CONF-930397--1

LA-UR- 93-224

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Submitted to:
NUMERICAL MODELING FOR UNDERGROUND
NUCLEAR TEST MONITORING SYMPOSIUM
DURANGO, CO
MARCH 23-25, 1993

Los Alamos
NATIONAL LABORATORY

EXPLOSIVE SHIELDING BY WEAK LAYERS

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ABSTRACT This paper presents the results of a series of computations which were carried out to determine the effect that a layer of extremely weak rock embedded in an otherwise strong rock matrix would have on the displacements and velocities which result from the detonation of a nearby explosive source. The motivation for the study was the apparently different measurements obtained on the Mission Cyber Nuclear Event when compared to results obtained from other events of equal yield in similar geologic media.

INTRODUCTION While investigating various reasons which might be responsible for the apparent differences in the experimental results obtained by Sandia National Laboratories when measuring the close-in stresses and accelerations from nuclear events in P Tunnel at the Nevada Test Site it became apparent that there is an extremely large variation in the properties of tuff from the Rainer Mesa Area.

Figure 1 is a graph depicting relative strength of tuff obtained from a vertical core hole near the Mission Cyber Event. The values of strength shown were the authors estimation of what the strength might be based upon examination of the core from the surface to a depth of 1000 feet which was well below the working point for the Mission Cyber Event. Figure 2 presents a comparison of the relative strength values assigned by the authors with actual strength values as obtained in testing conducted by Terra Tek [1]. Terra Tek values for both unconfined strength and strength as determined from tri-axial tests are shown. The relative strengths from the Terra Tek data were determined by finding the numerical average of the strengths and assigning that strength a relative strength value of 5. This resulted in some values being greater than 10 but these values were plotted as a 10 in Figure 2. Note that where strength values are available that the relative strengths assigned do correlate well with those assigned by the authors - except in the area of the working point. Near the working point the strength values as determined by the authors are considerable higher than the results obtained by Terra Tek. Note also that there is a wide variation in the values of relative strength as assigned. The relative strengths go from very low values (less than 1.5) at the surface up to 7.5 at a depth of 140 feet and remain at that value until a depth of 440 feet is reached. There the strength begins to decrease and actually reaches a value of zero from 720 feet to 760 feet and then begins to increase. At the working point the relative strength was found to be quite high (7.5) but relative strength again drops to zero after that point is passed. Figure 3 shows photographs of the best and the worst of the core as determined from our examination of the vertical core. As can be seen from the photographs, the weakest core resembles a crumbly sand while the rock that was assigned a relative strength of 7.5 is competent rock with high unconfined strength and tri-axial strength values. Figure 4 shows relative strength values determined from a horizontal core hole which was located near the Mission Cyber Event. In this case there is very little variation in the relative strength values assigned.

The large variations in strength were surprising and it was felt that such variations might provide a possible reason for the differences obtained from experimental measurements during the nuclear events. We therefore conducted a numerical study of the effect of weak layers such as those observed in the core library could have on the velocities and displacements resulting from the detonation of an explosive charge.

NUMERICAL STUDY The code that was used to predict the rock response was WONDY V, a one dimensional finite-difference wave propagation code developed and maintained by Sandia National Laboratories. The code integrates the one-dimensional Lagrangian differential equations of motion by use of finite difference analogs. We used the code in a spherical geometry and used an equation of state which was based on the P-alpha concept of void removal upon loading. This is the same equation of state utilized to predict response from nuclear events. The particular version that we used did not account for either strain rate effects or strength reduction due to damage caused by loading.

Figure 5 shows the model used in the computer code. In this particular case 3/8 gram of PETN covered with a thin jacket of PMMA makes up the explosive source. This is a geometry that had been used by Miller and Florence [2] at Stanford Research Institute to calibrate computer codes to predict the response of geologic material to explosive sources. We chose to run our computations in an Indiana Limestone material since this is one of the materials investigated by Miller and Florence [3]. Notice from Figure 5 that the weak layer is located 5 cm from the center of the model. For the case shown the thickness of the weak layer is 0.25 mm but in the study the layer thickness was varied from zero to 6 mm. The failure surfaces for both the weak and the strong layers are shown in Figure 6. Also shown in that figure is experimental results obtained for Indiana Limestone from static tests [3]. The three sets of experimental data are for dry, 50% saturated, and 100% saturated Indiana Limestone with the strongest rock being the dry limestone. The failure surface chosen represents the dry limestone but the failure values were increased to reflect the fact that the limestone is stronger than the static values at the high strain rates of the explosive tests. Notice that the strong rock has a strength of about 12 kbar for a confining (mean) stress value of 10 kbar. The weak rock on the other hand only has a yield of 2.2 kbar at a mean stress of 10 kbar. This is a reduction in yield strength of six. The other strength factors shown in Figure 6 are for the elastic pressure P_e and the crush pressure P_c. For the strong rock the elastic pressure was taken to be 0.6 kbar and for the weak rock 0.06 kbar. The crush pressure for the weak rock was also reduced by a factor of 10 from 24 kbar to 2.4 kbar. The reduction in yield surface and in elastic and crush pressures are merely a best guess and may or may not be accurate representations of appropriate values.

