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BLAST LOADING IN EXISTING STRUCTURES -
BASEMENT MODELS

George A. Coulter

Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

August 1972

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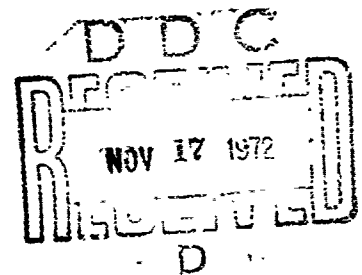
MEMORANDUM REPORT NO. 2208

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by

George A. Coulter

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George A. Coulter

Terminal Ballistic Laboratory

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I. INTRODUCTION

Initial results obtained from a 1/12th scale model of a basement shelter were reported from a study of the interior blast created flows obtained from the BRL 24-inch Shock Tube. The experiments were designed to simulate the flows and loading within a 100 person basement shelter when the above-ground floors have been removed by the incoming blast wave.

Earlier results obtained by a smoke tracer method from two-dimensional models indicated downward directed flows from the entrance. These results tend to be verified by the pressure-time records obtained from the present three-dimensional 1/12th scale model. In addition, low pressure vortex regions were measured from positions near the open stairway within the model.

A second phase of the experiments consisted of photographing with a high speed camera the flow-induced motion of linear scaled (1/12th) OCD survival packages placed within the basement model. The density of the scaled objects was left the same as the full-size packages.

This report shows pressure-time histories from various interior positions of the model, selected prints of frames from the high-speed photographs (Fastex at about 3000 PPS), calculations of average component velocities of some of the objects placed inside the model, and post-shot still photographs to show the final object placement after motion has stopped.

II. EXPERIMENTS

The results from the two-dimensional model reported in BRL Memorandum Report No. 2118 indicated strong downward directed flows when the shock waves entered overhead. The object of the first part of the present experiments was to measure the interior pressures which were indicated by the two-dimensional results. This was done with pressure probes using a three-dimensional model with a stairway as the entrance to the basement. During the second part of the experiments, the

pressure probes were removed and small objects were placed inside the model. High speed photography was then used to observe the motion of the objects as the shock wave entered down the stairway.

A. Pressure Measurements

The 1/12th scale model of a 100 person basement shelter which was used during the experiments is shown in Figures 1 and 2. The orientation to the shock wave is as shown with the shock wave moving down the stairs. The transducer locations are shown in Figure 2. The front of the pressure probes were positioned two inches above the floor, facing toward the stairs, and at the positions shown. The side-on pressure transducers were mounted two inches to rear of positions as shown, flush with the floor. Positions 1 and 1-A transducers were used as pressure monitors from shot to shot.

Susquehanna Instrument Model ST-2 transducers were used in both the flush positions and the probes. These piezoelectric transducers were coupled through Kistler Model 566 charge amplifiers to a Bell and Howell tape machine, Model VR-3300.

B. Photographic Recording

For the photographic phase the pressure transducers were removed except for one transducer to monitor the pressure at the center of floor. Small objects were made to 1/12th the linear scale of several OCD Survival Packages. These are listed in Table I with pertinent information. Pictures were taken of the motion of three of the nylon cylinders exposed to input shock overpressures of 5, 10 and 20 psi at several locations inside the model. Figure 3 shows these locations. The total number of objects were then stacked together to simulate possible storage positions of the OCD Survival Packages. Figure 4 shows the stacking and positions used.

The motion of the objects was observed through a window in the end of the model away from the stairway. A 16mm Fastex camera operated at about 3000 PPS slowed the motion sufficiently for observation. Five 500 watt photoflood lamps (DXC) placed very close to the glass windows gave sufficient light to record on either Tri X or on Extachrome 7242

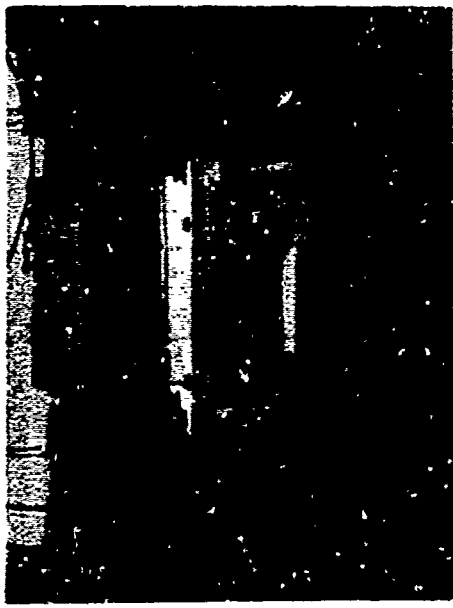
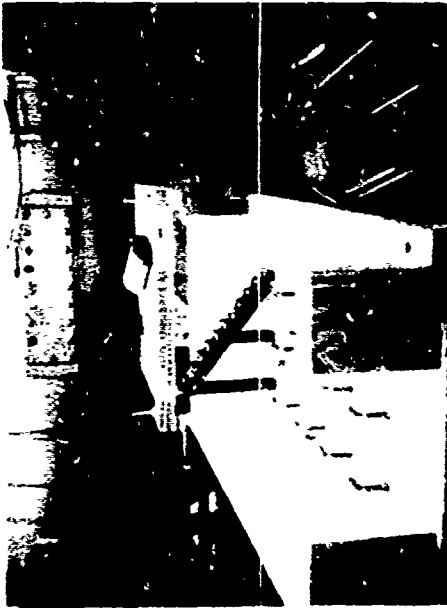


Figure 1. 1/12th Scale Basement Model

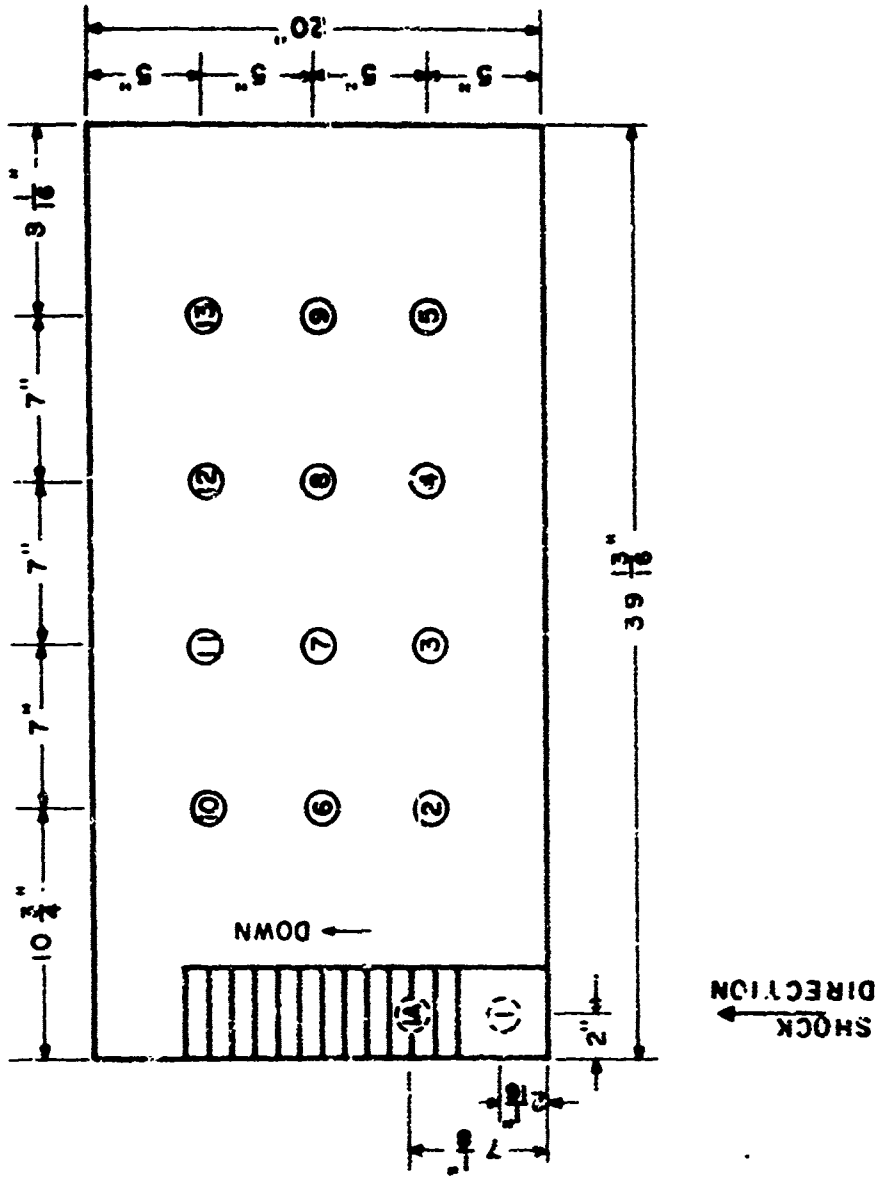


Figure 2. Gage Positions Model 40

Table I. Model OCD Survival Packages

Objects	Code	Quantity	Size, Inches	Mtl	Av. Wt., oz	Av. Density, lb/ft ³
Pedal Ventilator Kit	A	1	1.44 x 3.15 x 4.98	Styrefoam	0.67	3.2
Kearny Pump Kit (Box A)	B	1	0.46 x 3.50 x 2.65	Styrefoam	0.14	3.2
Kearny Pump Kit (Box B)	C	1	0.46 x 0.46 x 7.85	Cork	0.16	12
Circular Water Container (Box A)	D	1	0.53 x 1.60 x 2.00	Cork	0.19	12
Circular Water Container (Box B)	E	1	1.04 x 2.04 x 1.04	Cork	0.28	12
Dual Purpose Container (with drinking water)	F	4	1.33 x 1.48 x 1.33	Oak	1.06	44
Sanitation Kit-SK IV	G	2	1.38 D x 1.81	Balsa	0.16	6.3
Water Drums	H	4	1.28 D x 1.83	Nylon	1.56	71
Survival Biscuits	I	6	0.81 x 1.18 x 1.60	White Pine	0.37	26
Radiation Kit	J	2	0.88 x 0.90 x 1.35	Cork	0.12	12

NOTE - Model objects are 1/12th linear size of Survival Packages.

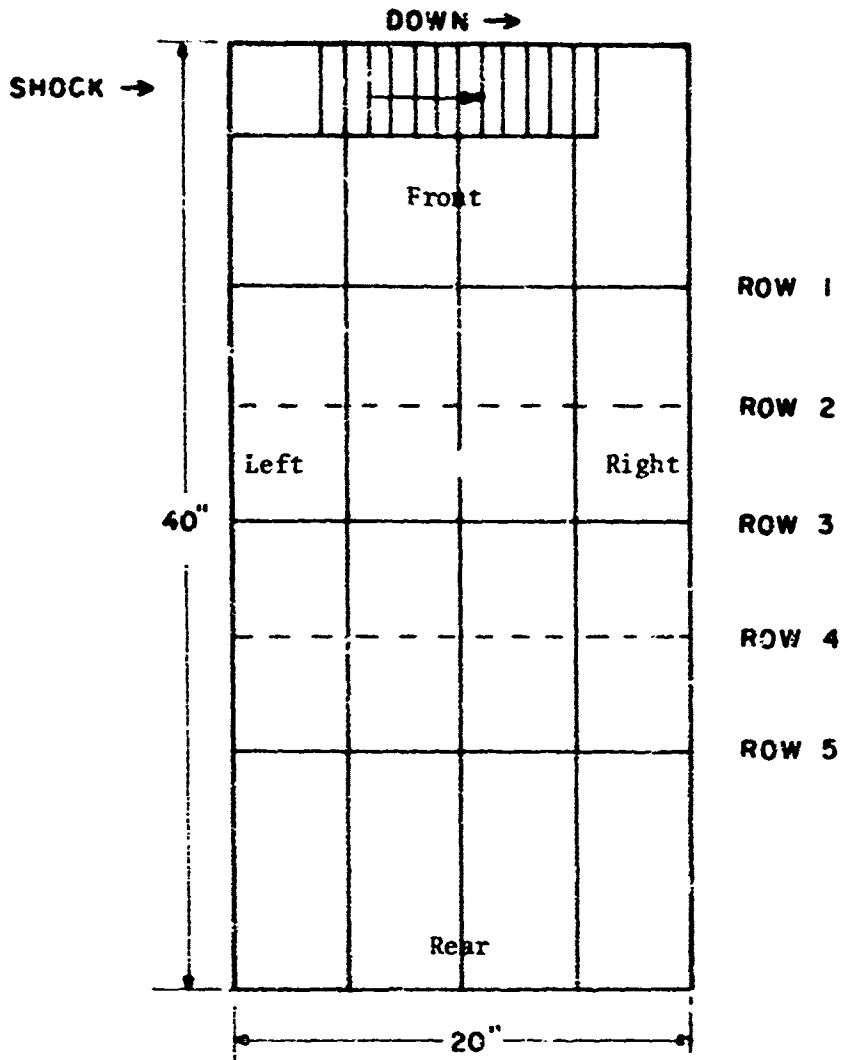
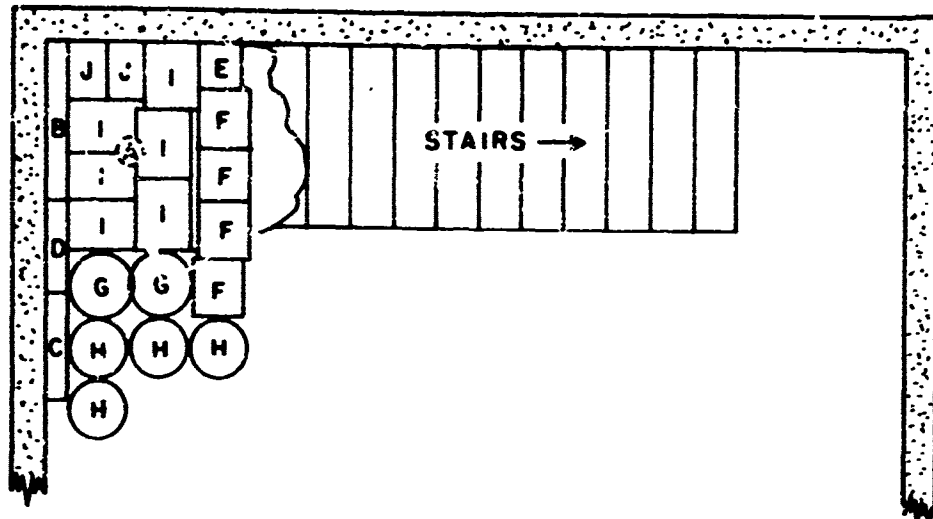
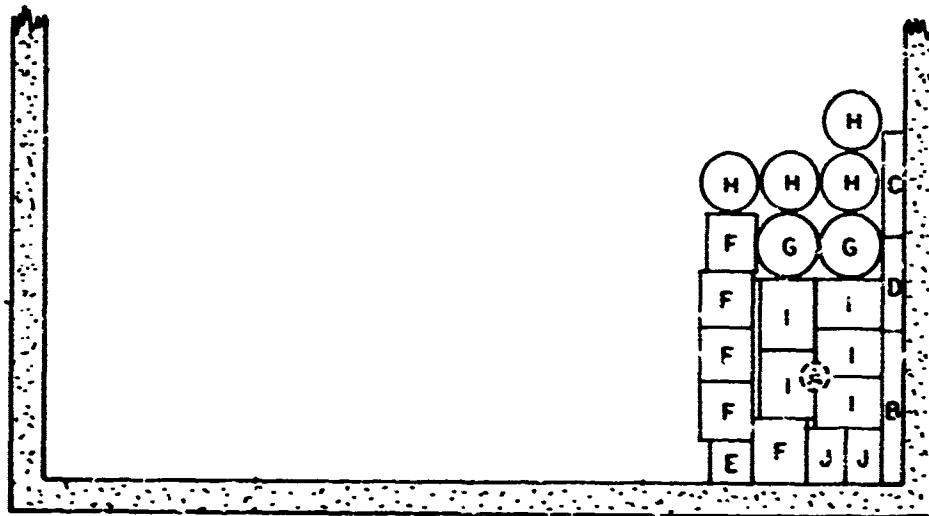


Figure 3. Floor Plan for Cylinder Experiments

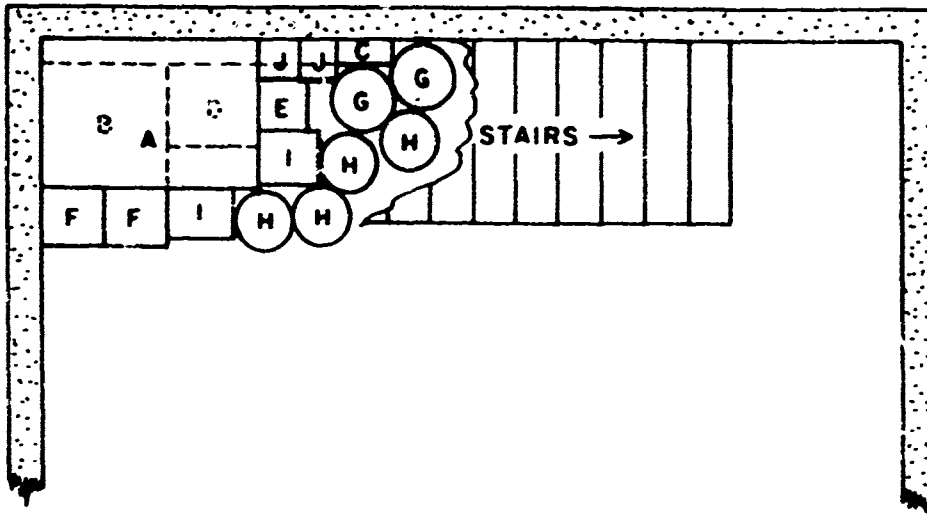


POSITION 1

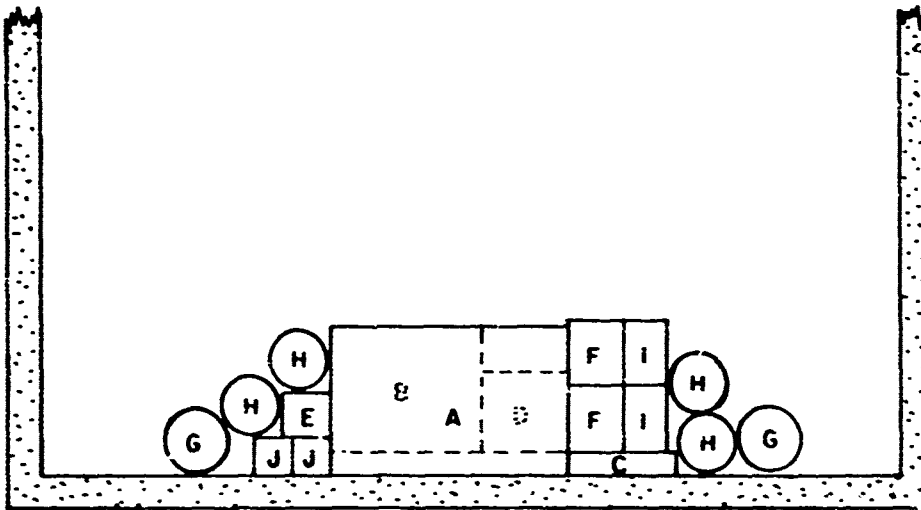


POSITION 2

Figure 4. Positions for Model Survival Packages

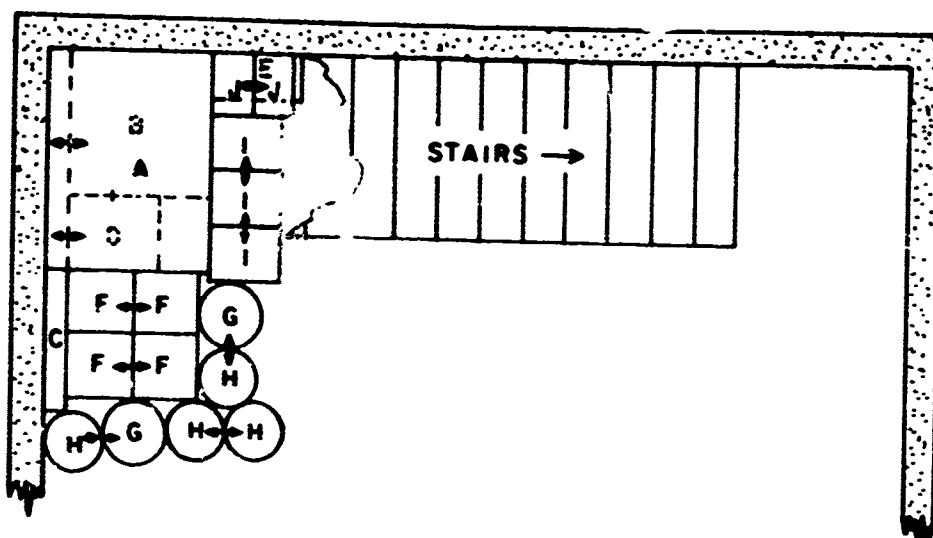


POSITION 3

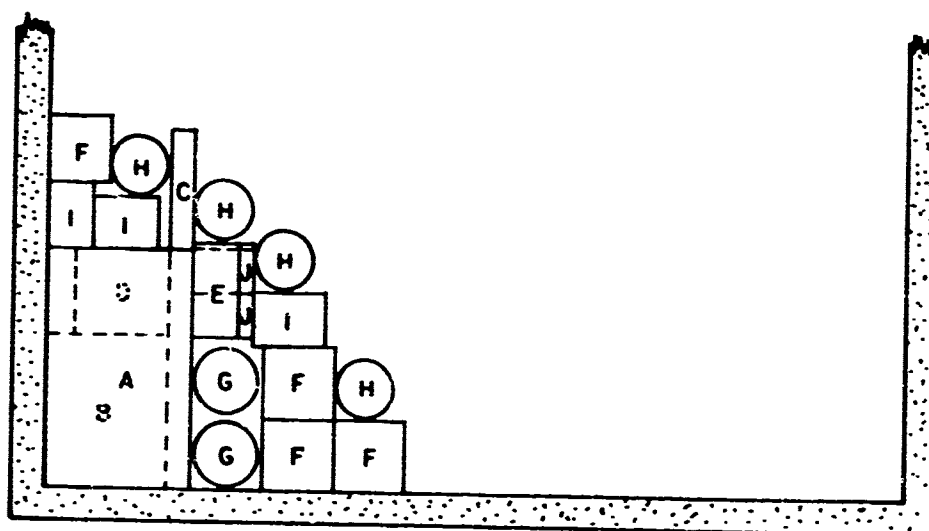


POSITION 4

Figure 4. (Continued)



POSITION 5



POSITION 6

Figure 4. (Continued)

color film if the developing were increased for the color film.

Still photographs of starting positions and end locations are presented in the Results Section along with prints of selected frames from the 16mm films to illustrate the motion of the small scaled objects.

III. RESULTS

The experimental results are presented as pressure-time records in Appendix B and as selected frames from the high speed films, shown in Appendix D.

A. Pressure-Time Records

Table A-I, Part A (Appendix A) lists information pertinent to the pressure transducers' locations, the ambient conditions, and descriptions of the observed waveforms. Figure 5 shows pressure-time records obtained from the front row probe positions for a shock wave of 5 psi outside the model entrance. Pressure-time records from other positions are shown in Appendix B. A study of the traces show several characteristics. (1) The traces from positions nearest the stairway showed large pressure dips between 3 and 5 milliseconds with the largest dips recorded near the bottom of the stairway. These dips probably indicate the presence of low pressure vortices from the stairwell edges. (2) Some of the positions (such as (1)) gave traces with quite large pressure peaks indicating probably reflections of the shock wave from the walls of the basement model. (3) Records from positions near the center of the floor showed most nearly ideal smooth fill records indicating a lack of both vortices and reflections. Figure 6 displays the results of the BRL room fill predictions with experimental data observed at the center of the floor. There is a slight displacement of the data from zero time (entrance of shock wave onto stairs) due to the arrival time of the diffracted shock at the center of the room. An entrance choking parameter and a plot routine (Figure 7) have been added to the program as reported in BRL Memo Report No. 1987, June 1969. The sonic fill case also has been included (see Figure 6-C at the beginning of the curve)

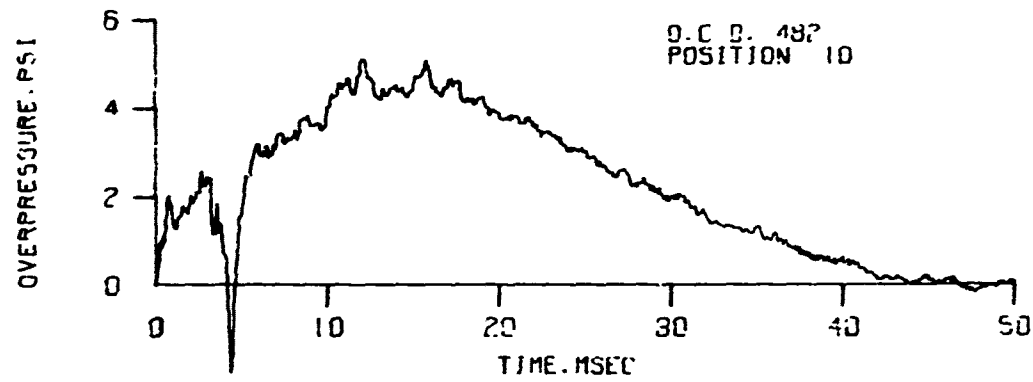
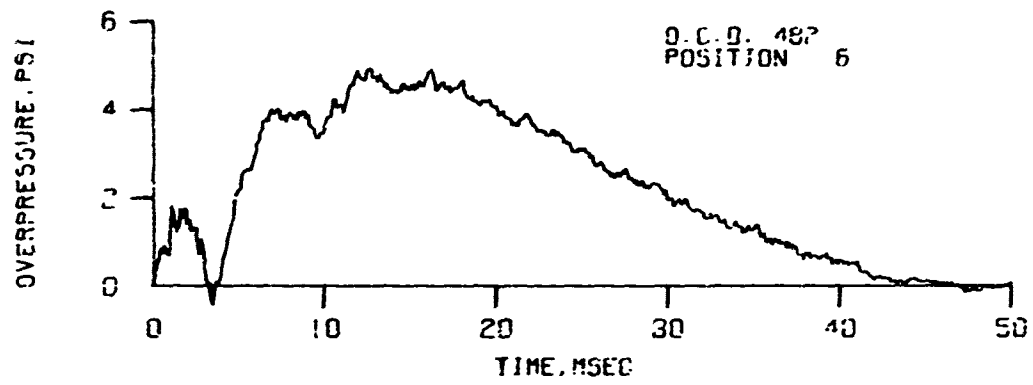
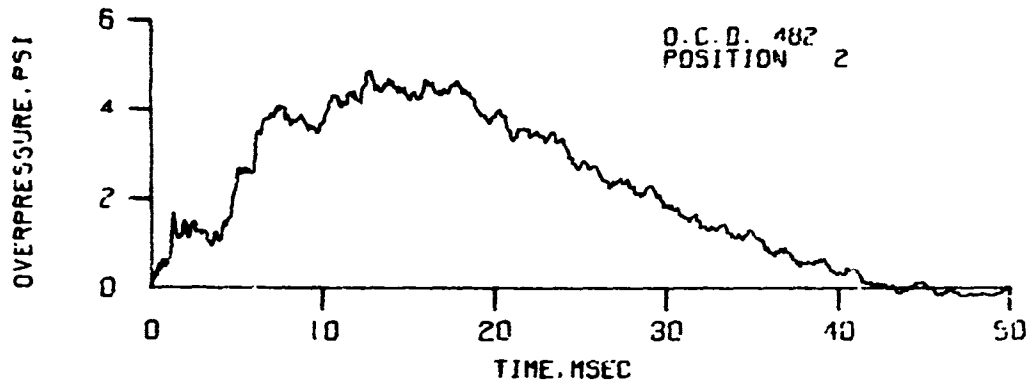
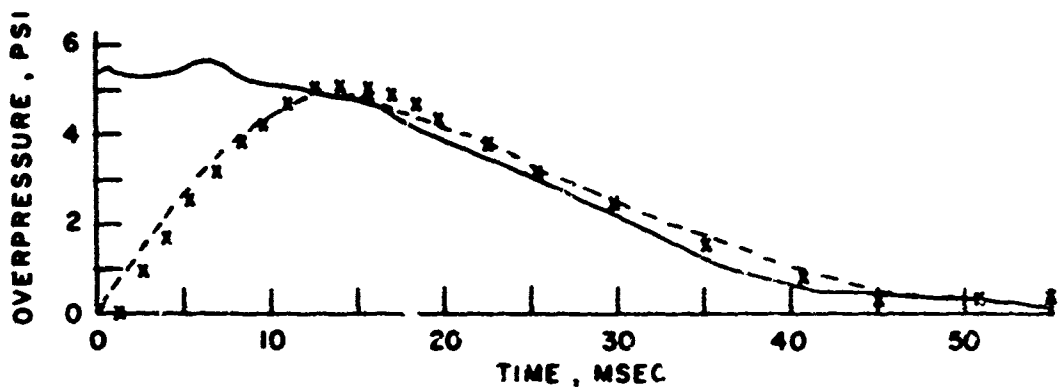
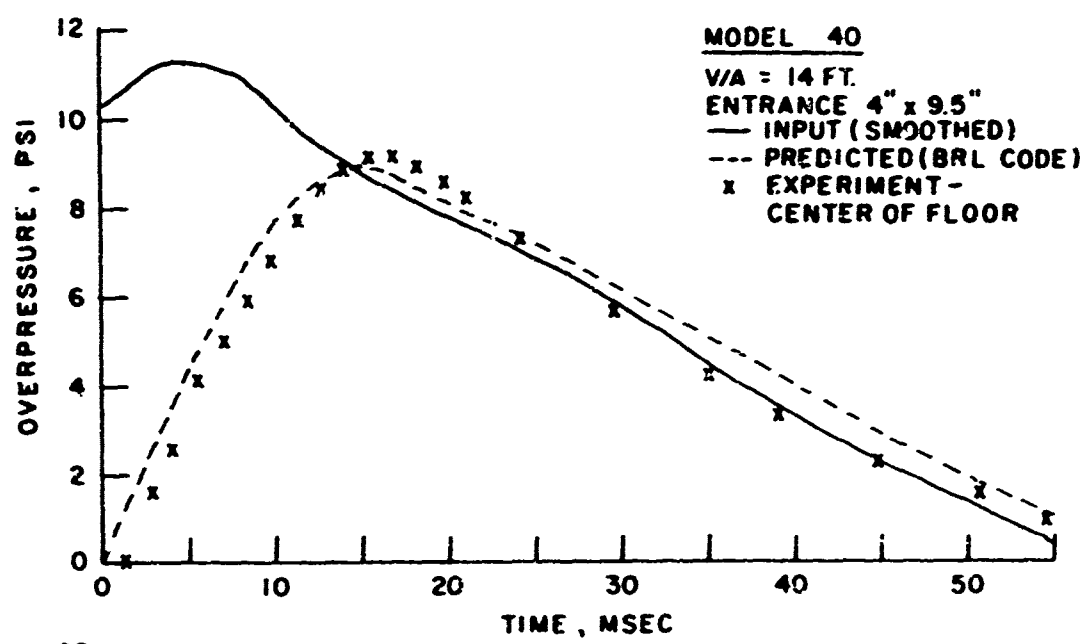


