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PRIMITIVE TWO-DIMENSIONAL CALCULATIONS OF THE EFFECTS OF REFLECTING LAYERS ON UNDERGROUND NUCLEAR EXPLOSION PHENOMENOLOGY

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ABSTRACT

Two-dimensional Langrangian calculations were used to study the effect of a dolomite reflector on the cavity shape and pressure and the particle velocity field from a nuclear explosion in alluvium. Reflectors were placed at distances between 0.5 and 3 times the expected (no-reflector) cavity radius from the explosion point. Energy reflection coefficients were generally 0.8. The cavity was just perceptibly distorted with a reflector distance of 2 cavity radii, and distorted more with closer reflectors. The cavity pressure at about 90 ms was increased by about 25% with the reflector at 0.5 cavity radii, decreasing to about 10% with the reflector at 2 radii. Particle velocities and displacements at 1.5 and 2.3 cavity radii on the side of the explosion away from the reflector were affected only slightly, and only at quite late times.

INTRODUCTION

The work reported here was performed in early 1972. At that time it was planned that this work be repeated at once with considerably better zoning and including a free surface, full-width layers and gravity. However, so far it has not been possible to produce successful calculations with either the better zoning or including gravity. Therefore, it seems reasonable to document the work that has been done. This report, then, is documentation of what originally was planned as preliminary work, but is the only successful work done to date.

The purpose of the work was to investigate the effect of dolomite layers at various distances from a nuclear explosion in alluvium. We wished to look at the energy reflection coefficient (as a function of distance from the explosion) and the effect of the dolomite layer on cavity shape. We also wished to look at the pressure and velocity field above the explosion when the dolomite layers were below the explosion.

EXPERIMENT SETUP

The two-dimensional Lagrangian, elastic-plastic-brittle failure code TENSOR[1] was used for these calculations. Two materials were used: (1) alluvium,[2] whose pressure-versus-volume curve is shown in Fig. 1 and whose shear strength versus pressure is shown in Fig. 2; and (2) dolomite, for which the corresponding

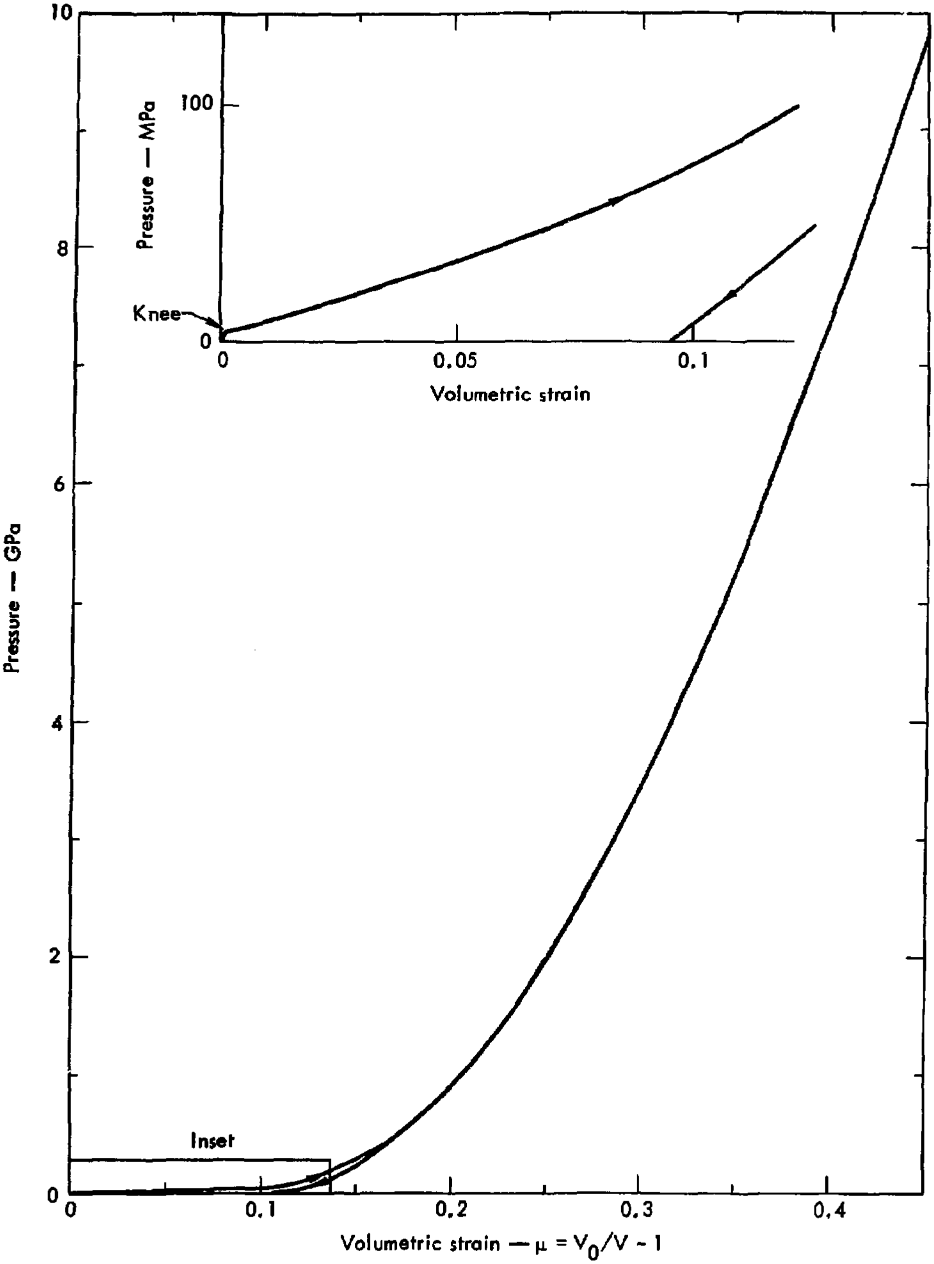


Fig. 1. Pressure-versus-volume curve used for alluvium.

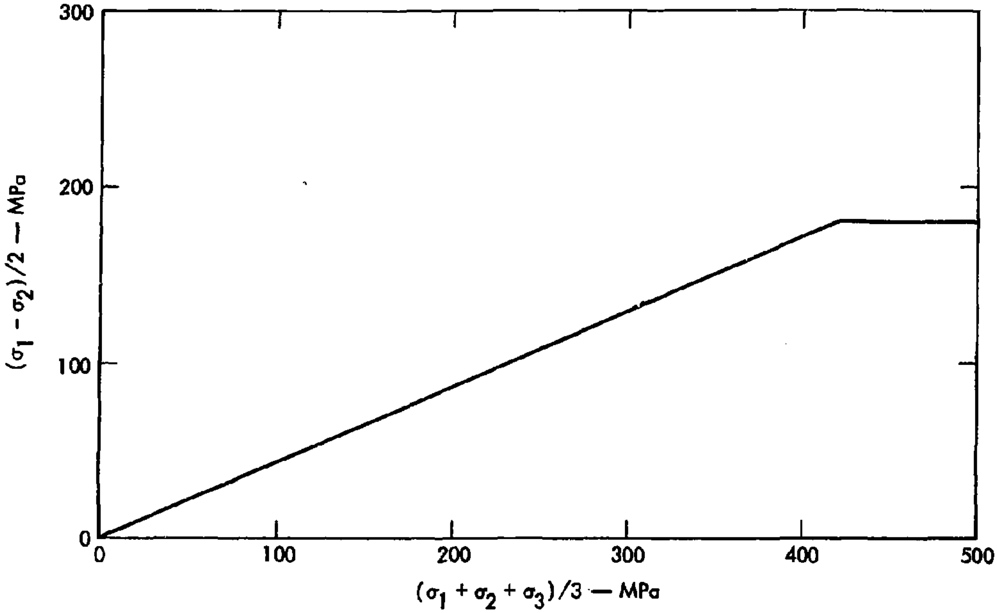


Fig. 2. Shear strength versus mean pressure used for alluvium.

curves are shown in Figs. 3 and 4. Here loading and unloading curves were taken as identical. Table 1 lists other constants of interest for the materials.

Figure 5 shows the zoning close to the cavity. For the first problem, the entire material was alluvium. For the second, all of the shaded regions were dolomite. Then, for each succeeding problem, the shaded region closest to the explosion was made alluvium; thus the layer was moved farther and farther from the cavity. We used layer distances of 0.5, 1.0, 1.5, 2.0, 3.0, and 5.0 times the expected final cavity radius of 25 m. (The points labeled 1 through 6 in Fig. 5 will be referred to below.)