RESULTS Figure 7 presents typical velocity values obtained from the calculations. In this case the radial particle velocities are shown for various thicknesses of weak rock layers located 50 mm from the charge center. When no weak layer was present the velocity at 65 mm from the charge center was 5 m/s. A layer of 0.5 mm thickness at 50 mm resulted in a decrease in velocity to a little more than 3 m/s while the thickest layer investigated (6 mm thick) reduced the velocity to about 1.7 m/s (or to about one third of the value if no weak layer were present). Figure 8 shows the loss in velocity as a function of weak layer thickness and Figure 9 shows the similar information for displacements. In this case the loss of velocity and displacement due to the presence of a weak layer are shown as a function of layer thickness. The presence of a layer of thickness 0.25 mm results in a loss of 1.2 m/s of velocity and 0.0006 mm of radial displacement. This is about 22 % of the velocity and 33.3 % of the displacement if no weak layer were present. As can be seen from Figures 8 and 9 the presence of a 6 mm thick layer results in a loss of about 67 % of the velocity and 60 % of the available displacement.

For the case being investigated the material at 50 mm from the charge center is under a state of elastic stress. In fact, an examination of the decay rate of the velocity with respect to distance from the charge center shows that the material between the charge center and out to about 25 mm undergoes large plastic deformation and the decay rates are large. From 25 mm outward the decay rate is much smaller and indicates elastic or low plastic loading. The above described computations were repeated with weak layers located at 35 mm from the charge center and at 10 mm from the charge center. The results for the weak layer at 35 mm were similar to those obtained when the weak layer was at the 50 mm location. At the 10 mm location the presence of the weak layers caused reductions in the magnitude of the velocity and unlike the results for the 50 mm and 35 mm locations the time duration of the velocity pulse increased significantly as the layer thickness increased. Figure 10 shows the velocities that are predicted at 25 mm from the charge center when the weak layer is located at 10 mm. Notice that there is very little difference between the no layer case and the case for the 1 mm thick weak layer. As the layer thickness increases, however, the pulse width increases greatly. For this case there were reductions in the displacements but they were not as severe as the reductions at greater distances from the charge center. Figures 11 and 12 give a summary of the results obtained in all three cases from the standpoint of velocities (Figure 11) and displacements (Figure 12). As can be seen from an examination of these figures when the layer is located at 50 mm the loss in displacement increases very rapidly up to a layer thickness of 1 mm and then continues to increase as layer thickness increases - but not so rapidly as between 0 and 1 mm. The same is true for the case when the weak layer is located at 35 mm. For the case where the weak layer is located very near to the charge center (@ 10 mm) there is a rapid loss of displacement for layers up to 1 mm in thickness (20 % loss) and then little additional loss. This is because at that location the loading is severe enough to cause the rock to behave hydrostatically irrespective of the strength and the net effect of adding the weak layers is not as great as it is at greater distances from the charge. This unusual behavior at close in locations is also evident from observing Figure 11 where two different regimes seem to be represented by the velocity loss curve for the case where the weak layers are located 10 mm from the charge center. In the first regime (for thinner layers) the presence of the weak layers on velocity is very small. In the second regime (for thicker layers) the effect on velocities seem to agree more with the results from the two more distant locations for the weak layers.

When scaled to nuclear explosions the results are quite significant. Figure 13 shows the results scaled to a 1 kiloton device for the situation where the weak layer is located 68 meters from ground zero. As shown an 8 meter thick weak layer results in a loss in displacement of 58 %. Figure 14 shows similar results. In this case two displacement versus time curves are shown that would exist past the weak rock layer. Here the thickness of layer was only 1.33 meters but the loss in displacement was 41 %. From our examination of the core (in the vertical hole) it is not difficult to find the presence of weak rock layers significantly larger than 8 meters in thickness.

