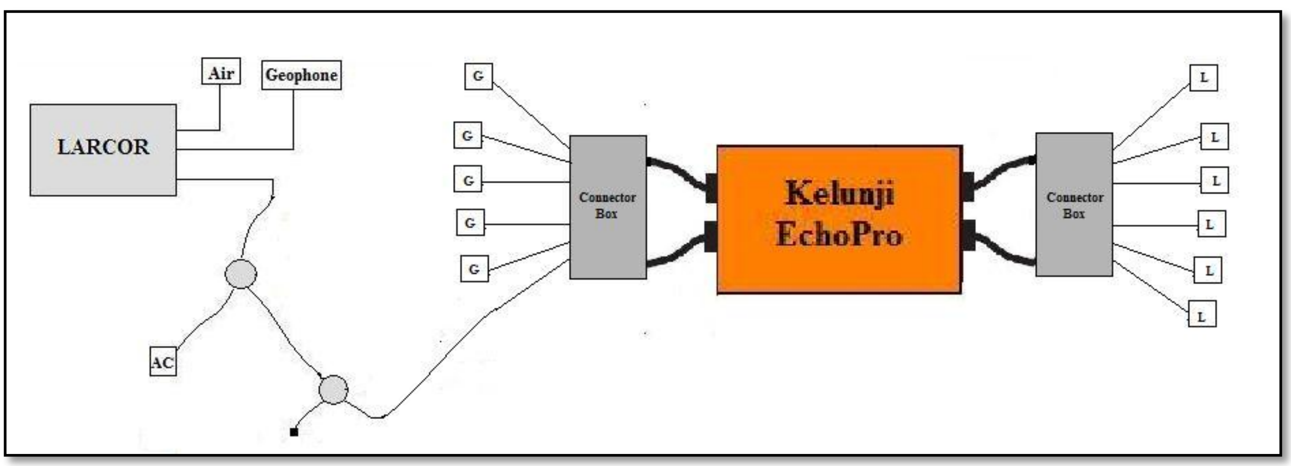


Figure 21: Components of the hybrid autonomous crack & structural monitoring (ACSM) system

-Sensor Summary

Table 7 summarizes the sensors installed with the Kelunji EchoPro. The first column is the EchoPro channel for the given sensor. Columns two and three give the channel name and type of sensor. Columns four, five, and six give the location of the sensor in the house, what the sensor is used for, and serial number of the sensor. Figure 22 to Figure 24 are photographs that show completed installation of sensors on the exterior E-W wall, interior E-W wall, and bedroom ceiling respectively. Figure 25 is a plan view of the house with the location of all sensors. The sensors unnumbered in those photographs are associated with other systems of instrumentation.

Table 7: Floit House Sensor Installation Summary

Channel	Channel Name	Sensor	Location	Use	Serial
1	LV_01K_Seam	LVDT – Displacement Transducers	Exterior E-W Wall	Crack	110890
2	LV_02K_Shear			Crack	102241
3	LV_03K_Null		Interior E-W Wall	Null	110886
4	LV_04K_IntHor			Crack	110885
5	LV_05K_IntVert			Crack	110884
6	LV_06K_Ceil		BR Ceiling	Crack	110887
7	HG_07K_Mid	Geophone – Velocity Transducer	Exterior E-W Wall	Horizontal	N/A
8	HG_08K_1FUp		Interior E-W Wall Upper Corner	Horizontal	N/A
9	HG_09K_1FDwn		Interior E-W Wall Lower Corner	Horizontal	N/A
10	HG_10K_2FUp		BR E-W Wall Upper Corner	Horizontal	N/A
11	VG_11K_2FCeil		BR Ceiling	Vertical	N/A
12	LC_12K_Trig	LARCOR	Outside of Exterior East Wall	Trigger	N/A