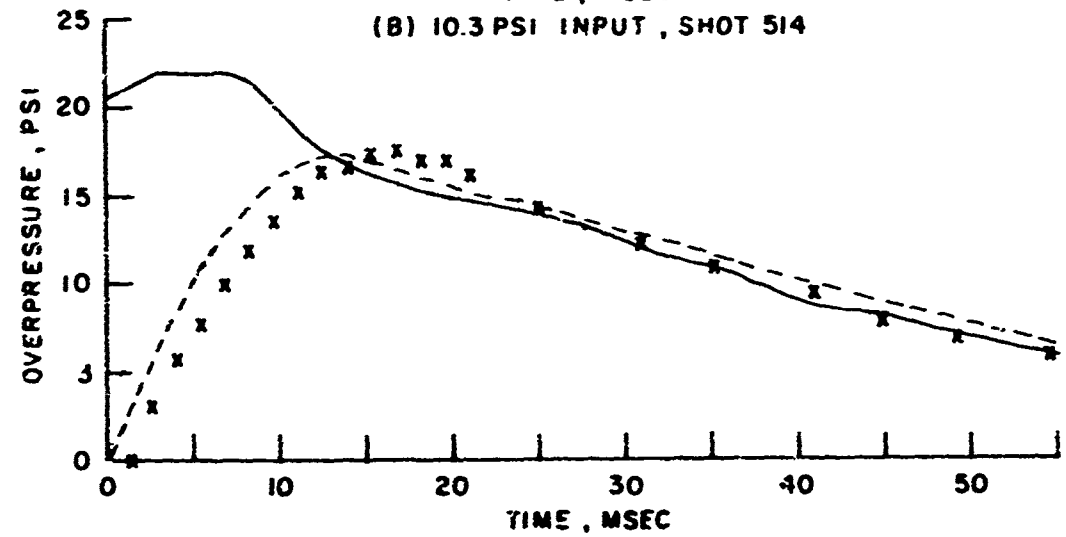
Figure 5. Records from the Pressure Probes - $P_s = 5\text{psi}$



(A) 5.4 PSI INPUT, SHOT 513



(B) 10.3 PSI INPUT, SHOT 514



(C) 20.5 PSI INPUT, SHOT 515

Figure 6. Pressure-Time Fill Predictions

CHAMBER FILL - BRL

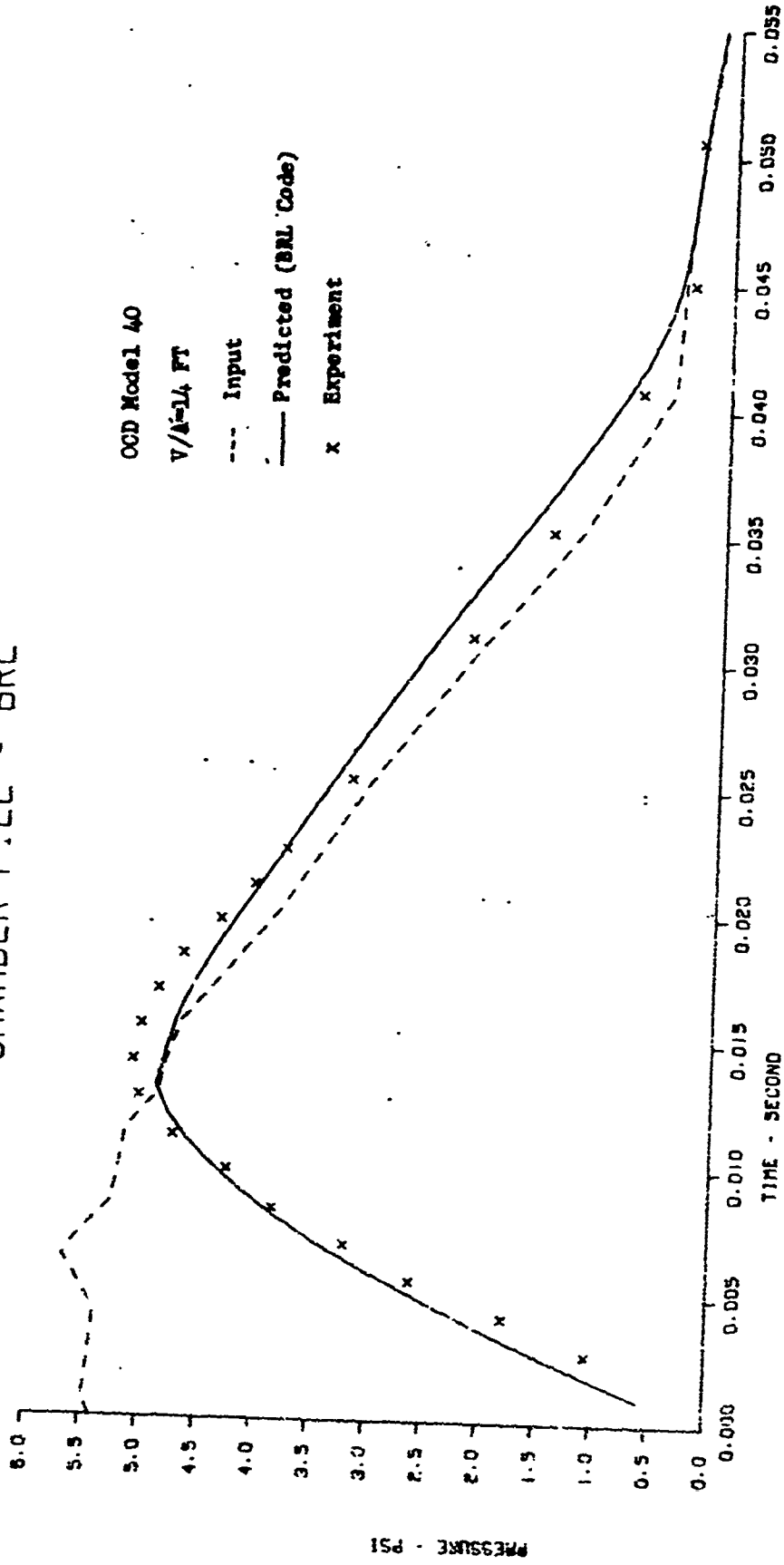


Figure 7. Plot Routine for Chamber Fill

but does not seem to better the predictions.

B. High Speed Photographs

Table A-I, Parts B and C (Appendix A) list the results of the experiments with small objects placed in the basement model. The motion as observed by the high speed camera is listed as a function of the type of stairway (open or closed), the position in the model, and the shock pressure, P_s , to which the model was exposed. Figure 8 illustrates one case of this motion. Other positions tested are shown in Appendix D. Post-shot still photographs are shown in Appendix E to show where the test objects finally ended up on the model basement floor. A general clockwise pattern of motion about the room was observed in the motion photographed. The details and magnitudes are summarized in Table A-I. These are pointed out in the Summary and Conclusion Section.

IV. SUMMARY AND CONCLUSIONS

The experiments reported made use of pressure transducers and high speed photography to measure the pressure-time profiles and flow effects at various locations inside a 1/12th scale model of a 100 person basement shelter.

The pressure transducers recorded three major wave shapes within the model during loading with exterior shock waves. (1) A low pressure dip was recorded at positions near the stairway and is attributed to a vortex sheet extending down from the stairwell. The greatest pressure dip, or lowest pressure, was measured near the widest stair opening which is at the foot of the stairs. (2) A generally smooth pressure filling curve was observed at positions near the center area of the floor. (3) Multiple pressure peaks were observed superimposed on the general filling curve when the transducer positions were near walls. These peaks were probably the result of internally reflected shock waves from the various interior surfaces.

SHOT 504

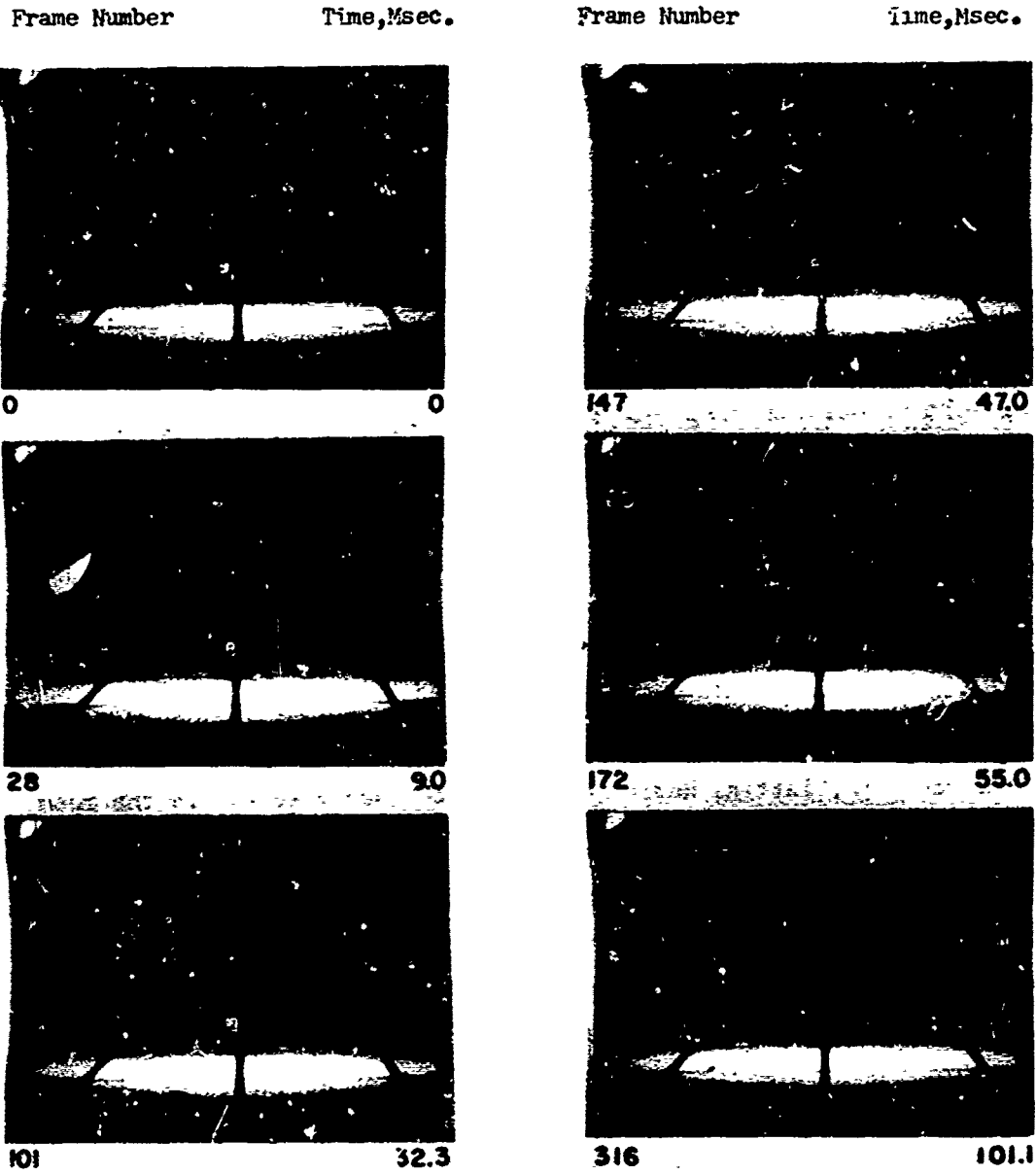


Figure 8. Open Stairway-Cylinders on Row 1 - 5.3psi

As the exterior loading shock wave was increased in over pressure from 5 - 20 psi, the low pressure vortex effect extended greater distances into the model, away from the stairway.

A comparison of the high speed pictures of the motion of the nylon cylinders for the case of the open stairway indicated the following things. (1) The general motion of all the cylinders indicated that the air flow spilled over the edge of the stairway and gave a clockwise rotation to the flow (for the model-shock wave orientation used). (2) The stronger flows existed near the bottom of the stairs since objects placed there showed the greatest motion. (3) Cross the floor components of velocity ranged from values of 4 - 14 ft/sec at Row 1 for initial motion (during time for the room to fill) to values of 1 - 2 ft/sec for long term velocities which occurred well after the room filled. (4) Motion appeared less at positions near the center area of the room.

The package containing all the objects moved much the same as the single cylinders did. The following observations were made. (1) The left front corner under the stairs seemed to give the most protection for the 5 and 10 psi loading. (2) All positions tested at the 20 psi loading showed motion of "pack". The component objects were blown out of the "pack" at velocities of 10 ft/sec to 82 ft/sec, for the lighter object "E". (3) Initial motion of the "pack" occurred within the room filling time.

A comparison of motions of the cylinders for the open and the closed stairway showed about the same kind of motion for each case. A somewhat smaller cross-room component of velocity was measured with the closed stairway except when the 20 psi shock wave was used. The incoming high speed flow was apparently expanded in area enough at the 20 psi loading to include the right end cylinder within the initial flow. The direction of motion changed from toward the right wall to a new direction, diagonally toward the left rear of the basement model. The long term motion of the cylinders seemed about the same for the open and closed stairways.

Work now in progress includes the addition of a side window to the present basement model to observe lengthwise motion along the room. A new model is being designed to simulate a 1000 shelteree size basement shelter. A much longer shock wave will be used to load the new model. This should help to predict the motion of the objects as a function of the exterior shock waveshape.

APPENDIX A

TABLE A-I. SUMMARY OF SHOTS

Table A-I. Summary of Shots - Model 40

A. Pressure Measurements

Shot	P_s , psi	Position	P_{max} , psi	Waveshape	Location of Transducers	Remarks
482	5.0	1	5.3	Large pressure peaks	Floor	Direction of shock wave travel is down the stairs. Open stairway. Pressure probes at all positions except Pos. 1. $F_1 = 14.81$ psi $T_1 = 21.80^\circ\text{C}$
		2	4.9	Small effect of vortex	Probe	
		3	1.9	Slight pressure peaks		
		4	4.8	Almost smooth fill		
		5	5.0	Medium pressure peaks		
		6	4.7	Pressure dip to zero		
		7	4.6	Similar to Pos. 3		
		8	5.3	Similar to Pos. 3		
		9	-	-		
		10	5.1	Large negative pressure dip		
		11	4.8	Similar to Pos. 8		
		12	4.9	Similar to Pos. 8		
		13	5.1	Medium pressure peaks		
491	5.2	1	5.9	Large pressure peaks	Floor	Pressure transducers are all flush in the floor. $P_1 = 14.87$ psi $T_1 = 21.57^\circ\text{C}$
		2	5.3	No effect from vortex		
		3	5.2	Slight pressure peaks		
		4	5.2	Nearly smooth fill curve		
		5	5.2	Larger peak than Pos. 3		
		6	5.4	Pressure dip from vortex		
		7	4.5	Similar to Pos. 3		
		8	6.0	Small peaks - like Pos. 3		
		9	5.6	Similar to Pos. 5		
		10	4.9	Similar to Pos. 6		
		11	5.3	Similar to Pos. 3		
		12	5.3	Small peaks - like Pos. 3		
		13	5.8	Similar to Pos. 5 and 9		

Table A-1. Summary of Shots - Model 40 (Continued)

A. Pressure Measurements (continued)

Shot	P_s , psi	Position	P_{max} , psi	Waveshape	Location of Transducers	Remarks
483	10	1	9.0	Large pressure peaks	Floor Probe	Pressure probes at all positions except Pos. 1. $P_1 = 14.79$ psi $T_1 = 21.95^\circ\text{C}$
		2	8.6	Medium pressure peaks		
		3	8.7	Slight pressure peaks		
		4	8.6	Nearly smooth		
		5	8.9	Medium pressure peaks		
		6	8.4	Negative pressure dip		
		7	8.3	Similar to Pos. 3		
		8	8.6	Similar to Pos. 5		
		9	-	-		
		10	9.0	Large negative dip		
		11	8.3	Pressure dips to zero		
		12	7.8	Similar to Pos. 5		
		13	8.9	Similar to Pos. 5		
492	10.3	1	11.7	Large pressure peaks	Floor	Pressure transducers are all flush in the floor. $P_1 = 14.9$ psi $T_1 = 21.7^\circ\text{C}$
		2	10.3	Small pressure dip		
		3	10.3	Very small pressure dip		
		4	10.0	Smoothest of all positions		
		5	10.4	Medium pressure peaks		
		6	9.8	Pressure dips near zero		
		7	8.2	Similar to Pos. 3		
		8	12.1	Similar to Pos. 5		
		9	10.9	Similar to Pos. 5		
		10	10.0	Pressure dips below zero		
		11	9.7	Similar to Pos. 3		
		12	9.7	Similar to Pos. 5		
		13	11.1	Similar to Pos. 5		

Table A-1. Summary of Shots - Model 40 (Continued)
 A. Pressure Measurements (continued)

Shot	P_s , psi	Position	P_{max} , psi	Waveshape	Location of Transducers	Remarks
493	20.5	1	20.6	Large pressure peaks	Floor	Pressure transducers are all flush in the floor.
		2	19.3	Small vortex dip		
		3	19.0	Similar to Pos. 2		
		4	19.3	Small peaks		
		5	18.3	Medium peaks		
		6	19.8	Vortex dip below zero		
		7	-	-		
		8	19.7	Similar to Pos. 4		
		9	18.9	Similar to Pos. 5		
		10	18.6	Vortex dip larger than Pos. 6		
		11	20.5	Similar to Pos. 10		
		12	18.2	Similar to Pos. 4		
		13	19.5	Similar to Pos. 5		
494	20.6	1-A	19.3	Large pressure peaks	Floor	Transducer flush in floor.
						$P_1 = 14.91$ psi
						$T_1 = 22.0^\circ\text{C}$
						$P_1 = 14.87$ psi
						$T_1 = 22.92^\circ\text{C}$

This document contains information which is exempt from release under the provisions of the Freedom of Information Act, 5 U.S.C. 552, and is not to be distributed outside the Department of Defense.

Table A-1. Summary of Shots - Model 40 (Continued)

B. Photographic Measurements - Stairway Open

Shot	P _s , psi	Position of Objects	Motion of Objects	Remarks
504	5.3	Row 1	Cylinder "H" tips, moves at 4 ft/sec to right at 4.2 ms and away from steps - rolls back from right wall after rotation at average cross velocity of 2 ft/sec.	P ₁ = 14.8 psi T ₁ = 22.7°C
505	5.2		Slight motion of cylinders "A" and "B" back toward stairs.	Rows refer to Fig. 3. Time is measured from shock arrival at the top of stairs.
506	10.1	Row 1	"A" slid two steps. "B" bottom moved left and side - rolled away from steps. "H" moved after 2.2 ms at 7.5 ft/sec - tilted two R. wall - spun off - airborne w/rotation about long axis - hit middle of room, moved left 10.5 ft/sec to wall and return. In motion after 296 ms.	P ₁ = 14.85 psi T ₁ = 22.62°C All velocities are components in directions noted.
507	20.3	Row 1	"A" and "B" airborne - "A" moved two steps. "B" moved away from steps. "H" apparently hit ceiling, then the floor and collided with "B". "A" began to move at 1.9 ms at 13.9 ft/sec. average 2.9 ft/sec to ceiling and return. In motion at 653 ms.	P ₁ = 14.82 psi T ₁ = 22.17°C

Table A-1. Summary of Shots - Model 40 (Continued)

B. Photographic Measurements - Stairway Open (continued)

Shot	P _s , psi	Position of Objects	Motion of Objects	Remarks
508	5.3	Row 2	"A" and "B" slid slightly to right of steps - did not fall. "H" tips right, falls twd wall. Motion begins at 6.1 ms, <u>2 ft/sec</u> to right. Motion at <u>2.5 ms</u> .	P ₁ = 14.84 psi T ₁ = 22.36°C
509	5.3	Row 3	Almost no motion for all cylinders.	P ₁ = 14.79 psi T ₁ = 21.82°C
510	10.3	Row 3	"A" moved toward stairs and to left. "B" and "H" moved to right - did not tip. Motion stopped after 155 ms.	P ₁ = 14.79 psi T ₁ = 21.92°C
511	10.2	Row 4	Movement to left at 5.6 ms-all lift off floor - slide toward stairs. "H" moved left at <u>2.1 ft/sec</u> . Motion stopped at 213 ms.	P ₁ = 14.8 psi T ₁ = 21.85°C All components in directions noted.
512	10.1	Row 5	All were airborne in direction away from right rear corner. "H" moved at 14.8 ms. Average velocity of "B" to return to floor, <u>1.8 ft/sec</u> . Motion at 298 ms.	P ₁ = 14.8 psi T ₁ = 21.82°C
513	5.4	Left corner under stairs	No noticeable motion of pack.	P ₁ = 14.69 psi T ₁ = 21.34°C All objects were used (See Table I).

Table A-1. Summary of Shots - Model 40 (Continued)

B. Photographic Measurements - Stairway Open (continued)

Shot	P ₁ , psi	Position of Objects	Motion of Objects	Remarks
514	10.3	Left corner under stairs.	Pack was slightly separated during shot, after 26.3 ms.	P ₁ = 14.83 psi T ₁ = 20.60°C
515	20.5	Left corner under stairs.	Pack was blown apart. Object "G" is thrown up and out of Pack. Motion began 9.8 ms. 106 ms for "G" to hit ceiling.	P ₁ = 14.83 psi T ₁ = 20.68°C
517	10.5	Left corner under stairs - tied.	Little motion.	P ₁ = 14.88 psi T ₁ = 22.47°C
518	20.5	Left corner under stairs - tied.	Scattered across room.	P ₁ = 14.94 psi T ₁ = 21.57°C
519	20.5	Left front wall under stairs.	Pack moved right in 2.2 ms. "G" hit right wall and returned, 36.7 ft/sec average. Motion continued after 576 ms.	P ₁ = 14.95 psi T ₁ = 22.45°C

Table A-1. Summary of Shots - Model 40 (Continued)

B. Photographic Measurements - Stairway Open (continued)

Shot	P _s , psi	Position of Objects	Motion of Objects	Remarks
520	21.0	Center of end wall away from stairs.	Objects scattered up left side of floor. Pack flew upwards, to left, and apart. "A" moved at 2.6 ms. "I" hit ceiling at 13.4 ft/sec. "F" moves left at 25.6 ft/sec. "G" circulates right at 5.9 ft/sec. Movement after 491 ms.	P _I = 14.95 psi T _I = 22.03°C All velocities are components in directions noted.
521	5.4	Row 1 - Cylinders tied.	To right and away from stairs.	P _I = 14.89 psi T _I = 22.0°C
522	5.3	Right rear corner, away from stairs.	Slight movement.	P _I = 14.88 psi T _I = 21.95°C
523	10.5	Right rear corner, away from stairs.	Pack scattered across rear of floor. Pack moved at 7 ms. "E" moved left at 12.6 ft/sec. "I's" still in air at 292 ms.	P _I = 14.88 psi T _I = 21.99°C
524	5.2	Left rear corner, away from stairs.	Almost no movement.	P _I = 14.89 psi T _I = 22.55°C
525	10.3	Left rear corner, away from stairs.	Pack moved slightly out from the corner.	P _J = 14.91 psi T _I = 22.19°C

Table A-1. Summary of Shots - Model 40 (Continued)

B. Photographic Measurements - Stairway Open (continued)

Shot	P_s , psi	Position of Objects	Motion of Objects	Remarks
526	20.7	Left rear corner, away from stairs.	Pack shifted left. "I" hit ceiling at 10.7 ft/sec average velocity. "E" moved right at average of 82 ft/sec. Pack bursts up at 491 ms. towards stairs.	Time used from Shot 525.
529	5.3	Streamers on Rows 1, 3 and 5.	Row 1 moved in 1.2 ms. Row 3 moved in 1.6 ms. Row 5 moved in 2.0 ms. Full flow about 17.2 ms. Reversed flow at 18.8 ms. Outflow stops about 200 ms.	Mylar streamers $P_1 = 14.88$ psi $T_1 = 21.85^\circ\text{C}$ No objects for this shot.