Figures 15 and 16 show the effects of the various input parameters when changed separately. For the study just described three parameters were all changed together -failure surface, elastic pressure, and crush pressure. In Figure 15 the failure surface is held constant and both the elastic and crush pressure are changed. There is very little difference between the first two cases in which the elastic pressure is 0.3 kbar and the crush pressure is 12 kbar versus the case where the elastic pressure is 0.6 kbar and the crush pressure is 24 kbar. For the last two cases shown in Figure 15 where the crush pressure is decreased to 2.4 kbar and the elastic pressure to 0 and .1 kbar the effect on velocity is quite dramatic. Figure 16 demonstrates that the most important input parameter with regard to shielding from an explosive source is the crush pressure. As shown in the figure for the same elastic pressure (0 kbar) a reduction in crush pressure from 12 to 2.4 kbar reduces the velocity by nearly a factor of two. Changes in the yield surface were found to affect the velocity and displacements but not nearly so much as the crush and elastic pressures.

CONCLUSIONS The study indicates that the presence of weak layers of reasonable thicknesses appear to have significant effects on velocities and displacements from an explosive source (and presumably also on accelerations and stresses). The examination of the core from the Test Site also indicates that most of the weaker tuff is never tested (It is too weak to make specimens) and therefore is not included in predictions of ground motions from nuclear events. Furthermore our calculations seem to indicate that the presence of these weak layers should be included in the numerical calculations related to confinement and verification. We say this since a simple averaging technique to account for the presence of the weak layers would not provide a good estimate of the effects as determined from our calculations.

From our examinations of the core in the vicinity of Mission Cyber the apparent differences in the events in the P Tunnel Complex is not felt to be due to the presence of unaccounted for weak layers since if anything the tuff nearest to Mission Cyber was better than that observed near to the other events in P and N Tunnel - especially in the horizontal direction where the instruments were located.

For the future we are planning to conduct laboratory tests on the sand like tuff to determine more appropriate values to use for the elastic and crush pressures. We also will conduct explosive tests in models in which we have embedded a very weak layer between otherwise strong rock layers. These tests will aide us in better predicting the effects of weak layers on wave propagation from explosive sources. We also plan to run two dimensional calculations for similar geometries to determine if the transmission of the signals through the stronger layers above and below the weak layer prevent these large reductions in velocity and displacement. Additional details on the computations conducted can be obtained from [4].

ACKNOWLEDGEMENTS Many people have contributed to our study. We thank Fred App for his patience in getting us started using WONDY and helping us understand ground motion calculations and results. We acknowledge the assistance and technical expertise of Barbara Harris-West at DNA at the Nevada Test Site in providing access to the United States Geological Survey core library at NTS. Also we appreciate the work of the staff at the core library, namely Jerry Magner, Mark Tsatsa, Ron Martin, Dick Hurlbut, and Harry Covington. Finally, we appreciate the efforts of Susan Freeman (EES-3) in keeping our computers humming.

REFERENCES

[1] Torres, G., "Characterization of Material from the Nevada Test Site, Final Report for the Period January 1986 through March 1988 - Volumes I, II, and III", DNA-TR-88-278-V1, V2, V3, 1988.

[2] Miller, S. A. and A. L. Florence, "Laboratory Particle Velocity Experiments on Indiana Limestone and Sierra White Granite", SRI Final Report PL-TR-91-2277, Phillips Laboratory, Oct. 1991.

[3] Heard, H. C., Abey, A. E., and Bonner, B. E., "High Pressure Mechanical Properties of Indiana Limestone", Lawrence Livermore National Laboratory Report UCID-16501, June 11, 1974.

[4] Dick, R. D. and W. L. Fourney, "Effects of Rock Properties on Explosive Source Modeling - Preliminary Results", Los Alamos National Laboratory Report LAUR-92-3277, September 1992.

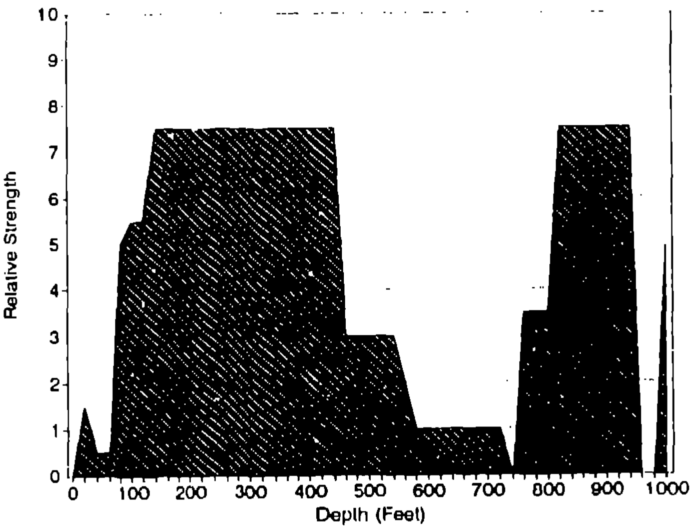


Figure 1. Relative strength versus depth for the vertical core from hole UE12P#4 near Mission Cyber.

