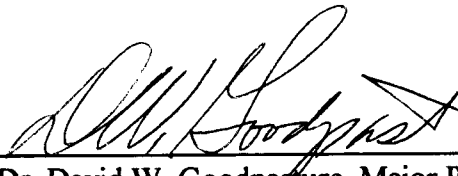
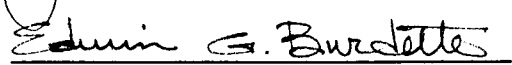


To the Graduate Council:

I am submitting herewith a thesis written by Laura Lynn Arico entitled "Instrumentation for Long Term Testing of Abutments on Stub Piles." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.


Dr. David W. Goodpasture, Major Professor

We have read this thesis and
recommend its acceptance :

Accepted for the Council:


Associate Vice Chancellor and
Dean of the Graduate School

**INSTRUMENTATION FOR LONG TERM TESTING OF
ABUTMENTS ON STUB PILES**

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Laura Lynn Arico
December 1997

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Abstract

The Tennessee Department of Transportation has been designing and constructing jointless bridges with integral abutments for some time. The particular concern with the integral abutment is the pile which supports it. As the span of the bridge increases, the lateral loads imposed by thermal movements can cause large deflections in the pile supporting the integral abutment. The University of Tennessee under contract with TDOT is investigating the effects of these deflections on the pile supporting the abutment.

Full scale lateral load tests were performed on a 40 foot pile supporting an abutment. The testing was performed over several months, and the instrumentation requirements were extensive. The pile was instrumented on the top 20 feet with weldable strain gages and pressure sensors. The loads and deflections were monitored with load cells and linear displacement voltage transducers (LVDT's), respectively. There were a total of 72 instrumentation devices to be monitored for each test.

The device known as the Optim MEGADAC used in conjunction with the Test Control Software (TCS) was invaluable to the data collection process. The MEGADAC converts the signals coming in from the gages and sensors into readings of strain, psi, kips, or inches. The sampling rate can be adjusted from test to test, and 1 sample per second was used for the two tests presented herein.

From the analysis of the data, it is shown that the most useful and reliable data obtained are from the strain gages. The pressure sensors simply do not hold up over time, and the results from them are not very consistent. Data reduction should therefore focus on the strain gage data, and the conversion of the strains into moments and pressures.

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Chapter 1

Introduction

The introduction of jointless bridges with integral abutments has been relatively recent. In the past, most bridges were designed as determinate structures, accomplished by breaking up the bridge into a succession of simple spans instead of one continuous span. Thus, the bridge could be analyzed using only the three equations of static equilibrium. The most obvious disadvantage of a bridge which is not continuous is the fact that expansion joints are a major cost. Not only is the initial expense of the materials and construction costly, but also the constant maintenance and repair become a burden over time. Expansion joints were noted for the high maintenance required to keep them functioning properly over any length of time. Jointless bridges with integral abutments were designed with no expansion joints, eliminating that expense and upkeep. Thus, as methods for solving indeterminate structures began to be developed, continuous span designs with no expansion joints between abutments became popular. Integral abutments were the next step for full continuity of the jointless bridge.

The Tennessee Department of Transportation (TDOT) designs and constructs jointless bridges with integral abutments as a standard practice ¹. The basis of the design has been sound engineering judgment with the aid of computer analysis, including a program named COM624P ². This program allows piles supporting integral abutments to be analyzed as they are subjected to lateral loads. With the input of soil parameters and

properties of the pile, the program produces output such as moments, deflections, and pressures with respect to the depth of the embedded pile. A concern of TDOT is the extent to which lateral loads affect the piles supporting the integral abutments. These lateral loads, which are induced mostly by thermal movements, are a source of sizable deflections in the pile.

Due to the complexity of the soil-pile interface and the pile-abutment interface, it is difficult to analyze the pile in a rational manner. Because of this difficulty TDOT sponsored a research contract with The University of Tennessee to perform research on the behavior of laterally loaded piles supporting integral abutments. The scope of this research is to perform full scale field tests that closely resemble piles supporting integral abutments for jointless bridges experiencing thermal movements. The test specimens are HP10x42 piles, instrumented with strain gages and pressure sensors throughout the first 20 feet of depth of the pile.

These field tests consist of driving the pile into the ground, building the abutment which the pile supports, and loading the pile laterally at a slow rate. A main issue of concern when performing research of this proportion is the instrumentation and data collection. It is crucial that the many instrumentation problems that may arise be kept to a minimum due to the expense involved in testing just one pile. Once the pile is driven into the ground and the abutment is built, the entire project then depends upon the reliability and the functionality of the instrumentation involved. For this reason, many measurements were taken to ensure the success of the data collection for this project; many of these measurements are presented and discussed herein.

The details of the test system, including the loading arrangement, were described in an earlier thesis⁸. The primary emphasis in this thesis is a description and explanation of the instrumentation, including both the measuring devices affixed to a test pile and the data gathering equipment.

Chapter 2

Areas of Concern

2.1 INTRODUCTION

This research will determine the capabilities of a flexible steel pile as well as the concrete abutment which it supports to remain intact under lateral loads imposed by thermal movements. TDOT has been designing these types of integral abutments for short to medium span bridges for quite some time. The practical advantages for this type of construction warrant the research required for engineers to apply the design procedures they have developed with confidence to longer span bridges. This research will determine whether or not the integral abutment supported by steel piles will remain intact and functional under the large deflections induced by thermal movements. As the span of the bridge increases, so do the deflections in the abutment and, in turn, the pile increase. The moments induced by these lateral loads will be calculated and compared with the design moments, the plastic moment of the steel pile, and the moment capacity of the concrete abutment.

2.2 PILE-ABUTMENT INTERFACE

There are some particular areas of interest on which this research project focuses. One is the pile-abutment interface. Here the concern is what happens to the portion of the

pile embedded in the concrete. The following are some questions which are addressed by this research:

- Will the pile reach its plastic moment before the abutment fails?
- What is the proper embedment length of the pile in the concrete?
- What sorts of stresses build up; is the abutment expected to crack; if the abutment cracks, where does it crack, and how does the crack affect its ability to function?

According to TDOT, the piles which support integral abutments can expect to see as much as an inch of deflection or more at the ground surface, a large deflection for the pile embedded in the abutment to withstand. The preliminary research on this project began with laboratory tests to model this pile-abutment interface. These tests are described in detail in a master's thesis by Zeind³, but the following is a brief summary of the findings from these tests.

A simulated abutment consisting of a 4ft x 2.5 ft x 2.67 foot deep concrete block was built with a four foot HP10x42 steel pile embedded in the concrete one foot. The concrete was not reinforced for the first test and was reinforced for the second test. In neither case did the pile come close to reaching its plastic moment before breaking out of the concrete under a lateral load. This result would suggest that the pile would not be able to attain the desired deflections which were expected for the field tests. It was concluded, however, that the laboratory test did not accurately model the situations in the field. However, the problem in the laboratory tests still raised some question as to whether or

still raised some question as to whether or not the pile in the field would actually reach its plastic moment before the abutment failed in tension.

2.3 EFFECTIVE LENGTH

Another point of interest is the effective length of the pile embedded in the ground. The effective length is defined as the point at which the pile is no longer being significantly affected by the applied lateral loads. In order to determine this, the soil-pile interaction must be investigated. TDOT predicts this effective length with the use of the computer program COM624P. From the soil parameters and the information given about the pile, this program gives relationships for moment, pressure, and deflection with respect to the depth of the pile. The unbraced length for that pile is then taken as the distance between the first two zero points on the moment versus depth curve. This parameter for the design of the pile is of great importance to TDOT. For design purposes, the effective length is established primarily on the basis of the curves established from the computer program. In order to validate this design procedure, the point of zero lateral pressure will be determined through the course of this research. The moment diagrams are obtained from the strain gage readings. Then, through integration and differentiation, the deflection and pressure diagrams with respect to the depth are established. These diagrams based on the strain gage readings are compared to those diagrams produced by the COM624P program. Also, the pressure sensors that are installed are intended to determine the points of zero pressure which can be compared to both the diagrams obtained from COM624P as

well as those from the double differentiation of the moment diagram. The effectiveness of these pressure sensors remains to be determined.

The main objective of this research is not only to verify current design procedures, but also to develop procedures for designing these integral abutments supported by flexible piles for longer span bridges. The accuracy and reliability of the computer program, COM624P, can be verified with the data presented.

Chapter 3

Review of Literature

3.1 INTRODUCTION

There has been some recent research done on laterally loaded piles of integral abutments, but much of it has been laboratory work or theoretical approaches to solving design problems. There have been few full scale tests like the one The University of Tennessee is currently performing. Some of the research of interest is presented herein.

3.2 IOWA STATE

A series of tests performed in the state of Iowa in 1987⁴ included a study on the effect of lateral loads applied to the flexible piles of integral abutments. A main objective of this research was to establish a methodology for the design of such integral abutments for jointless bridges. The full scale test included three different types of tests on HP steel piles. The three loading conditions were a vertical load test, a lateral load test, and a combination of these two. The research of interest to the project at The University of Tennessee is the lateral load test.

The lateral load tests were performed to develop relationships of the soil characteristics, known as p-y curves. These curves are a relationship between the lateral pressure and the lateral displacement the pile receives. The HP pile used was a 50 foot long pile and was instrumented with electrical resistance strain gages along its length.

These gages were located on the inside of the flange of the pile, one inch from the flange tip. There were a total of eighteen gage stations, and at each station there were two gages. The gages were spaced at 12 inches on center. The instrumentation was waterproofed and protected with a 16 gauge sheet metal conduit which was welded to the pile. At the bottom of the sheet metal conduit, a triangular wedge was welded to protect the open end of the sheet metal, as well as to ensure that the conduit remained in place as the pile was being driven.

The maximum horizontal displacement that was to be applied was established as 2 inches prior to testing. The lateral load which caused this displacement was 25 kips at a location of 20.5 inches from the ground surface, a load which produced strong axis bending. The loading rate was very slow and the test took a total of 30 hours. The test was deflection controlled; that is, a load was applied until a desired deflection was reached. The deflection increments for the test were .10 inches at the ground surface. Also, the rate at which the lateral load dropped off was also monitored and this became the criterion for applying the next load. The next deflection increment could not be applied until the load was dropping at a rate no greater than 400 lb./hr. This rate became harder to satisfy at larger deflections which is why the test took so long.

From these lateral load tests the p-y curves were calculated. The pressure was determined through the differentiation process based on the measured strains. These curves were plotted against and compared to theoretical p-y curves to determine some correlation. The experimental data and the theoretical curves compared with each other reasonably well for the lateral load test.

The purpose of this research was to establish design criteria. One very important parameter in the design of these piles is the equivalent length of the pile embedded in the ground. In order to determine this length, the pile was idealized as an equivalent cantilever. The equivalent length of this cantilever is defined as the distance from the ground surface to the fixed base of the equivalent cantilever. Also established from this idealization is the critical length of the pile. This critical length is defined as the depth at which the displacements and bending moments due to the lateral load are less than about 4% of those at the pile head. This length is qualitative in that it has no specific physical definition; rather it is a means of describing the pile and soil acting as a unit. Usually, piles in the field are longer than this parameter, and for design purposes these piles are considered infinitely long⁵.

Two recommendations for design were presented depending upon what type of situation was controlling. Noted as Alternative One, the first method is controlled by the strength of the pile and does not take any plastic redistribution into account. Therefore, for a fixed-head pile, the maximum moment is

$$M = \frac{6EI\Delta}{L^2}$$

This alternative suggests that the failure would occur when the elastic yield of the pile material is reached. No ductility at all is assumed.

Alternative Two, however, does consider some ductility and the ability of the pile to redistribute its moments. In order to use this alternative, the section of steel must be a

compact section in order to develop a mechanism before any type of buckling can occur at the plastic hinge. This also means that the section must be sufficiently braced.

From the comparison of each of these alternatives with a finite element program, IAB2D, the HP 10x42 did have the required rotation capacity to be considered under Alternative Two, even though it is a noncompact section.

3.3 CALIFORNIA

There was also some research including field testing on piles at bridge sites in northern California⁶. The scope of their research included the lateral load-deflection behavior of the piles, the comparison of theoretical versus measured values for the moments, pressures, and deflections, and the determination of the subgrade modulus for bridge embankments. Field tests that were performed included both fixed head and free head piles, and it was determined that the free head pile could only withstand half as much lateral load as the fixed head pile. One other major conclusion was that the effective length of the piles for bridge embankments varied from 8 to 12 feet. From this value it was determined that only the top portion of the compacted fill provides the lateral support for the pile, and the condition of the soil below that effective length has virtually no influence as far as lateral loads are concerned. As with the other research, the theoretical p-y curves were evaluated in this research. The soil modulus was then expressed in terms of the ratio of the soil reaction, p , over the depth of the pile, y .

The location of these test piles was known as the Occidental Drive Crossing. Six piles underwent lateral load tests, and they were all considered isolated piles with no

group action. The piles were instrumented with electrical strain gages along their lengths, and the measurements obtained by these gages were converted to determine the flexural moment in the pile when subjected to lateral loads. The piles were driven into the ground 28 feet, and the top 12 feet were backfilled with compacted pea-gravel.

The free head tests were load controlled for two of the piles and were deflection controlled for two of the piles. The deflections which the piles were loaded to were $\frac{1}{2}$ ", 1", $1\frac{1}{2}$ ", and 2". Each of these increments was held for two hours. For the load controlled tests, the increments were 5, 10, 15, 20 and 25 kips. Again, the loads were held for at least two hours or until the pile head movement was less than .010 in/hr. The measured and calculated values were reasonably comparable for these free head tests.

For the fixed head tests, the lateral load was unknown due to the test setup, but the strain gage readings were converted into moments, and the corresponding load based on the moment at the ground surface was assumed.

The conclusions previously cited were based on this research, and the effective length of 8-12 feet was defined as the depth at which the pile no longer transferred the lateral load to the soil. From the measured data, the effective length was determined to be the distance down to the first zero deflection point of the pile. The fixed head piles gave the longer effective length of 12 feet, based on the zero deflection point, while the free head piles averaged closer to 10 feet. For the research being performed currently at The University of Tennessee, the pile is a fixed head pile, so the expected effective length should be close to 12 feet based on this research.

Several others have developed theoretical approaches to the design of these flexible piles, and the most critical assumption is that of the soil modulus. Most of the time the soil-pile interaction is modeled as a beam with a stiffness EI , supported by a series of springs at an infinitely close spacing. The stiffness of these springs is the soil modulus⁷. In order to determine this soil modulus, the load-deflection relationship must be analyzed. A soil's load-deflection curve is not linear as it typically is with other materials in which a stiffness constant is desired, creating a less exact method of calculating this stiffness, for example using the secant modulus or the tangent modulus. Another difficulty with the determination of the stiffness of the soil along the length of the pile is that the stiffness of the soil may vary with depth. This difficulty is why computer programs such as COM624P require information about all of the different soil layers and then establish p-y curves in place of the lateral spring constants at these different depths. These p-y curves are the key to getting good results out of these types of finite element analysis programs. If the p-y curves can be determined to some degree of accuracy, then the results from the program correctly describe the pile-soil interaction, but if some of the soil parameters are unknown or some typical value for the soil is used without the benefit of performing tests on the soil, then the program can give results which are inaccurate.

The research cited gives good information as to test setup and instrumentation requirements, and it demonstrates that there is still much to be learned about integral abutments supported by steel piles.

Chapter 4

Experimental Program

4.1 INTRODUCTION

The testing program for this research project is somewhat complicated and is outlined in the following, first, a forty foot HP 10x42 pile was instrumented along its length with strain gages and pressure sensors. After this instrumentation was adequately protected, the pile was driven with only 2 feet of the pile above ground. Once the pile was driven, an abutment was built on top of the pile with one foot of the pile embedded in the abutment. Then the abutment was loaded laterally along the web of the pile until a 1 inch deflection in the pile was reached. The load was monitored by load cells at the jacking station and also at the vertical reaction of the abutment as it rotated. The deflection of the pile was measured above ground with LVDT's. All of this instrumentation was monitored during testing through the use of an Optim MEGADAC data acquisition system.

4.2 HP 10x42 PILE

The most useful data are obtained from the weldable strain gages that are along the length of the pile. These gages are located every 18 inches on center starting at the ground surface and ending at 19.5 feet into the ground. There are four gages per station, one on each of the flanges of the pile, for a total of fourteen stations. The gages were placed on the inside of the flange, three inches from the flange tip. The weldable gages come encased in a thin metal and are covered with a rubber protection. They are tack welded into place

with a small welding machine, with as many tiny welds as possible in a row, as close to the rubber protection as possible (Figure1)* . This type of gage is more expensive than the foil adhesive type, but its durability is much more reliable. It is important for the gages to be able to withstand the harsh vibrations created by the pile driver. Once the pile is driven into the ground, there is no way to replace lost gages. Thus, every measure had to be taken to ensure that as many gages as possible would be unaffected by the driving of the pile. The strains measured by these gages were converted to moments. Then, through a series of integration and differentiation, the pile deflection and the soil pressures were calculated. These deflections and pressures are of particular interest, so these strain gages are of utmost importance.

Also along the length of the pile are pressure sensors. These pressure sensors are located every 18 inches starting at 5'-3" from the ground surface and ending at 12'-9" from the ground surface on one side, and they start at 6'-9" and end at 14'-3" on the other side. The sensors are located on the outside of the flanges, centered along the web (Figure 2). They are 2" inches in diameter and were placed into a hole cut into the pile by a plasma cutter. The sensors are attached to tabs which were welded to the pile (Figure 3). These sensors are staggered with the strain gages such that the gages are 9" from the sensors, so as not to affect the section properties at the location of the strain gages. These gages read up to a maximum of 5 psi, and their purpose is to find the point of zero pressure below the ground surface. The maximum reading is small so that the zero point can be found with some degree of precision. This zero point can be compared to the pressure diagram

* All figures are located in Appendix.

obtained from the strain measurements. The locations of all of these strain gages and pressure sensors along the pile is shown in Figure 4.

Once all of this instrumentation was in place on the pile, the protection was added. This protection consisted of 18 gage sheet metal which was welded to the pile along its length. A triangular wedge was then welded at the bottom of the sheet metal to protect the conduit from becoming unattached during the pile driving. The sheet metal covered all of the strain gages and also protected the wires of both the gages and the pressure sensors. Foam was injected into holes in the sheet metal to further protect the gages and to keep the wires from vibrating too much as the pile is driven.

4.3 ABUTMENT

Once the pile was driven in the ground and the instrumentation on the pile was checked out, an abutment was poured in place, supported by the pile. The pile was embedded into the abutment 1 foot. The abutment was reinforced as is typical for an abutment constructed in Tennessee, with some extra reinforcing to ensure that the abutment would crack as little as possible, and to provide some ductility if an unexpected failure were to occur. The weight of the abutment is approximately 40 kips. An additional weight of about 30 kips was added in the form of concrete ballast, to provide assurance that the abutment would not overturn and pull the pile out of the ground under large lateral loading. According to TDOT, an HP 10x42 pile driven 40 feet into the ground can typically carry at least 100 kips in bearing. The abutment was built to try to simulate a realistic situation.

Inside the abutment is an embedment strain gage designed specifically for embedding in concrete. It was placed across the plane where internal cracks were

expected to occur. Embedded gages have advantages and disadvantages. For example, if correctly placed, the strain gage will give valuable information as to the stresses that build internally as the tip of the pile tries to pull out of the abutment. On the other hand, if the gage is not placed exactly along the cracking plane, it will be of little value. Even if it is close to the crack, the stress in the concrete has been relieved due to the crack and it will have no significant reading.

The best way to tell what happens to the abutment as the test is performed is to visually observe the behavior and be aware of any cracking where and when it may occur. Of course, a key focus of this project is the abutment-pile interaction, so any information that the embedded gage can provide is potentially helpful.

4.4 LOADING SETUP

This research is being performed to see how the pile and the abutment react to the stresses induced by the thermal moments, so the loading is lateral. The abutment was pulled through its centerline in the direction of the web of the pile. A dywidag bar was run through a 3" steel pipe that was cast into the abutment. This bar was attached to a loading frame with a capacity adequate to support the applied loading. A hydraulic jack was pumped manually to apply tension to the bar which was secured at the far side of the abutment. This pulled the abutment, and in turn the pile, laterally. The field test setup is shown in Figure 5. The load was monitored, but the test was controlled by deflections. There were LVDT's set up at the ground surface of the pile and at the bottom of the abutment. These LVDT's measured displacement and were monitored throughout the test. To monitor the loads that were being applied, there were load cells at two locations. One was at the point of jacking, so that the exact lateral force that was being applied to the abutment and the pile could be determined. Second, at the loading side of the abutment, a load cell was placed on the reaction beam which was set up to monitor the reaction of the

abutment as it rotated. These load cells were calibrated and give readings in kips. These readings were monitored and recorded throughout the test.

The time scale for the test is dependent on the deflection versus time. The loading rate of 1 inch in 6 hours was established prior to testing. This slow loading rate was chosen to simulate a change in temperature of the bridge throughout the day. Since a bridge does not change temperatures quickly, the loading rate must be slow enough to resemble what is actually happening and to establish results that can correlate directly to piles that are used in bridges today and in the future. In reality, the piles are slowly loaded up to a certain deflection. There were be a total of twelve tests, six in each direction. The first three tests were to pull the pile to 1/2" in 3 hours. The next three were to pull to 1" in 6 hours. Between each test, the soil was given at least overnight to remold around the pile and to restabilize before being loaded again.

Chapter 5

Details of Data Collection System

5.1 INTRODUCTION

In order to collect data, the instrumentation must be controlled and read by some type of system. The system used in this project was the MEGADAC 3000 Series. In combination with the Test Control Software (TCS), the MEGADAC can read input from all the different types of instrumentation. The software translates the signals from the MEGADAC to the user. The parameters of the instrumentation can be input to the computer software and then sent to the MEGADAC. This software is how the user communicates with the MEGADAC.

5.2 MEGADAC

The MEGADAC 3108 was not capable of reading more than 32 gages; therefore, an expansion chassis was added. The system has a capacity of 72 different channels. The MEGADAC and the expansion chassis consist of module slots which are filled with circuit cards, or modules. The module which gives the MEGADAC its capabilities is the ADC 3016 analog to digital module. The MEGADAC converts the signals coming from the instrumentation into a format that is usable to the computer software. Also, the parameters given by the software are converted into signals sent to the instrumentation by the MEGADAC. In order for the MEGADAC and the expansion chassis to work together, each contains an EXPM 0016 module which is connected to the other by a cable. The rest

of the slots are taken up by the modules used for reading the instrumentation. The different types of modules used are the analog input modules and the signal conditioning modules; these modules will be discussed in detail in subsequent sections. Figure 6 shows the MEGADAC and the expansion chassis with the present configuration.

5.3 INSTRUMENTATION MODULES

One type of analog input module used in the MEGADAC is an AD 885D, an eight channel module with each channel being independent of the others. That is, the parameters of one channel do not affect any of the other seven channels on that module. The gain on these can be set from 1 to 500. This type of module requires a signal conditioning module that allows signals to be sent to the instrumentation. The signal conditioning modules used are the SCI 88C and the SCV 884. The SCI 88C is used for instrumentation which works on a quarter bridge such as the strain gages, while the SCV sends a constant voltage to excite full bridges. The pressure sensors, load cells and LVDT's are wired into the SCV modules. The other type of analog input module is the AD-1 808FB-1 module, an eight channel module which works without a signal conditioning module and is capable of measuring quarter, half, or full bridges. Any type of instrumentation may be wired into the AD-1 808FB-1. The gain available from these modules is either 1 or 100.

Each of these modules must have their jumpers set before inserting them into their slots. The jumpers are used to designate the gain, channeling, voltage output, and other parameters directly on the module. Each module is assigned a set of eight channels using a particular jumper configuration.

The gain determines the range of the readings as well as into how many units the readings are divided. The larger the divisions are, the more of a range there is, but the readings become less precise. For example, if a sensor has a maximum reading of 5 psi, then the gain should be set accordingly. There is no reason to set the gain at 200 and have the readings range from 0 to 100 psi with divisions every .01 psi, when the gain can be set at 1 to provide a range from 0 to 9 psi with divisions every .001 psi. This way, the readings are more accurate, and they fall within a more reasonable range. The voltage is not as much of a choice as the gain is. The instrumentation documentation specifies a recommended range of voltages.

5.4 TERMINAL BLOCKS

The wires from the instrumentation are not wired directly into the MEGADAC's modules; instead they are wired into terminal blocks which are connected to the modules with cables. There are different types of terminal blocks for the different types of modules. The STB 884 terminals are used with the AD885D modules. These terminals must be connected to an AD module as well as to either an SCI or an SCV module. These STB 884 terminals have two cables which connect them to the appropriate module in the MEGADAC. The type of instrumentation being measured will determine into which kind of terminal the wires need to be connected. The STB 808FB-1 terminals use only one cable connection and wire into the AD-1 808FB-1. The instrumentation comes with literature that designates which wires are the input and output, and each type of instrumentation wires into the terminals differently. Each terminal can hold eight channels,

so each terminal is connected to either an AD-1 808FB-1 or an AD885D and an SCI or SCV. The configurations of the wirings for the strain gages, pressure sensors, load cells and LVDT's are shown in Figures 7 - 10.

5.5 TCS SOFTWARE

The only way to input the parameters of the instrumentation into the MEGADAC and to receive the data is through the computer software. The software has several different menus which allow the user to enter the required information. The user can also keep a notebook of the daily happenings during the test for future use. A test can be set-up on the computer without the MEGADAC being connected. In order to get the test set up in the software, several parameters must be established. The test is given a name and a brief description. Then the channels are entered. Each channel needs the following information about the gage that is wired into it. The Tag ID is the first thing that can be established. That is, each gage or sensor is given an ID so that it can be easily identified. For example, the strain gages on the pile were labeled according to which flange they were on, A, B, C, or D, as well as their station, or location from the ground surface, 1,2,3...etc. So a gage located on flange A, eighteen inches from the ground surface (station 2), has the tag ID A2.

Once the tag ID was established, the channel for that gage was determined. Also, the type of instrumentation being monitored on that channel must be entered. The options given by the software distinguish by the type of reading the gage will produce, e.g. strain, load, pressure, etc. Once a type of reading is chosen, a screen will come up asking for

further information on the instrumentation. The type of terminal and module being used, what type of voltage source, what voltage output used, the gage factor given by the company, and the maximum output are some of the types of input parameters required.

Once the instrumentation information is provided, the next input is the gain which the gage or sensor is using. As discussed previously, the gain controls the range of the output as well as the divisions of the readings, and this gain must match the gain provided by the jumper configuration on the module. Also, it is on this menu that the user determines whether or not the instrumentation will be balanced. Balancing the instrumentation is an important step during testing. After the test is set up and all of the instrumentation are connected to the MEGADAC, the gages are read. At this point, the gages have readings which are not zero. In order to begin a test, it is reasonable to begin with zero load and zero strains, pressures, and deflections. Therefore, the instrumentation is balanced. Also, if there are any gages which are not working or were reading off scale, this is the opportunity to catch these errors without running the actual test. Once the instrumentation is balanced, the test is ready to proceed.

5.6 INSTRUMENTATION

All of the instrumentation works on the basis of some type of circuit bridge. For example, the strain gages use a three wire Wheatstone bridge configuration, with two of the wires being common (Figures 7,8). The output from the bridge is in the form of a resistance produced by the strain gage. This is why the gage factor is such an important

parameter. It is this gage factor which is entered into the software that converts the output from Ohms into microstrains.