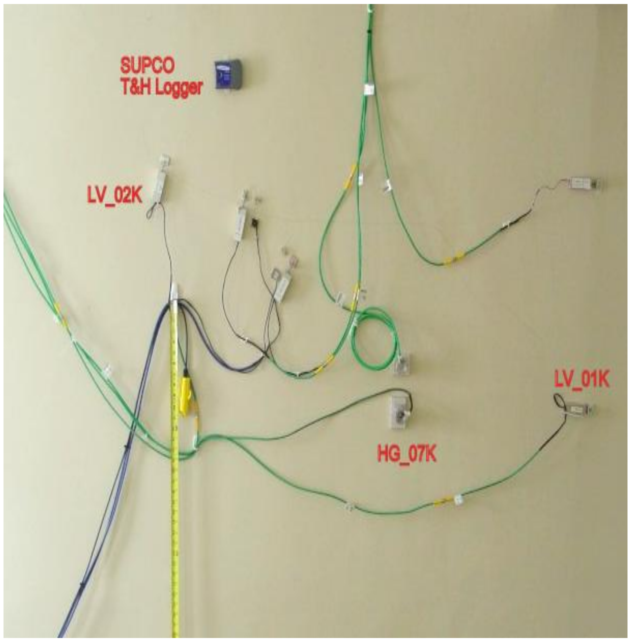


Figure 22: Exterior E-W Wall Sensors

Figure 23: Interior E-W Wall Sensors

Figure 24: Bedroom Ceiling Sensors

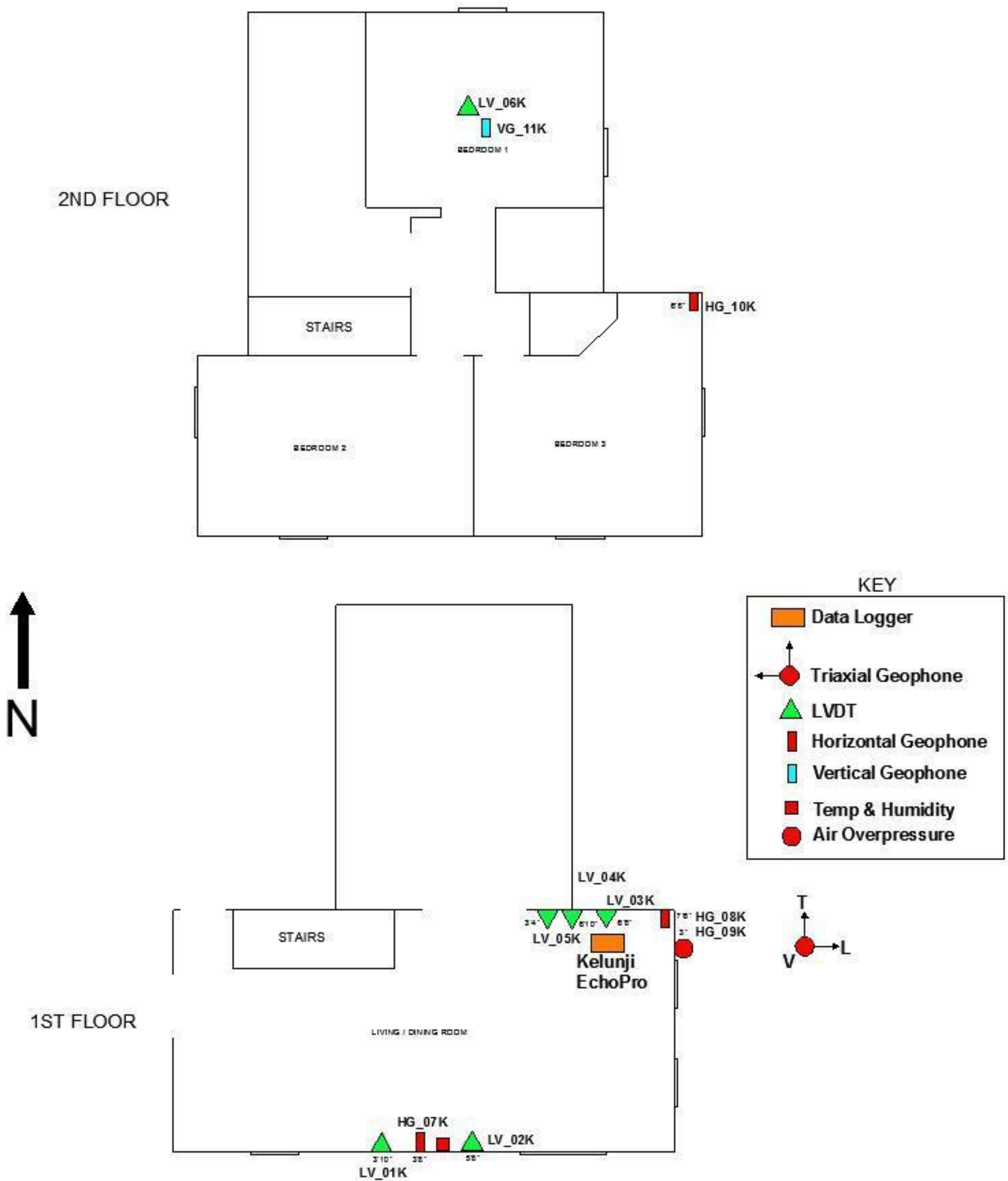


Figure 25: Plan View of Sensor Locations

Appendix B - eDAQ Information

-System Summary

The following information was included from a report by Charles Dowding and Jeffrey Meissner titled Sycamore Installation Report. This report and additional reports and information are available at http://iti.northwestern.edu/acm/publications.html

2.2 SoMat eDAQ System (wired)

The Floit House also has the traditional ACM *wired* system paradigm equipped with SoMat's eDAQ Classic data logger. The system is designed to autonomously monitor ground motion, air overpressure, structural response, and crack response. The data is stored short term in the Floit House, transmitted via the Internet connection in the QC house (shown in **Figure 2.12**), uploaded to an ITI server, and then broadcast over the web for viewing. The eDAQ is programmed to collect both data long-term (every hour) and during dynamic events (1000 Hz sampling) triggered by the triaxial and horizontal geophones.

Figure 2.12 describes the layout of the wired system. The data is transmitted via a Proxim Tsunami point-to- point wireless network connection back to the Internet connection in the QC house.

2.2.1 System Enclosure Contents

The wires running back from the sensors to the eDAQ all meet at an enclosure box behind the stairs in the Floit House. Photos of this enclosure are shown in **Figure 2.13** with **Table 2.1** describing its contents. Additionally, a wiring diagram of this box is shown in **Figure 2.14**.