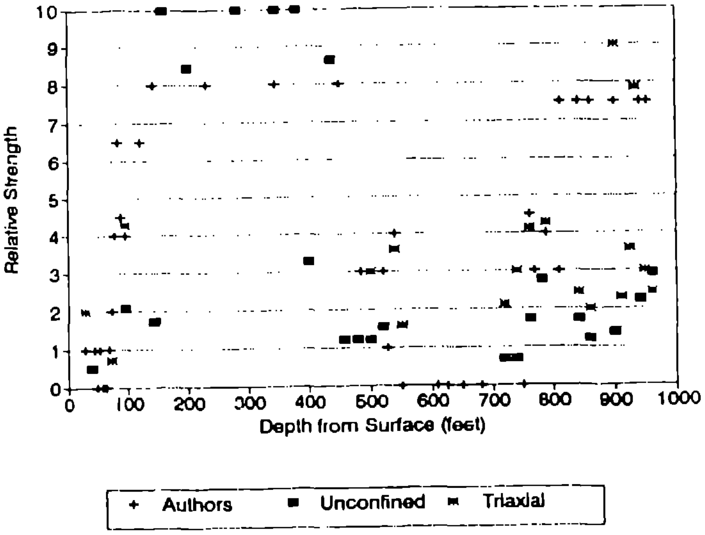


Figure 2. Comparison of relative strengths assigned by authors with strength data from testing conducted by TerraTek.

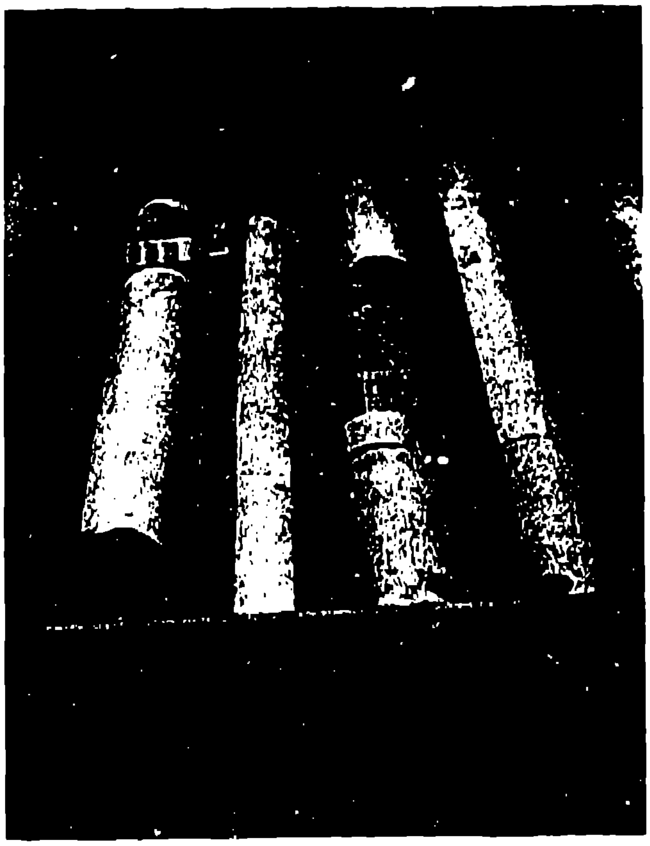


Figure 3a. Photograph of core from 822 feet (UE12P#4).

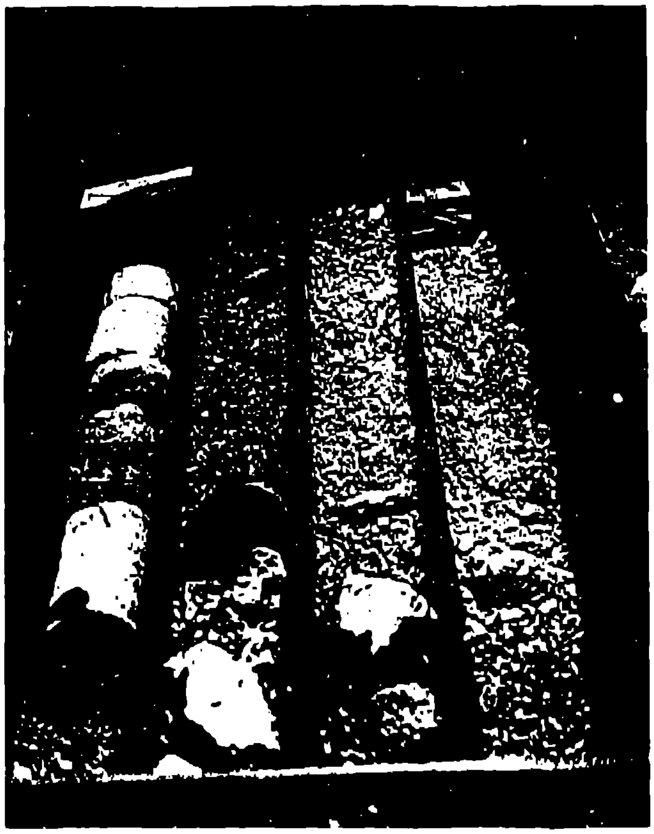


Figure 3b. Photograph of core from 680 feet (UE12P#4).

