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SHOCK WAVE LOADING ON A TWO-DIMENSIONAL GENERIC TRUCK/SHELTER MODEL

Gerald Bulmash

August 1983

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The BRL 57.5 cm shock tube was utilized to produce square and decaying waves. Pressure-time data were obtained for the diffraction and drag loading phases on a nonresponding two-dimensional model of a truck/shelter. Records were procured for the model, both with and without boundary conditions, at average input pressures of 34.3, 70.0, and 102.2 kPa. Comparisons with the NASA-Ames two-dimensional computer code are presented.

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I. INTRODUCTION

The motivation for this study is to represent the blast loading on a M35A2 2-1/2 ton cargo truck/S280 electronics equipment shelter combination[1,2] by testing a two-dimensional (approximately 1/66 scale) model in the BRL 57.5 cm shock tube.[3] The model was also designed from the viewpoint of providing experimental data for explicit comparison with the NASA-Ames two-dimensional computer hydrodynamic code.[4] The truck/shelter model is one of several generic shapes that have been tested to obtain basic blast loading data.[5]

The Procedure Section describes the model and experimental apparatus. An explanation of the shock tube test program and presentation of representative pressure-time histories are provided in the Results Section. In the Discussion Section comparisons between the model configurations are examined. Comparisons are also presented for the NASA-Ames two-dimensional hydrocode.

II. PROCEDURE

A. Model

The model is based on the M35A2 truck/S280 shelter combination. It is a simplified generic shape that may represent the truck/shelter or any vehicle of this general design. Refer to Figure 1 to see a drawing of the simplified model. Refer to Appendix A, Figure A-7 for exact location of gauges. The underbody has been enclosed; therefore, there is no airflow under the truck. The windshield has been removed to further simplify the airflow. The model is nonresponding; it is composed of solid steel and is securely mounted to the shock tube. It neither translates nor deforms under the influence of blast loading.

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[1] *W. J. Schuman, Jr. and W. D. Allison, "Retrofit Hardening of Electronics Shelters with Composite Panels," Fourth Conference on Fibrous Composites in Structural Design, November 1978.*

[2] *William J. Schuman, Jr., Garabed Zartarian, Raffi P. Yeghiayan, and W. Don Allison, "C³ Shelter Designs for the Tactical Battlefield," Army Symposium on Solid Mechanics, 1980, Designing for Extremes: Environ, Loading, and Structural Behavior, October 1980.*

[3] *George A. Coulter and Brian P. Bertrand, "BRL Shock Tube Facility for the Simulation of Air Blast Effects," BRL Memo Report No. 1685, August 1965 (AD 475669).*

[4] *Andrew Mark and Paul Kutler, "Computation of Shock Wave/Target Interaction," AIAA 21st Aerospace Sciences Meeting, January 1983.*

[5] *George A. Coulter, "Blast Wave Loading of a Two-Dimensional Circular Cylinder," BRL Memo Report No. ARBRL-MR--03207, November 1982 (AD A121600).*

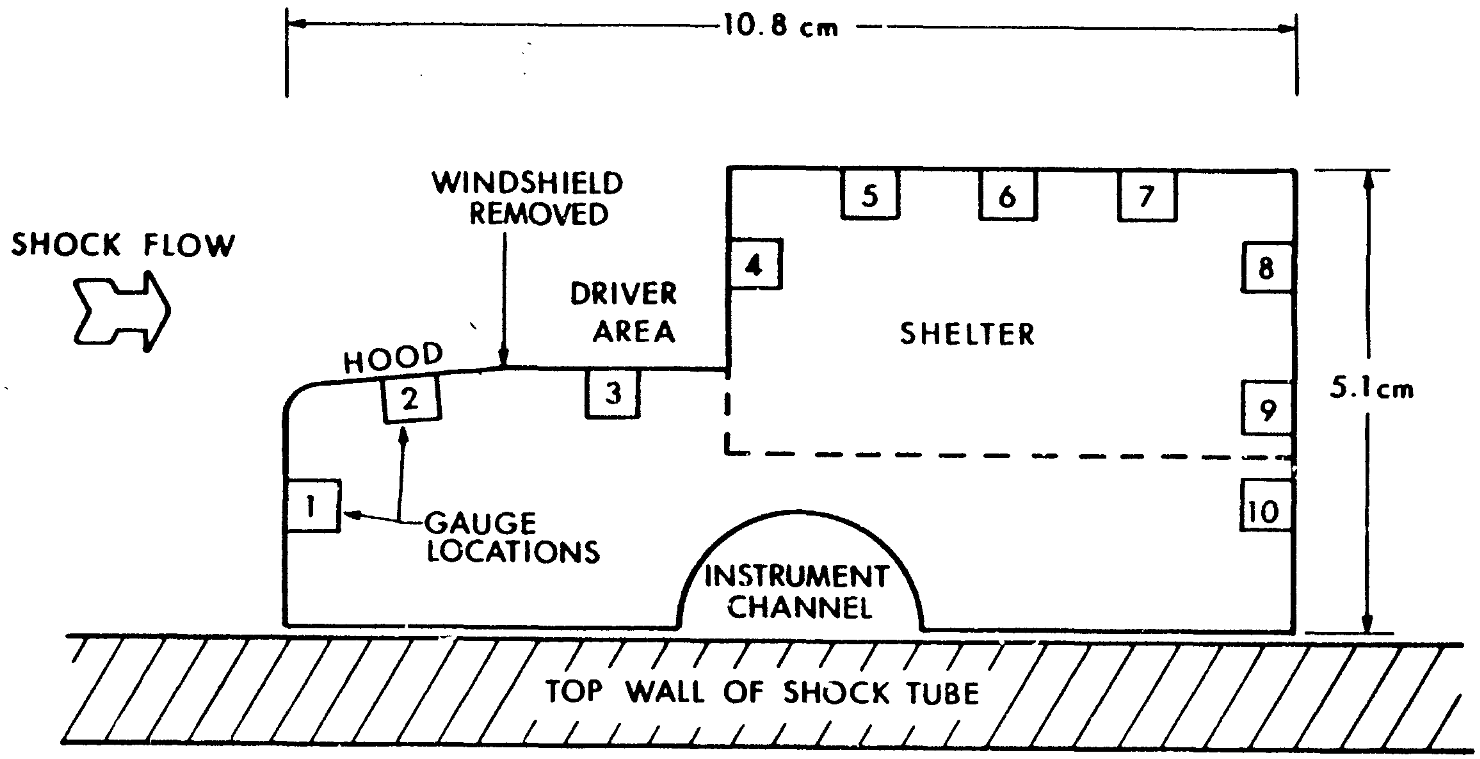


Figure 1. Generic Truck/Shelter Profile, Configuration One, with Boundary Conditions.

The model is approximately a 1/66th scale version of the truck/shelter. Raley* created a three-dimensional model of the truck/shelter which was in turn used to create a model of dimensions appropriate for testing in the 50.8 cm square test section of the BRL 57.5 cm shock tube.

The two-dimensional plane of interest in this study represents a cross section sliced from front to back along the center line of the truck/shelter. To assure the two-dimensional requirement, the width of the model has been enlarged so that this dimension extends from one wall of the shock tube to the opposite wall. Therefore, there is no airflow around the sides of the truck/shelter. These simplifications produced the shape that was tested. Refer to Appendix A for a set of shop drawings of the model.

In all cases the model was mounted in the shock tube with the front of the truck facing the shock flow. The model was created so that it could be tested in two configurations, i.e., with and without boundary conditions. In Configuration One the model was attached horizontally, upside down to the top wall of the shock tube for convenience in mounting. Refer to Figures 1 and 2. Therefore, the boundary condition that must be considered is the top wall of the shock tube. The 5.08 cm high model has a cross-sectional area that is 10%[6] of the test section area.

In Configuration Two boundary conditions were eliminated. The model was mounted vertically in the center of the test section; it was attached to the top and bottom walls of the shock tube. Refer to Figures 3 and 4.

To produce even airflow, a mirror image of the model was bolted to the model resulting in a symmetric shape. Since the instrumented portion of the model, i.e., center line, was as far from the shock tube walls as possible, boundary conditions were not a factor. Together the height of the model and mirror image is 10.16 cm resulting in a 20% blockage of the test section.

Ten pressure transducers were mounted in the model as close to the center line of the model as physical limitations allowed in order to assure the two-dimensional assumption. The gauges were mounted as follows: one each on the front of the truck, the hood, the driver's area, and the front of the shelter; three each on the top and back of the shelter.

B. Experimental Apparatus

1. Shock Tube

The model was tested in the BRL 57.5 cm inside diameter shock tube located on Spesutie Island, APG, Md. See Figure 5. In addition to the ten piezoelectric gauges mounted in the model, two gauges were mounted upstream in the shock tube to record free-field side-on and stagnation

*Private communication with Robert J. Raley, BRL, November 1981.

[6] Ethridge, Lottero, Wortman, and Bertrand, "Flow Blockage and Its Effects on Minimum Incident Overpressure for Overturning Vehicles in a Large Blast Simulator," Seventh International Symposium on Military Applications of Blast Simulations, 1981.

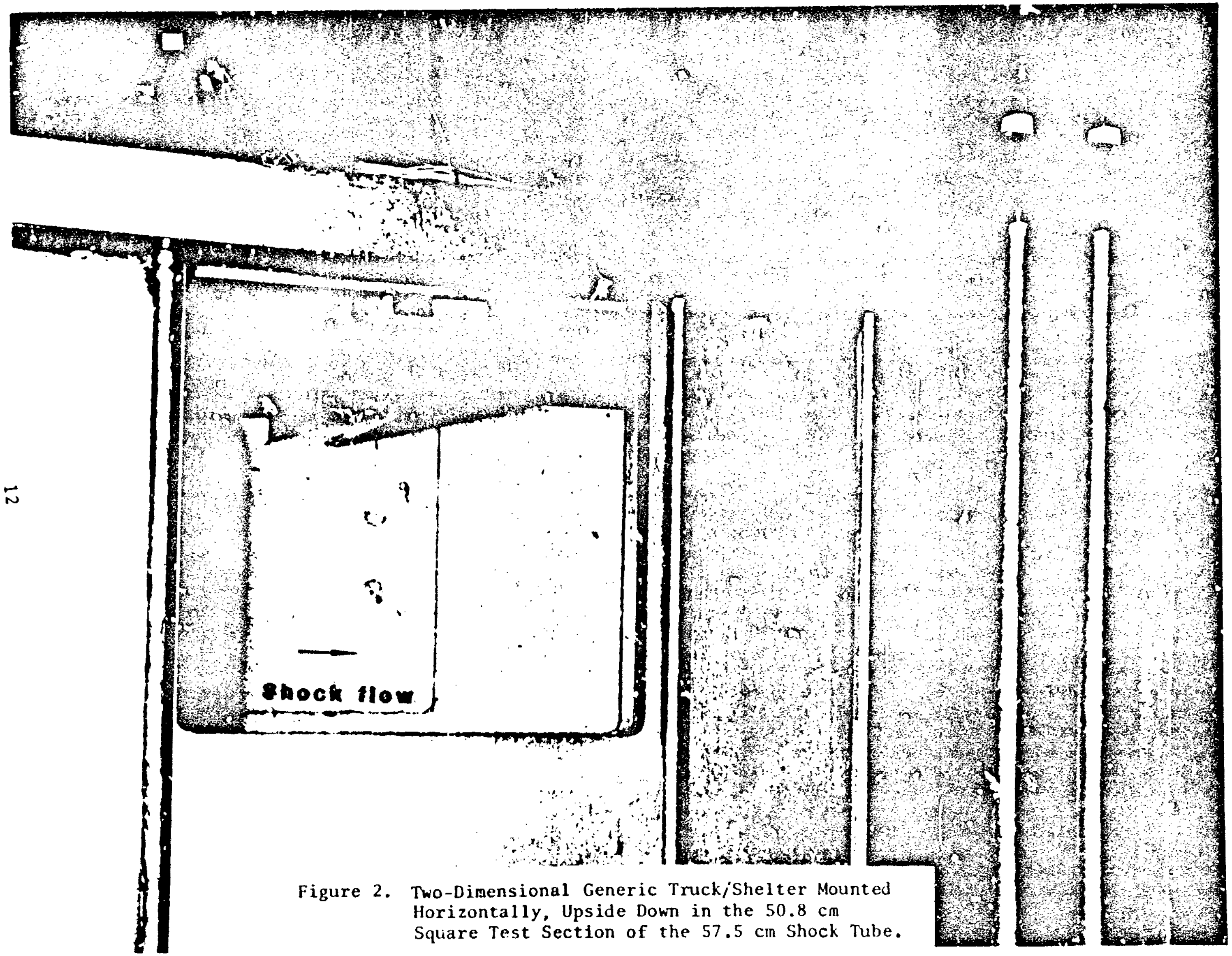


Figure 2. Two-Dimensional Generic Truck/Shelter Mounted Horizontally, Upside Down in the 50.8 cm Square Test Section of the 57.5 cm Shock Tube.

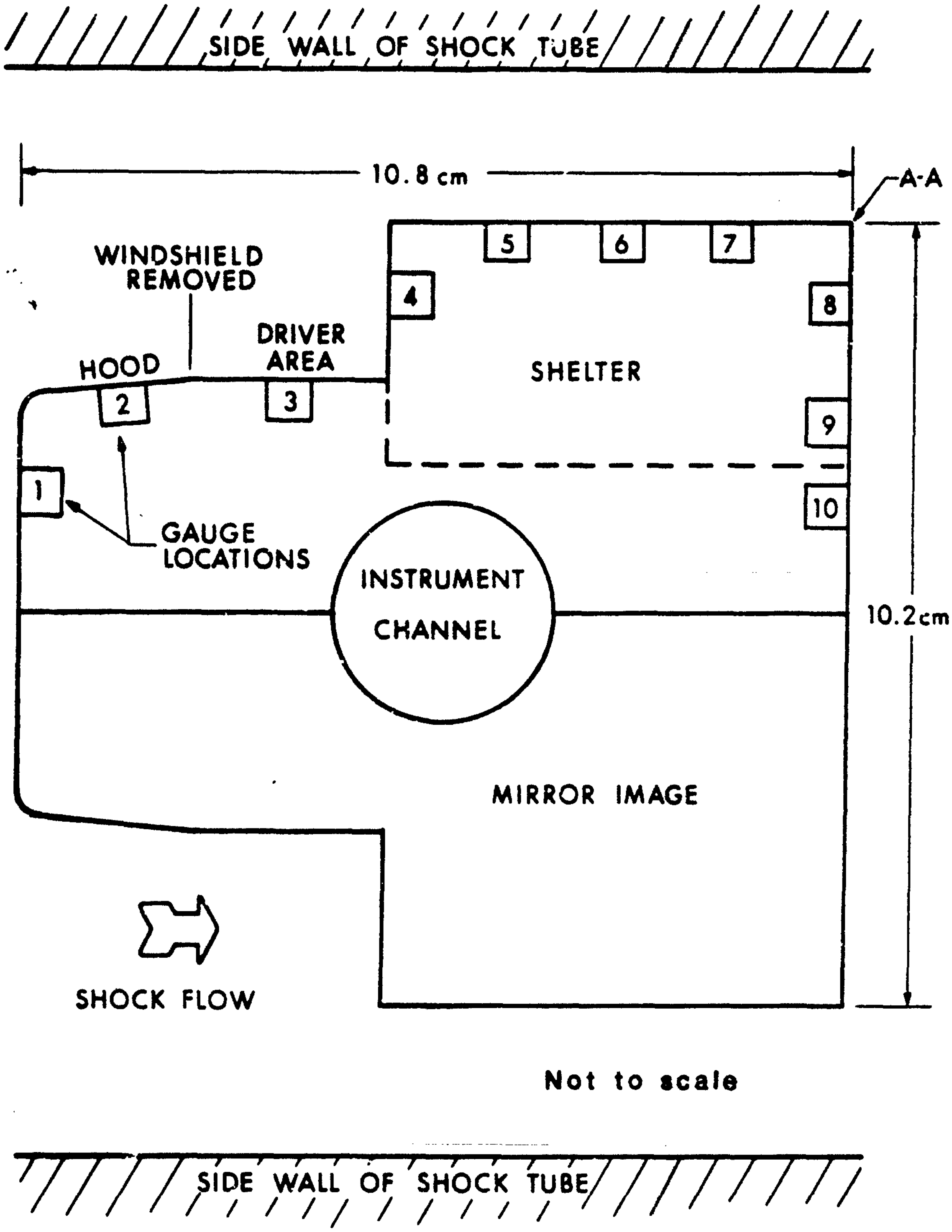


Figure 3. Generic Truck/Shelter Profile, Configuration Two, Boundary Conditions Inapplicable.

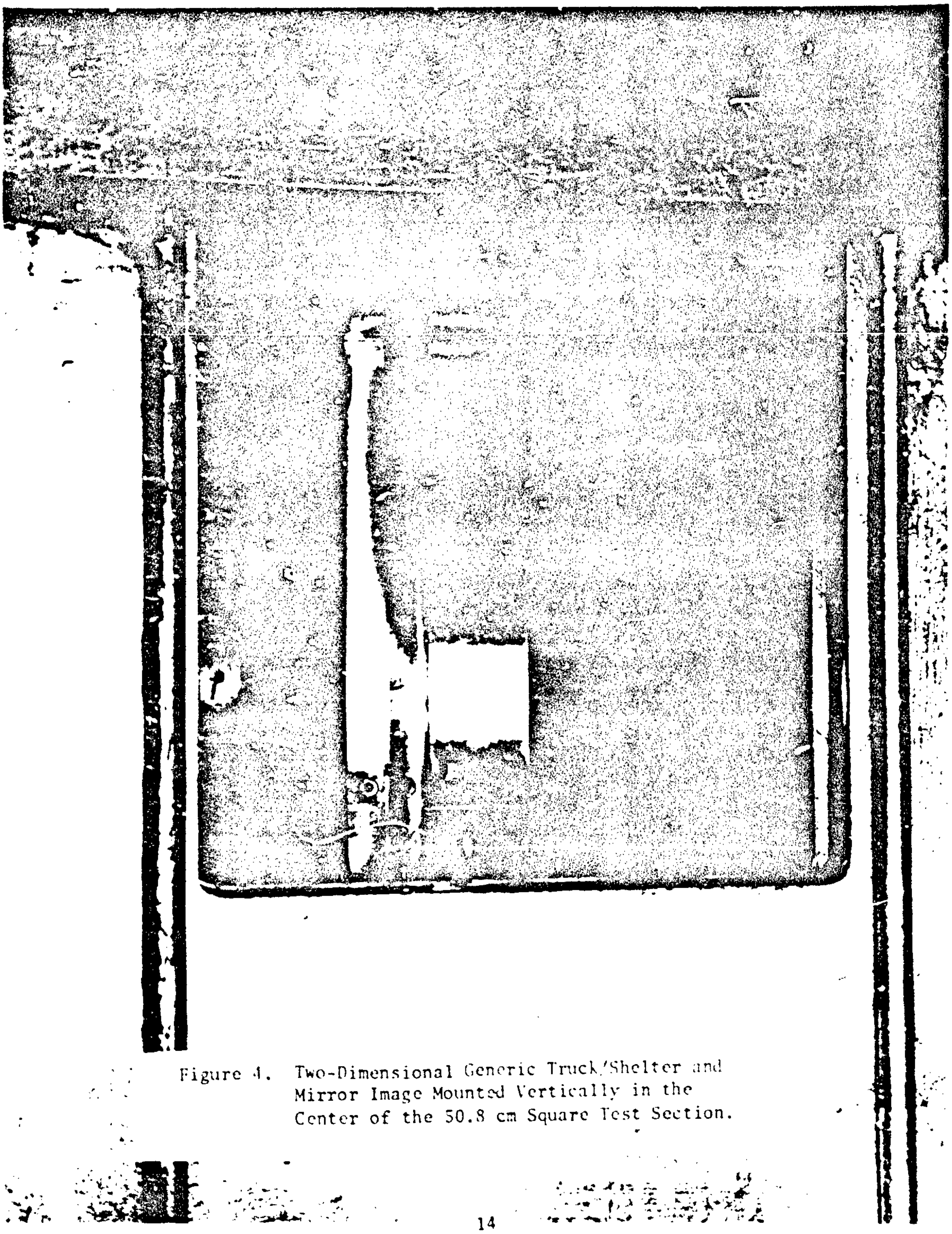


Figure 4. Two-Dimensional Generic Truck/Shelter and Mirror Image Mounted Vertically in the Center of the 50.8 cm Square Test Section.

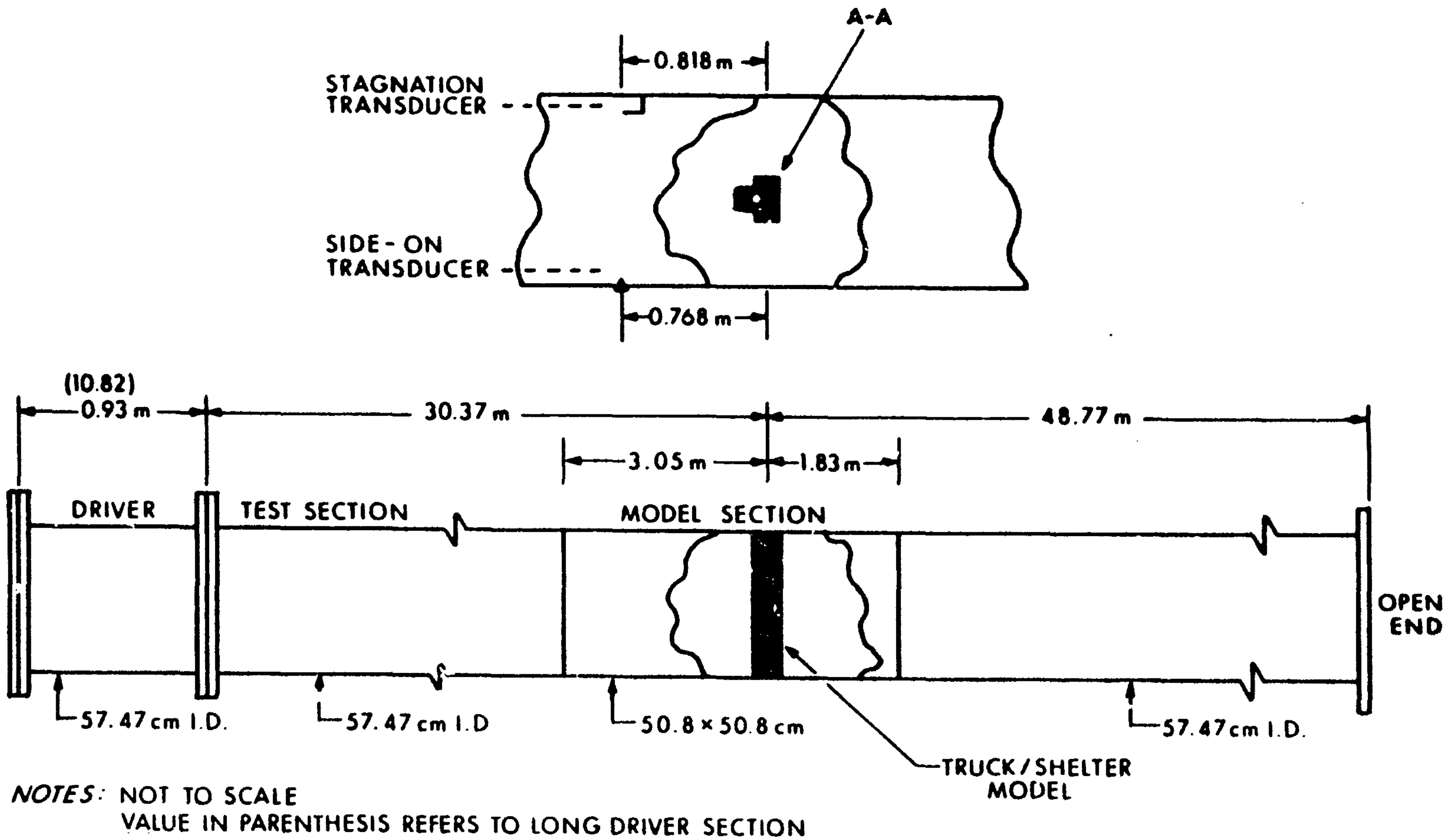


Figure 5. Illustration of the BRL 57.5 cm Inside Diameter Shock Tube with Dimensions Appropriate to Produce a Decaying Wave (Short Driver) or a Square Wave (Long Driver).

pressures. The shock tube was operated, using compressed air, with a short compression chamber (0.93 M) to provide a decaying wave and with a long compression chamber (10.82 M) to provide a flattop wave.

2. Electronics

The signals received from the piezoelectric pressure transducers mounted on the model and shock tube were conditioned, amplified, and reproduced on a Honeywell 7600 type recorder. Refer to Figure 6. The tape recorder has a response time of 10 microseconds (time required to reach 90% of the initial pressure) which suffices to capture reflected pressure peaks occurring on the front of the truck and shelter. The reflected pressure at these stations is not relieved by a rarefaction wave for about 30 microseconds, the approximate roundtrip time to the nearest relief surface. For a quick viewing the records were reproduced immediately on an oscillograph. A Biomation 1010 waveform recorder transformed the analog data to digital form and transmitted it to a Tektronix 4051 computer system which was utilized to format the data and plot it in final engineering unit form.

III. RESULTS

A. Shot Chronology

A thorough shock tube test series was performed. The model was tested both with and without boundary conditions being a factor. The model was also exposed to both a square wave and a decaying wave. In each configuration shots were fired at three pressure levels, averaging 34.3, 70.0, and 102.2 kPa. Additionally, free-field shots, i.e., without the model, were fired for a decaying wave and a square wave.

Table 1 provides a chronological summary of the test program. Twenty-one shock tube firings were required to obtain eighteen valid shots and 150 valid pressure-time histories. Shot 8 was excluded because of a faulty cable connection, shot 11 due to an errant gauge, and shot 18 because of an irregularity in the bursting of the diaphragm.

B. Initial Pressures and Impulses

All pressure-time plots created with the Tektronix 4051 computer system are reproduced in Appendix B. Tables 2 through 5 enumerate the inital over-pressure and the impulse for 10 milliseconds. The tables present the shots in ascending pressure order. Table 2 presents results for a square wave with boundary conditions inapplicable. Table 3 presents results for a square wave with boundary conditions applicable. Table 4 presents results for a decaying wave with boundary conditions applicable and Table 5 presents the results for a decaying wave with boundary conditions inapplicable. The impulse for 10 msec is provided to expedite comparison of the loading between cases with and without boundary conditions applicable. Comparisons of the impulse for 10 msec may also be made with other generic shapes, specifically Reference 5.

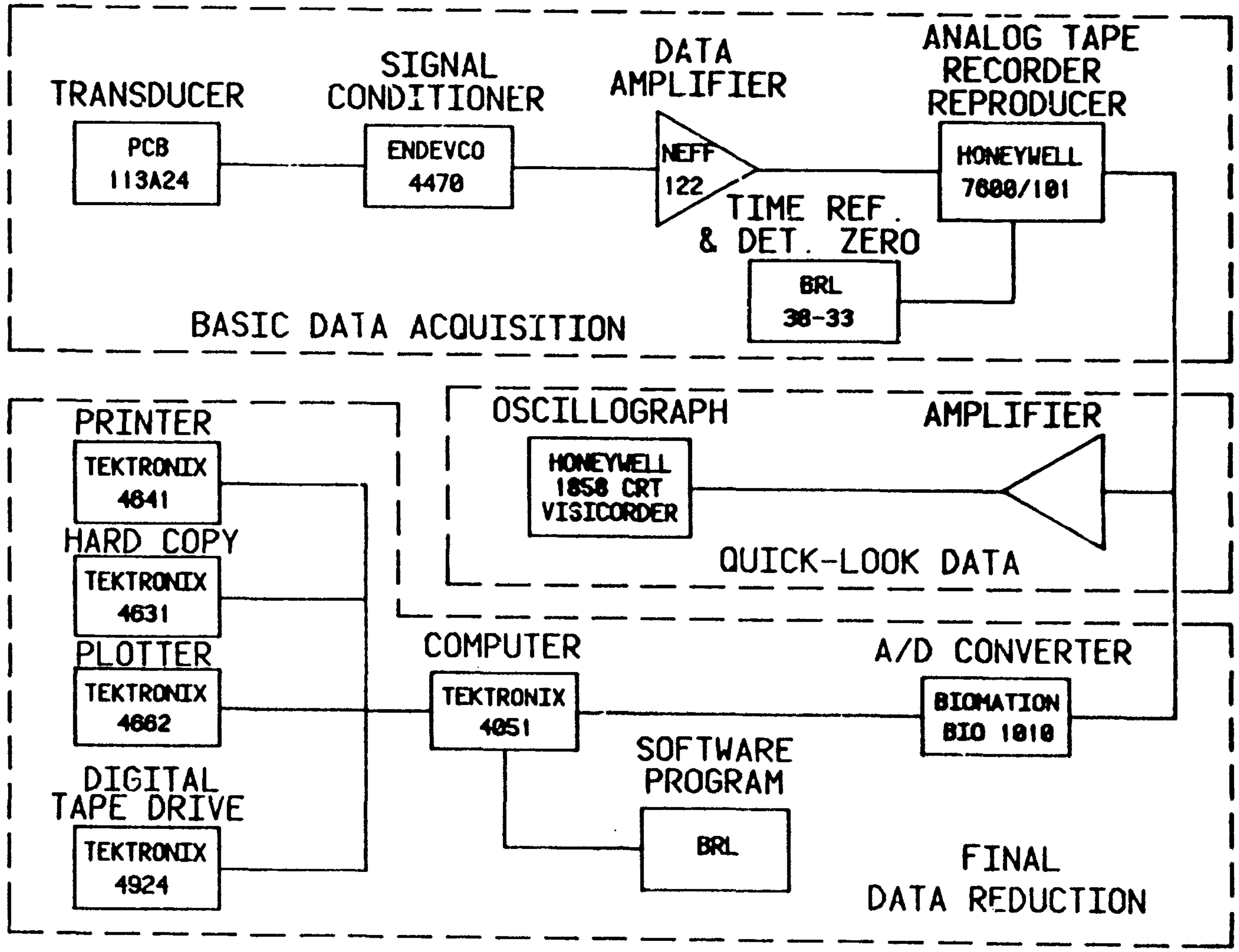


Figure 6. Schematic of the Data Acquisition and Reduction Method.

TABLE 1. SHOCK TUBE TEST SERIES

Shot*	Stations	Waveform	Model Configuration	Input Pressure (kPa)	Ambient Temperature (C^0)	Ambient Pressure (kPa)	Date
24-82-7	1 - 12	Square	No boundary conditions	33.9	18.93	104.2	12 Feb 82
24-82-9	1 - 12	Square	No boundary conditions	69.8	19.42	104.2	12 Feb 82
24-82-10	1 - 12	Square	No boundary conditions	101.4	19.72	104.0	12 Feb 82
24-82-12	11,12	Square	Free Field	102.9	15.70	102.2	16 Feb 82
24-82-13	11,12	Square	Free Field	69.9	15.71	102.2	16 Feb 82
24-82-14	11,12	Square	Free Field	35.1	15.78	102.2	16 Feb 82
24-82-15	1 - 12	Square	Boundary conditions	100.0	19.18	103.1	18 Feb 82
24-82-16	1 - 12	Square	Boundary conditions	69.5	19.30	103.1	18 Feb 82
24-82-17	1 - 12	Square	Boundary conditions	35.3	19.38	103.1	18 Feb 82
24-82-19	1 - 12	Decaying	Boundary conditions	33.9	19.12	102.3	19 Feb 82
24-82-20	1 - 12	Decaying	Boundary conditions	70.8	19.40	101.8	19 Feb 82
24-82-21	1 - 12	Decaying	Boundary conditions	104.5	19.61	101.7	19 Feb 82
24-82-22	1 - 12	Decaying	No boundary conditions	103.1	18.82	101.7	22 Feb 82

*24-inch tube, 1982, shot number.

TABLE 1. SHOCK TUBE TEST SERIES (Cont)

Shot*	Stations	Waveform	Model Configuration	Input Pressure (kPa)	Ambient Temperature (C°)	Ambient Pressure (kPa)	Date
24-82-23	1 - 12	Decaying	No boundary conditions	69.8	19.09	101.8	22 Feb 82
24-82-24	1 - 12	Decaying	No boundary conditions	34.0	18.94	101.8	22 Feb 82
24-82-25	11,12	Decaying	Free Field	33.2	19.59	102.4	23 Feb 82
24-82-26	11,12	Decaying	Free Field	68.0	20.17	102.1	23 Feb 82
24-82-27	11,12	Decaying	Free Field	99.9	20.15	102.1	23 Feb 82

*24-inch tube, 1982, shot number.

TABLE 2. TEST RESULTS: SQUARE WAVE, BOUNDARY CONDITIONS INAPPLICABLE

Shot	Transducer Location	Initial Overpressure (kPa)	Impulse for 10 msec (kPa-msec)
24-82-7	1	81.2	388.7
	2	77.5	372.3
	3	85.9	302.8
	4	85.6	323.3
	5	42.4	246.9
	6	42.0	285.9
	7	40.3	302.5
	8	16.7	300.6
	9	30.4	298.7
	10	31.0	298.4
	Side-on	33.9	352.1
	Stagnation	79.7	383.0
24-82-9	1	167.8	872.7
	2	140.2	710.6
	3	178.0	568.7
	4	181.7	621.2
	5	77.1	413.5
	6	75.2	495.1
	7	74.3	537.6
	8	25.9	555.2
	9	41.4	546.6
	10	50.0	552.0
	Side-on	69.8	773.9
	Stagnation	166.6	876.4
24-82-10	1	270.1	1414.4
	2	174.9	956.8
	3	291.1	813.8
	4	284.9	894.2
	5	115.3	412.3
	6	109.7	563.9
	7	109.2	658.1
	8	33.2	722.7
	9	32.3	716.0
	10	63.6	709.5
	Side-on	101.4	1090.4
	Stagnation	276.6	1403.0

TABLE 3. TEST RESULTS: SQUARE WAVE, BOUNDARY CONDITIONS APPLICABLE

Shot	Transducer Location	Initial Overpressure (kPa)	Impulse for 10 msec (kPa-msec)
24-82-17	1	83.2	361.4
	2	72.5	299.6
	3	86.0	316.8
	4	87.2	331.6
	5	42.2	276.2
	6	40.5	277.8
	7	39.7	301.7
	8	16.4	290.9
	9	29.1	313.5
	10	30.4	303.2
	Side-on	35.3	351.6
	Stagnation	81.9	386.3
24-82-16	1	173.3	790.9
	2	143.9	635.7
	3	183.5	614.4
	4	183.3	666.8
	5	78.5	445.6
	6	77.2	484.4
	7	75.7	557.3
	8	26.2	525.8
	9	40.1	570.7
	10	50.4	548.1
	Side-on	69.5	717.2
	Stagnation	167.3	867.5
24-82-15	1	273.2	1221.3
	2	168.3	962.0
	3	282.5	932.7
	4	293.5	1024.1
	5	111.0	535.2
	6	112.1	613.9
	7	106.8	730.0
	8	34.1	709.2
	9	32.9	767.7
	10	63.8	735.4
	Side-on	100.0	1057.6
	Stagnation	268.2	1371.1

TABLE 4. TEST RESULTS: DECAYING WAVE, BOUNDARY CONDITIONS APPLICABLE

Shot	Transducer Location	Initial Overpressure (kPa)	Impulse for 10 msec (kPa-msec)
24-83-19	1	77.7	245.5
	2	69.7	220.1
	3	82.6	223.4
	4	82.3	227.9
	5	40.7	197.8
	6	39.1	199.5
	7	38.0	217.9
	8	15.9	195.8
	9	27.8	223.3
	10	29.4	215.1
	Side-on	33.9	243.6
	Stagnation	74.5	262.8
24-82-20	1	178.8	608.6
	2	144.5	555.5
	3	186.8	504.6
	4	186.4	533.9
	5	78.6	382.3
	6	78.5	409.3
	7	76.6	462.1
	8	26.5	418.5
	9	39.9	469.6
	10	50.5	451.8
	Side-on	70.8	565.6
	Stagnation	175.3	666.5
24-82-21	1	292.2	985.0
	2	176.2	766.6
	3	302.7	768.3
	4	309.9	831.8
	5	116.5	493.8
	6	115.2	550.9
	7	111.7	652.0
	8	34.9	596.3
	9	34.0	681.6
	10	64.4	614.7
	Side-on	104.5	879.2
	Stagnation	280.1	1098.8

TEST 5. TEST RESULTS: DECAYING WAVE, BOUNDARY CONDITIONS INAPPLICABLE

Shot	Transducer Location	Initial Overpressure (kPa)	Impulse for 10 msec (kPa-msec)
24-82-24	1	78.7	246.8
	2	70.5	236.7
	3	81.7	216.0
	4	80.5	224.1
	5	39.9	175.3
	6	39.4	200.1
	7	38.1	211.4
	8	15.3	207.6
	9	28.4	208.2
	10	29.1	206.7
	Side-on	34.0	247.2
	Stagnation	76.4	264.7
24-82-23	1	175.0	624.7
	2	142.4	514.9
	3	186.6	424.3
	4	186.8	460.5
	5	78.3	334.4
	6	76.8	404.2
	7	76.0	453.3
	8	24.7	430.8
	9	40.3	415.0
	10	50.1	436.0
	Side-on	69.8	580.0
	Stagnation	166.5	676.9
24-82-22	1	281.1	911.0
	2	169.7	704.6
	3	301.1	627.3
	4	306.5	707.5
	5	119.4	374.0
	6	113.9	497.5
	7	111.8	603.8
	8	32.5	575.1
	9	32.4	570.4
	10	63.7	589.2
	Side-on	103.1	911.5
	Stagnation	289.1	1153.5

C. Description of Typical Pressure-Time Records

Figure 7 displays the pressure-time histories[*,7] for Shot 24-82-16. These results are for a square wave with boundary conditions applicable; the input pressure is 69.5 kPa.

Station 1, located on the front of the truck, is normal to the shock flow. This pressure-time record shows an initial rise to a reflected pressure peak which decays quickly due to successive rarefaction waves. The first rarefaction emanates from the front edge of the truck. The second rarefaction, which quickly follows, is a reflection of the first from the shock tube wall. A peak following these rarefactions originates from a reflected wave off the front shelter wall. Following rarefactions reduce the pressure to stagnation pressure level. The peak which occurs at 2.9 msec is a reflection from the opposite shock tube wall. Other lesser peaks happening at 2.9-msec intervals are caused by similar interactions. Disregard these peaks which do not correspond to a loading phenomenon experienced during a real blast event. Similar artificial peaks are apparent at all other stations on the model.

Station 2, located on the truck hood, is inclined 5 degrees to the shock flow. The record shows an initial rise to 1.15 times the input pressure followed rapidly by a spike due to reflection from the front of the shelter. Station 3 displays similar features. Here the reflection occurs sooner and is more pronounced because this station, located in the driver area, is closer to the shelter reflecting wall.

Station 4, located on the front of the shelter, shows an initial rise to reflected pressure that rapidly decays because of rarefactions to stagnation pressure level. These rarefactions emanate from the front edge of the shelter and from the driver area, which acts as a reflected surface for incoming rarefactions.

The maximum pressures occur at Stations 3(183.5 kPa) and 4(183.3 kPa). Large pressures also occur at Stations 1(173.3 kPa) and 2(143.9 kPa). The maximum impulse occurs at Station 1. Stations 4, 2, and 3 also experience large impulsive loading. Refer to Table 3.

Stations 5 to 7 on the shelter roof and 8 to 10 on the back of the shelter are subject to vortices. The blast loading characteristics are substantively different from Stations 1 to 4.

**Analytical assistance provided by private communication with Brian Bertrand and George Coulter, BRL, November 1982.*

[7] George A. Coulter, "Shock Tube Photography," BRL Ordnance Dept., 1951.

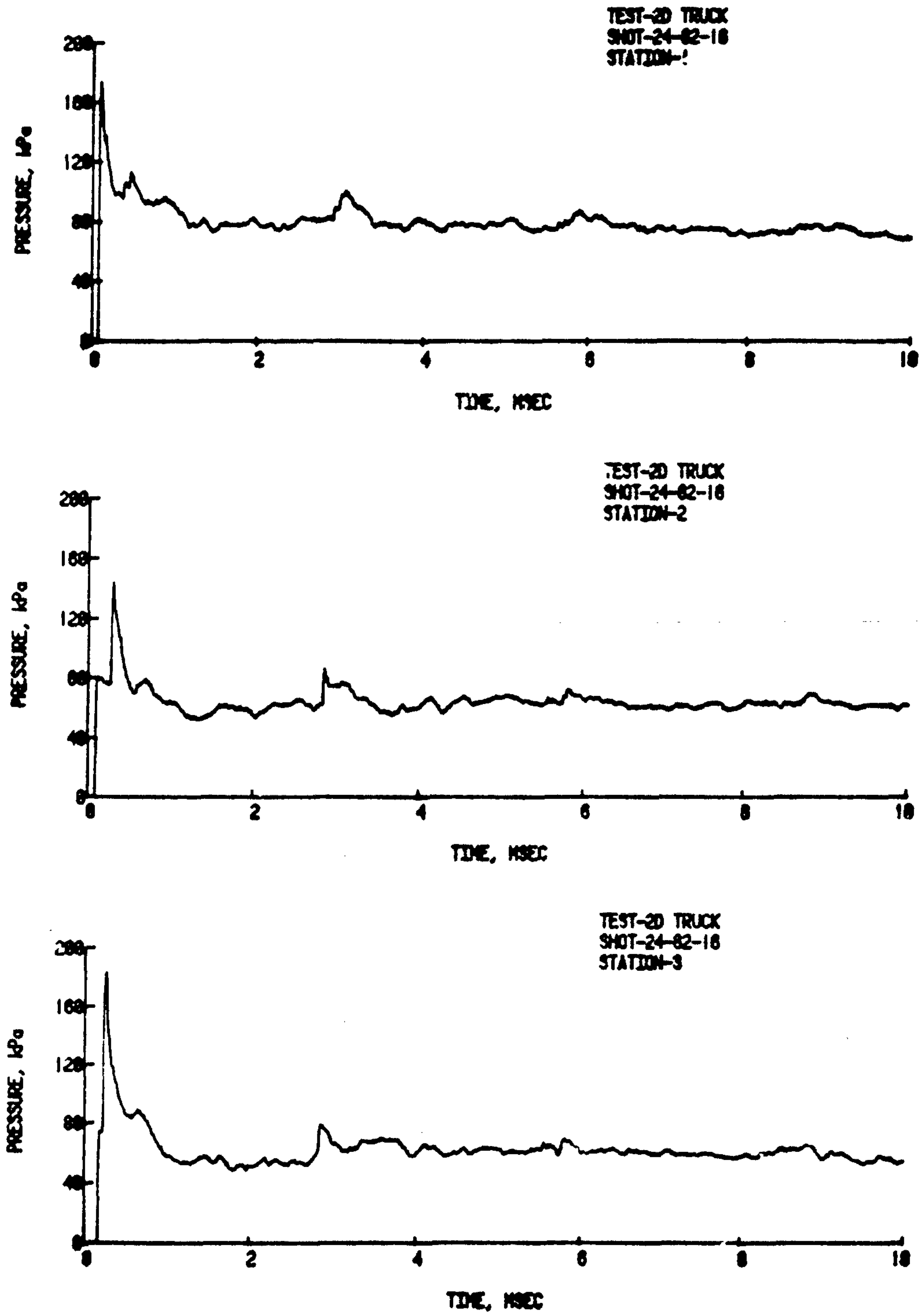


Figure 7. Pressure-Time Records for Shot 24-82-16, Input Pressure 69.5 kPa, Square Wave, Boundary Conditions Applicable.