Table A-1. Summary of Shots - Model 40 (Continued)

C. Photographic Measurements - Closed Stairway

Shot	P_s , psi	Position of Objects	Motion of Objects	Remarks
533	5.2	Row 1	Right cylinder moves from stairs, airborne towards right wall, hit and rolled back towards center at <u>1.8 ft/sec</u> . Other cylinders did not move.	4.75" X 8" door into model basement. $P_1 = 14.97$ psi $T_1 = 25.05^\circ\text{C}$ Time zero is shock arrival at doorway.
534	10.2	Row 1	Right cylinder airborne to right rear, away from stairs, <u>3.8 ft/sec</u> . Middle cylinder moved slightly right, <u>1.6 ft/sec</u> . Left cylinder did not move.	$P_1 = 14.92$ psi $T_1 = 23.37^\circ\text{C}$
535	10.2	Row 3	Right cylinder fell away from steps, rolled to center rear. The other two cylinders fell back toward stairway, <u>1-3 ft/sec</u> .	$P_1 = 14.92$ psi $T_1 = 23.41^\circ\text{C}$
536	10.2	Row 5	Right cylinder moved to rear and center, bounced back. The other cylinders move to left wall and back to wall at stairs, <u>1-3 ft/sec</u> .	$P_1 = 14.91$ psi $T_1 = 23.47^\circ\text{C}$

Table A-1. Summary of Shots - Model 40 (Continued)

C. Photographic Measurements - Closed Stairway (Continued)

Shot	P _s , psi	Position of Objects	Motion of Objects	Remarks
537	20.6	Row 1	Right cylinder airborne to left rear corner from stairs at 18.4 ft/sec. Center cylinder moves right 3-6 ft/sec, it is airborne. Left cylinder moves right airborne, 1 ft/sec.	P ₁ = 14.84 psi T ₁ = 21.26°C
538	21.0	Row 3	All cylinders became airborne. Right hand cylinder moved diagonally towards left rear at 8.7 ft/sec. The other cylinders moved left and to front near stairway 2-3 ft/sec.	P ₁ = 14.84 psi T ₁ = 21.32°C All velocities are components in directions noted.
539	20.7	Row 5	Right hand cylinder moved to center rear 3-4 ft/sec and bounced off to left wall. Other cylinders moved to left and back to stairs 1.5 - 2.2 ft/sec.	P ₁ = 14.81 psi T ₁ = 21.39°C

APPENDIX B

PRESSURE-TIME RECORDS - MODEL 40

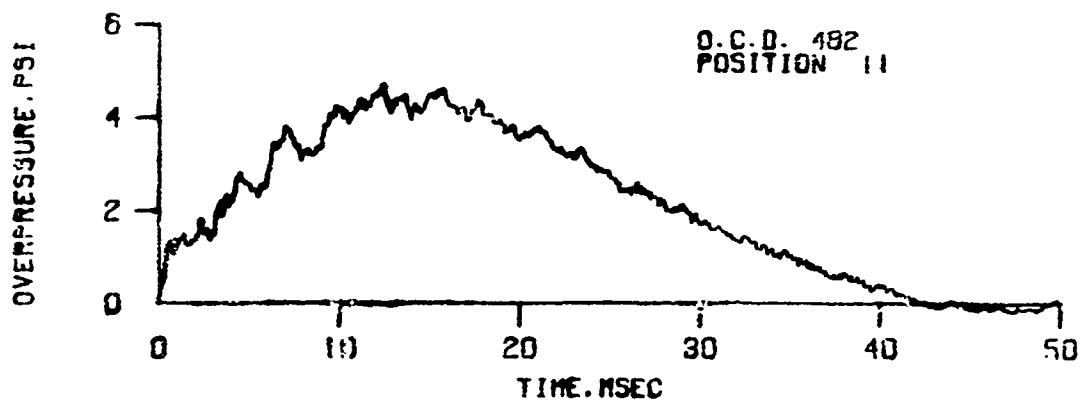
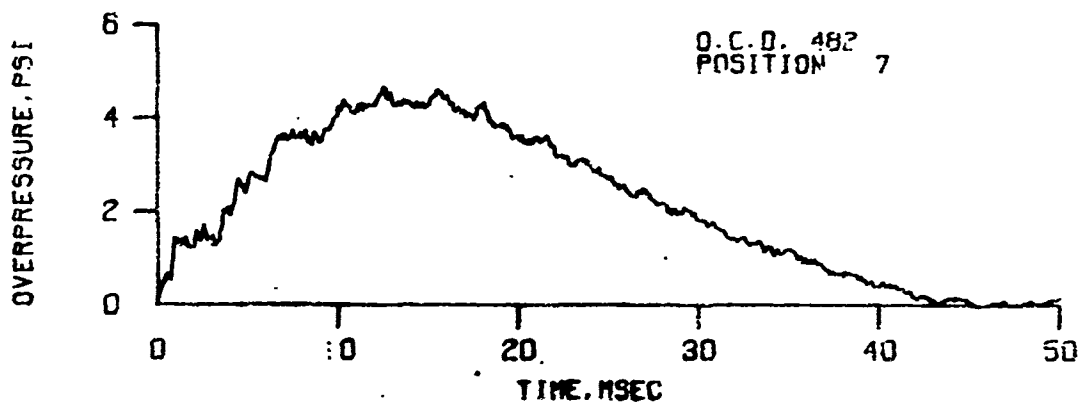
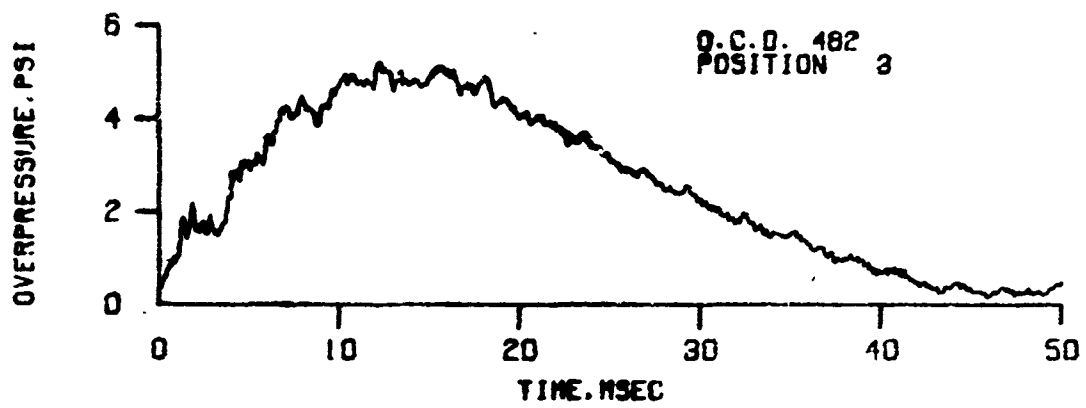


Figure B-1. Records from the Pressure Probes - $P_s = 5\text{psi}$

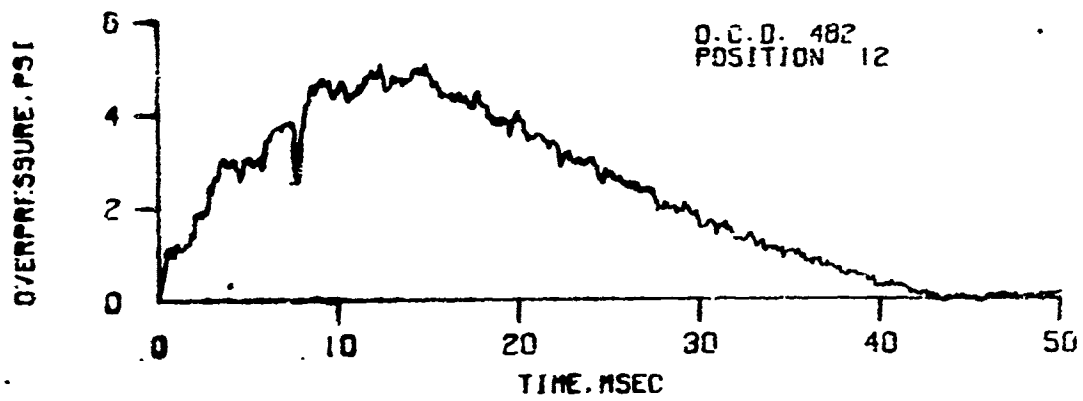
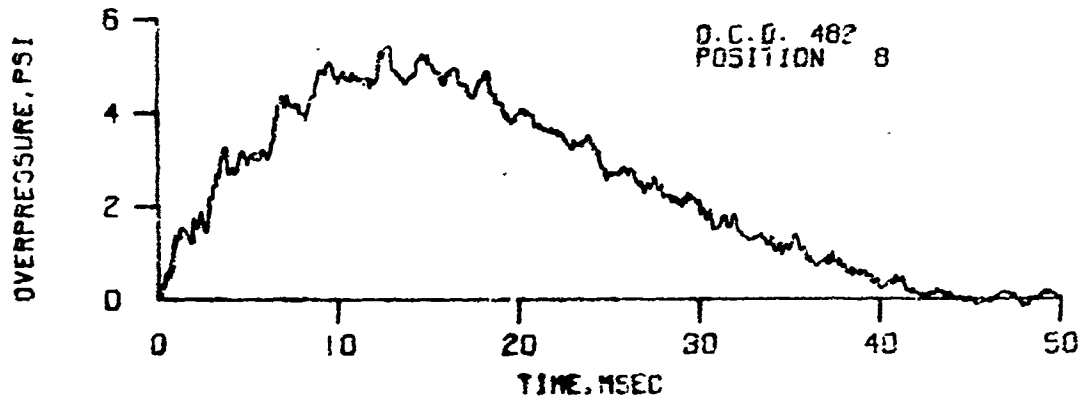
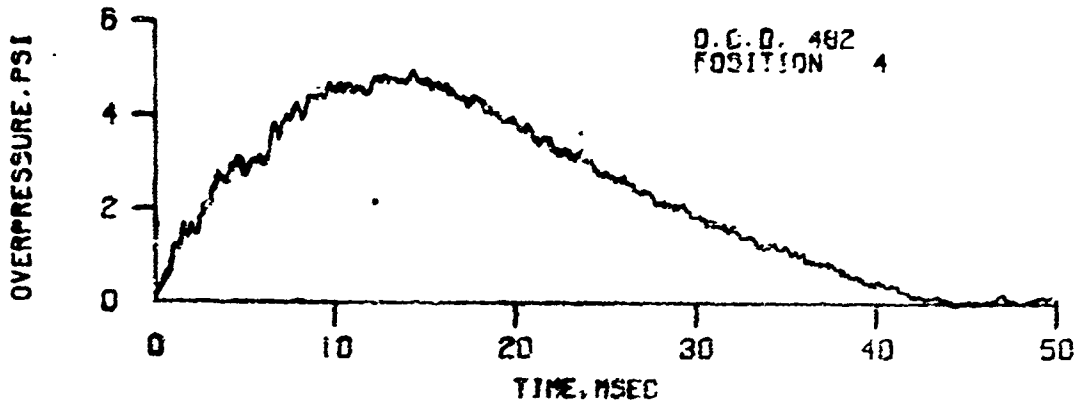
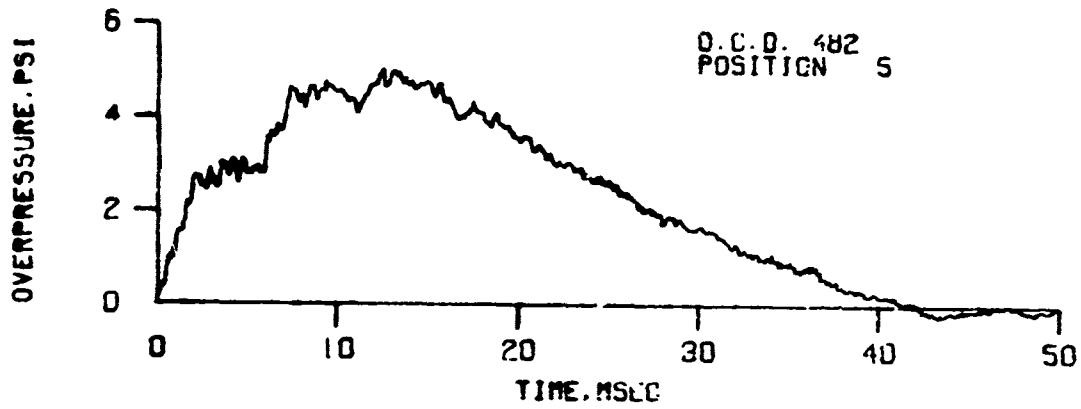


Figure B-1. (Continued)



Position 9 Lost

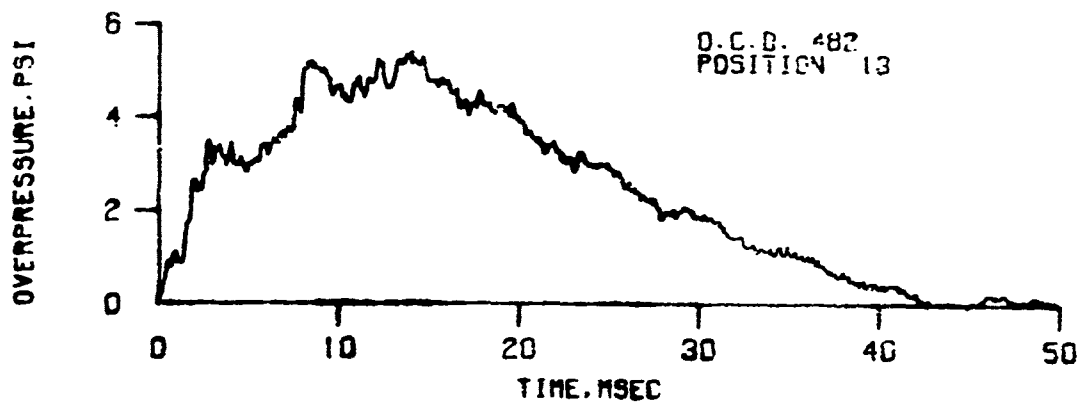


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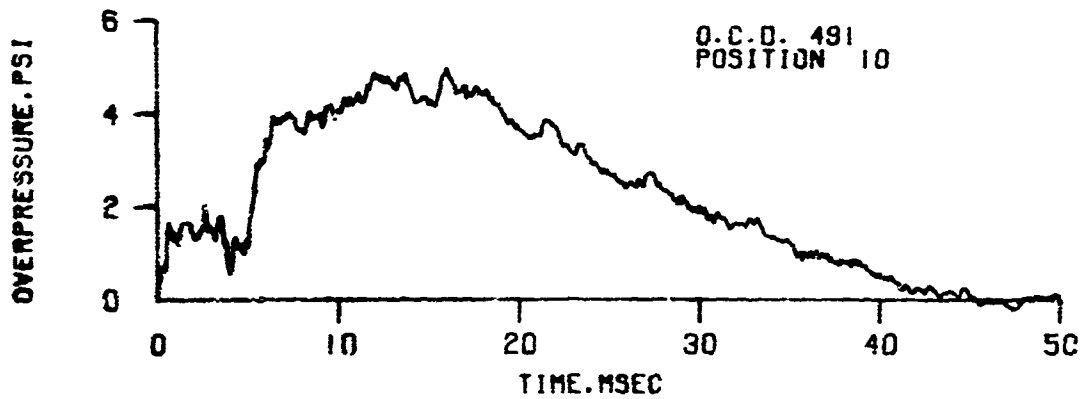
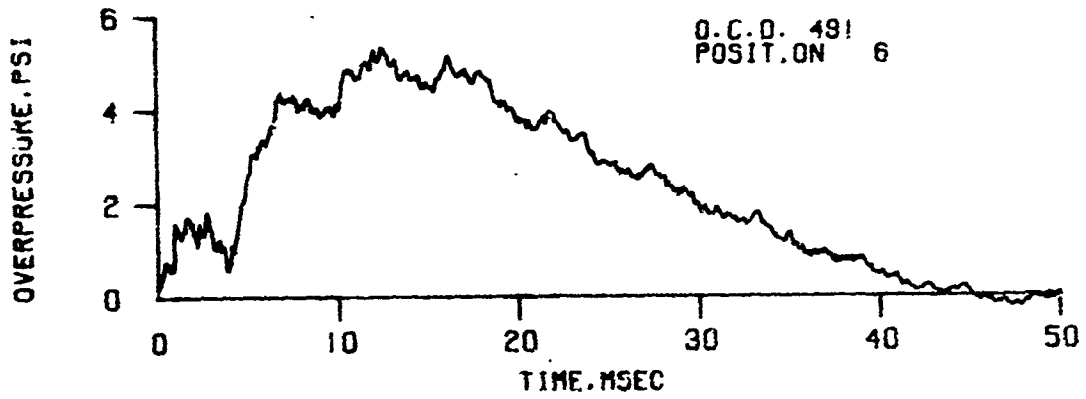
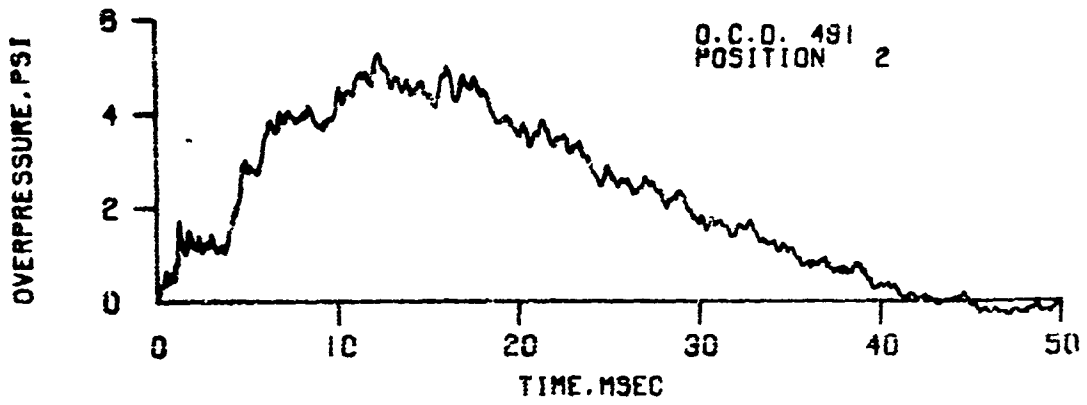


Figure B-2. Records from the Floor Transducers - $P_8 = 5.2 \text{ psi}$

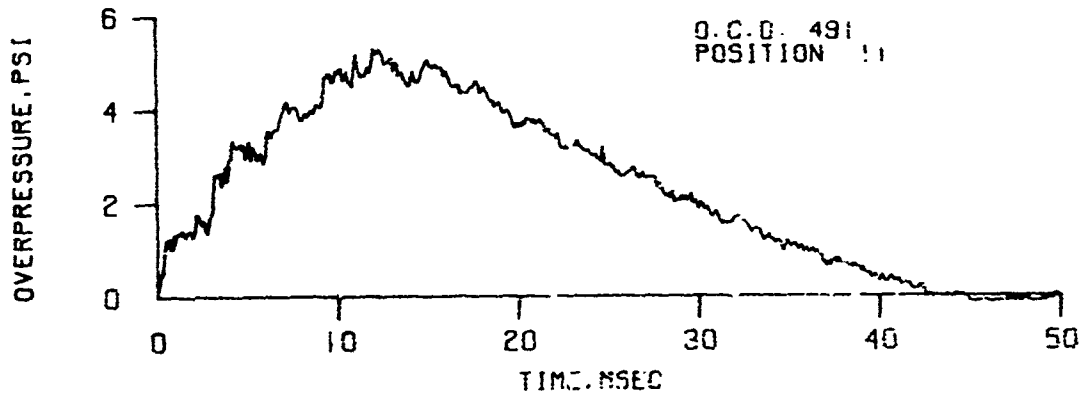
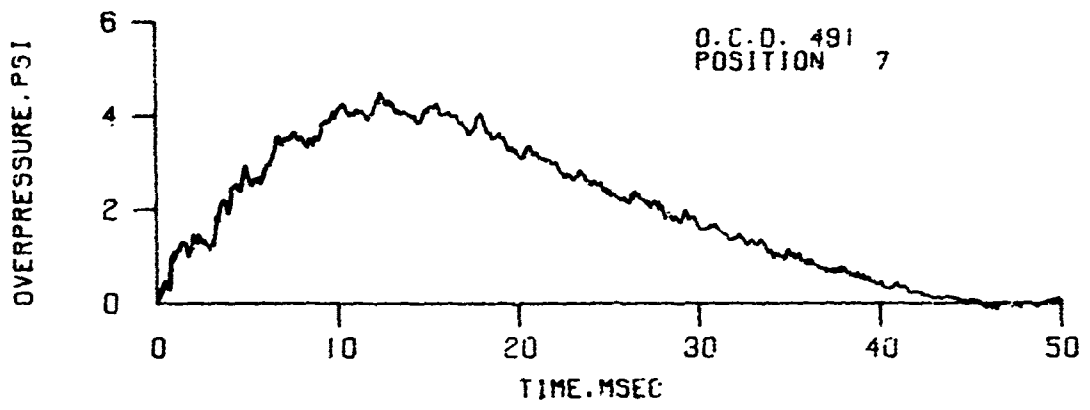
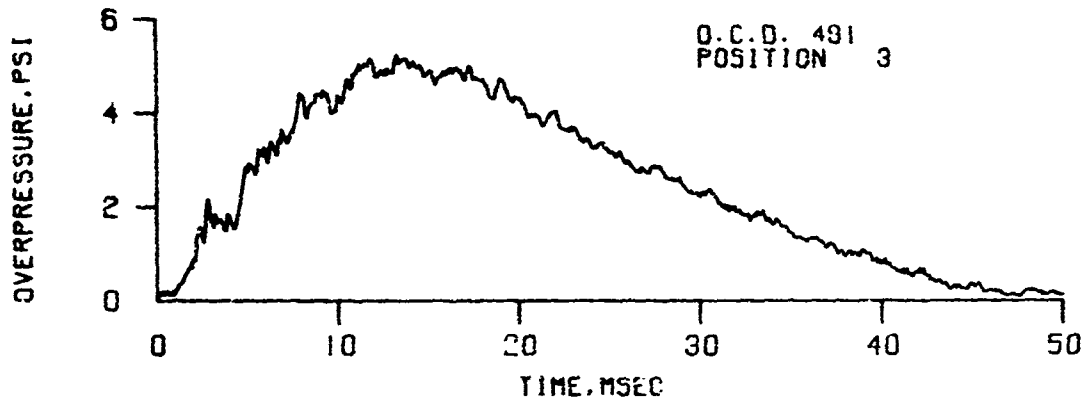


Figure B-2. (Continued)

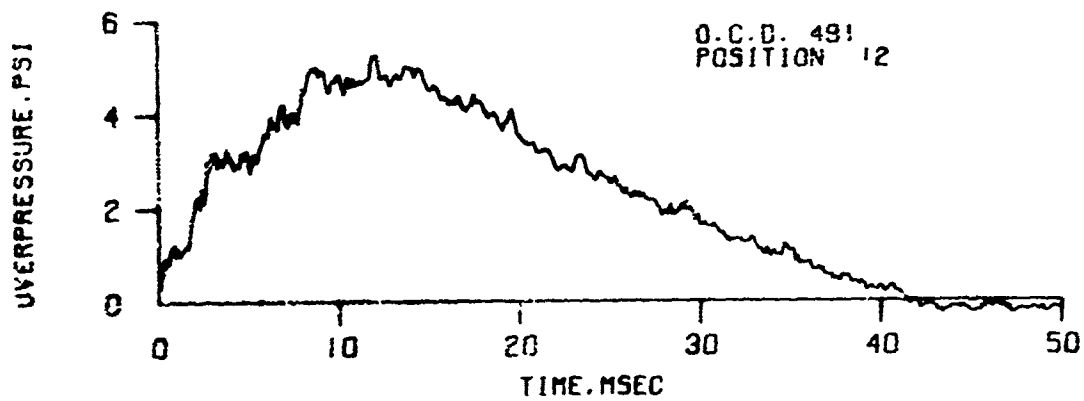
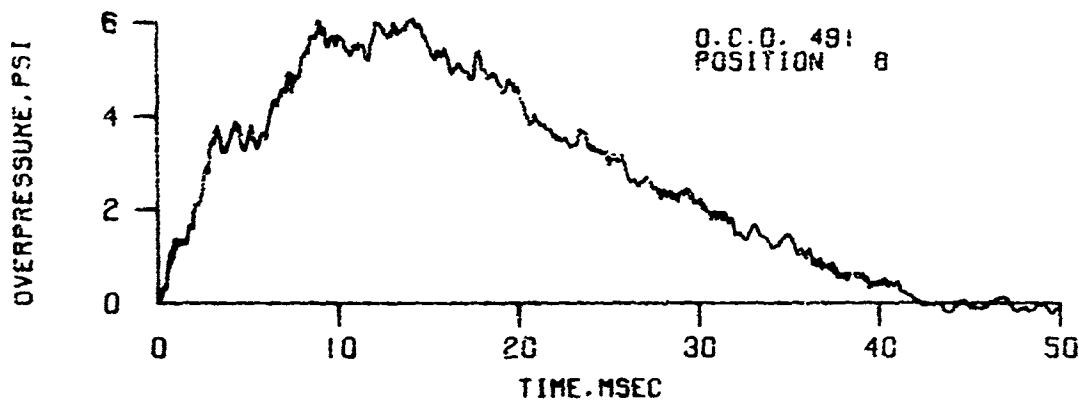
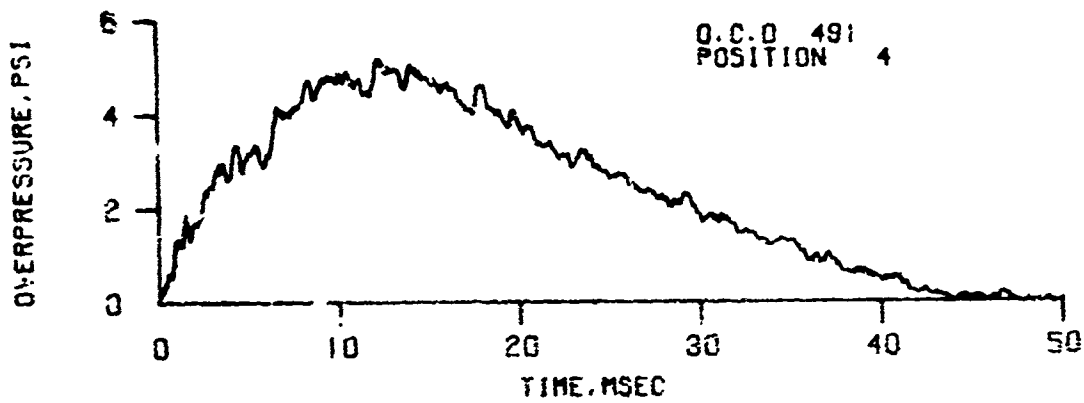


Figure B-2. (Continued)