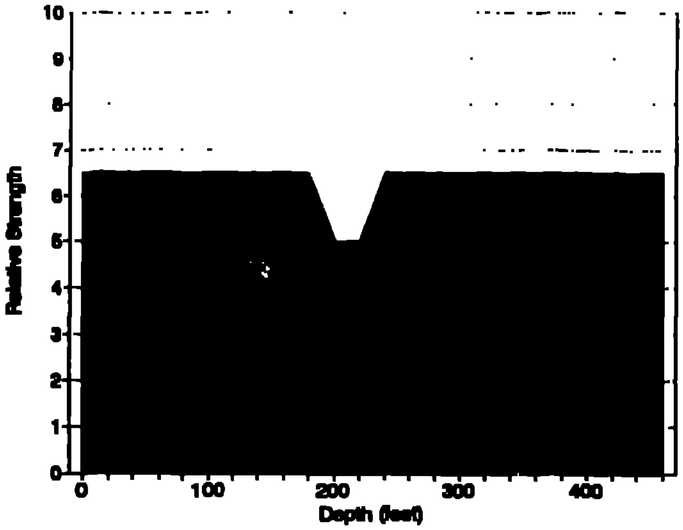


Figure 4. Relative strength versus depth for the horizontal core from hole U12P#02 IH-1 near Mission Cyber.

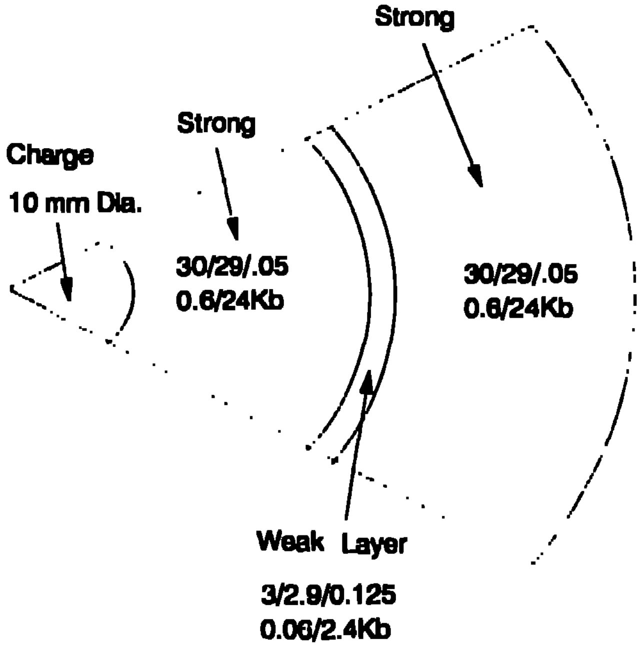


Figure 5. Geometry used in the study of effects of weak layers located at 50 mm from the charge center.

