Pre- and Post-Test Calculations for the Älvdalen 5000-kg Tests

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Abstract

In support of the 5000-kg test performed by the KLOTZ Club in the summer of 1989 at Älvdalen, Sweden, S-CUBED undertook a series of calculational simulations using our second-order hydrocode, SHARC. These simulations included a two-dimensional, rigid-wall calculation of the interior and two three-dimensional calculations of the exterior. Drag-sensitive particles were included in the interior calculation to simulate the steel-plate fragments and 155-mm shells used in the test as artificial debris. Cross-sectional area measurements from the tunnel interior were used to incorporate wall irregularities in the calculation corresponding to actual measurements.

Two versions of the exterior calculation were completed. One included the 7-m high berm in front of the tunnel exit; the other was done without the berm. Both of these included a representation of exterior terrain features. The exterior calculations were continued until the shock had traveled to a range of more than 100 m from the tunnel opening. Because the results of the pre-test calculations did not agree as well as had been expected with the experimental data, the interior calculation and a portion of the exterior calculation with berm were repeated after the test.

Results from these calculations are shown, and comparisons with experimental data are made where they are available. Suggestions are made which may improve calculational/experimental correspondence in the future.

1. Interior Calculations

The interior layout for the test simulated by the calculations reported here is shown in Figure 1. The tunnel complex consisted of an explosion chamber, Chamber A; an entrance tunnel; a "debris catcher"; and a side chamber, Chamber B. The tunnel was about 6 m wide; length dimensions

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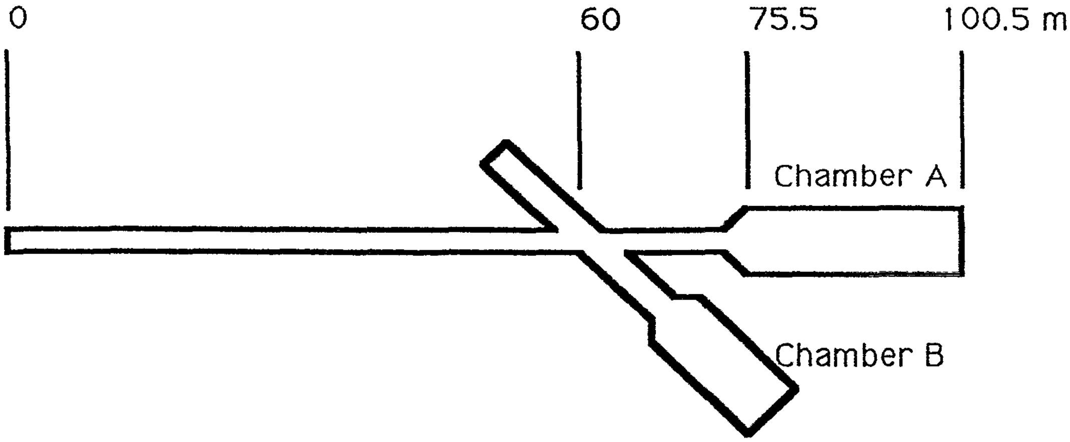


Figure 1. Internal Tunnel/Chamber Complex Layout

are shown in the figure. The test explosive consisted of 5000 kg of ammonium-nitrate/fuel-oil (AN/FO) in bags, stacked twelve high on a wooden pallet in Chamber A.

The interior calculation was set up to model the actual test configuration as closely as possible. From cross-sectional measurements of the chamber, a pattern of irregularities in the walls was defined to simulate the actual wall roughness. Because area measurements were available for only the back 5 m of Chamber A, this pattern was reflected end-for-end and across the centerline to provide a somewhat random distribution of wall roughness elements along the length of the chamber. The result for Chamber A is shown in Figure 2. This is a plan view; the calculation was two-dimensional, so a unit height for the entire internal configuration was taken at 2.3 m. The dotted lines in the figure indicate the locations of stations, at which calculated values of hydrodynamic parameters were saved as functions of time.

Figure 3 illustrates the calculational setup for the explosive charge and boxes of debris particles stacked in front of it. Because of the two-dimensional simulation, charge dimensions had to be altered somewhat in order to retain the appropriate total yield. The eight detonation point are shown, as are the initial locations of the debris particles, which were modeled as drag-sensitive massive spheres.