The pressure sensors, load cells, and LVDT's work on a four wire full bridge which needs an input voltage to excite it (Figures 9,10). This type of instrumentation responds to pressure, loads, and deflections as some voltage output. Again, the gage factors play an important role in deciphering these outputs. These factors convert the output from volts into psi, kips, and inches.

5.7 SPECIAL CONSIDERATIONS

There are some considerations aside from just the input parameters and wiring configurations which may arise. One such problem is noise. Noise in the system can be defined as an unreasonable variation between readings. A common reason for excess noise is that the wires are not correctly grounded or that the MEGADAC and the expansion unit are not properly grounded. In order to check the amount of noise in the system, the sampling rate can be adjusted to take a larger number of samples per second. Previewing the output over one or two seconds will show if there is any noise and if it follows a cyclic pattern.

Usually, the noise problem can be taken care of with proper grounding of the wires. The way such noise was prevented in this research was by grounding the MEGADAC and the expansion chassis together and then running the common ground to the testing vehicle on site. Also, the wires were grounded on the terminal end by

connecting the shielding from the lead wires together at each terminal. Then a wire was run from all the terminals to the MEGADAC's main ground to the vehicle.

Another problem are gages that do not balance. In order to balance a gage, the initial offset that the gage reads cannot be greater than 45 percent of the maximum reading of that channel. The usual error is that the gage is 100 percent off, which may mean a variety of things. One problem may be the wiring of the gage. Either the wires are not connected to the right slots in the terminal block, or perhaps the solder connection is bad. Another reason may be that the adjustments in the module are wrong, and the MEGADAC cannot find the gage because a jumper is not in the correct position. If all the channels that are wired into the same terminal block are reading off by 100 percent, there is almost surely some systematic error. This could be a bad module slot in the MEGADAC, a bad terminal block, bad cables which run from the block to the MEGADAC, or some other such error which can be found by trial and error.

Sometimes a gage will read some large offset but is working fine. For example, if a pressure sensor is deformed in some way, for example by bearing on a rock, then there may be a permanent offset reading by this sensor, and it will never return close to zero on its own. Of course, none of the gages or sensors ever read exactly zero on their own; this is the purpose of balancing them. But if this permanent offset is too high, then the sensor will not balance, and the readings will not have much meaning. One way to get around this problem is to change the gain so that the maximum reading of that channel is higher. Then the offset is a smaller percentage of the maximum, allowing the sensor to be balanced. As mentioned before, there is some sacrifice of precision, but that is not usually as important

as having readings that have been zeroed. This was done for some of the pressure sensors, because such problems did arise.

It has been determined that the MEGADAC is very susceptible to random problems, and that it is very fragile in the sense that it is very particular about the way parameters are input and even the way that the machines are turned on. The following are such random problems which consumed a great deal of time in some cases:

- The software does not read any signals coming from the MEGADAC. The solution was to simply turn the MEGADAC off and back on.

- The MEGADAC does not read any signals coming from the expansion chassis. The problem occurred from turning the machines on in the wrong order. The MEGADAC must be on first; then the expansion chassis can be turned on.

- If the system is being run by an inverter in a vehicle, and the expansion chassis does not seem to be working, the solution can be to turn the machines on while the vehicle engine is not running; then start the engine in order to keep the battery charged.

These examples demonstrate some of the problems with the MEGADAC system and that sometimes, even though there is nothing wrong within the system itself, problems can still arise which can cause major delays in the project. The only way to be completely familiar with the system is through trial and error and a great deal of experience. One cannot expect to go into the field and perform a test without having checked out all of the equipment thoroughly.

Chapter 6

Data Interpretation

6.1 INTRODUCTION

This research project is heavily dependent on the interpretation of the overwhelming amount of data obtained from the instrumentation. There are a total of twelve field tests for each pile, and each test is 3 - 6 hours long. The sampling rate for a field test was $\frac{1}{2}$ Hz., and there were a total of 72 channels being monitored. A simple multiplication gives an idea as to the amount of data there is to sort through for each test. In order to achieve a greater understanding of the data obtained and also to verify the validity of the instrumentation, laboratory tests were performed on the pile before it was driven in the ground. The focus here is not so much the actual results and findings of this research project -- it is much too early to present that -- rather presented herein is the reliability of and procedures for interpreting the data so far obtained. However, the easiest and clearest way to present such ideas is in the form of lab and field test results. First though, each different type of instrumentation is presented with respect to the reliability and the conversion of the measurements acquired from them into results which can be analyzed further.

6.1.1 STRAIN GAGES

By far the majority of the data were obtained from the strain gages. These gages measure strains directly. Since there were four gages at each station of the pile, the strains

were averaged in order to account for any twisting which may have occurred. These strains were converted to bending moments using the following relationships,

$$\sigma = \frac{My}{I} \quad \text{and} \quad E = \frac{\sigma}{\epsilon}$$

where ϵ = measured strain, (in/in)

σ = stress (ksi)

y = distance from centroid of pile to strain gage (in)

I = moment of inertia, (in⁴)

M = bending moment due to lateral load (kip-in)

E = modulus of elasticity of steel, (ksi)

Even though the gages are supposed to read in actual strains, it has been determined through several laboratory tests, including tensile tests using both weldable and epoxy strain gages³, that the weldable gages produce readings consistently lower than actual. For the first pile which was driven, it was determined that the factor 1.10 should be used when calculating the moments. Whenever strain gage data were used in any of the following results, it should be noted that this factor was used.

Once the moments were determined, a moment versus depth relationship was plotted. Using a best fit sixth order polynomial, an equation for this relationship was determined. This equation was differentiated twice in order to get the pressure versus depth diagram. This information based on the strain gage readings is the most valid and most useful in describing the behavior of the soil-pile interface.

6.1.2 PRESSURE SENSORS

Besides being instrumented with strain gages, the pile also had pressure sensors attached to it. The pressure sensors only read to a maximum of 5 psi, and their purpose was to find the points of zero pressure. The main problem with the pressure sensors is that they appear to be very sensitive, and considering the harsh environment to which the pile was subjected, the pressure sensors were not considered to be very reliable. However, after checking the pile out after it was driven, only one pressure sensor was off scale. Over time though, several of the sensors were no longer functional. Several reasons for the unreliability are as follows:

- The pressure sensors were located on the face of the pile in order to read the soil pressure; thus, they were not protected on the surface.
- Pressure sensors take measurements based on deformation of the sensor face; however, as the sensor deforms, the soil tend to arch around it, decreasing the pressure reading.
- If the pile hit a rock as it was being driven, the pressure sensor could be damaged on its way down.
- With a maximum output of only 5 psi, the sensors were easily maximized and were useless for future tests.

The pressure sensors are very expensive; in fact they are the most expensive type of instrumentation by far. Also, they seem to be the most unreliable as far as durability, not to mention the fact that the results obtained from them are questionable at best.

6.1.3 LOAD CELLS

There were two 100 kips load cells used to monitor loads. The first monitored the lateral load being applied to the abutment/pile, and the other was located at the reaction of the abutment on the reaction beam as the abutment rotated. These load cells were very accurate, as each had recently been tested on a laboratory testing device so that the loads reported would be very reliable.

Although the tests were deflection controlled, it was important to monitor the load that was applied to the abutment for several reasons. First, in order to calculate the moment at the ground surface of the pile, both the horizontal load and the vertical load along with their moment arms must be known. This moment is a good check on the strain gages that are located at the ground surface. Also, a very accurate way to describe the behavior of the system is with load-deflection data. The lateral load in combination with the deflection data obtained from the LVDT's, yielded these results.

6.1.4 LVDT'S

The LVDT's (linear voltage displacement transducers) were located in two different places. One was placed on the pile as close as possible to the ground surface. A second one was located on the abutment itself, near the bottom of the concrete. Both were placed in the center of the pile-abutment system. Since the test was controlled by deflections, and because the basis for the research was dependent upon what deflection could be seen by the abutment, this deflection data needed to be very reliable. For the first few tests, dial gages were placed very near the LVDT's as a double check, and they read

same. The only exception was that the LVDT's can be read to several decimal places, and are read on digital display, while the dial gages are only as reliable as the eyes that are reading them. It was therefore concluded that the LVDT's were not only accurate enough, but were actually more accurate than the dial gages.

The deflections that controlled the loading increments were taken as the deflection of the abutment. Though the deflections on the abutment and the pile were close, there was some difference. The deflection at the ground surface was still very important in terms of the load-deflection curves. These relationships are perhaps the most reliable data obtained from the tests, if only for the reason that the instrumentation from which they were obtained was not attached to the pile that was driven into the ground with the pile driver. Also, they were stored indoors between testing and were easily calibrated or verified in a laboratory setting. The strain gages and pressure sensors, on the other hand were "stored" up to almost 20 feet under ground where, although they were protected and waterproofed, they were under much harsher conditions during the months that passed between driving the pile and the last test.

6.2 LABORATORY TESTS

The laboratory tests were performed on the pile as a means to check out all of the instrumentation before driving the pile into the ground. At that point, finding out that none of the gages were working would create a terrible situation. During the laboratory tests, the strain gages were checked by performing a simple beam test on the pile where all of the moments could be calculated and checked with those calculated from the strain gage

data. The pressure sensors were checked by placing a known pressure on the sensor and checking that the pressure read from the sensors matched that which was applied. Every step was made to ensure successful field tests, and that included a complete analysis of the data obtained from these tests

6.2.1 SIMPLE BEAM TEST

The setup for the simple beam test consisted of supporting the beam on small steel rollers on each end, and applying a load on the pile to induce bending about its strong axis. The test setup and dimensions are shown in Figure 11. The wires to the gages were all carefully connected to their proper terminal blocks and all of the cables were connected. The first step was to determine that all of the gages were working properly and that they would balance on the MEGADAC. The gages that did not balance immediately were checked at all solder joints and at the connections to the terminal blocks. When all of the wiring was corrected, all of the gages were able to be balanced. There was still much to be done, however, as the MEGADAC sometimes balances channels that do not have any gages wired into them.

Once all of the gages appeared to be working, a load was applied to the beam. The moments at all of the strain gage stations were calculated using the principles of statics and were also determined using the strain gage data. The calculated data refer to results obtained from the equations of static equilibrium while the measured data refer to the moments obtained from the strain gage data. Though these moments were calculated as

well, they were ultimately based on the measurements taken by the instrumentation; thus, they were measured data.

Besides determining if the gages were all in working order and were reading correctly, the noise level was checked for these gages. As was expected the noise level was low. The lead wires were not very long, and the test was performed in a laboratory setting, so any sign of excess noise would have been a real problem to have been dealt with, but after properly grounding all of the wires, the noise was in a very reasonable range for the laboratory tests.

Figures 12 - 25 show the actual measurements given by the MEGADAC versus time. The strain gage data were converted into moments and Figure 26 shows the correlation between the measured and calculated values. From these plots, it can be concluded that the strain gages were in perfect working order prior to driving, and it can be assumed that the data obtained in the field were reliable and accurate representations of the pile behavior.

6.2.2 PRESSURE TESTS

The pressure sensors were tested in the laboratory by placing a known pressure on the sensor and then removing it while viewing the measured pressure on the MEGADAC. The pressure was applied using a small, round piece of steel that was smaller in diameter than the pressure sensor face. This load was then spread out with a pad that was cut as the same diameter as the pressure sensor face. All of the pressure sensors were working prior to driving.

6.3 FIELD TESTS

The test setup and loading regimen for the field tests are described generally in previous sections of this paper, and are discussed in greater detail in the thesis by Harvey⁸. The results from one of these tests is presented herein to demonstrate the usefulness of and the need for reliability of the instrumentation involved in this type of project.

The results that are presented are those from ½" tests that were performed on June 24, 1997. The actual measurements from the strain gages taken by the MEGADAC are shown in Figures 27 - 40. What is presented are the data that were taken with respect to time. From these plots, the noise level of all of the gages can be seen. For example, gage A8 had an unreasonable amount of noise (Figure 34) , and did not follow the pattern of the other gages. When such a problem arose, the data were interpreted as well as possible by trying to follow trends from other tests or other gage stations. If the C gages consistently produced a reading that was a certain percent lower than the D gages, then at a station where the C gage was not functioning properly, the data could be manipulated to follow the same patterns that were occurring. Fortunately, there were very few gages that were not operating as they should have. Table 1 indicates which gages were having problems, and what the problem was.

Table 1. Nonfunctioning Strain Gages.

Gage	Description of Problem
C3	somewhat noisy but still follows trend; can be used with caution
D4	somewhat noisy but still follows trend; can be used with caution
C5	somewhat noisy but still follows trend; can be used with caution
C6	not connected; not functional due to previous tests; can not be used.
A8	very noisy, should not be used

The results from this test in the form of moment diagrams and pressure diagrams are shown in Figures 41-42.

The pressure sensors, on the other hand, were not so easily interpreted. There were only six pressure sensors on each side, so if one was not working, it was difficult to piece together the existing data. Figures 43-44 show the actual data taken by the MEGADAC, and from these plots, it is easy to understand why the pressure sensors were not considered as reliable as other instrumentation. In comparison with the strain gages which follow some expected pattern, some of the pressure sensors seem erratic at best. Not to mention the fact that two out of the twelve sensors were not working as a result of previous tests. Even so, the purpose of these pressure sensors was to try to find the points of zero pressure, so an attempt was made to plot the pressure versus depth diagram based on these pressure sensors. They are shown for each flange in Figure 45.

The other instrumentation being monitored were the two load cells and the two LVDT's. The measured data from these load cells and LVDT's are plotted versus time in Figures 46-47. As is shown in the figures, there were no problems with either of these types of instrumentation. A load-deflection curve obtained from these measurements is presented in Figure 48.

All of the field tests were performed in this manner, and the results for each are comparable, with some differences based on the stiffness of soil and deflections reached. For the most part, the strain gages functioned very well over time, while the pressure sensors got less reliable with time. As time passed between tests, the pressure sensors would be more off scale each time, and different gains had to be used to get them to

balance after a few tests. Also, since the range was so low, a sensor was lost almost each time a new deflection increment was reached.

The instrumentation used provided very good indications of the behavior of the pile supporting the integral abutment as the lateral load was applied. From this field test, much was learned about the instrumentation of and the test setup for future piles.

Chapter 7

Conclusions

Long term field testing requires that the instrumentation be both durable as well as reliable. For such full scale research as is this project, a field test involves a great deal of time and money, and the results from this type of investigation should give valuable insight to questions raised. In order to serve this purpose, the data obtained is crucial for the success of this project. It has been proven that future data from this project yet to be presented will be valuable information and provide very useful conclusions.

Thus far, the following statements can be made about the instrumentation and data collection procedures of this research project:

- The most valid data are obtained from the strain gages. This form of instrumentation is durable over time and provides consistent and meaningful information.
- The pressure sensors used are not durable over time and are of considerably less value in terms of describing the behavior and providing meaningful curves; however, they may be useful in determining points of zero pressure, and can be compared to strain gage data in that respect.
- The MEGADAC, when properly operated, is an invaluable tool in the data collection process; when all is working well, the ease of recording the data far outweighs the random problems that may occur.
- The setup and procedure for testing is appropriate, with few modifications needed for future tests.

There is still much work to be performed on this research project, and there is a large amount of data yet to be reduced and analyzed. The validity of the instrumentation and how the data obtained from it are interpreted has been presented. The results obtained from this investigation will provide substantial information about steel piles supporting integral bridge abutments.

List of References

LIST OF REFERENCES

1. Wasserman, Edward P., and Walker, John Houston, "Integral Abutments for Steel Bridges." Highway Structures Design Handbook, Volume II, Chapter 5. October, 1996.
2. Ensoft, Inc., "Com624P- Laterally Loaded Pile Analysis Program for the Microcomputer, Version 2.0." Austin, Texas. June, 1993.
3. Zeind, Anthony Francis, "Development of Field Testing Procedures to Determine the Behavior of Steel Piles Supporting Integral Abutments." Thesis submitted in partial fulfillment for the requirements for the degree of Master of Science. University of Tennessee, Knoxville, Tennessee. 1997.
4. Greimann, L.F., Abendroth, R.E., Johnson, D.E., and Eber, P.B., "Pile Design and Tests for Integral Abutment Bridges." Iowa DOT Project HR-273, Final Report. December, 1987.
5. Randolph, M.F., "The Response of Flexible Piles to Lateral Loading." Geotechnique Vol. 31, No. 2. Pg. 247-259. 1981.
6. Padauna, Joseph A., and Yee, Wilfred S., "Lateral Load Tests on Piles in Bridge Embankments." Transportation Research Record, Issue No. 517. 1974.
7. Davisson, M.T., "Lateral Load Capacity of Piles." Highway Research Record, No. 333. 1970.
8. Harvey, Kenneth Ryan, "Behavior and Analysis of Integral Abutments" Thesis submitted in partial fulfillment for the requirements for the degree of Master of Science. The University of Tennessee, Knoxville, Tennessee. May, 1997.

Appendix

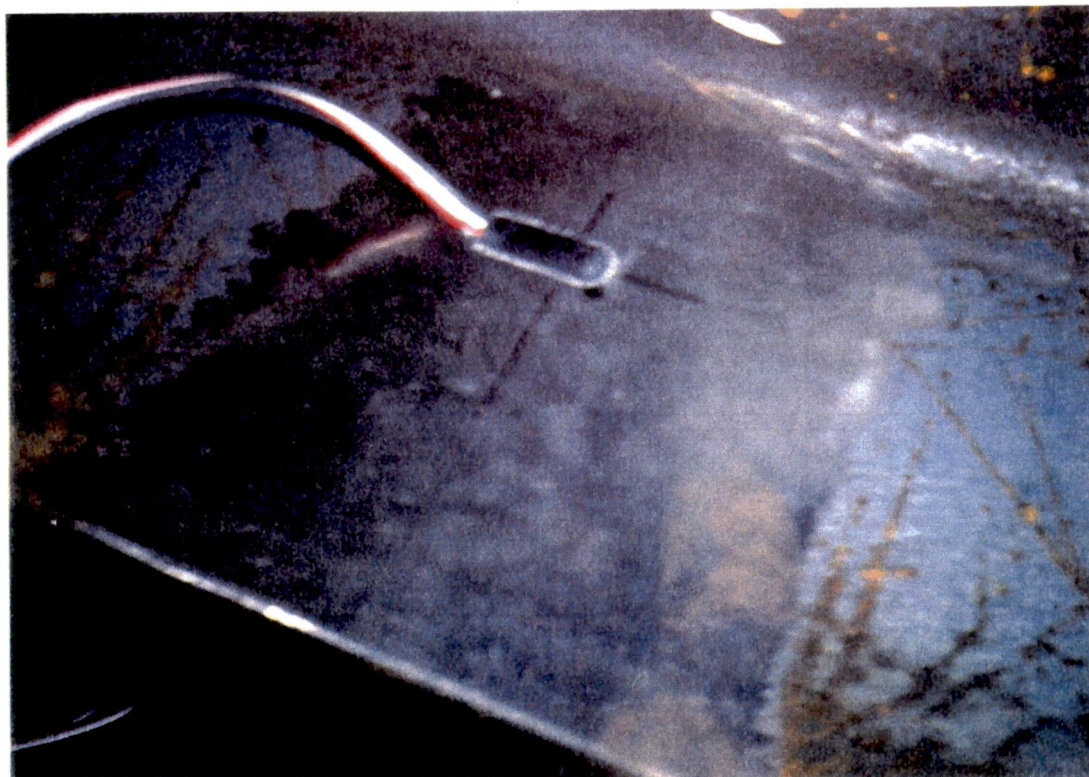


Figure 1. Weldable strain gage affixed to pile.

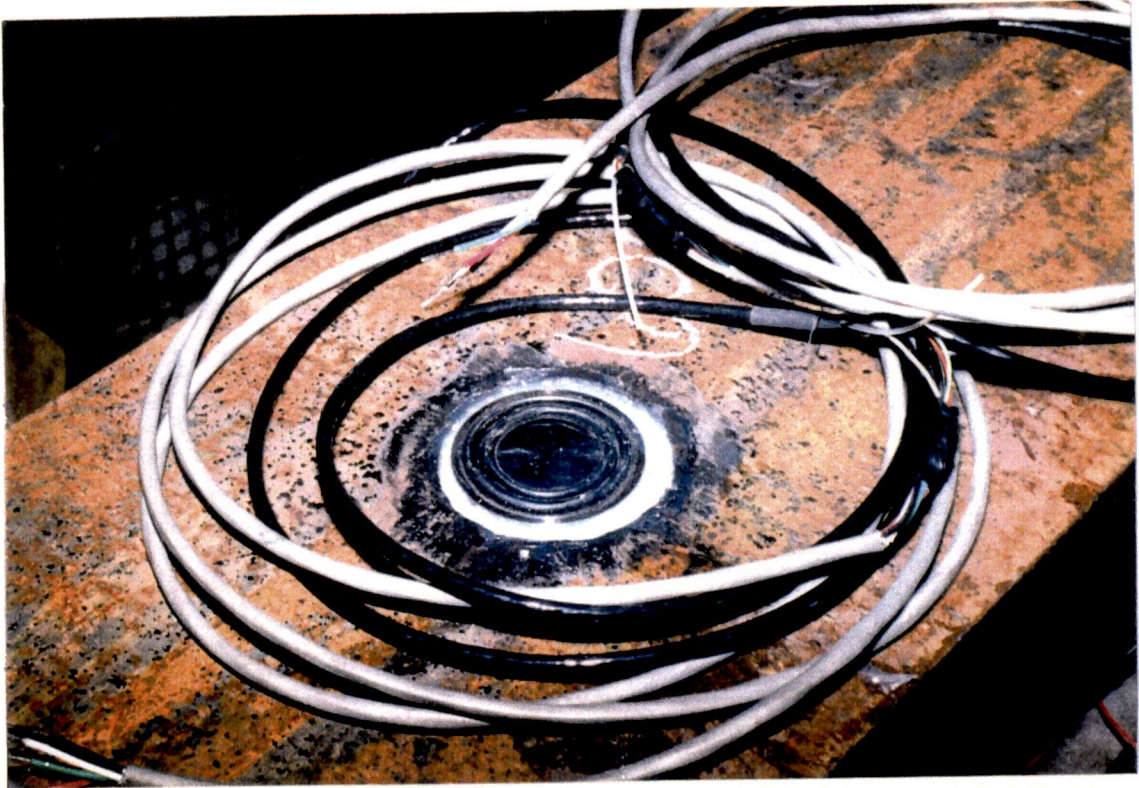


Figure 2. Pressure sensor; View: top of flange.

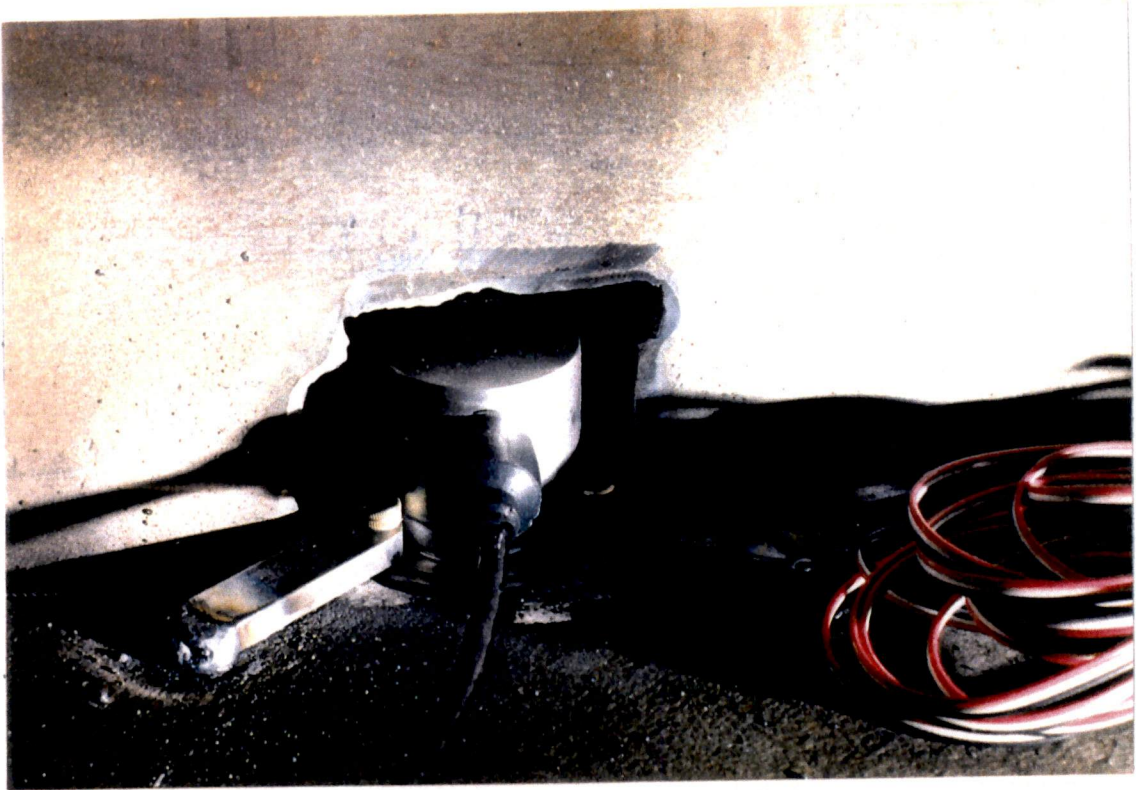


Figure 3. Pressure sensor; View: side of web.