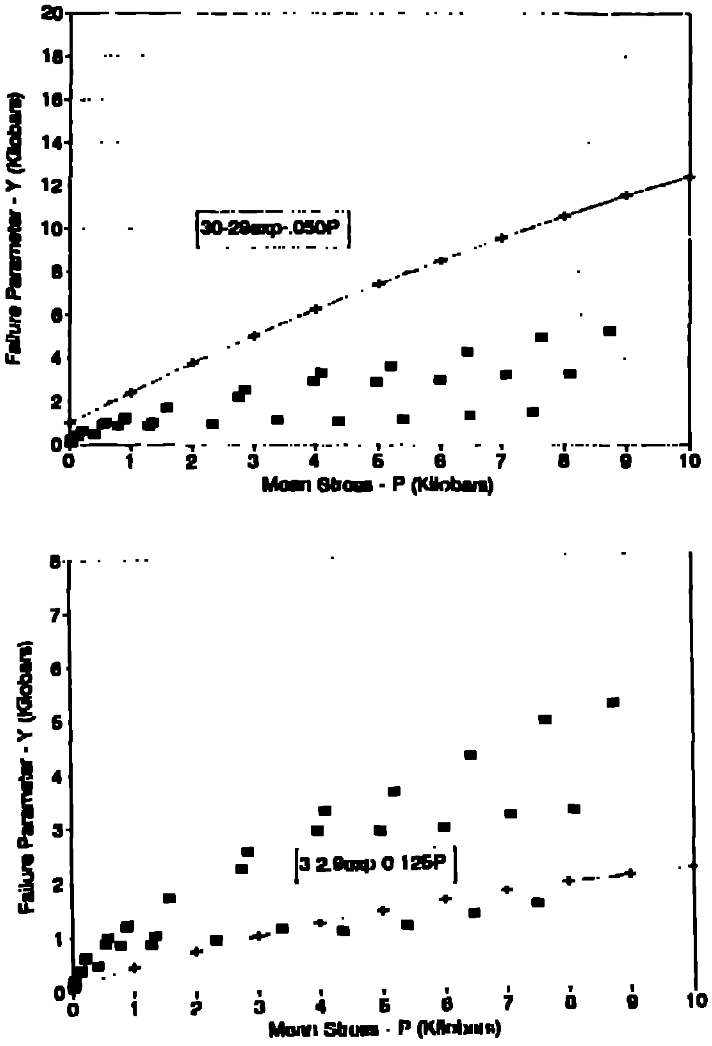
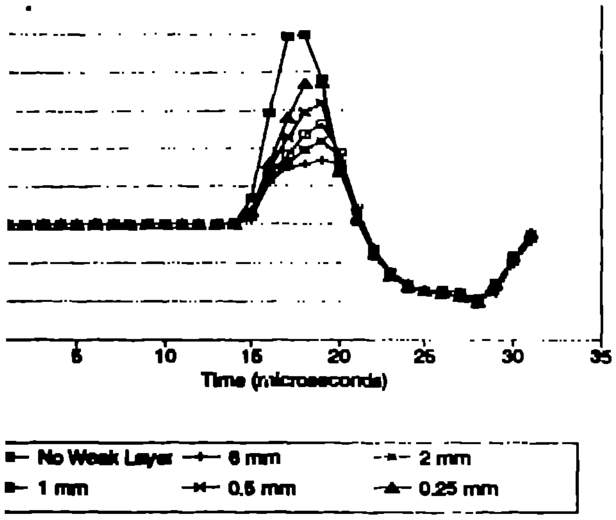
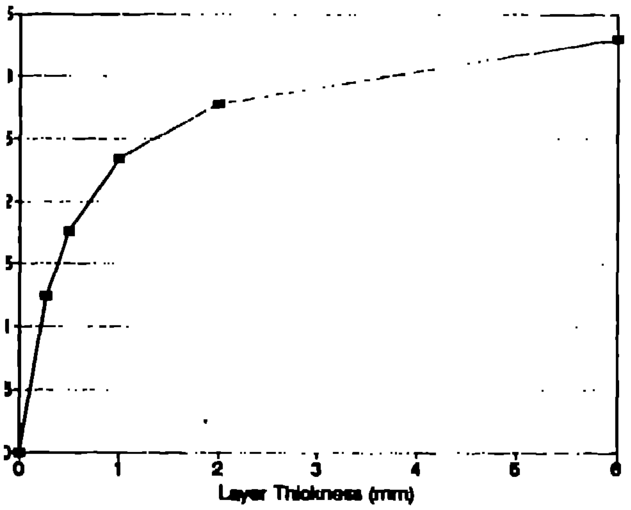


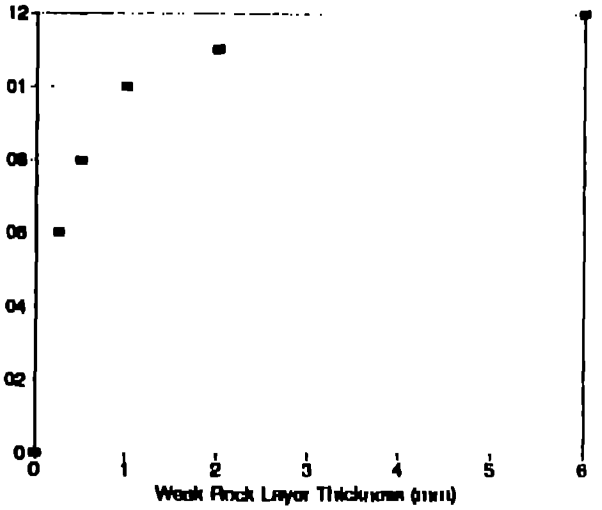
Figure 6. Comparison of failure surfaces for two selections of rock properties for a weak layer located at 10 mm.



re 7. Velocities at 65 mm with weak layer located at 50 mm.



8. Loss of velocity across a weak layer as a function of weak layer thickness - layer at 50 mm.



). Loss of displacement across a weak layer as a function of weak layer thickness - layer at 50 mm..