The cavity was driven with what is called a "gas profile." A one-dimensional SOC calculation was performed using a 7.4-kiloton explosion in alluvium. The pressure in the cavity as a function of radius was taken from this SOC calculation and used as input to the TENSOR calculation, where Table 2 is entered with average cavity radius, and a pressure is obtained. This pressure profile drives the TENSOR problem which cannot handle the explosive itself.

We did not include in the problems any free surface whose effects could be observed at times of interest; in fact, the first free surface observed was at the bottom of the dolomite (344 m below the shot) and, when a rarefaction wave from it was seen near the cavity, the problem was terminated.

RESULTS

Table 3 shows the energy reflection coefficient as a function of layer distance. These coefficients were determined by comparing the energy entering the reflecting layer with that entering the same volume when the material was alluvium.

Table 1. Other constants used in the equation of state.

Property	Alluvium	Dolomite	Units
Density	2.04	2.84	Mg/m^3
Poisson's ratio	0.33	0.24	
Maximum shear strength	500	1050	MPa
Elastic limit	500	—	MPa
Brittle-ductile transition	100	100	MPa

Table 2. Selected values of the gas profile; average cavity radius vs gas pressure.

Average radius (m)	Pressure (GPa)
4.02	101
4.035	99.7
4.18	79.8
4.35	59.8
4.46	49.8
4.59	39.8
4.76	30.0
4.86	25.0
4.99	20.0
5.24	15.0
5.6	10.0
6.27	5.0
8.2	1.0
9.17	0.5
12.35	0.1
14.7	0.05
22.6	0.01
27.7	0.005

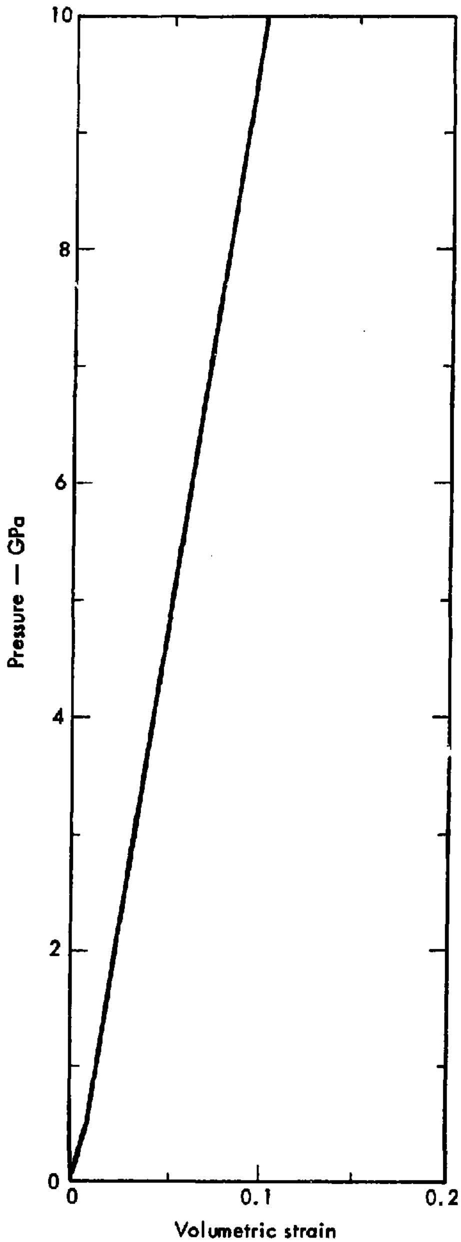


Fig. 3. Pressure-versus-volume curve used for dolomite.

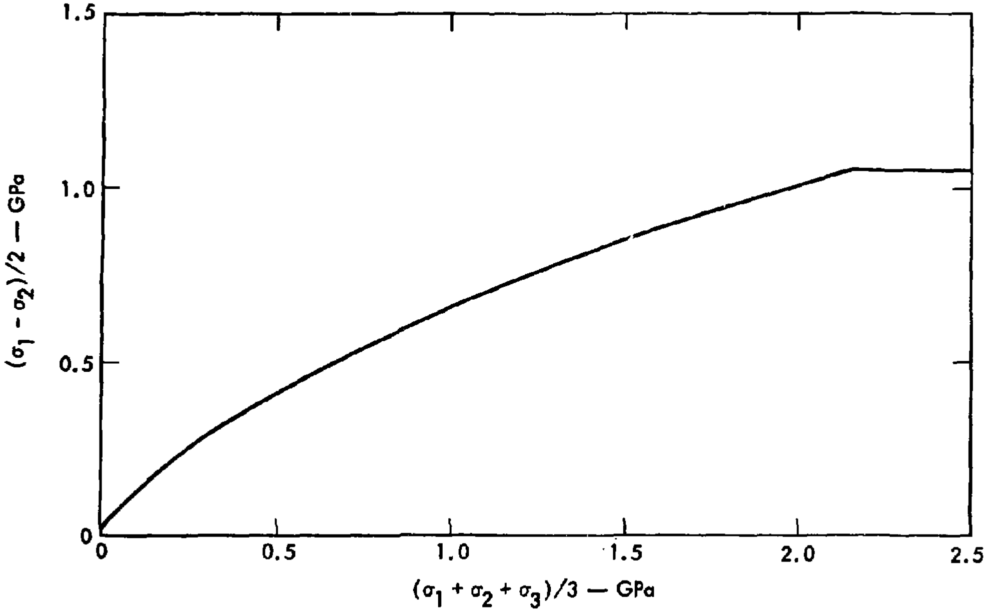


Fig. 4. Shear strength versus mean pressure used for dolomite.

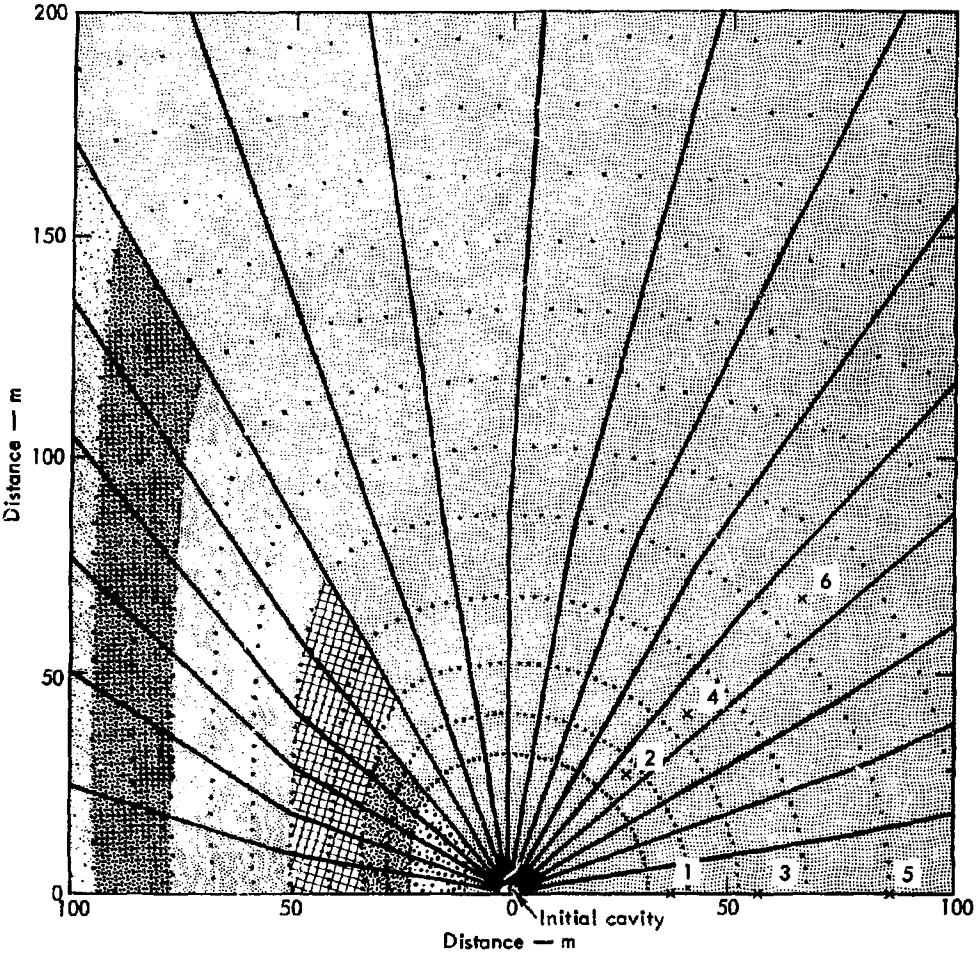


Fig. 5. Setup of the problem. Each shaded region is the top of a reflector, consisting of it and all shaded regions below it.

