NORTHWESTERN UNIVERSITY

Autonomous Crack Comparometer

A Thesis

Submitted to the Graduate School
In Partial Fulfillment of the Requirements

For the Degree

MASTER OF SCIENCE

Field of Civil Engineering

By

Damian R Siebert

EVANSTON, IL

June 2000

ACKNOWLEDGEMENTS

I would like to thank my advisor Professor Charles Dowding not only for his support and encouragement in the writing of this Masters Thesis, but for being a friend and a mentor. Professor Richard Finno, Professor Howard Reeves, and Professor Raymond Krizek are thanked for their support and teaching during my time at Northwestern University.

Thanks are also given to the staff of the Infrastructure Technology Institute and in particular Dan Marron for all his advice and assistance during the project (good luck with the baby).

I would like to thank all of the fellow graduate students and friends I have made while at Northwestern University for their support, encouragement and friendship, including Sebastian Bryson, Kristi Kawamura, Michele Calvello, Richard Cole, Joe Schulenburg, Jejung Lee, Hsiao-chou Chao, Elisa Budyn, Dan Priest, Peter Babaian, Jill Roboski, Amy Rechenmacher, Matthew Fortney, Benoit Paineau, and Bill Bergeson. Good luck to Michael Loius who will take over this research.

I would like to express thanks to all my friends who encouraged me in this undertaking and have kept me sane throughout the process.

I would like to thank my family, Mom, Dad, and Peter for their support, encouragement, and love.

I would especially like to thank Liz Canter who has, encouraged, aided, and put up with me throughout this entire process. Her love and understanding has helped me more than I can describe. I would be lost without her. I promise I won't make her read it again!

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

NEED FOR NEW APPROACH TO VIBRATION MONITORING

Public concern over construction vibration-induced cracking has led to the development of a radically new approach to vibration, an autonomous crack comparometer (ACC). This thesis chronicles the first step of developing equipment and software necessary for this system. The new system will automatically compare long-term weather induced micrometer changes in crack width with those produced by habitation ground motion. This comparison will then be displayed in real time via the Internet without human interaction.

Comparison of long-term changes in crack width along with weather and vibration-induced changes in crack width can change public perception of the effects of vibration. As can be seen in the detailed case study by Dowding (1996), long-term and weather-induced distortion of structures is greater than that caused by present levels of allowable construction-induced vibration. However, since humans feel vibration response and not weather response, vibration is invariably blamed for defects noticed by neighbors who are upset by construction activity.

Furthermore, graphic display of the parameters over the Internet allows a visual comparison of these differing phenomena that is otherwise not possible. Visual comparison avoids the abstract complexity of vibration time histories and required belief of past studies that compare vibration levels with crack initiation. Most importantly of all, the Internet provides a mechanism for direct public participation in data collection and interpretation.

PRINCIPLE OF MICROMETER MONITORING OF CRACKS

Micrometer changes in crack width are conducted with proximity sensors developed for computerized numerically controlled (CNC) manufacturing. The robustness of these systems necessary to survive the manufacturing floor is sufficient for use within structures adjacent to construction projects. These proximity devices are able to respond dynamically as well as statically. Thus the same gages are able to measure micrometer changes in width produced by both long-term changes in temperature and humidity as well as dynamic, construction-induced excitation. This project integrates these micrometer devices with existing miniaturized vibration monitors to relate crack width changes to construction vibration events. Thus it has not been necessary to develop an entire system from whole cloth.

PROJECT GOALS

There are two goals of this project. The first is to implement and commercialize seismographic instruments that can measure micrometer changes in crack width produced by both transient construction vibrations and long-term environmental effects. The second is to provide via the Internet these data in real time to the public in a form that allows direct visual comparison. This new approach has the potential to be a cost effective means of informing the lay public of, and controlling that which is of concern, crack movement, during vibration producing construction. The overall objectives of this project are to:

- Determine the optimal micrometer proximity measurement system for measuring crack movement;
- Integrate proximity measurement and environmental observation with traditional vibration measurement;
- Display the comparisons of long-term and vibratory crack deformation in real time via the Internet;
- Demonstrate the robustness, reliability, cost effectiveness, and limitations of micrometer proximity measurement within structures;
- Report the results of field trials of this equipment.

This thesis is a major step toward the realization of these project goals.

ADVANTAGES OF PROPOSED TECHNOLOGY

The proposed technology directly measures crack behavior. Rather than measure only ground motion, which in turn is correlated with the results from previous studies, crack behavior is also measured directly. This direct measurement is simple to understand and requires no reliance upon previous work by others. Most importantly, the same device, when placed across a crack can be employed to measure changes in crack width that result from either vibratory or environmental effects such as temperature and humidity. Full time-histories of vibratorally-induced changes in crack width can be recorded along with the long-term effect of environmental changes by the same gage or sensor.

The current approach of comparing measured ground motions time-histories with those that caused past cracking in representative structures is inherently complex to understand, and requires belief in the results of previous studies of critical levels of ground motion. These two requirements sometimes lead to illogical results in court. Despite volumes of evidence, some juries to ignore the basic physics of the situation. While there are no doubt many reasons for this dismissal of science, the complexity of ground motion's description and the need to believe past reports certainly are at the head of the list.

The crack measurement approach eliminates the need to convince anyone of validity of past correlations or to instruct them about ground motion with all of its attendant scientific complexity.

UNIQUENESS UPON THE TECHNOLOGICAL STAGE

This project combines two technologies not heretofore integrated along with delivery over the Internet. Internet delivery increases public access to data, which in this case should lead to greater appreciation of the relative effects of the forces affecting crack response. These data can be accessed and compared with relatively little explanation.

The device is unique in that it will be the first portable instrument to provide the ability to relate time-histories of crack movements to particle velocity time-histories on the same time scale. It combines micrometer proximity measurement with miniaturized, digital seismograph technology.

ESTIMATED MARKET POTENTIAL

The market potential for this equipment can be estimated (Dowding 1999). There are three stages in the development of the market. The initial stage will involve concept development. During this stage only those closely involved in the development will push for deployment. In the second stage, professional adoption, consultants other than the original equipment manufacturers (OEM's) will suggest deployment and competing OEMs will offer similar products. The third stage, codification, will involve the adoption by the regulators and professional societies. Market size will be estimated for the first and second stages together, and the ultimate market separately.

The ultimate market size is in the low thousands. All significant infrastructure renewal projects involve construction close enough to structures for vibrations to be perceptible. It is not an overstatement to estimate that there is at least one lawsuit over alleged vibration cracking in each of the fifty United States of America while this sentence is being written. Thus it would seem that ultimately each year there are some fifty to one hundred lawsuit driven situations that could and should have involved such a monitoring approach. In addition, there are thousands of coal mines and quarries that are required to employ vibration monitoring instruments. Not all of the instruments presently deployed need to be replaced by a crack monitoring unit. Ten per state, or five hundred would be a reasonable estimate. Thus ultimately there is a potential market size in the high hundreds to one thousand for these instruments in the United States alone.

In the near term during the developmental and professional adoption stages, the number of deployed instruments should double each year for the next ten years. It is expected that in the first year some two to four units would be deployed. Currently three primative versions of the concept are deployed in Date County, Florida to illuminate the factors that affect changes in crack width (Dowding, 2000).

FOCUS OF THESIS

This thesis describes in detail three phases of the Autonomous Crack Comparometer (ACC) development and implementation with a focus on the first phase (I). A comprehensive description of the system developed at Northwestern University, presentation of results from the current test site, and recommendations for future work are included. Phase I is the system as it is operating currently. Phase II and III are the modifications of the system required to create a complete and fully functional product. The ACC measures micrometer displacements of cracks in a house and can compare changes in crack width with those caused by weather, habitation vibrations, and construction or blast vibration. These comparisons, along with past research, will show which factor has the greatest impact on crack movement (weather, habitation, or ground motion).

Organizationally, the thesis builds outward from the sensors to the Internet and includes an analysis of the relative effects of weather and habitation vibration. Chapter Two will discuss the sensors employed to measure micrometer crack displacement as well as give solutions for sensor variations. The hardware that comprises the system is described in Chapter Three. This chapter also lists the changes in Phase I equipment required for the system when a standard vibration monitoring device is installed. A crucial attribute of the system is it complete automation that eliminates mush of the data analysis once the hardware is installed. Complete automation is accomplished by a variety of software packages and programs, which are described in Chapter Four. Field measurements in a wood frame house made with Phase I instrumentation are presented in Chapter Five, along with correlations with past research that confirm the results. The web site that displays the information from the ACC is described in Chapter Six. This Chapter presents the organization of the site and the methodology of its design. Chapter Seven outlines the cost of the current system along with the expected costs for installation of this system by others if given the software. Finally, Chapter Eight summarizes the accomplishments to date and the limitations of the current ACC system in order to recommend future improvements.

CHAPTER 2

MICROMETER DISPLACEMENT

INTRODUCTION

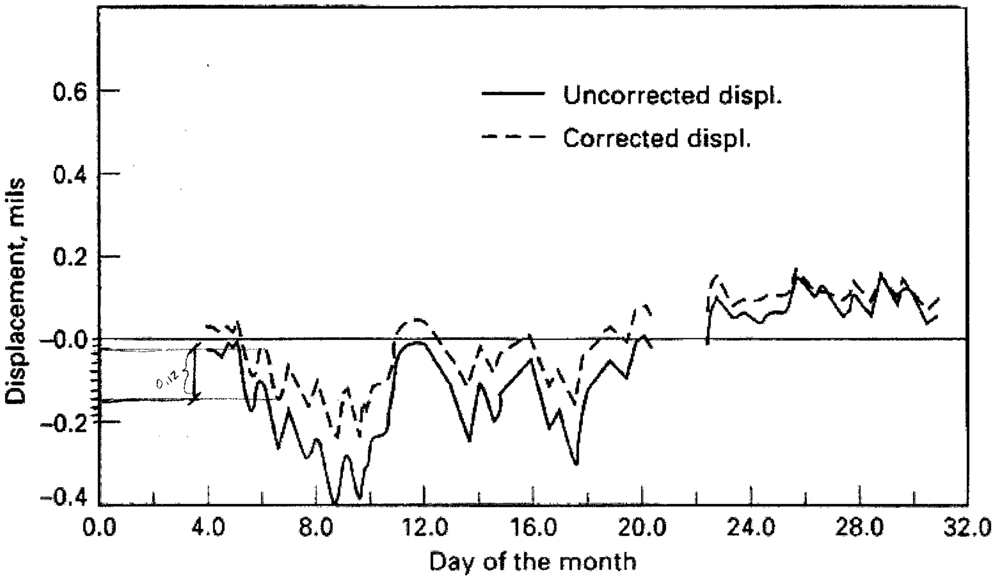
A number of types and brands of micrometer displacement sensors are envisioned to be compatible with ACC system. As a first step several were evaluated to determine which would be best-fit current system requirements. Attributes of importance include: price, size, resolution, and range. This chapter describes the requirements and compares the attributes of the displacement sensors tested, as well as possible procedures to improve sensor accuracy.

MICROMETER DISPLACEMENT SENSOR REQUIREMENTS

There are several requirements of the displacement sensors for the current system. First, they must be small, so they do not interfere with household activity or seem too obtrusive to those who would live with them on their home walls. Since they would be placed predominantly inside a house they should be as inconspicuous as possible. Second, they must be inexpensive as price is always an issue. Normally the “best” equipment is not the lowest priced equipment. The system will eventually be marketed to companies and therefore it must be affordable.

Third, they must have high resolution, which is determined from experience. Figure 2.1 from past measurement portrays changes in crack width over a thirty-two day time period (Dowding, 1996). Over a one-day time period the crack width changes cyclically 3 micrometers (0.00012 inches). To make apparent such small changes over a twenty-four period, a resolution thirty times greater than this movement is desirable, which results in a desired resolution of 0.1 micrometers (4 microinches).

Fourth, they must have an appropriately high measuring range. Figure 2.2 from past experience illustrates crack width changes over two-thirds of a year that includes the January heating season. The total movement of the crack during the heating season does not exceed 0.1 mm or 100 micrometers. Since not all cracks behave the same, this range could be extended +/-200% to account for cracks with a larger movement potential. This results in a measuring range of 400 micrometers. If the displacement sensor is placed in the middle of this range it is required to follow movements of no less than +/- 200 micrometers.



0.12 mils $\frac{0.12 \text{ mils}}{30}$ = .004 mils or 4 μin

Figure 2.1 Crack Width Change During Passage of Several Weather Fronts Plotted at a Scale to show Daily Oscillations and Required Resolution (Dowding, 1996)

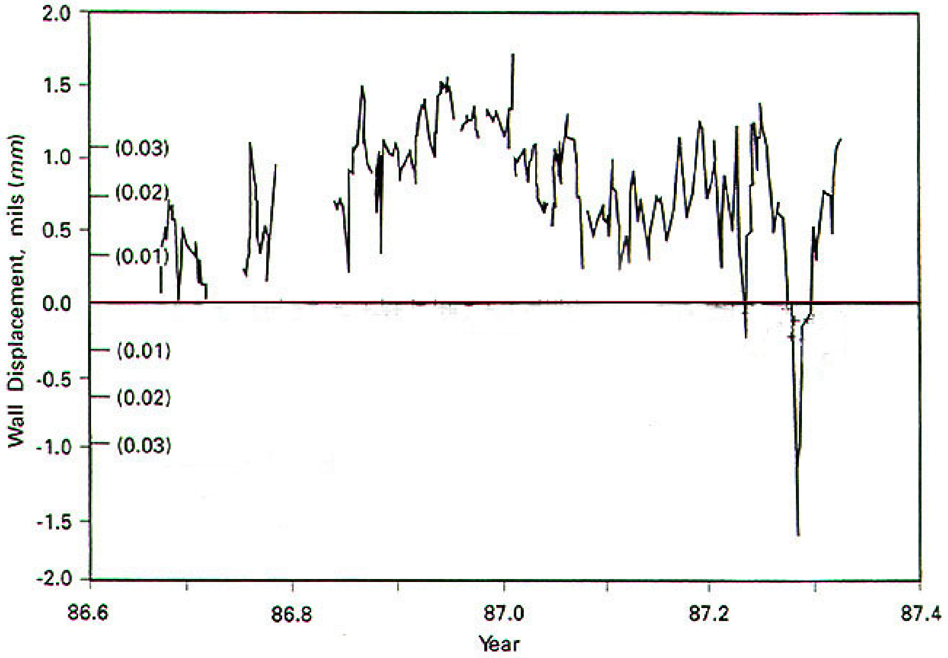


Figure 2.2 Crack Width Change During Two-Thirds of a Year Including the Heating Season

CRACK DISPLACEMENT DEFINITION

Change in crack width is defined with the help of Figure 2.3. The sensors do not measure total crack width but rather the change in the crack width. As illustrated by the Figure the crack changes width during various events that are described in greater detail throughout this paper. From this point on this change in crack width will be referred to as displacement.

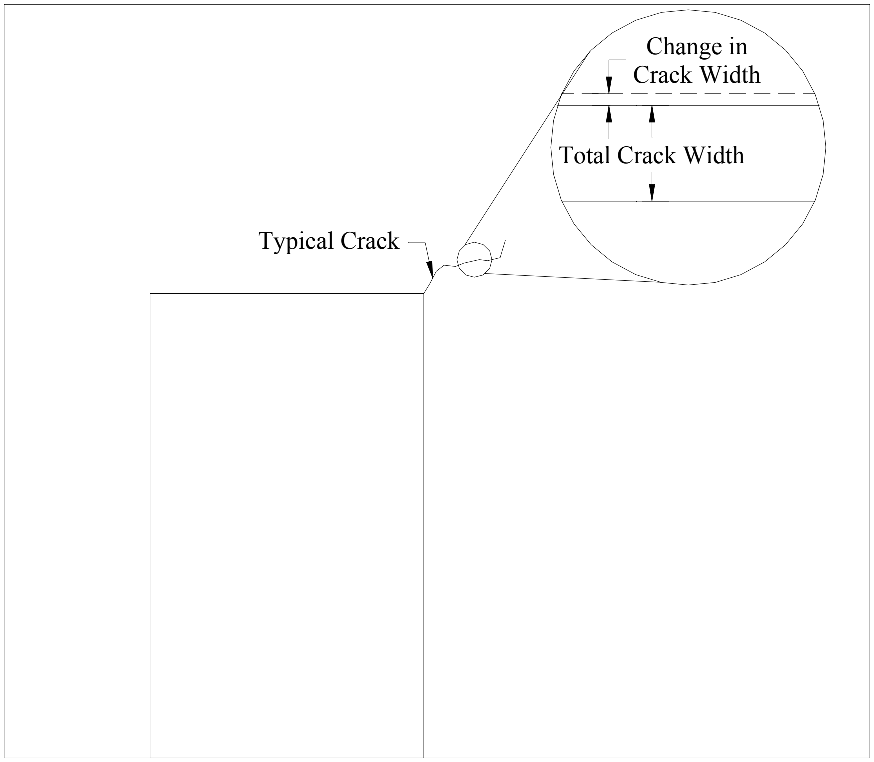


Figure 2.3 Definition of Crack Width Displacement and its Measurement

The change in crack width that is measured is very small change. Figure 2.4 compares the average diameter of a human hair with the maximum change in crack width for this thesis.

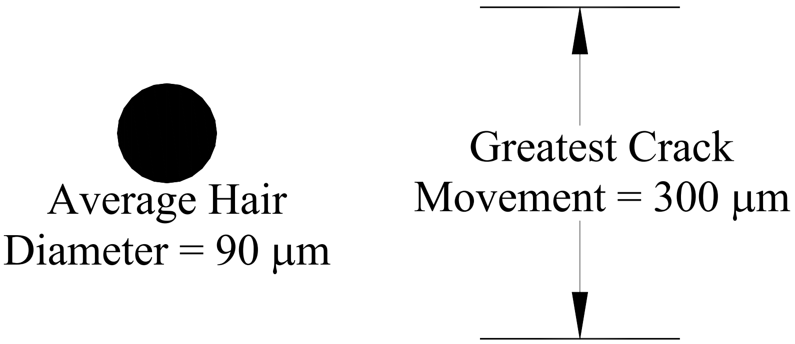


Figure 2.4 Comparison of Hair Diameter to Crack Movement

SENSORS STUDIED

There are many different types of displacement sensors on the market; however, only two were analyzed during Phase I: the Linear Variable Differential Transformer (LVDT) and the lowest priced Kaman eddy current sensors. Figure 2.5 shows a schematic drawing of the LVDT sensor. An LVDT is a small transformer that consists of encapsulated coils of wire around a cavity in thermally stable material, which is further encapsulated against moisture within a stainless steel housing. The moving element in the LVDT is a tubular core of magnetically permeable material that is free to move axially within the coil's cavity. Changes in the magnetic field in the cavity, caused by movement of the core, are converted by integrated electronics into a voltage signal proportional to the displacement of the core.

The resolution of the LVDT is theoretically infinite and depends upon the analog to digital (A/D) converter to which it is connected. However, limitations such as electronic noise prevent infinite resolution. The A/D converter employed with the LVDT has 12-bit resolution. The scale factor that converts voltage to displacement for the LVDT employed on this project is 7.87 volts/mm.

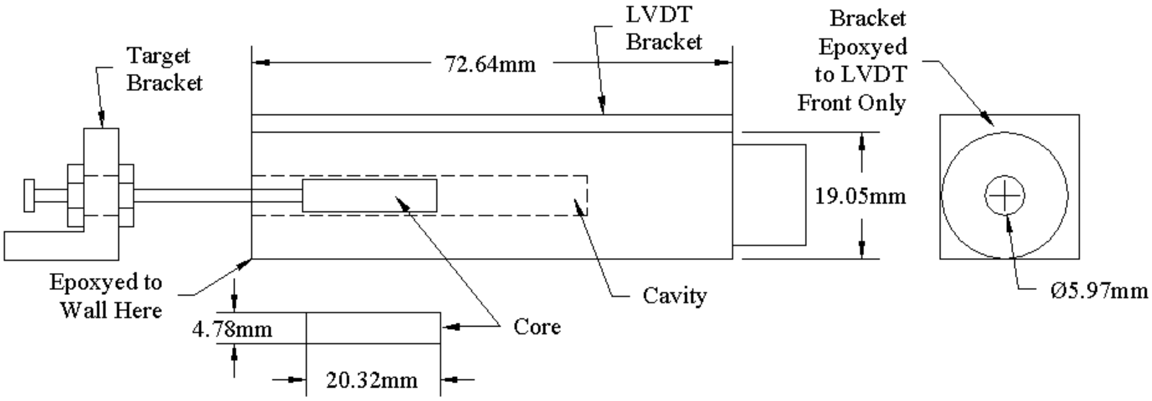


Figure 2.5 Schematic Drawing of LVDT Sensor Showing Target and Mounting Brackets

A 12-bit A/D converter can resolve 4096 (2^12) steps. If the number of possible increments is multiplied by the required resolution per increment, the measuring range of the sensor can be determined. This range is calculated in mm and is converted to volts in Equation 2.1. In order to take advantage of the full 12-bit range the voltage range should be set to +/-3.2 volts/2 = 1.6 volts. This setting allows for adjustment if the sensor moves out of range, which will be discussed later in this chapter. Equation 2.1 shows the formula used to calculate the measuring range of the sensor based upon a 0.1-micrometer resolution.

$$7.87 \text{ volts/mm} \times 0.0001 \text{ mm/div} \times 4096 \text{ div/range} = 3.23 \text{ volts/range} \qquad \text{(Eqn. 2.1)}$$

Figure 2.6 shows a schematic of the Kaman sensor. The Kaman sensor employs eddy current technology, which sends an AC current to the sensor coil to produce an oscillating electromagnetic field. Placing the coil a nominal distance from an electrically conductive target induces a current flow on the surface and within the target. This current, called an eddy current because of its circular pattern, produces a secondary magnetic field that opposes and reduces the intensity of the original field, thus creating a coupling effect. The strength of the electromagnetic coupling between the sensor and target depends on the gap between them. This coupling is converted by the sensor electronics into a voltage signal proportional to the gap distance. The maximum resolution of the Kaman sensor is not infinite, but is much smaller than the 0.1 micrometers required of this project.

Like the LVDT, the Kaman resolution depends on the A/D converter, which in this case has 12-bit resolution. The scale factor that converts voltage to displacement for the Kaman sensor employed on this project is 0.787 volts/mm. Equation 2.2 shows the formula to calculate the measuring range of the sensor based upon a 0.1-micrometer resolution.

$$0.787 \text{ volts/mm} \times 0.0001 \text{ mm/div} \times 4096 \text{ div/range} = .323 \text{ volts/range} \qquad \text{(Eqn. 2.2)}$$

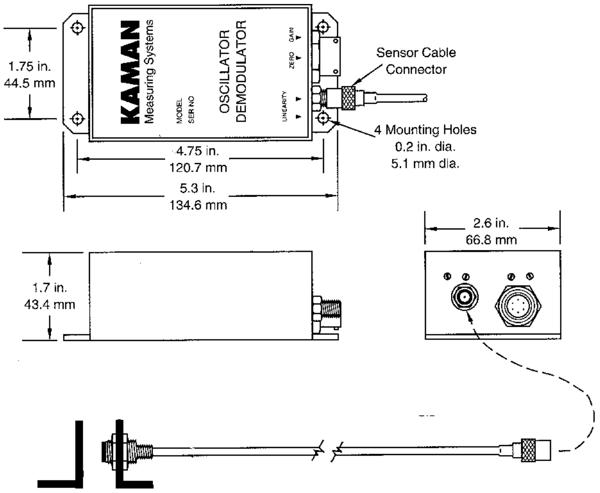


Figure 2.6 Kaman Sensor

As with the LVDT 12-bit A/D converter can resolve 4096 (2^12) steps. If this is multiplied by the required resolution per increment, the measuring range of the sensor can be determined. This range is calculated in mm and is converted to volts in Equation 2.2 above. In order to take advantage of the full 12-bits, the input range of the Somat should be set to +/-.32 volts/2 = .16 volts. This setting allows for adjustment if the sensor moves out of range, which will be discussed later in this chapter.

IMPORTANCE OF MEASURING RANGE

For some sensors, temperature sensitivity of gage and electronics is proportional to the range. Thus deployed sensors should have the smallest, but field supportable ranges. The full scale measuring range on both sensors that were tested is 1270 micrometers, which corresponds to +/- 10 volts on the LVDT and +/- 1 volt on the Kaman. When the voltage range of the sensors is reduced it increases the resolution and should decrease the thermal sensitivity. As indicated by past research the maximum range of the sensor could be reduced to 250 micrometer and still monitor the full movement of most cracks.

MOUNTING SYSTEMS

Brackets were designed to facilitate the mounting of the sensors on walls. The goal of the brackets is to firmly hold the sensor on a wall with the minimal distance between the wall and the sensor. The brackets were designed to minimize the thermal effects from material expansion and contraction. Finally the brackets need to allow for easy adjustment of the sensors once they were mounted.

Kaman

Figure 2.7 illustrates the brackets for the Kaman sensors, which are designed to hold the sensor and act as target they have a low profile to keep the sensor close to the wall. The brackets are aluminum, which is required to produce a current flow as previously described. The brackets are attached to the wall with a quick-setting epoxy and the sensor is placed into the bracket. The sensor is secured in place by lock nuts.

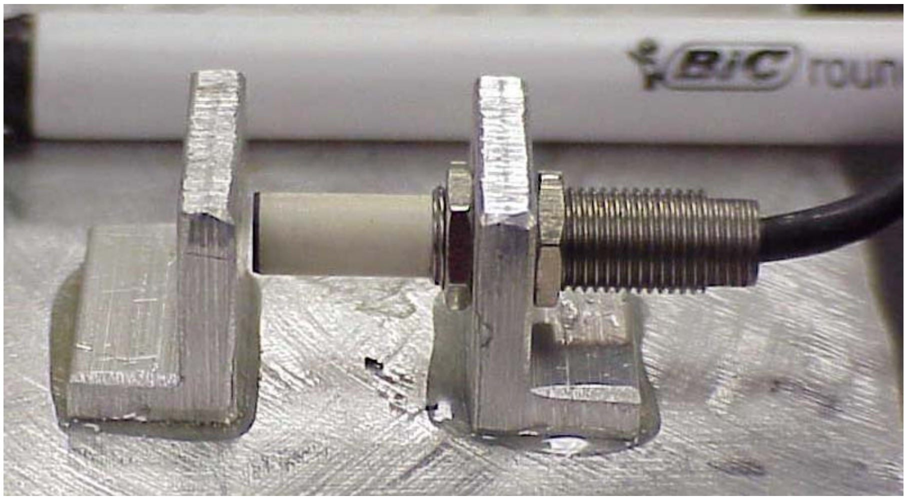


Figure 2.7 Kaman Mounting Brackets with Pen in Background for Scale

LVDT

Figure 2.8 illustrates the brackets for the LVDT sensor. The brackets are designed to hold the sensor and the core that fits into the sensor. The bracket to hold the core was designed identically to the bracket for the Kaman sensor. The bracket that holds the large outer LVDT casing proved more difficult to design. Since the electronics and sensor are housed in the same body and are larger than the Kaman sensor they required a different bracket. In order to reduce the thermal effects of the LVDT casing, only the front of the sensor is epoxyed to the bracket. Thus expansion of the bracket and/or LVDT will not change the results of the crack displacement reading. When the LVDT is mounted care must be taken in centering the core in the sensor. Failure to center (with respect to either directions perpendicular to the center axis) may inhibit the core sliding. This centering should not be a problem if the core in centered because there is ample clearance, and the large momentum of the moving wall movement would overcome any frictional resistance between the core and sensor.

Figure 2.8 LVDT Mounting Bracket

SENSOR CONSIDERATION FOR LONG-TERM MOVEMENT

Electronic drift and cyclical temperature changes posed two major challenges. In order to quantify the effects of these two phenomena the following test was performed. First, the sensors were mounted on an aluminum block of a known coefficient of thermal expansion (CTE). Thermocouples, temperature composed of a bi-metallic junction, were mounted on the block to determine the current temperature. All sensors and electronics together were subjected to temperatures that cyclically ranged between 20 ^{o}C and 31^{o}C

(68 °F and 88 °F) during daily temperature changes. Readings where taken every five minutes for 19-days. The electronics and the sensors followed the same temperatures during the test by virtue of their identical location.

Figure 2.9 is a plot of output converted to displacement versus temperature during the 19-day test of the sensors. The increased output at similar temperatures demonstrates the drift. Figure 2.10 plots the average converted output for each day versus time that indicates the drift is in only one direction. It is unknown if this drift would have continued indefinitely however; it is assumed that the drift would have switched directions and cycled back. (Siebert, 2000)

Computing the theoretical displacement value and comparing it to the measured displacement value determined the output that should have been produced by the cyclical temperature change. The theoretical displacement values of the aluminum were calculated by equation 2.3 and shown by the thick line sloping upward to the right.

(CTE) x (Gap between sensor and target) x (temperature change) = theoretical (Eqn 2.3)

Ideally the best correlation would be a linear relationship between the theoretical displacement values and the measured displacement values. Figure 2.9 also shows the thermal hysteresis loop in a one-day cycle. By looking at a one-day cycle the effect of electronic drift discussed in the previous paragraph is removed because the electronic drift is a long-term effect, and should have minimal effect in a one-day cycle. Depending upon the magnitude of the hysteresis the error of the sensor can be determined. It is difficult to

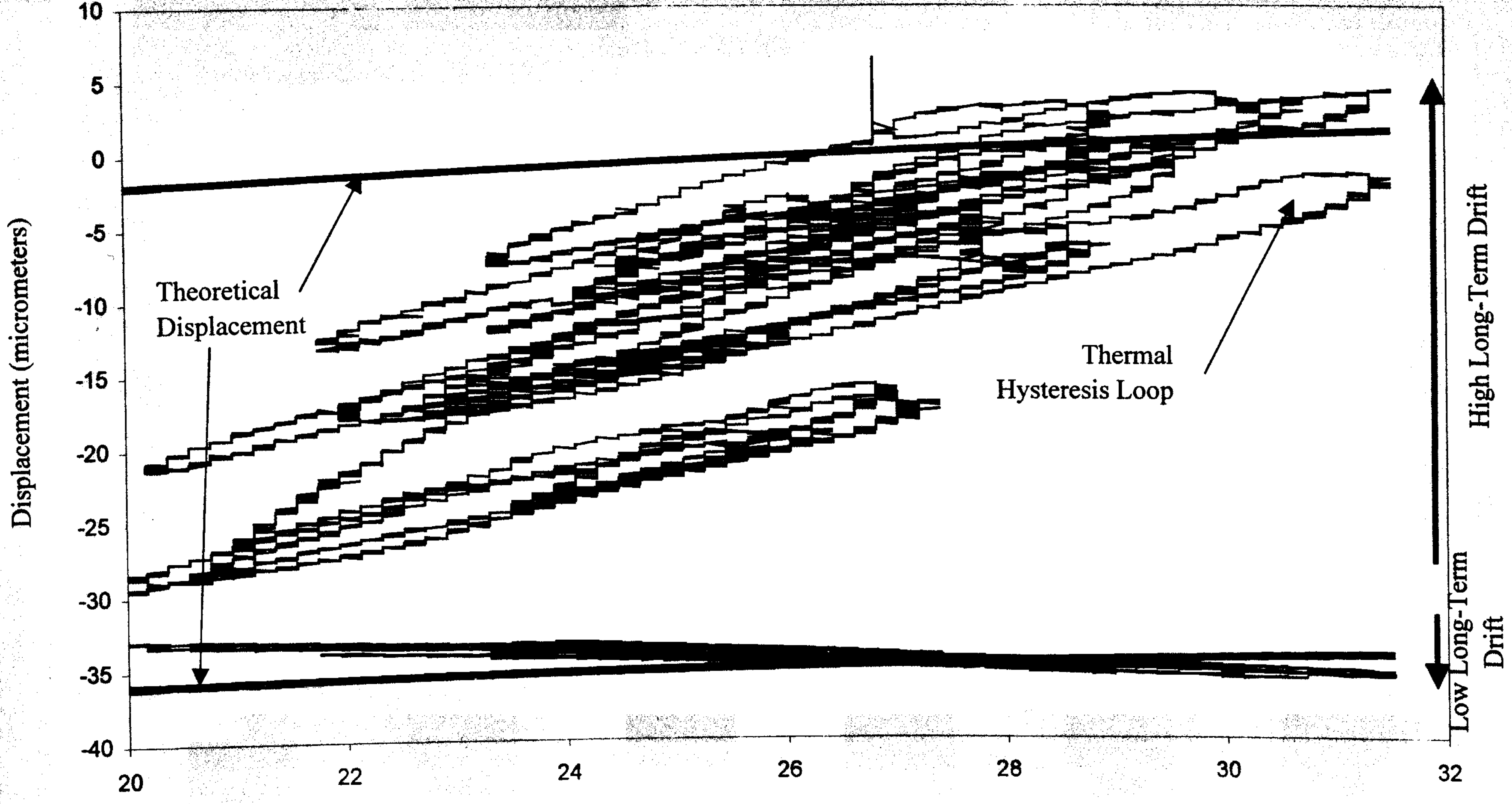


Figure 2.9 Comparison of Sensors with Low and High Long-term Drift and Illustration of Thermal Hysteresis Loop

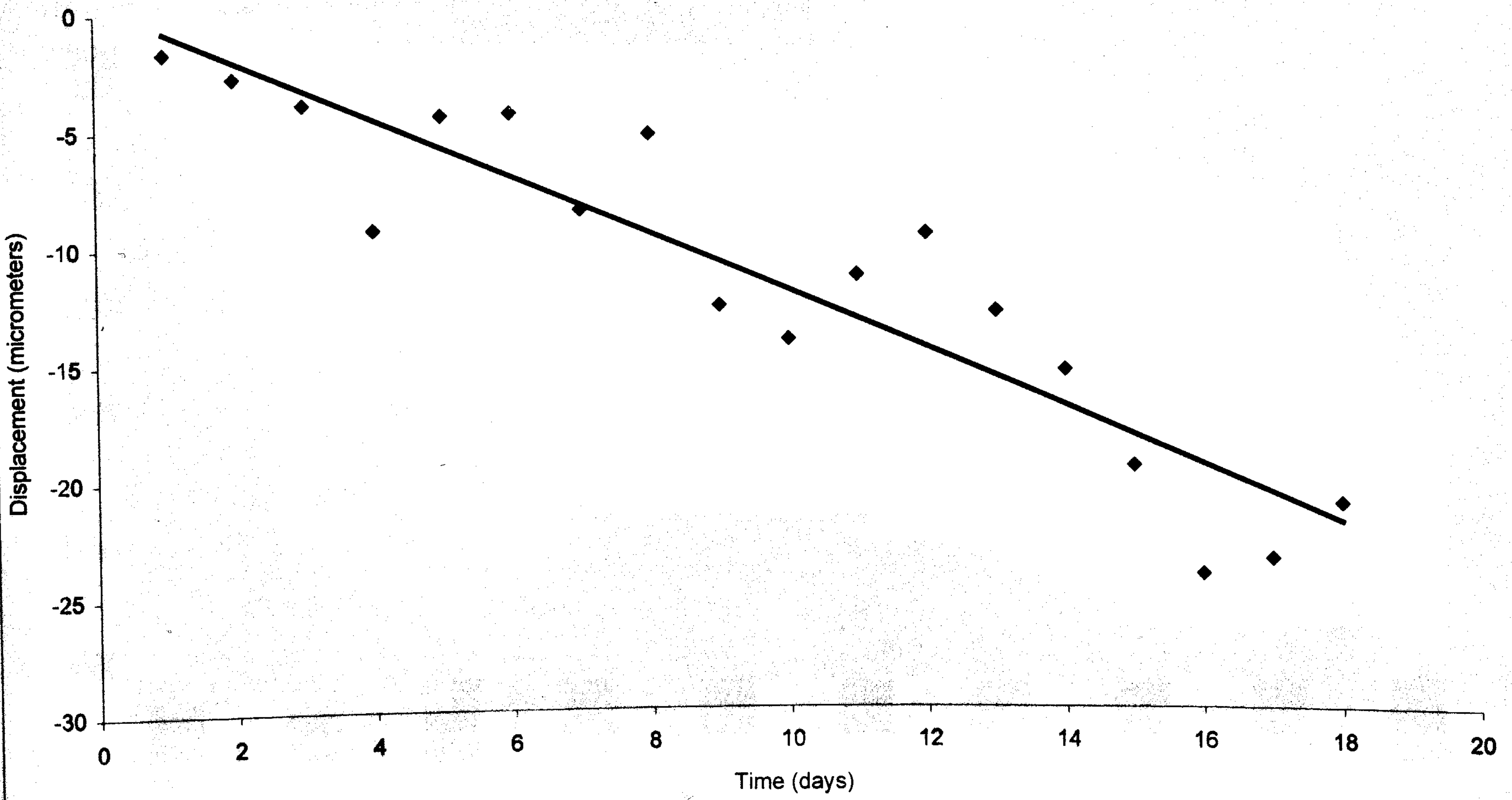


Figure 2.10 Thermal Drift Analysis: Average Daily Displacement vs. Time

correct for this error since it depends upon the direction of the temperature change (heating or cooling). (Siebert, 2000)

COMPENSATION FOR DRIFT AND THERMAL HYSTERESIS

Sensors still require that both drift and thermal hysteresis be minimized. There are two feasible procedures for overcoming this: a relative correction with a null displacement sensor or an absolute correction with a mathematical expression. The absolute correction could be developed from the displacement sensor test described in this Chapter (Siebert, 2000). The selected displacement sensor should be mounted on a material with a known CTE. The temperature should be changed at the same rate and magnitude as the predicted field temperatures. The theoretical displacement and the actual displacement should be calculated with the procedure described in this chapter so that a mathematical expression, which will transform the actual displacements into the theoretical, can be determined. In the field, the temperature of the sensor can be monitored and the developed expression can be employed to correct the displacement values. The problem with this method is that electronic drift and cyclical temperature changes are not taken into account.

