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PREFACE

The project was instituted solely as an instrumentation service to various AFSWP and FCDA structures design agencies. Originally, no formal project was organized for this purpose, but because the Ballistic Research Laboratories (BRL) electronic instrumentation is packaged in units of 20 recording channels each and must be protected by expensive blast shelters, it was apparent that efficient operation would often demand sharing of facilities among the various agencies to be served by BRL instrumentation.

To minimize the complexities of the administration and financial accountability that would occur if such an effort were not consolidated, a Memorandum of Understanding (Appendix A) between Field Command, AFSWP; FCDA; CETG; and BRL established a combined Project 3.7/30.5 to accomplish structures instrumentation for the various AFSWP and FCDA agencies. The duality of the assigned project number is a consequence of the projects being jointly supported by AFSWP and FCDA. All AFSWP funding was to Project 3.7 while FCDA funding was to Project 30.5. Support of Project 3.7/30.5 was in proportion to the number of instrumentation channels supplied each organization: the AFSWP share being 60 percent and the FCDA share being 40 percent. Instrumentation was installed for AFSWP Projects 3.1, 3.2, 3.3, and 3.6, and these projects were assessed the following proportions of the total AFSWP support; Project 3.1, 30 percent; Project 3.2, 5 percent; Project 3.3, 5 percent; and Project 3.6, 60 percent.

This AFSWP report is organized as a complete and detailed description of the BRL structures instrumentation program; therefore, it actually includes a report on the Project 30.5 portion of the BRL instrumentation effort, as well as of the Project 3.7 portion. In addition, appendixes based on this

report have been prepared for inclusion in the various project reports of the structures design agencies.

Grateful acknowledgement is extended to E. J. Bryant, Project Officer, Project 1.1, for his assistance and cooperation. Appreciation is also extended to LCDR J. F. Clarke, Director, Program 3, Field Command, AFSWP, whose cooperation and coordination proved very helpful.

CHAPTER 1

INTRODUCTION

Among the various damaging aspects of a nuclear detonation, air blast is one of the subjects studied. Two approaches to this study are necessary, one being an investigation of the characteristics of blast waves under various specified conditions and the second being an investigation of the effect of a given blast wave on various structures or structural components. This report is a discussion of the measurement techniques and procedures used by the Ballistic Research Laboratories (BRL) to enable the investigation of the loading or response, or both, of structural designs of several project agencies on Operation Plumbbob.

1.1 OBJECTIVE

The objective of the project was to provide instrumentation, electronic and self-recording, to obtain air blast and ground shock loading and response of structures for the various structures projects in Program 3, AFSWP (DOD) as well as for Programs 30 and 31, FCDA (CETG).

The scope of the program included installation of transducers, recording of transducer signals, and presentation of the recordings as linearized, time-dependent plots of the measured variable in the specified appropriate units. Measurements were obtained using both self-contained, direct-recording units and remote-recording magnetic-tape units. A total of 330 recording channels were supplied. Of these, 161 were magnetic tape, 127 were time-dependent self-recording, and 42 were peak indicating.

A tabulation indicating the general success of the instrumentation recording operations and a discussion of anomalies is presented. Finally, recommendations for more-effective instrumentation practices are listed.

WT-1426

[1959]

OPERATION PLUMBBOB - PROJECT 3.7

INSTRUMENTATION OF STRUCTURES FOR AIR-BLAST AND GROUND-SHOCK EFFECTS

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ABSTRACT

The objective was to provide instrumentation, electronic and self-recording, for obtaining air blast and ground shock loading and response of the structures employed by the various structures projects. Included was installation of transducers, recording of transducer signals, and presentation of the recordings as linearized, time-dependent plots of the measured variable in the specified appropriate units. A total of 330 recording channels were utilized; of these 161 were electronic recording on magnetic tape, 127 were self-recording time-dependent gages, and 42 were peak indicating.

A basic description of the instrumentation employed by the Ballistic Research Laboratories during Operation Plumbbob in taking these structural measurements for Projects 3.1, 3.2, 3.3, 3.6, 30.1, 30.2, 30.3, 31.4 and 31.5 is given in this report. Self-recording gages for measuring peak pressures, pressures versus time, dynamic pressures versus time, and displacement versus time are described; electronic gages for obtaining time-dependent records of pressure, dynamic pressure, acceleration, displacement, and earth pressure are described.

For each type of gage, details are given on the recording mechanism, transducer element, gage mount, calibration, and data presentation. Also, a plot of the field layout is shown.

1.2 BACKGROUND

The history of BRL participation in nuclear testing extends from Operation Sandstone. During that operation mechanical self-recording and peak-indicating gages were used, but beginning with Operation Greenhouse, various systems of electronic recording have been utilized. All measurements taken by BRL previous to Operation Upshot-Knothole (i.e.,Operations Sandstone, Greenhouse, Buster-Jangle, and Tumbler-Snapper) were free-field measurements concerned with blast-wave characteristics. For Operation Upshot-Knothole, however, BRL obtained and rebuilt the Webster-Chicago magnetic-tape recording equipment used by Sandia Corporation during Operation Greenhouse and utilized this for an extensive structures instrumentation program. (Meszaros, J.J. and Randall, J.I.;"Structures Instrumentation"; Project 3.28.1, Operation Upshot-Knothole, WT-738, June 1953; Confidential Restricted Data). Before Operations Teapot and Redwing, further improvements in this equipment were made, and during those operations, the equipment was used for both structures measurements and free-field measurements. During Operation Teapot, several standard commercial recording oscillograph units were also used for recording data similar to that recorded on the Webster-Chicago equipment; however, these units did not prove to be as rugged, reliable, or versatile as the modified Webster-Chicago Recorders.

Each Webster-Chicago electronic unit records 20 channels of information on a magnetic tape 35 mm wide. To each channel a phase-modulated information signal and a reference signal are supplied. Phase modulation is obtained by combining the 3,750-cps amplitude-modulated output signal from the gage with another signal of 3,750 cps but 90 degrees different in phase. The reference signal (7,500 cps) is mixed with the information signal, and the two are amplified and recorded simultaneously on the same magnetic track. Thus, the reference signal is subjected to exactly the variations in amplification or tape characteristics experienced by the information signal and their relative phase is maintained unchanged. In addition, an Edgerton, Germeshausen and Grier, Inc. (EG&G) Blue Box was used to produce a sharp, amplitude-modulated zero-time marker, which was recorded on one magnetic track set aside for the purpose.

The playback system later recovers the information from the magnetic tape by separating the reference and the information signals and applying them to a phase discriminator that produces an output voltage proportional in magnitude to the tangent[1] of the measured variable. Also, timing pulses are derived from the 7,500-cps reference signal. The signal, the timing pulses and the zero time marker are then recorded on an oscillographic recorder to produce a final record.

During the operations prior to Upshot-Knothole, the disadvantages of electronic instrumentation for field work became apparent. Such systems were expensive, cumbersome to install, time-consuming to adjust, and often highly sensitive to conditions normally encountered in field work. The desire for a more-adaptable system led to several designs for completely

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[1]Operation is normally in the linear portion of the curve of ϕ versus tan ϕ where ϕ is the measured variable, so that output is directly proporational to the measured variable.

self-contained, mechanical gages capable of recording pressure as a function of time for use during Operation Upshot-Knothole. The success of these gages then prompted the design of standard models of a self-recording overpressure-versus-time gage and a dynamic-pressure-versus-time gage.

In these, a precisely governed, battery-operated motor rotates an aluminized glass disk. A stylus attached to a compact metal bellows element traces on the rotating disk a record of the dilations of the bellows as they are subjected to the pressures of the blast wave. In this way a time-dependent record of the blast pressure is impressed on the disk. The motor is set in operation by a signal received from a thermal or a photo initiation circuit or remotely by wire from timing relays. Gages, the essentials of which are described above, were used with great success during Operation Castle. Since then, the gages have been refined in many minor, but important aspects; they have been used with continuing success under a wide range of conditions during Operation Teapot and Redwing. Because of their relatively low cost, they may be used in larger quantities as required in the field wherever anomalies are to be expected. Also, because of the ease of installation, ruggedness, and versatility of these gages, they may be reused on consecutive shots and rapidly adapted to changeable field schedules.

However, there are certain instrumentation measurements for which a better time resolution is required than can be provided by the self-recording gages. In such cases, electronic recording instrumentation must be utilized.

Extensive use was made of both electronic and self-recording gages in this structure-instrumentation effort.

CHAPTER 2

OPERATIONS

The instrumentation systems used were of the two general types: electronic recording and self-recording. Both types were used to obtain a variety of required measurements for the various structures project agencies. Explicit and detailed coverage of the two recording systems is presented in the following order: (1) self-recording gages, (2) electronic recording gages, (3) transducers, (4) gage mounts, (5) calibration, and (6) data presentation.

2.1 SELF-RECORDING GAGES

2.1.1 Physical Configuration of Pressure-Time Gage. The recording mechanism for the pressure-time gages was enclosed in a heavy, air-tight case (Figure 2.1), the top of which acted as a baffle plate. Each baffle plate had holes drilled in it for housing the photocell and the thermal initiator plunger. It also had holes to allow the blast pressure to reach the recording capsule and for the gage arming screw. The pressure hole was covered by a small screen at the top to prevent the entrance of dirt and to assist in damping capsule oscillations. The recording capsule was mounted on the inner side of the baffle plate; near it, on the same side, was welded a short length of channel iron, which served as a chassis for the turntable assembly and initiation circuits (Figure 2.2). The turntable assembly consisted of the motor, shaft, angular-contact ball bearings, and a dural turntable. Also attached to the chassis was a star-cam counter, which limited the rotations of the turntable to a predetermined number.

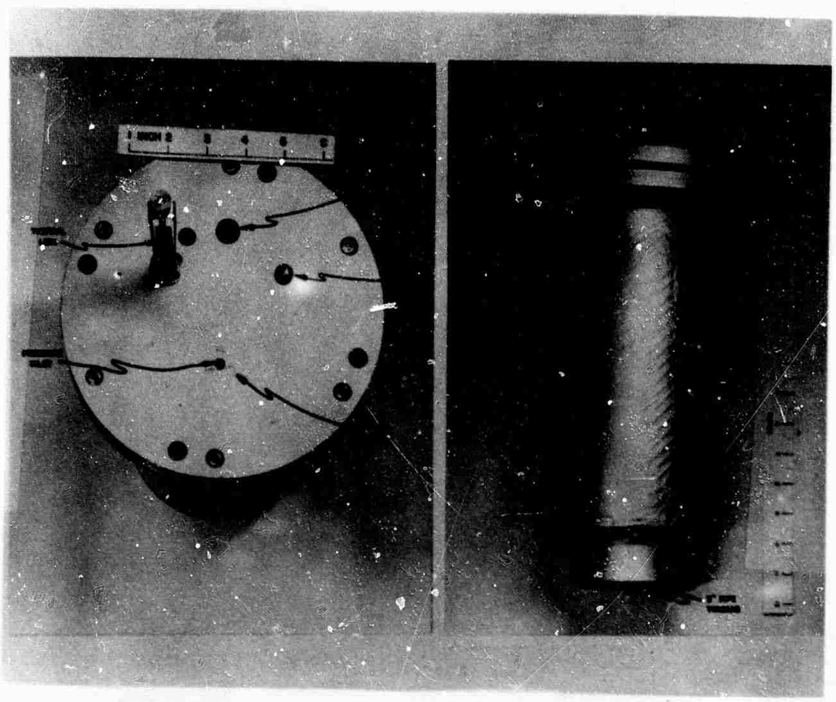

Figure 2.1 Pressure-time gage enclosed in casing.

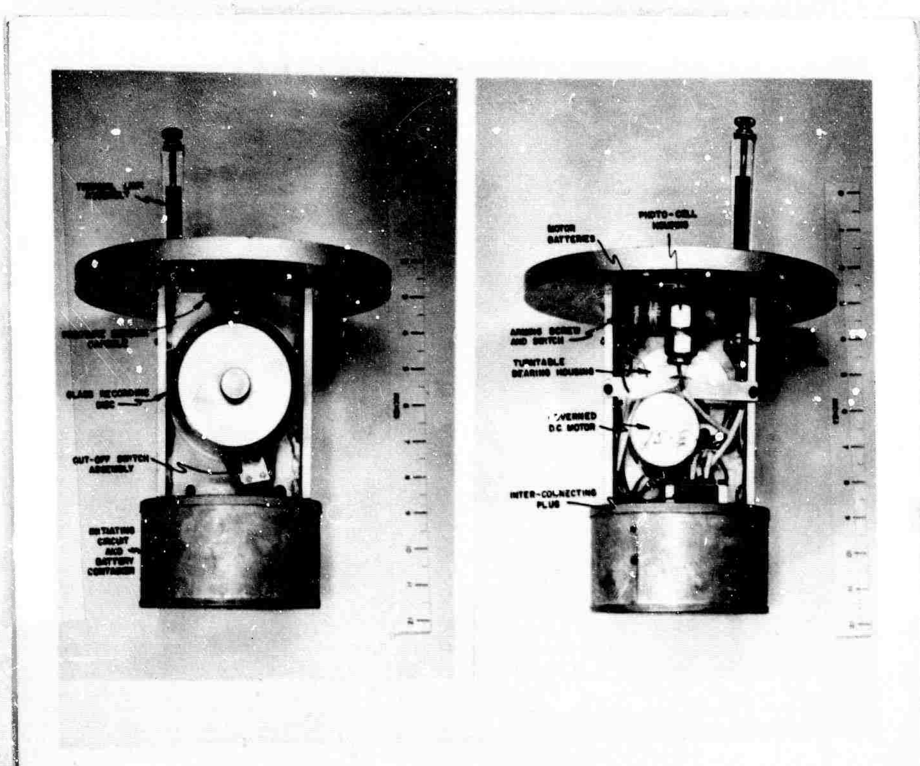

Figure 2.2 Pressure-time-gage recording mechanism.

The entire design of the recording mechanism was such as to reduce its sensitivity to acceleration. The use of the angular-contact bearings in the turntable assembly allowed the shaft to be secured against either axial or transverse motion, and the use of dural in the turntable and shaft reduced the distorting forces in these members.

Drop tests and shake-table tests showed satisfactory operation of the gage at 50g, in that latching relays did not release, motor speed was essentially unaffected, and turntable vibration was acceptably low. At higher accelerations, up to 80g, motor speed varied up to 5 percent, and often the glass recording disks broke.

2.1.2 Disks. The basic recording medium of the self-recording equipment was an aluminized glass disk or plate on which a trace of the motion of a mechanical transducer element was scratched by an osmium-tipped stylus. With accurate regulation of the manufacturing process by which the glass disk or plate was given its aluminum coating and careful control of the recording stylus pressure, trace widths of less than a thousandth of an inch could be obtained.

Two types of self-recording gages were used: one which utilized a stationary aluminized glass plate to record the maximum excursions of the sensing element, and one which utilized a rotating glass disk to obtain a time-dependent record of the motion of the sensing element.

2.1.3 Drive Motor. The drive motor that turned the disk (Figure 2.3), was an A. W. Haydon Company Model A-5615 "chronometrically governed" DC electric motor. It used a self-contained, oscillating balance wheel to

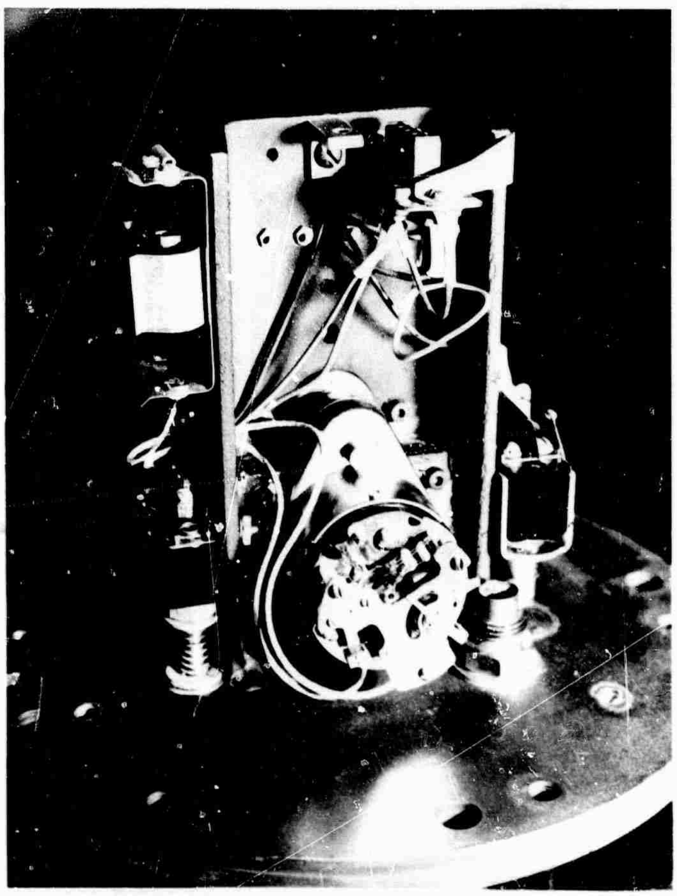

Figure 2.3 Disk-drive motor for self-recording gage.

generate a simple-harmonic reference. The rotation of the motor was translated into simple-harmonic motion, and the phase of this was compared with the phase of the reference by a pair of electrical contacts, one of which was actuated by the reference generator and the other by the motor. The contacts were so arranged that, when closed, they directly bypassed a series resistor through which current to the motor was fed. The relative phase of the simple-harmonic motions of the two contacts determined by the portion of a cycle during which the contacts, being simultaneously actuated, bypassed the resistor and, consequently, determined the total power delivered to maintain a constant speed of rotation.

Motors having rotational speeds of 3, 10, and 40 rpm were used, depending on the application and time resolution required. These were also the obtainable turntable speeds for all except the dynamic-pressure gages. The latter gages incorporated a two-to-one speed reduction, which, with motor speeds of 10 and 40 rpm, gave turntable speeds of 5 and 20 rpm. The motor was powered by an 8-volt mercury battery capable of running the motor at full load and rated speed for over 6 hours.

2.1.4 Initiators. The motor was set in operation by one of two self-contained initiator circuits used contemporaneously or, alternatively, by a signal transmitted by wire from a central control point with the self-contained circuits used for backup.

The self-contained circuits operated on reception of either thermal or visible radiation from the detonation. An electronic initiator, sensitive to the bomb light, used a cadmium sulfide photo-cell and latching relay circuit.

The light was guided to the photocell by a vertical length of 5/16-inch lucite rod. The rod was ground to a 45-degree bevel at the end, where the light entered to allow more efficient light capture. Only the voltages produced by transient light pulses were amplified to close the relay. In addition to the control contact the relay was fitted with a pair of contacts which, when closed, caused a high current to flow through the relay coil, thereby holding the relay closed.

The second self-contained initiator consisted of a spring-loaded plunger held cocked by a thermal link made of two brass strips soldered together with low-melting-point solder and painted black. Thermal radiation falling on this initiator rapidly heated it, and when the solder reached a temperature of 169°F the brass strips parted and allowed the spring to press the plunger against a microswitch, thereby starting the motor.

2.1.5 Start-Up Time. Because of inertia and the time needed for establishment of the proper phase relationships in the governor, the motors do not reach a stable speed immediately. The 3-rpm motors reach their rated speed in 90 msec but oscillate about that value for an additional 300 msec. The 10-rpm and 40-rpm motors reach their speed gradually and without instability in 400 msec.

2.1.6 Hard-Wire Initiation. To prevent distortion of the record along the time axis, all gages used for diffraction studies in areas where blast arrival times are less than 400 msec were initiated previous to zero-time by a signal transmitted by wire from one of the BRL instrument

instrument shelters[2]. This signal was produced by the closure of a standard Edgerton, Germeshausen and Grier (EG&G) timing relay at minus 5 seconds and was used to close the electrically latching relay normally used with the photocell. The operation of this relay was duplicated by a second relay at minus 1 second. The self-contained initiating circuits were retained for backup in case the hard-wire signals failed.

2.1.7 Physical Configuration of Dynamic-Pressure Gage. The dynamic-pressure-time gage was a pitot-static tube that used separate pressure-sensing elements to record the stagnation pressure and the side-on pressure. The gage is pictured in Figures 2.4 and 2.5. A hole, 5/32 inch in diameter, was drilled down the axis of the nose section to transmit the stagnation pressure to the appropriate capsule. Also, a hole 1/8 inch in diameter transmitted the side-on pressure to the other capsule. The two capsules were mounted at right angles to one another in a hollowed-out portion of the nose section. The styluses of the two capsules were arranged so that both could make their traces on the same disk. The two traces were made at different radiuses, and events recorded by the two styluses appeared simultaneously on the disk but separated circumferentially by 90 degrees.

The end of the nose section containing the recording mechanisms screwed

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[2] This requirement was placed on all gages for Project 3.6/30.1. All other gages supplied by Project 3.7 were either outside the 400-msec range or were for the pressure measurements that did not require the accuracy of timing needed for diffraction studies.

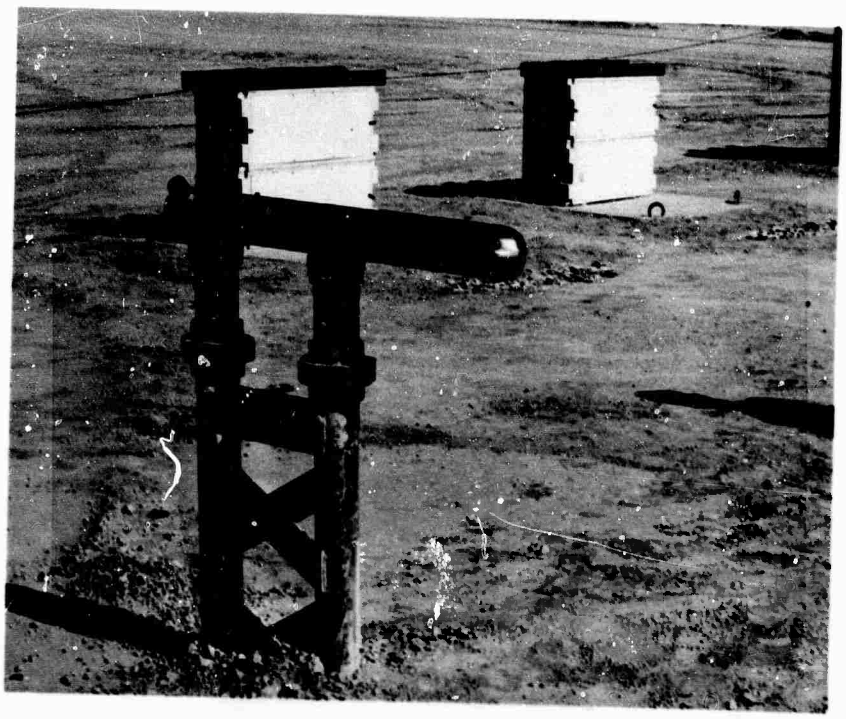

Figure 2.4 Fully assembled dynamic-pressure gage.

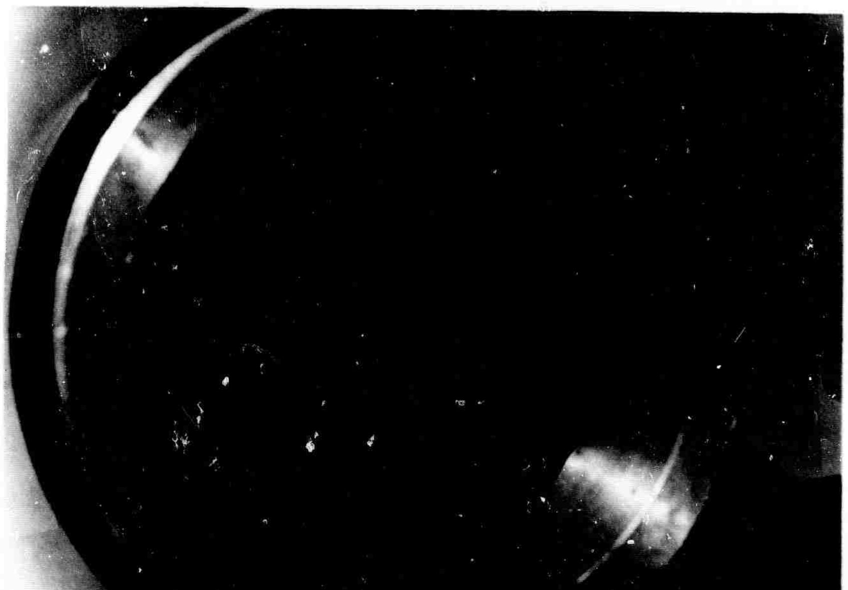

Figure 2.5 Hollowed-out portion of dynamic-pressure-gage nose section.

into a hollow, cylindrical section, which contained the motor power supply and initiation circuits. Also, two pipe nipples were welded to the outside of the casing and, by means of pipe unions, served to attach the dynamic-pressure gage to its mount.

The thermal initiator used was similar to the one used for the pressure-time gage, except it used a phototube detector, a sensitive relay, and a mechanically latching relay. The initiator circuitry was all mounted on a plexiglass "sled" (Figure 2.6) which fitted inside the casing. On the rear of the sled, a panel was mounted with three switches and four pin jacks. This arrangement allowed a quick and complete check of all the gage circuits and convenient arming of the gage just prior to the test. The rear end of the hollow casing was sealed by an aluminum plate, after testing and arming were completed.

2.1.8 Physical Configuration of Displacement-Gage Mechanism. The recording mechanism for the displacement gage (Figure 2.7) was similar to the others. The entire assembly mounted as a unit inside the gage case (Figure 2.8). The governed motor drove a ball-bearing-mounted turntable, and a machined screw converted the rotary motion of the gage pulley to a small, linear motion of the stylus.

2.1.9 Self-Recording Accelerometers. A self-recording accelerometer was developed on an experimental basis following the lines of the self-recording pressure gage (Figure 2.9). The chassis for the turntable assembly was milled from solid steel stock to produce a more-rigid assembly. The motor and disk were mounted as in the pressure gage. The accelerometer element consisted of a cantilever beam with a weight attached to its free

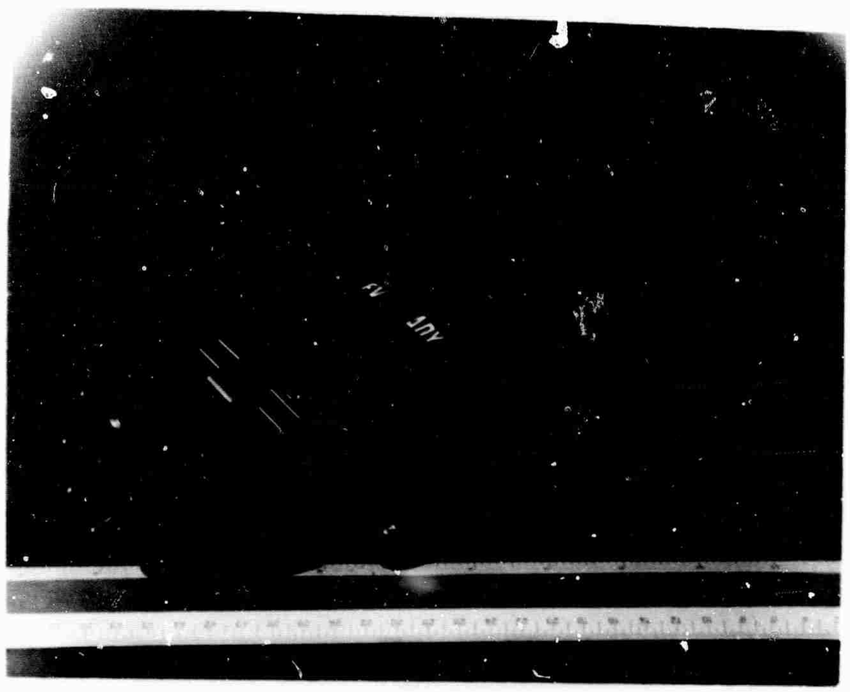

Figure 2.6 Dynamic-pressure-gage power supply and initiator chassis.

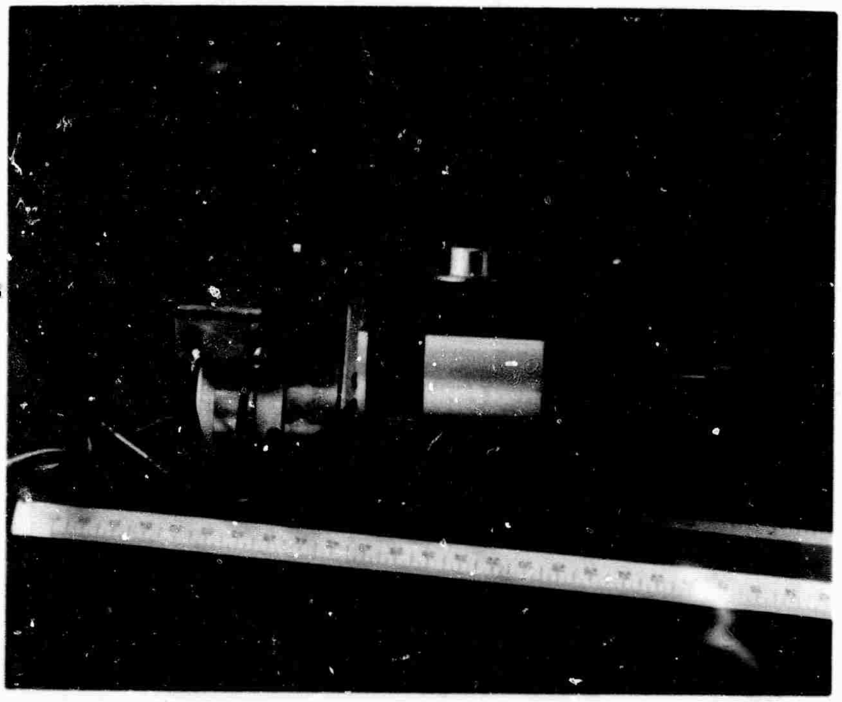

Figure 2.7 Self-recording displacement-gage recording unit.

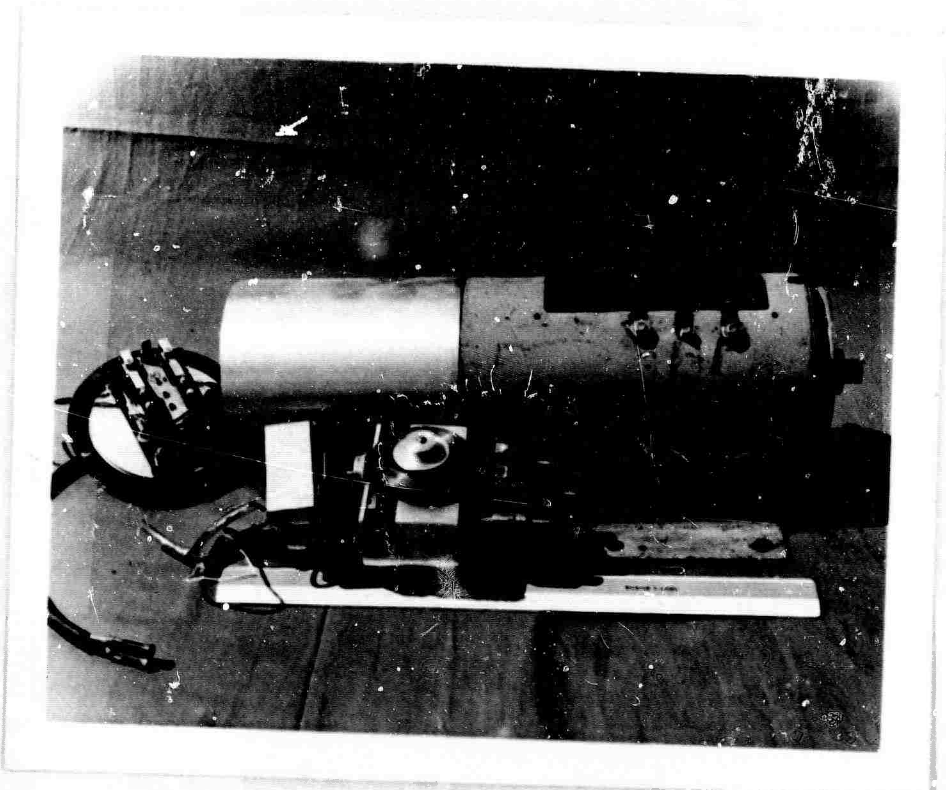

Figure 2.8 Assembled self-recording displacement gage.

Figure 2.9 Self-recording accelerometer.

was attached to the gage chassis so that, as the weight oscillated in the plane of the disk, the stylus scratched a record of its excursions on the disk. Each beam was shaped to prevent oscillations in any direction except that desired. The gage mechanism was covered by a light sheet-metal cup. The accelerometer baffle plate fit the standard pressure-time-gage casing so that, where high blast pressures were expected and the additional weight of the casing was not detrimental, these casings were used to protect the gage mechanism. All self-recording accelerometers were hard-wire initiated.

2.1.10 Peak-Pressure Gages. Two types of gages were used in taking measurements of peak pressure. One of these was a conventional pressure gage from which the motor and initiation circuits were missing and in which the turntable was blocked to prevent its movement. A round glass disk was used as the recording medium.

The other was a smaller gage designed for the specific purpose of taking peak measurements. This gage had a baffle plate the size of those used on the pressure-time gages, and the pressure capsule was mounted similarly. The recording medium was a 1/2-by-1-inch aluminized glass rectangle glued to a movable block. The block was put in place under the capsule stylus, moved to produce a zero-deflection marker, and then locked in place by means of screws. In this way, peak positive and negative excursions of the capsule were registered. A heavy, steel cup was bolted over the mechanism to maintain it at a constant pressure during passage of the blast wave (Figure 2.10).

2.1.11 Peak Accelerometers. The peak accelerometer was basically the same as the peak-pressure gage. A heavy milled block was welded to a 4-inch-

Figure 2.10 Peak-pressure gage.

diameter base plate, and the accelerometer element (Section 2.1.9) was attached to the milled block (Figure 2.11). The recording blank (Section 2.1.10) was glued to a sliding carriage, which after calibration, was secured to the milled block by screws. After the accelerometer element was installed so that its stylus would produce a trace on the recording blank, the sliding carriage with the blank attached was moved to obtain a fiducial mark. The mark served as a reference from which the positive and negative acceleration records were read. The movable, sliding carriage was then locked into position.

2.1.12 Peak-Displacement Gage. The peak-displacement gage consisted of two parts: an aluminum rod welded to a circular aluminum base and a plate drilled to allow the rod to pass through freely. The plate had a spring-loaded knife edge attached, which scratched the moving rod. For installation, the rod assembly was attached to the moving member,

Figure 2.11 Peak accelerometer.

the drilled plate was slipped over the rod, and the plate was then attached to a stationary reference point. After the gage was positioned, the rod was painted with black paint; thus, when the rod was activated by the blast, the knife edge scratched a record of the maximum position and negative deflection.

2.2 ELECTRONIC RECORDING GAGES

2.2.1 Recording Mechanism. Each electronic recording system was, basically, a 20-channel, phase-modulated-carrier, magnetic-tape recorder. It was designed for use with gages based on passive impedance elements, which modify a constant input voltage as a function of the physical activation being measured. A block diagram of the circuitry is shown in Figure 2.12.

Each gage contained, or was used in conjunction with, a full-reactance bridge that was balanced when no physical activation was applied to the gage. In case such balance were not inherent in the gage, provision was made in the coupling unit for simulating unequal reactances in adjacent arms of the bridge, whereby it could be balanced. The power supply produced an alternating input (E_1) having a crystal-controlled frequency of 3,750 cps and a potential of 18 volts, which was fed to the balanced bridge in each gage through its coupling unit. The phase of the voltage measured across the gage was determined by a phase-shift network in the coupling unit and by the reactances in the gage and its cable.

When physical activation was applied to the gage, the bridge became unbalanced, and the output of the gage changed from zero volts, its balance value, to a small (hundredths of a volt) value (E_0). This voltage was closely proportional to the magnitude of the unbalance and was dependent on E_1.

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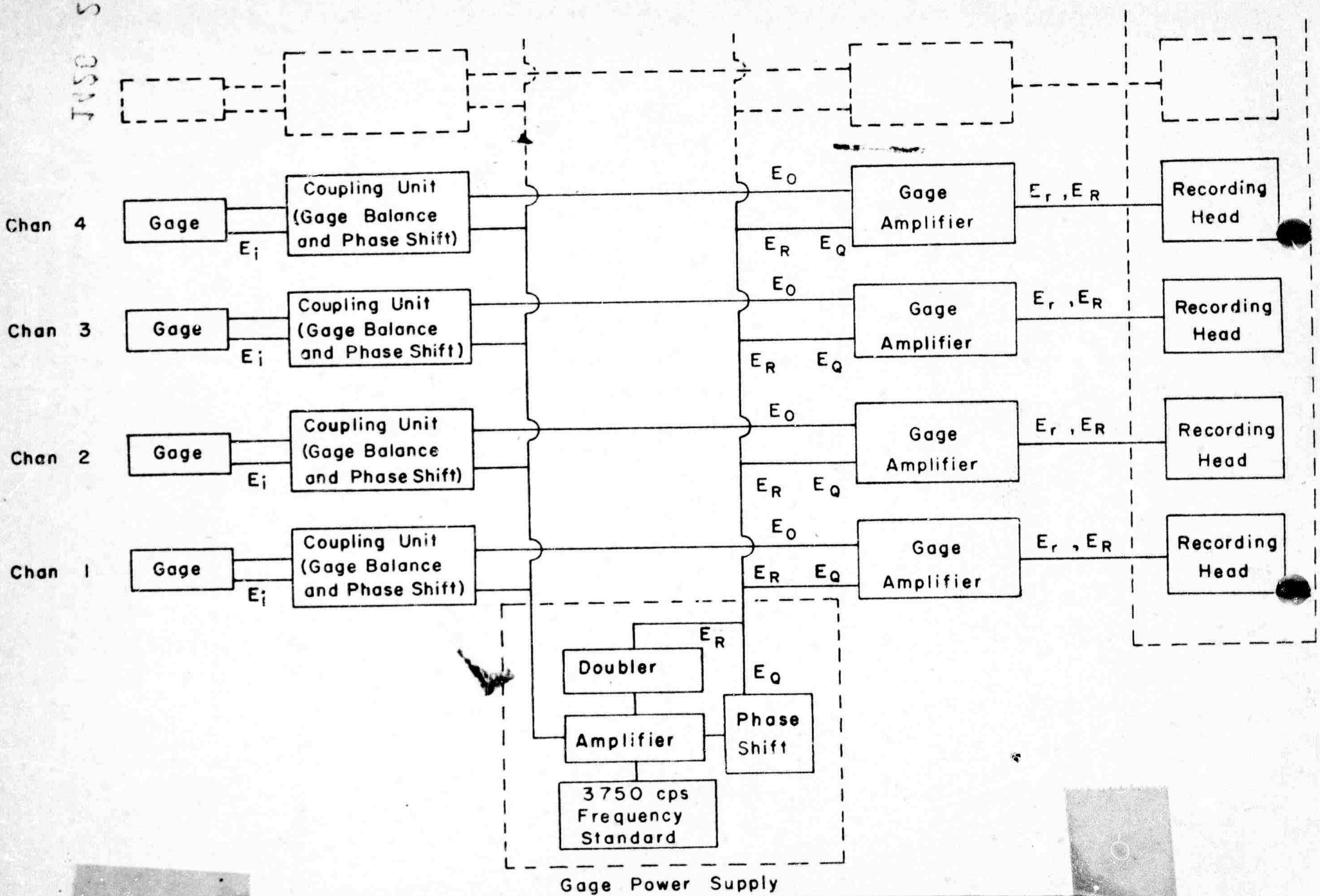

Figure 2.12 Referenced, phase-modulated recorder circuitry.

The gage-output voltage, E_o, was fed through a 1-to-10 transformer into the gage amplifier. In the first stage of this amplifier E_o was combined with a 3,750-cps quadrature voltage (E_Q) and a fixed voltage (E_R), twice the frequency of E_Q and of fixed phase. These voltages were derived from the same supply as E_i and, in the event of any small amplitude or frequency fluctuation in E_i, were affected proportionally.

The quadrature voltage was so called because its phase differed from that of E_o by 90 degrees. This phase shift was obtained by the combined effect of three phase-shift networks. The first of these, incorporated in the power supply, also determined the phase relationship between E_Q and E_R. The second network was incorporated in the coupling unit and gave the additional phase shift necessary to obtain, approximately, the total 90-degree shift. The third network, included in the amplifier, provided a fine adjustment for setting exactly the 90-degree shift.

The voltage-vector diagram of Figure 2.13 shows how E_o and E_Q combine

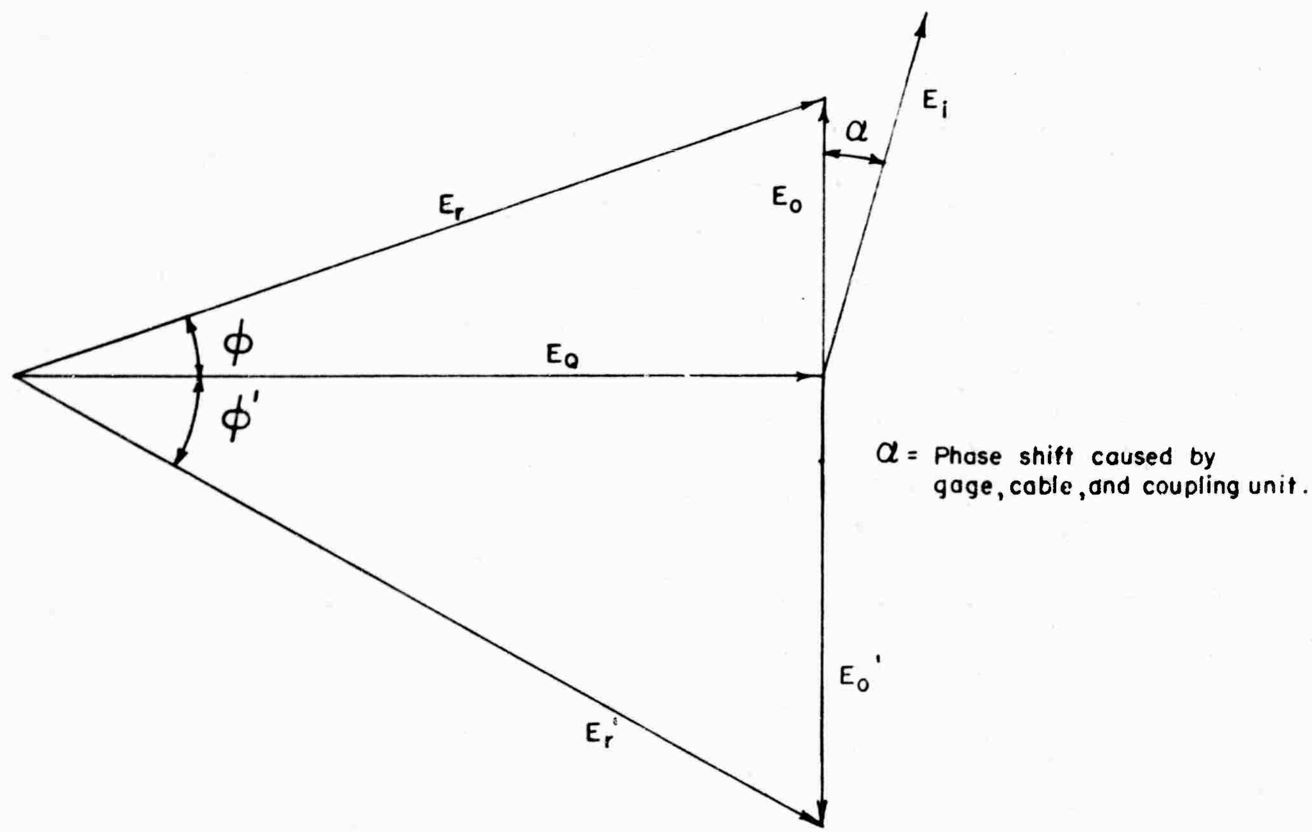

Figure 2.13 Voltage relationships in referenced, phase-modulated recorder.

to form a resultant voltage, E_r, having a phase angle, ϕ with reference to E_0. When E_0 is a continuously varying voltage, ϕ is, then, a continuously varying function of E_0 and $\phi = \arctan (E_0/E_R)$

The voltages E_r and E_R are then amplified ten times and impressed on the recording head. These two voltages are simultaneously recorded by the same head on the same strip of tape. This process distinguishes the recording system for the voltage E_R, which is the reference on which interpretation of the recorded signal E_r depends, is subject to precisely the same recording and playback variations as the signal itself. The variations mentioned are changes in spacing between recording head and tape, differences in thickness and sensitivity in adjacent regions of the tape, and weaving of tape and variations in speed as the tape is transported through the head. These variations seriously afflict amplitude-modulated and unreferenced or separately referenced phase systems.

2.2.2 Play Back. The data recorded on the tape is in the form of a phase-modulated signal, which is not directly useable until it is passed through a phase discriminator and converted to an amplitude-modulated signal.

A block diagram of the entire play-back unit is shown in Figure 2.14 The play back uses the same head and transport mechanism used in recording, however, a different drive motor is used and pulls the tape through at half the recording speed. Thus the signal voltage E_r appears with a mean frequency of 1,875 cps and the reference voltage E_R, with a frequency of 3,750 cps. These two voltage components are separated by band-pass filters, and the output of each filter is then differentiated to give a series of alternately

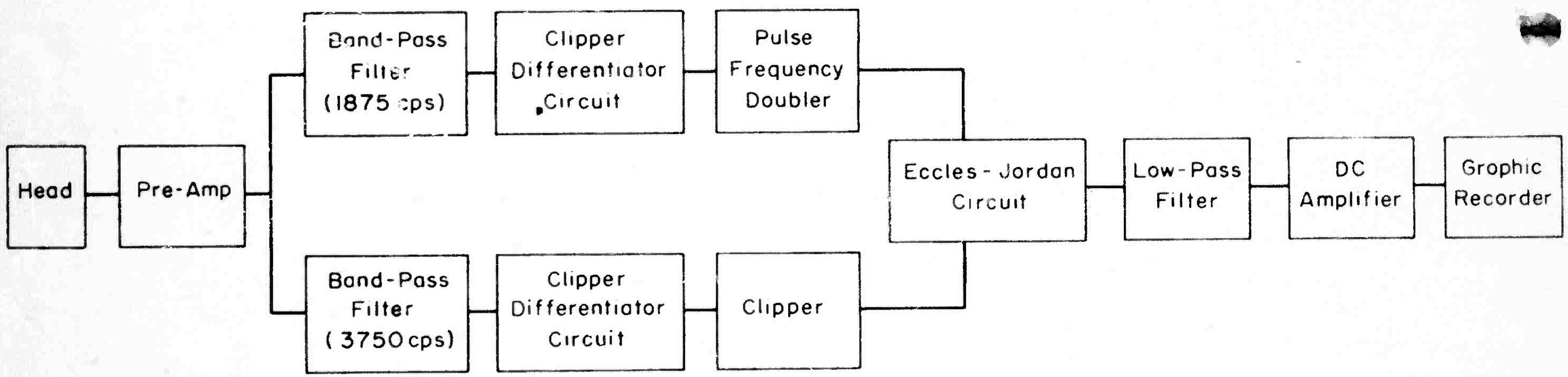

Figure 2.14 Circuitry of play-back unit for referenced, phase-modulated records.

positive and negative pulses having repetition rates and phases identical with those of input signals. The set of pulses corresponding to E_r is passed through a circuit that separates the positive pulses from the negative, inverts them, and recombines them to give a series of negative pulses having a mean repetition rate of 3,750 cps and phase shifts proportional to those of E_r. The set of pulses corresponding to E_R is passed through a circuit that removes all positive phases and gives a series of negative pulses having a repetition rate of 3,750 cps.