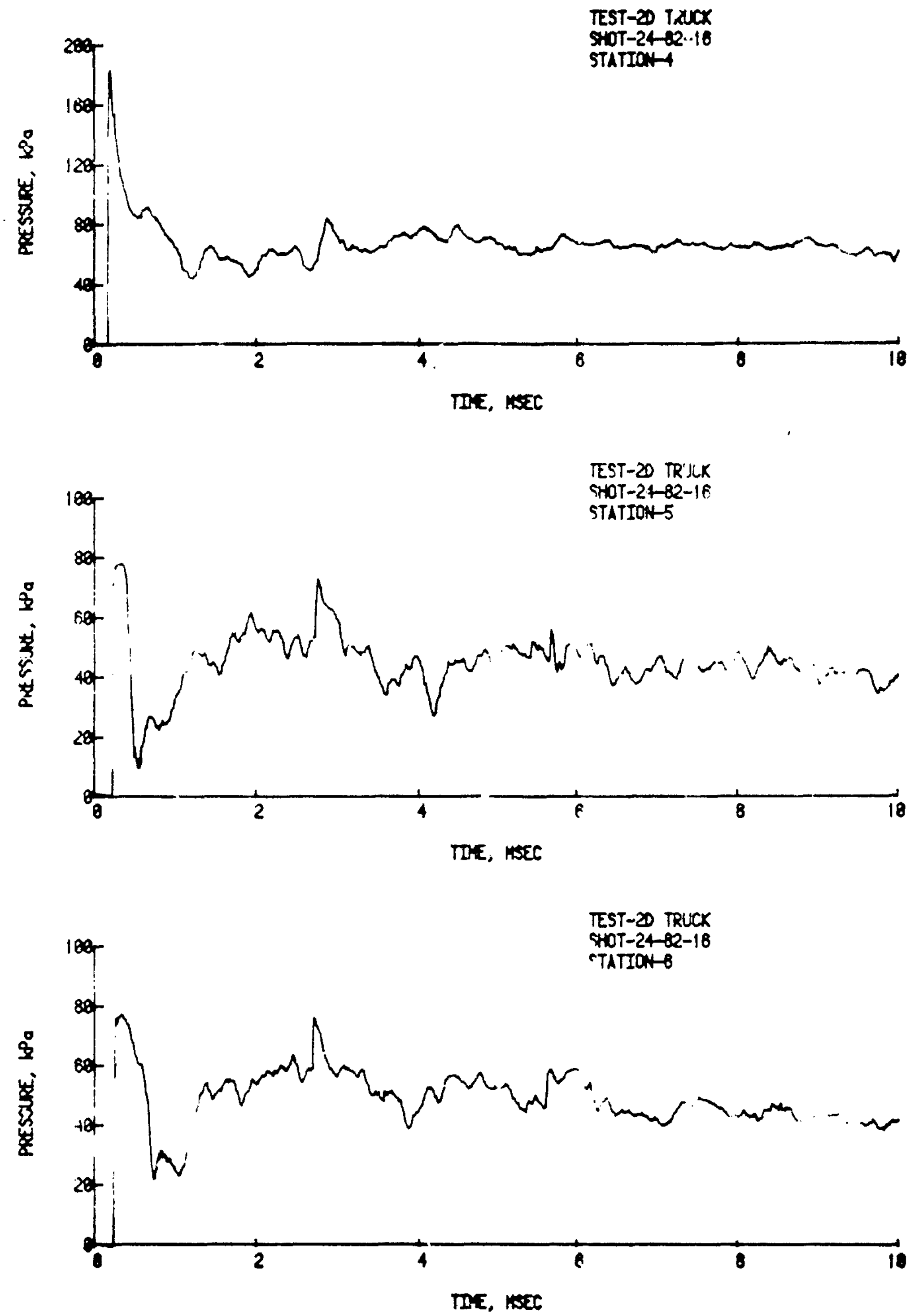


Figure 7. Pressure-Time Records for Shot 24-82-16, Input Pressure 69.5 kPa, Square Wave, Boundary Conditions Applicable. (Cont)

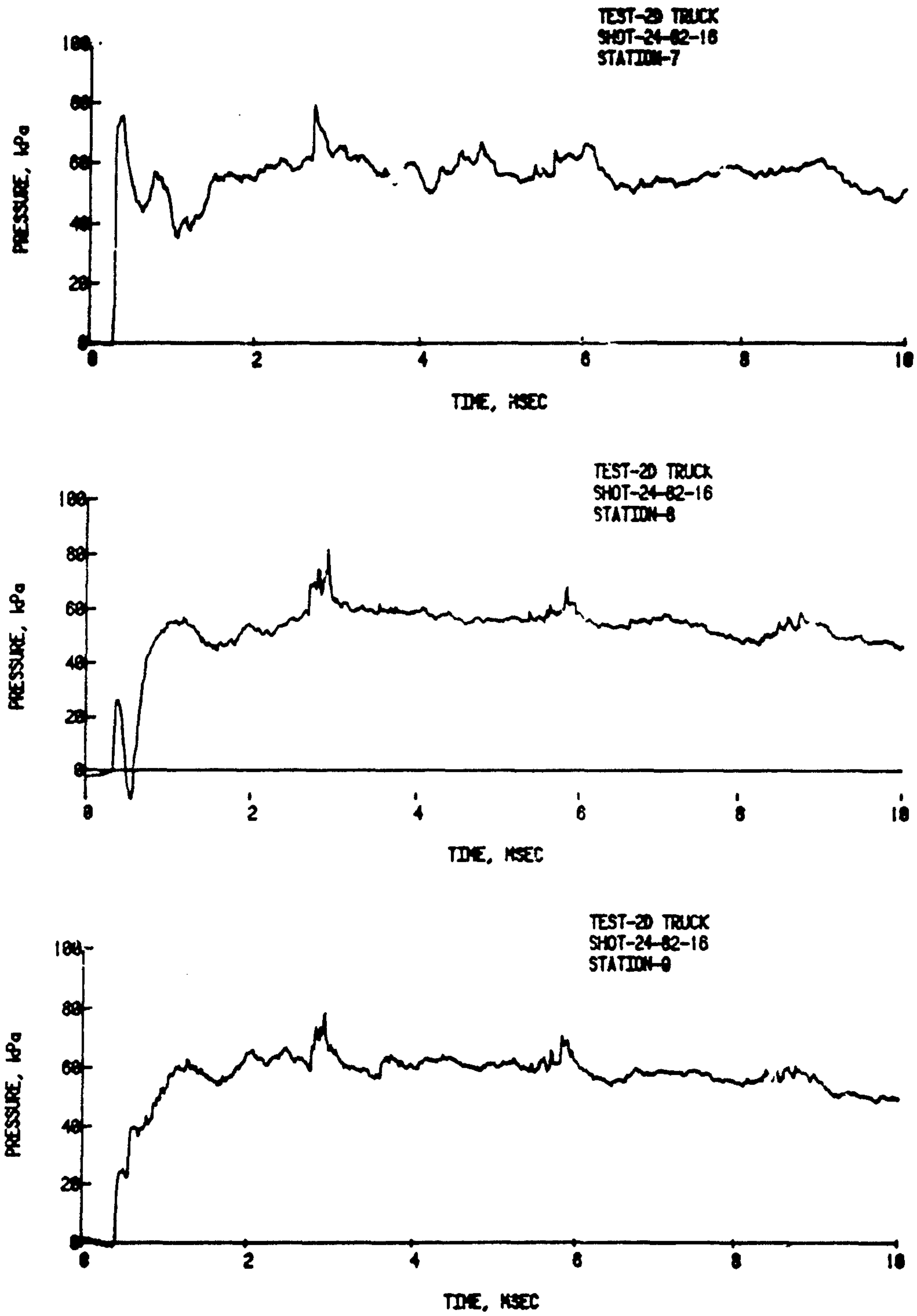
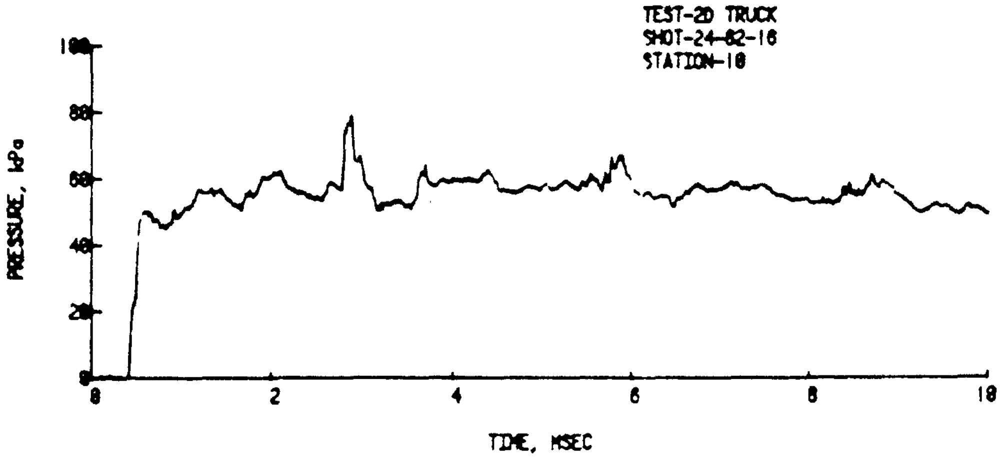
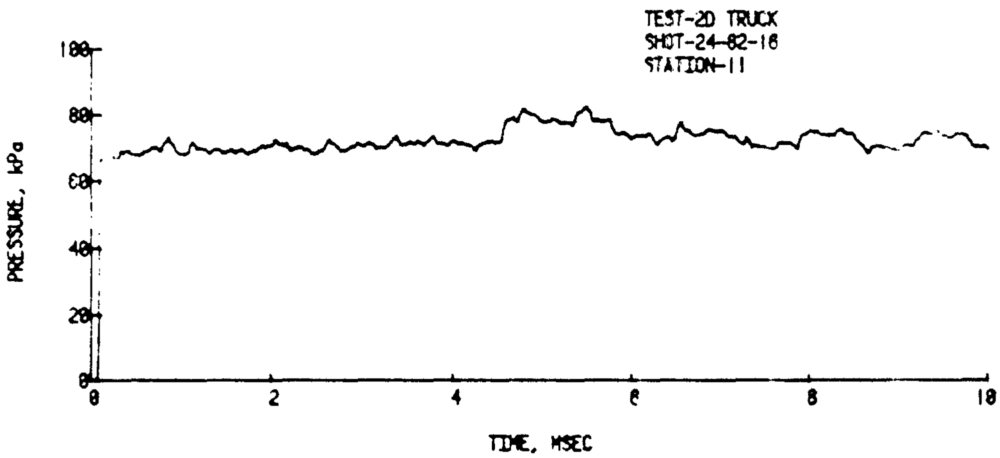


Figure 7. Pressure-Time Records for Shot 24-82-16, Input Pressure 69.5 kPa, Square Wave, Boundary Conditions Applicable. (Cont)





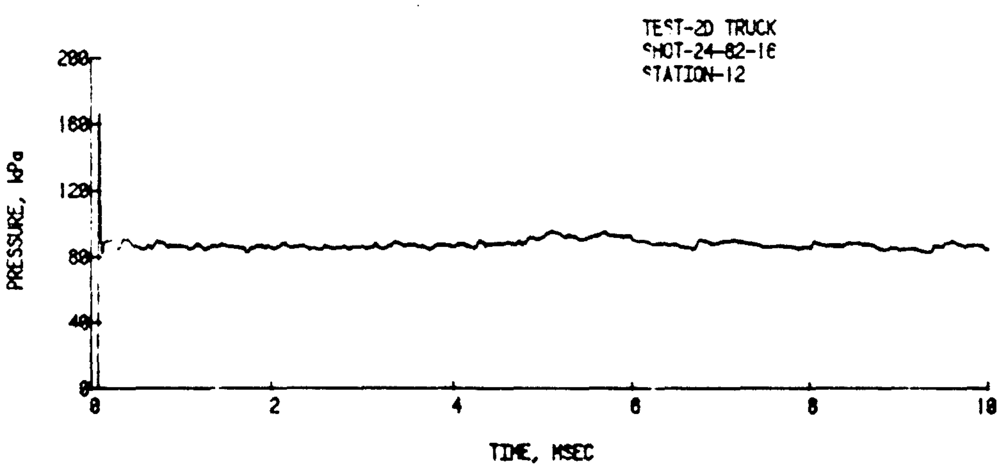


Figure 7. Pressure-Time Records for Shot 24-82-16, Input Pressure 69.5 kPa, Square Wave, Boundary Conditions Applicable. (Cont)

Station 5, closest to the front of the shelter, exhibits an initial rise to 78.5 kPa followed by a sharp decay to 9.8 kPa which is vortex induced. This vortex forms at the front edge of the roof where it is most pronounced and decreases in strength as it moves toward Stations 6 and 7. After the vortex passes Station 5, the pressure increases momentarily to 26.9 kPa and again decays to 22.4 kPa. The second decay is caused by a rarefaction wave originating at the back edge of the shelter. The pressure then increases to approximately 50 kPa in the drag loading phase.

Station 6 shows an initial rise to 77.2 kPa, vortex decay to 22.0 kPa, a small local peak, rarefaction decay to 22.9 kPa, and an increase to about 50 kPa in the drag phase. Station 7 displays an initial rise to 75.7 kPa. The rarefaction from the back of the shelter reduces the pressure to 43.9 kPa. The pressure rises to 57.2 kPa before arrival of the weakened vortex reduces the pressure to 35.4. The pressure increases to about 55 kPa in the drag phase.

Stations 8, 9, and 10 are on the back of the shelter from top to bottom, respectively. A vortex forms on the back top edge of the shelter and moves downward. Station 8 shows a strong vortex superposed on a dispersed expansion wave. Initially the pressure climbs to 26.2 kPa. The vortex reduces the pressure to -10.8 kPa, below ambient pressure. This is followed quickly by a reflected wave from the shock tube wall. Pressure increases and stabilizes at 60 kPa during the drag phase.

Station 9 shows arrival of the vortex and reflection wave virtually simultaneously. Station 10 shows the reflection before any vortically induced decay.

Finally, Stations 11 and 12 are upstream side-on and stagnation gauges mounted in the shock tube wall. Station 11 exhibits 69.5 kPa input pressure and Station 12 shows a 167.3 kPa initial pressure spike and instantaneous decay to stagnation pressure, about 89 kPa. A small increase in pressure at 4.5 msec observed at Station 11 is an upstream reflection from the model.

IV. DISCUSSION

A. Comparison of Cases

A brief description of the salient features for Shot 24-82-16 was presented in the results section. This flattop wave of 69.5 kPa input pressure with boundary conditions applicable displays a waveform that is representative of the entire two-dimensional truck study. The features of this waveform are remarkably similar at all pressure levels, for both model configurations for a flattop or decaying wave. The reader may wish to examine pressure-time records in Appendix B to verify this generalization.

1. Effects of Increasing Pressure Level

The wave profiles are similar as the input pressure is increased. The strength of the vortices originating on the front edge of the shelter hood and top edge of the back of the shelter is proportional to the input pressure. These vortices are most pronounced at Stations 5 and 8; refer to Figure 8 showing the increase in vortical decay at Station 8 as a function of input pressure for Shots 24-82-7, 9, and 10, flattop waves with boundary conditions inapplicable. The peak which occurs at one msec is a reflection off the shock tube wall. Similar periodic peaks occur for all shots with the model in the center of the tube. Increasing vortical decay as a function of input pressure may be generalized to include other cases, a flattop wave with boundary conditions and all decaying waves in this study.

2. Effects of Boundary Conditions

Inspection of the pressure-time records suggests that the effects of the shock tube wall boundary is negligible. The records for Configuration One (Figures 1 and 2) with boundary conditions applicable and Configuration Two (Figures 3 and 4) without wall boundary conditions are quite similar.

Stations 8, 9, and 10 are of particular interest when comparing the two model configurations. Figure 9 shows the pressure-time histories for Shot 24-82-9, Stations 8, 9, and 10, a 69.8 kPa flattop wave with boundary conditions inapplicable. These plots may be compared with Figure 7, Stations 8, 9, and 10. In each case, initially a weakened expansion wave rises to less than side-on pressure and is followed by a reflected pressure wave. For Configuration One, i.e., boundary conditions in effect, the reflected wave emanates from the shock tube wall near Station 10. For Configuration Two, without boundary conditions, the reflected wave is due to the collision of the two waves travelling around the back of the symmetric model. The effects are virtually identical.

The primary differences between the cases where boundary conditions are applicable and where boundary conditions are inapplicable are the magnitude and arrival time of the reflected wave from the shock tube wall. This is determined by the location of the model with respect to the shock tube wall rather than boundary layer effects.

3. Decaying Waves

The preceding presentation of results and analysis applies equally to the decaying wave cases. Except for exponential decay these wave forms are analogous to the flattop cases. Further discussion of the decaying wave portion of this shock tube study would be redundant.

B. Experimental-Computational Comparisons

A specific design of this shock tube program was to provide experimental data for comparison with the NASA-Ames two-dimensional hydrodynamic code.

Mark has completed an intensive computational study of the truck/shelter shape using the NASA-Ames 2-D code on the BRL Cyber computer system. See Reference 4.

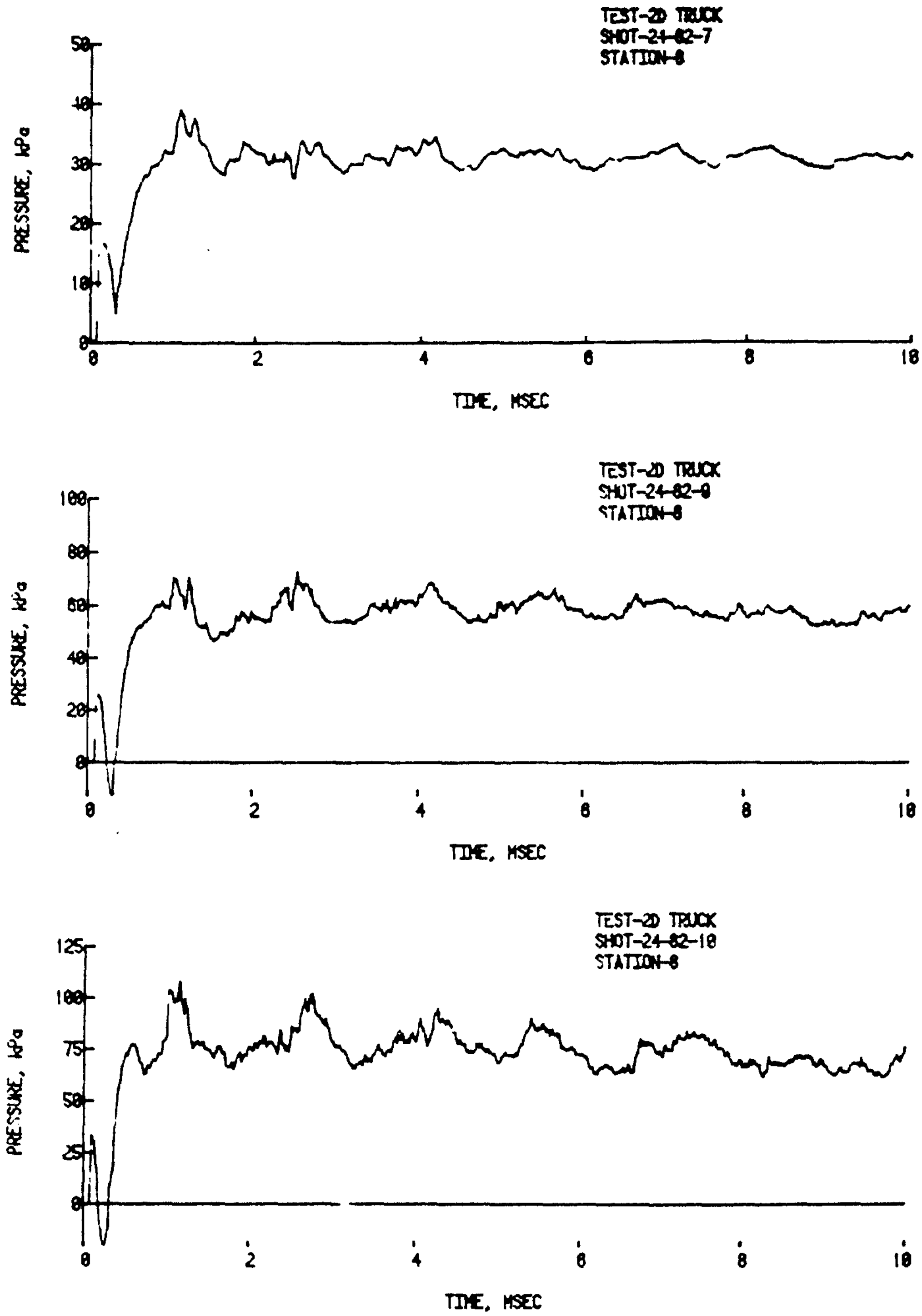


Figure 8. Pressure-Time Records for Shots 24-82-7, 9, and 10, Station 8, Square Wave, Boundary Conditions Inapplicable.

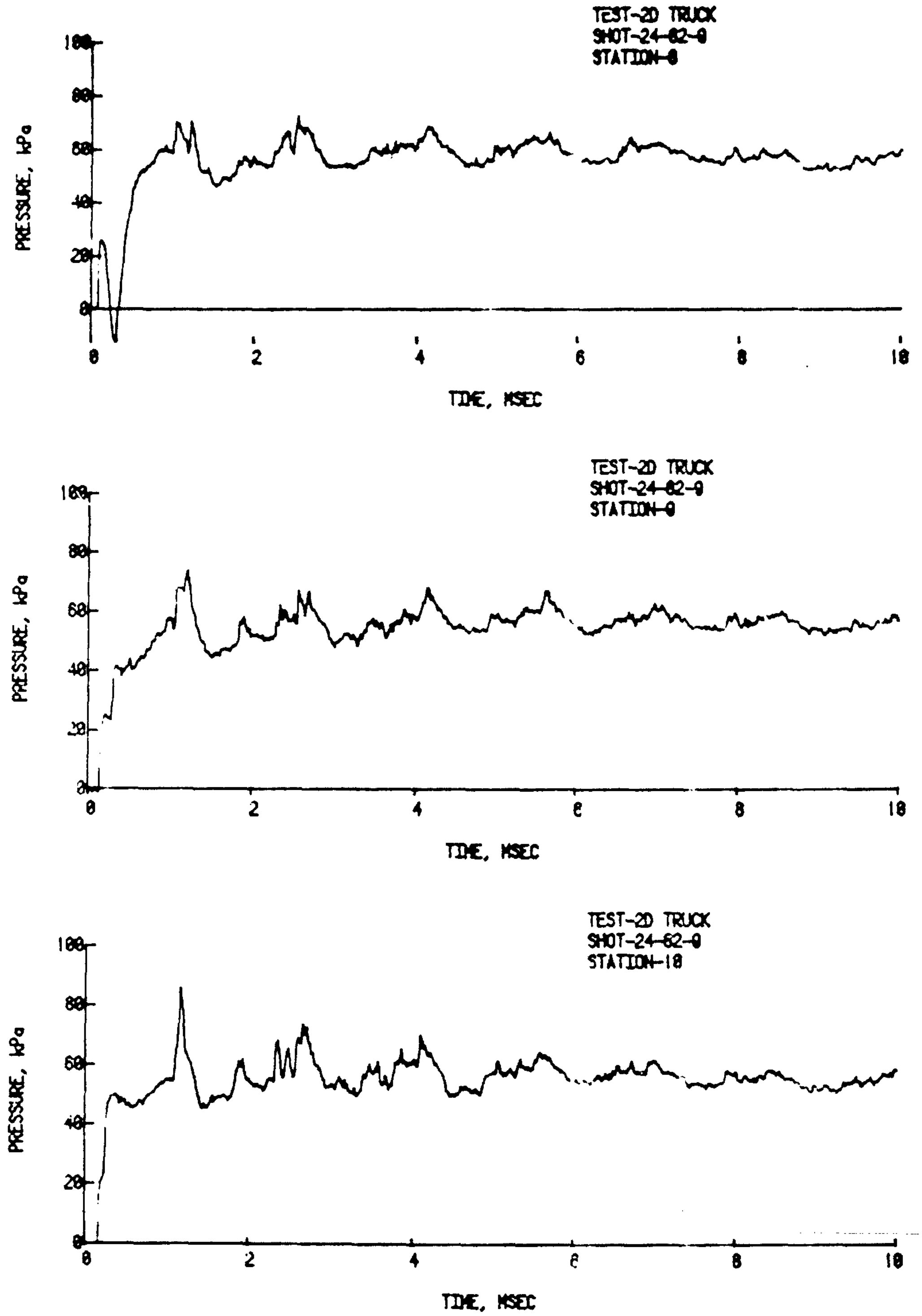


Figure 9. Pressure-Time Records for Shot 24-82-9, Stations 8, 9, 10, 69.8 kPa, Square Wave, Boundary Conditions Inapplicable.

Direct experimental-computational comparison was facilitated by the computer program listed in Appendix C. This provides a method for transferring experimental data to the mainframe computer which is capable of running large computer codes.

Figure 10 shows a comparison of computer code results with experimental Shot 24-82-7, 33.9 kPa, boundary conditions inapplicable. This comparison shows that the truck/shelter model provides credible data for a computational model. Note that the computational example does not display periodic reflection from the shock tube wall. The pressure obtained computationally for the drag phase is approximately equal to the average pressure achieved experimentally.

V. CONCLUSIONS

The pressure-time histories provide waveform profiles that manifest the blast loading on a real truck/shelter combination when the simplifying assumptions used to create the model are taken into account. The pressure levels at each station, reflected pressure peaks, and vortices obtained experimentally appear to be reasonable values.

Similarity with the NASA-Ames two-dimensional hydrocode shows that the model provides adequate data for computational comparison. Conversely, one can be confident in computational results when such observational correlation is obtained.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to the following individuals who assisted significantly in this project. Richard Thane operated the shock tube and displayed great skill in improvising the model to obtain the best results. George Watson diligently recorded and digitized the data. Charles Fisher assisted with electronics and computer hardware problems and helped to create the 4051-to-Cyber data transfer program. The author particulary wishes to acknowledge the aid of George Coulter whose expertise contributed to the successful completion of this project.

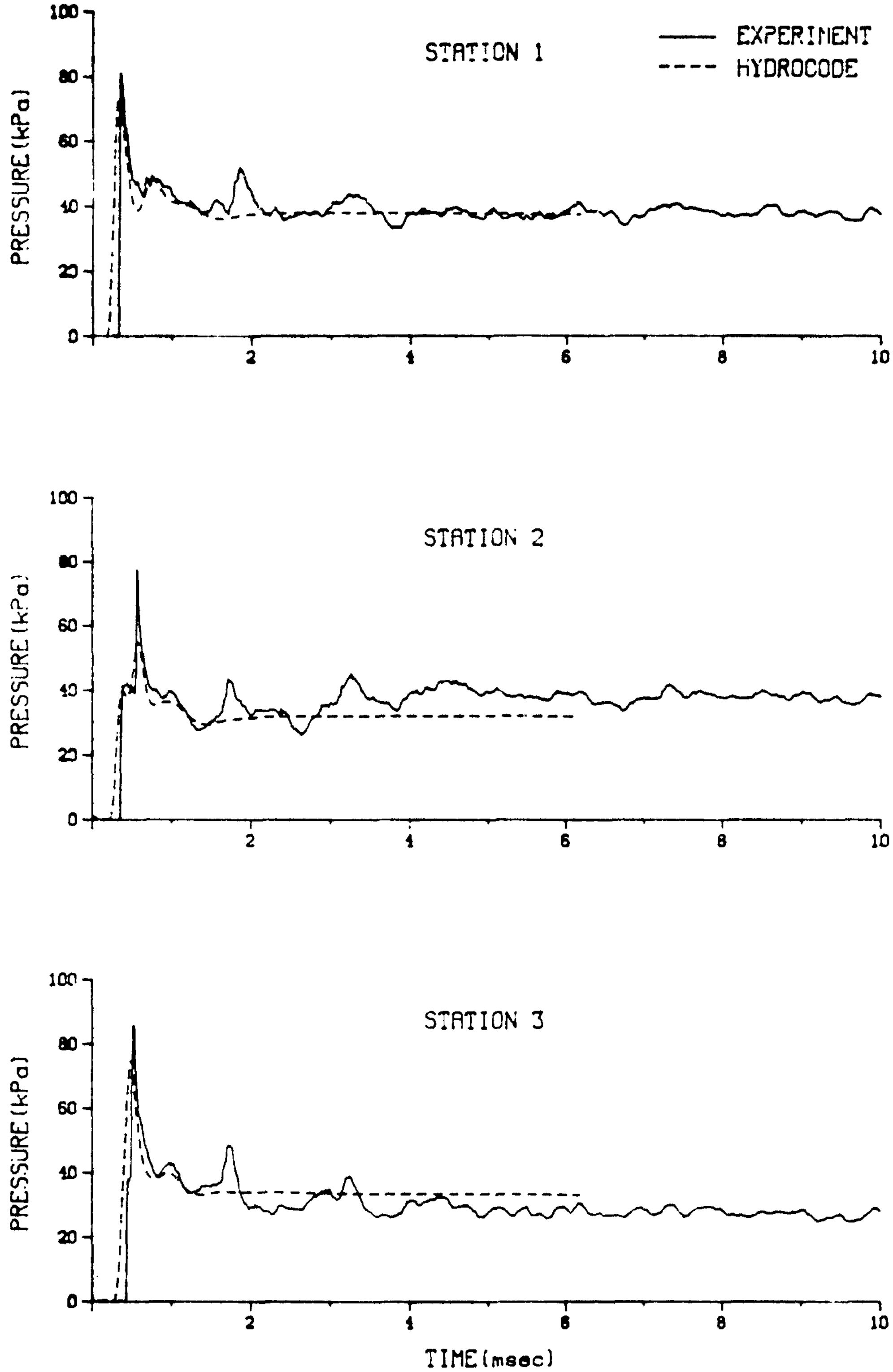


Figure 10. Comparison of Experimental Shot 24-82-7, 33.9 kPa, Boundary Conditions Inapplicable, with Results from the NASA-Ames Two-Dimensional Hydrocode.

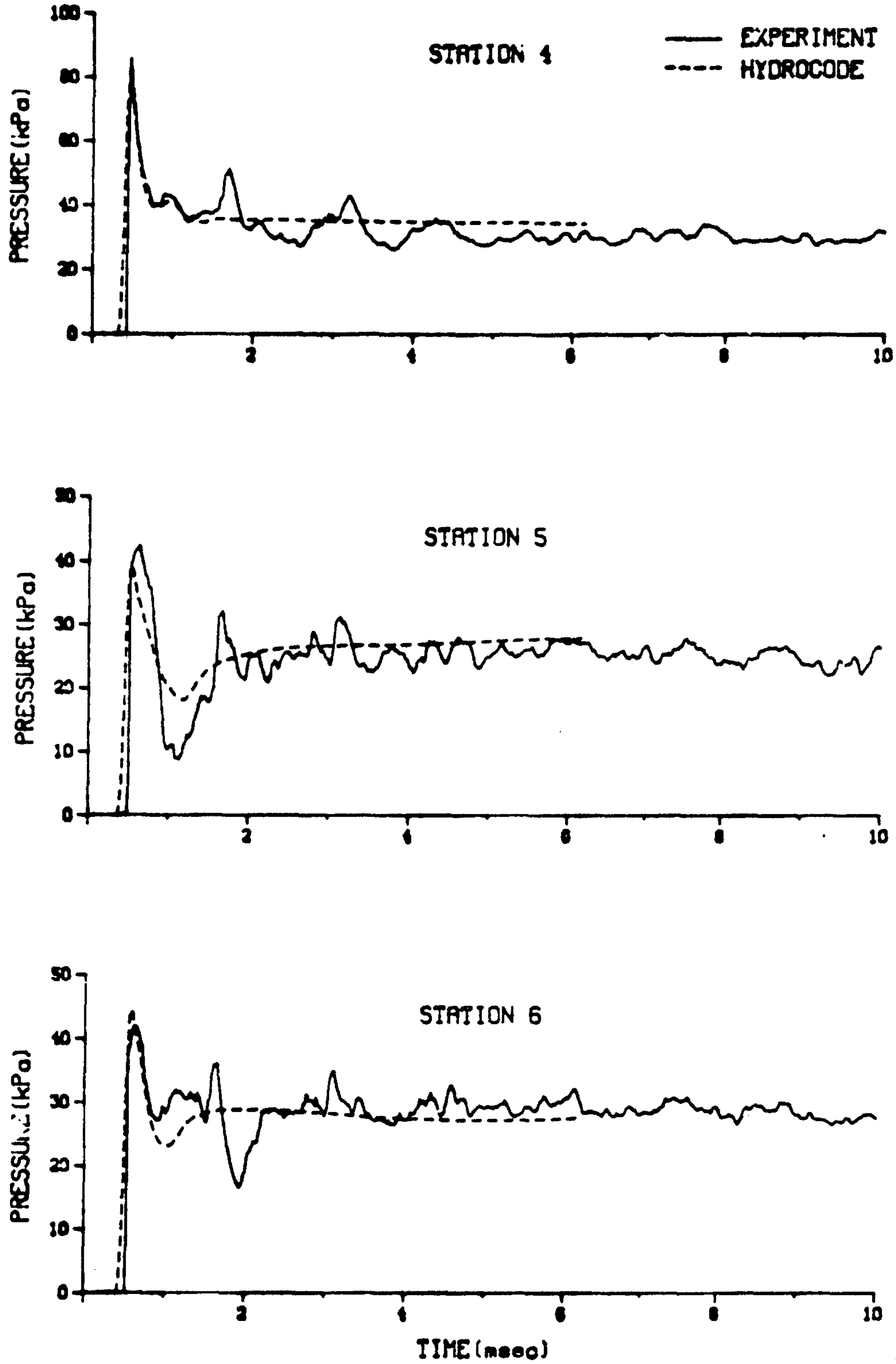


Figure 10. Comparison of Experimental Shot 24-82-7, 33.9 kPa, Boundary Conditions Inapplicable, with Results from the NASA-Ames Two-Dimensional Hydrocode. (Cont)

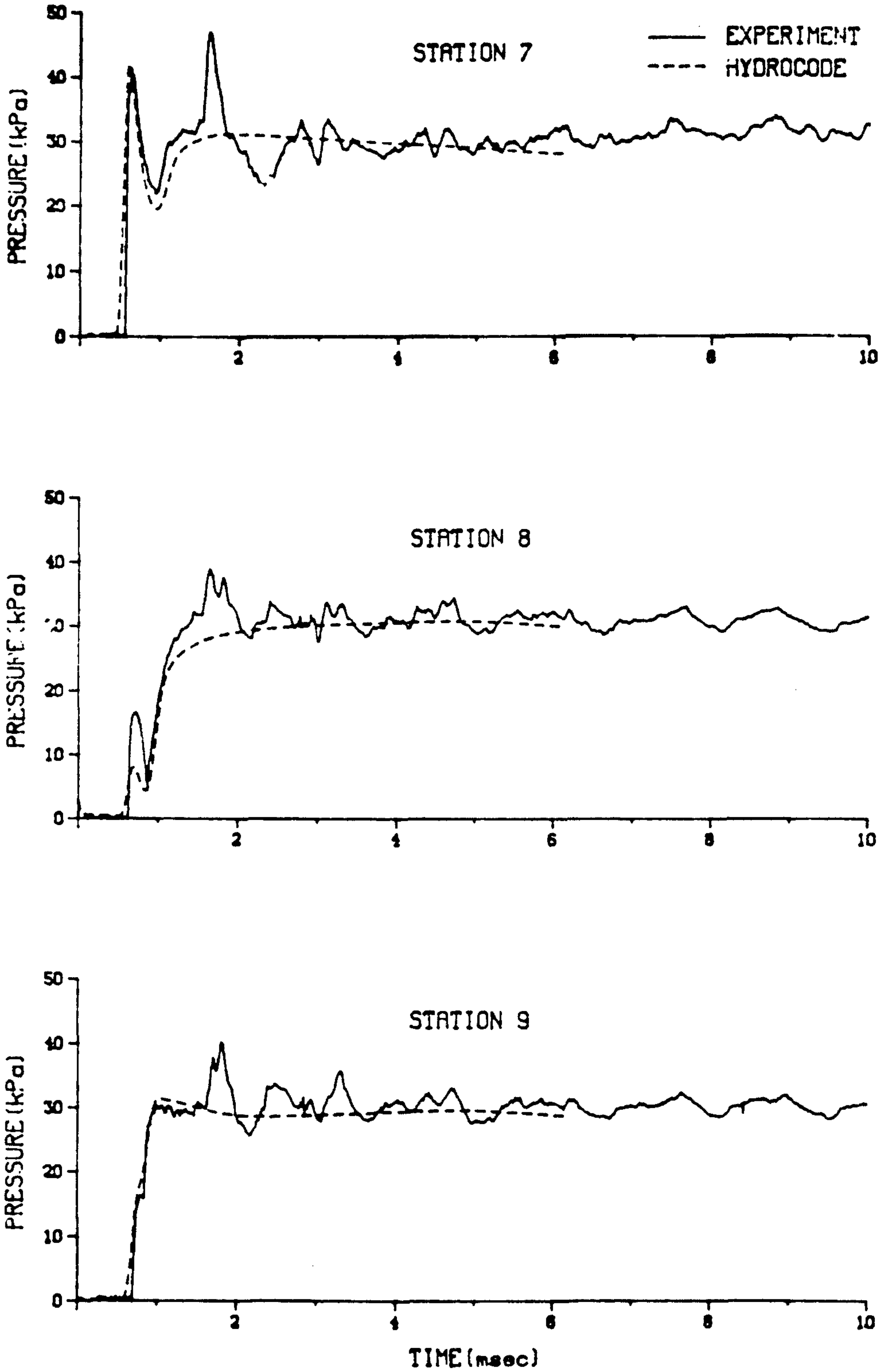


Figure 10. Comparison of Experimental Shot 24-82-7, 33.9 kPa, Boundary Conditions Inapplicable, with Results from the NASA-Ames Two-Dimensional Hydrocode. (Cont)

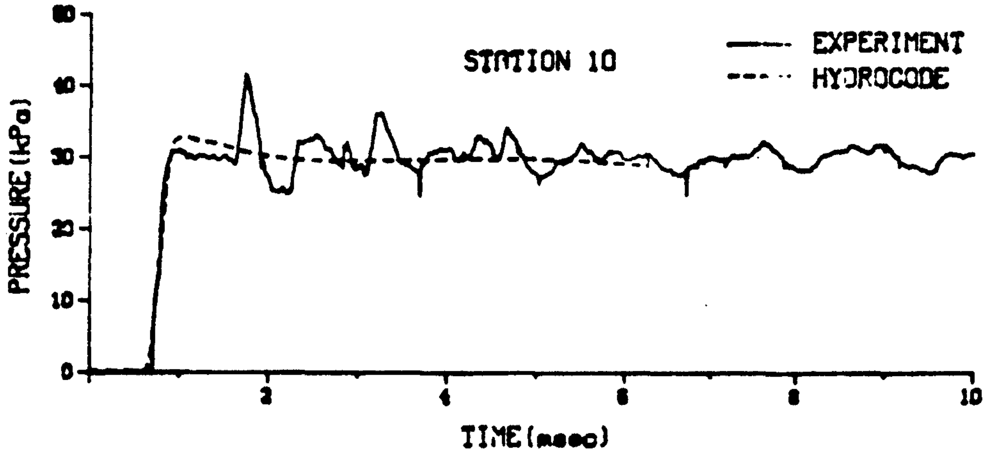


Figure 10. Comparison of Experimental Shot 24-82-7, 33.9 kPa, Boundary Conditions Inapplicable, with results from the NASA-Ames Two-Dimensional Hydrocode. (Cont)

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1. W. J. Schuman, Jr. and W. D. Allison, "Retrofit Hardening of Electronics Shelters with Composite Panels," Fourth Conference on Fibrous Composites in Structural Design, November 1978.

2. William J. Schuman, Jr., Garabed Zartarian, Raffi P. Yeghiayan, and W. Don Allison, "C^3 Shelter Designs for the Tactical Battlefield," Army Symposium on Solid Mechanics, 1980, Designing for Extremes: Environ, Loading, and Structural Behavior, October 1980.

3. George A. Coulter and Brian P. Bertrand, "BRL Shock Tube Facility for the Simulation of Air Blast Effects," BRL Memo Report No. 1685, August 1965 (AD 475669).

4. Andrew Mark and Paul Kutler, "Computation of Shock Wave/Target Interaction," AIAA 21st Aerospace Sciences Meeting, January 1983.

5. George A. Coulter, "Blast Wave Loading of a Two-Dimensional Circular Cylinder," BRL Memo Report No. ARBRL-MR-03207, November 1982 (AD A121600).

6. Ethridge, Lottero, Wortman, and Bertrand, "Flow Blockage and Its Effects on Minimum Incident Overpressure for Overturning Vehicles in a Large Blast Simulator," Seventh International Symposium on Military Applications of Blast Simulations, 1981.