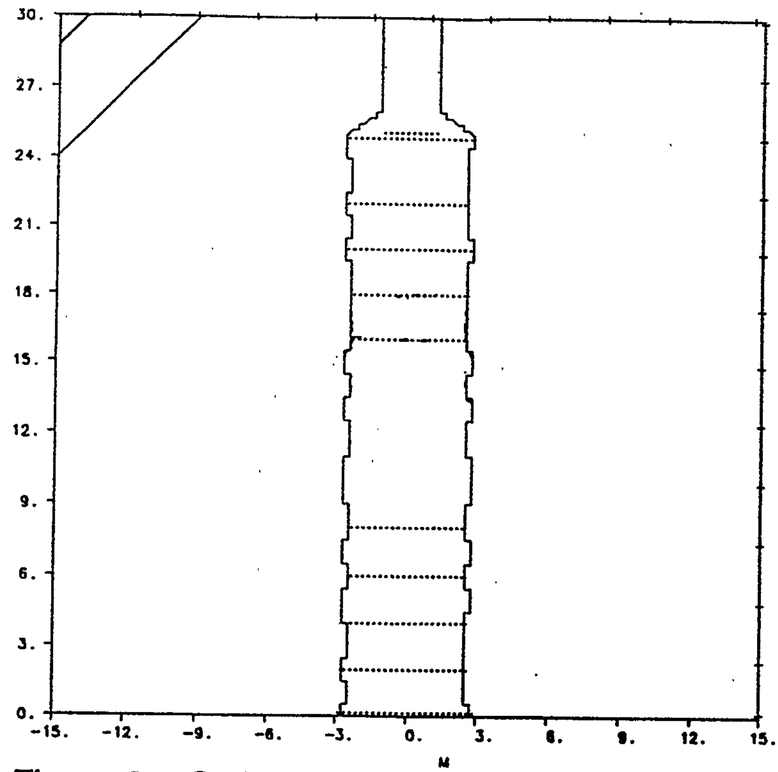


Figure 2. Outline of Chamber A in Calculation

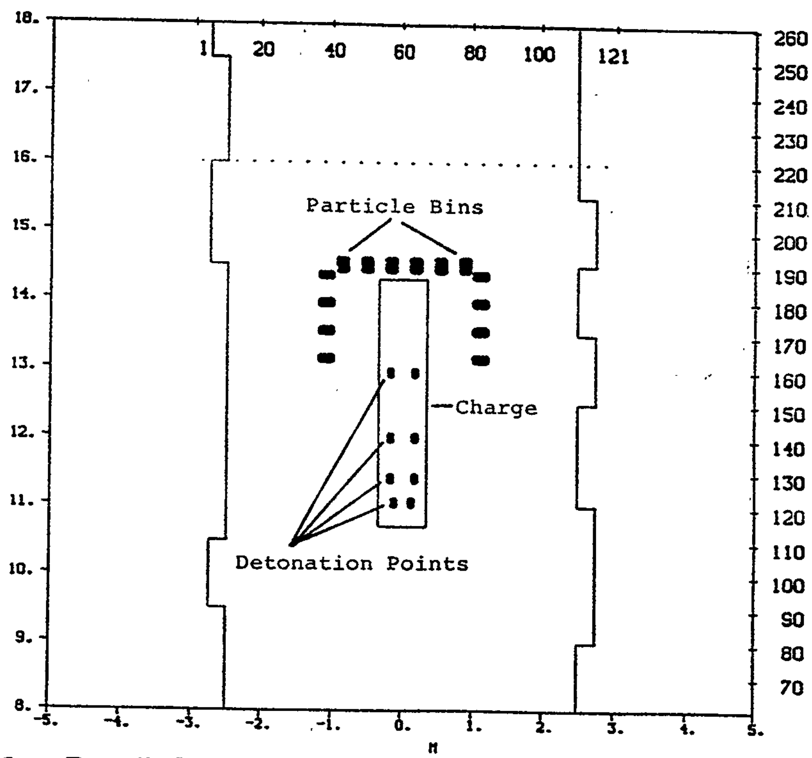


Figure 3. Detail Showing Charge as Simulated in Calculation

2. Exterior Calculations

For the exterior portion, the calculation was transferred to a three-dimensional mesh. Boundary conditions from the interior portion were fed in at a plane within the tunnel, 25 m back from the opening. The plan view and elevation sketch of Figure 4 illustrate the general configuration as it was defined for us. A long, triangular apron slopes downward from the mouth of the tunnel. Beyond the road, the slope is upward. On each side of the tunnel mouth, there are embankments formed by cutting away the mountain to build the portal. In Figure 5, details of the berm, which was placed in front of the mouth as a blast deflector and debris catcher for the 1989 shot, are shown. The berm was 7 m high, and consisted of a concrete facing wall filled in with dirt on the downslope side. As shown, the berm was 7 m from the tunnel opening.