The pulses are amplified, clipped, and sharply differentiated in the pulse-generator circuits. The resulting spikes are fed into the two control grids of an Eccles-Jordan "flip-flop" circuit; the E_r spikes going to one grid and the E_R spikes going to the other. The constant phase E_R spikes turn the flip-flop "on" and the varieble phase E_r spikes turn it "off".[3] The resulting rectangular wave train is fed to a low-pass filter, which produces a voltage output proportional to the "on" time of the flip-flop. The 500-cps cutoff of the filter is sufficiently high to allow data containing frequency components up to 400 cps to be passed without serious attenuation.

The output voltage, being directly proportional to ϕ, is proportional to the tangent of the magnitude of the physical activation measured. When ϕ is kept sufficiently small by proper choice of the voltage E_o

$$\tan \phi = \phi$$

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[3] The terms "on" and "off" were arbitrarily chosen to differentiate between the two stable states assumed by the "flip-flop" circuit.

and the operation is essentially linear; however, the system is always calibrated to provide added precision and to allow satisfactory treatment of over load signals.

Minor additions to the system as described allow an accurate timing system to be included. The output of a standard EG&G Blue Box was fed directly to an auxiliary recording head, which put a sharp zero-time fiducial marker on the tape. During play-back, the pulses formed from the reference voltage E_R were fed into a series of decimal divider circuits which produced a set of pulses having a repetition rate of 375 pulse/sec[4]. Every tenth one of these pulses was doubled in magnitude, and every hundredth pulse was tripled.

<u>2.2.3 Electrical Calibration Steps.</u> The calibration of the system was performed as much as 2 or 3 weeks before the actual test. To take into account any system-sensitivity differences which might have occurred in that time, provision was made for shunting a fixed resistor or inductance across one of the gage bridge elements. This simulated an activation of the gage, the magnitude of which was dependent on the size of the resistor or inductance. The simulated activation was produced just prior to calibration and again, just prior to the test. If the simulated-activation amplitude was small enough to keep it within the linear range of the recorder, the signals produced in the play back were proportional to the system sensitivity at each time, and the proportionality factor indicated could be applied directly to the linearized record (see Section 2.6.2). These signals appeared on each finished oscillogram as "Electrical Cal Steps".

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[4]This corresponded to a repetition rate of 750 pulse/sec at recording speed.

2.2.4 Data Presentation. The final presentation of the data was obtained by applying the three signals - data, zero time marker, and timing pulse - to three galvanometers, in a photographic paper graphic recorder.

2.2.5 System Details. The tape used was of 35-mm-width, iron-oxide-coated mylar. It was pulled during recording by a capstan drive at a speed of 28 in/sec. The heads were incorporated in two blocks of eleven each, displaced in relation to the tape so that 22 record tracks in all were produced (interspaced) on the tape. Twenty of these tracks were used for recording data, and one (at the edge of the tape) was used to record the zero time pulse. The remaining track was not used. Bias coils were provided in each head, but were not used. The gage amplifiers and the gage coupling unit were all separate, one of each being used for a channel. These were housed in racks on blocks of twenty each.

The drive motors operated from 28 volts direct current, which was supplied by storage batteries. The tube filaments and high-voltage-supply dynamotors operated from these batteries also.

The recorders have shown themselves to be reliable: Few failures have occurred, and the accelerations to which they were subjected during the passage of ground shock and blast waves have produced only small transient effects.

2.2.6 Blast Shelters. Recording equipment was housed in blast shelters (Figures 2.15 and 2.16), partially or completely buried. The shelters were

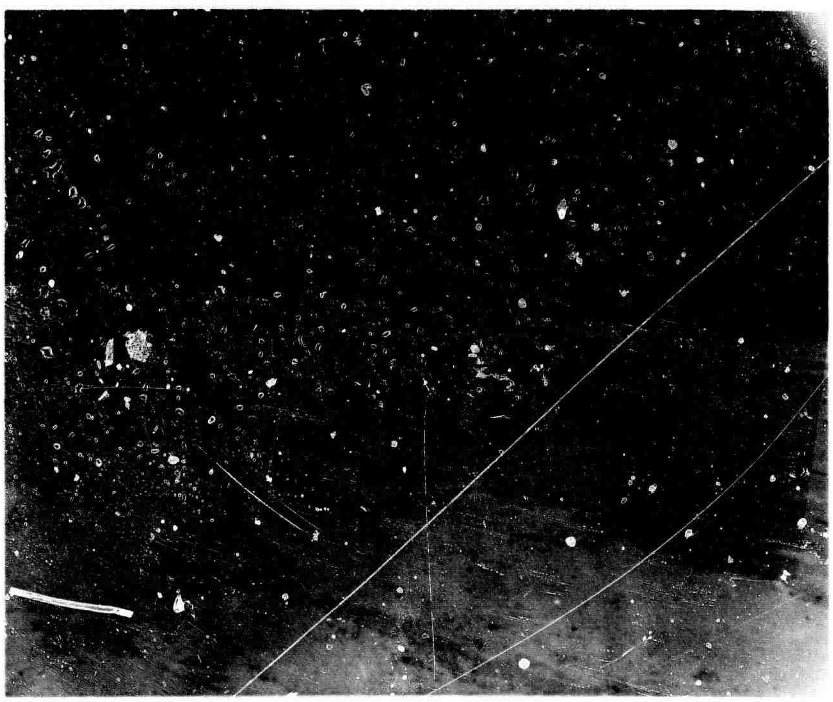

Figure 2.15 External view of blast shelter.

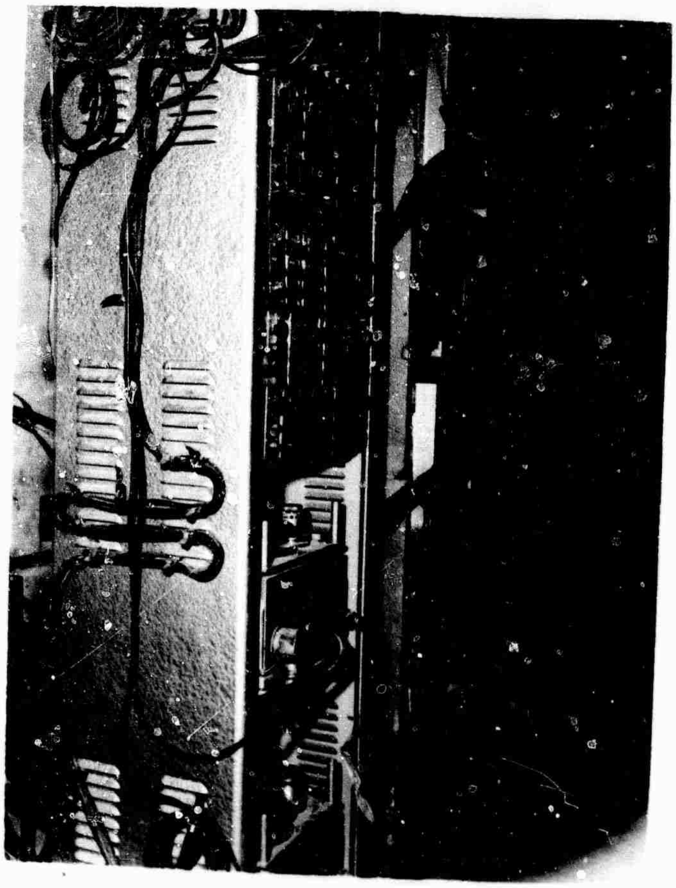

Figure 2.16 Recording equipment installed in shelter.

placed at a maximum of 1,500 feet from the gages, and generally, at a distance from ground zero greater than the corresponding distance from gages to prevent complete loss of records should the passing blast wave over the shelter cause failure of recorders. Standard 110 volts alternating current was supplied for operation of the recorders during the period of preparation prior to the test. This voltage supply was not relied on during the test: Battery supplies were used in all cases.

2.2.7 Initiation. Initiation and control of the recorder operation was by means of timing signals supplied by EG&G Project 9.2.

The EG&G installation consisted of the proper timing lines run into the shelter and five relays, one being provided to close at each of the following times: minus 30 minutes (that is, 30 minutes before the instant of detonation), minus 15 minutes, minus 15 seconds, minus 5 seconds, and minus 1 second. EG&G guaranteed the closure of each relay. But since EG&G gave no promise that the relays would remain closed, they were connected to operate latching relays in a sequence-timer unit. The closure of the latching relays then activated the recording equipment.

The signal that closed the minus-30-minute relay actuated the latching relay, connecting the 28-volt battery to the amplifier filaments and to the high-voltage power supplies. To prevent loss of records in case of failure or ineffectuality of this signal, closure of the minus-15-minute relay applied excitation to another latching relay, which duplicated the operation of the first.

Two more operations were necessary, and the three remaining relays were provided to insure their being performed. Normally, the first operation was effected by the minus-15-second closure. This operation consisted of activating the "Electrical Cal Step" relays and the tape drive motors. The minus-5-second closure had, as its prime purpose, the initiation of a 2.5-second time-delay but was also capable of performing the function of the minus-15-second closure if the latter should fail. The 2.5-second-delay relay removed the "Electrical Cal Step" and started an auxiliary timer. The minus-1-second signal duplicated the operation of the time-delay relay.

After two minutes, the auxiliary timer applied and removed a postshot "Electrical Cal Step", stopped the tape, and removed power from the system.

2.3 TRANSDUCERS

2.3.1 Self-Recording Pressure Element. Two views of the self-recording pressure element used in the pressure-time and dynamic-pressure gages are shown in Figure 2.17. Basically, this element is a chamber formed by the welding together at their edges of two diaphragms, each of which is impressed with a series of concentric corrugations. Pressure is transmitted to the inside of the element through an inlet port, which passes through a heavy, brass mounting flange. In operation, the element is mounted on the inside of the gage baffle plate with the inlet port of the element lining up with the pressure hole in the baffle plate. Thus the blast pressures are transmitted to the inside of the element while the outside is held at the constant pressure sealed inside the gage casing (Section 2.1.1). This causes the element to bulge and move the stylus out from the element mount a distance dependent on the pressure.

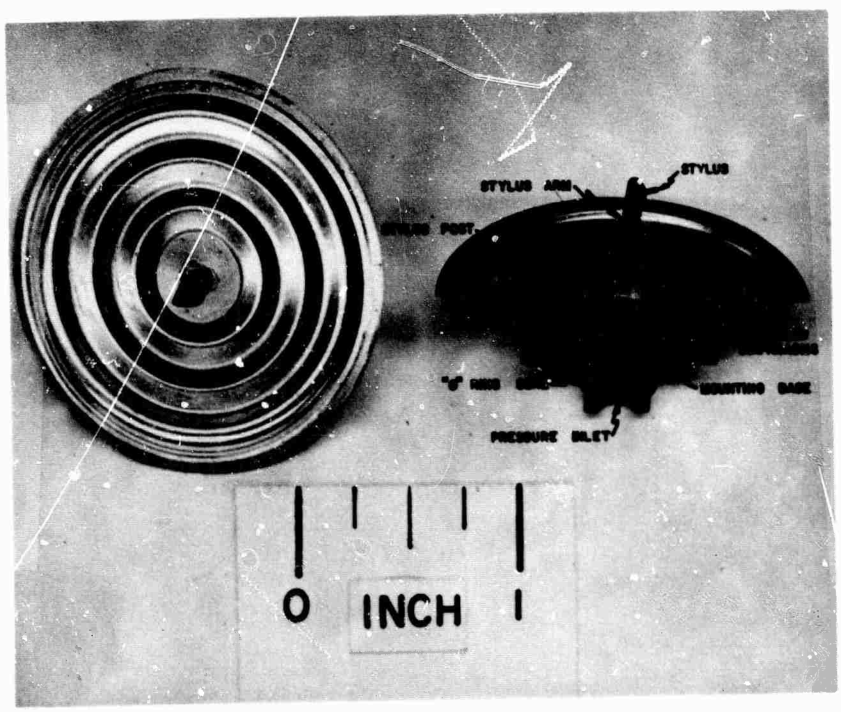

Figure 2.17 Self-recording-gage pressure element.

Without the concentric corrugations, elements of this type display severe nonlinearity of deflection versus pressure. In a corrugated element, however, each of the sections bounded by one of the corrugations is sensitive to essentially one small range of pressures and responds linearly over that range. Over the total range of the element, which is the sum of the ranges of all the sections, the response is, then, practically linear. The actual value of linearity is ± 0.5 percent.

To ensure a minimum element volume, with a corresponding short fill time, the corrugations of the two diaphragms forming the chamber were designed to nest with one another. The volumes achieved require a fill time not exceeding 3 msec.

By careful choice of diaphragm material (Ni Span C stainless steel was used) hysteresis was kept down to ± 0.1 percent, and elements could be operated linearly and without damage up to pressures 150 percent of the rated ranges. Depending on the pressure range, the elements had undamped natural frequencies of 250 to 2000 cps.

Careful control of metal qualities and manufacturing processes insured that the path traced by the stylus, as the element expanded, was within 1 degree of being a perfectly straight line normal to the mount surface. The allowable discrepancy produced a stylus motion in the direction of the time axis of the disk corresponding to ± 1/2 msec at a disk speed of 10 rpm. This error would not be found in arrival time measurements, but represents the time error which might be found in determining occurrence of a peak.

The stylus was an osmium phonograph needle tip mounted on a phosphor-bronze spring arm. Stylus pressure was adjusted by the bending of this arm until a small auxiliary spring scale indicated proper tension. No special attempts were made to damp the motion of the capsules for use in the pressure-time gages, since with the dust screen used, damping was adequate for any capsule range and overshoot was never objectionable.

The total-pressure capsule, used at the end of the long tube in the nose of the dynamic pressure gage, was more susceptible to overshoot and was effectively damped to 0.7 of critical. This was accomplished by changing the fill time with a sieve. Its head was placed directly over the capsule inlet port. The sieve was made by drilling sixteen No. 80 holes in a piece of brass shim stock.

2.3.2 Self-Recording Displacement Transducer. The displacement gage was mounted on a stable surface and measured the relative movement of an object by means of a hardened steel wire connected from the gage to the object.

This wire was wrapped around a pulley mounted on a shaft supported by journals in the ends of the gage case (Figure 2.8). A heavy coil spring inside the case applied torsion to the pulley shaft so that the wire was held in tension and would wind on or off the pulley as the object moved. A ratchet on the pulley shaft allowed the spring to be wound to and held at a high value of torque prior to installation of the wire. A release of the ratchet applied tension to the wire.

The free end of the pulley shaft was attached to the recording mechanism (described in Section 2.1.8). The gage sensitivity was determined by the pulley size, smaller pulleys being used with smaller displacements. The tension in the wire was about 60 pounds, and the gage was able to follow a displacement rate of 25 ft/sec.

The range of displacements measured by the self-recording gage lay between 1 inch and 18 inches.

2.3.3 Electronic Displacement Transducers. Two standard-type electronic transducers were used (Figures 2.18 and 2.19) depending on the magnitude of the displacement. Both types used the ratchet-wound, spring-loaded pulley assembly described in Section 2.3.2. The large-displacement model (1 inch to 18 inches) produced the required modulation of the carrier voltage by means of a continuous-rotation, wire-wound potentiometer attached to the pulley shaft. The housing of this potentiometer, rather than being permanently fixed to the gage casing, could be rotated by a knob with a calibrated scale. By rotating this knob in a direction opposite to the expected rotation of the displacement gage pulley, the pulley rotation could be exactly simulated and, by means of the calibrated scale, the magnitude of a corresponding displacement determined. This procedure was followed in the calibration of the recording channels used with this gage. The potentiometer was then locked in place.

The small displacement model (0 to 1 inch) used a linearly variable, differential transformer (LVDT) as a variable-impedance element. The coil of the LVDT was composed of three windings, the middle one of which was the input (or primary) winding that was connected to the gage power supply. The motion of the armature differentially varied the coupling between this winding and winds on either side of it. The outside pair of windings was

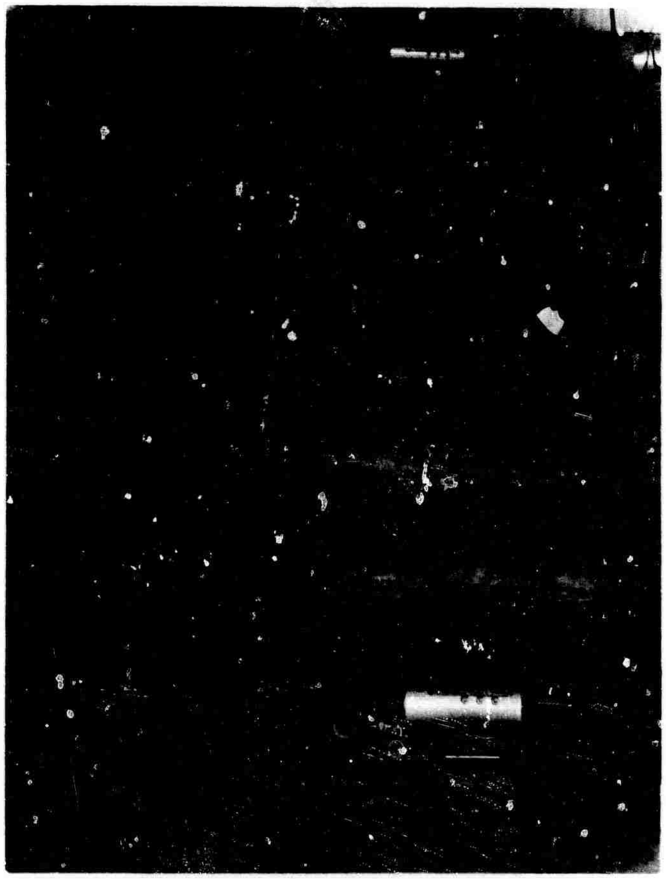

Figure 2.18 Large-displacement gage.

Figure 2.19 Small-displacement gage.

connected in series with the recorder so that the output voltages opposed one another. When the armature was centered between them, the net voltage output applied to the recorder was zero. As the armature was displaced from its balance point, an output voltage proportional to the motion was produced. The hollow, cylindrical armature of this transformer was threaded over the gage wire and clamped in place, and the solenoid winding of the transformer (inside which the armature moved axially) was held by a rigid frame. Thus, the gage sensed directly the axial motion caused by the displacement, and the pulley arrangement served only to produce tension in the wire.

The coil was not permanently fixed to its support; but to simulate a motion of the armature, the coil could be moved with respect to the stationary armature. This movement was measured by a dial micrometer to effect a calibration (see Section 2.5.7). After calibration, the coil was locked into position.

These gages could follow a displacement rate of 25 ft/sec.

Three special-application displacement gages were also designed. One measured the bending of the sliding blast-door used on the Project 30.2 Parking Garage (Figure 2.20). A hardened steel wire was stretched from one edge of the door, over a 12-inch-long perpendicular stud at the center of the door, and attached by a strong spring to the other edge of the door. A hollow, cylindrical armature for a linearly variable, differential transformer (LVDT) was threaded on the wire and clamped close to the spring. As the door bowed in, the stud forced the wire to stretch the spring, consequently, the position of the armature changed relative to the edge of the door. The

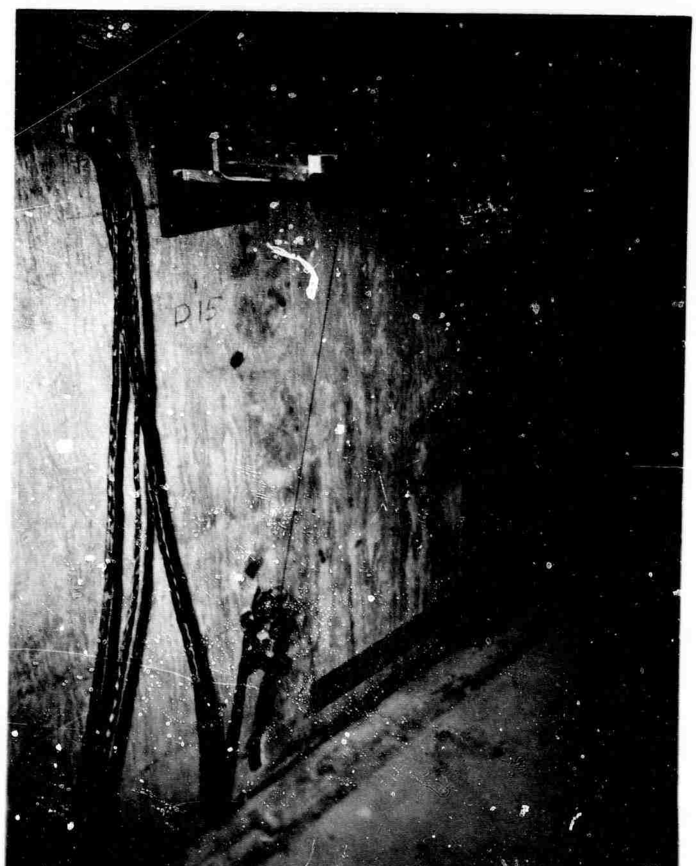

Figure 2.20 Special displacement gage, Project 30.2 (bending of door)

LVDT coil was mounted close to the edge of the door and sensed the motion of the armature.

Also, an LVDT coil was mounted on the garage floor with its axis perpendicular to the sliding door (Figure 2.21). The armature was forced into the coil against spring tension and held there by the door. Thus, any linear motion of the door relative to the floor was followed by the armature.

Finally, LVDT's modified by the manufacturer (Schaevitz Engineering Corporation) to have an extended range (5 inches) were used to record the operation of blast valves tested by Project 31.5 (Figure 2.22). The armatures were attached directly to the moving part of the valve, whereas the coil was held fixed with respect to the valve seat. Thus, the entire cycle of the poppet could be followed.

2.3.4 Pressure Transducers. Measurements of blast pressure were made using Wiancko 3PAD-R pressure gages (Figure 2.23). Each gage was contained in a heavy brass casing, which minimized transient temperature effects. A threaded flange around the sensitive end of the casing allowed the gage to be screwed into its mount. A plug in the other end of the casing provided a signal-cable connection. The gage was a variable-differential-inductance type using a twisted-bourdon-tube sensing element. One end of the tube was open to the atmosphere, and the other was closed and attached to an armature held in close proximity to an E coil (Figure 2.24). As pressure was applied to the open end, it tended to straighten the twisted tube and, in so doing, rotated the armature.

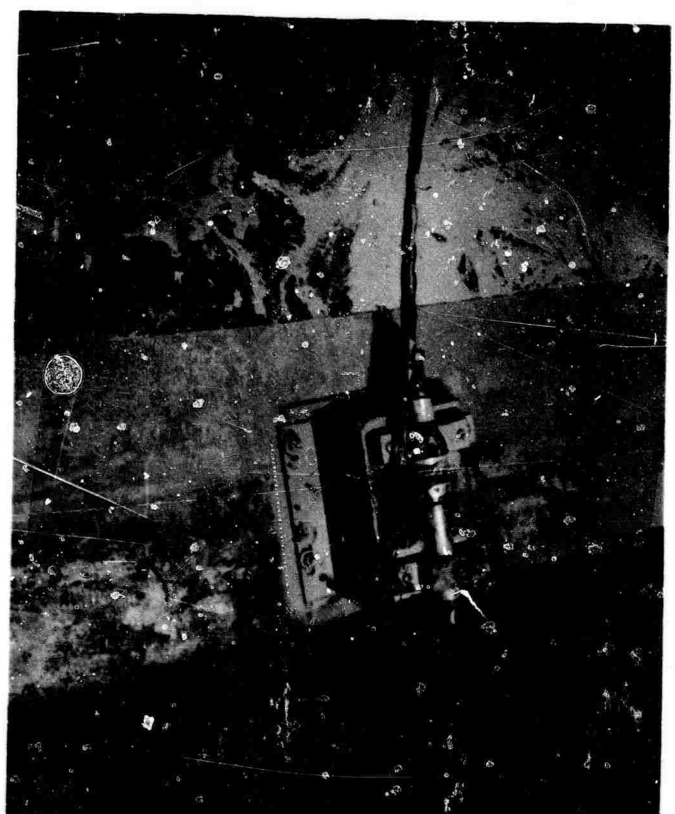

Figure 2.21 Special displacement gage, Project 30.2 (movement of door)

Figure 2.22 Special displacement gage, Project 31.5.

Figure 2.23 Wiancko pressure gage.

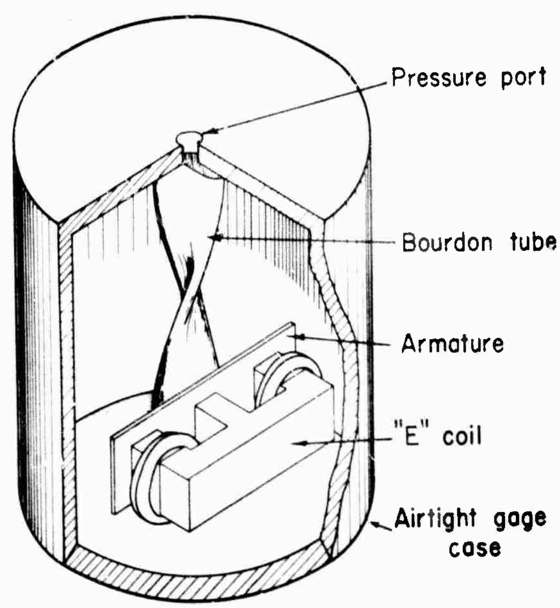

Figure 2.24 Schematic drawing of pressure-gage configuration.

The E coil consisted of two windings wound on the extreme legs of an E-shaped magnetic core. As the armature rotated, it decreased the reluctance of the magnetic path composed of the armature, the center leg, and one extreme leg of the E and increased the reluctance of the other, similar path. With the two windings connected into a full-impedance bridge, a voltage unbalance was created that was proportional to the applied pressure.

The response time of this type gage varied with its range, but was, in all cases, smaller than the response time of the recording system (about 2 msec).

Wherever these gages were used close to and facing the blast, shields of aluminum foil were used to prevent thermal radiation entering the pressure port and distorting the bourdon tube.

2.3.5 Electronic Dynamic-Pressure Gage. The dynamic-pressure gage used was one designed by the Sandia Corporation (Figure 2.26). It employed two Wiancko pressure elements (as described in Section 2.3.4, except without the brass casing) installed in a pitot tube. One element measured the difference between the total and the side-on pressure, and the other element measured only side-on pressure. Consequently, the gage produced two signals (recorded on separate channels), the first being a function of dynamic pressure and the second being a function of side-on pressure.

2.3.6 Accelerometers. Acceleration measurements were made with Wiancko type 3 AAT accelerometers (Figure 2.26). The sensing element consisted of an armature bonded at its center to the vertex of a V-shaped spring member and held in close proximity to an E coil of the type described in Section 2.3.4 (Figure 2.21). A weight, the mass of which depended upon

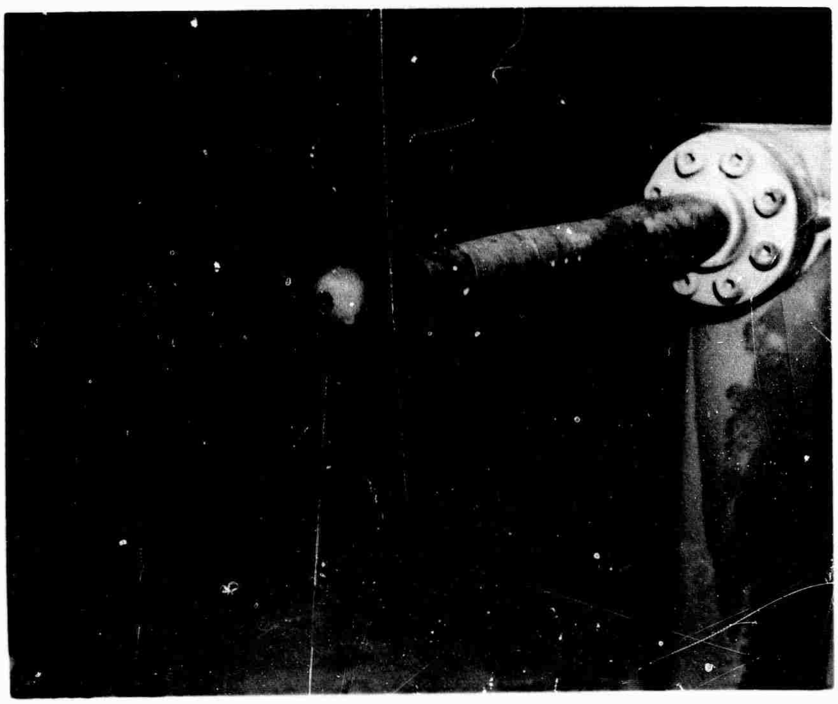

Figure 2.25 Sandia dynamic-pressure gage.

Figure 2.26 Wiancko accelerometer.

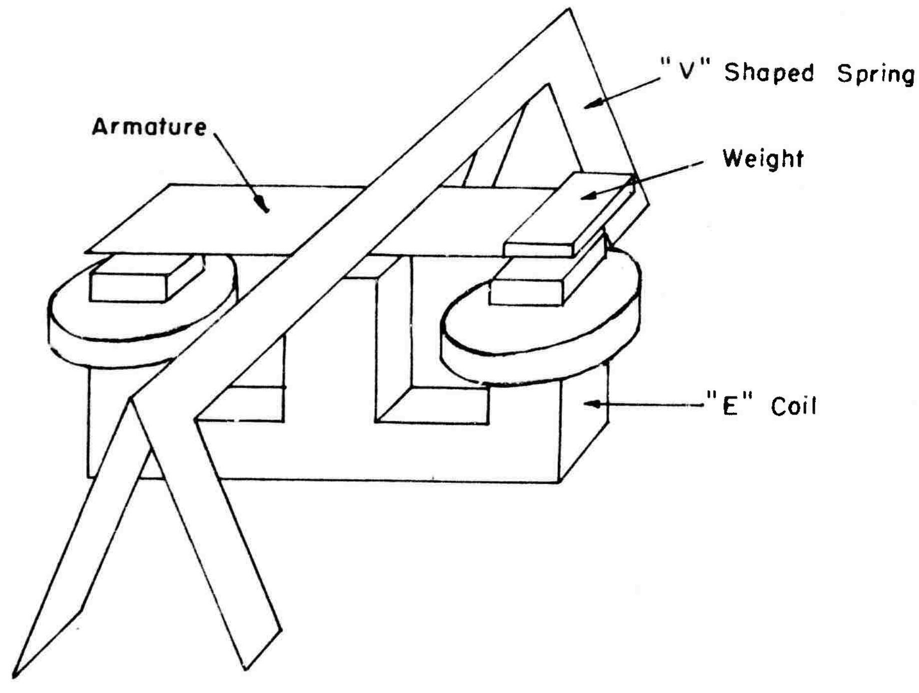

Figure 2.27 Schematic drawing of accelerometer spring mechanism.

the range of the accelerometer, was attached to one end of the armature so that an acceleration in a direction normal to the armature caused it to rotate about the vertex of the spring. The rotation of the armature caused unbalance in a full-impedance bridge, of which the windings of the E coil were a part.

The accelerometer was, incidentally, sensitive to rotational accelerations, so it could not be used where these were present. The stiffness of the spring was such that linear accelerations in only the direction of the axis of the case were measured.

The natural frequency of a 5-g accelerometer was approximately 70 cps; of a 100-g accelerometer, approximately 450 cps. The gages were damped to 0.70 of critical at a temperature of 80°F.

2.3.7 Earth Pressure Gages. The earth-pressure measurements were made with a Wiancko Carlson Type 3-PE footing stress gage (Figures 2.28 and 2.29). The sensing mechanism consisted of two inflexible circular plates with thinned edges, separated and welded such around the periphery that the edges acted as a flexible section. The small chamber volume between the plate inner surfaces could be varied by pressure on the external surfaces. The chamber was filled with fluid, usually mercury or oil. The center section of one plate was thinned to form a diaphragm which bulged outward when externally applied pressure squeezed the two plates together. This motion was coupled to an armature (Figure 2.29) and caused it to move near an E coil (described in Paragraph 2.3.4). The diaphragmed plate was the base for the gage and was placed against the footing. As pressure was applied, the

Figure 2.28 Wiancko-Carlson earth-pressure gage.

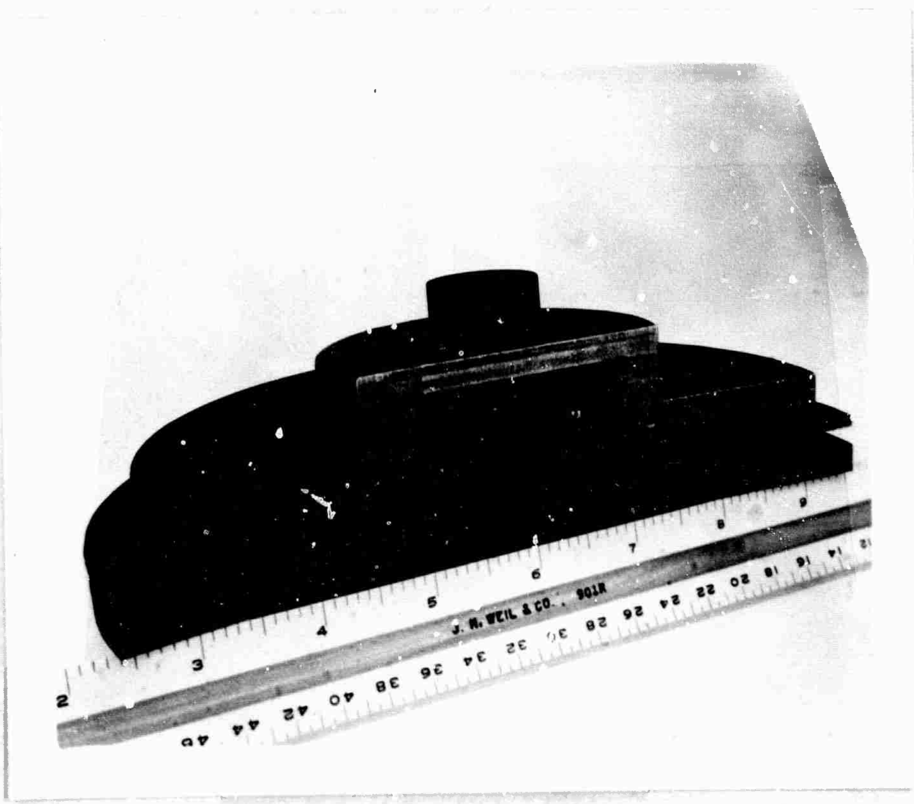

Fig. 2.29 Cutaway Photograph of earth-pressure-gage sensing mechanism.

motions of the solid plate and the flexible diaphragm were in the same direction, but the amplitudes of their motions were in inverse proportion to their respective areas. The resulting amplification of motion permitted relatively large gage output, while maintaining high-frequency response.

2.4 GAGE MOUNTS

2.4.1 Self-Recording Pressure Gages. Several methods were used to mount the pressure-time gages. The requirements of Projects 3.6 and 30.1 and part of Project 31.4 were for gages to measure diffraction patterns of the blast wave, and there it was necessary to mount the gage baffle plate flush with the surrounding surface. To allow this, the gage casings were cast into the concrete during construction of the test objects; later, the gage mechanisms mounted on the baffle plates were inserted into their casings, and the baffle plates were bolted in place (Figures 2.30 and 2.31). In all other cases, where the gages were used to indicate the fill time and maximum pressures inside a structure, a nipple welded to the bottom of the gage casing was screwed onto a threaded length of 3-inch pipe cast into the concrete of the structure (Figure 2.32) or attached to a 12-inch steel disk held in place by sand bags.

2.4.2 Self-Recording Dynamic-Pressure Gages. The dynamic-pressure gages were provided with two short nipples (see Section 2.1.7) for mounting in low-pressure regions. Mounts were constructed using a pair of parallel lengths of 3-inch pipe braced and held at a constant spacing by short lengths of steel plate welded between them (Figure 2.33). Two lengths were used, 5 feet for gages to be mounted 3 feet above the surface and 12

Figure 2.30 Installation of pressure-time gage using cast-in mount.

Figure 2.31 Complete surface installation of pressure-time gage.

Figure 2.32 Pressure-time gage mounted for fill-time measurement.

Figure 2.33 Mount for a 3-foot self-recording dynamic-pressure gage.

feet for gages to be mounted 10 feet above the surface. The pipes were embedded in concrete at the base and steadied by guy wires, where needed. Pipe unions were used to attach the gage nipples to the mount pipes. For the high-pressure regions, a much-heavier mount was used (the Standard AFSWP gage tower design) in conjunction with a special casing that butted up to a flange provided on the front surface of the mount (Figure 2.34).

2.4.3 Deflection Gages. The self-recording and the standard electronic deflection gages used identical mounts; four properly spaced, 1/4 inch bolts were cast or "Ram-set" into the stable mounting surface, and the gage, with four corresponding bolt holes, was set over them and secured with nuts (see Figure 2.35).

The mounting details of the two special-type deflection gages are given in the description of the gages in Section 2.3.3.

2.4.4 Self-Recording Accelerometers. These gages were mounted both inside structures and along the blast line.

Where a gage was mounted inside a metal-floored structure, a steel mounting plate with four threaded studs protruding from it was welded to the floor of the structure. The gage baffle plate, with four properly spaced holes, was then slipped over the studs and secured in place. Where a gage was mounted inside a concret-floored structure, the steel mounting plate was attached to the floor by means of expansion bolts.

Where a gage was used to take ground-acceleration measurements, a hole was dug to the proper depth, and a standard pressure-time gage casing was positioned in the hole with its axis vertical and with the plane, in which the disk was to lie, parallel to a line through ground zero. Then, the

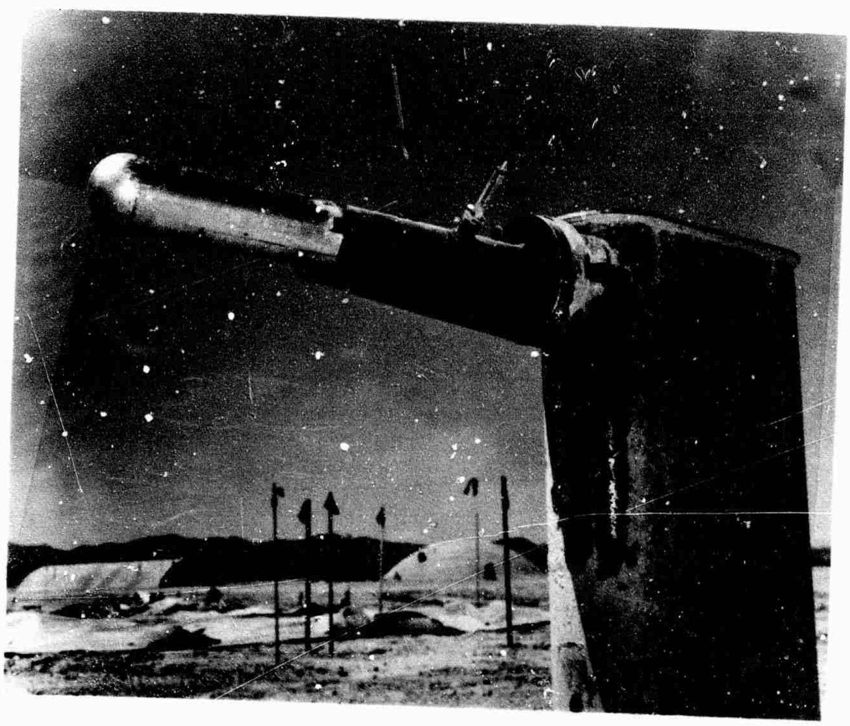

Figure 2.34 BRL dynamic-pressure gage adapted to standard AFSWP mount.

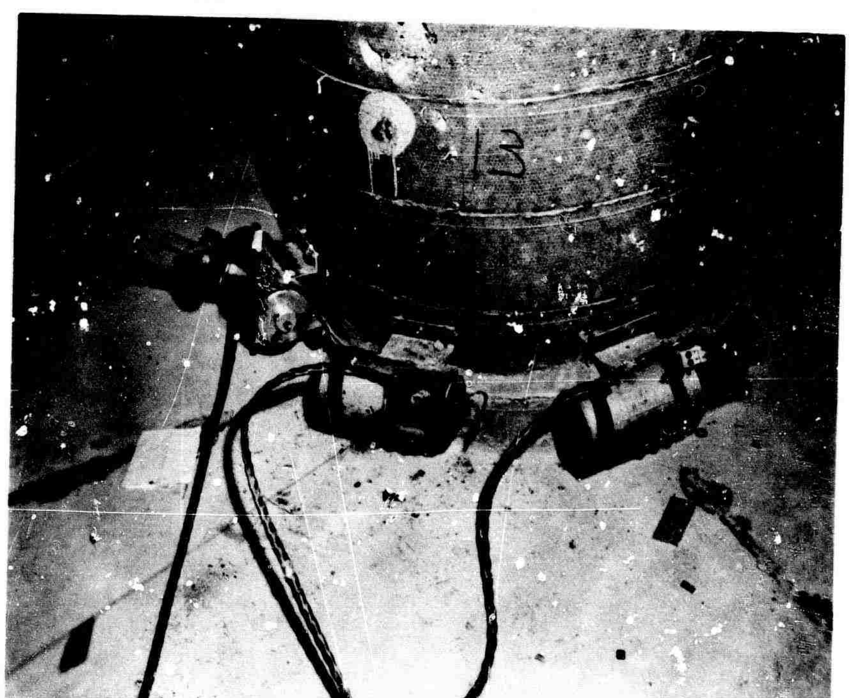

Figure 2.35 Typical installation of BRL displacement gages.

space around the gage was filled with Cal-Seal to assure a good coupling with the surrounding soil. The accelerometer mechanism was then inserted in the casing and its baffle plate bolted in place.

2.4.5 Peak-Pressure Gages. These gages, using standard self-recording pressure-gage cases were mounted as described in Section 2.4.1.

The specially designed peak-pressure gages were mounted with the face of the baffle plate toward the mounting surface. Studs were driven into the surface. Properly spaced holes in baffle plate allowed it to be slipped over the studs and secured in place. Spacers were placed on the studs to hold the pressure port away from the surface.

2.4.6 Peak Accelerometers. When mounted on a metal surface, the base of this type of gage was welded to the surface. When mounted on concrete, four studs were driven into the surface, and matching holes in the base plate allowed it to be slipped over them and secured in place.

2.4.7 Electronic Pressure Gages. The electronic pressure gages were used in both concrete and aluminum structures.

Seamless steel tubes, threaded to accept the gage casings, were cast into the concrete structures (Figure 2.36). The aluminum structures were drilled and threaded to allow the gage casing to be screwed into place (Section 2.3.4).

2.4.8 Electronic Dynamic Pressure Gages. Standard heavy AFSWP vertical pipe mounts were provided for these gages (Figure 2.31). The mount consisted of a pair of 8-inch pipes spaced by tangential steel plates welded between them. A flange facing ground zero was provided, and to this was bolted a section tapered to the diameter of the pitot tube. The pitot tube was

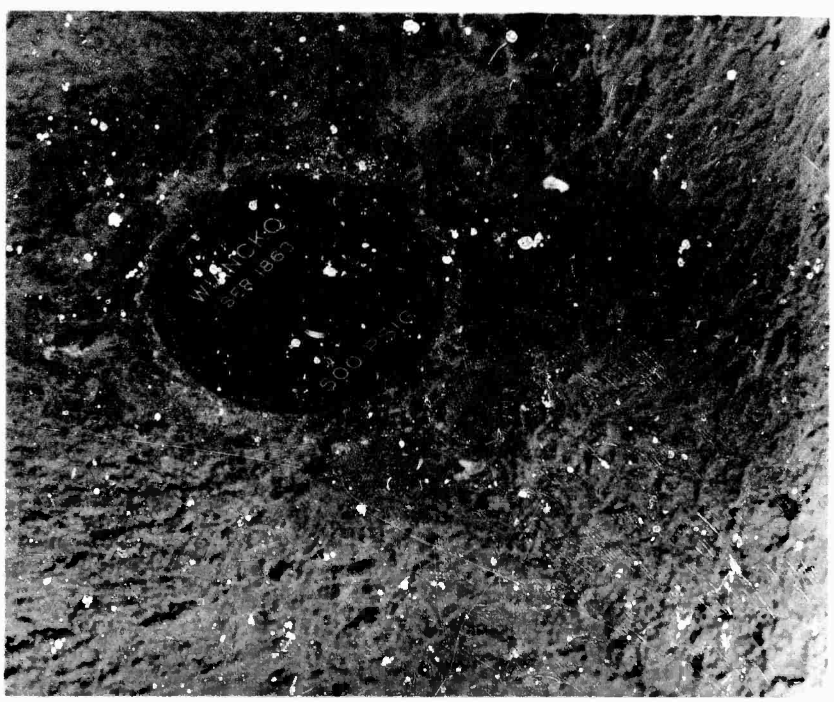

Figure 2.36 Typical installation of Wiancko pressure gages.

Figure 2.37 Sandia dynamic-pressure gage on standard AFSWP (Sandia) mount.

inserted in this section and locked into position by set screws.

2.4.9 Accelerometers. The accelerometers were mounted on the member in which the acceleration was being measured. A lead plate 3/16-inch thick and the diameter of the gage was installed between the gage and member to eliminate gage ringing effects. Three properly spaced threaded studs were cast or Ram-set into the concrete. The gage was positioned so that three holes drilled in a flange around one end of the gage case were fitted over the studs. Thus, the gage was mounted with its sensitive axis (the axis of the cylindrical case) lying parallel to the direction of the acceleration being measured.