The low coefficient for a distance of 5 cavity radii is because the low stress level at that distance is below the "knee" of the pressure-volume curve for alluvium, as shown in Fig. 1. The low coefficient at 0.5 radii is because at stresses corresponding to such a short distance, the alluvium has a bulk modulus of about a third that of dolomite instead of the modulus of about a tenth that of dolomite farther out.

Table 3. Energy reflection coefficients.

Reflector distance in cavity radii	Energy reflection coefficient
0.5	0.24
1.0	0.80
1.5	0.87
2.0	0.87
3.0	0.80
5.0	0.46

Figures 6 and 7 show particle velocity as a function of time at the points labeled 1, 2, 3 and 4 on Fig. 5 for various reflector distances. Reflection arrivals cannot be clearly observed, but a reflection from 3 cavity radii below the device should arrive at points 3 and 4 by about 100 ms, and sooner for closer reflector distances. This indicates that the layer has little effect on the velocity field. Only at times well after the peak can any significant difference be seen, and even then it is quite small compared to the peak.

Table 4 shows cavity pressure at some times of interest for various reflector distances. Pressure at early times can be increased by as much as 25% by placing the reflector at 0.5 cavity radii. Figures 8 through 12 show selected views of the grid at different times for various reflector distances. From these it can be seen that reflector distances of 0.5 and 1.0 radii cause severe cavity distortion, a distance of 1.5 radii shows significant distortion, and a distance of 2.0 a slight distortion (but some displacement). At a distance of 3.0 radii, the distortion is negligible.

Table 5 shows radial displacements at the points marked 1 through 6 in Fig. 5. Differences among problems are small.

Table 4. Cavity pressure versus time for different reflector distances.

Reflector distance in cavity radii	None	0.5	1.0	1.5	2.0	3.0
Time (ms)	Cavity pressure (MPa)					
5	216	216	216	216	216	216
20	39.7	47.5	41.0	39.8	39.8	39.8
30	28.9	34.7	32.1	28.9	28.9	28.9
50	20.2	24.1	24.7	20.4	20.2	20.2
70	16.4	19.4	20.7	17.8	16.4	16.4
90	13.9	16.7	—	16.6	14.0	13.9
150	10.1		12.6		11.8	10.2

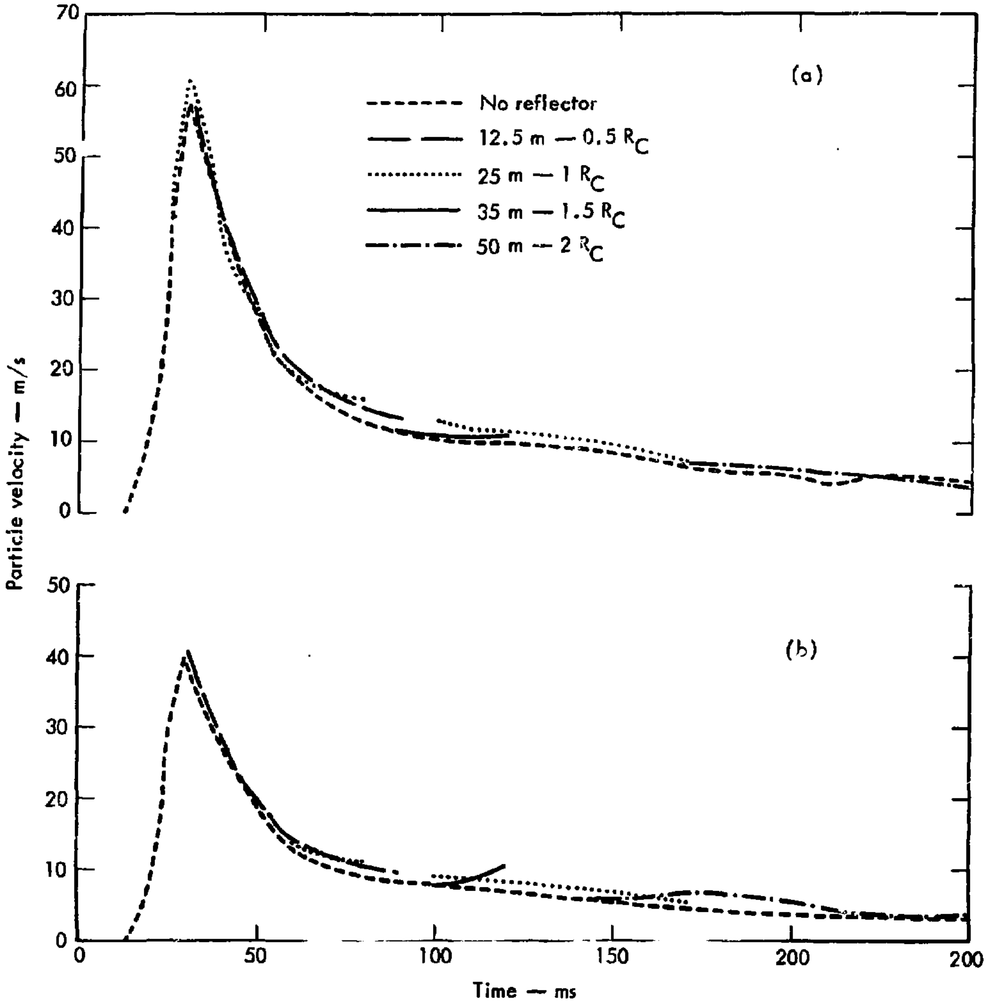


Fig. 6. Particle velocity versus time at points 1 (6a) and 2 (6b) (Fig. 5).

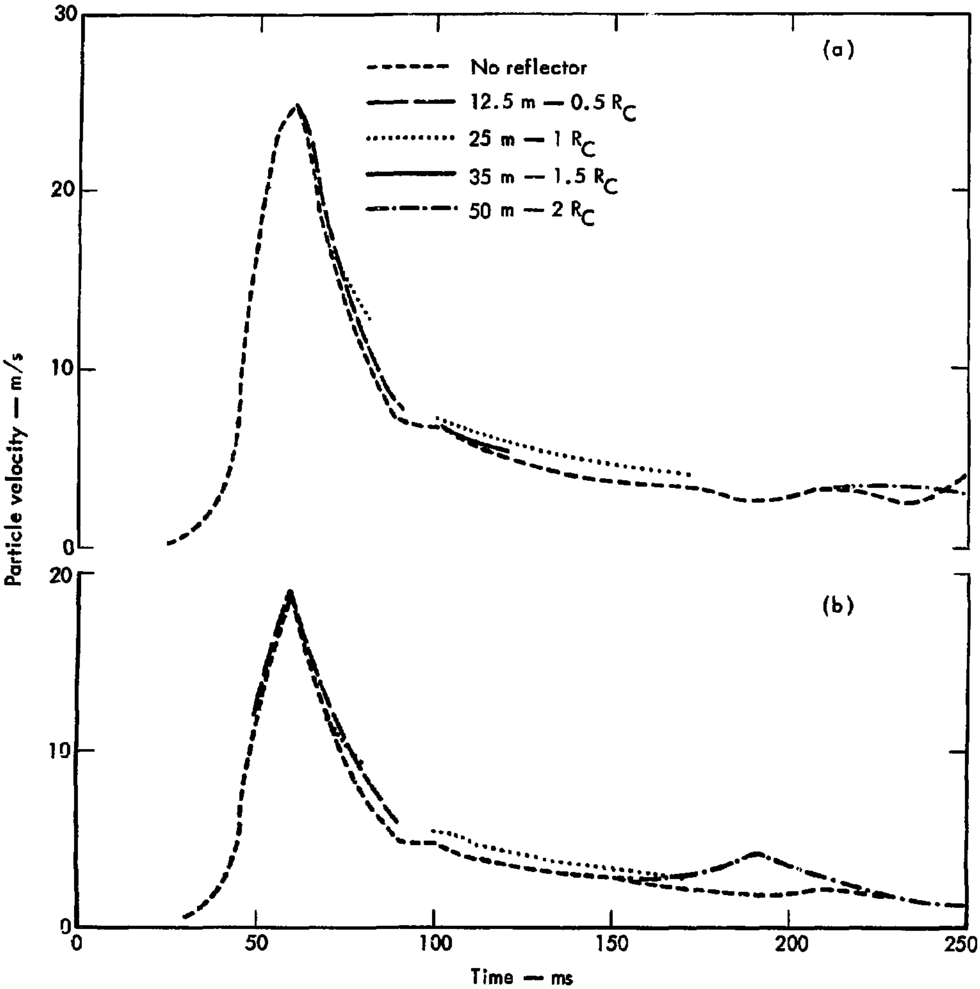


Fig. 7. Particle velocity versus time at points 3 (7a) and 4 (7b) (Fig. 5).