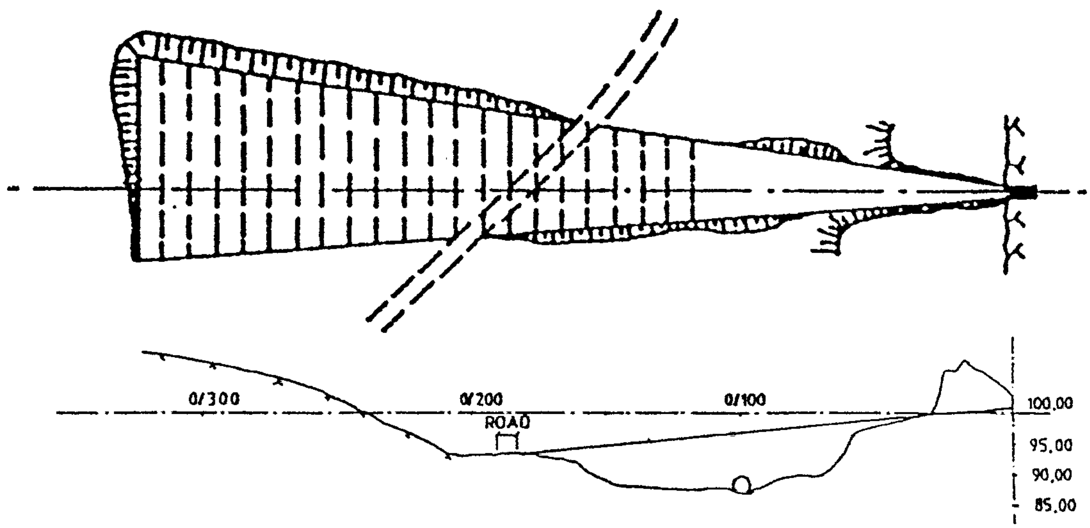


Figure 4. Exterior Plan View and Elevation Sketch

An earlier test event, in 1987, used essentially the same configuration without the berm. The embankments at the sides were carved away slightly to allow for placement of the berm. Figure 6 shows the configuration as modeled in the calculations. To save calculation time, only half of the test bed was modeled. A mirror image was assumed, reflected at the tunnel centerline. Figure 6 is the configuration without the berm. The tunnel opening (actually, half of the tunnel opening) can be seen at the back on the right. The berm configuration is identical except for placement of the berm in front of the tunnel opening.