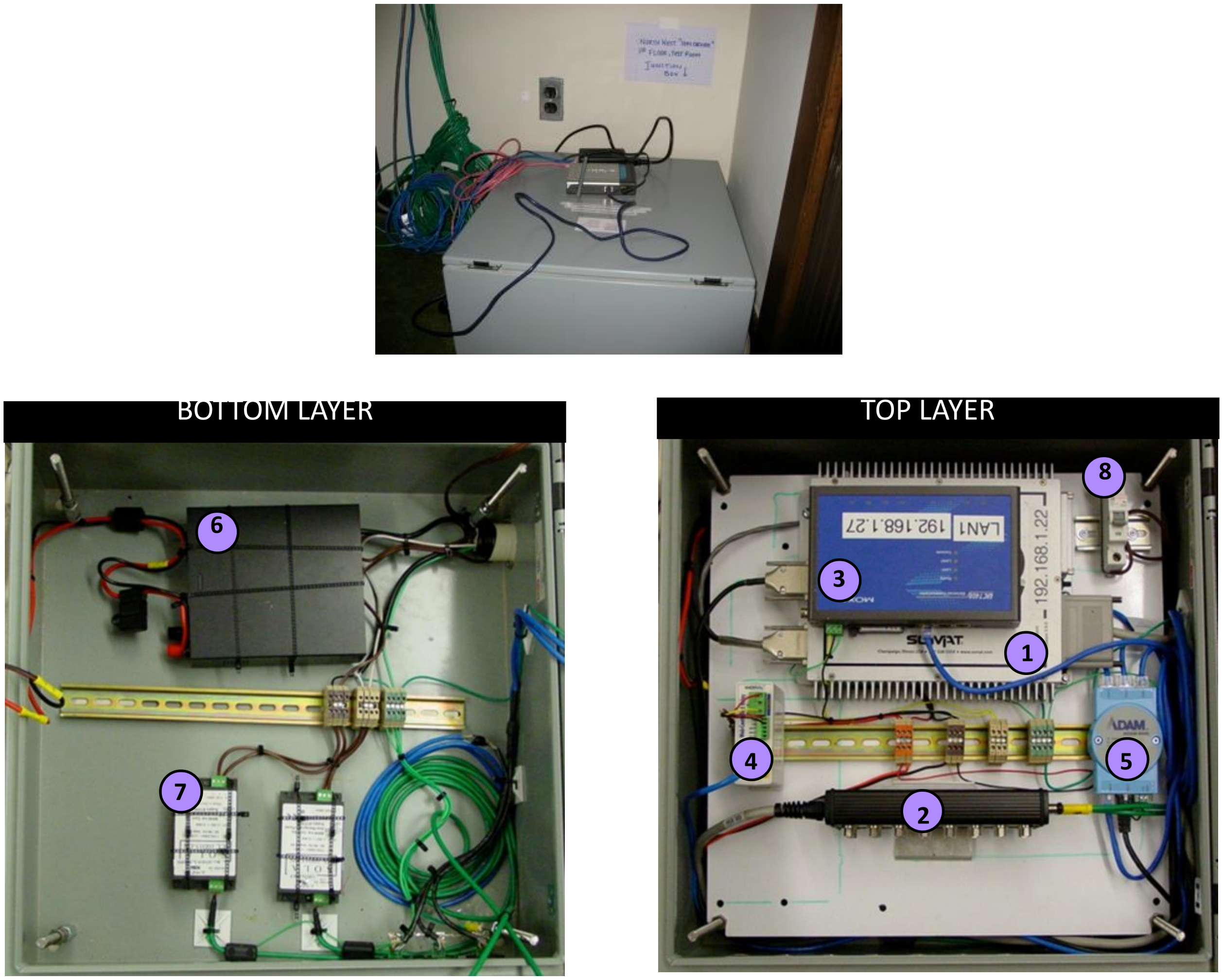


Figure 2.13 - Photographs of enclosure with both top and bottom layer contents

No.	Manufacturer / Product	Model No.	Function
1	SoMat eDAQ Classic	ECPU-HLB	Data Logger with 16 high level analog input channels
2	Analog Input Break Out Box, modified by ITI	1-EHLB-AIBOX-2	16 Channel Board to connect sensors with SoMat jacks
3	MOXA Universal Communicator	UC-7408	Embedded GNU/Linux computer to buffer data and control communication
4	Xytronix Web Relay	X-WR-1R12-1I5-5	Web-based watchdog timer to reset UC necessary
5	Advantantech ADAM Ethernet Switch	ADAM-6520	5-port Industrial 10/100 Mbps Ethernet Switch
6	Radioshack 1.5 amp 13.8 volt DC power supply	22-508	Provides DC power to non-sensor devices
7	SOLA Linear Power Supplies	SCL4D15-DN	Provides low noise, low voltage DC to sensors
8	Cutler Hammer Circuit Breaker	WMS1B15	Provides power protection and acts as power switch