7. George A. Coulter, "Shock Tube Photography," BRL Ordnance Dept., 1951.

APPENDIX A

SHOP DRAWINGS OF TRUCK/SHELTER MODEL

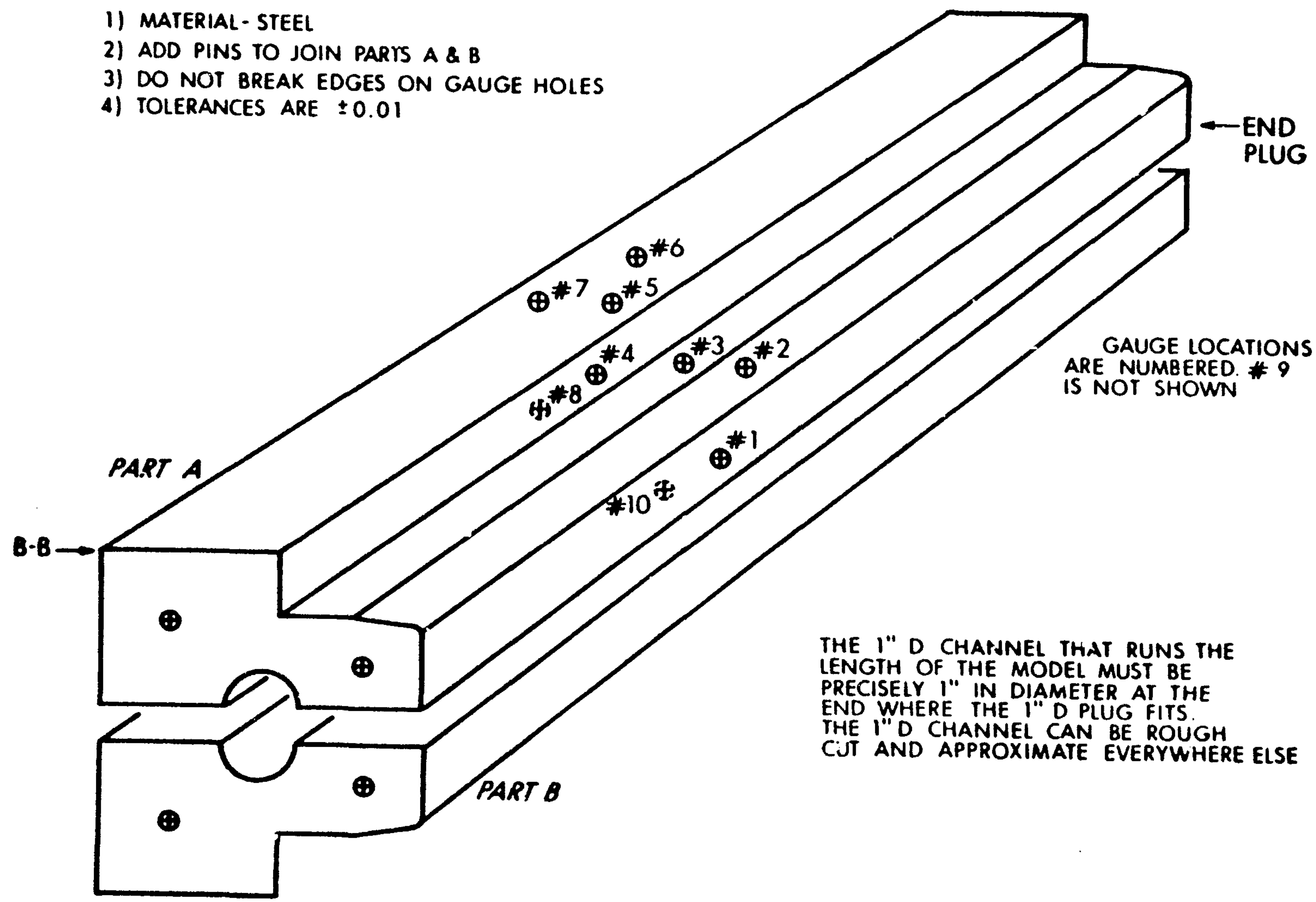


Figure A-1. Sketch of the Truck/Shelter and Mirror Image.

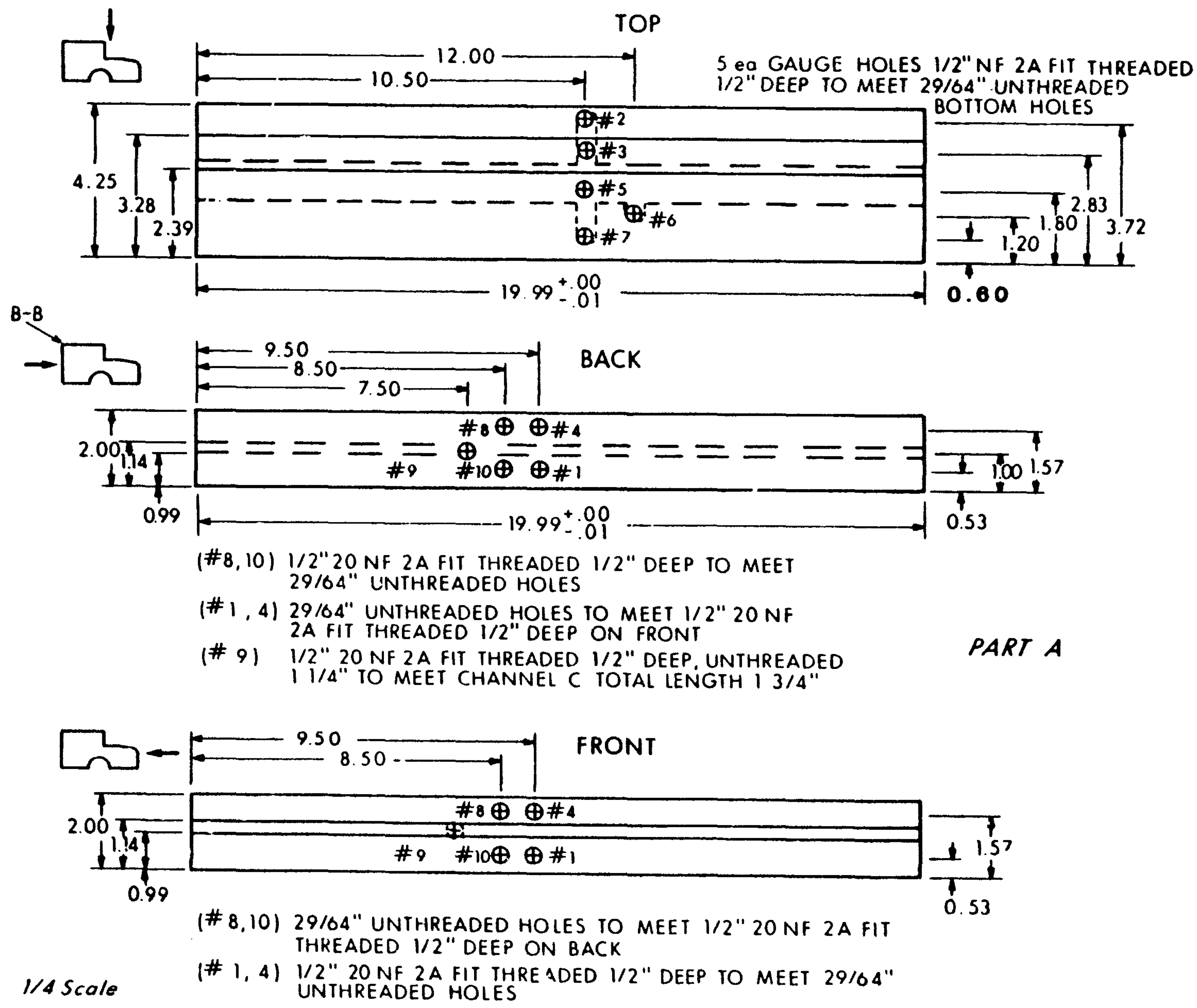
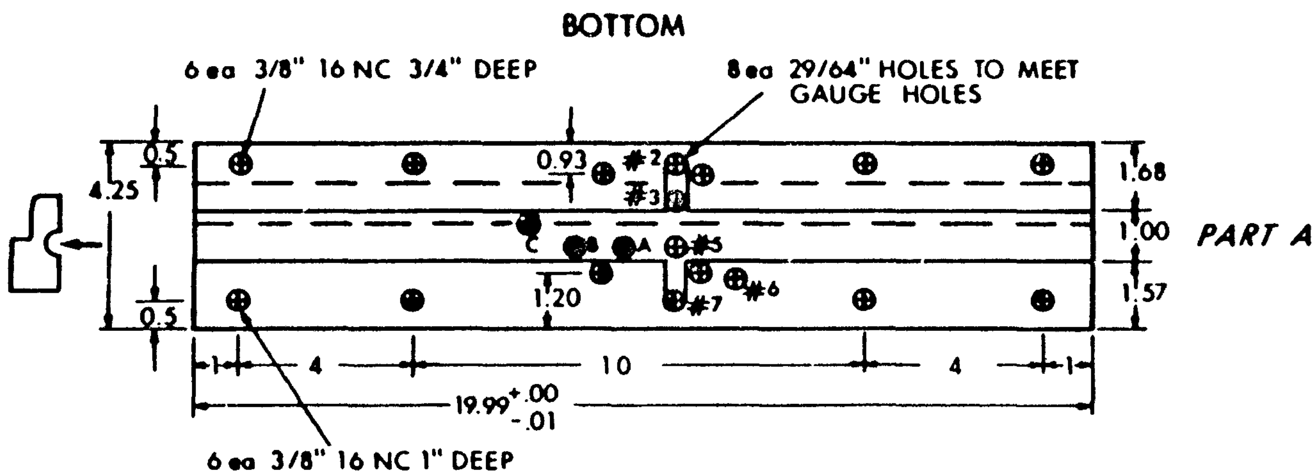


Figure A-2. Part A of the Model: Top, Back and Front Views.



MAKE 1/4" R GROOVE TO CONNECT GAUGE HOLES #2,3,6 & 7 TO MAIN 1/2" R CHANNEL.
THE 4 CENTRAL BOLT HOLES ARE ON 3" B. C. 90° APART. THE CENTER IS AT 10", 2.26".

DRILL CHANNEL A AT 50° TO MEET GAUGE HOLE #4.

DRILL CHANNEL B AT 90° TO MEET GAUGE HOLE #8.

DRILL CHANNEL C AT 65° TO MEET GAUGE HOLE #9.

GAUGES	LOCATION X	LOCATION Y
#7	10.5	0.60
#5	10.5	1.80
#3	10.5	2.83
#2	10.5	3.72
#6	12.0	1.20
(# 1 & 4)A	9.5	1.81
(#10 & 8)B	8.5	1.81
(# 9)C	7.5	2.32

1/4 Scale

Figure A-3. Part A, Bottom View.

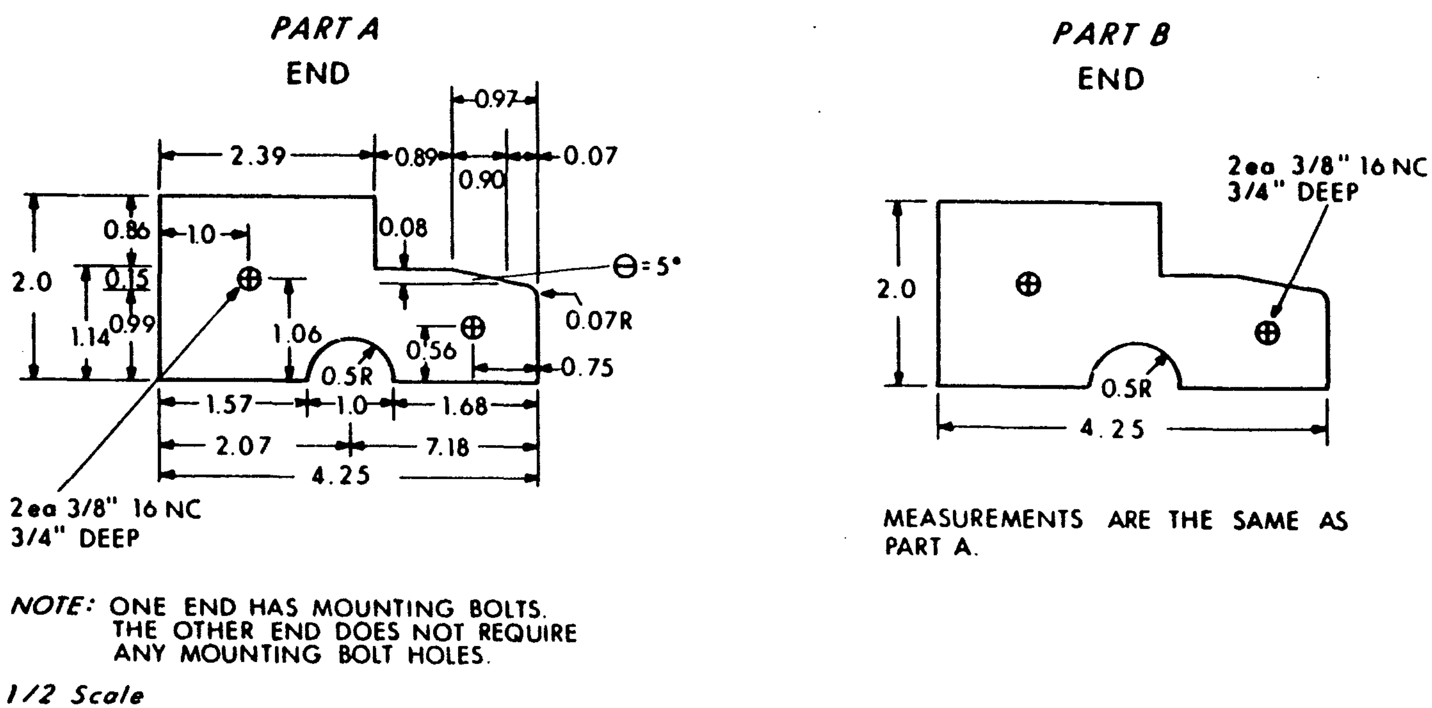
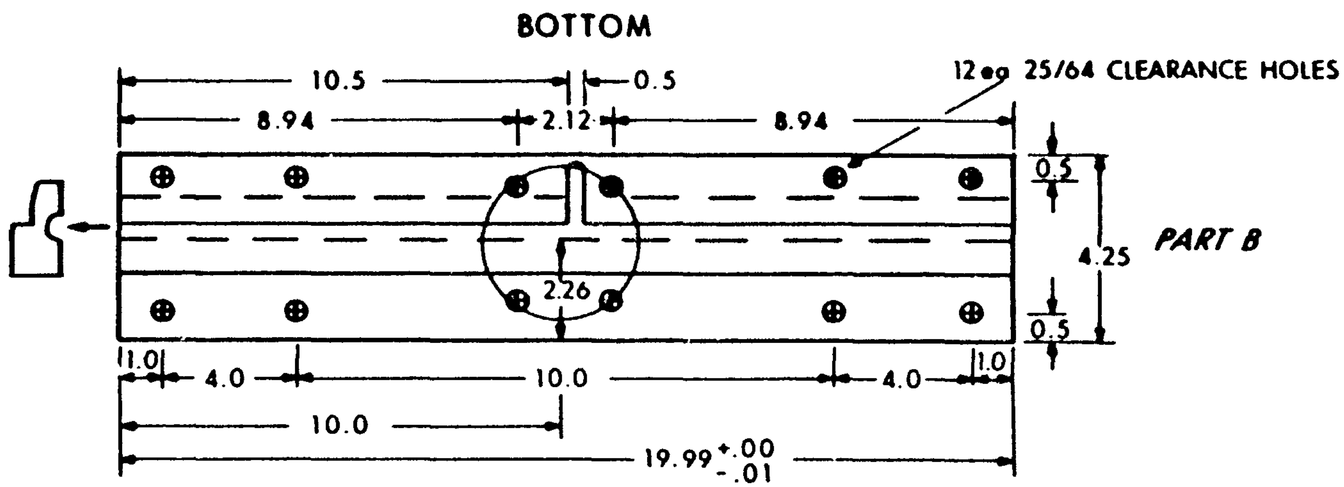


Figure A-4. Parts A and B, End View.



MAKE 1/4" R GROOVE CONNECTING TO 1/2" R CHANNEL.
THE 4 CENTRAL BOLT HOLES ARE ON 3" B.C. 90° APART.
THE CENTER IS AT 10", 2.26.

1/4 Scale

Figure A-5.Part B, Bottom View.

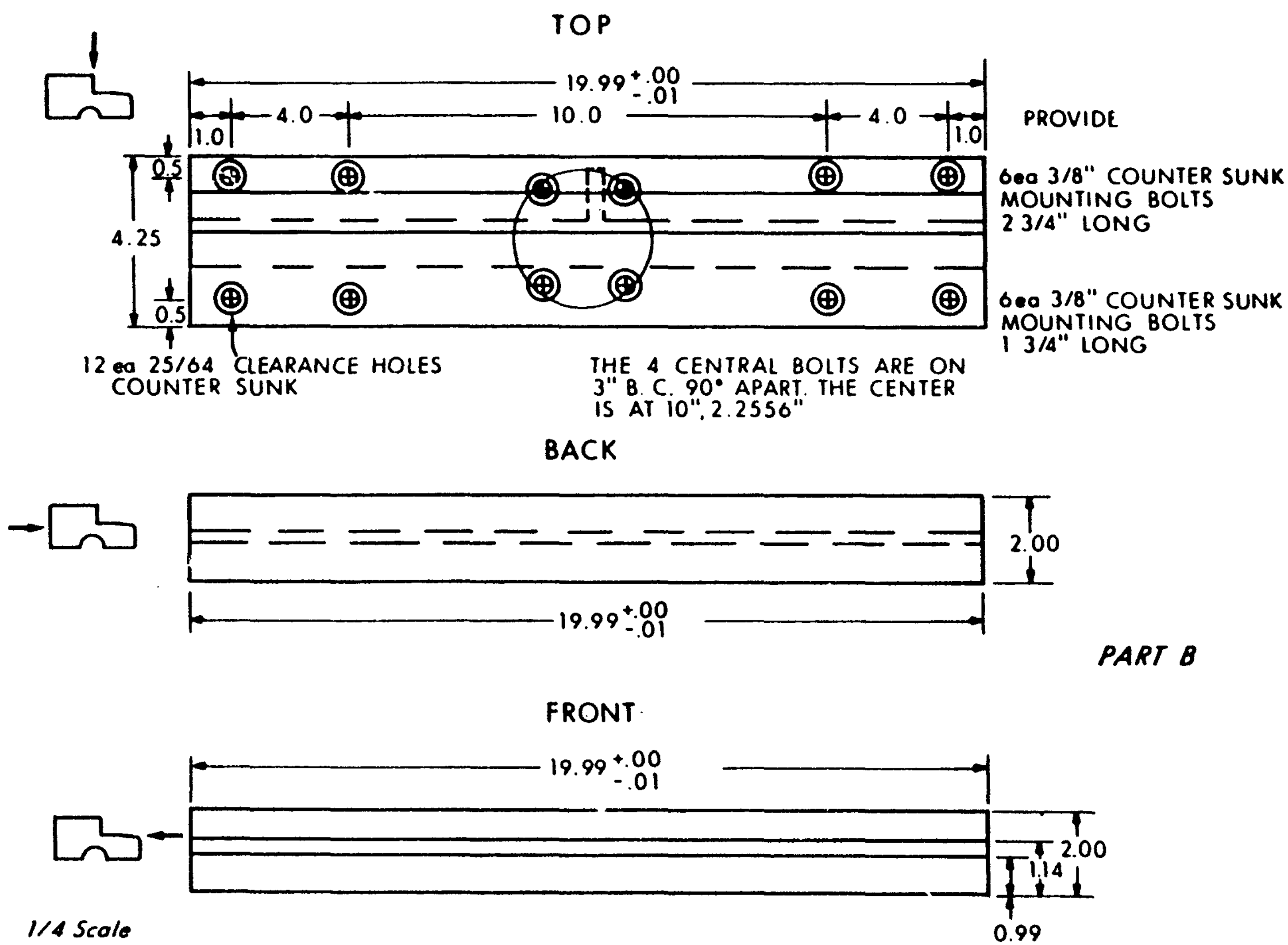
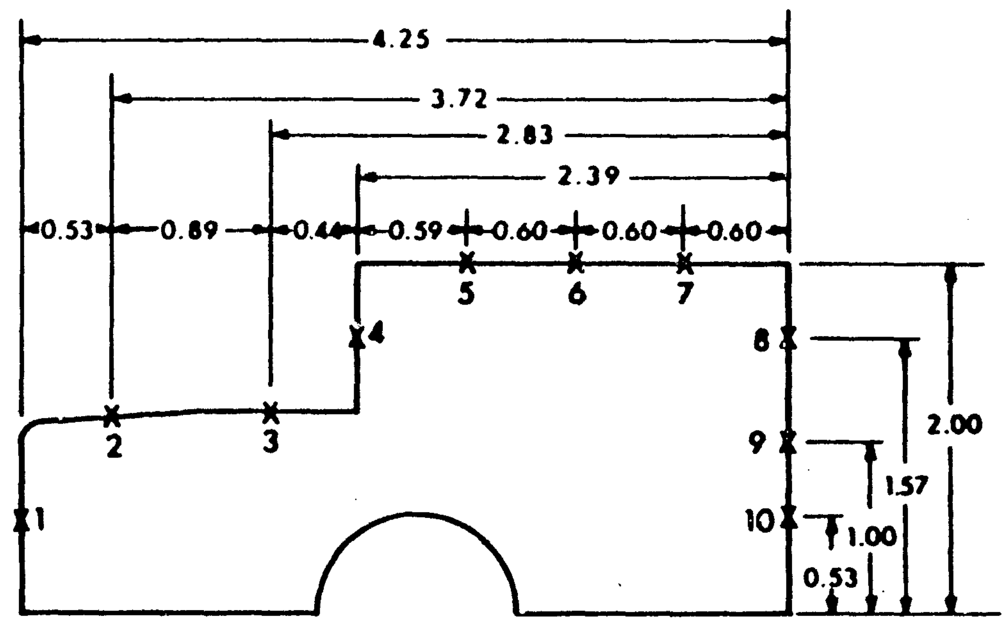


Figure A-6. Part B of the Model: Top, Back and Front Views.



FULL SCALE CROSS SECTION OF TWO DIMENSIONAL TRUCK/SHELTER SHOWING ALL 10 GAUGE POSITIONS. MEASUREMENTS IN INCHES. GAUGES # 1 & 4 ARE AT THE SAME HEIGHT AS # 10 & 8 RESPECTIVELY.

Figure A-7. Cross Section of the Model Showing Gauge Positions.

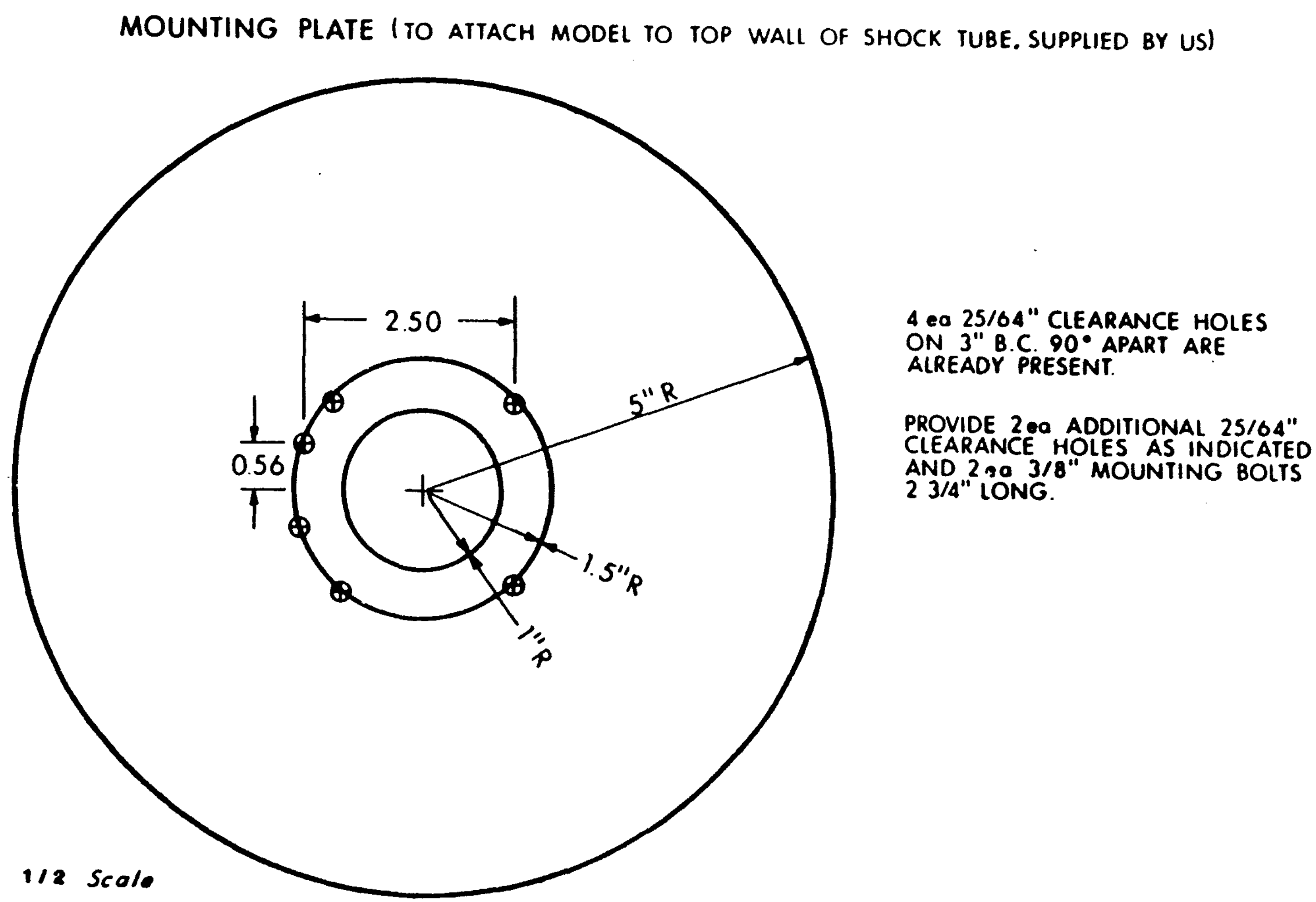
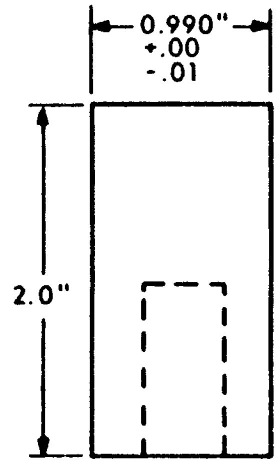


Figure A-8. Top Mounting Plate.

END PLUG (TO ATTACH MODEL TO BOTTOM WALL OF SHOCK TUBE)



DRILL 1/2" 20NF 2A FIT 1" DEEP AT CENTER POINT OF 0.99" DIAMETER PLUG.

Full Scale

Figure A-9. Bottom Mounting Plug.

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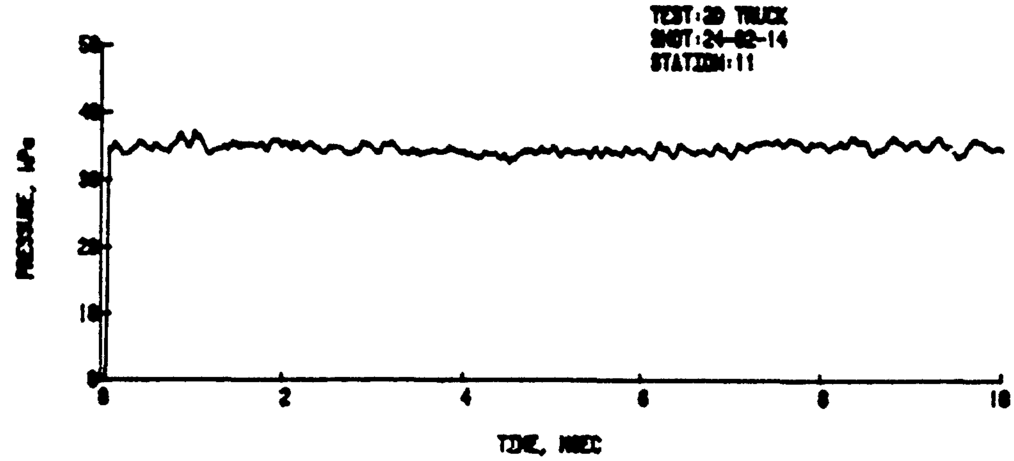
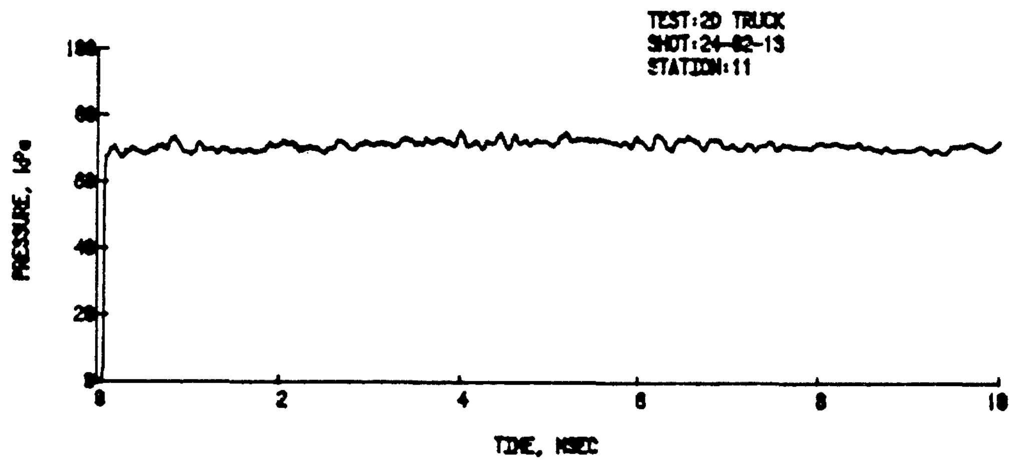
APPENDIX B

PRESSURE-TIME RECORDS





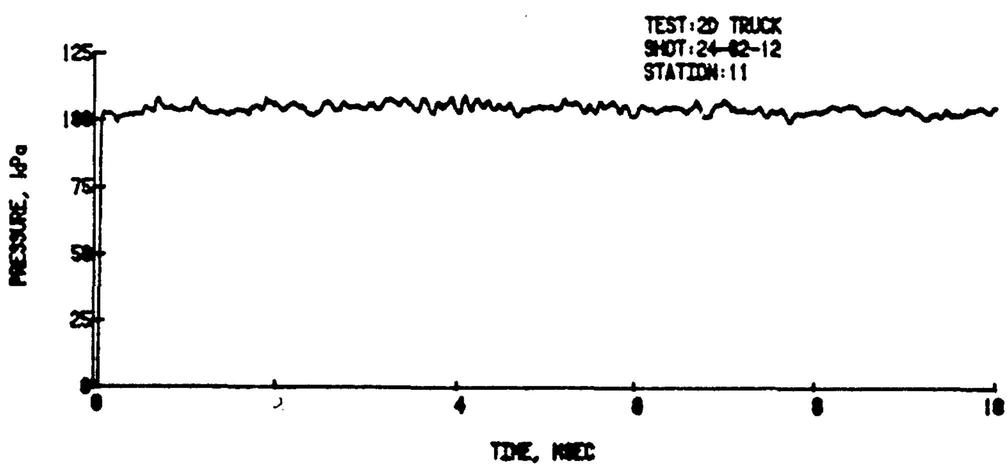
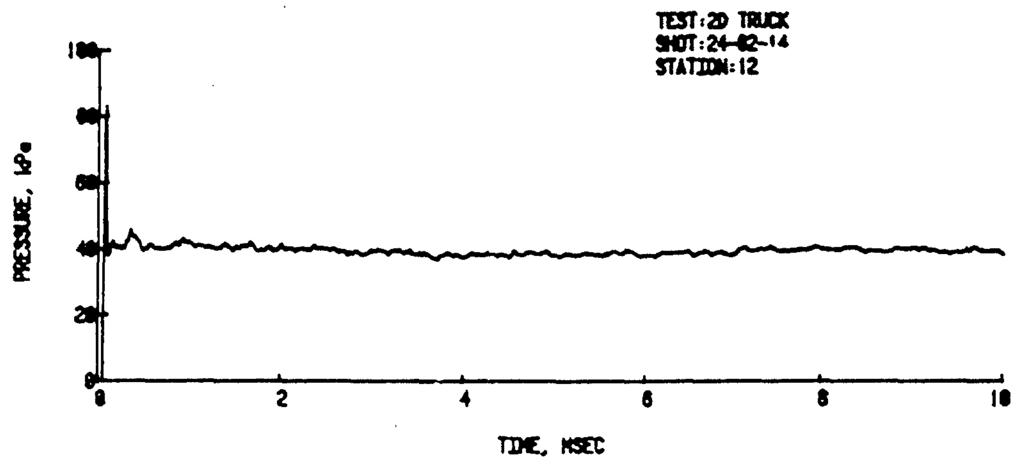
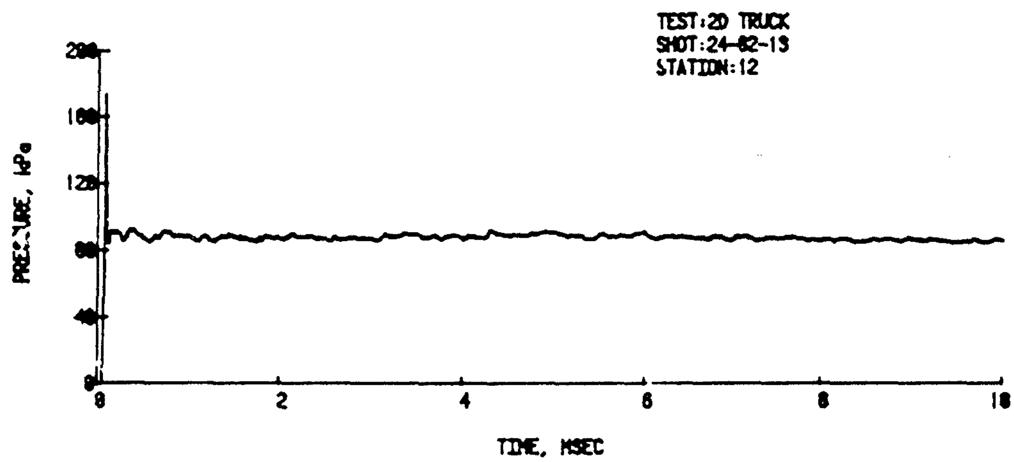


Figure B-1. Shots 24-82-14, 13, and 12; Square Wave, Free-Field Side-on Pressure, 35.1, 69.9, and 102.9 kPa.





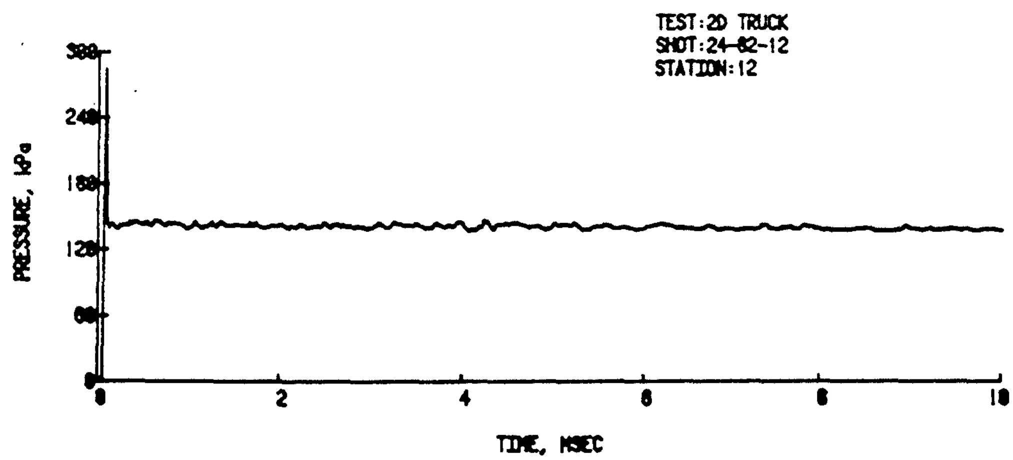


Figure B-2. Shots 24-82-14, 13 and 12; Square Wave, Free-Field Stagnation Pressure, 83.0, 173.8, and 284.4 kPa.

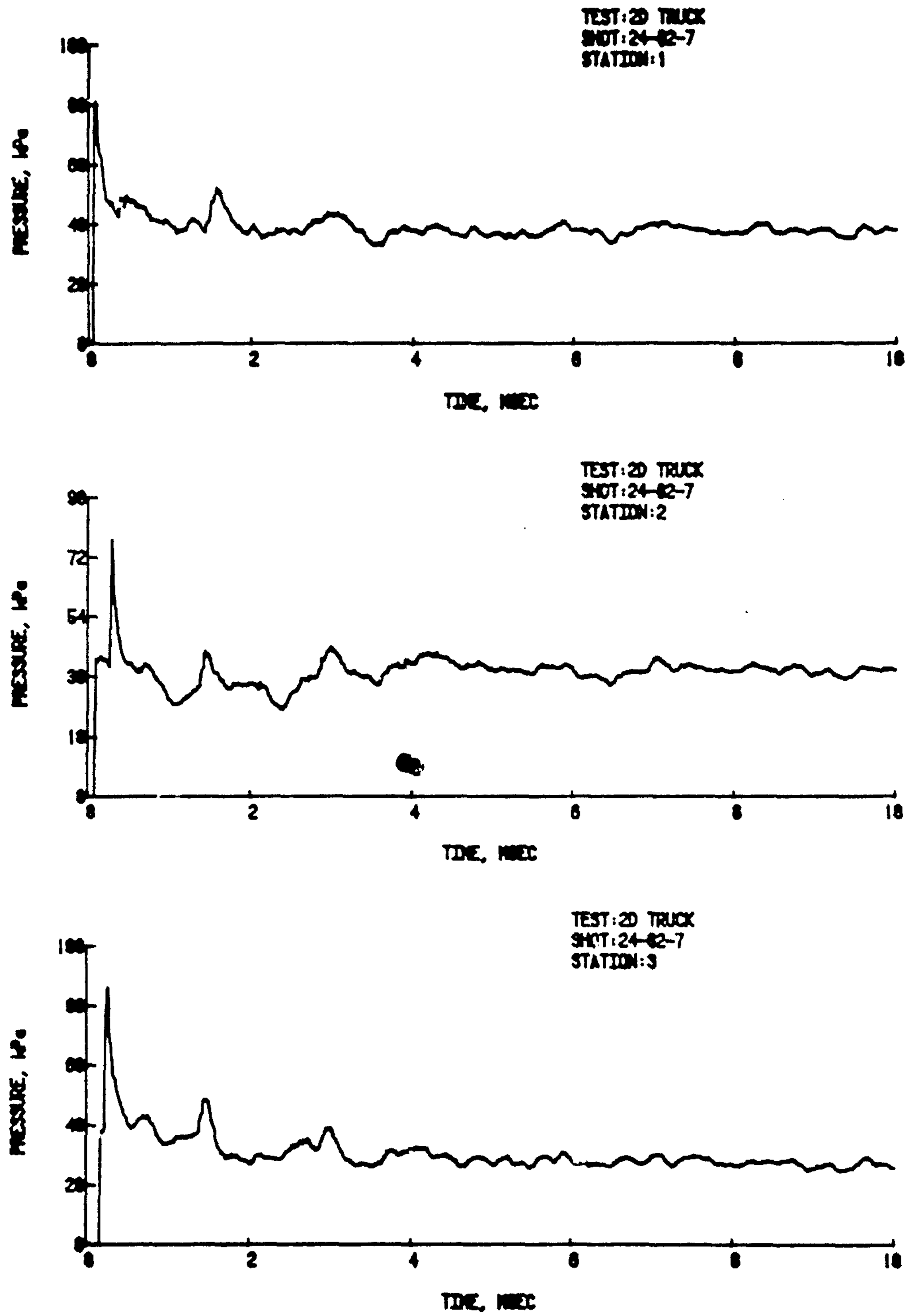
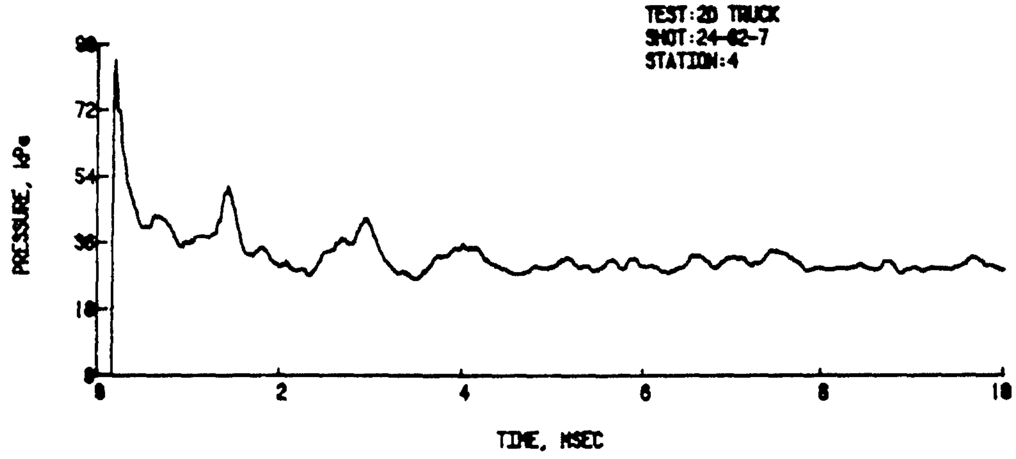
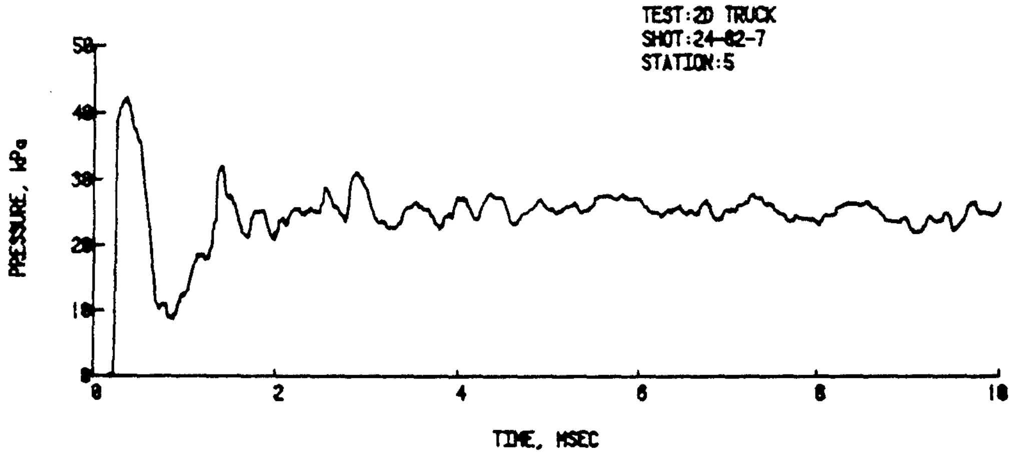
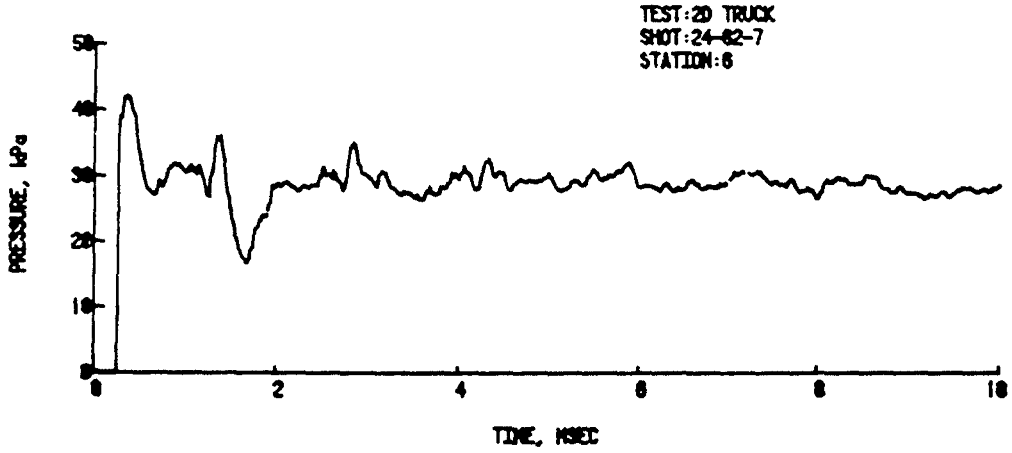


Figure B-3. Shot 24-82-7, Square Wave, Boundary Conditions Inapplicable, 33.9 kPa.