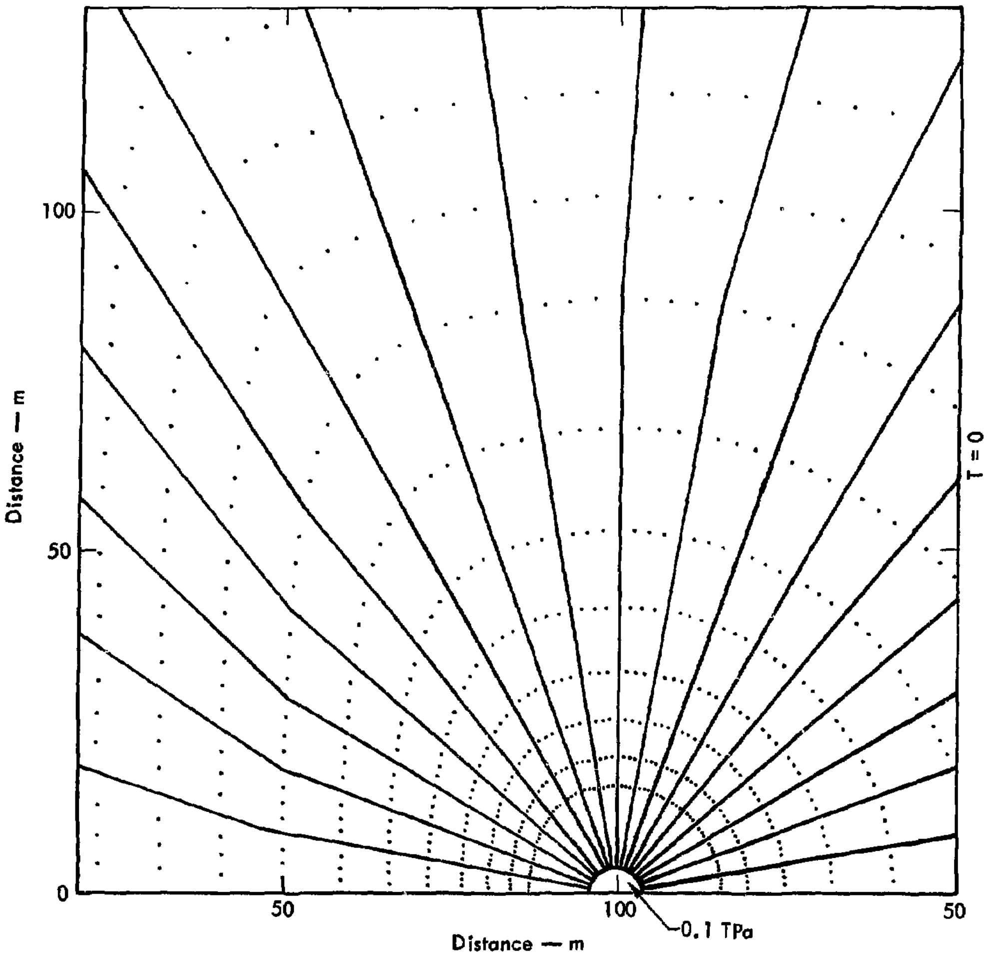


Fig. 8. Views of the grid at several times with the reflector 3 cavity radii from the shot point. This is essentially an undisturbed case.

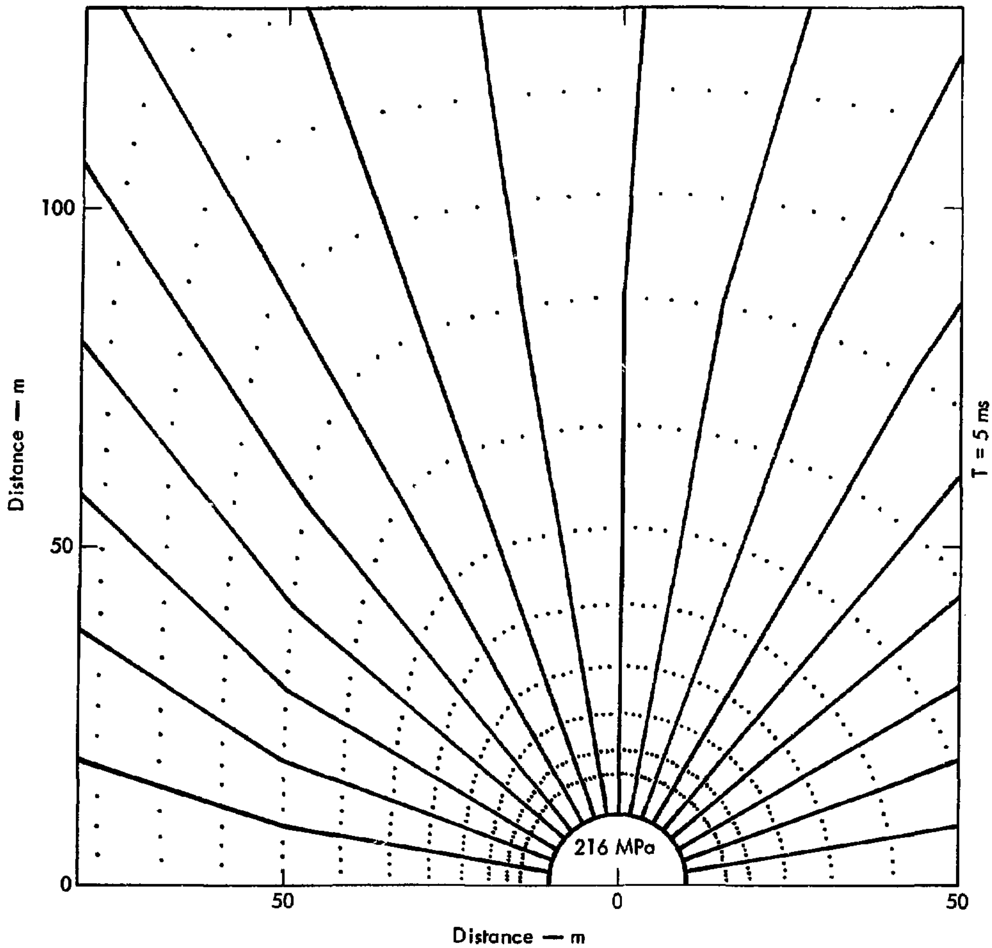
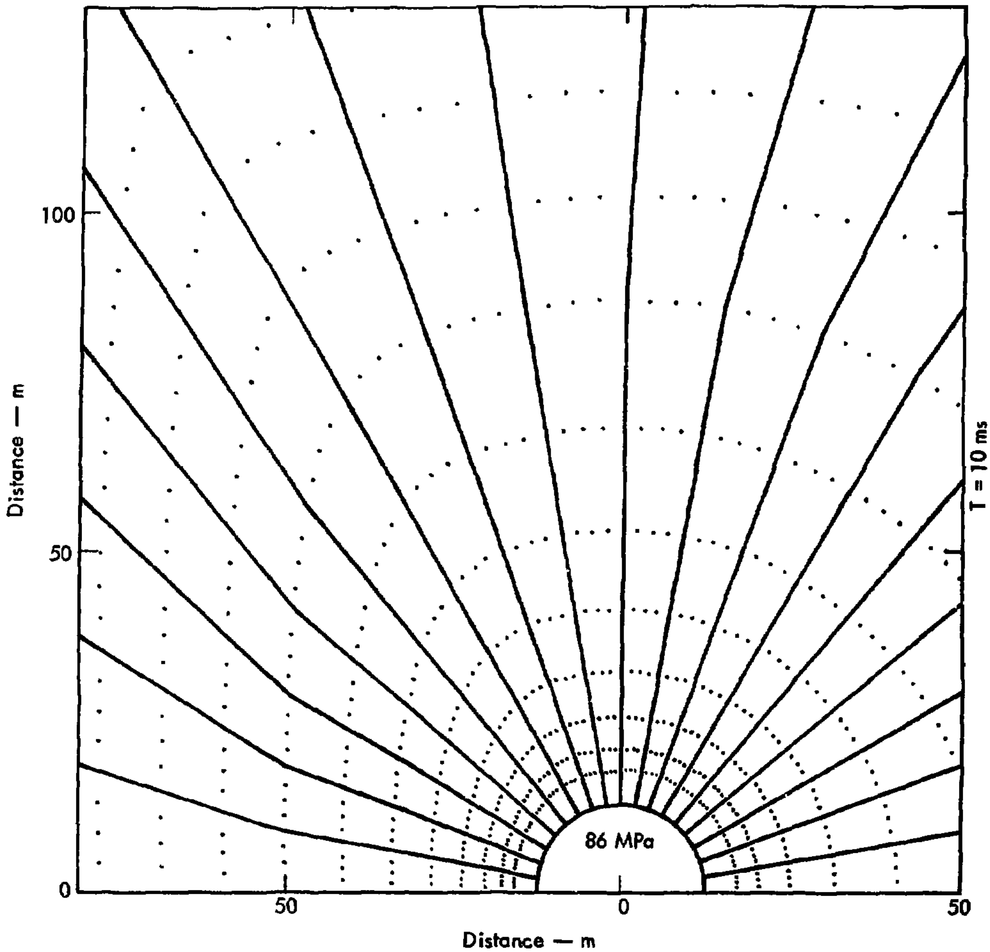


Fig. 8. (continued).