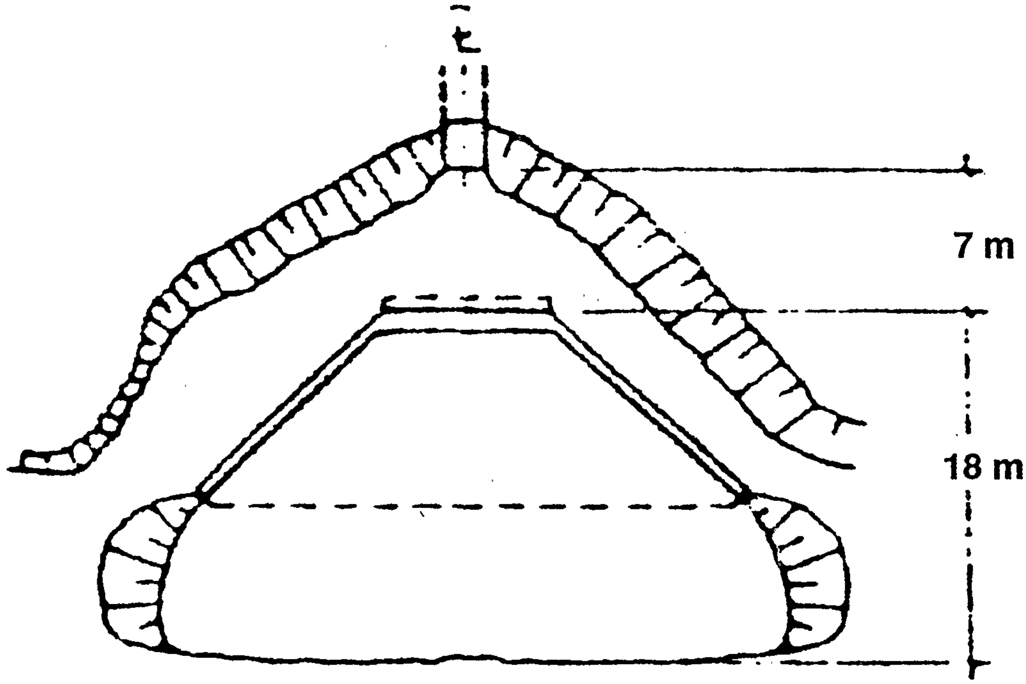


Figure 5. Exterior Detail and Berm

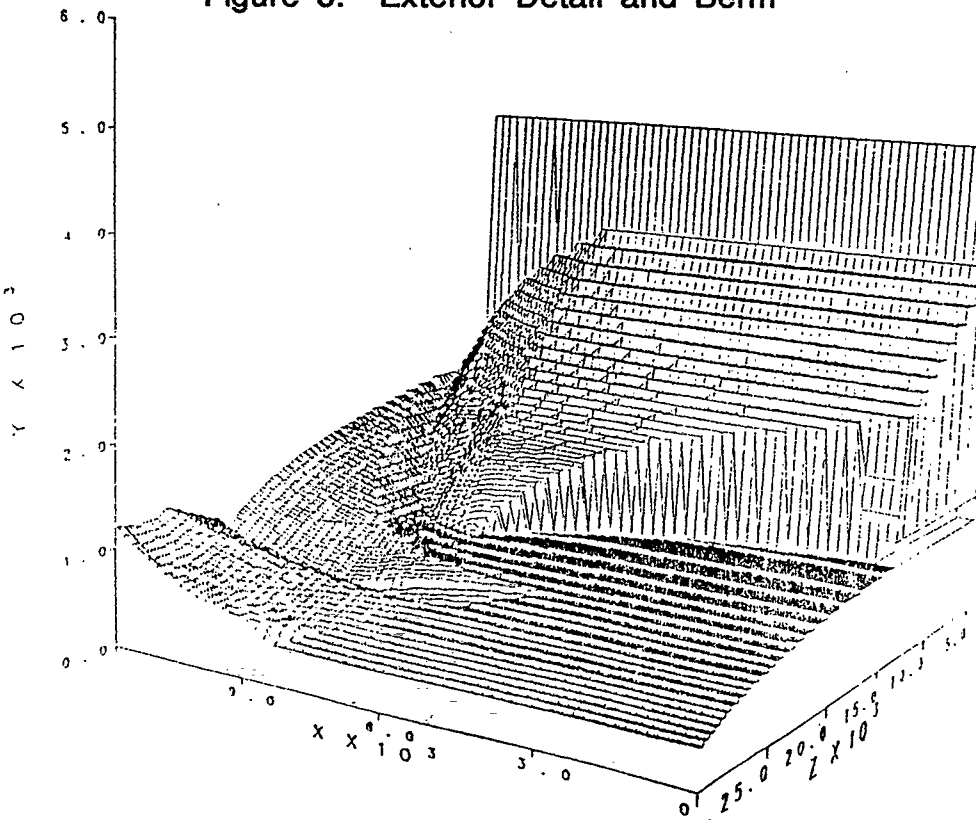


Figure 6. Terrain Plot Without Berm

3. Results

The results of the pre-test calculations were not in good agreement with the experimental data, so they are not presented here. They are documented in our report on the subject*. Figure 7, which was prepared by Dr. John Dewey for his report on the smoke-puff photography for the test, illustrates these results. Maximum overpressure amplitudes predicted by the calculations were in some cases as much as an order of magnitude above those observed. Because of this, we looked very carefully at the calculations in order to determine the cause of the discrepancy. Previous