2.4.10 Earth-Pressure Gages. Depending on the application, three methods of mounting the earth-pressure gages were employed. In every case, provision was made for allowing a solid, flat surface for support of the gage base plate and an even distribution of pressure over the sensitive plate (see Section 2.3.7). Where measurements underneath a structure were made, a square hole was left in the concrete so that after calibration the gage could be lowered into the hole until its sensitive face lay directly on the ground. Reinforcing rods were left protruding from the walls of the holes; thus, when concrete was poured and filled the hole, the gage was cast into a block that was essentially a part of the structure. The ground under the sensitive plate was prepared to allow even distribution of pressure and the concrete gripped the base plate firmly.

Where measurements were made on the side or top of buried structures, alternate installation methods, as chosen by the structure designers, were used.

For the buried arches of Project 3.1, a hole the size of the housing for the gage-sensing mechanism was cast in the wall of the structure. The gage was then set against the structure, with the sensing mechanism housing fitting into its hole and the base plate resting squarely on the structure surface. A length of pipe, threaded over the gage cable, was screwed into the sensing mechanism housing so that it extended through to the inside of the structure. Over this pipe, in sequence, were placed a washer having a diameter greater than that of the hole in the wall, a helical spring, and a nut (which screwed on to the end of the pipe to compress the spring). The force produced in the compressed spring held the gage firmly against the outside surface of the wall. A fairing of grout was applied around the gage to smooth the contours of the installation. Sieved sand was packed over the face of the gage to give an even pressure distribution.

In the case of the Project 30.2 garage, cavities matching the contours of an earth-pressure gage were cast in the concrete. The gages were then grouted into position and, as the structure was backfilled, sieved sand was carefully packed over each gage face to ensure a uniform pressure distribution.

2.5 CALIBRATION

<u>2.5.1 Self-Recording Pressure Gages.</u> Calibration of the pressure capsules was performed by the manufacturer. The calibrations were plotted using a Leeds-Northrup X-Y recorder. The output of a Statham strain-gage-type pressure transducer was fed through amplifiers to the pen (X-axis) of the recorder. Capsule deflection was measured by a micrometer head equipped with a null detector and servo system operating a slide-wire potentiometer which,

in turn, controlled the chart drive (or Y-axis). The resulting presentation gave a plot of capsule deflection as a function of applied pressure (see Figure 2.38).

The disk-drive motors were also individually tested for startup time and speed. The speed was tested by comparing the frequency of the pulses produced by the governor contacts with pulses from a precision signal generator.

The startup time was deduced from a plot of angular displacement of the motor shaft versus time (Figures 2.39a and b). To obtain the plot, the shaft of a potentiometer (Helipot) having 0.05 percent linearity was attached to the center of the gage turntable. The potentiometer, which was powered by a battery, produced an output that was registered by a moving-paper oscillograph. The oscillograph provided a time base while the potentiometer output was proportional to the angle through which the shaft had turned. Another channel of the oscillograph recorded a fiducial marker at the instant voltage was applied to the motor.

The slope of the recorded curve thus indicated velocity, the constant terminal velocity being indicated by that portion of the curve having a constant slope. The times of occurrence of all variations from this constant velocity were also clearly indicated. Finally, when the constant-slope portion of the curve was extended through the time axis, its intersection gave a starting delay time to be added to event times computed on the basis of an instantaneously achieved, constant motor speed.

2.5.2 Self-Recording Dynamic-Pressure Gages. The procedure of Section 2.5.1 was used in calibrating the self-recording dynamic-pressure gages.

2.5.3 Self-Recording Displacement Gages. These gages were calibrated

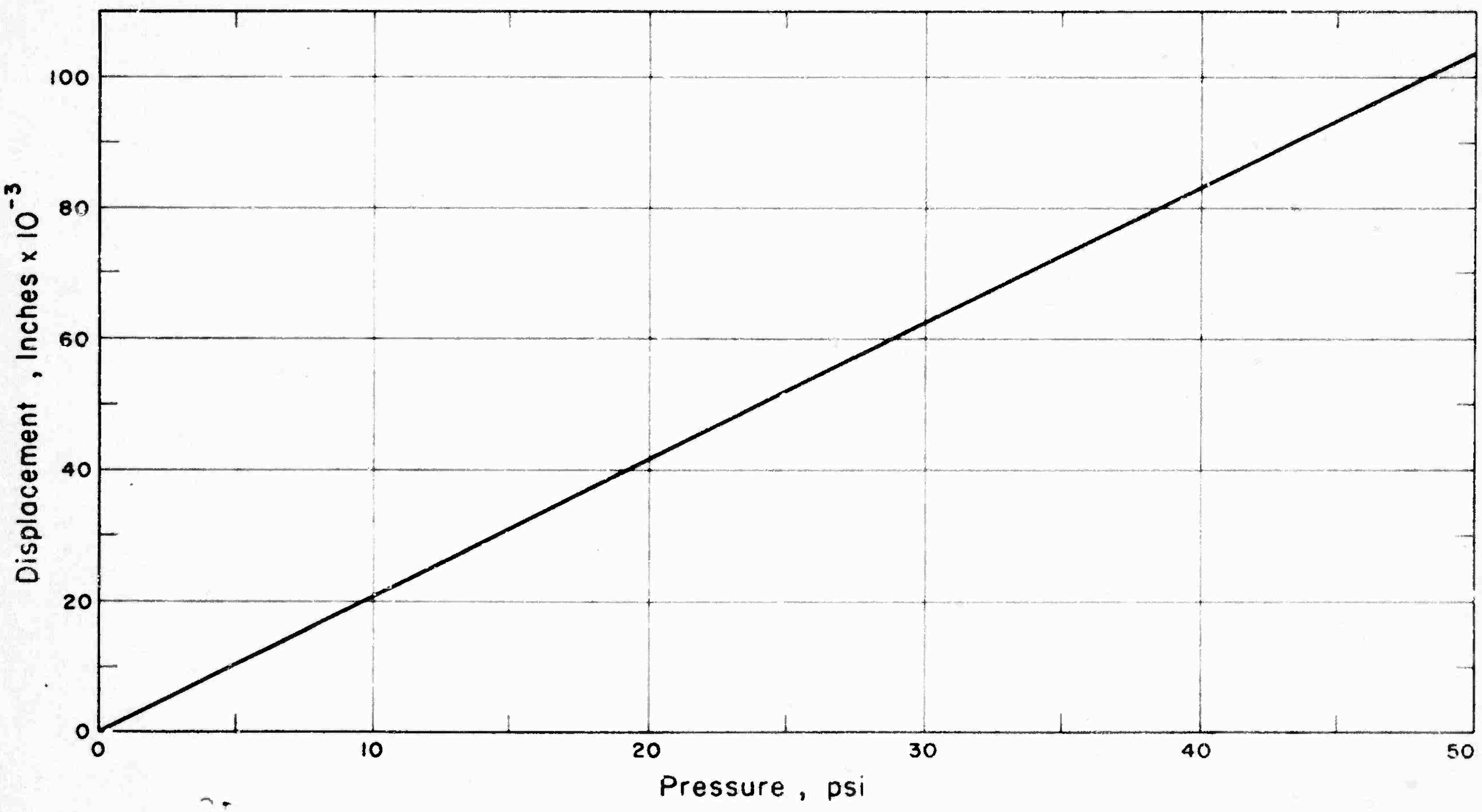

Figure 2.38 Typical curve of pressure versus displacement for self-recording-gage capsule.

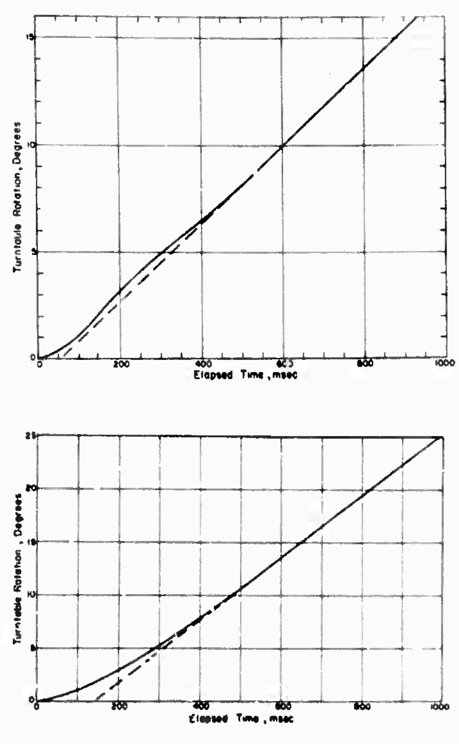

Figure 2.39 Angular displacement versus time of self-recording-gage motor: (a) at top, for 3-rpm motors; (b) at bottom, for 10-rpm motors.

before assembly by installation of a disk, turning of the recording mechanism shaft through one revolution, and measurement of the height of the step produced on the disk. With the circumference of the pulley known, the displacement corresponding to this step height was readily deduced. The gage was linear, so the slope of the curve of stylus motion versus displacement obtained in this manner could be extended over the full range of the gage.

2.5.4 Self-Recording Accelerometers. Calibration of the accelerometer elements was performed by clamping them in a support similar to the one in the gage. This support was then placed on a calibrated drop table to be subjected to transient acceleration. The drop table consisted of a heavy metal plate which could be raised to a predetermined height and then allowed to fall freely. The fall was terminated by a box of sand into which the plate fell flat. The accelerations produced when the plate was stopped were accurately reproducible, and by means of a standard accelerometer, has been related to the height from which the plate was released.

Elements were calibrated in both positive and negative directions.

2.5.5 Peak-Pressure Gages. These gages used the same elements that were used in the self-recording pressure gages and calibration procedures were the same (see Section 2.5.1).

2.5.6 Peak Accelerometers. The elements used in the peak accelerometers were the same as those used in the self-recording accelerometers. A description of their calibration is given in Section 2.5.4.

2.5.7 Electronic Displacements Gages. Calibration of the gages was necessarily performed after installation of gages and recording system. For all gage types, this was done by moving the normally stationary element of transducer relative to its normally movable element.

The normally stationary element of the large-displacement gage was the potentiometer housing. This housing could be rotated by a linearly calibrated knob (see Section 2.3.3), a full-scale rotation from its centered position corresponding to a half turn in the opposite direction by the gage pulley. The corresponding displacement was equal to one half the pulley circumference. The full range of the calibrated scale was divided into five equal segments on each side of its centered position; thus, positive and negative displacements of 20, 40, 60, 80, and 100 percent of the maximum calibration value could be obtained. Where displacements were obtained greater than half the pulley circumference, the potentiometer rotated past the extreme point on its scale and began a second cycle. The calibration for this cycle was identical with that for the first cycle except that a displacement equal to the pulley circumference was added to (or subtracted from) the indicated displacement value. Whether the constant value was to be added or subtracted was dependent on the slopes of the curve of displacement versus time just prior to the sharp discontinuity marking the beginning of a new cycle. Positive slopes indicated addition; negative slopes indicated subtraction.

The small-displacement gages were calibrated by using a dial micrometer as a standard. The micrometer measured the motion of the coil relative to its support or armature position. After the clamp which held the linear variable differential transformer coil in place was loosened, a slotted block which held the micrometer, was slipped over the coil support (see Figure 2.40) and locked in position. The coil was moved until its electrical center (the position giving an output voltage null) was found. Then the

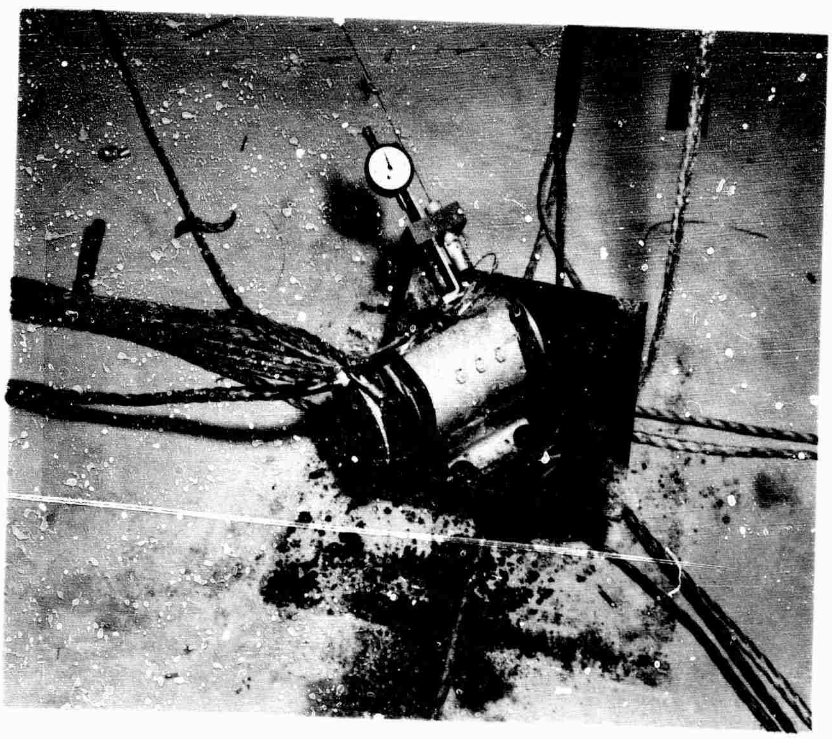

Figure 2.40 Small-displacement gage calibration.

reading indicated by the micrometer was taken as the zero reading and, from this point, the coil was moved in a direction opposite to the actual displacement to produce calibration steps. Values, both positive and negative of 20, 40, 60, 80, 100, 120, 140, and 160 percent of the expected maximum were used.

2.5.8 Electronic Pressure Gages. Steady pressure controlled by a system of regulators was applied to the bourdon tube through a tubing fitting screwed into the pressure inlet port (See Figure 2.41). The regulators were contained behind a control panel, which also mounted dial gages having ranges adequate to indicate all required pressures with an accuracy of ± 2 percent. The steady pressures were applied after installation of the gages and recording system, with positive pressures 20, 40, 60, 80, 100, and 150 percent of the expected maximum being applied. Where required, negative pressures in the same elements were also applied.

2.5.9 Electronic Dynamic Pressure Gages. The calibration procedure for these gages was identical with that described in Section 2.5.8. Negative calibrations were made for the side-on but not for the dynamic pressure elements.

2.5.10 Accelerometers. The accelerometers were given static calibrations on a spin-table accelerator before their installation (see Figure 2.42). The spin table was a disk which was rotated at a speed determined accurately by an electronic tachometer. The accelerometer was mounted on the disk with its sensitive direction parallel to the radius of the disk. Connections to the recorder cable were made through slip rings. An accurate knowledge of the distance of the accelerometer sensing element from the center of the disk and the rotational velocity of the disk were used to find the radial acceleration

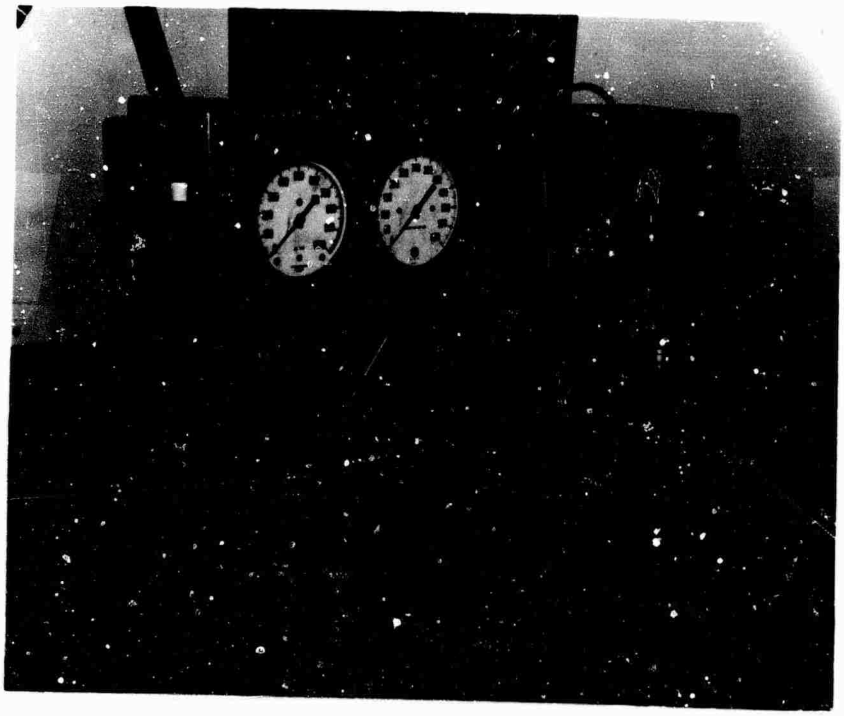

Figure 2.41 Typical calibration of Wiancko pressure gages.

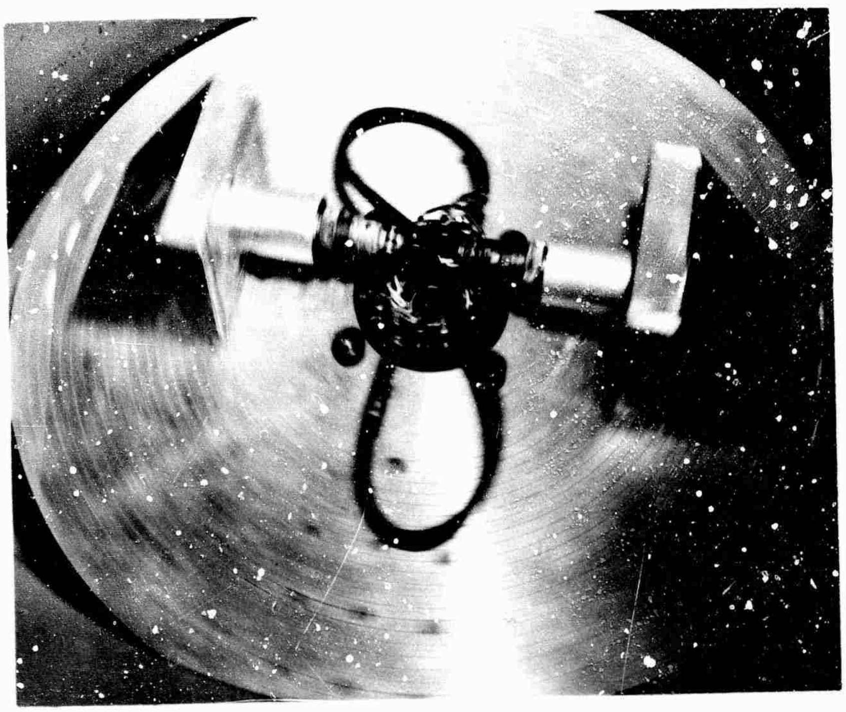

Figure 2.42 Calibration of accelerometer.

produced in the sensing element. The disk velocity was varied to produce accelerations 20, 40, 60, 80, 100 and 150 percent of the expected maximum. Spin-table acceleration values could be computed with an accuracy of 2 percent.

2.5.11 Earth-Pressure Gages. These gages were generally calibrated in pairs or groups of four before being placed in their mounts (see Figure 2.45). Two gages were placed with their sensitive faces together, but separated by a layer of blotting paper. An aluminum ring, slotted to allow exit of the gage cable, was placed against each base plate to protect the protruding section of the gage containing the sensing element (see Section 2.3.7). This sandwich was then placed, with a Baldwin SR-4 load cell, between the jaws of a hydraulic press. The force applied through the aluminum rings to the base plates was measured by the load cell to an accuracy of better than 1 percent. The blotting paper allowed an even distribution of load over the sensitive faces of the gages. Where convenient, several of such sandwiches could be calibrated simultaneously.

2.6 DATA PRESENTATION

2.6.1 Self-Recording Gages. The data obtained from each self-recording record contains the arrival time and deflection versus time. The records, being scribed on rotating glass disks, are presented in polar coordinate form. Conversion to rectilinear coordinates simplifies working with the data. To do this, a Gaertners Toolmakers Microscope with a rotating table was utilized. The microscope was modified by the addition of digital read-out heads giving 1000 counts per revolution of the reading head shaft.

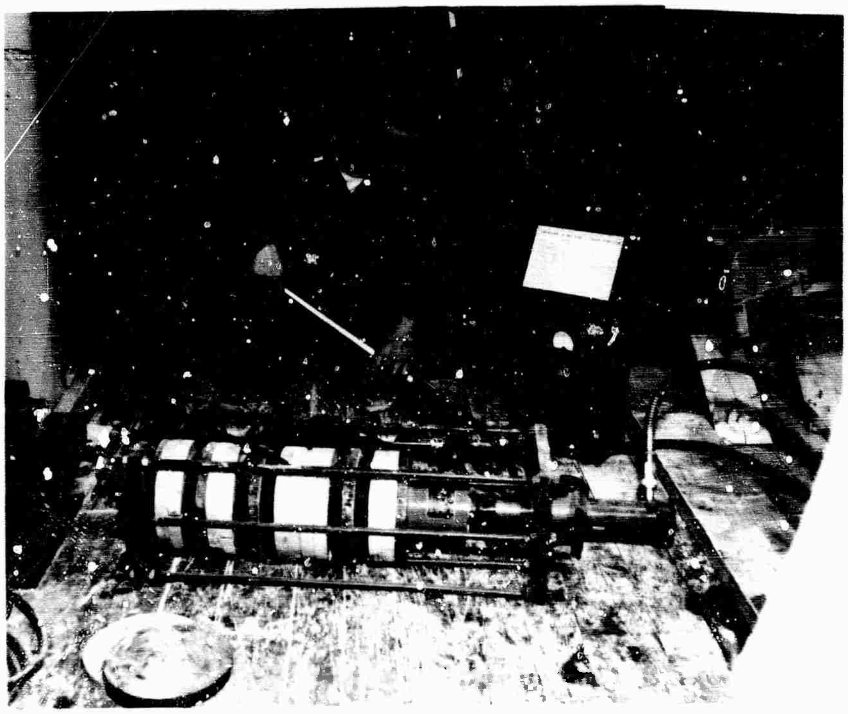

Figure 2.43 Calibration of earth-pressure gage.

Record deflection is represented by 0.000025 inches per count or 40 counts per mil of deflection. For the time base readings, one revolution of the turntable (360°) will read 45000 counts or 125 counts per degree.

The data from the readout heads of the microscope are converted to digital form and punched on IBM cards by Telecordex equipment. These cards are utilized in final processing.

2.6.2 Electronic Gages. The playback of the magnetic tape recordings produced by the electronic gages were presented as oscillograms on strips of 7-inch-wide photographic paper. The data from each channel was presented on a single oscillogram. The information included: (1)"Electrical Cal Step" made immediately prior to calibration (Section 2.2.3), (2) calibrations steps, each made by running the recorder for a short period while the transducer was statically activated (Section 2.5), (3) "Electrical Cal Step" made immediately prior to detonation (Section 2.2.7), (4) the trace deflection caused by the physical activation, (5) "Electrical Cal Step" made shortly following the completion of the records, (6) zero-time marker (Section 2.2.2), and (7) a series of timing pulses produced at the bottom of the paper (Section 2.2.2). The relative heights of the "Electrical Cal Step", H_c, taken during the calibration run, and H_t, taken during the actual test run were proportional to the values of system gain during those times.

The calibration steps multiplied by the ratio, H_t/H_c, determined the spacing of the ordinates of the plot, whereas the timing pulses determined the abscissas. Each minor timing pulse represented 1-1/3 msec; the larger spikes corresponded to 13-1/3 msec and 133-1/3 msec.

The oscillograms were read on a Telereader which uses magnetic reading heads to convert the time, calibration, and record displacements to a digital form. The information in digital form is punched in IBM cards which are used as input data for the EDVAC for final processing.

2.6.3 Final Data Presentation The IBM cards, representing readings taken at close intervals throughout the span of the records, together with cards representing calibration readings and in the case of the self-recording data - time interval information, are used as input data for the EDVAC high-speed digital computer. The program as coded for the EDVAC uses a straight line equation. The deflection values are calculated from a straight line interpolation between the various calibration steps. The timing calibration is applied to the readings and concurrently the impulse is summed as the cards are processed. The final output of the EDVAC is time (msec) and deflection - linearized and punched on IBM cards. These cards are fed to an Electronic Associates Vari-Plotter, Model 3033B2LP. This line plotter can plot and connect 66 points per inch with an accuracy of 1/64 inch. The final plots are from this plotter.

After Operation Plumbbob some new nomenclature was established for dynamic pressure measurements in order to distinguish the type of blast in which the measurement was obtained and also to separate corrected from non-corrected data. A high-speed computer was utilized for processing the data in accordance with the method outlined in Chapter 6 of The Blast Handbook (NAVORD Report 6085). The dynamic pressure parameters plotted for each station are as follows:

(1) $\Delta P_p^{*'}$ - the as read total head overpressure in dusty flow with no corrections.

(2) $\Delta P'$ - the as read uncorrected side on overpressure.

(3) q_c^* - is the difference between the total head and side on after the gage corrections have been applied.

(4) q^* - the corrected dynamic pressure in an air-plus-dust blast move.

(5) M^* - the Mach number calculated from the ratio of the corrected total and static pressure measured in dusty flow.

Photographs of original records and linearized record plots with sketches showing their locations are included in Appendix B.

2.7 INSTRUMENTATION REQUIREMENTS

All requirements for instrumentation were set by the requesting agencies: Projects 3.1, 3.2, 3.3, 3.6, 30.1, 30.2, 30.3, 31.4, and 31.5. After the basic instrumentation type (electronic or self-recording) had been specified, choice of recorders, transducer types, and transducer mounts was the responsibility of BRL.

In cases where diffraction and loading studies were made electronic instrumentation was preferred to self-recording equipment because the latter had no provisions for marking zero time.

A listing of structures, channels, types of measurements, and ranges is given in Table 2.1.

2.8 FIELD LAYOUT

Figure 2.44 shows the locations of structures instrumented, blast shelters, and ditching.

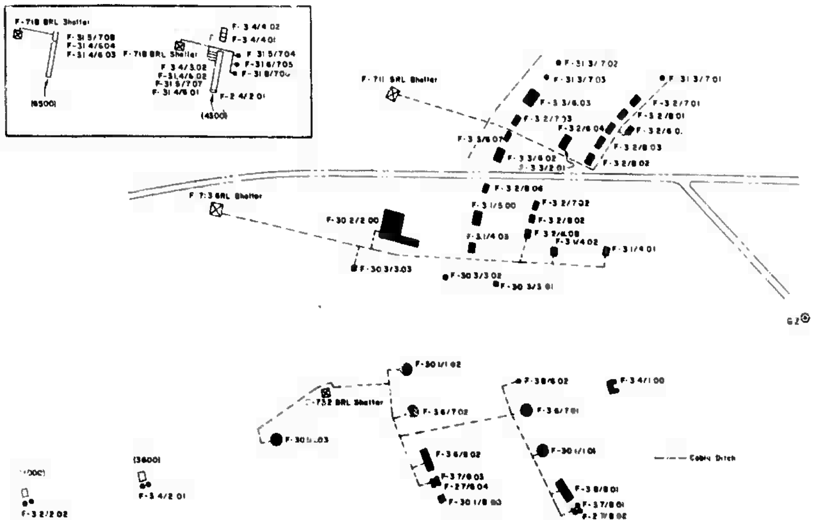

Figure 2.44 Field layout.

TABLE 2.1 STRUCTURES AND INSTRUMENTATION

Project/Structure	Gage Type	No. of Gages	Ranges
3.1/9014.01	Accelerometer	2	100g, 50g
	Earth Pressure	7	200 psi
	Deflection	3	1 to 6 in.
	Self-Recording Deflection	4	1 to 6 in.
	Self-Recording Pressure	2	200 psi, 100 psi
3.1/9014.02	Accelerometer	2	50g, 25g
	Earth Pressure	8	100 psi
	Deflection	3	1 to 6 in.
	Self-Recording Deflection	4	1 to 6 in.
	Self-Recording Pressure	2	100 psi, 25 psi
3.1/9014.03	Accelerometer	2	25g, 10g
	Earth Pressure	1	25 psi
	Deflection	3	0 to 1 in.
	Self-Recording Pressure	2	50 psi, 25 psi
3.2/9016.01	Accelerometer	1	50g
	Peak Pressure	1	25 psi
	Peak Accelerometer	1	50g
	Self-Recording Pressure	1	150 psi
3.2/9016.02	Accelerometer	1	50g
	Peak Pressure	1	50 psi
	Peak Accelerometer	1	50g
3.2/9016.03	Peak Pressure	1	50 psi
	Peak Accelerometer	1	50g
3.2/9016.04	Self-Recording Pressure	1	100 psi
	Peak Pressure	1	50 psi
	Peak Accelerometer	1	50g
3.2/9016.05	Self-Recording Pressure	1	100 psi
	Peak Pressure	1	25 psi
	Accelerometer	1	50g
	Peak Accelerometer	1	50g
3.2/9016.06	Peak Pressure	1	25 psi
	Peak Accelerometer	1	50g
3.2/9016.07	Peak Pressure	1	25 psi
	Peak Accelerometer	1	50g
3.2/9017.01	Peak Pressure	1	25 psi
	Peak Accelerometer	1	50g
3.2/9017.02	Peak Pressure	1	50 psi
	Peak Accelerometer	1	50g
3.2/9017.03	Accelerometer	1	50g
	Self-Recording Accelerometer	1	50g
	Peak Pressure	1	25 psi

3.2/9018.01	Peak Pressure	1	50 psi
	Peak Accelerometer	1	50g
3.2/9018.02	Peak Pressure	1	25 psi
	Peak Accelerometer	1	50g
3.3/9019.01	Accelerometer	1	50g
	Self-Recording Accelerometer	1	50g
	Peak Pressure	1	25 psi
	Self-Recording Pressure	1	100 psi
3.3/9019.02	Accelerometer	1	50g
	Self-Recording Accelerometer	1	50g
	Peak Pressure	1	25 psi
	Self-Recording Pressure	2	50 psi, 5 psi
3.3/9019.03	Accelerometer	1	50g
	Peak Accelerometer	1	50g
	Peak Pressure	1	25 psi
	Self-Recording Pressure	1	50 psi
3.4/9021.00	Self-Recording Pressure	2	150 psi
	Self-Recording Dynamic Pressure	1	400 - 400 psi (2 channels)
3.4/9022.01	Self-Recording Dynamic Pressure	1	25 - 15 psi (2 channels)
3.4/9022.02	Self-Recording Dynamic Pressure	1	15 - 5 psi (2 channels)
3.4/9023.02	Self-Recording Pressure	2	15 psi
3.4/9024.01	Self-Recording Pressure	2	15 psi
	Self-Recording Dynamic Pressure	1	15 - 15 psi (2 channels)
3.4/9024.02	Pressure	3	10 psi
3.6/9026.02	Pressure	5	460-250-70 psi
3.6/9027.01	Pressure	13	460-250-70 psi
	Self-Recording Pressure	11	400-100-70 psi
3.6/9028.01	Pressure	6	460-70 psi
3.6/9028.01	Self-Recording Pressure	13	400 - 100 psi
3.7/9028.01	Dynamic Pressure	1	390 - 70 psi (2 channels)
3.7/9028.02	Self-Recording Dynamic Pressure	1	400 - 100 psi (2 channels)
3.6/9028.02	Pressure	6	235 - 35 psi
3.6/9028.02	Self-Recording Pressure	13	200 - 50 psi

3.7/9028.03	Dynamic Pressure	1	200 - 35 psi
3.7/9028.04	Self-Recording Dynamic Pressure	1	400 - 50 psi (2 channels)
30.1/8001.01	Accelerometer	4	75-40-7.5-4g
	Pressure	5	460-250-70 psi
30.1/8001.02	Accelerometer	4	40-20-4-2g
	Pressure	5	235-180-35 psi
30.1/8001.03	Pressure	7	150-100-20 psi
30.1/8008.00	Peak Pressure	1	5 psi
30.2/8002.00	Pressure	5	300-100-40 psi
	Earth Pressure	11	200-50-25-15 psi
	Deflection	18	0 to 6 in.
	Dynamic Pressure	1	200 - 40 psi (2 channels)
	Self-Recording Pressure	2	50 - 5 psi
	Self-Recording Dynamic Pressure	1	200 - 50 psi (2 channels)
30.3/8003.01	Self Recording Pressure	1	100 psi
	Peak Pressure	1	15 psi
30.3/8003.02	Self-Recording Pressure	1	50 psi
	Peak Pressure	1	5 psi
30.3/8003.03	Self-Recording Pressure	1	50 psi
	Peak Pressure	1	5 psi
	Deflection	2	0 to 1 in.
31.4/8006.01	Self-Recording Pressure	3	15 psi
	Peak Pressure	1	5 psi
	Peak Deflection	5	0 to 5 in.
	Deflection	1	0 to 0.75 in.
31.4/8006.03	Self-Recording Pressure	3	15 - 5 psi
	Peak Deflection	5	0 to 5 in.
31.5/8007.01	Deflection	1	0 to 5 in.
	Self-Recording Pressure	2	100 - 25 psi
31.5/8007.02	Deflection	1	0 to 5 in.
	Self-Recording Pressure	2	50 - 15 psi
31.5/8007.03	Deflection	1	0 to 5 in.
	Self-Recording Pressure	2	50 - 15 psi
31.5/8007.04	Deflection	1	0 to 5 in.
	Self-Recording Pressure	2	15 - 5 psi
31.5/8007.05	Deflection	1	0 to 5 in.
	Self-Recording Pressure	2	15 - 5 psi
31.5/8007.06	Deflection	1	0 to 5 in.
	Self-Recording Pressure	2	15 - 5 psi

31.5/8007.07	Deflection	3	0 to 5 in.
	Self-Recording Pressure	7	15 - 5 psi
31.5/8007.08	Deflection	2	0 to 5 in.
	Self-Recording Pressure	5	15 - 5 psi

Chapter 3

RESULTS AND DISCUSSION

3.1 ACCEPTABILITY OF DATA

The operation of the gages and recording equipment is summarized in Table 3.2. The comment for each gage indicated the technical success of the measurement.

In brief, from an instrumentation point of view, 117 records of 161 electronic measurements were perfect, 68 records of 127 self-recording measurements were perfect, and 27 records of 42 peak-recording methods were perfect. In addition, 9 electronic records were amenable to interpretation without speculation and 36 self-recording records gave useable peak-value indications. In several instances, "No apparent record" is noted. Here, even though all indications are that the equipment was functioning properly, the record was not numbered with those considered useable.

3.2 ANOMALIES AND THEIR TREATMENT

In general, the results of the instrumentation were considered satisfactory. A better percentage of records were obtained from electronic gages than from the self-recording gages.

Failure to receive records from electronic gages was principally due to having the gages either underranged or overranged. Gages that were principally underranged were the earth pressure gages (EP), in which case the signals received from the gages were saturated giving rise to a flat plateau. The overranged gages were principally the accelerometers. Here, the deflections of the records were small, and the reading of these records to any degree of accuracy is questionable. In several cases, an incomplete

TABLE 3.1 CLASSIFICATION OF DATA

The symbols used to specify gage types are defined as follows:

Electric Gages:	Self-Recording Gages:	Peak Recording Gages:
A Accelerometer	SA Acceleration	PA Acceleration
D Displacement	SD Displacement	PD Displacement
E Earth Pressure	SP Pressure	PP Peak Pressure
D Dynamic Pressure (-gage)	ST Total Pressure (-Gage)	
S Side-on Pressure (-gage)	SS Side-on Pressure (-Gage)	

Numbers following the symbols are gage numbers.

Project/Structure	Gage No.	Type of Measurement	Comments
3.1/9014.01	A1	Acceleration	Good Record
	A2	Acceleration	Good Record
	D1	Deflection	Good Record
	D2	Deflection	Good Record
	D3	Deflection	Good Record
	E1	Earth Pressure	No Record - Cable shorted
	E2	Earth Pressure	Good record small zero shift
	E3	Earth Pressure	Bad zero shift - no record
	E4	Earth Pressure	No Record - cable shorted
	E5	Earth Pressure	No Record - cable shorted
	E6	Earth Pressure	Poor Record
	E7	Earth Pressure	Good Record
	SD1	Deflection	Poor Record
	SD2	Deflection	Poor Record
	SD3	Deflection	Poor Record
	SD4	Deflection	Poor Record
	SP1	Pressure	Good Record
	SP2	Pressure	Good Record
3.1/9014.02	A1	Acceleration	Good Record - zero shift
	A2	Acceleration	Good Record
	D1	Deflection	Good Record
	D2	Deflection	Good Record
	D3	Deflection	Good Record
	E1	Earth Pressure	Good record - negative zero shift
	E2	Earth Pressure	Good Record
	E3	Earth Pressure	Good Record
	E4	Earth Pressure	Good record - small zero shift
	E5	Earth Pressure	Good Record
	E6	Earth Pressure	Good Record
	E7	Earth Pressure	Good Record
	E8	Earth Pressure	Good Record
	SD1	Deflection	Poor Record
	SD2	Deflection	Poor Record
	SD3	Deflection	Poor Record
	SD4	Deflection	Poor Record
	SP1	Pressure	Good Record
	SP2	Pressure	Good Record

TABLE 3.1 CONTINUED

Project Structure	Gage No.	Type of Measurement	Comments
3.1/9014.03	A1	Acceleration	Good record
	A2	Acceleration	Good record
	D1	Deflection	Good record-zero shift
	D2	Deflection	Good record-zero shift
	D3	Deflection	Good record-zero shift
	E1	Earth Pressure	Good record
	SP1	Pressure	Peak pressure only
	SP2	Pressure	Good record
3.2/9016.01	A1	Acceleration	Good record
	PP	Peak Pressure	Good record
	PA	Peak Acceleration	Poor record
	SP	Pressure	Good record
3.2/9016.02	A1	Acceleration	Good record
	PP	Peak Pressure	Good record
	PA	Peak Acceleration	Poor record
3.2/9016.03	PP	Peak Pressure	Good record
	PA	Peak Acceleration	Poor record
3.2/9016.04	SP	Pressure	Good record
	PP	Peak Pressure	No record
	PA	Peak Acceleration	Poor record
3.2/9016.05	SP	Pressure	Good record
	A1	Acceleration	Good record
	PP	Peak Pressure	Good record
	PA	Acceleration	Poor record
3.2/9016.06	PP	Peak Pressure	Good record
	PA	Peak Acceleration	Poor record
3.2/9016.07	PP	Peak Pressure	Good record
	PA	Peak Acceleration	Poor record
3.2/9017.01	PP	Peak Pressure	Good record
	PA	Peak Acceleration	Poor record
3.2/9017.02	PP	Peak Pressure	Good record
	PA	Peak Acceleration	Poor record
3.2/9017.03	A1	Acceleration	No apparent record
	SA	Acceleration	Poor record
	PP	Peak Pressure	Good record
3.2/9018.01	PP	Peak Pressure	Good record
	PA	Peak Acceleration	Poor record
3.2/9018.02	PP	Peak Pressure	Good record
	PA	Peak Acceleration	Poor record

TABLE 3.1 Continued

Project/Structure	Gage No.	Type of Measurement	Comments
3.3/9019.01	A1	Acceleration	No apparent record
	SA	Acceleration	Poor record
	PP	Peak Pressure	Good record
	SP	Pressure	Peak pressure only
3.3/9019.02	A1	Acceleration	No apparent record
	SA	Acceleration	Poor record
	PP	Peak Pressure	Good record
	SP1	Pressure	Partial record
	SP2	Pressure	Good record
3.3/9019.03	A1	Acceleration	Good record
	PA	Peak Acceleration	Poor record
	PP	Peak Pressure	Good record
	SP	Pressure	Good record
3.4/9021.00	SP1R	Pressure	Peak pressure only
	SP1D	Pressure	Good record
	S4T	Dynamic pressure	Peak pressure only
	S4S	Dynamic Pressure	Peak pressure only
3.4/9022.01	S4T	Dynamic Pressure	Good record
	S S	Dynamic pressure	Good record
3.4/9022.02	S4T	Dynamic Pressure	Good record
	S S	Dynamic Pressure	Good record
3.4/9023.02	SP1N	Pressure	Poor record
	SP1S	Pressure	Peak pressure only
3.4/9024.01	SP1C	Pressure	Good record
	SP1B	Pressure	Peak pressure only
	S T	Dynamic pressure	Good record
	S S	Dynamic Pressure	Good record
3.4/9024.02	P1	Pressure	Good record
	P2	Pressure	Good record
	P3	Pressure	Good record
3.6/9026.02	P1	Pressure	Good record
	P2	Pressure	Good record
	P3	Pressure	Good record
	P4	Pressure	Good record
	P5	Pressurd	Good record
3.6/9027.01	P1	Pressure	Fair record-zero shift
	P2	Pressure	Good record
	P3	Pressure	Good record
	P4	Pressure	Good record
	P5	Pressure	Good record
	P6	Pressure	Good record
	P7	Pressure	Good record
	P8	Pressure	Good record
	P9	Pressure	Good record

TABLE 3.1 Continued

Project/Structure	Gage No.	Type of Measurement	Comments
3.6/9027.01	P10	Pressure	Good record
	P11	Pressure	Bad record
	P12	Pressure	Good record
	P13	Pressure	Good record
	SP14	Pressure	Good record
	SP15	Pressure	Good record
	SP16	Pressure	Fair record
	sp17	Pressure	Peak pressure only
	SP18	Pressure	Good record
	SP19	Pressure	Good record
	sp20	Pressure	Good record
	SP21	Pressure	Good record
	SP22	Pressure	Good record
	SP23	Pressure	Good record
	SP24	Pressure	Fair record
3.6/9027.02	P1	Pressure	Good record
	P2	Pressure	Good record
	P3	Pressure	Good record
	P4	Pressure	No apparent record
	P5	Pressure	Good record
	P6	Pressure	Good record
	P7	Pressure	Good record
	P8	Pressure	No apparent record
	P9	Pressure	Good record
	P10	Pressure	No record
	P11	Pressure	Good record
	SP12	Pressure	Good record
	SP13	Pressure	Good record
	SP14	Pressure	Fair record
	SP15	Pressure	Good record
	SP16	Pressure	Fair record
	SP17	Pressure	Peak pressure only
	SP18	Pressure	Peak pressure only
	SP19	Pressure	Good record
	SP20	Pressure	Good record
	SP21	Pressure	Good record
	SP22	Pressure	Good record
36/9028.01	P1	Pressure	Good record
	P2	Pressure	No record
	P3	Pressure	Good record
	P4	Pressure	Bad record
	P5	Pressure	Bad record
	P6	Pressure	No record
3.7/9028.01	QD	Dynamic Pressure	Good record
	QS	Dynamic Pressure	Good record
3.6/9028.01	SP7	Pressure	Fair record
	SP8	Pressure	Partial record
	SP9	Pressure	Peak pressure only
	SP10	Pressure	Peak pressure only
	SP11	Pressure	Good record

TABLE 3.1 Continued

Project/Structure	Gage No.	Type of Measurement	Comments
3.6/9028.01	SP12	Pressure	Good record
	SP13	Pressure	Good record
	SP14	Pressure	Partial record
	SP15	Pressure	Good record
	SP16	Pressure	Good record
	SP17	Pressure	Good record
	SP18	Pressure	Good record
	SP19	Pressure	Peak pressure only
3.7/9028.02	S[illegible]T	Dynamic Pressure	Peak pressure only
	S[illegible]S	Dynamic Pressure	Peak pressure only
3.6/9028.02	P1	Pressure	Bad record
	P2	Pressure	Good record
	P3	Pressure	Good record
	P4	Pressure	Good record
	P5	Pressurd	Good record
	P6	Pressure	Bad record
3.7/9028.03	[illegible]D	Dynamic Pressure	Partial record
	[illegible]S	Dynamic Pressure	Bad record
3.6/9028.02	SP7	Pressure	Good record
	SP8	Pressure	Good record
	SP9	Pressure	Peak pressure only
	SP10	Pressure	Good record
	SP11	Pressure	Peak pressure only
	SP12	Pressure	Good record
	SP13	Pressure	Good record
	SP14	Pressure	Good record
	SP15	Pressure	Peak pressure only
	SP16	Pressure	Good record
	SP17	Pressure	Good record
	SP18	Pressure	Good record
	SP19	Pressure	Good record
3.7/9028.04	S[illegible]T	Dynamic Pressure	Poor record
	S[illegible]S	Dynamic Pressure	Good record
30.1/8001.01	P1	Pressure	Good record
	P2	Pressure	Good record
	P3	Pressure	Good record
	P4	Pressure	Bad record
	P5	Pressure	Good record
	A25V	Acceleration	Fair record-zero shift
	A26H	Acceleration	Bad record
	A27V	Acceleration	Fair record
	A28H	Acceleration	Fair record
30.1/8001.02	P1	Pressure	Good record
	P2	Pressure	Good record
	P3	Pressure	Bad record
	P4	Pressure	Good record
	P5	Pressure	Good record
	A23V	Acceleration	Fair record
	A24H	Acceleration	Fair record
	A29V	Acceleration	Bad record
	A30H	Acceleration	Bad record

TABLE 3.1 CONTINUED

Project/Structure	Gage No.	Type of Measurement	Comments
30.1/8001.03	P1	Pressure	Good record
	P2	Pressure	Good record
	P3	Pressure	Good record
	P4	Pressure	No apparent record
	P5	Pressure	Good record
	P6	Pressure	Good record
	P7	Pressure	Fair record
30.2/8002	P1	Pressure	Good record-shift during shot
	P2	Pressure	Good record
	P3	Pressure	Good record
	P4	Pressure	Bad record
	P5	Pressure	Good record
	E6	Earth Pressure	Good record
	E7	Earth Pressure	Good record
	E8	Earth Pressure	Good record
	E9	Earth Pressure	Good record
	E10	Earth Pressure	Bad record
	E11	Earth Pressure	Good record
	E12	Earth Pressure	Good record
	E13	Earth Pressure	Good record
	E14	Earth Pressure	Good record
	E15	Earth Pressure	Bad record
	E16	Earth Pressure	Bad record
	D1	Deflection	Good record
	D2	Deflection	Bad record
	D3	Deflection	Good record
	D4	Deflection	Good record
	D5	Deflection	Good record
	D6	Deflection	Good record
	D7	Deflection	Good record
	D8	Deflection	Good record
	D9	Deflection	Good record
	D10	Deflection	Good record
	D11	Deflection	Good record
	D12	Deflection	Good record
	D13	Deflection	Good record
	D14	Deflection	Good record
	D15	Deflection	Bad record
	D16	Deflection	Gage failed
	D17	Deflection	Gage failed
	D18	Deflection	Bad record
	QD	Dynamic Pressure	Bad record
	QS	Dynamic Pressure	Good record
	SQT	Dynamic Pressure	Peak pressure only
	SQS	Dynamic Pressure	Peak pressure only
	SP1	Pressure	Good record
	SP2	Pressure	Peak pressure only

TABLE 3.1 CONTINUED

Project/Structure	Gage No.	Type of Measurement	Comments
30.3/8003.01	SP	Pressure	Good record
	PP	Peak Pressure	Peak pressure only
30.3/8003.02	SP	Pressure	Bad record
	PP	Peak Pressure	Peak pressure only
30.3/8003.03	SP	Pressure	Good record
	PP	Peak Pressure	Peak pressure only
	D1	Deflection	Good record
	D2	Deflection	Good record
31.4/8006.01	SP1	Pressure	Godd record
	SP2	Pressure	Good record
	SP3	Pressure	Good record
	PP	Peak Pressure	Good record
	PD1	Deflection	Structure failed
	PD2	Deflection	Good record
	PD3	Deflection	Good record
	PD4	Deflection	Good record
	PD5	Deflection	Good record
	D1	Deflection	Good record
31.4/8006.03	SP1	Pressure	Peak pressure only
	SP2	Pressure	Peak pressure only
	SP3	Pressure	Good record
	PD1	Deflection	Good record
	PD2	Deflection	Good record
	PD3	Deflection	Good record
	PD4	Deflection	Good record
	PD5	Deflection	Good record
31.5/8007.01	D1	Deflection	Gage failed
	SP1	Pressure	Peak pressure only
	SP2	Pressure	No record
31.5/8007.02	D1	Deflection	Good record
	SP1	Pressure	Peak pressure only
	SP2	Pressure	Good record
31.5/8007.03	D1	Deflection	Good record
	SP1	Pressure	Peak pressure only
	SP2	Pressure	Peak pressure only
31.5/8007.4	D1	Deflection	Good record
	SP1	Pressure	Peak pressure only
	SP2	Pressure	Peak pressure only
31.5/8007.05	D1	Deflection	Good record
	SP1	Pressure	Good record
	SP2	Pressure	Peak pressure only

TABLE 3.1 CONTINUED

Project/Structure	Gage No.	Type of Measurement	Comments
31.5/8007.06	D1	Deflection	Good record
	SP1	Pressure	Good record
	SP2	Pressure	Good record
31.5/8007.07	D1	Deflection	Good record
	D2	Deflection	Good record
	D3	Deflection	Good record
	SP1	Pressure	Peak pressure only
	SP2	Pressure	Peak pressure only
	SP3	Pressure	Peak pressure only
	SP4	Pressure	Good record
	SP5	Pressure	Good record
	SP6	Pressure	Good record
	SP7	Pressure	Good record
31.5/8007.08	D1	Deflection	Good record
	D2	Deflection	Good record
	SP1	Pressure	Peak pressure only
	SP2	Pressure	Good record
	SP3	Pressure	Good record
	SP4	Pressure	Peak pressure only
	SP5	Pressure	Good record

record obtained from the electronic gages was attributed to the structure failure. For example, such was the case of the displacement gages located in the ramp of Structure 30.2-8002. The wires were broken when the wall of the ramp collapsed.