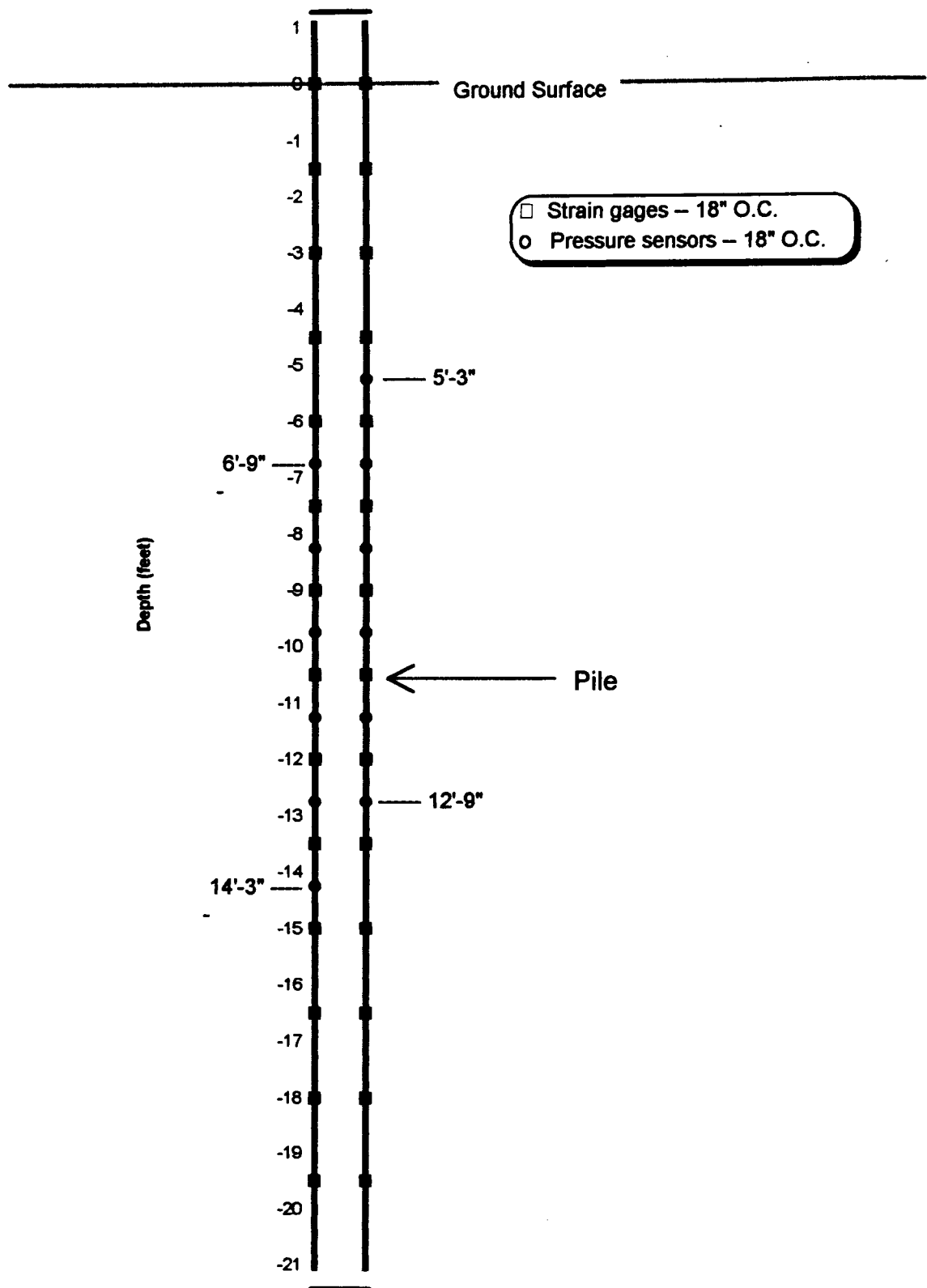


Figure 4. Layout of gages and sensors on test pile 1.

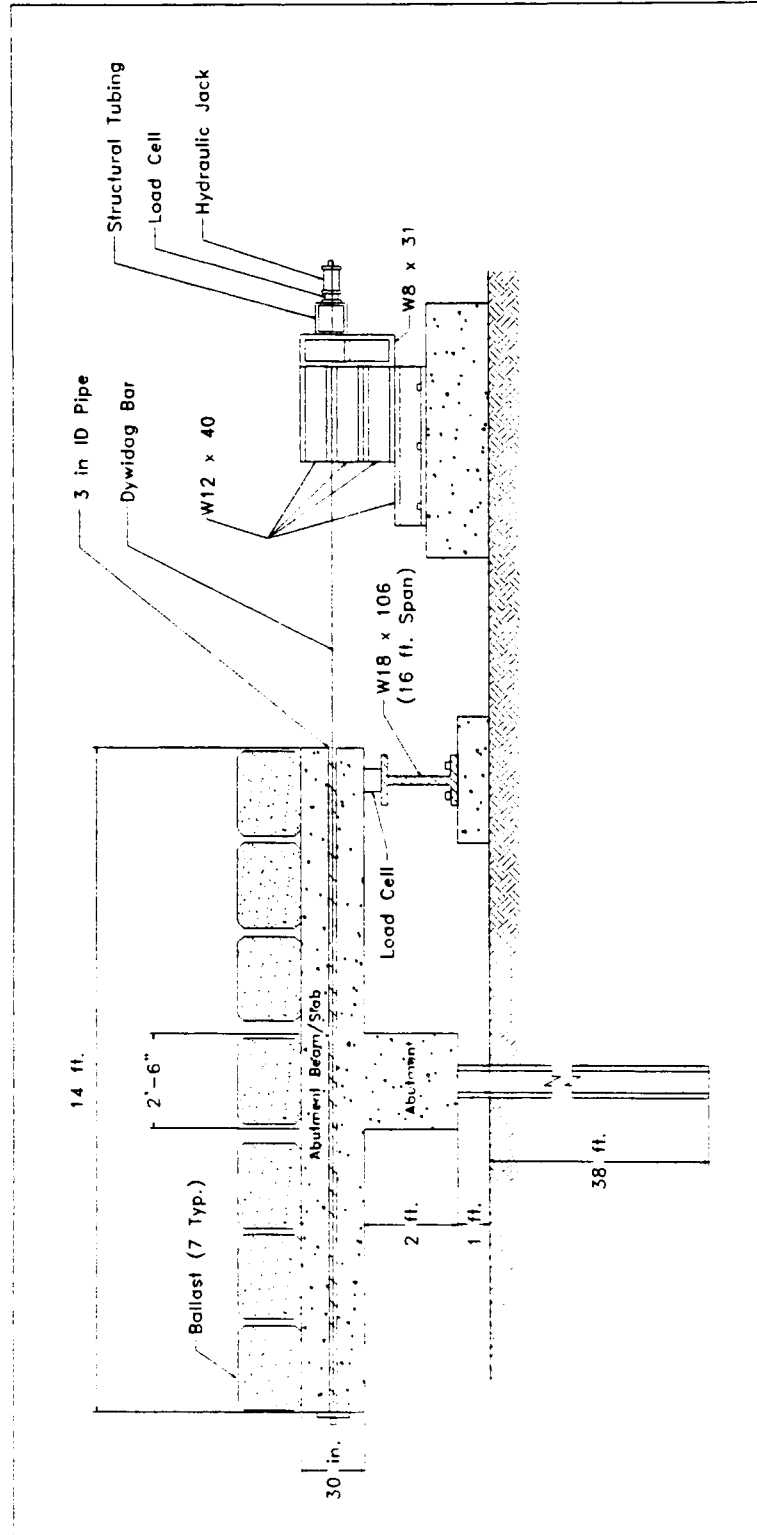


Figure 5. Field test set up.

Source: K.R. Harvey, "Behavior and Analysis of Integral Abutments." Thesis submitted in partial fulfillment for the requirements for the degree of Master of Science. The University of Tennessee, Knoxville. May, 1997.

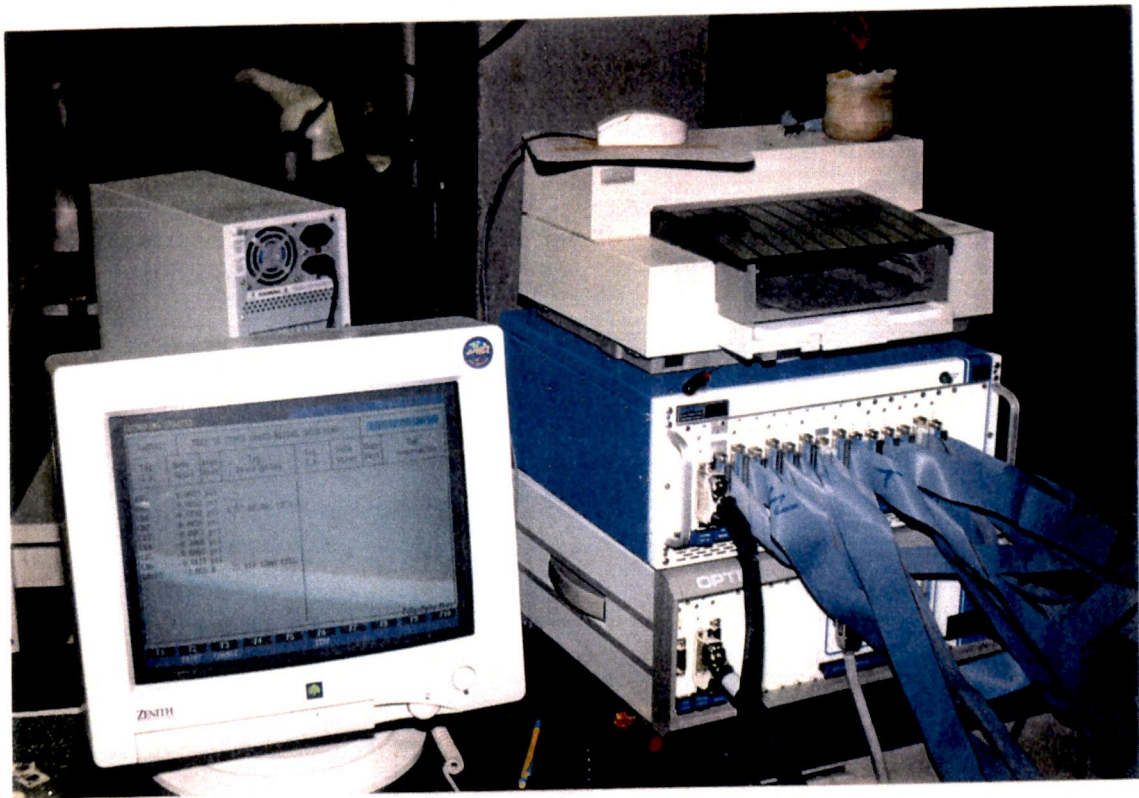


Figure 6. MEGADAC configuration with expansion chassis and computer.

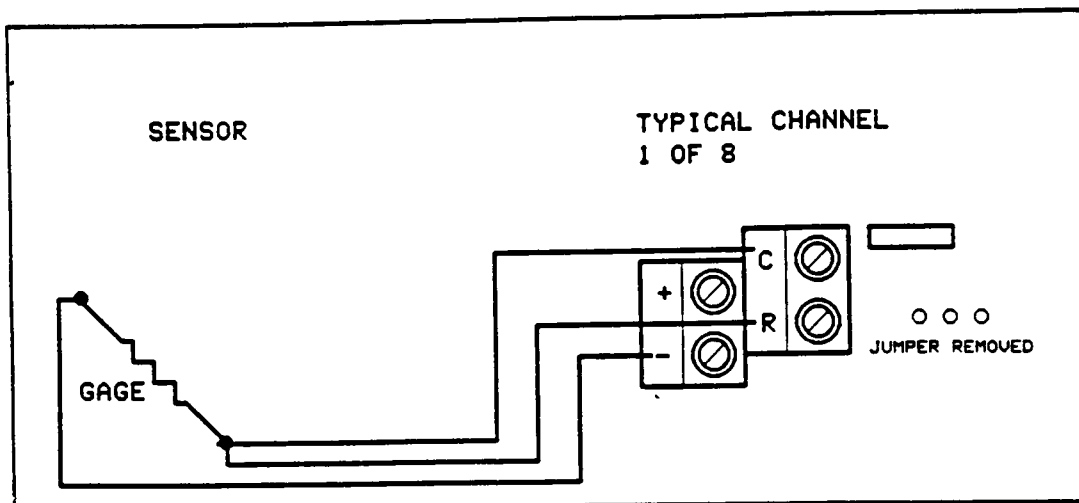


Figure 7. Three wire quarter bridge connection to STB884/SCI; for strain gages.

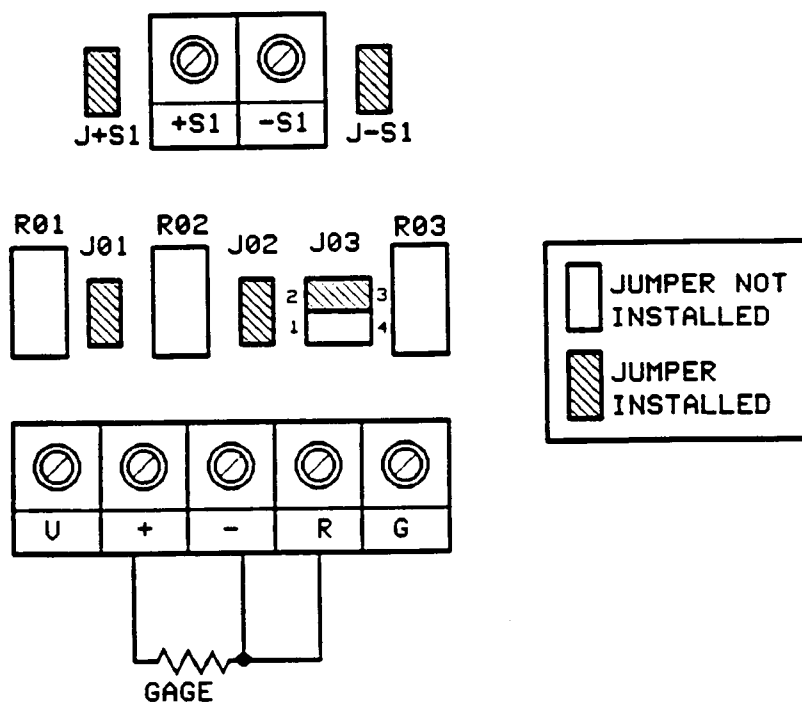


Figure 8. Three wire quarter bridge connection to STB808FB; for strain gages.

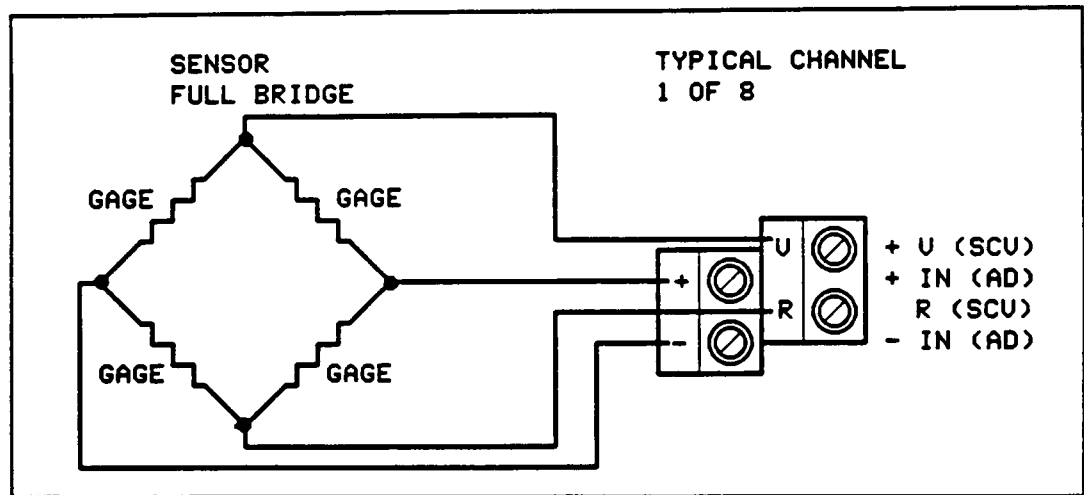


Figure 9. Four wire full bridge connection to STB884/SCV;
for pressure sensors, load cells, and LVDT's.

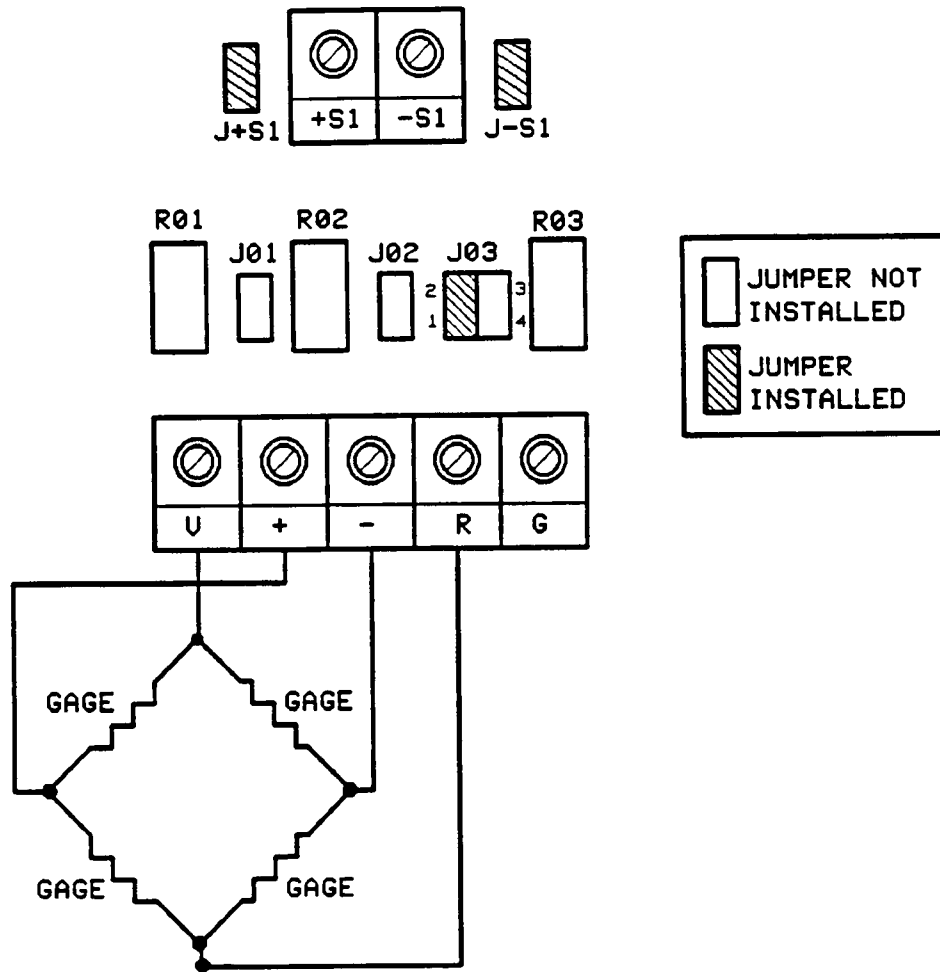
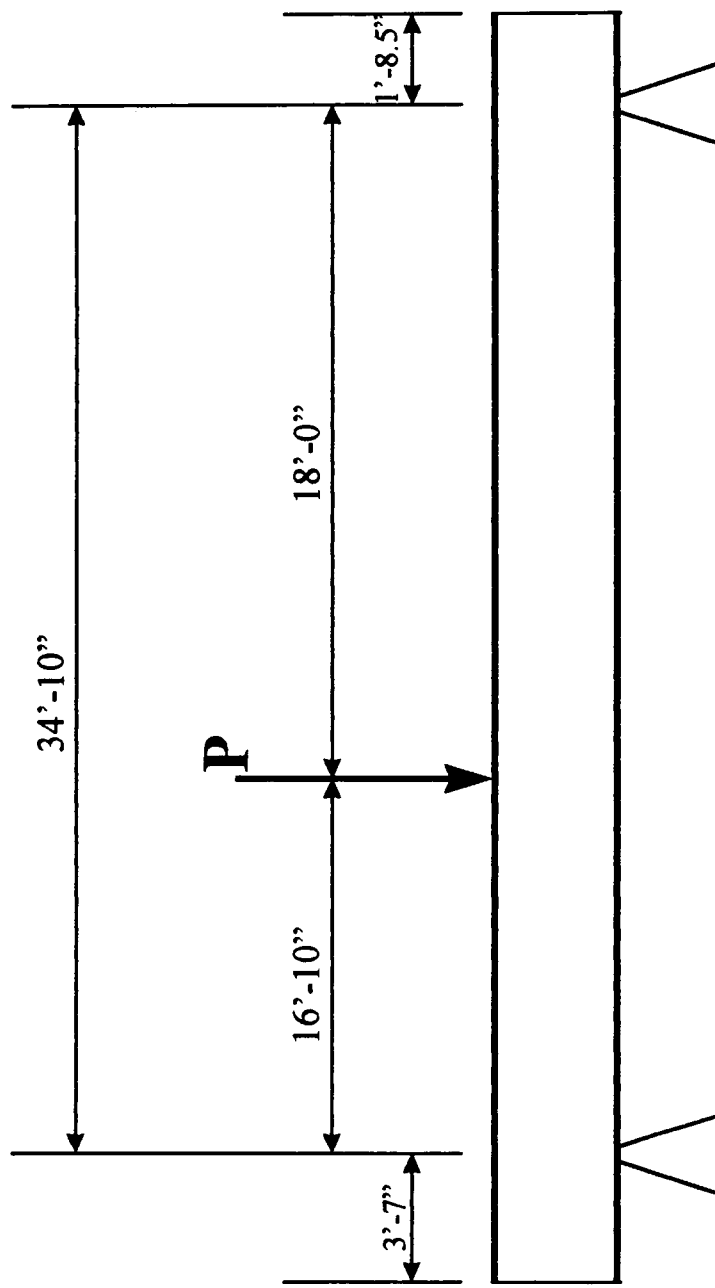


Figure 10. Four wire full bridge connection to STB808FB;
for pressure sensors, load cells, and LVDT's.



N.T.S

Figure 11. Simple beam test setup. Feb. 4, 1997.

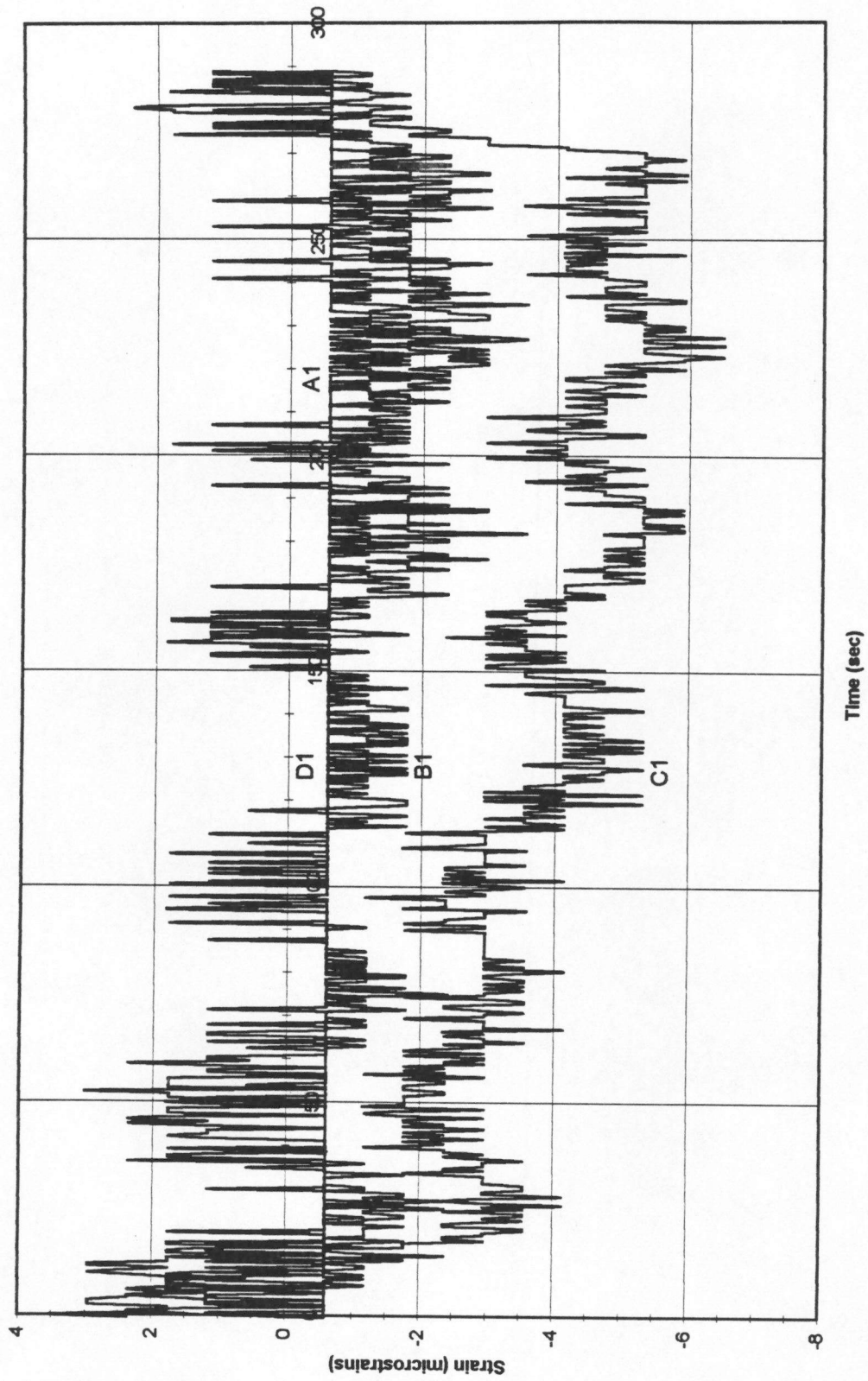


Figure 12. Strain vs Time. Feb. 4, 1997 Lab test; Station 1.

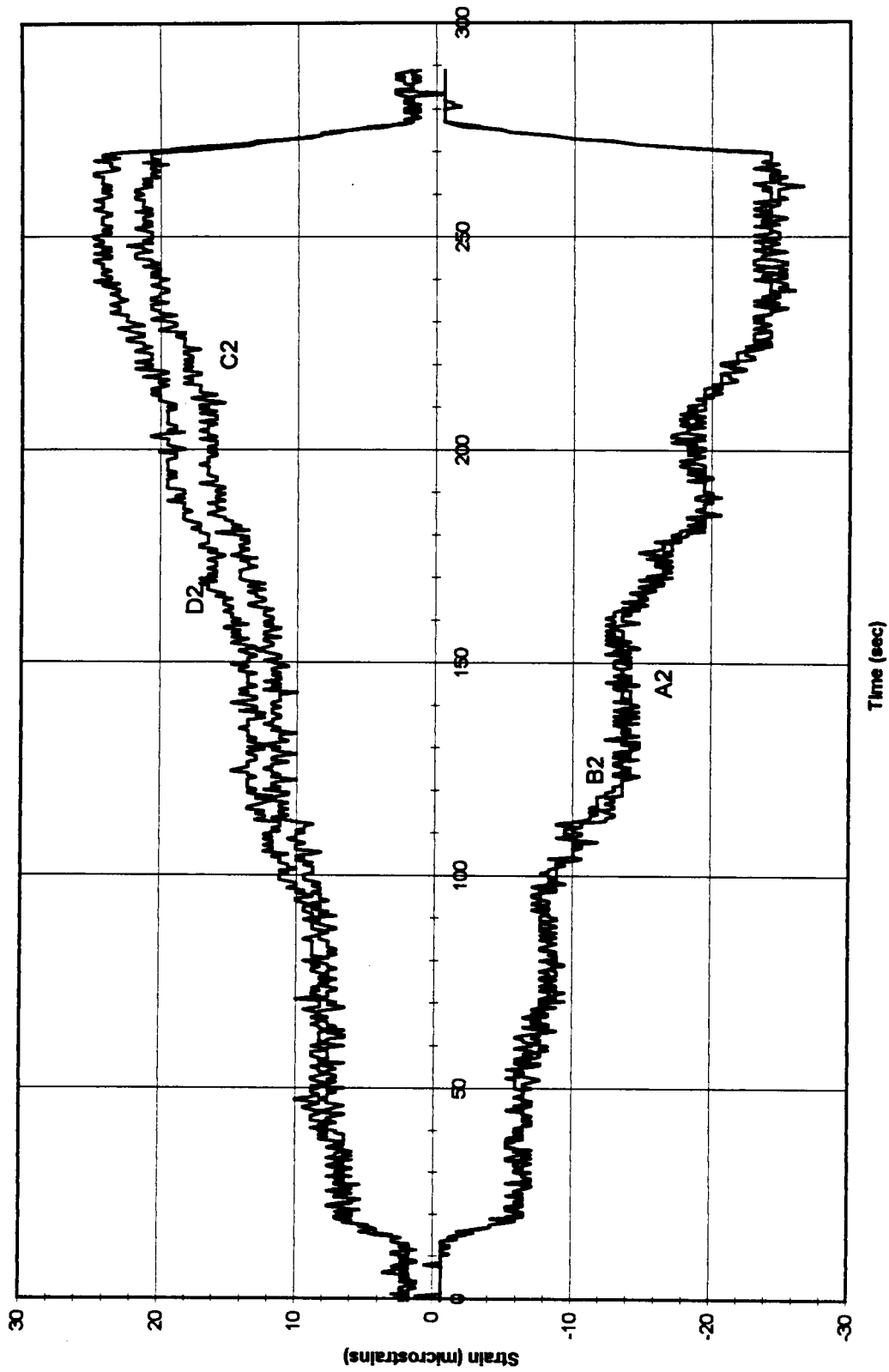


Figure 13. Strain vs Time. Feb.4, 1997 Lab test; Station 2.