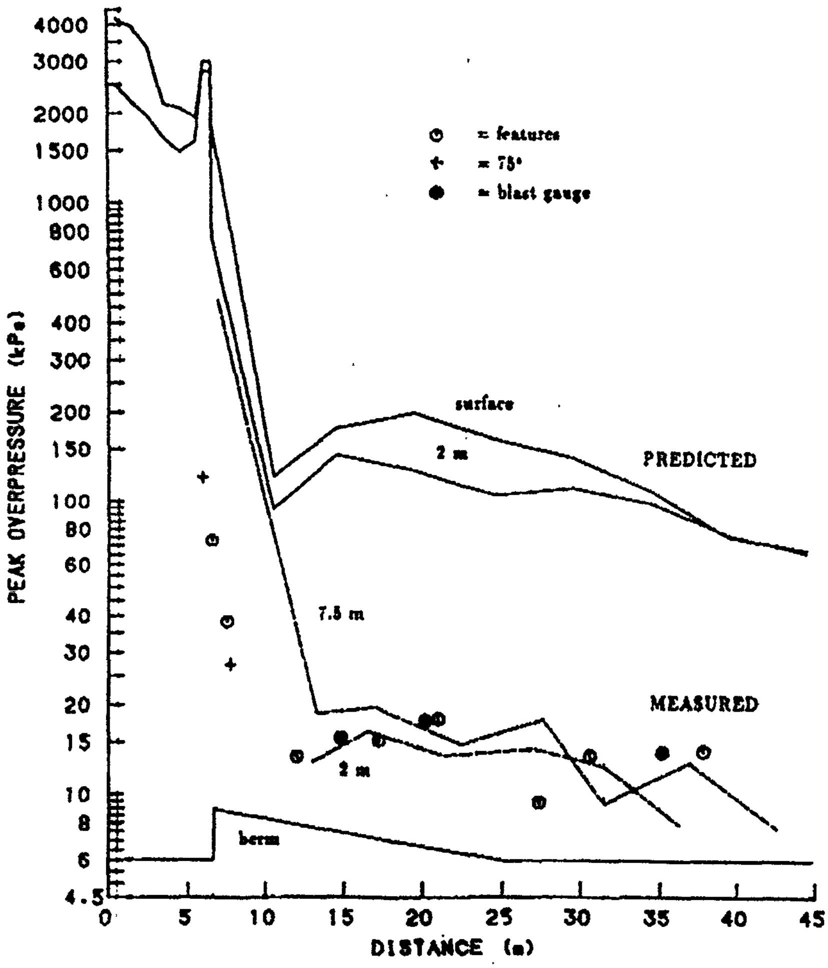


Figure 7. Comparison of Pre-Test Calculational Results with Experimental Peak Overpressures, as Functions of Range

* L.W. Kennedy, K.D. Schneider, and J.E. Crepeau, "Prediction Calculations for KLOTZ Club Tests in Sweden," S-CUBED Report SSS-TR-89-11049, December 1989.

experience with our hydrocode made us certain that the basic calculational method was sound, but there were possibilities about the modeling assumptions that could be reviewed.

No serious mistakes were found in the way the calculations had been set up. We did find two areas where we had misinterpreted the information that was provided. First, we had understood that the volume of Chamber B, the side tunnel expansion chamber, was 126 m^3. In actuality, it was 223 m^3. Also, the total mass of the steel debris particles was 4992 kg, not 546 kg as we had thought. This latter misunderstanding occurred because the provided figures referred to numbers of kg of particles, rather than to numbers of particles.

Neither of these changes had large effects on the calculational results. What did make a difference was a revision we incorporated after talking with John Dewey and Charles Needham, experts who have been involved in high-explosive testing, and specifically in testing with AN/FO, for many years. They pointed out that, because AN/FO is a non-ideal explosive, it is difficult to get it to detonate completely in an unconfined configuration. The shock front in an AN/FO detonation may run 10 to 15 cm ahead of complete energy release, so that when this shock wave reaches the outer surface, it reflects as a tensile wave, causing the outer portion of the AN/FO to separate from the rest of the charge without detonating. Additional degradation can occur in non-spherical explosives if the shock reaches one free surface earlier than it reaches other free surfaces, as would occur with the rectangular shape and multiple detonation points for this test.

Based on this information, we deleted 8 cm of explosive from all free surfaces of the charge except the bottom (which was confined by the wooden pallet). The undetonated explosive could burn later, when exposed to the hot gases of the detonation products, but its energy would not contribute to the shock wave. The net result of this was that only 68%, or 3400 kg, of the AN/FO was retained for the post-test calculations. This change, as might be expected, had a significant effect on the results.

4. Results of Post-Test Calculation

Results of the post-test calculation are shown in the following figures. Figure 8 is a calculated overpressure waveform compared with an experimental record from inside the tunnel. It is from a point on the floor 25 m back from the portal. As can be seen, the correspondence is reasonable although not exact. Peak values at the wavefront are about the same, as are levels behind the front. Individual spikes can be attributed to differences in placement or sizes of irregularities on the tunnel walls. This leads to the conclusion that the interior and the AN /FO yield are being treated approximately as tested.