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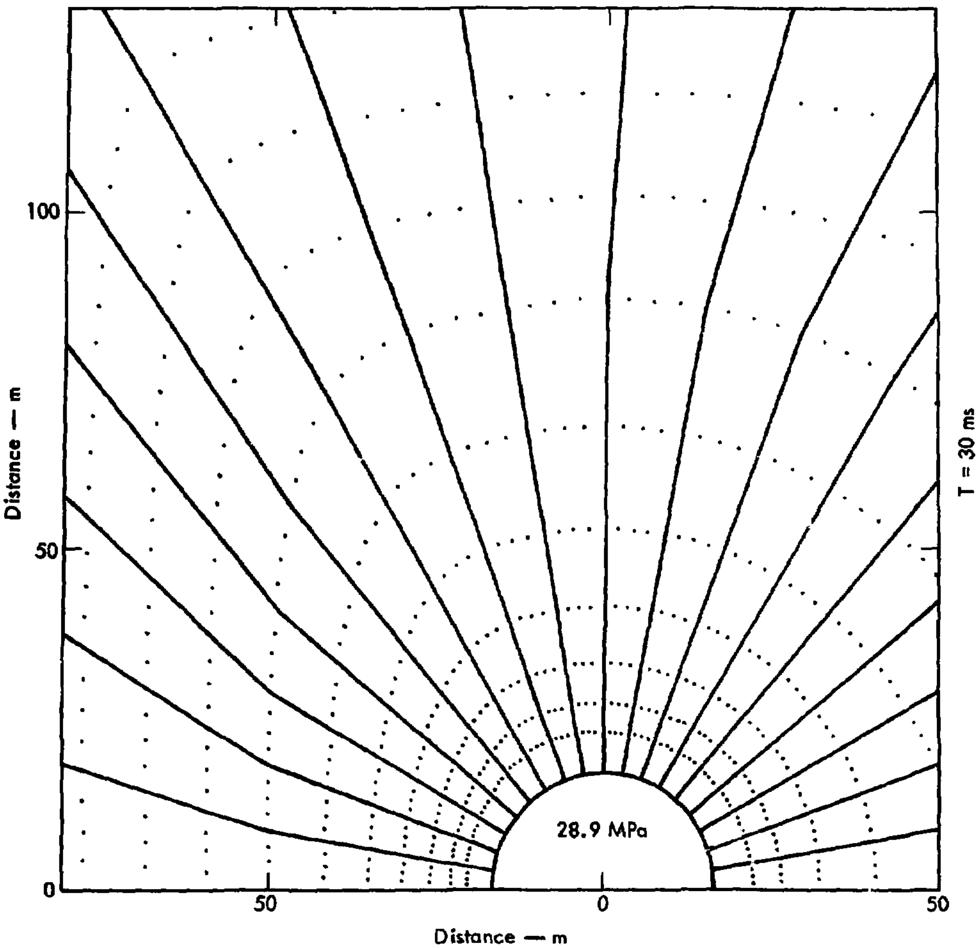

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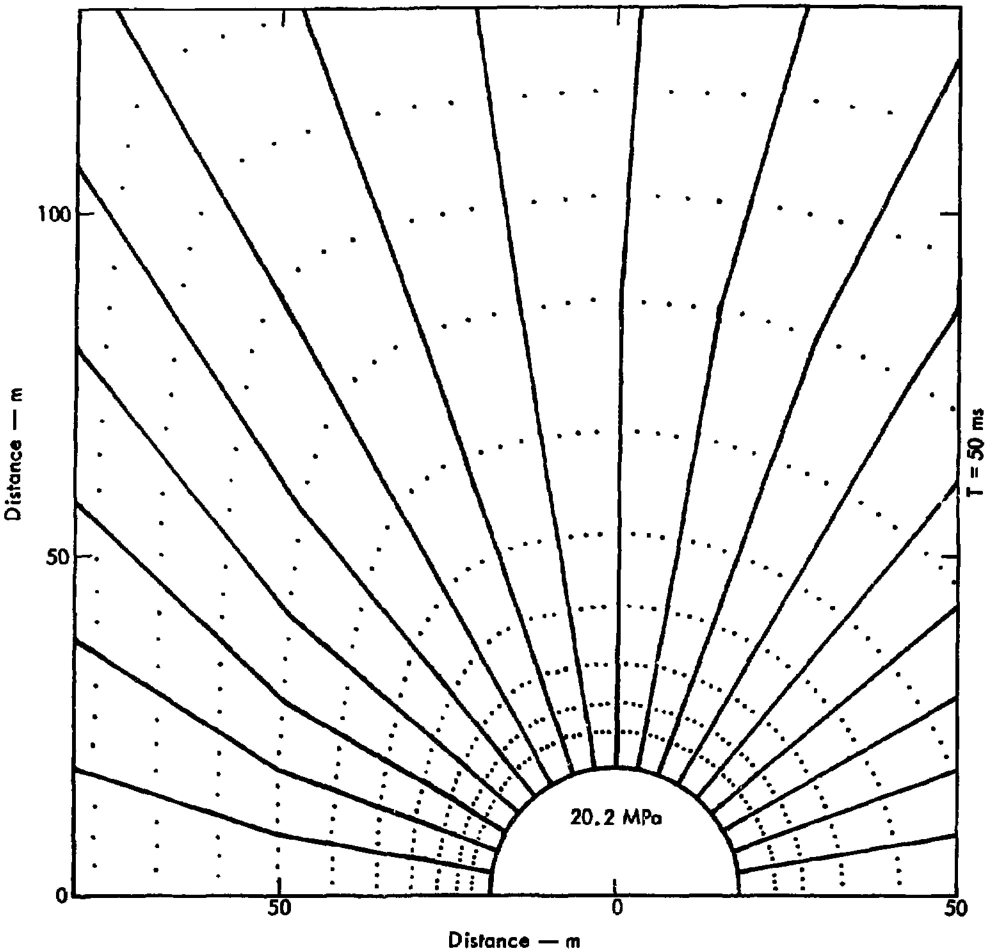

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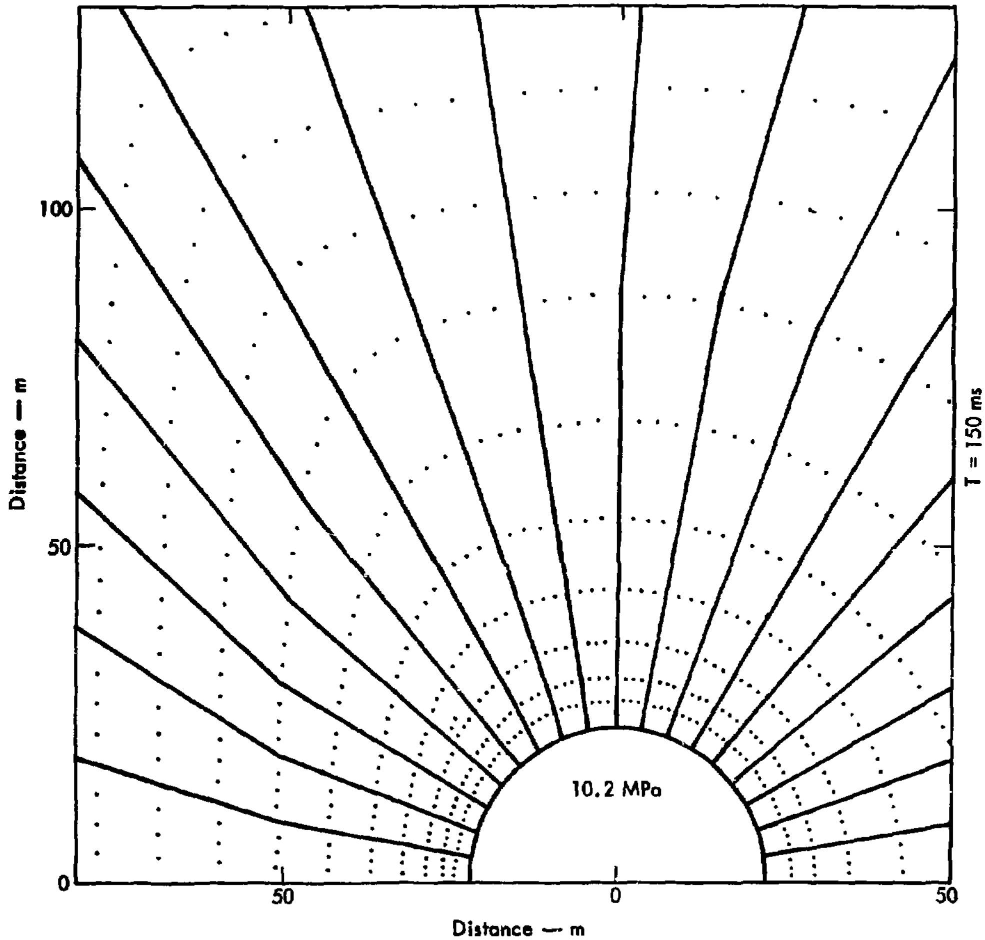