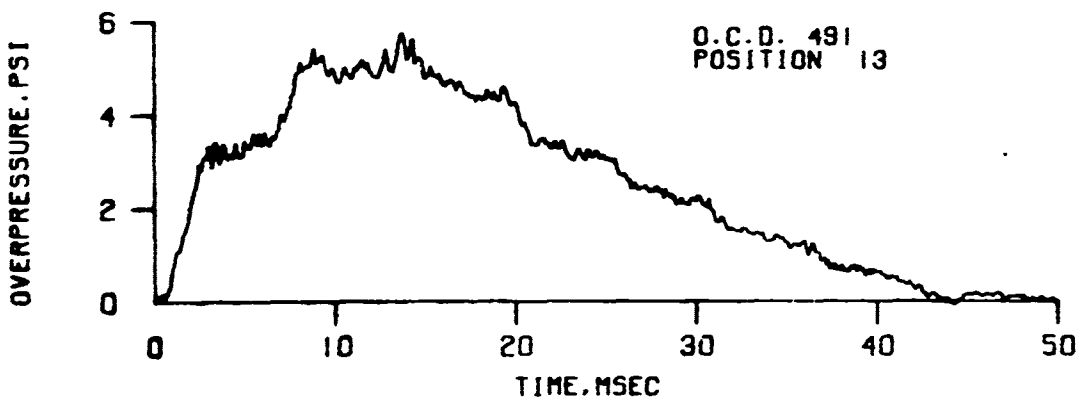
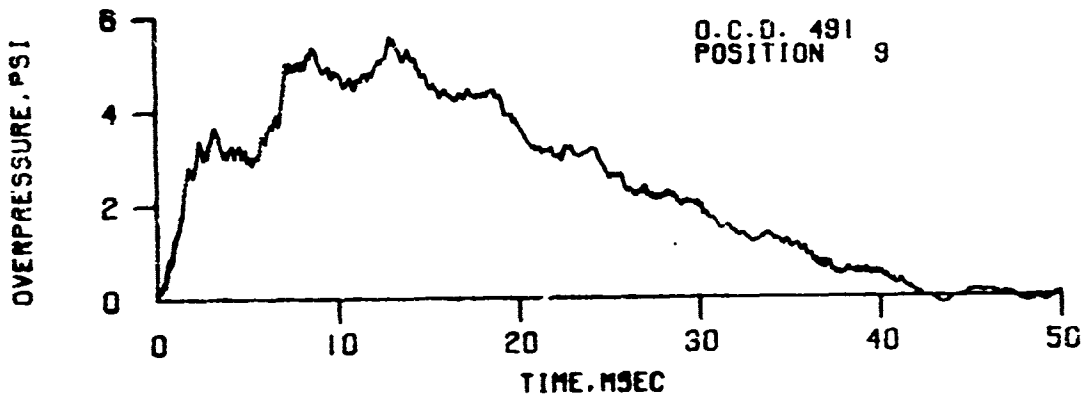
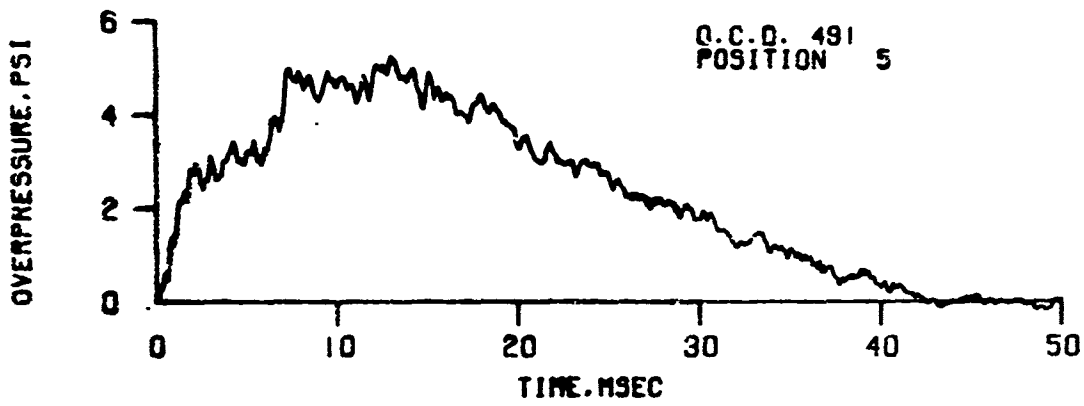


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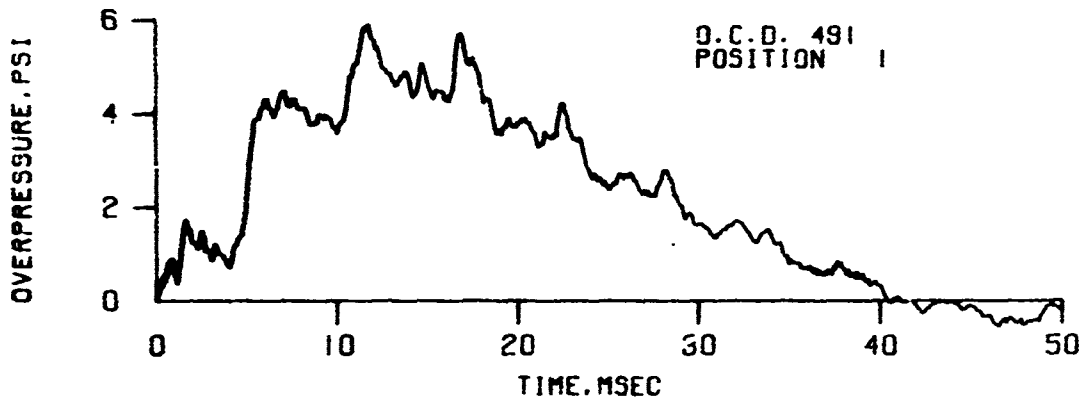
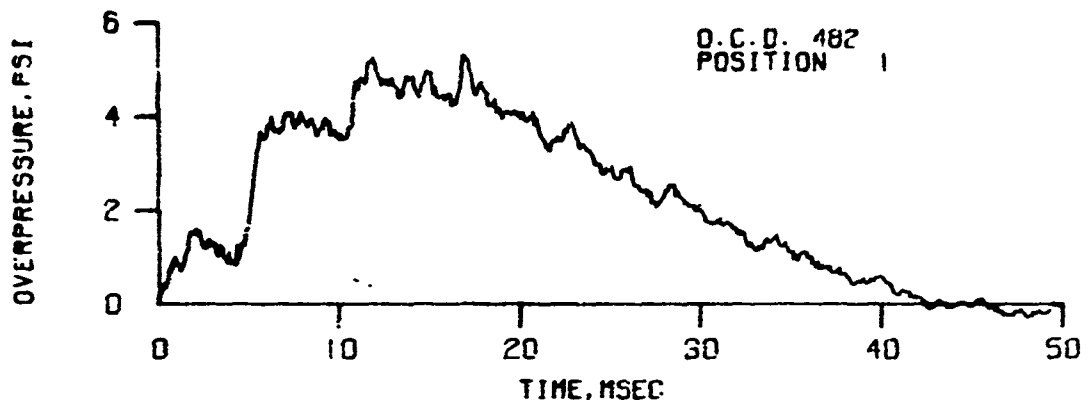


Figure B-3. Comparison of Position 1 - $P_s = 5\text{psi}$

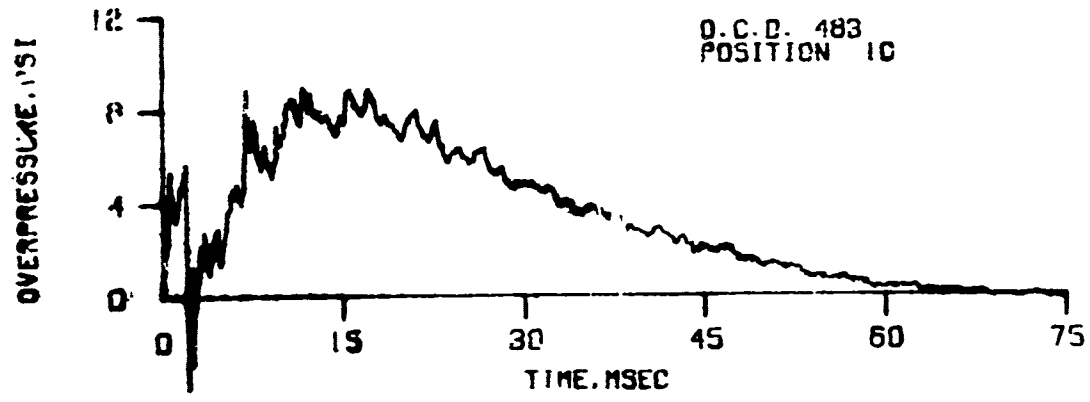
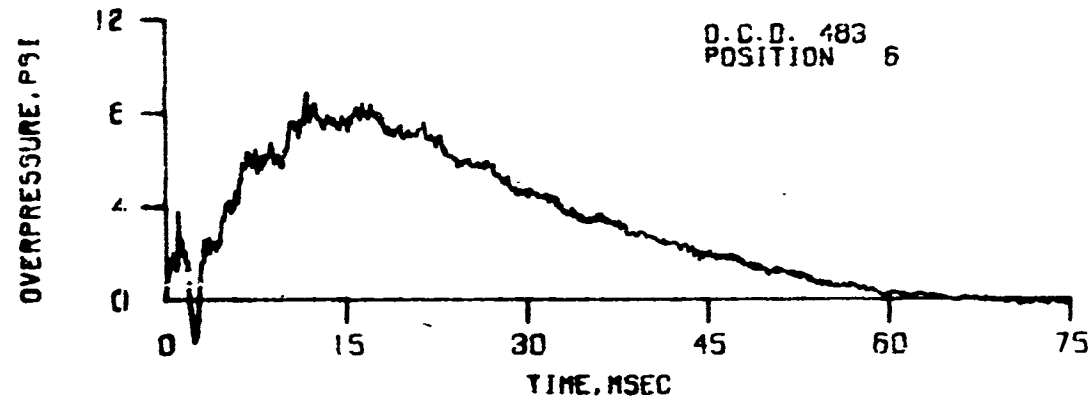
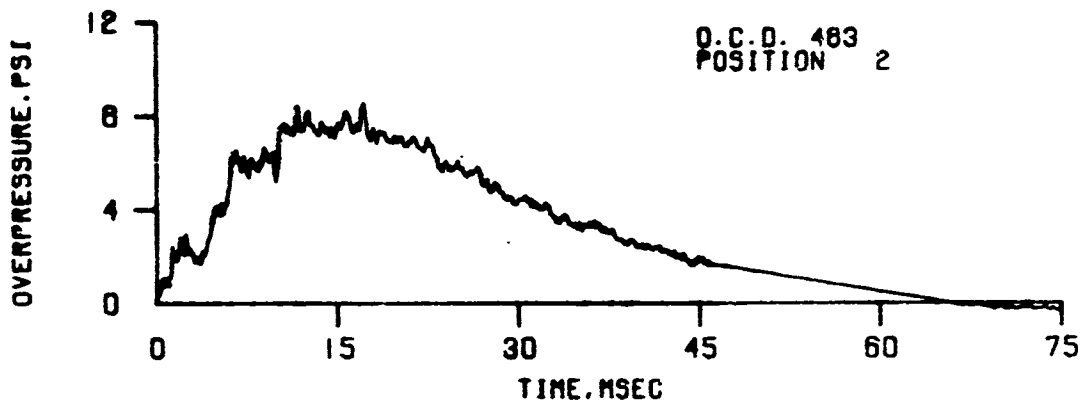


Figure B-4. Records from the Pressure Probes - $P_3 = 10\text{psi}$

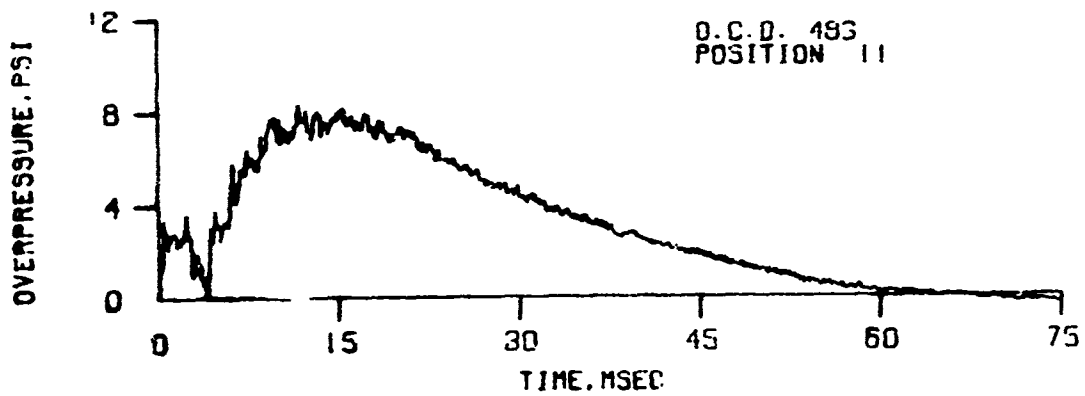
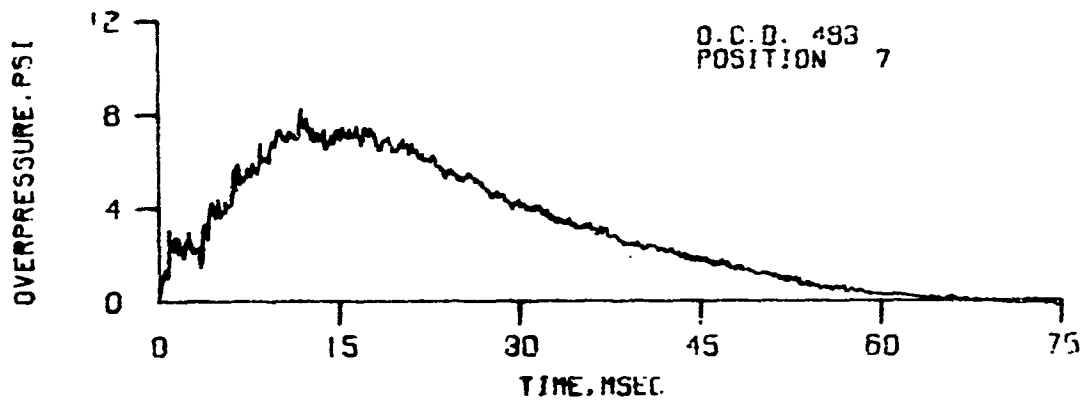
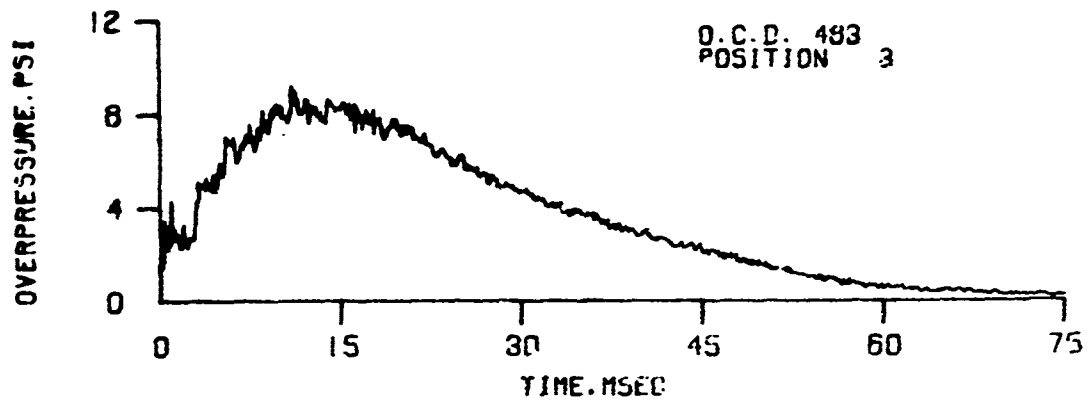


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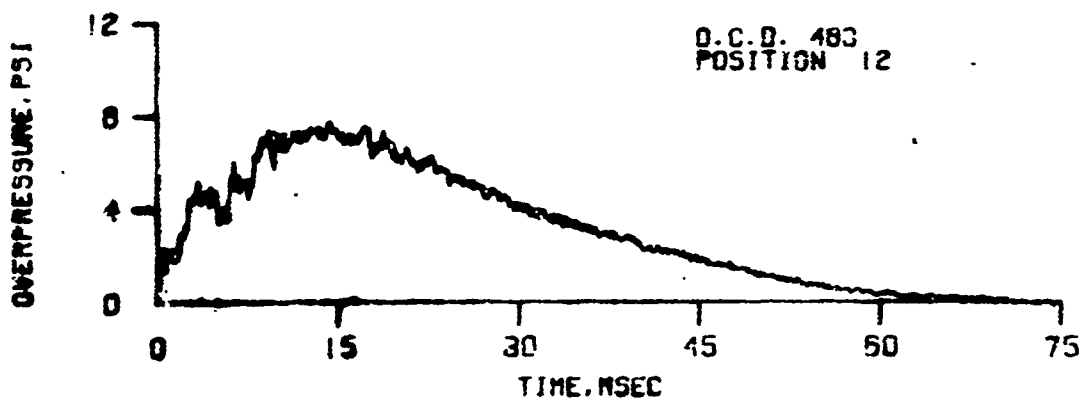
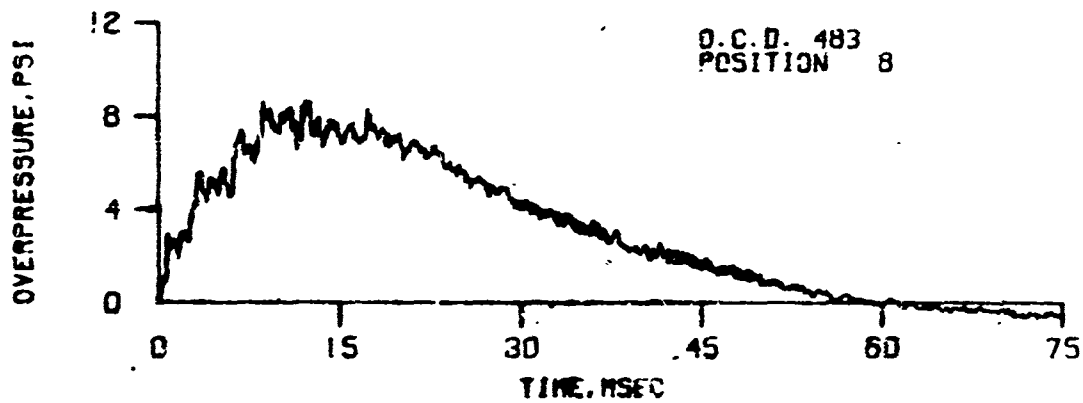
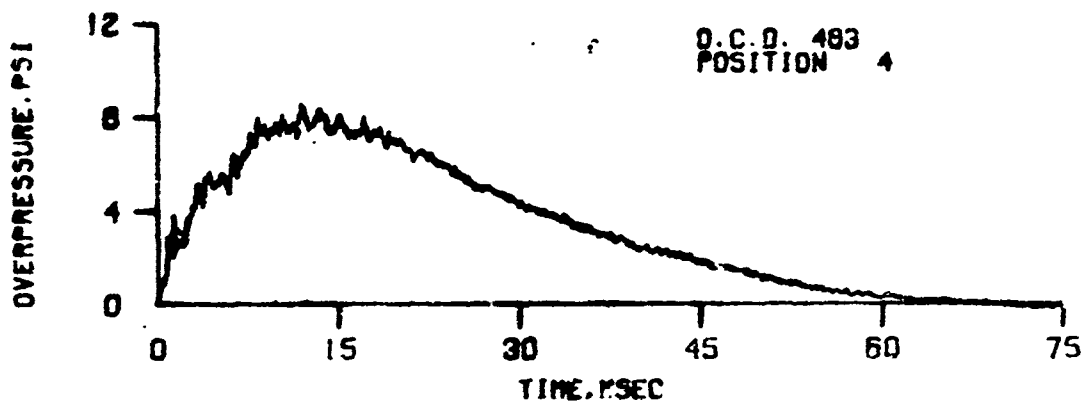
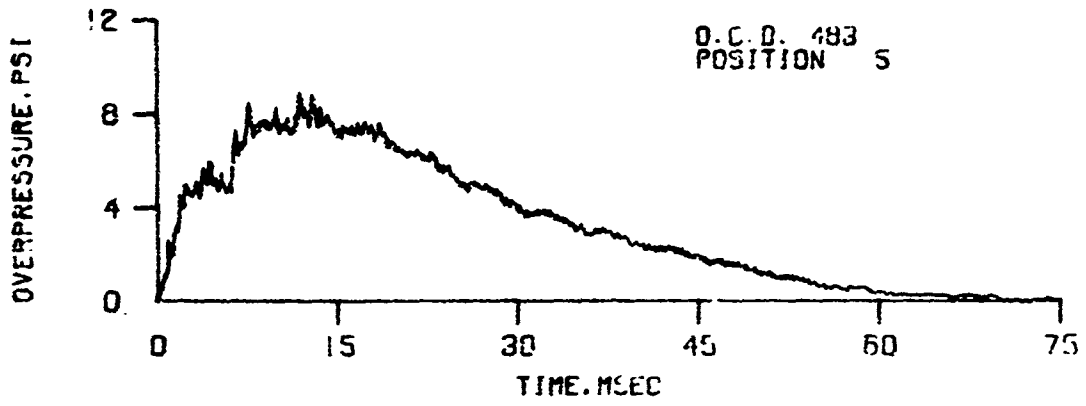


Figure B-4. (Continued)



Position 9 is Missing

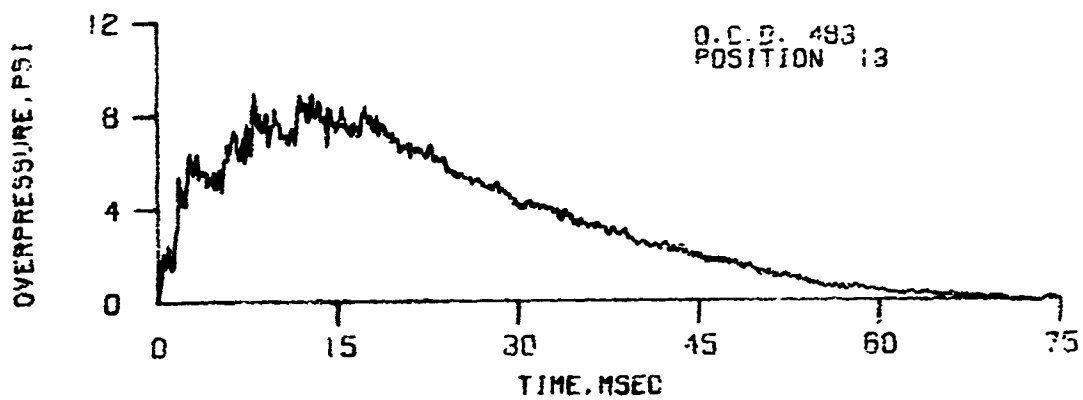


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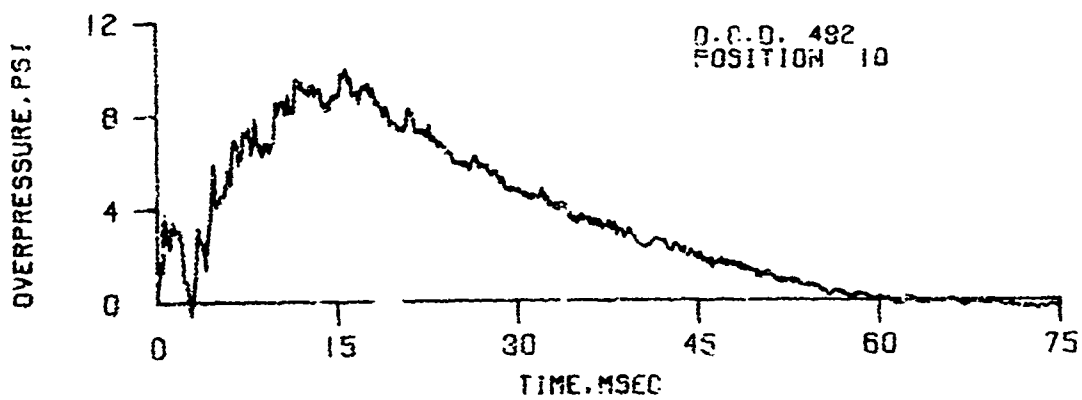
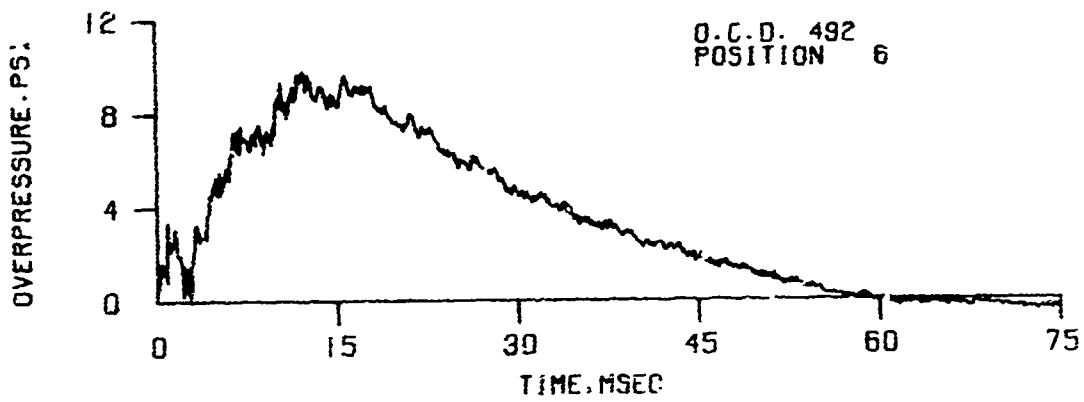
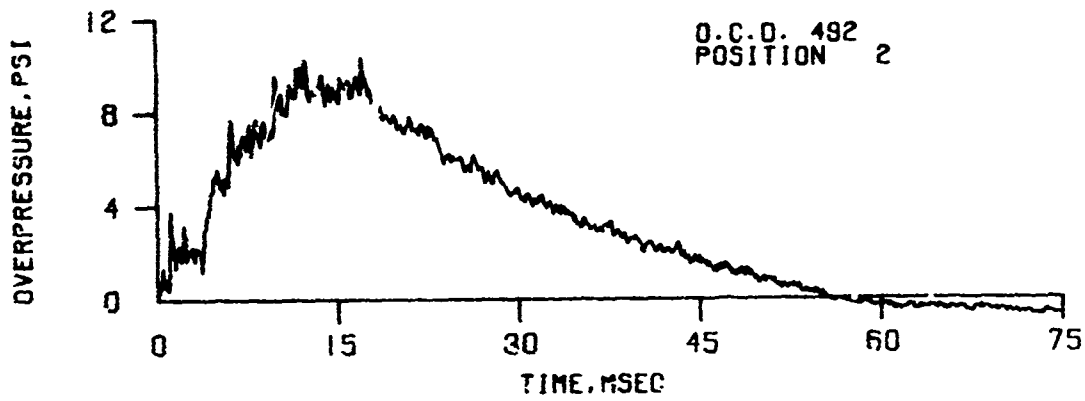


Figure B-5. Records from the Floor Transducers - $P_s = 10.5 \text{ psi}$

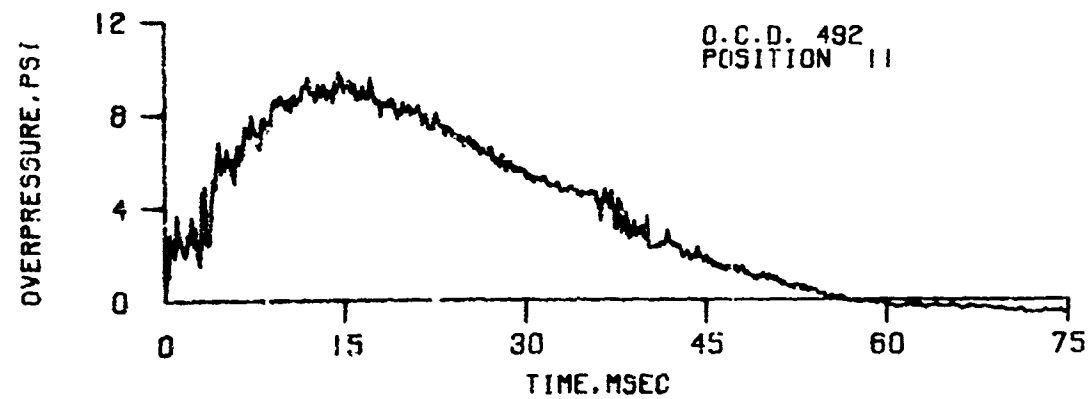
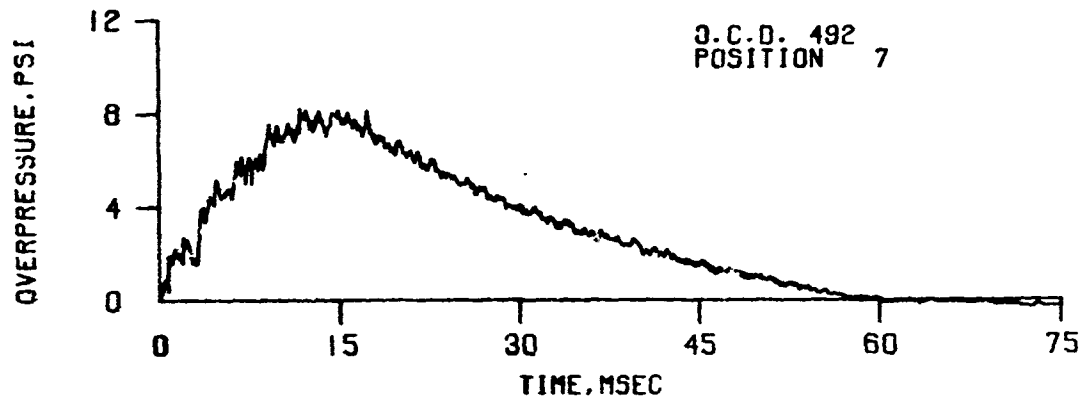
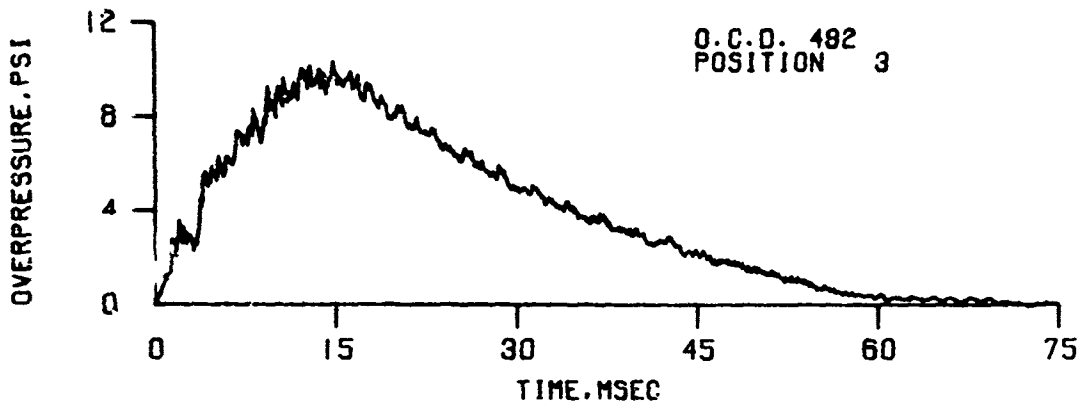