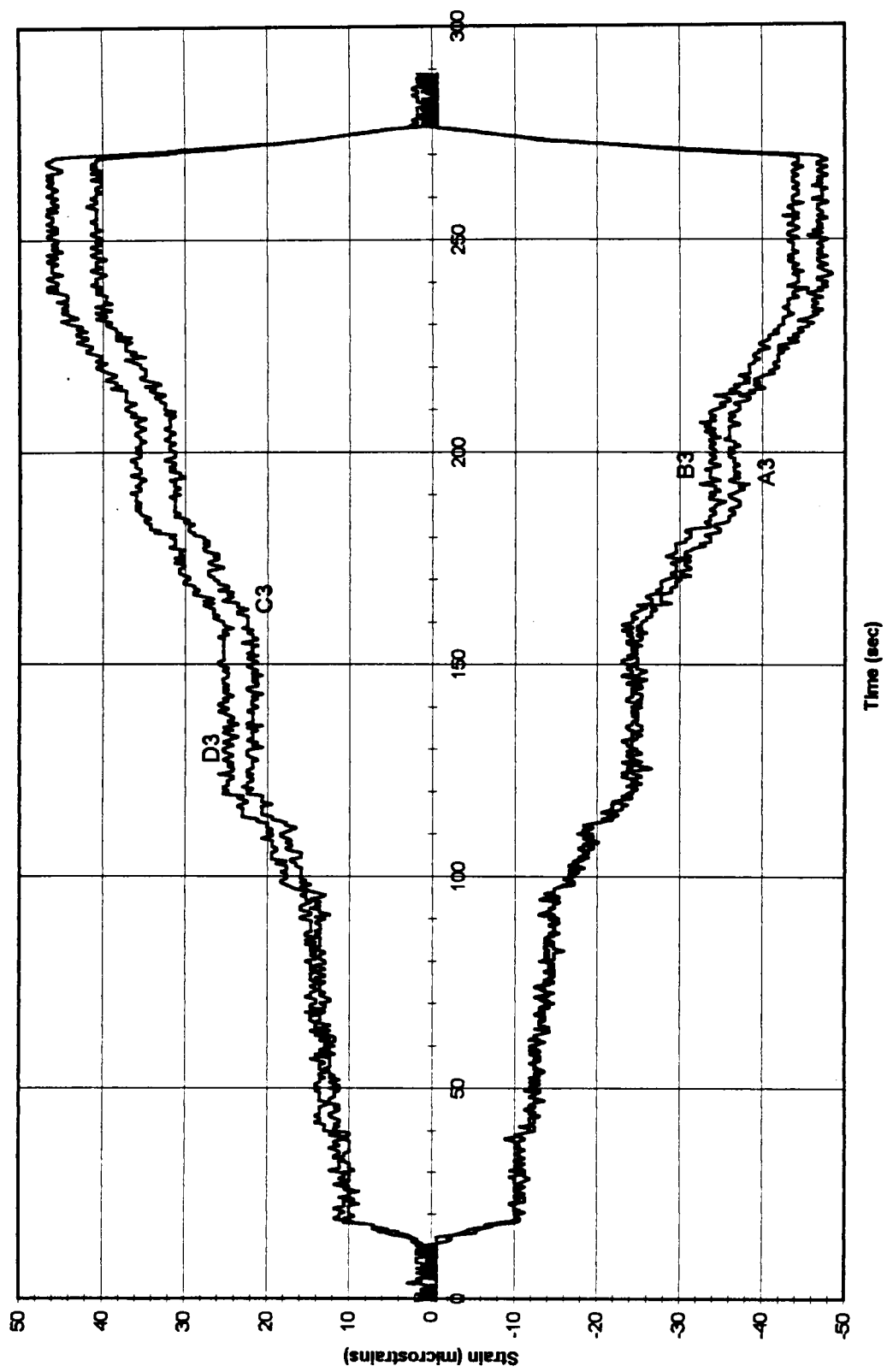


Figure 14. Strain vs Time. Feb. 4, 1997 Lab test; Station 3.

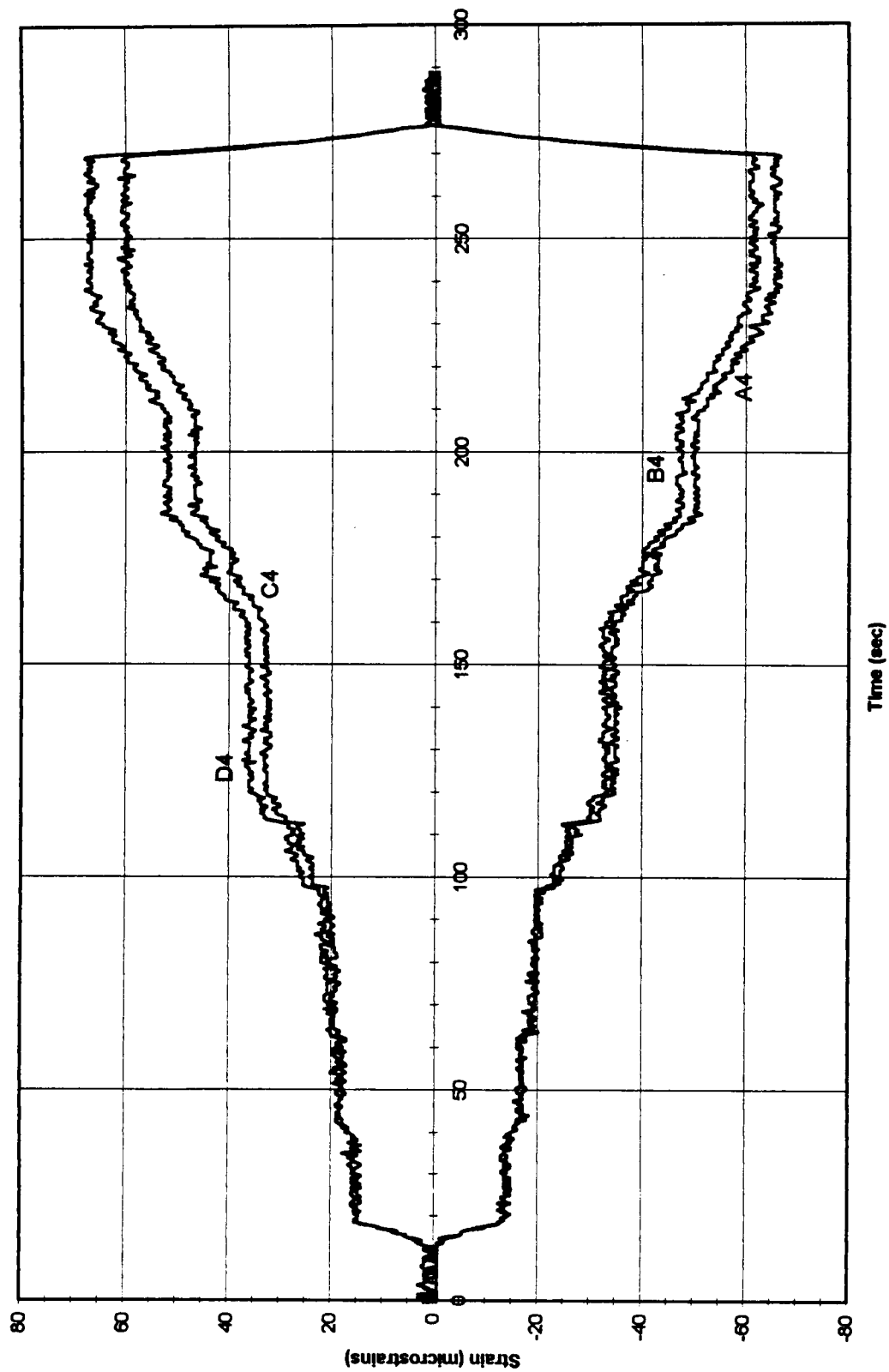


Figure 15. Strain vs Time. Feb. 4, 1997 Lab test; Station 4.

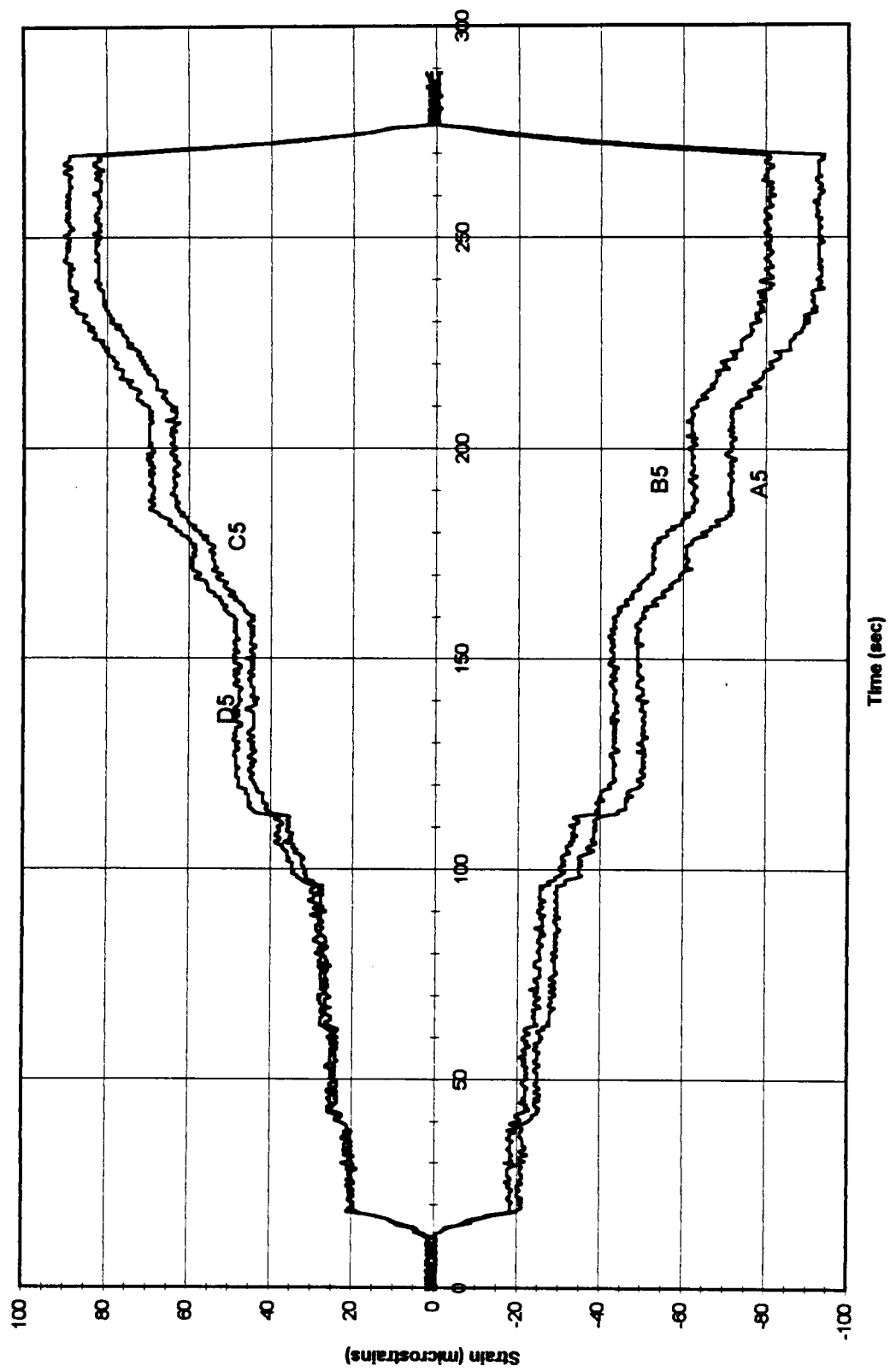


Figure 16. Strain vs Time. Feb. 4, 1997 Lab test; Station 5.

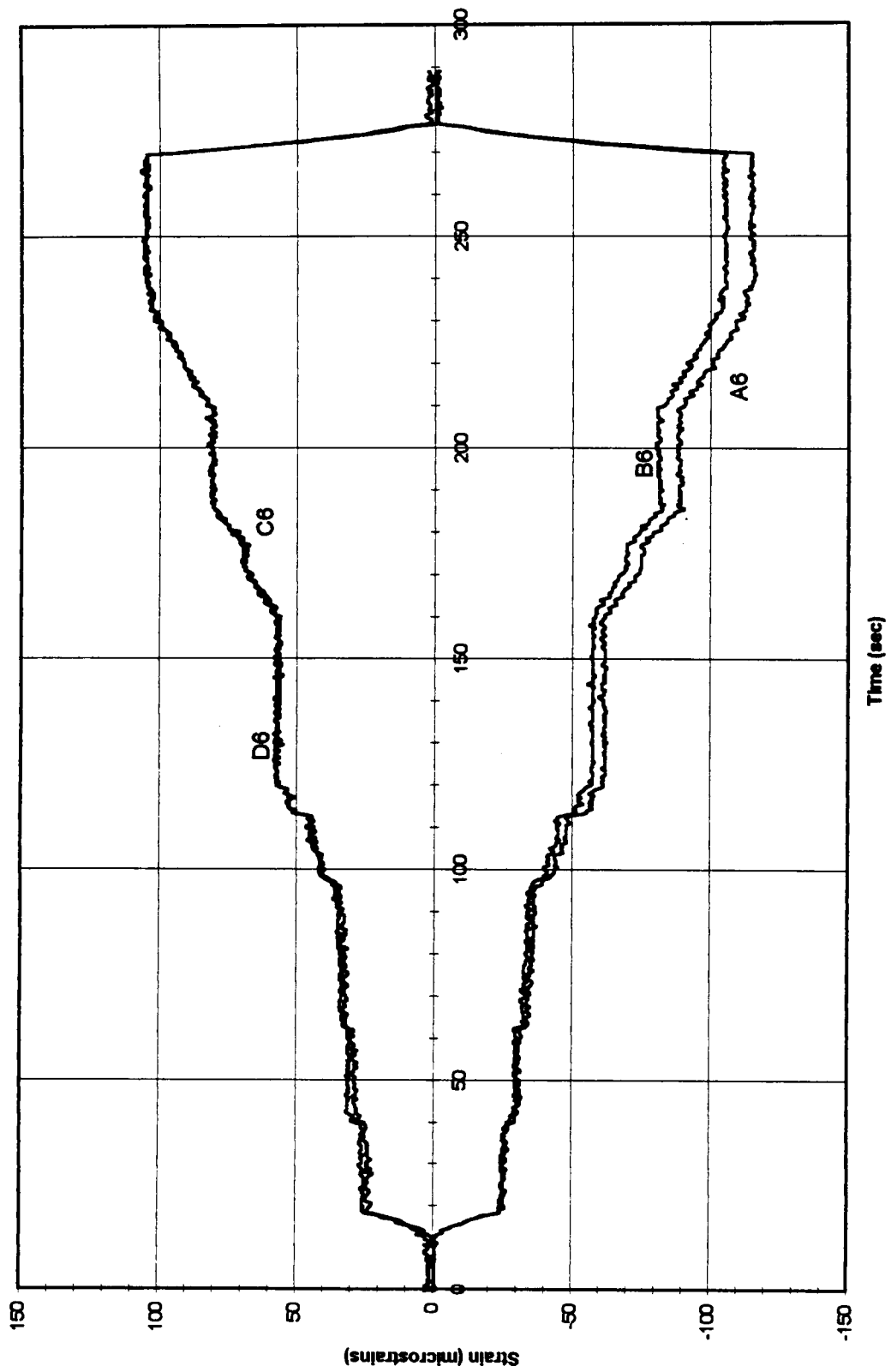


Figure 17. Strain vs Time. Feb.4, 1997 Lab test; Station 6.

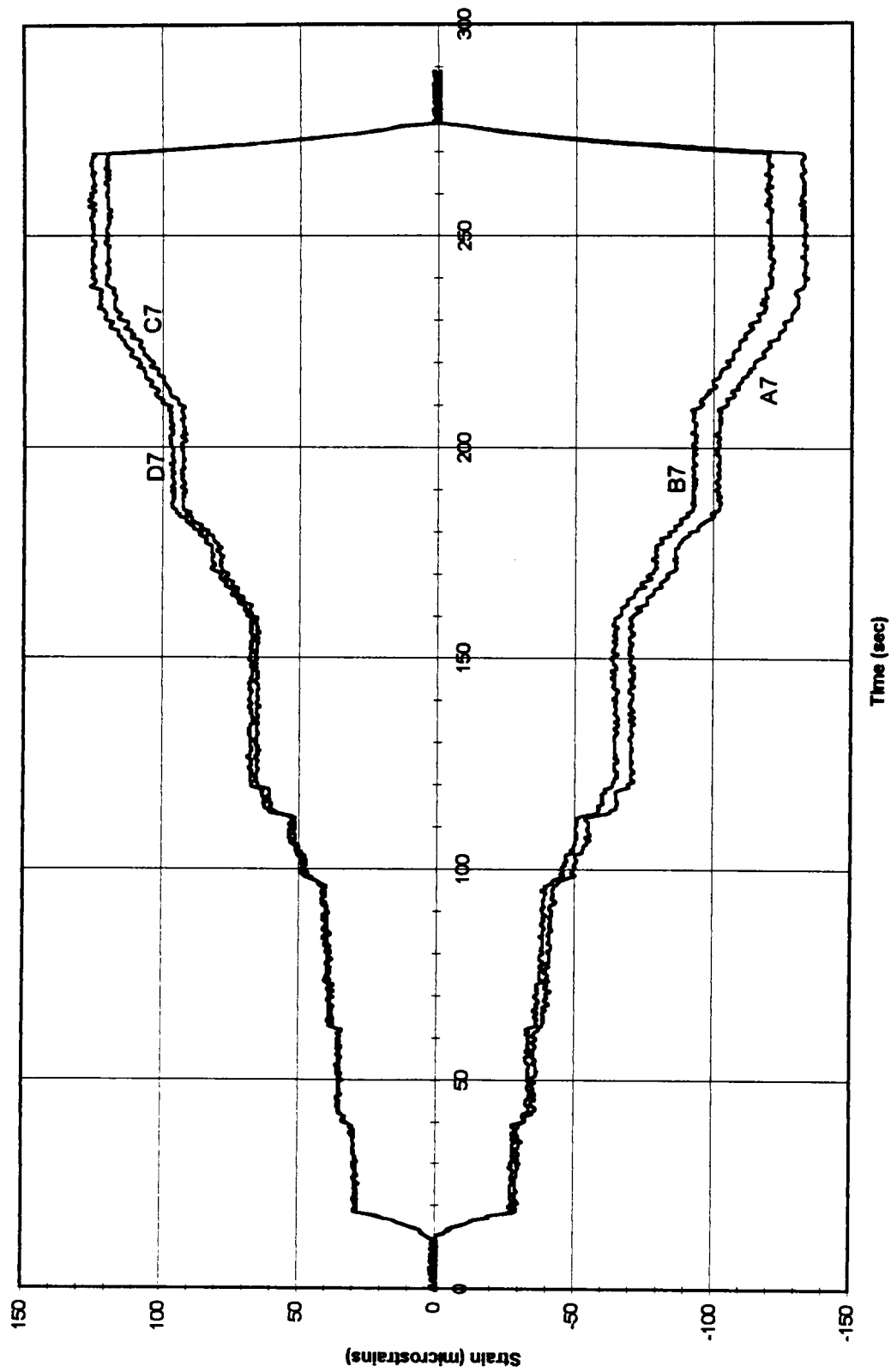


Figure 18. Strain vs Time. Feb.4, 1997 Lab test; Station 7.

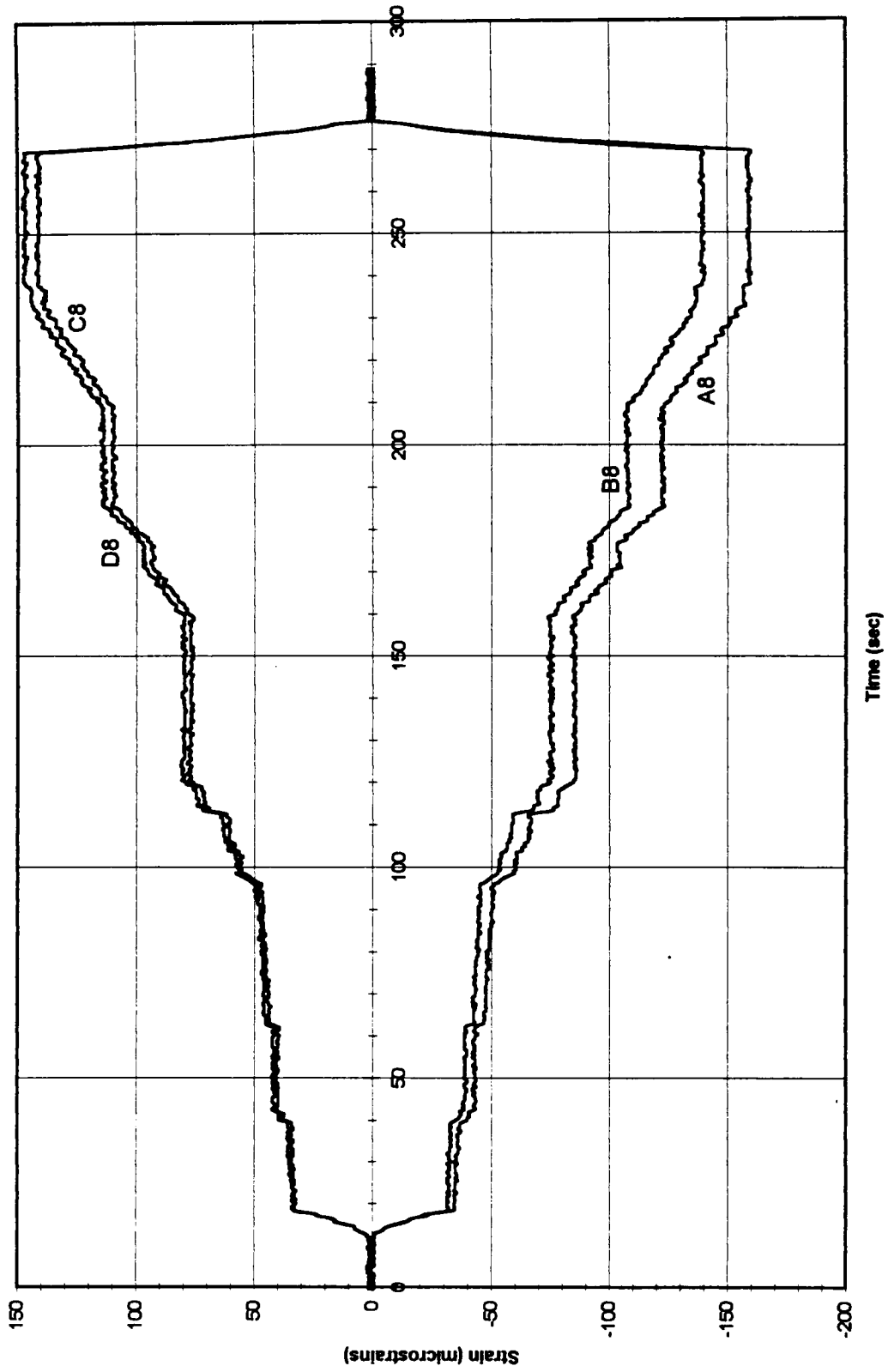


Figure 19. Strain vs Time. Feb. 4, 1997 Lab test; Station 8.

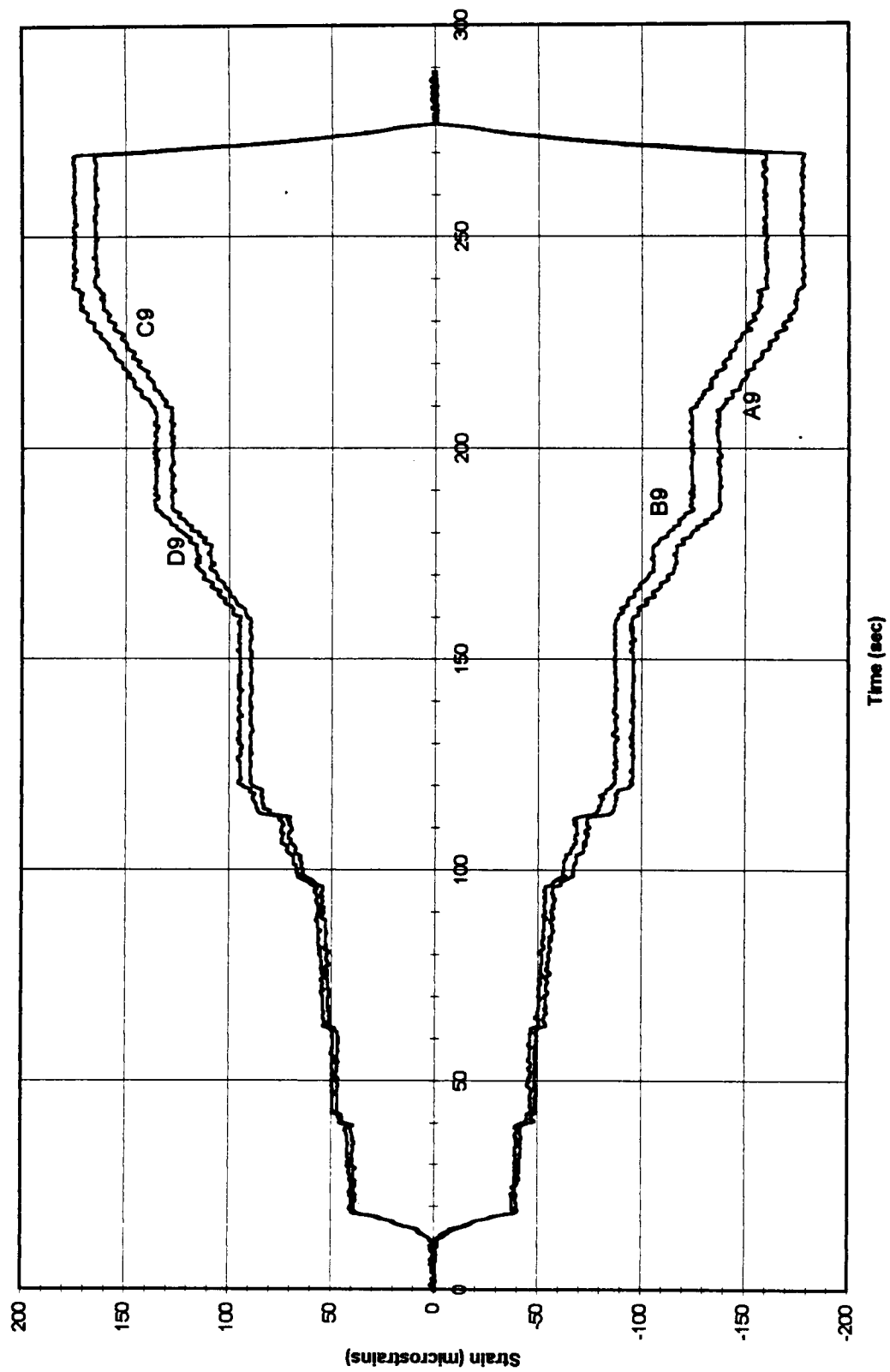


Figure 20. Strain vs Time. Feb.4, 1997 Lab test; Station 9.