The relative method to correct the displacement sensors and the one currently employed, involves a null displacement sensor attached to an un-cracked section of wall next to the crack displacement sensor. The null sensor should be identical to the displacement sensor over the crack except that it is not placed over a crack, but as close as possible as illustrated in Figure 2.10. All geometry (in the case of the LVDT the separation distance between the core and electronics) should be the same on both sensors.

Figure 2.11 illustrates the relative response of the LVDT. If the temperature increases and the material that the sensors are mounted on expands, the core will pull out of the null LVDT while the core of the sensor spanning the crack will be pushed in to the sensor. This opposite movement of the null sensor should be subtracted to obtain the actual crack movement. Furthermore any other response of the null should be subtracted from the crack sensors, as the null's crack response should be zero. The advantages of this method is that the temperature does not need to be recorded for the correction and all effects, such as the mounting brackets material around the crack, as well as electrical drift and thermal hysteresis are accommodated.

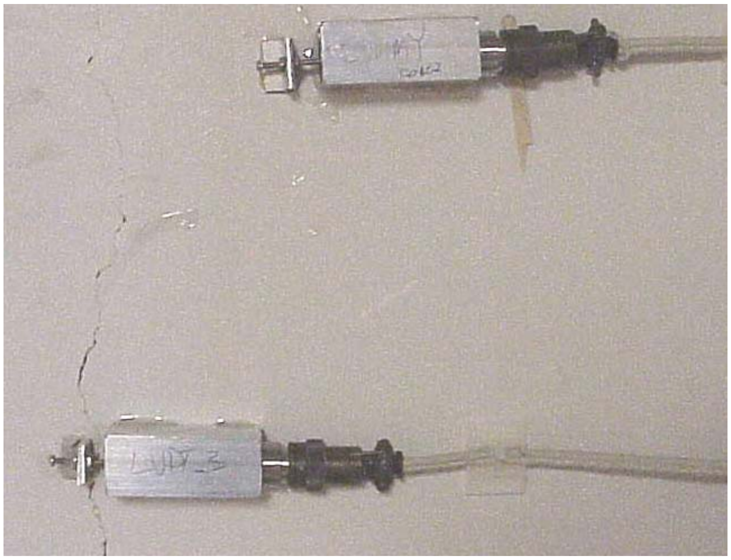
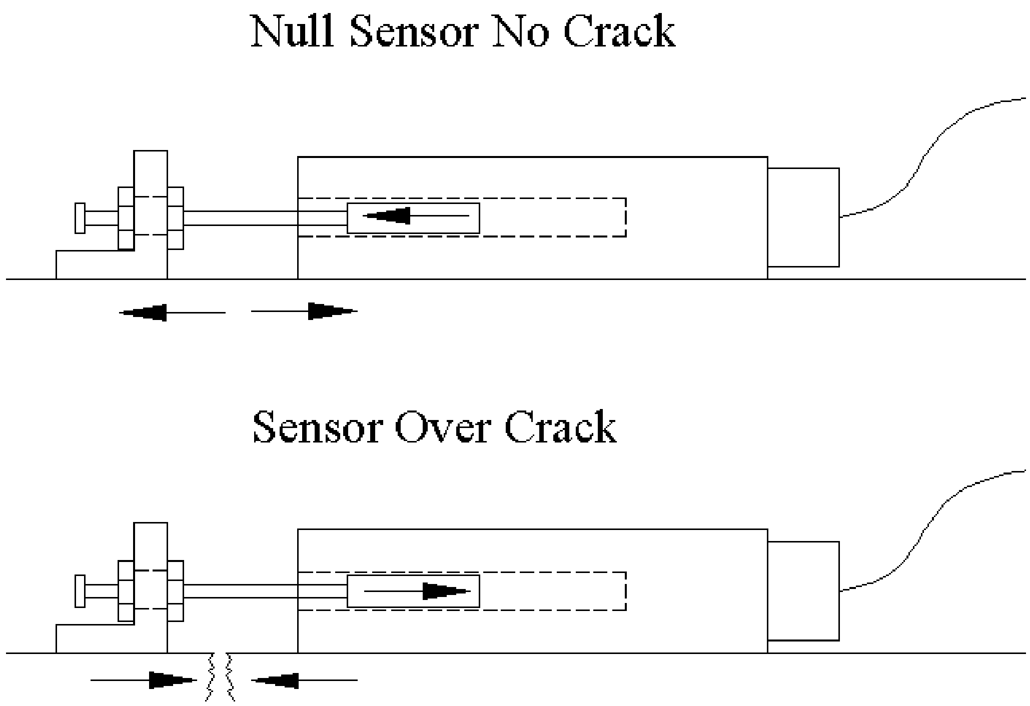


Figure 2.11 Null Sensor Placement Near-by but not Across the Crack


Null Sensor No Crack

Sensor Over Crack

Figure 2.12 Null Sensor Movement is in the Opposite Direction for Rising Temperature When Continuous Material Between the Transducer and Target Expand

CONCLUSION

After identification of the major challenges of long-term monitoring, several solutions were developed. It appears that displacement sensors with smaller measuring ranges may be less sensitive. Additionally, other available micrometer displacement sensors need to be evaluated. It appears the null sensor approach will be operable for any transducer; however, an alternative that consumes fewer computer resources would be highly desirable.

CHAPTER 3

HARDWARE

INTRODUCTION

Hardware for the crack monitoring system is composed of a number of components, which can be subdivided into the server-side at the ITI (Infrastructure Technology Institute) lab and the client-side at the Phase I test house. The Phase I client-side test site is located at 1908 Sheridan Road Evanston, IL. This field hardware records changes in crack movement, both long term and transient, as well as fluctuations in the inside temperature and humidity. The server is currently located at ITI laboratory, Northwestern University 1801 Maple Ave. Evanston, IL. This server performs all of the data analysis, which will be discussed in Automation of System, Chapter 4. In addition to the Phase I hardware, this chapter presents both hardware and software changes anticipated to be necessary to incorporate a commercial vibration monitor in additional Phases II-b and III. Anticipated costs of each Phase are discussed in Costs Chapter 7.

Existing vibration monitors are programmed to easily acquired triggered transient data. Some may not be easily reprogrammed to acquire both triggered and pre arranged, long-term data. Therefore to avoid extensive software changes an alternative method of acquiring long-term data may be necessary. One possibility outlined herein involves low speed data loggers, modem switches and dual wiring of crack displacement sensors.

CURRENT SYSTEM PHASE I

The configuration of the current system, Phase I is illustrated in Figure 3.1. On the left the server or central computer is connected through a modem to the client or field computer on the right. The field computer in turn is connected to a data acquisition system that reads information from the transient/long-term displacement sensors as well as the weather sensors. There are four transient/long-term displacement sensors over various cracks in the house as well as a temperature and humidity sensor to record the weather.

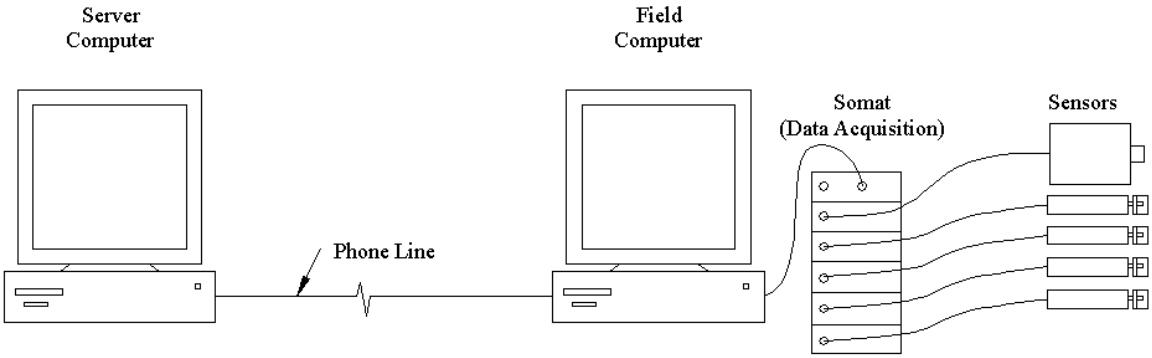


Figure 3.1 Phase I Configuration Showing Server-Side Connected to the Client/Field-Side by a Phone Line

Server Computer

There are a number of considerations that contribute to the robust operation of the server computer. The first is the processor speed; the faster the processor, the faster the Java applets operate to convert, normalize, catalog, and display data on the web pages. The Java applets are described in detail in the Automation of System, Chapter 4. Storage space is also an important consideration, as each day a file is uploaded to the computer and analyzed with the Java applet, which creates yet another file. While these files are typically under 1Mb, after several months they will consume larger amounts of storage, it is also anticipated that there will be a number of client sites recording data. In addition the DB2 database, WinTCS, EASE, and other software must be loaded onto the server, which also consumes space. Finally, The server computer must incorporate a high-speed modem for communication with the client hardware in the field.

It is anticipated that in the Phase III or final configuration, the communication and data logging will be a function of the commercial vibration monitor linked to a modem. In Phase I it was necessary to employ hardware that was familiar to the research team and which was on hand. During the initial Phase, proof of concept, rather than compact configuration was the primary goal. Thus description of Phase I realistically includes two processors because the data acquisition system did not have the capability of communication with a modem.

Client Side Field Computer

In the Phase I configuration the field computer is required primarily for communication. It serves as a link between the data acquisition system and the server computer with its built in modem. Both should not be necessary with most vibration monitors. Speed, power, and size were the only concerns in Phase I because of the temporary nature of the component. A stripped down 500MHZ computer with 24MB of RAM, 8.4 GB hard drive, and a 44x CD-ROM, equipped with Windows 98 was purchased. A CD-ROM was added to facilitate installation of software. This minimal configuration was more than adequate. Though unnecessary, the purchased computer came with a large hard drive that allows an excess of data storage.

Client Side Data Acquisition System

A Somat 2100 turbo is employed for the client side data acquisition system. It is made up of several machined aluminum alloy layers with rubber gaskets to seal out moisture and dust. Each layer contains 8 threaded holes that are screwed together to form a tight system known as a stack. When stacked an assembled sandwich of these components is shown in Figure 3.2. The data acquisition system records information from various sensors in digital form. Each layer has a specific task in the data acquisition process. The basic system contains a processor layer and a power/communications layer.

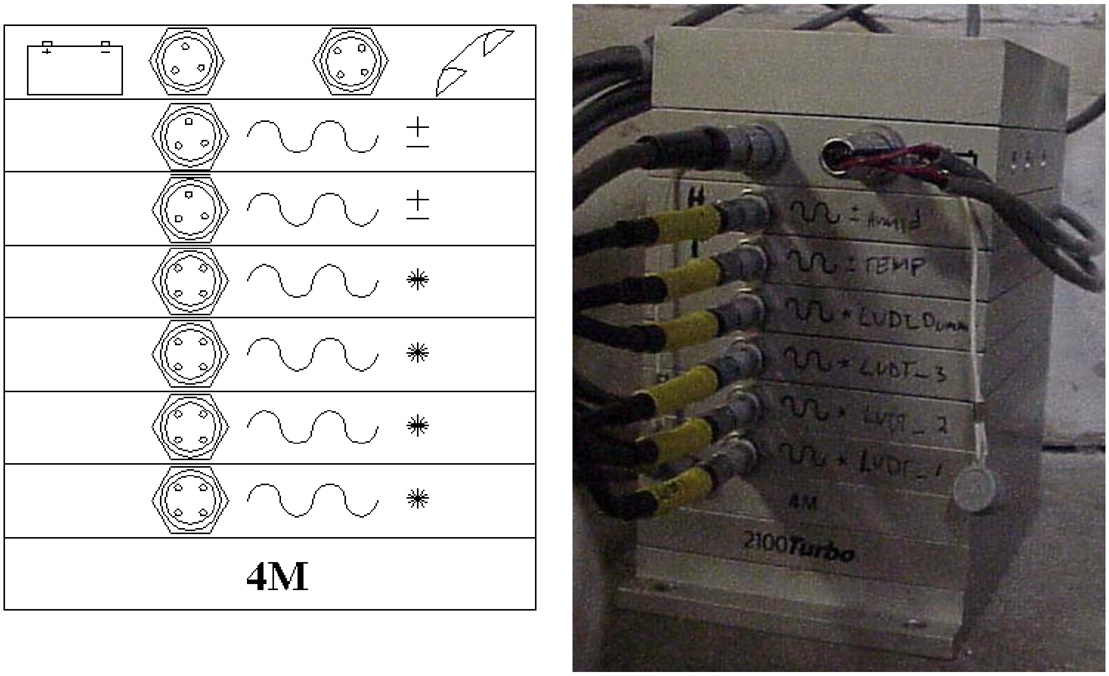


Figure 3.2 Phase I Schematic and Photo of Somat Data Acquisition System

The basic system is approximately 12.7cm x 7.6cm x 5.1cm with each additional layer adding 1.3cm to the height. The weight of the basic system is 1.3 kg. with each additional layer adding .14 kg. The current system contains the basic system (two layers) plus six additional layers to obtain data. These additional layers will be discussed in detail in the following sections.

The Somat's current options for communications are limited since it may only be directly connected to a computer or communicate over a radio transmitter. Direct communication via modem will not be supported until the next software update in April 2000. Unfortunately communication over a radio transmitter has a limited range, typically a 20-mile maximum if unobstructed. In addition to range limitation, it can be difficult to obtain a clear radio connection without interference from other electrical instruments. Because of these challenges, radio linkage was left for addition at a later date.

Layers

The Somat operates with a variety of different types of layers. Figure 3.3 shows a typical size and dimension of a Somat layer. There are four different types of layers stacked in Phase I: 1) processor, power/communications, 2) extended memory, 3) 8-bit A/D converter, and 4) 12-bit A/D converter. Each channel can be identified by the symbols on the front. Figure 3.4 describes these symbols and the layer to which they correspond. The processor layer forms the core of the system, holding the circuitry needed to support the microprocessor and 32k of base memory. The power/communications layer provides regulated power to the other parts of the Somat and provides a serial communication port to link the Somat to a computer. The extended memory layer provides 4 MB of extra storage memory required for the Phase I system.

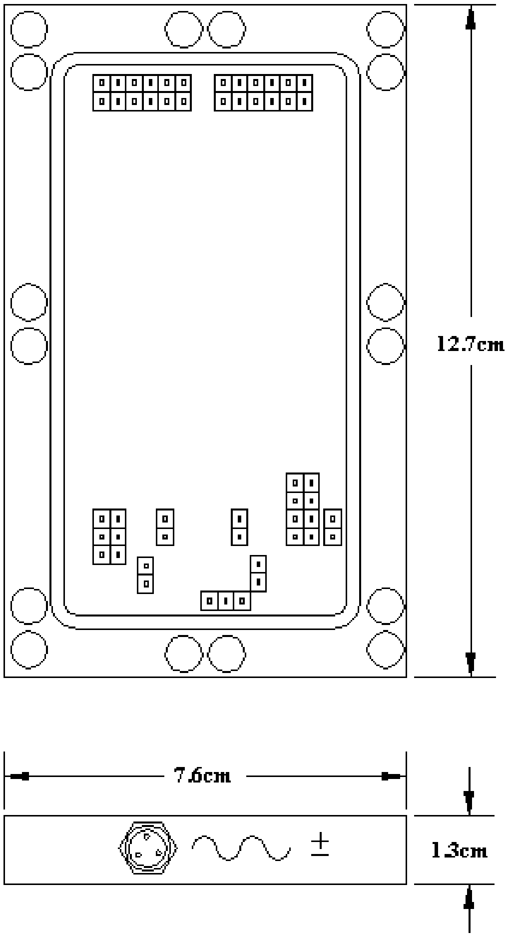


Figure 3.3 Individual Somat Layer

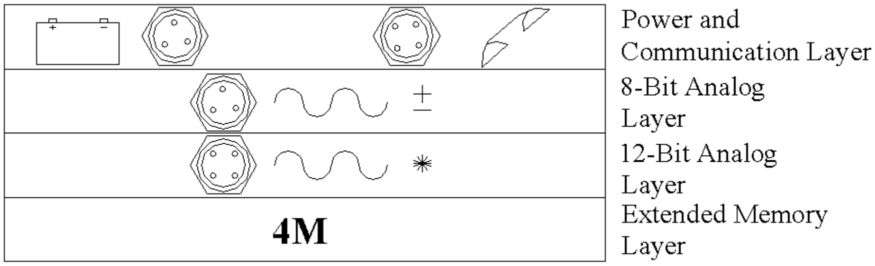


Figure 3.4 Somat Layer Definitions

The 8-bit A/D converter layer transforms transducer analog voltages to digital form. Since it has limited resolution it is employed with temperature and humidity data, for which 2^8 = 256 levels of resolution are sufficient. No external signal conditioning is required and the transducer can be connected directly to the system. The 12-bit A/D converter digitizes crack movement signals, as they require greater resolution. Again no external signal conditioning is required and the transducer can be connected directly to the system. The resolution of this layer is 2^12 = 4096 subdivisions of the full-scale range.

From this point forward the Somat with all of the aforementioned layers will be referred to as the stack. Before each layer is screwed together in the stack, the jumpers must be set in the correct position. A jumper is a cluster of pins on a layer. When certain combinations of the pins are connected it indicates to the layer what kind of data it will receive. The software WinTCS provides diagrams for the setup of the jumpers for each layer, the next section will discuss where this is located.

WinTCS

The Somat Test Control Software for Windows, WinTCS (Somat, 1999) program provides a Windows 95/98/2000/NT interface between the Somat 2100 system and the field computer. WinTCS allows the user to; setup a test; start and stop test; collect and store test data; and upload data to the field computer. A complete and detailed description of how WinTCS is operated for the current Phase I system is located in an internal report prepared for the Infrastructure Technology Institute (Siebert, 2000) .

Sensors to Measure Displacement

While a wide variety of sensors can be employed to measure crack displacement, the Phase I system relies on LVDT's. A full description of the LVDT (Linear Variable

Differential Transducer) is presented in the Sensor chapter. Connection to the Somat is accomplished by a Lemo connecter, the brand employed by Somat to link sensors to the stack. The LVDT does not have an internal power source and must be wired to allow connection to the power strip. For complete wiring details refer to the LVDT manual (Macrosensor, 1999). Sensors should be located as close to the data acquisition system as possible to reduce the possibility of electrical noise in the data.

Sensors to Measure Weather

As with displacement, various types of sensors can be employed to measure temperature and humidity. For the Phase I system temperature and humidity are measured with a single Omega sensor (Omega, 1989) shown in Figure 3.5. It uses a thin film polymer capacitor to sense relative humidity, and the temperature sensor is a thin film permalloy. Figure 3.6 shows the required wiring. In order to connect the Omega to the Somat, both the relative humidity and the temperature sensors need to be wired to a Lemo connector. As with the LVDT's the Omega does not have an internal power source and must be wired to allow connection to a power strip. For complete wiring detail refer to the Omega manual (Omega, 1989). Again temperature and humidity sensors should be placed as close to the data acquisition system as possible to reduce the electrical noise in the data.

Figure 3.5 Omega Weather Sensor

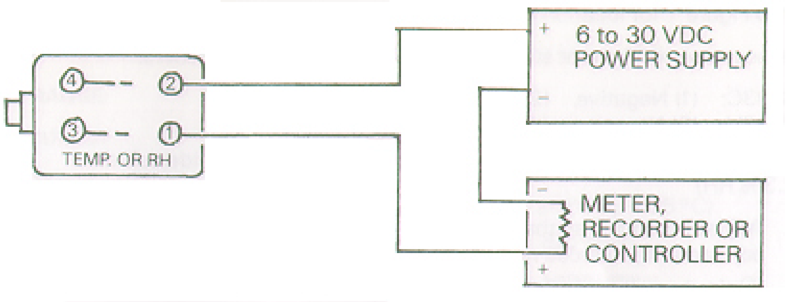


Figure 3.6 Omega Wiring Diagram

Mounting of Sensors

Mounting of the various sensors can be a quick, painless process if several preliminary steps are followed. First, it is necessary to map out the location of the sensors and data acquisition system and precut wires to 10% greater than this length. Then the tool list is required. Lastly, it is important to practice with a mock installation of the system in the lab to identify problem areas and tools before traveling to the site.

The following list is tools that should be taken. Depending on the site more may be required.

- Crimpers
- Wire cutters
- Flat and Philips head screw drivers of various sizes
- Voltmeter
- Wrenches of various sizes
- Break-out box
- Pliers
- Wire ties
- Tape
- Heat gun
- Solder kit
- Razor blade
- Hammer
- Epoxy
- Paper towels
- Gloves, safety glasses

For the Phase I installation the sensors were mounted on walls with a quick setting epoxy, Araldite 90-second. The epoxy needs to be mixed thoroughly, and once mixed there is a 90-second window before the epoxy sets. The epoxy must be strong enough to hold the sensors on the wall with a minimal amount of creep. In this case creep is the slow movement of the sensor due to gravity.

Once the sensors are fastened to the wall, the LVDT's cores must be centered within their measuring range. A breakout box and a voltmeter are necessary to accomplish this. A breakout box is a small instrument that allows a sensor to be connected to the Somat and still allows a voltmeter to read the output of the sensor. The goal is to move the core until the voltmeter reads 0.000 millivolts. Once centered the core must be locked off by tightening the nut on the bolt attached to the core. If the crack moves out of range the same procedure can be employed for readjustment.

Selection of the wire to connect the sensors to the Somat is important for electrical reasons. The better insulated and shielded the wire, the less outside electrical noise will influence the system. Any extra wire should be coiled next to the Somat to be kept out of the way. A wrapping technique to reduce electrical noise is to coil one half of the wire in one direction and the other half in opposite direction, which should cancel out any electrical noise in that portion of the wire.

PHASE II AND III TRANSITION TO TYPICAL VIBRATION MONITORING HARDWARE

The ultimate goal (Phase III) is to substitute a vibration monitor for the current Phase I computer and data acquisition system. In order to facilitate this transition Phase II will be divided into a and b. Typical vibration monitoring equipment measures ground movements and air blasts with multichannel A/D converters linked to a processor with communication capabilities. Several hardware modifications are needed to facilitate this transition. Modifications are required because typical vibration monitoring hardware may only record triggered transient data and not pre-timed long-term data. To make this system attractive as possible for a broad range of vibration monitors, it was thought necessary to reduce the rewriting of software for standard vibration monitors to zero if possible.

First, since the vibration monitoring hardware may only handle triggered data, an additional long-term data acquisition system could be employed. Second, both the data acquisition system and the monitor have built in modems. So the field computer of Phase I can be eliminated since its primary function is communication. Third, in order to access the data, a phone line will need to be present and a modem splitter will need to be employed to cycle between the vibration monitoring hardware and the long-term data acquisition system. The following Phase III system that is proposed is only one possibility. There are many substitute products that can be interchanged.

Phase II Transition

In order to facilitate the transition from Phase I to Phase III, Phase II-a and II-b will be employed. Figure 3.7 illustrates Phase II-a, which is the addition of vibration monitoring transducers to Phase I. Phase II-b shown in Figure 3.8 will emulate a system with a standard vibration monitor by including the addition of a low speed data acquisition system and a modem splitter. The following section describes in detail these changes.

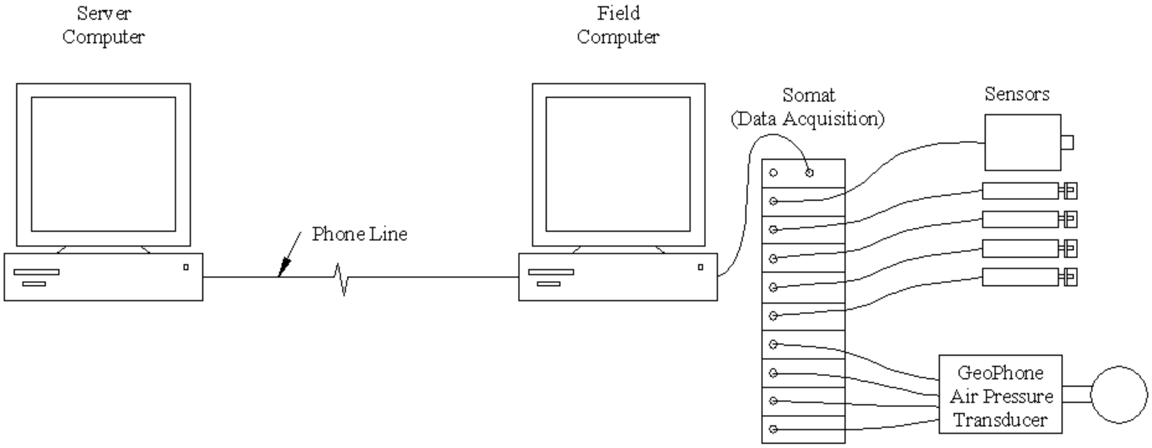


Figure 3.7 Phase II-a Configuration

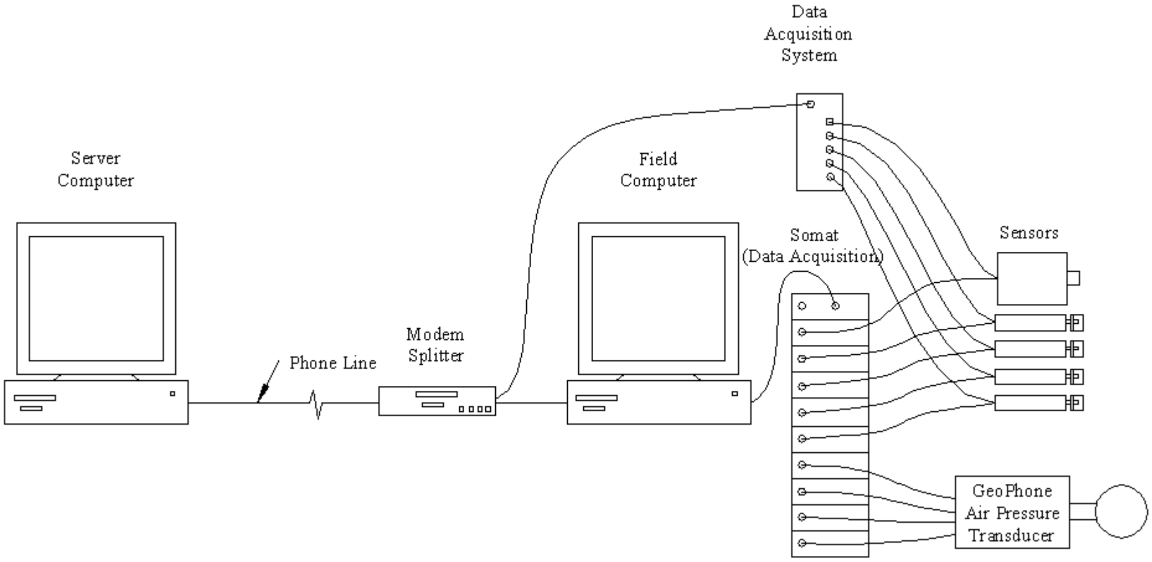


Figure 3.8 Phase II-b Configuration

Vibration monitoring devices measure three axes of ground motion as well as air blast pressure. These components will be added in Phase II-a to the current Phase I Somat data acquisition system. The only hardware changes to the current system that are required are the addition of four 8-bit channels.

Data Acquisition System for Long-term and Weather Data

In Phase II-b, after the addition of the vibration monitoring transducers in II-a, a low speed data acquisition system will be added along with a modem splitter. The low speed data acquisition system will record the long-term sensor data. The current Somat data acquisition system will need to be configured to emulate a typical vibration monitor. The proposed data acquisition system is one of many such systems on the market, and further research for other systems may be required. The system proposed is the SmartReaderPlus, a 12-bit data logger approximately 10.7cm x 7.4cm x 2.5cm with a weight is 5 oz. It is available with up to 1.5Mb of memory. The SmartReaderPlus has eight channels available, one internal thermistor to record temperature and seven analog inputs. Data can be sampled from every eight seconds up to every eight hours. This system meets all the requirements. It is accessible over a modem, has an adequate number of channels, has an adequate sample rate, and is small.

Modem Splitter

A modem splitter is required in order to switch between the field computer connected to the Somat and the long-term data acquisition system. The modem splitter proposed is a code-operated switch II (COS II) that allows the users to control up to eight serial devices from the server computer, and is approximately 5.8cm x 31.0cm x 27.9cm and weighs 3.6 kg. The server computer calls the client-side modem splitter, which is connected to the field computer and the data acquisition system, and enters a code that will toggle between the two devices.

Phase III Transition

The required hardware changes to transition from Phase II-b to Phase III, are illustrated in Figure 3.9. The field computer and Somat data acquisition system will be removed and replaced by a typical vibration monitor. There are two options for Phase III that depend upon the capabilities of the monitoring device employed. Typical monitoring devices vary from system to system, but they all measure ground motions [Longitudinal, Vertical, and Transverse (L, V, and T)] and air blast overpressure. It is assumed that there is the potential for four additional sensors. It will be further assumed the devices also have a built in modem to facilitate communication. The server side of the system will be designed so the vibration monitoring device will only have to record transient, habitation, construction vibration. All computations and analysis will be performed on the server computer after the data have been uploaded. This approach allows for compatibility in the design with any monitoring device because no modification of the device is required to operate with this system. If vibration monitor software is specially written the long term data acquisition system would also be removed and replacing it with a typical vibration monitor.

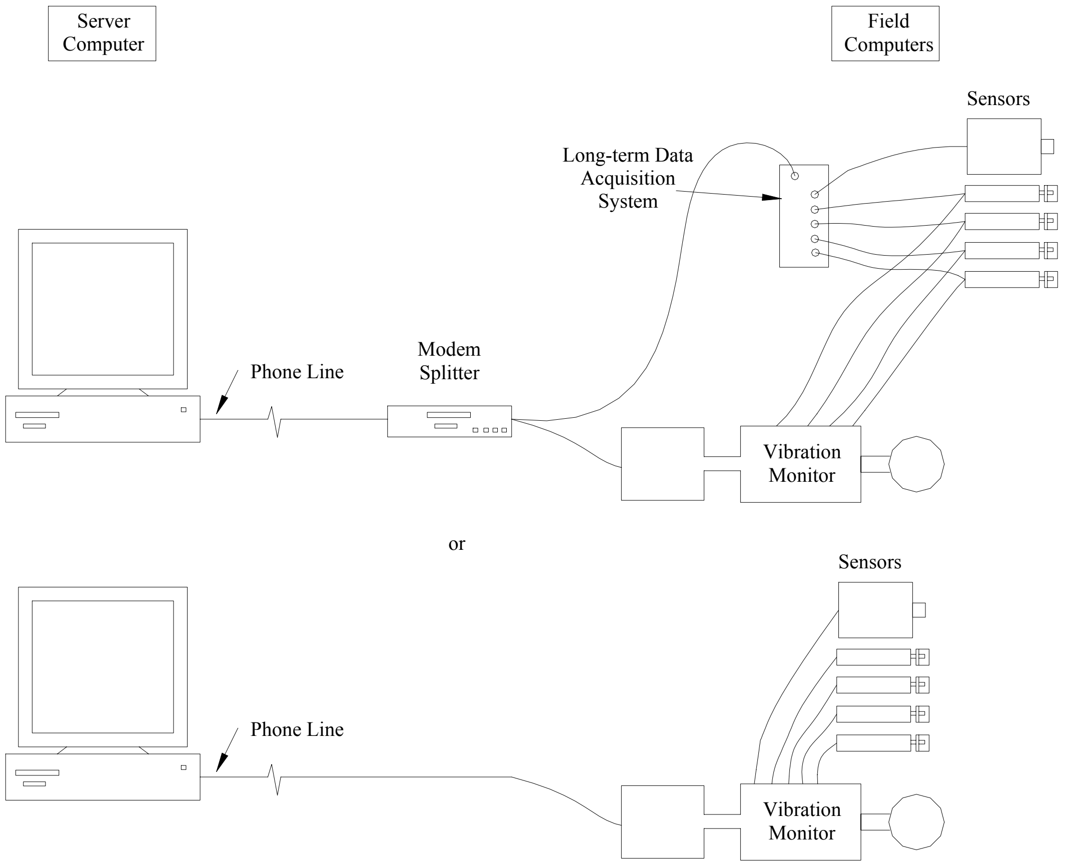


Figure 3.9 Phase III Configurations Showing Options (a) Without Additional Vibration Monitoring Software and (b) With Additional Software written for Typical Vibration Monitors

Sensors

Transition to a typical monitoring system in Phases II and III should have no effect on the sensors employed to measure displacement or weather. The long-term data acquisition system suggested above has a built in temperature sensor that would eliminate the need for an additional temperature sensor. The only change may be the wiring of the displacement sensors. If vibration monitoring software is not rewritten, as explained they would need to be wired to both the data acquisition system and the typical monitoring system, as illustrated in Figure 3.9

CONCLUSION

This Chapter outlined the current Phase I system hardware as well as the changes that are required when Phase II and III are implemented. By subdividing Phase II into two small steps ensure that progress is continual and does not depend upon full integration of typical vibration monitors until the very end of the project. The ultimate goal by Phase III is to have a system that can be marketed to companies manufacturing typical vibration monitor.

CHAPTER 4

AUTOMATION OF SYSTEM

INTRODUCTION

This Chapter discusses the automation of the current Phase I system as well as what is required substitute to typical vibration monitoring equipment for the present field computer in Phase II and III. The software, input files, output files, and scripts are explained in detail. The transition that is required for compatibility with typical vibration monitoring equipment is a very important aspect of the project and is described in detail in order to facilitate the transition.

PROGRAM DESCRIPTION

AutoMate (Unisyn, 2000) is a software tool for Windows computers that enables autonomous entry of commands in multiple applications without manually pressing keys or employing macrocodes. AutoMate breaks down common user actions into basic tasks. These tasks are built step by step in logical progressions. They take the place of human induced commands. Once triggered at a scheduled time, AutoMate carries out "actions" in the order specified during the task without human assistance.

CURRENT PHASE I SYSTEM

There are two current computers running separate AutoMate tasks in Phase I, the field and the server computer. Figure 4.1 illustrates the current tasks AutoMate performs at both the field and server computer. The complete AutoMate task for both field (left side of Figure) and server (right side of Figure) computers are given in an internal report prepared for Infrastructure Technology Institute (Siebert, 2000).

Uploading Data From Field Computer

As shown in Figure 4.1 every day, at 12:01 am on the internal clock of the field computer, the AutoMate task (sheridanfield.amt) is initiated. From this point on this task will be referred to as SF. This task saves the current day's data into a specified folder on the hard drive of the field computer. SF is performed at 12:01 am because it represents the end of a calendar day. This timing allows the system to operate on a standard 24-hour day schedule. AutoMate first opens WinTCS. WinTCS (Somat, 1999) is a software package supplied by Somat as an operating system for its data acquisition system, which is described in detail in Chapter Hardware. AutoMate's first task is to stop the data acquisition system from recording information. AutoMate then uploads the data recorded during the last 24 hours. AutoMate contains a unique features that allows the current date and time to be added to the data file. The data is stored in a directory on the field computer with the following format (dataddmmy.dat). This file is a typical compressed data file from the Somat data acquisition system.