Because of the severe radiation-induced electromagnetic pulse present at time zero, a signal was induced on the recording mechanism. Often the base line returned to zero before the blast arrived at the transducer, in which case the records were immediately useable. However, in some cases, the records experienced a permanent zero shift. In these cases, the records obtained from the electronic gages required adjustment of the calibration data to compensate for the zero shift.

The predominant cause of malfunction of the self-recording gages was initiation difficulties. The largest portion of these failures was due to pre-initiation; either from premature operation of photocells or a short circuit of the hardwire lines. Some gages were never initiated because of faulty arming devices. A small percentage of failures occurred from battery failures, open circuits in hardwire lines, and erratic relay closures.

Self-recording accelerometers used in this operation did not function properly. These gages are in the devvlopment stage, and improvements are necessary. Particularly, damping of the element is required to minimize overshoot and high-frequency oscillations. The failure of the self-recording displacement gages resulted from malfunction of the releasing mechanism that spring loads the gage to follow the motion of displacement. Records of the peak-pressure recorders are somewhat questionable, in view of the fact that the structures were nominally pressure sealed and no appreciable damage to the structures resulted. The deflections noted on the records could very well result from the accelerations sustained by the structure.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 GAGE IMPROVEMENTS

As is generally the case during the course of a project of this type, several methods suggest themselves to ease the workload for completion of the instrumentation requirements and to improve the caliber of records obtained. The calibration of displacement gages that were to measure displacement of a minute fraction of an inch was critical. Much time was spent in calibrating these gages to be assured that the calibration was valid. A modification of the calibration apparatus is being considered.

The self-recording peak accelerometers can be made more useful by better damping. The records produced by these instruments show much vibration and overshoot, and proper damping of the element would eliminate this difficulty. The difficulties encountered with the initiation have been diagnosed, and several new experimental circuits have been developed.

4.2 RECORDER IMPROVEMENTS

The Webster-Chicago recording equipment proved satisfactory during Shot Priscilla. However, this system has been in use since Operation Greenhouse. It has been rebuilt and modified several times. Due to this extended service and repeated rough handling in shipment, it is felt that the system is rapidly deteriorating, as well as becoming obsolete.

It is recommended that the recording system either be replaced with a more-modern and more-compact system or a new system be built along the present lines of the Webster-Chicago system, incorporating the latest electrical components available.

4.3 SCHEDULE IMPROVEMENTS

As has often occurred during past test operations, usually due to the very-short, tight construction time schedule, the structures were not actually complete at the time scheduled for instrumentation to begin. Therefore, considerable time and motion of the BRL instrumentation personnel were lost, because of the unavoidable interference of construction personnel concurrently working in the test area. It is strongly recommended that the time-period schedule specified prior to an operation for instrumentation calibration and installation be adhered to in order to allow adequate time for completion and readiness.

Appendix A

MEMORANDUM OF UNDERSTANDING REGARDING INSTRUMENTATION OF STRUCTURES IN FRENCHMAN FLAT AREA, NTS, MERCURY, NEVADA FOR OPERATION PILGRIM BETWEEN FIELD COMMAND, ARMED FORCES SPECIAL WEAPONS PROJECT; FEDERAL CIVIL DEFENSE ADMINISTRATION; CIVIL EFFECTS TEST GROUP; AND BALLISTIC RESEARCH LABORATORIES, USA.

1. In view of the plan for Operation Pilgrim whereby:

a. The Ballistic Research Laboratories (BRL) will be responsible for supplying electronic instrumentation for several Program 3 structures projects in the DOD Weapons Effects Program, Operation Pilgrim . Specifically, these are Projects 3.1, 3.2, 3.3, and 3.6, and will involve approximately a total of 100 electronic channels.

b. In addition to the instrumentation indicated in the preceding paragraph, in conformance with previous mutual agreement between Headquarters, Armed Forces Special Weapons Project (AFSWP) and the Federal Civil Defense Administration (FCDA), Civil Effects Test Group (CETG), it has already been determined that BRL also will be responsible for supporting the FCDA (CETG) projects on Frenchman Flat, Operation Pilgrim, with up to 85 electronic channels of instrumentation.

c. The physical layout of the AFSWP Program 3 structures Projects and the FCDA Projects will place them in relatively close proximity. The capability limitations of the total number of channels of BRL recording equipment is to be such, that for BRL to properly accomplish this major instrumentation effort, it will be necessary for BRL to utilize various channels of a single recording installation in the several instrumentation shelters, for more than one, i.e., several, different projects. Such joint utilization should also provide the structures instrumentation requirements at maximum overall economy of manpower, material and money.

d. Because of the close interrelationship of the instrumentation of the structures as described above, the scope of this effort, and the inherent problems of administration and financial accountability for the various portions of this effort, it is deemed very desirable to establish a separate AFSWP project, and a similar, affiliated, separate FCDA (CETG) project, to facilitate accomplishment of the structures instrumentation.

2. Accordingly, the organizations concerned: FC,AFSWP; FCDA; CETG; and BRL, do hereby agree, for the mutual benefit of all in this effort for Operation Pilgrim, that:

a. There is hereby established, for the reasons indicated above, the following AFSWP project:

<u>Project No</u>: 3.7 <u>Title</u>: Structures Instrumentation

<u>Agency</u>: BRL/AFSWP

<u>Shot Participation</u>:	<u>Project Officer</u>:
DOD Shot only	Mr. J. J. Meszaros Explosion Kinetics Branch Terminal Ballistic Laboratory Aberdeen Proving Ground, Maryland Phone: Aberdeen 1000 Ext: 22222

<u>Objective</u>: To procure, and operate suitable instrumentation to obtain the data required by Projects 3.1, 3.2, 3.3, and 3.6.

Description and Experimental Procedure: It will be the responsibility of each of the Project Officers, Projects 3.1, 3.2, 3.3, and 3.6, to work closely with and assure ~~themselves~~ himself that BRL is adequately meeting all of the instrumentation requirements of their individual projects. Responsibilities of BRL include obtaining the instrumentation requirements from each of the individual projects and, as appropriate, consolidating these requirements for the purpose of procuring and operating suitable instrumentation to obtain the data required by the individual projects.

b. There is hereby established for the reasons indicated above the following FCDA (CETG) project:

Project No: 30.5 Title: Shelters and Structures Instrumentation

Agency: BRL/FCDA

Shot Participation: DOD Shot only

Project Officer:
Mr. J. J. Meszaros
Explosion Kinetics Branch
Terminal Ballistic Laboratory
Aberdeen Proving Ground, Maryland
Phone: Aberdeen 1000
Ext: 2222

Objective: To procure, and operate suitable instrumentation to obtain the data required by FCDA shelters and structures projects.

Description and Experimental Procedure: It will be the responsibility of the Program Director, FCDA (CETG) Shelter Program to work closely with and assure that BRL is adequately meeting all of the instrumentation requirements of the FCDA individual projects. Responsibilities of BRL include obtaining the instrumentation requirements for each of the individual projects and, as appropriate, consolidating these requirements for the purpose of procuring and operating suitable instrumentation to obtain the data required for the individual projects

c. The close relationship of the two foregoing structures instrumentation projects is indicated by the following procedures hereby agreed to:

Monthly Status Reports and Construction Requirements:

BRL will prepare and submit in the usual manner to WET, FC, AFSWP the normal Monthly Status Reports and Construction Requirements for the consolidated requirements of Project 3.7 including proposed project personnel, materiel, equipment, support required, construction required, etc. These consolidated requirements will, of necessity, include those requirements necessary to accomplish the instrumentation of each of the AFSWP Projects 3.1, 3.2, 3.3, and 3.6, and also for those FCDA (CETG) structures projects on Frenchman Flat.

This will actually mean that the total BRL consolidated requirements for the structures instrumentation of AFSWP Project 3.7 and FCDA (CETG) Project 30.5 will be handled by and appropriate action taken through WET, FC, AFSWP channels, i.e., for the following requirements normally covered by the Monthly Status and the Construction Requirements reports: (1) Instrumentation Experimental Plan, (2) Timing Signal Requirements, (3) Communications Requirements, (4) Radiation Monitors, (5) Photographic Requirements, (6) Office Equipment Requirements, (7) Vehicle Requirements (For Special Consideration of this item, see below, Financial and Budgetary considerations) (8) Equipment Purchased (Control of and title to all equipment will remain with the AFSWP Equipment Pool, since the equipment to be purchased is to be a relatively small component part of and should be considered a modification to already existing AFSWP equipment), (9) Construction Requirements and

Changes, (10) Project Personnel and Clearance Data.

BRL will also furnish copies of these reports to Projects 3.1, 3.2, 3.3, and 3.6, and also FCDA (CETG), to keep them advised.

Financial and Budgetary Considerations:

Introduction . Based upon the above consolidated requirements, BRL will prepare a total consolidated budget for AFSWP Project 3.7 and FCDA (CETG) Project 30.5. The total consolidated budget will then be prorated between the various projects approximately on the basis of the number of channels utilized by each project. By mutual agreement between WET, FC, AFSWP and FCDA (CETG), based on the approximate total number of instrumentation channels to be used by each, 60 percent of the total budget will be chargeable to AFSWP Project 3.7 and 40 percent will be chargeable to FCDA (CETG) Project 30.5.

Of the 60 percent of the total budget chargeable to AFSWP Project 3.7, based on the approximate total number of instrumentation channels to be used by each, the projects involved will be chargeable as follows:

Project 3.1: 30 percent

Project 3.2: 5 percent

Project 3.3: 5 percent

Project 3.6: 60 percent

Timing Signals. The cost of the timing signal requirements is an item not normally budgeted for by each specific project, but is budgeted for a lump sum total support cost for timing signals furnished all AFSWP projects by the AEC sub-contractor concerned, EG&G. However, since the timing signals requirements represent a sizeable item of cost, it is agreed that AFSWP (in behalf of Project 3.7) will assume 60 percent of the total estimated cost of all timing signal requirements for BRL structures instrumentations to be furnished by EG&G, and that FCDA (CETG) will assume 40 percent.

Vehicles. In recognition of: (1) the difficulties inherent in, and the normal lack of specific project budgeting for project used vehicles and therefore the difficulty in prorating vehicle costs, and (2) the general supplementary administrative support to be furnished by WET, FC, AFSWP to the FCDA (CETG) portion of the BRL structures instrumentation effort (such as processing the combined personnel, equipment, office requirements, and materiel requirements), it is further agreed, supplementing the foregoing Financial and Budgetary prorating, that FCDA (CETG) will furnish the total number of vehicles required for this effort by BRL (probably about eight: (three- carryalls, five - 1/2 ton pickup trucks), from the AEC, NTS Motor Pool. Fuel and service requirements, routine maintenance, including financial responsibility for same, and control of these vehicles, will be the responsibility of the AEC, NTS Motor Pool in accordance with arrangements between AEC and FCDA (CETG).

General. All of the above percentage allocation figures will be used throughout the Operation Pilgrim, unless it becomes obvious that due to major changes in the current plans of the number of instrumentation channels required, that a revised set of percentage allocations should be adopted.

Copies of the consolidated budget, including the prorated shares for the participating projects, as prepared by BRL and forwarded to WET, FC, AFSWP will also be furnished to the participating Projects 3.1, 3.2, 3.3, and 3.6, and also to FCDA (CETG).

Field Work Orders Requests: For all field work order requests written by BRL to accomplish items, such as all trenching, for Project 3.7/30.5, LVBO, AEC will be requested to total monthly all such W. O. charged against Project 3.7/30.5 and to prorate these costs on the basis of 60 percent for Project 3.7 and 40 percent for Project 30.5. Such work orders will include all those for all BRL structures instrumentation work. The 60 percent for Project 3.7 will be redistributed to the participating AFSWP projects at the close of the Operation by WET, FC, AFSWP on the same percentage basis indicated under the financial and budgetary considerations paragraph above.

The submission of all such field work orders by BRL will be through the Requirements Branch, WET, FC, AFSWP organization channels, for implementation. Appropriate copies of such field work orders will also be furnished to FCDA (CETG).

Funding: Subject to the above, BRL will receive funds from FC, AFSWP, as appropriate, chargeable to Projects 3.1, 3.2, 3.3, and 3.6 for their respective prorated percentage of 60 percent of the total combined budget for Project 3.7 structures instrumentation.

BRL will receive funds direct from FCDA, as appropriate, for the 40 percent of total combined budget for FCDA (CETG) Project 30.5 structures instrumentation.

Field Work Order Requests for structures instrumentation projects will be chargeable on a prorated basis: AFSWP Project 3.7/60 percent and FCDA (CETG) Project 30.5/40 percent, directly against FC,AFSWP and FCDA funds, respectively.

Summary: It is believed the above arrangements, as agreed to by the appropriate representatives of FC,AFSWP; FCDA; CETG; and BRL at a conference at the office of US AEC, Las Vegas Branch Office, Las Vegas, Nevada on 17-18 October 1956, will enable this structures instrumentation effort for Operation Pilgrim to be accomplished in the most expeditious, administratively equitable basis, to the satisfaction of all interested parties.

3. The senior representatives present from each of the organizations concerned, who were at the conference at which the above memorandum of understanding was drawn up andagreed upon, were:

H. D. Pickett
Captain, USN
Asst. Deputy Chief of Staff,WET,
FC, AFSWP

E. R. Saunders
Coordinating Director of Technical
Tests, FCDA

J. J. Meszaros
Chief, Explosion Kinetics
Branch, BRL

R. L. Corsbie
Director,
CETG

To facilitate earliest action on this major BRL instrumentation effort for Operation Pilgrim, it was agreed that for practical purposes the agencies concerned, especially BRL, would proceed at once on the premise that this memorandum of understanding was acceptable to the parent organizations of all concerned.

4. Accordingly, the above memorandum of understanding, as drawn up and

now prepared in finished form, is furnished for the confirming validation or signature by the appropriate representative of each parent organization concerned:

s/HARRY D. PICKETT
t/Captain, USN
Asst. Deputy Chief of Staff
Weapons Effects Tests
(FC,AFSWP Representative)

s/CHARLES L. REGISTER
t/Colonel, Ord Corps
Director, Ballistic
Research Laboratories
(BRL Representative)

s/WILLIAM S. HEFFELFINGER
t/Assistant Administrator
General Administration
(FCDA Representative)

s/ROBERT L. CORSBIE
t/Director, Civil Effects Test Group
Nevada Test Organization
(CETG Representative)

APPENDIX B

Appendix B presents photographs of a representative group of electronic channel original records and linearized plots of these records. Also presented are linearized plots of all self-recording Pt gages determined as usable in Table 3.1. With each group of plots there is a sketch identifying the plots with their station locations.