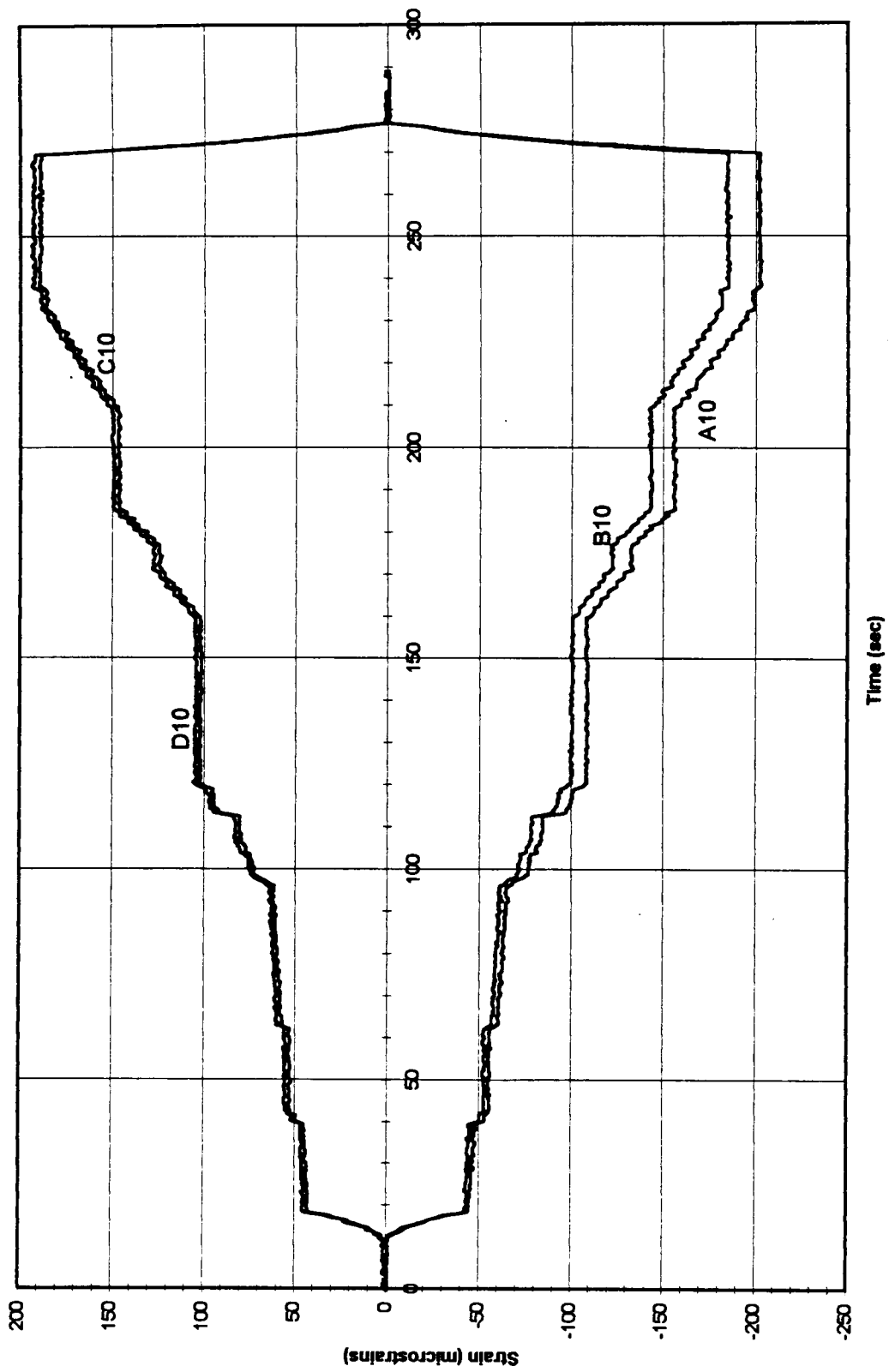


Figure 21. Strain vs Time. Feb. 4, 1997 Lab test; Station 10.

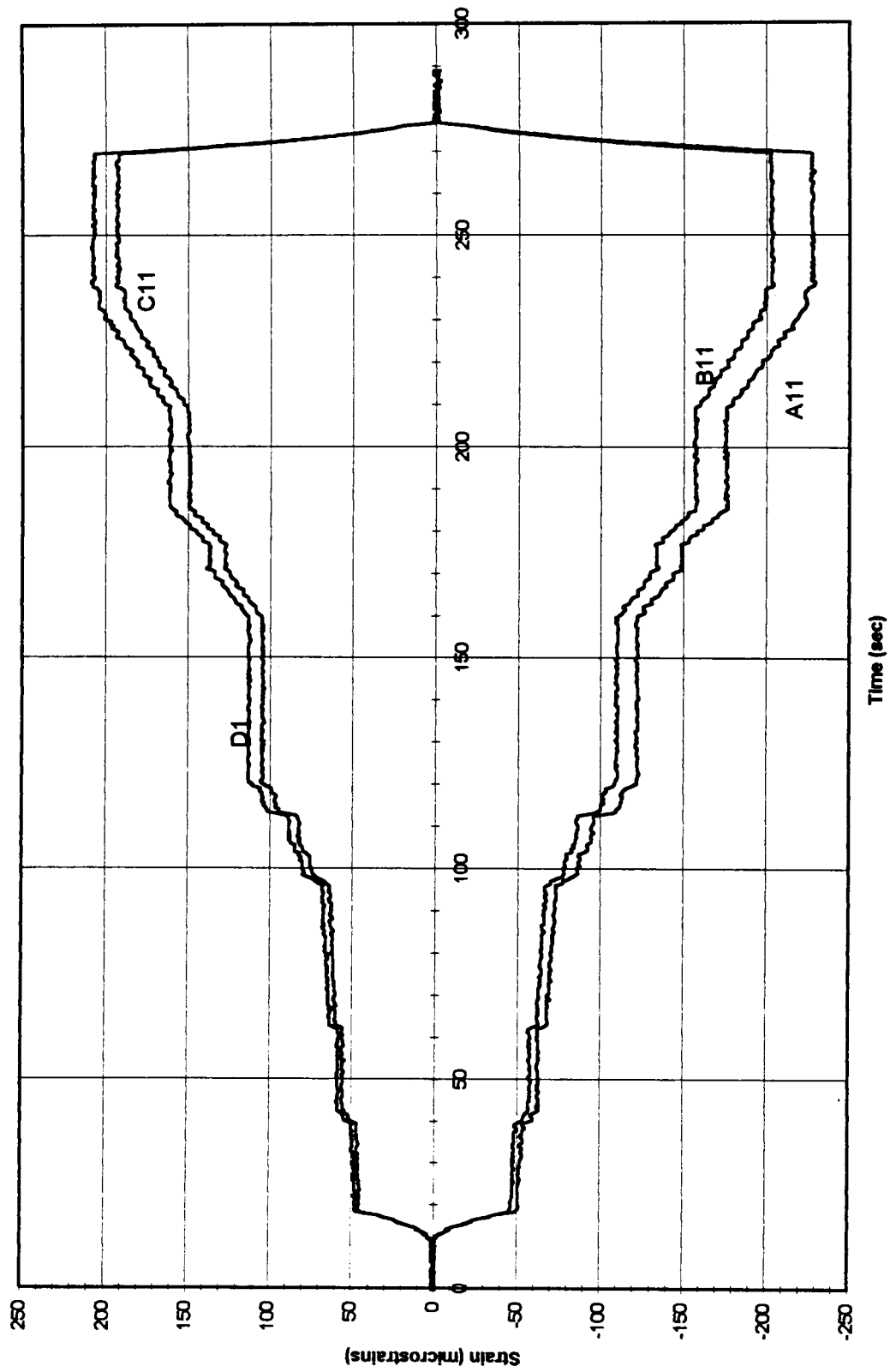


Figure 22. Strain vs Time. Feb. 4, 1997 Lab test; Station 11.

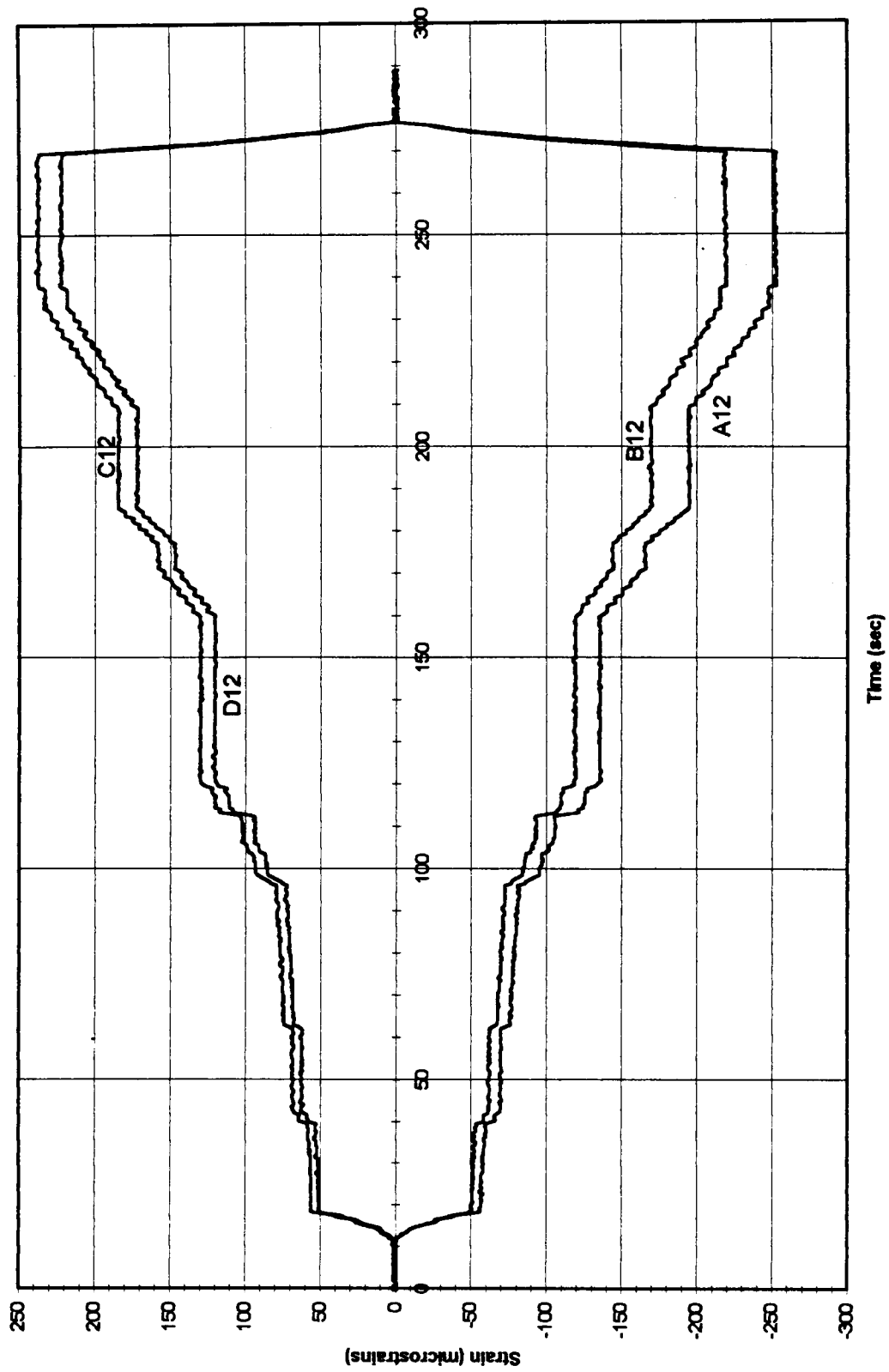


Figure 23. Strain vs Time. Feb. 4, 1997 Lab test; Station 12.

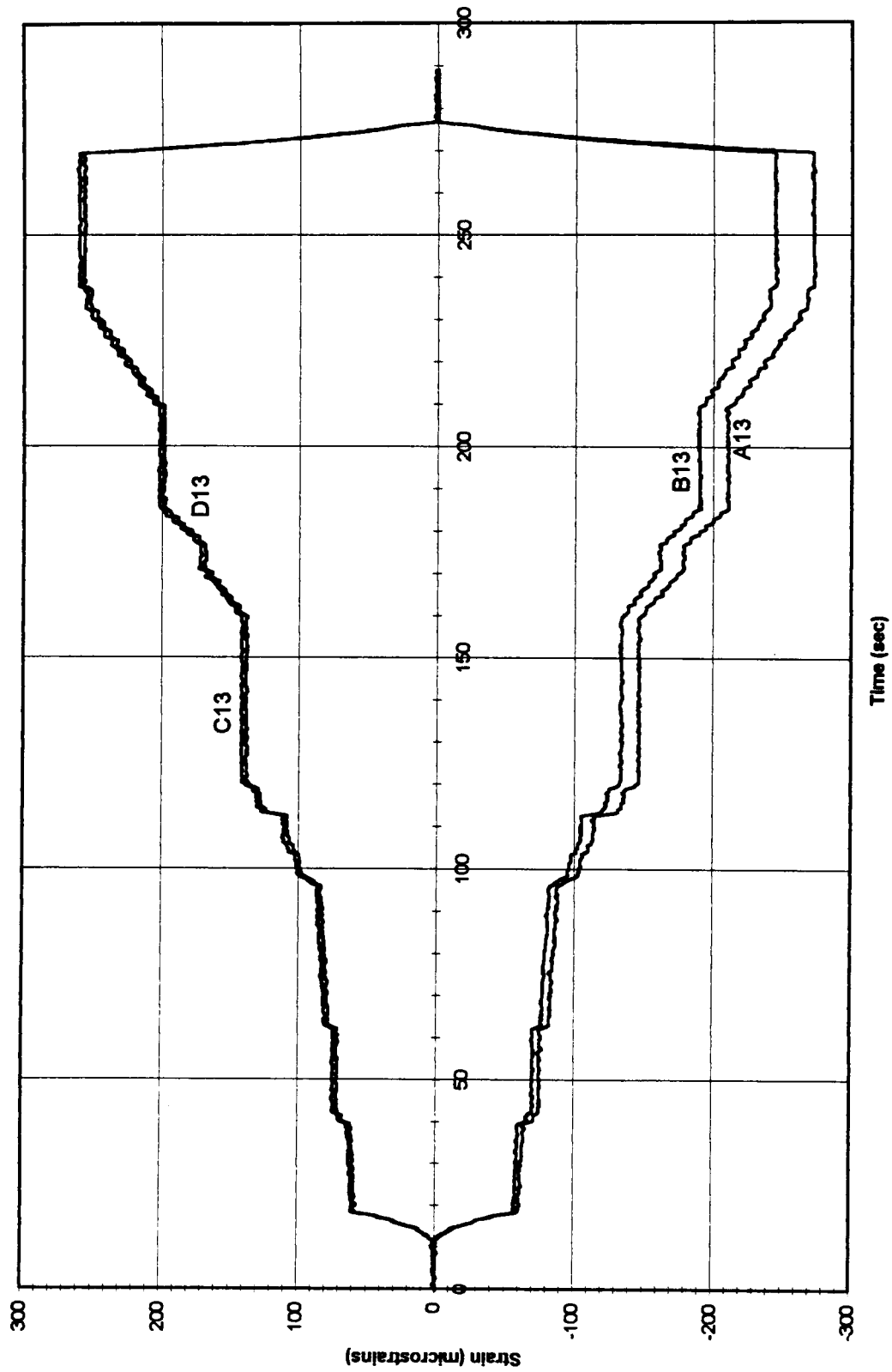


Figure 24. Strain vs Time. Feb. 4, 1997 Lab test; Station 13.

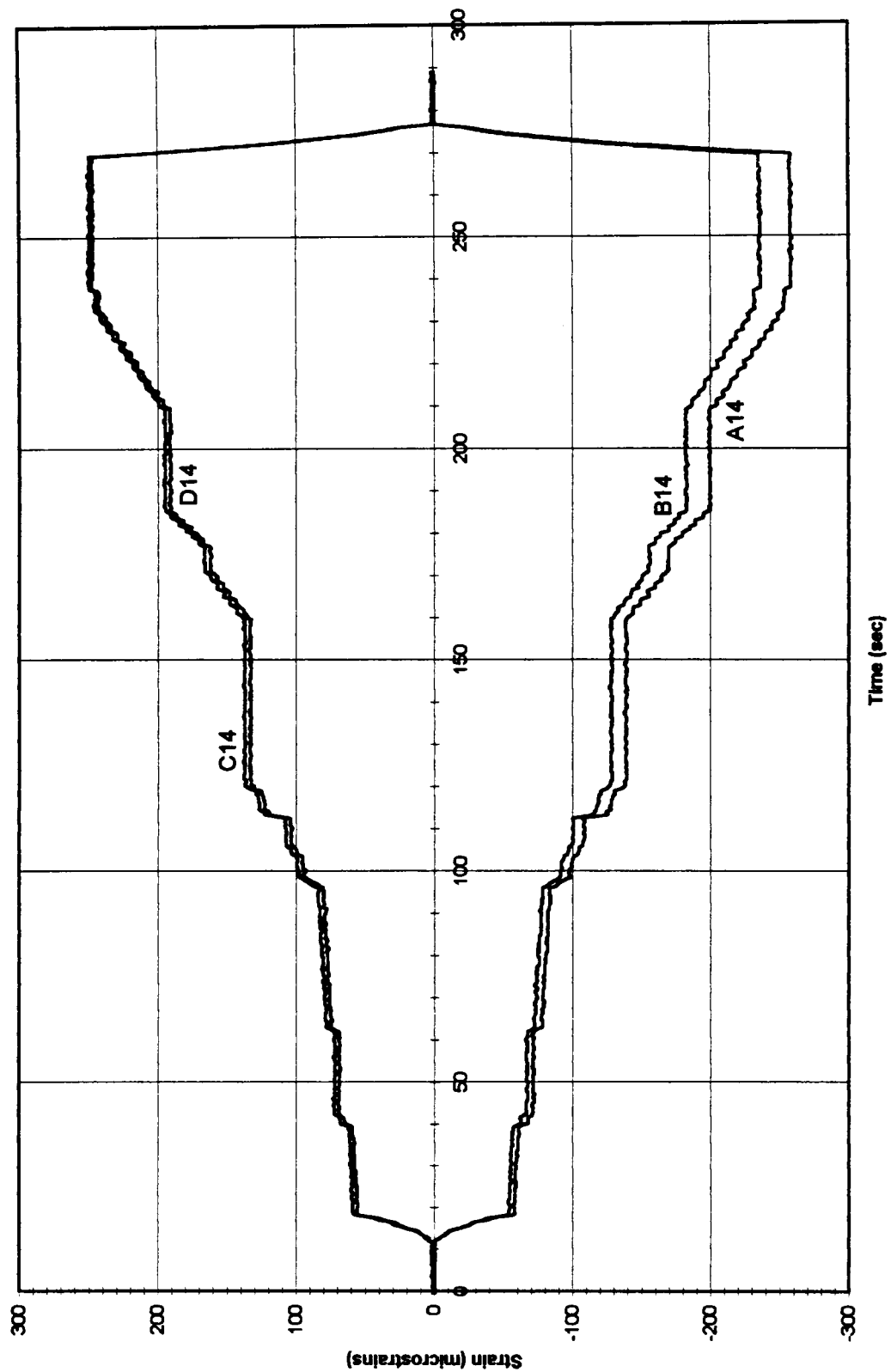


Figure 25. Strain vs Time. Feb.4, 1997 Lab test; Station 14.

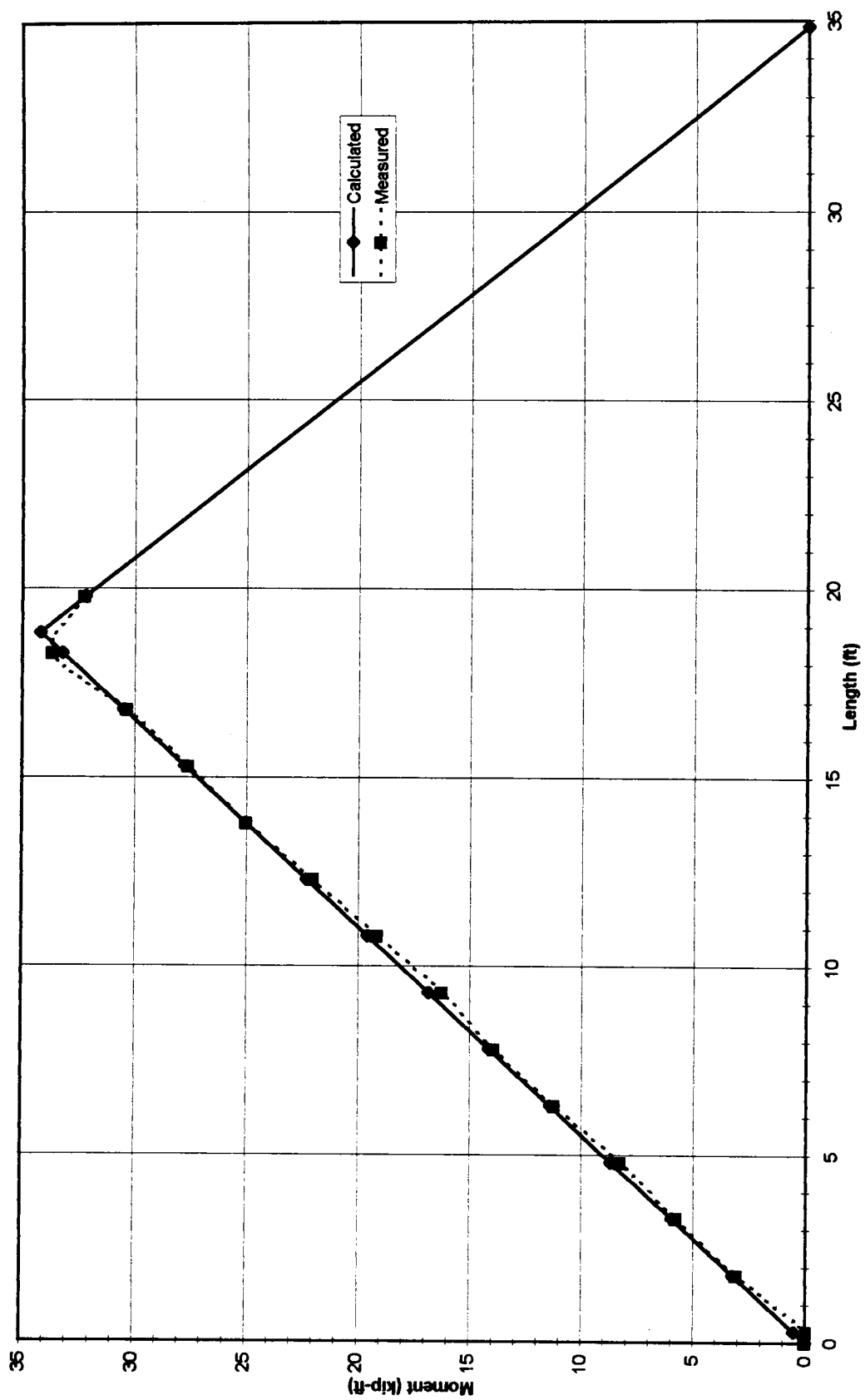


Figure 26. Moment vs. Length of span. Feb. 4, 1997 Lab Test. Load = 4.0 kips.

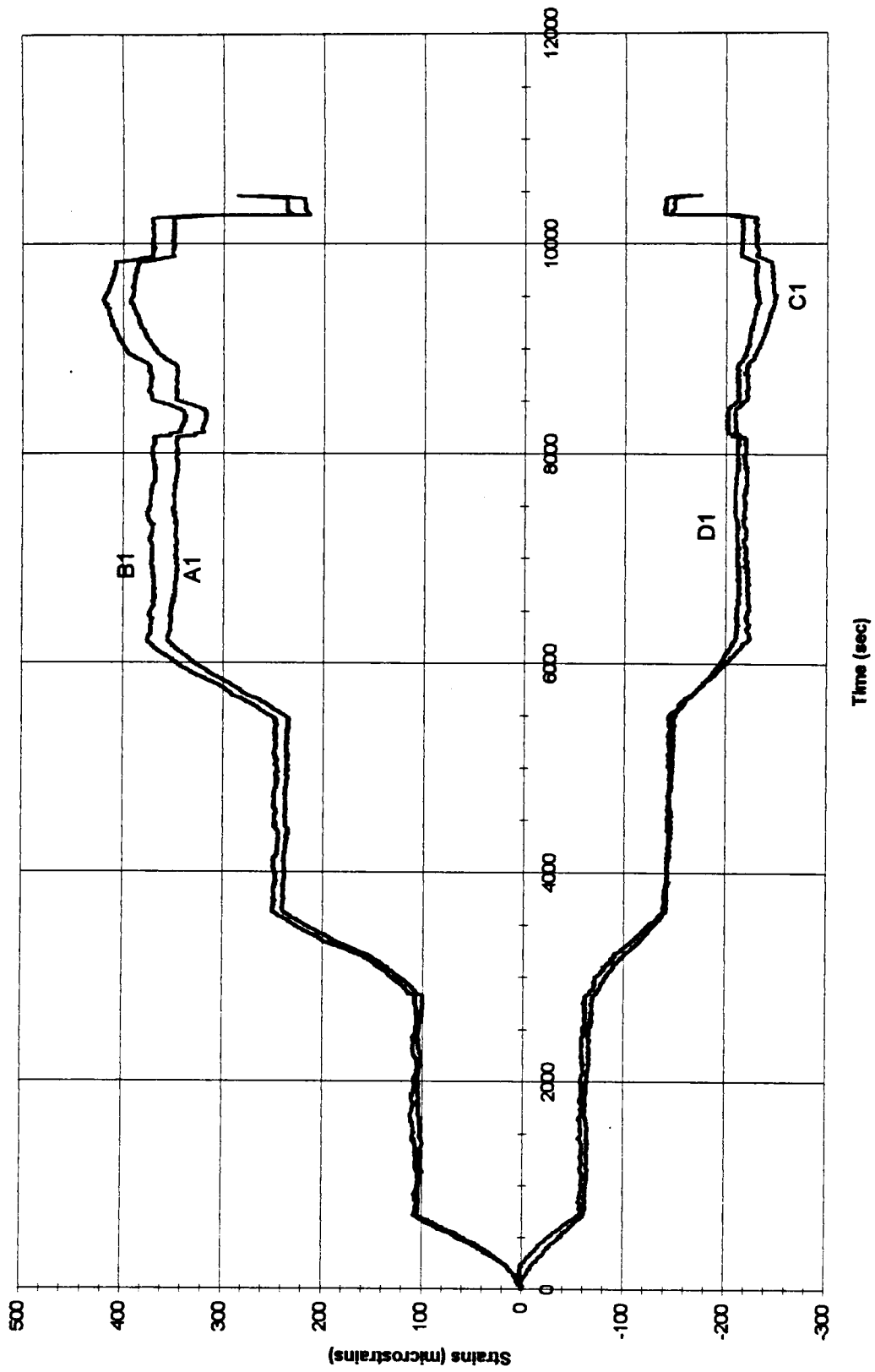


Figure 27. Strain vs. Time. June 24, 1997 field test; Station 1.