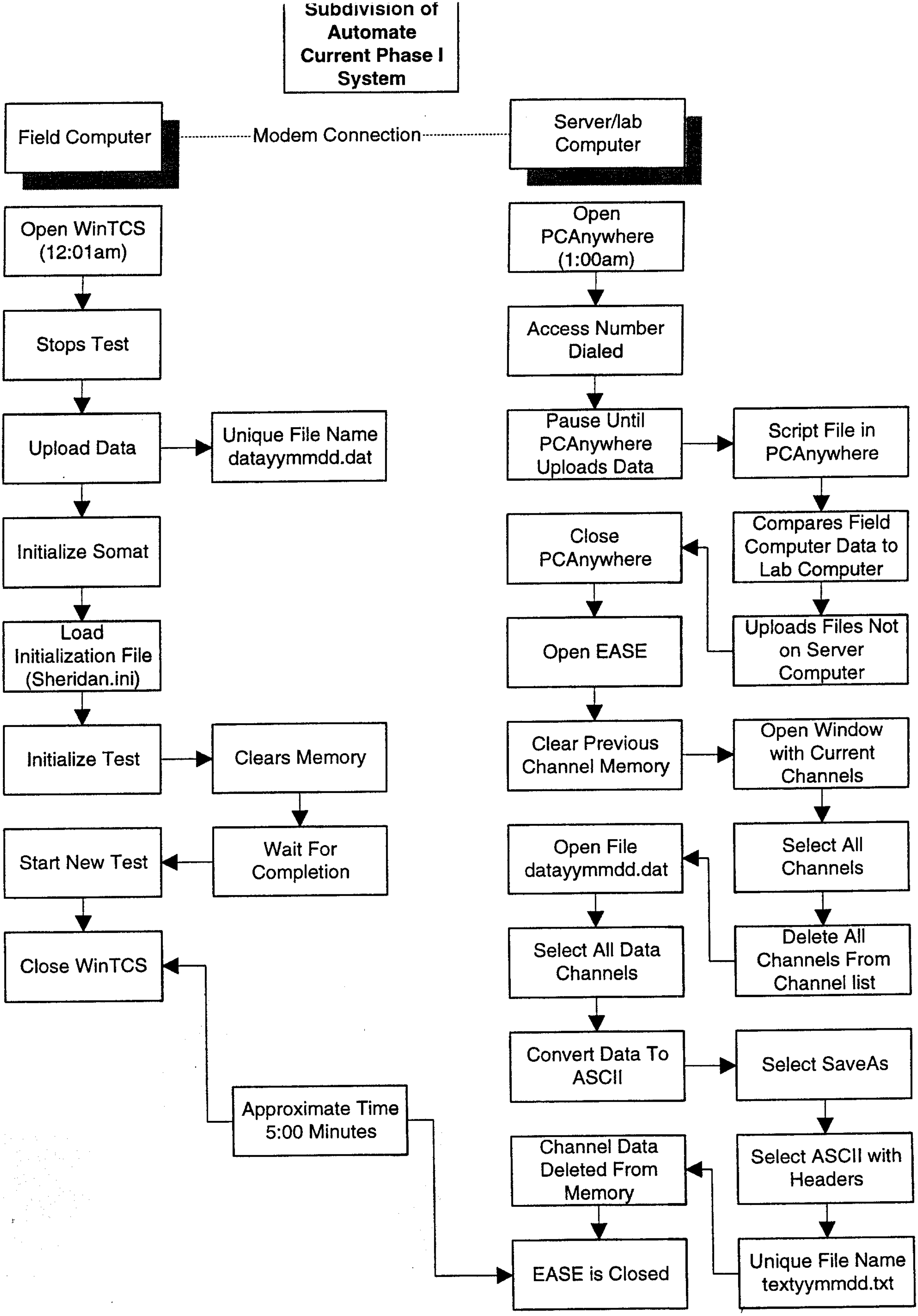


Figure 4.1 Operations Performed by AutoMate in Current, Phase I, System

The memory must then be cleared on the Somat before a new test can be started. Memory is cleared by AutoMate by loading the initialization file (sheridan.ini), which is described in detail in Hardware Chapter 3. Changes to the initialization file can be made at any time, during the running of test, and will take effect when the file is reloaded by AutoMate.

Once the initialization file is loaded, AutoMate directs the data acquisition system to clear the current memory. AutoMate waits until a completion window is displayed on the screen before continuing. This pausing is another very powerful tool in AutoMate, as it will wait for a specified window to appear before continuing its current task. Once the initialization is complete AutoMate starts a new test. WinTCS is then closed. The approximate time to perform SF is five minutes. The time varies due to the ".dat" file size and time required to clear the memory.

Server Computer

File transfer

Every night at 1:00 am on the internal clock of the server computer, the AutoMate task (sheridan.amt) is initiated, from this point on the task will be referred to as SS. SS uploads the data from the field computer and converts it to a text format. The only constraint on when SS is performed is that the field computer must be finished with SF before it begins. The sooner SS is run the sooner the web page is updated with the previous day's data.

In order to communicate with the field computer, the server computer runs SS, which opens PCAnywhere. PCAnywhere (Symantec, 2000) is a remote access program that allows the user to communicate with another PC via the Internet or, in this case, a modem. PCAnywhere is employed for field system modification and file transfer; however it must be loaded on both computers, each of which must contain a modem. AutoMate runs the script file (sheridan.pca) in PCAnywhere. PCAnywhere dials the access number to reach the field computer. Once connected PCAnywhere performs a check on the specified directory on the field computer. Any files contained on the field computer that are not in the server directory are transferred to the server computer. Once the transfer is complete PCAnywhere disconnects from the field computer. Unfortunately there is not a window that appears upon completion of the file transfer. Therefore, AutoMate is simply given a five-minute pause before it performs its next task, ample time for PCAnywhere to perform the file transfer.

Text conversion

After the five-minute pause AutoMate opens EASE (Somat, 1999), a data analysis program from Somat. EASE reads data from virtually any source, from any number of files, and from any number of channels simultaneously, rendering the type of data acquisition system irrelevant. EASE also saves the data once it is open in a variety of formats, such as ASCII text files. Once in EASE, the first task is to clear the program of any previously selected channels. This is accomplished by opening the channels list window. All channels are then selected and removed from the channels list. A complete description on this clearance can be found in an internal report prepared for Infrastructure Technology Institute (Siebert, 2000).

Once the previously selected channels have been removed from the channels list, AutoMate opens the file that PCAnywhere has just transferred by listing the directory and file name (In this case C:\iti_web\sheridan\data\dataddmmyy.dat). Once the file has been opened all of the channels are selected. A complete description of this selection can be found in an internal report prepared for Infrastructure Technology Institute (Siebert, 2000). As discussed in the Hardware Chapter, a channel represents data recorded from a sensor attached to the data acquisition system. SaveAs is selected from the EASE file menu and, the ASCII text with header option is chosen. The Java script, discussed in following section, requires the header information in order to perform that data manipulation. The ASCII text is given a unique name with the following format for consistency with the .dat file, textddmmyy.txt. Finally the channel information is cleared from the channel list in the same manner as before and EASE is closed.

Java applet for ASCII text file analysis

The last task AutoMate performs is to run the Java applets (a web based programming language) which analyze the text file and create graphs for display on the web page. A small script file within the Java applet called a servlet extends the functionality of the web server. Complete Java servlet scripts with explanation are given in an internal report prepared for Infrastructure Technology Institute (Siebert, 2000). A typical text file with a vibration event is reproduced in an internal report prepared for Infrastructure Technology Institute (Siebert, 2000). The text file, created from the original data file by AutoMate and EASE, is divided into three sections, header information, four-hour data, and vibration data. The first section, or header information, contains each channel recorded, the number of data points in each channel, the time the test was started, and other test information. The second section, or four-hour data, contains long-term sensor and weather data. The final section, or vibration data, contains the transient sensor data.

The Java script opens the text file with the current date. The header information is removed and set aside. The Somat system records time in seconds from the beginning of the test. That is converted to the modified Julian date, a universal time standard providing precision down to the millisecond, that is described in an internal report prepared for Infrastructure Technology Institute (Siebert, 2000).

Database structure

The database currently running on the web server is IBM DB2, a relational database that stores all data for the project and allows queries for certain time periods. All data can be accessed by the modified Julian date. The three databases required for the current configuration are four-hour data, maximum of transient or burst data, and all burst data, which will be referred to as 4H, Max, and All respectively. The term burst refers to the data collected during a vibration event.

Four-hour data stores temperature, humidity and displacement taken at four-hour intervals. The maximum of burst data stores Julian date and the absolute maximum from the first data point that occurred at that time. The "all burst data" stores Julian date and all one thousand points for each vibration event time-histories. While any number of points may be stored, one thousand was chosen for this Phase. During Phase III the number of data points will increase to 5000 or more and represent 50 or more seconds.

Four-hour data (4H)

These data are grouped into six one-second or thousand-point bursts for a total of six thousand points in twenty-four hours. Every four hours a one-second thousand-point burst is recorded. The thousand points in each four-hour reading must be averaged to eliminate the electronic noise from the system. This averaging produces six data points for each channel, one every four hours for each twenty-four hour day. The Java script takes this information and appends the information onto the four-hour data table with the appropriate Julian date. The data are recorded in volts that must be converted into displacements for the displacement sensors. The Java script converts volts to micrometers before saving the information in the database. The current sensors conversion from volts to millimeters is 0.127 mm/v or: Volts * 127 = Micrometers.

Vibration data

The Java script reads the last list of information from the data file, vibration data. The Somat records the vibration data in one thousand point bursts. The number of vibration bursts depends upon the number of vibration events for the day. The Java script determines the absolute maximum and minimum displacement during each one thousand-point vibration event. These data are also converted into micrometers and stored in the vibration event database that can be accessed later by the Julian date.

Dynamic generation of graphs for web site

Java servlets also dynamically generate graphs for the web site (Kosnik, 2000). They take the place of other server-side counterparts and eliminate the need for client-side applets. The servlet can read from and write to the databases previously created (4H, Max and, All). Server-side refers to the server computer performing data analysis and graphing. While client-side refers to web viewers computers. Graphing at the clients would require the viewers web browser to perform this analysis. Elimination of client side applets allows for quick loading of the web site with any version browser or speed connection. Web design strategies are discussed in Web Design Chapter 6.

As discussed in Web Design Chapter 6 and illustrated in Figure 4.2 there are five types of plots required in Phase I for presentation on the web page. All plots show variation with respect to time of:

1. humidity
2. temperature
3. long term crack displacement compared to humidity
4. long term crack displacement compared to temperature
5. transient crack displacement from habitation and/or construction vibrations superposed on long term changes

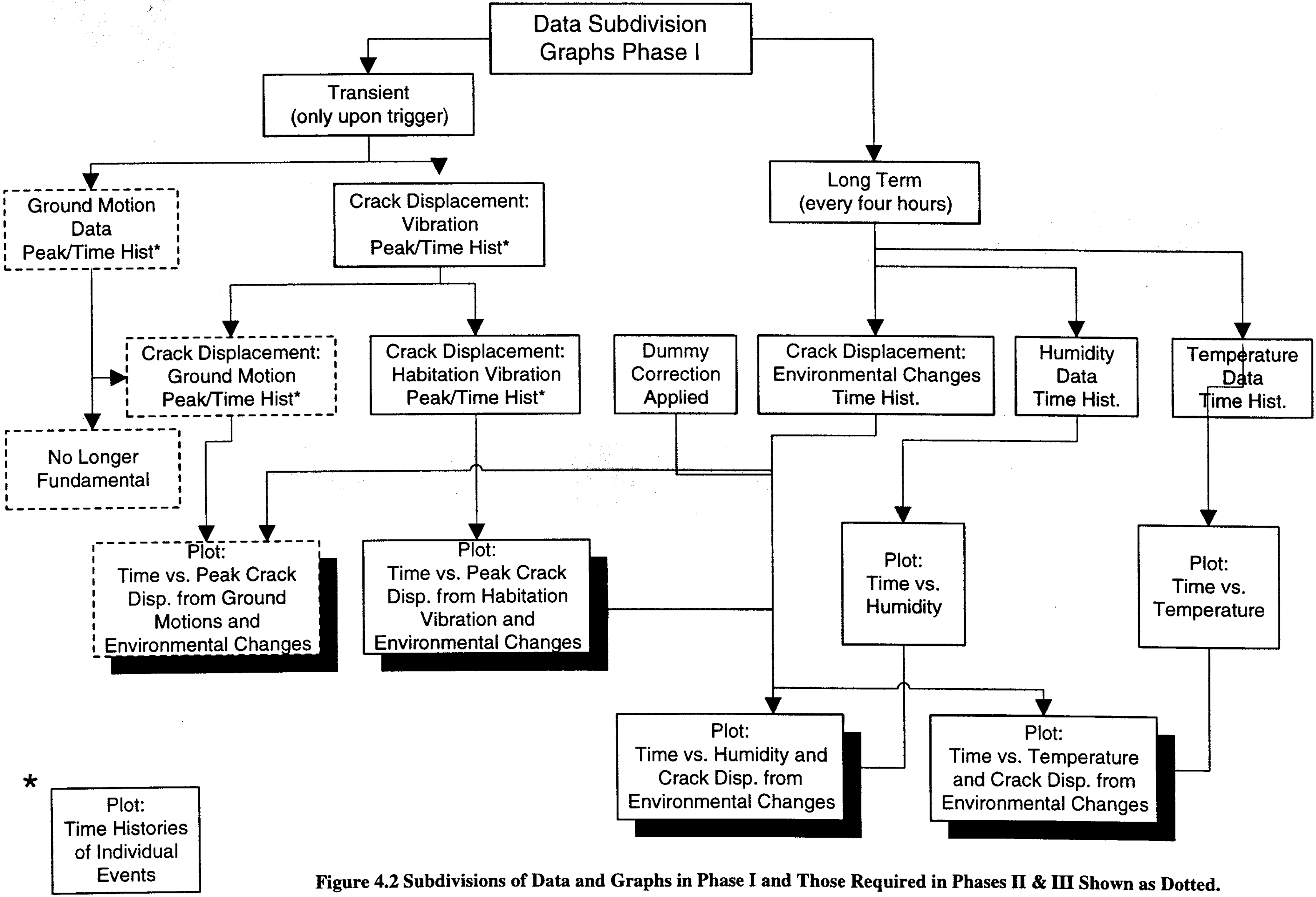


Figure 4.2 Subdivisions of Data and Graphs in Phase I and Those Required in Phases II & III Shown as Dotted.

Each of these plots is graphed for a variety of time intervals that range from the past twenty-four hours, week, month, and year. In addition, the dashed boxes on the left side of the Figure indicate additional plots and data that will be required in Phase II and III.

Process

The complete process involved in creating these graphs with the Java applet is located in an internal report prepared for Infrastructure Technology Institute (Siebert, 2000). The viewers browser sends a request for one of the various types of plots and a time interval. The servlet takes the request and queries the appropriate database. Data retrieved from the database is parsed into a format suitable for the graphing package. The servlet initiates the graphing program and captures an image of the graph. The graph is sent to the user as a GIF image.

PHASE II TRANSITION

Hardware change for transition to Phase II

Figure 4.3 illustrates the hardware changes that are required for the transition to Phase II-a as discussed in the Hardware Chapter. The ultimate goal is to modify both the software and hardware to inexpensively incorporate a standard vibration monitor. Phase II-a will include the addition of vibration monitoring transducers. This addition will require little change in the reprogramming of the software. The only change will be the addition of four columns of data from the vibration monitoring transducers (Longitudinal, Vertical, Transverse, and air blasts).

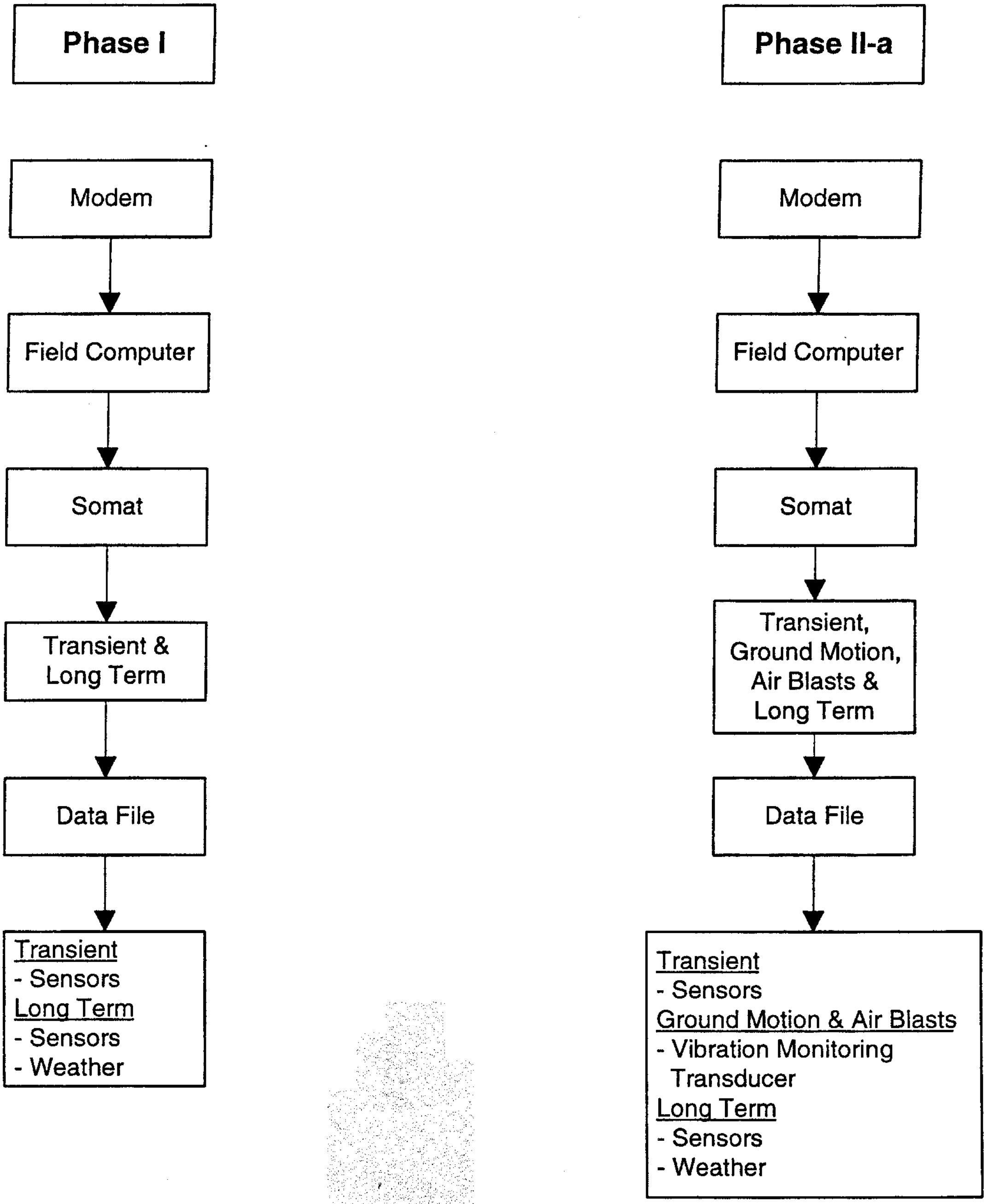


Figure 4.3 Transition From Phase I to Phase II-a by Adding Motion Transducers

As discussed in Hardware, Chapter 3, Phase II-b, illustrated in Figure 4.4, will include the addition of a low speed data acquisition system and a modem splitter. It is anticipated that typical vibration monitors can only capture triggered/transient information without extensive reprogramming. Therefore a separate low speed data acquisition system might be employed for the long-term weather and sensor data with vibration monitors that do no already have such a provision. The Somat data acquisition system will need to be configured to emulate a typical vibration monitor would acquire data. A modem splitter must be employed in this Phase to switch between the Somat data acquisition system and the low speed data acquisition system, which is designed to directly communicate via a modem.

AutoMate changes for transition to Phase II

Figure 4.5 illustrates the required steps that AutoMate will need to perform when the system is transferred to the new equipment in Phase II-b. The addition of the vibration monitoring transducers in Phase II-a will require no modification of the AutoMate files in Phase II-b. AutoMate first opens PCAnywhere and runs the script file (1.pca). This script file dials the access number for the field hardware and contains the modem splitter code to access the Somat data acquisition system. Once connected AutoMate stops the current test, then saves files with a unique name tranyymmdd.xxx, clears the memory of the field equipment, and new test is started. PCAnywhere is then closed, disconnecting from the field equipment.

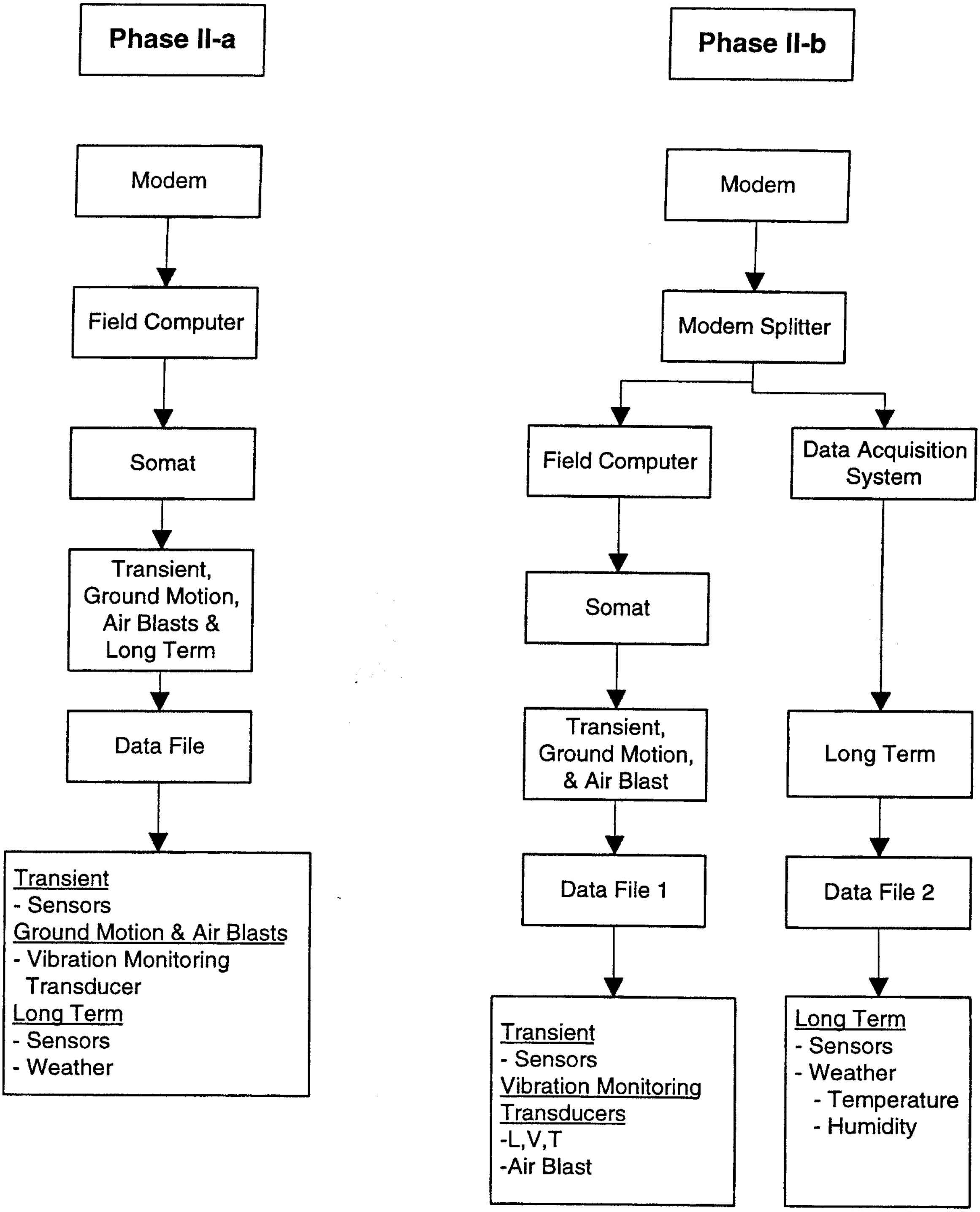


Figure 4.4 Transition From Phase II-a to Phase II-b by Adding Long-Term Data Acquisition System

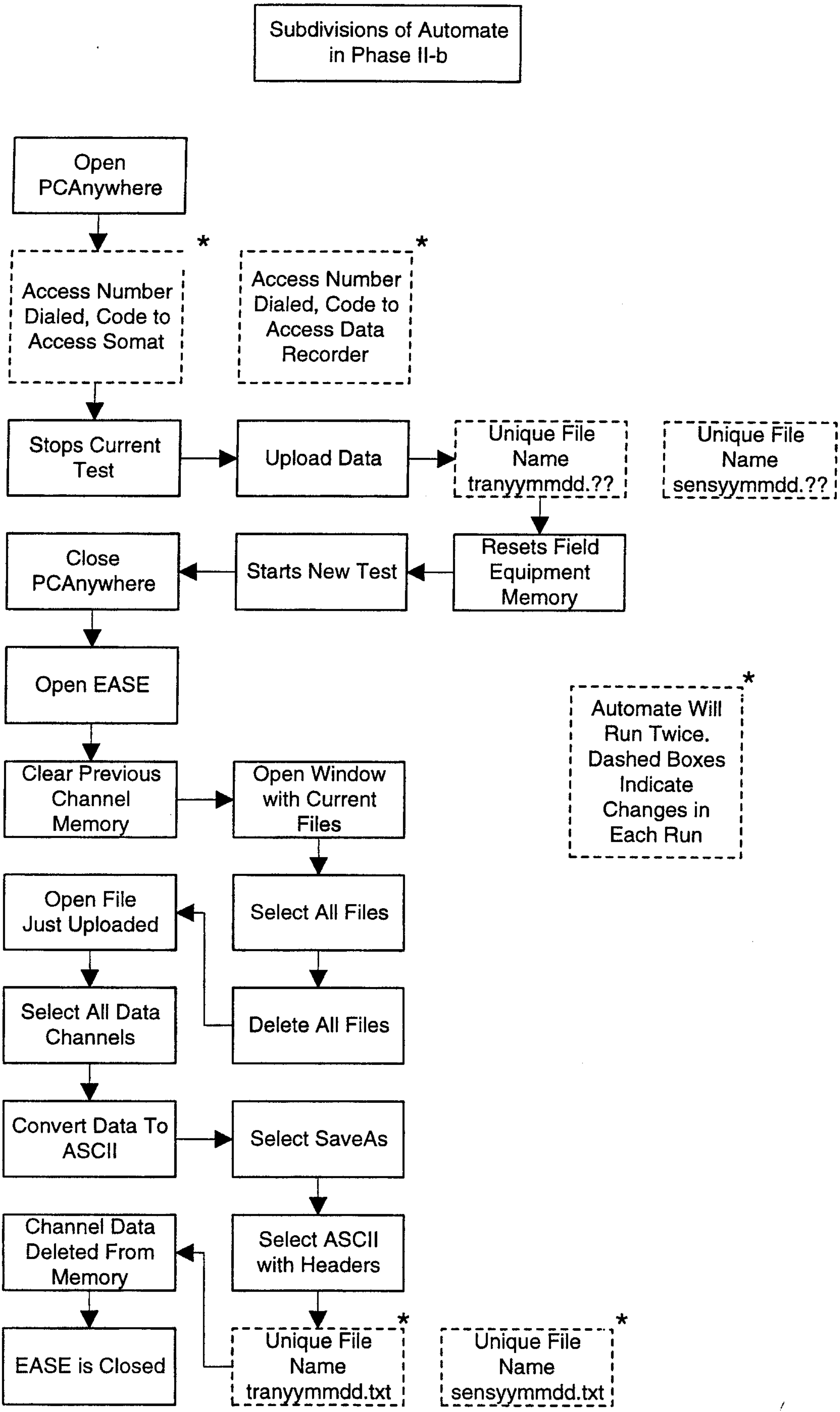


Figure 4.5 Changes to AutoMate to Modify System to Accommodate Standard Vibration Monitor

Next, AutoMate opens PCAnywhere and runs script file (2.pca). This script file performs the same tasks as before except the modem splitter code now accesses the low speed data acquisition system with the long-term sensor and weather data, and the files are saved with the following name sensyymmdd.xxx.

After both data files are saved on the server, AutoMate opens EASE. Once in EASE, the first task is to clear the program of any previous data, by opening the window with current files in memory. All files are then selected and removed from EASE's memory. Once the previous files have been removed from memory AutoMate opens the files one by one, that PCAnywhere has just transferred, and begins the text conversion process by listing the directory and file name (ex. C:\iti_web\sheridan\tranyymmdd.xxx). Once each file has been opened, all of the channels are selected. After the selection of the channels SaveAs is selected from the EASE file menu. ASCII text is selected and is given a unique name with the following format tranddmmyy.txt. Finally the channel information is cleared from memory in the same manner as before. AutoMate then opens the second file sensyymmdd.xxx and performs the same tasks ending with the closing of the program EASE. For complete description on selection and deleting of channels refer to an internal report prepared for Infrastructure Technology Institute (Siebert, 2000).

Changes to the Java applet for transition to Phase II

The changes that are required in the Java applet in Phase II-a for the ASCII text analysis are the addition of the three components of ground motion (L, V, and T) and air blast pressures. The same procedure as discussed previously in this Chapter is applied to this new data. The additional data should cause little programming problems in this Phase.

The changes that are required in the Java applet in Phase II-b for the ASCII text analysis are the addition of a different number of data points, ground motion, air blasts, and two data files instead of one. The file tranyymmdd.xxx contains data from a typical vibration monitor that records ground motion in three components longitudinal, vertical, and transverse (L, V, and T). In addition to the ground motion data, the system records the air blasts pressure time histories. Transient motion will occur over longer time spans of five to fifteen seconds (5000 to 15,000 points at 1000Hz sample rate) thus the record length will change from the thousand-point burst record in Phase I. As before the sensor voltages must be converted to displacements and the absolute maximum must be found. This information must also be saved in a database and have the ability to be keyed by the Julian date.

The file sensyymmdd.xxx contains the long-term sensor voltages. This data should look similar to the Phase I system. This data must be averaged, converted to microinches, and saved in a database with the Julian time stamp. The database format should be made identical to the original database. This will create no change in the graphing program.

Once the data has been placed in the various databases the creation of the graphs should be identical. Only the addition of ground motion and air blasts to the transient data is required.

Graph generation changes for transition to Phase II

As stated before the changing of the system in Phase II-a or II-b should not change the structure of the databases (4H, Max, and All). The additional ground motion and air blast data can be plotted with the vibration data. Figure 4.6 demonstrates the similarity of a typical graph showing the three components of ground motion, air blast and crack sensor displacement.

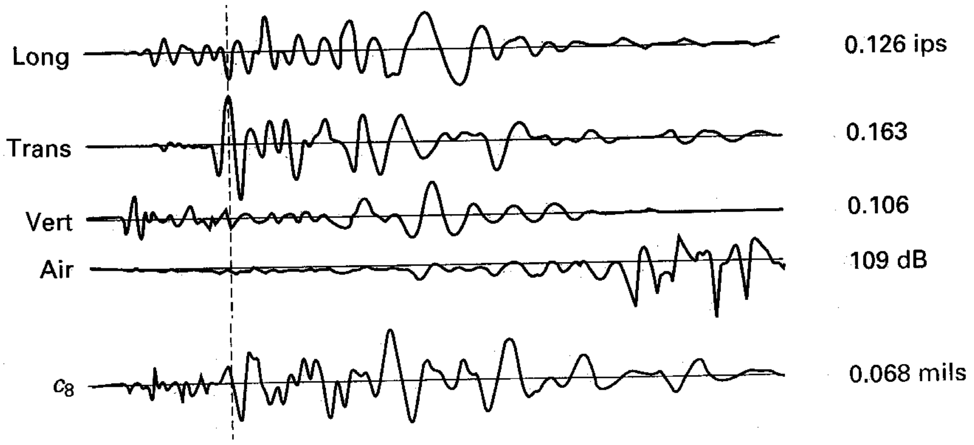


Figure 4.6 Comparison of Ground Motion and Air Blast Time-histories (L,V,T, and Air) with Crack Movement Time-histories

The All database in Phase II-b will now include a minimum of five thousand points for each vibration event at each sensor as well as, the three components of ground motions (L, V, and T) and air blast pressure.

TRANSITION PHASE II TO PHASE III

The transition from Phase II to Phase III should require no modification of the system. Since Phase II mimics the mock system that will be marketed to various companies, Phase III should require no changes over Phase II.

LIMITATIONS

There are a few limitations to the system that must be considered, as it is currently configured and operated. When the AutoMate tasks are being performed the server computer cannot be used for any other purpose. This should not be a problem if AutoMate is set to run late at night when the computer will not be in use. A solution to this singular operation is to purchase a duel processor computer for a server. Thus one processor can be dedicated to data analysis and graphing while the other can remain active for queries to the database from web users. The server must remain on at all times so the web site can be accessed and so the AutoMate script can run. Also, the AutoMate date function can only enter the current date. When the file is uploaded at 12:01 am the name given to the data is a day off. This offset is easily accounted for in the data conversion program.

The communication between the server and field equipment can take place only over a modem. Phone lines or a reliable cellular phone signal must therefore be available for both the field and the server computer.

CONCLUSIONS

Features of AutoMate transform standard Somat data acquisition software to an automated version. This automation then coordinates the field and computer computers to store data obtained at pre arranged long term and weather times as well as transient vibration data that occur at random times. Consolidating all computations at the server allows use of systems with standard vibration monitors.

Web operation is simplified by production of all graphs at the server though server-side applets. Thus any browser may be employed to access data, and the widest of audiences is ensured.

CHAPTER 5

MEASURED RESPONSE

INTRODUCTION

This Chapter compares time histories of crack response with those of inside temperature and humidity as measured with the Phase I system at 1908 Sheridan Road. Furthermore the long-term displacements are compared with habitational vibration responses. The measurements confirm that crack displacement is greatly affected by weather and habitational vibration. First, a description of various long-term weather and habitational responses of the test house will be analyzed. Next, applications of the null sensor correction will be presented to demonstrate its effect. Finally, additional data will be identified to be analyzed in Phase II and III.

1908 SHERIDAN ROAD TEST HOUSE

House description and sensor location

As shown by the photograph of the outside of the house in Figure 5.1, the Phase I test house is a three-story wood-frame structure with a basement. Three displacement sensors (from now on referred to as basement, stairs, and first floor), one null sensor, one humidity sensor, and one temperature sensor were placed in a cluster about the back stairwell. As discussed in the sensor section, the temperature and humidity sensor are housed in the same box and will be called the weather sensors. A plan and an elevation view of the core stairway in which the sensors were placed can be viewed in Figures 5.2 and 5.3. Their locations were determined by the presence of large cracks. These cracks were determined to be active as the facility was plastered and painted only two years ago and the cracks have already become obvious.

Figure 5.1 1908 Sheridan Road

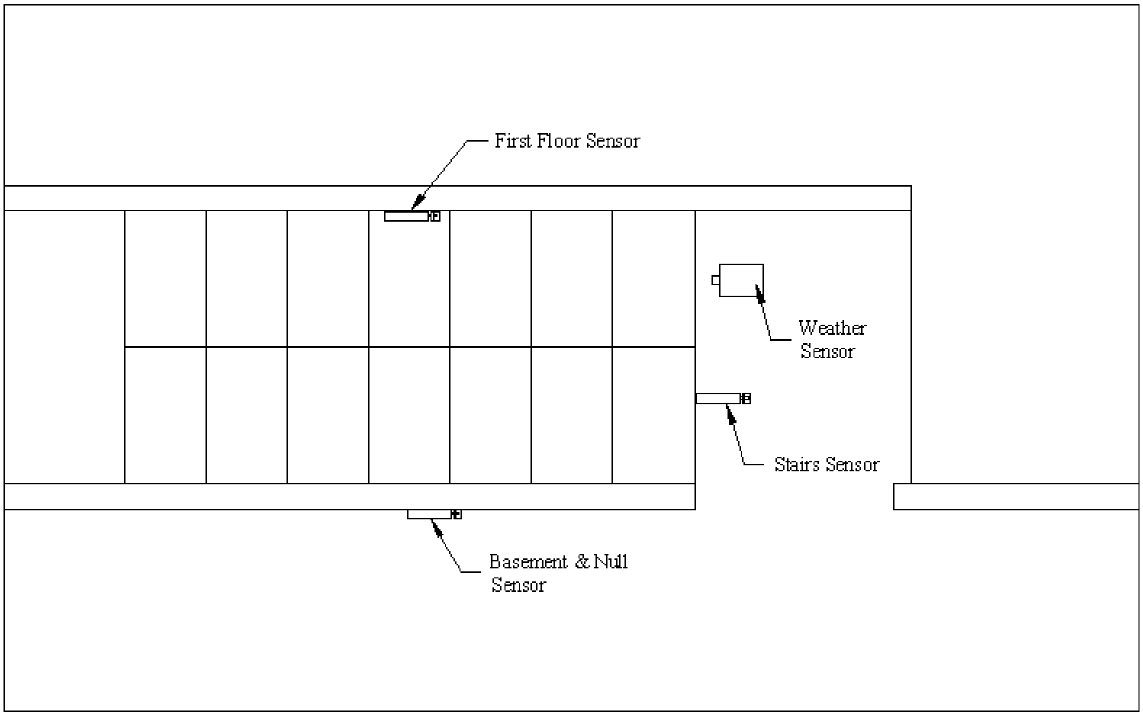


Figure 5.2 Plan View of House with Sensor Location

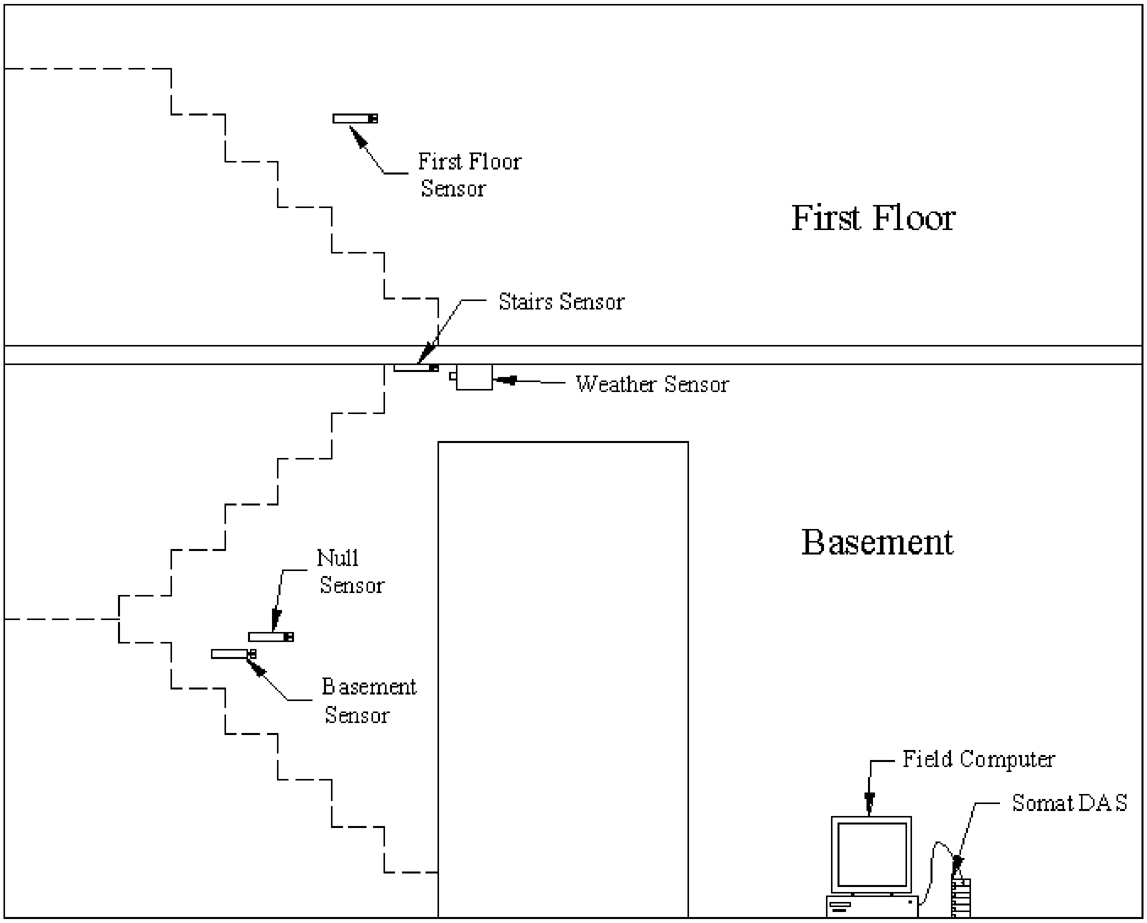


Figure 5.3 Elevation View of House with Sensor Location

The description of the sensors begins in the basement where the null sensor and the first crack displacement sensor (basement) are located. The photograph shown in Figure 5.4 shows the basement of the house. The photo shown in Figure 5.5 pinpoints the crack over which the basement sensor is placed. The location of the null sensor with respect to the basement sensor can be seen in Figure 5.6.