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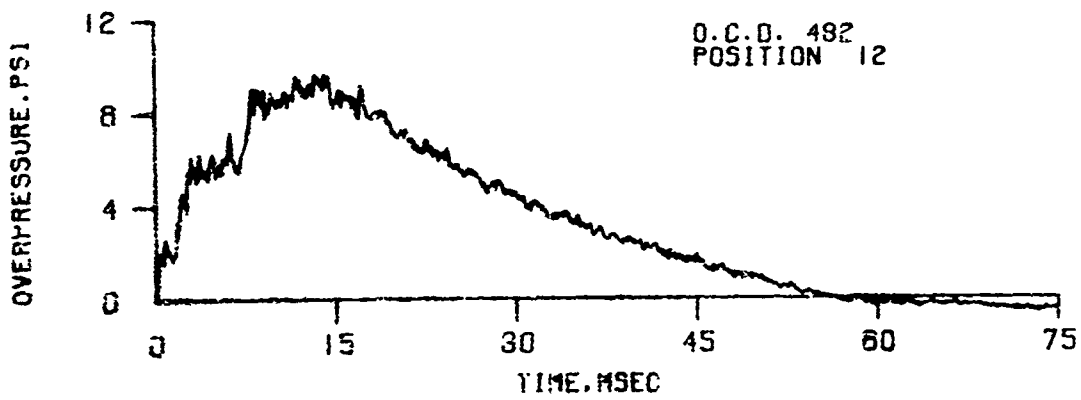
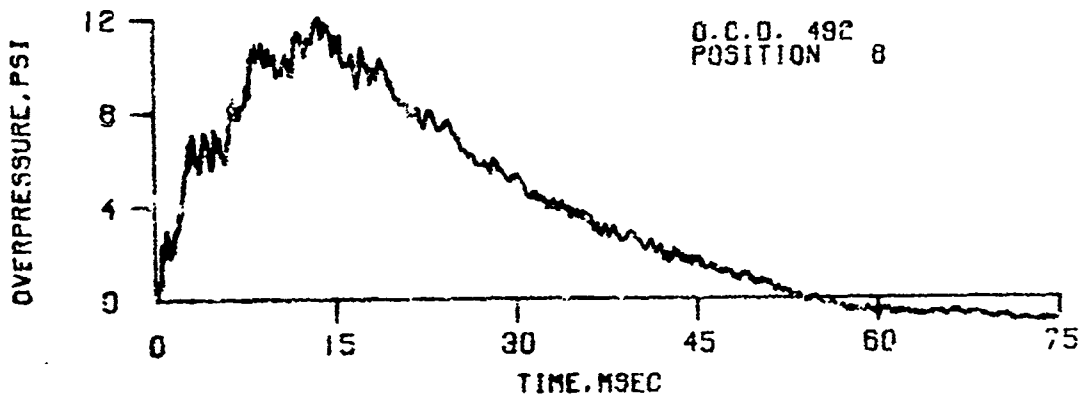
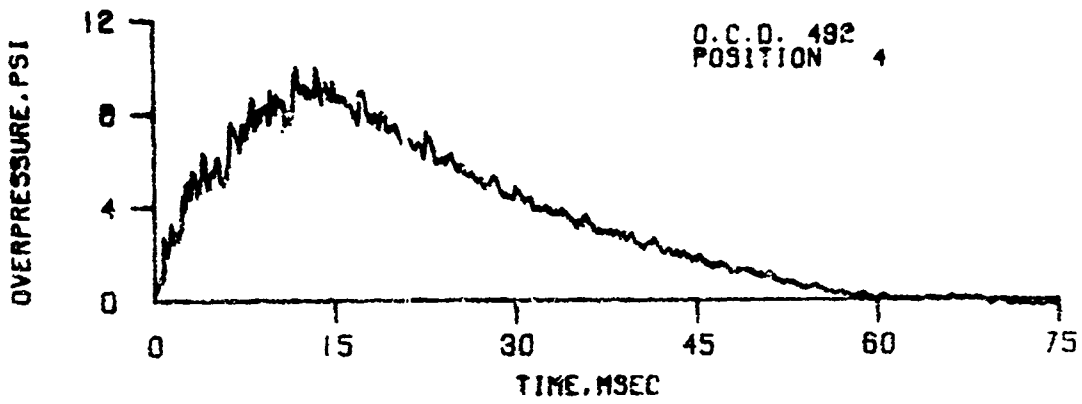


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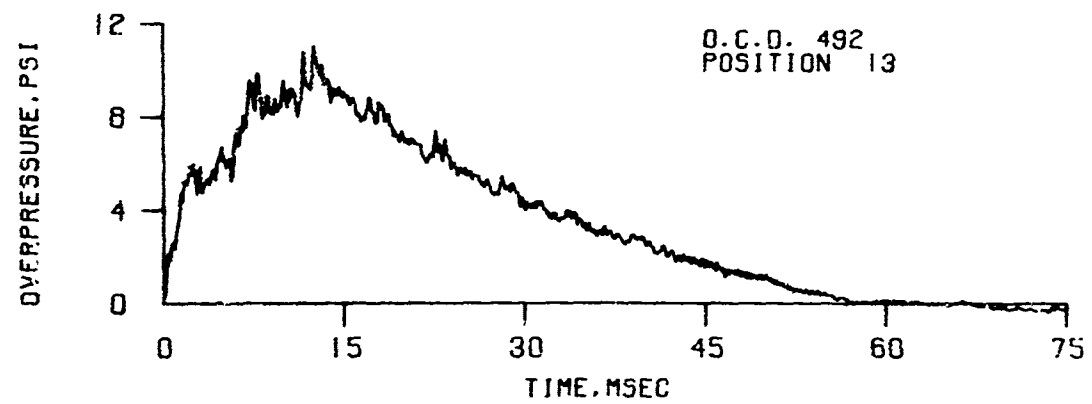
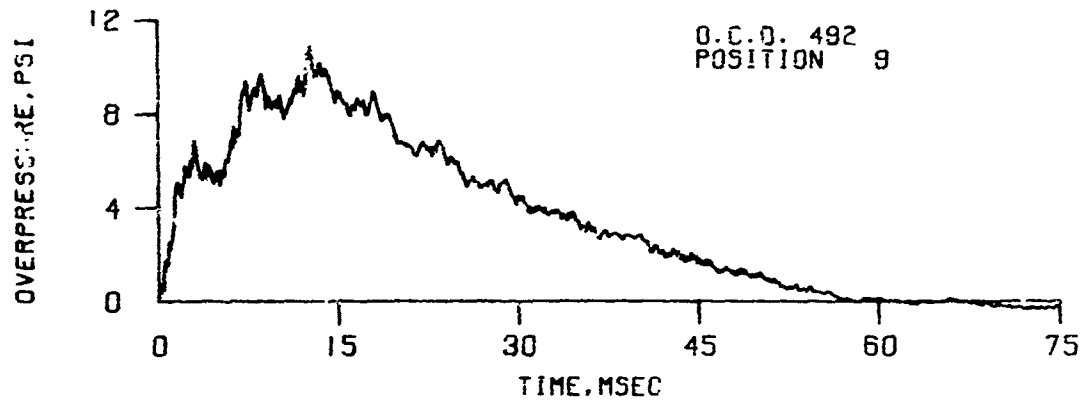
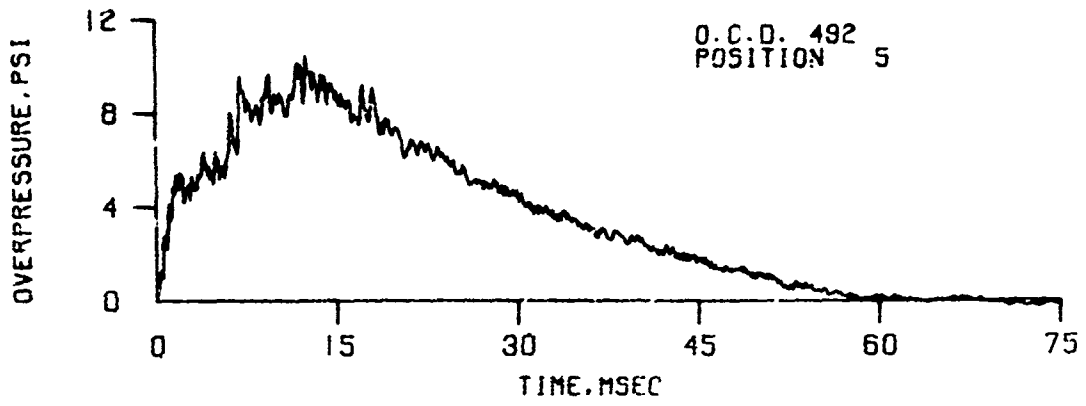


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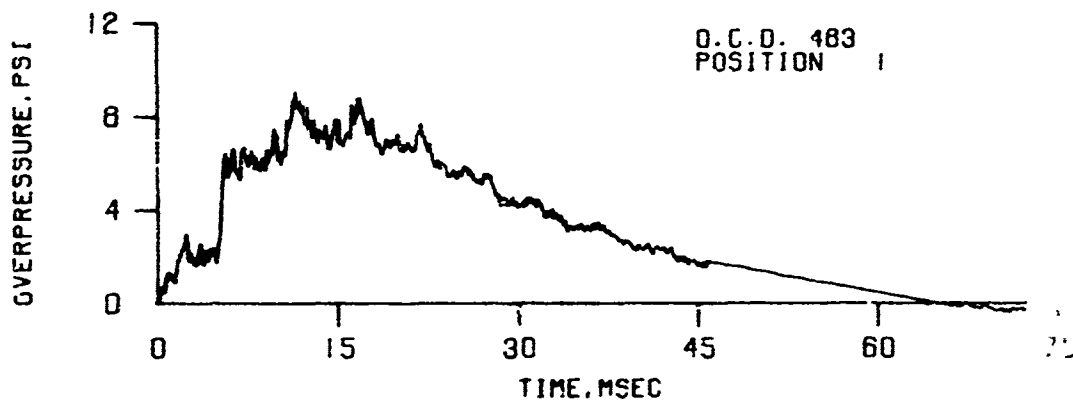
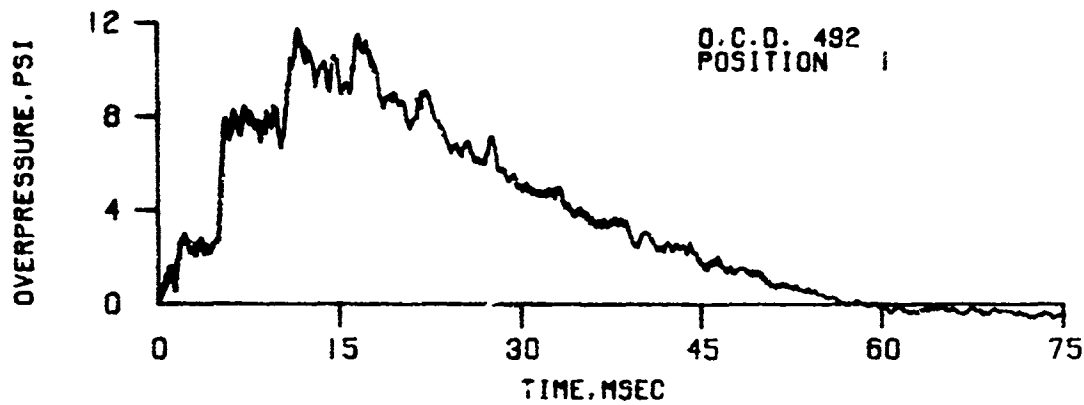


Figure B-6. Comparison of Position 1 - $P_S = 10\text{psi}$

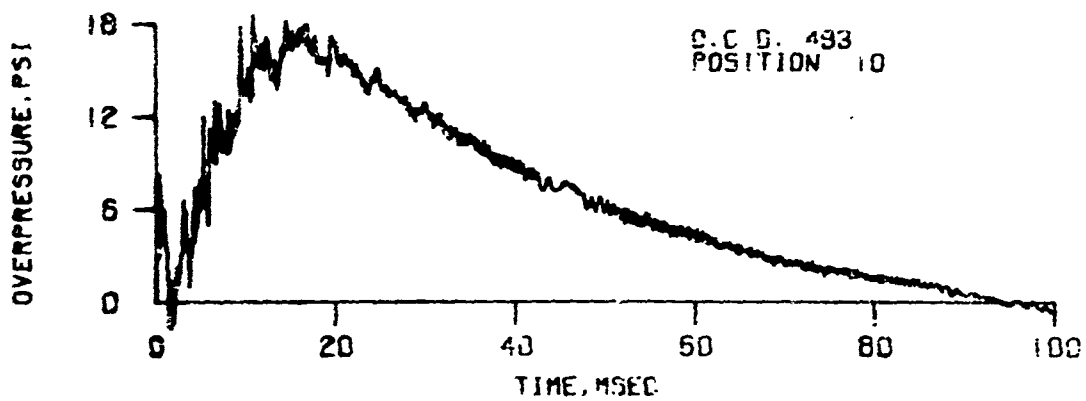
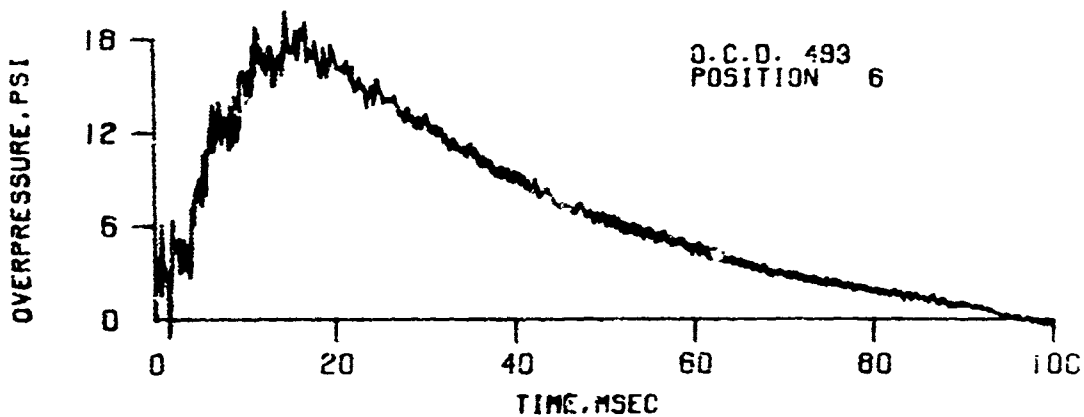
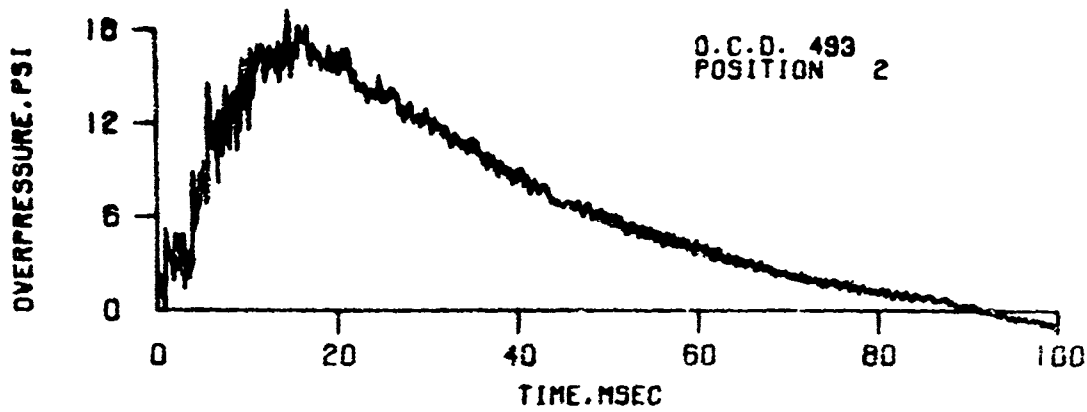
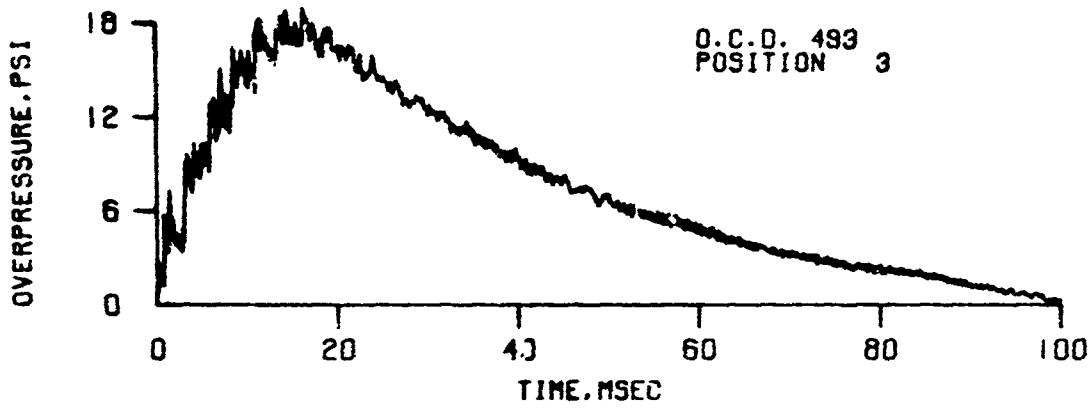


Figure B-7. Records from the Floor Transducers - $P_s = 20\text{psi}$



Position 7 is Missing

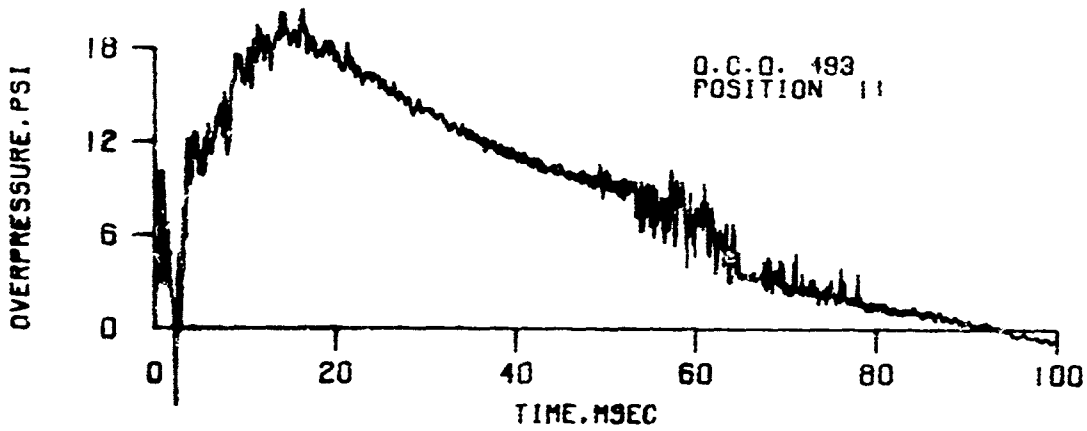


Figure F-7. (Continued)

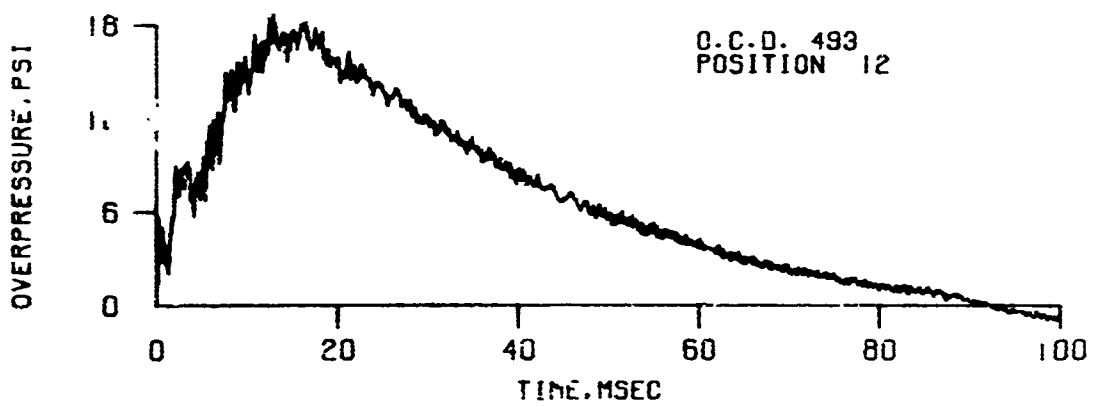
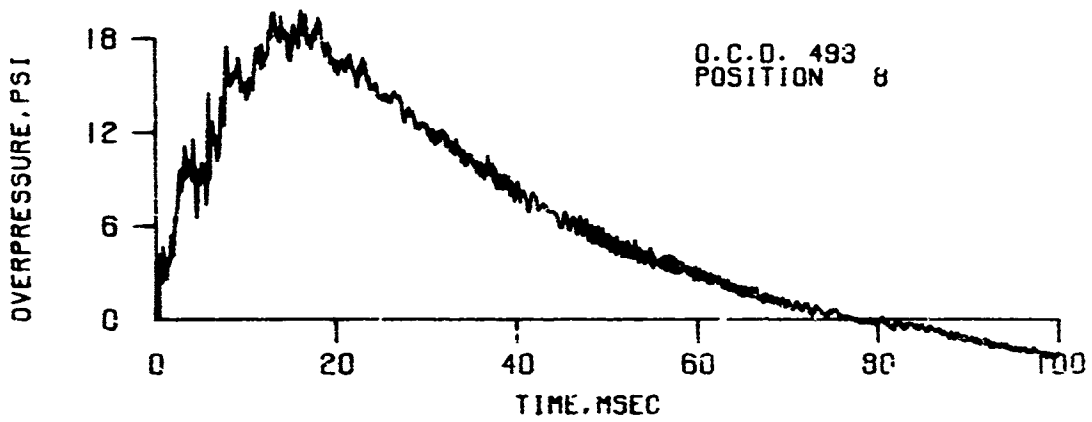
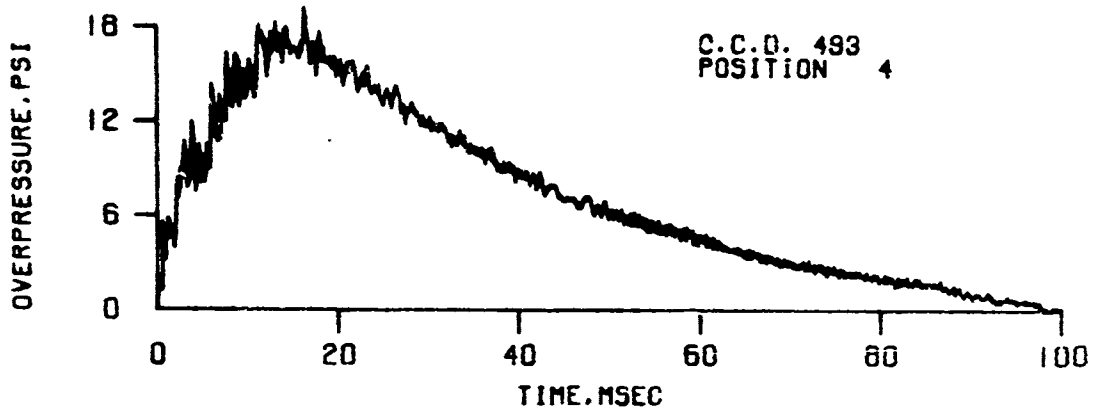


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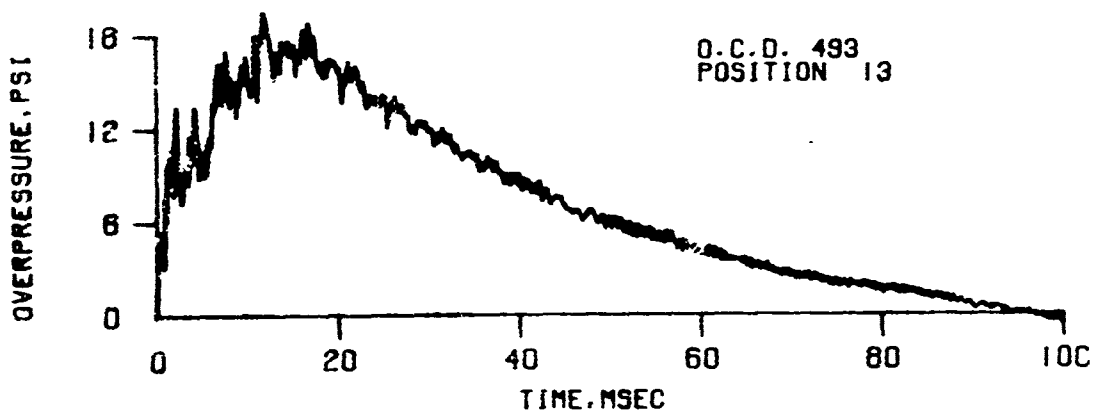
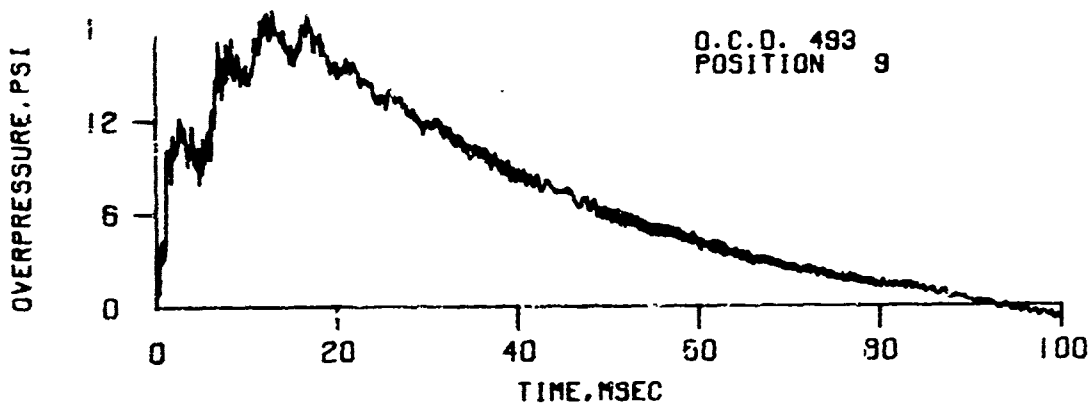
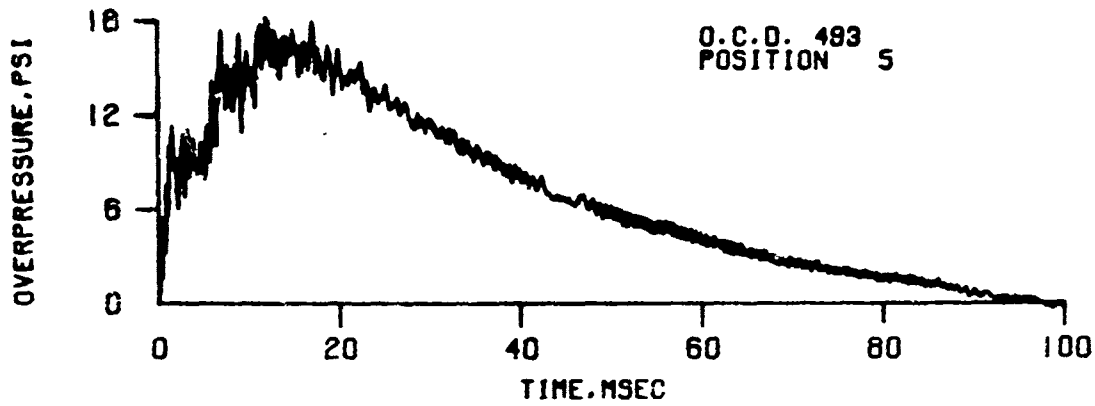