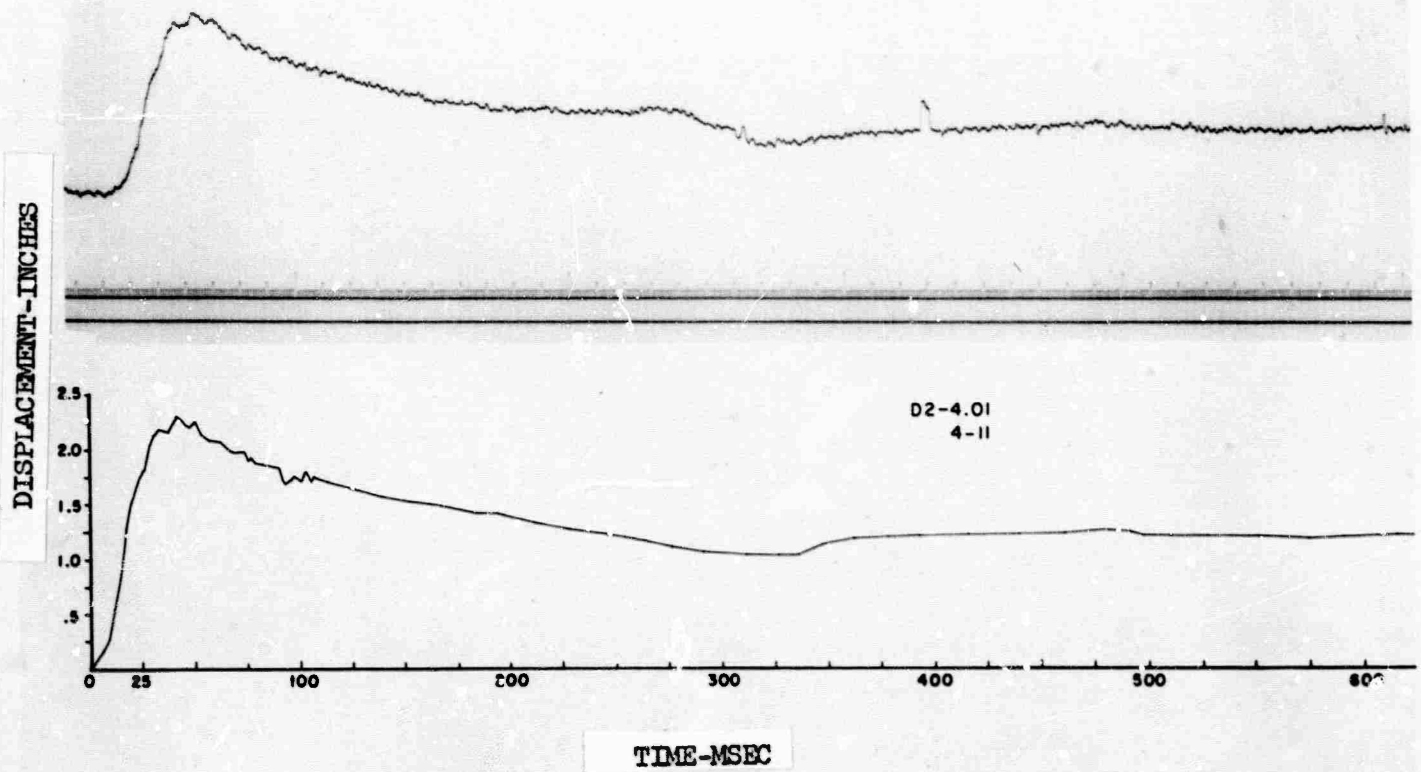

Figure B.1 Displacement-Time Record, Gage D2, Station 3.1/4.01

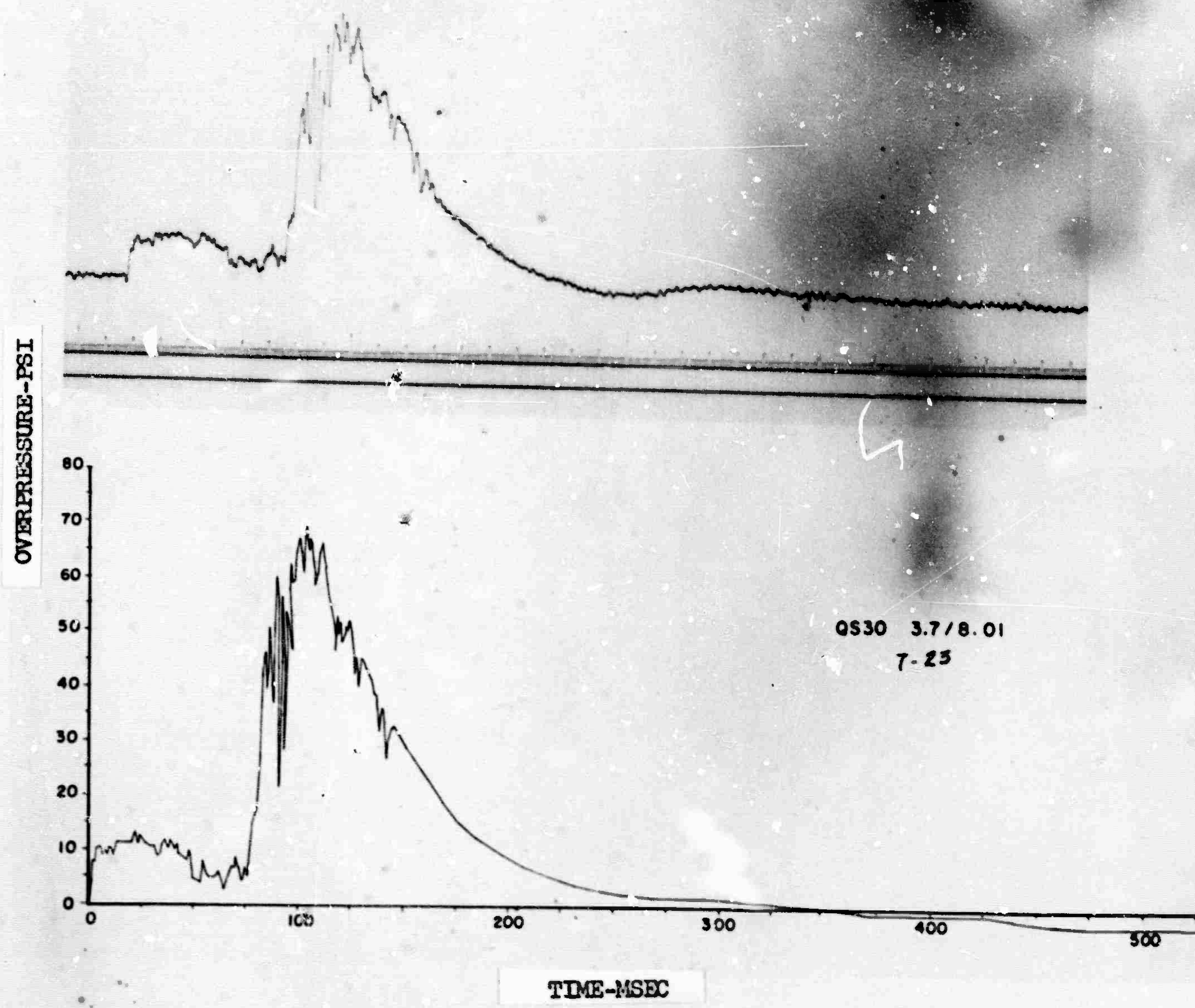

Figure B.2 Side-On Over-Pressure-Time Record, Gage QS30, Station 3.7/8.01

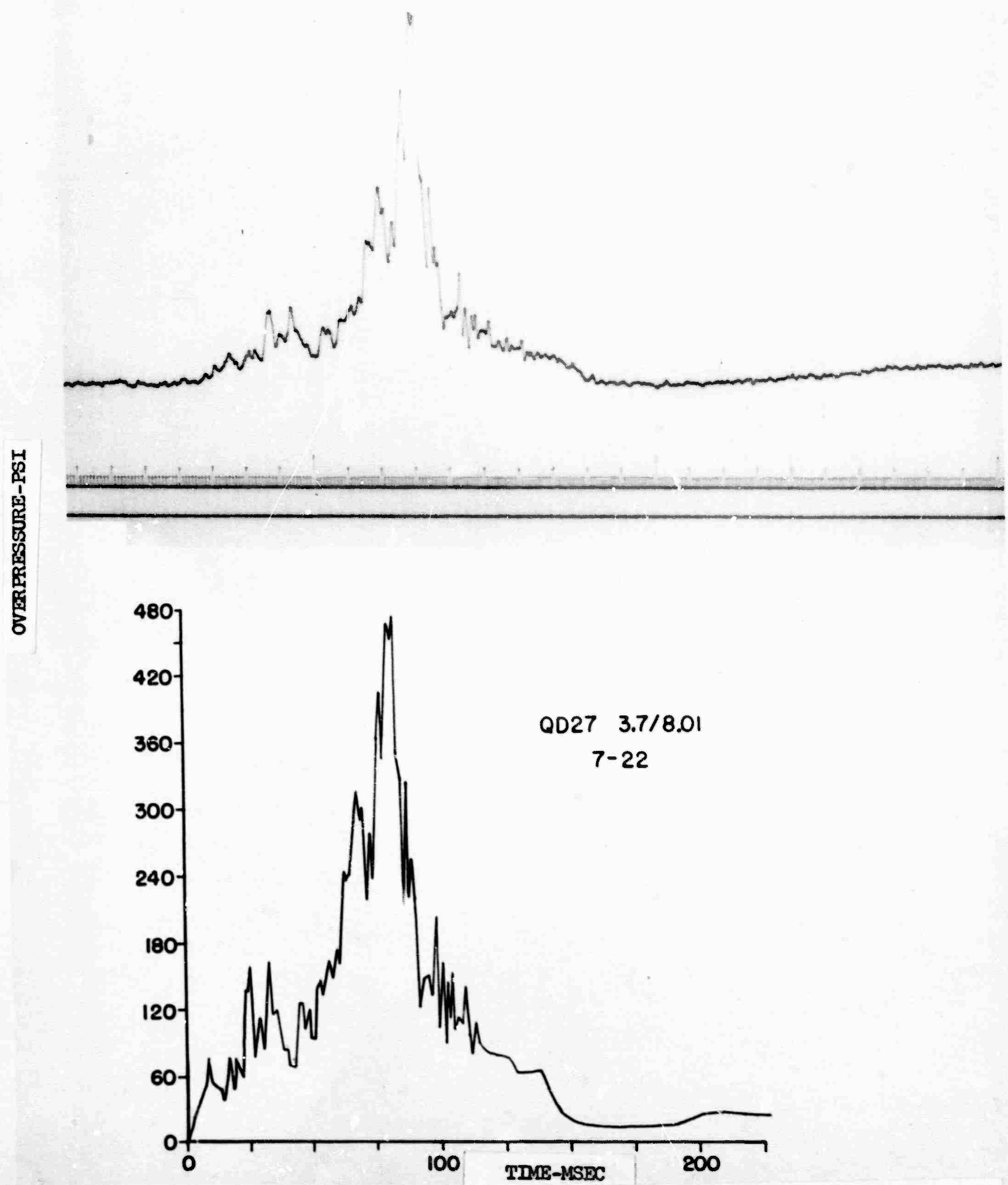

Figure B.3 Dynamic Over-Pressure-Time Record, Gage QD27, Station 3.7/8.01

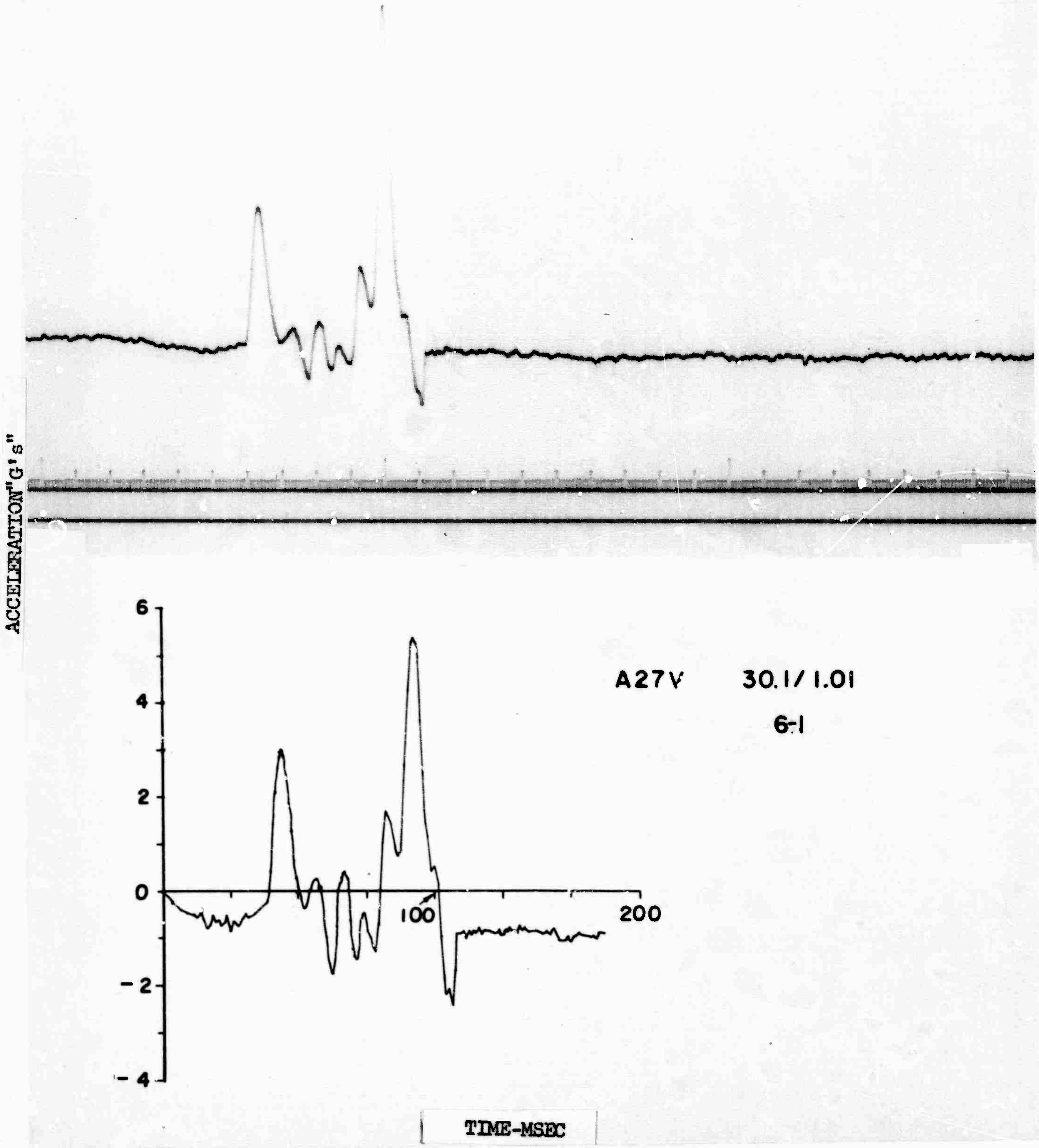

Figure B.4 Acceleration-Time Record, Gage A27V, Station 30.1/1.01

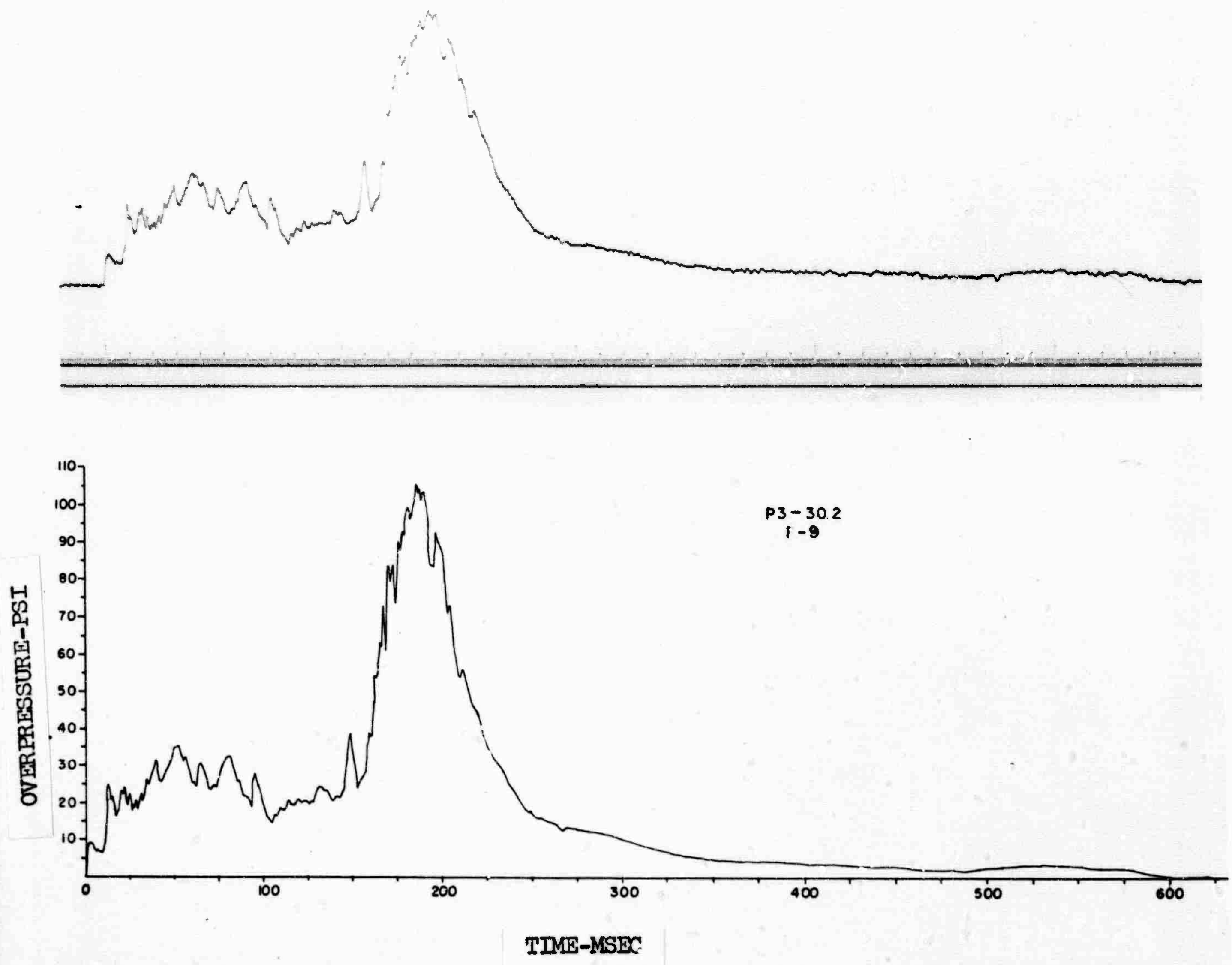

Figure B.5 Over-Pressure-Time Record, Gage P3, Station 30.2/2.00

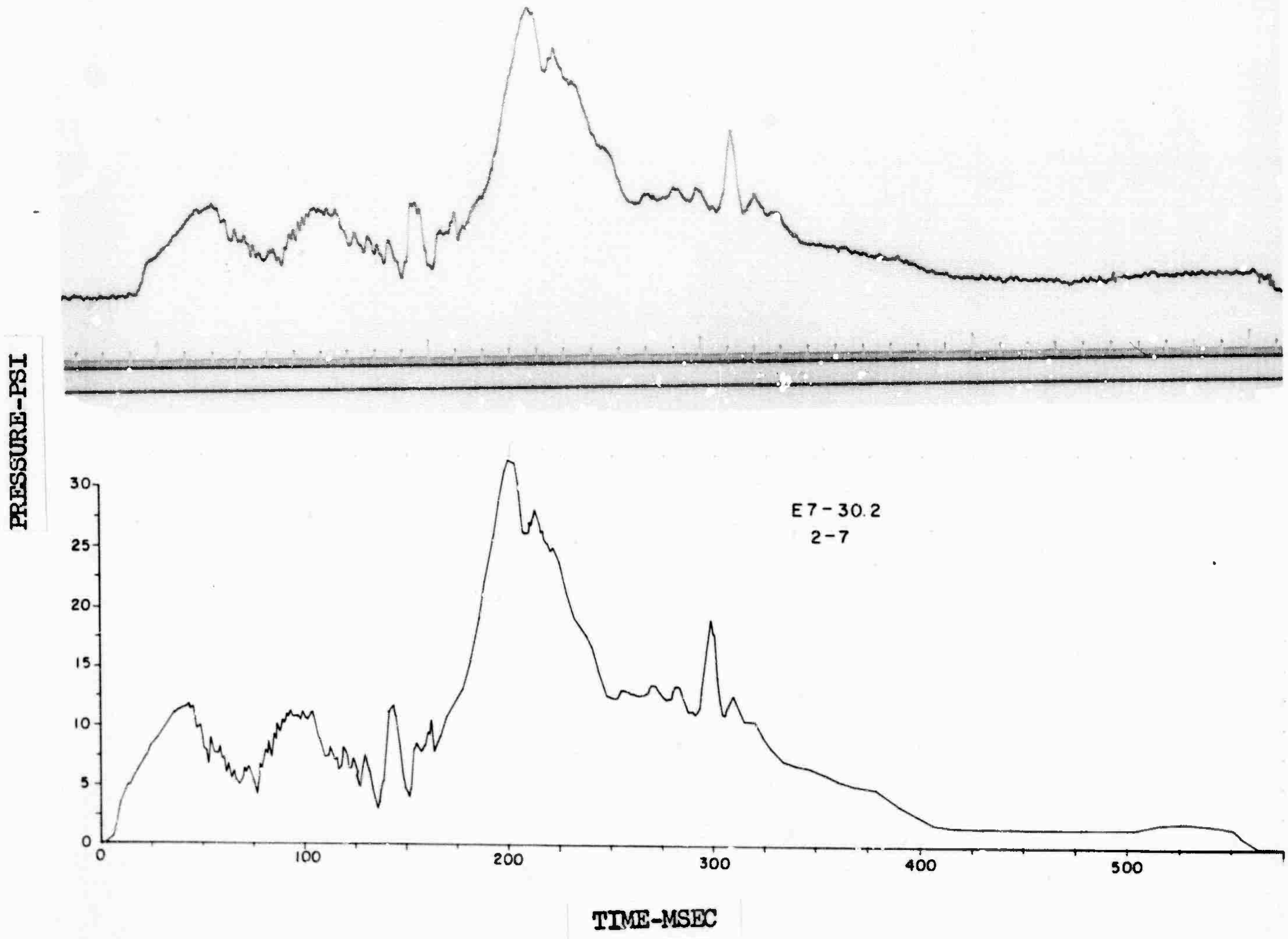

Figure B.6 Pressure-Time Record, Gage E7, Station 30.2/2.00

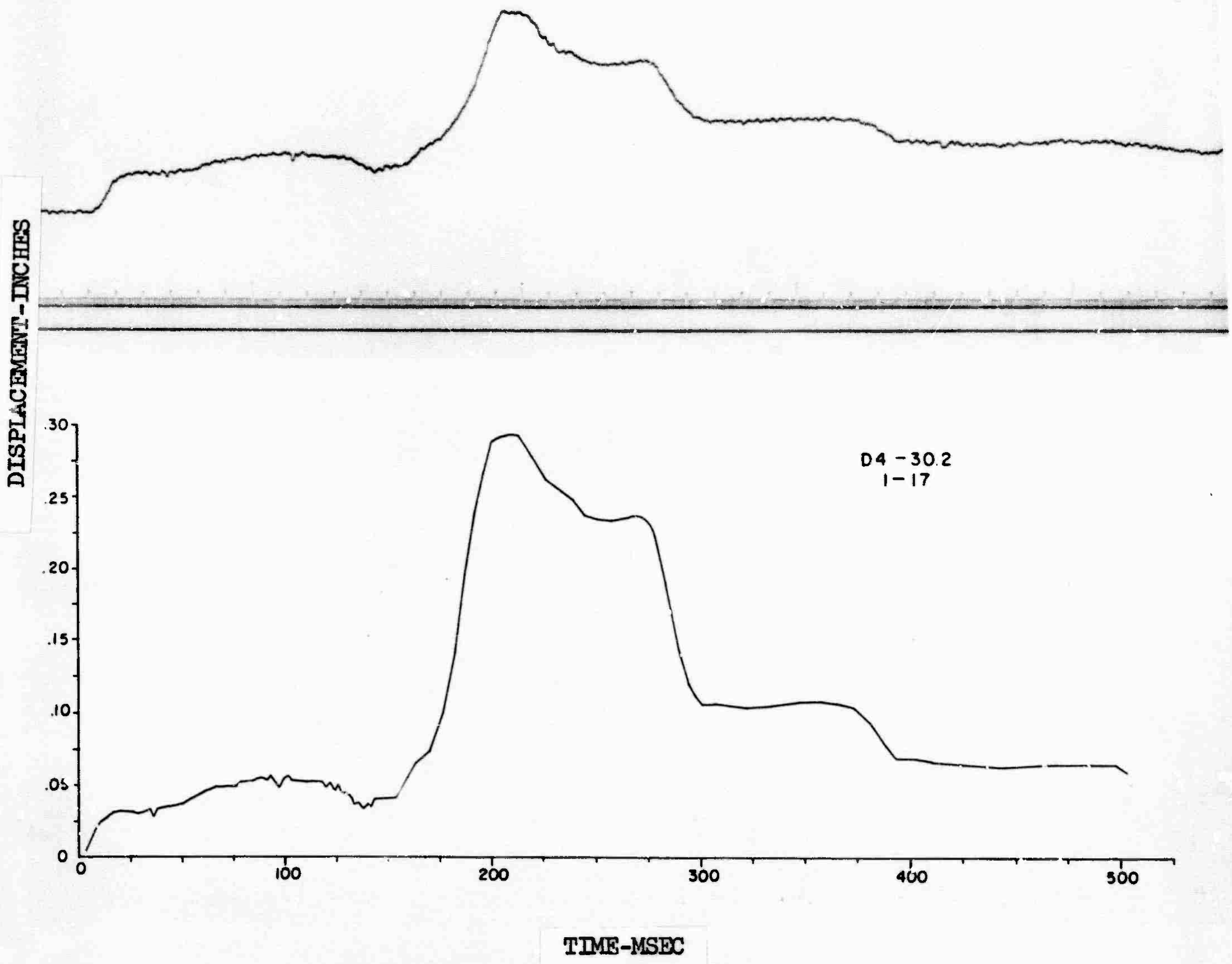

Figure B.7 Displacement-Time Record, Gage D4, Station 30.2/2.00

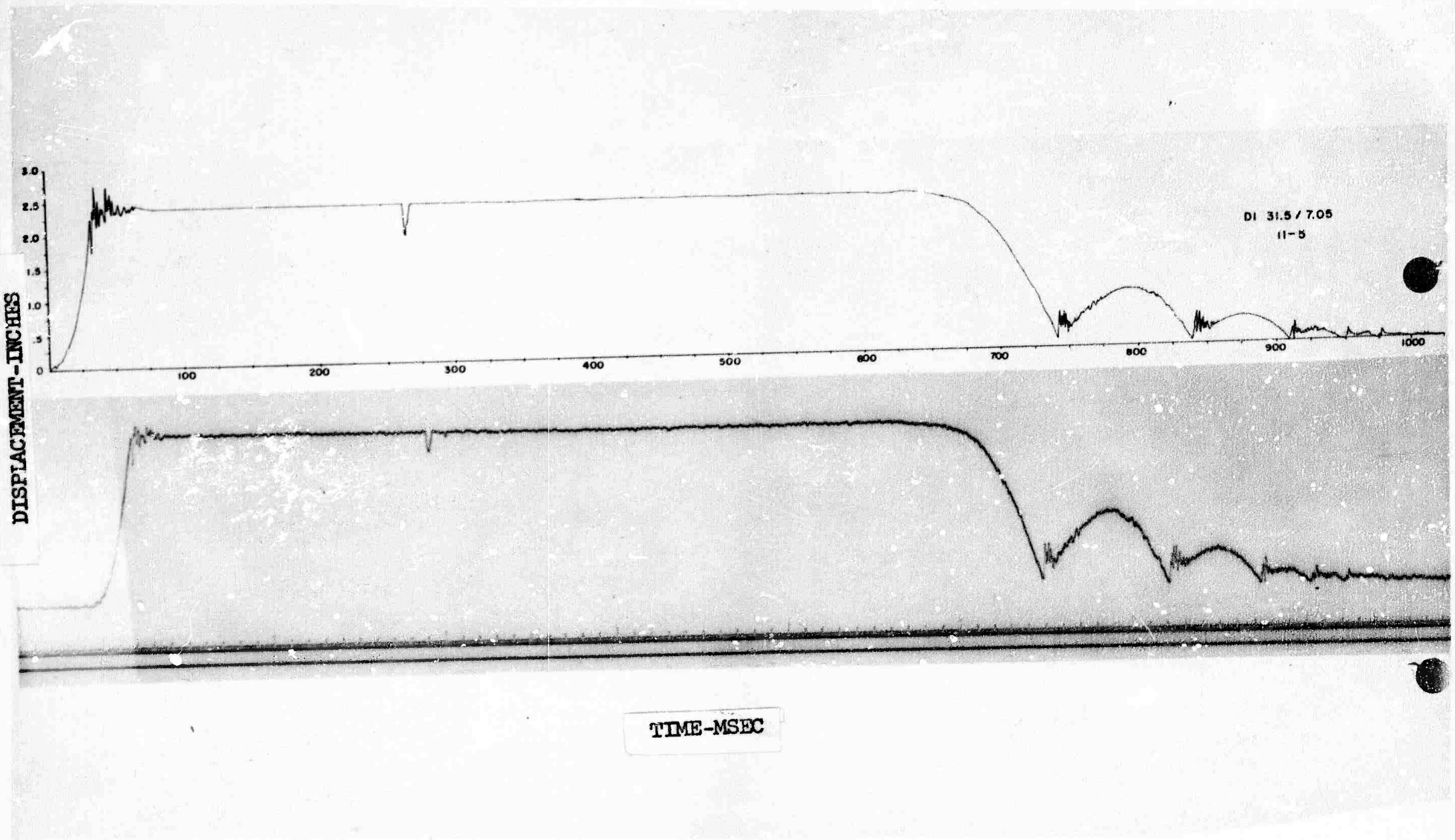

Figure B.8 Displacement-Time Record, Gage D1, Station 31.5/7.05

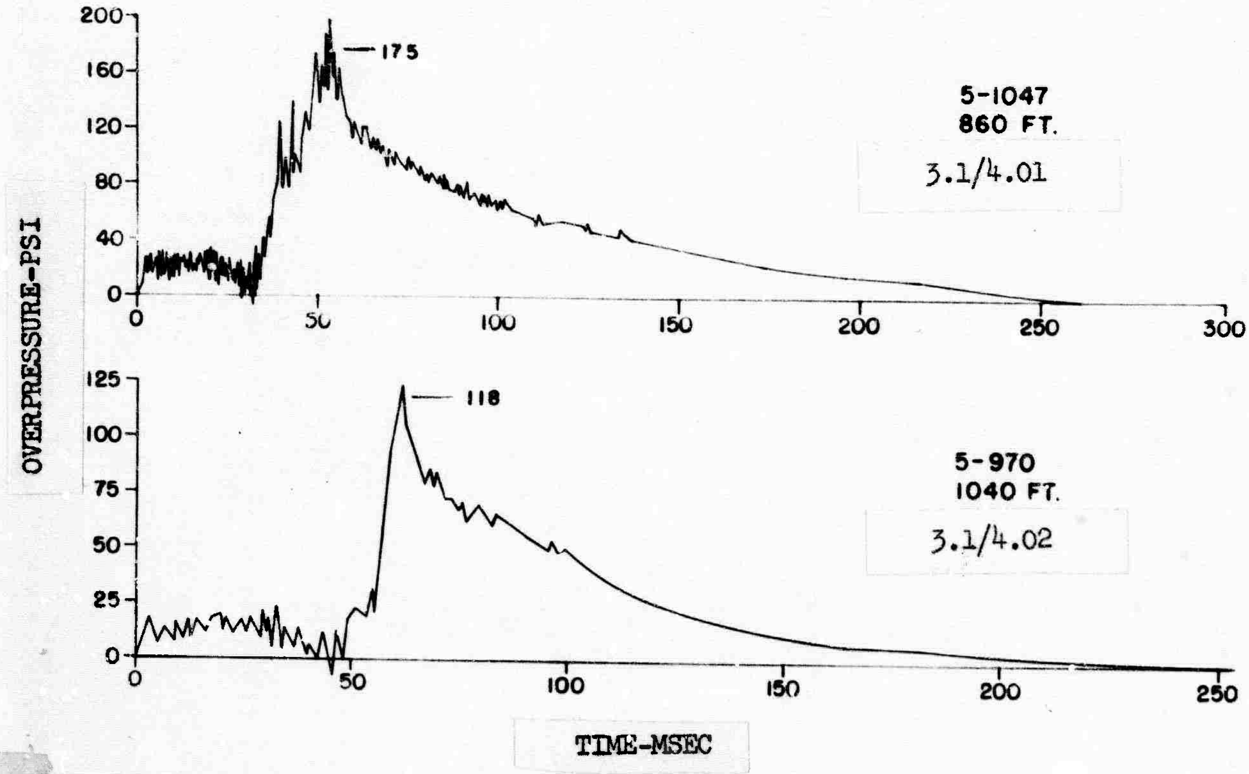

Figure B.9 Over-Pressure-Time Records, Outside Gages SP1, Station 3.1/4.01/4.02

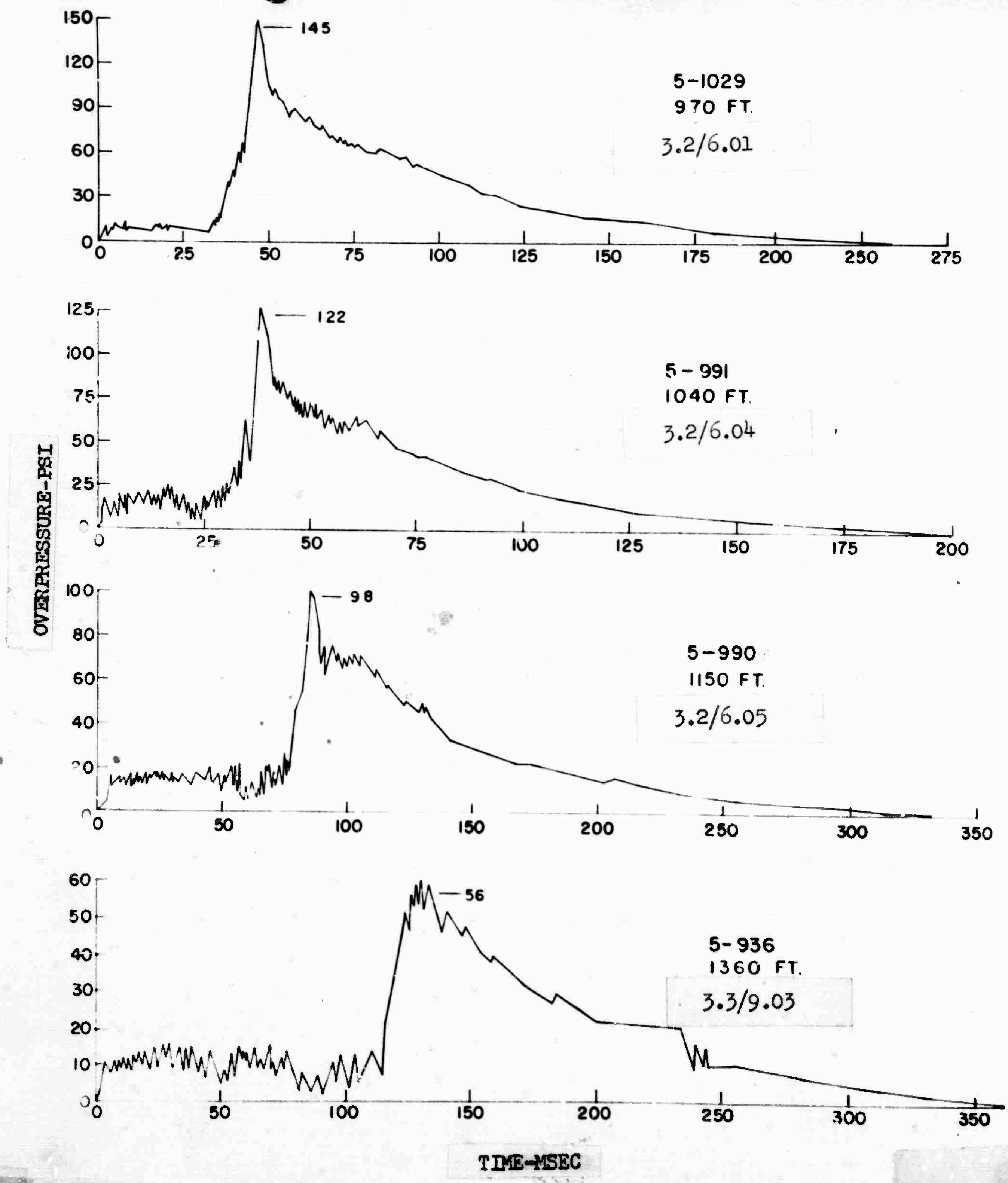

Figure B.10 Over-Pressure-Time Records, Outside SP Gages Near 3.2 & 3.3 Stations

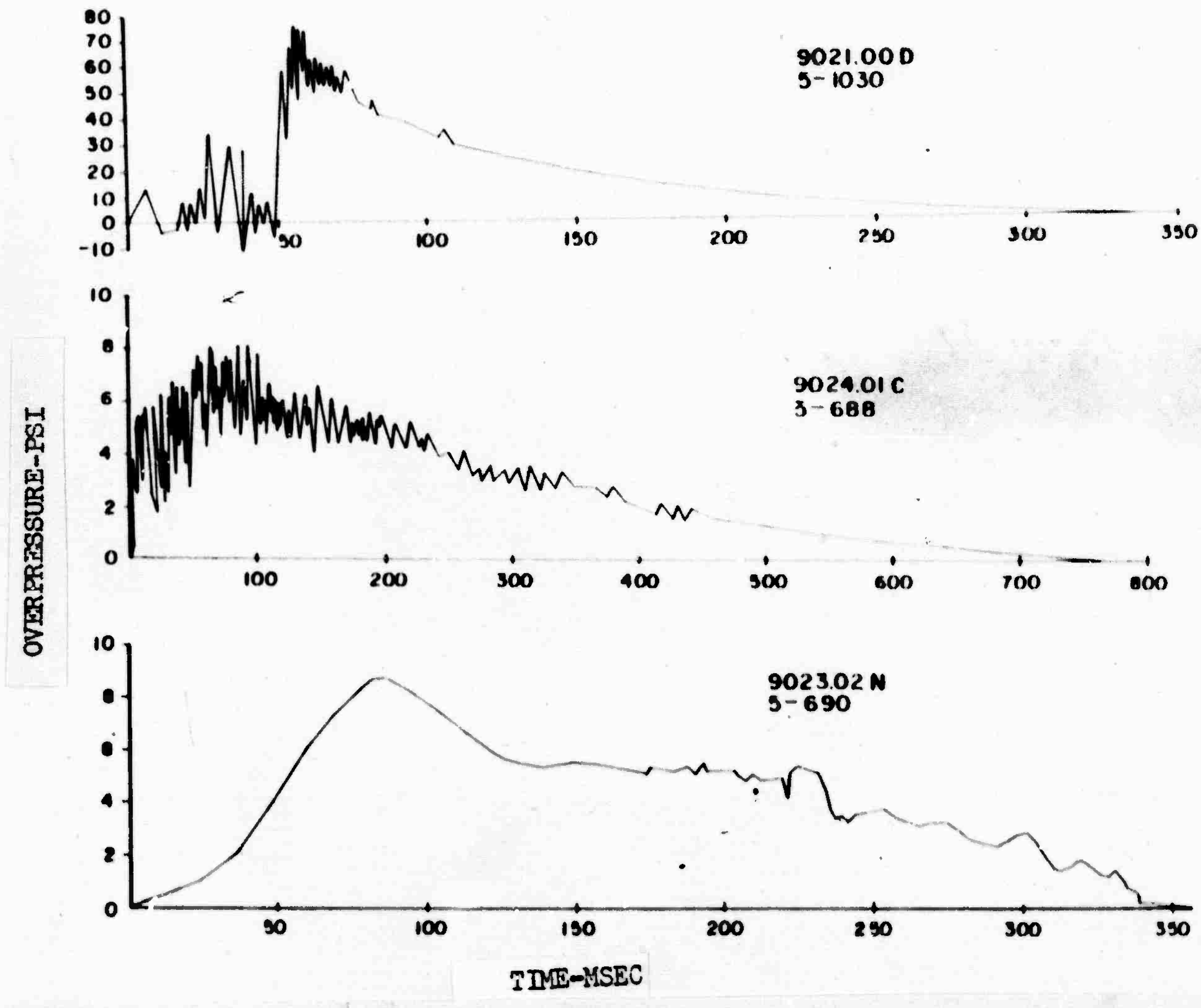

Figure B.11 Over-Pressure-Time Records, Inside SP Gages, Station 3.4/1.00/3.02/4.01