Table 2.1 - Contents of Enclosure with description of function

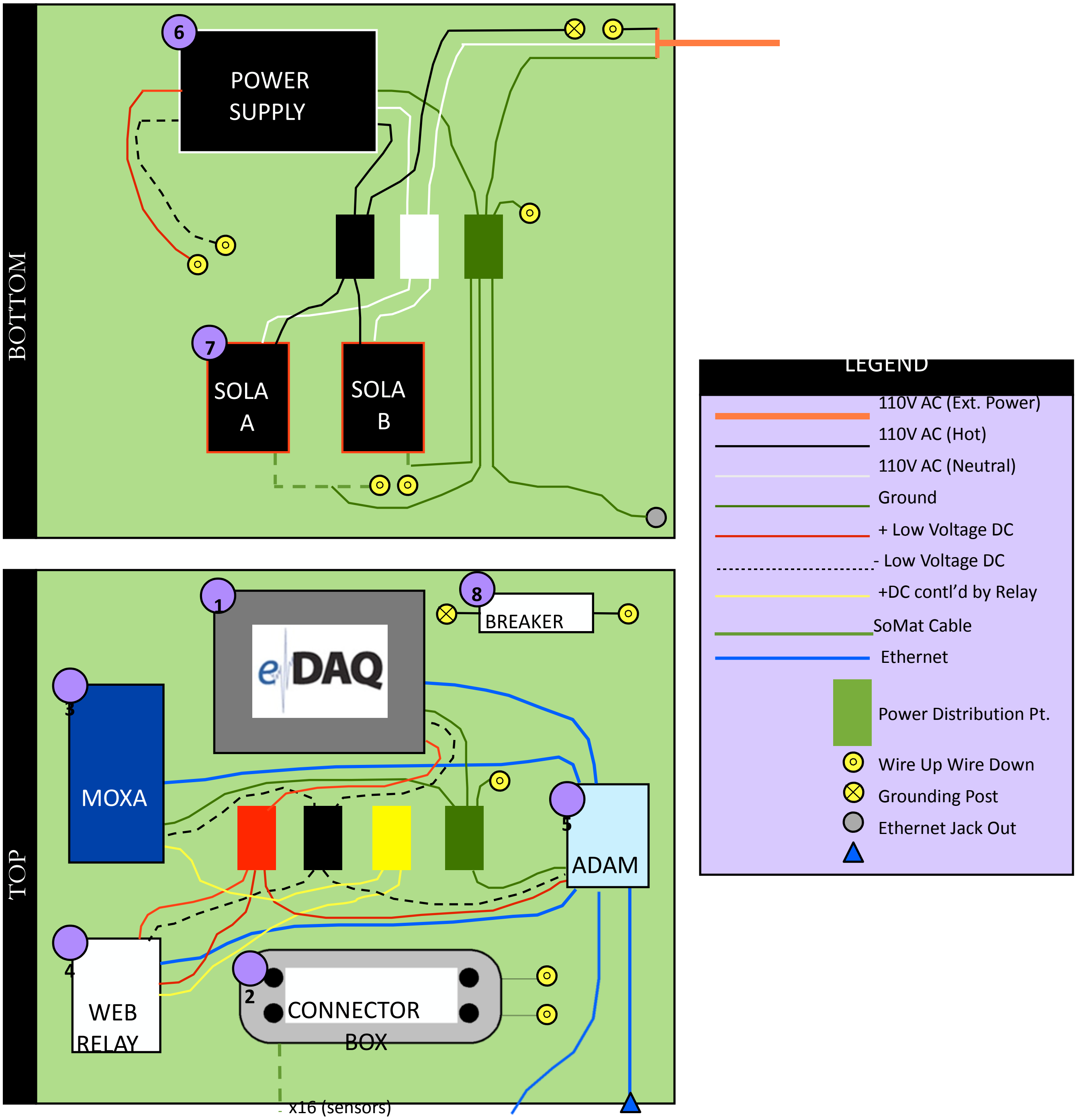


Figure 2.14 - Wiring diagram of top and bottom layers of enclosure in Floit House

2.2.2 Sensor Locations and Nomenclature

The eDAQ has the capability of monitoring 16 channels of which only 12 are occupied in this installation. **Figure 2.15** shows the connector box layout, and **Table 2.2** lists the sensors along with their channel designations and detailed descriptions. **Figure 2.16** shows the sensors' exact locations within the house. Photographs of the sensors are also shown in **Figures 2.17-2.22**. Please see **Appendix C** for calibration sheets for these sensors.

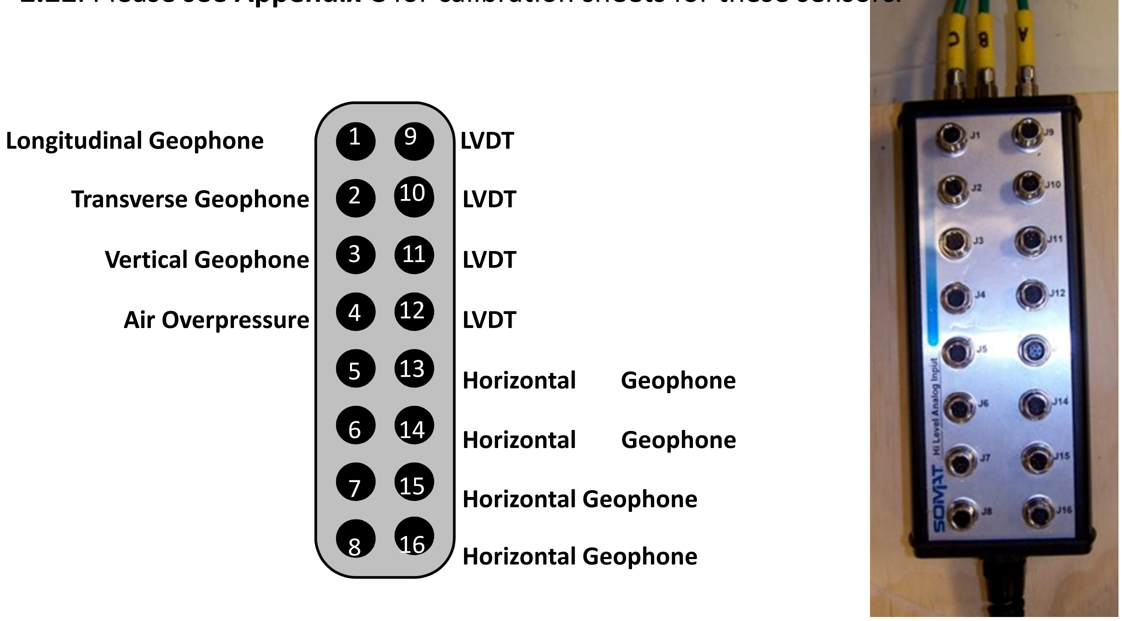


Figure 2.15 - Diagram and photograph of SoMat Connector Box and channel designations

Channel	Channel Name	Sensor	Manufacturer	Model	Serial No.
1	Geo_1_L	Triaxial Geophone (buried)	GeoSonics	N/A	ACM installation Franklin, WI
2	Geo_2_T				
3	Geo_3_V				
4	4_Air	Air Overpressure	GeoSonics	3000 Series	NW 3
5	Vac nt Channels				
6					
7					
8					
9	LVDT_9_Shear	Linear Variable Differential Transformer	MacroSensors	DC-750-050	Old LVDT 5
10	LVDT_10_Null				Old LVDT 6
11	LVDT_11_Seam				Vegas recovered A
12	LVDT_12_Ceil				89735
13	HG_13_Bottom1	Horizontal Wall Geophone (wall-mounted)	GeoSpace	HS-1-LT 98449	N/A
14	HG_14_Top1				
15	HG_15_Top2				
16	HG_16_Midwall				