Figure B-7. (Continued)

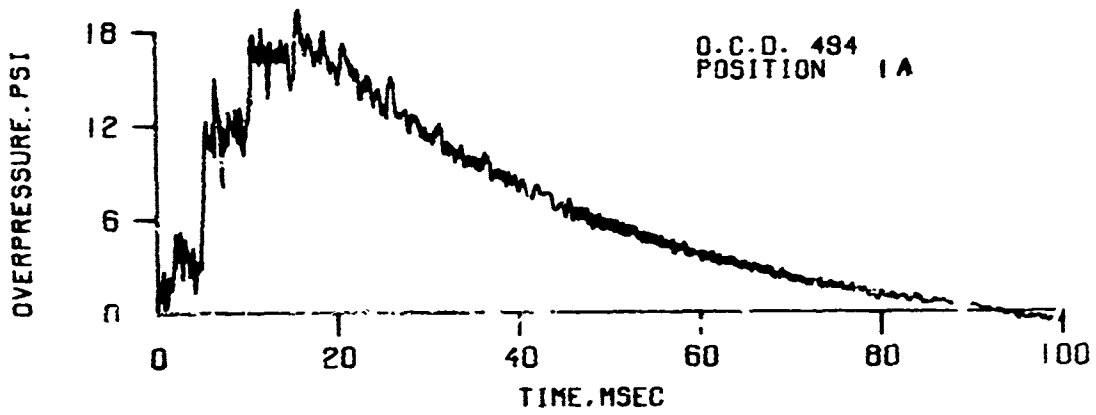
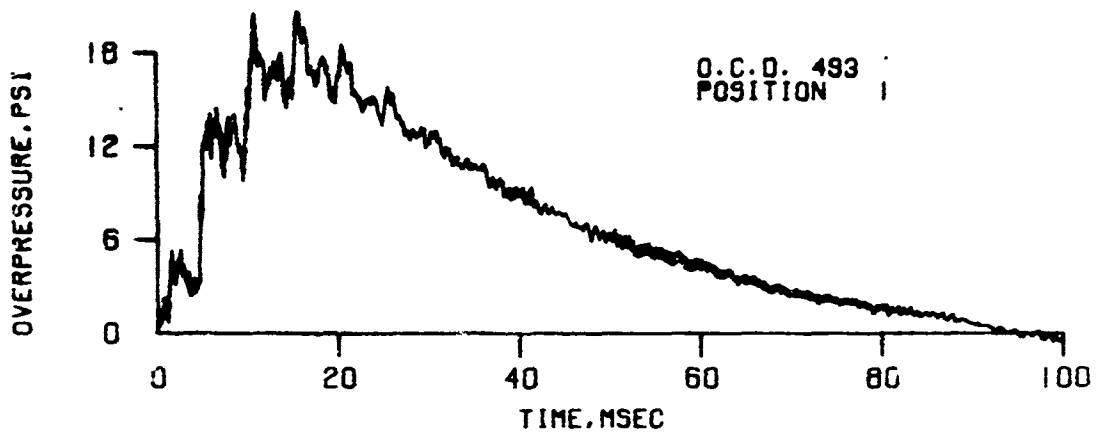


Figure 3-7. (Continued)

APPENDIX C

COMPUTER PROGRAM FOR PRESSURE FILL

USE OF APPENDIX C

The computer program for the prediction of the average pressure-time fill of a room is written in Fortran IV with slight modification for the BFL computer. The plotting routines are for the Calcomp Plotter. See ARDC Tech. Report No. 6, July 1970, Aberdeen Proving Ground, Md. 21005.

The input data are shown at the end of the program. In the order listed, they are: the area of the entrance (square feet) to the room, the volume of the room (cubic feet), a characteristic time (seconds) chosen to give a smooth filling curve, for example, about equal to $(.05) (\text{Volume/Area}) / (\text{Ambient Sound Velocity})$, ambient pressure (psi) before the shock wave enters the room, and the density (slugs per cubic feet) of the input shock wave.

The second set of input data is made up of time (seconds) and pressure (psi) points from the input shock wave.

The third set of data (after the negative control card) is time (seconds) and pressure (psi) points from the experimental fill curve that is being compared. A negative control card separates sets of data.

The ambient density in the room before the shock wave enters is given on Line 31 of the program as D3. This value is changed as needed for new conditions.

Fill curve tables are printed out as a function of time and a plot is made which contains the input wave, the predicted fill curve, and the experimental data points.

*	7B175 FORTRAN CHAMBER FIL RAITV - COULTER FEB 72	1
	LIST(CARDS)	2
3	MAXT(3) MINS	3
4	MAXO(2000) INES	4
	DIMENSION X(500),Y(500),TX(500),P2(500),T1(10),T2(10),T3(10),	5
	1YY(500)	6
	COMMON B3(5000)	7
1	FORMAT(=E:2.6)	8
2	FORMAT(=12.3,4E16.6)	9
3	FORMAT(=0X)	10
4	FORMAT(=X,5HAREA1,9X,6HVO UMF,12X,4HTIME,11X,8HPRESSURE,	11
1	8X,7HDENSITY)	12
5	FORMAT(=X,4HTIME,10X,8HPRESSURE,10X,4HDENS,13X,2HU2,	13
1	13X,3HDPT)	14
6	FORMAT(=X,7HSECONDS,10X,3-PSI,10X,8HUE-S2/F4,11X,3HFPS,	15
1	12X,3HPSI)	16
	G1=,714286	17
	G2=,285714	18
	G3=7.	19
10	READ(5,*)A2,V3,T1,P30A,D1	20
	WRITE(6,3)	21
	WRITE(6,4)	22
	WRITE(6,2)A2,V3,T1,P30A,D1	23
	WRITE(6,3)	24
	WRITE(6,5)	25
	WRITE(6,6)	26
	WRITE(6,3)	27
	I=1	28
	T=0.	29
	P30=P30A*144.	30
	D3=,60233	31
	P3=P30	32
	J=0	33
20	READ(5,*)RT,RP,A,B,C,H	34
	IF(RT.LT.0.0) GO TO 30	35
	X(I)=RT	36
	X(I+1)=A	37
	X(I+2)=C	38
	Y(I)=RP	39
	Y(I+1)=B	40
	Y(I+2)=H	41
	I=I+3	42
	GO TO 20	43
30	N=I-1	44
	NN=N	45
	I=1	46
	DO 40 K=1,NN	47
	YY(I)=Y(I)	48
	Y(I)=Y(I)*144./P30	49
40	I=I+1	50
50	TA=T+TI	51
	CALL DVDINT(T,PA,X,Y,NN,2)	52
	CALL DVDINT(TA,PB,X,Y,NN,2)	53
	P1=(PA+PB)/2.	54
	D1T=((P1/Y(1))*G1)*D1	55
	IF(P1.GT.P3)GO TO 60	56
	P13=P1/P3	57
	CH=0.915-0.1474*P13	58
	UE2=(G3*P3/D3)*(1.-P13**G2)	59

```

      UE=SQRT(UE2)
      JE=CM*UE
      DE=(P13**G1)*D3
      RE=UE*DE*A2*T1
      R3N=D3*V3-RE
      D3N=R3N/V3
      P3N=P3-(RE/V3)*(U1/2/G3+P1/DE)
      U2=UE
      D2=DE
      GO TO 70
60    P31=P3/P1
      CM=0.915-0.345*P31
      IF(P31.LT.0.528)GOTO 90
      U22=(G3*P1/D1T)*(1.-P31**G2)
      GOTO 91
90    J22=(0.833**P1/D1T)/31
91    J2=SQRT(U22)
      J2=CM*U2
      D2=(P31**G1)*D1T
      R2=U2*A2*D2*T1
      R3=D3*V3
      R32=R3/R2
      D3N=(R2-R3)/V3
      P3N=D3N*(U22/G3+P3/D2+P3*R32/n3)/(1.+R32)
70    T=T+T1
      P3NA=(P3N-P30)/144.
      PDT=D2*U2*U2/288.
      WRITE(6.2)T,P3NA,D3N,U2,PDT
      P3=P3N
      D3=D3N
      CALL HOLD(T,P3NA,TX,P2,J)
      IF(T.LT.X(N)) GO TO 50
      CALL OUT(X,Y,TX,P2,J,N)
      GO TO 10
END
SUBROUTINE DVJINT(X,FX,XT,FT,AP,ND)
      DIMENSION XT(1),FT(1),T(16)
      N=ND
31    N1=(N-1)/2
      N2=N/2
      N3=NP-N2+1
      IF(NP-N)30,41,41
41    N4=N1+2
      IF(XT(1)-XT(2))22,80,60
22    CONTINUE
      IF(X-2.*XT(1)+XT(2))20,20,21
21    IF(X-2.*XT(NP)+XT(NP-1))42,42,20
42    IF(X-XT(N4))45,43,43
43    IF(N4-N3)44,45,44
44    N4=N4+1
      GOTO 42
45    N4=N4-1
      N5=N4-N1
      D0451=1.-N
      T(1)=FT(N5)
46    N5=N5+1
      L=(N+1)/2
      TR=T(L)
      N6=N4
      N7=N4+1

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DDIN 94
DDIN 95
DDIN 96
DDIN 97
DDIN 98
DDIN 99
DDIN 100
DDIN 101
DDIN 102
DDIN 103
DDIN 104
DDIN 105
DDIN 106
DDIN 107
DDIN 108
DDIN 109
DDIN 110
DDIN 111
DDIN 112
DDIN 113
DDIN 114
DDIN 115
DDIN 116
DDIN 117
DDIN 118

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	JU=1	DDIN 119
	N2=N-1	DDIN 120
	UN=1.0	DDIN 121
	DO12J=1.N2	DDIN 122
	N5=N4-N1	DDIN 123
	N3=N-J	DDIN 124
	DO9I=1,N3	DDIN 125
	N8=N5+J	DDIN 126
	T(I)=(T(I+1)-T(I))/(XT(N8)-XT(N5))	DDIN 127
9	N5=N5+1	DDIN 128
	GO TO (10,11),JU	DDIN 129
10	UN=UN*(X-XT(N6))	DDIN 130
	JU=2	DDIN 131
	N6=N6-1	DDIN 132
	GO TO 12	DDIN 133
11	UN=UN*(X-XT(N7))	DDIN 134
	JU=1	DDIN 135
	N7=N7+1	DDIN 136
	L=L-1	DDIN 137
12	TR=TR+UN*T(L)	DDIN 138
	FX=TR	DDIN 139
	RETURN	DDIN 140
20	PRINT50,X,XT(1),XT(NP)	DDIN 141
	STOP	DDIN 142
50	FORMAT(23H ARG. NOT IN TABLE X= ,F14.7,9H XT(1)= ,	DDIN 143
1	E14.7,19H XT(NP)= ,E14.7,6H DDIN)	DDIN 144
30	PRINT51,NP,ND	DDIN 145
51	FORMAT(22H TABLE TOO SMALL NP= ,I5,6H ND= ,I5,6H DDIN)	DDIN 146
	STOP	DDIN 147
60	IF(X-2.-XT(1)+XT(2))61,20,20	DDIN 148
61	IF(X-2.-XT(NP)+XT(NP-1))20,72,72	DDIN 149
72	IF(N-XT(N))73,73,45	DDIN 150
73	IF(N4-N3)74,45,74	DDIN 151
74	N4=N4+1	DDIN 152
	GO TO 72	DDIN 153
80	PRINT 52 ,XT(1)	DDIN 154
	STOP	DDIN 155
52	FORMAT(23H CONSTANT TABLE XT(1)= ,E14.7,6H DDIN)	DDIN 157
*	LIST	158
	END	159
C		160
*	COMPILE DISC, LABELA, ALL	161
C		162
	SUBROUTINE OUT(X,Y,T,P2,J,NN)	163
	DIMENSION X(500),Y(500),T(500),P2(500),T1(10),T2(10),T3(10)	164
	COMMON BB(5000)	165
	NT=JS J=0	166
50	FORMAT('CHAMBER FILL - BRL',1F>>)	167
51	FORMAT('PRESSURE - PSI',1H>>)	168
52	FORMAT('TIME - SECOND',1H>>)	169
	CALL PLTCCR(16,0,1,BB(1),BB(5000))	170
	ENCODE(100,50,T1)	171
	ENCODE(100,51,T2)	172
	ENCODE(100,52,T3)	173
	YNN=Y(NN) Y(NN)=0.0	173A
	CALL FIXSCA(Y(1),NN,6.0,PS,PHIN,PMAX,PIN)	174
	Y(NN)=YNN	174A
	CALL FIXSCA(T(1),NT,12.0,TS,TMIN,TMAX,TIN)	175
	CALL PLTCCS(2.0,10.0,TMIN,PHIN,TS,PS)	176
	CALL PLTCCD(1.0,T(1),P2(1),NT,0,TMIN,TMAX,PHIN,PMAX)	177