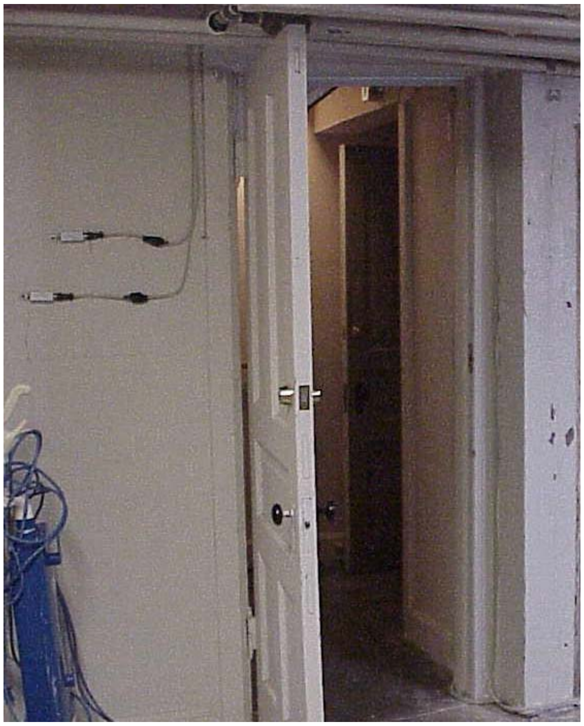


Figure 5.4 Basement of House

Figure 5.5 Basement Sensor

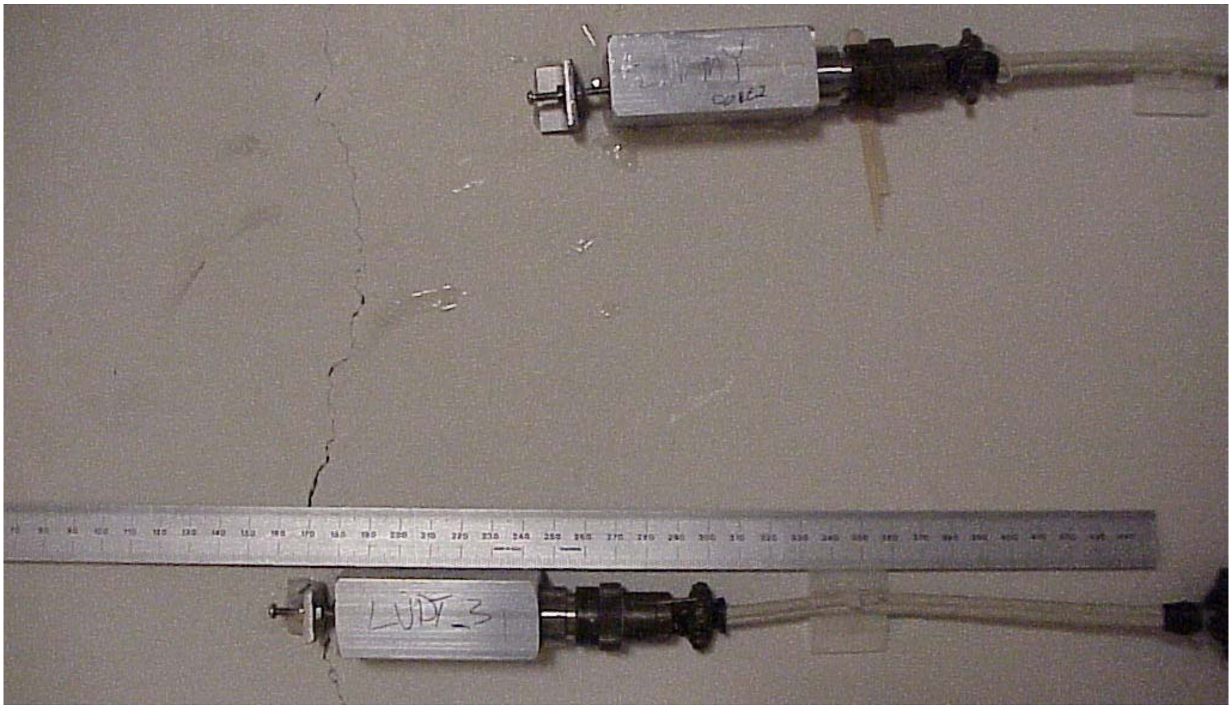


Figure 5.6 Basement and Null Sensor

The weather sensors and the second crack displacement sensor (stairs) are located under the stairs that lead down to the basement as shown photographs in Figures 5.7 and 5.8 is placed. Photographs in Figure 5.9 and 5.10 show separation distances and size of the weather sensor with respect to the stairs sensor. The crack appears to be at the connection of the stairs to the first floor. Figure 5.11 illustrates a typical framing detail of similar stairs. The crack could have formed due to of incorrect construction of the stair framing.

Figure 5.7 Weather Sensors

Figure 5.8 Stairs Sensor

Figure 5.9 Weather and Stair Sensor

Figure 5.10 Stairs leading to Basement

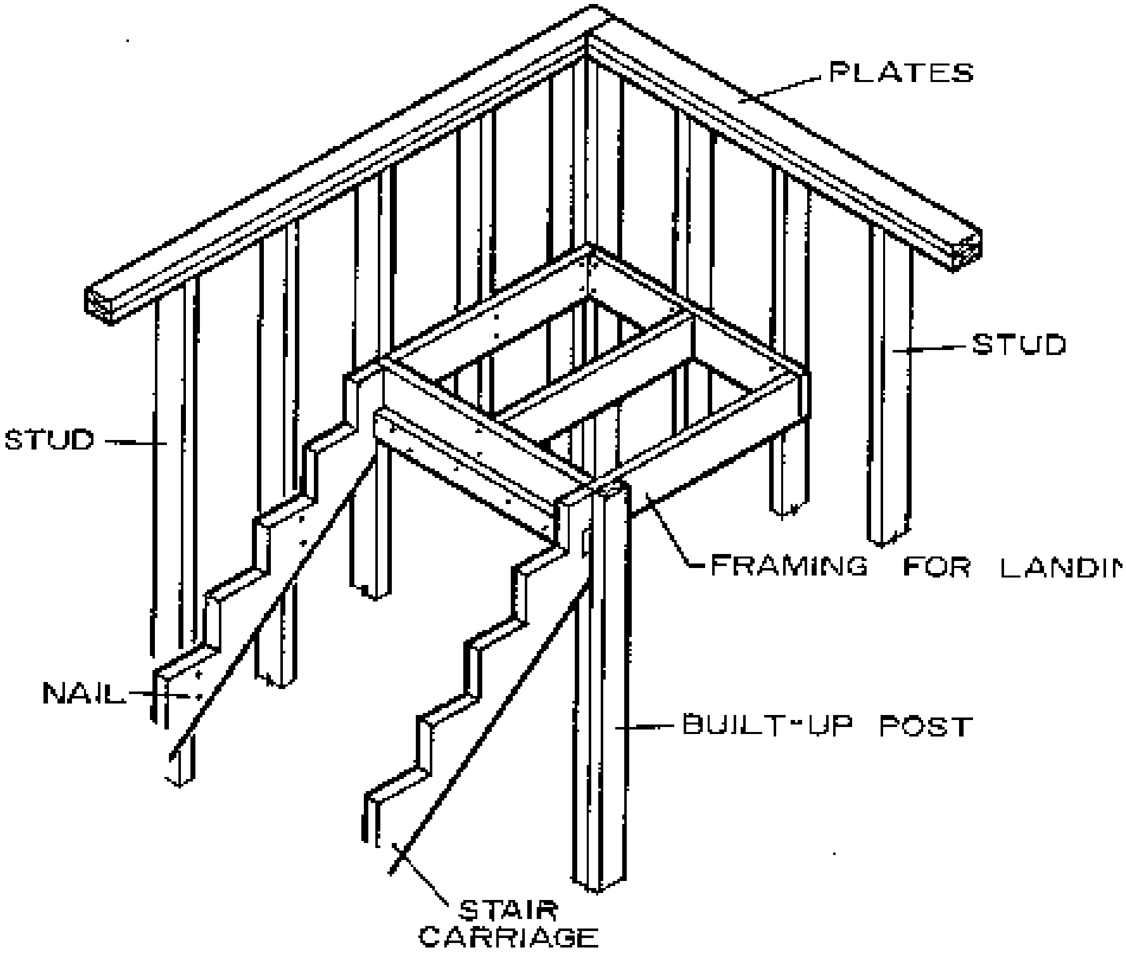


Figure 5.11 Typical Framing Detail for a Stairwell

The third crack displacement sensor (first floor) is located on the wall of the stairwell between the first and second floors. The first floor sensor and the crack over which it is positioned are identified in the photograph in Figure 5.12. The photograph in Figure 5.13 shows the first floor stairwell that leads to the basement and the second floor.

Figure 5.12 First Floor Sensor

Figure 5.13 First Floor Leading to Basement

The sensors are all located on interior walls within approximately 4 meters of each other. This proximity is important when the null sensor is taken into account as discussed below. The system began recording data on December 17, 1999, roughly at the beginning of the season of intense heating.

Null Sensor Correction

The null sensor response, as described in Micrometer Displacement Sensors, (Chapter 2), must be subtracted from that of the sensors spanning cracks to eliminate the effects of electronic drift, thermal hysteresis, and material expansion. The null sensor is employed to convert all sensors spanning cracks because of their close proximity. Future systems may require more or fewer null sensors as a function of the temperature sensitivity of the electronics. Material effects that are included in the null sensor correction are the mounting brackets for the sensors and the wall material, in this case plaster. The reported null sensor displacement vs. temperature over the 100-day test period is graphed in Figure 5.14. Ideally the graph should show a linear relationship with temperature change. Figure 5.14 shows a maximum movement of approximately 6.2 micrometers during the 100 days. This movement is not a continuously increasing function but instead is cyclical, as indicated by the start and end of the 100 days, which is only 3.0 micrometers apart.

The variance is caused by the electronic drift and material effects and therefore must be subtracted from the crack displacement sensors' data. Subtracting the null sensor displacement from the crack sensor displacement should reduce the total response of each crack sensor when plotted vs. temperature, as is illustrated in Figure 5.15. Here, the null sensors maximum excursion is 2/3 that of a crack spanning sensor. All four displacement sensors were established with the same distance between sensor and target brackets so that the correction could be made by simple subtraction.

When viewed against time, as shown in Figure 5.16, the uncorrected and corrected crack displacement vary during the period. At first the null sensor correction data tends to simply displace the values upward but does not change relative short-term amplitude. Toward the end the corrections are much smaller and again do not change the amplitude of the opening and closing cycle. Null sensor displacement with time is shown in Figure 5.17 and illustrates that early in the test there is greater displacement that requires correction, while towards the end of the test there is less displacement from the

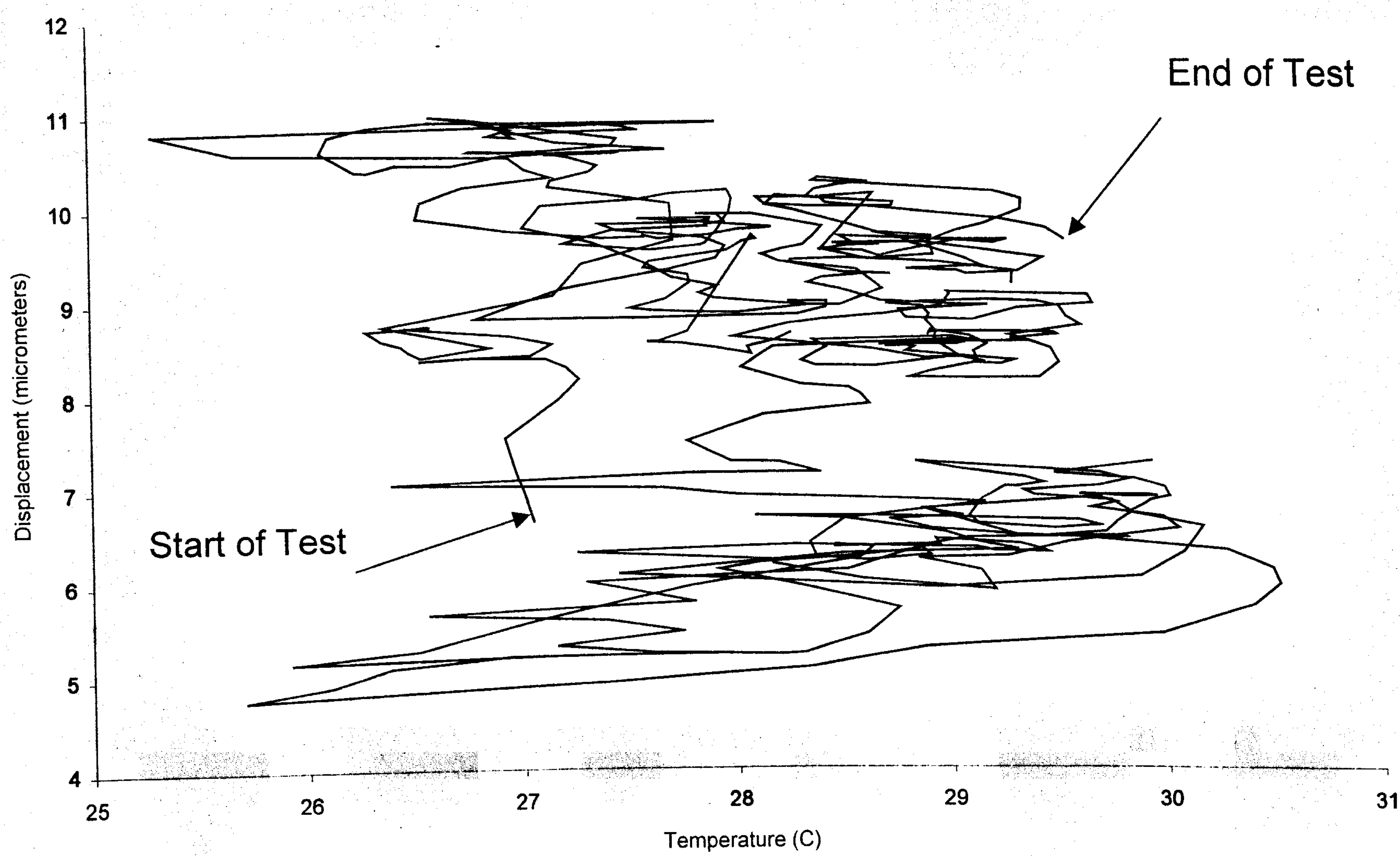


Figure 5.14 Null Sensor Displacement vs. Temperature

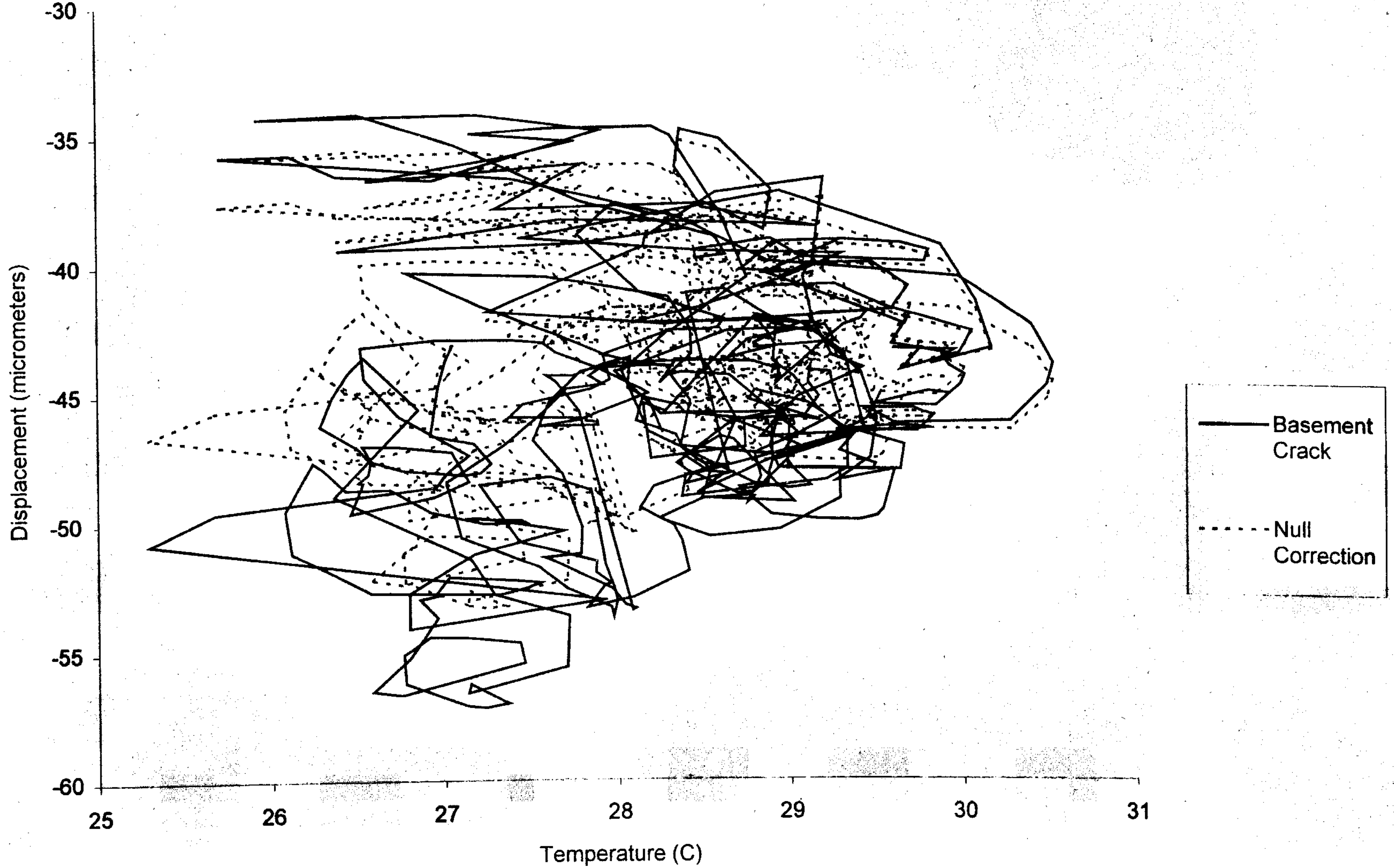


Figure 5.15 Basement Crack with Null Correction

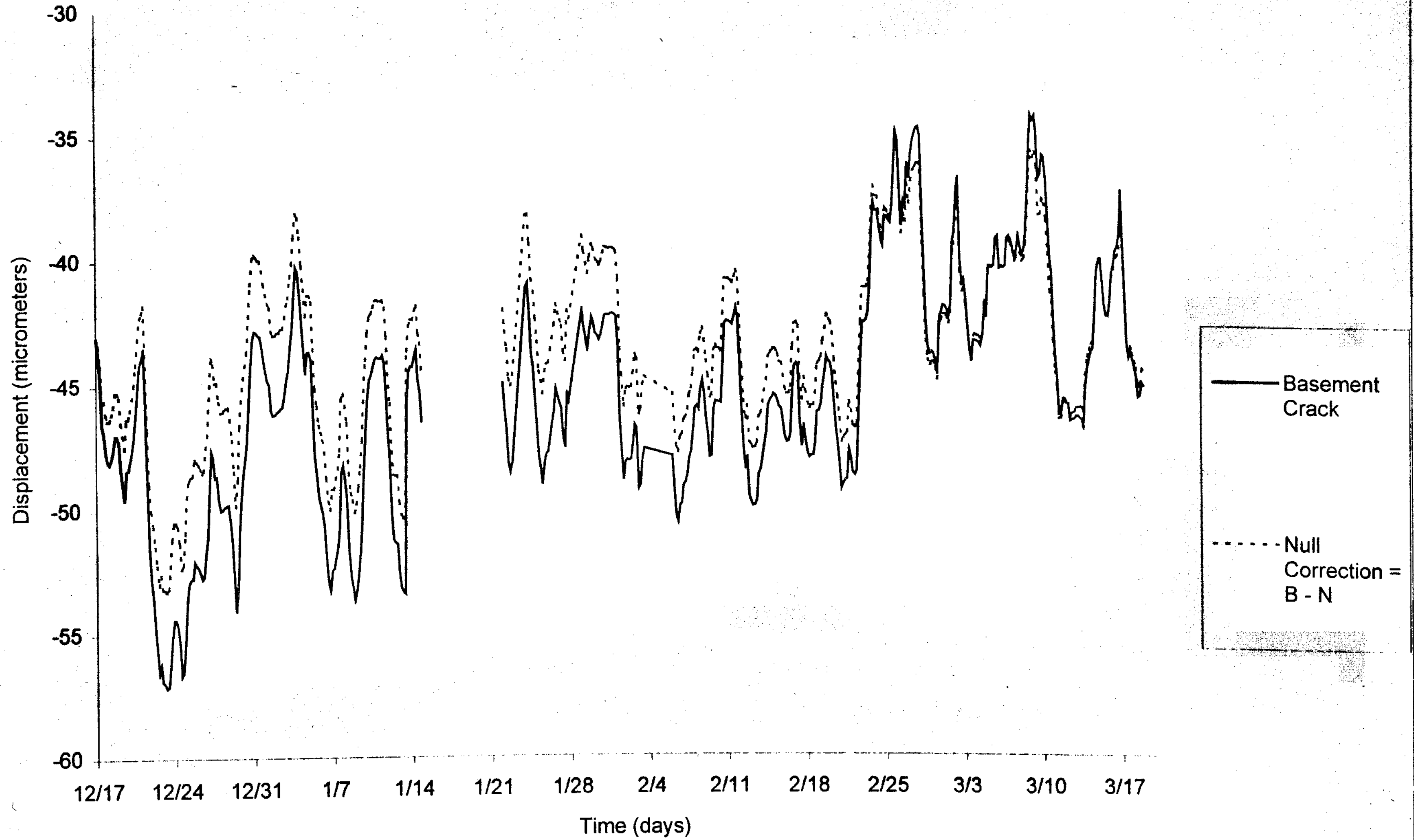


Figure 5.16 Basement Crack Correction vs. Time

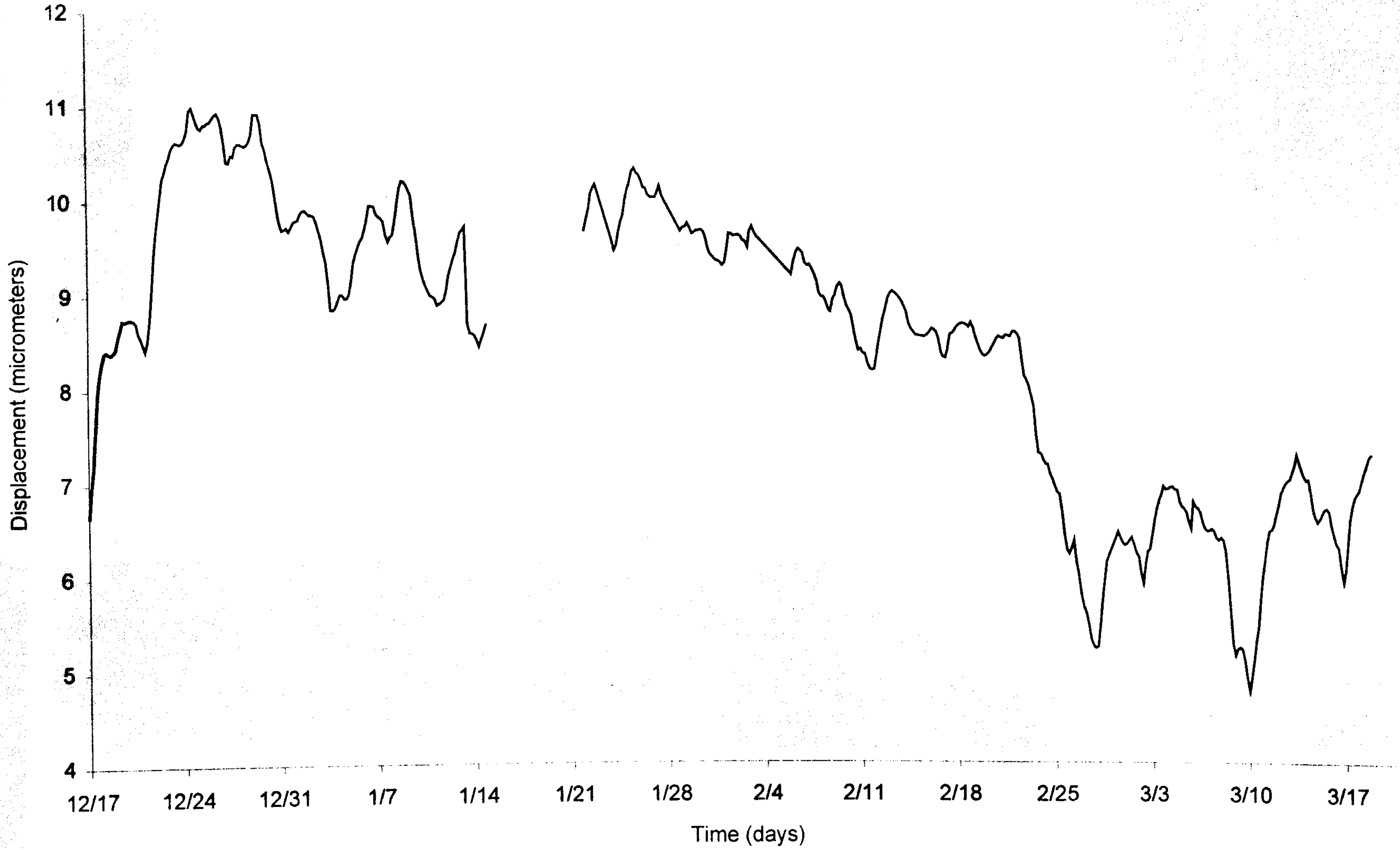


Figure 5.17 Null Sensor vs. Time

initial reading at time zero. An internal report prepared for Infrastructure Technology Institute (Siebert, 2000) illustrates the corrected displacement of each sensor in the test house.

Crack Displacement vs. Weather

Crack displacement is greatly affected by variations in the temperature and humidity. During the winter the house is heated almost continually, which dramatically lowers the inside humidity, and dries out the wood framing. This combined effect of increased heat and decreased humidity cause the reactive materials in the house, such as wood, to shrink, which leads to structural distortion and associated crack movement. In the summer the opposite effects occur. The house is not heated and the natural humidity, which is much greater during the summer increases in accordance with area climate. This theory is substantiated by Figure 5.18, which shows the heat consumption for a typical house for the past two years. The heat consumption, measured in therms, increases in the winter months, November to May, and decreases in the summer months, May to October.

To further confirm this hypothesis of the effect of heating a time history, the first floor crack displacement is compared to heating degree-days in Figure 5.19. A degree-heating day is defined as the average temperature below 65 degrees for twenty-four hours. At the beginning, the degree-days were in the teens. Then they increased to two peaks of fifty to sixty during a severe, mid-January cold period. This extended cold period causes constant heating of the house and subsequently low humidity inside the house, which dries out the reactive materials. From February until the end of March the

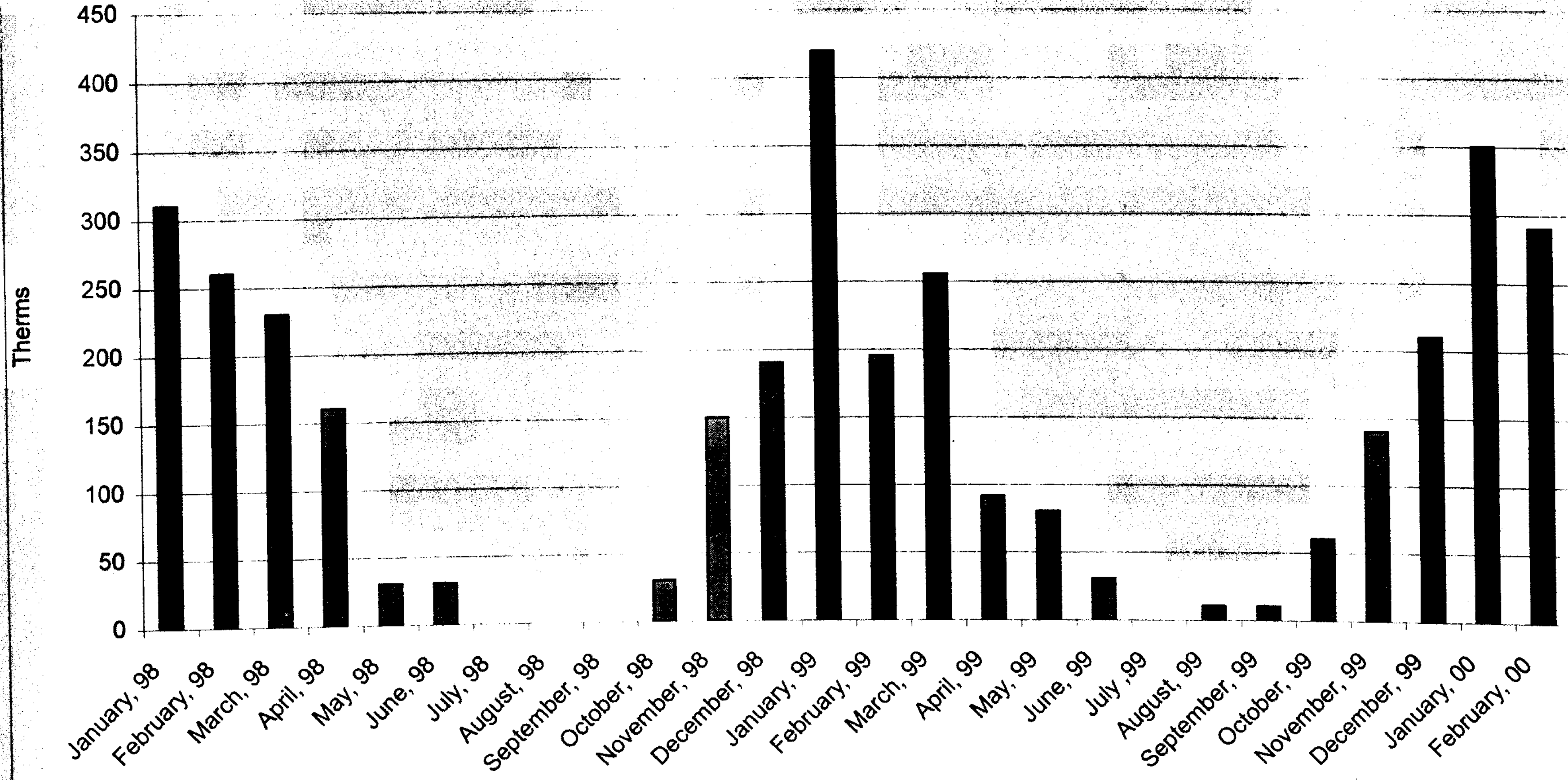


Figure 5.18 Two-Year Heating Usage for a Typical House in Therms

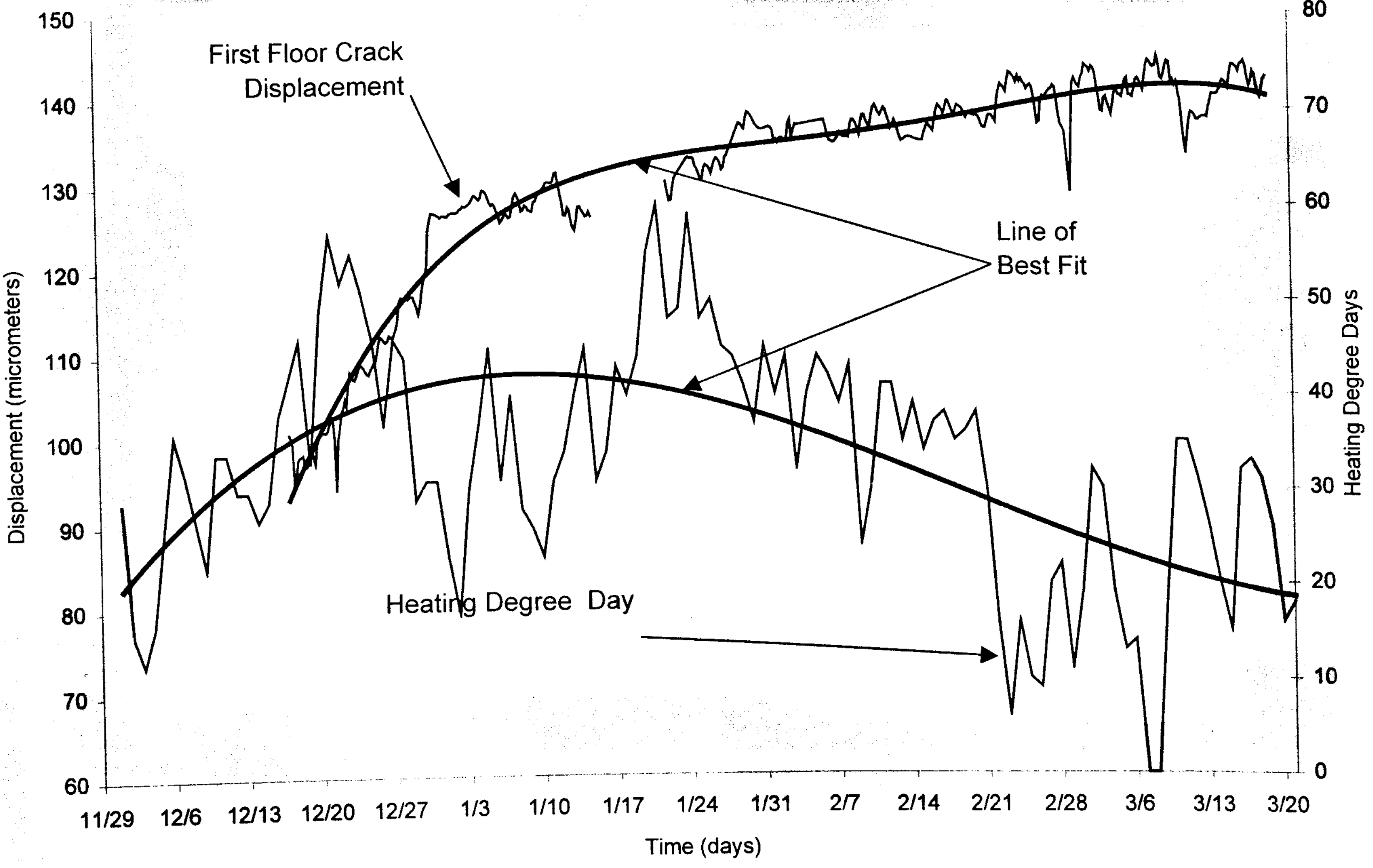


Figure 5.19 First Floor Crack Displacement & Heating Degree Day vs. Time

average degree-heating days declines to around fifteen, which allows less heating and desiccation and thus re-hydrates the reactive material.

This long period of heating causes cracks to react as shown by the response of the first floor crack in Figure 5.19. As the degree-heating days increase, the crack moves considerably. As the heating degree-days plateau and begin to decline the crack stabilizes. As the month's progress and the degree-heating days begin to decline, the materials will gain moisture and the crack will move again.

Effects of temperature and humidity on the basement crack sensor are illustrated in Figures 5.20a and 5.20b respectively. The right scale on the graphs is that of temperature (C) or humidity (%), while the left scale indicates crack displacement. . Figure 5.20a illustrates that when the humidity dips or peaks the basement crack displacement also dips or peaks. Figure 5.20b shows that when the temperature dips or peaks the basement crack dips or peaks as well. As discussed above, temperature and humidity are related and it is difficult to tell which has a greater effect on crack change. However, Figure 5.21 and 5.22 indicate that there is a greater correlation between the changes in crack width and humidity than with temperature.

When past research is consulted, shown in Figure 5.23, the same effect confirming the results can be seen. The circles indicate large crack movements associated with large changes in humidity. The other sensors in the house show the same results and can be found in an internal report prepared for Infrastructure Technology Institute (Siebert, 2000).