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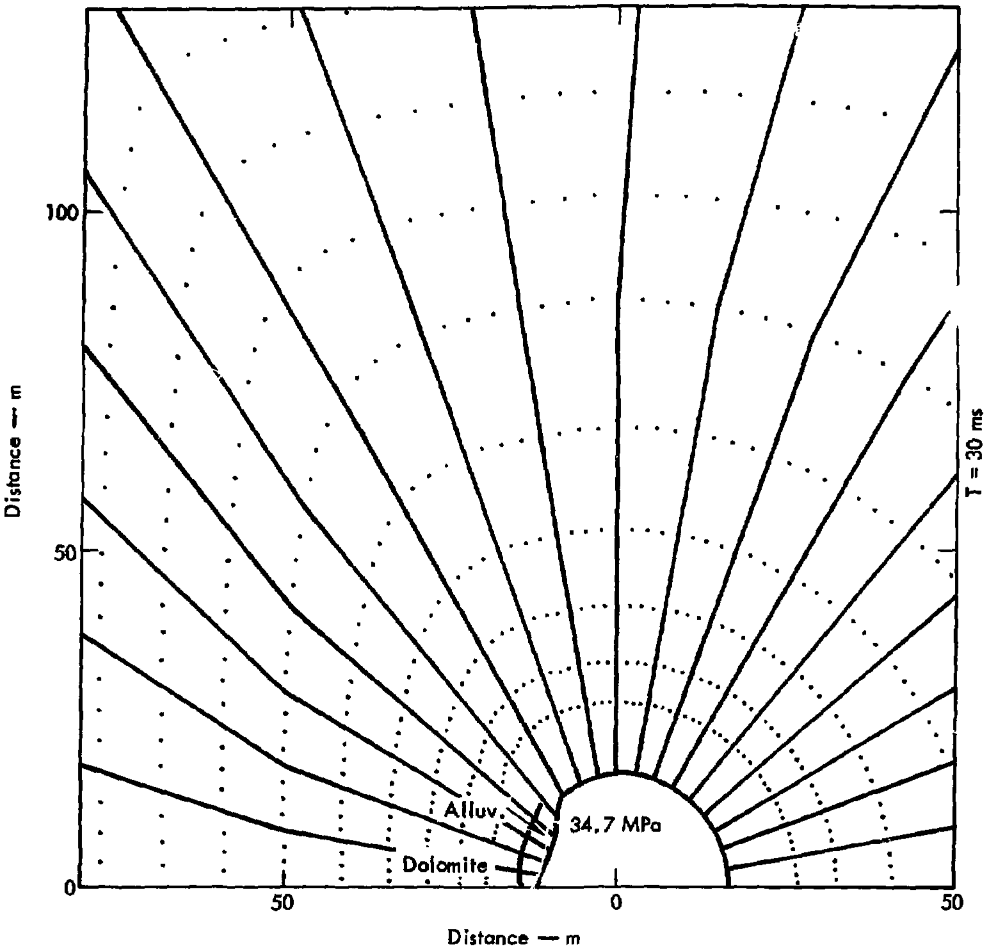

Fig. 9. Views of the grid at several times with the reflector 0.5 cavity radii from the shot point.

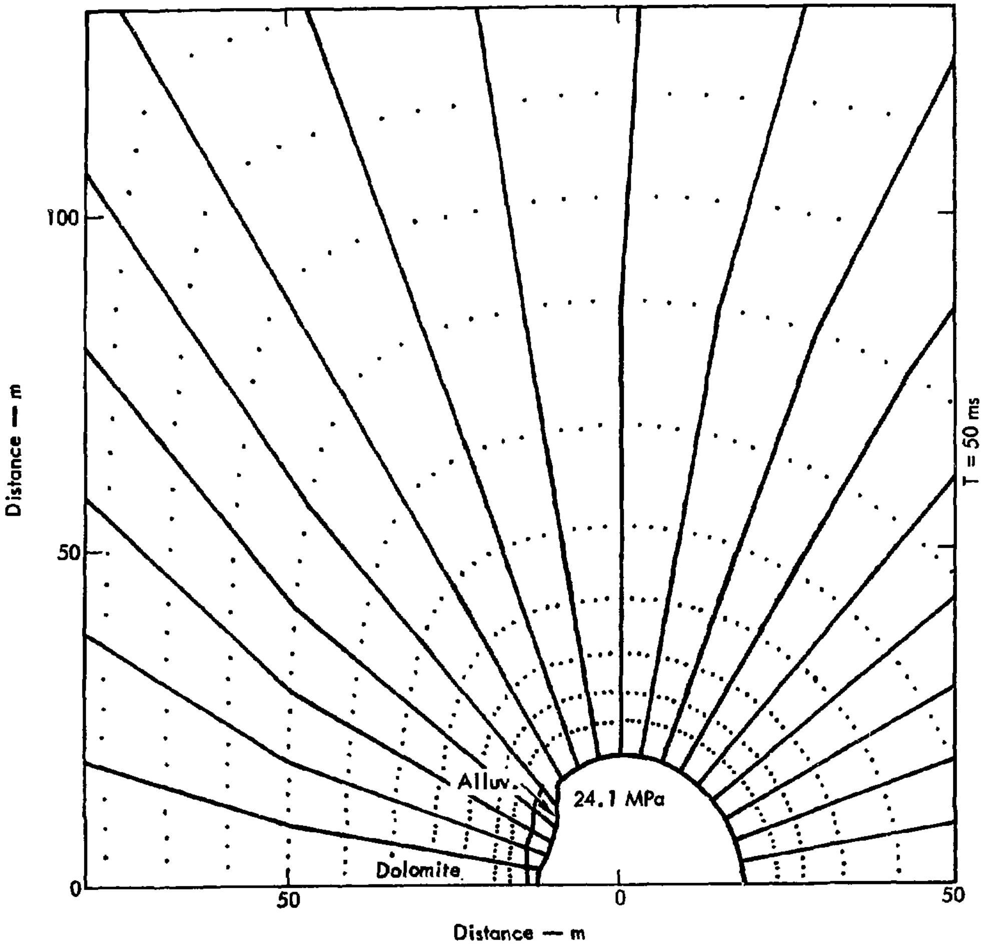

Fig. 9. (continued).