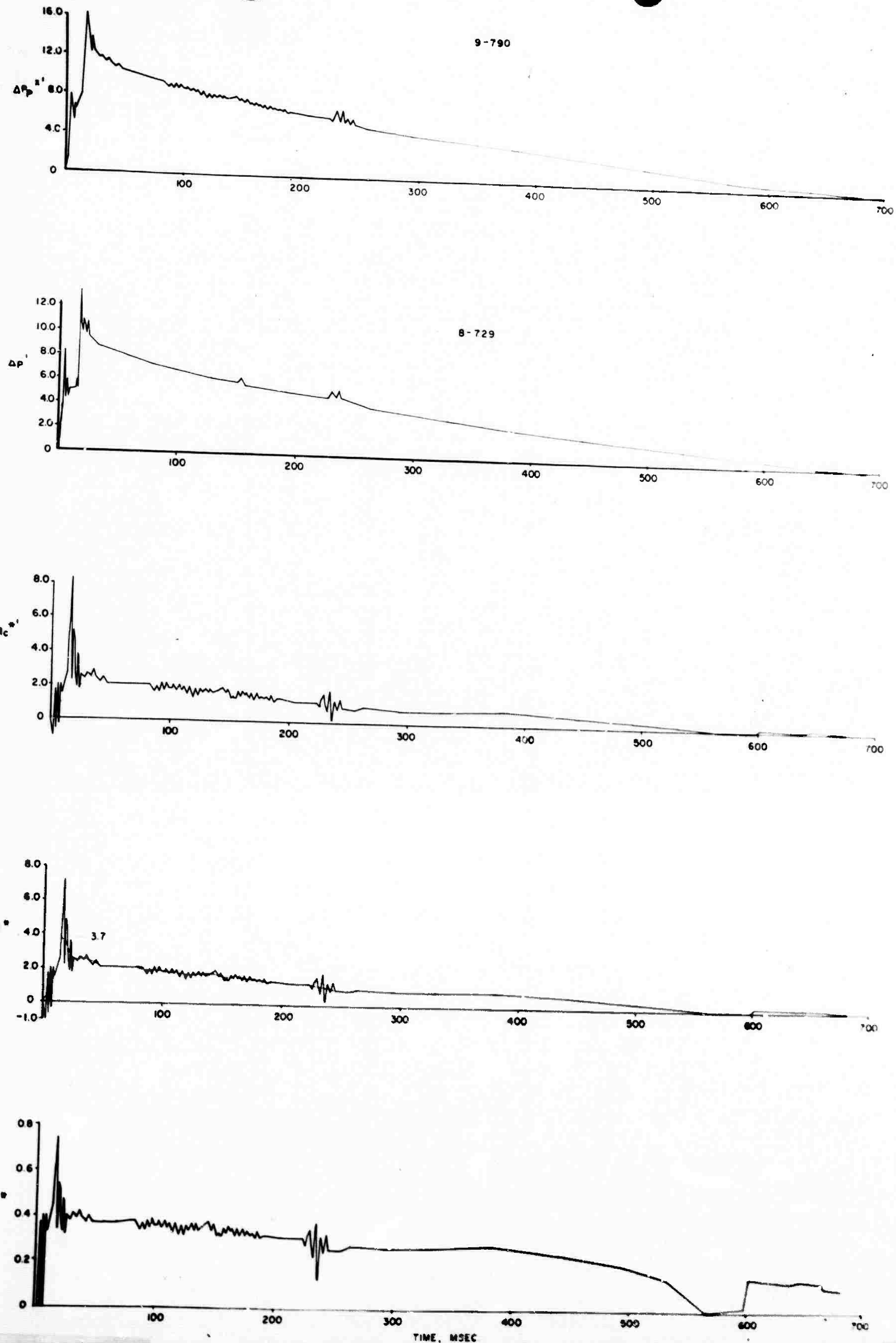

Figure B.12 Pressure & Mach No.-Time Records, Gages SQT, SQS, Station 3.4/2.01

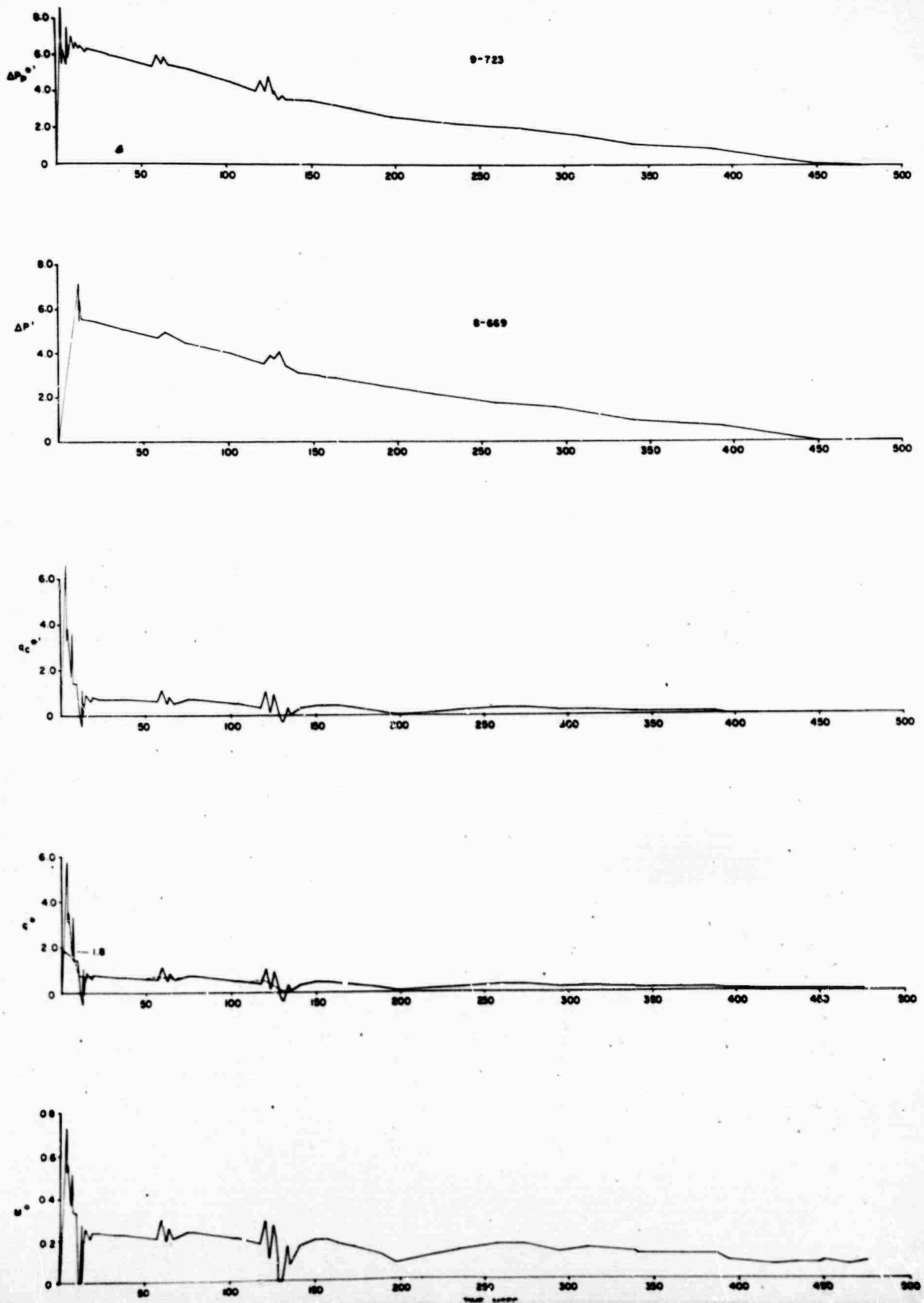

Figure B.13 Pressure & Mach No.-Time Records, Gages SQT, SQS, Station 3.4/2.0M

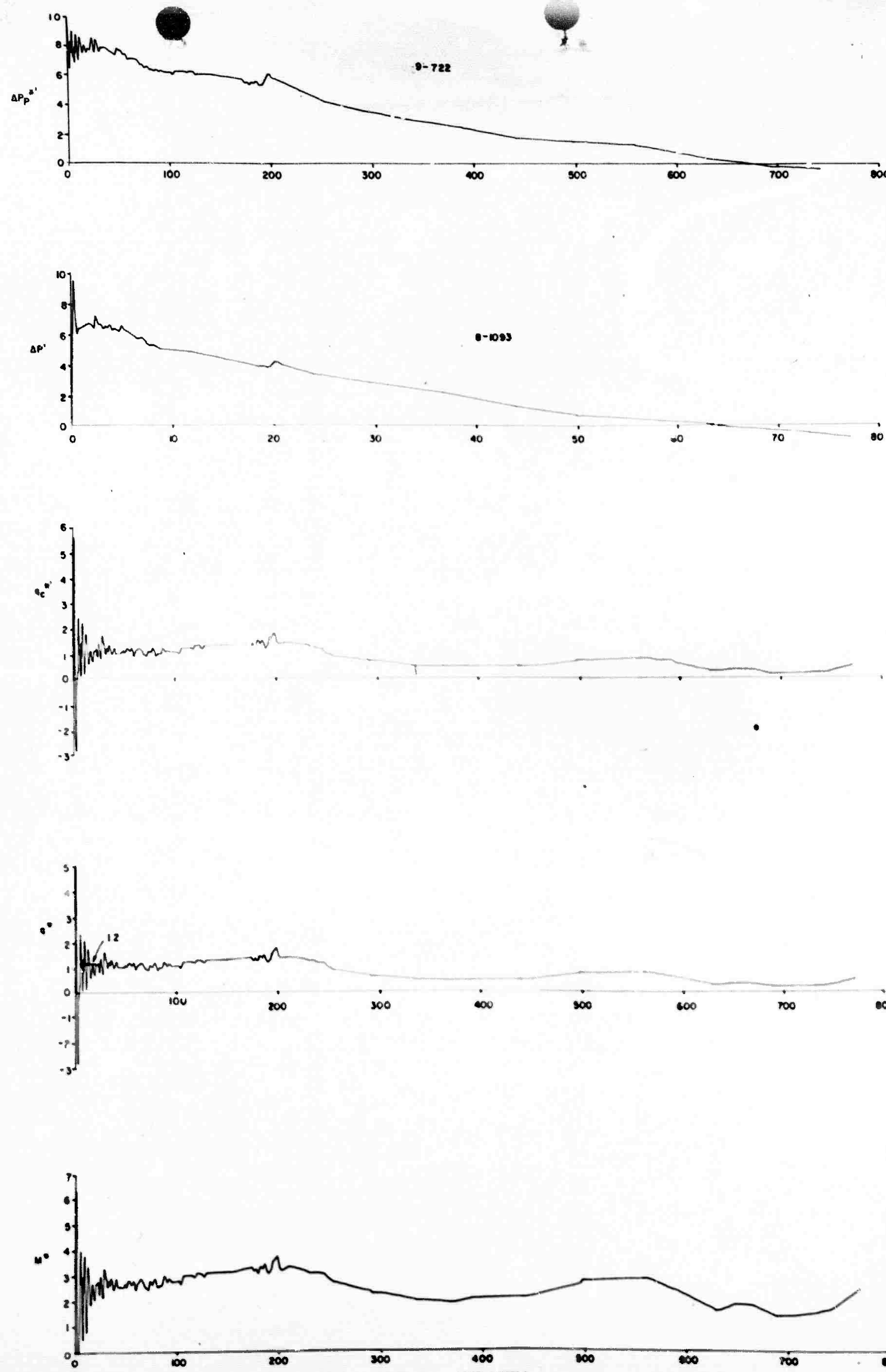

Figure B.14 Pressure & Mach No-Time Records, Gages SQT, SQS, Sta. 3.4/4.01

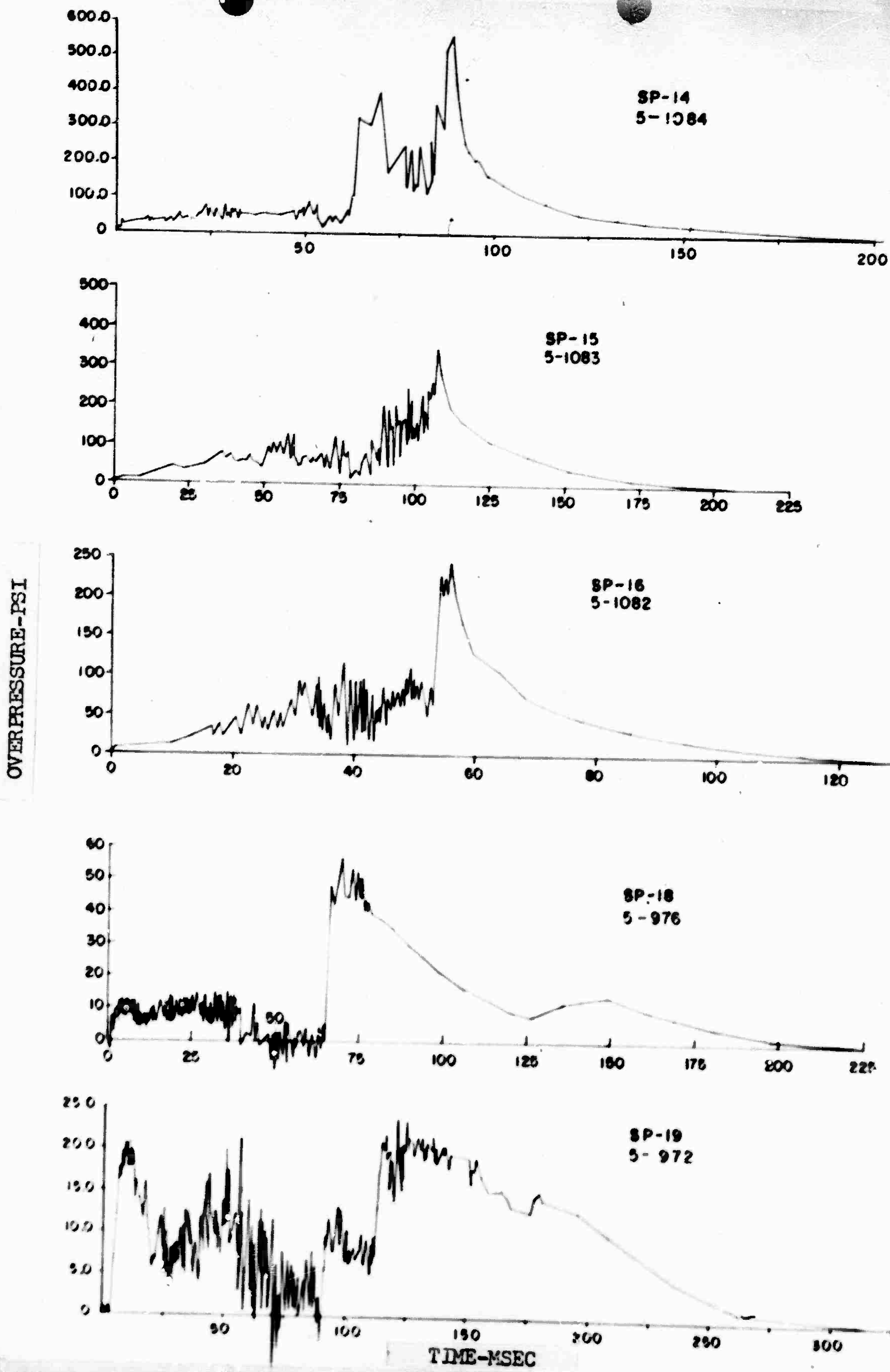

Figure B.15 Over-Pressure-Time Records, Gages SP 14 to SP 19, Station 3.6/7.01

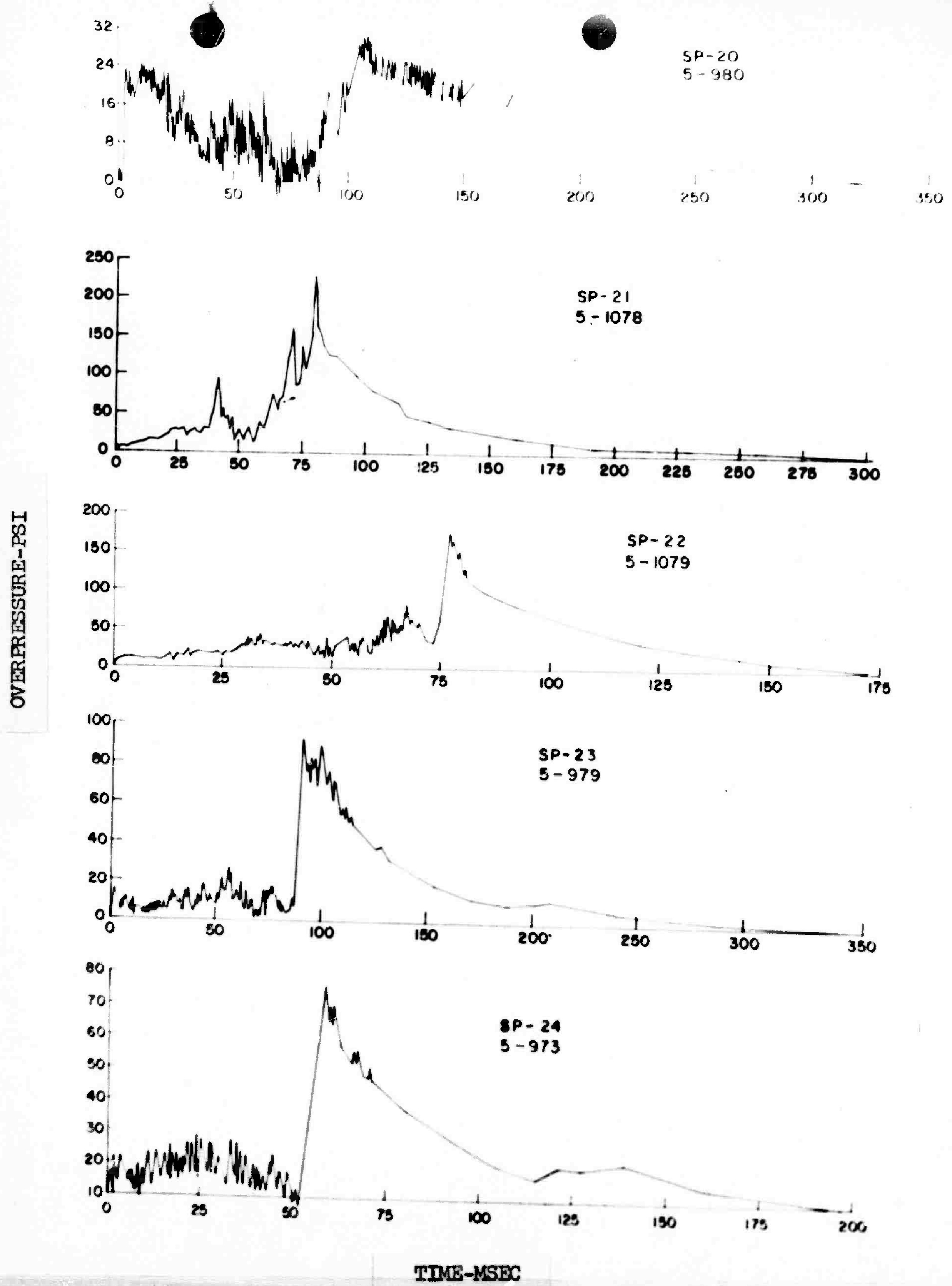

Figure B.16 Over-Pressure-Time Records, Gages SP 20 to SP 24, Station 3.6/7.01

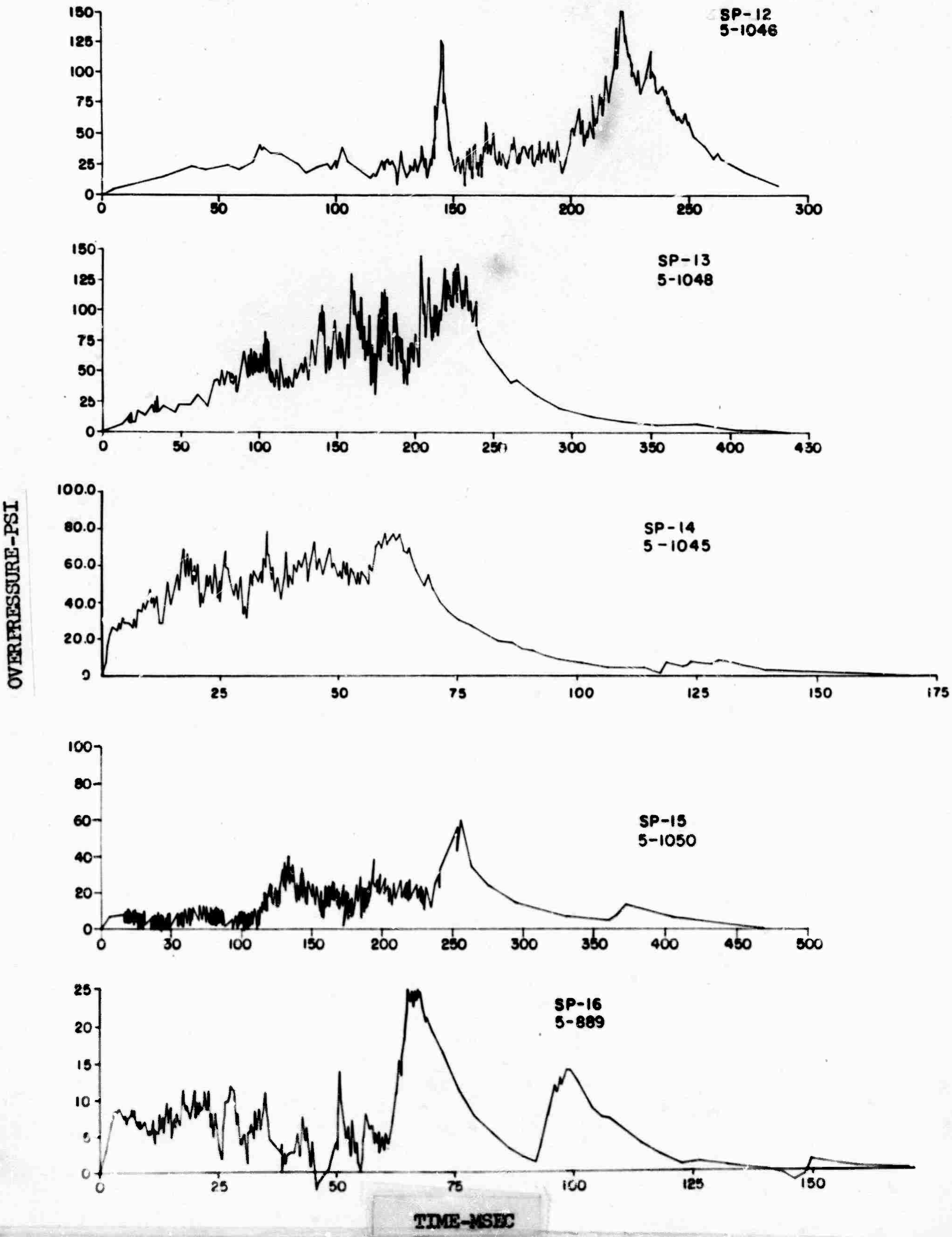

Figure B.17 Over-Pressure-Time Records, Gages SP 12 to SP 16, Station 3.6/7.02

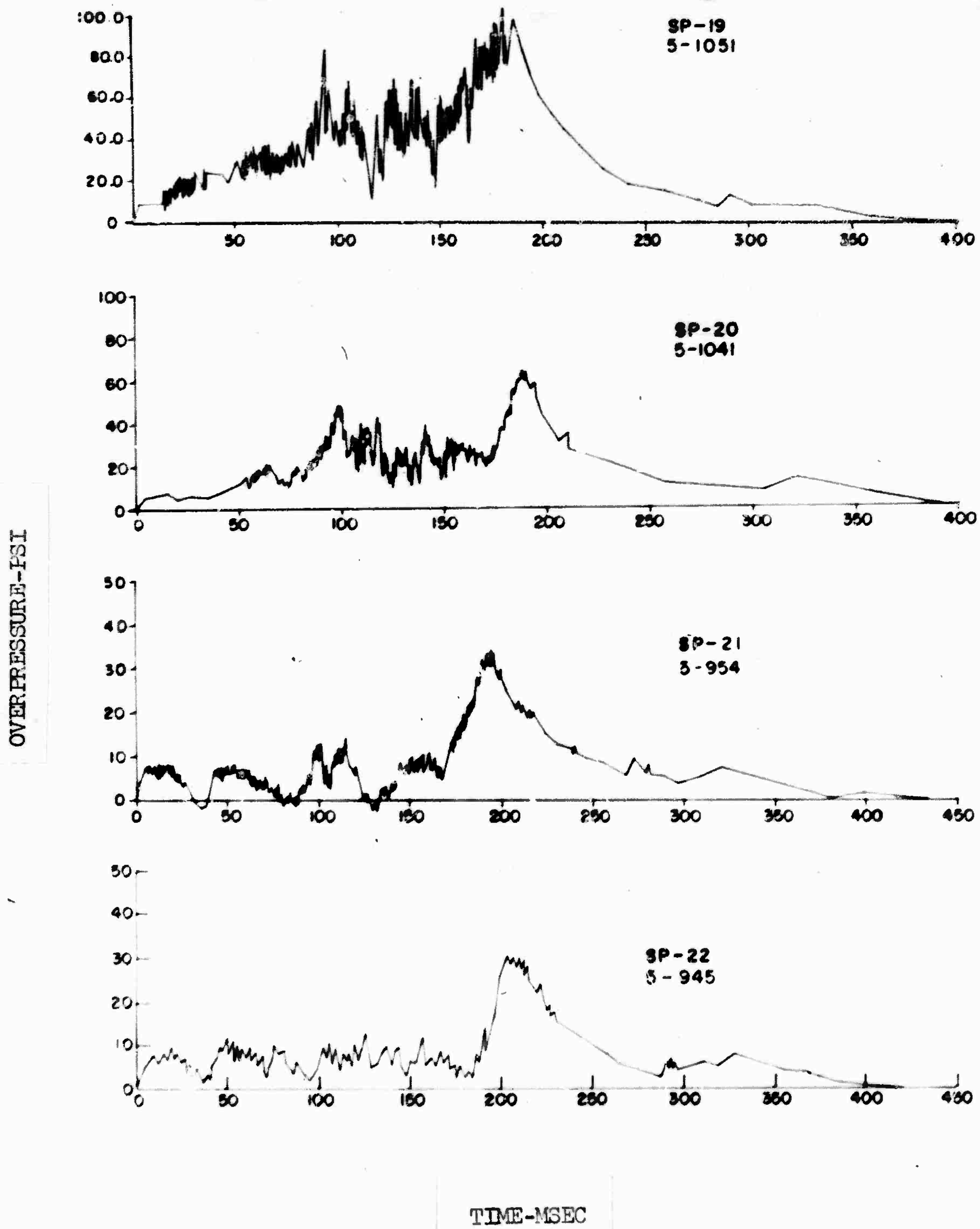

Figure B.18 Over-Pressure-Time Records, Gages SP 19 to SP 22, Station 3.6/7.02

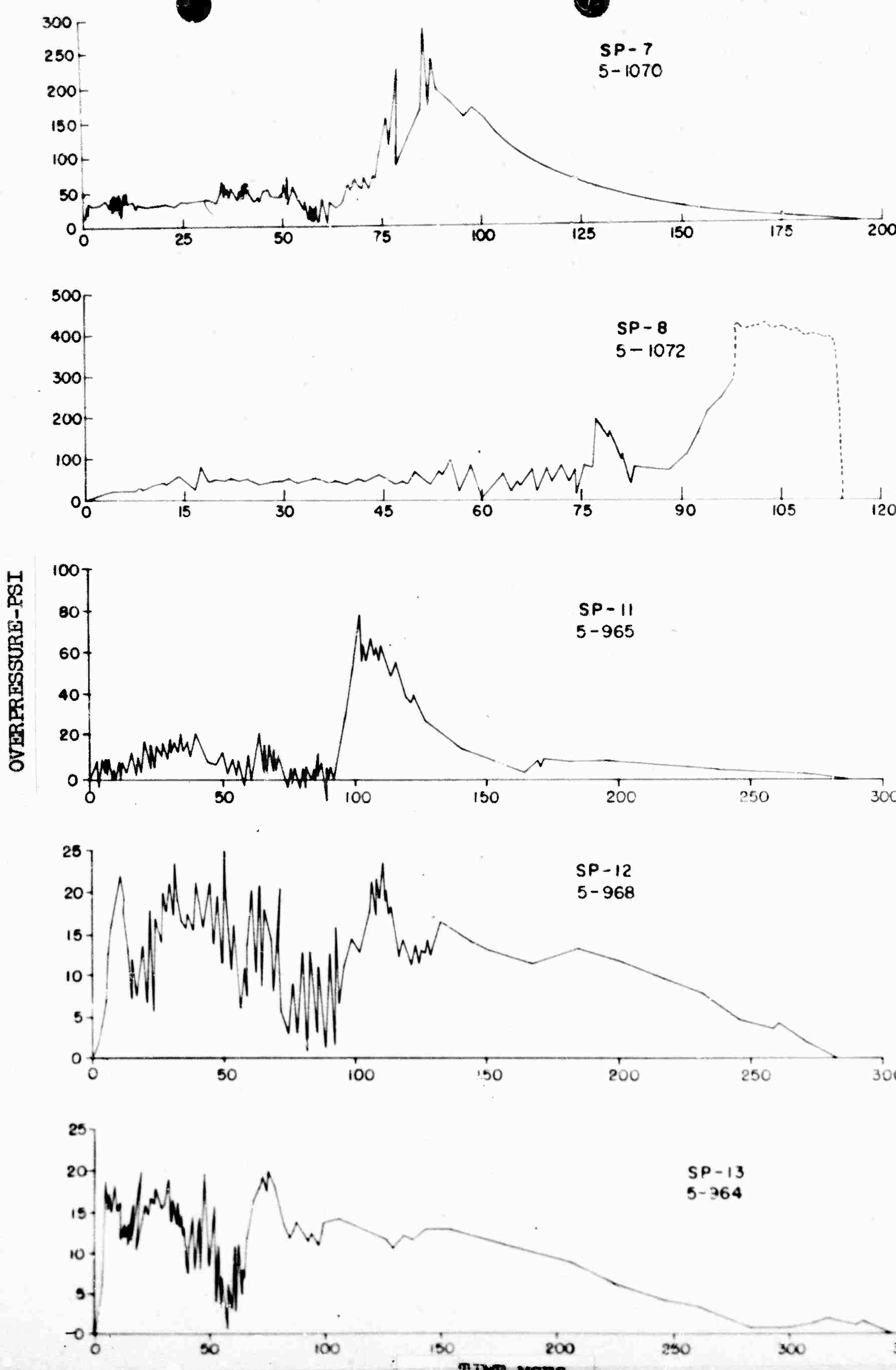

Figure B.19 Over-Pressure-Time Records, Gages SP 7 to SP 13, Station 5.6/8.01

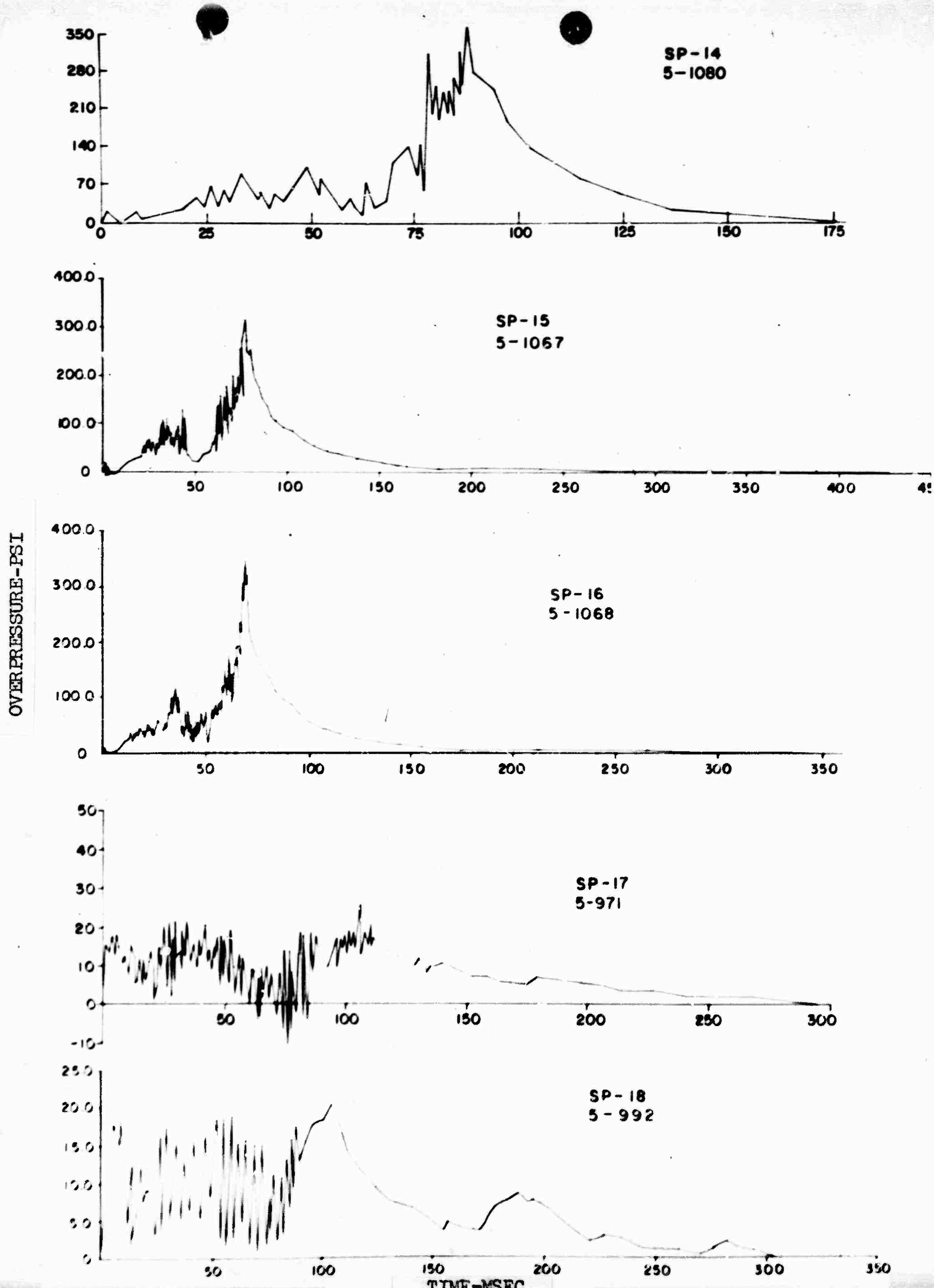

Figure B.20 Over-Pressure-Time Records, Gages SP 14 to SP 18, Station 3.6/8.01

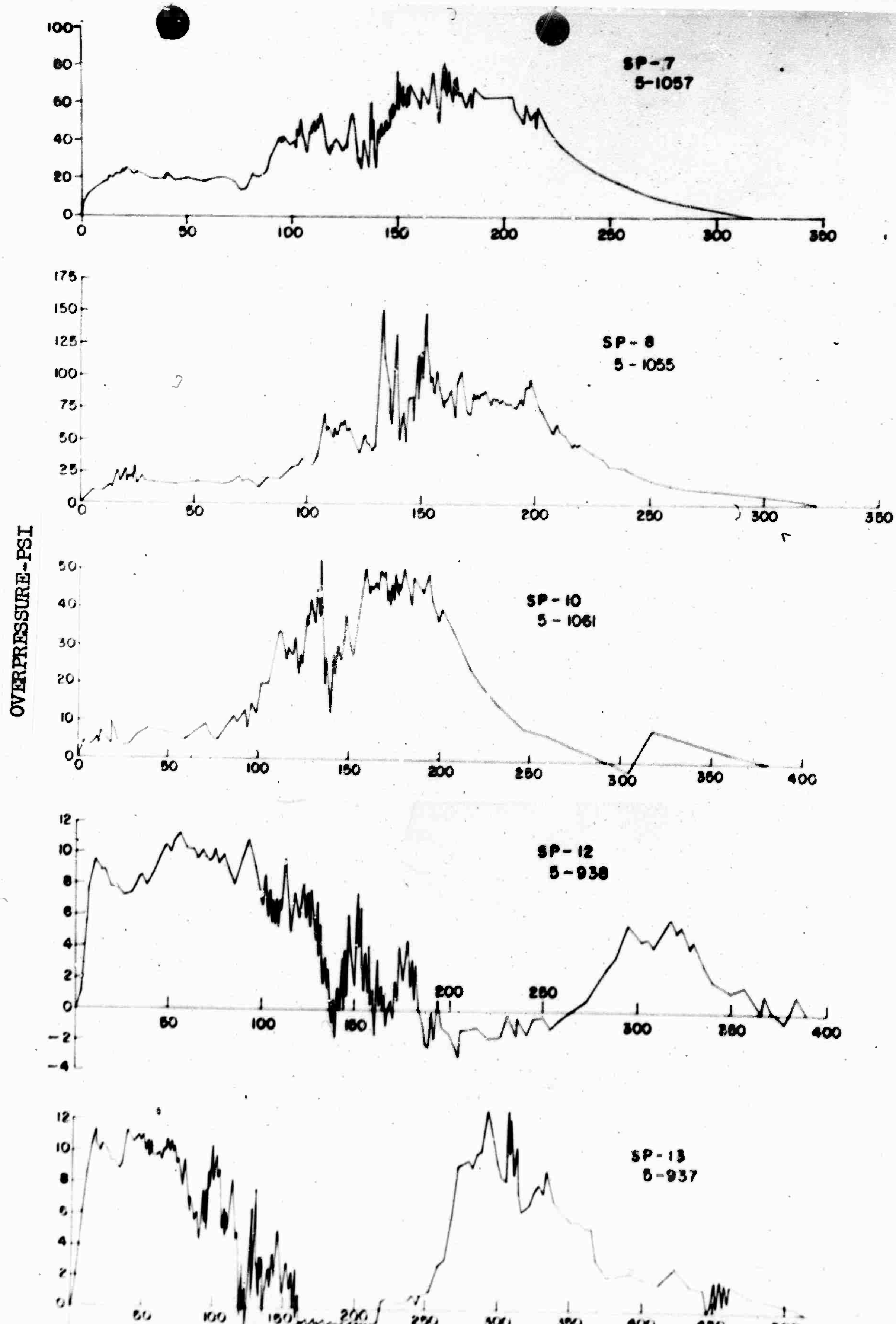

Figure B.21 Over-Pressure-Time Records, Gages SP 7 to SP 13, Station 5.6/8.02

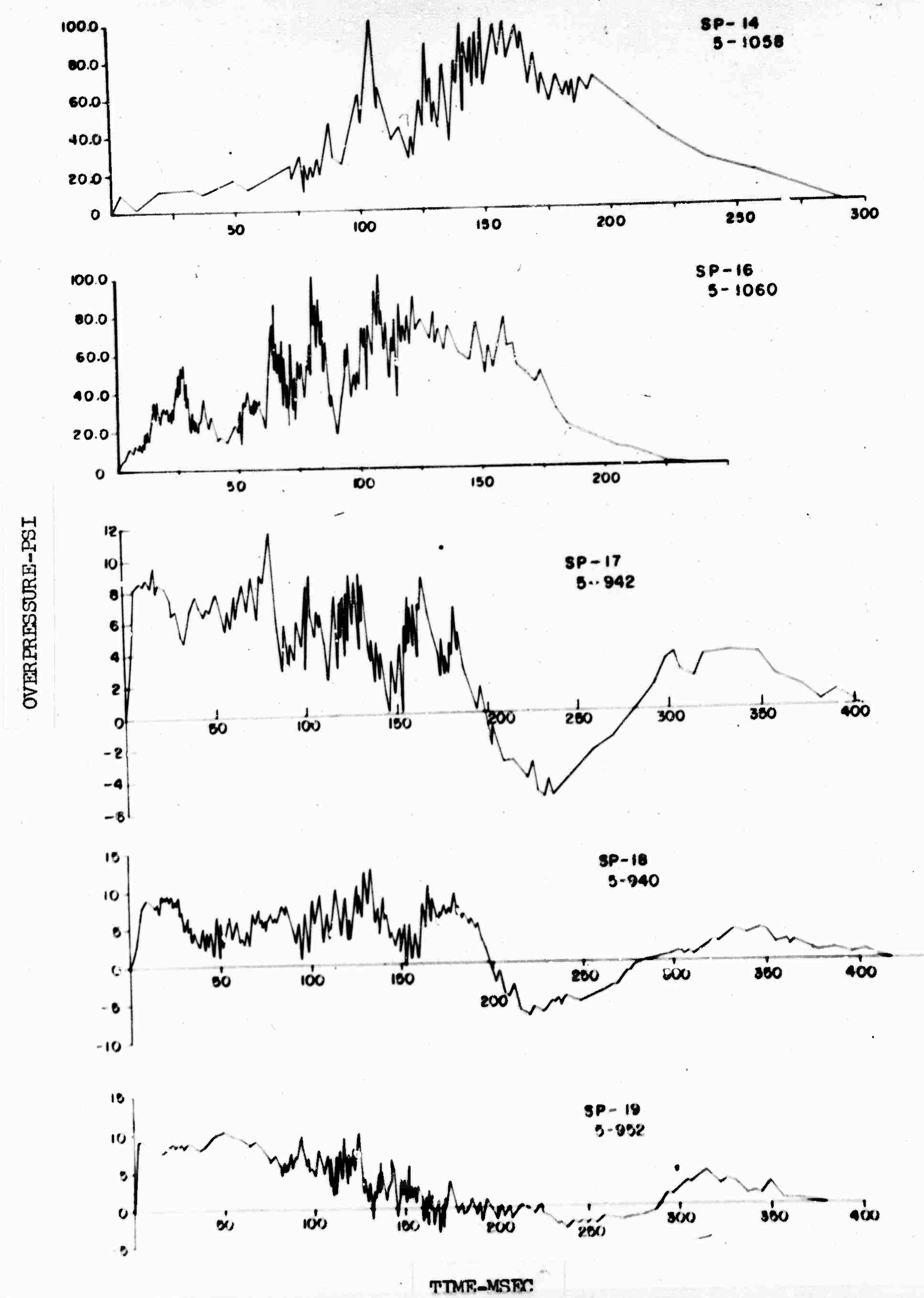

Figure B.22 Over-Pressure-Time Records, Gages SP 14 to SP 19, Station 3.6/8.02

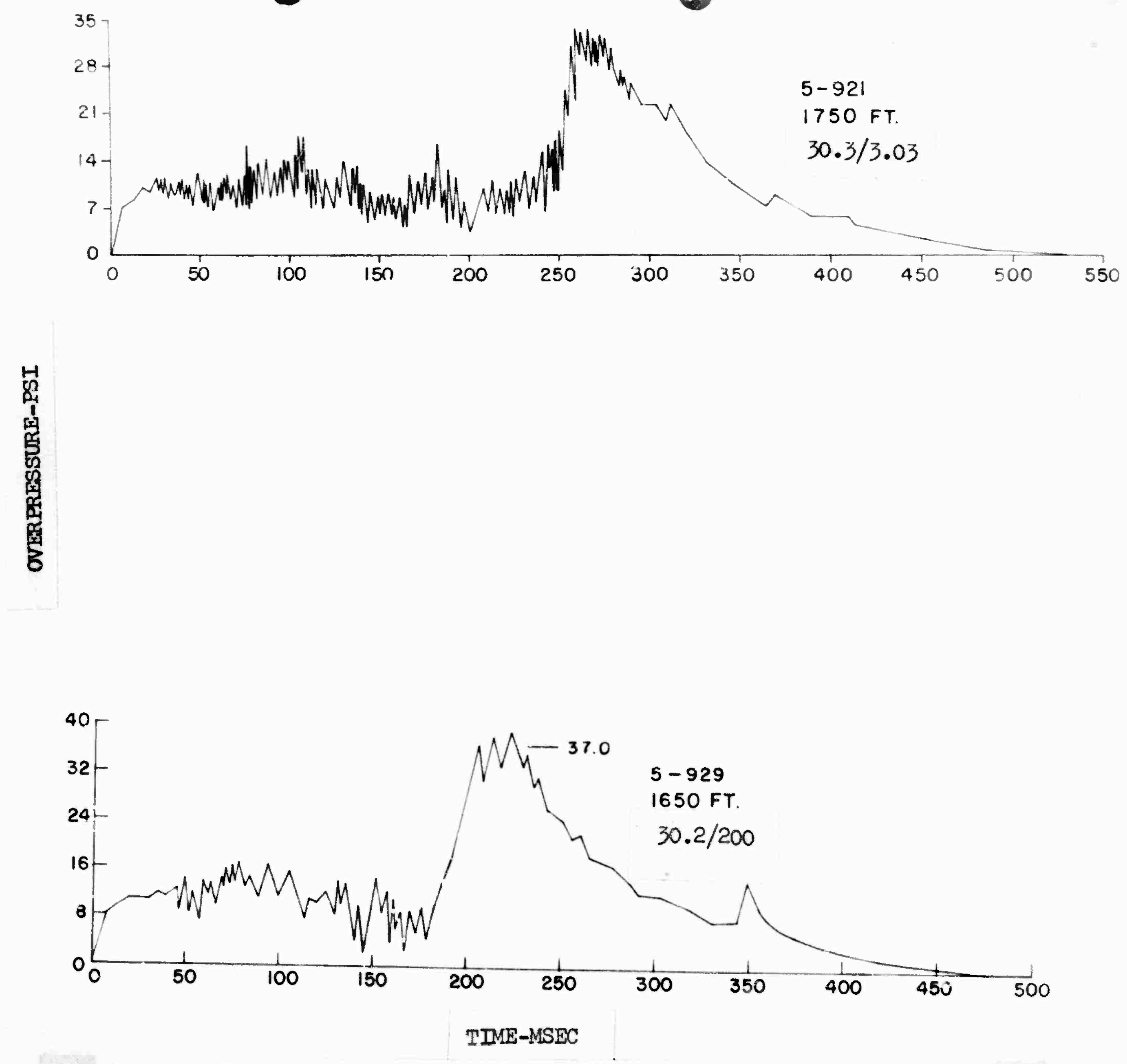

Figure B.25 Over-Pressure-Time Records, Gages Outside 30.2/2.00, 30.3/3.03

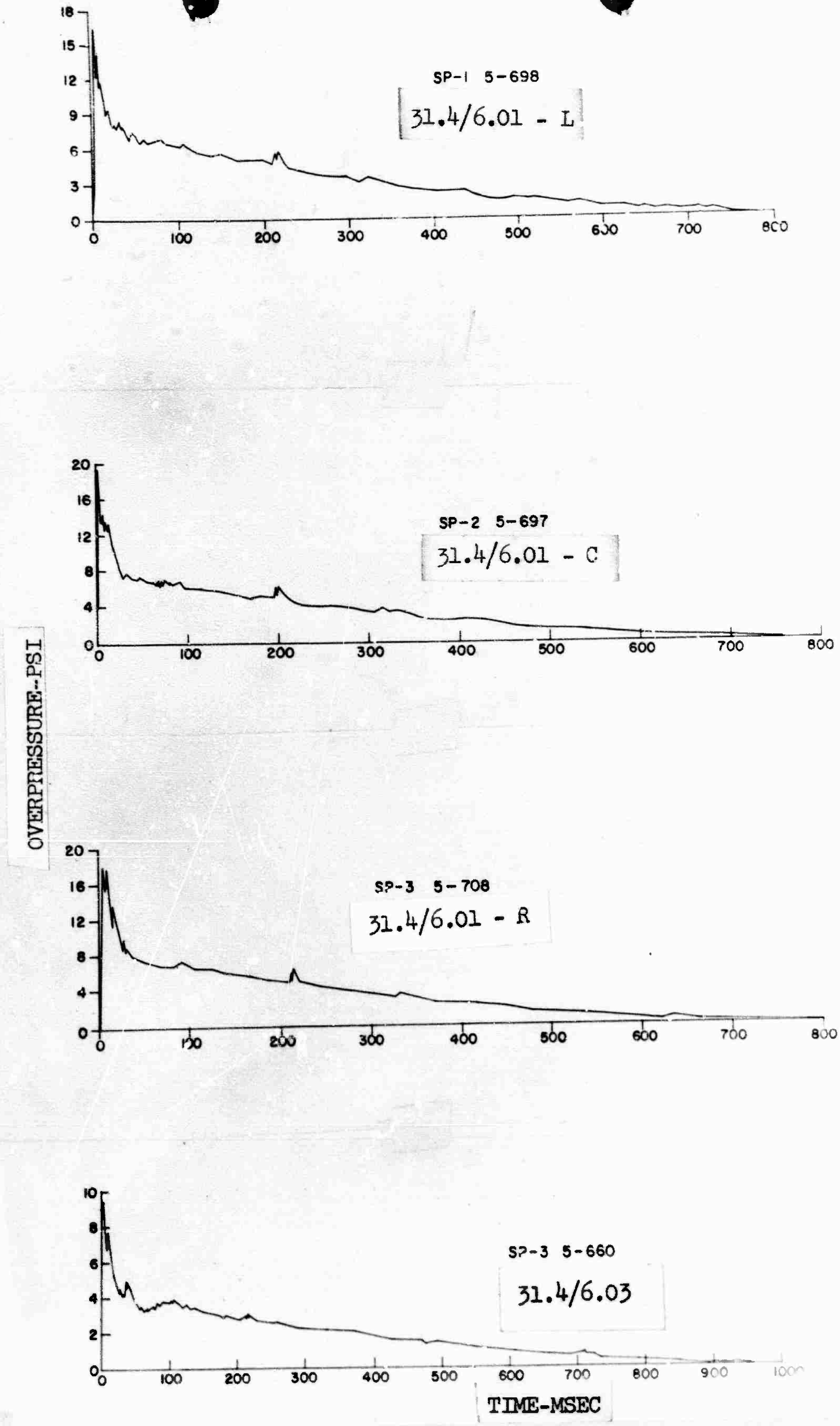

Figure B.24 Over-Pressure-Time Records, Gages Outside Station 31.4/6.01/6.03

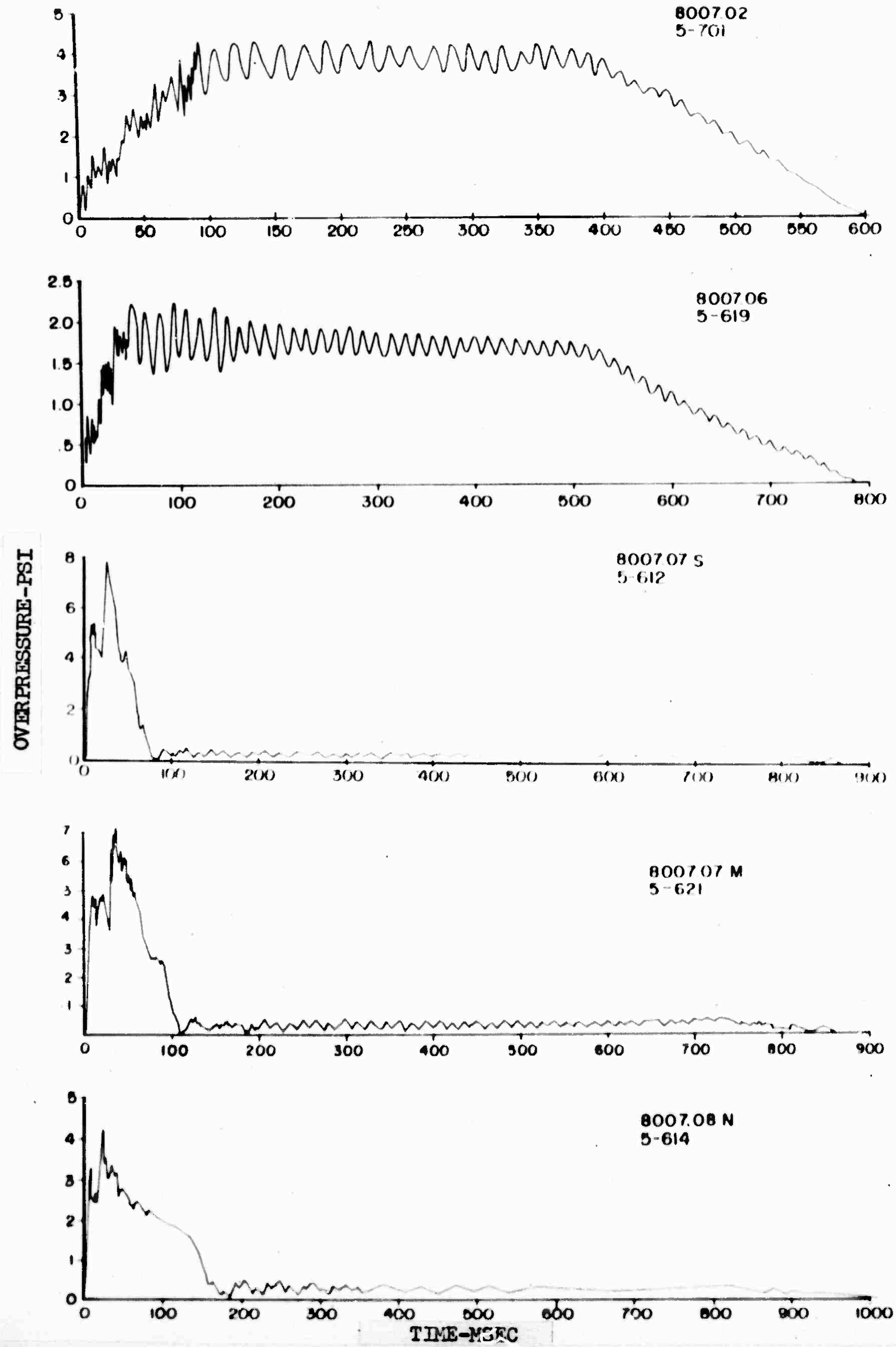

Figure B.25 Over-Pressure Time Records, Gages Inside Valves, Sta. 31.5/7.02/7.06/7.07/7

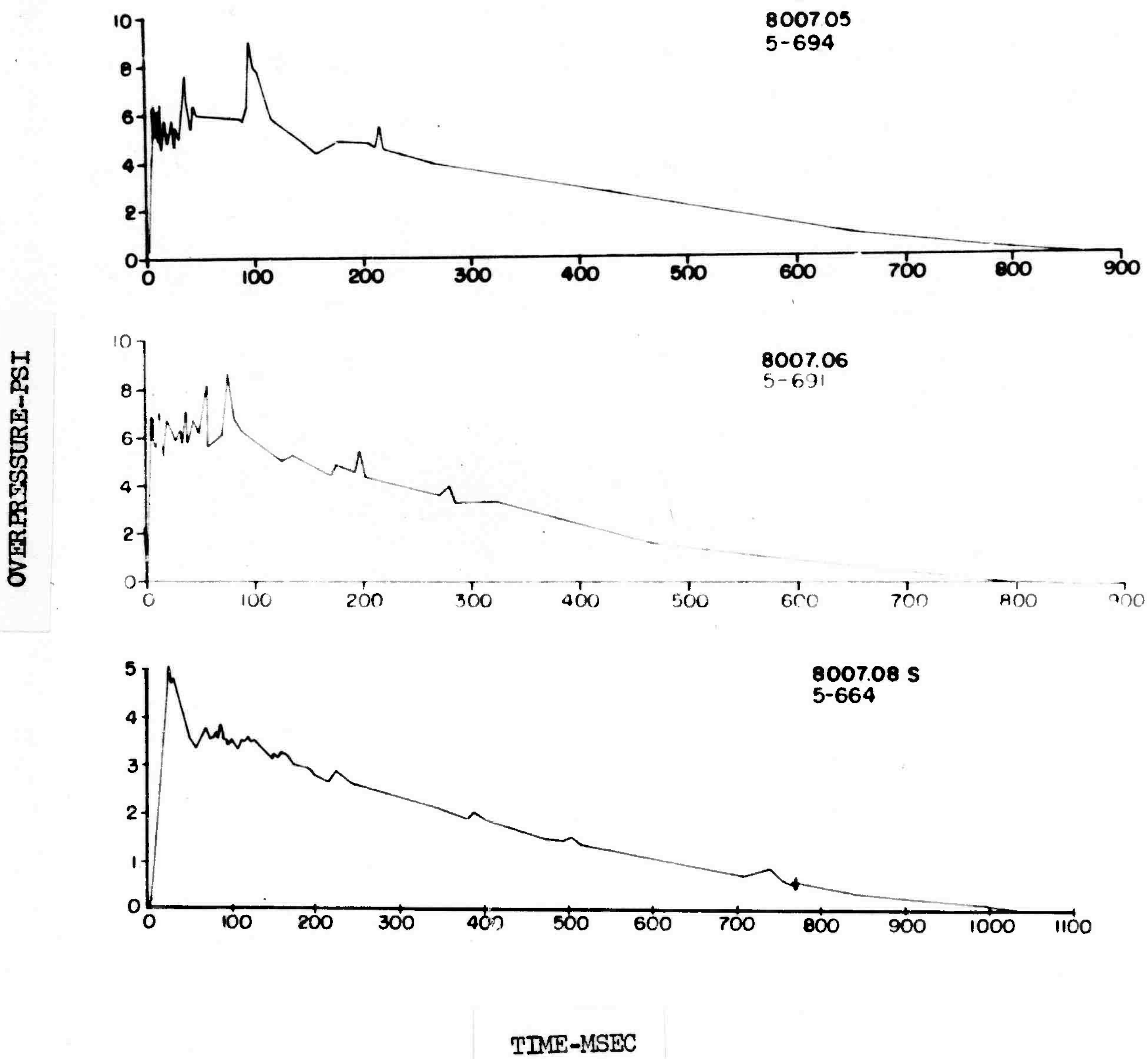

Figure B.26 Over-Pressure-Time Records, Gages Outside Valves, Sta. 31.5/7.05/7.06/7.08

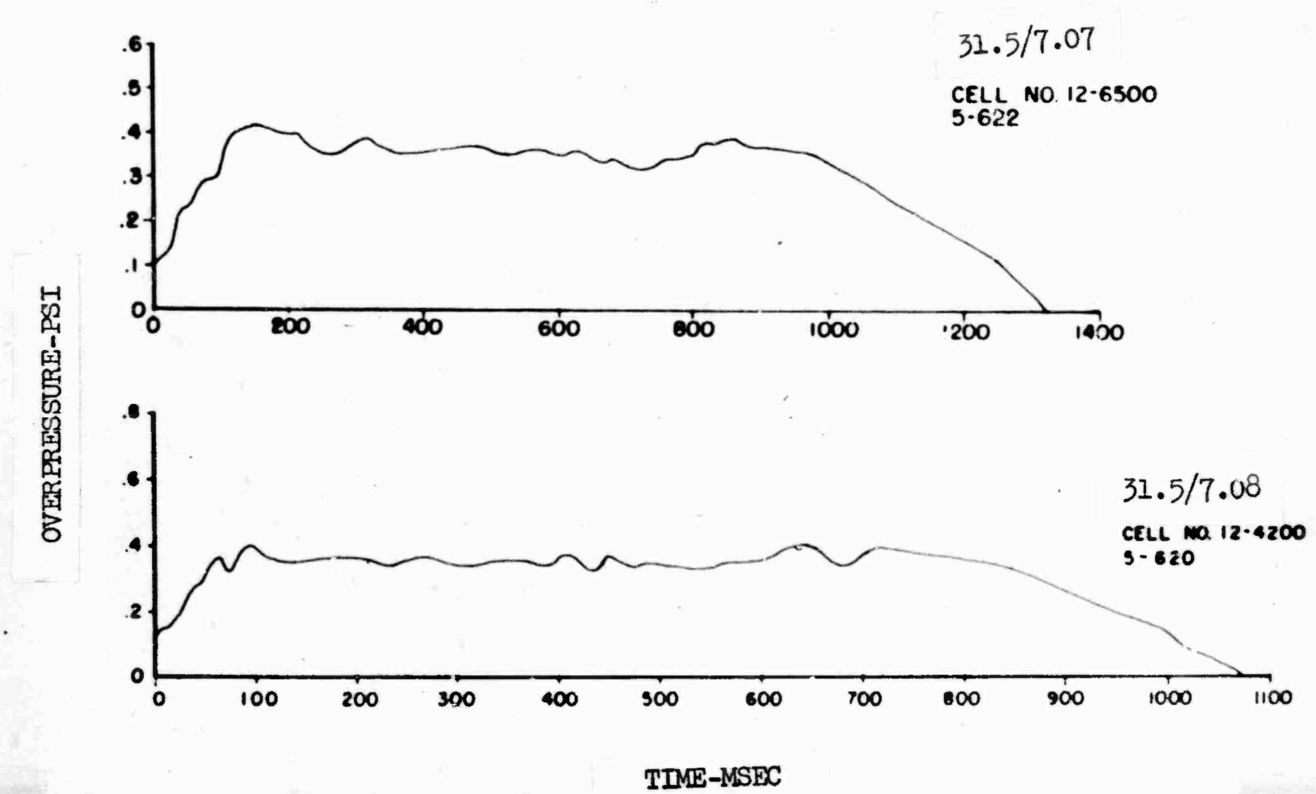

Figure B.27 Over-Pressure-Time Records, SP Gages Inside Station 31.5/7.07/7.08

NOTES

1. ALL DEFLECTION GAGES ACT RADIALLY - EXCEPT SD 4 WHICH ACTS ALONG DOTTED LINE.
2. ONLY THOSE UNDERLINED GAGES WERE USED ON STA. 9014.03.
3. EXPERIMENTAL GAGE (E8) ON STA. 9014.02 WAS MOUNTED NEXT TO E6.