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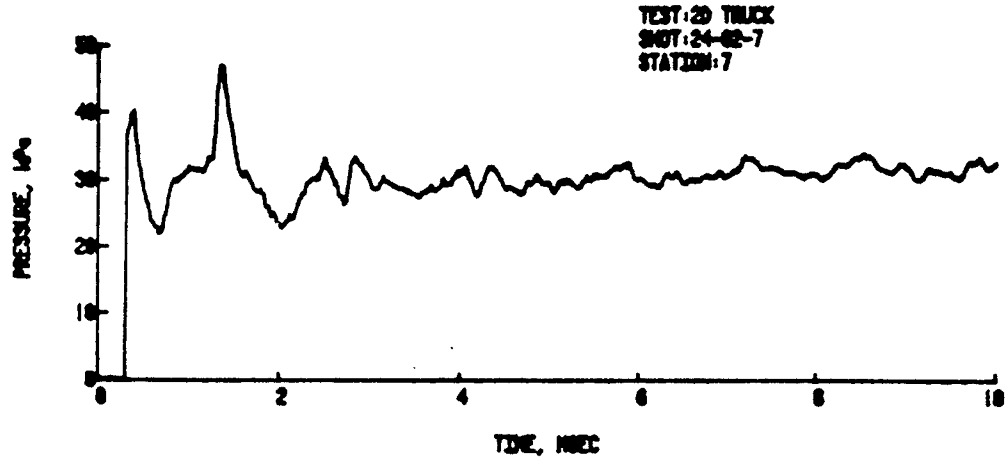

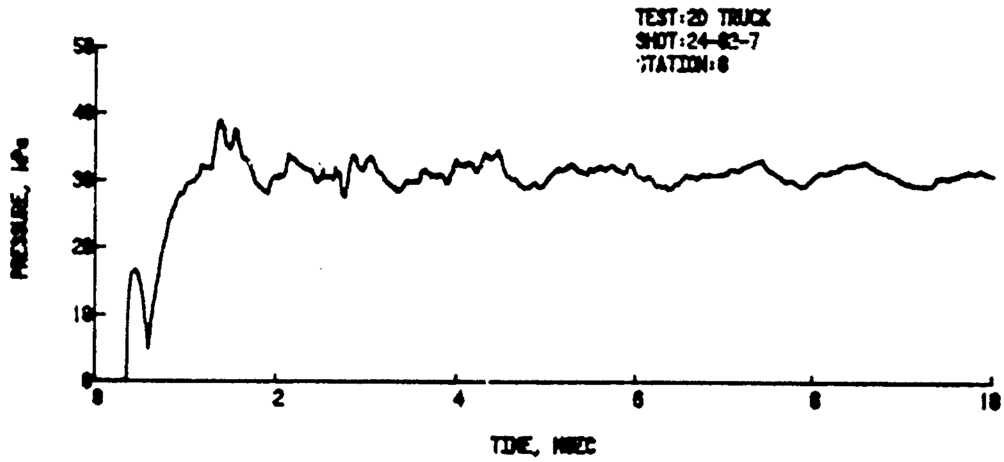

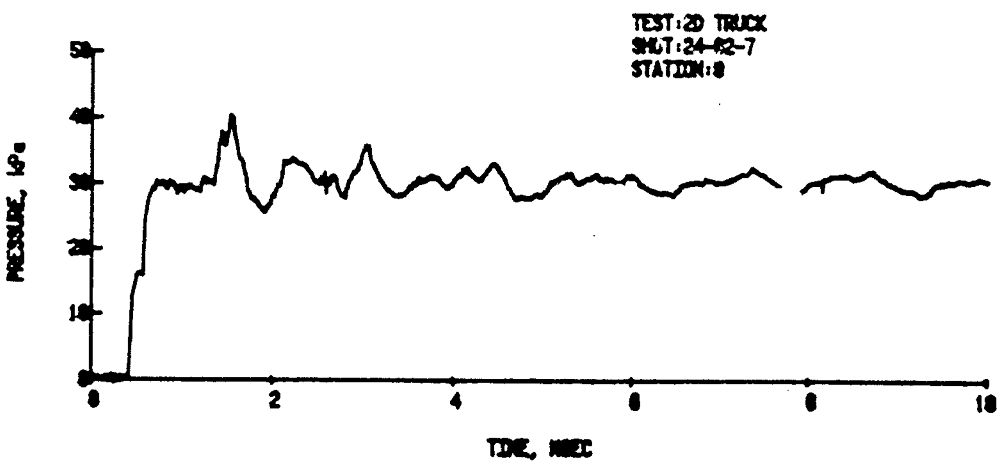

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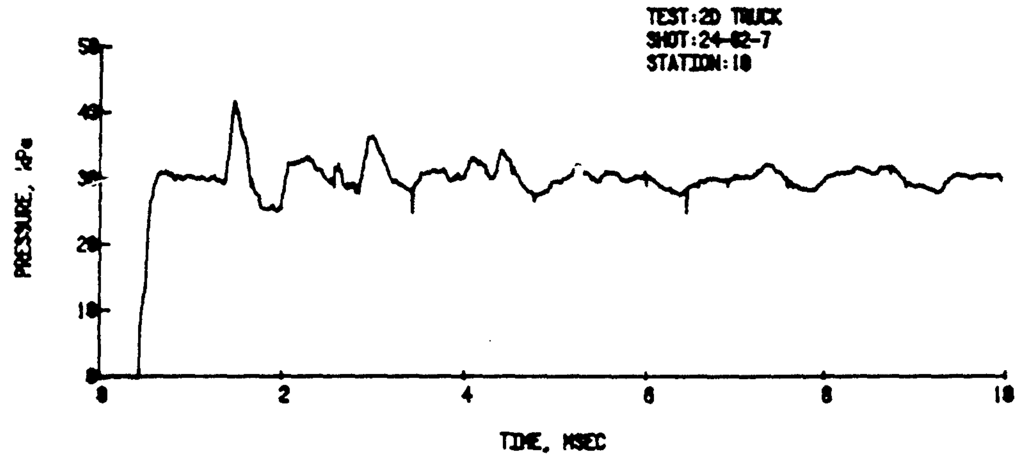

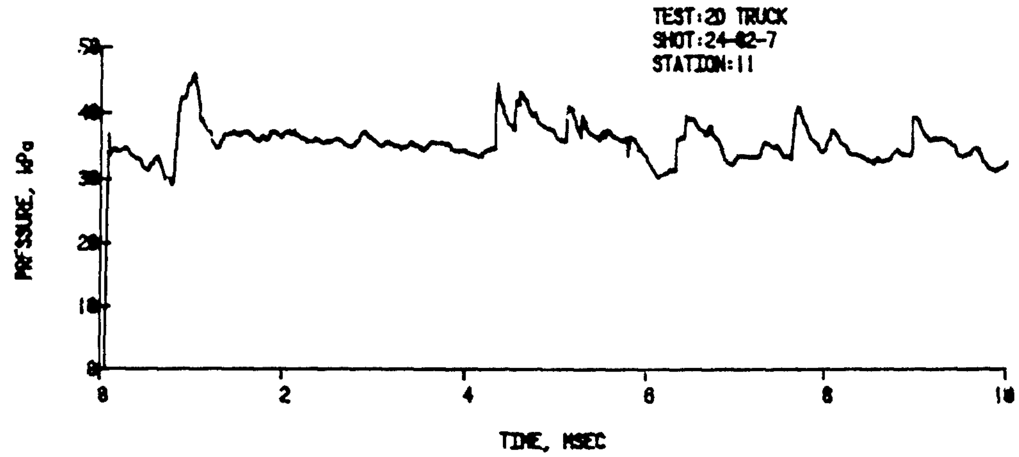

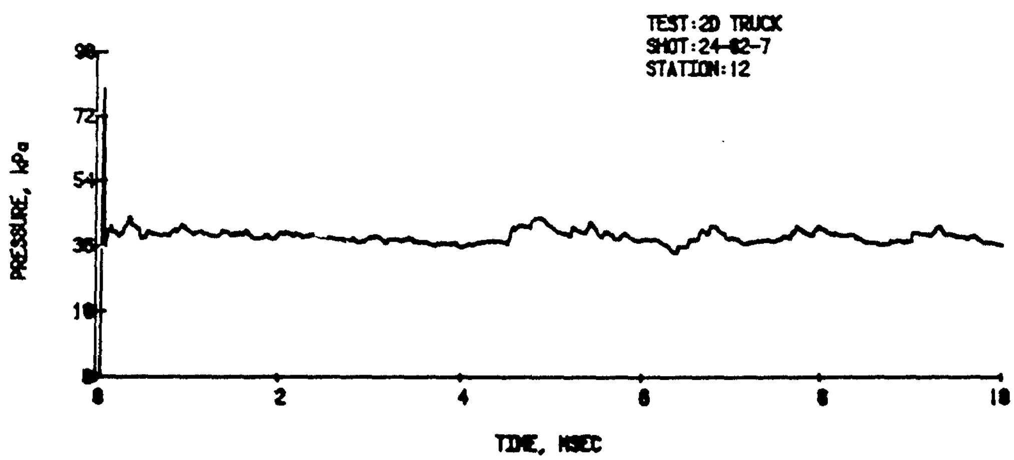

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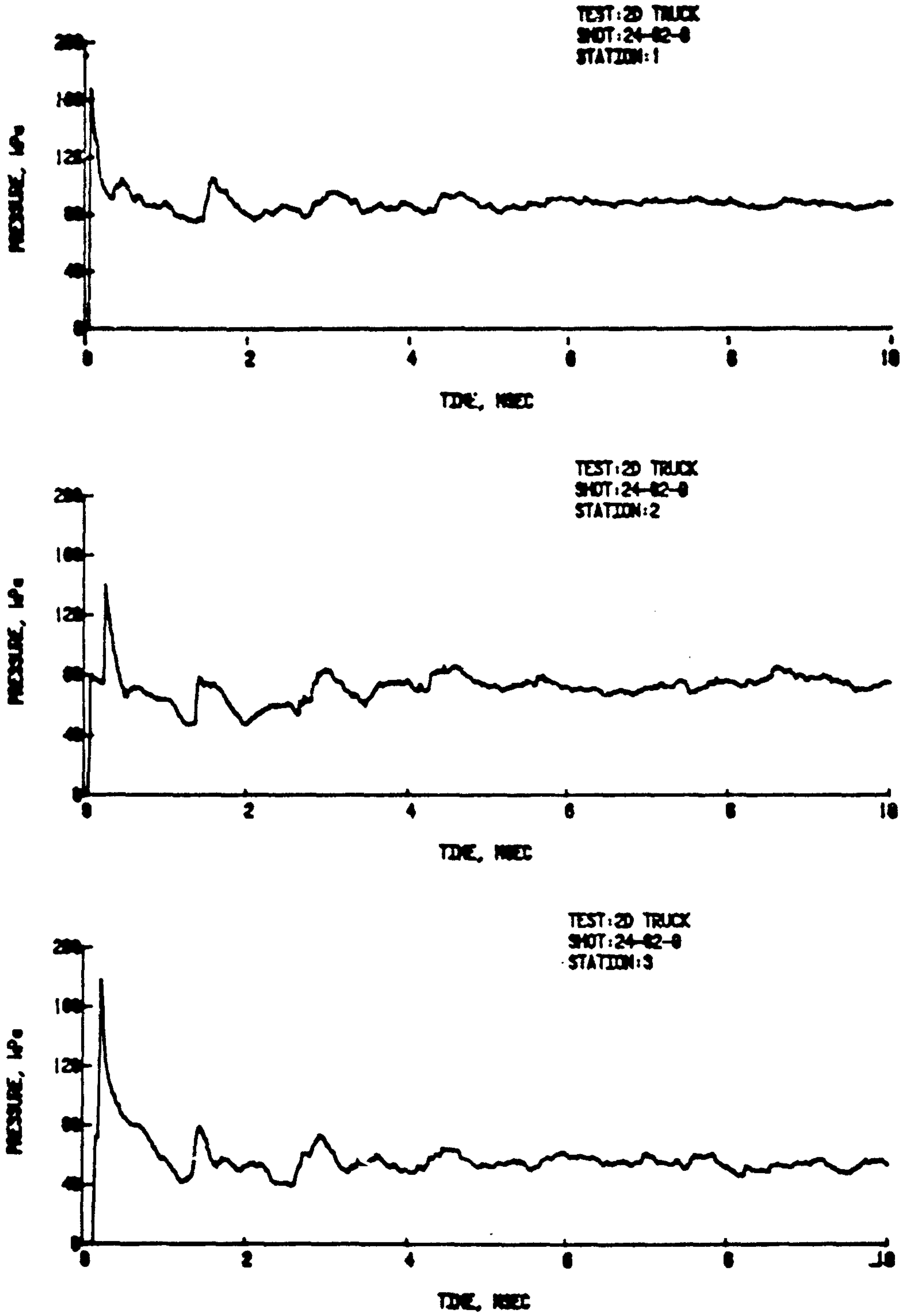
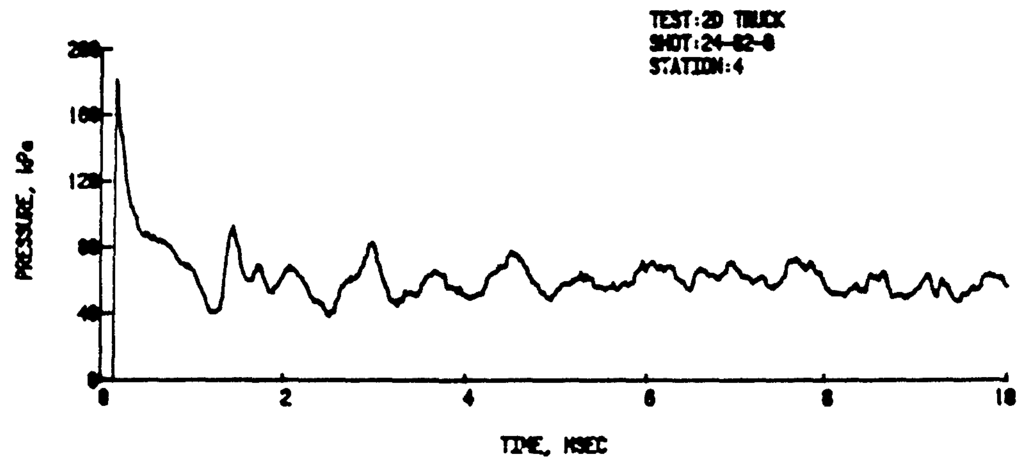
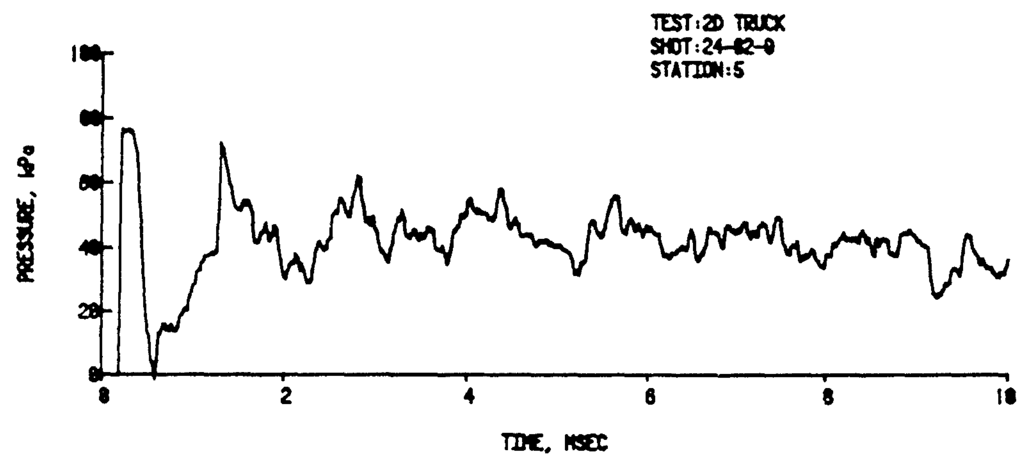
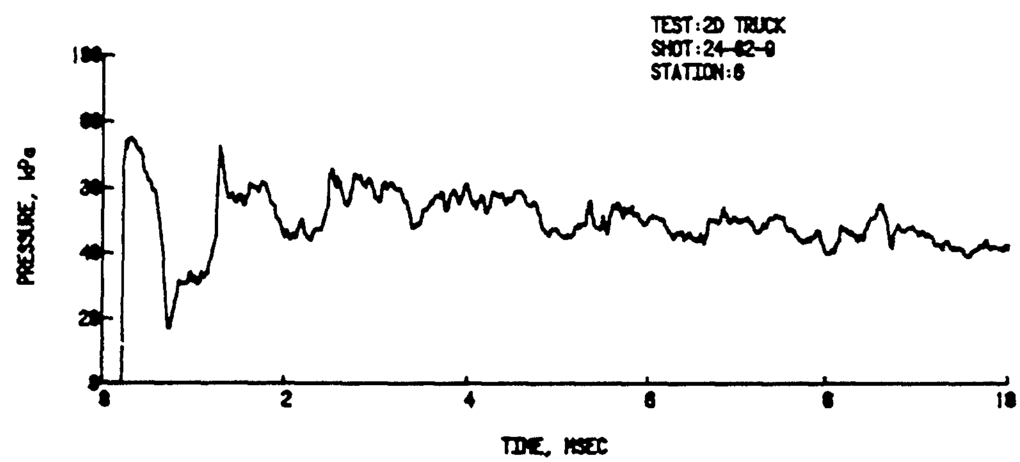


Figure B-4. Shot 24-82-9, Square Wave, Boundary Conditions Inapplicable, 69.8 kPa.







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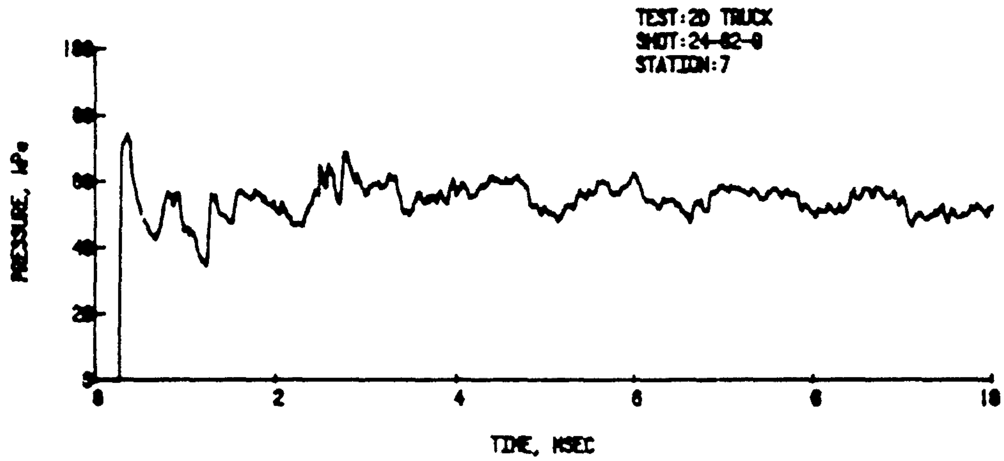

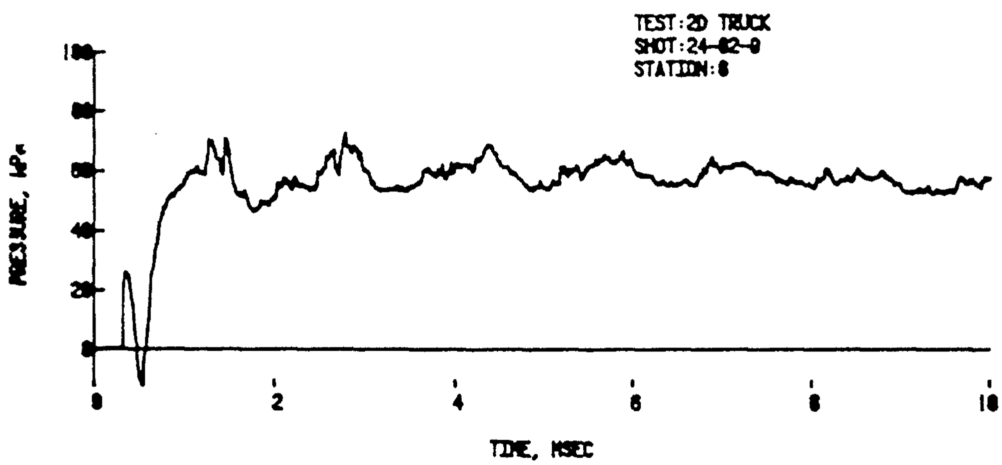

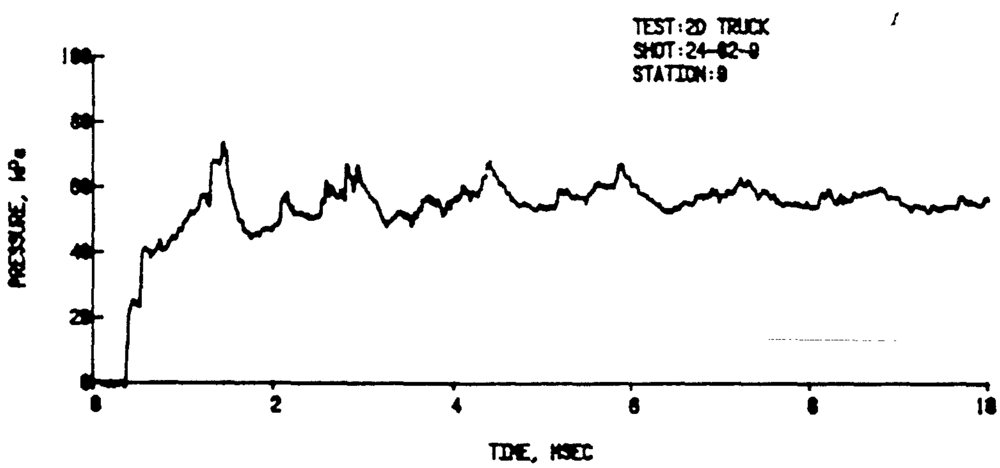

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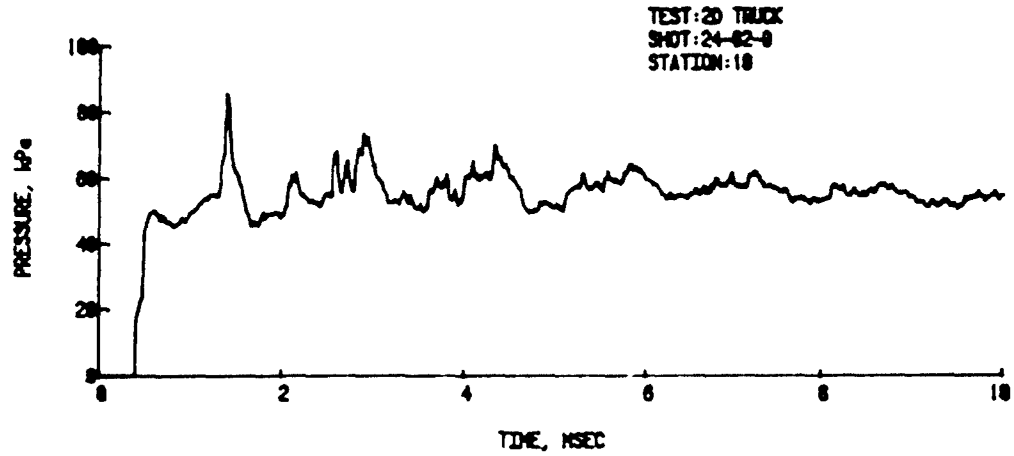
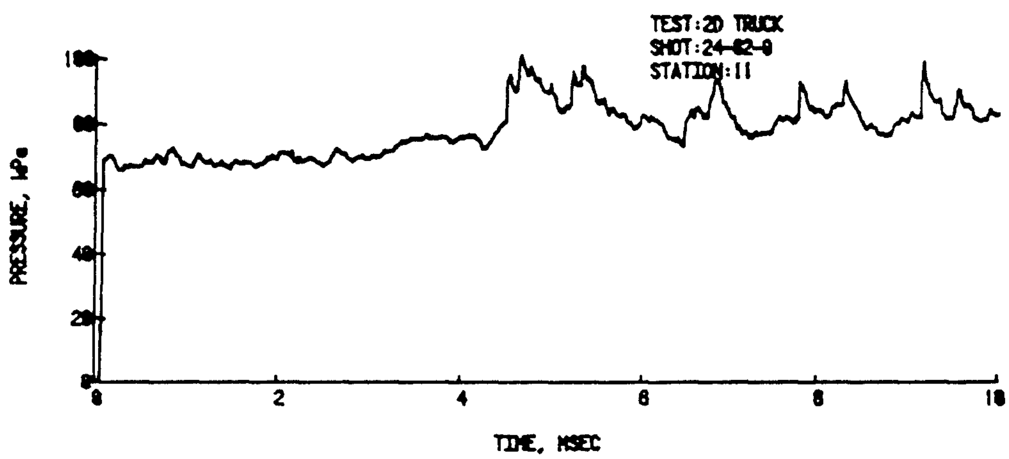




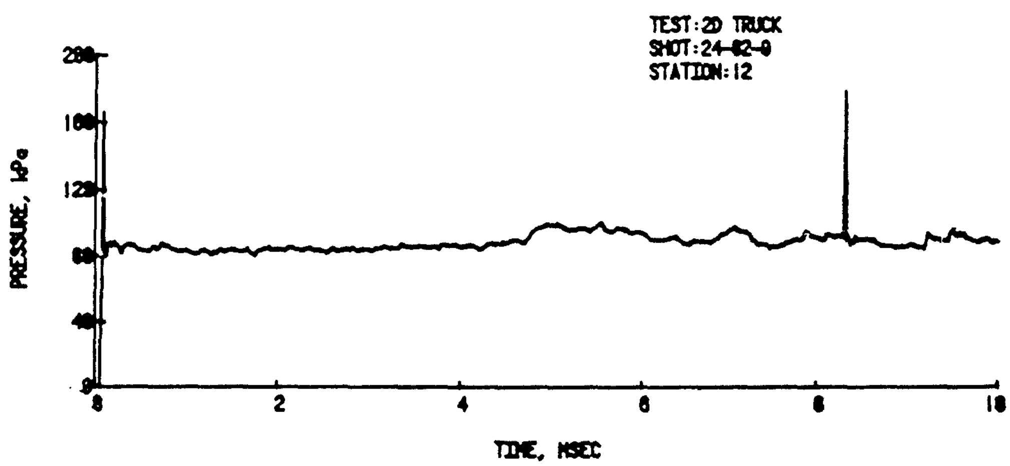


Figure B-4. Shot 24-82-9 (Cont)

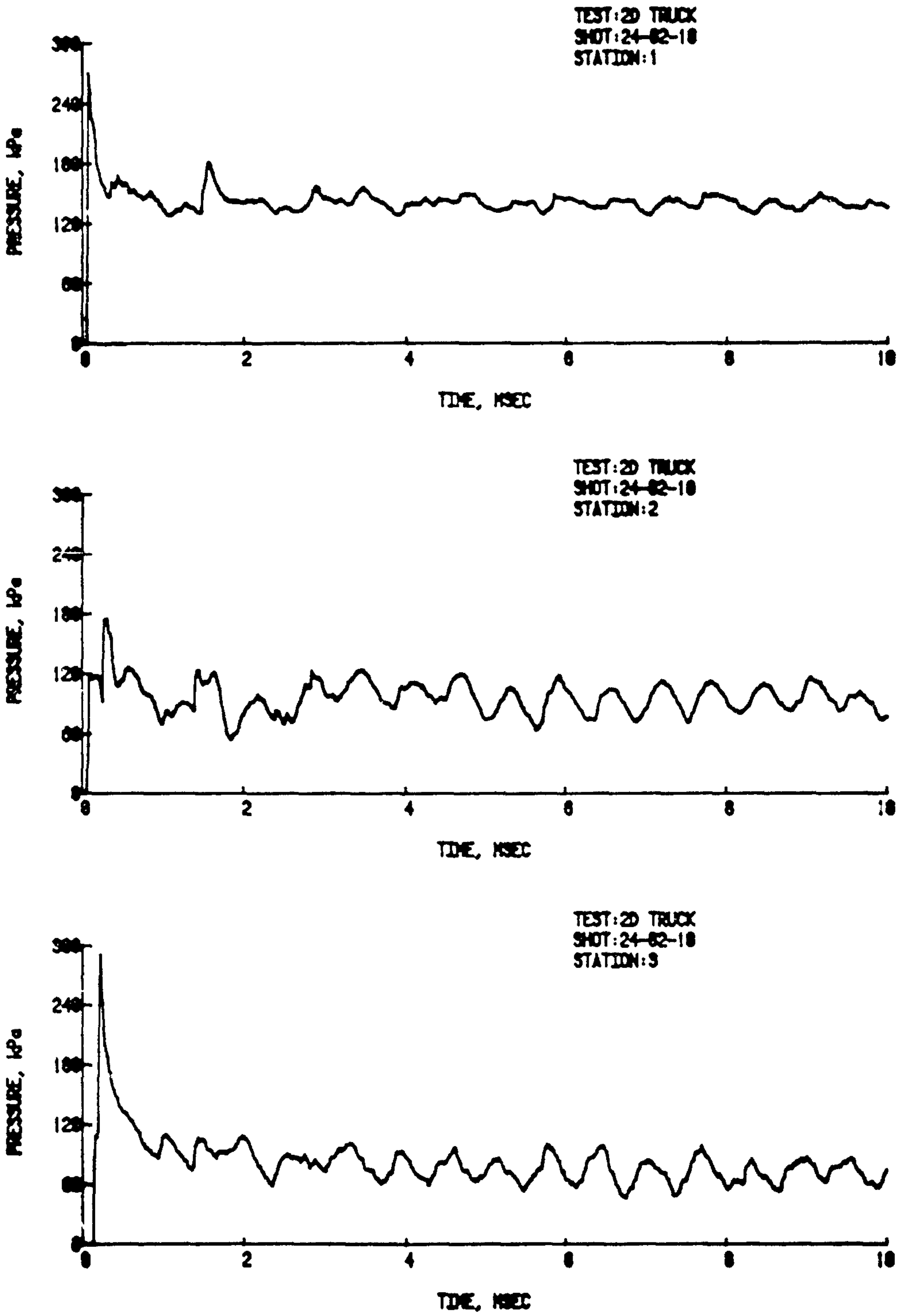
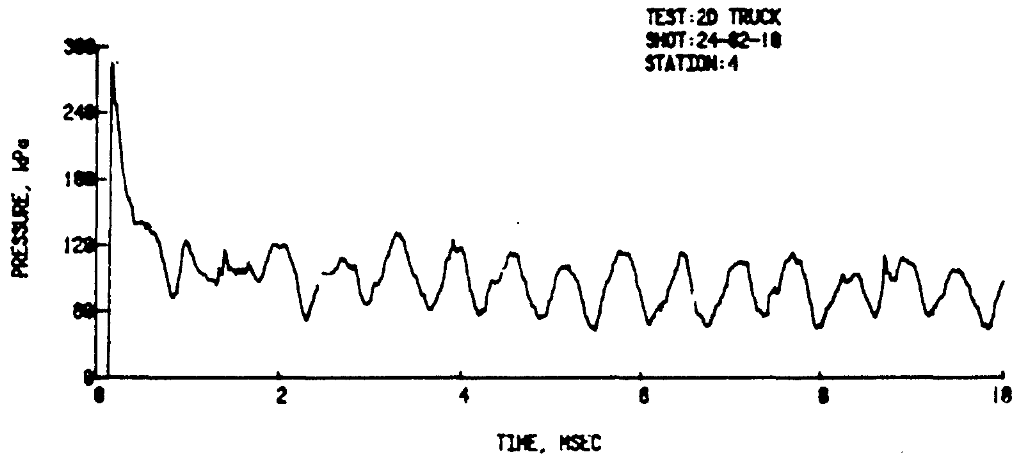
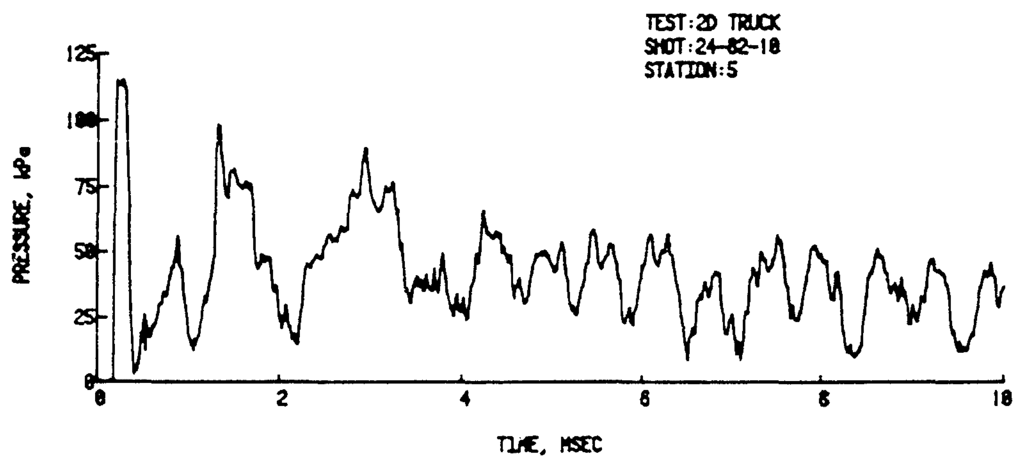
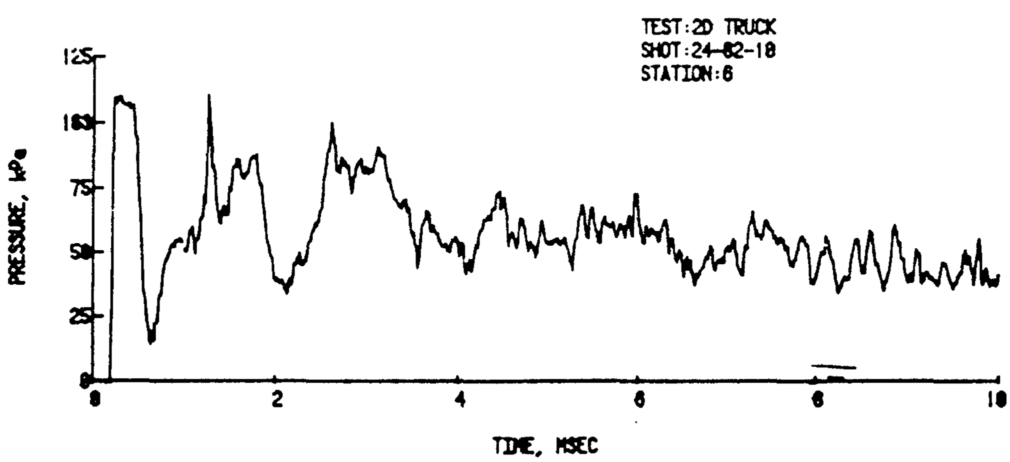


Figure B-5. Shot 24-82-10, Square Wave, Boundary Conditions Inapplicable, 101.4 kPa.







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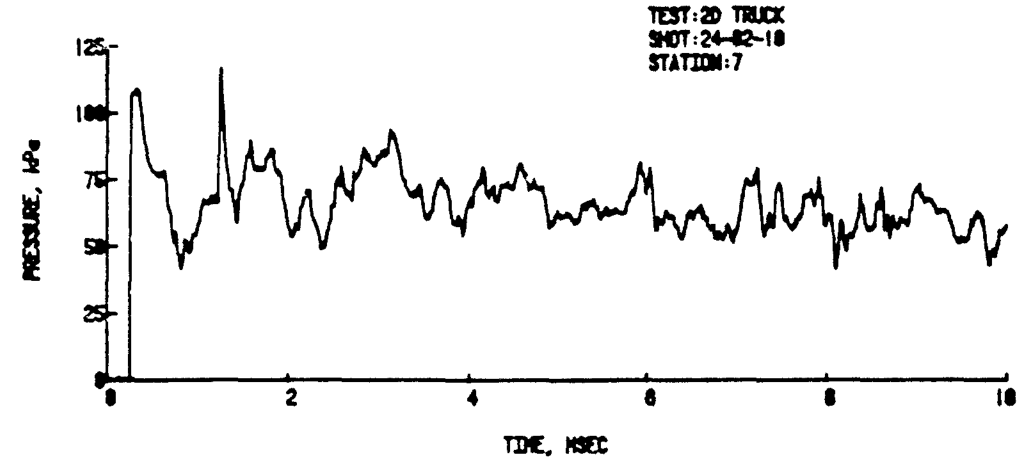

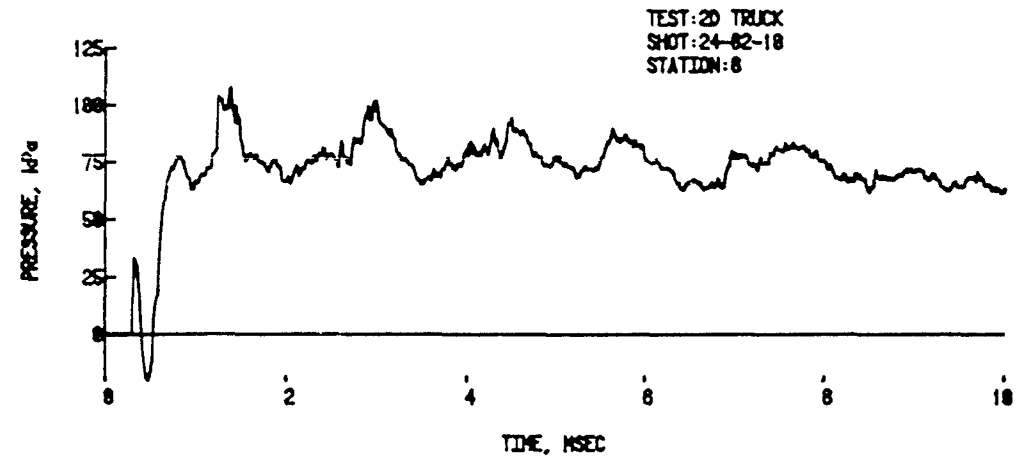

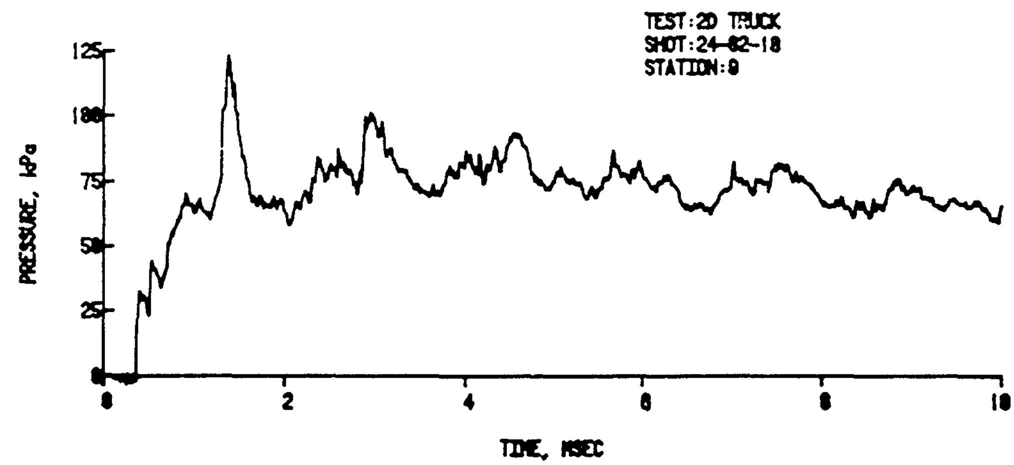

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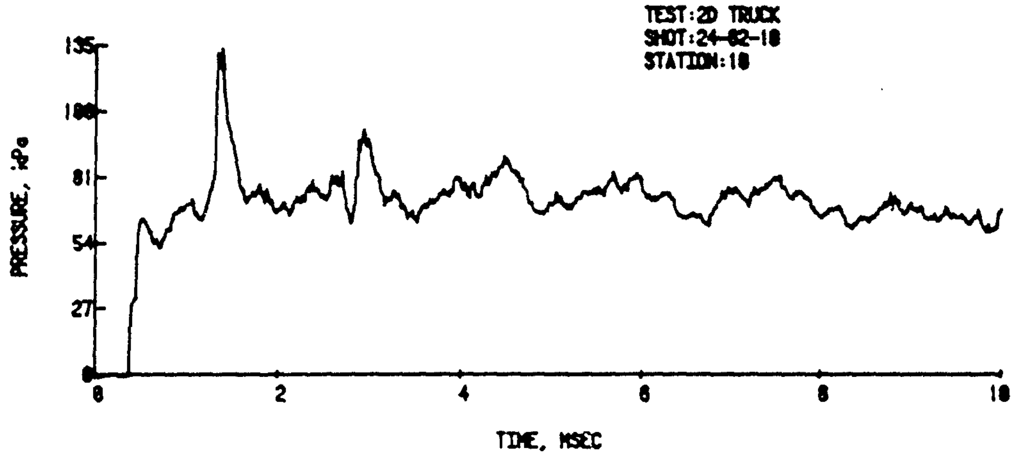
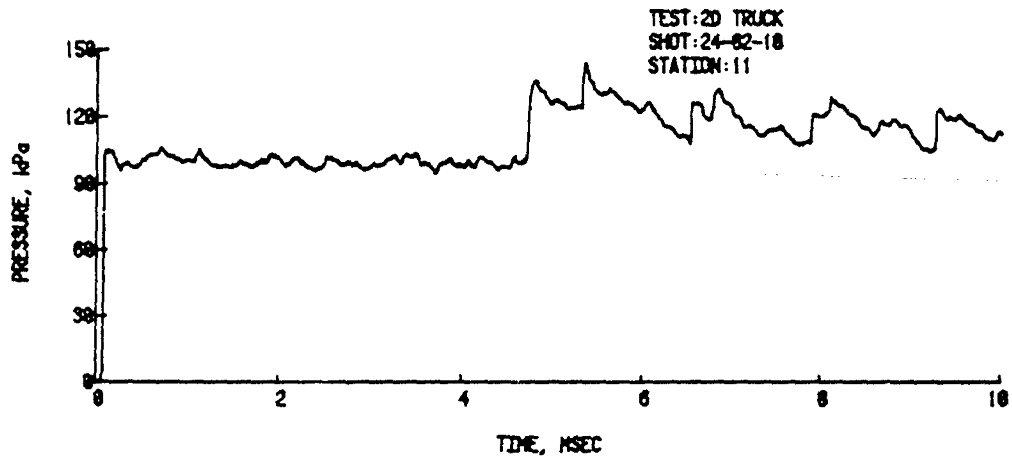