```

CALL PLTCCD(4.0,X(1),Y(1),NN,0,TMIN,TMAX,PMIN,PMAX)
CALL PLTCCA(TIN,FIN,TMIN,TMAX,PMIN,PMAX,0)
XT=TMIN+YS*0.8$ YT=PMIN+PS*2.5
CALL PLTCCCT(0.1,T2(1),1.0,0.0,XT,YT)
XT=TMIN+TS*5.0$ YT=PMIN-PS*0.6
CALL PLTCCCT(0.1,T3(1),0.0,1.0,XT,YT)
XT=TMIN+TS*3.5$ YT=PMAX+PS*0.25
CALL PLTCCCT(0.2,T1(1),0.0,1.0,XT,YT)
DX=TIN
CALL LABELA(DX,FIN,TMIN,TMAX,PMIN,PMAX,1.0,1.0)
DO 25 M=1,NTS P2(M)=0.05 T(M)=0.0
25 CONTINUE
DO 30 I=1,100.5
READ(5,300)T(I),P2(I),T(I+1),P2(I+1),T(I+2),P2(I+2),
1T(I+3),P2(I+3),T(I+4),P2(I+4)
300 FORMAT(10(F8.0))
DO 28 IK=1,5$ JK=JK-1
9 IF(T(I+JK),T.0.0)GOTO 29
28 CONTINUE$ GOTO 30
29 NT=I+JK-1$ GOTO 31
30 CONTINUE
31 IF(NT.EQ.0)GOTO 40
CALL PLTCCD(2.1,T(1),P2(1),NT,0,TMIN,TMAX,PMIN,PMAX)
40 CALL PLTCCP
RETURN
END
C
SUBROUTINE HOLD(T,P3NA,TX,P2,J)
DIMENSION TX(500),P2(500)
J=J+1$ TX(J)=TS P2(J)=P3NA
RETURNS END
DATA
.264E00 .3704E01 .25E-03 .149E02 .3349-02
.0E00 .103E02 .14E-02 .107E02 .281E-02
.421E-02 .113E02 .561E-02 .113E02 .699E-02 .112E02
.842E-02 .108E02 .982E-02 .102E02 .112E-01 .111E02
.127E-01 .939E01 .14E-01 .91E01 .154E-01 .975E01
.168E-01 .843E01 .182E-01 .814E01 .197E-01 .864E01
.211E-01 .764E01 .253E-01 .676E01 .309E-01 .783E01
.351E-01 .443E01 .407E-01 .621E01 .449E-01 .545E01
.505E-01 .128E01 .547E-01 .68E00 .449E-01 .23E01
-1.0E-02 .604E-01 .53E00
0.0 0.0 .0014 1.59 .0028 2.63 .0042 4.14 .0056 5.02
.007 5.97 .0084 6.78 .0098 7.75 .0112 8.44 .0126 8.88
.014 9.10 .0154 9.10 .0168 8.91 .0162 8.61 .0197 8.19
.00211 7.66 .0253 6.55 .0323 4.56 .0379 3.41 .0435 2.34
.0505 1.28 .0533 0.95 .0561 0.61 .0590 0.38 .0604 0.28

```

PROB

210

APPENDIX D

HIGH SPEED PHOTOGRAPHS - MODEL 40

SHOT 521


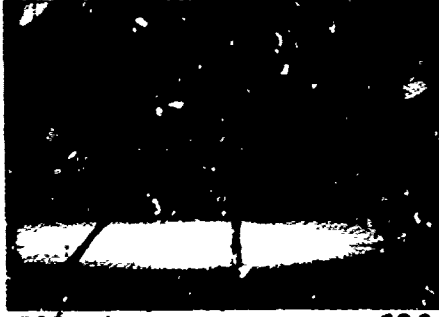

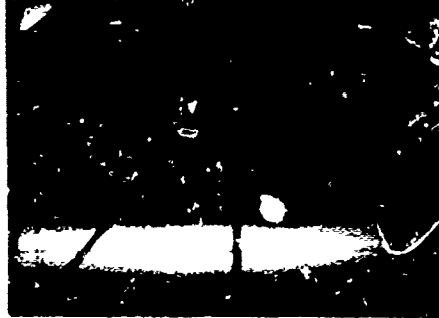




Frame Number	Time, Msec.	Frame Number	Time, Msec.
 0	0	 200	60.9
 40	12.2	 250	79.1
 80	24.3	 380	115.7
 140	42.6	 500	152.2

Figure D-1. Open Stairway-Cylinders Tied, Row 1 - 5.4psi

SHOT 507

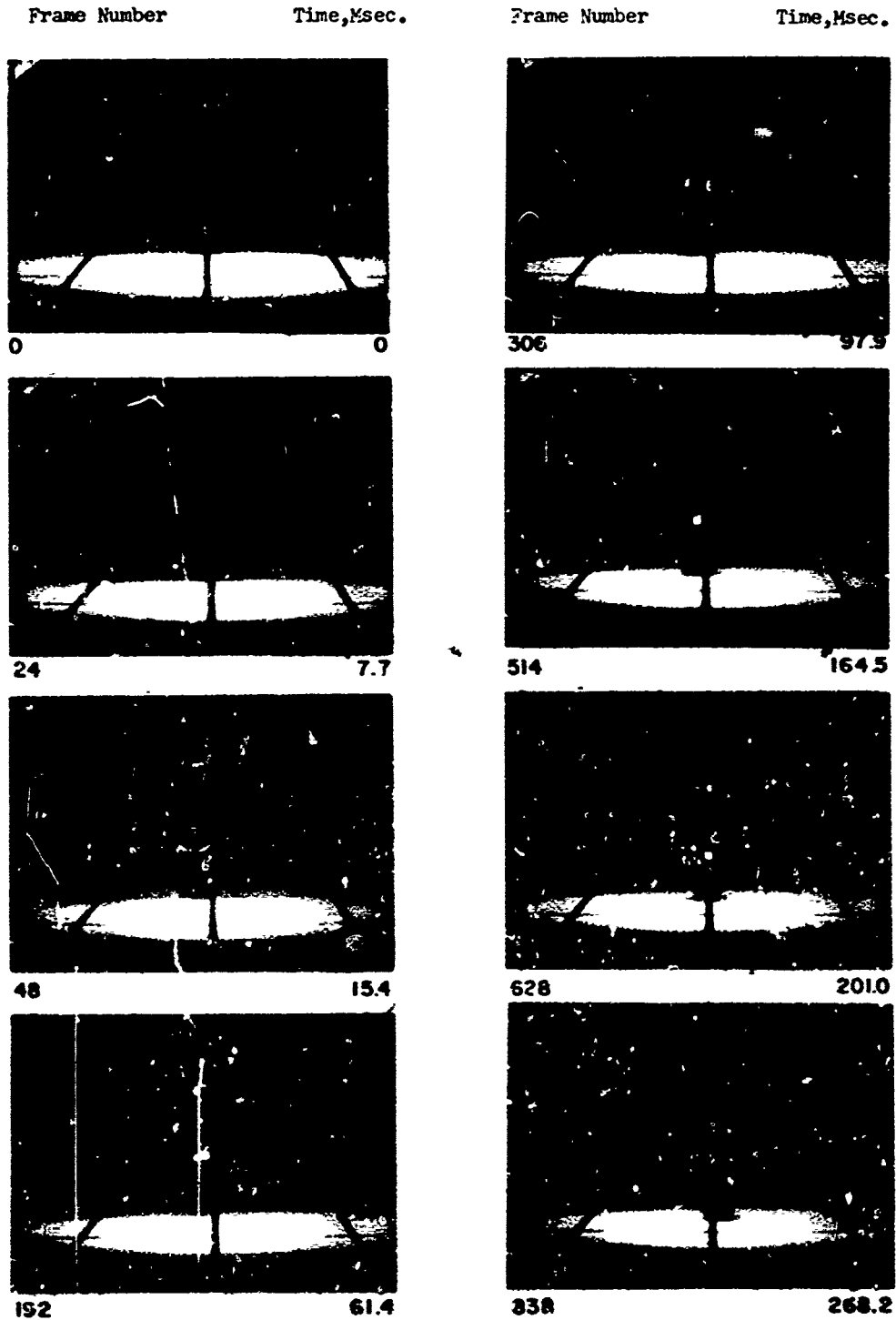


Figure D-2. Open Stairway- Cylinders on Row 1 - 20.3psi

SHOT 511



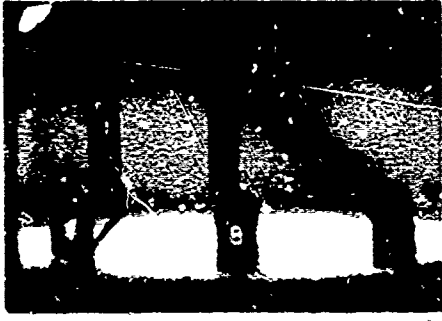





Frame Number	Time, msec.	Frame Number	Time, msec.
	0		28.9
	11.9		118.5
	23.7		154.1
	65.2		183.7

Figure D-2. Open Stairway-Cylinders on Row 4 - 10.2psi

SHOT 512

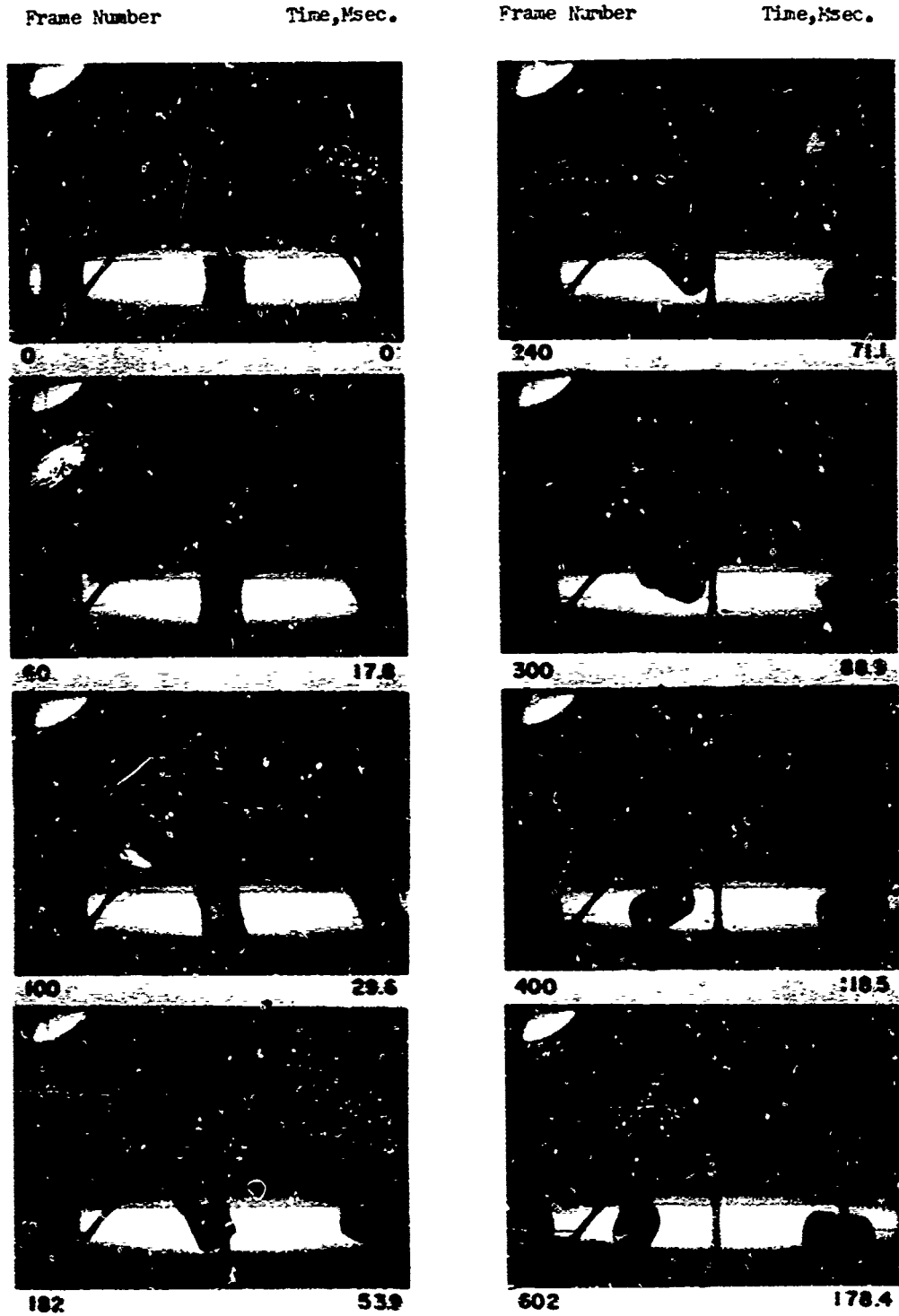


Figure D-4. Open airway - Cylinders on Row 5 - 10.1 psi

SHOT 514

Frame Number	Time, Msec.	Frame Number	Time, Ksec.
0	0	184	57.5
70	21.9	323	100.9
116	36.3	391	122.2

Figure D-5. Open Stairway-Pack Left Front - 10.3psi

SHOT 515

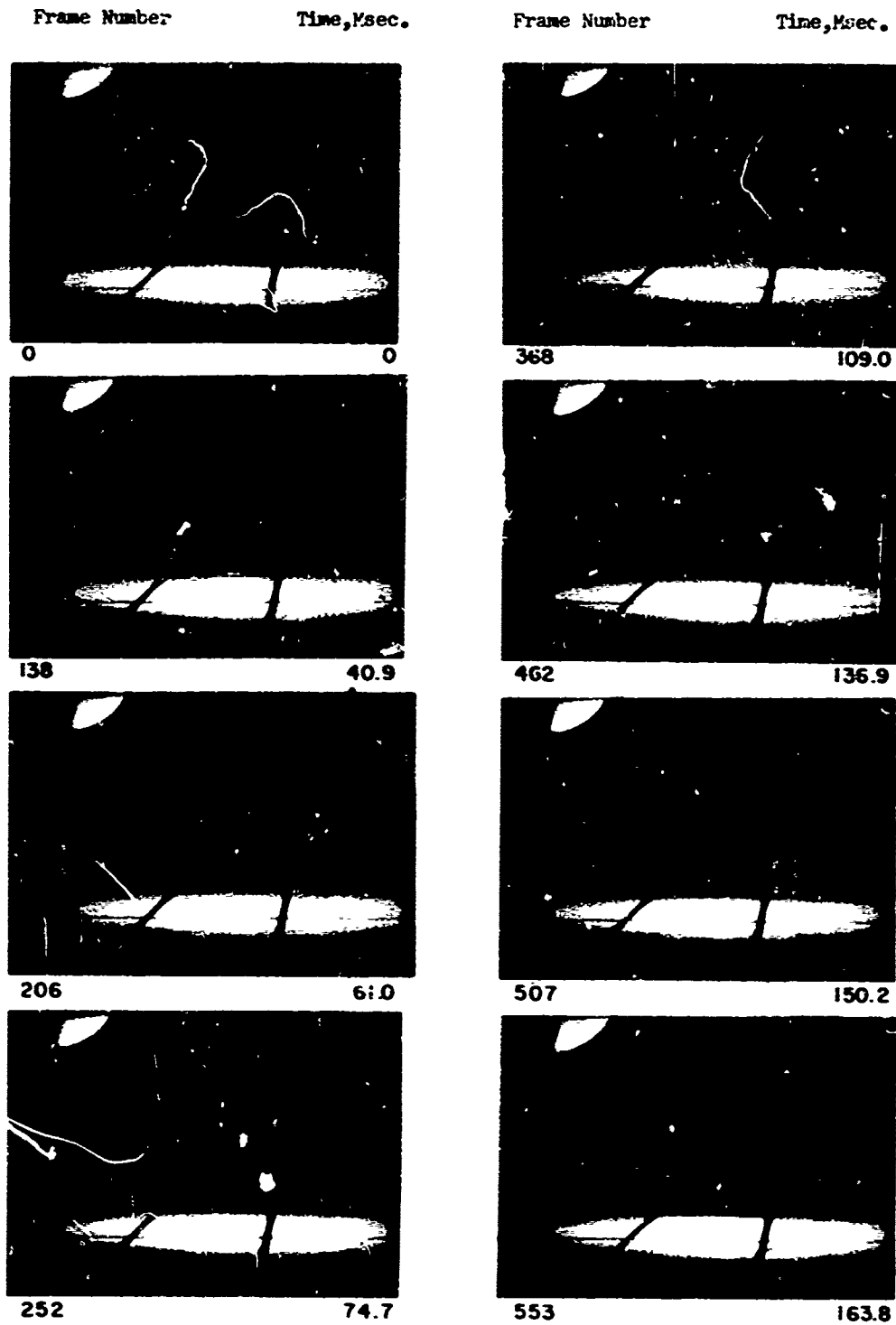


Figure D-6. Open Stairway-Pack Left Front - 20.5psi

SHOT 526

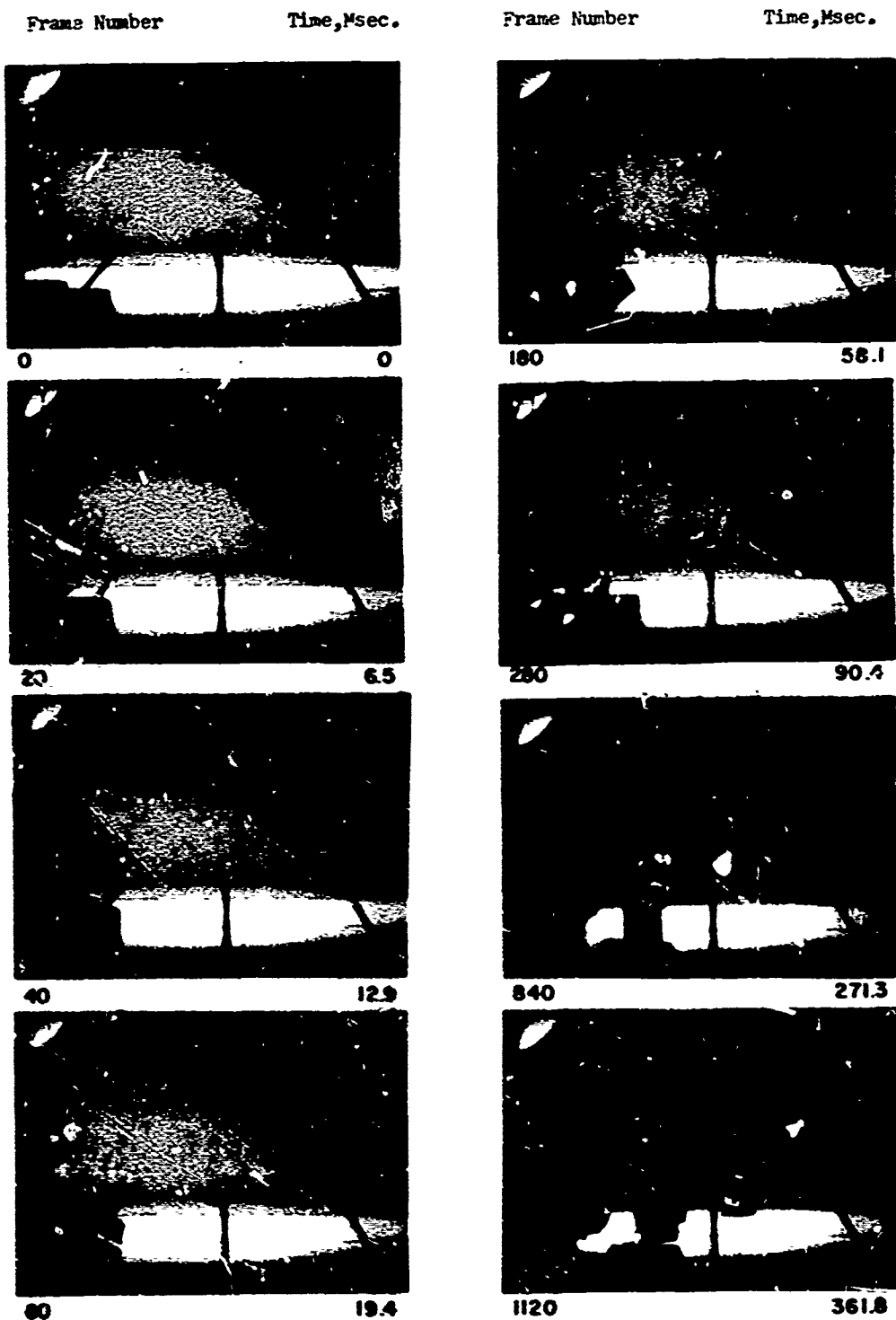


Figure D-7. Open Stairway-Pack Left Rear - 20.7psi

SHOT 520

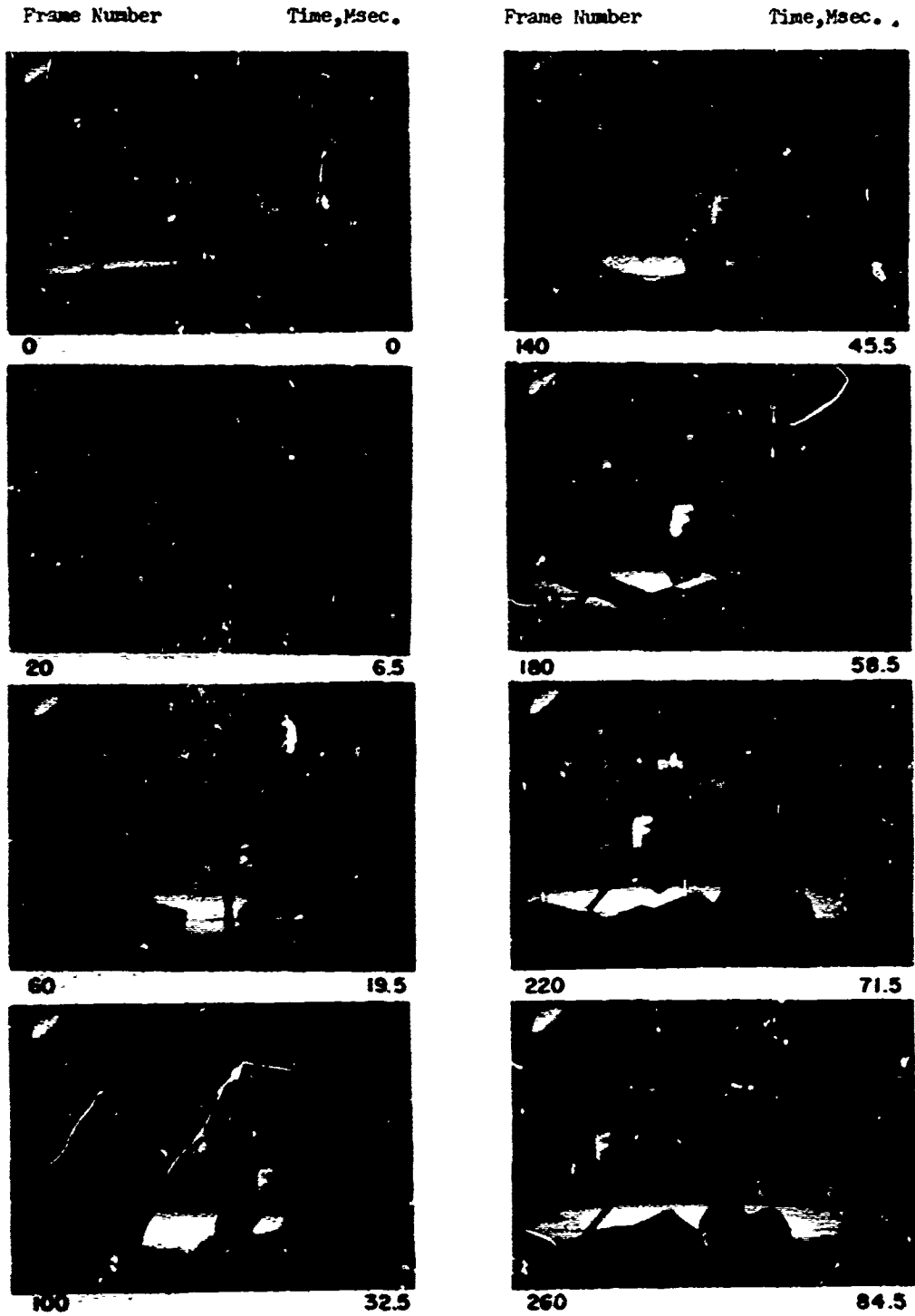


Figure D-3. Open Stairway-Pack at Rear - 21psi

SHOT 523


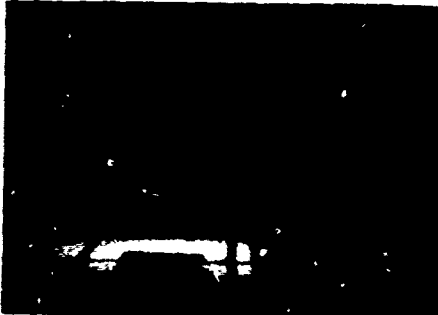






Frame Number	Time, Hsec.	Frame Number	Time, Hsec.
	0		85.2
	36.5		103.5
	48.7		140.0
	60.9		158.3

Figure D-9. Open Stairway-Pack at Right Rear - 10.5psi

SHOT 533

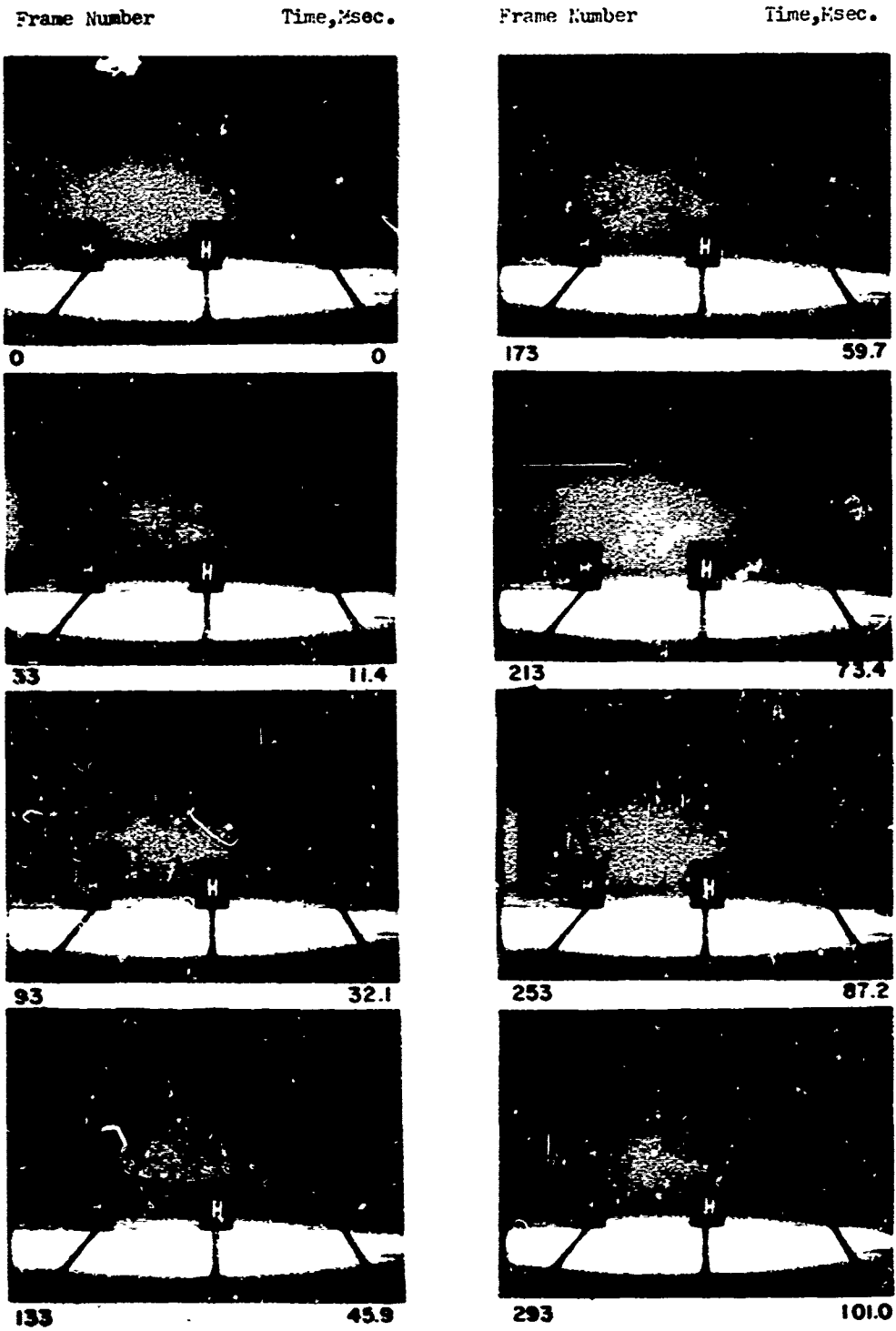


Figure D-10. Closed Stairway-Cylinders on Row 1 - 5.2psi

SHOT 534

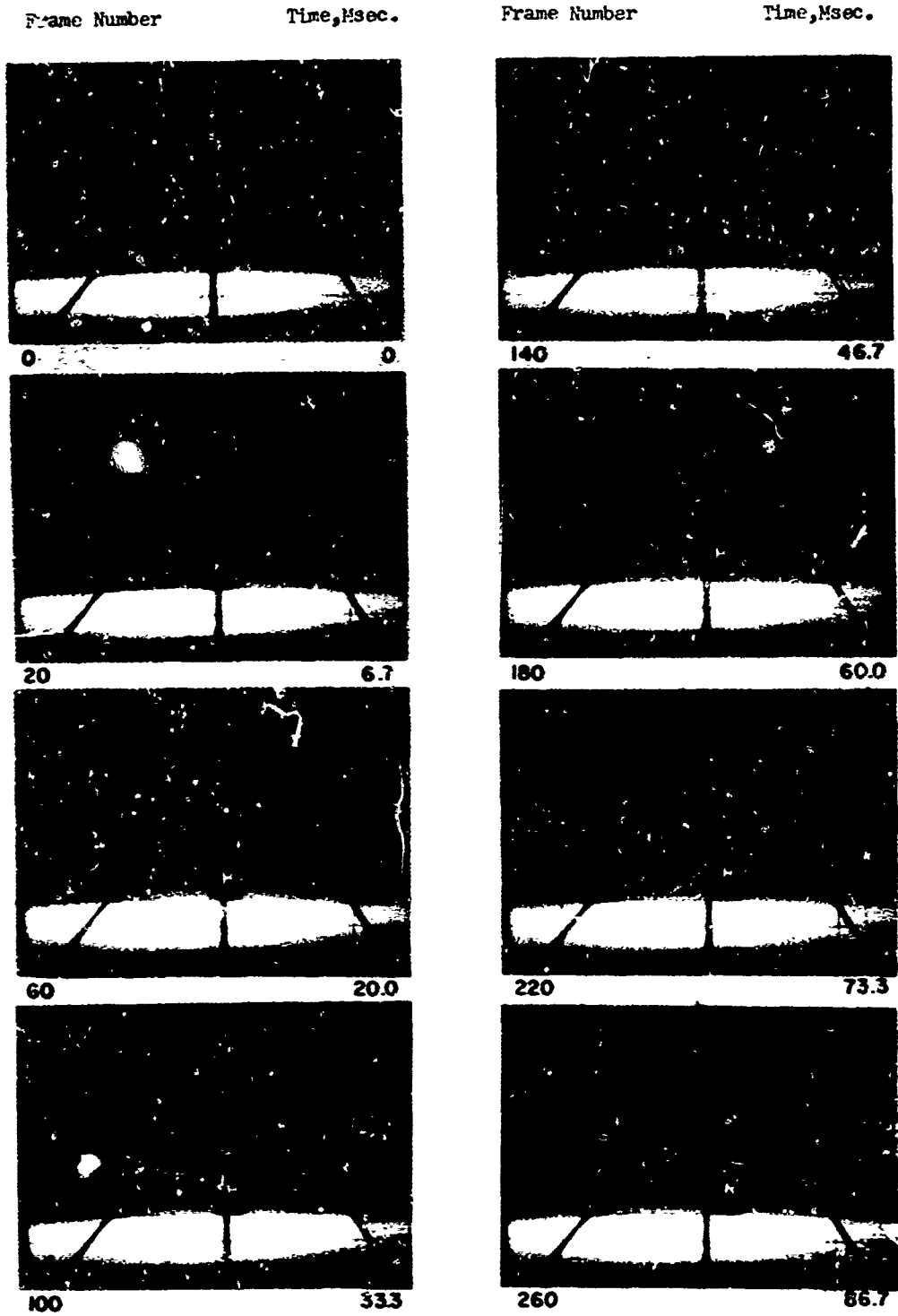


Figure D-11. Closed airway-Cylinders on Row 1 -- 10.2psi

SHOT 537

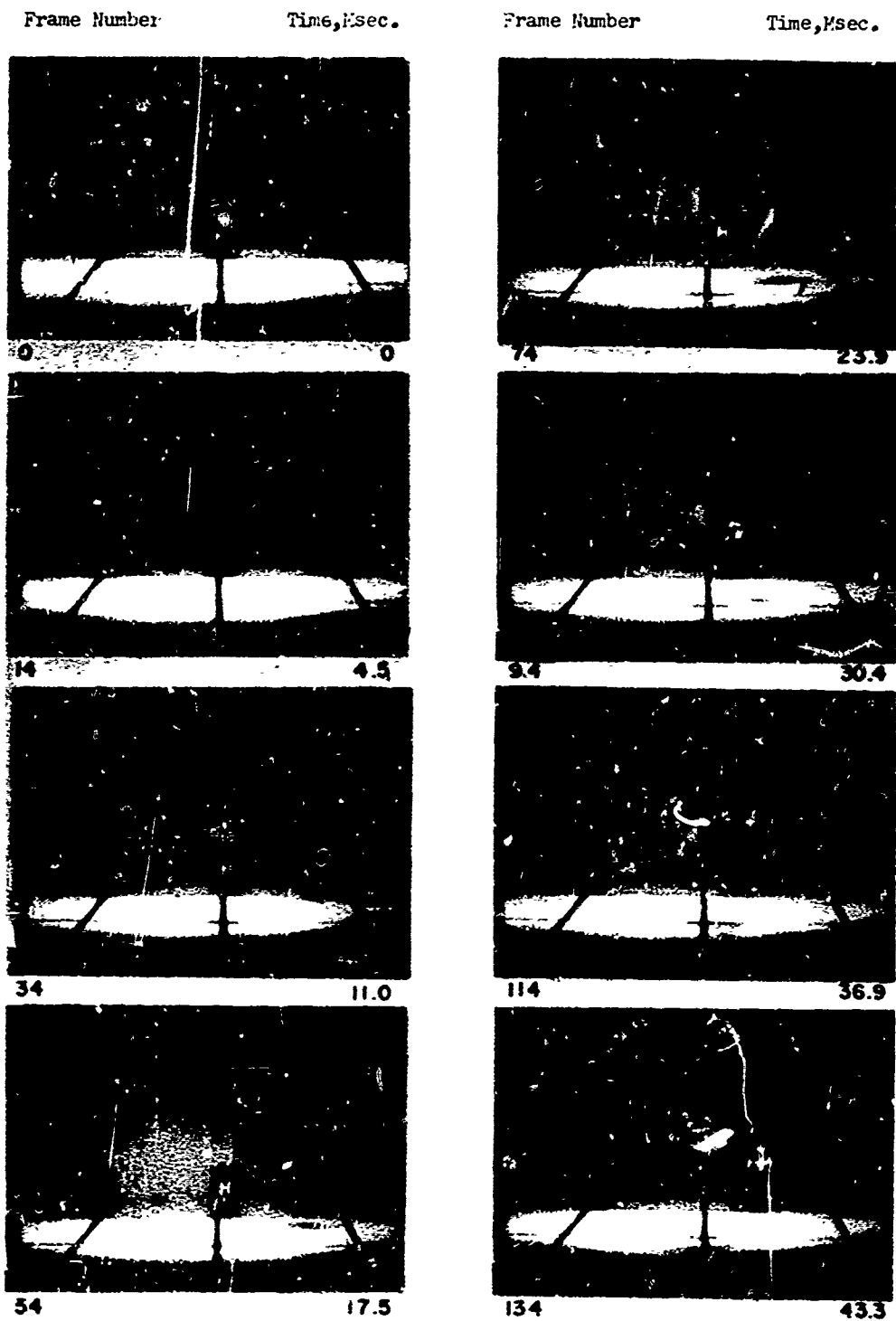


Figure D-12. Closed Stairway-Cylinders on Row 1 - 20.6psi

SHOT 537

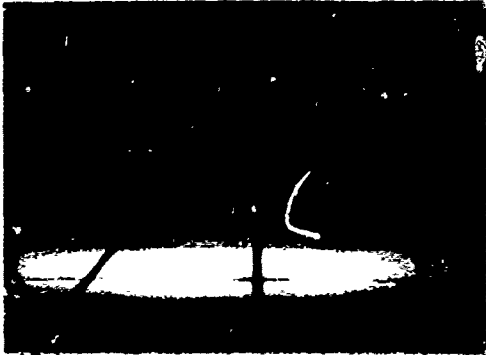

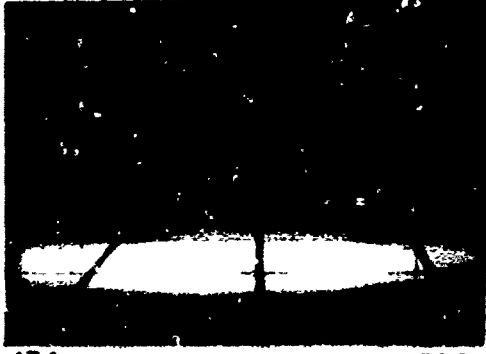

Frame Number	Time, Ksec.	Frame Number	Time, Ksec.
	49.8		62.8
154		194	
	56.3		69.2
174		214	

Figure D-12. (Continued)

SHOT 535

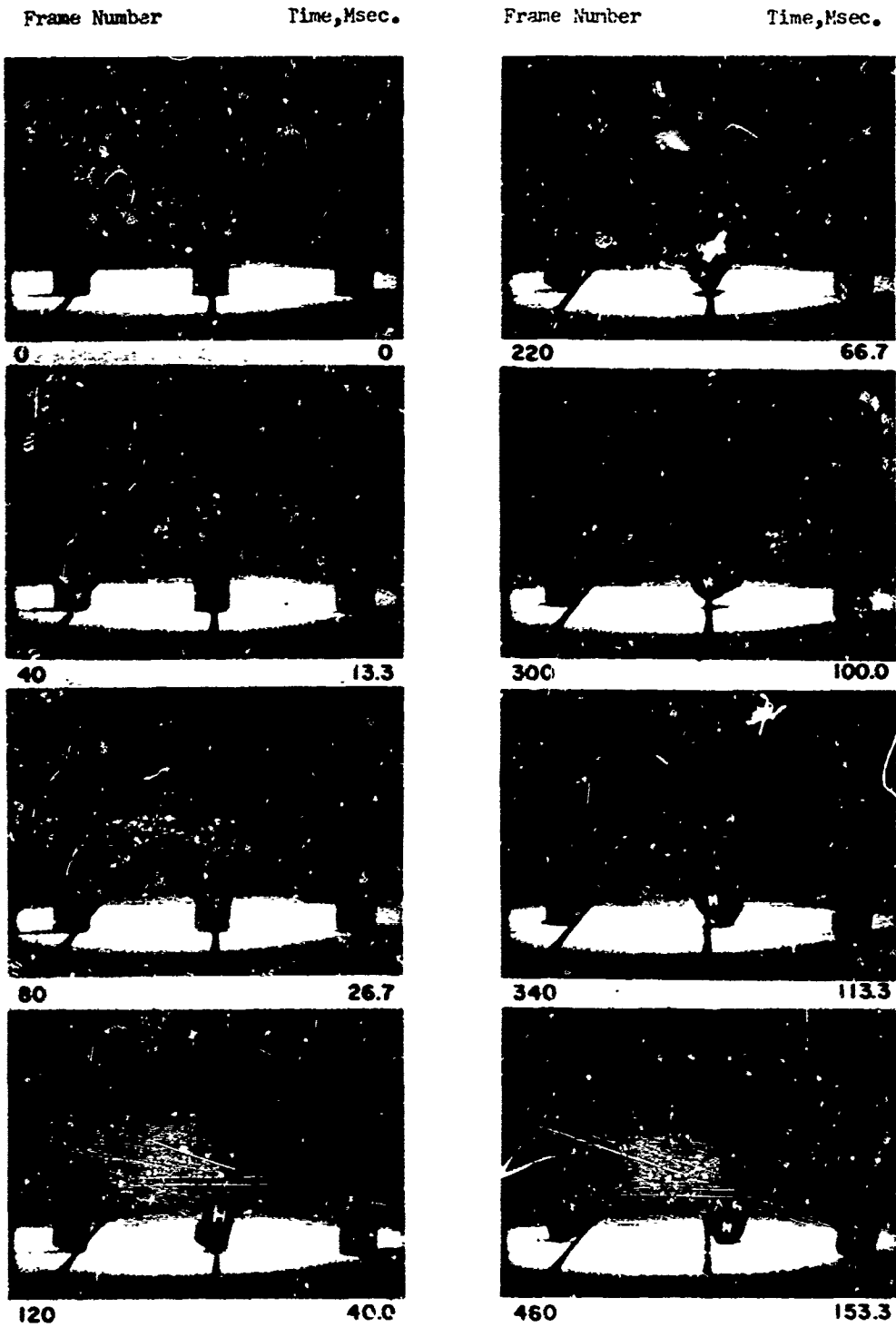
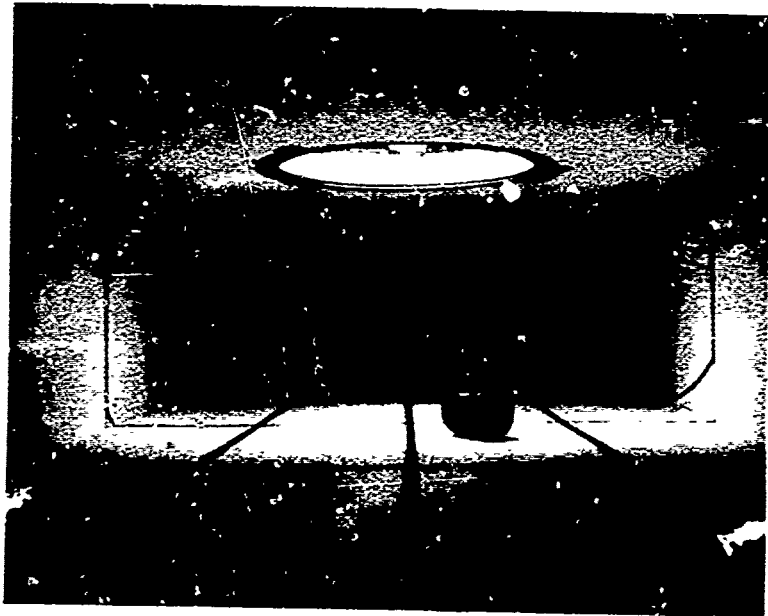


Figure D-13. Closed Stairway-Cylinders on Row 3 - 10.2psi

APPENDIX E

POST-SHOT PHOTOGRAPHS - MODEL 40

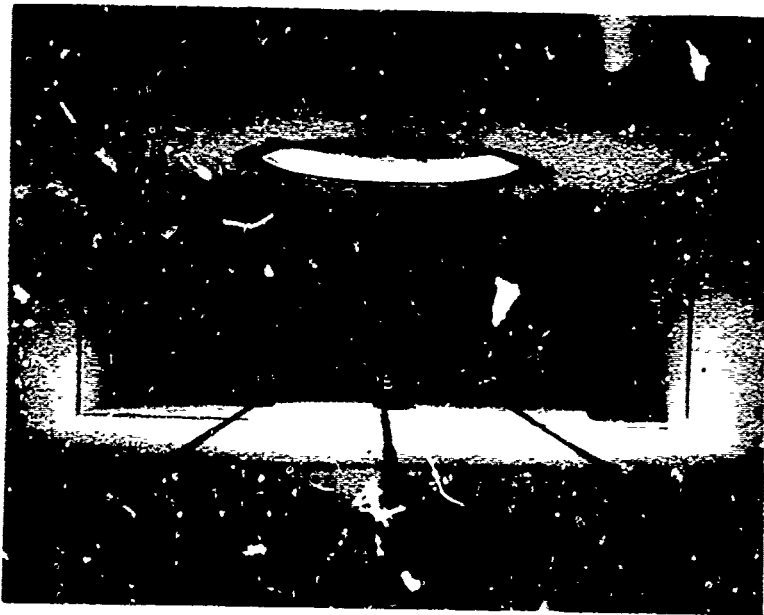


SHOT 505

ROW 1

5 PSI

(A)



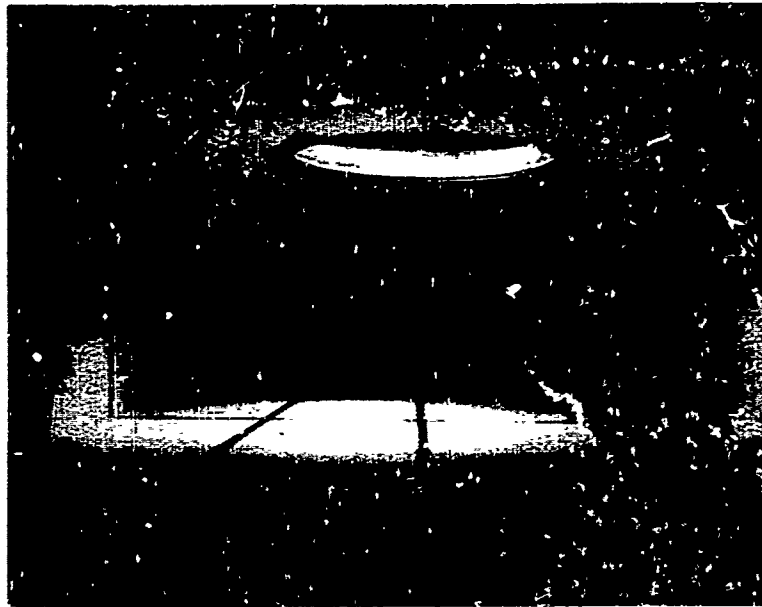
SHOT 508

ROW 2