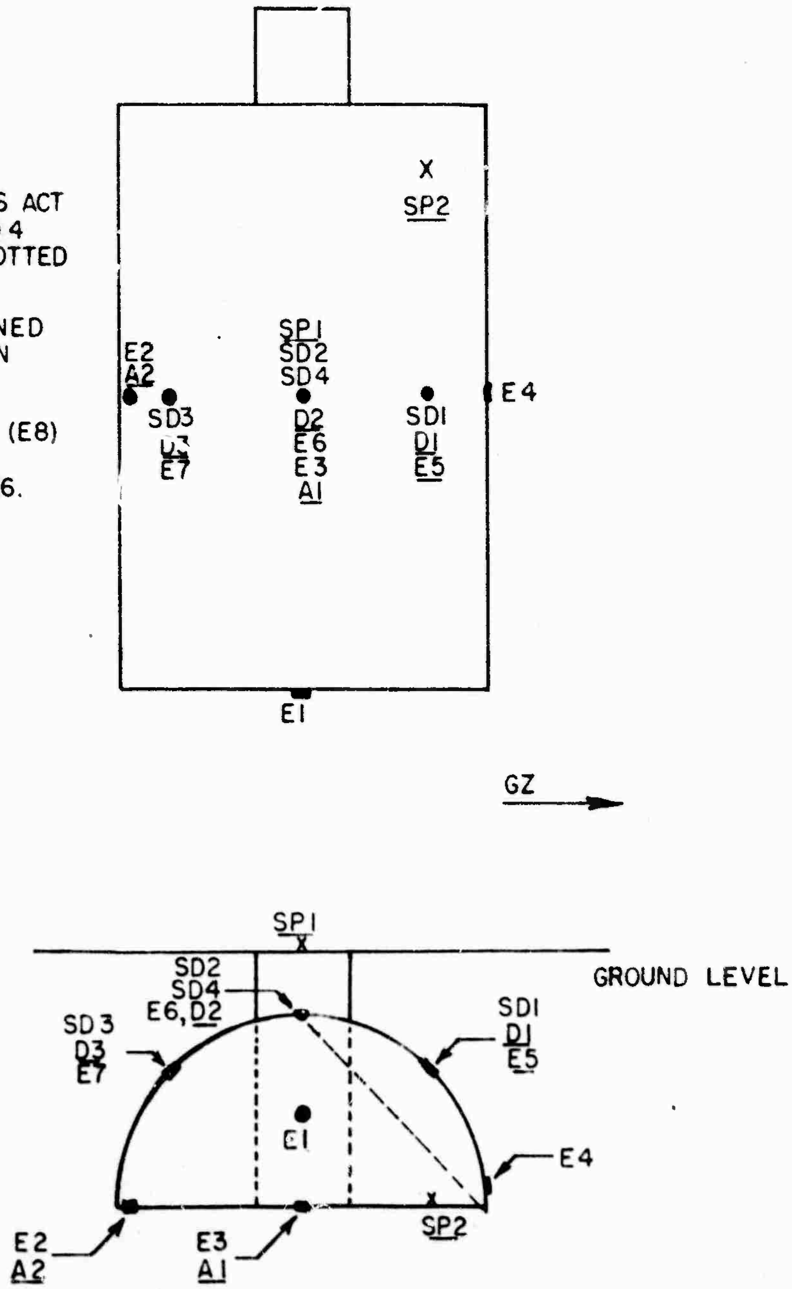

Figure B.28 Gage Locations of Structure 3.1/4.01/4.02/4.03

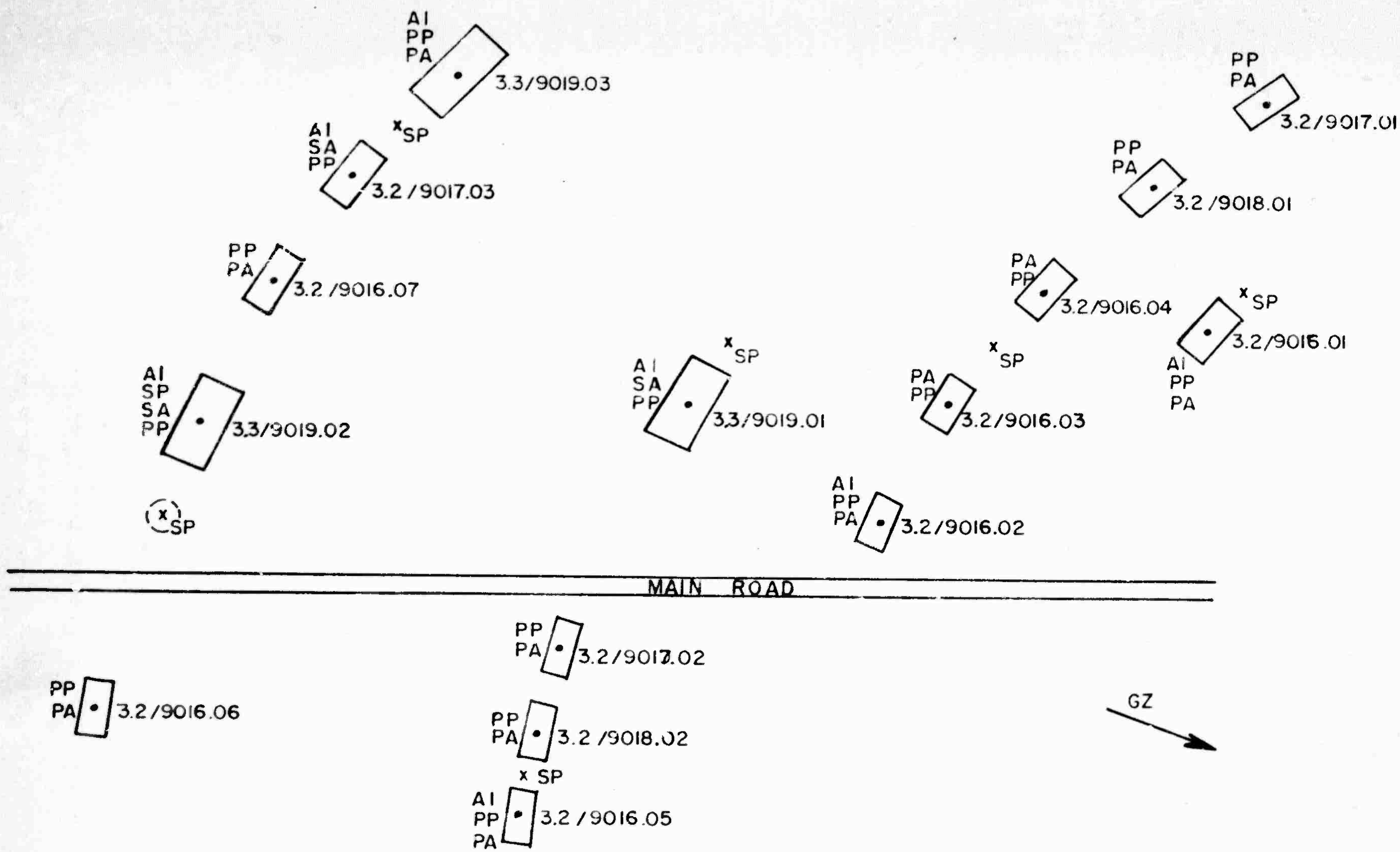

Figure B.29 Gage Locations of Projects 3.2 and 3.3 Stations

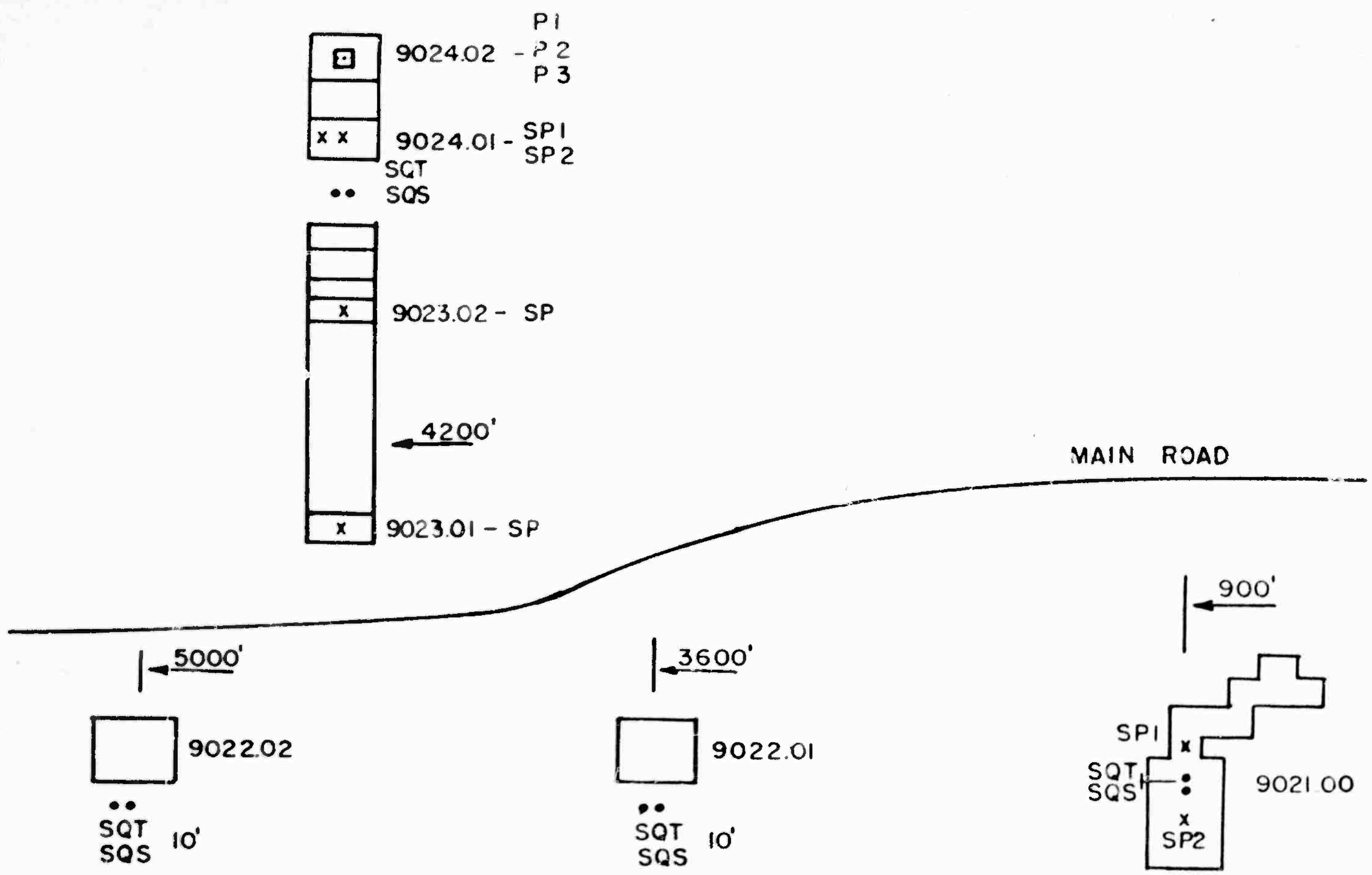

Figure B.30 Gage Locations of Project 3.4 Stations

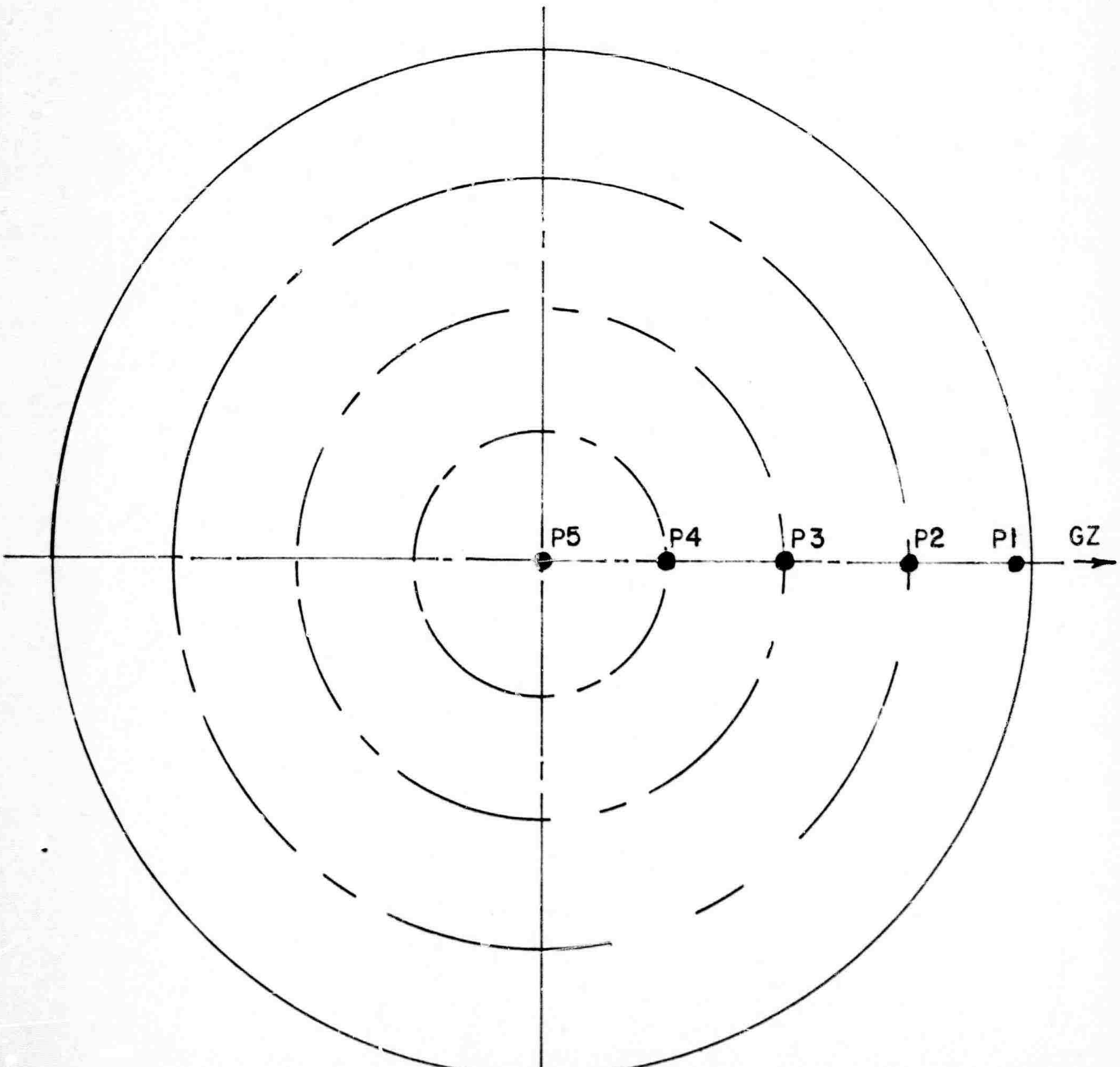

Figure B.31 Gage Locations of Structure 3.6/6.02

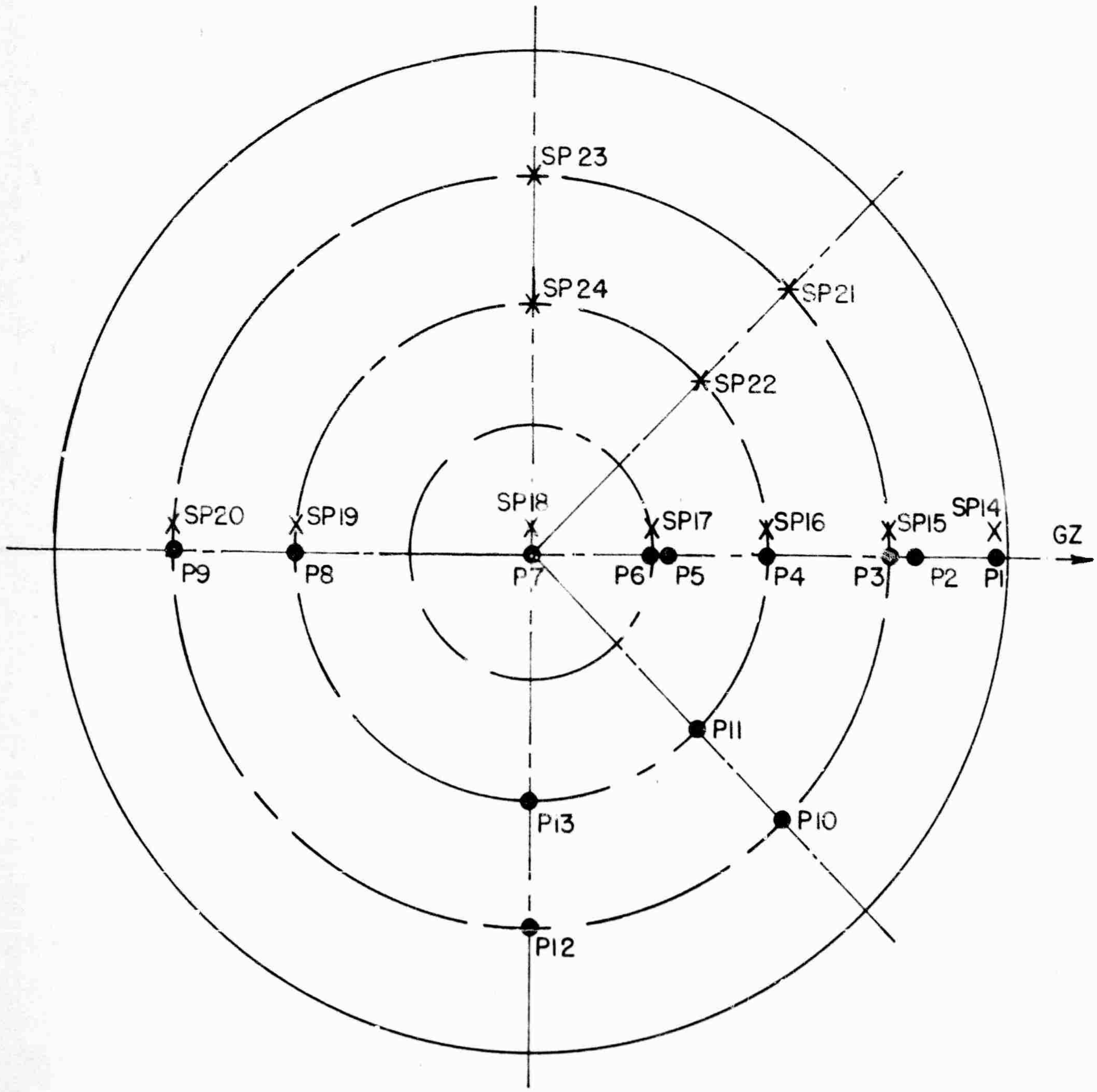

Figure B.32 Gage Locations of Structure 3.6/7.01

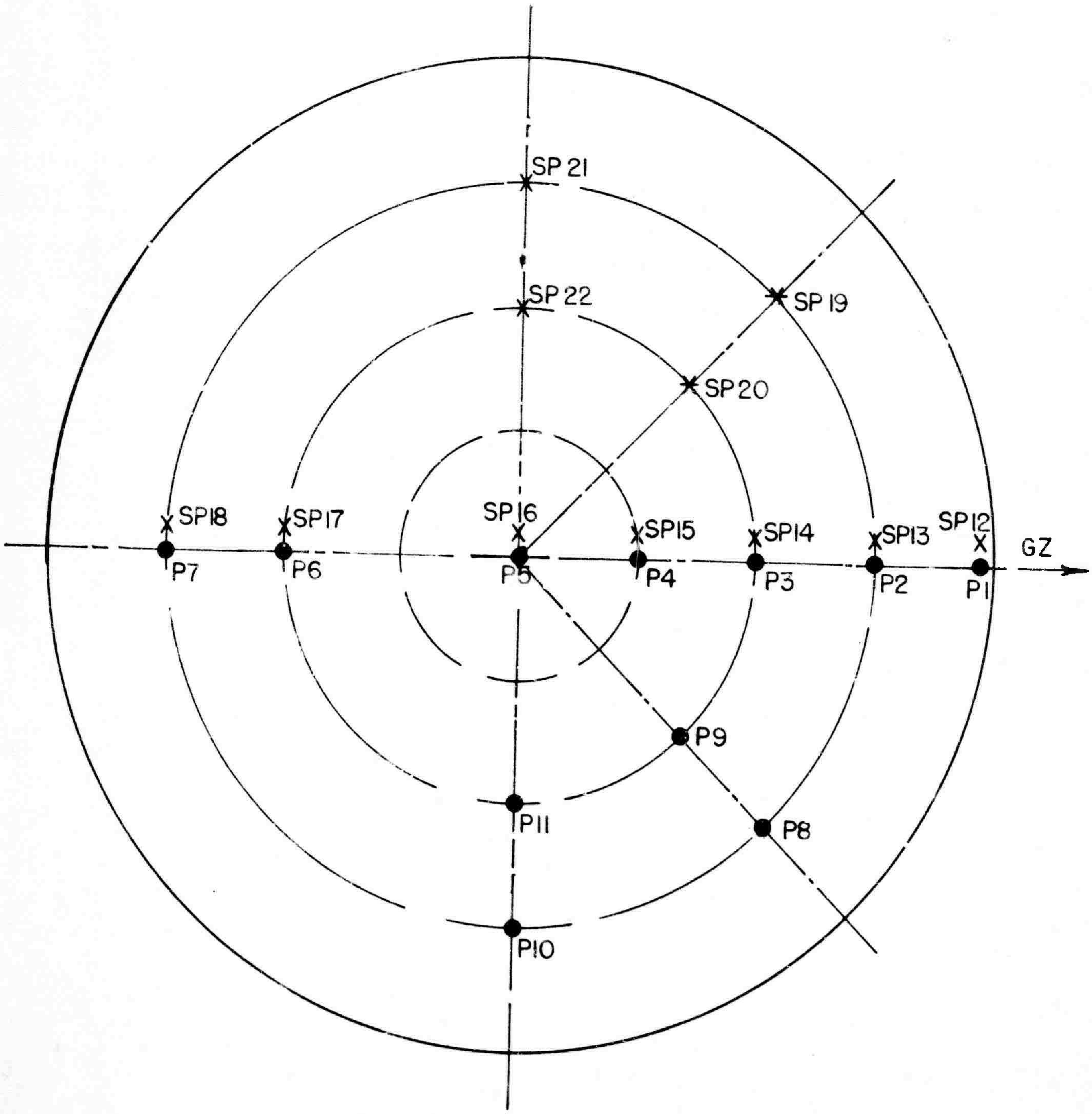

Figure B.33 Gage Locations of Structure 3.6/7.02

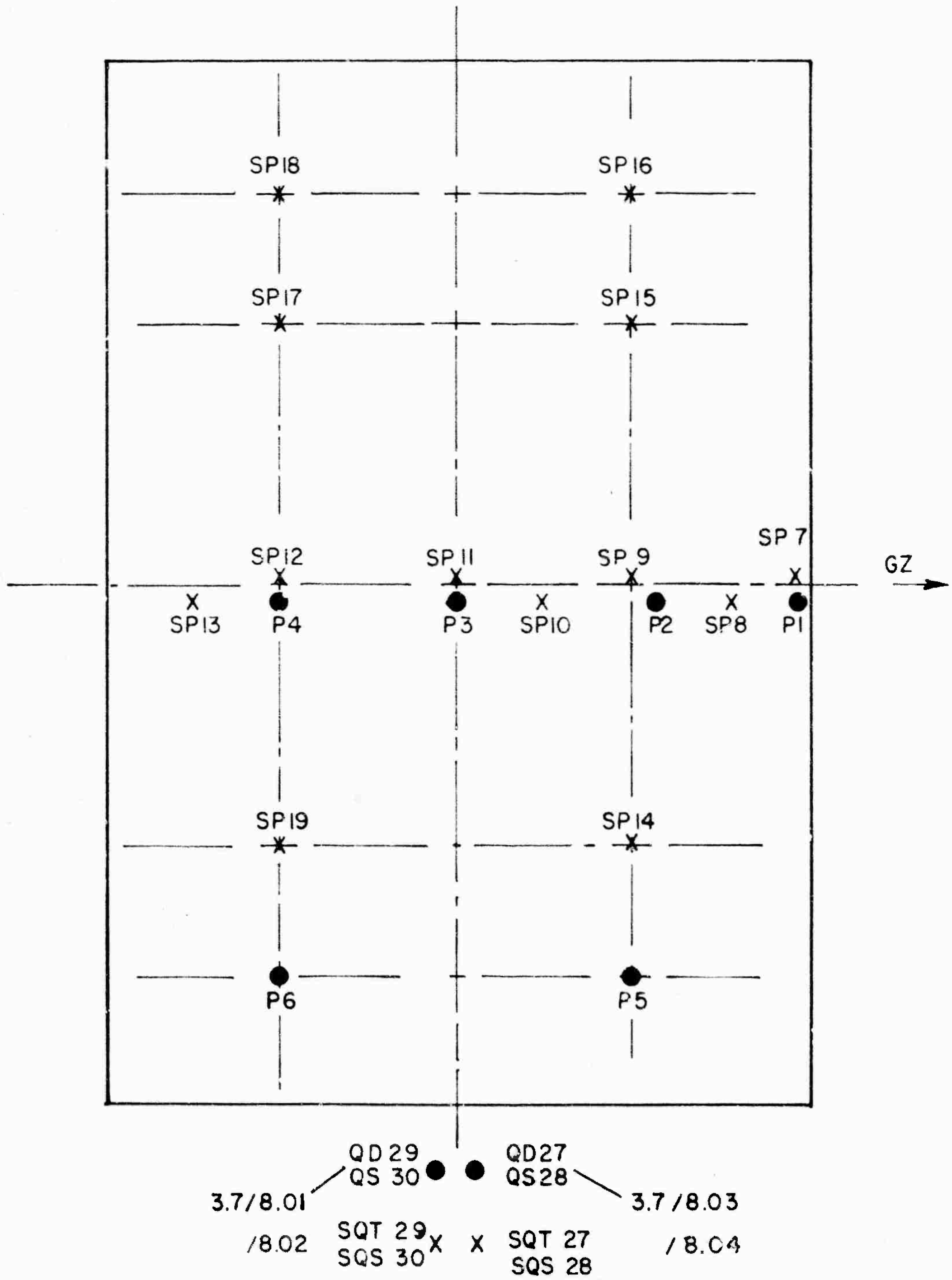

Figure B.34 Gage Locations of Stations 3.6/8.01/8.02 & 3.7/8.01/8.02/8.03/8.04

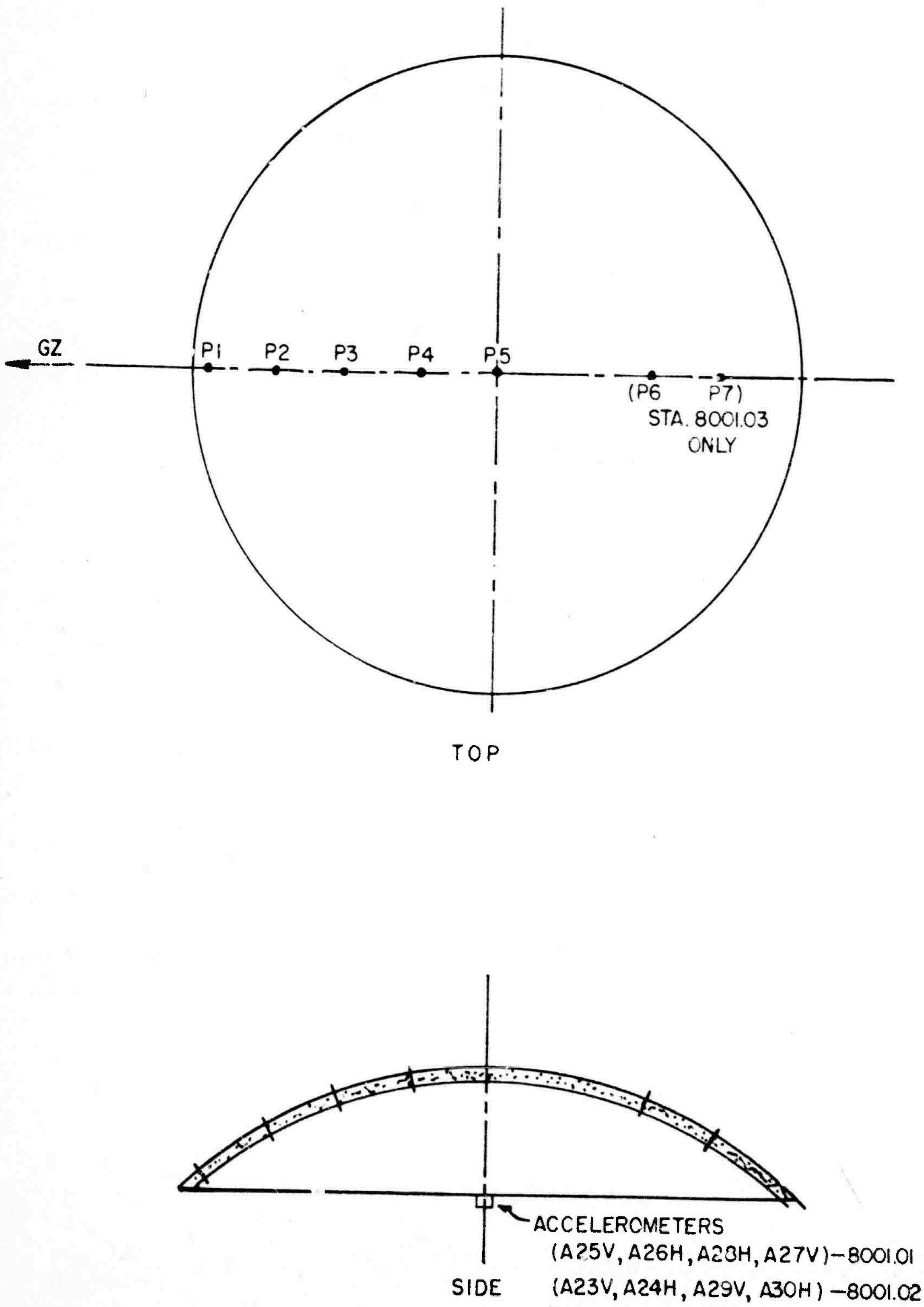

Figure B.35 Gage Locations of Station 30.1/1.01/1.02/1.03

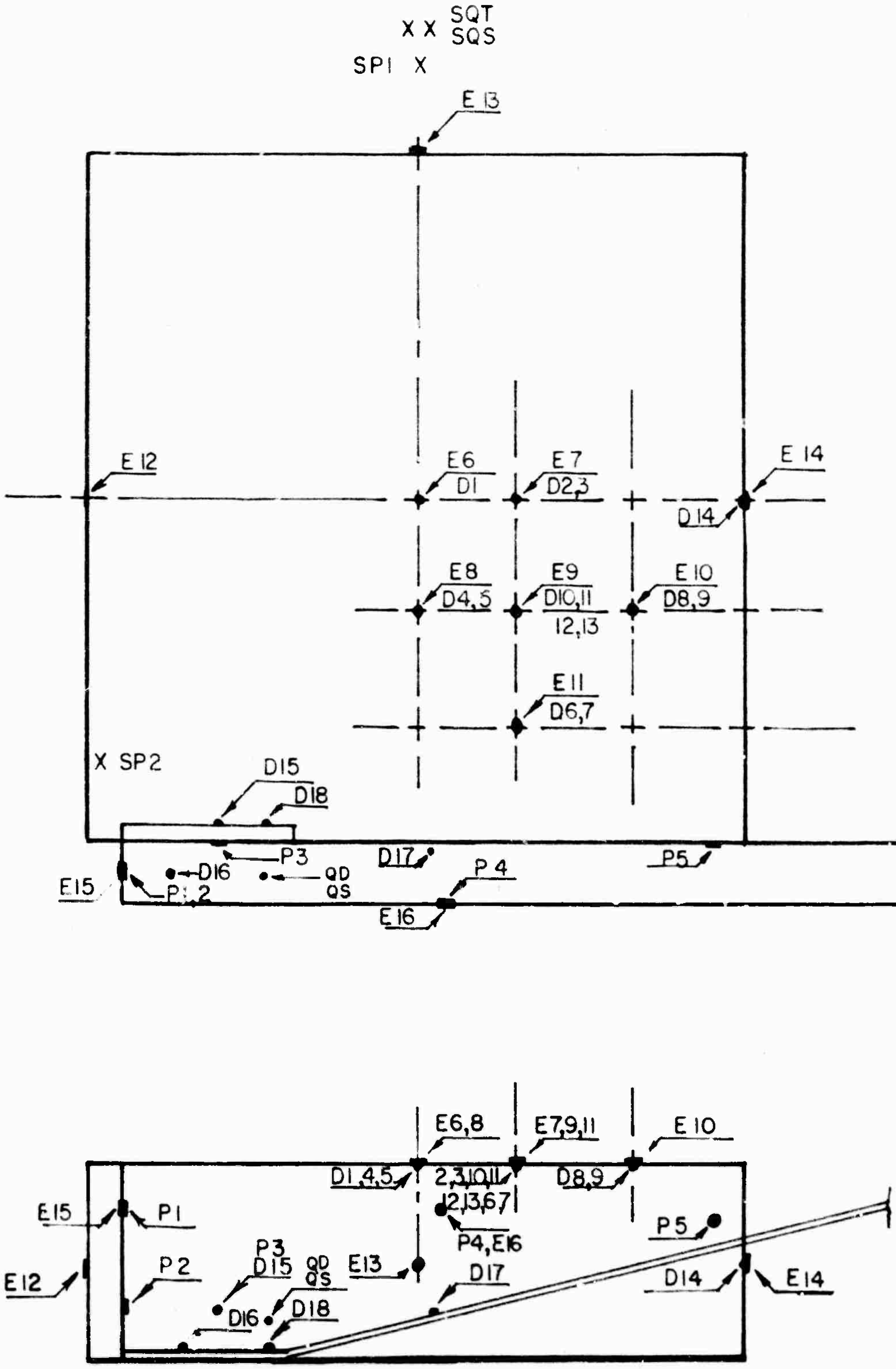

Figure B.36 Gage Locations of Structure 30.2/2.00

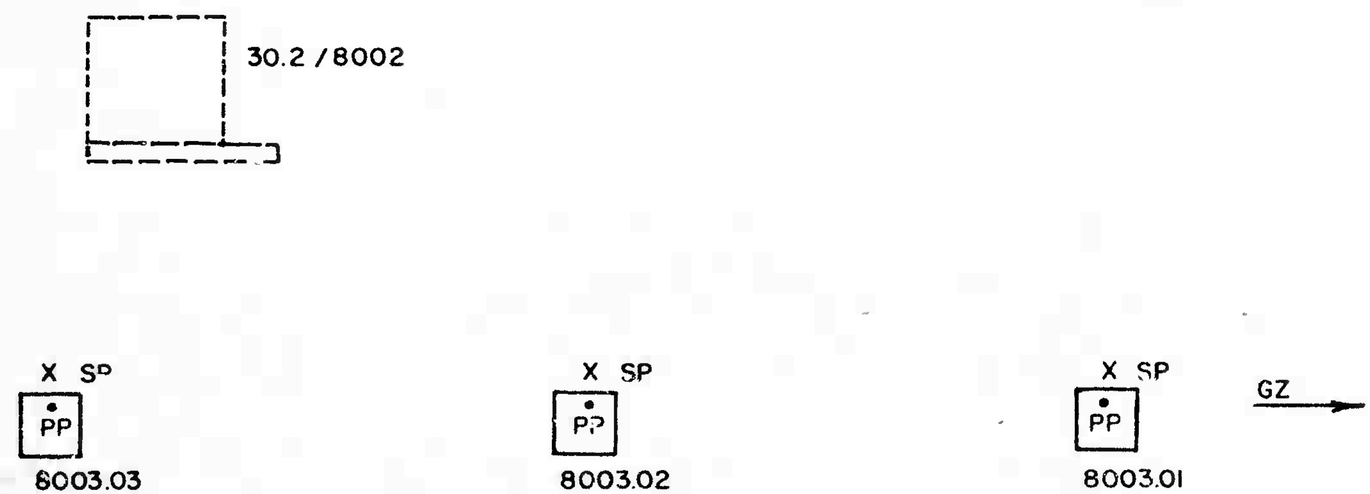

Figure B.37 Gage Locations of Stations 30.3/3.01/3.02/3.03

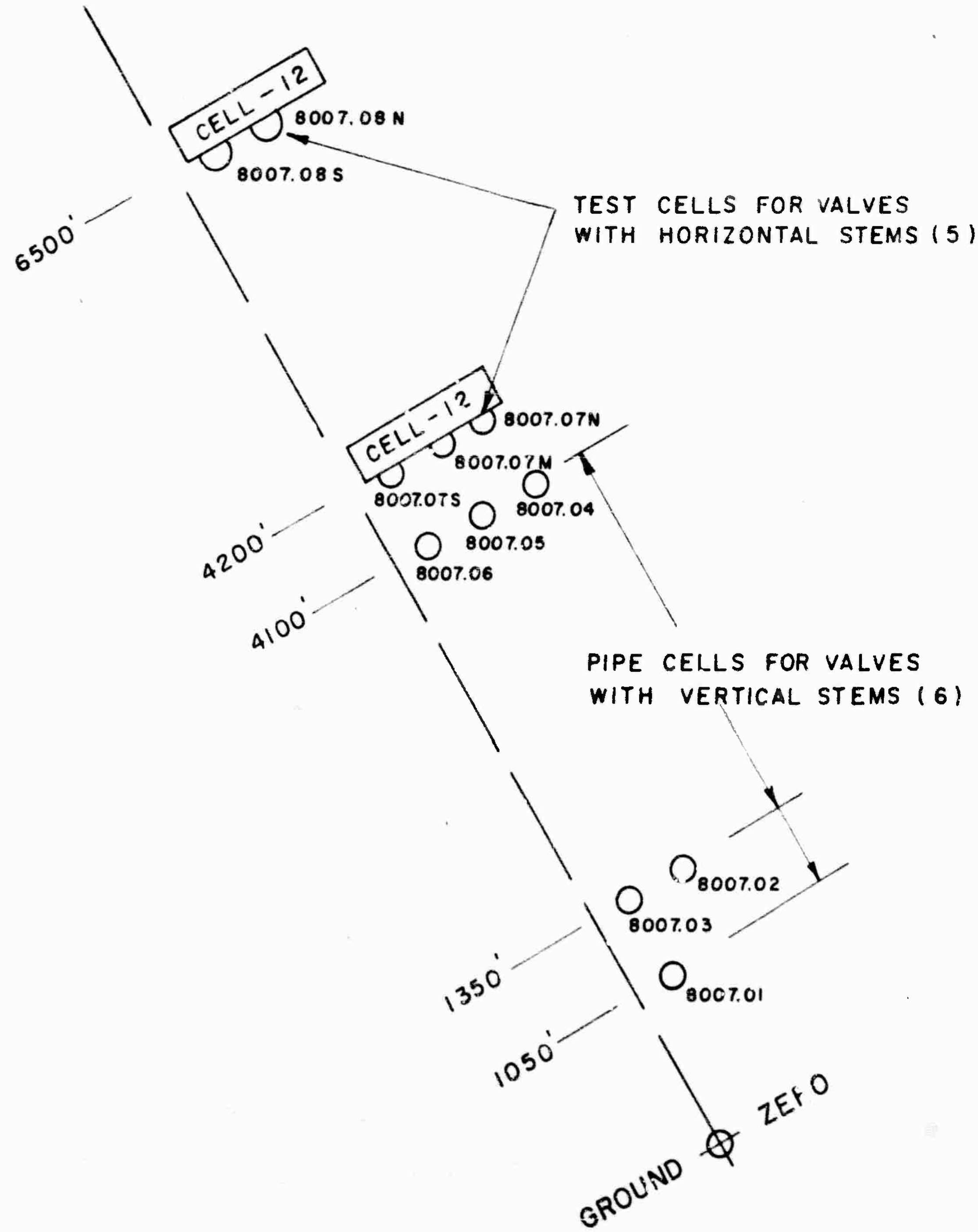

Figure B.38 Gage Locations on Project 31.5 Structures

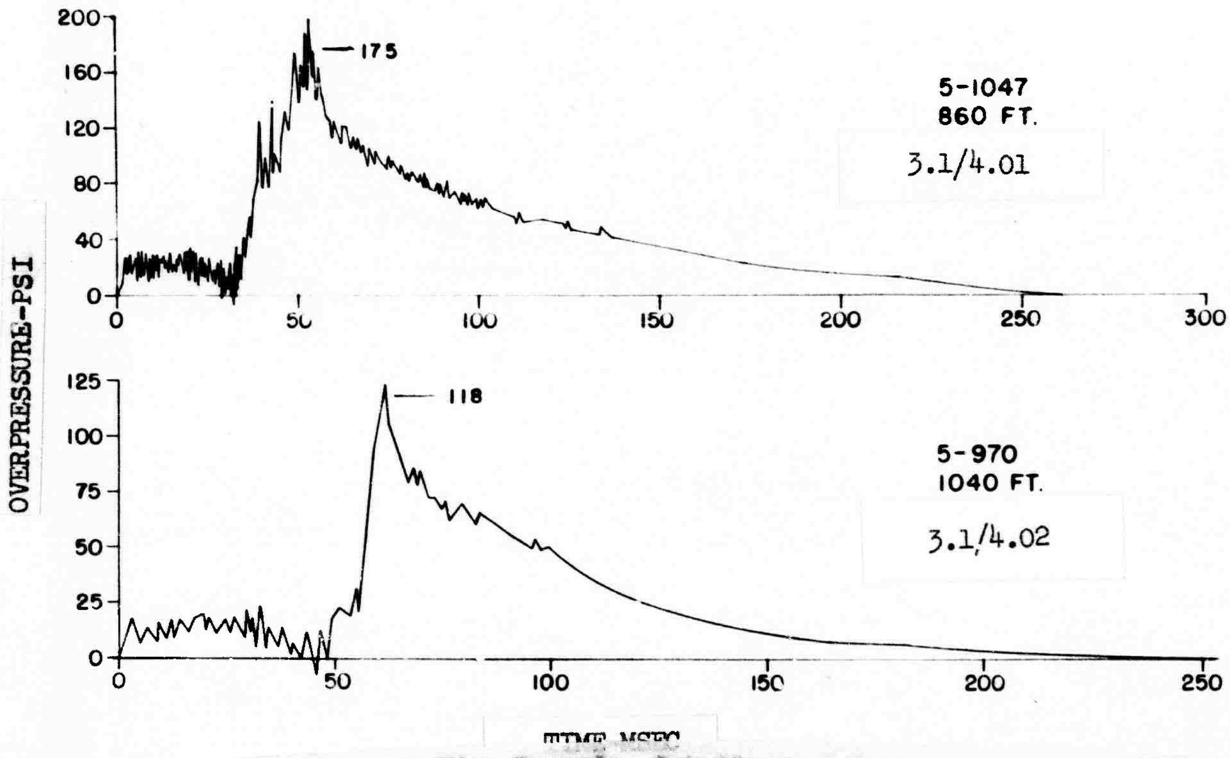

Figure B.9 Over-Pressure-Time Records, Outside Gages SP1, Station 3.1/4.01/4.02

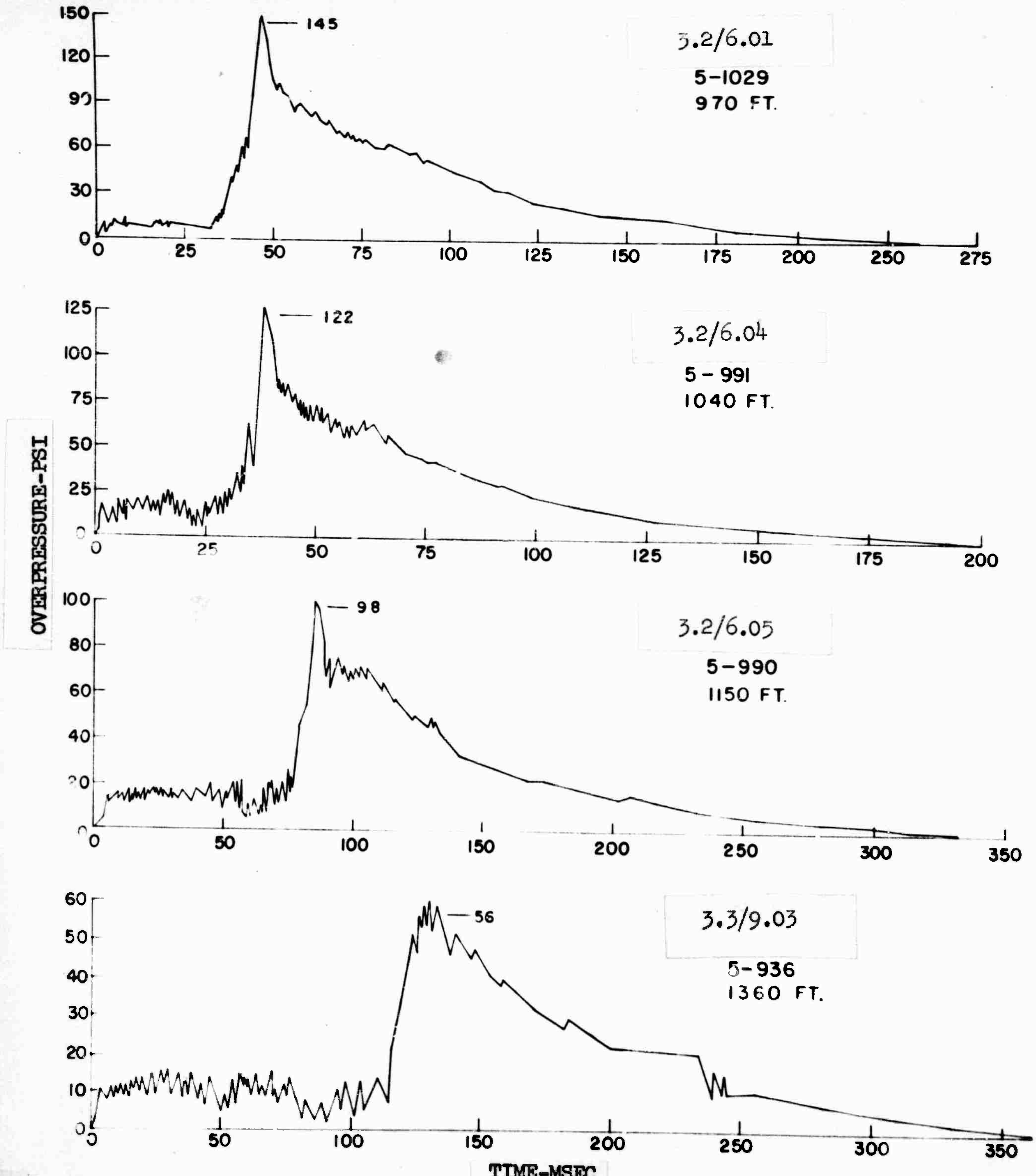

Figure B.10 Over-Pressure-Time Records, Outside SP Gages Near 3.2 & 3.3 Stations

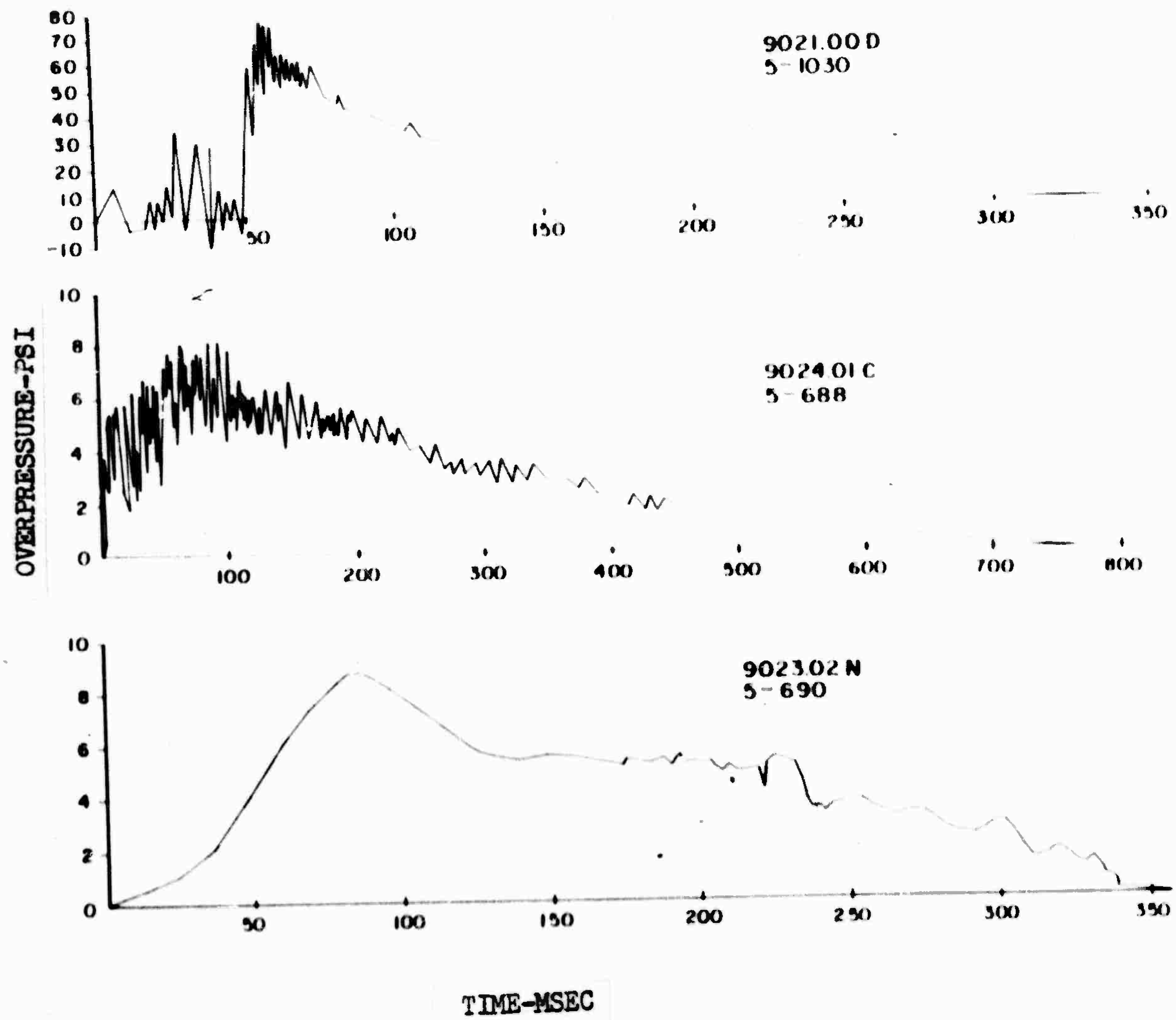

Figure B.11 Over-Pressure-Time Records, Inside SP Gages, Station 3.4/1.00/3.02/4.01