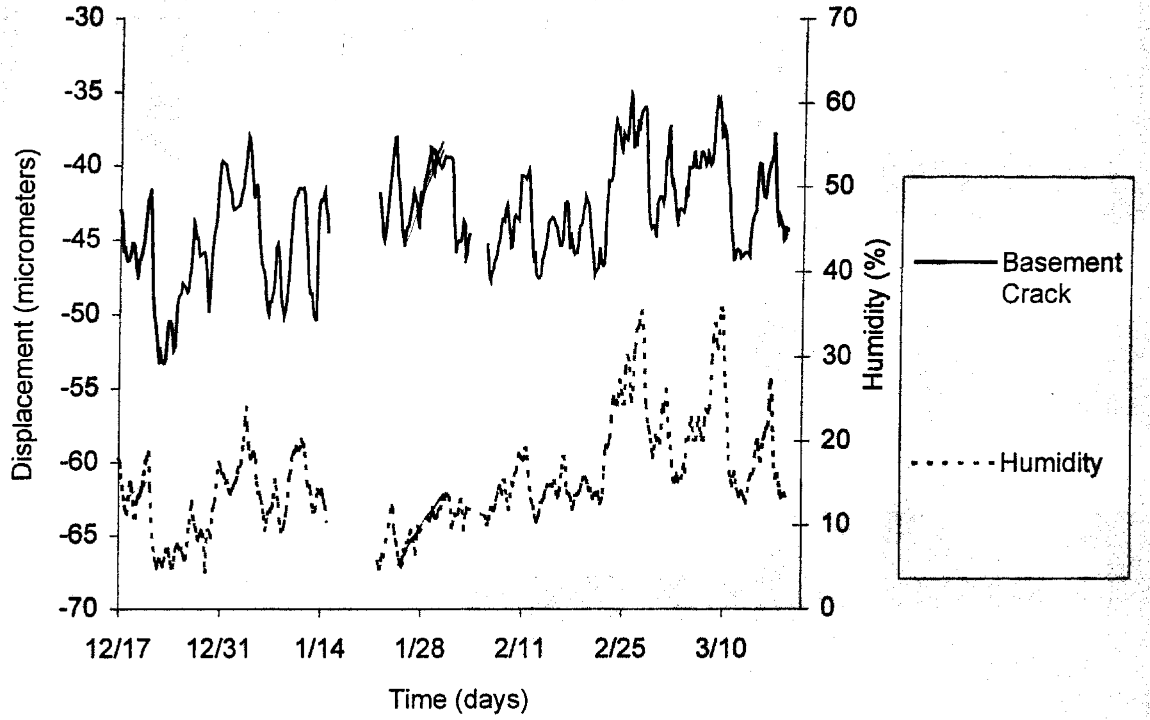


Figure 5.20a Basement Crack Displacement & Humidity vs. Time

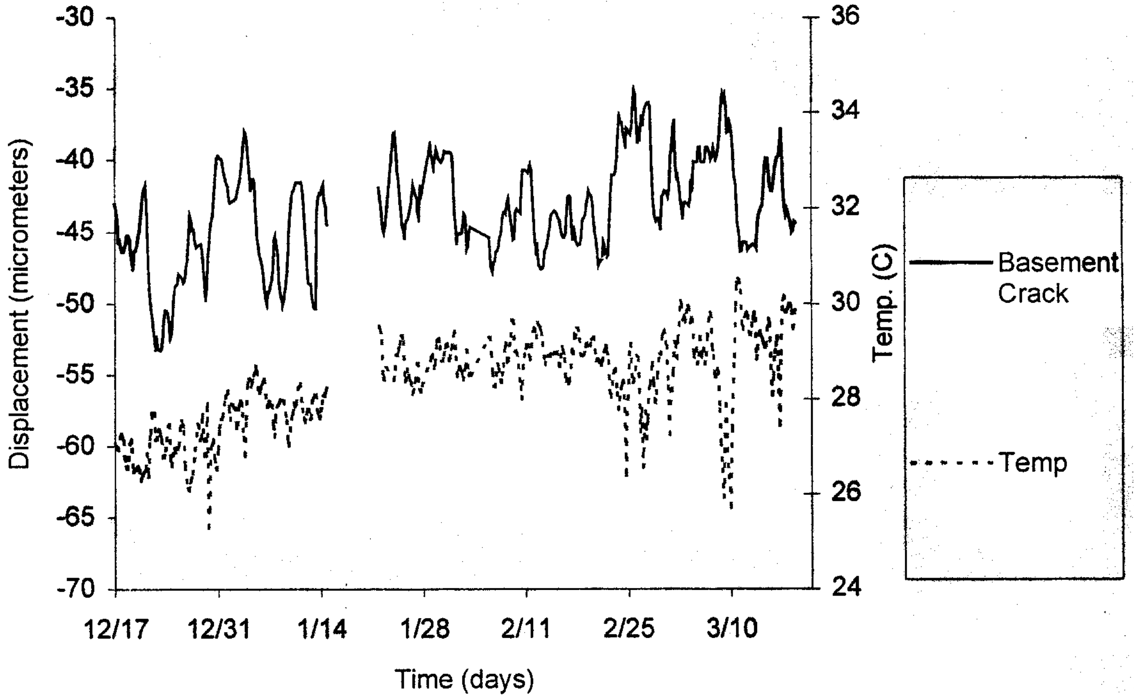


Figure 5.20b Basement Crack Displacement & Temperature vs. Time

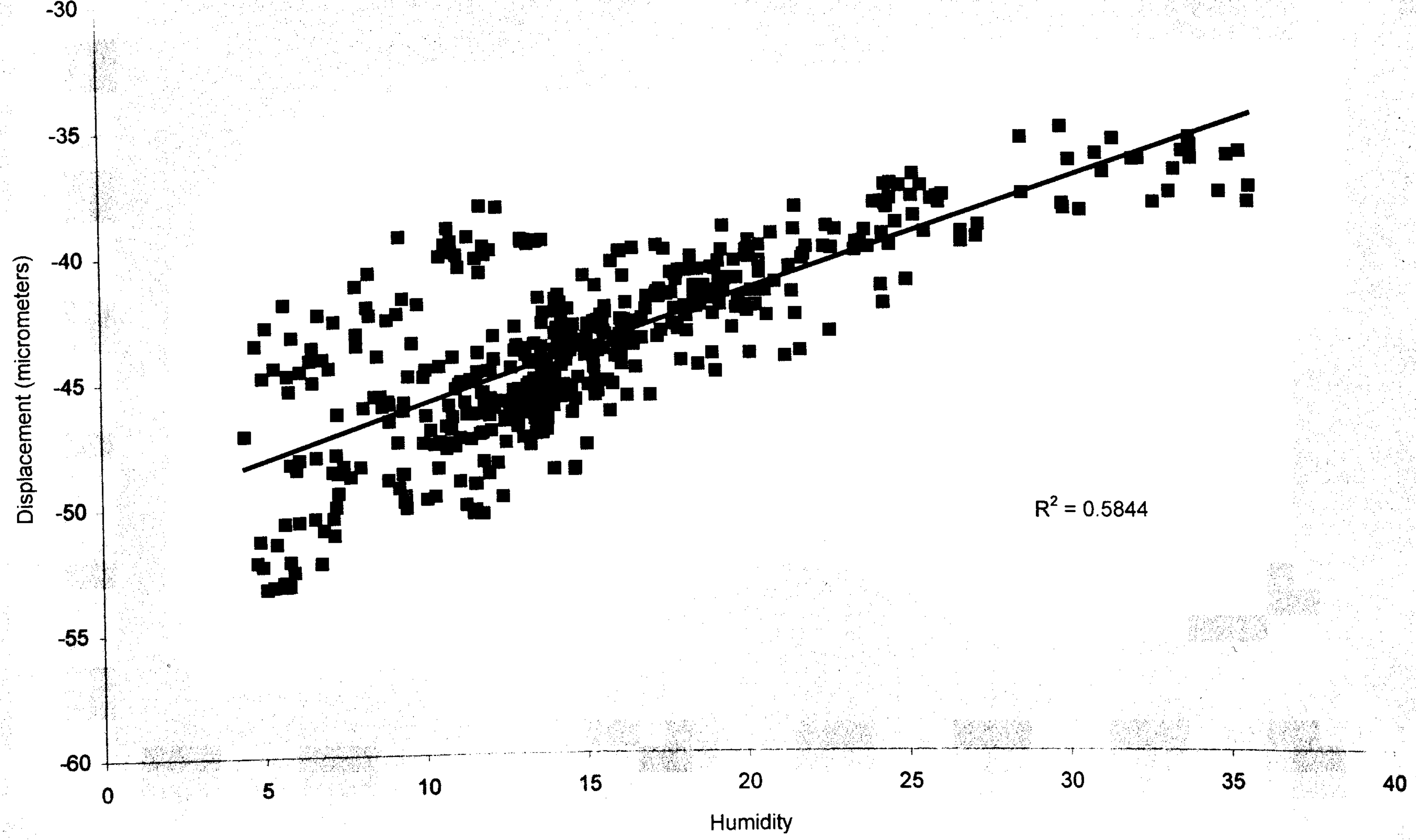


Figure 5.21 Basement Crack Displacement vs. Humidity

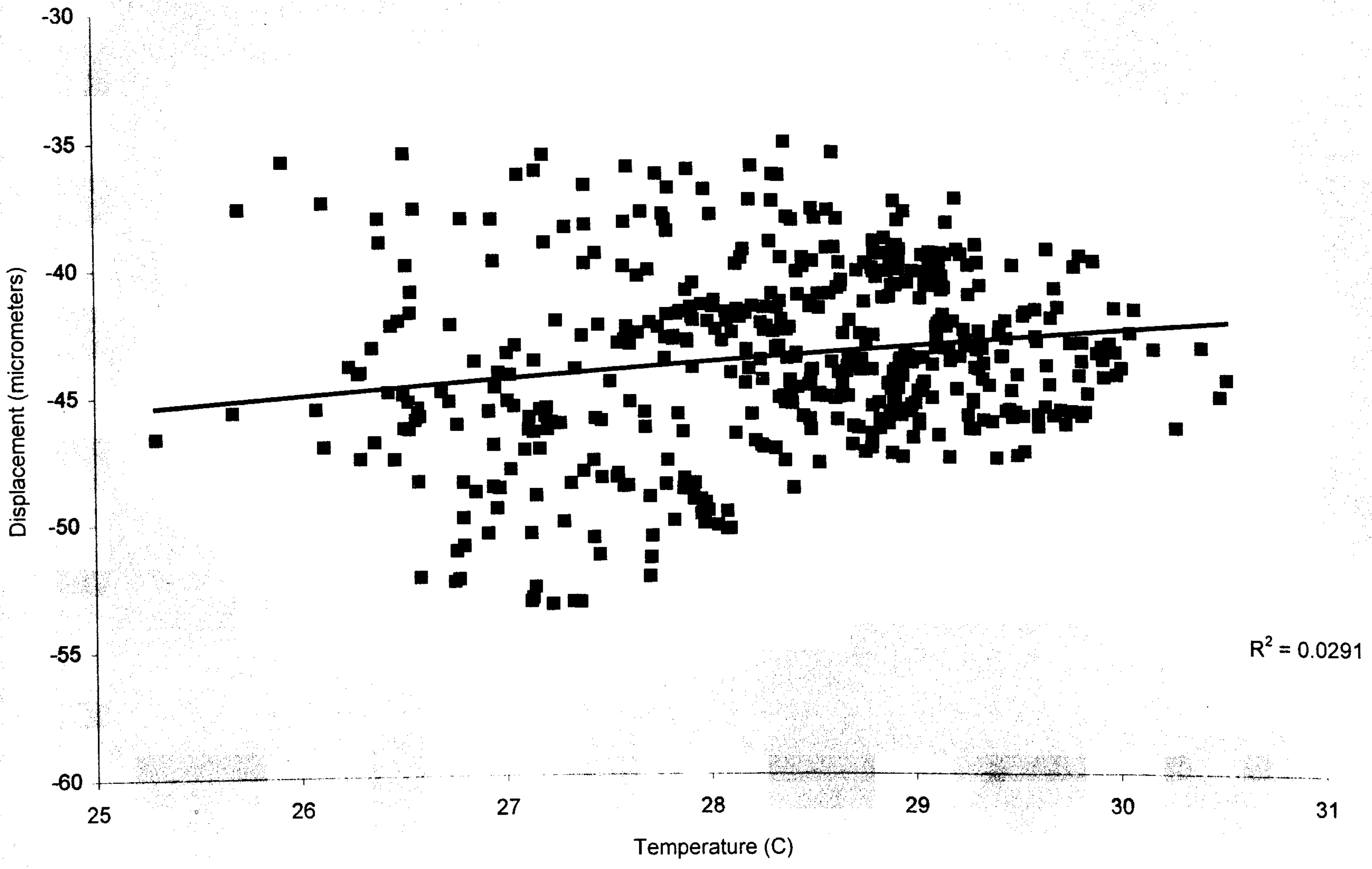


Figure 5.22 Basement Crack Displacement vs. Temperature

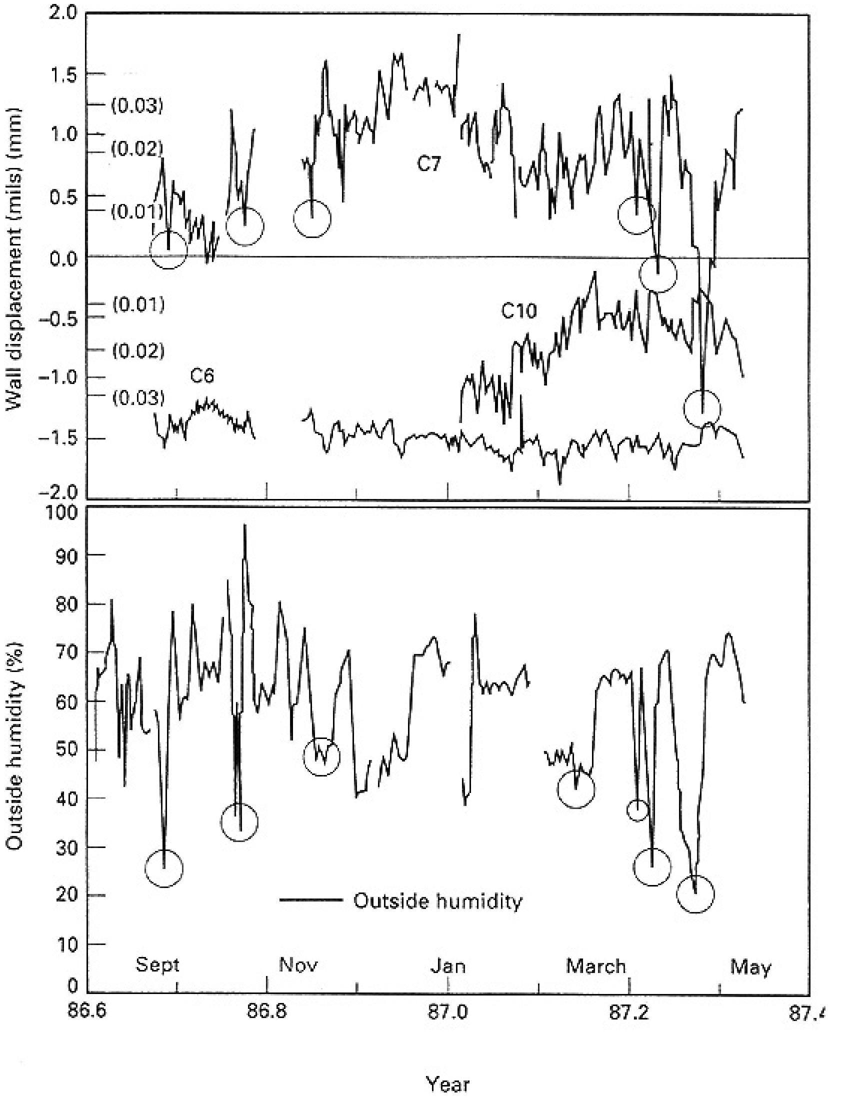


Figure 5.23 Correlation of Humidity and Crack Displacement vs. Time for Another Test House Showing Correlation of Peak Displacement with Large Changes in Humidity (Dowding, 1996)

Crack Displacement vs. Habitational Vibration

Habitational vibration events such as walking up or down stairs, closing doors, and simply walking across the floor cause structures to vibrate locally. This local structural vibration leads to transient crack width variation. Figure 5.24 presents a four-month time history of crack movement as measured by all three sensors. Superimposed

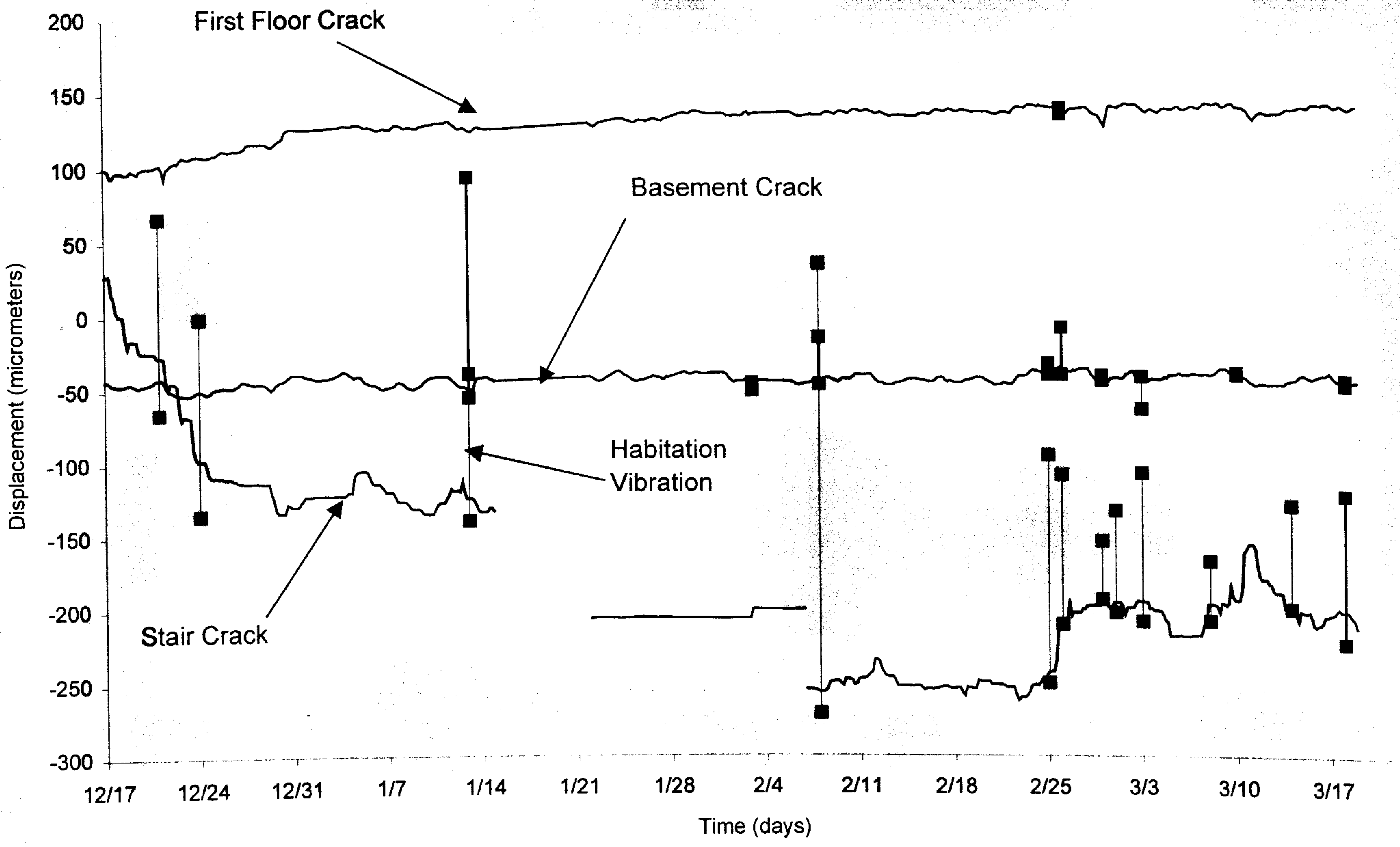


Figure 5.23 Crack Displacements Produced by Lont-term Weather Effectrs are Equivalent to those Produced by Habitation Vibration

on the long-term history are the peaks of the habitational crack disturbance. These are all the events that produced dynamic crack width changes greater than 1.9 micrometers, the trigger level. The vibration events are added to the plot by taking the maximum and minimum displacement value during the vibration event and placing them with long term movements at the time of occurrence. From January 14-21, 2000 the system was down and no data were recorded because of a failure in the modem connection. This problem was solved by manually resetting the field computer.

While all of the sensors have vibration events, the stairs sensor is the most responsive crack as shown by the events on 25 of February. The stairs sensor is also the most responsive to long-term weather effects. The magnitude of the vibrations for the basement and first floor sensors are substantially less than that of the sensor stairs. Thus not all cracks behave the same way in a house and some are more responsive than others. This observation confirmed by results of past studies is shown Figure 5.23 where C7 was very responsive, as the stairs are in the Sheridan Road case.

Crack displacement vs. time with habitational vibrations for the sensor stairs is plotted alone in Figure 5.25 to focus on details of the response. In addition to the time when the system was down this sensor was out of range from January 21-February 7, 2000. Hence the horizontal line for the sensor displacement during this time period. The basement in the test house is used for storage and is not a high traffic area. However, each time a person walks up or down the stairs it produces a large vibration event as indicated on the graph. The magnitude of the habitational vibration is far larger than the weekly weather induced vibration events. However even the largest habitation vibration is not greater than the winter season heating event.

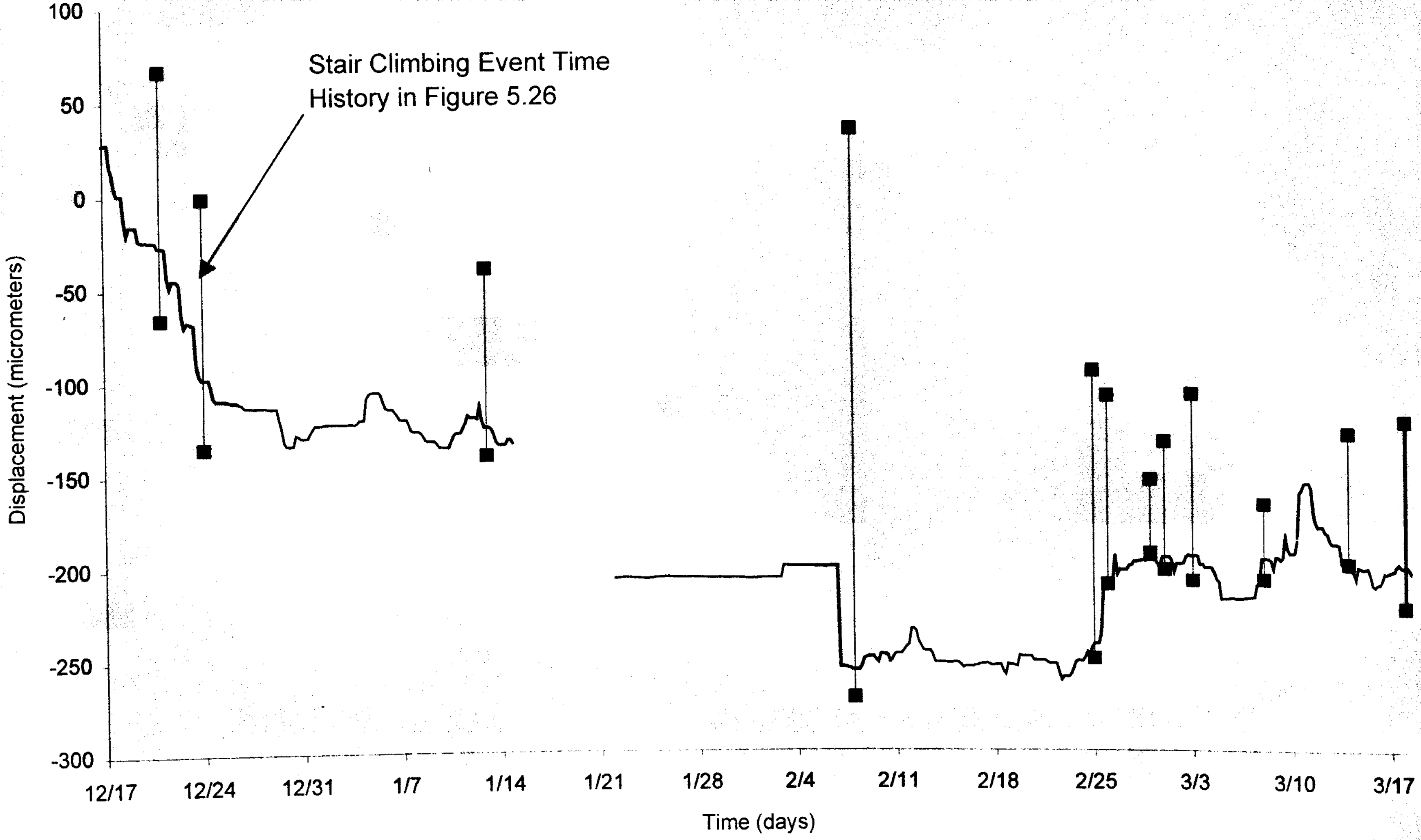


Figure 5.25 Stairs Crack Deformation & Habitational Vibrations

Furthermore it appears that the crack expands more than it contracts for each of these habitational vibration events. This can be explained with the detailed three-second vibration event of the author running up the stairs marked on Figure 5.26. As each stair is impacted it produces a new vibration event on the graph. Each individual step on the stairs adds to the crack in width that gives the appearance in Figure 5.25 that the crack is only expanding with transient movement. In this case the crack does not immediately return to the pre-vibration width. However before the next four-hour reading the crack has returned to its pre-vibration width, as indicated by the return in Figure 5.25. The response to the added human weight on the stairs is somewhat viscous. This viscous response may be a result of sliding friction of the LVDT core. Such a viscous response may not be observed with other sensor types.

The basement sensor is on a wall that abuts the stairs. A person walking down the stairs also produces a vibration event on this sensor, as seen by the large events in Figure 5.27. These vibration responses are much smaller than those induced at the stairs sensor because the basement sensor is farther away from the vibration source.

When the door to the basement is shut it produces habitational vibration events on the basement sensor like that in Figure 5.28. The magnitude of the basement vibration is substantially less than that of a vibration on the stair sensor. The basement crack returns to its pre-vibration state that indicates that there is no permanent crack displacement.

Despite heavy stair traffic, Figure 5.29 indicates by the low number of habitational events that the first floor sensor is the least responsive of the three displacement sensors to habitational vibration events. A possible explanation for this could be that the wall on which the sensor is mounted is not connected to the stairs

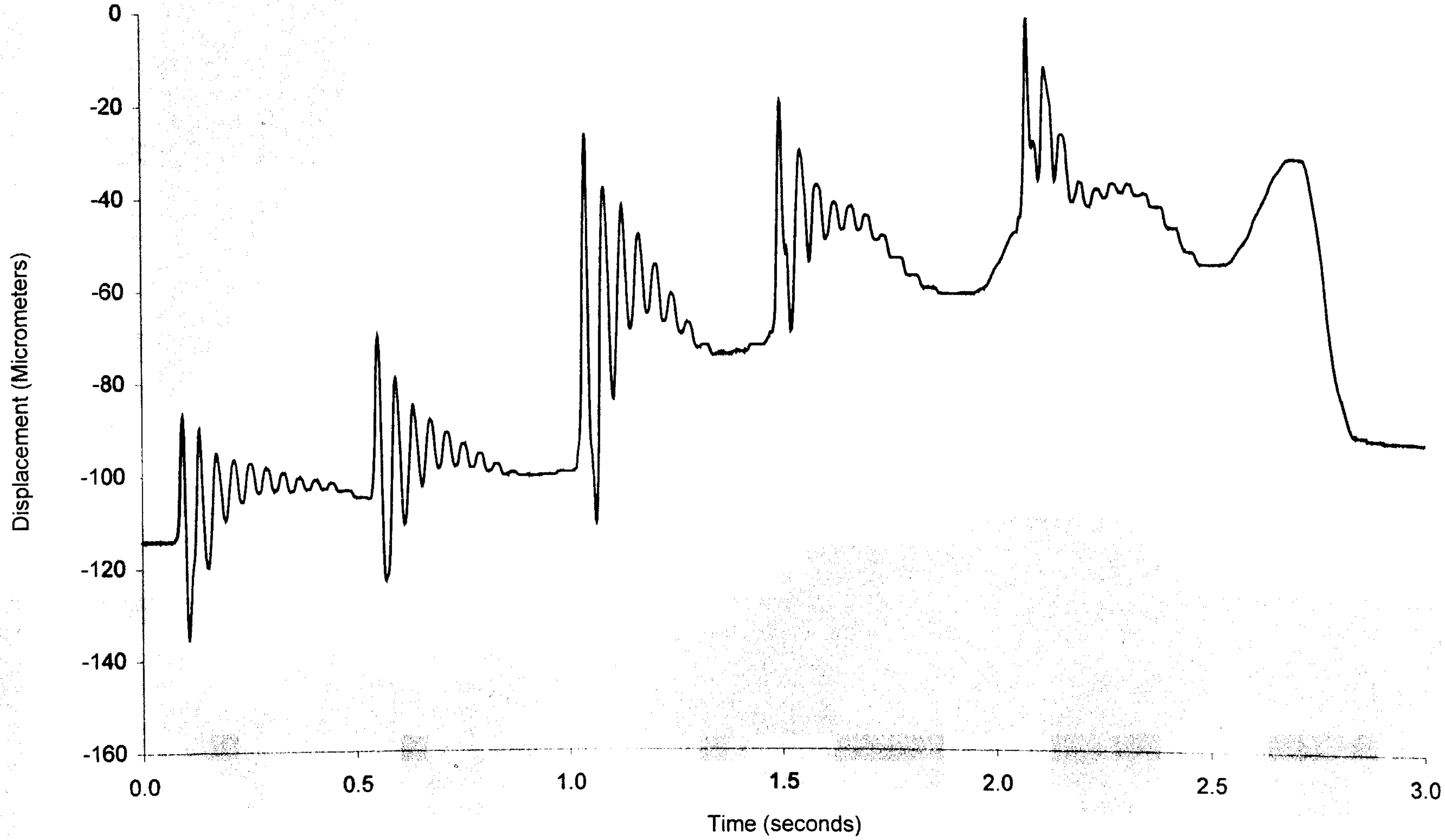


Figure 5.26 Vibration Response to Walking Upwards of Crack Under Stairs

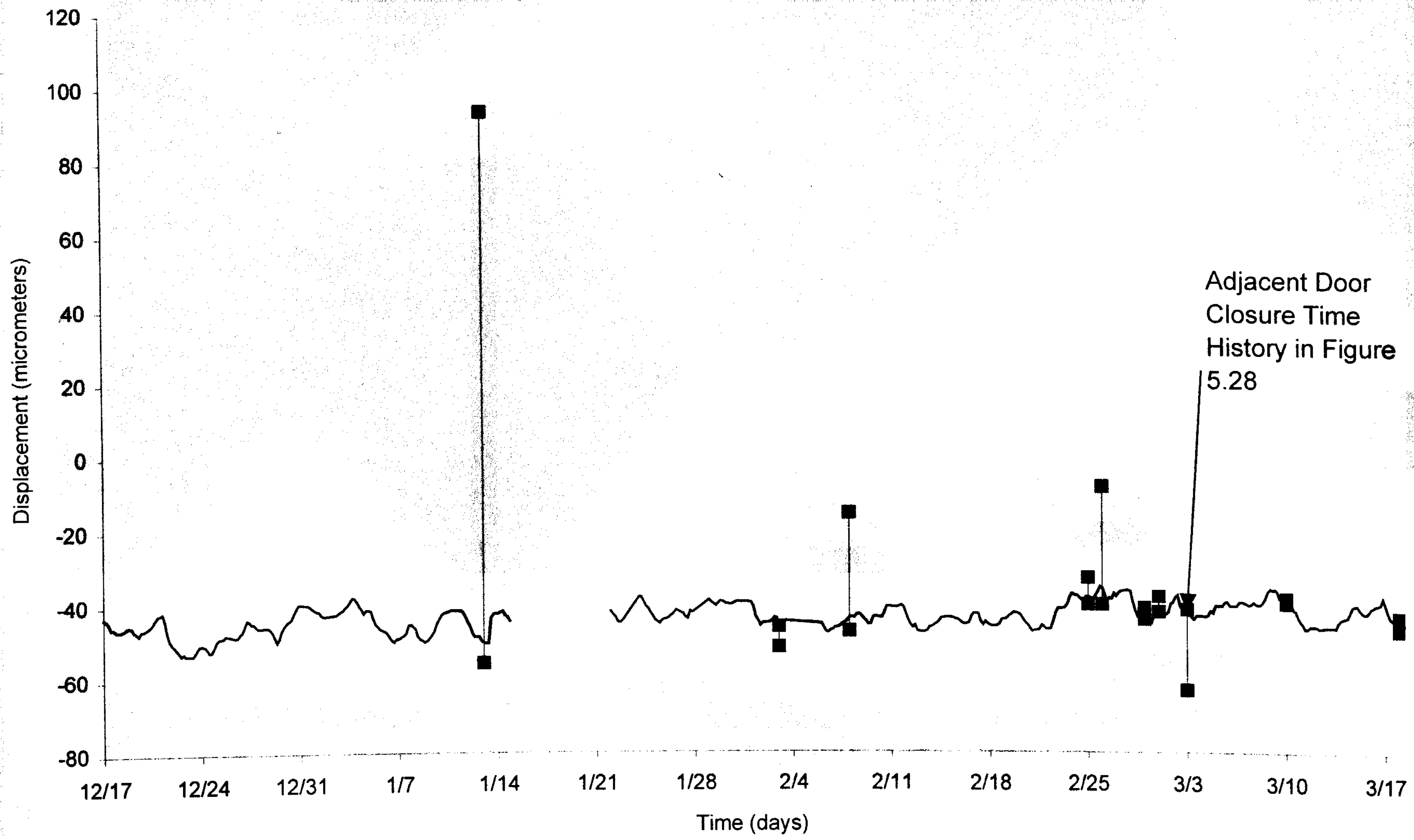


Figure 5.27 Basement Crack Displacement & Habitational Vibrations

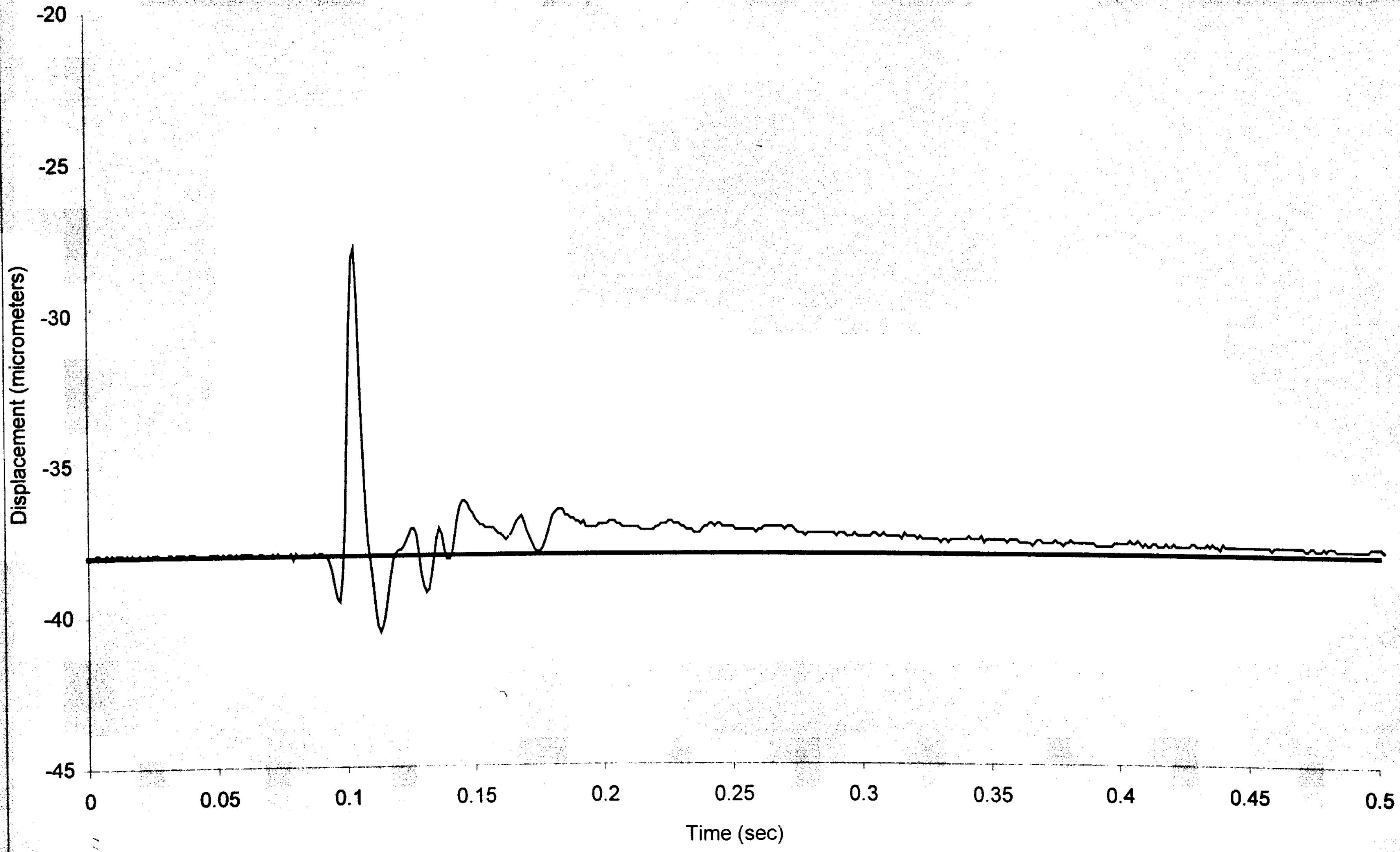


Figure 5.28 Basement Crack Habitational Vibration (door closing)

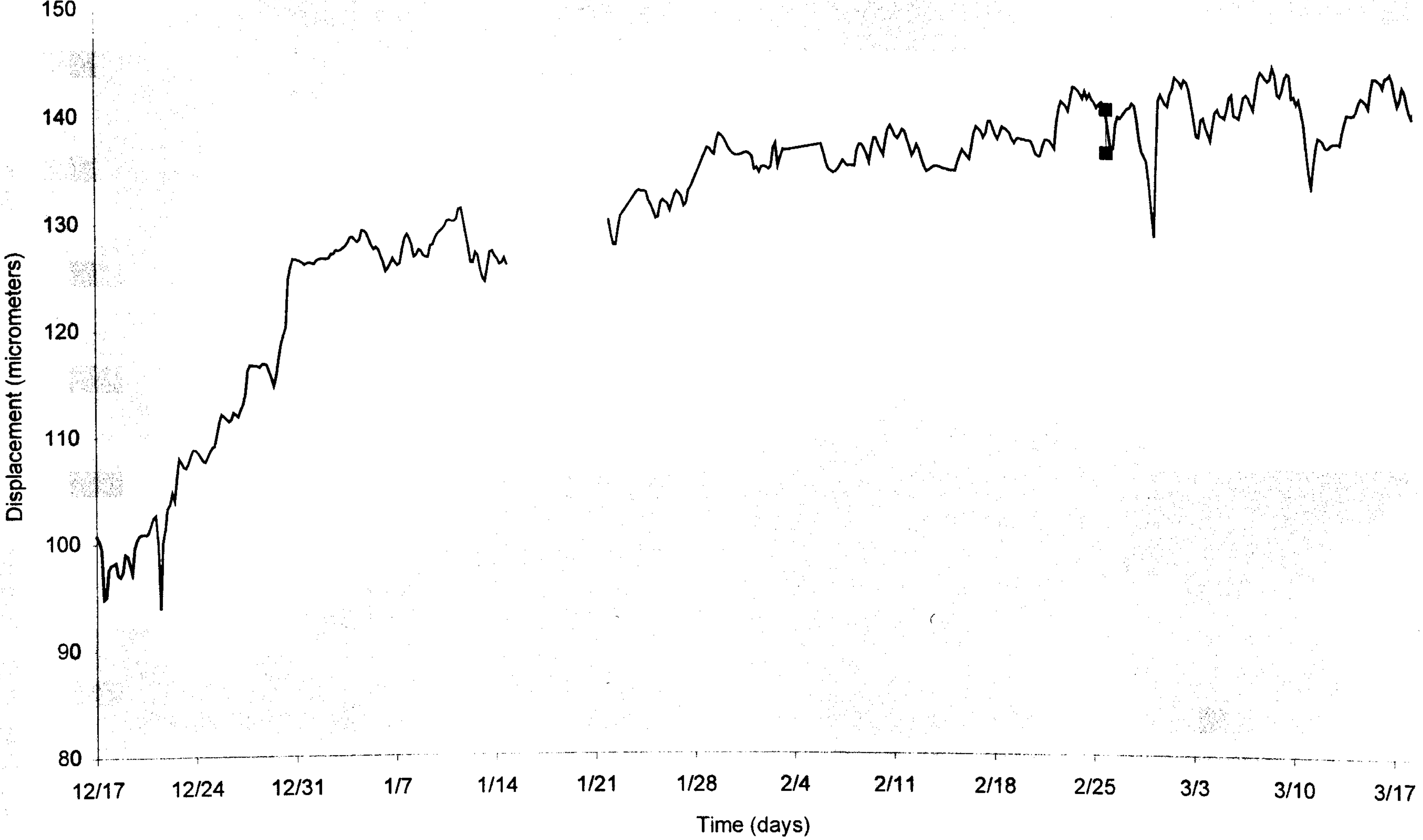


Figure 5.29 First Floor Crack Displacement & Habitational Vibrations

treads' stringer. The sensor responds to the heating season as indicated on Figure 5.24 by the rise at the beginning during the initiation of the intense heat. This difference in behavior further reinforces that cracks behave differently and are affected by different vibrations depending on their locations.