5.3 PSI

(B)

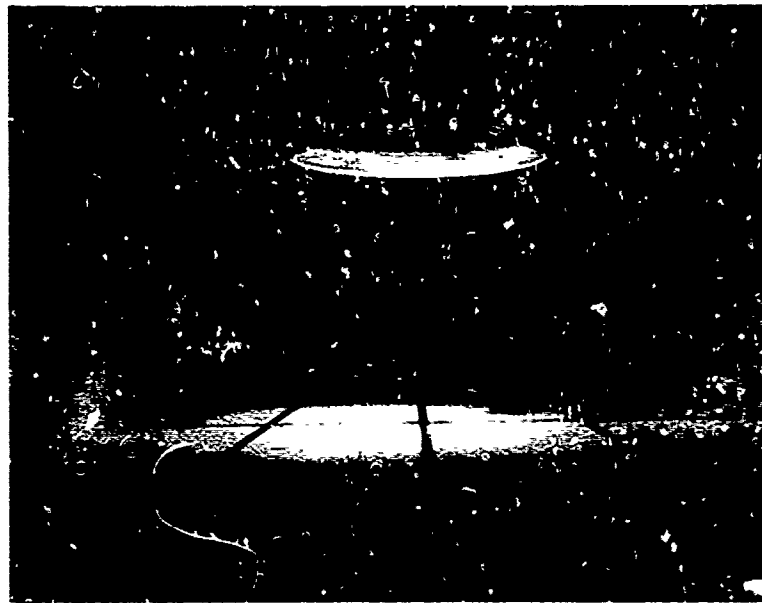
Figure E-1. Final Position of Cylinders - 5psi



PRE - SHOT 521

ROW 1

(C)



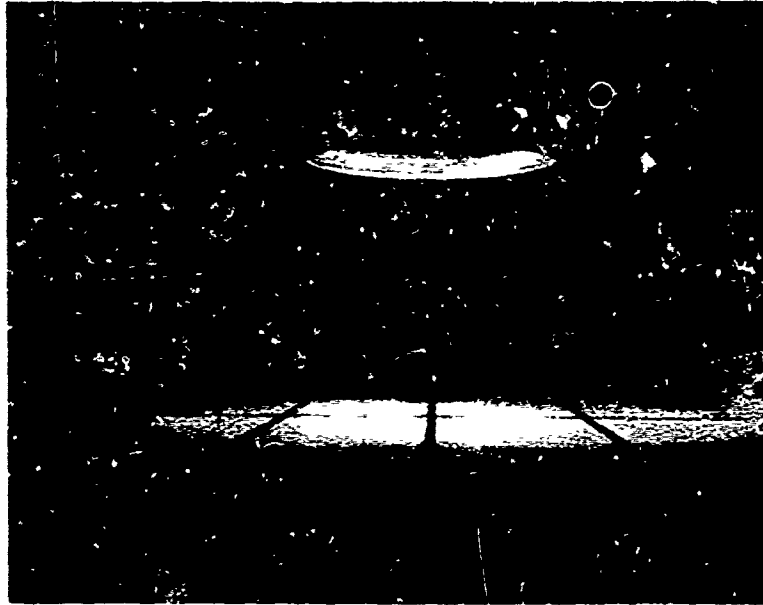
SHOT 521

ROW 1

5.4 PSI

(D)

Figure E-1. (Continued)

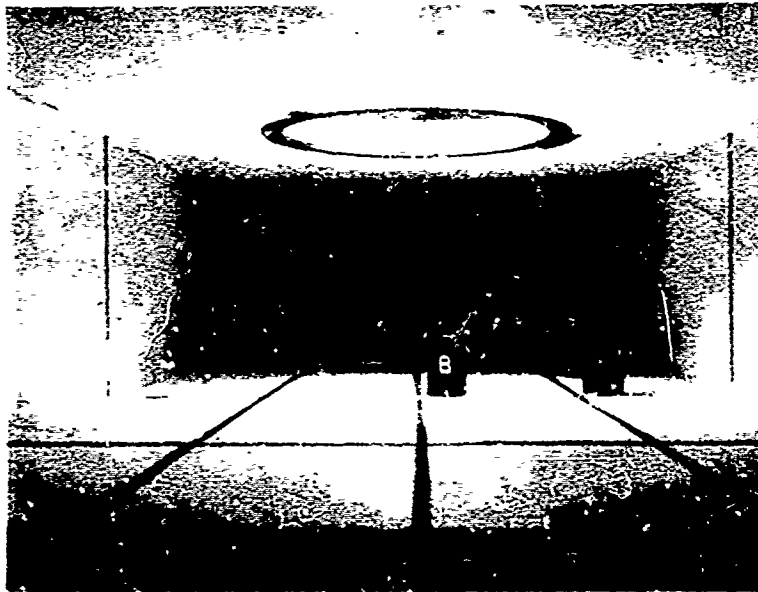


SHOT 506

ROW 1

10.1 PSI

(A)



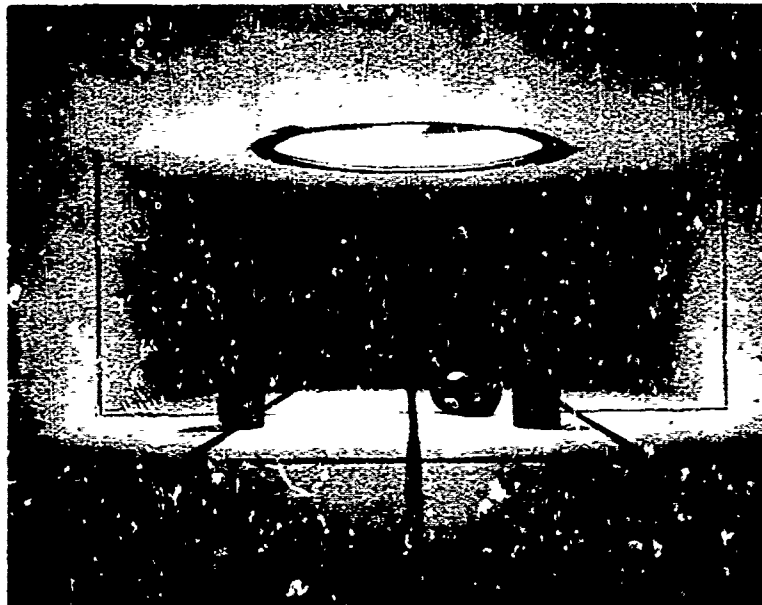
SHOT 510

ROW 3

10.3 PSI

(B)

Figure E-2. Final Position of Cylinders - 10psi

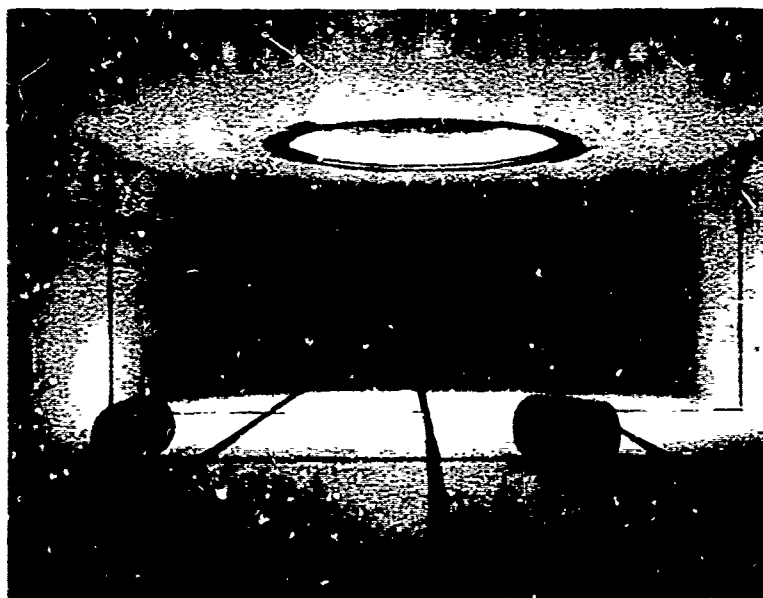


SHOT 511

ROW 4

10.2 PSI

(C)



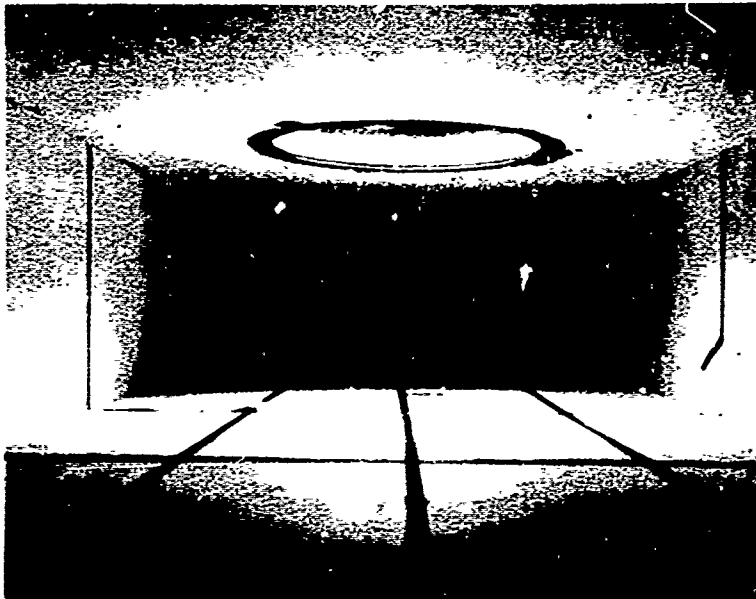
SHOT 512

ROW 5

10.1 PSI

(D)

Figure E-2. (Continued)

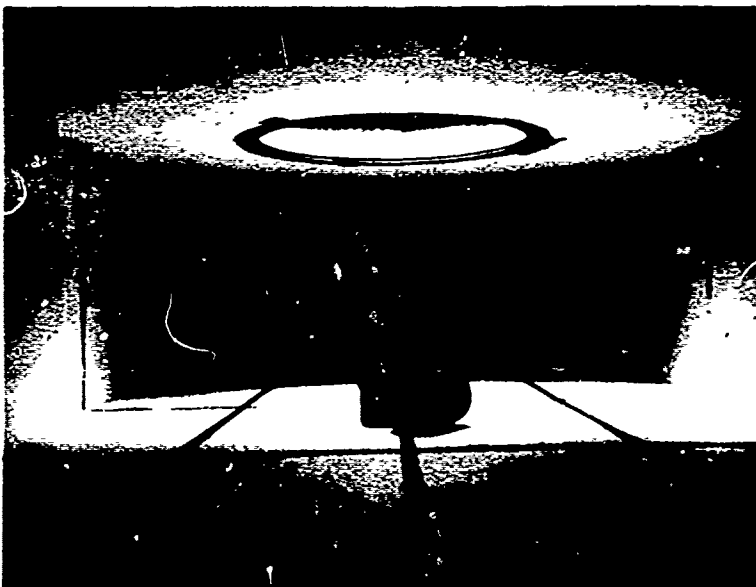


SHOT 514

POSITION 1

10.3 PSI

(A)



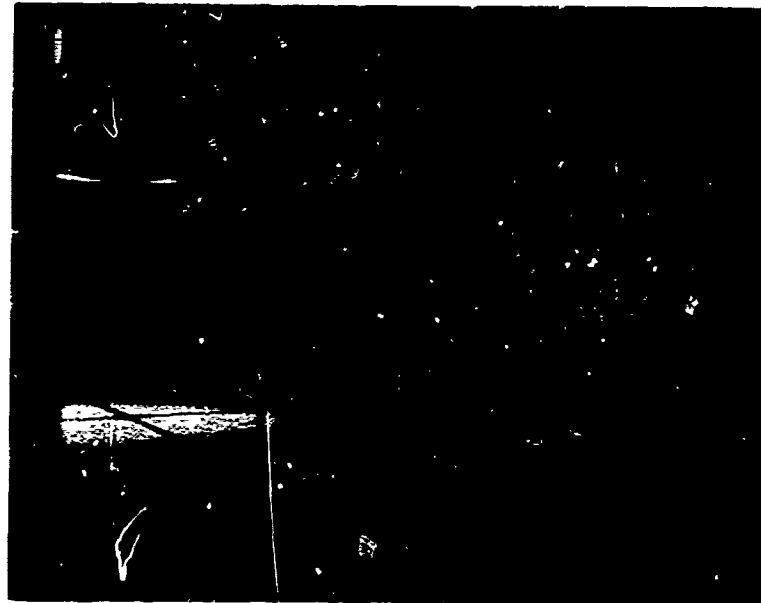
SHOT 515

POSITION 1

20.5 PSI

(B)

Figure E-3. Pack Started in Position 1



SHOT 522

POSITION 2

5.3 PSI

(A)



SHOT 523

POSITION 2

10.5 PSI

(B)

Figure E-4. Pack Started in Position 2



PRE-SHOT 519 POSITION 3

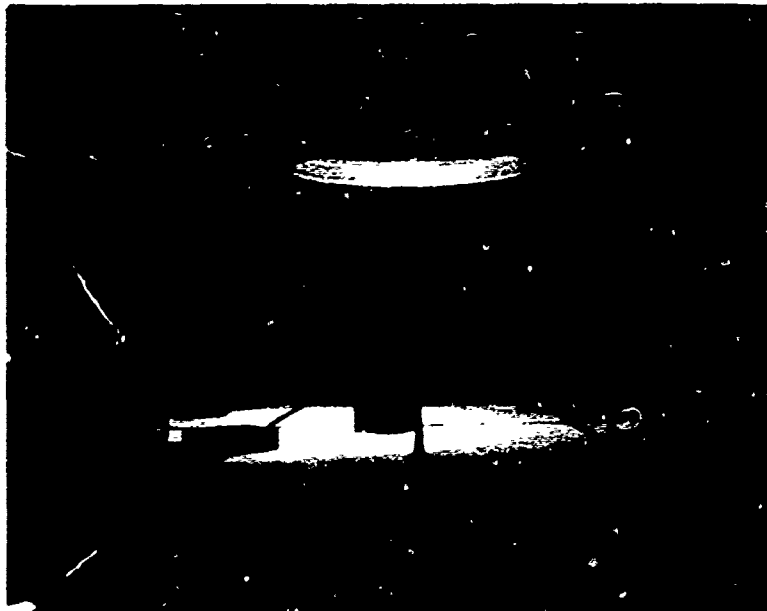
(A)



SHOT 519 POSITION 3 20.5 PSI

(B)

Figure E-5. Pack Started in Position 3

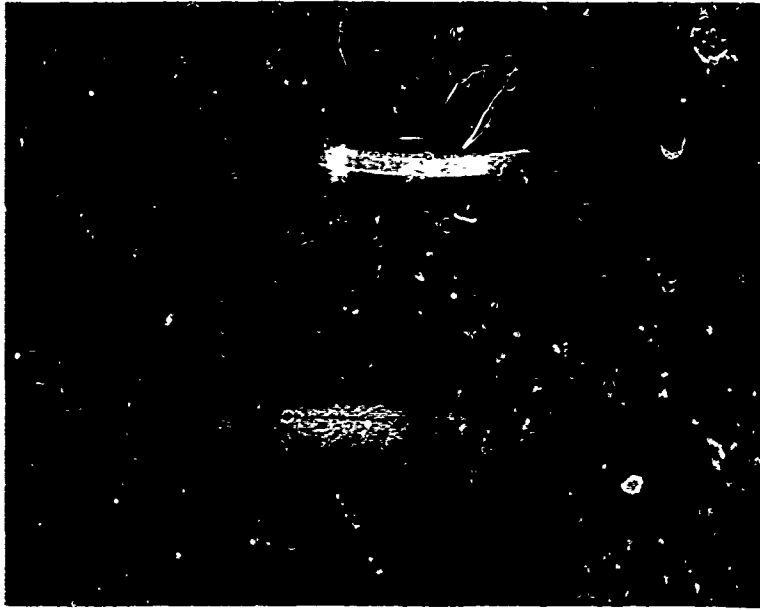


SHOT 520

POSITION 4

21.0 PSI

Figure E-6. Pack Started in Position 4

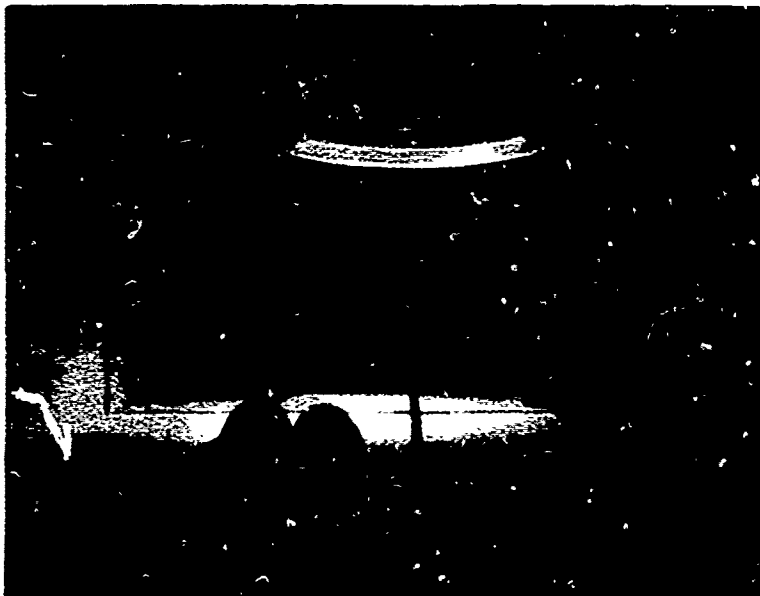


SHOT 517

POSITION 5

10.5 PSI

(A)



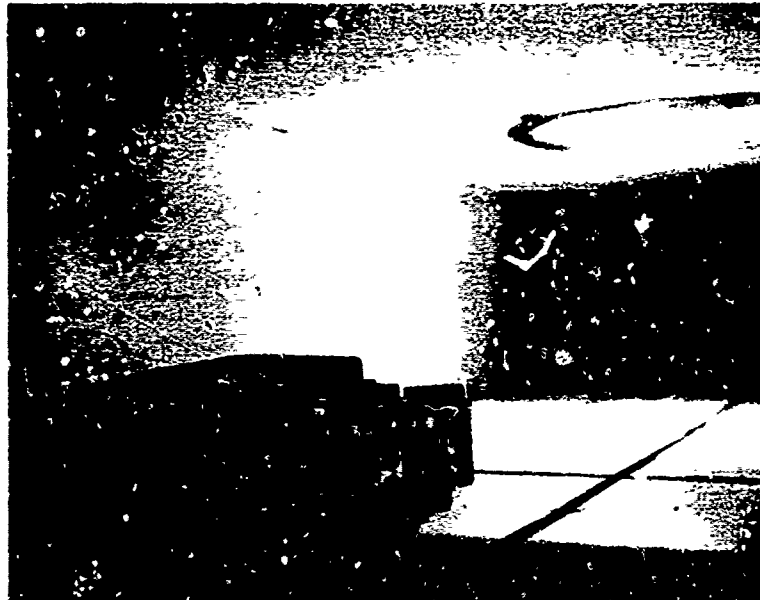
SHOT 518

POSITION 5

20.5 PSI

(B)

Figure E-7. Pack Started in Position 5

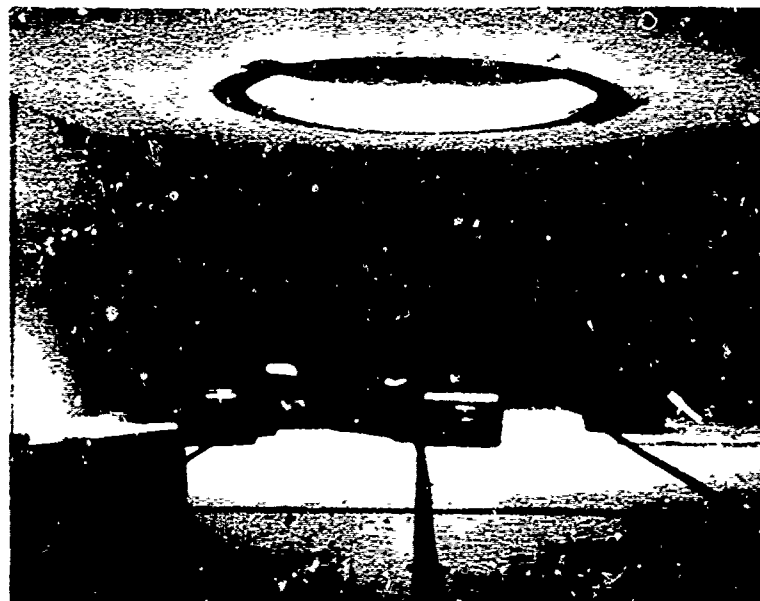


SHOT 525

POSITION 6

10.3 PSI

(A)



SHOT 526

POSITION 6

20.7 PSI

(B)

Figure E-8. Pack Started in Position 6

BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 2208

AUGUST 1972

SUMMARY
BLAST LOADING IN EXISTING STRUCTURES - BASEMENT MODELS

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Approved for public release; distribution unlimited.

Progress Report to Office of Defense Civil Preparedness Agency
Work Order No. DAHC 20-70-C-0310
Work Unit 1123C

ABERDEEN PROVING GROUND, MARYLAND

I. INTRODUCTION

The results are presented from a study of shock wave induced flows in the interior of a 1/12th scale basement model. The experiments were designed to simulate the flows and loading within a 100 person basement shelter when the above ground floors have been removed by the incoming blast wave.

II. EXPERIMENTS

The 1/12th scale basement model was mounted beneath the BRL 24 inch shock tube. The shock waves of input pressures 5, 10 and 20 psi were directed down the connected stairway, into the interior. Pressure transducers were mounted in the floor and in probes mounted two inches off the floor to record the interior pressures. During a second phase of the experiments, the probes were removed and small objects were placed inside the model. High speed photography was then used to observe the motion of objects under the effect of the internal flows.

III. RESULTS AND CONCLUSIONS

The appendixes of the report contain a summary of the shots, pressure-time records, and selected frames from the high speed films.

The following major pressure-time records were recorded within the interior of the model.

- A. A low pressure vortex dip near the stairway was observed.
- B. A generally smooth pressure filling curve was observed near the center area of the floor.
- C. Multiple pressure peaks were observed superimposed on the general filling curve when the transducer positions were near walls.

A comparison of the high speed pictures shows a general small object rotation around the interior in a clockwise direction (for the model-shock wave orientation used). Velocity components across the floor

ranged from values of 4-14 ft/sec initially at the front to lower values of 1-2 ft/sec for greater times after the interior was filled with pressure.

Work now in progress include the addition of a side window to the present model to observe lengthwise motion along the room. A new model is being designed to simulate a 1000 shelter size basement.