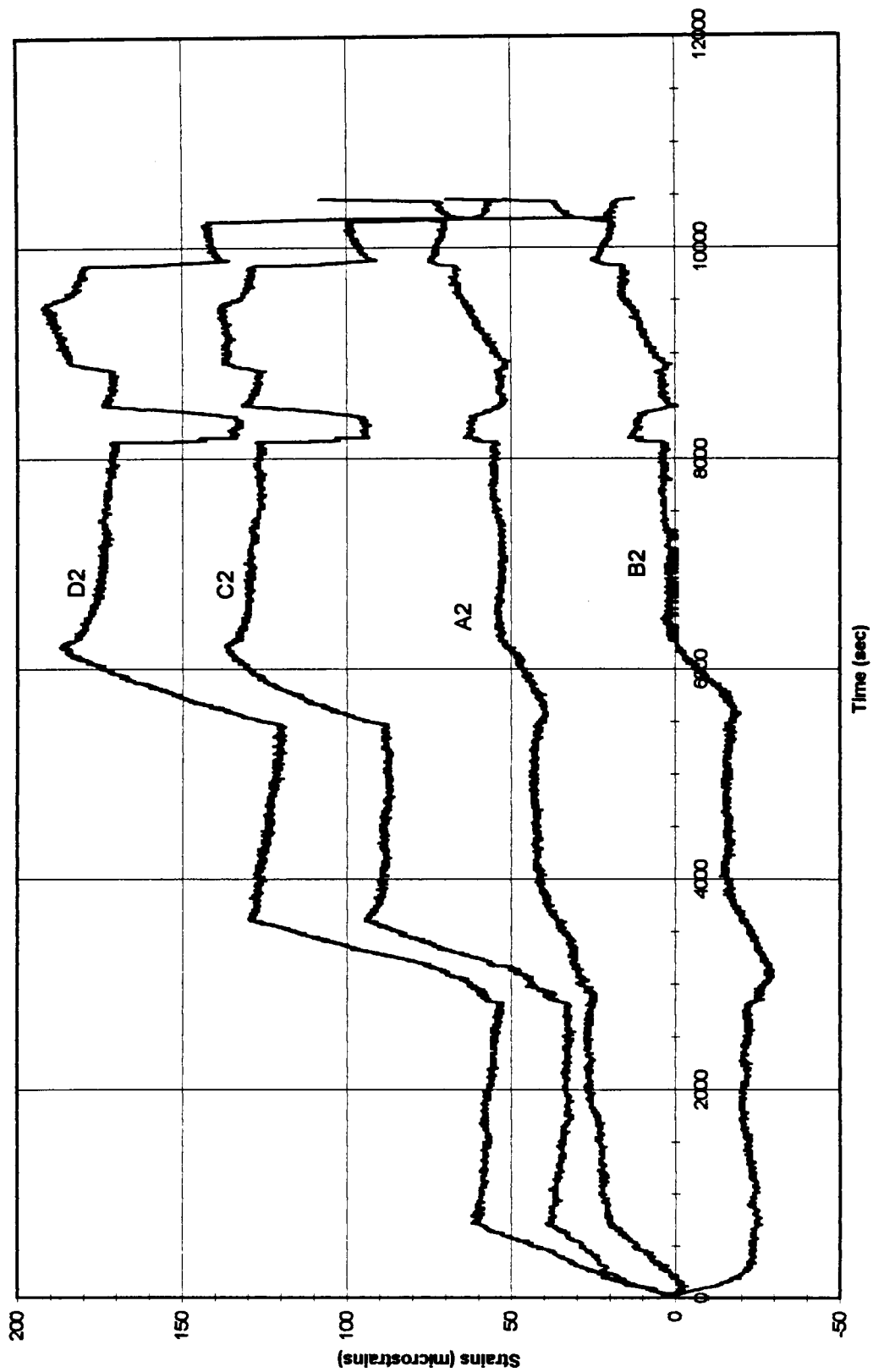


Figure 28. Strain vs. Time. June 24, 1997 field test; Station 2.

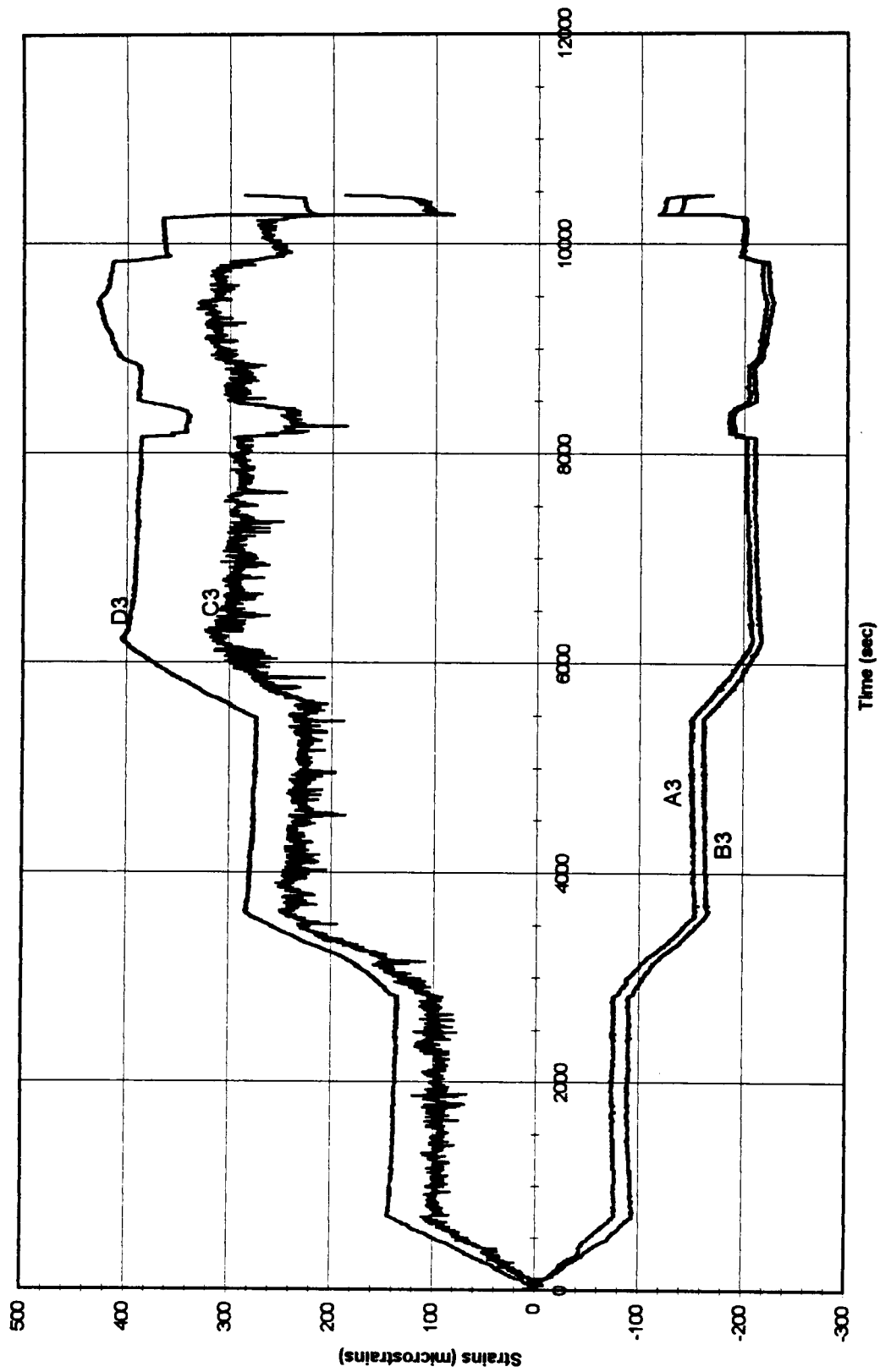


Figure 29. Strain vs. Time. June 24, 1997 field test; Station 3.

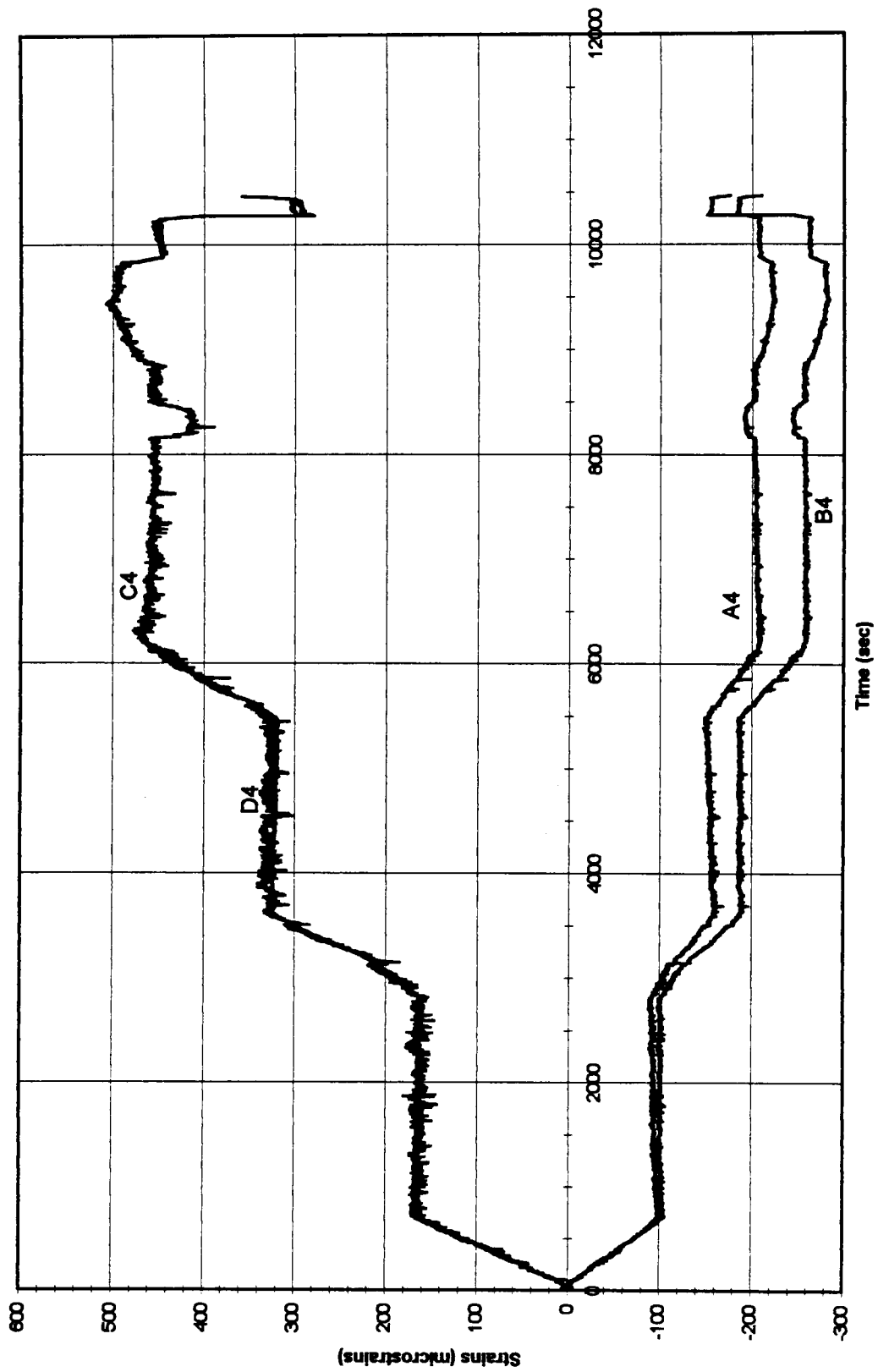


Figure 30. Strain vs. Time. June 24, 1997 field test; Station 4.

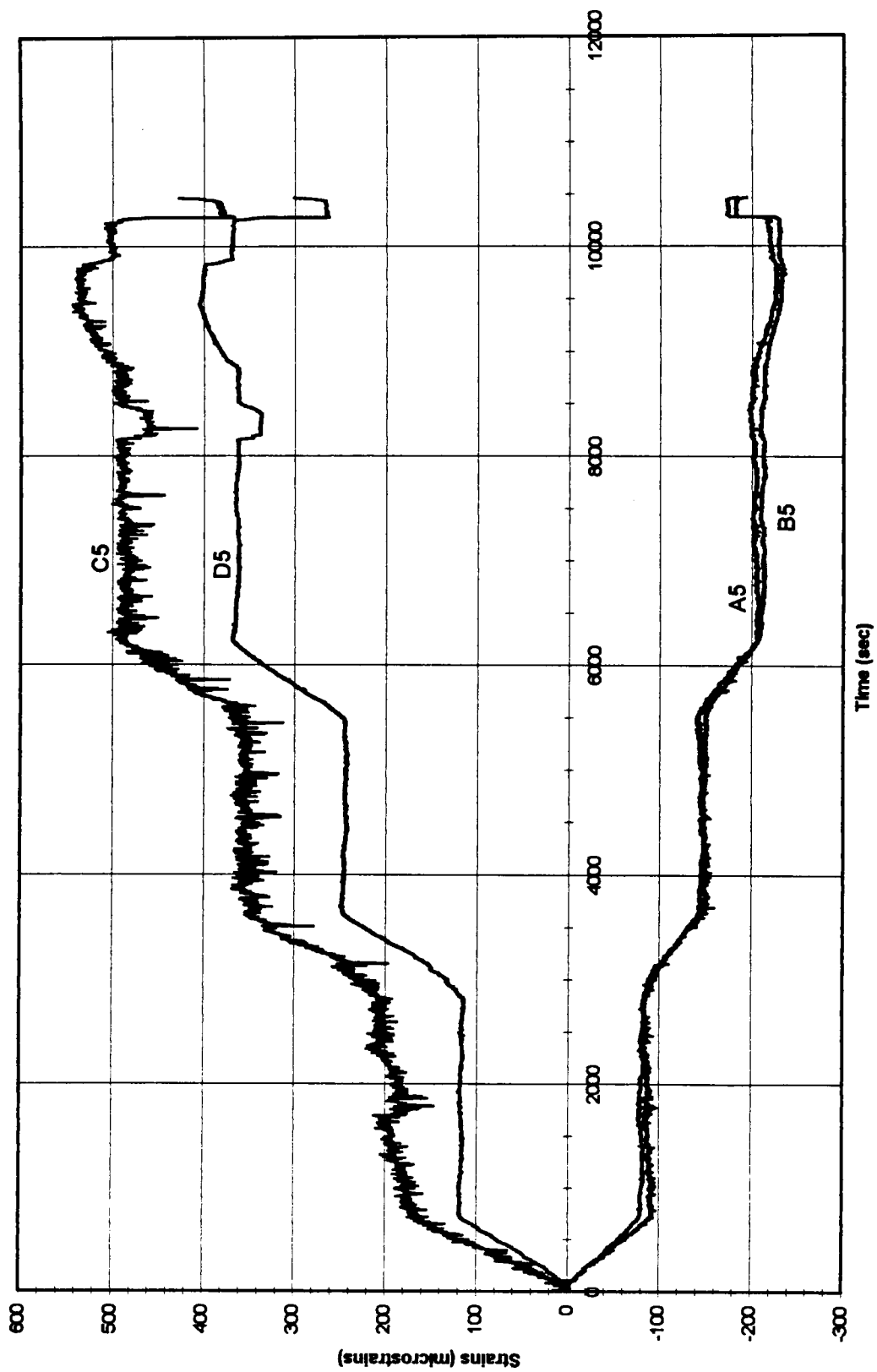


Figure 31. Strain vs. Time. June 24, 1997 field test; Station 5.

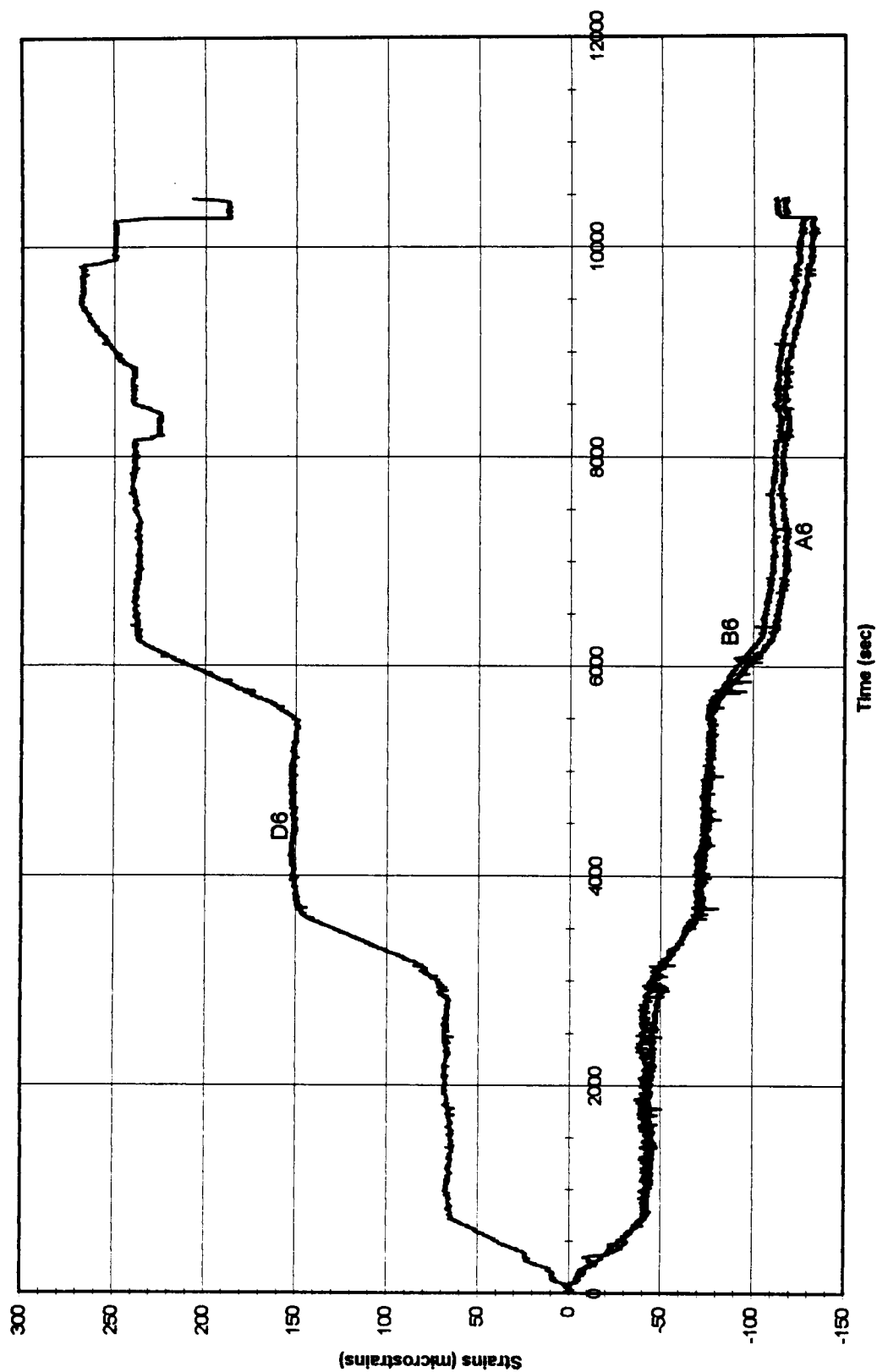


Figure 32. Strain vs. Time. June 24, 1997 field test; Station 6.

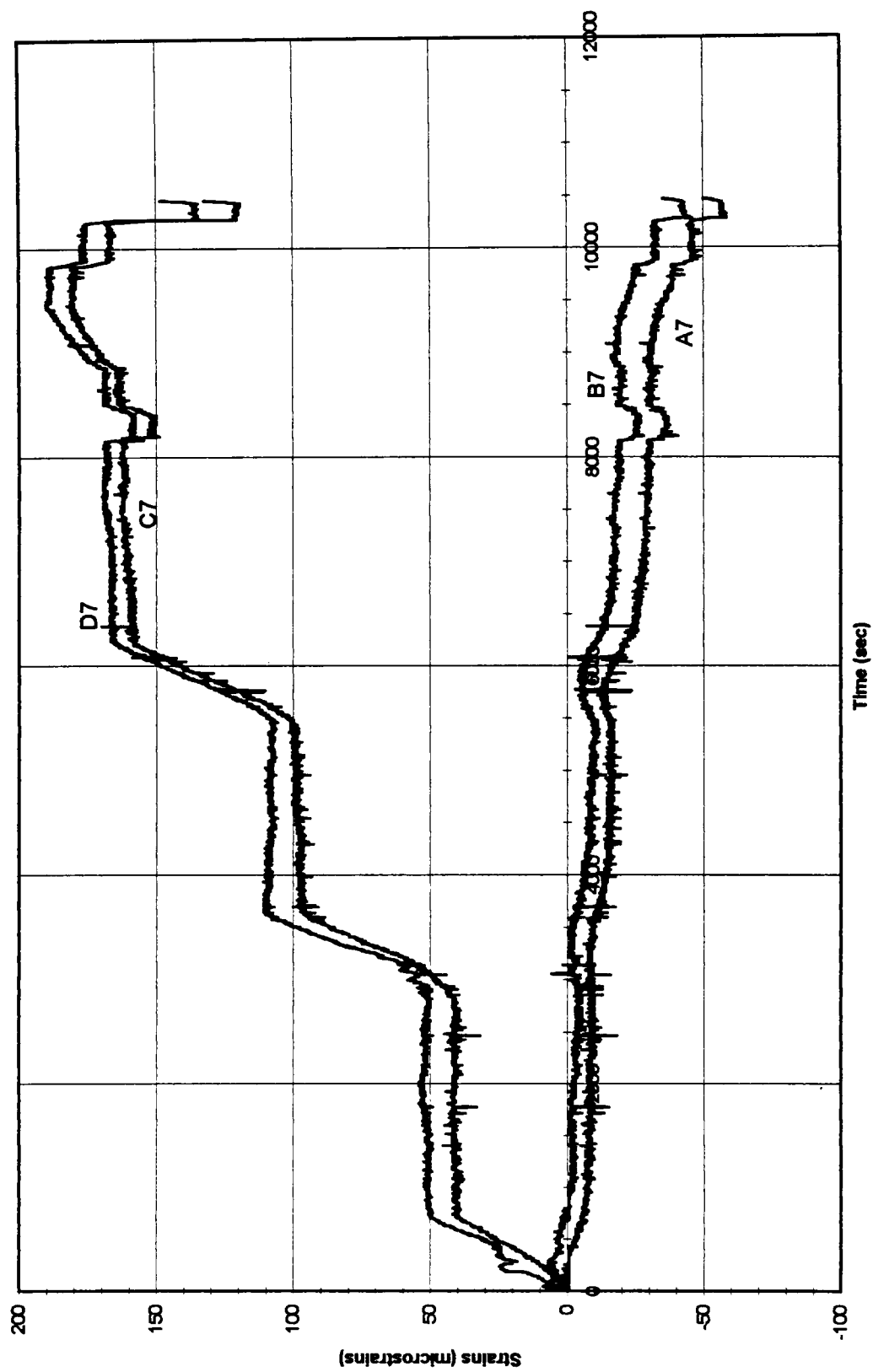


Figure 33. Strain vs. Time. June 24, 1997 field test; Station 7.

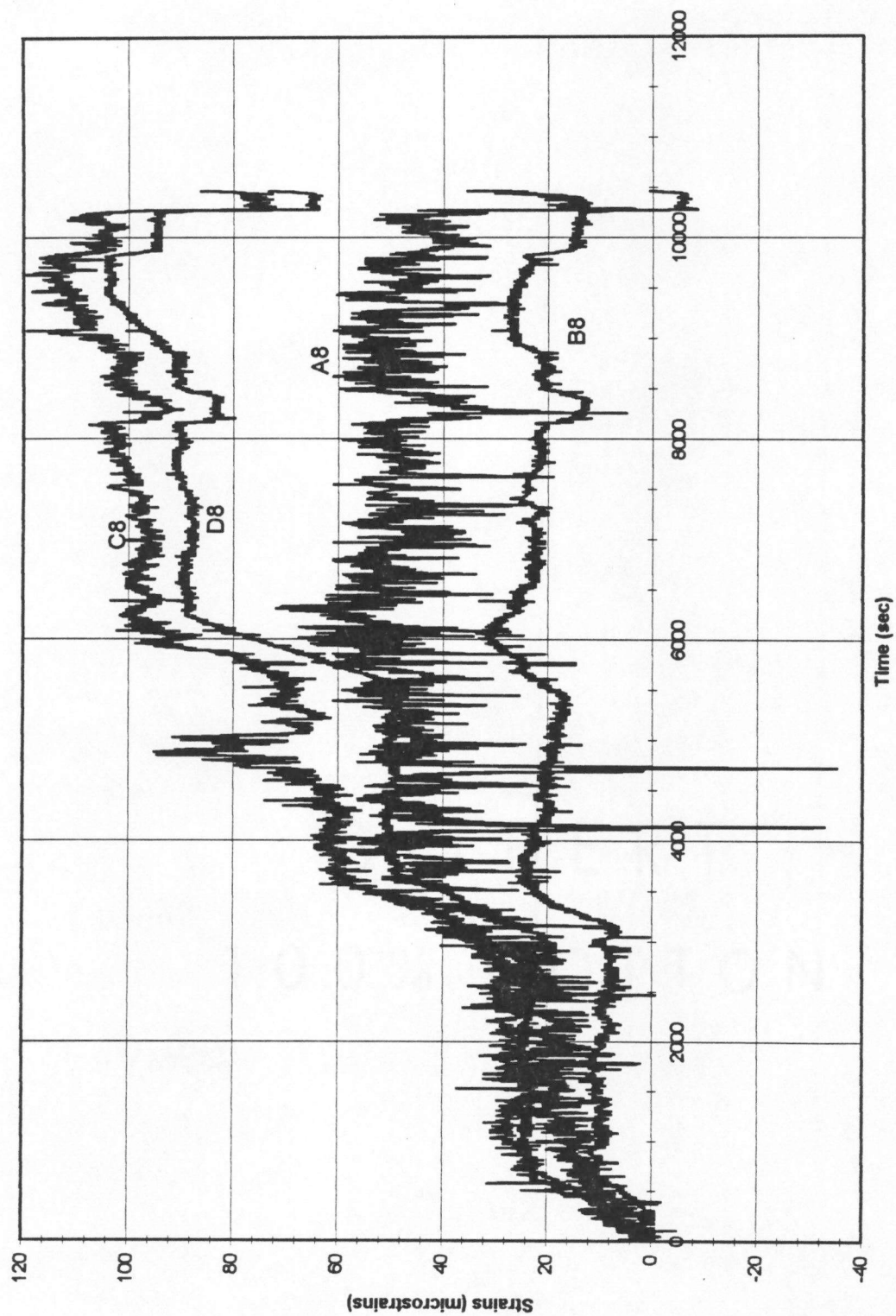


Figure 34. Strain vs. Time. June 24, 1997 field test; Station 8.