Table 2.2 - Exhaustive description of sensors and channel designation

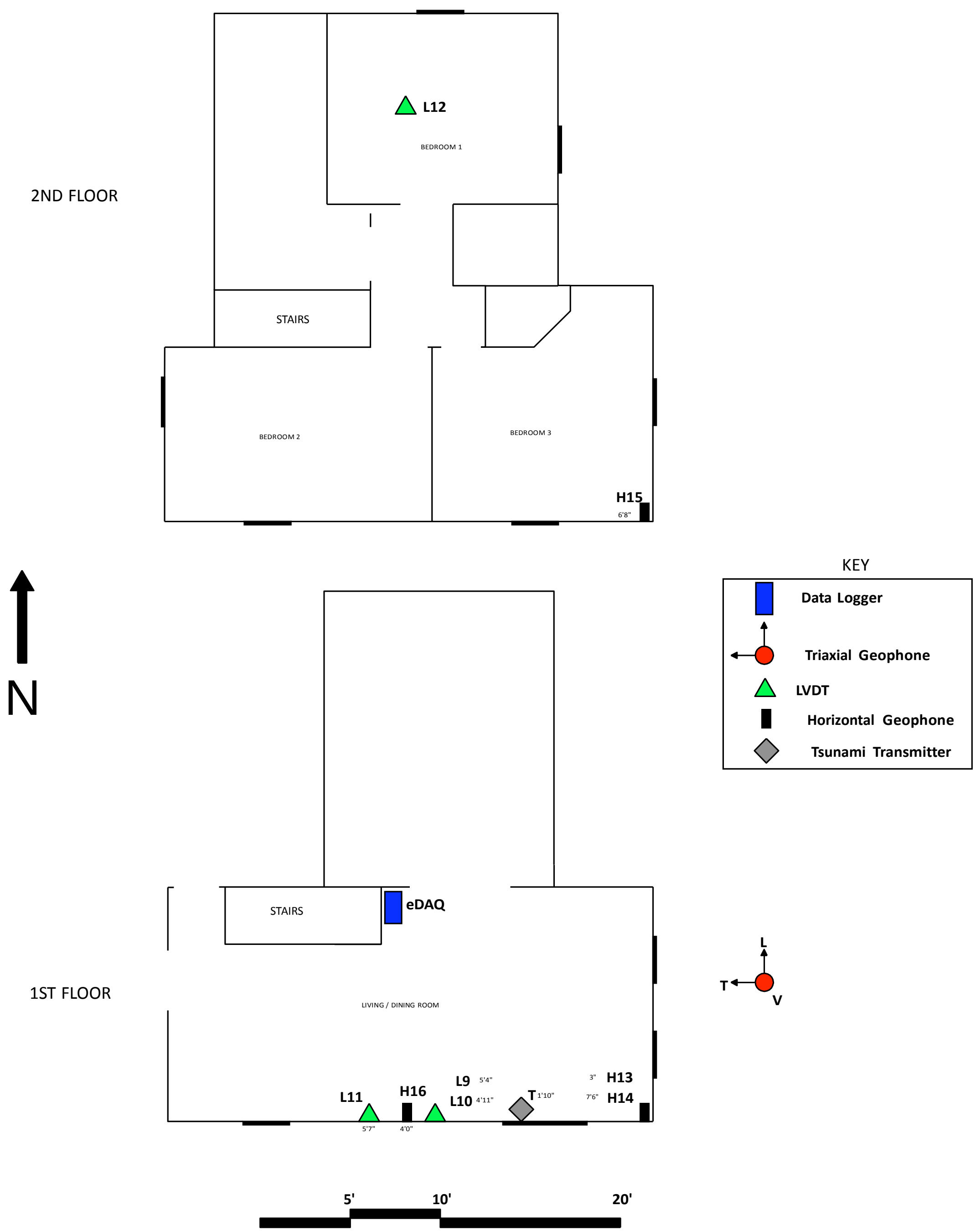
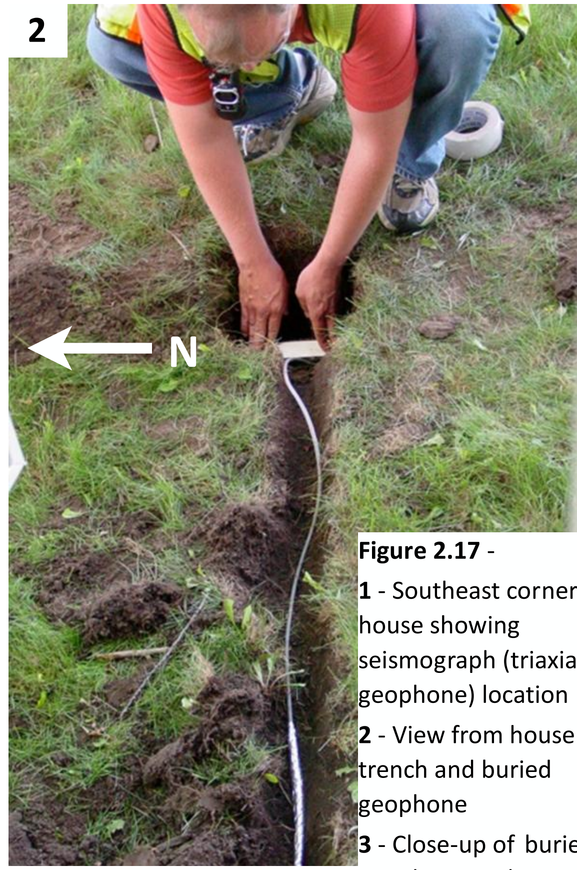


Figure 2.16 - Exact sensor and equipment locations within house. Measure given is distance up wall