COMPARISONS WITH EXPECTED GROUND MOTION RESPONSES

The test house is not located near a quarry or a site that produces construction induced vibration events so a comparison cannot be made between crack movement and blast-induced vibration events. However, the current data can be superimposed onto data from past research in Figure 5.30 for comparison. Here significant (18mm/s peak particle velocity) blast-induced vibration events produce substantially lower crack displacement than both habitational vibration and weather events.

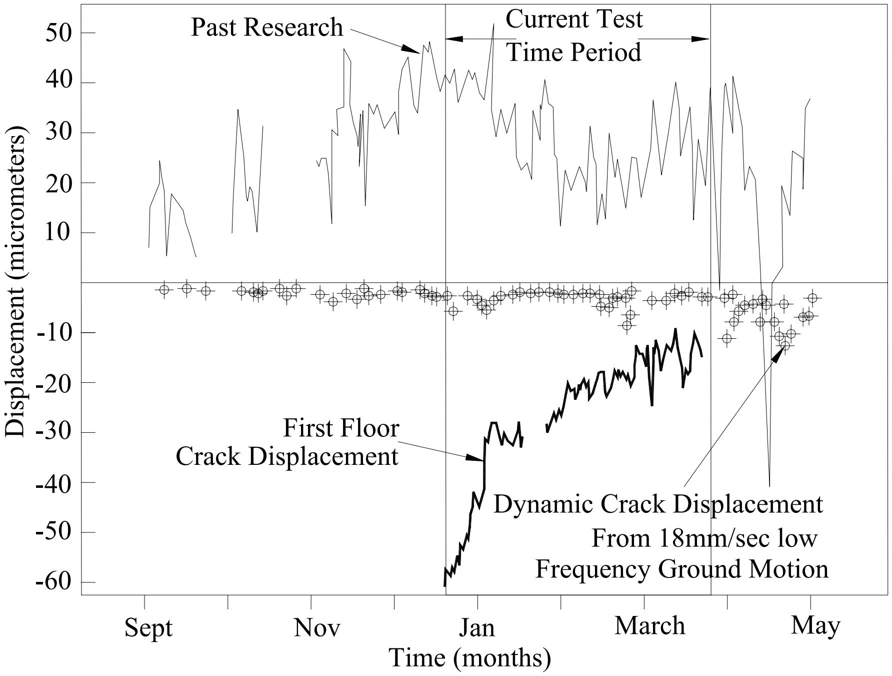


Figure 5.30 Comparison with Past Crack Displacement Data to Show Expected Low Response to Intense Ground Motions

CONCLUSIONS

Response of the three displacement sensors in the test house demonstrates that all cracks do not respond the same. Comparisons of long term and transient crack width changes with the same gauge show that weather and vibration events affect each crack differently. For example, habitational vibration induced movements on the stairs sensor were larger than the weather induced movements. Thus the dynamic application of a localized 70-90 kg stair stepping motion produces a greater effect than the weather. On the other hand, the basement sensor’s vibration displacements from habitation events were on average smaller than the weather-induced changes. Finally, the first floor sensor had only one visible habitation vibration event, and was affected much more by changes in weather. The crack with the greatest habitation vibration response also displays the greatest weather response. Further research at another site in Phase II and III into how the cracks behave with blast induced vibration events should confirm that weather and habitational events have a greater impact on crack width.

CHAPTER 6

WEB DESIGN

INTRODUCTION

The Internet web page is a critical component of autonomous crack monitoring because it enables access to and displays the information for the public. The web pages must present clearly, assist interpretation, and explain the live data stream to the lay public. Primary viewers of the site are assumed to be those who live near a vibration producer such as a quarry or construction site and not the scientific community. Furthermore it is assumed that if area residents have access to computers with Internet capabilities at all, they may not be equipped with the most up-to-date technology. Therefore, the site must be quick to load and be able to operate on older web browsers.

DESIGN REQUIREMENTS

Several requirements were set forth for the initial web design. First, each page must load in less than 10 seconds with a 56k modem. Second, the site must be viewable with any web browser. Third, the site must be easily extensible, as new pages will be added for other monitoring sites. Fourth, the lay public must be able to easily understand and navigate through the site.

A number of features make it possible for the pages to load quickly with modem connections. Rather than designing a few large pages to present data which require scrolling, a sequence of many small pages are employed along with a content bar that displays all options. Each page has a few small or well-compressed images. In some cases, thumbnail images are used, which are smaller versions of a larger image. The viewer can enlarge the image by clicking on the thumbnail version. Compression of graphics also improves the download times. The GIF image format is best suited for logos, such as the Northwestern and ITI logos, and graphs, whereas JPEG compression is most effective with photographs. A choice approach with many small pages coupled with compression of images allows for the presentation of graphical information without long download times. An added benefit of this approach is a reduced need for scrolling to unseen options.

In order for the site to be useful to the general public, it must be compatible with all web browsers. This requirement introduces several constraints to the design. First, no browser-specific hypertext markup language (HTML) can be used. For example, some HTML can only be viewed in Netscape Navigator, Microsoft Explorer, or other designated browser. Furthermore, more recent extensions to the HTML language, which are not supported by older browsers, cannot be employed. These include: frames which divide a web site into several distinct windows; JavaScript, a client-side scripting language which extends the functionality of HTML; and Java applets, client-side program elements that run in the web browser. To avoid any compatibility issues, only standard HTML code is employed to display the site.

A distinction must be made between Java applets, which run in the client's web browser, and server-side Java programs, which run on the web server. The use of applets is disallowed by the design specification, as older web browsers do not support this technology. However, server-side Java programs are used extensively in the back end of the site, as they do not depend on the capabilities of the client's browser. These programs are discussed in Automation of the System Chapter 4.

An HTML template is used in order for the web site to be easily extended to include numerous monitoring sites. This template can be emulated with little difficulty to produce pages for each new monitoring site, while maintaining a consistent look throughout the entire site. Since the template is written in standard HTML code it is easily reproducible.

The most important aspect of the site is that the lay public be able to understand what they are viewing. Each page on the site must fit onto one computer screen with little scrolling. Scrolling occurs whenever the user must slide the bar on the right side of the screen up or down to see all of the page. Such a restriction is accomplished by inserting a hierarchical side bar as shown in Figure 6.1. The viewer can see all of the choices on one page without having to use the scroll bar to search. Furthermore all subsequent pages are restricted to avoid scrolling. The banner and left side choice bar is repeated on each page, which provides clear and consistent navigation throughout the site. The bulleted list in the left side bar is visible on every page and allows the user to reach any page on the web site at all times.

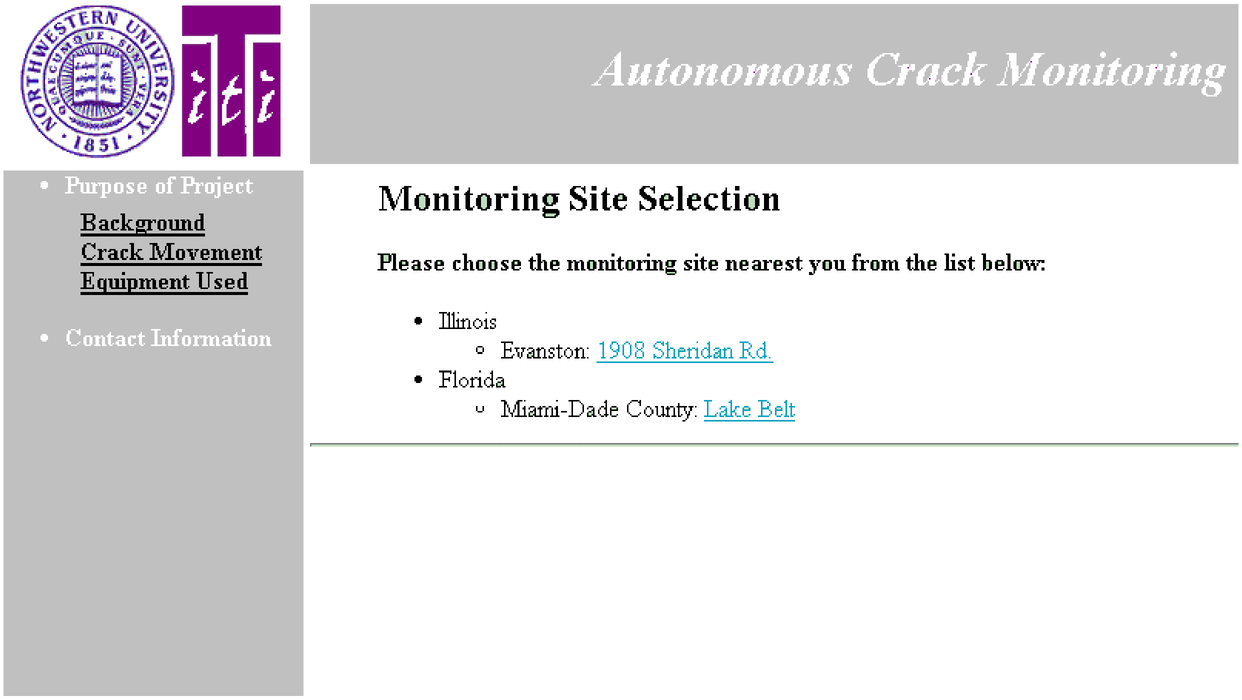
Figure 6.1 Consistent Banner and Choice Side Bar

CURRENT PHASE I SITE

During this early Phase the site must cater to the needs of its two primary groups: those who live around a vibration producer such as a quarry a construction site and; engineers, regulators, and owners who may be interested this approach for research, project control, public relations, and/or litigation. Initially, surveys of focus groups were conducted to assess target group’s needs and to aid in the design and presentation of the web site. A copy of this survey and its responses are located in an internal report prepared for Infrastructure Technology Institute (Siebert, 2000).

OPENING PAGE

As discussed above, neighbors of vibration generating operations are the primary audience for the web site. Figure 6.2 shows the site is designed for general education on the behavior of crack movement and graphically presents results of the monitoring site in their area. In Phase I the only site in operation is the test house at 1908 Sheridan Road. The opening page of the site introduces the banner and left bullet topic site bar, which will remain present on all pages. The left bar organizes the links of monitoring sites for easy access to residential users. To add credibility to the site, both the Northwestern University logo and the ITI logo is present on every page and linked to their respective sites.



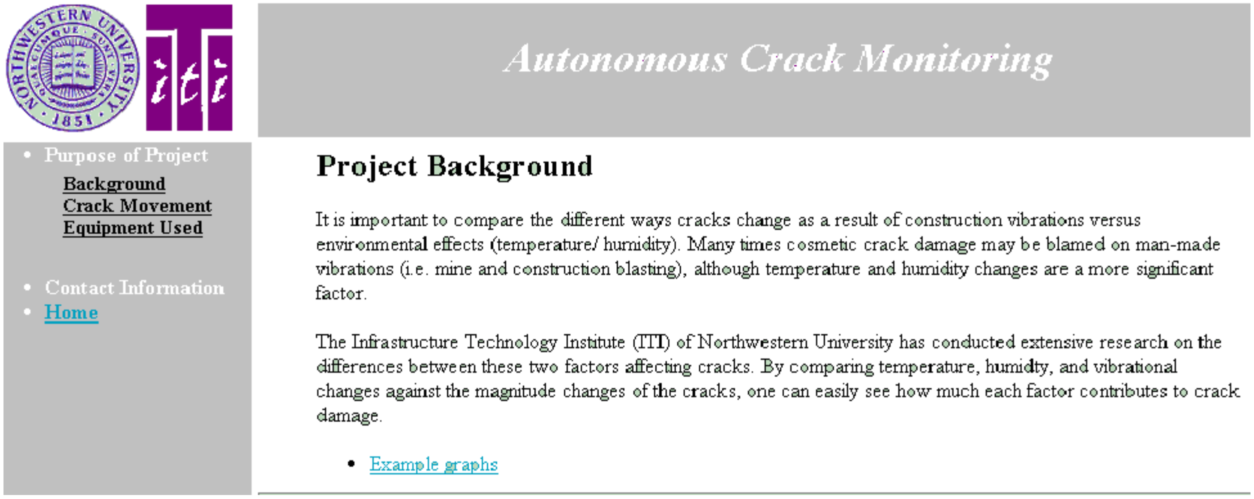
Monitoring Site Selection

Please choose the monitoring site nearest you from the list below:

- Illinois
    - Evanston: 1908 Sheridan Rd.
- Florida
    - Miami-Dade County: Lake Belt

Figure 6.2 First World Wide Web Page Showing Consistent Banner and Choice Side Bar

To educate the public, the sidebar (located on the left side of the opening page) contains a category entitled purpose of the project. The purpose of the project is divided into three subjects: background, crack movement, and equipment. These pages will not only assist the lay public to understand crack monitoring but will educate the engineering and legal communities as well. Figure 6.3 shows the first background page, which presents general information on what is being monitored and why. Currently the page gives a brief description of what is being monitored and shows example graphs without explanation. During Phase II and III changes the web page will be updated to explicitly explain how to interpret the information in the graphs.



Project Background

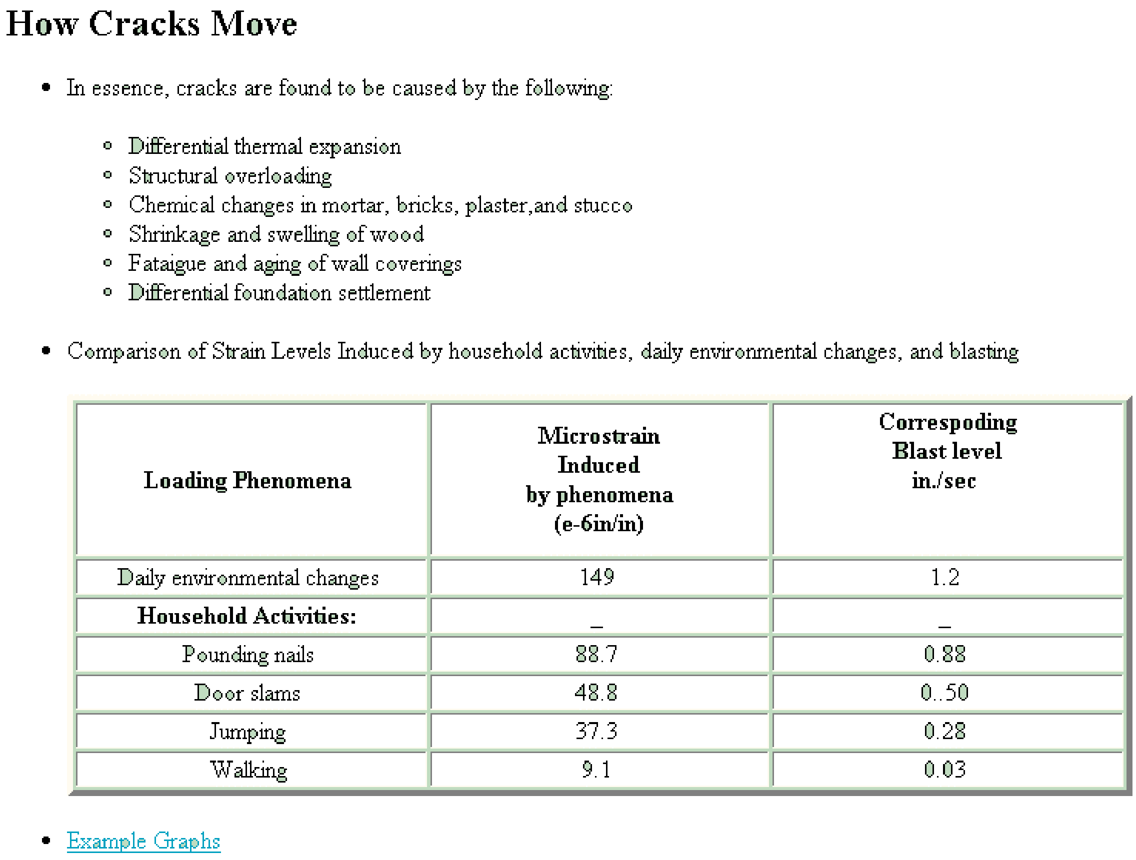
It is important to compare the different ways cracks change as a result of construction vibrations versus environmental effects (temperature/ humidity). Many times cosmetic crack damage may be blamed on man-made vibrations (i.e. mine and construction blasting), although temperature and humidity changes are a more significant factor.

The Infrastructure Technology Institute (ITI) of Northwestern University has conducted extensive research on the differences between these two factors affecting cracks. By comparing temperature, humidty, and vibrational changes against the magnitude changes of the cracks, one can easily see how much each factor contributes to crack damage.

- Example graphs

Figure 6.3 Background Page that Describes Crack Movement

The crack movement page shown in Figure 6.4 currently describes how cracks are caused and shows graphs on how cracks typically move based on past research. In Phase II and III the page will describe where house cracks typically develop. This should presentation should be followed by graphs of past monitoring sites and how they were affected by weather and vibration events.



How Cracks Move

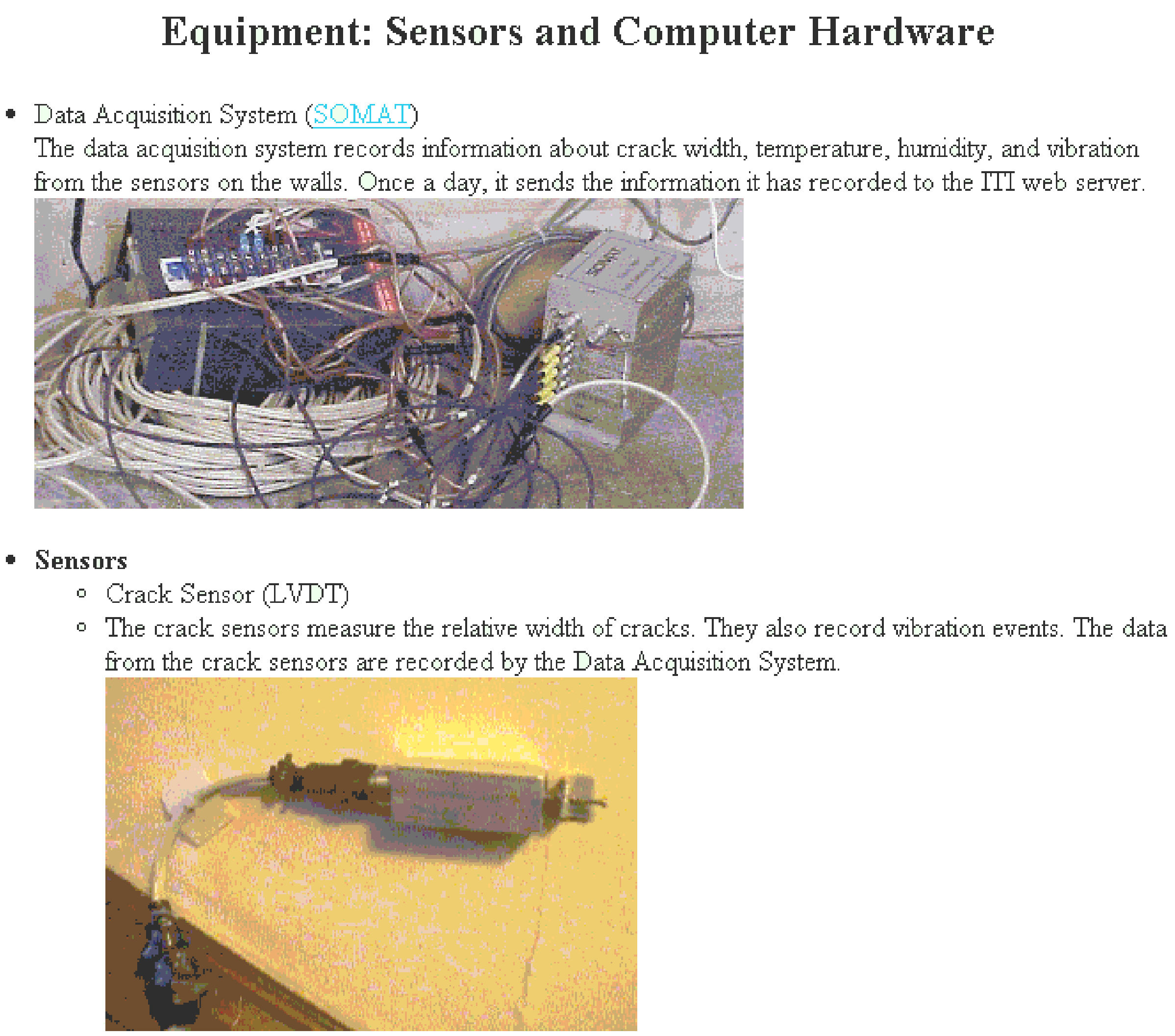
- In essence, cracks are found to be caused by the following:
  - Differential thermal expansion
  - Structural overloading
  - Chemical changes in mortar, bricks, plaster,and stucco
  - Shrinkage and swelling of wood
  - Fataigue and aging of wall coverings
  - Differential foundation settlement
- Comparison of Strain Levels Induced by household activities, daily environmental changes, and blasting

Loading Phenomena	Microstrain Induced by phenomena (e-6in/in)	Correspoding Blast level in./sec
Daily environmental changes	149	1.2
Household Activities:	_	_
Pounding nails	88.7	0.88
Door slams	48.8	0..50
Jumping	37.3	0.28
Walking	9.1	0.03

- Example Graphs

Figure 6.4 Crack Movement Page that Illustrates the Affects of Ordinary Occurrences

The final page, equipment employed, is shown in Figure 6.5. It presents the equipment currently in operation at the monitoring site. This page also contains links to the various manufacturers of the equipment. Photographs of the sensors and the cracks that they span foster a familiarity with the size of the instruments. Links to manufacturers’ sites allow those who want more information about the equipment to find it easily.



Equipment: Sensors and Computer Hardware

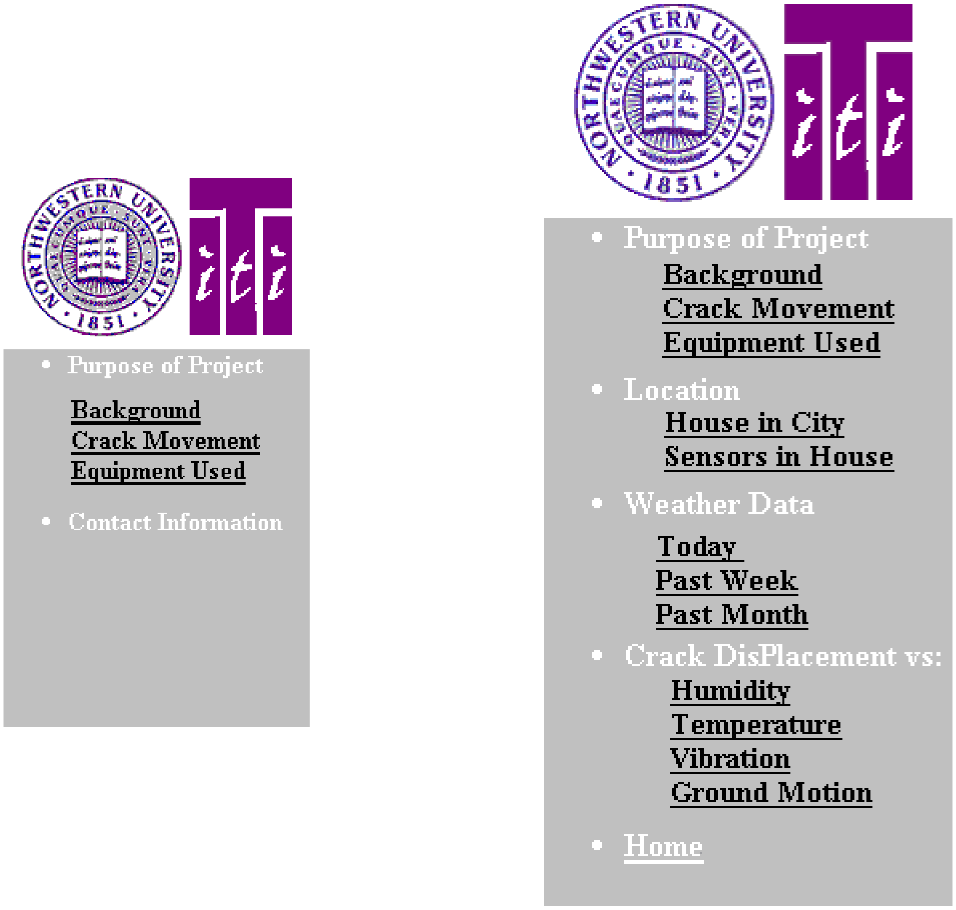
- Data Acquisition System (SOMAT)
  The data acquisition system records information about crack width, temperature, humidity, and vibration from the sensors on the walls. Once a day, it sends the information it has recorded to the ITI web server.
- **Sensors**
  - Crack Sensor (LVDT)
  - The crack sensors measure the relative width of cracks. They also record vibration events. The data from the crack sensors are recorded by the Data Acquisition System.

Figure 6.5 Page Showing the Computers and Crack Displacement Transducers

Site specific toolbar

After a specific monitoring site is selected, the left side bar will become a site-specific toolbar beneath the “purpose of the project”. These options, location, weather data, and crack displacement shown in Figure 6.6 provide easy navigation through the monitoring site’s pages. This tool bar, located on the left side of the screen, is always present so that first-time viewers need not recall contents.

In Phases II and III the site will need to add security protection on this page. Access will only be granted to residents near the vibration source through a password. Only the neighborhood or vibration activity would be visible; the other sites in existence should not appear on the viewer's screen.



- Purpose of Project
  - Background
  - Crack Movement
  - Equipment Used
- Contact Information

- Purpose of Project
  - Background
  - Crack Movement
  - Equipment Used
- Location
  - House in City
  - Sensors in House
- Weather Data
  - Today
  - Past Week
  - Past Month
- Crack DisPlacement vs:
  - Humidity
  - Temperature
  - Vibration
  - Ground Motion
- Home

General **Site Specific**

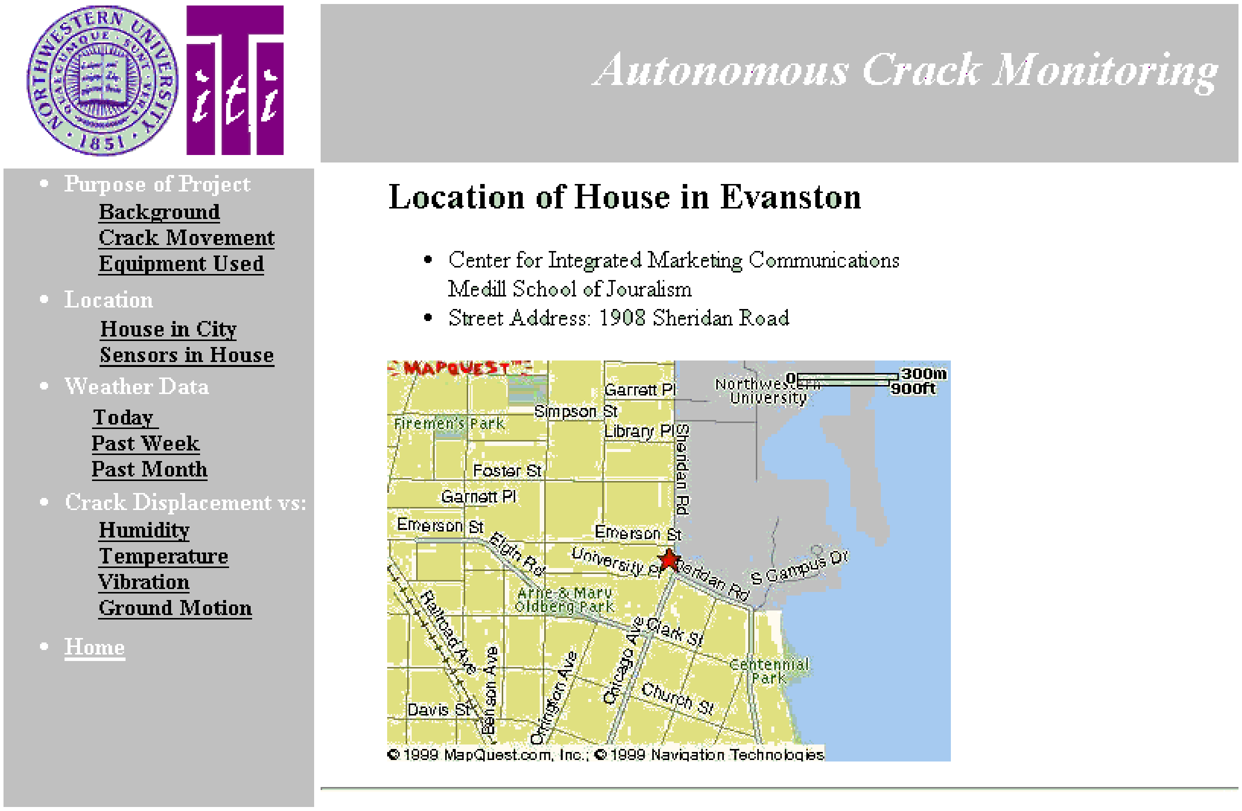
Figure 6.6 Site Specific Side Bar

Opening page: specific monitoring site

The opening page of the 1908 Sheridan Road monitoring site, Figure 6.2, contains information about the structure of the house and its location. It also links to a photo gallery that contains pictures of the exterior and interior of the house. These visual aids allow the viewers to visually identify with the test house and draw comparisons to their own house or situation.

Location

Location on the side bar in Figure 6.7 provides two options for the information about the geographical location of the house: a road map, as well as sensor location inside the house. Figure 6.7 is a copy of the page with the location of the house in the surrounding city. This page will eventually contain the location of other relevant places such as the activity producing the vibrations. This map allows the viewer to see the distance between the test house and the vibration source so that they can relate it to their distance from the vibration source. Future work on the page will include the addition of concentric rings emanating from the vibration source at constant distances so viewers can simply "count" how far they are located from the source.



Autonomous Crack Monitoring

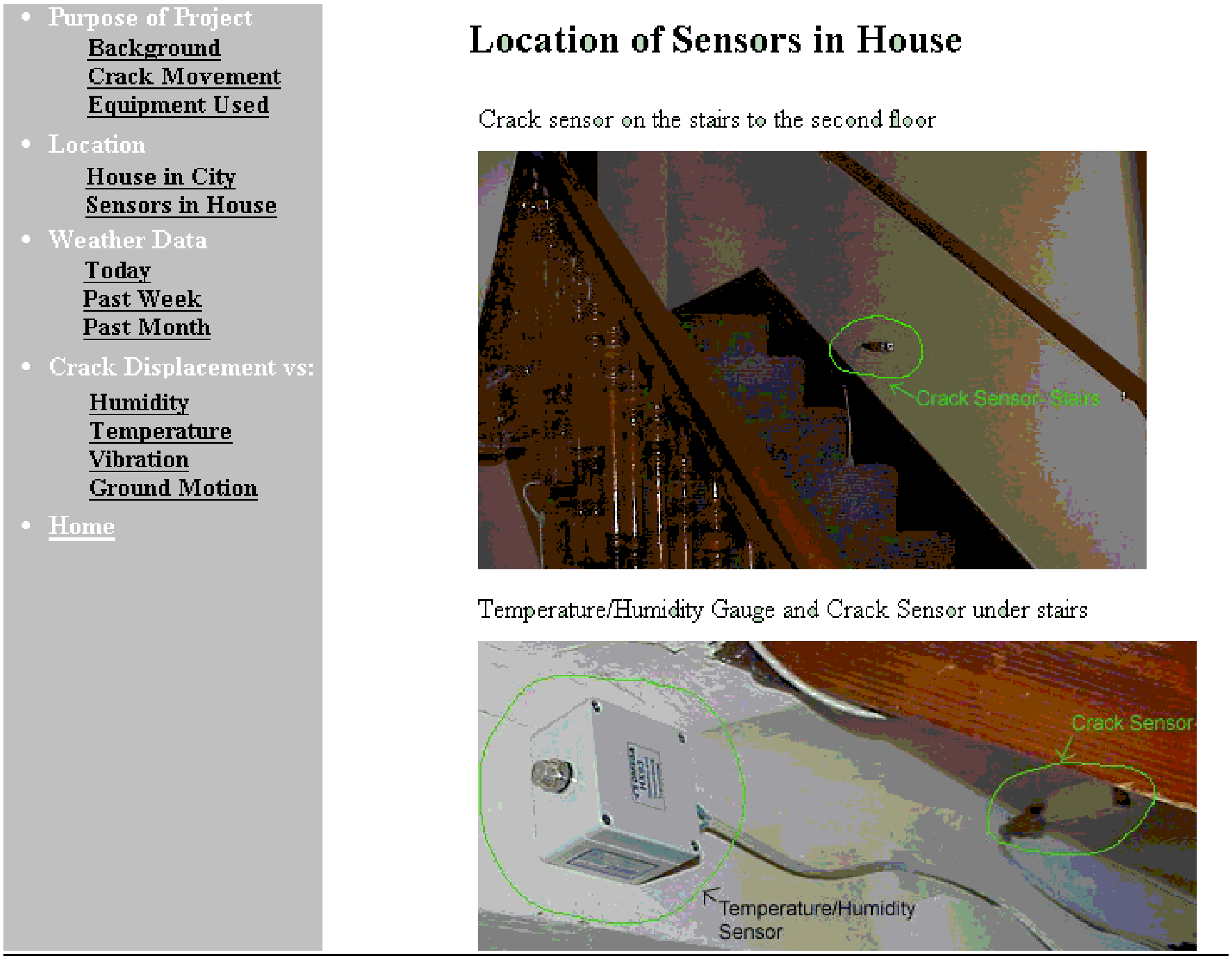
- Purpose of Project
  - Background
  - Crack Movement
  - Equipment Used
- Location
  - House in City
  - Sensors in House
- Weather Data
  - Today
  - Past Week
  - Past Month
- Crack Displacement vs:
  - Humidity
  - Temperature
  - Vibration
  - Ground Motion
- Home

Location of House in Evanston

- Center for Integrated Marketing Communications
  Medill School of Jouralism
- Street Address: 1908 Sheridan Road

Figure 6.7 House in City Page

The page with the location of the sensors in the house is presented in Figure 6.8, shows views of both the sensors and the crack. Viewers can visibly compare these cracks with their own. This page will also be helpful for viewers who are interested in possibly having sensors installed in their own home or office.