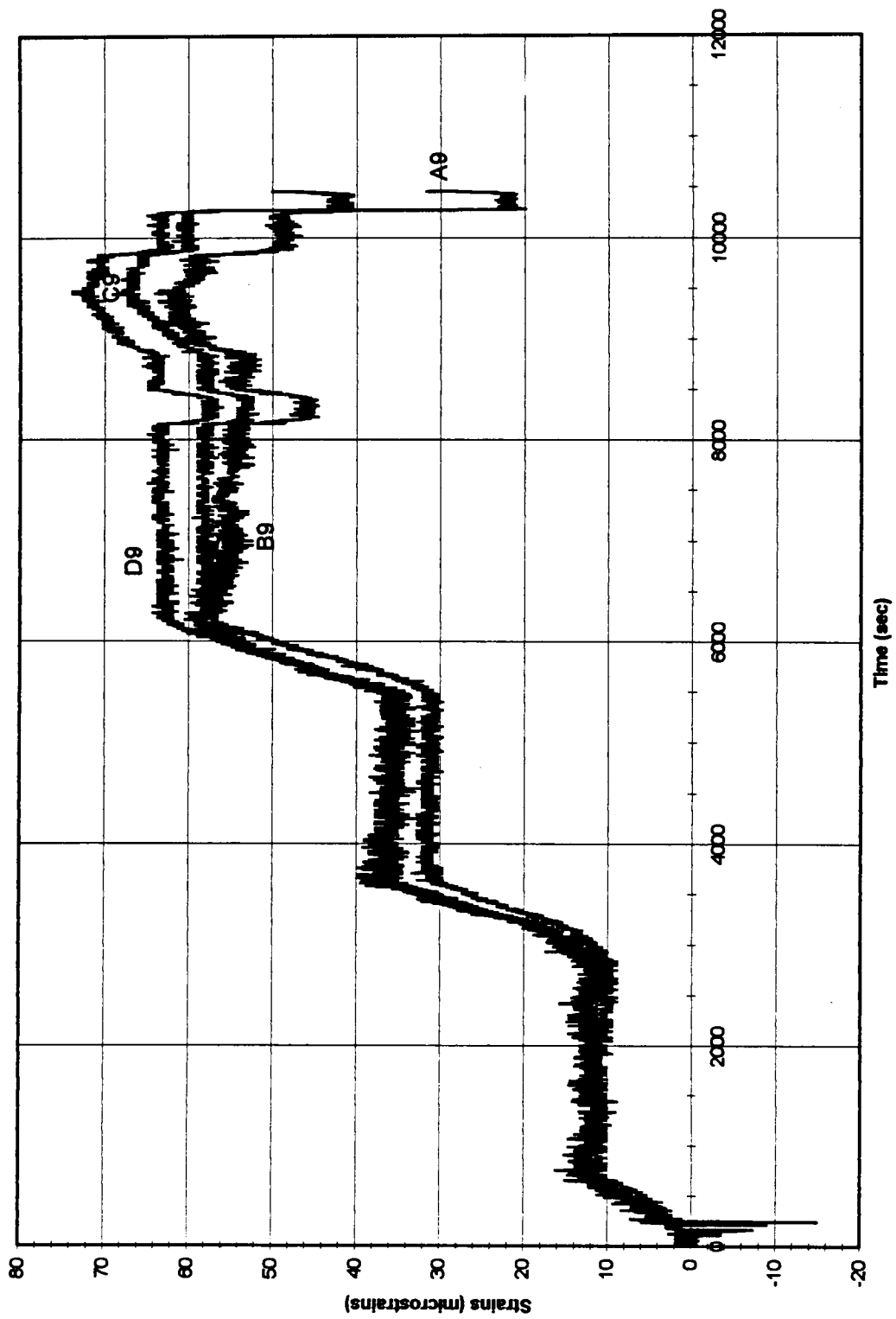


Figure 35. Strain vs. Time. June 24, 1997 field test; Station 9.

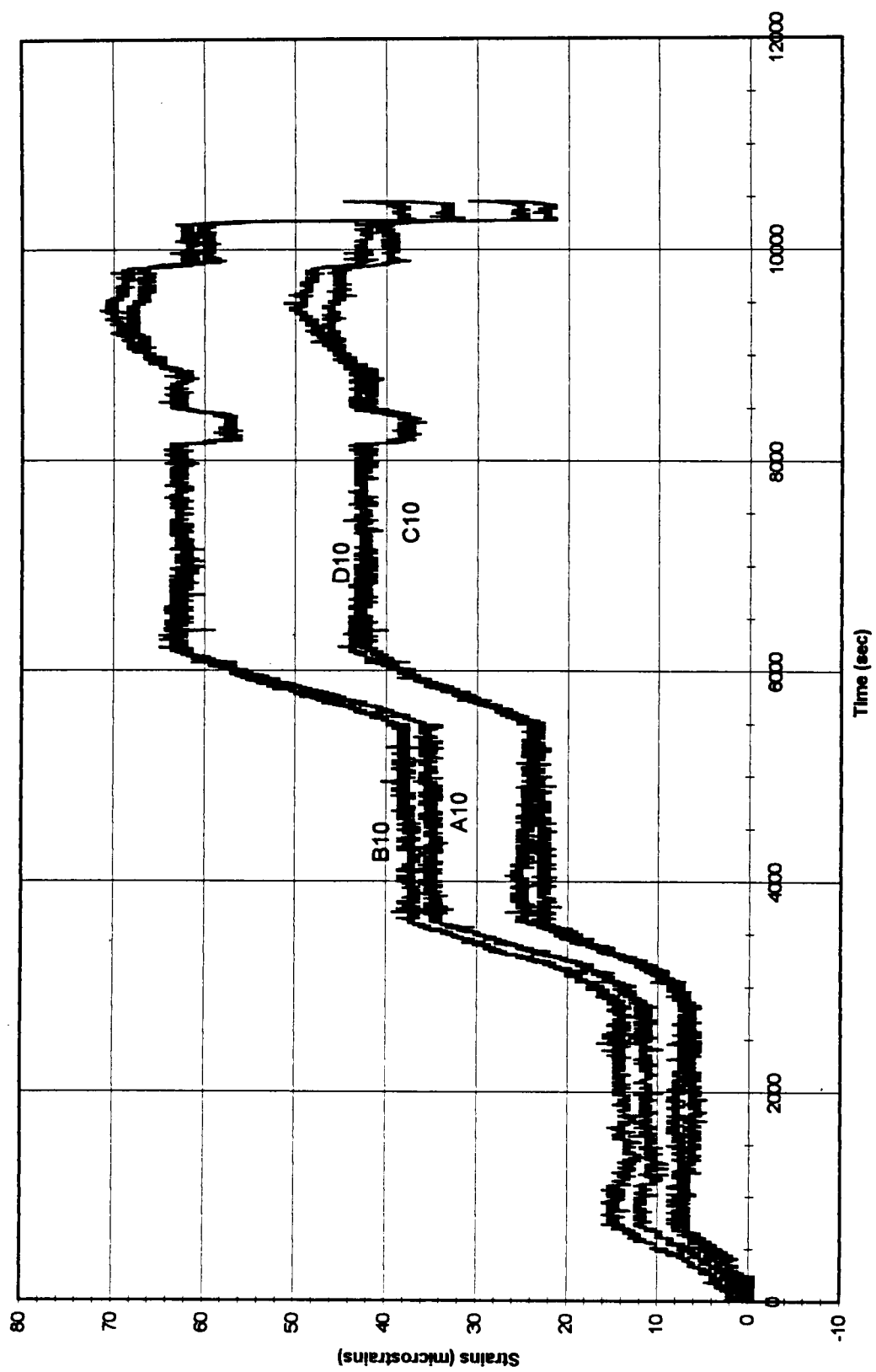


Figure 36. Strain vs. Time. June 24, 1997 field test; Station 10.

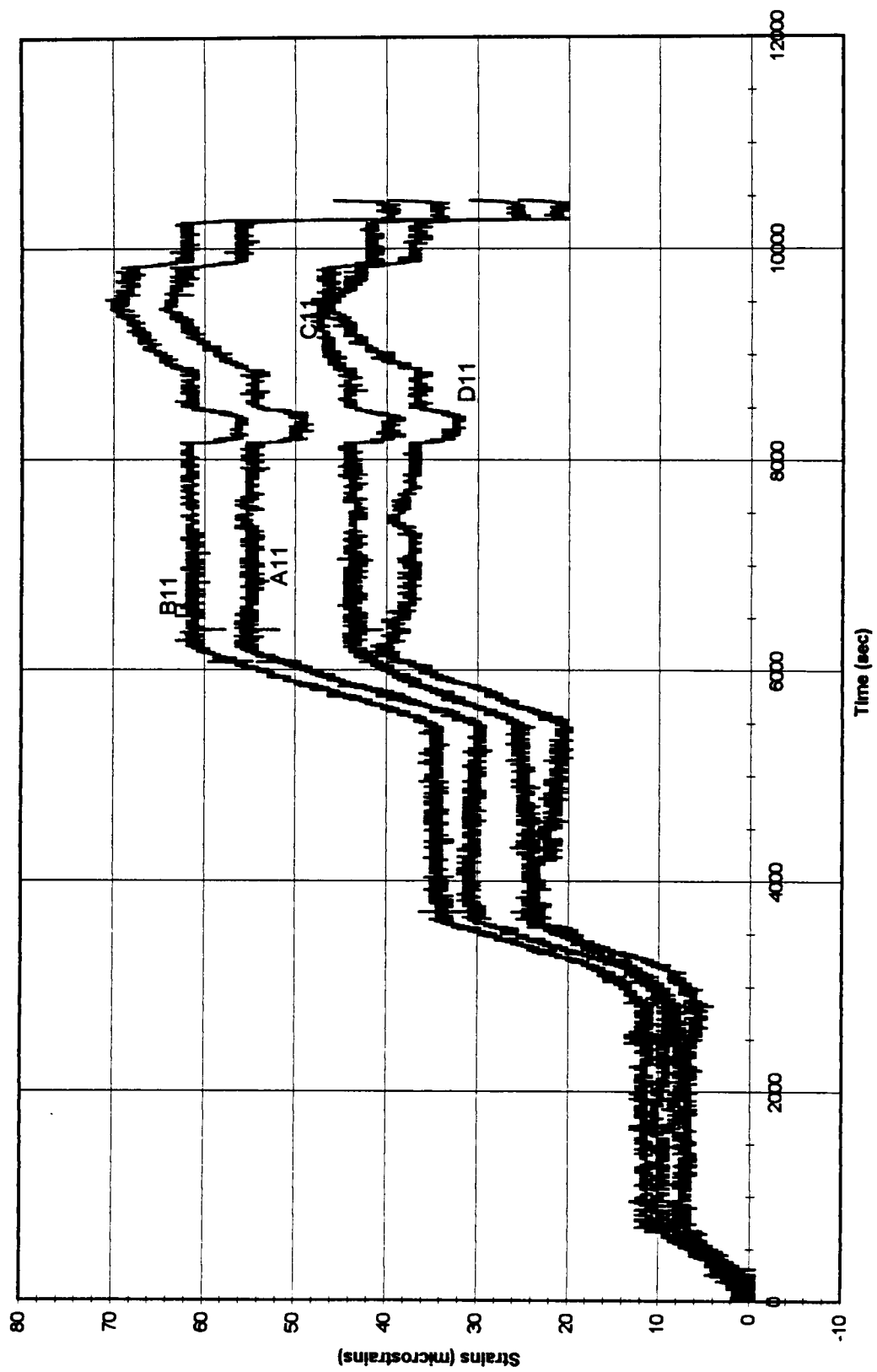


Figure 37. Strain vs. Time. June 24, 1997 field test; Station 11.

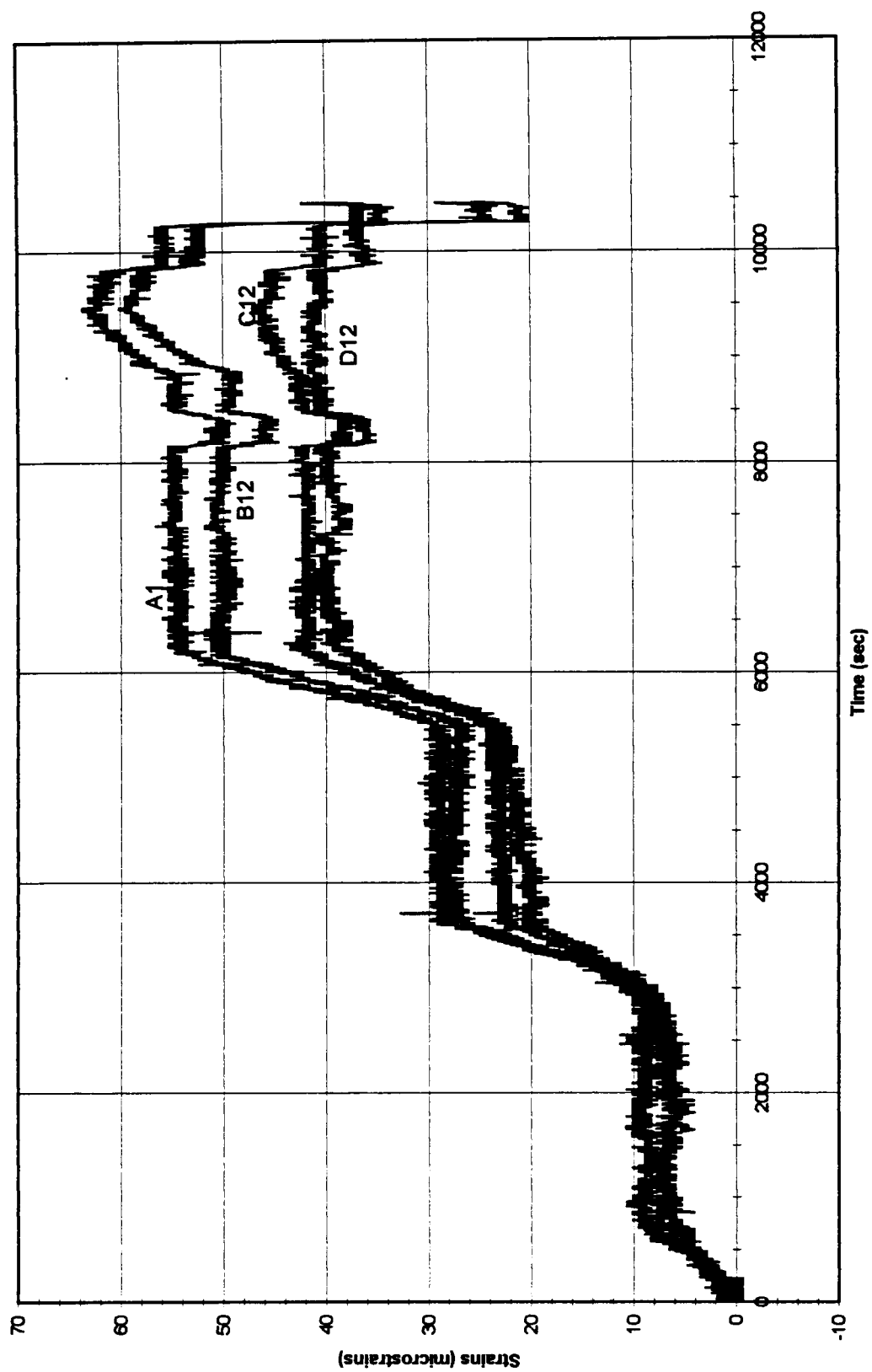


Figure 38. Strain vs. Time. June 24, 1997 field test; Station 12.

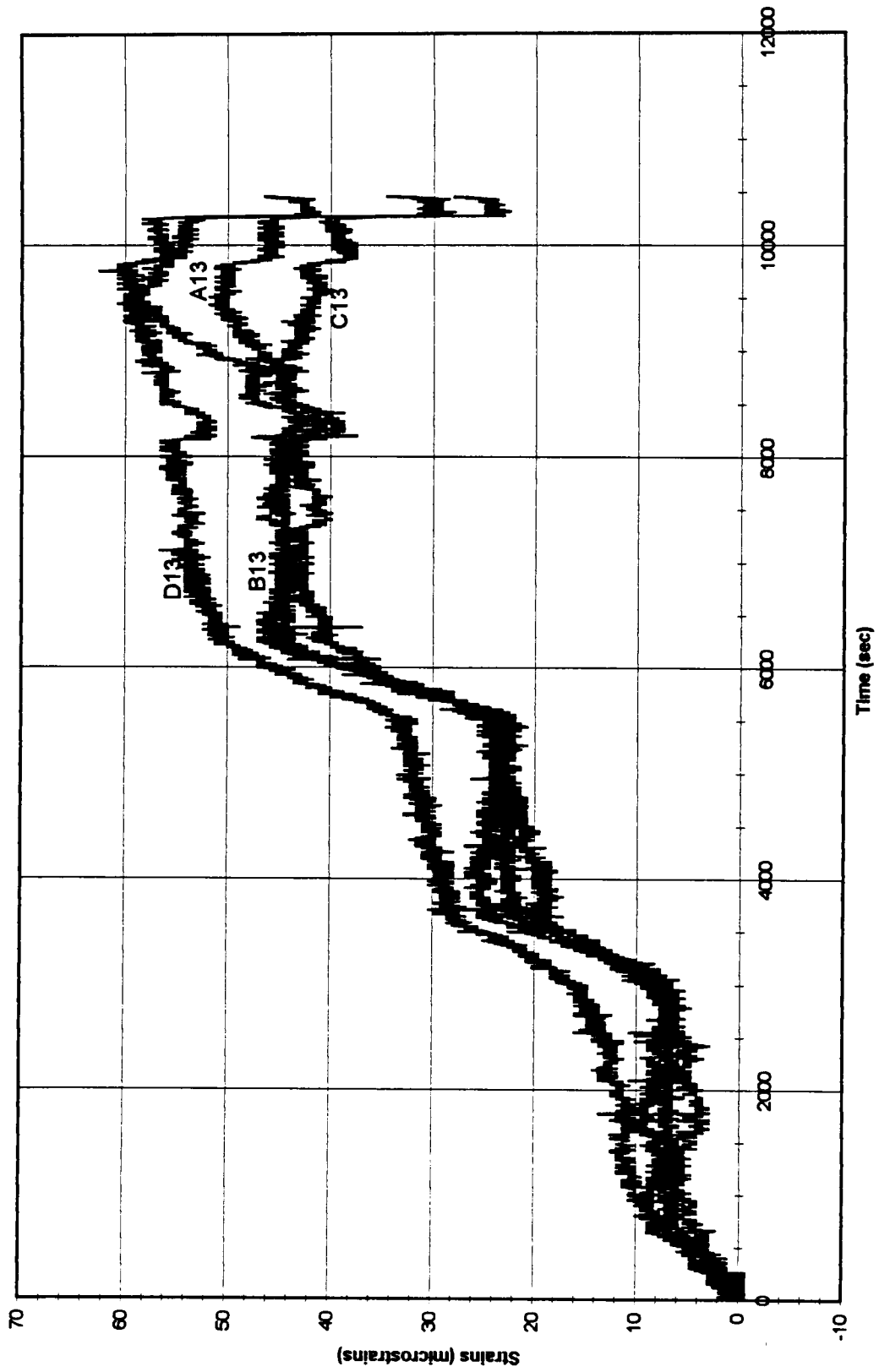


Figure 39. Strain vs. Time. June 24, 1997 field test; Station 13.

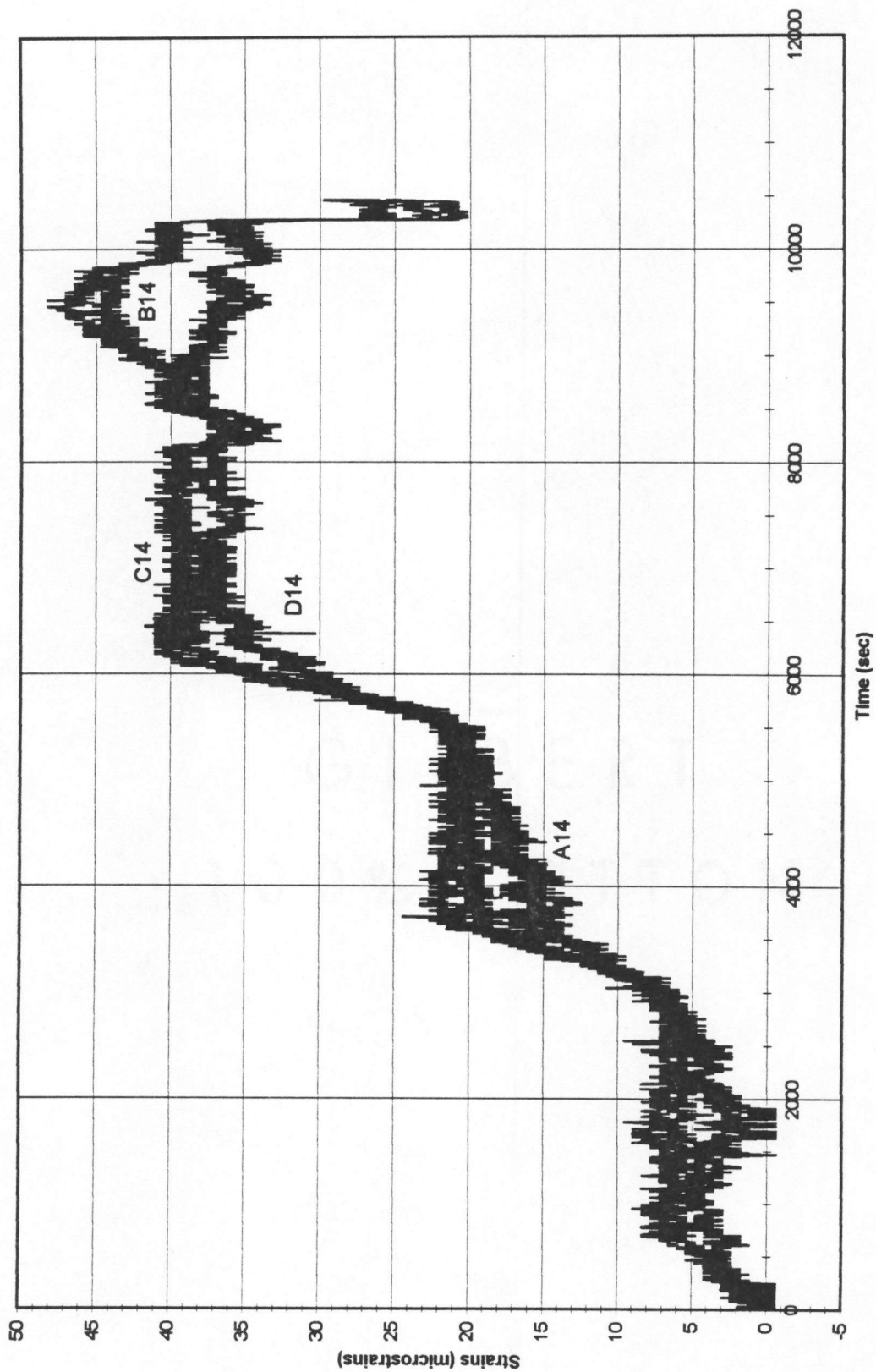


Figure 40. Strain vs. Time. June 24, 1997 field test; Station 14.

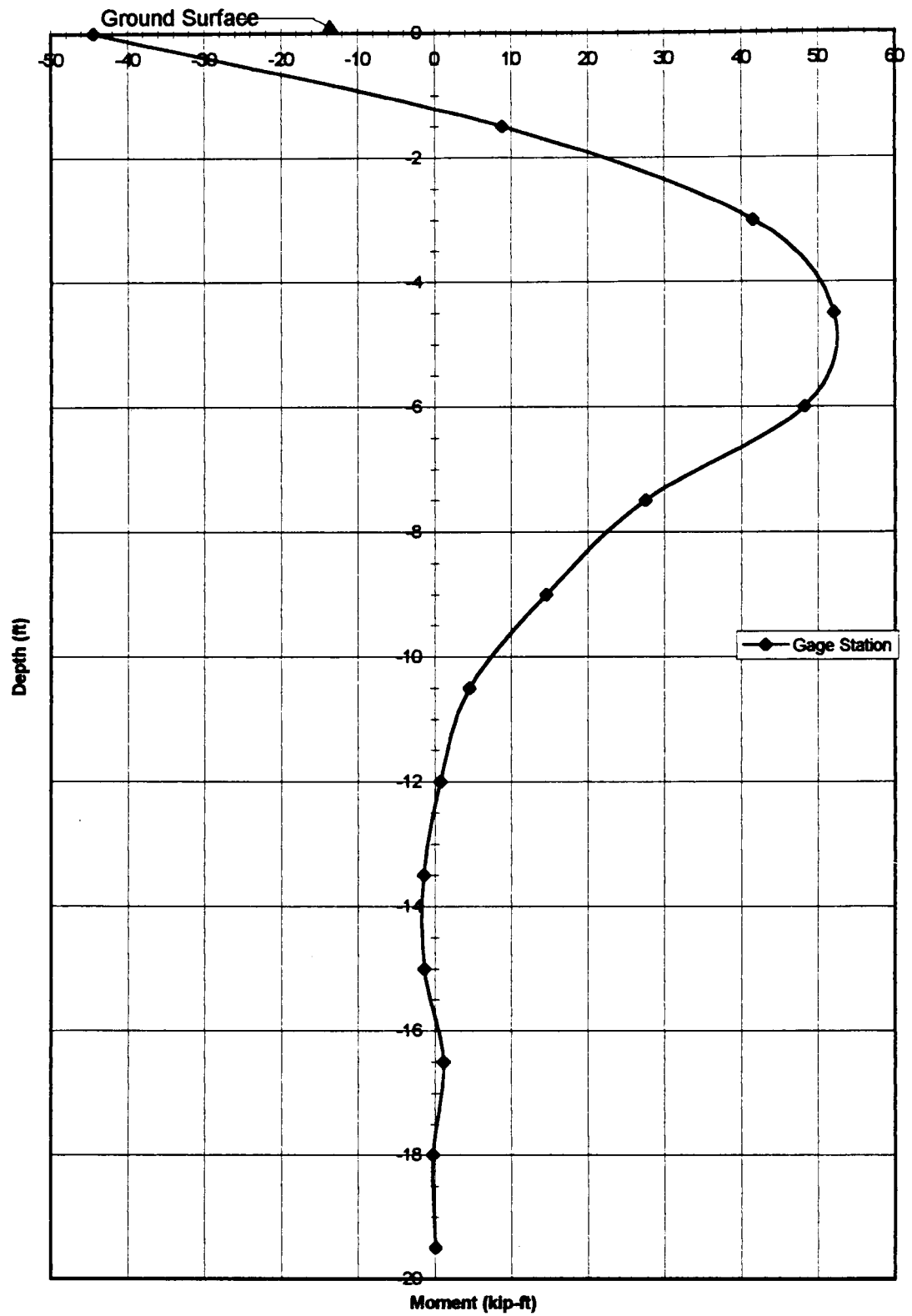


Figure 41. Moment vs. Depth. June 24, 1997 Field Test. Defl. = .420" ; Load = 41.3 kips.