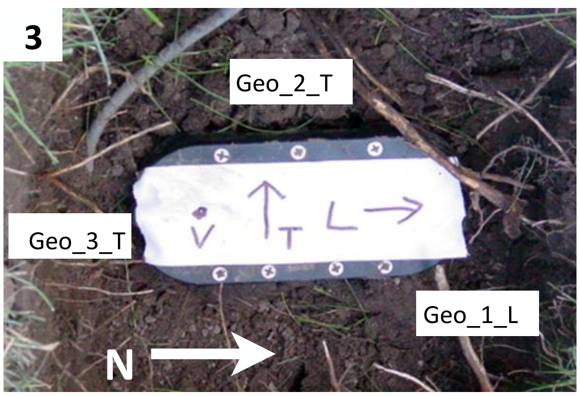
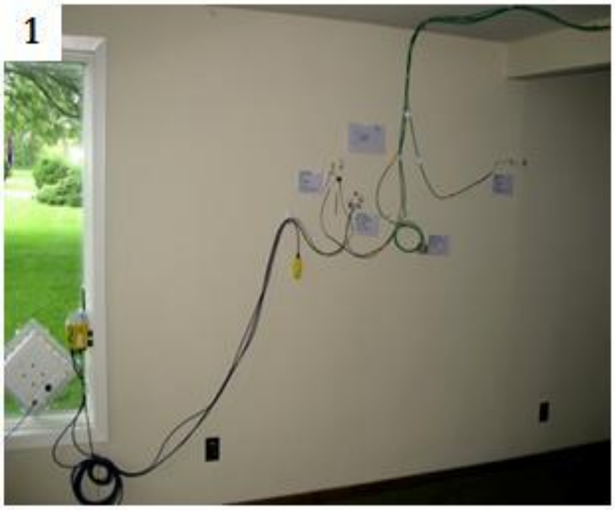
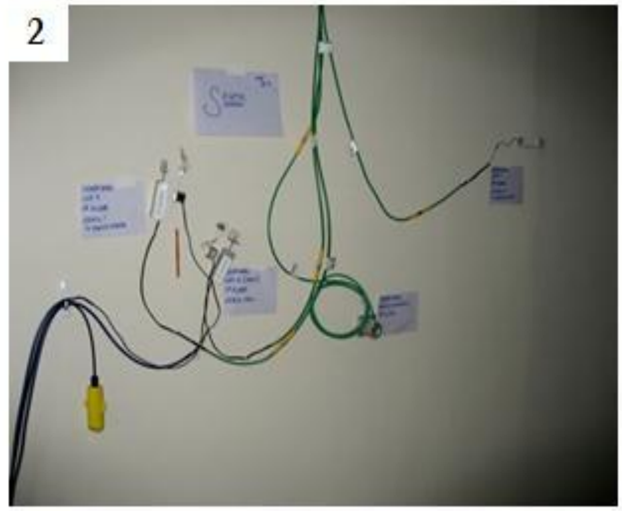
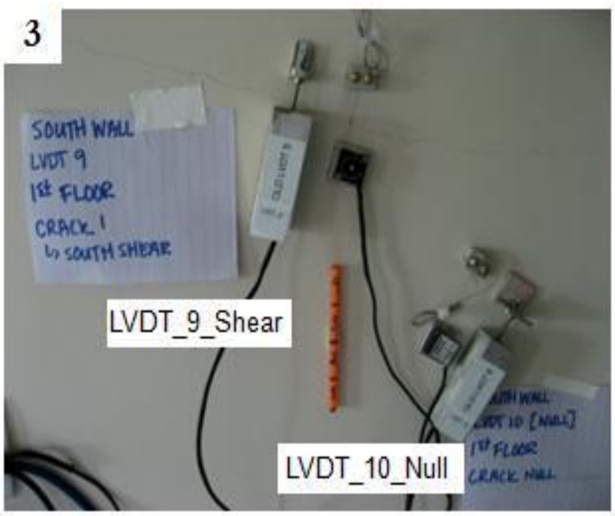
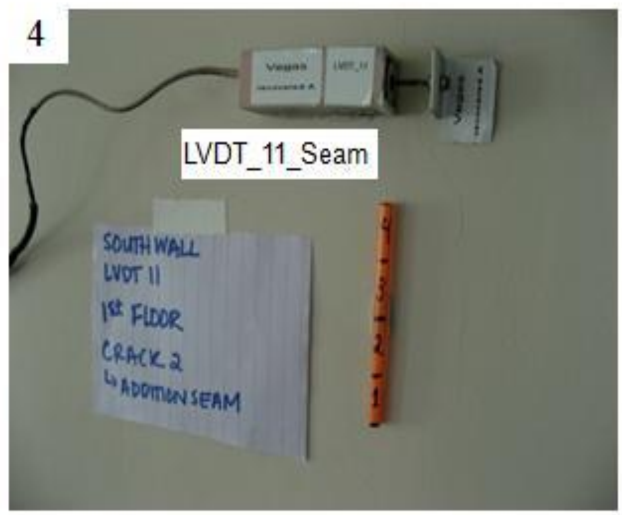


Figure 2.17 -
1 - Southeast corner of house showing seismograph (triaxial geophone) location
2 - View from house of trench and buried geophone
3 - Close-up of buried geophone with longitudinal axis pointing north toward the quarry









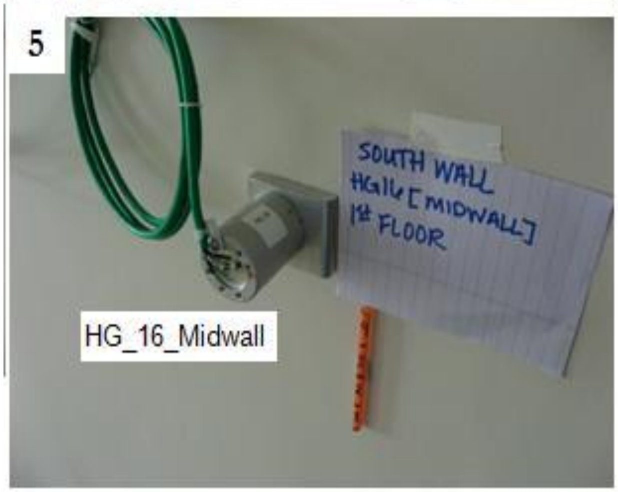


Figure 2.19 -

1 - Overall view of sensor suite on south wall (first floor)

2 - Closer view of suite on south wall

3 - Close-up of Shear crack monitored by LVDT_9 and Null gauge LVDT_10

4 - Close-up of Addition Seam crack monitored by LVDT_11

5 - Close-up of midwall geophone monitored by HG_16

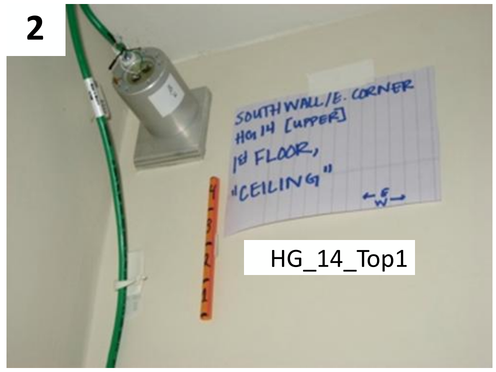
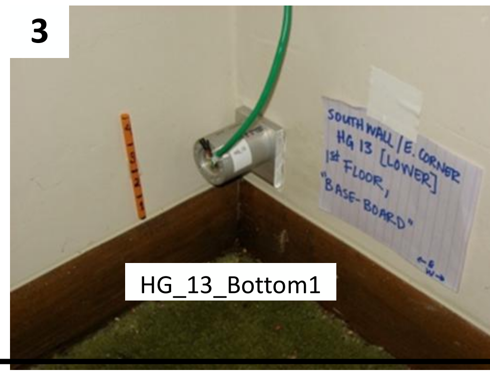