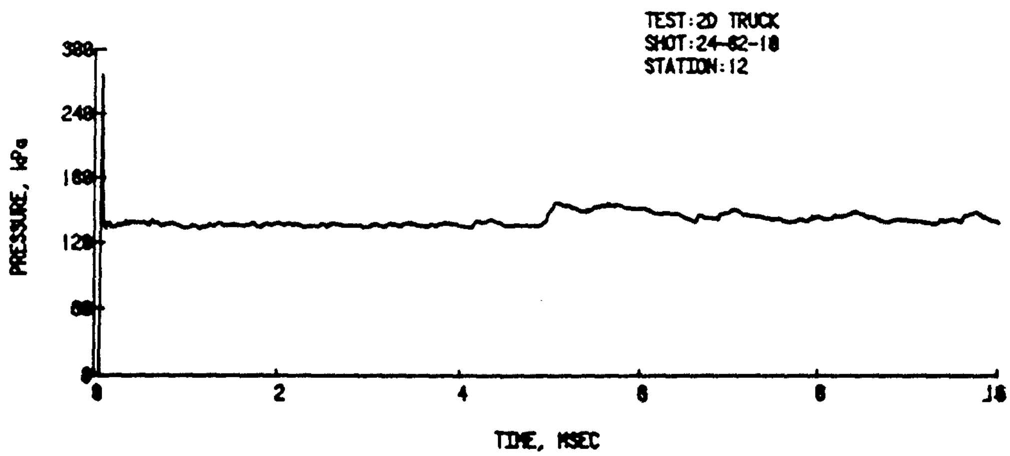


Figure B-5. Shot 24-82-10 (Cont)

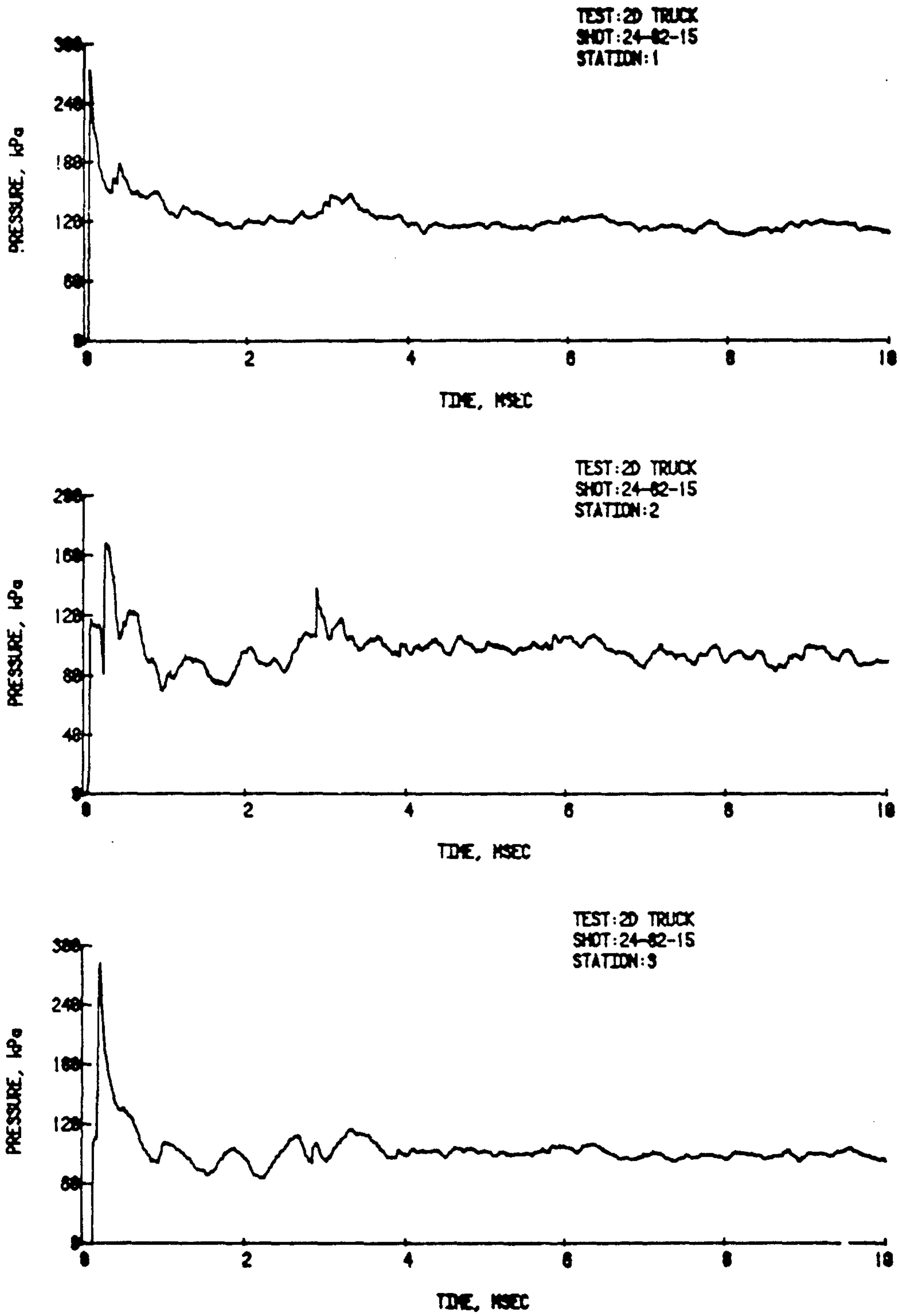
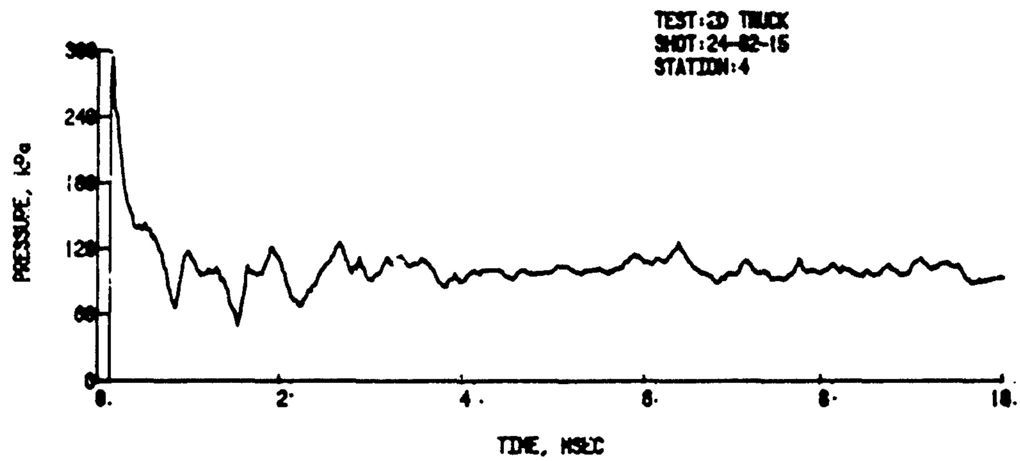
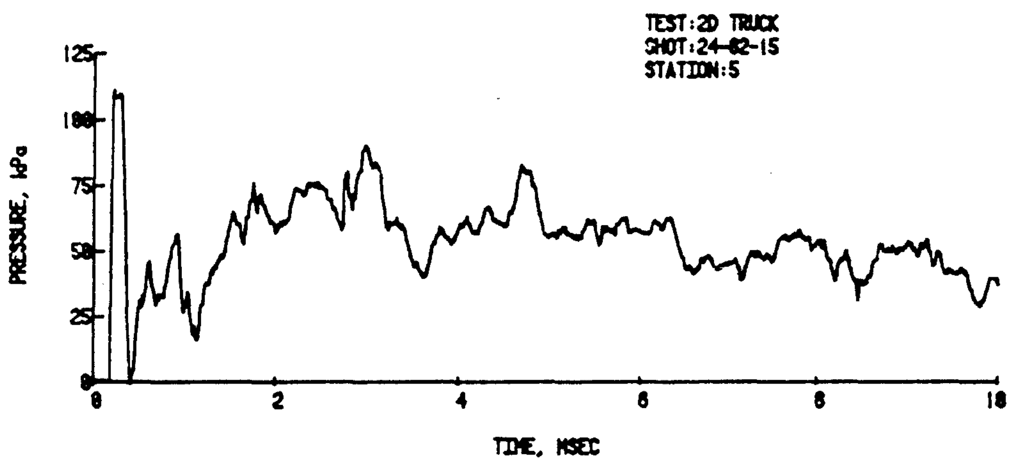


Figure B-6. Shot 24-82-15, Square Wave, Boundary Conditions Applicable, 100.0 kPa.





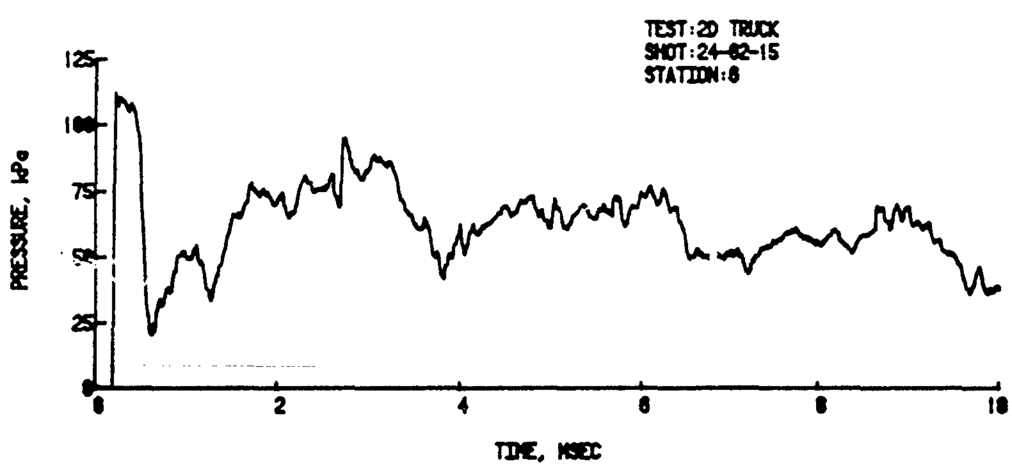
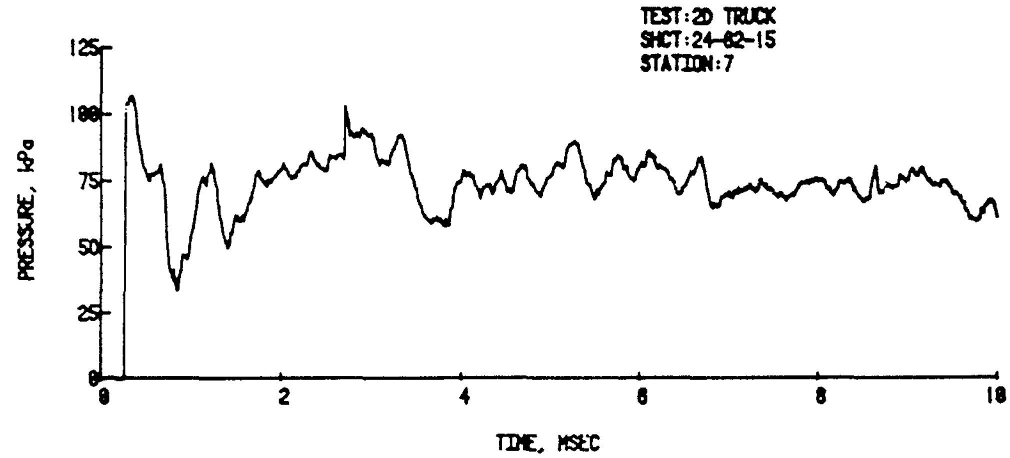
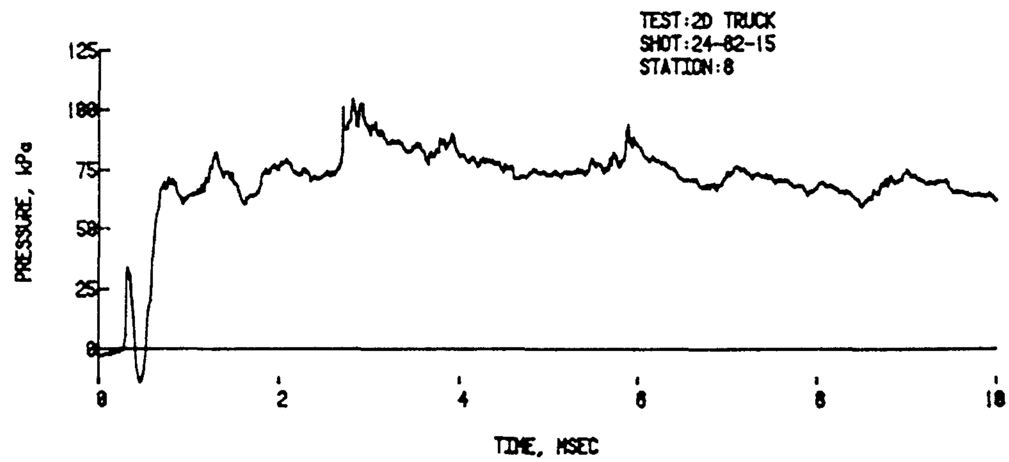


Figure B-6. Shot 24-82-15 (Cont)





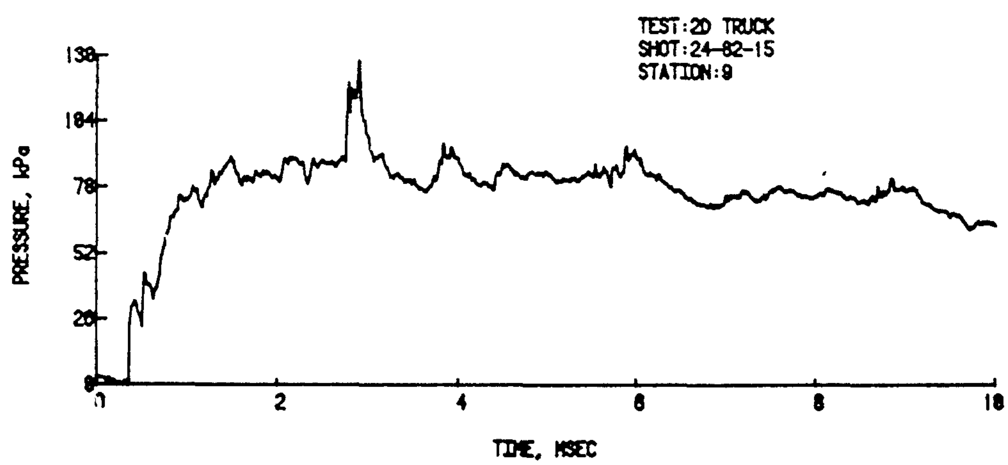
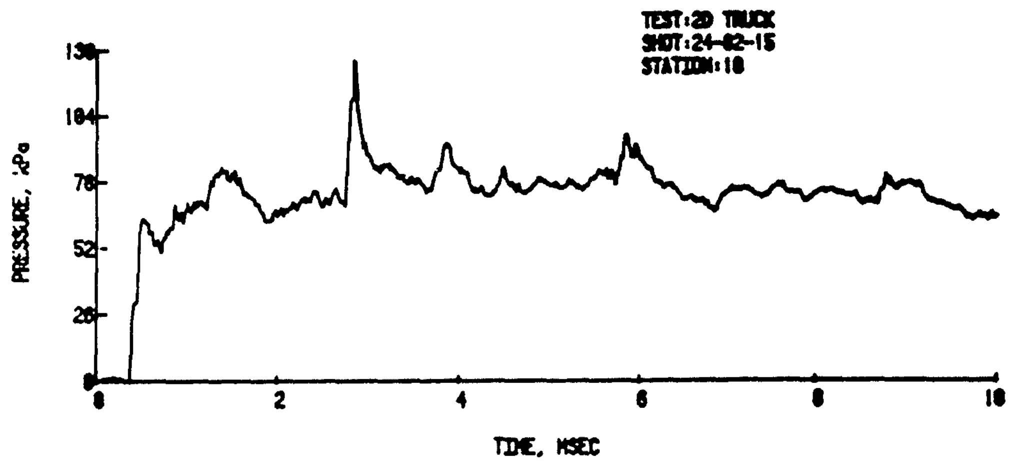
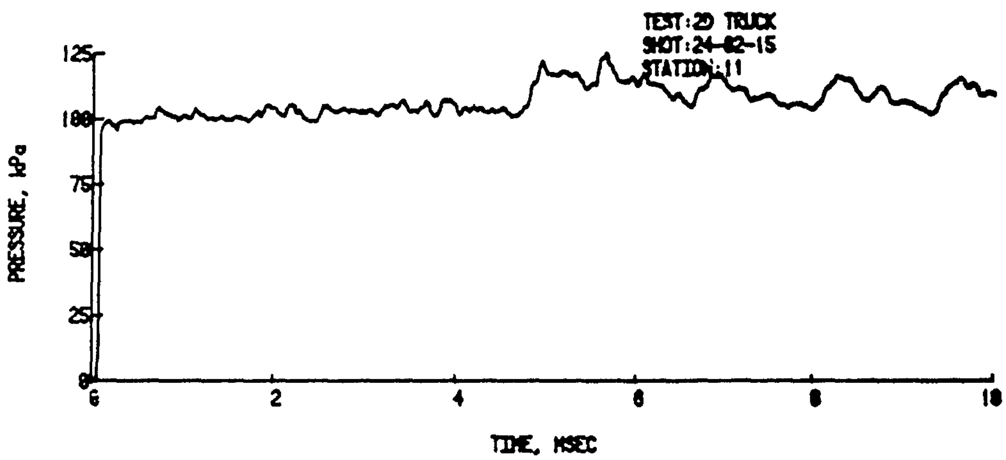


Figure B-6. Shot 24-82-15 (Cont)





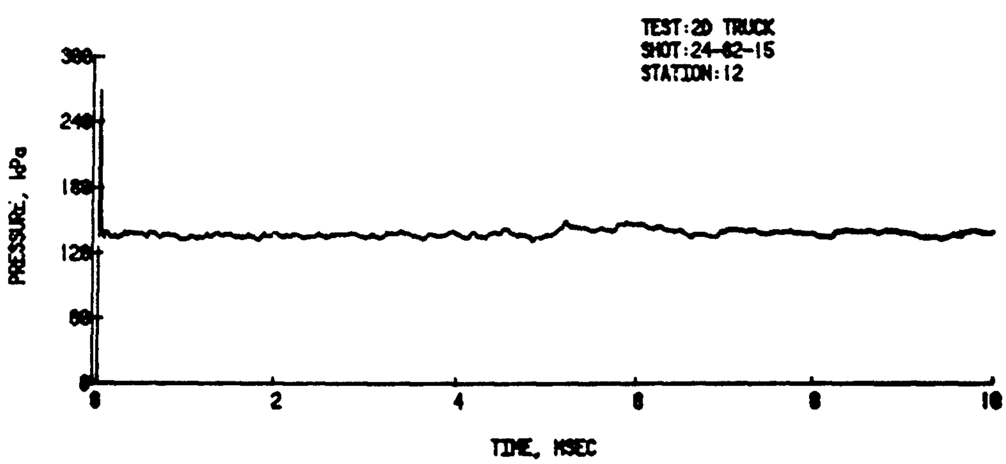


Figure B-6. Shot 24-82-15 (Cont)

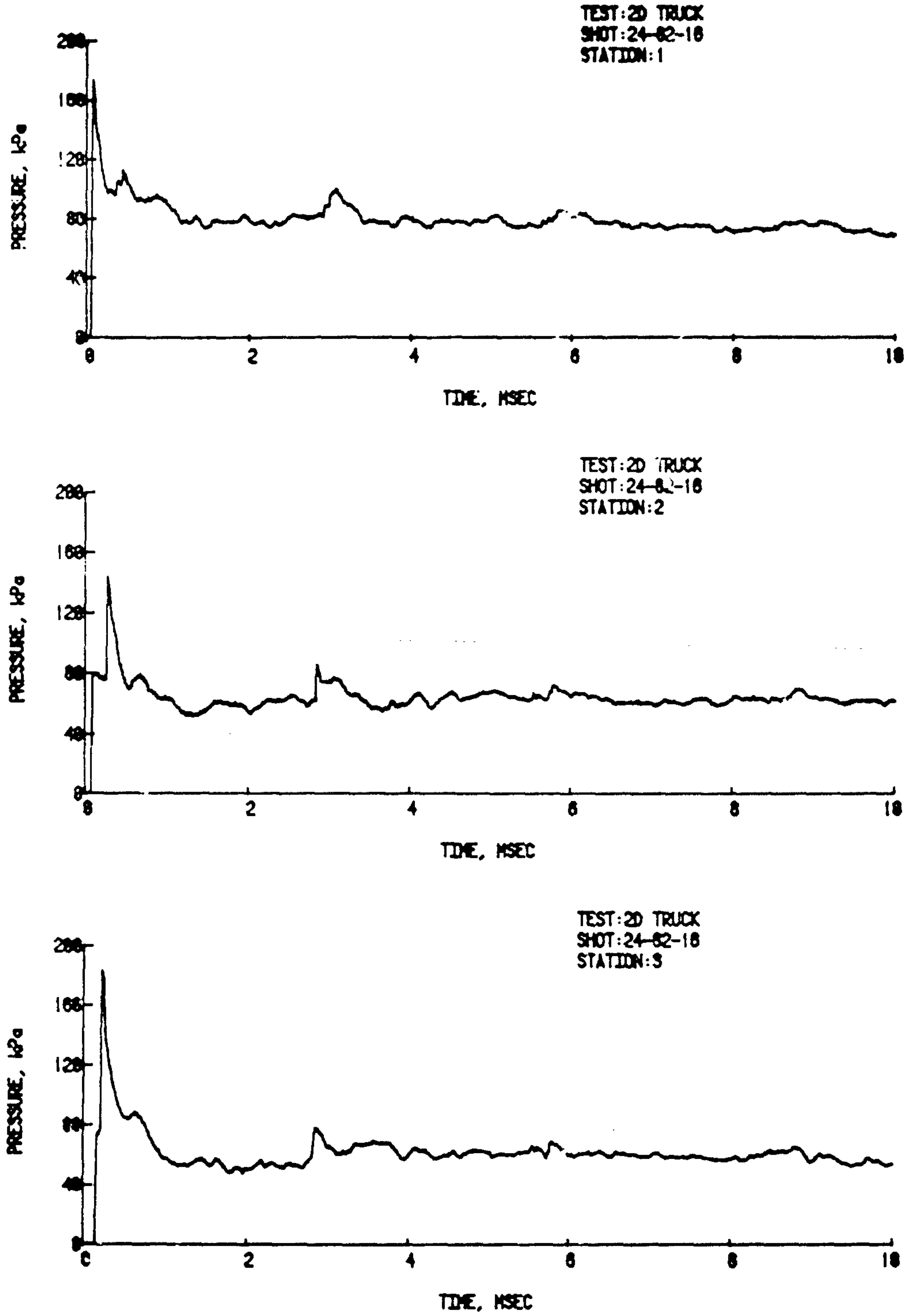


Figure B-7. Shot 24-82-16, Square Wave, Boundary Conditions Applicable, 69.5 kPa.

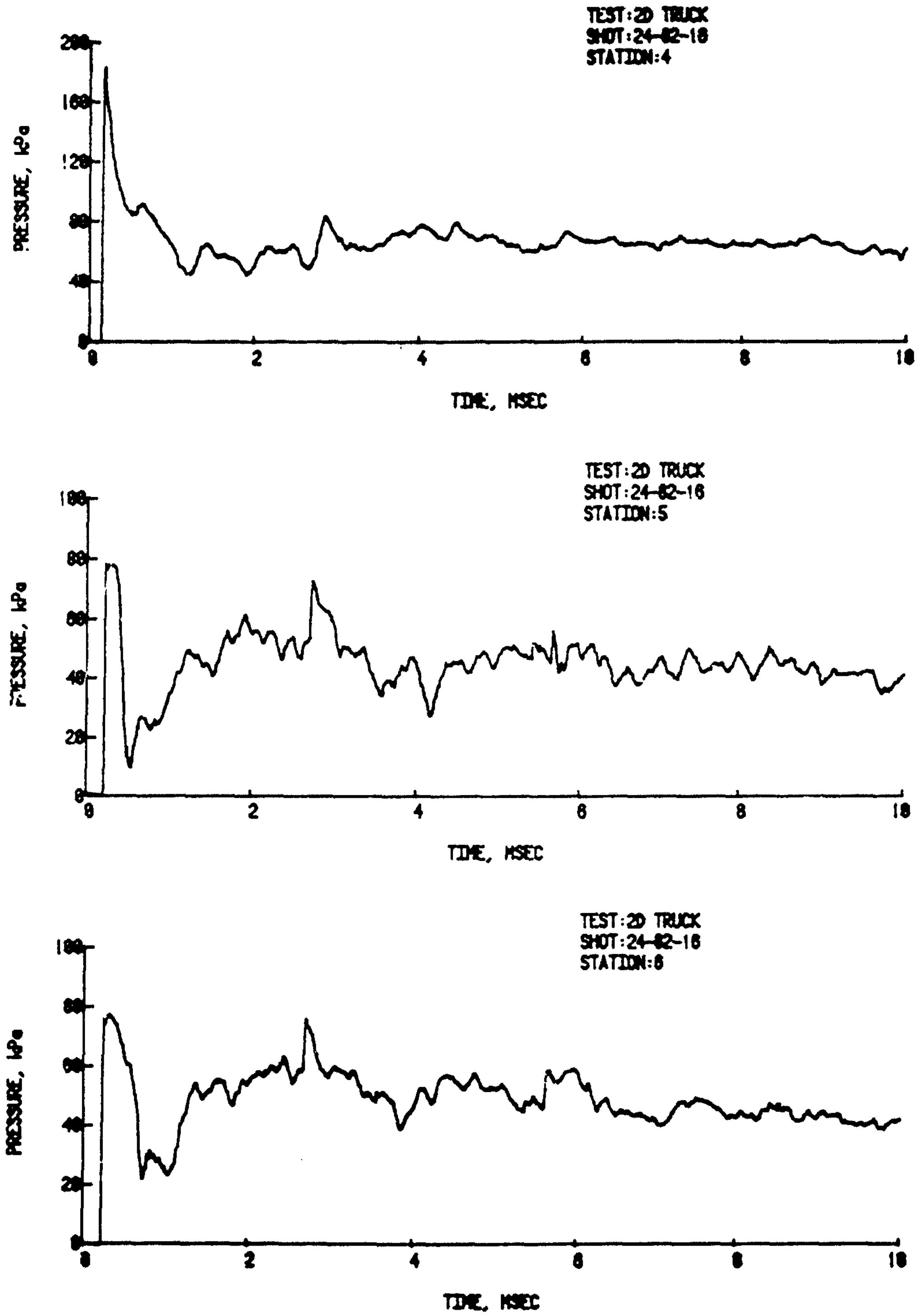
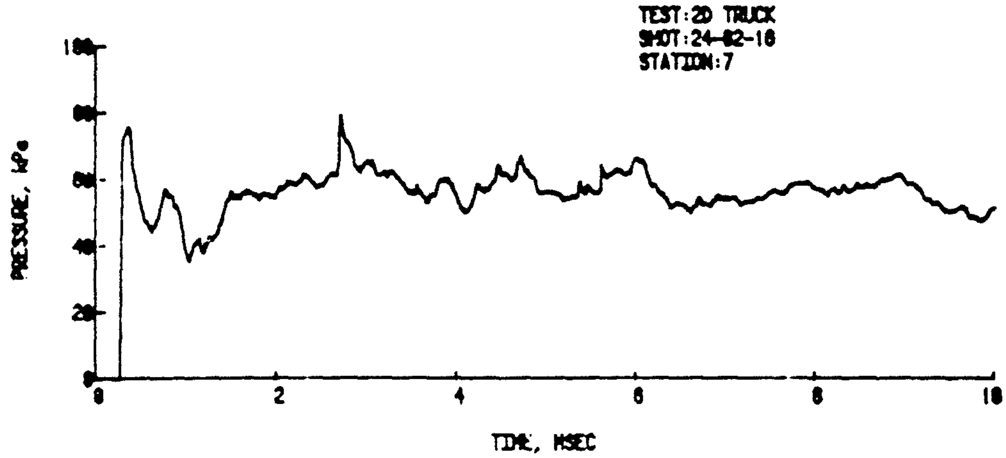
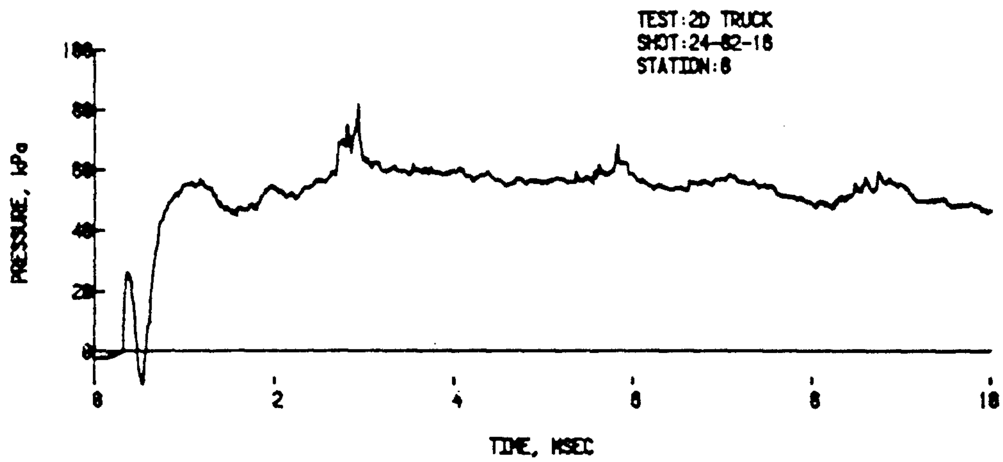


Figure B-7. Shot 24-82-16 (Cont)





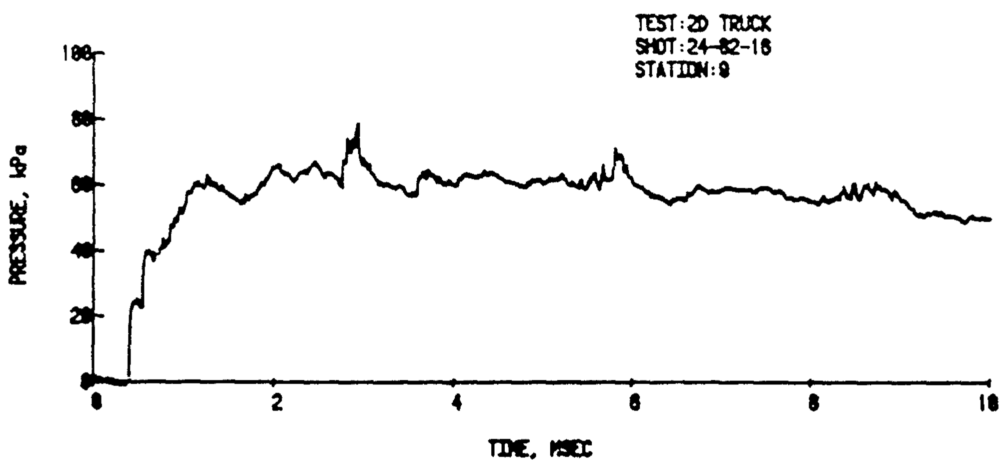
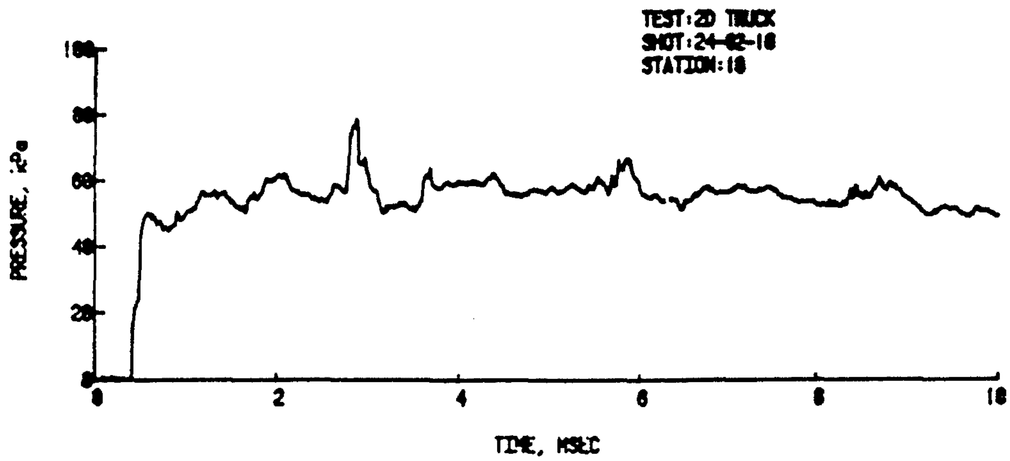
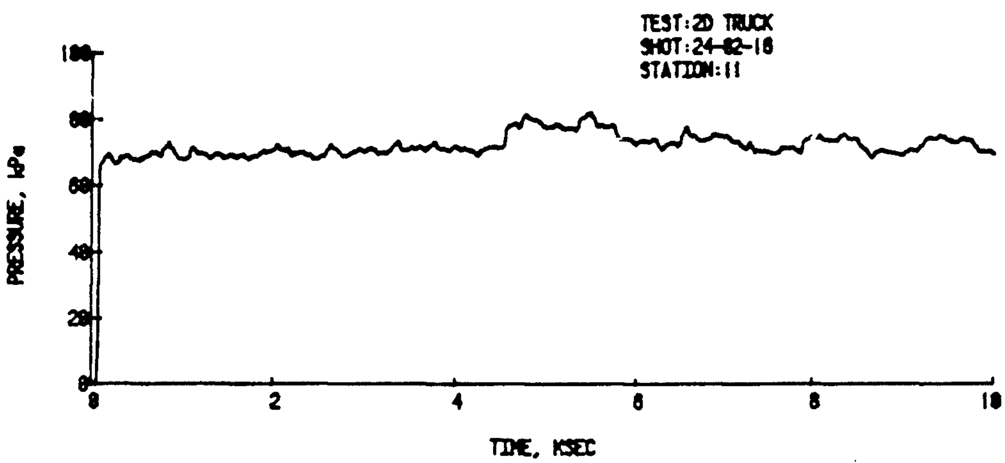


Figure B-7. Shot 24-82-16 (Cont)





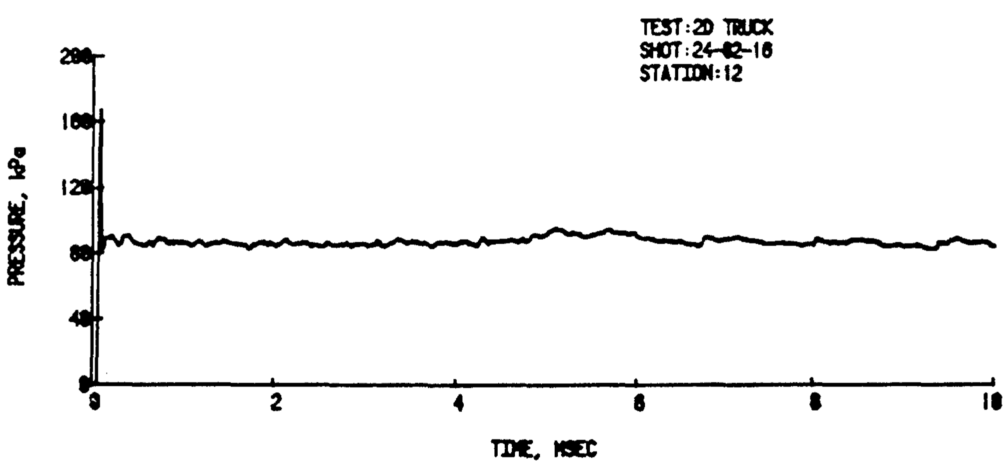


Figure B-7. Shot 24-82-16 (Cont)

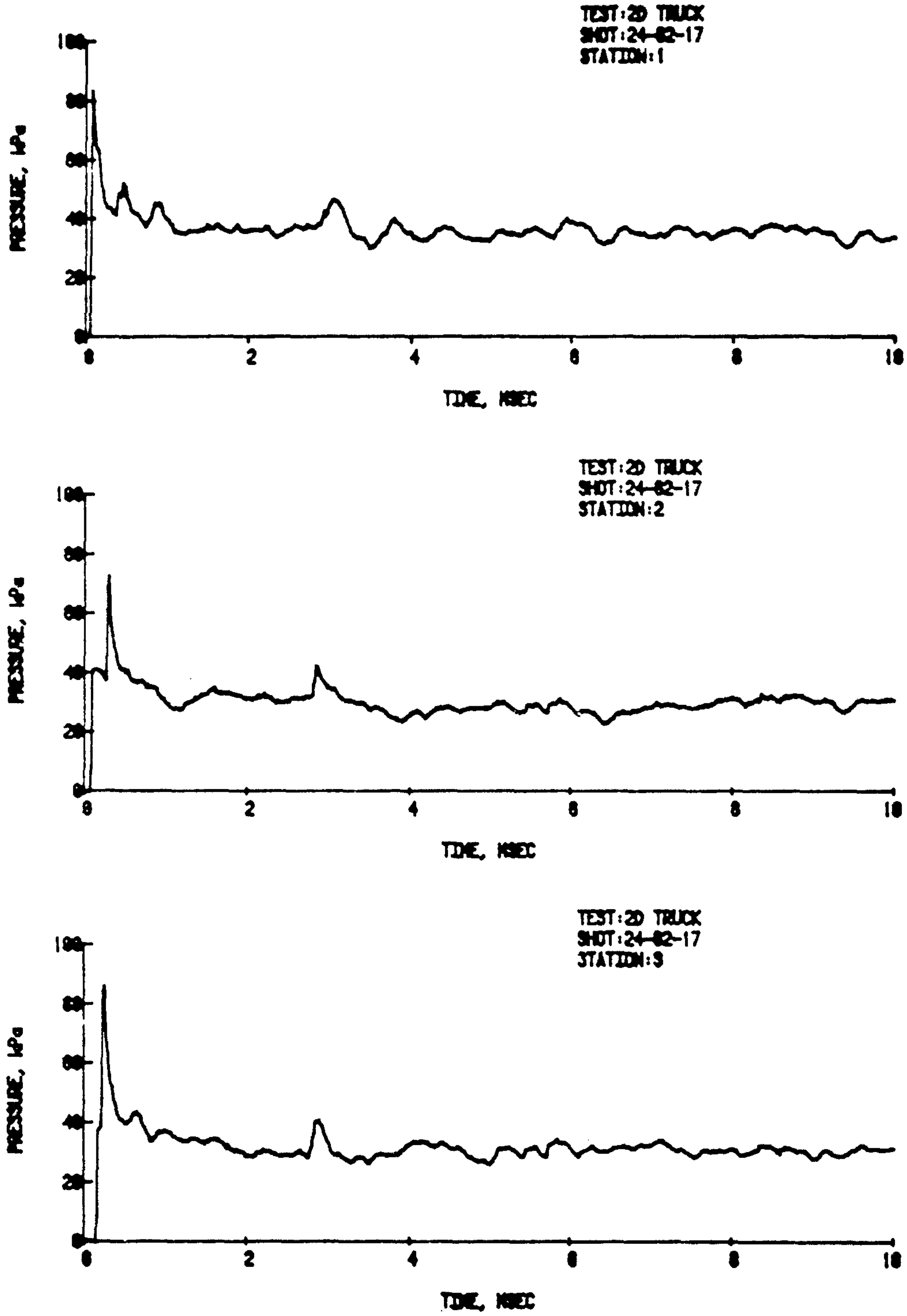
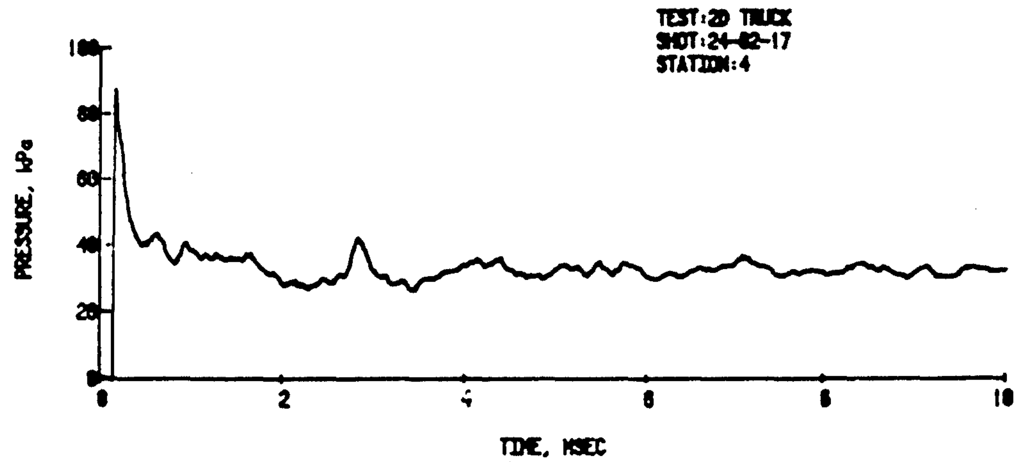
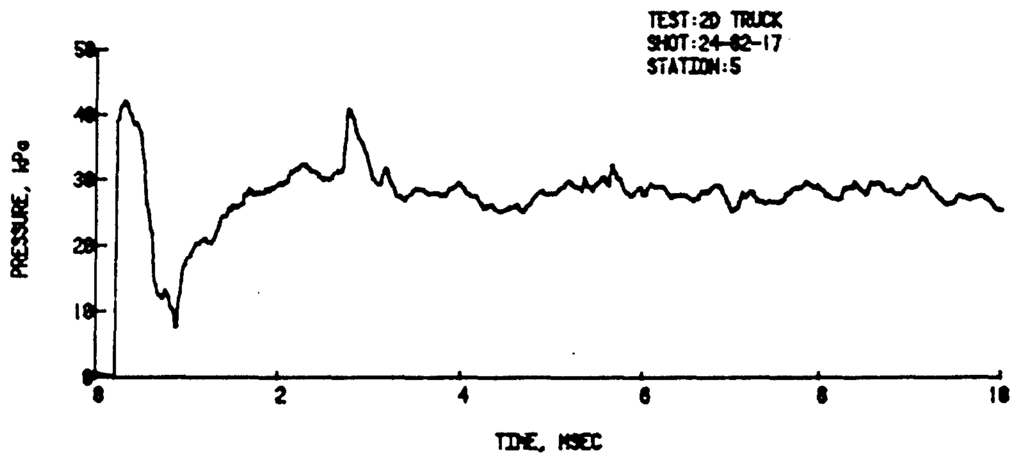


Figure B-8. Shot 24-82-17, Square Wave, Boundary Conditions Applicable, 35.3 kPa.