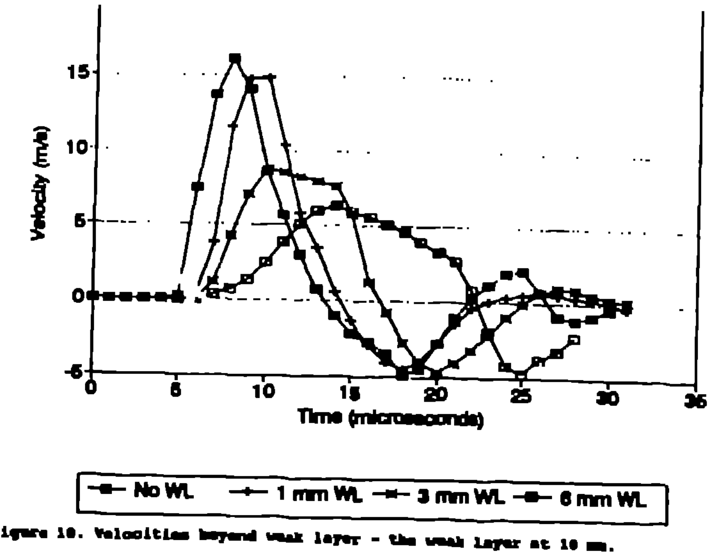


Figure 10. Velocities beyond weak layer - the weak layer at 10 mm.

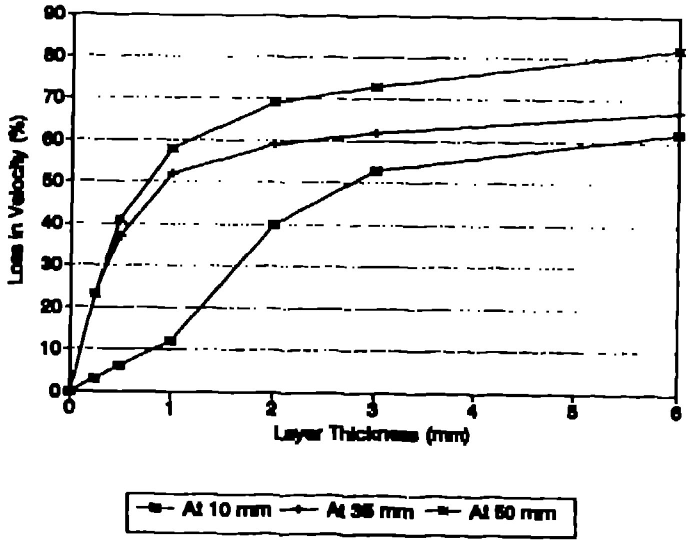


Figure 11. Loss of velocity versus layer thickness for layers located at 10, 35, and 50 mm.

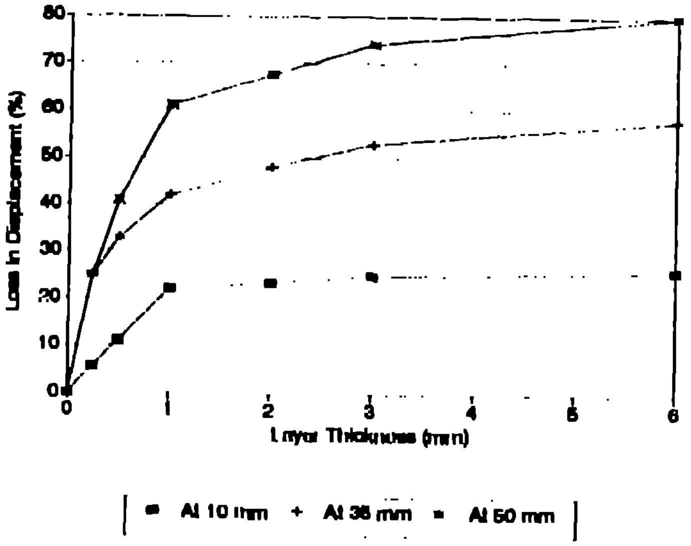
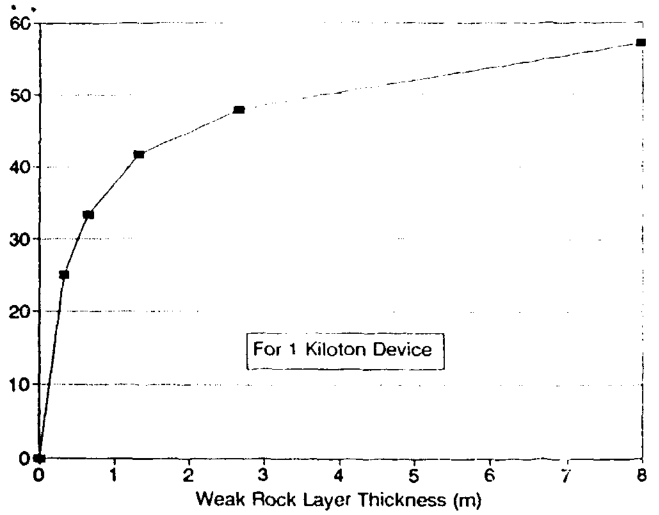
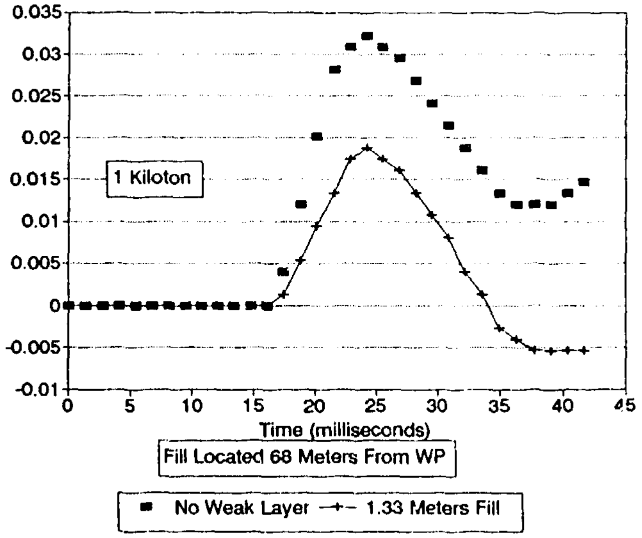