- Purpose of Project
  - Background
  - Crack Movement
  - Equipment Used
- Location
  - House in City
  - Sensors in House
- Weather Data
  - Today
  - Past Week
  - Past Month
- Crack Displacement vs:
  - Humidity
  - Temperature
  - Vibration
  - Ground Motion
- Home

Location of Sensors in House

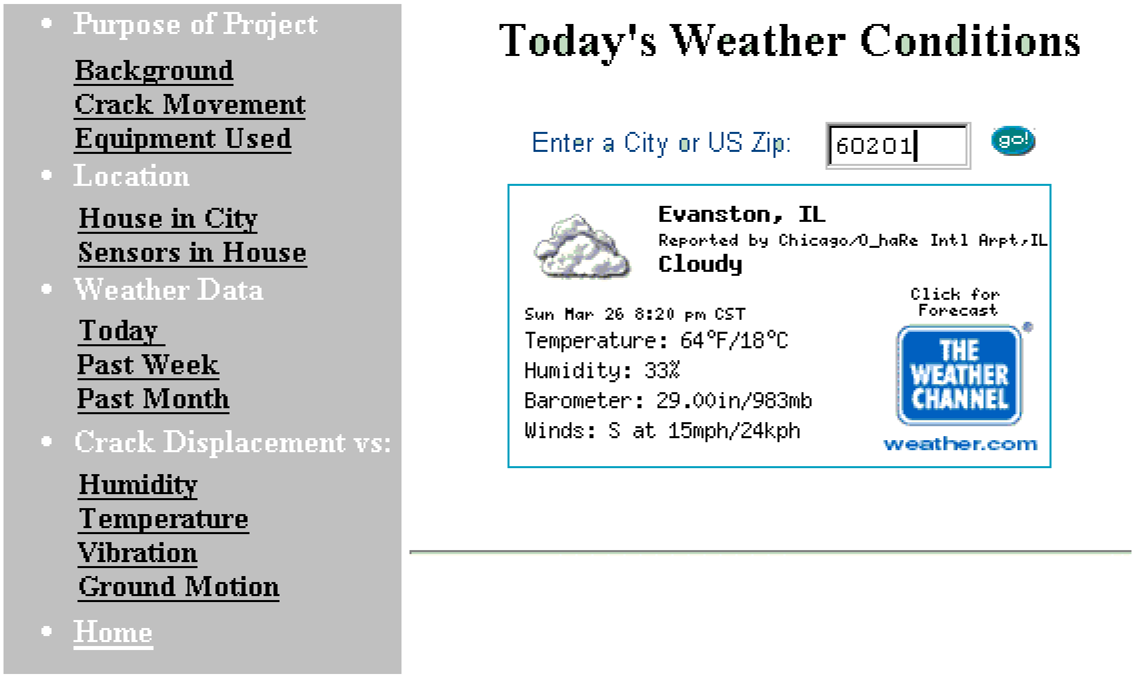
Crack sensor on the stairs to the second floor

Temperature/Humidity Gauge and Crack Sensor under stairs

Figure 6.8 Location of Sensors in House Page

Weather data

Weather data on the side bar currently presents three options: information about the weather from today, last week, and last month. The weather data for today, illustrated by Figure 6.9, brings viewers to a page where they can see their current weather after showing their zip codes. This service is provided free of charge by the Weather Channel. This option allows viewers to confirm the current weather, more specifically temperature and humidity, through a third party unrelated to the project. The weekly and monthly links, Figure 6.10, bring up dynamic graphs which are updated daily, that display the temperature and humidity inside the house for the past week or month. The process by which the graphs are dynamically updated is described in Chapter Automation of System and in an internal report prepared for Infrastructure Technology Institute (Siebert, 2000).



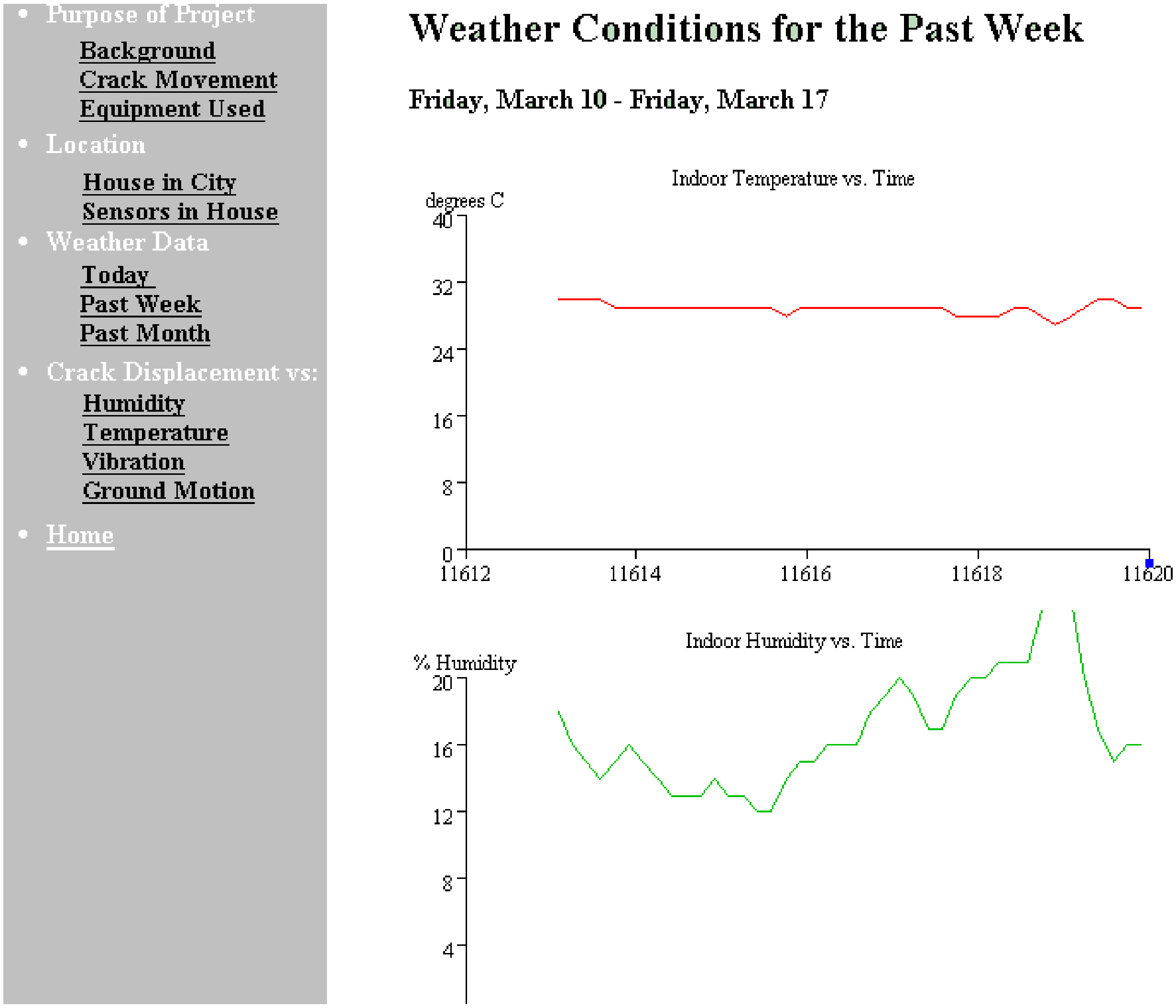
Today's Weather Conditions

Enter a City or US Zip: 60201

Evanston, IL
Reported by Chicago/O_haRe Intl Arpt,IL
Cloudy

Sun Mar 26 8:20 pm CST
Temperature: 64°F/18°C
Humidity: 33%
Barometer: 29.00in/983mb
Winds: S at 15mph/24kph

Figure 6.9 Weather Data for Today Page



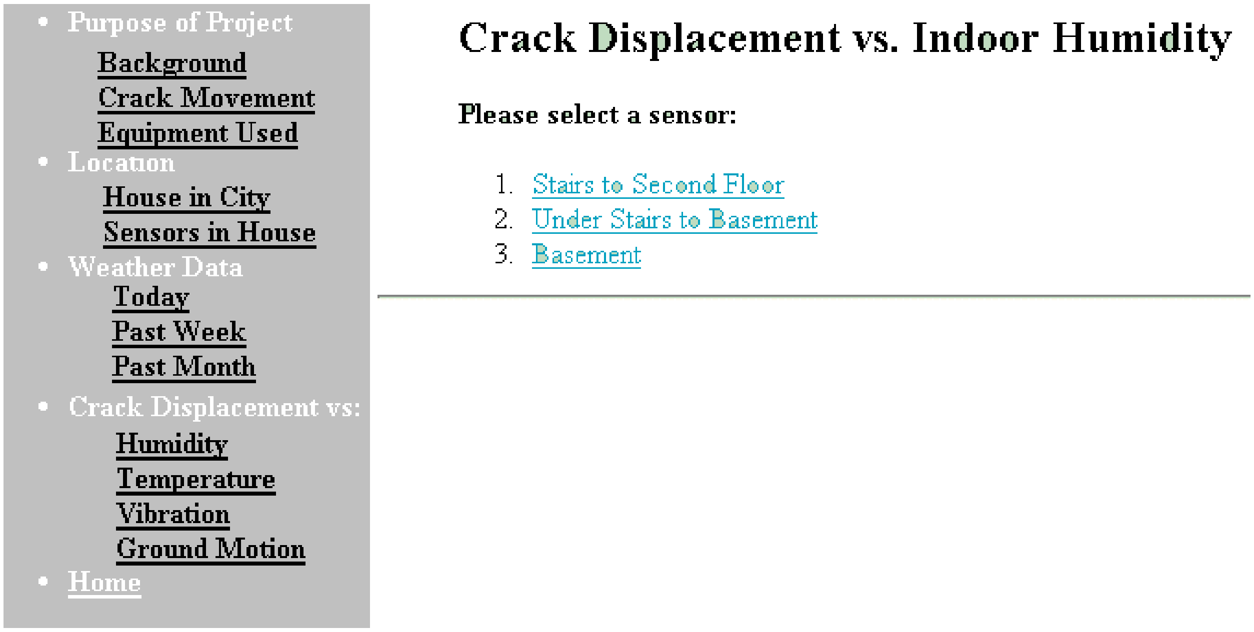
Weather Conditions for the Past Week

Friday, March 10 - Friday, March 17

Figure 6.10 Environmental Conditions During the Past Week

Crack Displacement vs.

Crack displacement vs. on the side bar provides three comparisons of long-term crack displacement with: humidity, temperature or vibration events. Once any selection is made the viewer is given a list of the sensors available in the house as shown in Figure 6.11. When the desired sensor is selected, they can then choose a time period option of today, last week, last month, or last year. After the time interval is selected the viewer is presented with a dynamically generated graph, as illustrated in Figure 6.12, that shows the relationship of environmental and vibration changes to the crack over the selected timeframe.

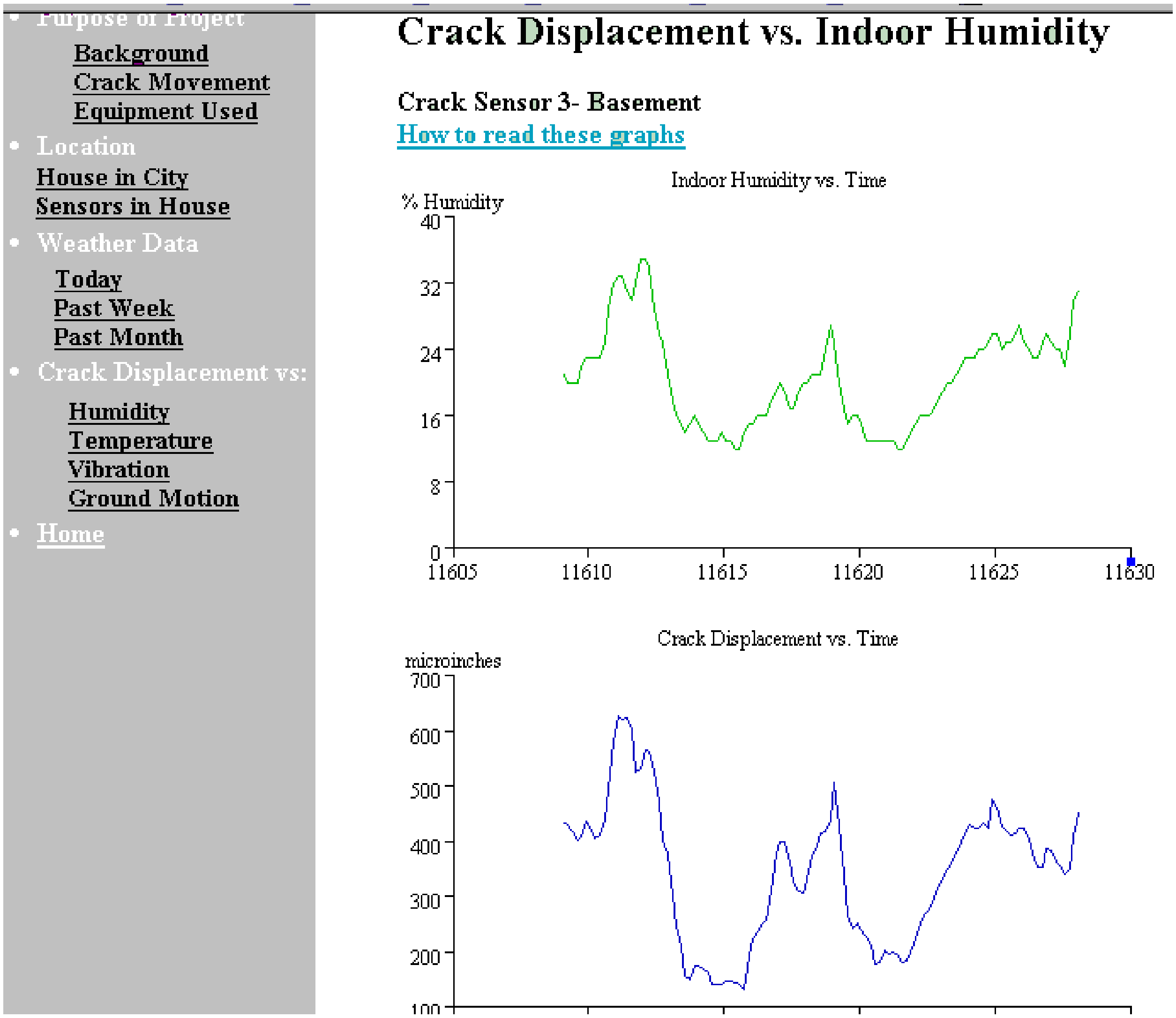


Crack Displacement vs. Indoor Humidity

Please select a sensor:

1. Stairs to Second Floor
2. Under Stairs to Basement
3. Basement

Figure 6.11 Crack Displacement vs: Sensor Page Showing the Location of the Sensors to be Selected



Crack Displacement vs. Indoor Humidity

Crack Sensor 3- Basement

How to read these graphs

Figure 6.12 Example Comparison of Crack Displacement vs: Time with Humidity vs. Time

CONCLUSIONS AND RECOMMENDATIONS FOR MODIFICATION

Simple, quickly transmitted graphics can be combined to present an attractive image that is easy to understand. This simplicity allows access by the oldest of computers still in operation. Side bar options prevent long screens that lead to scrolling. Since sidebars do not consume horizontal space they can remain on all screens so viewers need not recall possible options.

Links to third party daily weather and maps lead an air of credibility to the site without diverting the viewer's attention.

During Phase II and III several additions and improvements to the web site are needed. Currently the site is not password protected. Security will be required for commercial use to prevent unwanted viewers from exploring the site, and protect the database from any tampering. However for public relation purposes, security walls pose a challenge to the design objective of universal access.

Currently in Phase I there are no blast induced vibration events. In Phase II the system will be moved to a quarry and the web site will need to accommodate this new information. Each vibration induced crack displacement will be added to the long-term crack displacement vs. time graphs as shown in Measured Response Chapter 5 Figure 5.23. Each of these vibration events will need to be keyed to its equivalent time history in the database. When the viewer selects a specific vibration event on the long-term crack displacement graph, a transient time history of that event will be displayed.

Information currently contained in the background portion of the site needs to be reviewed and modified to better explain with graphical prompts how to interpret the graphs, and how cracks behave. Future improvements to the weather information will include the addition of symbols that pictorially represent low and high temperature and humidity such as a sun or a snowflake and a cactus or a raindrop.

Finally the web site will need to go "live" and to allow typical viewers to comment. This next evaluation should be conducted in connection with potential clients who would purchase this system.

CHAPTER 7

COST

INTRODUCTION

This Chapter presents the cost to construct the Phase I crack monitoring system as well as estimate the future costs of Phase II and III. Phase II will further be broken down into Phase II-a and Phase II-b, to facilitate easy placement at a quarry. Phase II will include purchasing of a typical vibration monitoring system and other equipment required to emulate a system that can be marketed to various vibration monitoring companies. Phase III costs are those for a company to purchase the server-side portion, each remote monitoring site, and displacement sensors for the system.

CURRENT PHASE I SYSTEM COST

The cost of the complete Phase I system as it is currently operating, as described in the Hardware Chapter is itemized in Table 7.1. The current Phase I system consists of a server computer, field computer, Somat data acquisition system, four LVDT displacement sensors, one Omega temperature and humidity sensor, software, and miscellaneous electronics. The software packages used are WinTCS, EASE, PCAnywhere, and AutoMate. WinTCS and EASE are software that is free when the Somat data acquisition system is purchased. There are additional costs of the mounting brackets and epoxy that were not included in the price breakdown because these items where in stock in the lab and were not purchased. The cost of the server computer was not included in the total cost of the current system because it was an existing computer, not purchased for this project. The cost of the software program EASE was also excluded since it was included with the purchase of the Somat data acquisition system. However this program will need to be purchased for the Phase III system because the Somat data acquisition system will no longer be employed but some software to convert data to an ASCII text file will be required. This need can be satisfied with vibration monitor interpretation software installed on the server.

Table 7.1 Phase I Cost

Phase I Cost Running 3 Crack and 1 Nul Sensor					
Item	**Description**	**Manufacturer**	**Cost**	**Qty**	**Total**
Displacement Sensors					
LVDT	HSD 750-125	Macrosensor	$ 350.00	4	$ 1,400.00
Weather Sensors					
Temp/Humid	HX93U	Omega	$ 210.00	1	$ 210.00
A/D Converter and Processor					
Data Acquisition s	Processor	Somat	$ 690.00	1	$ 690.00
	Memory	Somat	$ 1,075.00	1	$ 1,075.00
	Power	Somat	$ 625.00	1	$ 625.00
	8-bit	Somat	$ 715.00	2	$ 1,430.00
	12-bit	Somat	$ 895.00	4	$ 3,580.00
Software					
PCAnywhere	Communication software	Symantec	$ 150.00	1	$ 150.00
Automate	Automation software	Unisyn	$ 60.00	1	$ 60.00
WinTCS	Data acq. sys. software	Somat	$ -	0	$ -
EASE	Conversion software	Somat	$ 2,095.00	0	$ -
IBM DB2	Database software	IBM	$ 345.00	1	$ 345.00
Communications and Data Storage					
Field PC	PC with modem		$ 540.00	1	$ 540.00
Server PC	PC with modem	Dell	$ 2,300.00	0	$ -
Power supply	12v DC 5 amp	Neward	$ 108.00	1	$ 108.00
Power Regulators for Equipment					
DC-DC converter	+-15v	Datel	$ 44.00	6	$ 264.00
		Total System Cost=			**$ 10,477.00**

PHASE II

Phase II is subdivided into II-a and II-b to ensure operability in a quarry as soon as possible. Phase II-a will only require the addition of three geophones to measure ground motions and a pressure transducer to measure air blast pressures, which will be connected to the Phase I system. In order to connect the vibration monitoring transducers to the current Somat four 8-bit analog input layers are required. These four additional layers for the Somat will be borrowed from ITI at zero additional cost. Phase II-b represents the first step in the transition to a typical vibration monitor, it will include the addition of a low speed data acquisition system and a modem splitter. The costs for Phase II-a and II-b are listed in Table 7.2 and 7.3 respectively. Many of the items required, such as software, have already been purchased in Phase I and are not included in the cost of the Phase II system. The costs outlined in the tables are for use with an LVDT sensor. This cost will change if a different sensor is selected.

Table 7.2 Additional Cost for Phase II-a

Phase II-a Cost					
Item	**Description**	**Manufacturer**	**Cost**	**Qty**	**Total**
Vibration Monitoring Equipment					
Vibration Monitoring Transducers	GeoPhones/ air pressure	Geosonics	$ 650.00	1	$ 650.00
A/D Converter and Processor					
Data Acquisition system	8-bit	Somat	$ 715.00	4	$ 0.00*
		Total System Cost=			**$ 650.00**

* The Four 8-bit layer will be borrowed from ITI and therefore will cost $0.00

Table 7.3 Additional Cost for Phase II-b

Phase II-b Costs					
Item	**Description**	**Manufacturer**	**Cost**	**Qty**	**Total**
A/D Converter and Processor					
Data Acquisition system	SmartReader 7 (1.5MB)	ACR	$ 1,614.00	1	$ 1,614.00
Communications and Data Storage					
Modem Splitter			$ 430.50	1	$ 430.50
		Total System Cost=			**$ 2,044.50**

The additional low speed data acquisition system will capture the long-term sensor data. As discussed in the Hardware Chapter, the modem splitter is required to switch between the Somat data acquisition system and the low speed data acquisition system. While the software packages will remain the same, certain scripts will need to be modified in order to accommodate the new equipment. These modifications are outlined in Automation of System, Chapter 4.

PHASE III COSTS (COMMERCIAL VIBRATION MONITOR)

Table 7.4 outlines the anticipated Phase III costs for a company to initiate remote crack vibration monitoring. These costs include substitutions of the field computer and the Somat data acquisition system and the addition of a typical vibration monitor, as discussed in detail in the Hardware Chapter. Table 7.4 is divided into three sections: central server-side start-up cost, minimum cost for each remote monitoring site, and cost for each additional sensor at those sites. After the installation of the first site the cost substantially decreases if another site is required because the sites can share the server side equipment. Once again the costs are based upon the use of LVDT's as the crack sensor devise. This cost will change if different crack sensors are selected. The costs of all equipment and software tested can be found in an internal report prepared for Infrastructure Technology Institute (Siebert, 2000).

Table 7.4 Anticipated Costs of Phase III

Phase III Central Server-Side Start-up Costs					
Item	**Description**	**Manufacturer**	**Cost**	**Quantity**	**Total**
Software					
PCAnywhere	Software	Symantec	$ 150.00	1	$ 150.00
Automate	Software	Unisyn	$ 60.00	1	$ 60.00
EASE	Software	Somat	$ 2,095.00	1	$ 2,095.00
IBM DB2	Software	IBM	$ 345.00	1	$ 345.00
Communications and Data Storage					
Server PC	PC with modem	Dell	$ 2,300.00	1	$ 2,300.00
				Total Cost=	**$ 4,950.00**

Minimum Cost For Each Remote Monitoring Site					
Displacement Sensors					
LVDT	HSD 750-125	Macrosensor	$ 350.00	2	$ 700.00
Weather Sensors					
Temp/Humid	HX93U	Omega	$ 210.00	1	$ 210.00
Vibration Monitoring Equipment					
Vibration Monitor	Microprocessor/ modem GeoPhones	Geosonics	$ 4,000.00	1	$ 4,000.00
A/D Converter and Processor					
Data Acquisition system	SmartReader 7 (32K)	ACR	$ 989.00	1	$ 989.00
Power Regulators for Equipment					
DC-DC converter	+-15v	Datel	$ 44.00	2	$ 88.00
Power supply	12v DC 5 amp	Neward	$ 108.00	1	$ 108.00
Communications and Data Storage					
Modem Splitter			$ 430.50	1	$ 430.50
				Total Cost=	**$ 6,525.50**

Cost For Each Additional Sensor					
Displacement Sensors					
LVDT	HSD 750-125	Macrosensor	$ 350.00	1	$ 350.00
Power Regulators for Equipment					
DC-DC converter	+-15v	Datel	$ 44.00	1	$ 44.00
				Total Cost=	**$ 394.00**

DATA REDUCTION BENEFITS OF CURRENT SYSTEM

Past research in this area required several pieces of equipment taking different forms of data. Figure 7.1 shows each type of data required. To obtain the long-term crack movement one system was employed. The weather information required a second system to obtain temperature and humidity data. A third system was employed to record vibration events such as ground motion and air blasts. The fourth type data was crack displacement from vibration events. Integration of this separately recorded data required considerable effort over long periods of time. Data for projects of four and eight months duration are shown in Figure 7.2. The integration procedure took place over several months and required a great deal of keystroking to develop the necessary graphical and tabular comparisons.

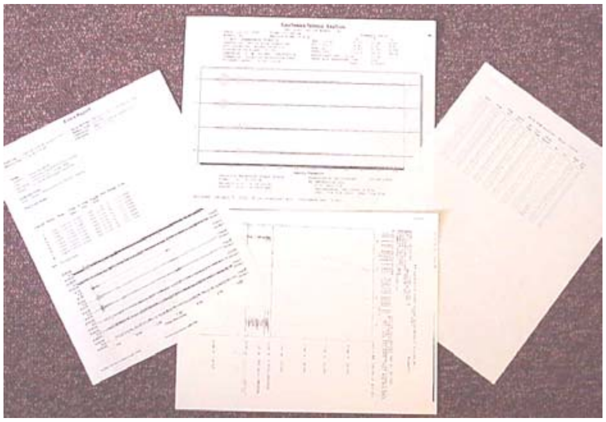


Figure 7.1 Four Different Data Types

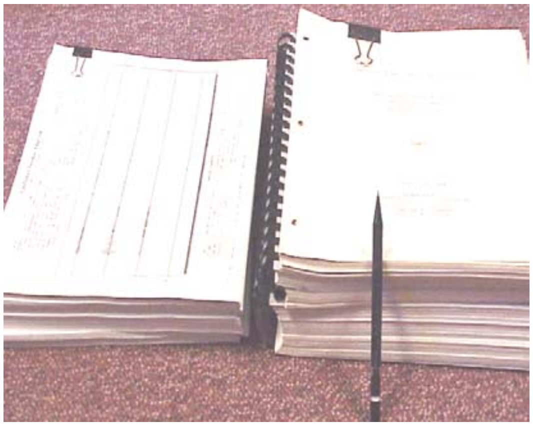


Figure 7.2 Two Projects with Six and Eight Months of Data

The Internet based system provides a mechanism to reduce labor costs of data compilation. The data are automatically compiled and reduced in the database that resides on the server. With previous systems, presentation of the data, such as graphs and charts, required a great deal of time and effort to produce. With the integration of the web site, reduction of data to comparative graphical form not only occurs automatically but also is easily accessible. Obviously, expenditures of time and money will be greatly reduced when the system becomes fully integrated with ground motions in Phases II and III.

Production of the graphs in Measured Response Chapter 5 provides a comparative example of the savings in effect resulting from automatic data reduction. These graphs in the response Chapter were produced in only several days from already reduced data that resided in the DB2 database. For comparison, reduction of the 8 months of data shown in Figure 7.2 required six months of a graduate students time. Thus it appears that the automation required for autonomous display may decrease data reduction efforts by several orders of magnitude.

CONCLUSION

Server-side hardware and software start-up costs of the Phase III system may seem high however, the addition of each site, and sensors at those sites, is substantially less. The software programs employed in Phase I will remain essentially the same throughout Phase II and III but will require reprogramming in order to accommodate the new equipment. Phase II is broken down into two parts in order to help facilitate this transition. Cost of data reduction are dramatically reduced by the automatic processing of the data. The autonomous presentation of data may decrease data reduction efforts by several orders of magnitude.

CHAPTER 8

CONCLUSIONS AND FUTURE WORK

CONCLUSIONS

Public concern over construction vibration-induced cracking has led to the development of a radically new approach to vibration, an autonomous crack comparometer (ACC). This thesis chronicles the first step of developing equipment and software necessary for this system. The new system automatically compares long-term weather induced micrometer changes in crack width with those produced by habitation ground motion. This comparison is displayed in real time via the Internet without human interaction.

The Autonomous Crack Comparometer (ACC) effectively illustrates that weather cycles have the greatest effect on micrometer changes in crack width. While habitational vibrations cause transient changes in crack width they return to the same position as the pre-vibration width. The current system is not in a location to receive construction or quarry ground motions; however when blast induced vibrations from a quarry in past research are compared with the current data, it is apparent that ground motion should have the least effect on crack deformation.

Micrometer displacement sensors are affected by electronic drift and thermal hysteresis. Further research into different sensors is required in order to determine the most accurate sensor for this application. However, changing sensors will not require changes to other portions of the system. Currently electronic drift and thermal hysteresis are corrected by subtraction of null sensor response.

FUTURE WORK

The current Phase I system does not measure ground motions or air blasts. To do so requires additional hardware as well as additional automation software to compare crack width change to vibration events from construction, mining or quarry operation. This paper outlines the anticipated changes necessary in order to facilitate this transition. After this transition is accomplished the final system can be marketed to companies interested in monitoring crack displacement.

Internet display allows viewers to compare changes in crack width produced by long-term weather changes to those produced by habitation and vibration motions on a variety of time scales. Data for the web site are automatically recorded and updated daily, which eliminate the costly and time consuming manual data analysis and reduction required with other systems. The web site currently does not have an appropriate graphical description for quickly interpreting the information on the site. This description will need to be added before the sites address can be given out to the public for comments. The site also does not have any security checks such as password protection. This is an important issue from a legal standpoint and will need to be addressed in the future.

Upon complete development, the ACC site and concept will have to be evaluated by installation in a concerned community.

REFERENCES

Anderson, L. O. (1970), Wood-Frame House Construction. U.S. Government Printing Office, Washington, D.C. Chapter 4.

Dowding, C. H. (1996) Construction Vibrations, Prentice Hall, Upper Saddle River, New Jersey, Chapter 13, "Comparison of Environmental and Vibration-Induced Crack Movement".

Dowding, Charles H. (1999), “NSF Proposal: Instrumentation for Microinch Crack Width Measurement,” Department of Civil Engineering, Northwestern University, Evanston, IL.

Dowding, Charles H. (2000), Personal Communication. Professor, Department of Civil Engineering Northwestern University, Evanston IL.

Kosnik D. (2000), Personal Communication, Student, Department of Electrical and Computer Engineering, Northwestern University, Evanston, IL.

Kosnik, D. (2000) “Java Applet” Internal Report, Infrastructure Technology Institute, Northwestern University, Evanston, IL.

Kosnik, D. et. al, (2000), “ Autonomous Crack Monitoring,” Internal Report for Infrastructure Technology Institute, Northwestern University, Evanston, IL.

Macrosensor (1999). 815 Hylton Road, Unit #8 Pennsauken, NJ. “http://www.macrosensors.com/ghsa.htm”.

Omega Engineering, Inc. (1989). Omega Manual Model HX93 Relative Humidity and Temperature Transmitter: Operations Manual. One Omega Drive Stamford, CT.

Siebert, D. (2000), Appendixes for Autonomous Crack Comparometer Phase I. Internal Report for Infrastructure Technology Institute, Northwestern University, Evanston, IL.

Somat Corporation, (1999), “EASE Ver 3.0” SoMat Corporation 702 West Killarney Urbana, IL.

Somat Corporation, (1999), “WinTCS Ver. 1.6.2. “ SoMat Corporation 702 West Killarney Urbana, IL.

Symantec Corporation, (2000), “PcAnywhere Ver. 9.0” Symantec Corporate Offices, 20330 Stevens Creek Blvd., Cupertino, CA.

Unisyn Software, LLC (2000), “AutoMate, Ver. 4.0” 3440 Wilshire Boulevard Suite 910, Los Angeles, CA.

NORTHWESTERN UNIVERSITY

Autonomous Crack Comparometer
Appendixes

By

Damian R Siebert

EVANSTON, IL

June 2000

List of Appendixes

APPENDIX A
TEMPERATURE CORRECTION FOR ALL SENSORS TESTED

Appendix B
WinTCS Program Description

WinTCS is installed on both the field and server computer. The program is started in the same manner as other applications, by double-clicking the icon or by entering the correct path at the command prompt. Figure B.1 shows the main screen that appears when the program is opened. This screen is where all WinTCS functions and activities of the Somat take place. It is displayed constantly while WinTCS is active. There are two major sections to this screen. The right side contains the current test tree diagram that graphically represents the elements in the test such as channels, data modes, and hardware layers used. Appendix B lists the icons used and their description. The left side lists the toolbar buttons that can be employed during a test.

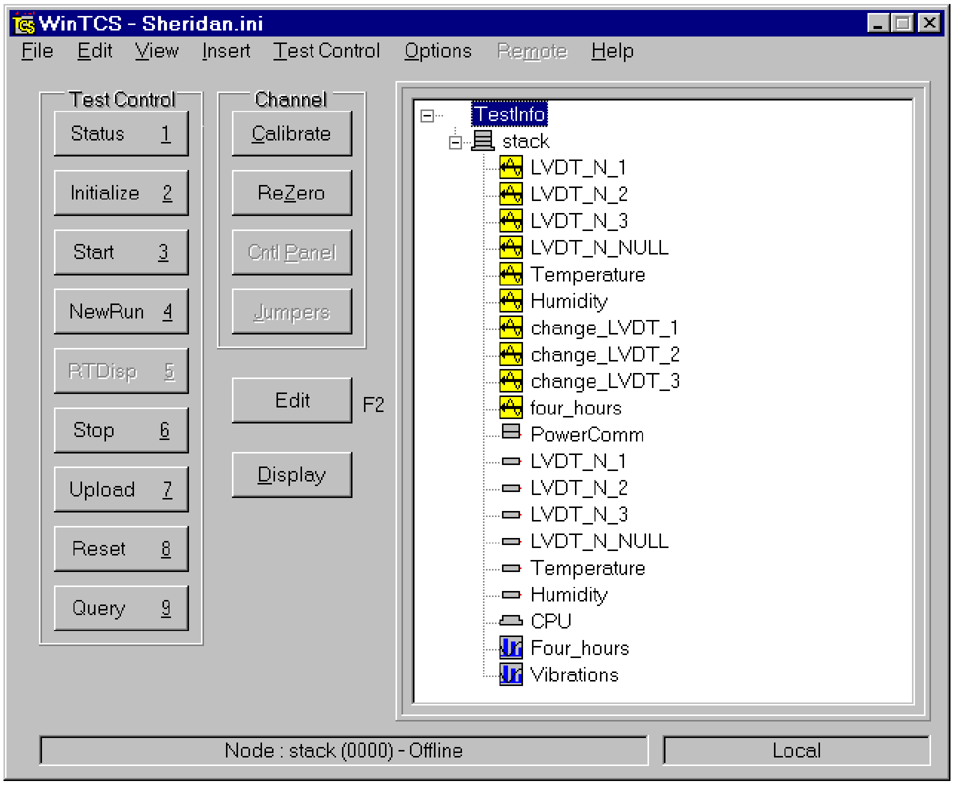


Figure B.1 WinTCS Opening Screen

Current Test Setup

WinTCS allows the user to setup an initialization file that defines sample rates, channels and triggers for a test. For a complete description on the setup of a new test for WinTCS refer to the Somat 2100 FCS User's Guide. The phase I initialization file for the Somat is shown in Figure B.1. The setup of the data channels and data modes will be discussed in more detail in the following sections.

Stack Setup

The most important feature in setting up the stack is identifying the master sample rate. The master sample rate is set in Hertz (Hz, or cycles per second) and is applied to all the data channels and data modes in the system. The current system is setup to sample at 1000 Hz/sec., meaning that for every second that data is recorded from each channel there will be 1000 data points. The sample rates for individual channels and data modes can be individually set, but cannot exceed the master sample rate.

Raw Data Channels

A data channel identifies for the software the type of layer that was installed in the stack. As shown in Figure B.2 there are several different types of layers in the stack there are also several types of channel: phase I configuration includes two 8-bit A/D converter channels, four 12-bit A/D converter channels, and four computed channel.