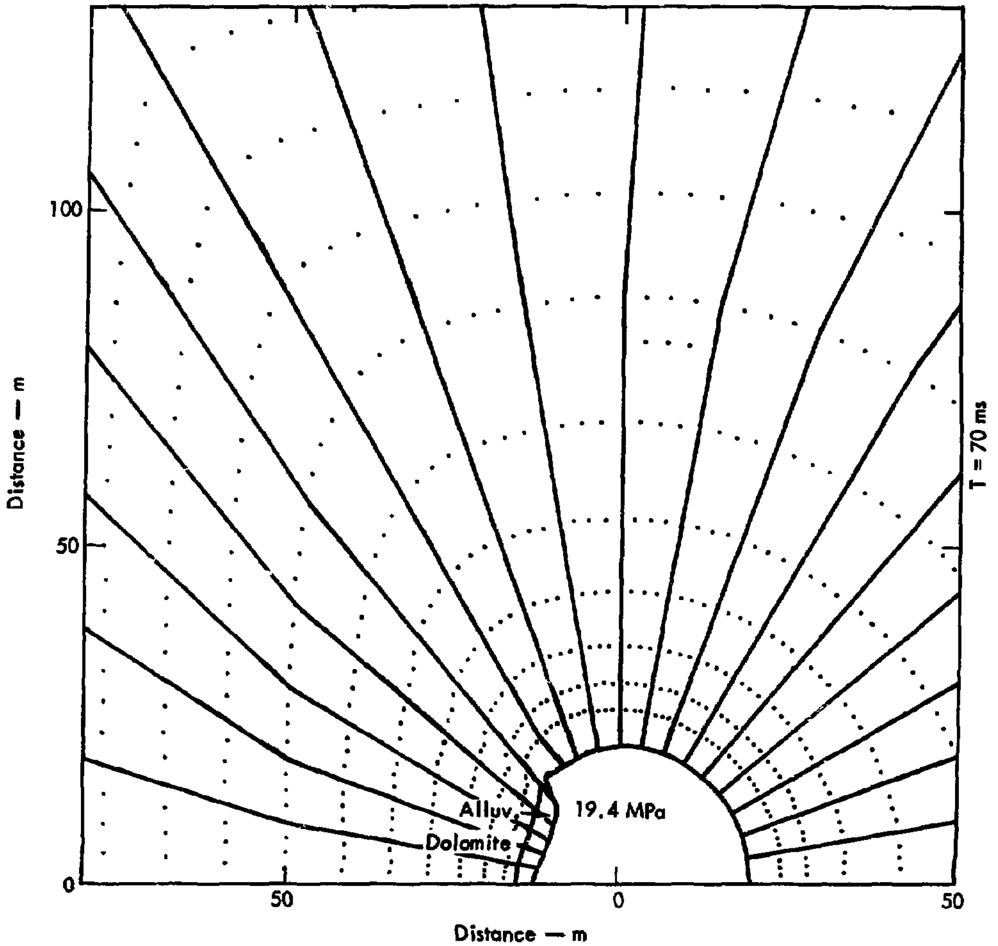

Fig. 9. (continued).

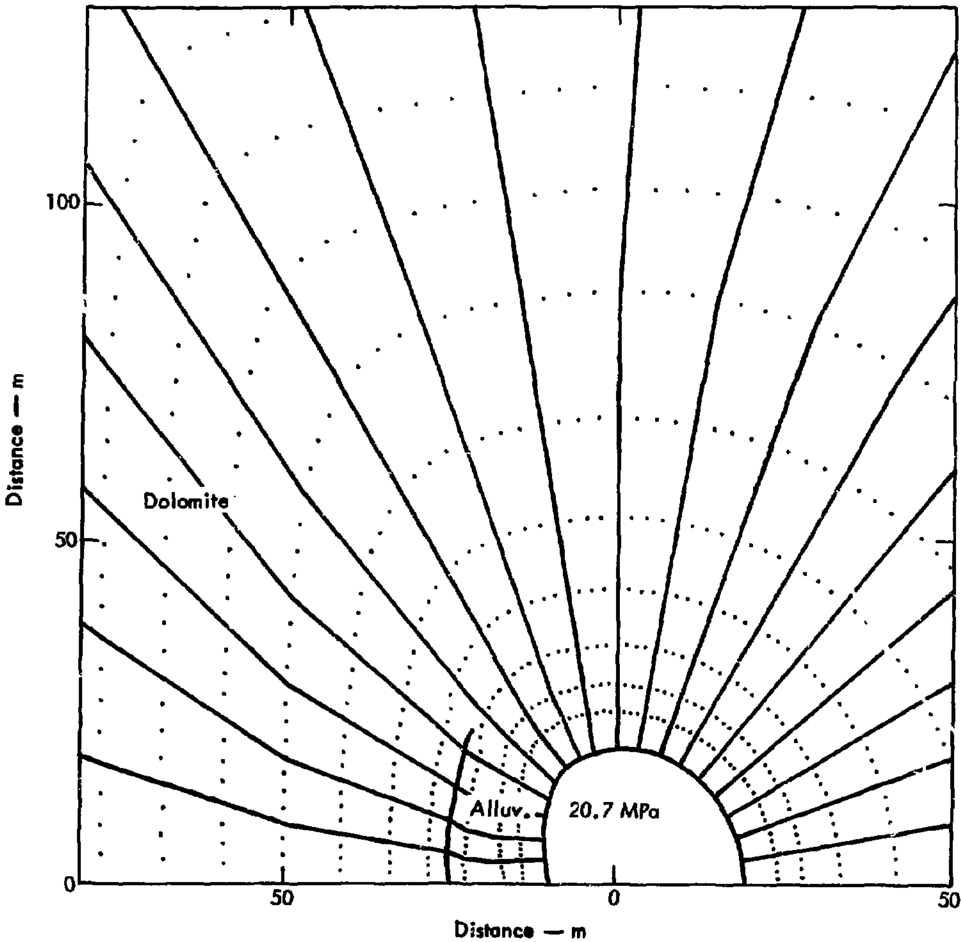

Fig. 10. View of the grid at 70 ms with the reflector 1 cavity radius from the shot point.

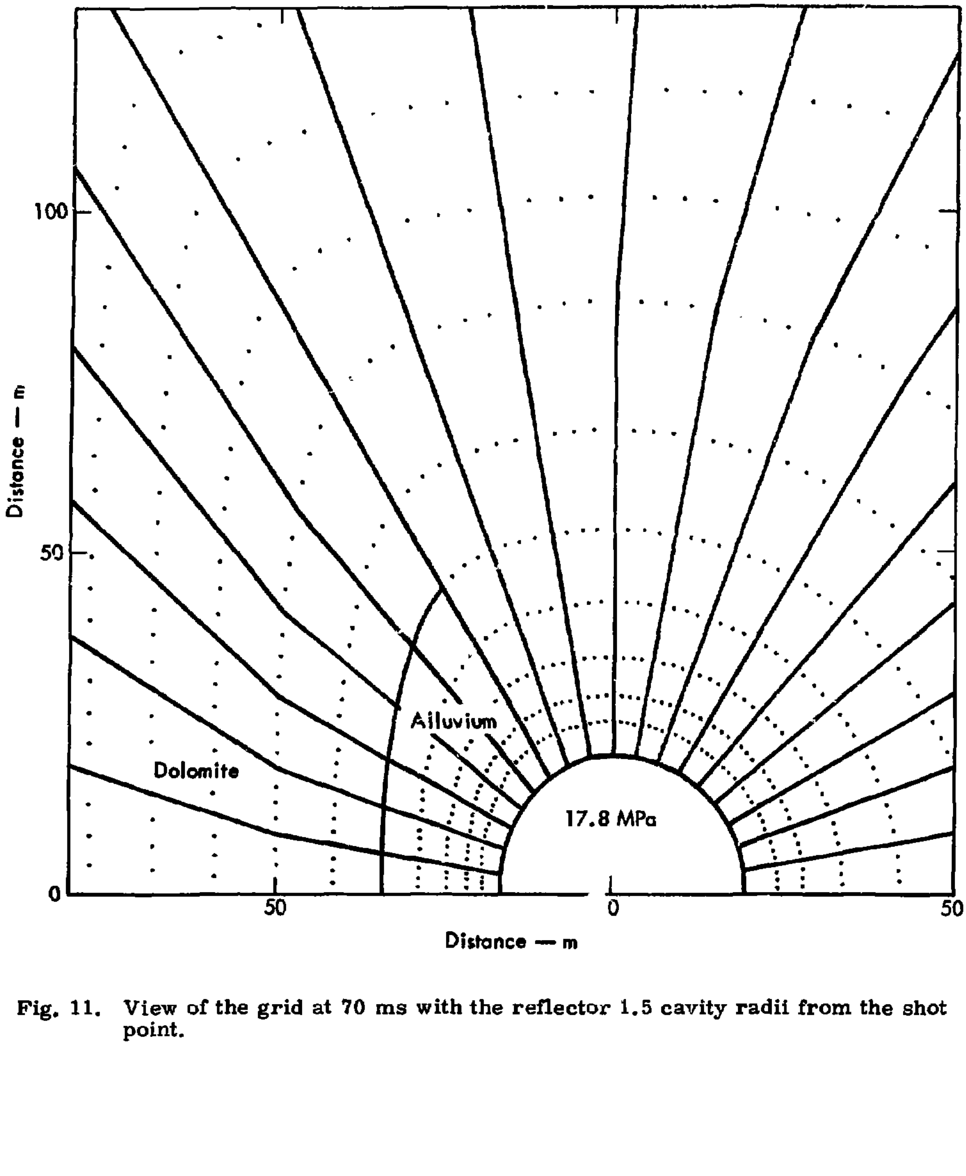

Fig. 11. View of the grid at 70 ms with the reflector 1.5 cavity radii from the shot point.