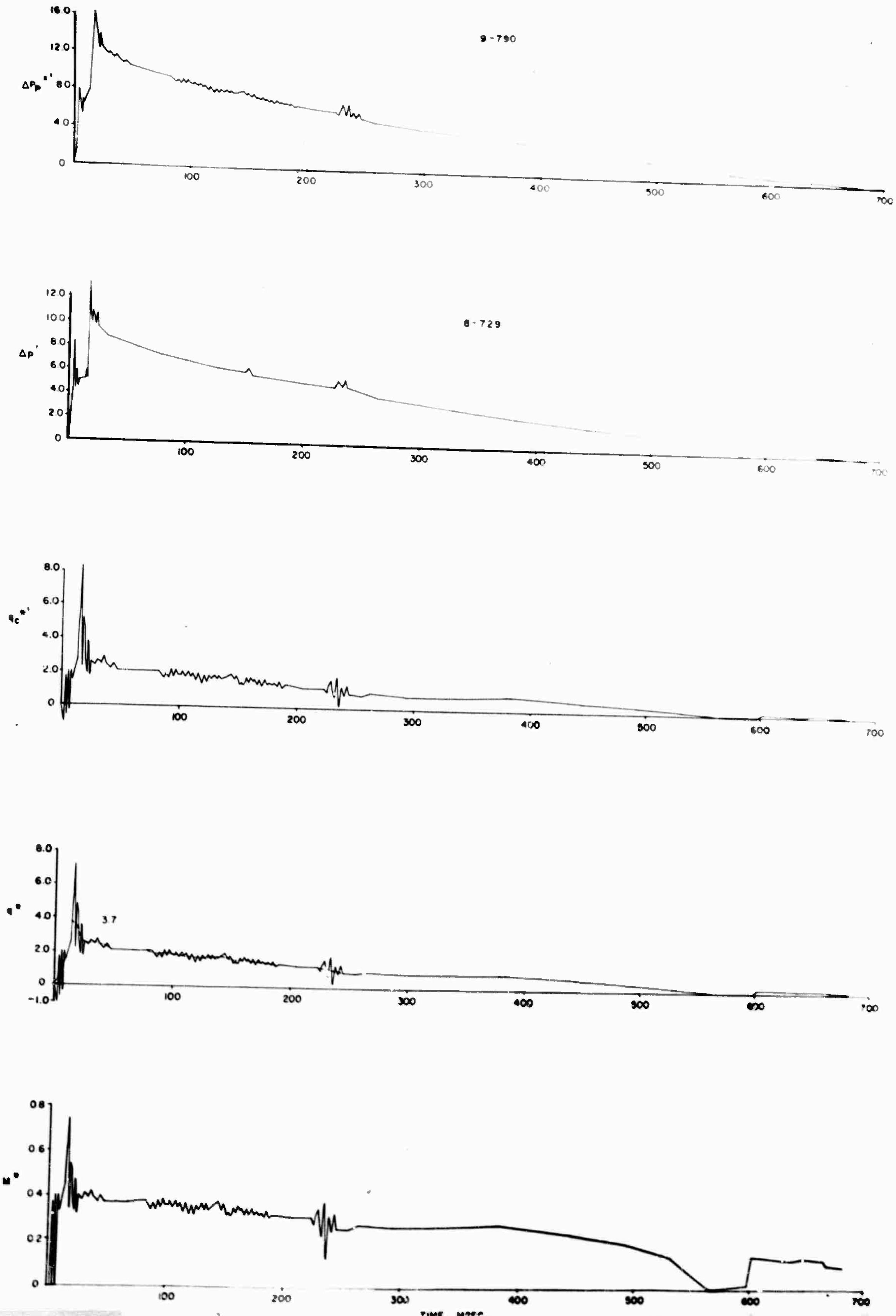

Figure B.12 Pressure & Mach No.-Time Records, Gages SQT, SQS, Station 5.4/2.01

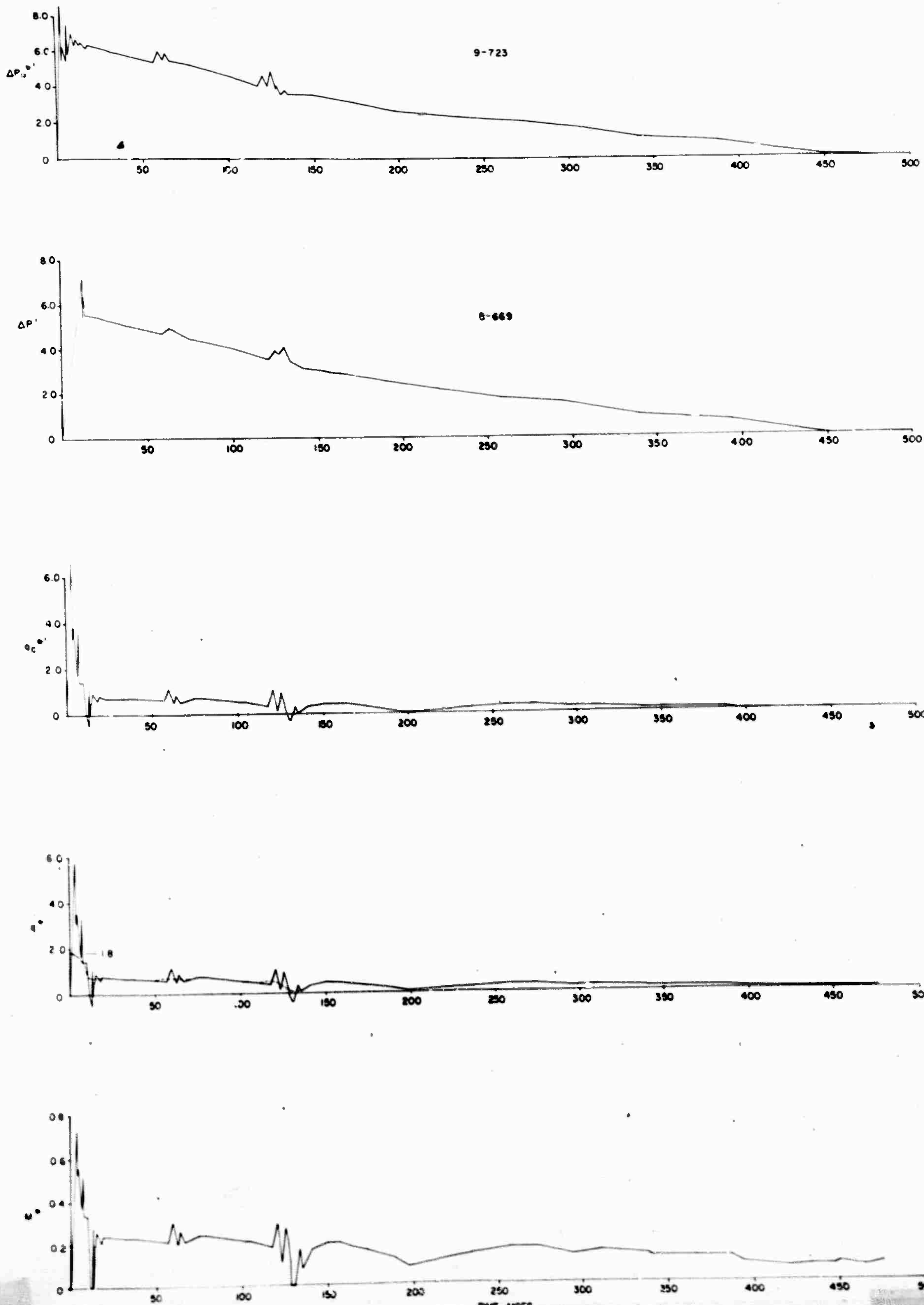

Figure B.13 Pressure & Mach No.-Time Records, Gages SQT, SQS, Station 3.4/2.02

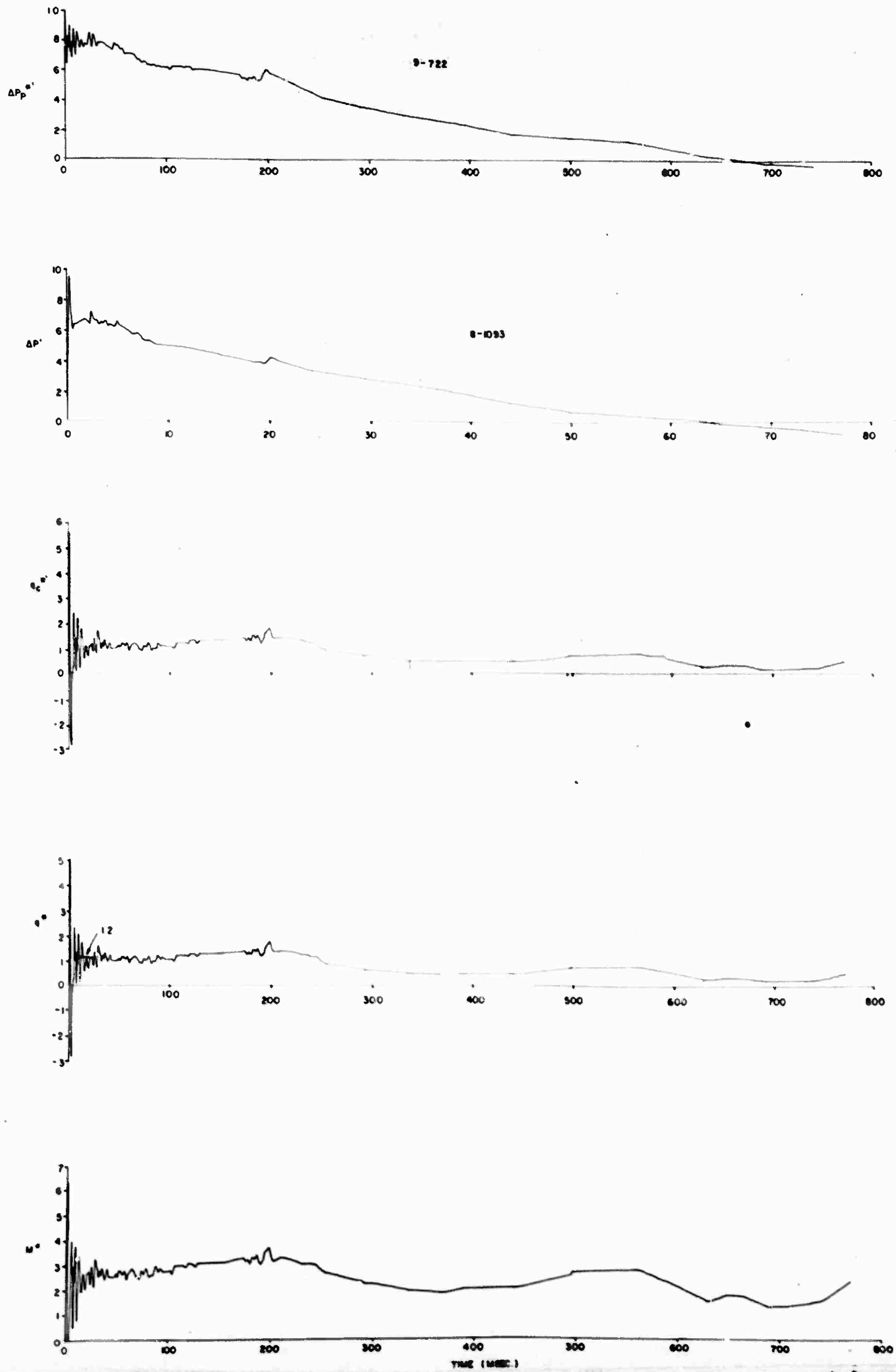

Figure B.14 Pressure & Mach No-Time Records, Gages SOT. SOS. Sta. 3.4/4.01

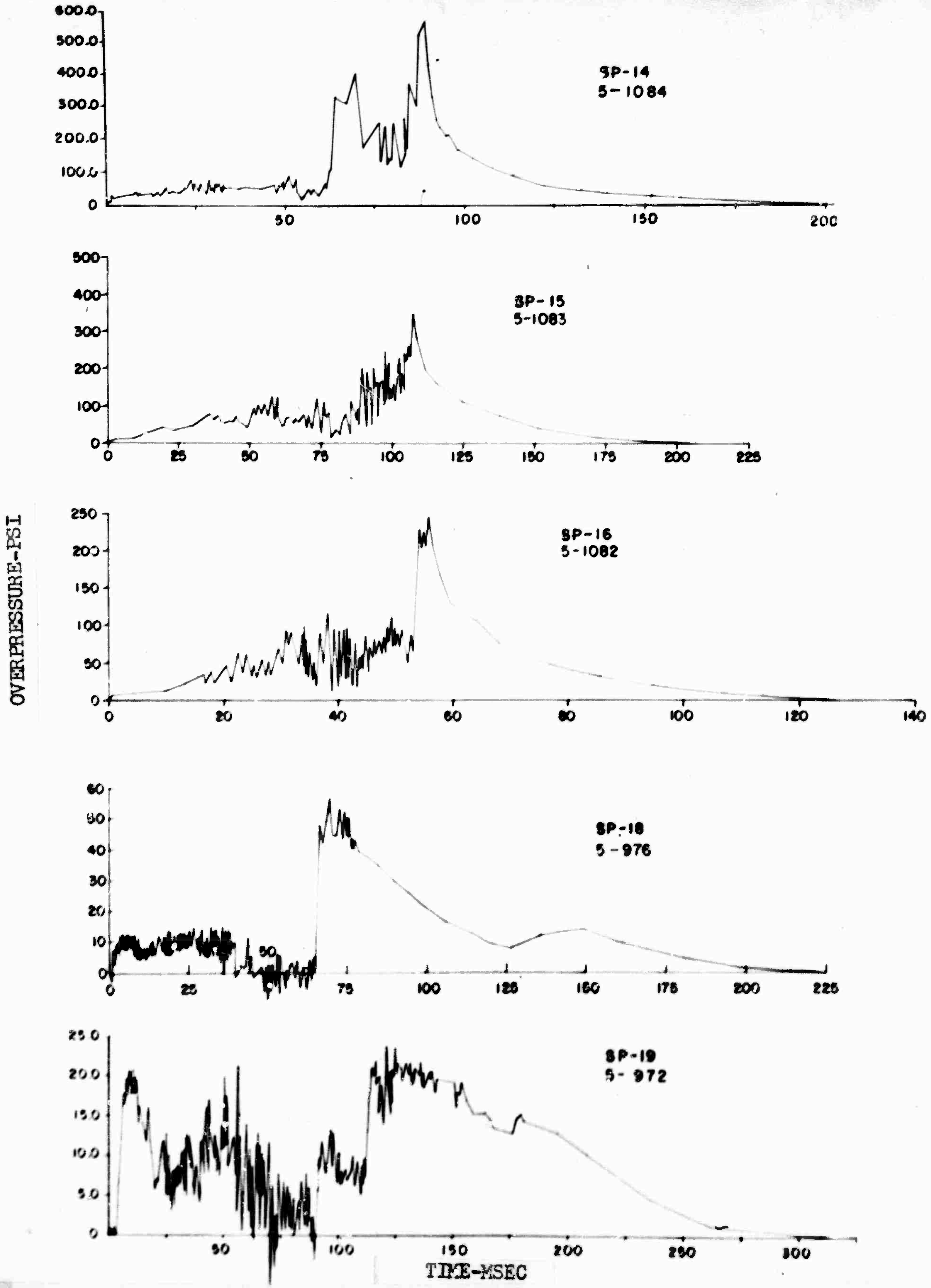

Figure B.15 Over-Pressure-Time Records, Gages SP 14 to SP 19, Station 3.6/7.01

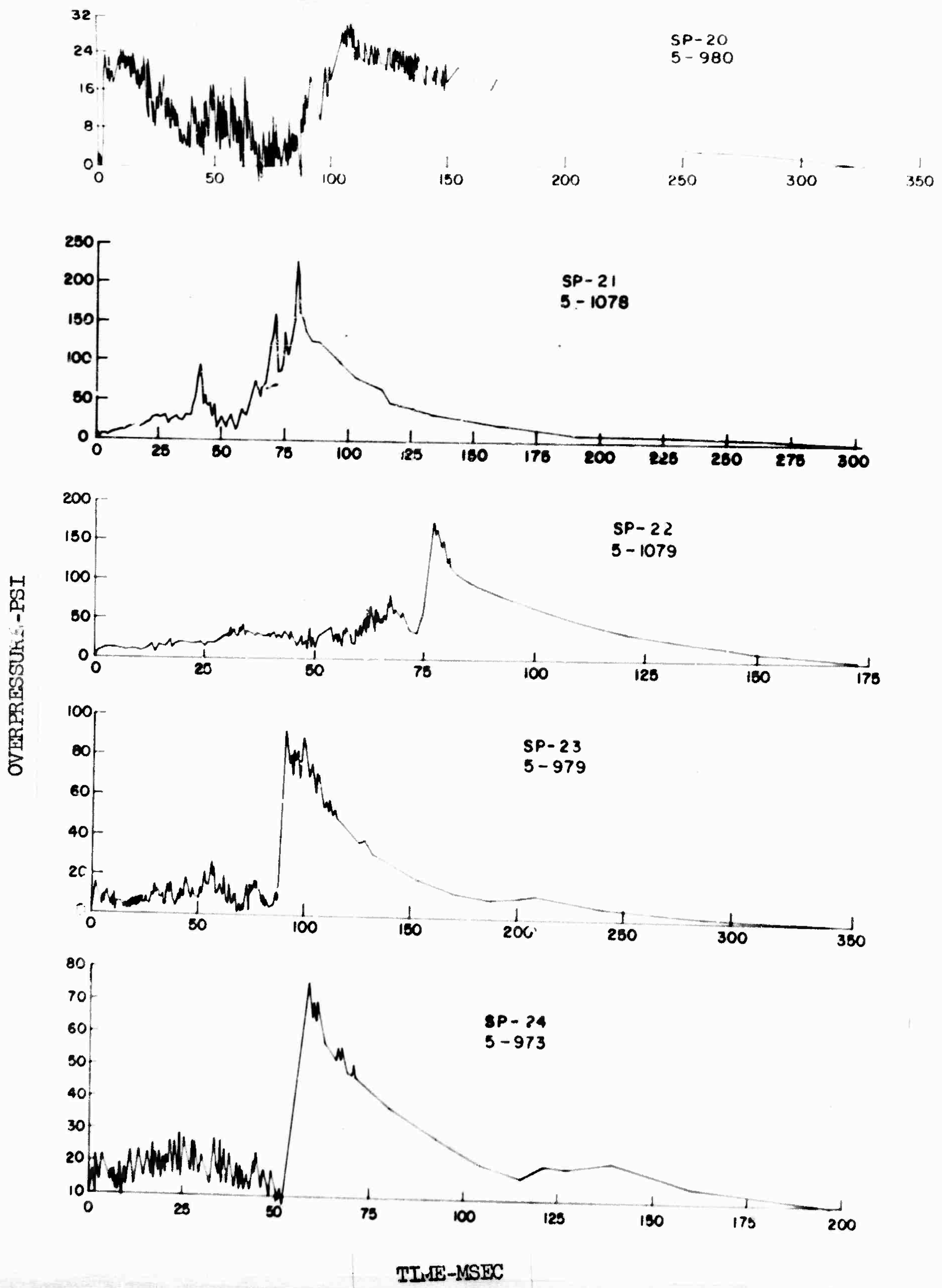

Figure B.16 Over-Pressure-Time Records, Gages SP 20 to SP 24, Station 3.6/7.01

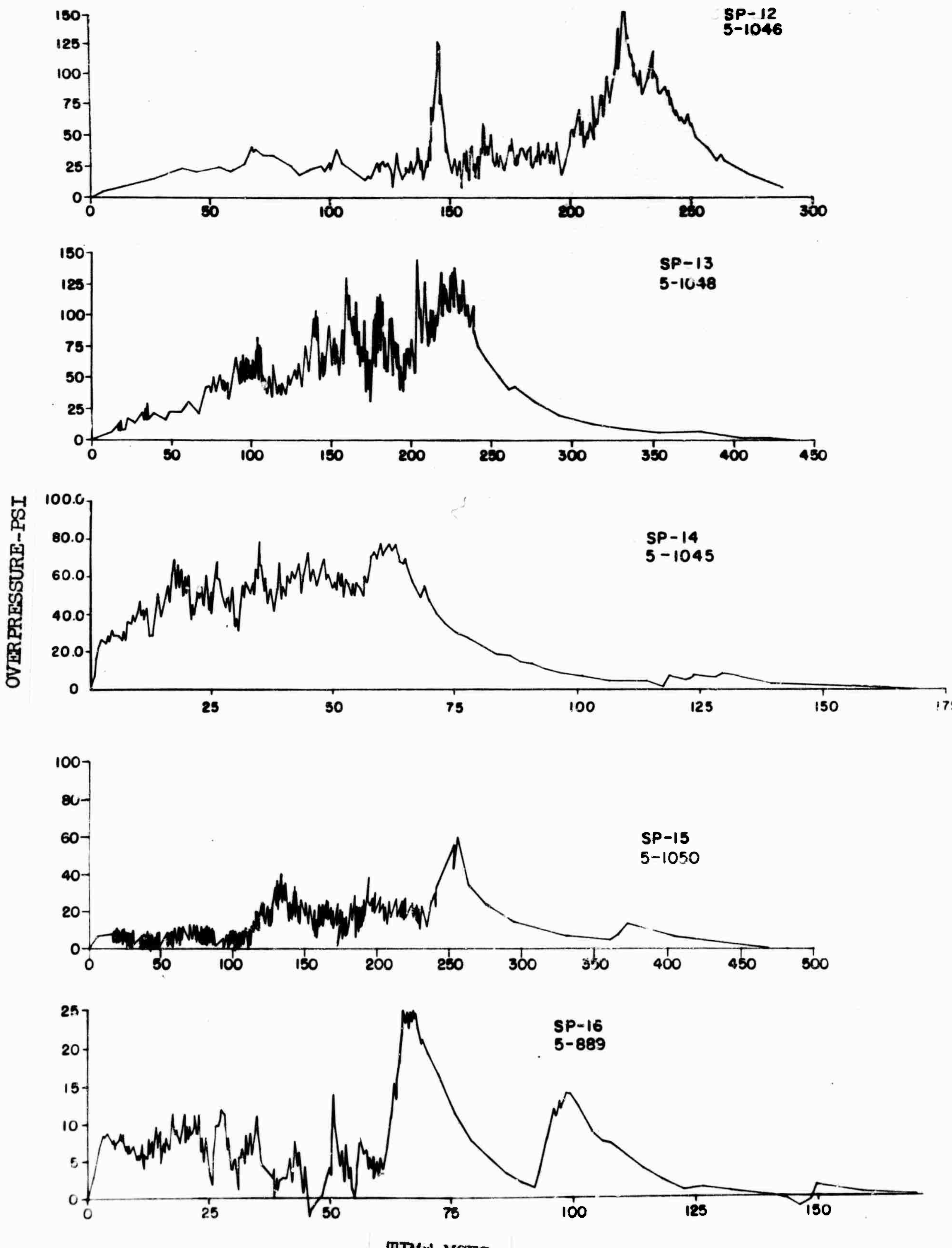

Figure 3.17 Over-Pressure-Time Records, Gages SP 12 to SP 16, Station 3.6/7.02

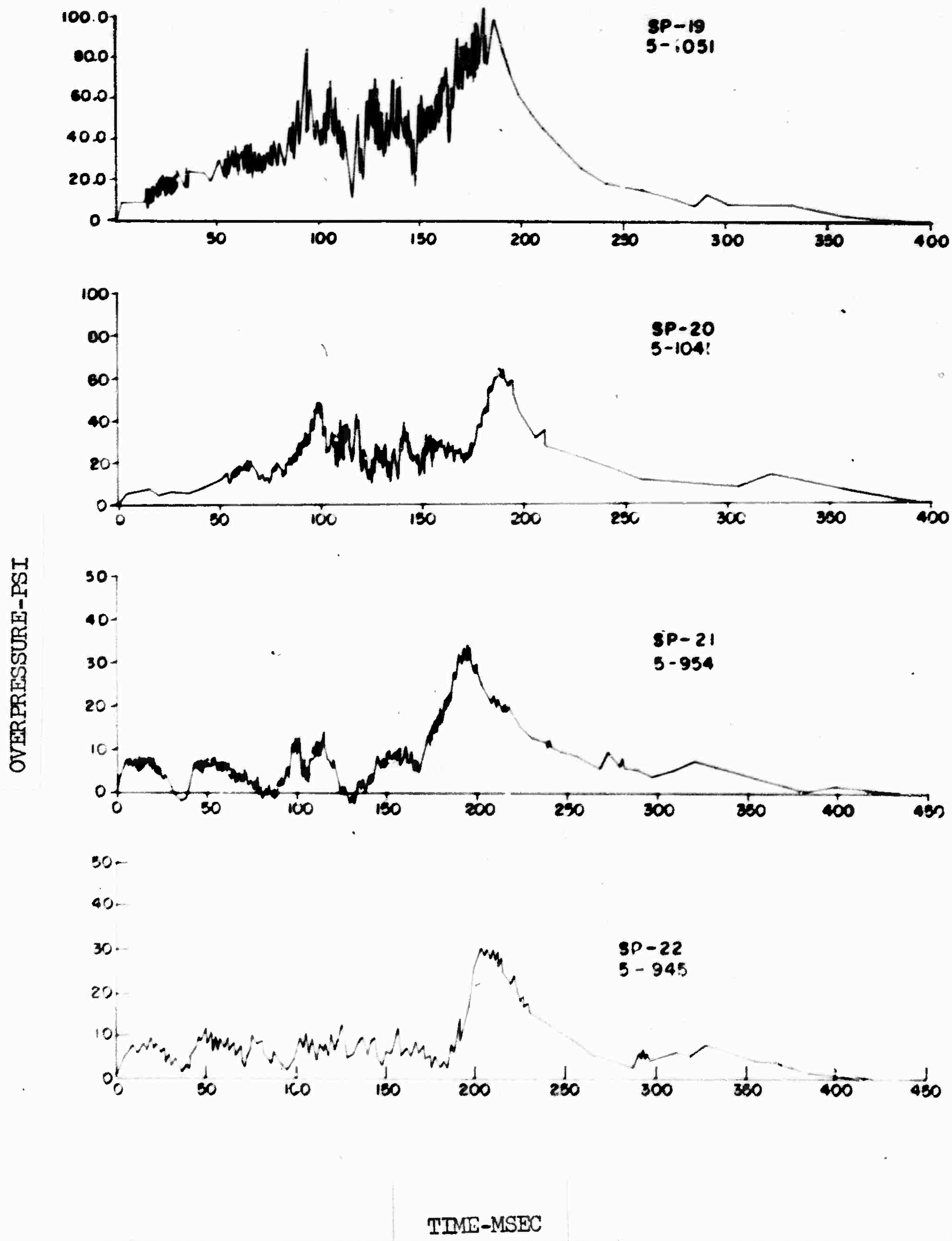

Figure B.13 Over-Pressure-Time Records, Gages SP 19 to SP 22, Station 5.5/7.02

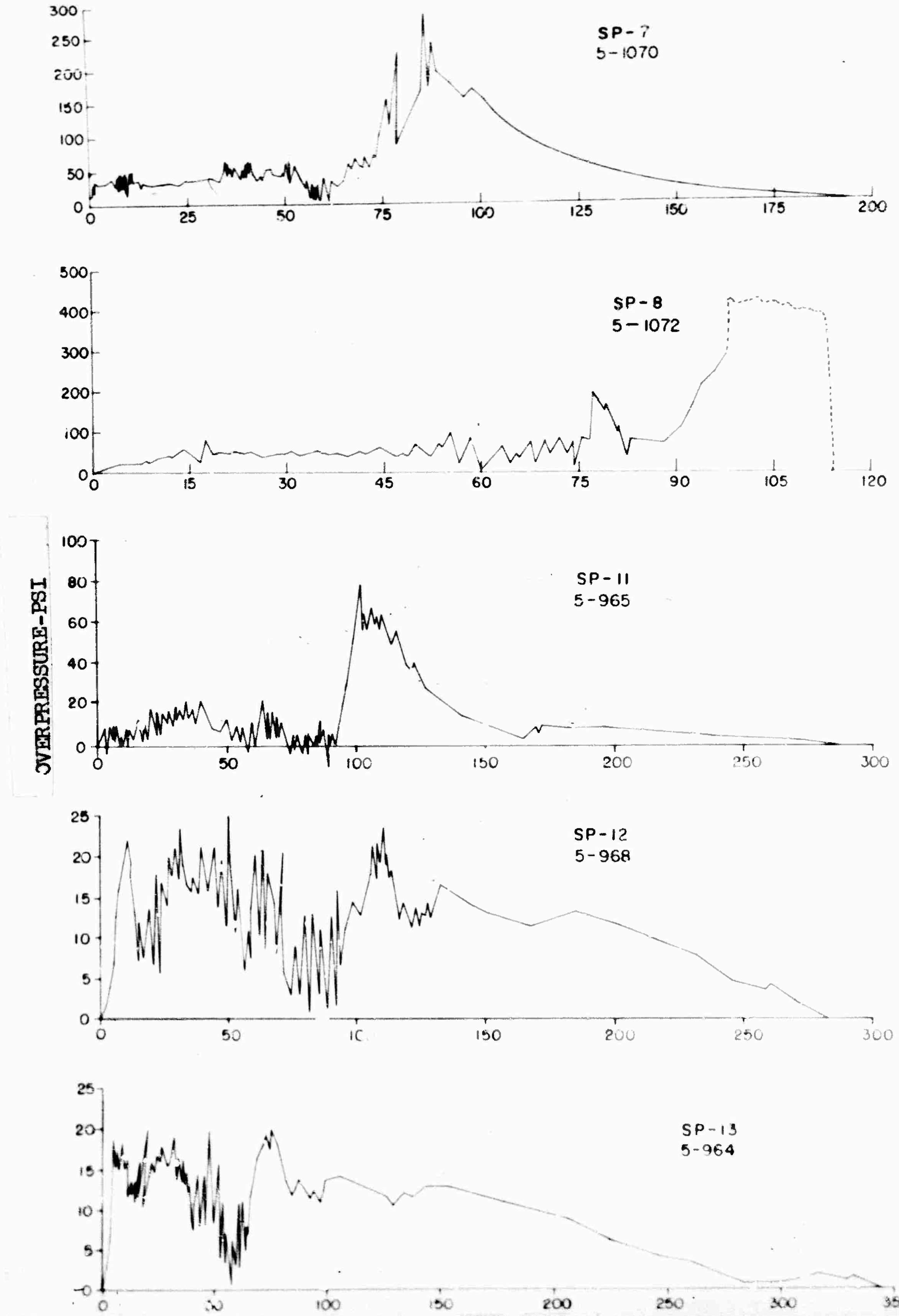

Figure B.19 Over-Pressure-Time Records, Gages SP 7 [redacted]

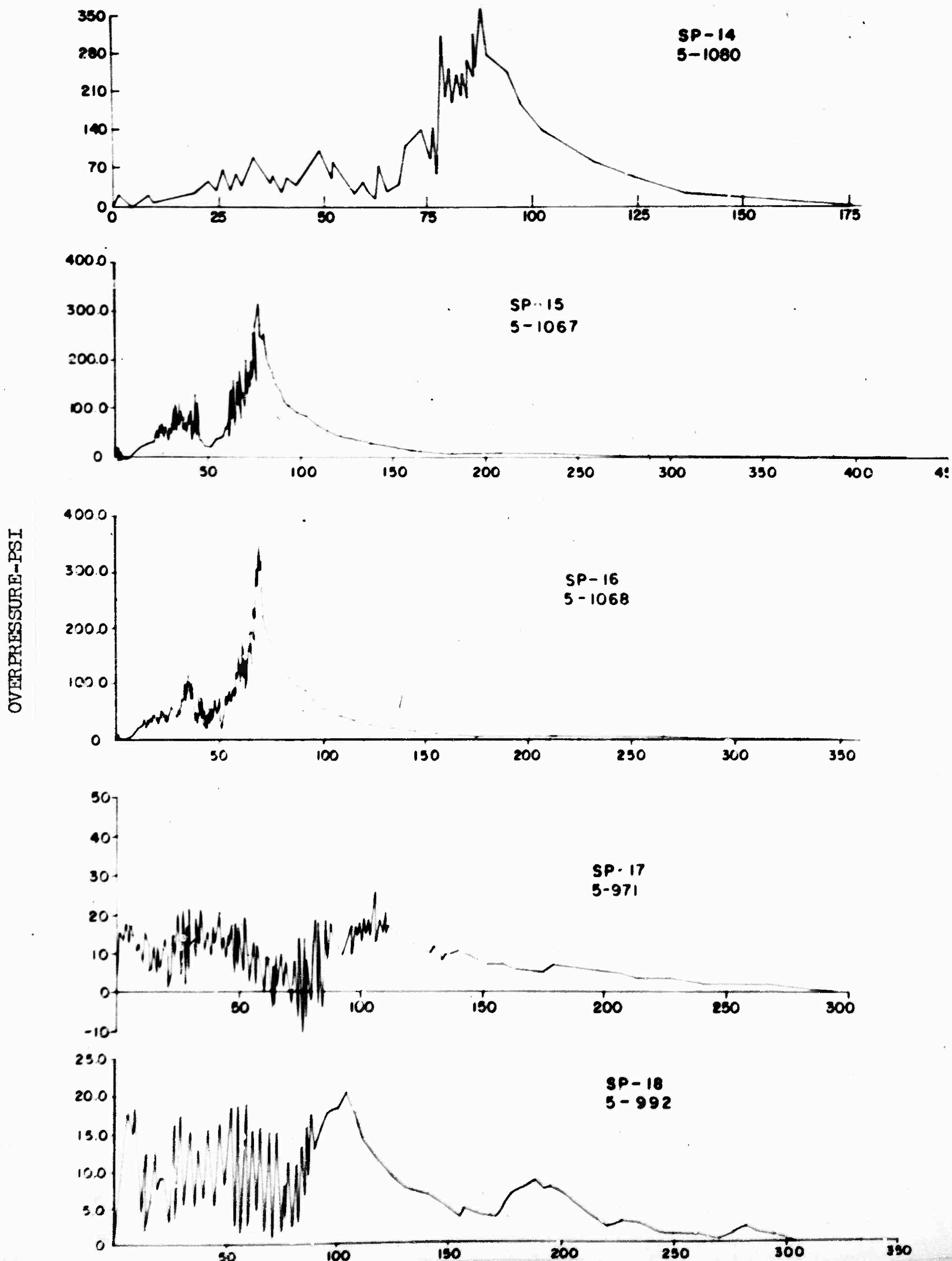

Figure B.20 Over-Pressure-Time Records, Gages SP 14 to SP 18, Station 3.6/8.01

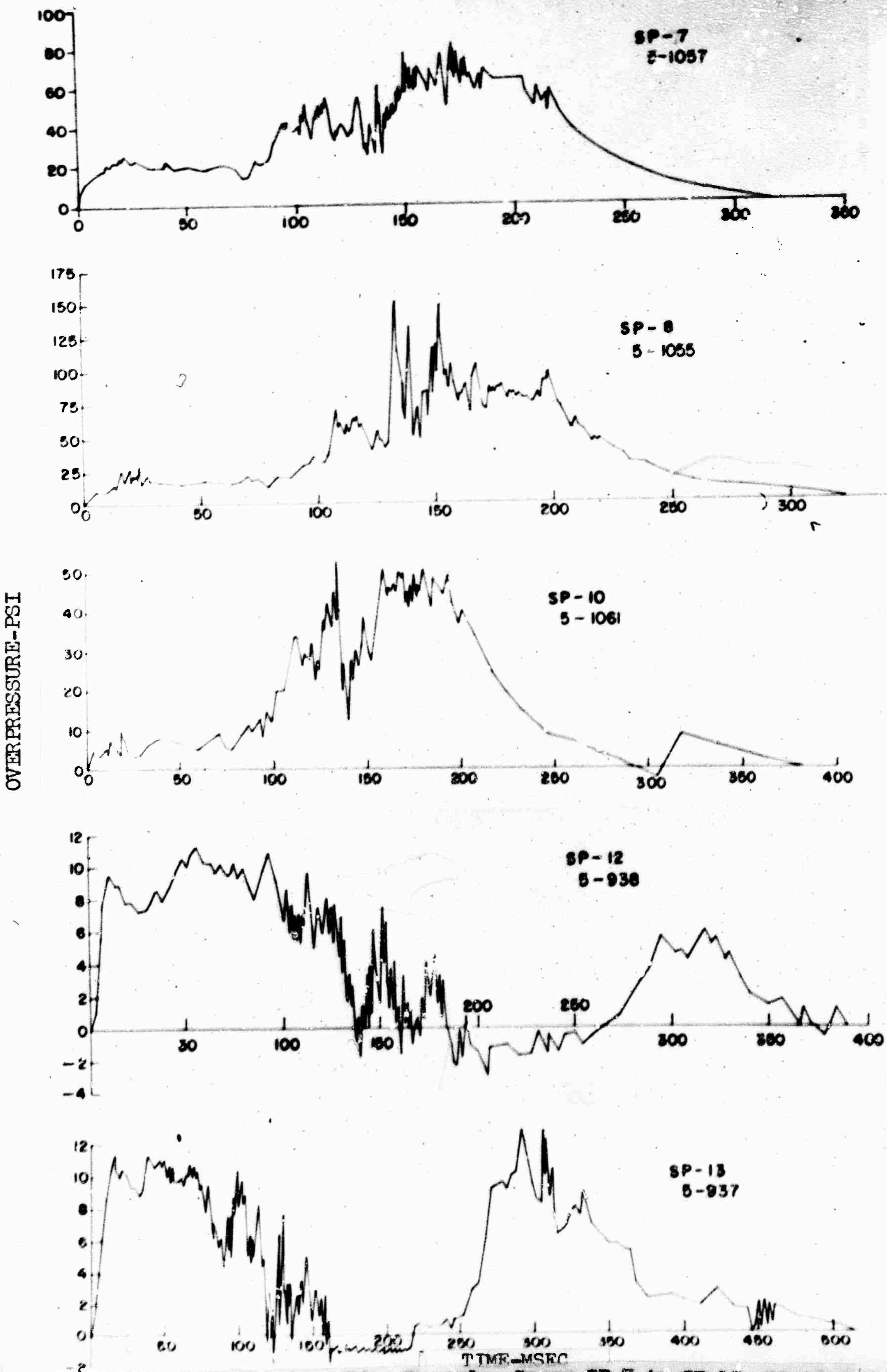

Figure B.21 Over-Pressure-Time Records, Gages SP 7 to SP 13, Station [illegible]/8.[illegible]

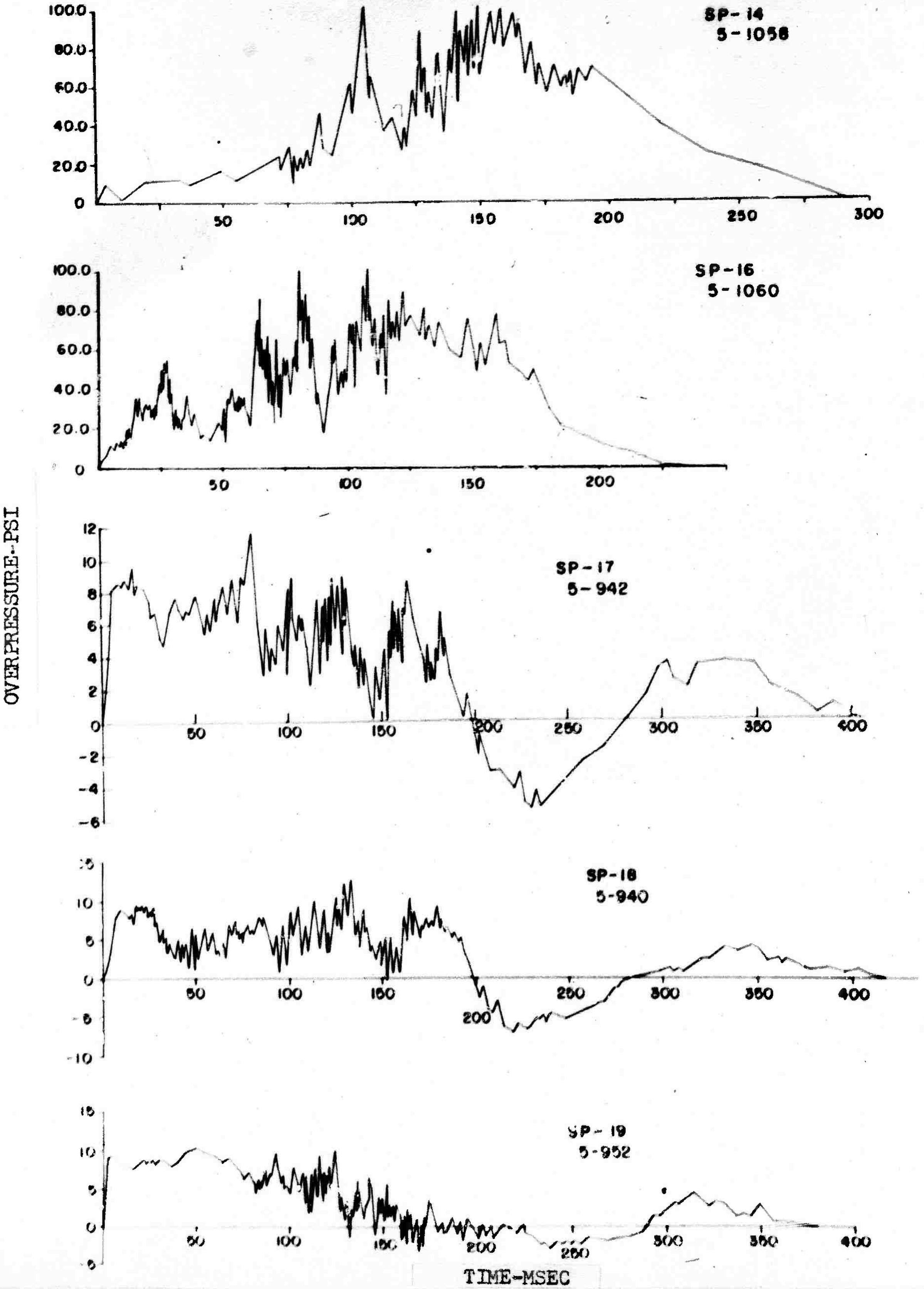

Figure B.22 Over-Pressure-Time Records, Gages SP 14 to SP 19, Station 3.6/8.02

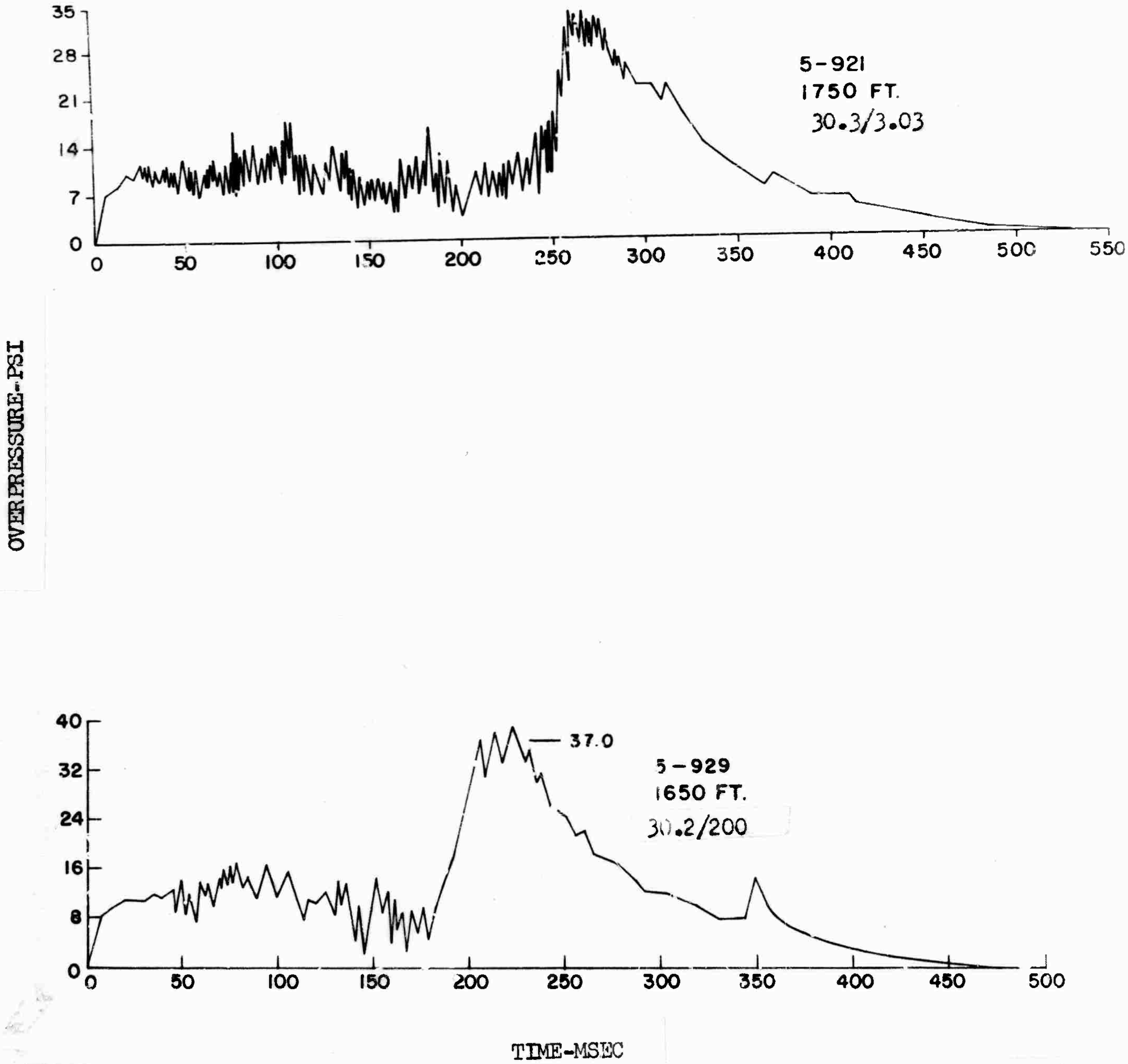

Figure B.23 Over-Pressure-Time Records, Gages Outside 30.2/2.00, 30.3/3.03

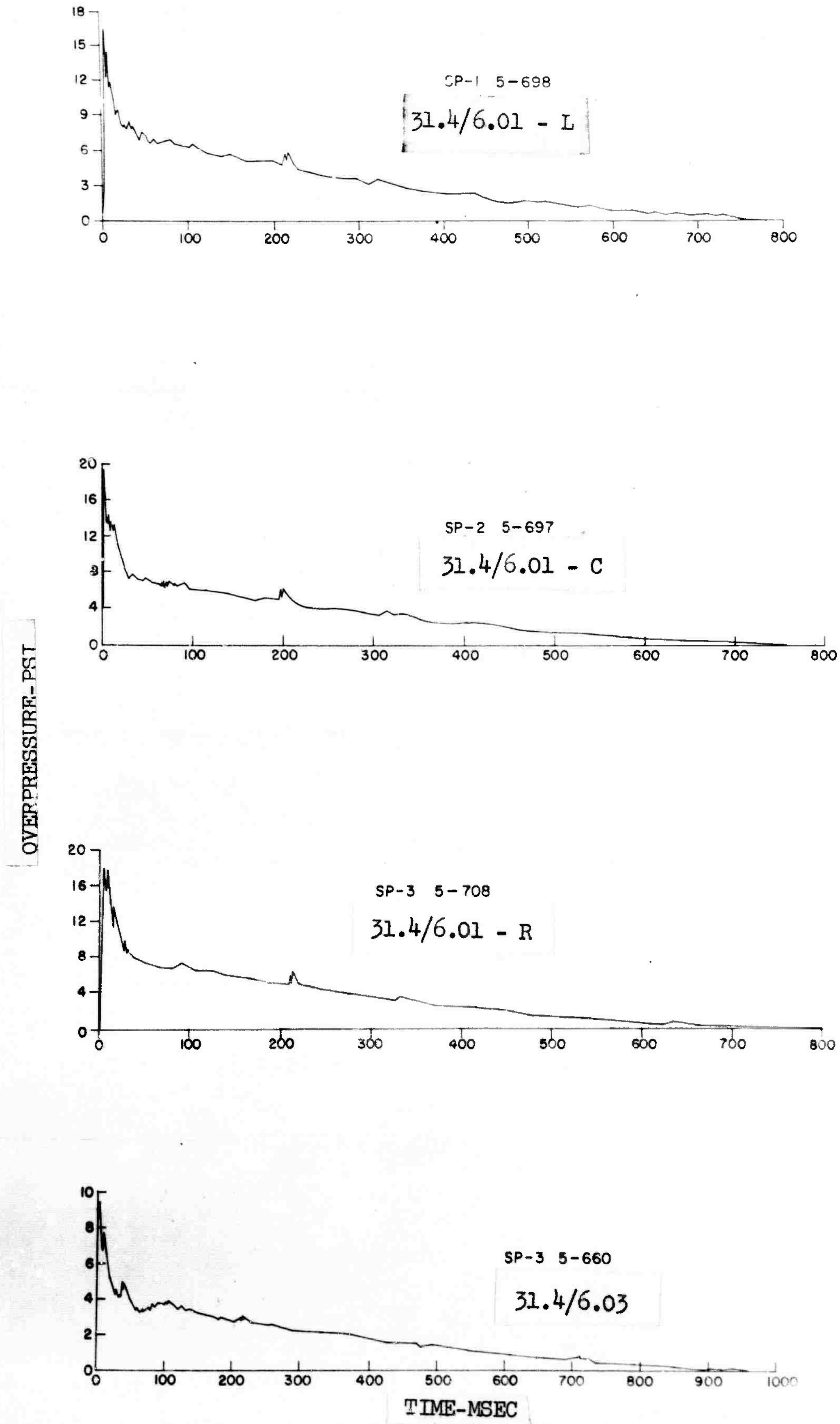

Figure B.24 Over-Pressure-Time Records, Gages Outside Station 31.4/6.01/6.03

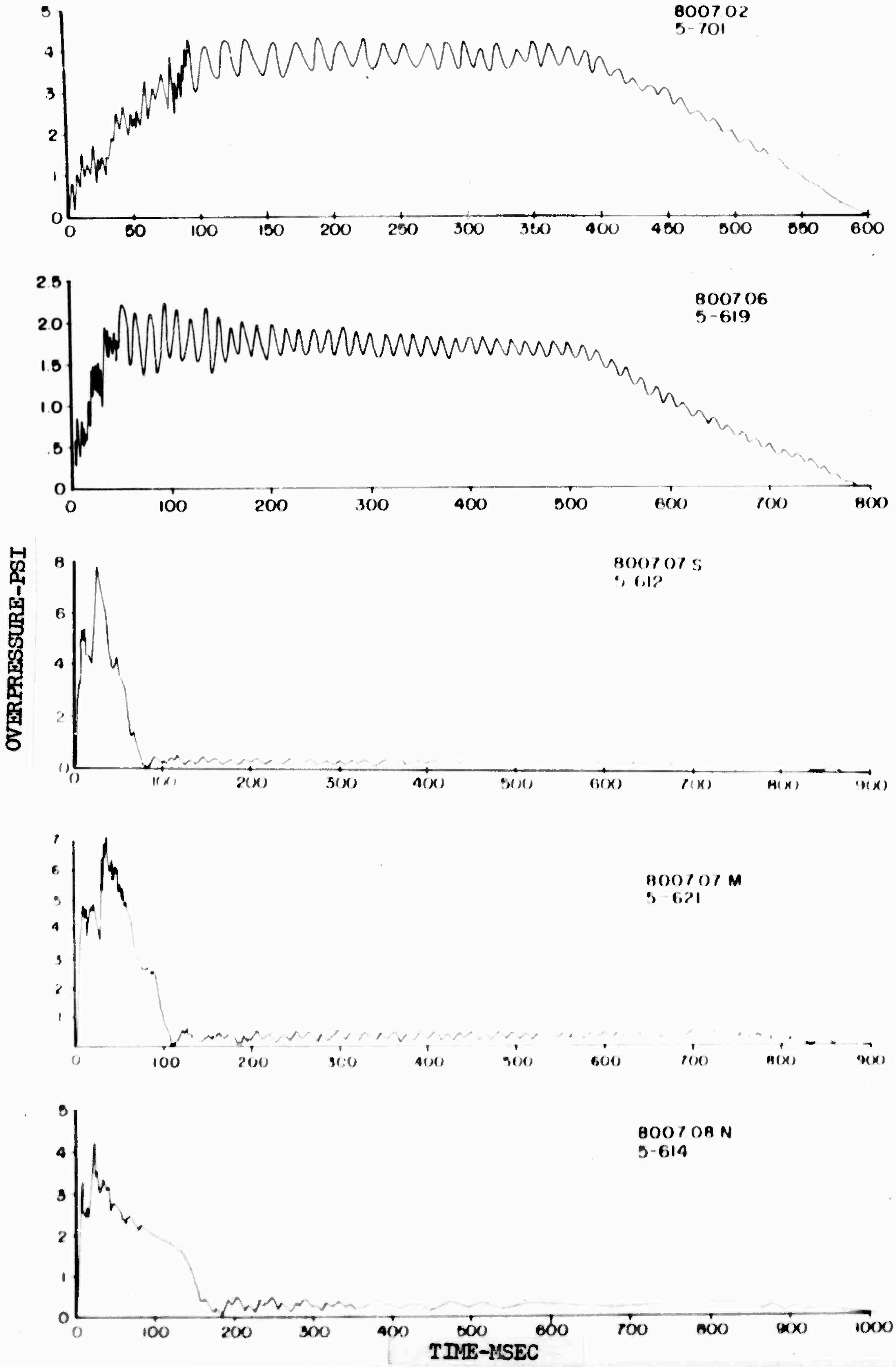

Figure B.25 Over-Pressure-Time Records, Gages Inside Valves, Sta. 31.5/7.02/7.06/7.07/7.

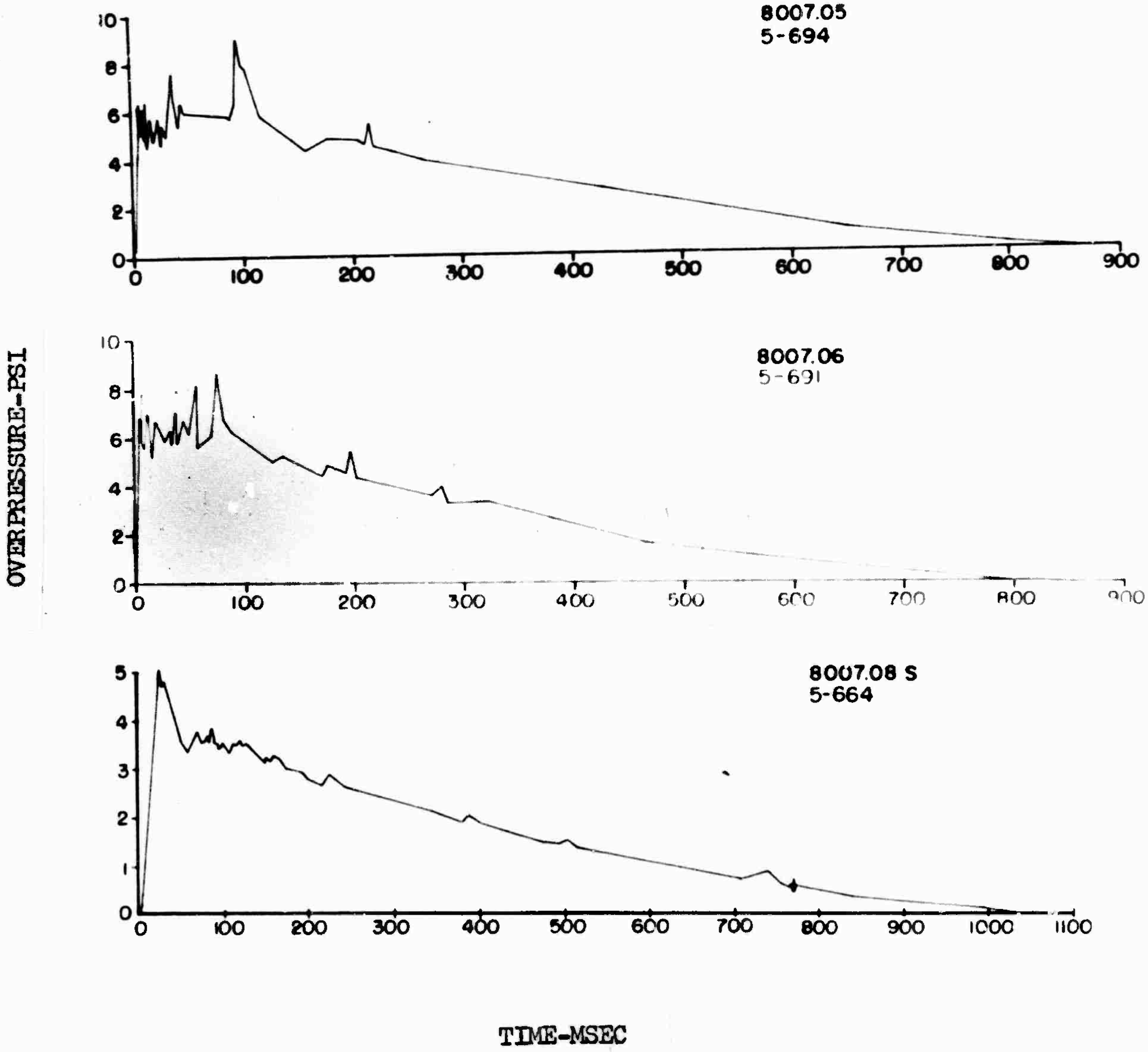

Figure B.26 Over-Pressure-Time Records, Gages Outside Valves, Sta. 31.5/7.05/7.06/7.08

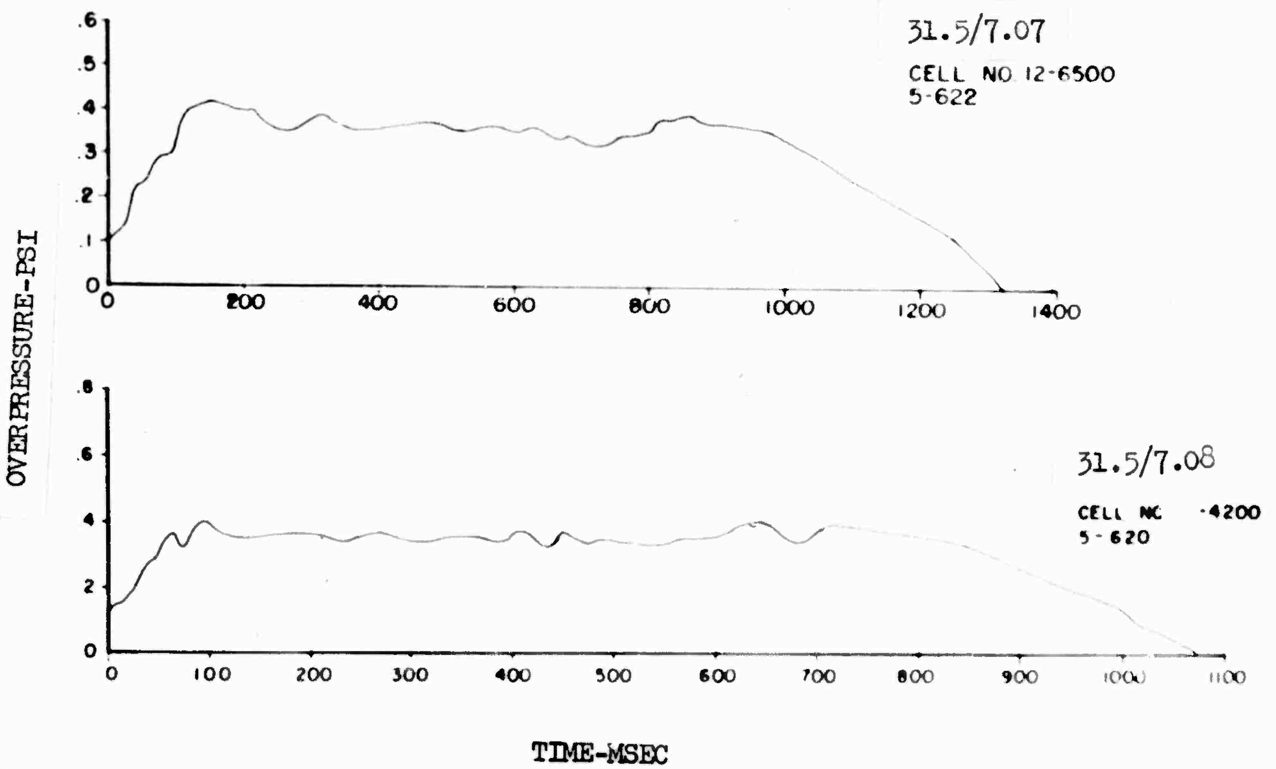

Figure B.27 Over-Pressure-Time Records, SP Gages Inside Station 31.5/7.07/7.08