Figure 2.20 -

1 - Overall view of southeast corner geophones on first floor

2 - Close-up of top geophone monitored by HG_14

3 - Close-up of bottom geopohone monitored by HG_13



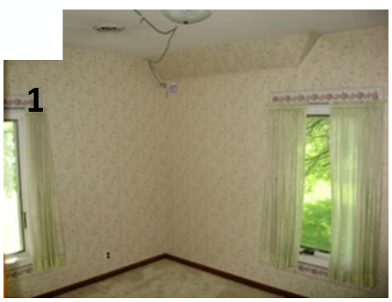


Figure 2.21 -

1 - Overall view of second floor bedroom geophone on south wall

2 - Closer view of geophone below slanted ceiling in top corner

3 - Close-up of top geophone monitored by HG_15

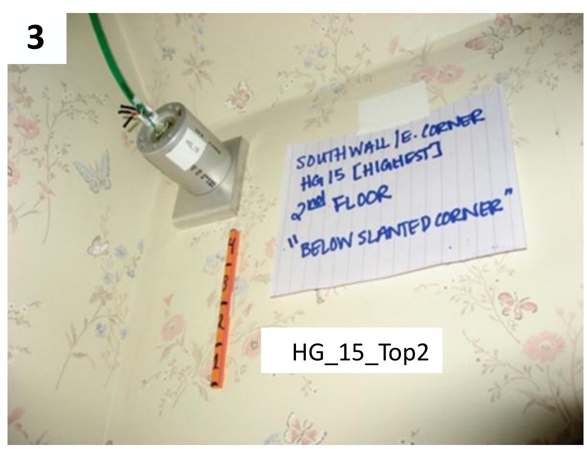


Figure 2.22 -

1 - Overall view of ceiling crack from hallway outside bedroom (looking North)

2 - Closer view of ceiling crack inside bedroom (looking West)

3 - Close-up of ceiling crack monitored by LVDT_12

Appendix C - ēKo Mote System Information

-System Summary

The following information was included from a report by Charles Dowding and Jeffrey Meissner titled Sycamore Installation Report. This report and additional reports and information are available at http://iti.northwestern.edu/acm/publications.html

2.1 ēKo Mote System (wireless)

The REG installed a wireless sensor network (WSN) to monitor long-term changes in two cracks at the Floit House in conjunction with temperature and humidity. The WSN in Sycamore is a multi-hop system that consists of 4 nodes (motes) and a base station at the QC house. Data is collected from the sensors at the nodes and is then relayed back to the base station. **Figure 2.1** shows the location of the nodes within the wireless mesh network. **Figures 2.3-2.6** below also show detailed photographs of the mote locations.

2.1.1 Mote Locations

Figure 2.2 - Exterior view of southwest corner of instrumented Floit House, showing where Node 2 is inside.

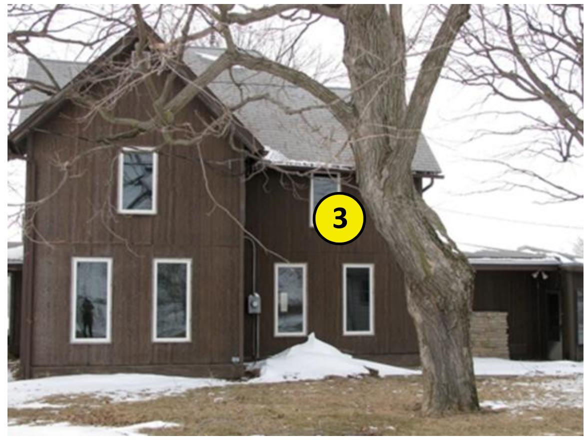


Figure 2.3 - Exterior view of east wall of instrumented Floit House, showing where Node 3 is inside.

Figure 2.4 - Node 4 as relay point on telephone pole

Figure 2.5 - Node 5 as relay point on telephone pole

Figure 2.6 - Node 0 is base station inside QC house

2.1.2 Sensor Locations and Nomenclature

The Floit house is outfitted with 3 high precision String Potentiometers (Firstmark Controls 150 series). S1 and S3 measure cracks, while S2 is a null gauge. **Figure 2.7** shows the exact sensor locations within the house and **Figures 2.8-2.11** show photographs of the installed equipment.

Figure 2.7 - Exact sensor and equipment locations within house. Measure given is distance up wall