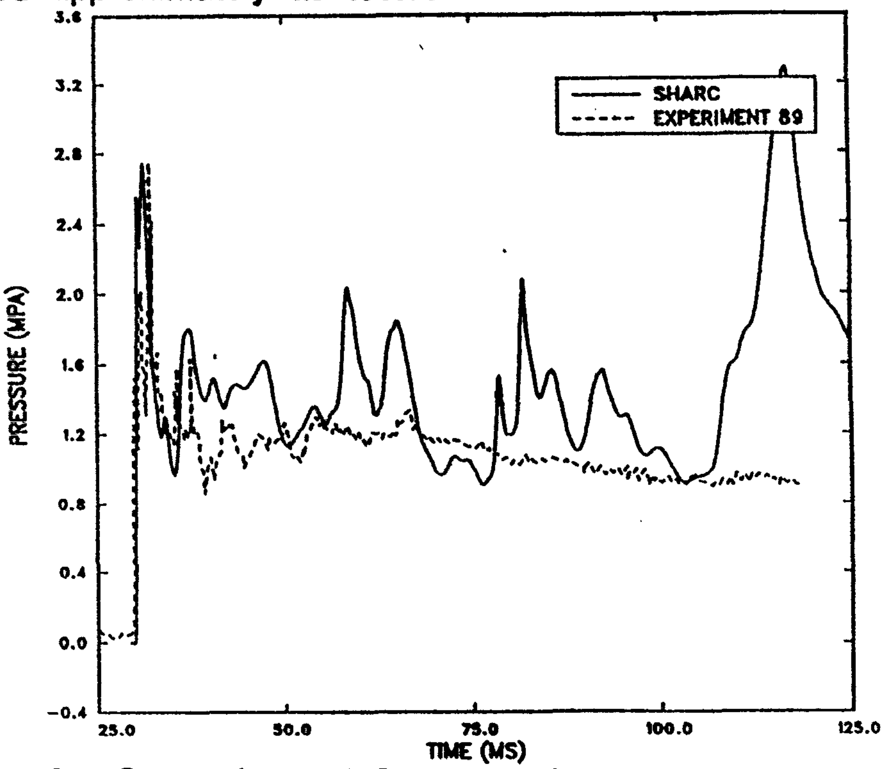


Figure 8. Comparison of Post-Test Calculation with Experimental Overpressure Record, 25 m Inside Entrance Tunnel

A different story emerges for the exterior. At the base of the berm (Figure 9), the calculated waveform appears to be high, both near the wavefront and behind it. At the top of the berm (Figure 10), there are similarities in the waveforms, but the calculated peak value is still high by a factor or two. A more definitive comparison appears in Figure 11, in which smoke puff displacement/time data is compared with a massless

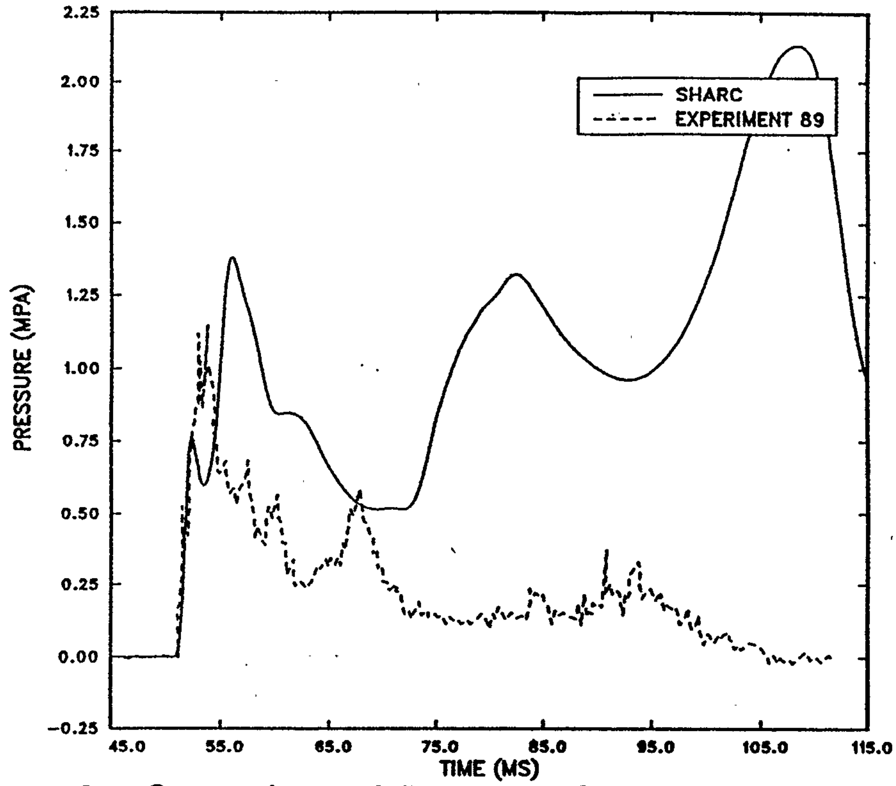


Figure 9. Comparison of Post-Test Calculation with Experimental Overpressure Record, at Base of Berm