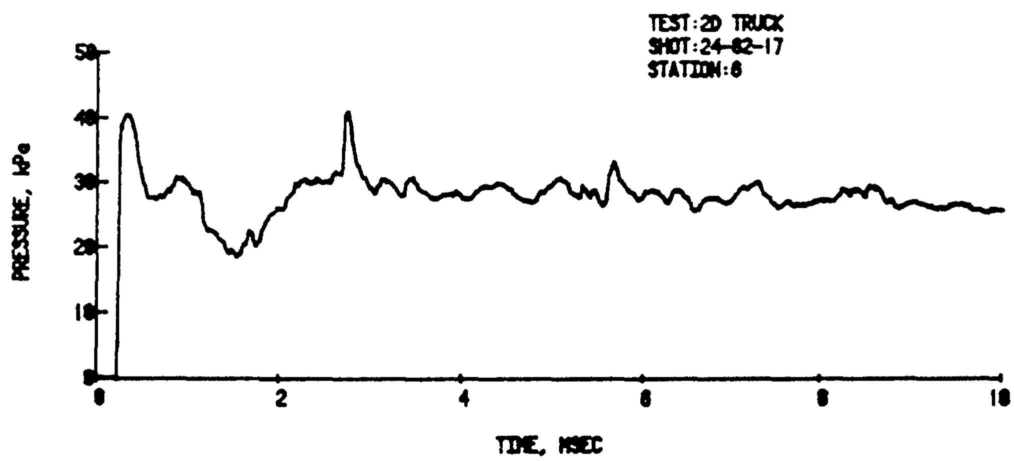
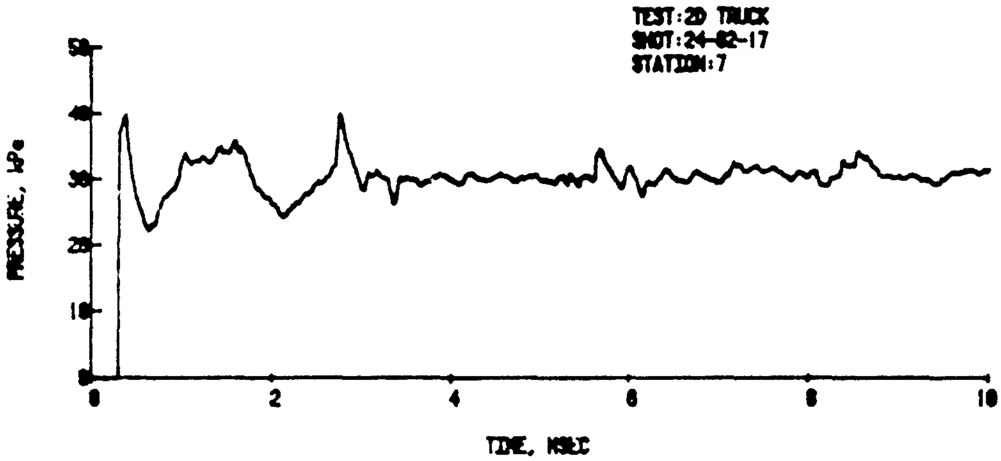
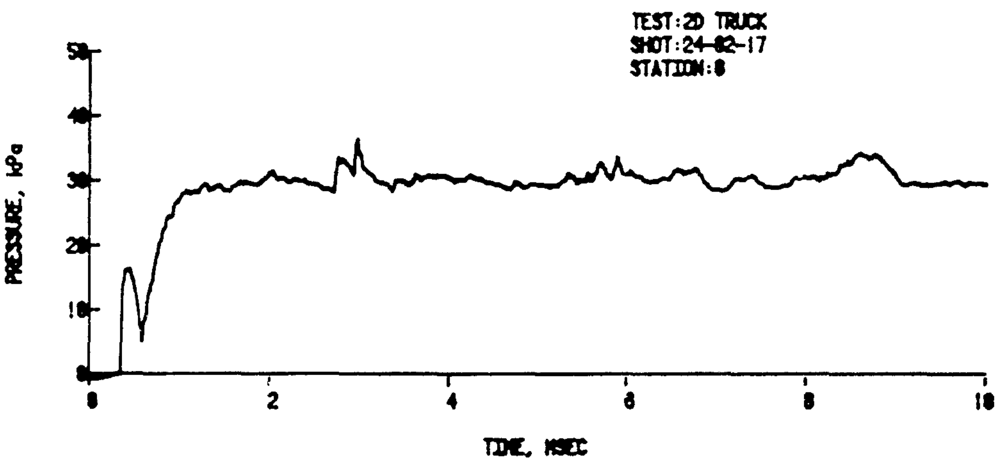


Figure B-8. Shot 24-82-17 (Cont)





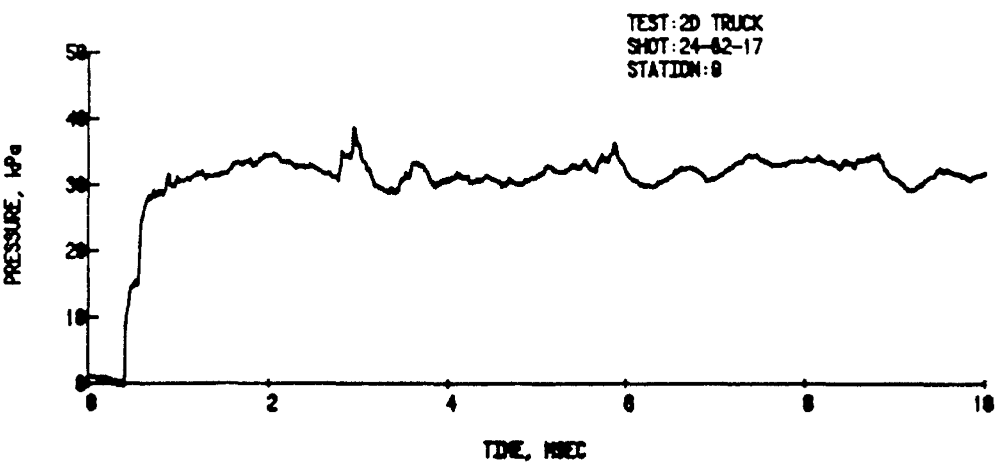
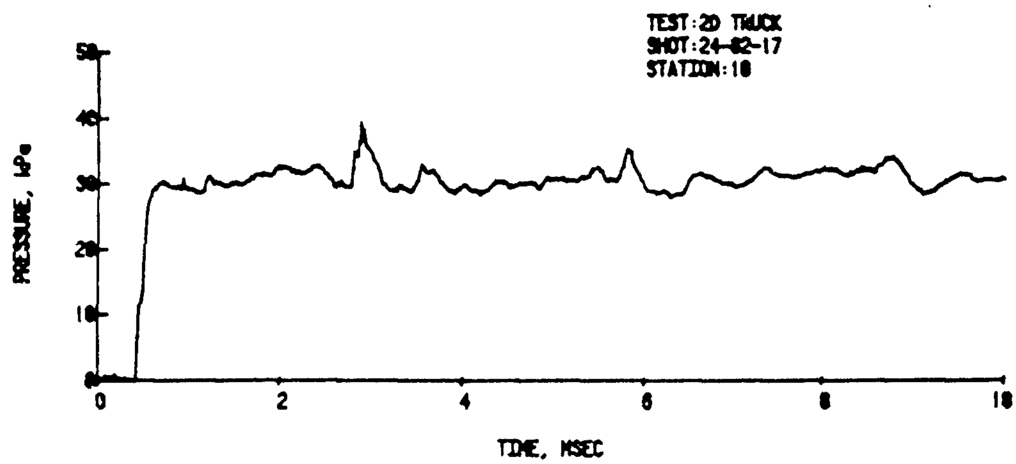
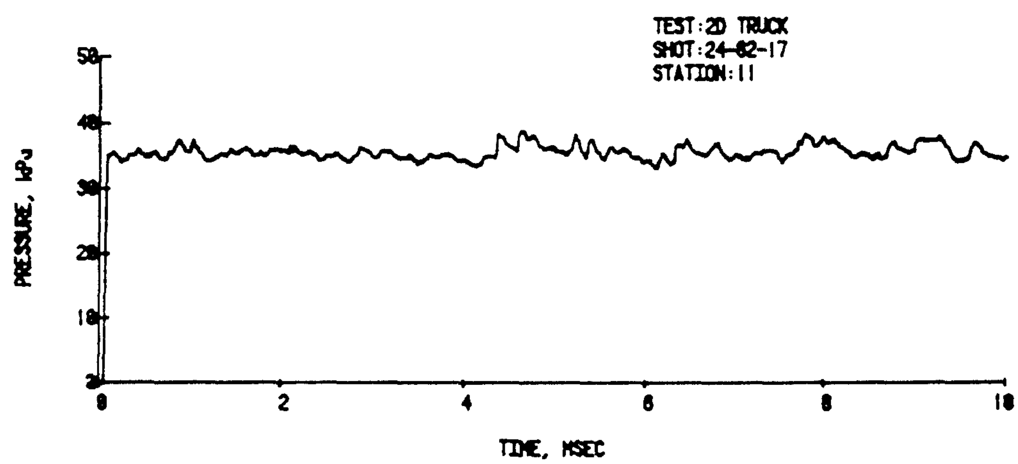


Figure B-8. Shot 24-82-17 (Cont)





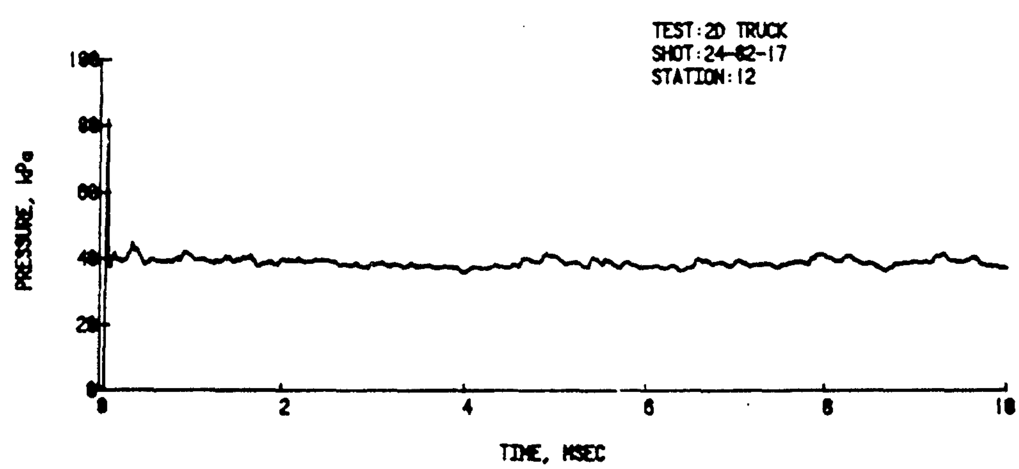


Figure B-8. Shot 24-82-17 (Cont)

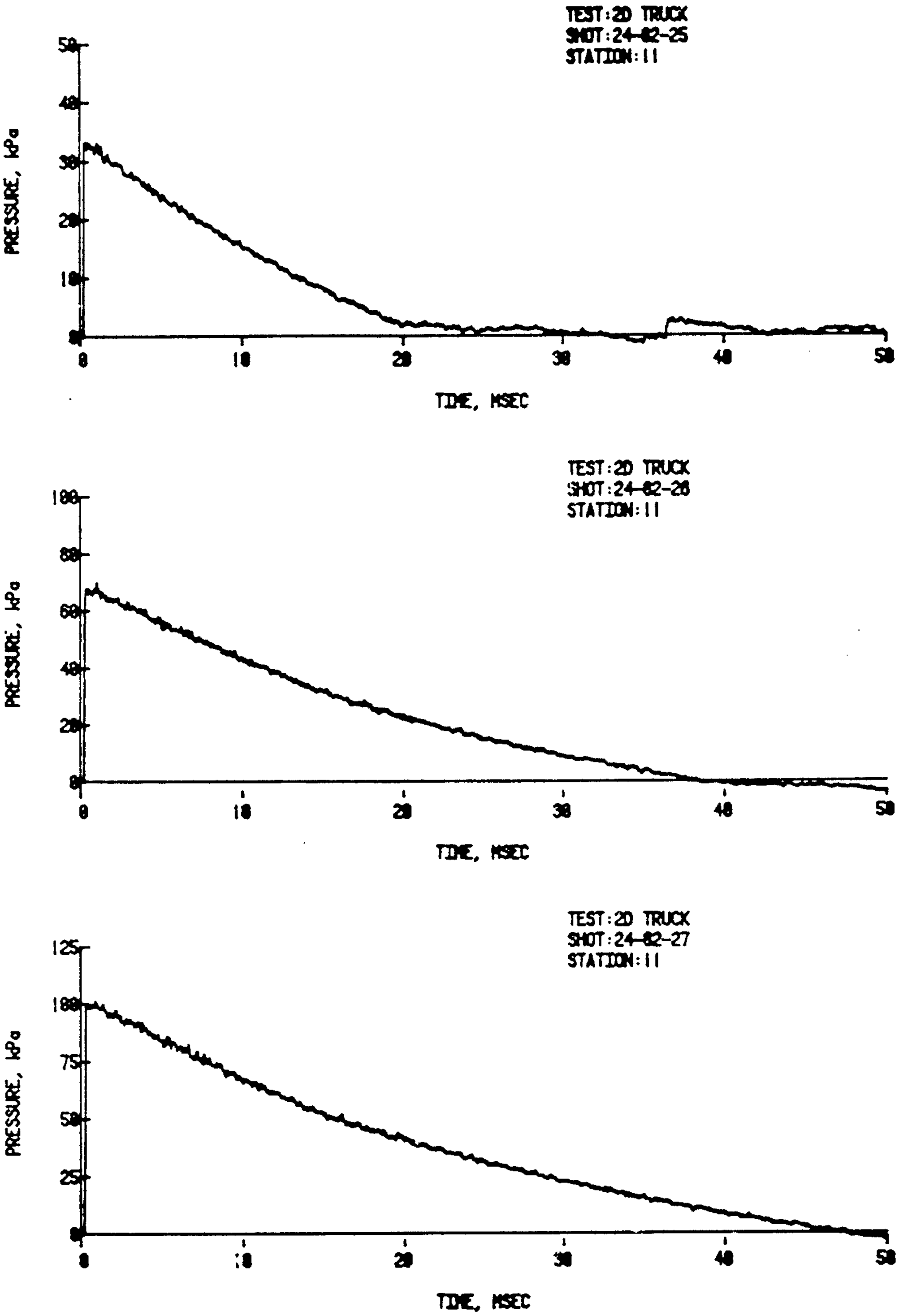


Figure B-9. Shots 24-82-25, 26, and 27; Decaying Wave, Free-Field Side-on Pressure, 33.2, 68.0, and 99.9 kPa.

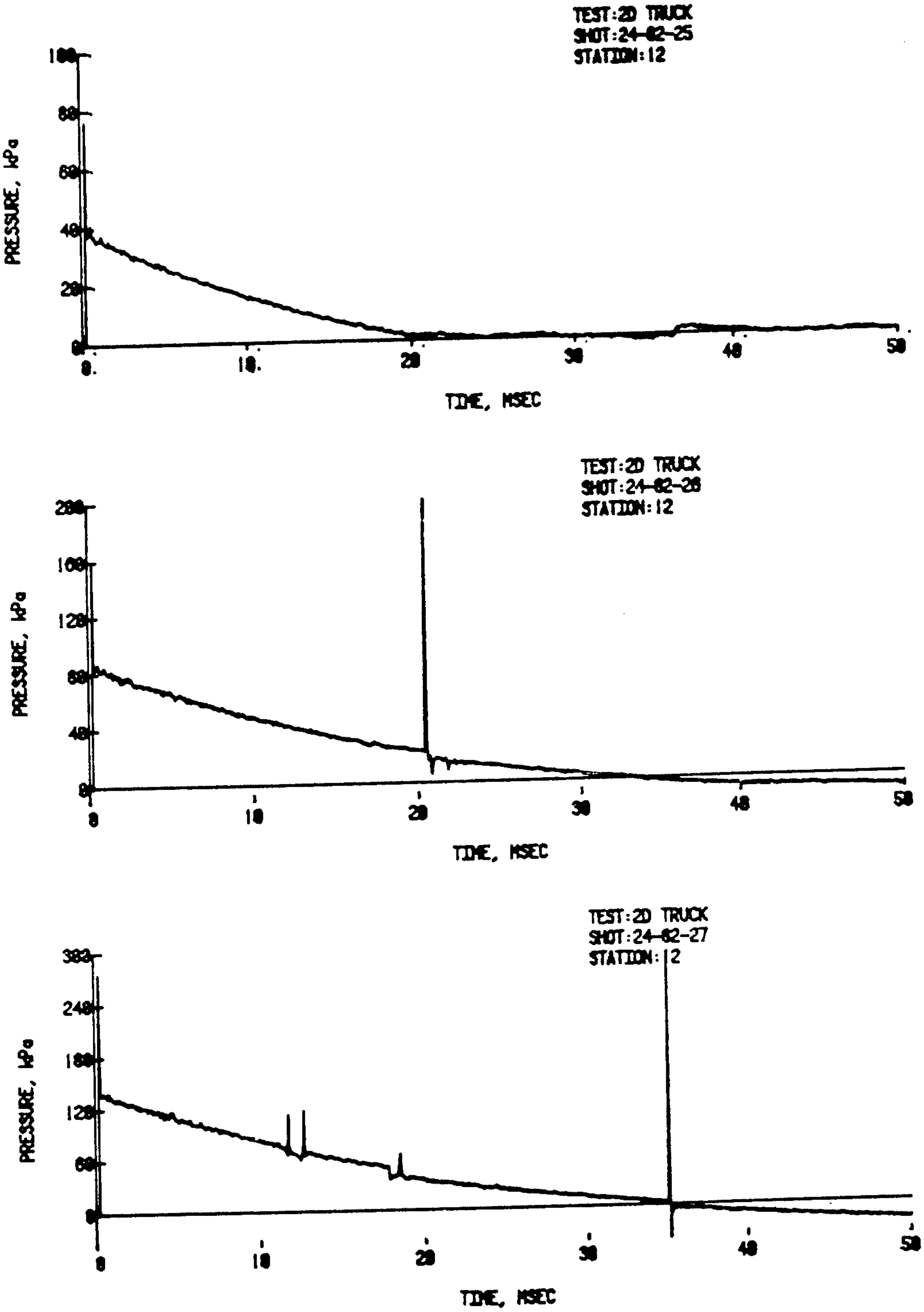


Figure B-10. Shot's 24-82-25, 26, and 27; Decaying Wave, Free-Field Stagnation Pressure, 76.3, 160.5, and 275.7 kPa

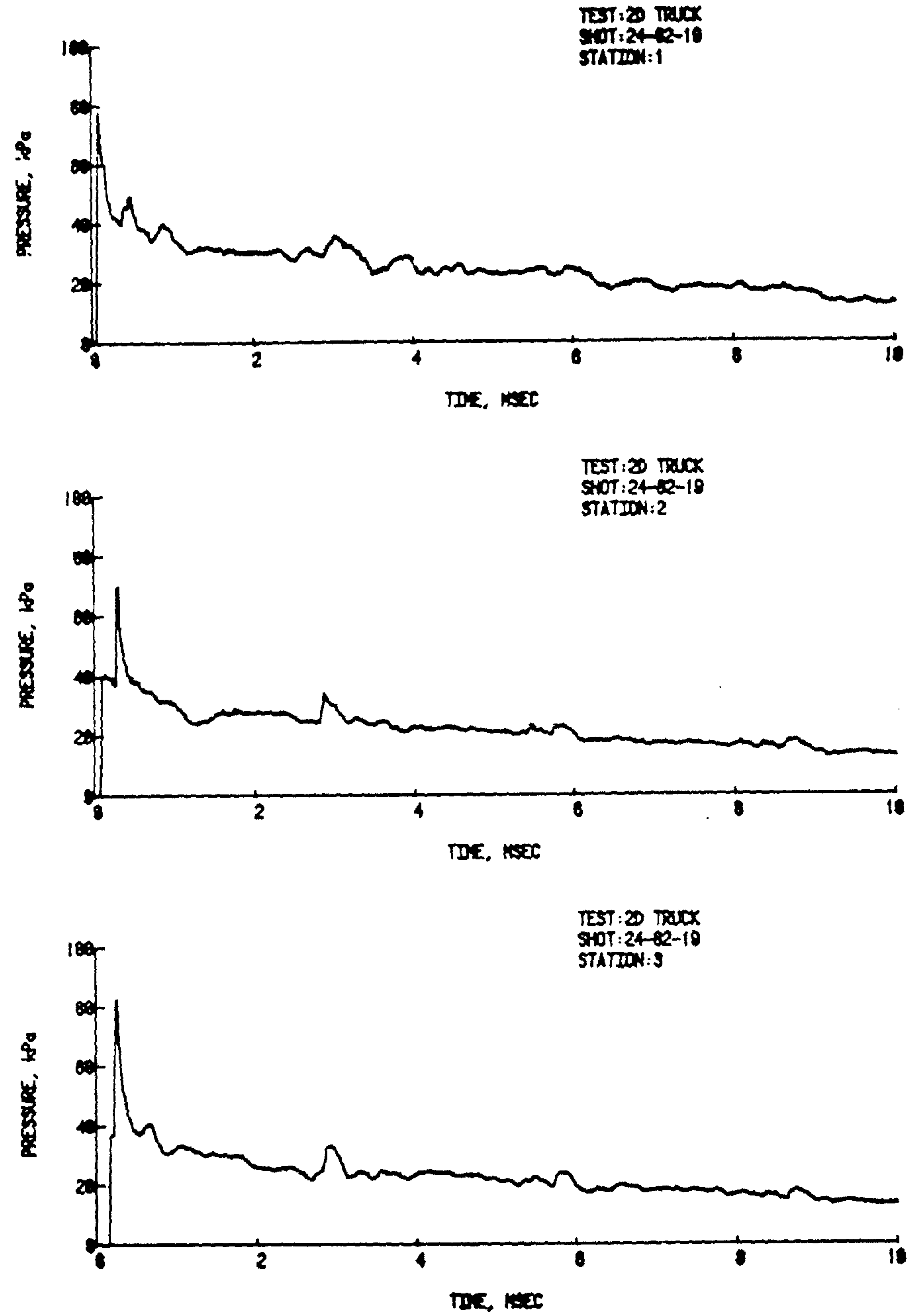
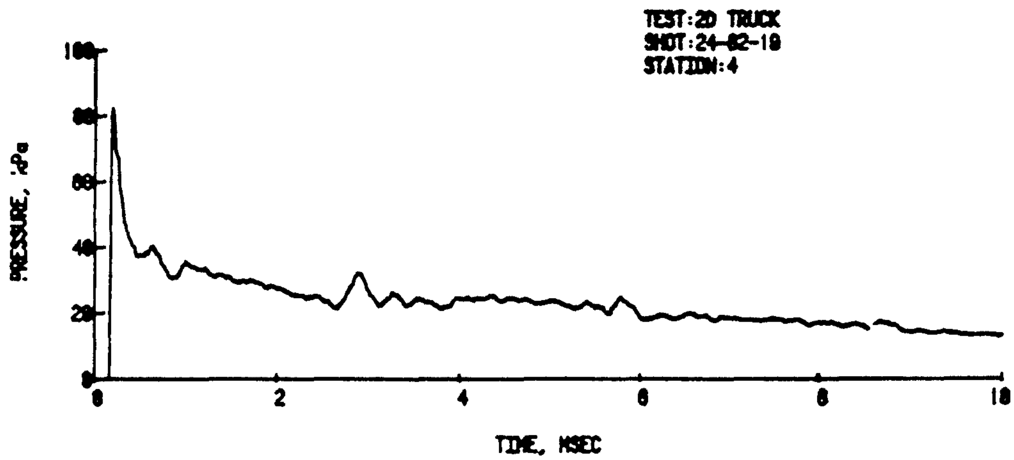
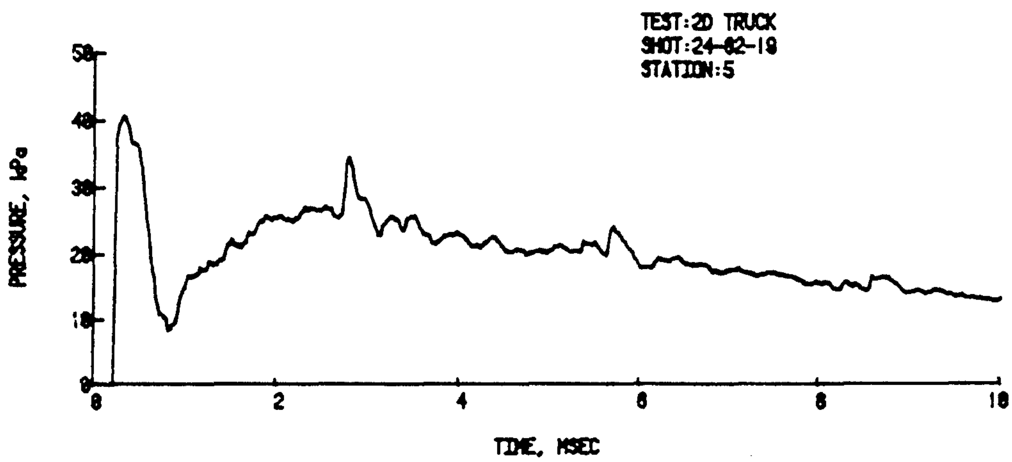


Figure B-11. Shot 24-82-19, Decaying Wave, Boundary Conditions Applicable, 33.9 kPa.





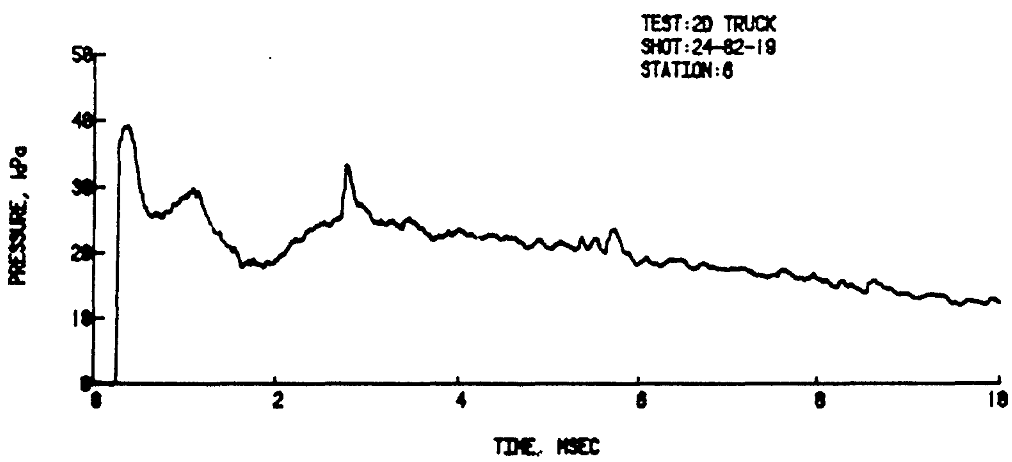
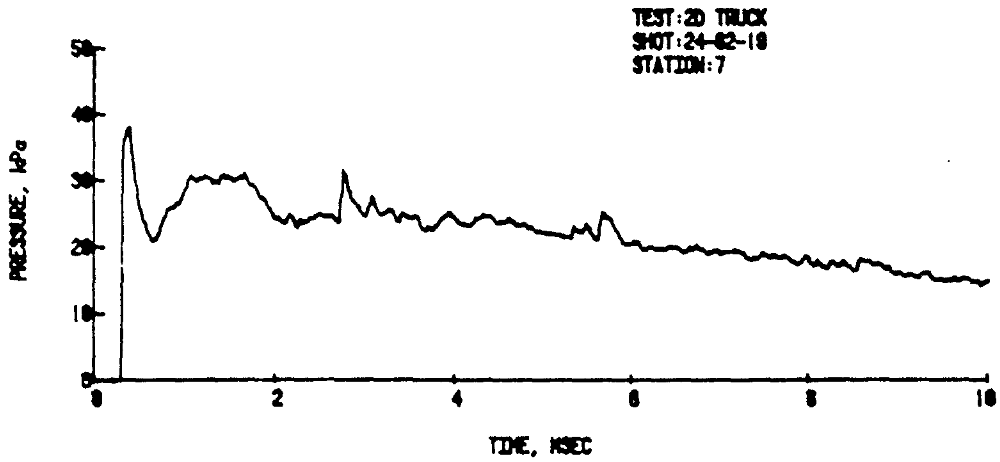
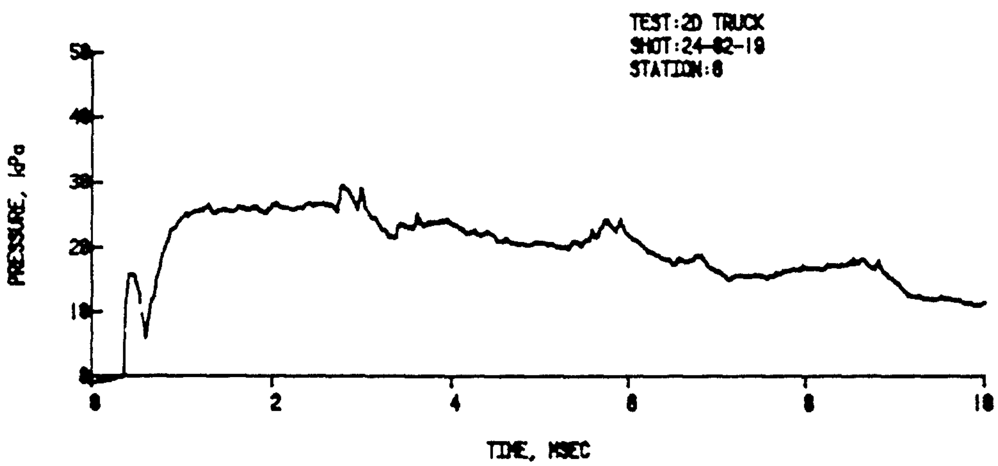


Figure B-11. Shot 24-82-19 (Cont)





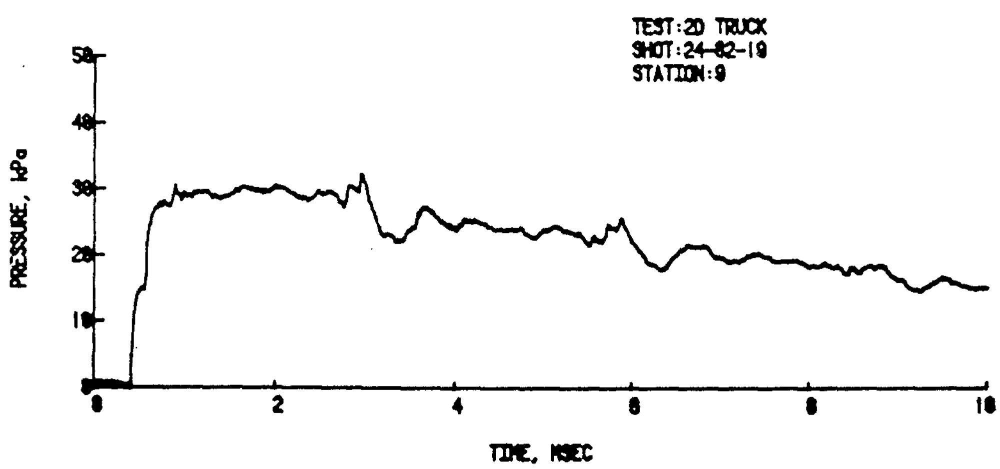
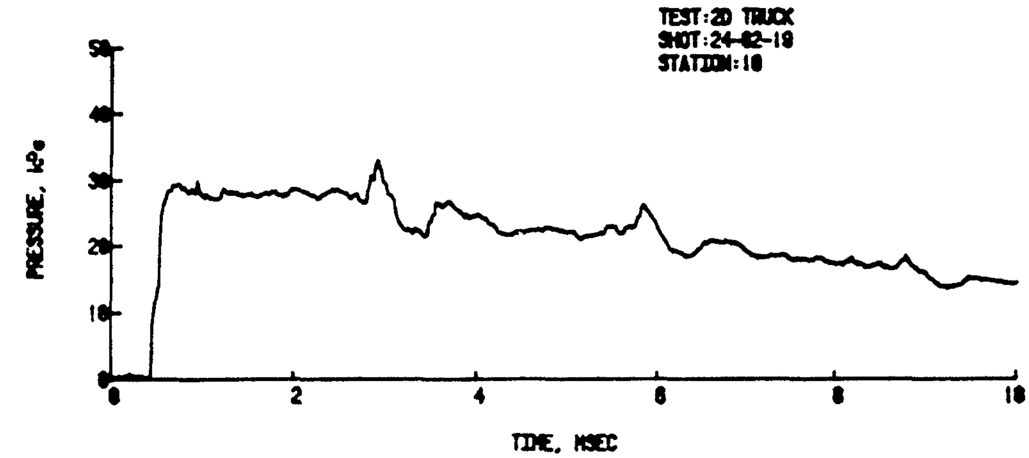
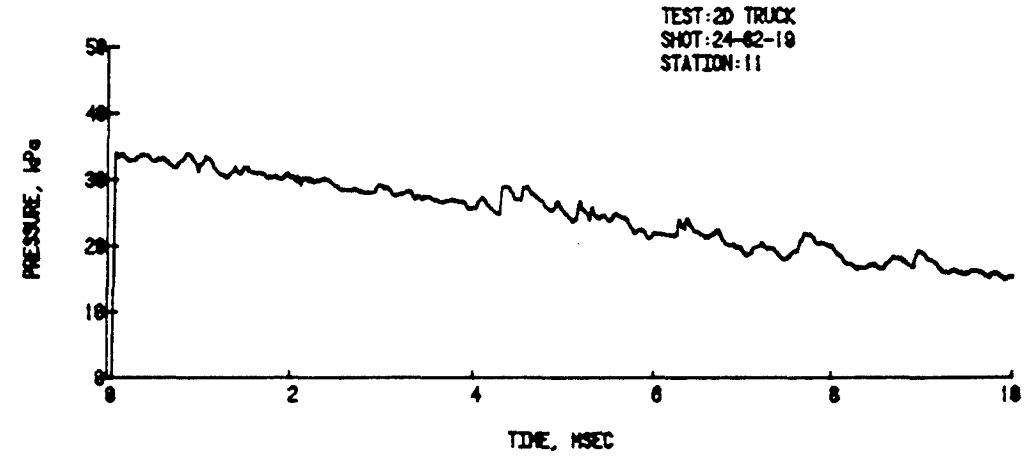


Figure B-11. Shot 24-82-19 (Cont)





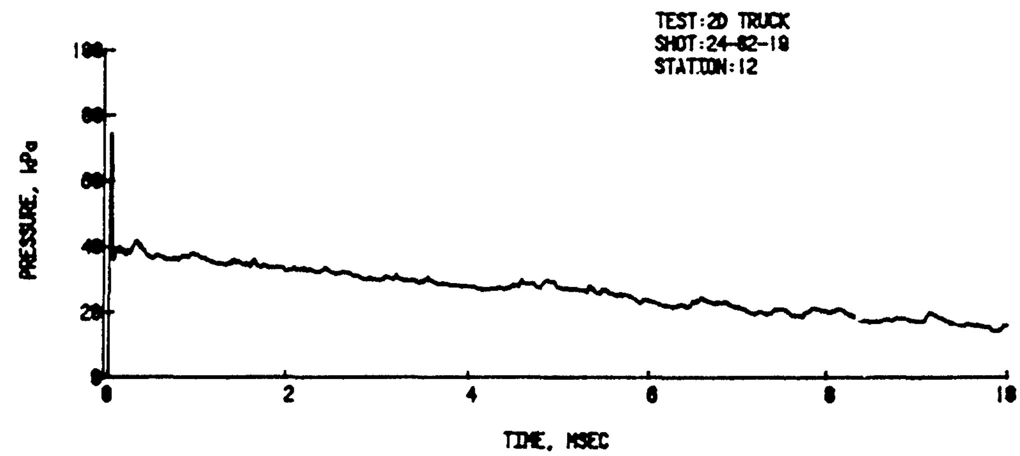


Figure B-11. Shot 24-82-19 (Cont)

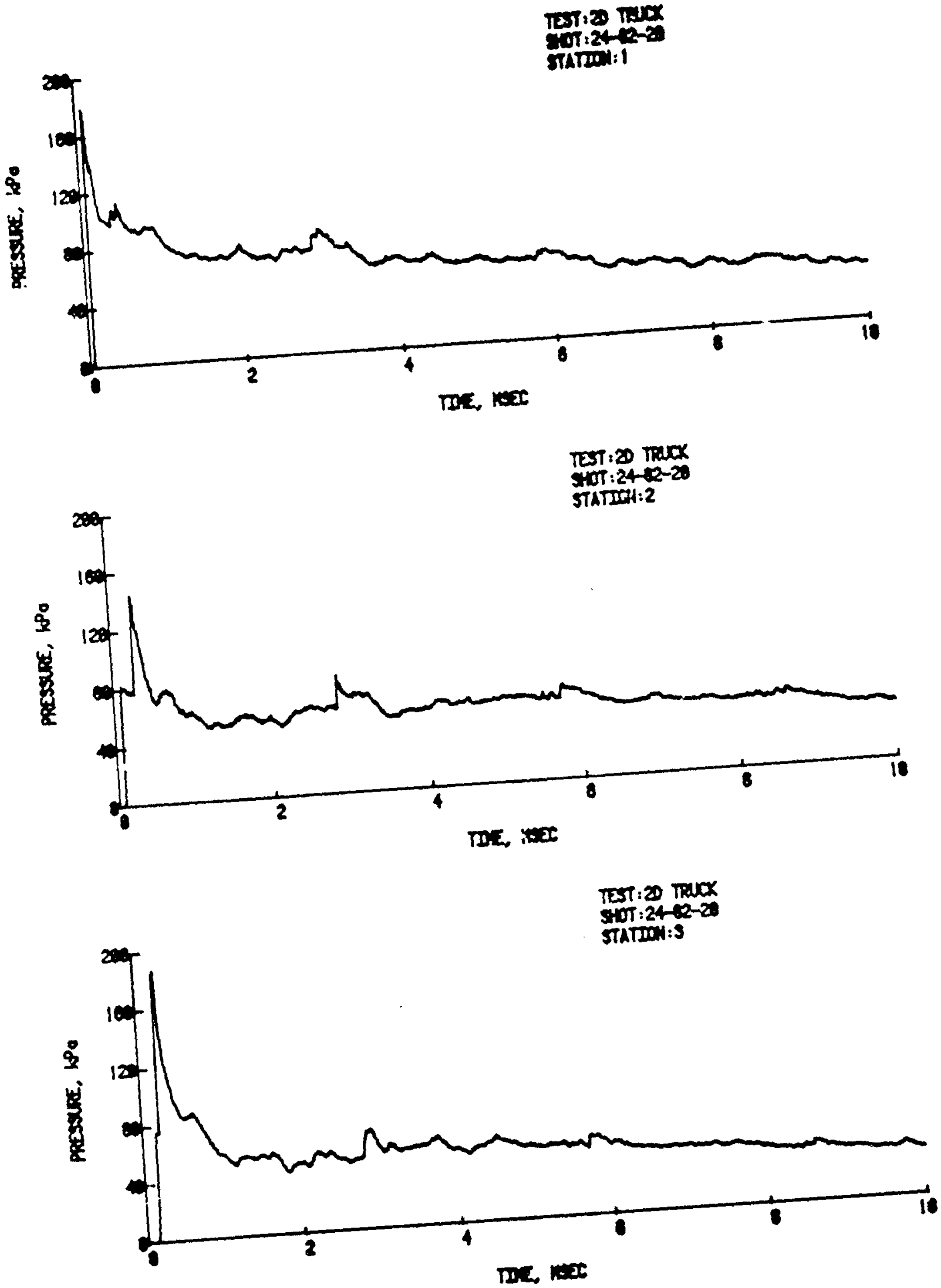
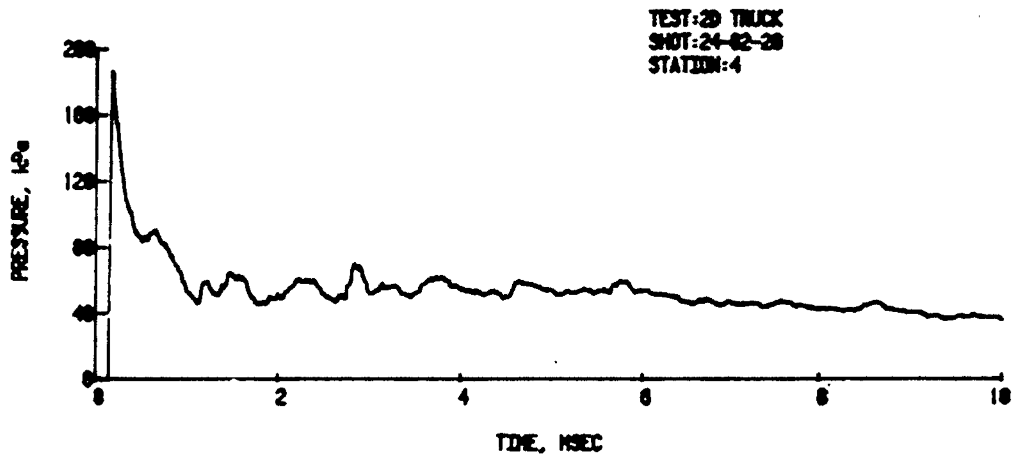
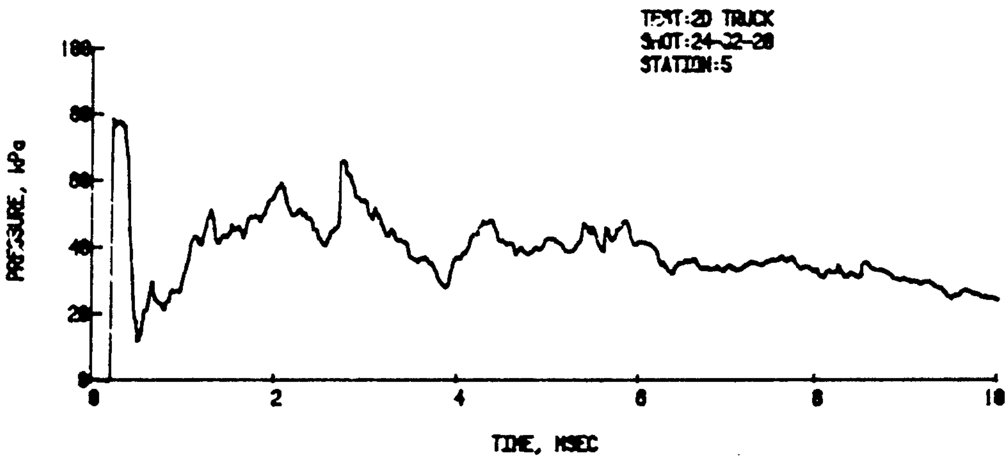