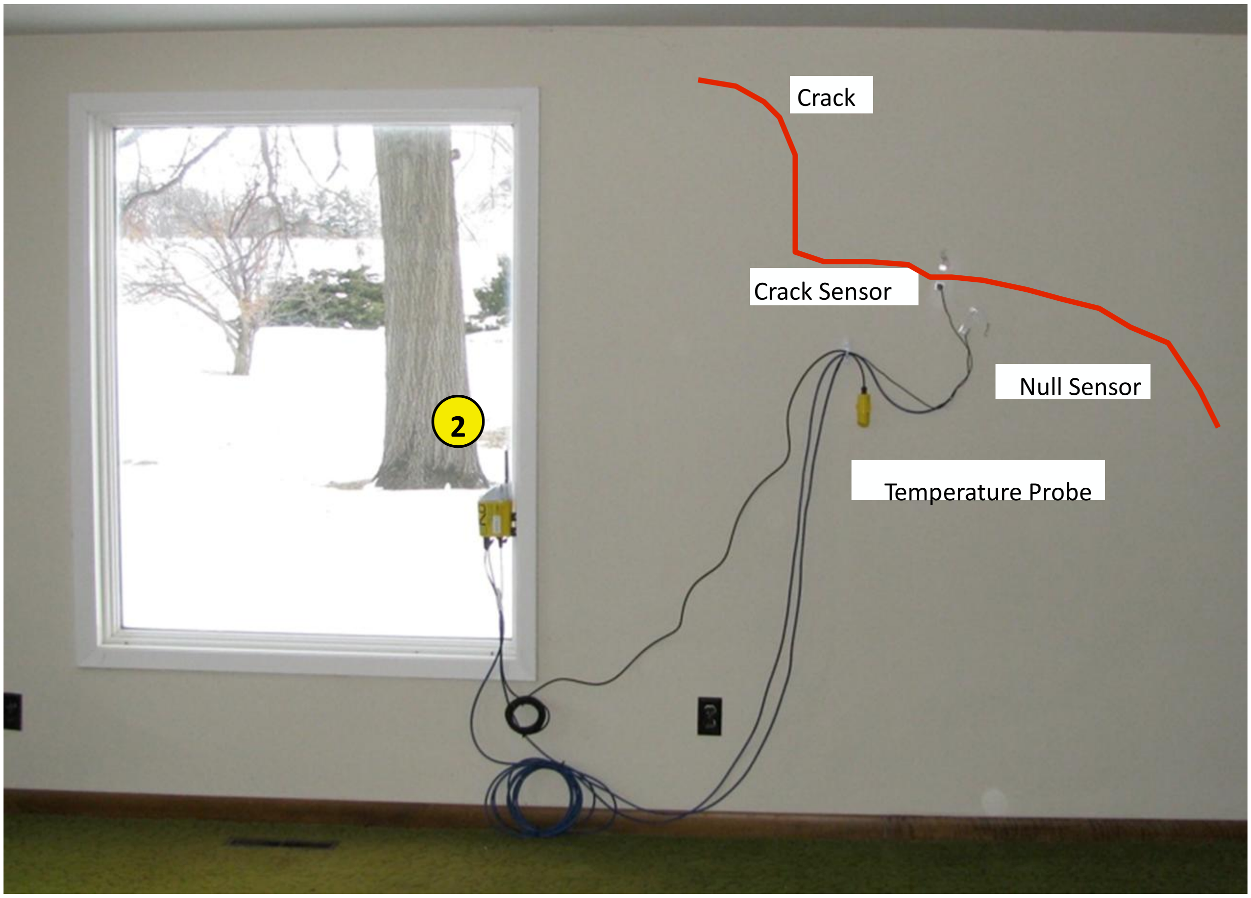


Figure 2.8 - Interior view of Node 2 in living room. Crack sensor, null sensor, and temperature probe connected to eKo
Mote.

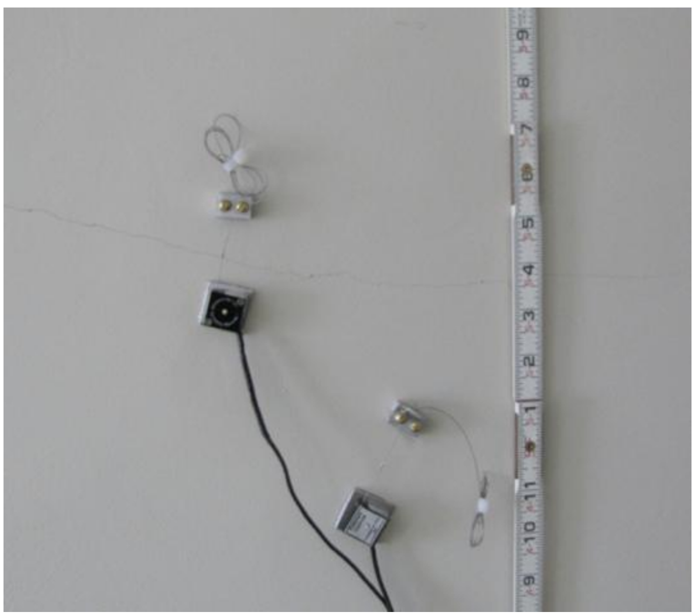


Figure 2.9 - Close-up of crack sensor and null sensor. Both instruments are string-potentiometers

Figure 2.10 - Interior view of Node 3 in upstairs bedroom. Crack sensor connected to eKo Mote.

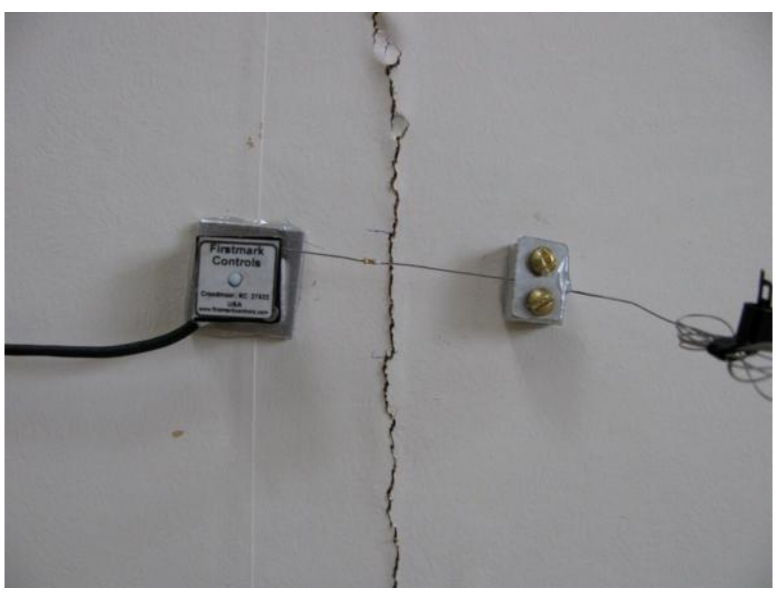


Figure 2.11 - Close-up of string-potentiometer across ceiling crack