Figure 12. Loss of displacement versus layer thickness for layers located at 10, 35, and 50 mm from the source.



jure 13. Prediction of loss of displacement from weak layers scaled to a one kiloton device.



.gure 14. Loss of displacement at 70.7 meters for a 1.33 meter thick weak layer at 68 meters from a one kiloton device.

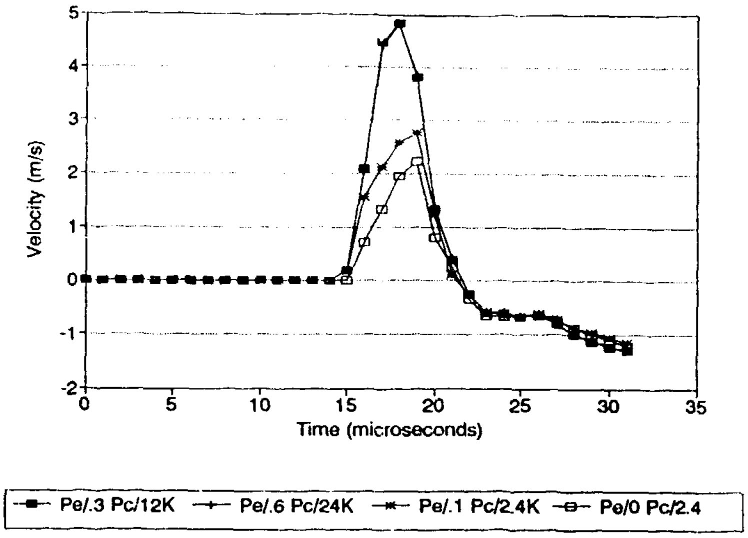


Figure 15. Comparisons of velocities at 65 mm when changes are made in elastic pressure and crush pressure with failure surface parameters held constant. Weak layer at 50 mm.

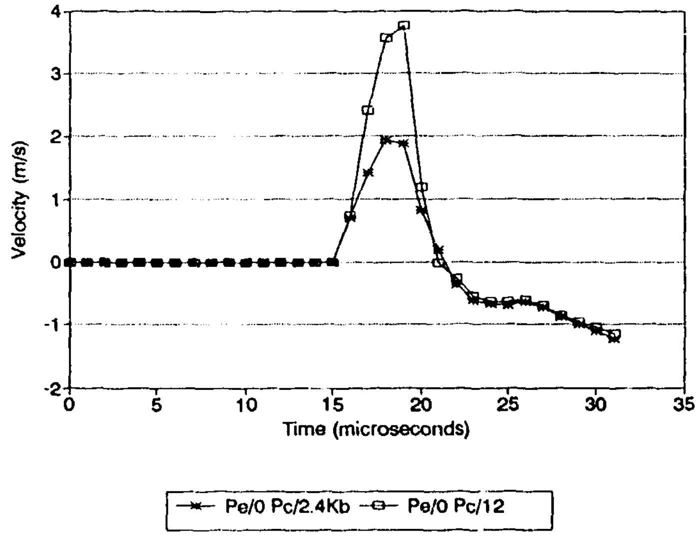


Figure 16. Comparisons of velocities at 65 mm when change[illegible] made in crush pressure with failure surface and [illegible] pressure parameters held constant. Weak laye[illegible] 50 mm.