Figure B-12. Shot 24-82-20, Decaying Wave, Boundary Conditions Applicable, 70.8 kPa





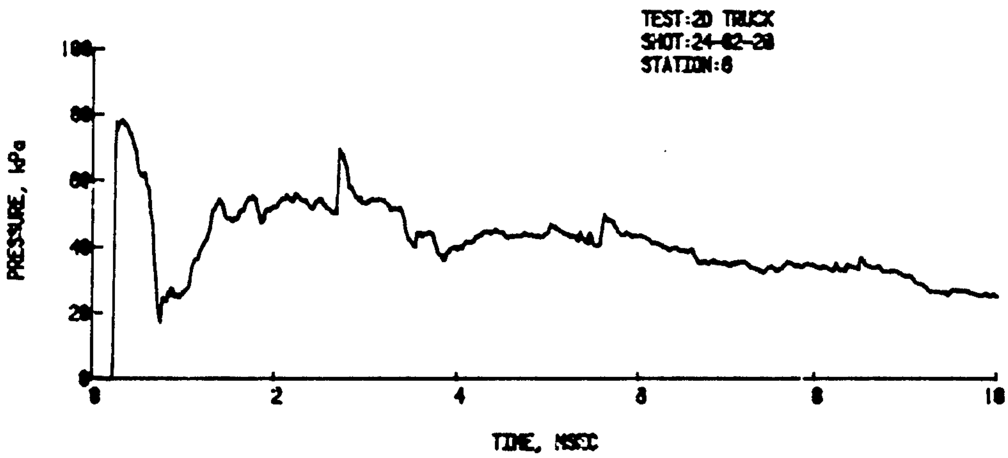


Figure B-12. Shot 24-82-20 (Cont)

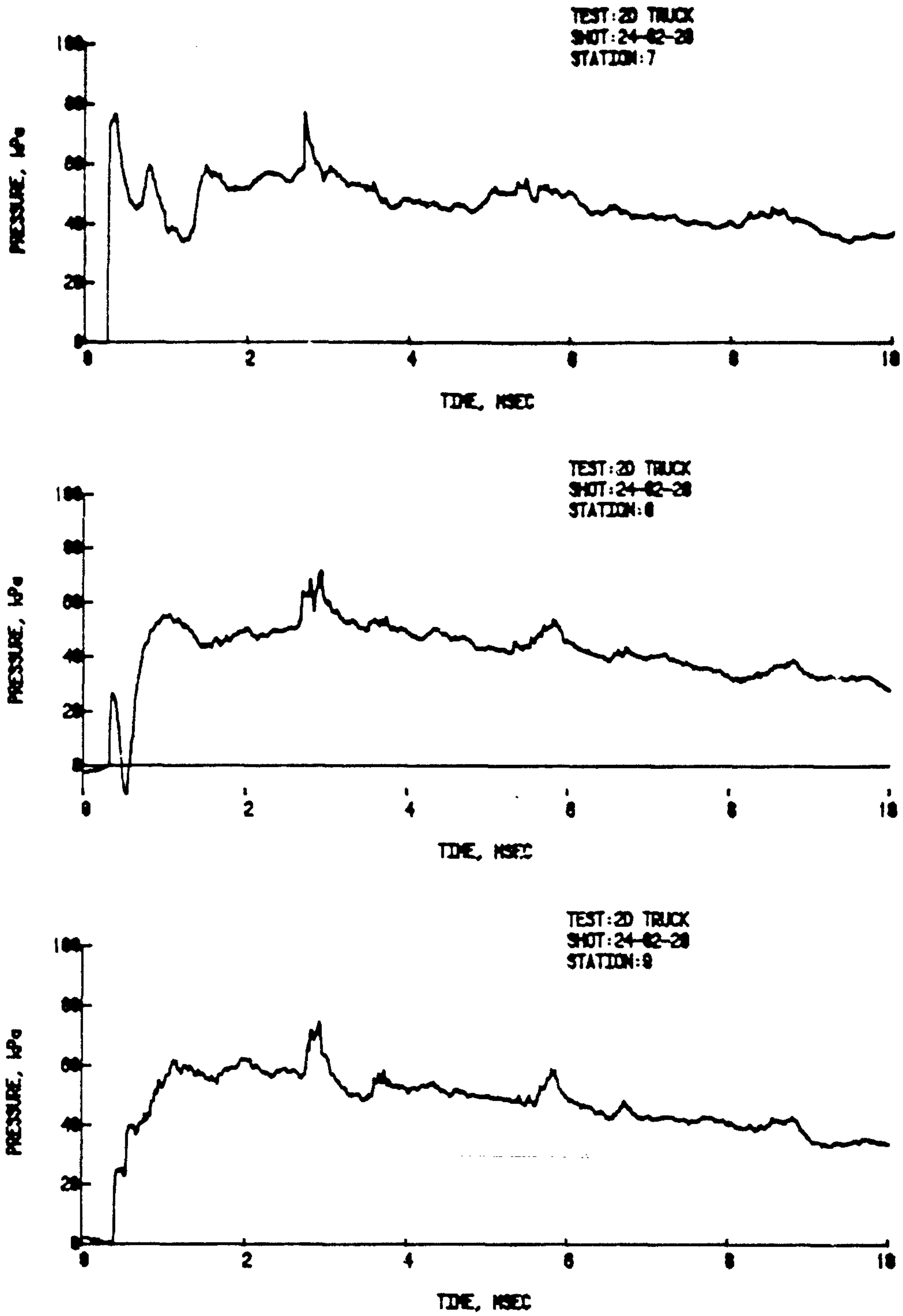


Figure B-12. Shot 24-82-20 (Cont)

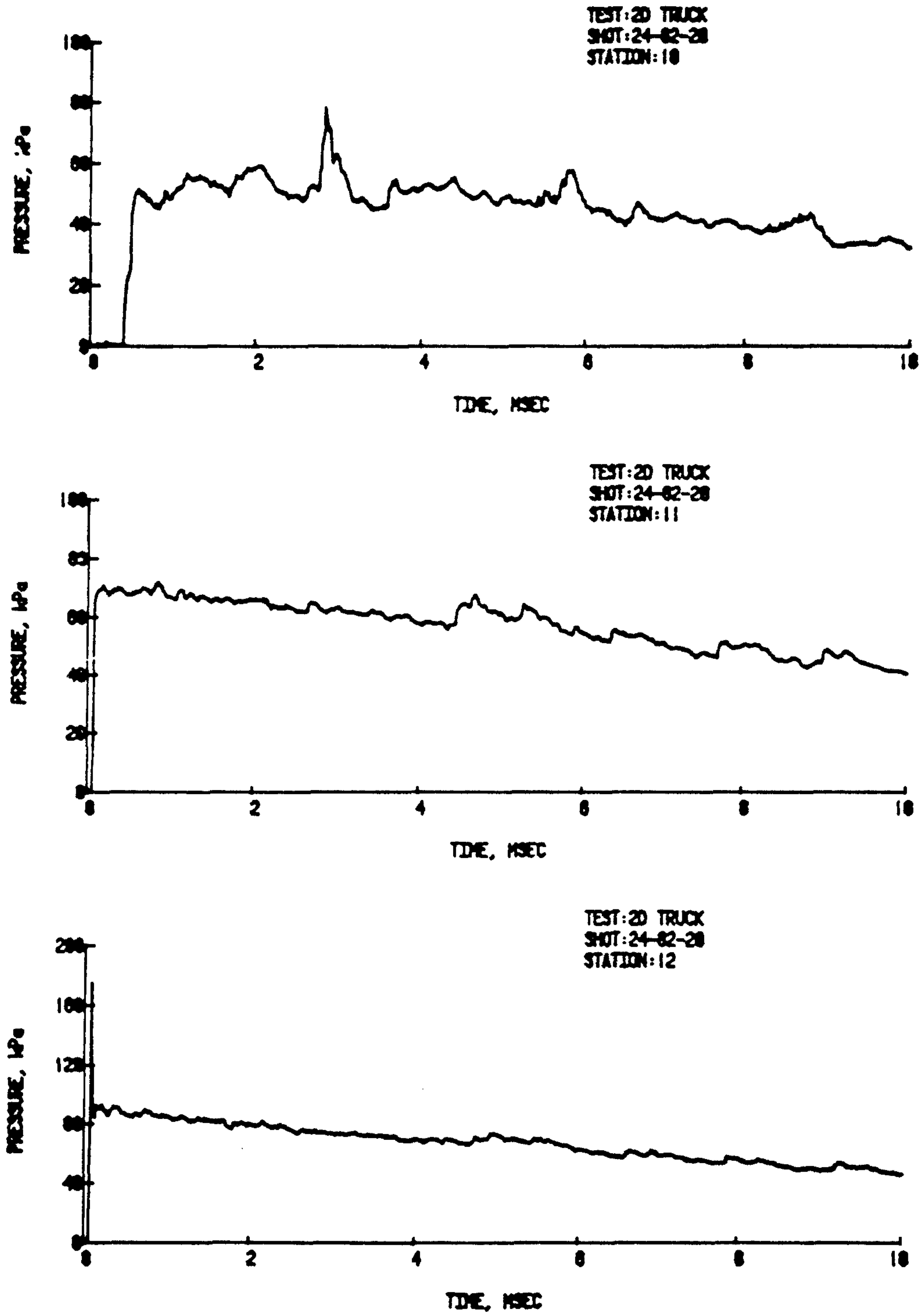


Figure B-12. Shot 24-82-20 (Cont)

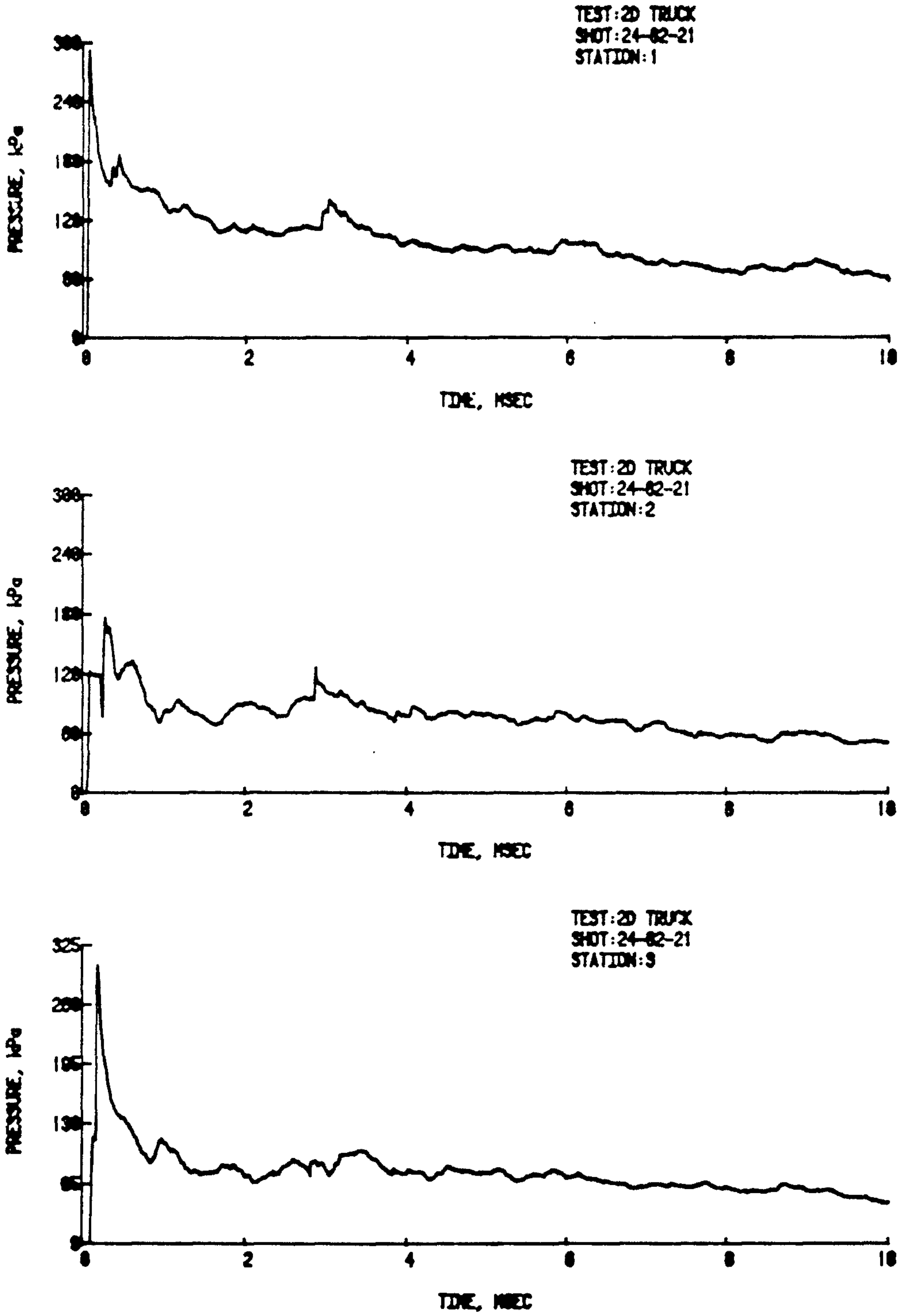
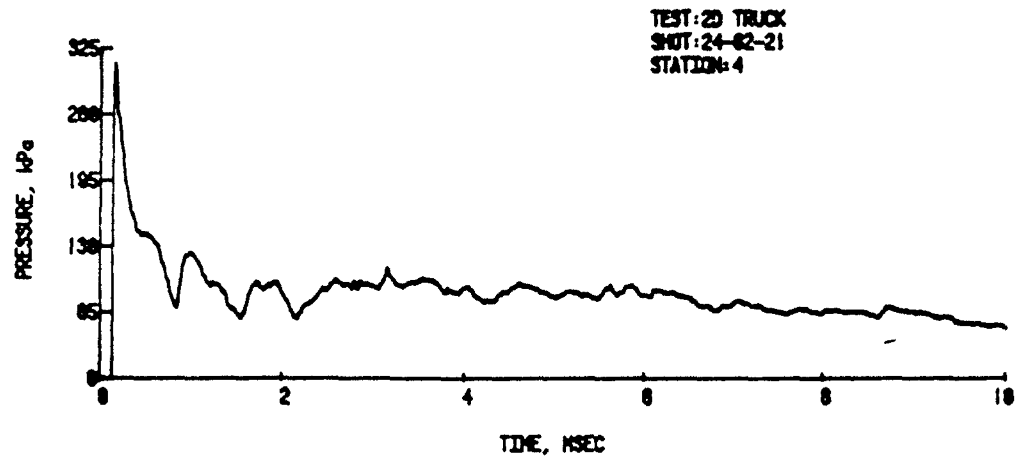
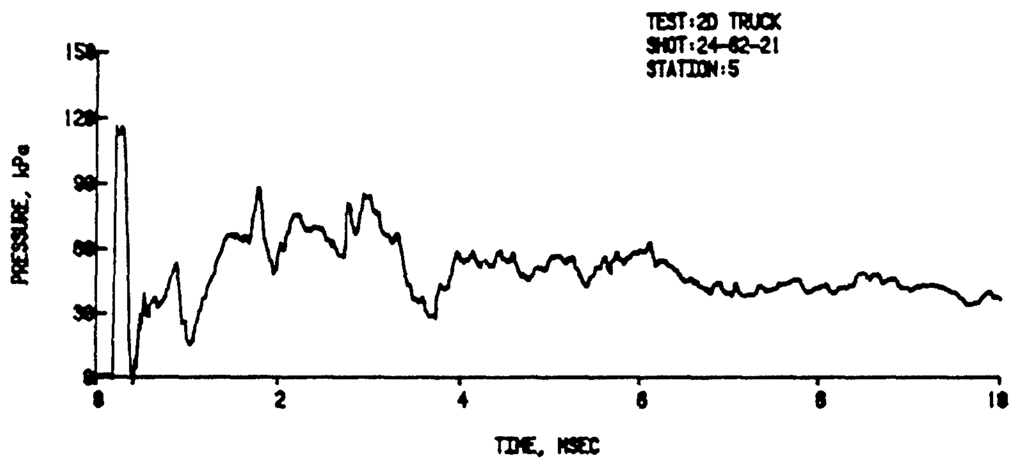


Figure B-13. Shot 24-82-21, Decaying Wave, Boundary Conditions Applicable, 104.5 kPa





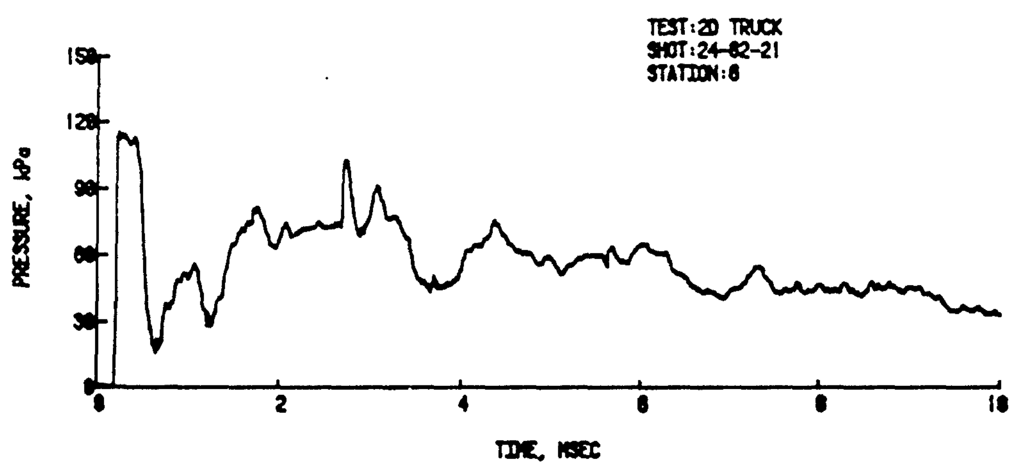
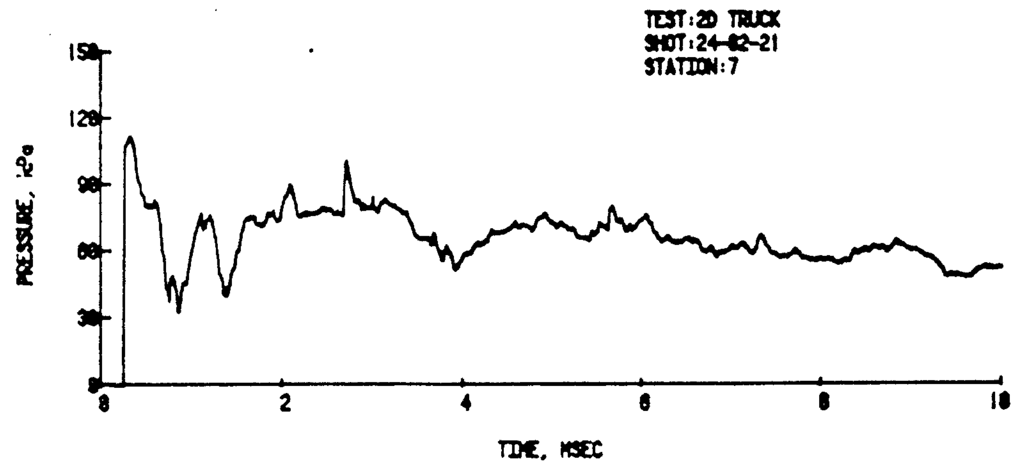
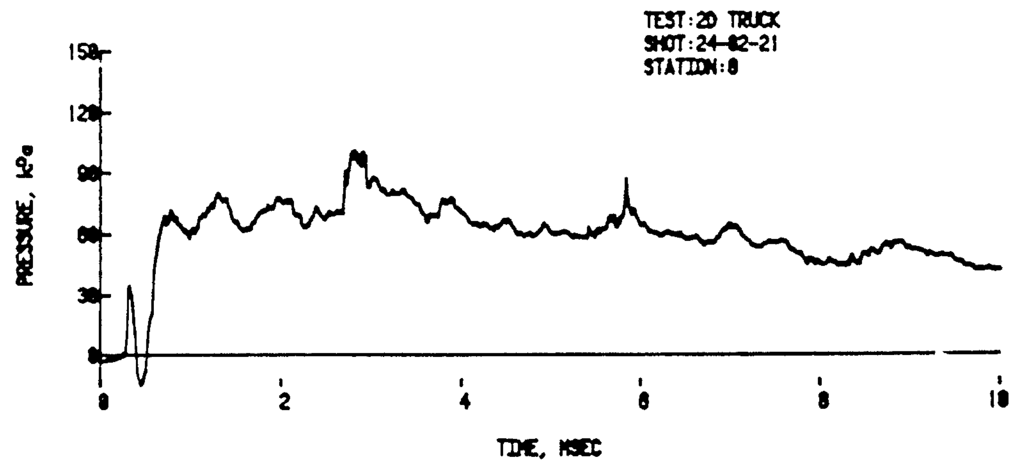


Figure B-13. Shot 24-82-21 (Cont)





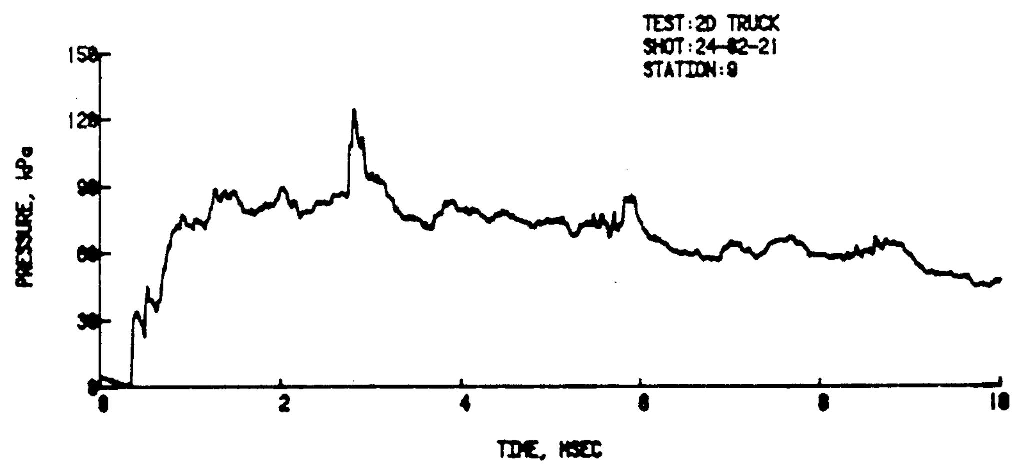
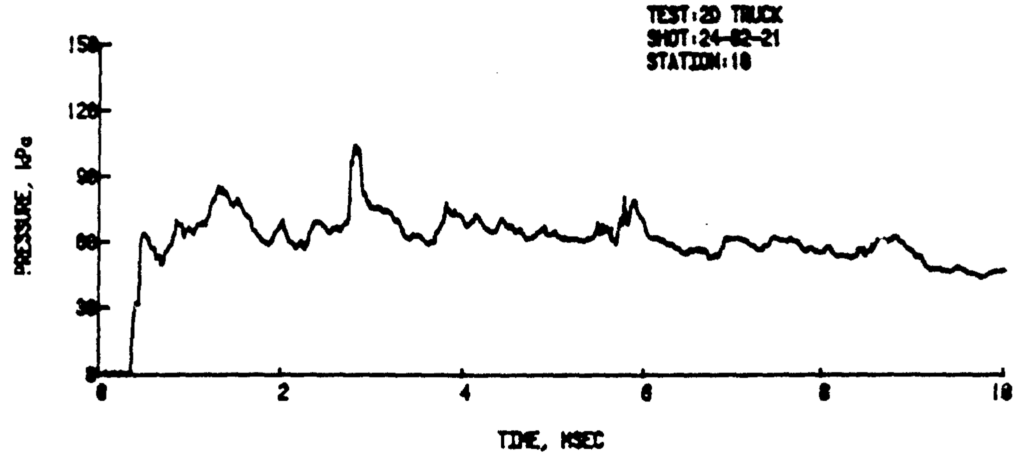
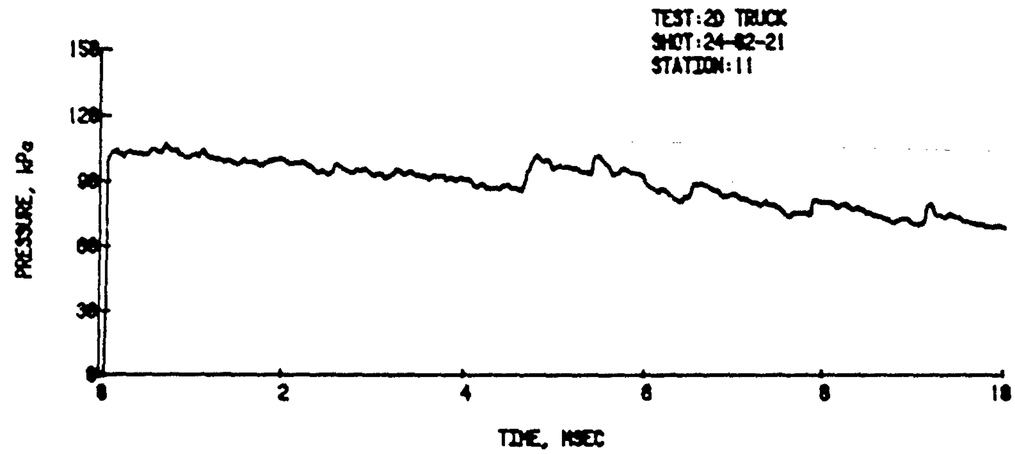


Figure B-13. Shot 24-82-21 (Cont)





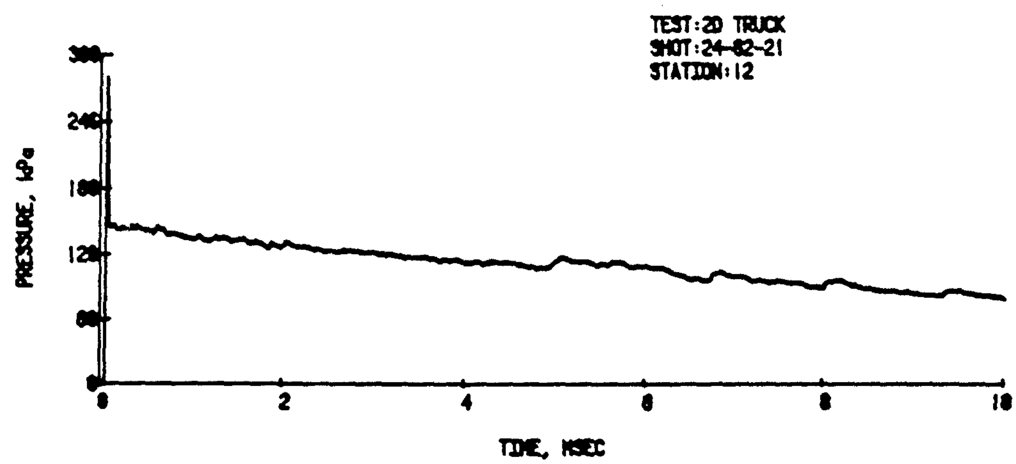


Figure B-13. Shot 24-82-21 (Cont)

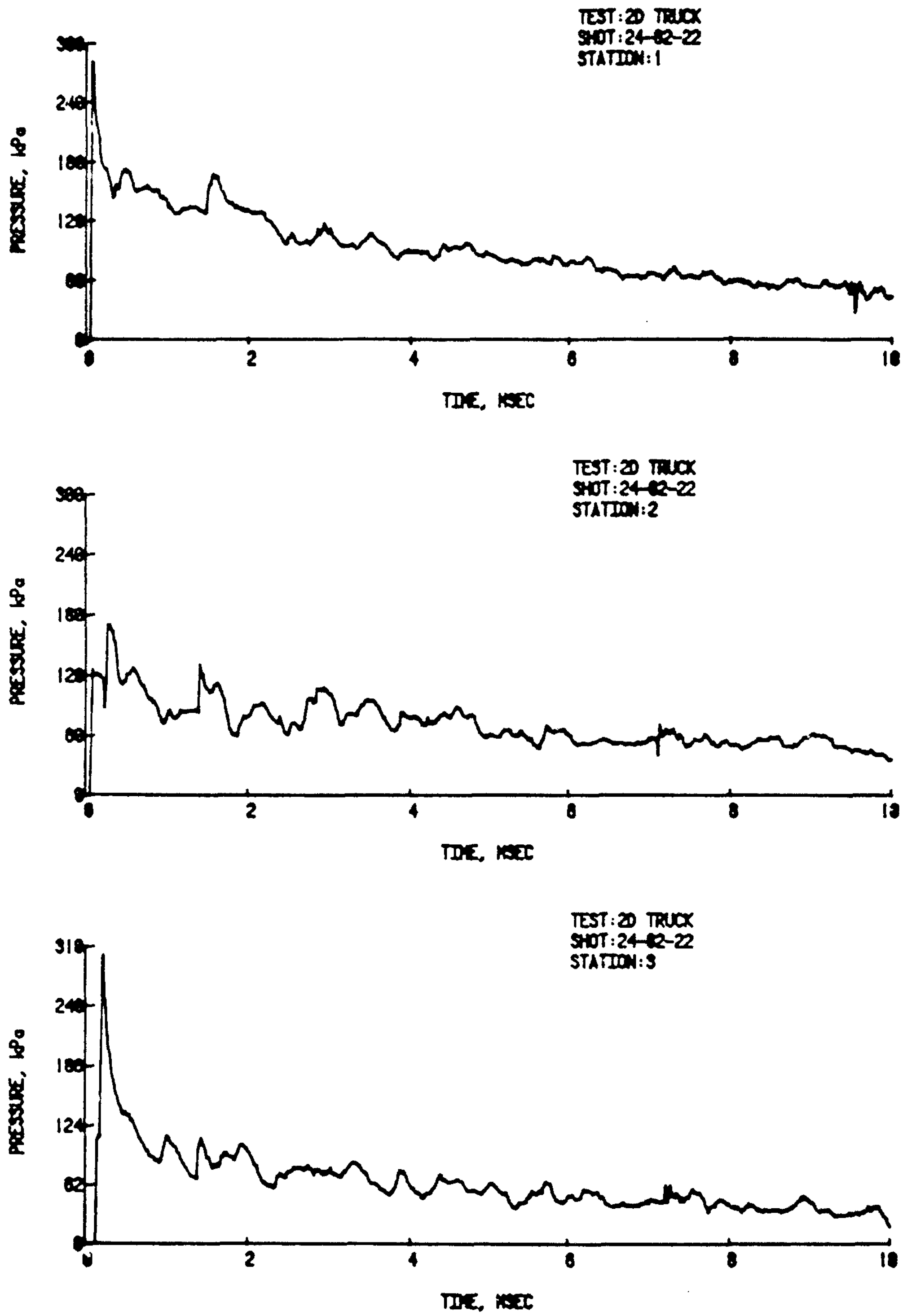
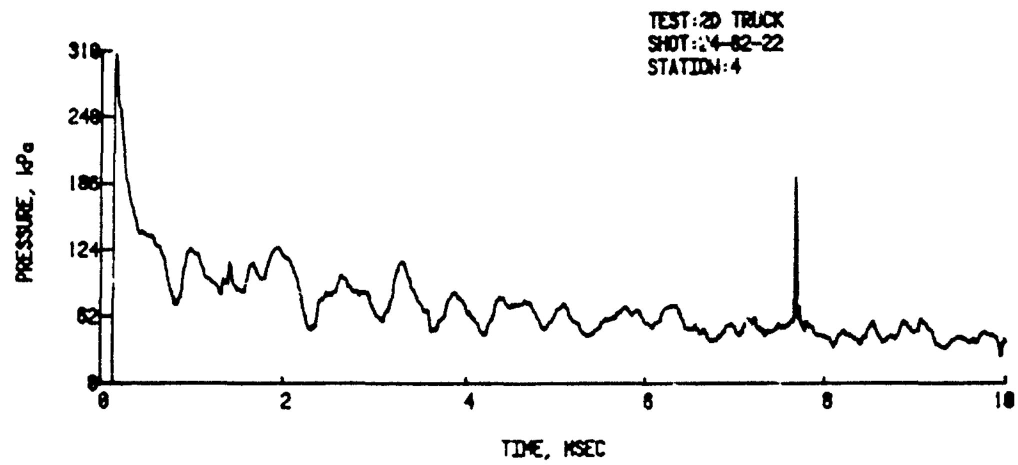
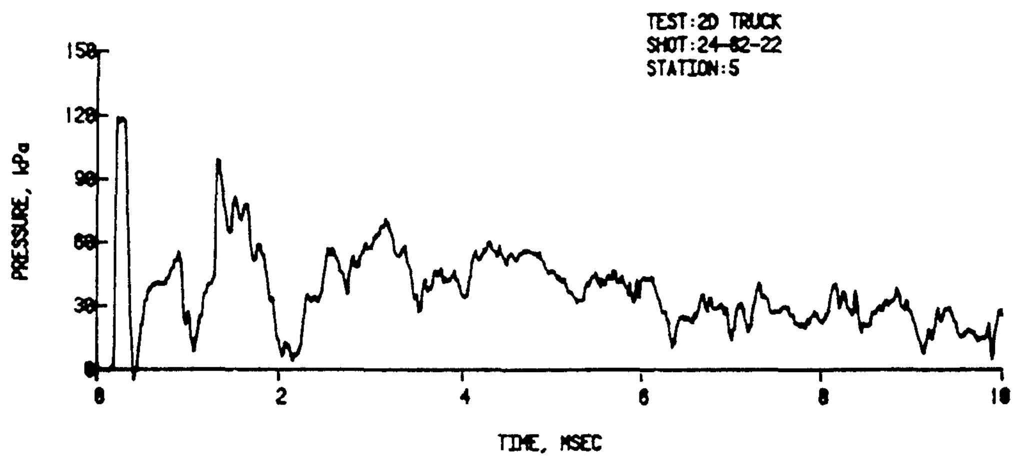


Figure B-14. Shot 24-82-22, Decaying Wave, Boundary Conditions Inapplicable, 103.1 kPa





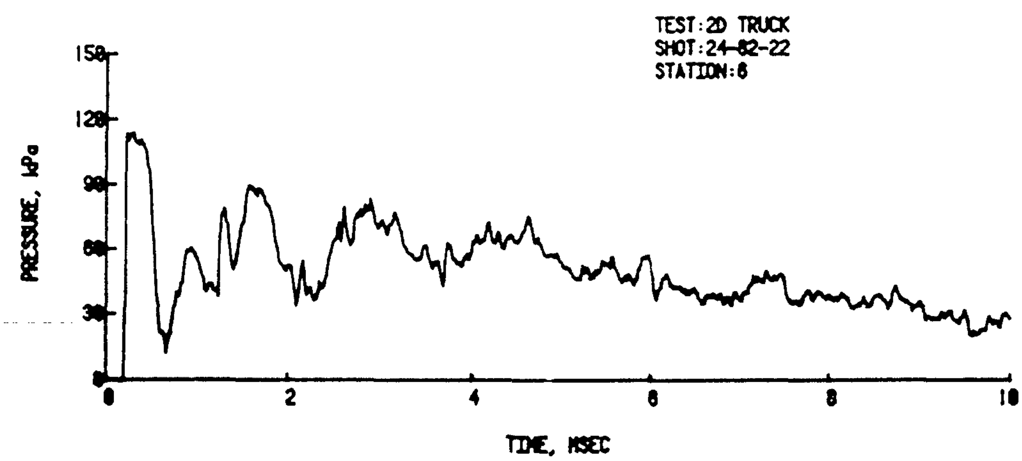
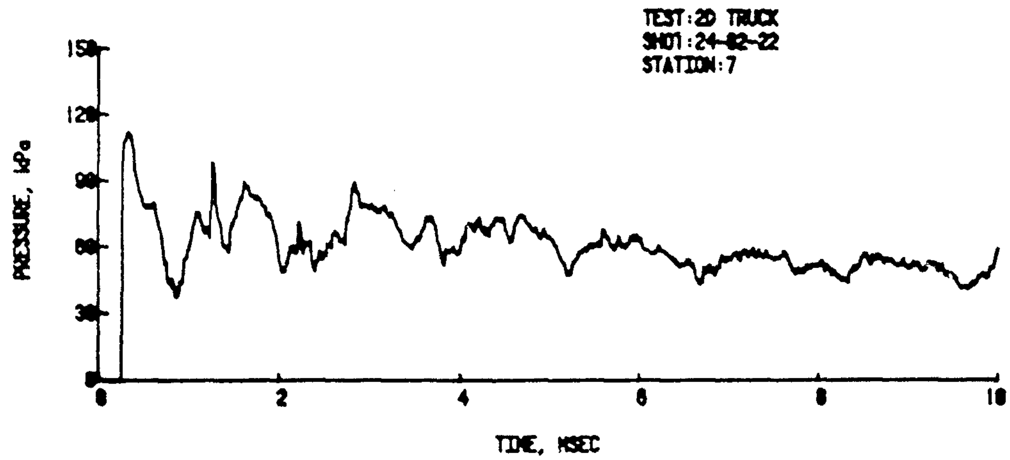
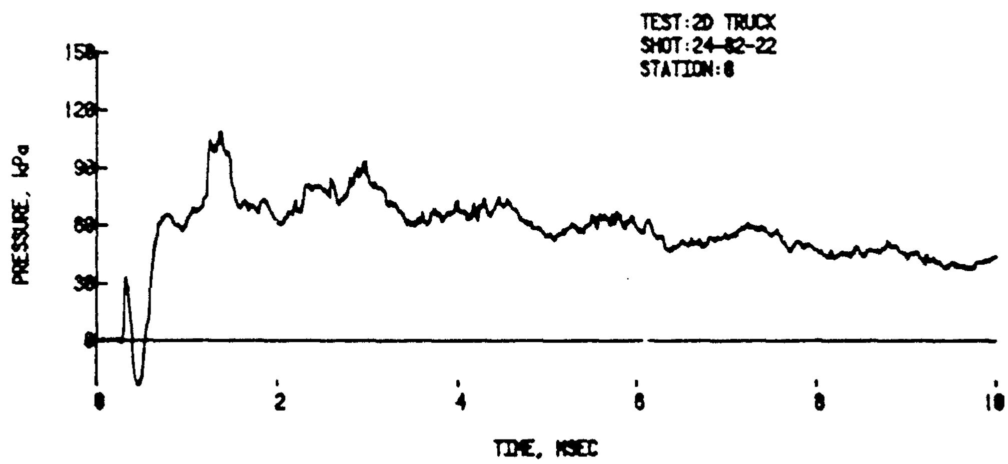


Figure B-14. Shot 24-82-22 (Cont)





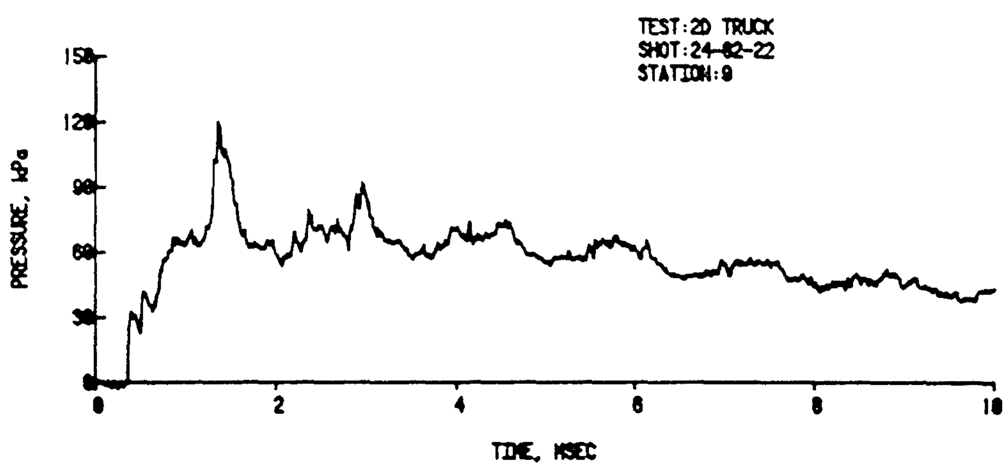
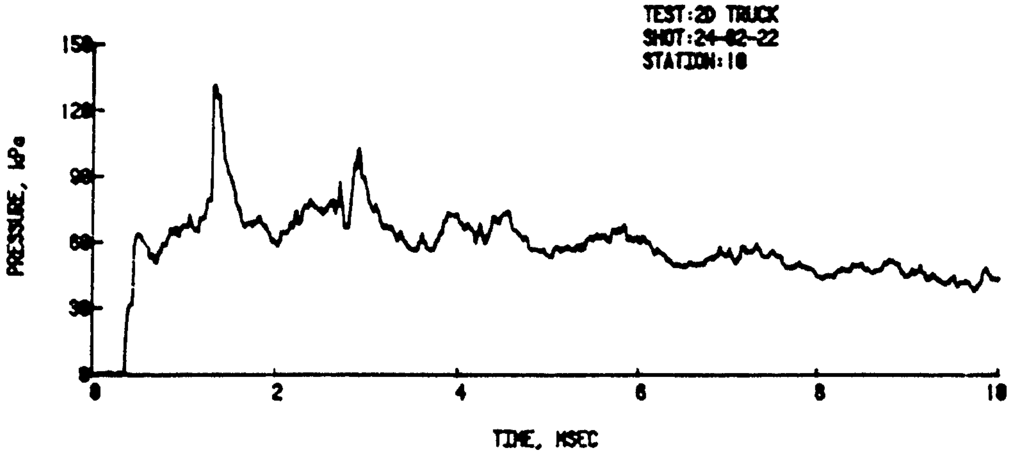
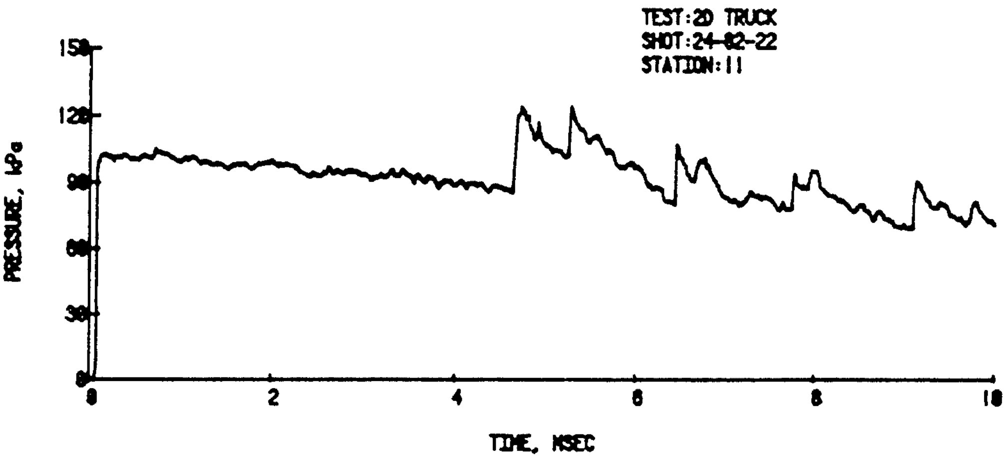