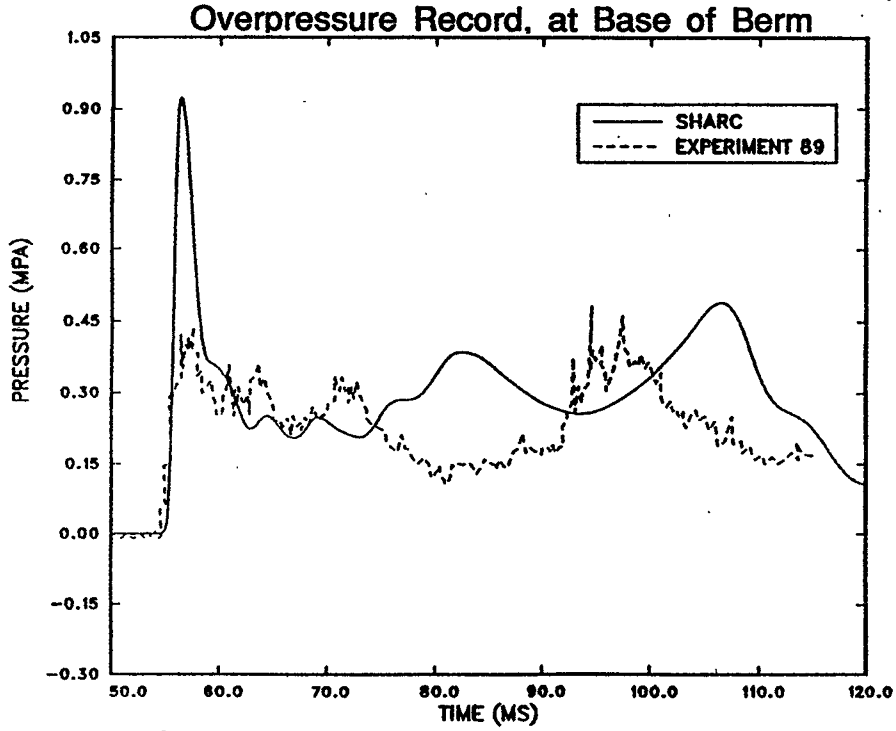


Figure 10. Comparison of Post-Test Calculation with Experimental Overpressure Record, at Top of Berm