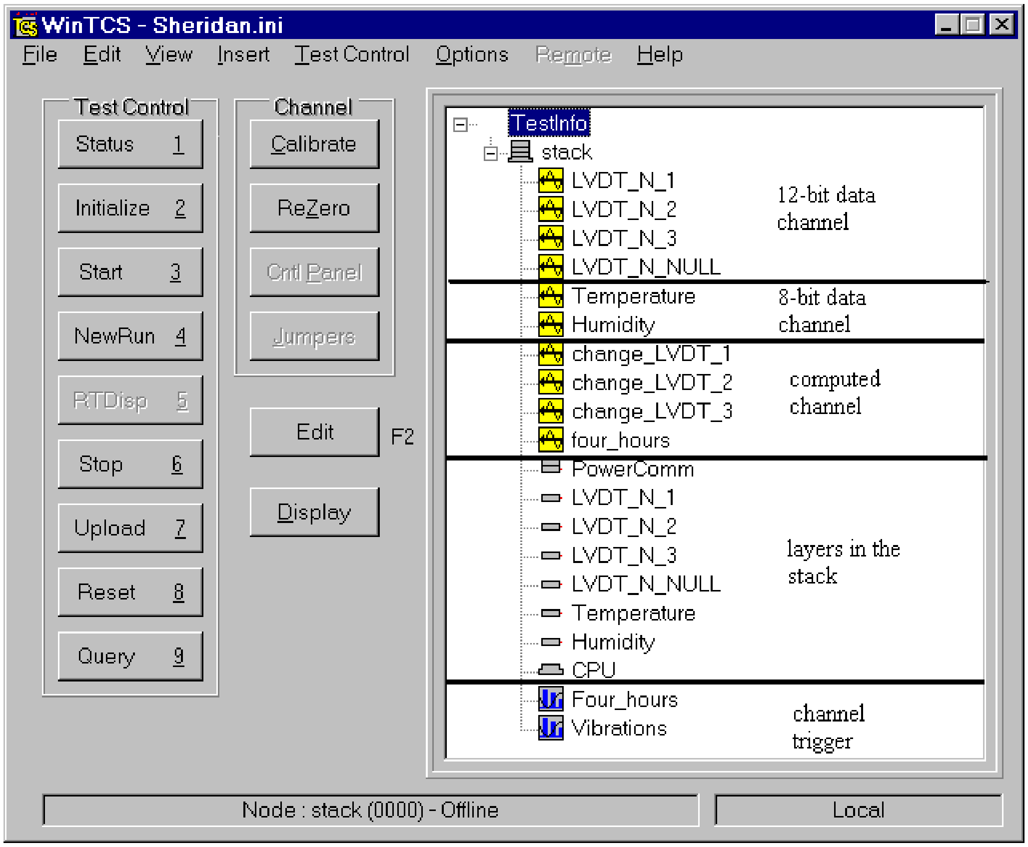
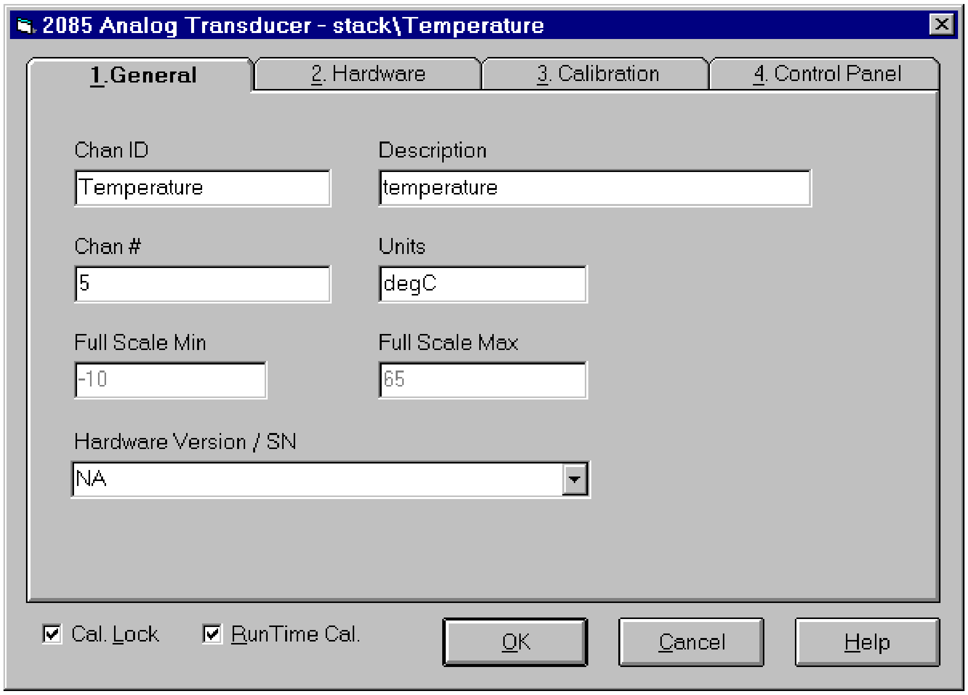


Figure B.1 Somat User Window Definitions

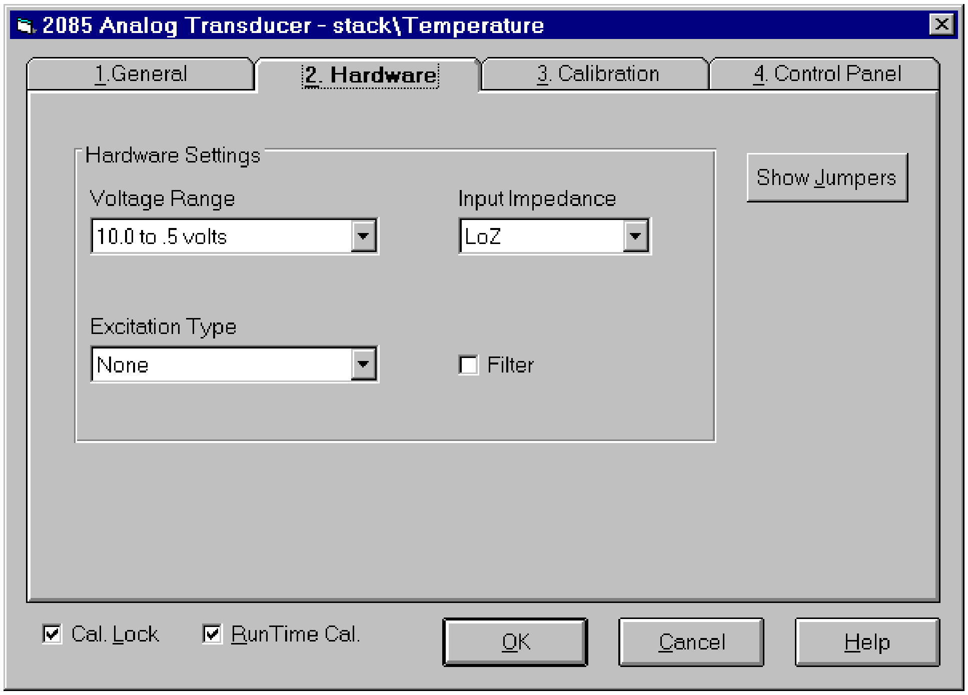
The 8-bit channels are used for the temperature and humidity sensors, because these sensors do not need high resolution as already discussed. One channel is required for each sensor. Figure B.3 shows the general dialog box to control an 8-bit temperature channel. There are four sections in this dialog box: general, hardware, calibration, and control panel. The general dialog box allows the user to set the name of the channel as well as the maximum and minimum range of the sensor attached to it. The range shown in this dialog box is for the current temperature sensor, which may change with the sensor. The next dialog box shown in Figure B.4 shows the hardware setup. This setup is dependent upon the type of sensor, and the voltage range that the sensor specifies. A box on the right side of the dialog box may be checked if a digital filter is desired to reduce electrical noise. The current system does not employ filters because the vibration monitoring equipment does not have them and a design objective was emulation of such a monitor. The third dialog box, calibration, must be set in accordance with the sensor. The last dialog box, control panel, allows the user to visually see the data coming into the Somat from the sensor.



Chan ID: Temperature
Description: temperature
Chan #: 5
Units: degC
Full Scale Min: -10
Full Scale Max: 65
Hardware Version / SN: NA

☑ Cal. Lock
☑ RunTime Cal.

Figure B.3 8-bit Channel General Dialog Box



Voltage Range: 10.0 to .5 volts

Input Impedance: LoZ

Excitation Type: None

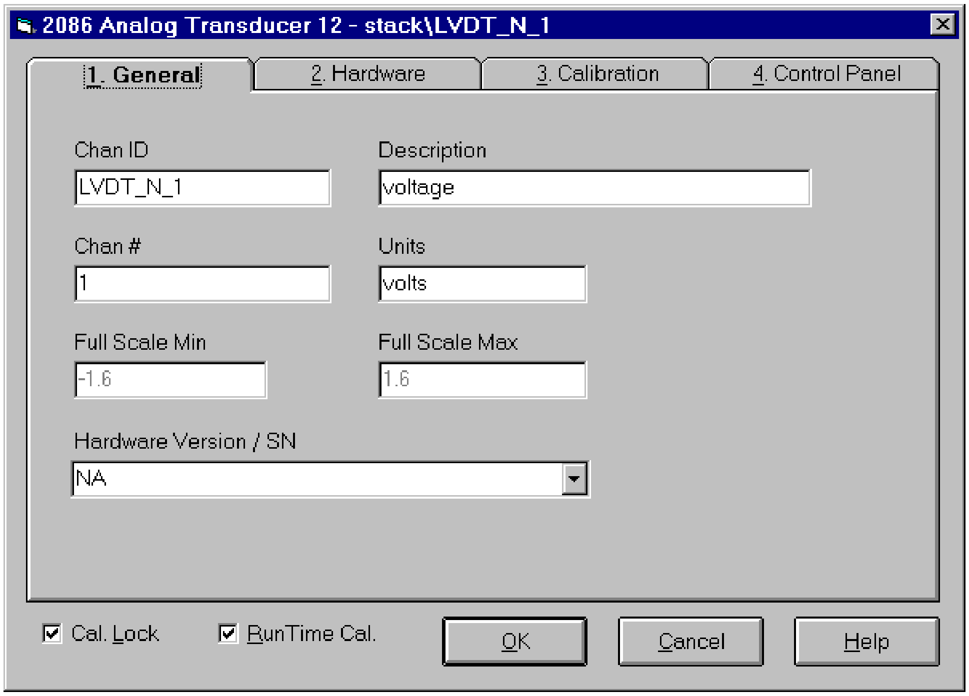
☐ Filter

☑ Cal. Lock

☑ RunTime Cal.

Figure B.4 8-bit Channel Hardware Dialog Box

The 12-bit A/D converters are employed for the displacement sensor voltages because they require the maximum resolution possible as discussed in the Sensor chapter. One channel is required for each of the four displacement sensors in the current system; therefore four channels are required. The 12-bit dialog box display is identical to the 8-bit dialog box display, except that the values may vary with sensor type. Figure B.5 shows the set up for the current displacement sensor, an LVDT. The full scale minimum and maximum range is set to +/- 1.6 volts, which is necessary for the required resolution as described in the Sensor chapter.



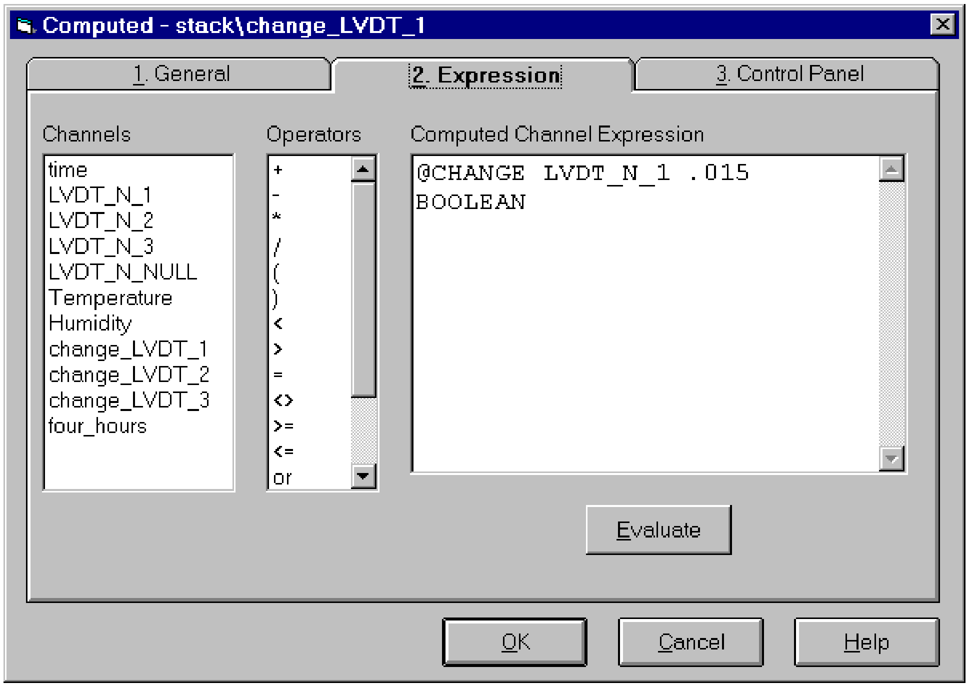
Chan ID: LVDT_N_1
Description: voltage
Chan #: 1
Units: volts
Full Scale Min: -1.6
Full Scale Max: 1.6
Hardware Version / SN: NA
☑ Cal. Lock
☑ RunTime Cal.

Figure B.5 12-bit Channel General Dialog Box

Computed Data Channels

The computed channels do not correspond to a layer in the stack but rather to the results of a computation with data received by another channel. This is very important for the data modes that will be discussed next. The current system includes two primary types of computed channels; one to compute the change in the data from the last point to the current point that is necessary for the 1000 Hz dynamic data and a second that captures 1000 Hz data at four hour internals to track/monitor long-term crack movement.

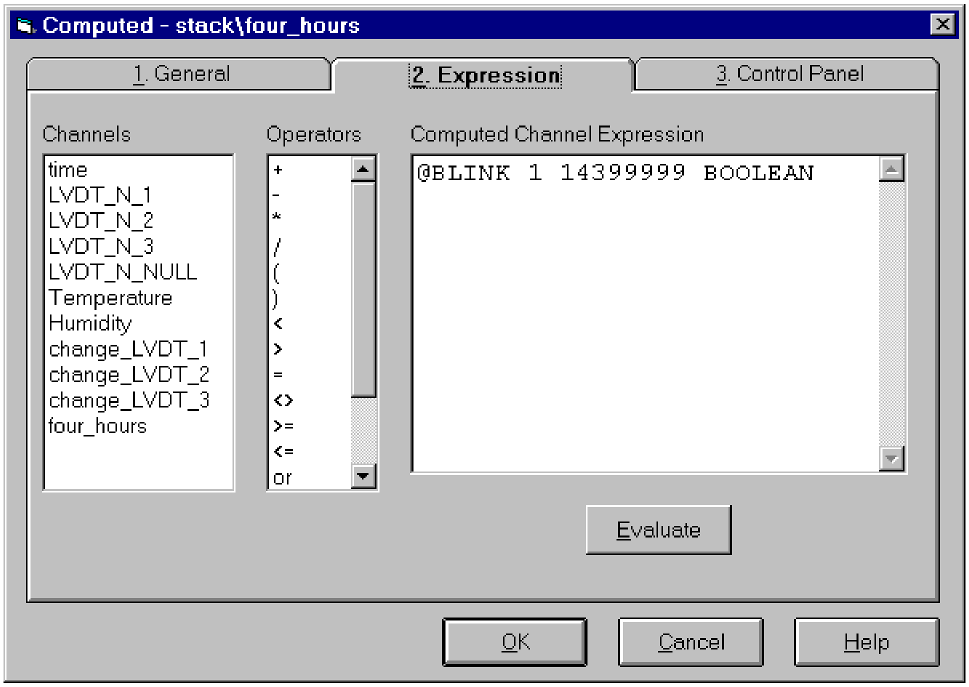
There is a different channel for each LVDT. The first computed channel generates a trigger whenever a change in the value of the LVDT channel exceeds the amount specified in the input parameter, in this case .015 volts or 1.9 micrometers. Figure B.6 shows the proper expression to perform this command.



```
@CHANGE LVDT_N_1 .015
BOOLEAN
```

Figure B.6 Computed Channel 1

The second computed channel employs a command called blink. This command causes the trigger condition to be true periodically whenever a specified number of periods have elapsed. The period is the period of the master sample rate. It is used to acquire small group of samples at regular four-hour intervals. The proper expression to perform this command is shown in Figure B.7.



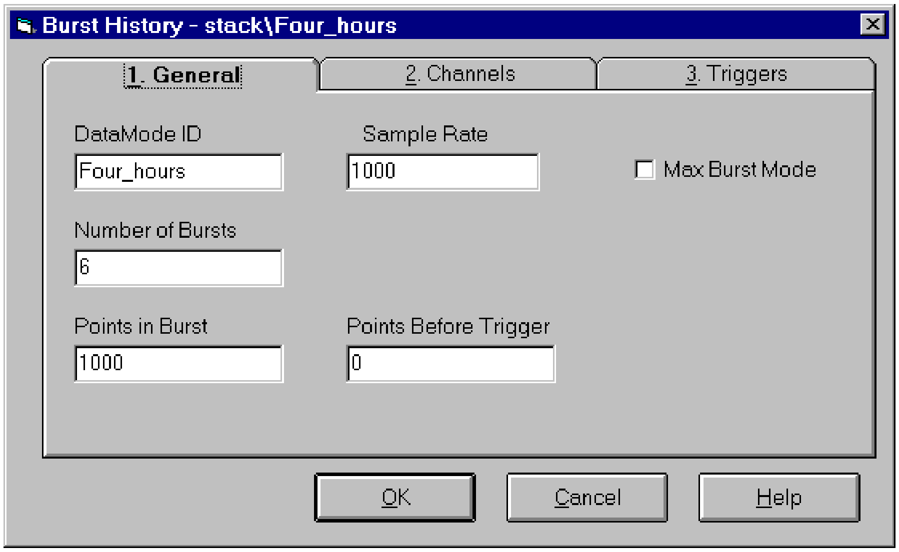
```
@BLINK 1 14399999 BOOLEAN
```

Figure B.7 Computed Channel 2

Data modes

A data mode is a collection of samples from one or more data channels. While WinTCS contains many types of data modes, only the burst history mode is employed. A burst history can include data before and after a condition is met. There are two burst data modes for the phase I system, one for the long-term weather and displacement data, and one for the transient vibration event data. The triggers for each of these data modes are different.

For the first trigger, long-term weather and displacement data, and the required pieces of information are the temperature, humidity, and sensor displacement values. Figure B.8 shows the general dialog box for this channel. In this dialog box the name of the data mode, sample rate, number of samples, and number of points in the burst is specified. The current system records a one-second burst every four hours in a twenty-four hour cycle, equaling six bursts per day. The sample rate is 1000Hz for one-second that produces 1000 points. Figure B.9 shows how the trigger for this data mode is set by time, which is recorded in seconds, from the start of the test.


Burst History - stack\Four_hours

DataMode ID: Four_hours

Sample Rate: 1000

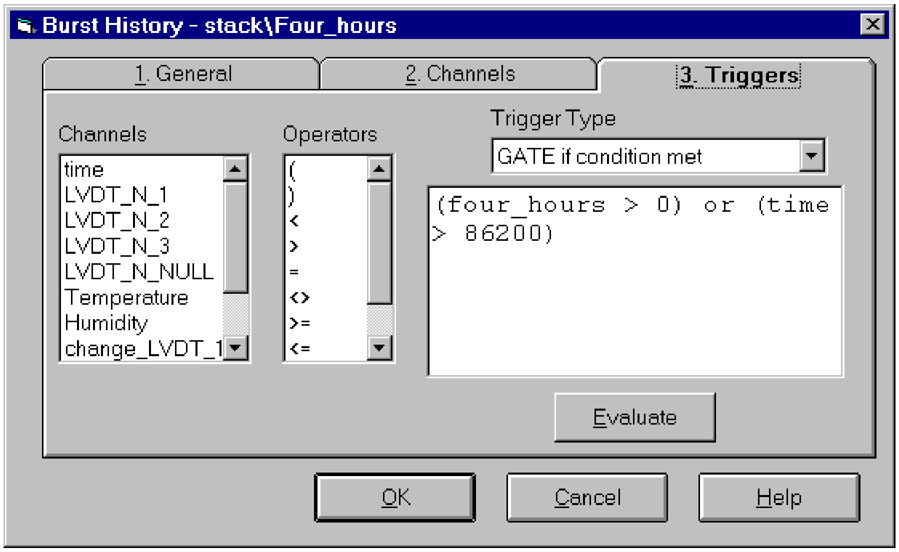
☐ Max Burst Mode

Number of Bursts: 6

Points in Burst: 1000

Points Before Trigger: 0

Figure B.8 Triggered Channel Long-term General Dialog Box

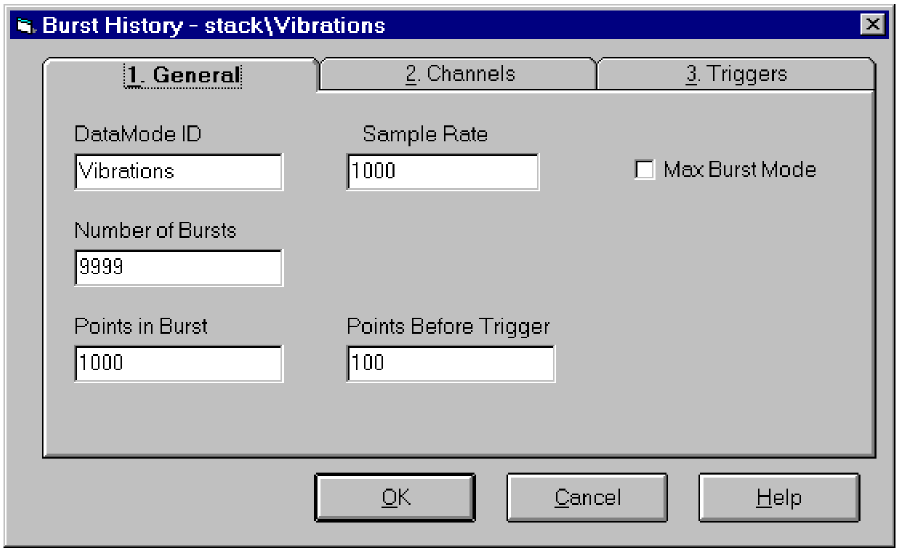

Burst History - stack\Four_hours

Trigger Type: GATE if condition met

```
(four_hours > 0) or (time
> 86200)
```

Figure B.9 Triggered Channel Long-term Triggers Dialog Box

For the second data mode, vibration events, the pieces of information required are the four sensor displacement channels. The general dialog box shown in Figure B.10 illustrates where the name of the data mode, sample rate, number of samples and number of points in the burst are specified. The current system records a one-second burst every time the computed channel for the LVDT sensors changes more than 1.9 micrometers. The channel is set to record 100 points before the trigger was activated insuring that the full vibration event is captured. The trigger for how this data mode is set is shown in Figure B.11. When this system is moved to a quarry in phase II the length of these bursts will be increased to capture the full ground motion and structure response.



DataMode ID: Vibrations

Sample Rate: 1000

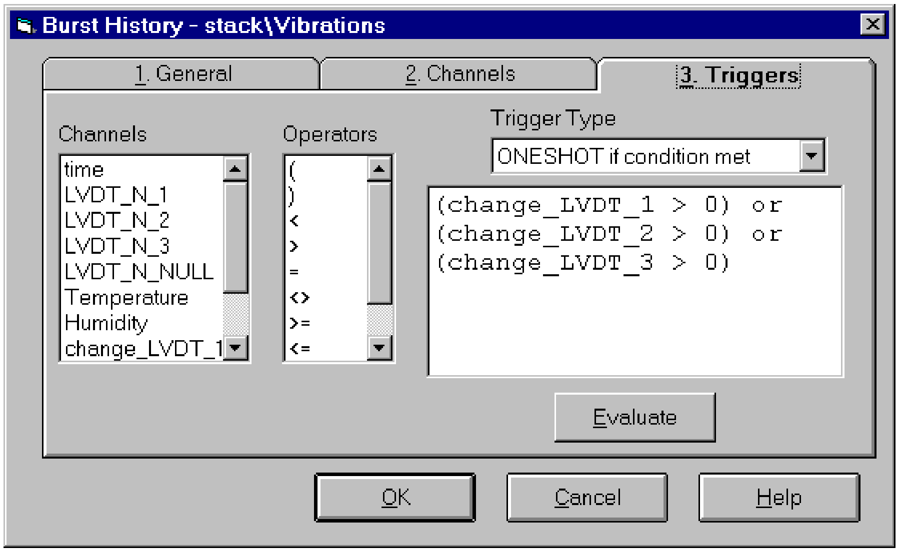
☐ Max Burst Mode

Number of Bursts: 9999

Points in Burst: 1000

Points Before Trigger: 100

Figure B.10 Triggered Channel General Dialog Box



Trigger Type: ONESHOT if condition met

```
(change_LVDT_1 > 0) or
(change_LVDT_2 > 0) or
(change_LVDT_3 > 0)
```

Figure B.11 Triggered Channel Triggers Dialog Box

APPENDIX C
AUTOMATE FILES

APPENDIX D
AUTOMATE TIPS

Tips and tricks for AutoMate

The AutoMate script files contain a two-second pause after each command that does not require a windows notification to proceed. This allows the computer and the program time to process the command that was just sent by AutoMate. If the pauses are not placed the system may lock-up and require rebooting. Many of the common windows keyboard commands can be used in AutoMate to access various components of software packages. A list of the commands and there use follows:

- Tab = allows user to toggle between fields in a selection window
- Shift = allows the user to select multiple items in sequential order
- Alt = allows users to enter the command menu in a program
- Ctrl = allows users to select multiple items not is sequential order
- Arrow keys = allows user to move through lists

Selection and deletion of channels

To select and delete channels from AutoMate refer to the script file on the following page. The steps are outlined with keyboard commands that can be easily followed.

APPENDIX E
JAVA DESCRIPTION

David Kosnik, Northwestern University, wrote the following description.

INTRODUCTION

Java is a platform-independent programming language developed by Sun Microsystems. Java programs are employed in several parts of the crack monitoring project. Applets, Java components which run inside a client's web browser, are disallowed by the design specification and are not used in the site. However, a number of tasks which must be completed on the web server- and therefore are not dependent upon the client's browser- are performed by Java programs. These modules run on the web server and are collectively referred to as the server-side Java component of the web site.

PARTS OF SERVER-SIDE JAVA COMPONENT

The server-side Java components of the crack monitoring system provide the basis for the automation of the data storage, data retrieval, and data presentation. There are two distinct parts of the Java component. The first part is the conversion program, a stand-alone application which processes the data from the field hardware. The second part consists of a suite of programs which run in conjunction with the HTTP server. These programs are called "servlets," because they extend the functionality of the HTTP server. The servlets generate the graphs shown on the "Crack Displacement vs…" pages.

The final part of the server-side component is the relational database. This is not a Java component in any way; however, both the conversion program and servlets use the database for storage and retrieval of data. Presently, the database system which is used is DB2 from IBM. The database contains four data tables: a long-term data table, and three burst data tables. One burst data table stores complete records of all vibration events, and the two remaining tables store the minimum and maximum values from the vibration events, respectively.

CONVERSION PROGRAM

The conversion program is a stand-alone application run by Automate. It is an application program that does not depend upon the context of a web browser. The conversion program performs two tasks critical to the automation of the crack monitoring site. First, the program parses the data file from the field hardware and converts the data from voltages into the appropriate units for each sensor channel. Second, the program automatically enters the new data into the project database for future use by the graphing servlets. Java is the language of choice for the conversion program because it contains a flexible interface for direct communication with a variety of databases. This interface, called Java Database Connectivity, makes it possible for the conversion program to load the data directly into the database.

The first tasks performed by the conversion program involve timekeeping. Time must be measured with at least one second accuracy for many months or longer. To solve this problem, the crack monitoring system uses truncated Julian dates. The truncated Julian date is a modification of the Julian dates first invented for use in astronomy. The truncated Julian date is the number of days since an arbitrary epoch: May 24, 1968, at midnight, Greenwich mean time. For example, the truncated Julian date for one second after noon on March 23, 2000 is 11626.5000115741. The truncated Julian date system is well-suited to this application because it provides a record of the date, with second or greater accuracy, in a simple decimal format which is easily stored in the database. The truncated Julian dates provide a convenient primary key, or index, for the database, which makes it easy to compare dates and to query the database for events in any given time period.

The date and time of the beginning of the test is present in the headers of the data file. The program reads this timestamp and converts it to Greenwich mean time and then to a truncated Julian date. The timestamps for all the other data in the file are given in terms of seconds relative to the start time. As the program parses the data in the file, these relative times are converted to truncated Julian dates as well.

There are two distinct types of data that may be present in the data file: long-term data, which is sampled at four hour intervals, and burst data, which is sampled only when a vibration event is detected. All data files contain long-term data, but not all contain burst data, as vibration events do not necessarily occur on a daily basis. Before the program can parse the data in the file, it must determine whether burst data is present in the file. If there are burst data, there will be a line in the data file indicating that a second data mode is used in the file. This second data mode refers the is the burst data. Consequently, if this flag is present, there is burst data in the file.

If burst data are present, they are converted from volts to micrometers. The entire time history of each event (1000 points for every second of duration) and the truncated Julian date at which it occurred are stored in the all-vibration data table in the database.

Then, the absolute maximum and minimum values for each vibration event are determined and stored in the maximum and minimum vibration tables, respectively.

Finally, the program parses the long-term data. The long-term data is sampled at 1000 Hz for one second every four hours. The 1000 data points for each set are averaged, eliminating noise from the final result. For the four LVDT channels, a the same conversion factor used for the burst data is applied to convert the long-term displacement data to micrometers. The temperature and humidity data are already in units of degrees Celsius and percent relative humidity, respectively, so no conversions are made to those channels. The program then adds the six new data records to the four-hour data table. As with the vibration data, the data is indexed by truncated Julian date.

The program then closes the database connections and terminates. The original data files are preserved and archived. The archiving of the original data files prevents loss of data in the event of damage to the database. If, for example, the data in the database were to be corrupted by an equipment failure or malicious act, it could be reconstructed from the archived data without any loss of information. Likewise, if a flaw were to emerge in the conversion program, the database could be reconstructed to remove the error once the flaw had been corrected.

GRAPHING SERVLETS

The second aspect of the server-side Java component is the graphing servlets. These programs work in the context of the web server- as opposed to that of the client's web browser- to dynamically generate plots of environmental data and crack displacement.

Servlets and the Web Server

As with all web sites, the HTML files which compose the static parts of the site exist on the web server- a computer connected to the Internet which runs an HTTP server program. The HTTP server program, also known as a daemon, listens for requests for files on the public directories of the computer. When a request is made, the daemon sends the file to the machine that requested it. The communication standard for these file transfers is HTTP, or Hypertext Transfer Protocol; HTTP forms the backbone for communication on the World Wide Web. The HTTP daemon in the crack monitoring project is Apache, available free from The Apache Group, (www.apache.org).

Java servlets extend the functionality of the HTTP daemon. These small Java programs run on the web server in much the same way as Java applets run in a web browser- hence the name. The advantages of the servlet programming model lie in the fact that the client requests data from the servlet in exactly the same way as it would request an HTML file or an image. For example, an images are embedded in a web page with the following syntax:

```
<IMG SRC="http://iti.birl.nwu.edu/xyz/image.gif">
```

This tells the browser that the image named "image.gif" which exists in the "xyz" directory on the server "iti.birl.nwu.edu" should be embedded in the page at that point. The browser then requests this image from the server, and the HTTP daemon responds by sending the appropriate image file. By changing the address of the embedded image, however, we can tell the browser to embed the image generated by a servlet instead of a static image:

```
<IMG SRC="http://iti.birl.nwu.edu/GraphServlet">
```

This line of code tells the browser to request the image GraphServlet on the "iti.birl.nwu.edu" server. The HTTP daemon, which has been configured to run servlets, intercepts this request and sends it to the servlet engine. The servlet engine is an extension to the HTTP daemon which provides a context for servlets to run. The servlet engine in the crack monitoring project is the Apache JServ product, also available from The Apache Group. Once a request has been passed to the servlet engine, it instantiates the appropriate servlet and passes the request to it. The servlet performs whatever task it is designed to carry out and sends the result back to the HTTP daemon, which finally sends it back to the user. The response from the servlet can be in nearly any format-plain text, a web page, or an image, to name a few. As a result, the client can interact with a Java program on the web server through the simple HTTP communication standard, which is supported by all web browsers throughout the world.

In addition, servlets in the crack monitoring project provide an ideal mechanism for displaying data from a database. Using the Java Database Connectivity interface, the servlets can query the project database to obtain environmental or crack data for a given time period. Since the servlets can obtain information directly from the database, they provide an efficient means of displaying data to a client.

Environmental Data Servlet

The environmental data servlet (iti.crack.WeatherVsTime) is designed to generate a plot of weather data for a given time period and return this plot to the viewer's web browser. The servlet accepts a number of input parameters, including type of data (temperature or humidity), range of dates to display, and maximum and minimum values on the y-axis. These parameters are passed to the servlet through a standard HTTP GET request. The GET request is the standard HTTP method by which web browsers request static HTML pages and images. By definition, all web browsers are capable of making these requests. Arguments are passed as a suffix, or query, to the servlet address. That is, the address of the servlet is `/servlet/iti.crack.WeatherGraph`, but the request looks like this:

`/servlet/iti.crack.WeatherVsTime?time=w&xData=TJD&yData=HUMID`.

For example, the following HTML tag would embed a graph of temperature over the past week: `<IMG SRC= "/servlet/iti.crack.WeatherGraph?time=w&xData=TJD&yData=TEMP">`

It is also possible to specify any particular range of dates. This is accomplished by using the `time`, `xMin`, and `xMax` arguments, where xMin and xMax are the truncated Julian dates for the start and end of the desired time period. The argument `time=o` indicates that a specific range of dates- rather than a request to simply graph the last week or month- follows in the request. To embed in a graph of humidity data from March 23 to March 31, 2000 in a web page, the following syntax would be used:

```
<IMG
SRC="/servlet/iti.crack.WeatherGraph?time=o&xData=TJD&yData=HUMID&xMin=
11626&xMax=11634">
```

To specify a scale of 0 to 40% humidity for the y-axis, the yMin, yMax, and noAutoScale parameters are employed. The noAutoScale=true argument indicates that the specific range of y-values to be displayed are indicated in the query.

```
<IMG
SRC="/servlet/iti.crack.WeatherGraph?time=o&yData=HUMID&xMin=11626&xMax
=11634&yMin=0&yMax=40&noAutoScale=true">
```

A line similar to the preceding is all that is required in the web page which displays this graph. All the data necessary to display the graph is passed to the servlet through the GET request.

When the HTTP daemon receives a request for the environmental data servlet, the request is passed to the servlet engine, which in turn instantiates the servlet and passes the request to it. The servlet parses the request and determines what type of data and what date range is being requested. Once these have been determined, the servlet opens a connection to the database through the Java Database Connectivity interface and queries the database for the requested data type over the requested date range. The database returns two columns of data: timestamps (truncated Julian dates) and sensor data (degrees Celsius or percent humidity). The servlet internally stores the results of the query for use by the graphing package.

The graphing package is an external program that the servlet runs in order to actually draw the graph. At this point, the package used is KavaChart, available from Visual Engineering (www.ve.com). The two columns of data are passed as parameters to the graphing program, which generates a plot of the requested data type versus time for the requested time period. The graph is then encoded and returned to the client as a GIF image.

Crack Data Servlet

At this time, the crack data servlet (iti.crack.CrackVsTime) works in exactly the same way as the environmental data servlet. The only difference is in the request for the image: a specific LVDT is requested for the y-axis data instead of temperature or humidity. For example:

```
<IMG SRC=
“/servlet/iti.crack.CrackVsTime?time=w&xData=TJD&yData=LVDT_3”>
```

would return a graph of crack displacement for LVDT 3 for the past week. Arguments for displaying a specific period of time or a specific scale on y-axis can be used in the same fashion as with the environmental data servlet.

In the future, the crack data servlet will indicate the relative magnitudes of vibration events on the long-term crack displacement graph. This will be accomplished by placing vertical bars on the displacement graph where vibration events occurred. The top of the bar will correspond to the absolute maximum value of the crack displacement during the vibration event, and the bottom of the bar will correspond to the absolute minimum displacement during the event. This will make it easy to see how much the crack changed during the event, and will communicate that crack changes during vibration events are several orders of magnitude smaller than long-term changes due to environmental conditions.

Future Plans

The next step in servlet development will be to implement a system that will show the bars indicating vibration events on the crack displacement graph. In addition to that, the crack displacement graph will become a clickable image map such that the user can click on a vibration event to see a graph of the 1000 points making up the event. These features will enhance the user’s understanding that long-term crack changes are much larger than those caused by vibration.

APPENDIX F

TYPICAL DATA FILE WITH VIBRATION EVENT

APPENDIX G
CORRECTED DISPLACEMENT OF ALL SENSORS

APPENDIX H

SENSORS COMPARED WITH TEMPERATURE AND HUMIDITY

APPENDIX I

ENGINEERING DESIGN AND COMMUNICATION REPORT WITH SURVEYS

APPENDIX J
COST OF ALL ITEMS CONSIDERED