Figure B-14. Shot 24-82-22 (Cont)





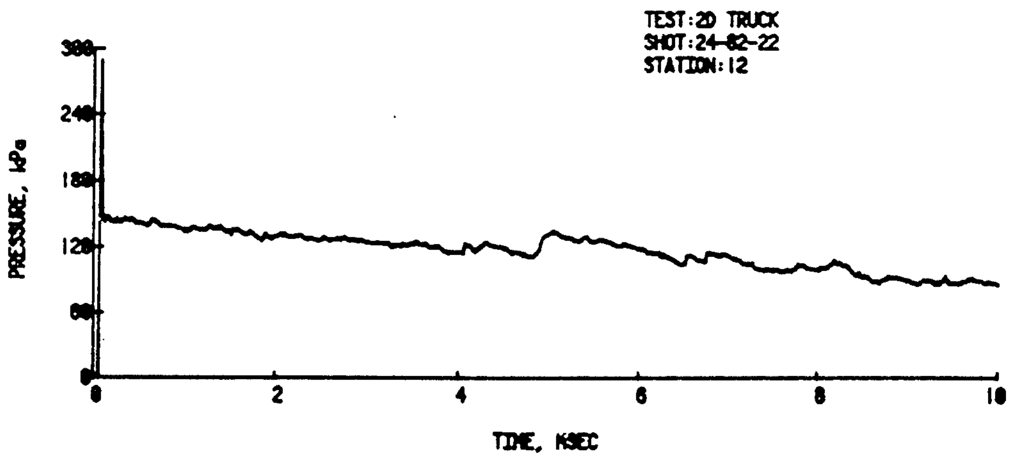


Figure B-14. Shot 24-82-22 (Cont)

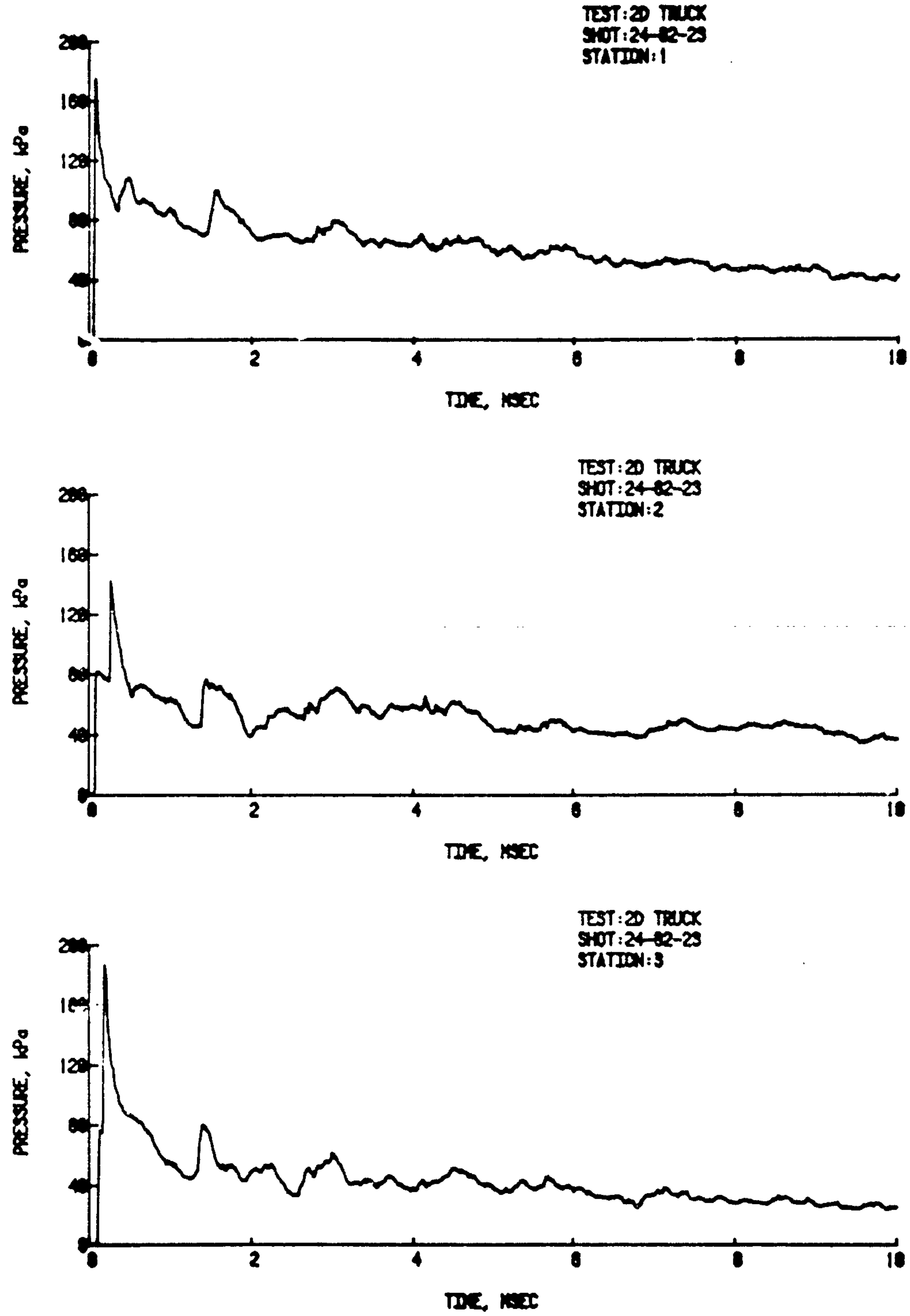
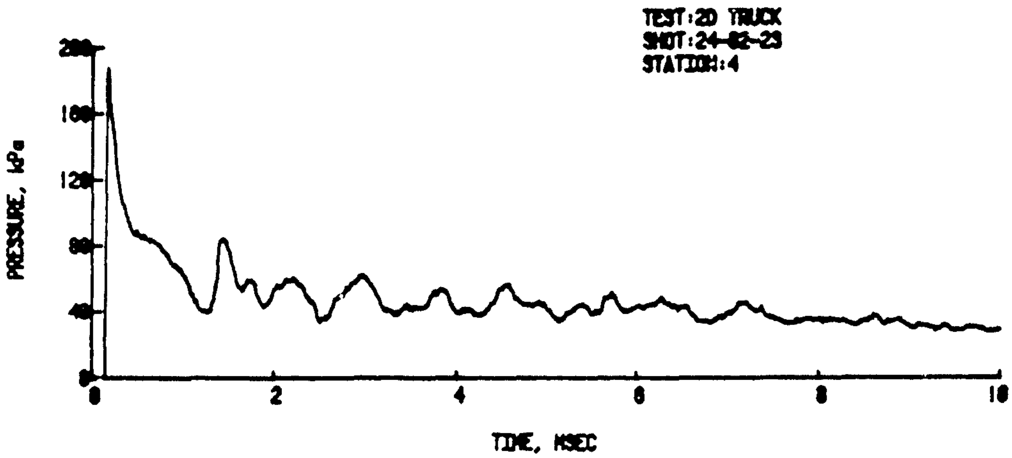
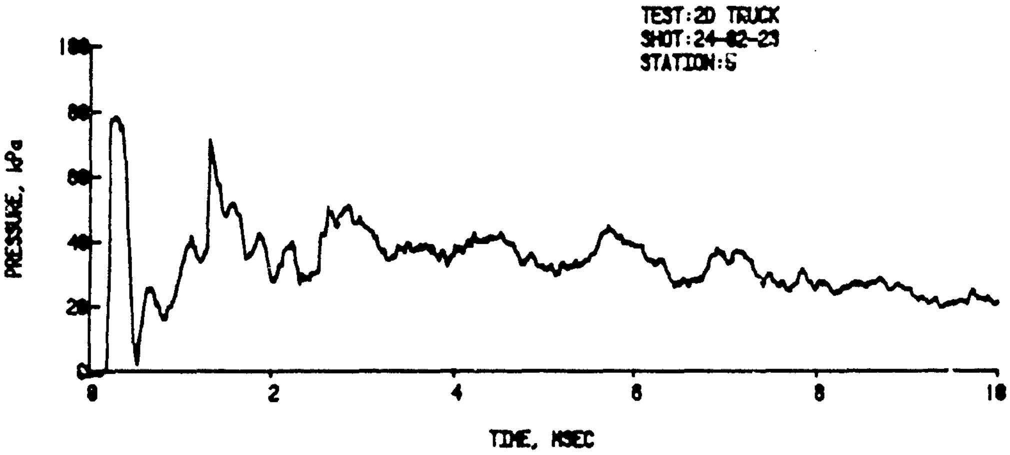


Figure B-15. Shot 24-82-23, Decaying Wave, Boundary Conditions Inapplicable, 69.8 kPa.





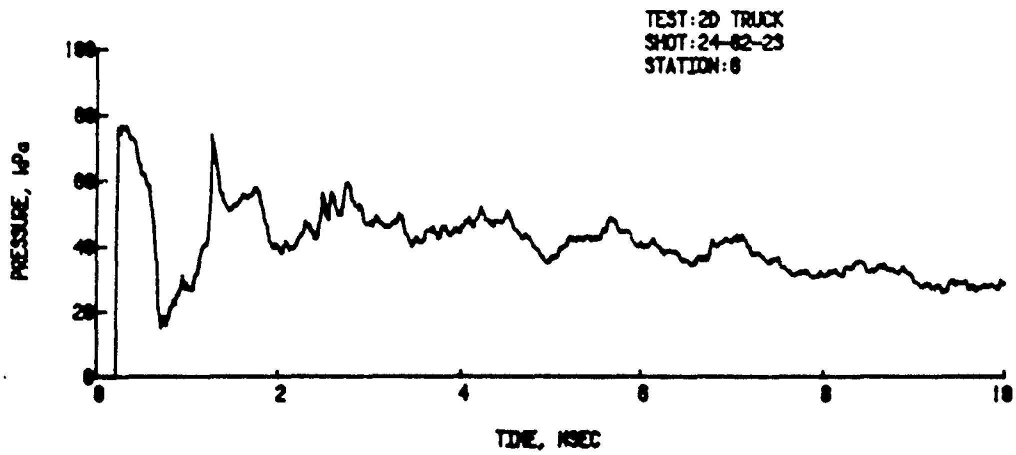
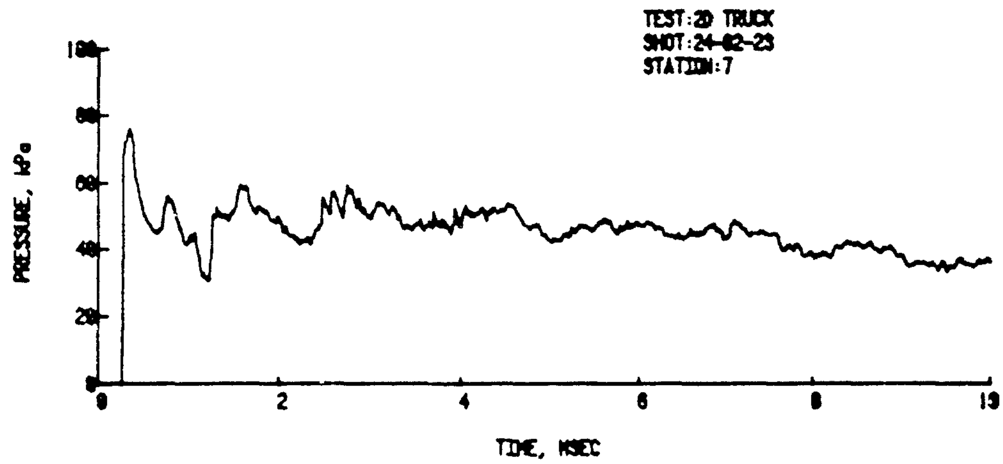
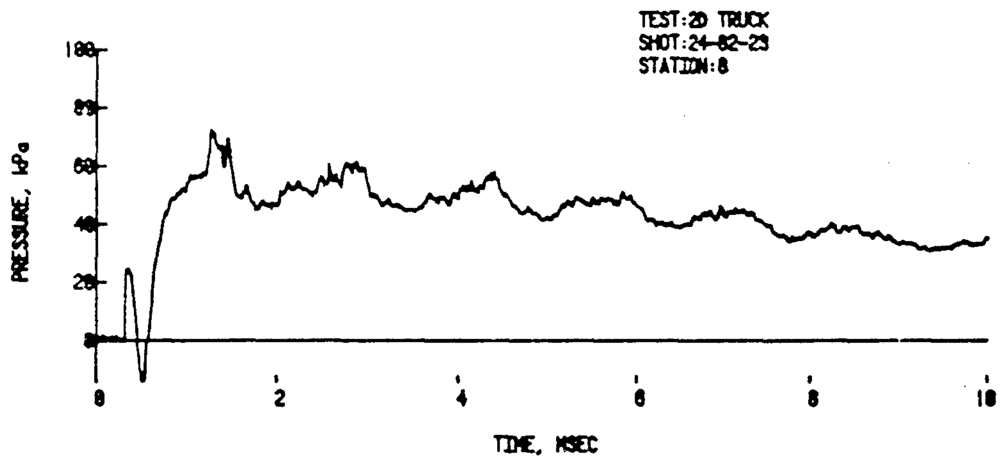


Figure B-15. Shot 24-82-23 (Cont)





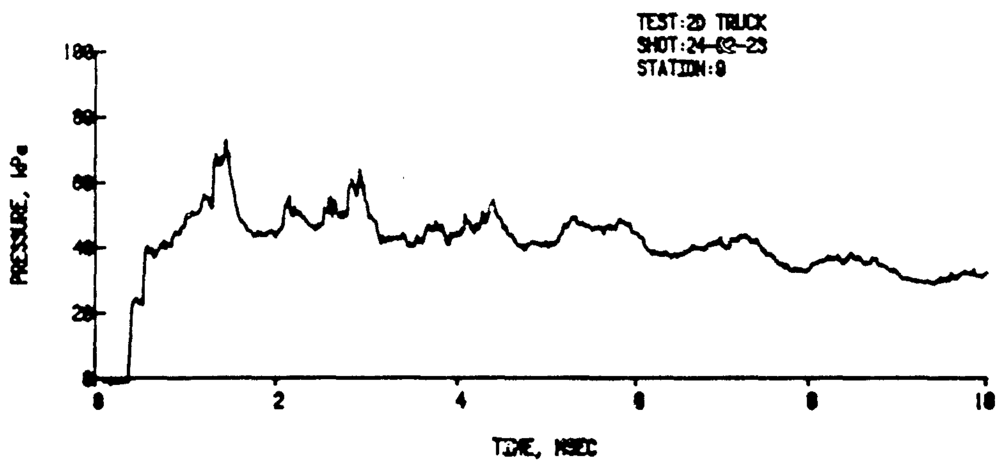
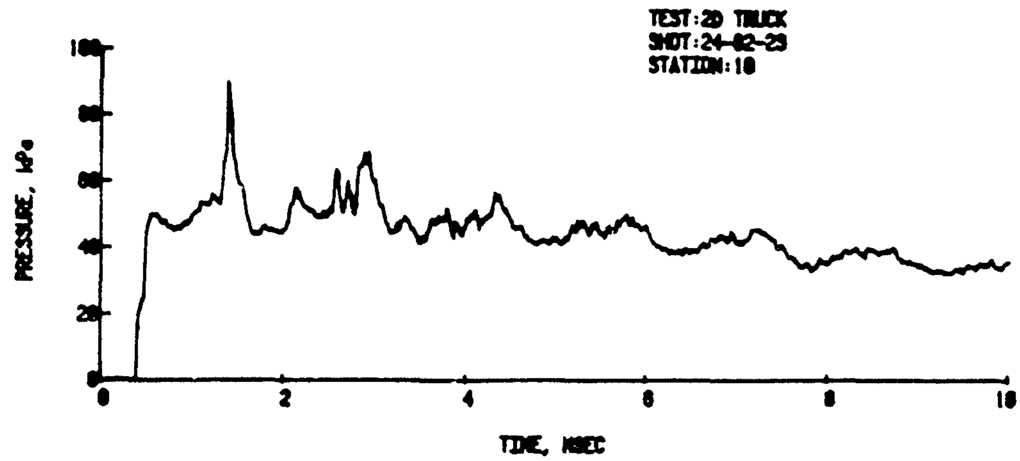
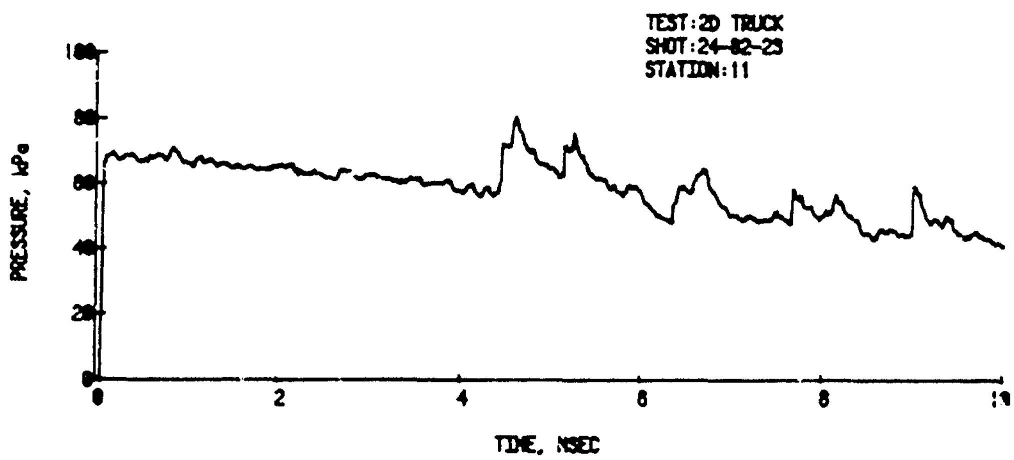


Figure B-15. Shot 24-82-23 (Cont)





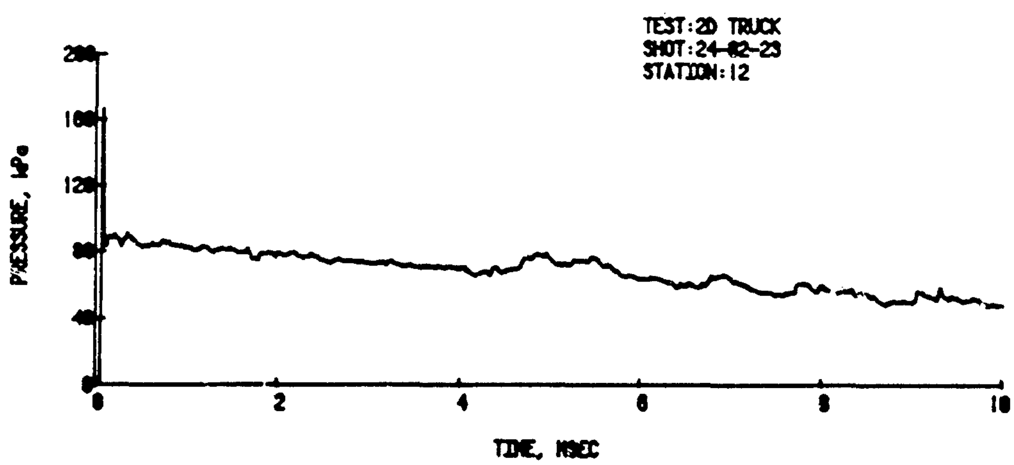


Figure B-15. Shot 24-82-23 (Cont)

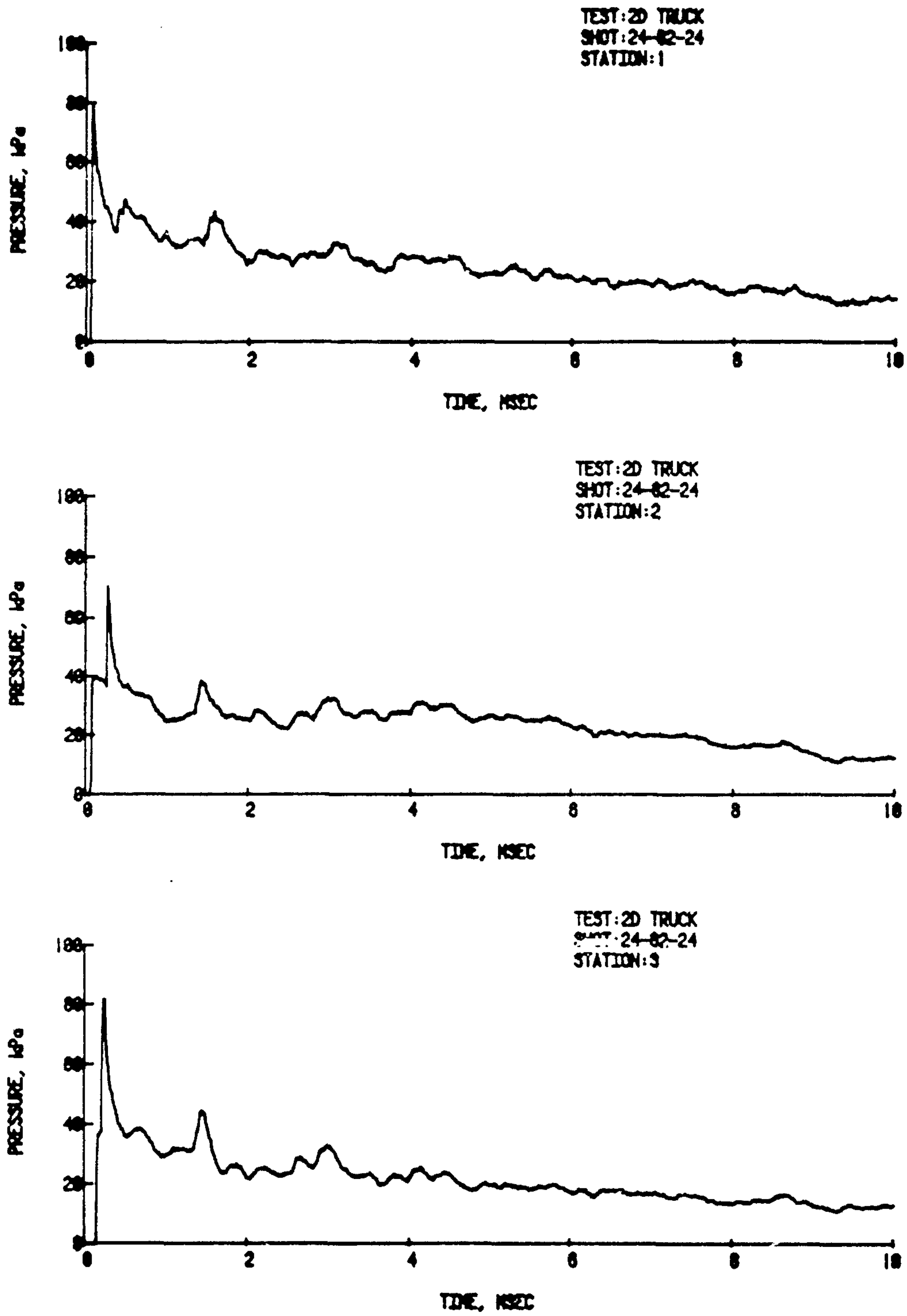
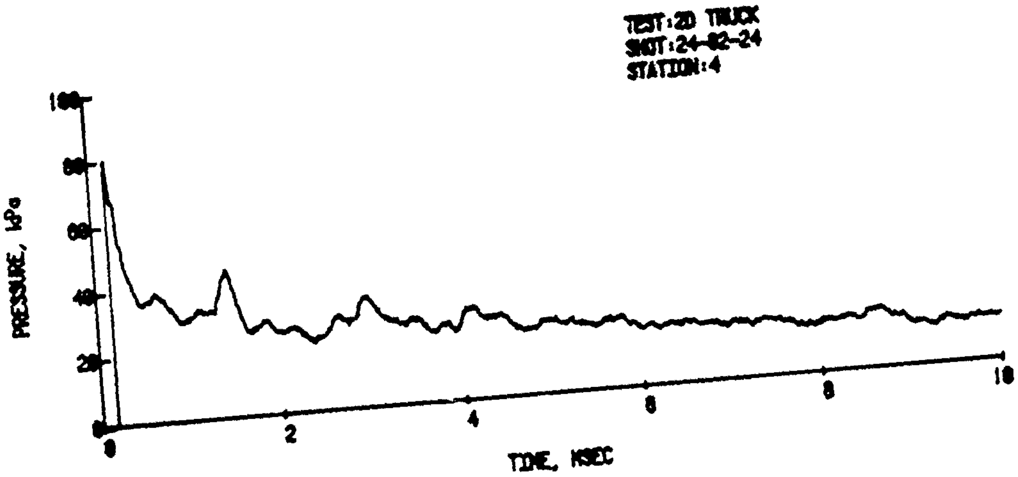
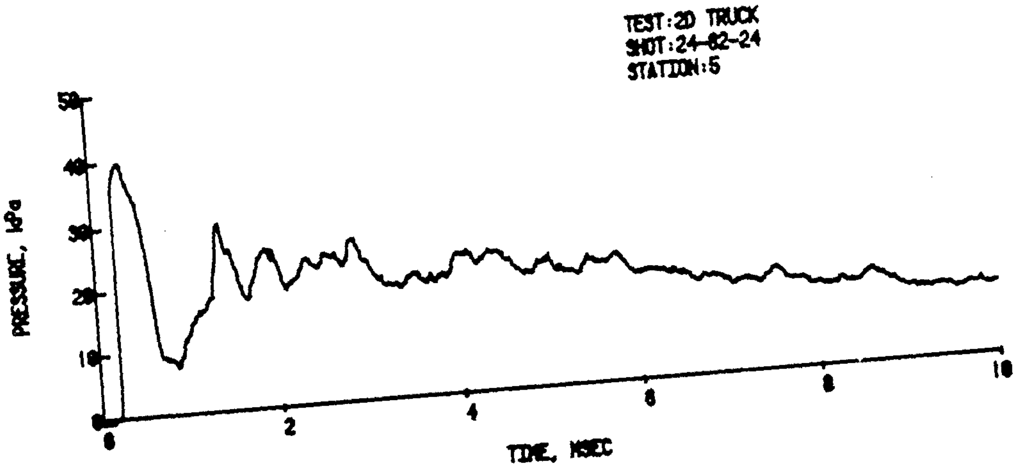


Figure B-16. Shot 24-82-24, Decaying Wave, Boundary Conditions Inapplicable, 34.0 kPa.





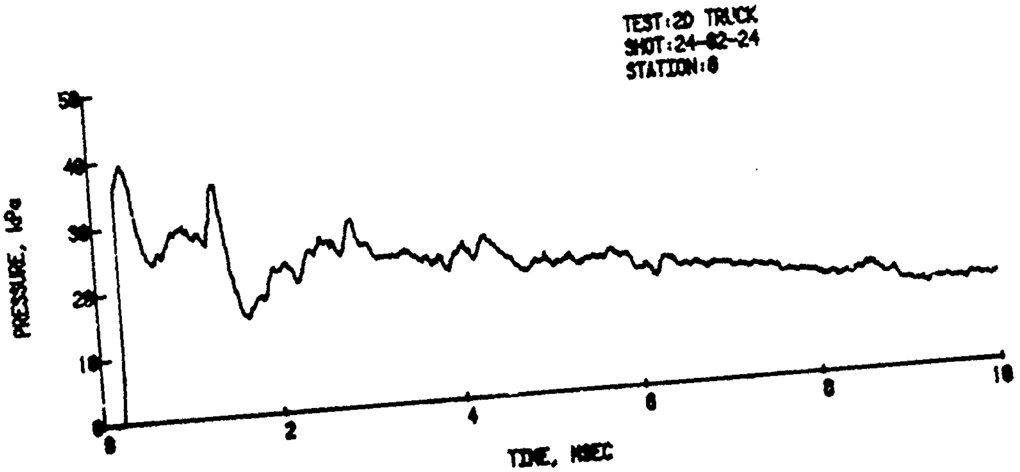
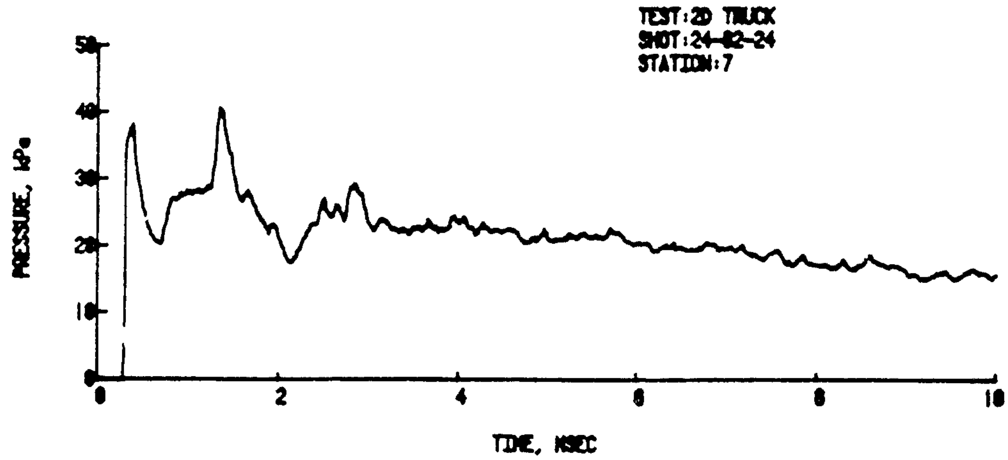
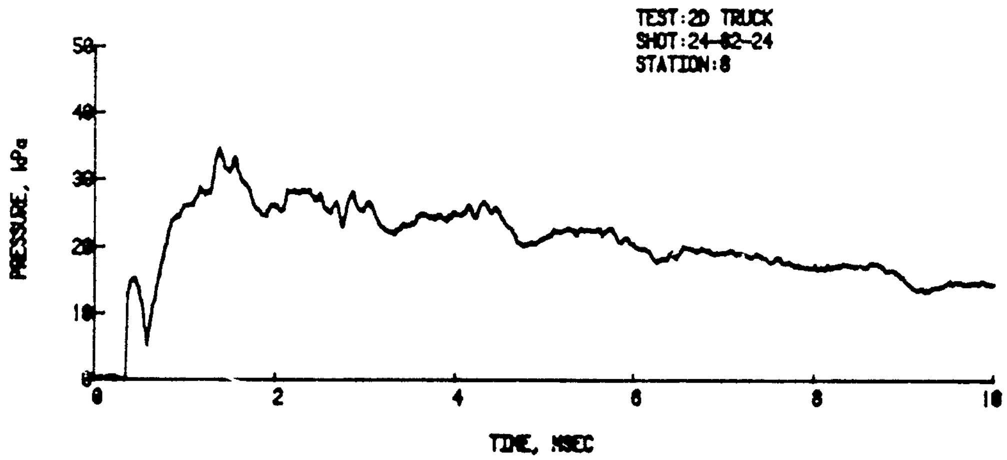


Figure B-16. Shot 24-82-24 (Cont)





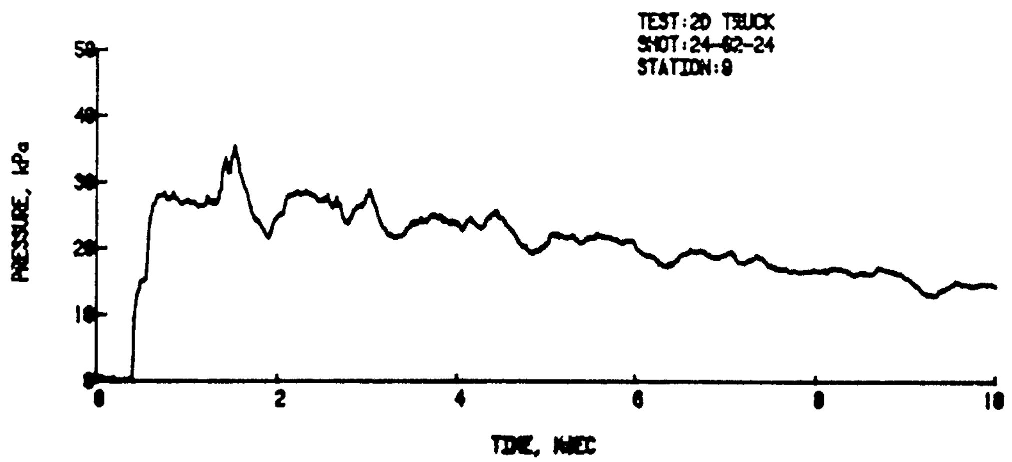
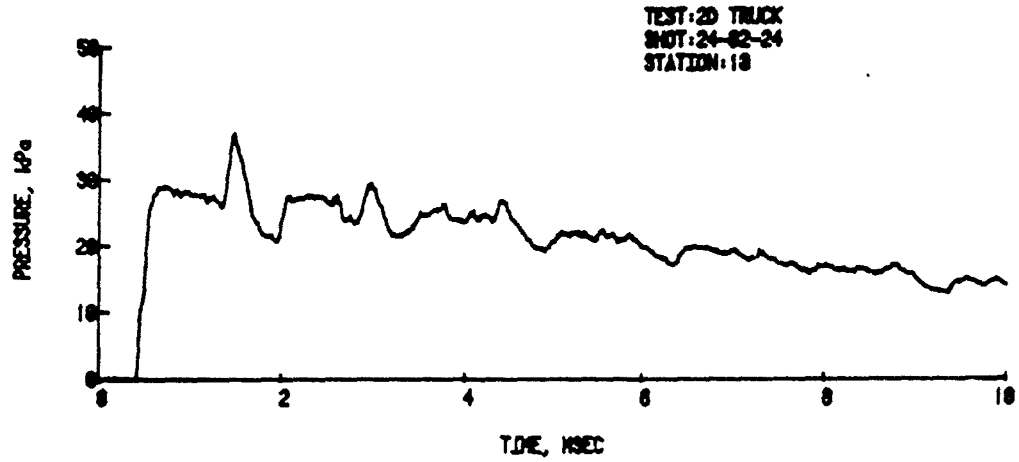
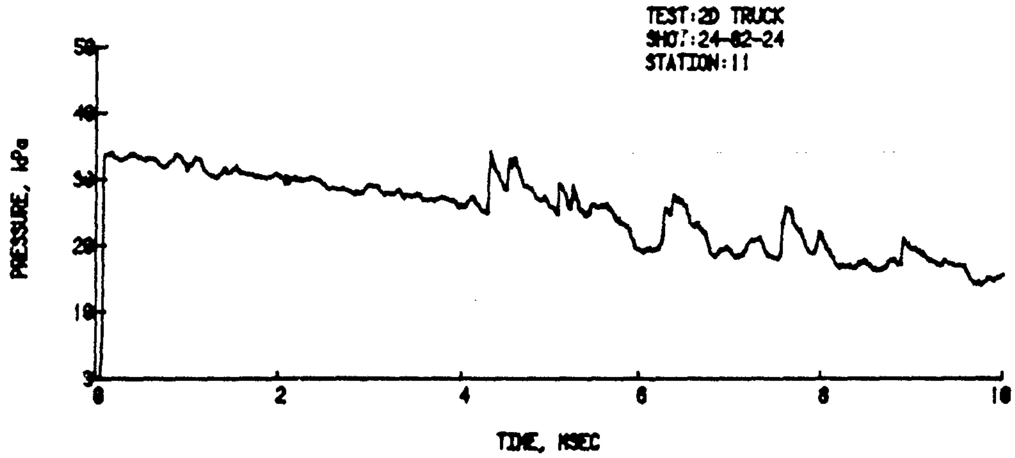


Figure B-16. Shot 24-82-24 (Cont)





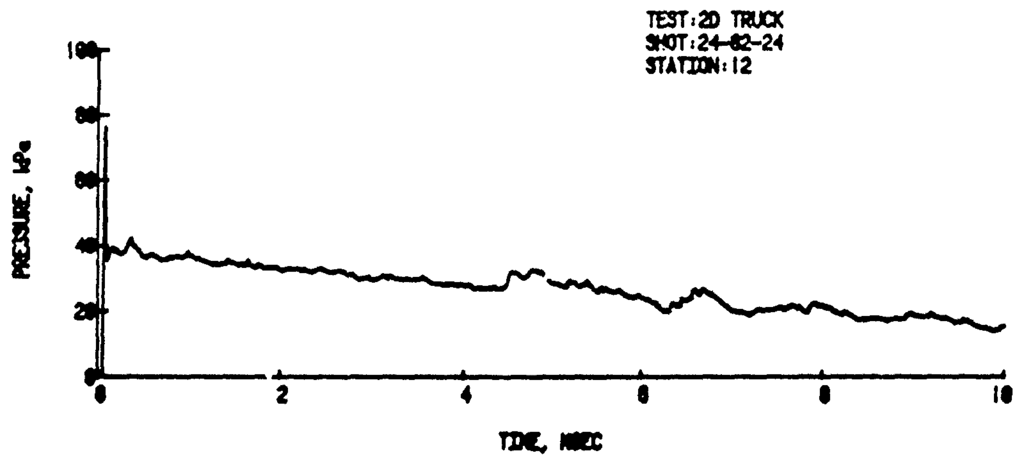


Figure B-16. Shot 24-82-24 (Cont)

APPENDIX C

DATA TRANSFER PROGRAM

This BASIC program, which runs on a Tektronix 4051 microcomputer, is useful to transfer digital experimental data files from the 4051 to the BRL Cyber mainframe computer system.

```
2 REM USER KEY #1 TO BEGIN
4 RUN 100
8 RUN 400
12 RUN 520
16 RUN 700
100 PAGE
110 PRINT "THE 4051 IS NOW A CYBER TERMINAL."
120 PRINT "THE FUNCTION OF EACH USER KEY IS DESCRIBED ON THE"
130 PRINT "DATA COMMUNICATION INTERFACE OVERLAY."
140 PRINT " "
150 PRINT "PHOTOCOPY THESE INSTRUCTIONS."
160 PRINT " "
170 PRINT "1) HIT RETURN. LOGIN IF FIRST RUN."
180 PRINT "2) TYPE IN 'NEW,filename'."
190 PRINT "3) TYPE IN 'TEXT'."
200 PRINT " "
210 PRINT " "
220 PRINT "HIT USER KEY 5, 'RETURN TO BASIC'."
230 PRINT "HIT USER KEY 2 TO SEND AN 8 BYTE DATA FILE"
240 PRINT "OR KEY 3 TO SEND A SMALL 2 BYTE FILE"
250 PRINT "OR KEY 4 TO SEND A LARGE 2 BYTE FILE"
260 PRINT "CREATED ON A 4052."
270 CALL "RATE",2400,0,2
280 B$=CHR(0)
290 D$="/"
300 E$=""
310 CALL "BREAK",1,"@","@"
320 CALL "EOLCHR",13,E$,0
330 CALL "TSTRIN",B$,B$,B$
340 CALL "PROMPT",0,200,D$
350 CALL "RSTRIN",E$,E$,E$
360 CALL "TCRLF",1,2,0
370 CALL "CMSET"
380 CALL "TERMIN"
390 END
400 INIT
410 PAGE
420 L=0
430 PRINT "WHAT 8 BYTE DATA FILE IS TO BE READ?"
440 INPUT F2
450 FIND F2
460 READ @33:A$,B$,C$,D$,E$,P$
470 READ @33:N,P,P1,T0,T2,T3,T5,T6,W2,W3,E2
480 DIM B1(T6)
490 READ @33:B1
500 PRINT "8 BYTE FILE # ";F2;" HAS BEEN READ.JJJ"
510 GO TO 800
520 INIT
530 PAGE
540 L=0
550 PRINT "WHAT SMALL 2 BYTE DATA FILE IS TO BE READ?"
560 INPUT F2
570 FIND F2
580 READ @33:A$,B$,C$,D$,E$,P$,O$
590 READ @33:D4,D6,M,M1,N,P,P1,R,T0,T1,T2,T3,T4,T5,T6,W2,W3,E2
600 DIM B1(T6),I$(2*T6)
```


PRECEDING PAGE BLANK-NOT FILMED

```
610 I$=''
620 B1=1
630 CALL 'PACK',I$,B1,T6,2
640 READ @33:I$
650 CALL 'UNPACK',I$,B1,T6,2
660 B1=B1/M1
670 B1=B1+M
680 PRINT '2 BYTE FILE # ';F2;' HAS BEEN READ.JJJ'
690 GO TO 800
700 INIT
710 PAGE
720 L=1
730 PRINT 'WHAT LARGE 2 BYTE DATA FILE IS TO BE READ?'
740 INPUT F2
750 FIND F2
760 READ @33:A$,B$,C$,D$,E$,F$,O$
770 READ @33:D4,D6,M,M1,N,P,P1,R,T0,T1,T2,T3,T4,T5,T6,W2,W3,E2
780 DIM I$(2*T6)
790 READ @33:I$
800 PRINT 'TRANSMISSION TO CYBER IN PROGRESS.'
810 PRINT @40:A$
820 PRINT @40:B$
830 PRINT @40:C$
840 PRINT @40:D$
850 PRINT @40:E$
860 PRINT @40:F$
870 PRINT @40:N
880 PRINT @40:P
890 PRINT @40:P1
900 PRINT @40:T0
910 PRINT @40:T2
920 PRINT @40:T3
930 PRINT @40:T5
940 PRINT @40:T6
950 PRINT @40:W2
960 PRINT @40:W3
970 PRINT @40:E2
980 IF L=1 THEN 1060
990 PRINT @40:B1
1000 PRINT 'GGGGG'
1010 PRINT 'FILE ';F2;' HAS BEEN TRANSFERRED.'
1020 PRINT 'TYPE 'CONTROL T' TO EXIT TEXT MODE.'
1030 PRINT 'TYPE 'SAVE''
1040 CALL 'TERMIN'
1050 END
1060 DIM G$(2),B(1)
1070 B=0
1080 FOR A=1 TO 2*T6 STEP 2
1090 G$=SEG(I$,A,2)
1100 CALL 'UNPACK',G$,B,1,2
1110 B=B/M1
1120 B=B+M
1130 C=B(1)
1140 PRINT @40:C
1150 NEXT A
1160 GO TO 1000
```

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