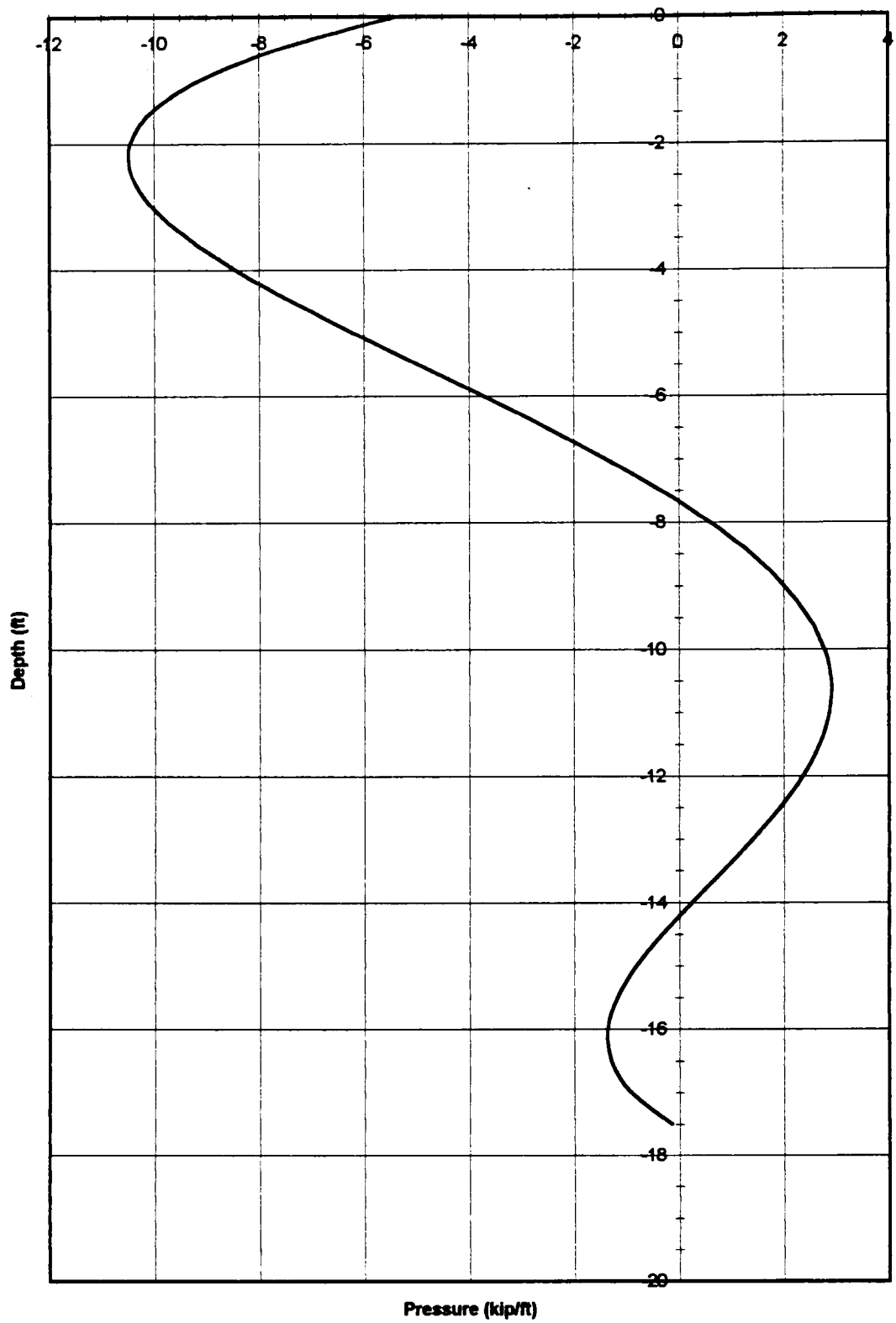


Figure 42. Pressure vs. Depth. Based on moment diagram. June 24, 1997 Field Test.

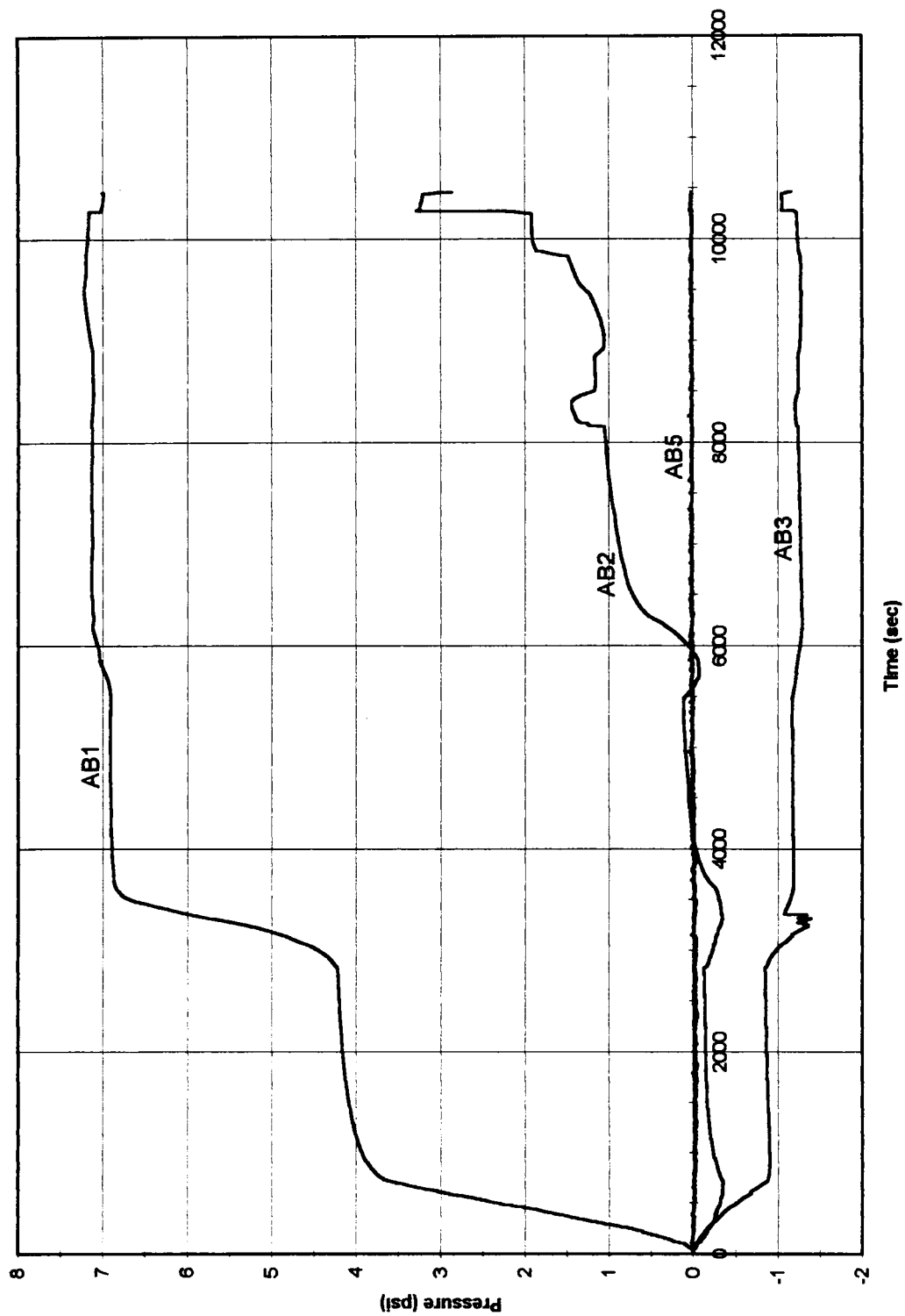


Figure 43. Pressure vs. Time. June 24, 1997 field test; Flange AB.

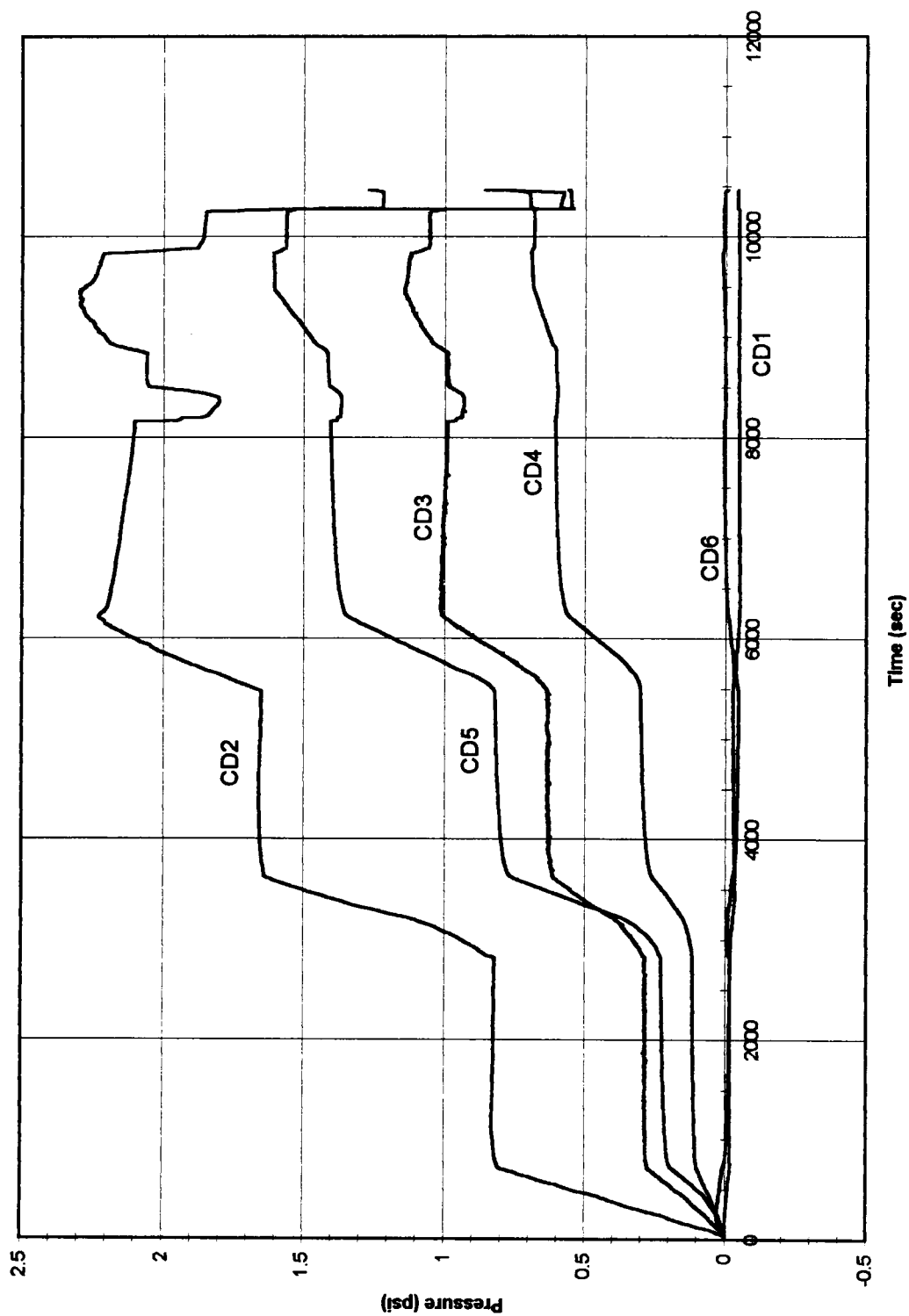


Figure 44. Pressure vs. Time. June 24, 1997 field test; Flange CD.

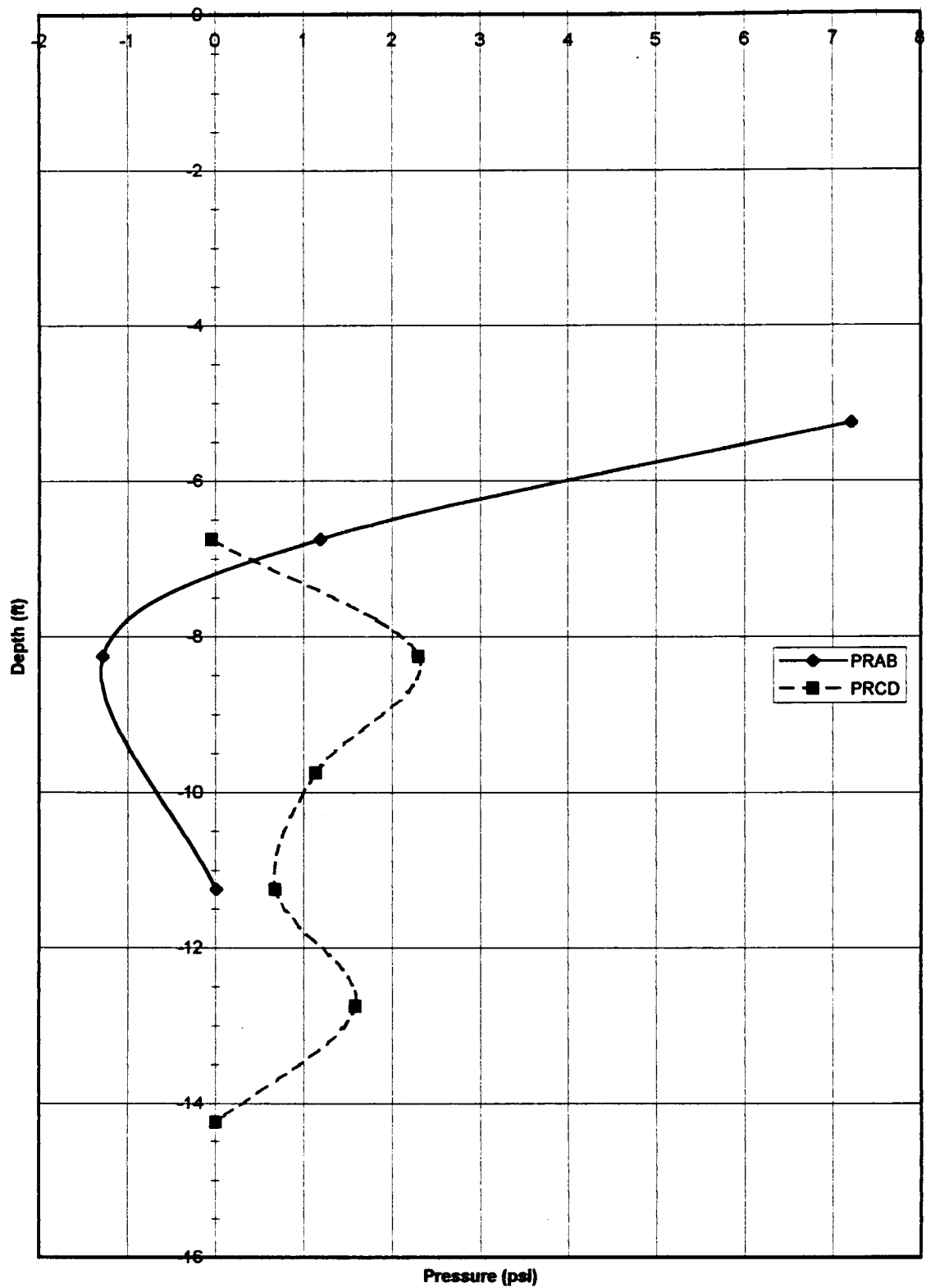


Figure 45. Pressure vs. Depth. Based on pressure sensors. June 24, 1997 Field Test. Defl. = .42"

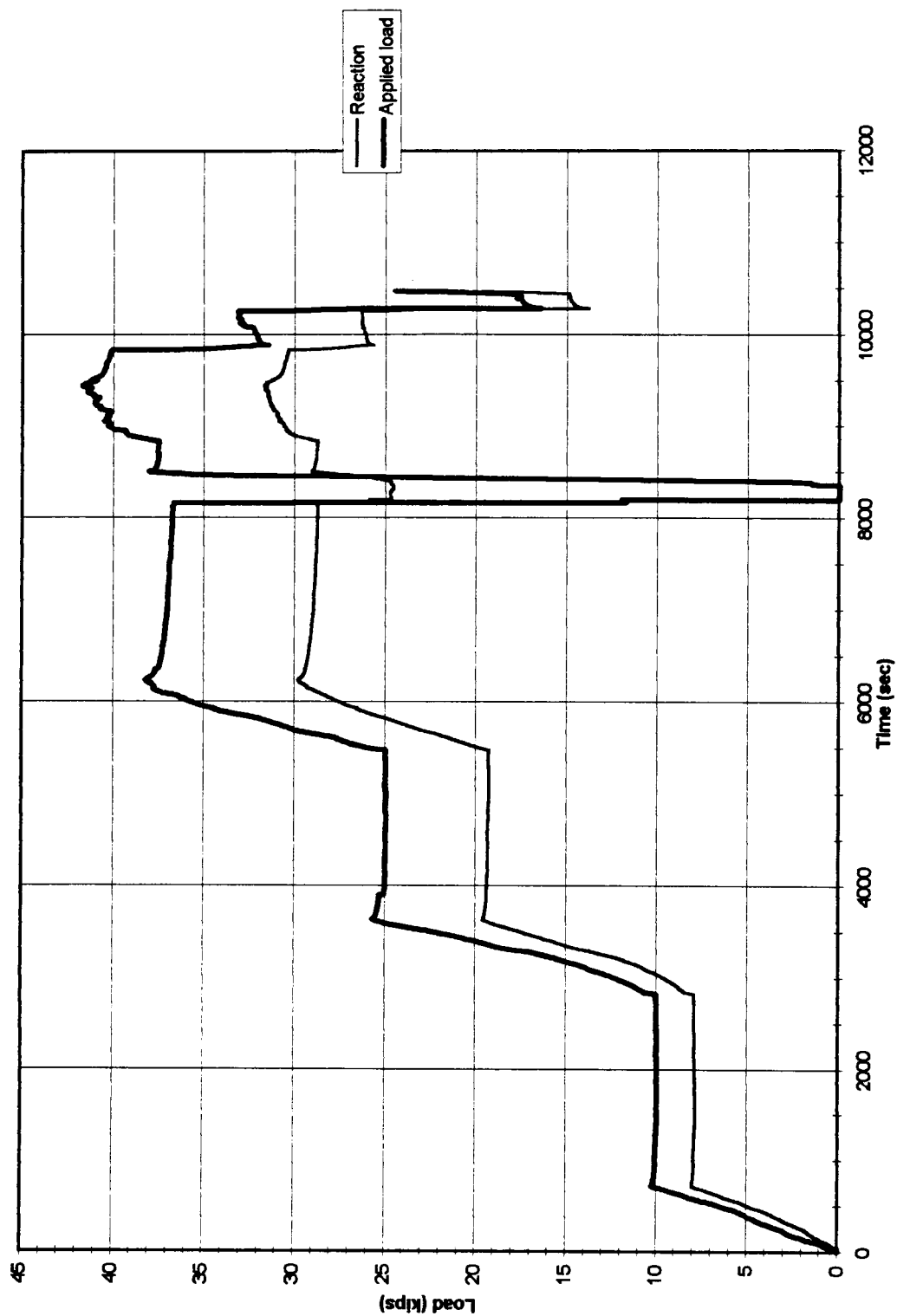


Figure 46. Load vs. Time. June 24, 1997 field test.

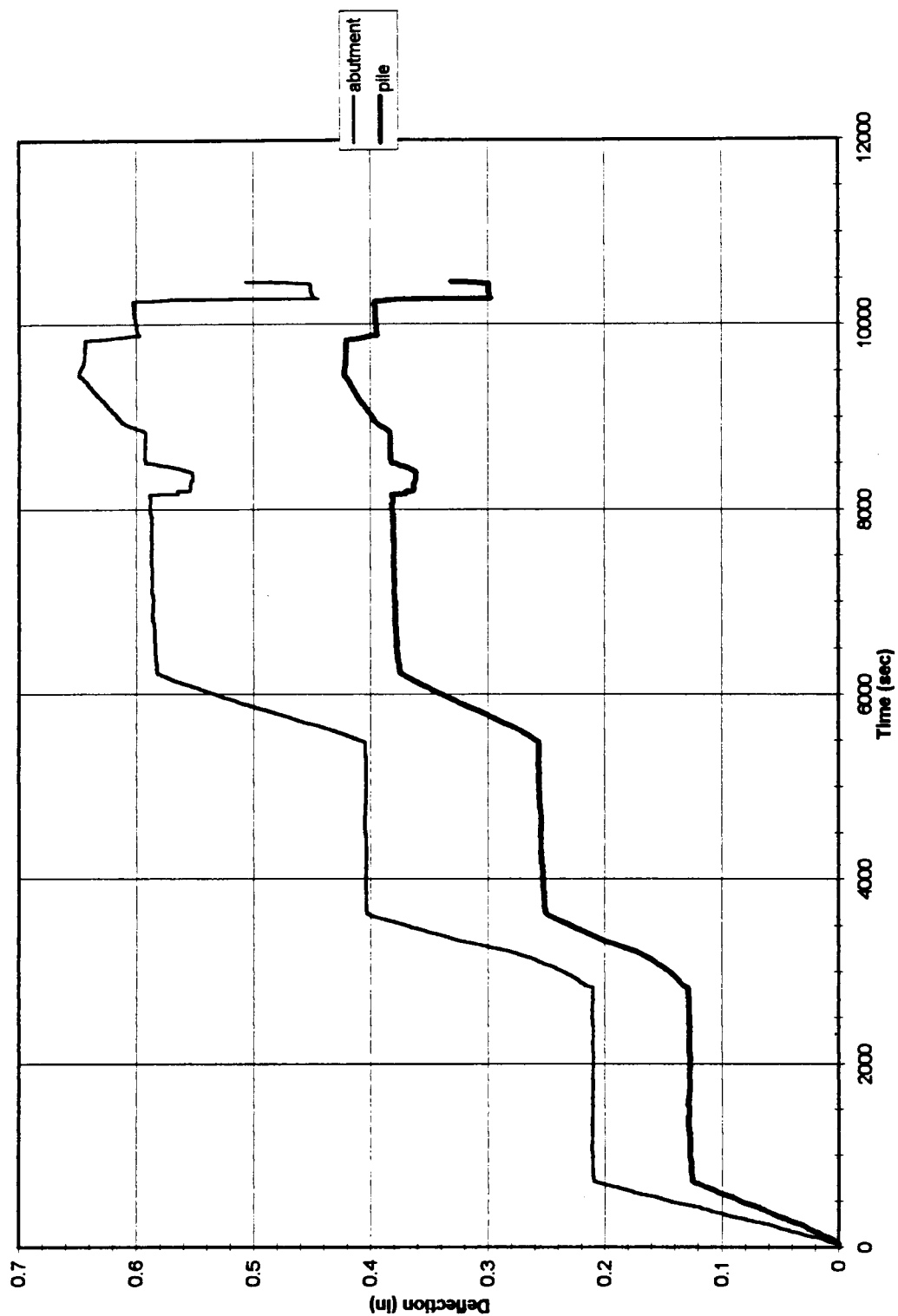


Figure 47. Deflection vs. Time. June 24, 1997 field test.

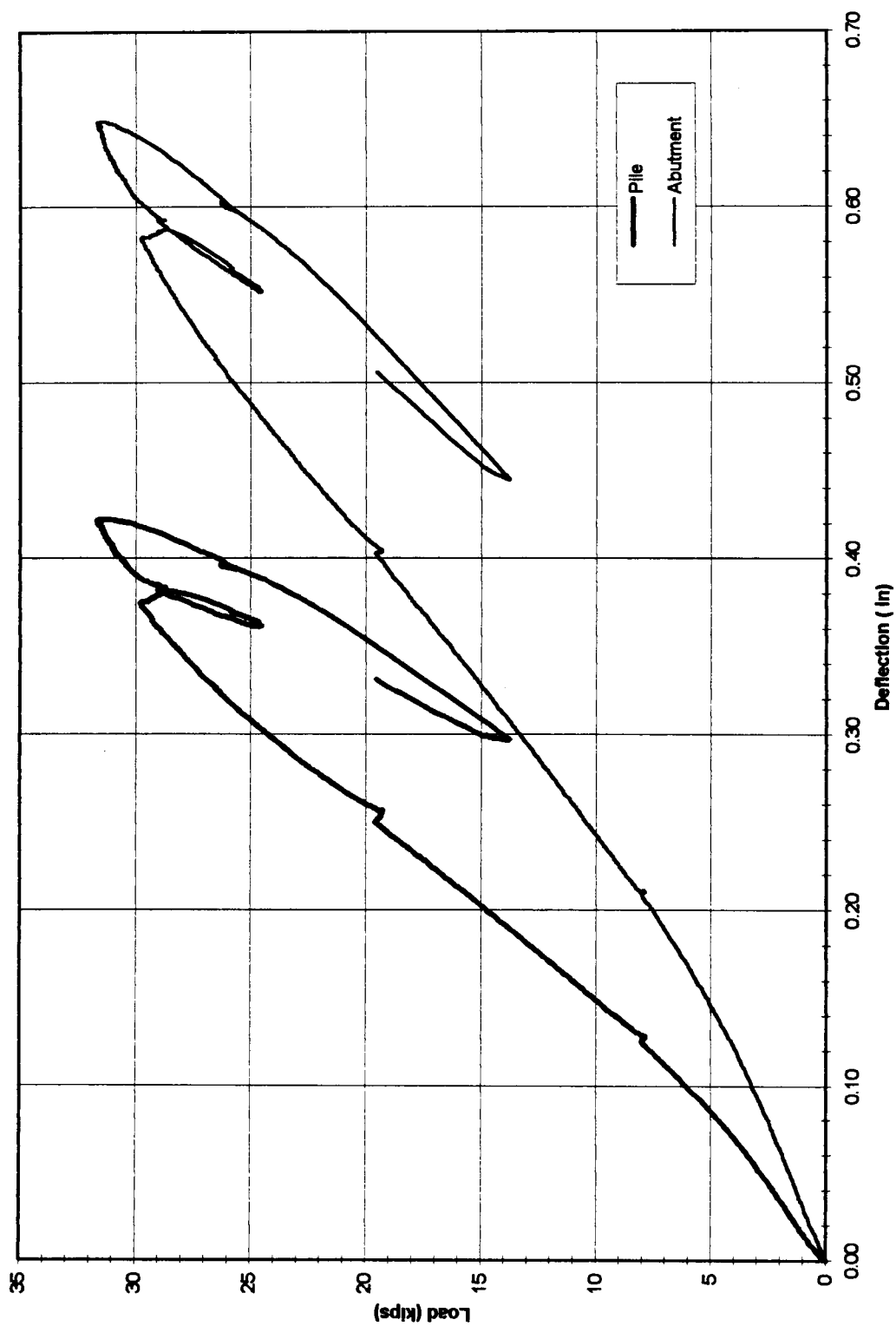


Figure 48. Load vs. Deflection. June 24, 1997 field test.

Vita

Laura Lynn Arico was born in Knoxville, Tennessee on November 22, 1973. She graduated from Farragut High School in 1991, and began her undergraduate studies at The University of Tennessee in August of that year. In December of 1995, she graduated with a Bachelor of Science in Civil Engineering. January 1996, she began her graduate studies, and received her Master of Science degree in Civil Engineering in August, 1997.