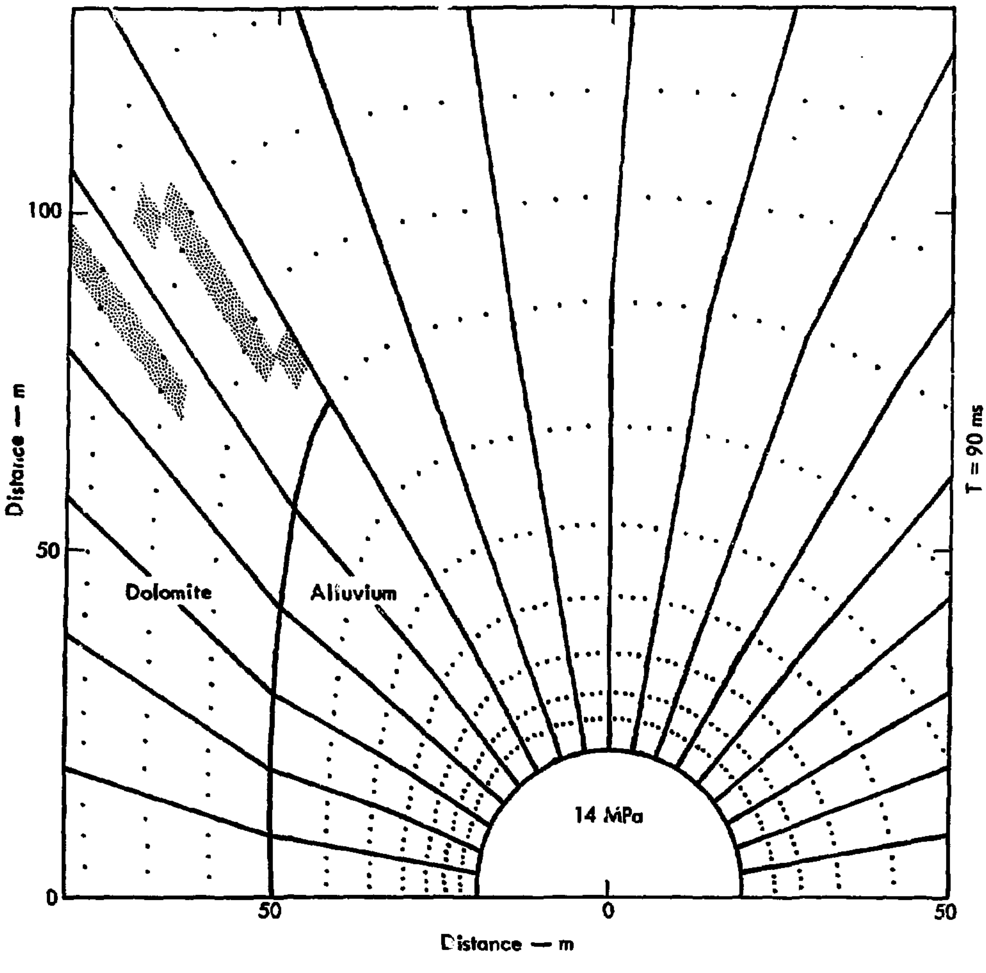

Fig. 12. Views of the grid at two times (a) at 90 ms, (b) at 150 ms, with the reflector 2 cavity radii from the shot point. Shading shows regions of negative comparison.

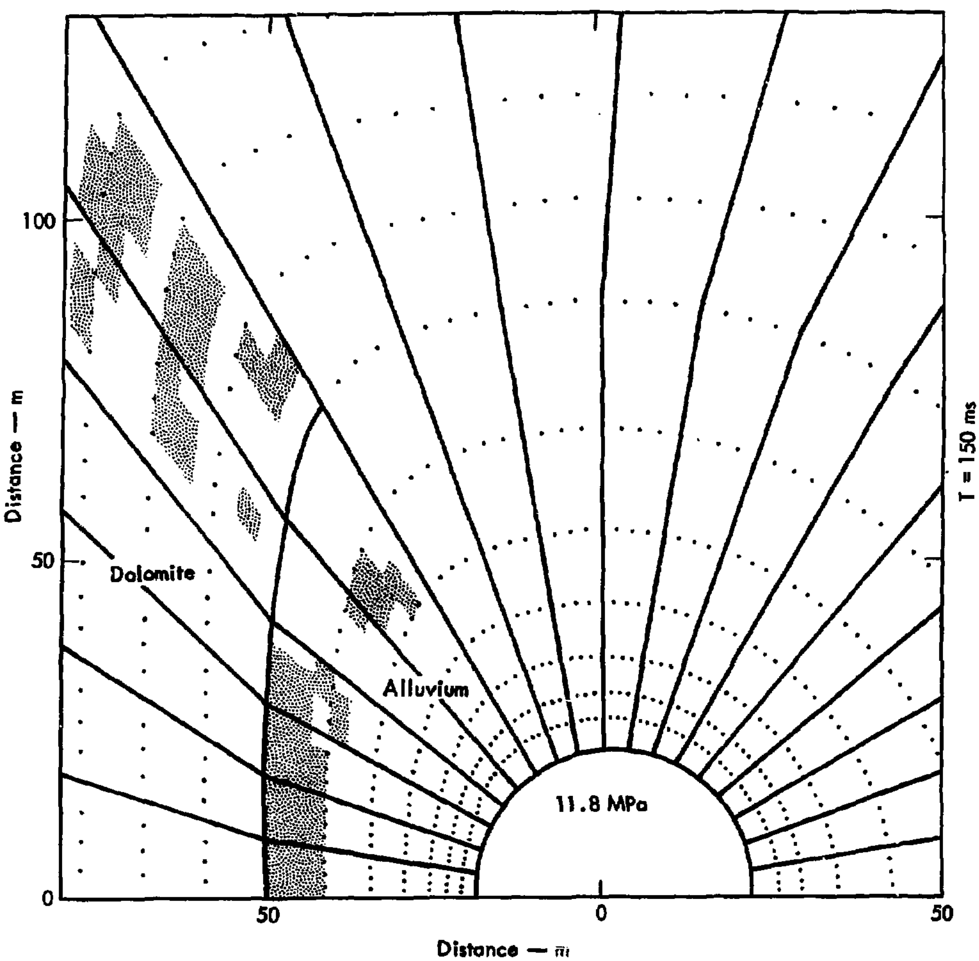

Fig. 12. (continued).

Table 5. Radial displacement at points 1 through 6 (Fig. 5) for different reflector distances.

Reflector distance	Radial displacements (m) 95 ms: None	0.5	1.0	1.5	2.0	3.0
Point No.						
1	1.9	1.9	1.9	1.9	1.9	1.9
2	1.9	2.0	2.0	1.9	1.9	1.9
3	0.8	0.8	0.8	0.8	0.8	0.8
4	0.9	0.9	0.9	0.9	0.9	0.9
5	0.2	0.2	0.2	0.2	0.2	0.2
6	0.1	0.1	0.1	0.1	0.1	0.1

Distance	150 ms: None	1.0	2.0	3.0
Point No.				
1	2.5	2.6	2.5	2.5
2	2.4	2.6	2.4	2.4
3	1.1	1.1	1.1	1.1
4	1.1	1.3	1.1	1.1
5	0.5	—	0.5	0.4
6	0.4	0.5	0.5	0.4

Distance	200 ms: None	200 ms: 2.0	250 ms: None	250 ms: 2.0
Point No.				
1	2.8	2.8	3.0	3.0
2	2.8	2.9	3.0	3.1
3	1.2	1.2	1.4	1.4
4	1.3	1.3	1.4	1.5
5	0.5	0.5	0.6	0.6
6	0.5	0.5	0.6	0.7

We studied regions of negative compression in the problem where the dolomite layer is 2 radii away. It was found that no such region existed above the explosive; and those below it appeared to be caused by rarefactions from the bottom of the problem, and are not real.

DISCUSSION

Strong reflectors, even as close as 0.5 cavity radii below the explosion, produced small effects on the velocity field 1.5 to 2.3 cavity radii above the explosion.

Reflectors out to about 1.5 radii produced significant distortion of the cavity, which might lead to leakage. Distortion, while noticeable, is small at a distance of 2 radii.

Therefore, from this work we may conclude that a strong reflector at a distance of 2 cavity radii below an explosion will have an insignificant effect on phenomena more than 2 radii above it.

REFERENCES

1. J. C. Cherry et al., Two-Dimensional Stress-Induced Adiabatic Flow, Lawrence Livermore Laboratory, Rept. UCRL-50987 (1970).
2. J. R. Hearst, One-Dimensional (SOC) Calculations of the Effects of Four Nuclear Events in Alluvium, Lawrence Livermore Laboratory, Rept. UCID-15783 (1971).