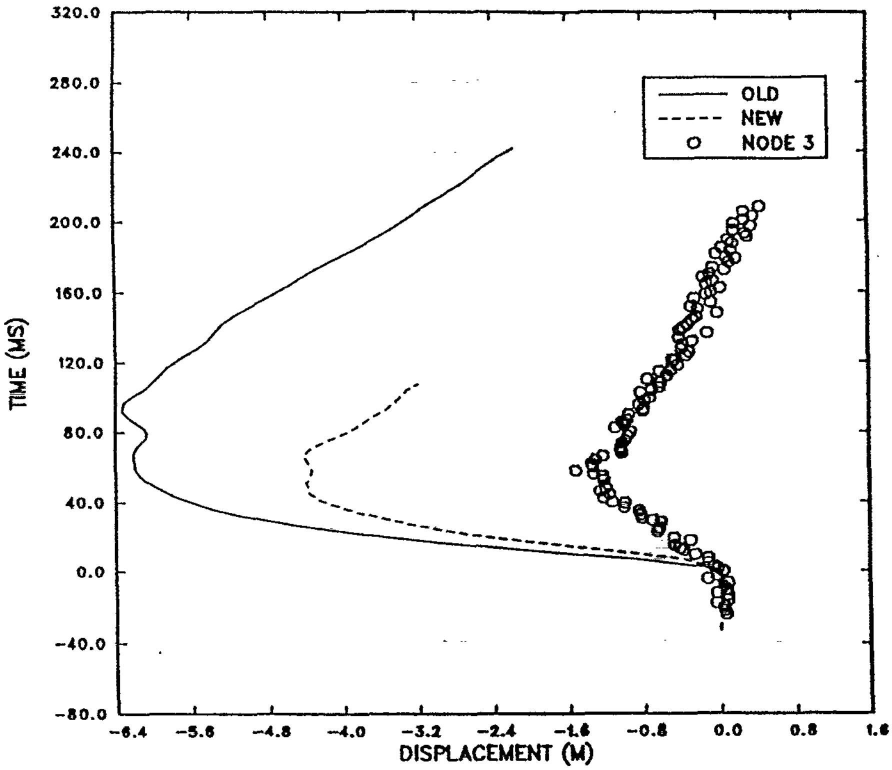


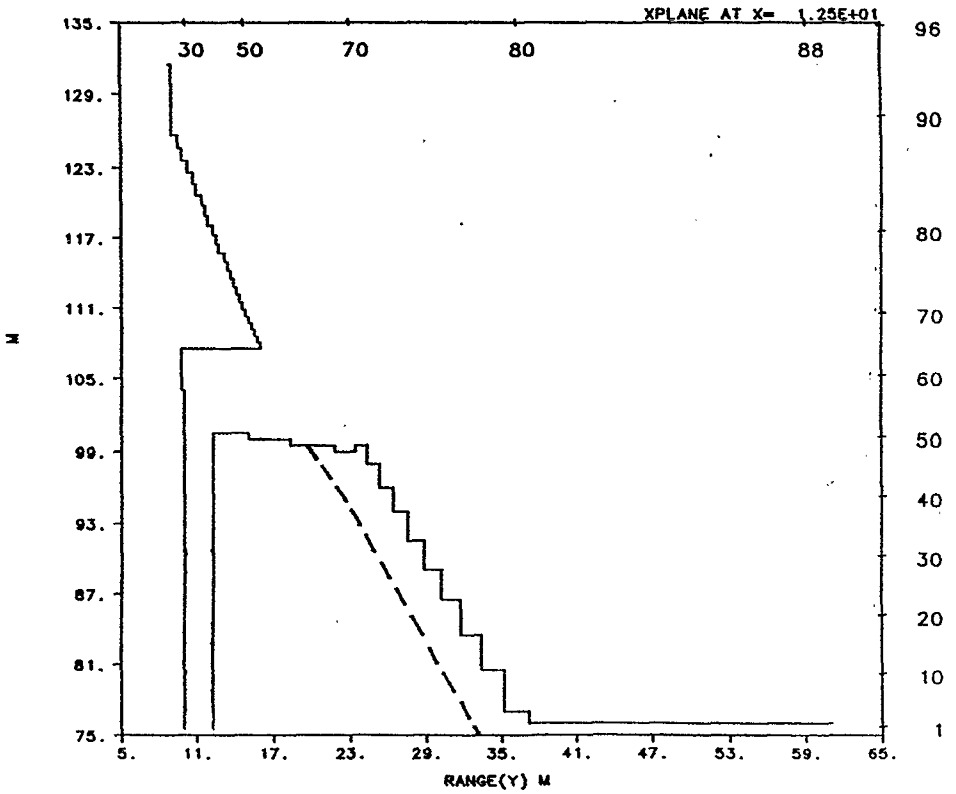
Figure 11. Comparison of Tracer Particle Record with Trajectory of Smoke Puff Node, 17 m from Portal over Berm

tracer particle trajectory from the calculation. The tracer particles were originally placed at locations corresponding to those for smoke-puff deployment. In the figure, which is an example from a node at 17 m from the portal over the berm, the circles are the experimental data, the solid line is the pre-test calculation, and the dotted line is the post-test calculation.

5. Possible Reasons for the Discrepancy

There are several possible reasons that can be cited as to why these differences between calculations and experiment occurred. First, it is possible that the detonation was even less complete than the 68% assumed, so that the effective yield of the explosive charge was less than 3000 kg. Second, the rigid walls and two-dimensional configuration of the calculation may not adequately model the physical response of the tunnel interior. We did find that in the larger China Lake test, in which the tunnel complex was destroyed, some energy was absorbed in the walls and overburden, so that these materials needed to be treated with a real equation-of-state. Both of these reasons, however, would be expected to affect the interior results as well as the exterior, whereas our interior results were in fairly good agreement with the data.

A third possibility involves modeling of the terrain in the immediate vicinity of the portal. If the space available for expansion of the shock into the exterior is not modeled correctly, it could influence the channeling of that shockwave and hence its magnitude at important measuring points. The last two figures, Figures 12 and 13, illustrate what this means. The first, Figure 12, is an x-plane plot of the tunnel, berm, and overburden. This plane is vertical and runs along the centerline of the tunnel. The overburden is shown to be high and massive. But the actual profile of the ground over the portal was more like that shown by the dashed line, so that more space was available into which the emerging shock could expand. Figure 13 is a z-plane plot, again vertical but this time perpendicular to the tunnel centerline. At 8 meters from the portal,



SHARC ALVDALEN TEST EXTERIOR WITH BERM JUN 90 (KEN)

Figure 12. X-Plane Plot of Berm and Overburden, Showing Uncertainty of Configuration Profile

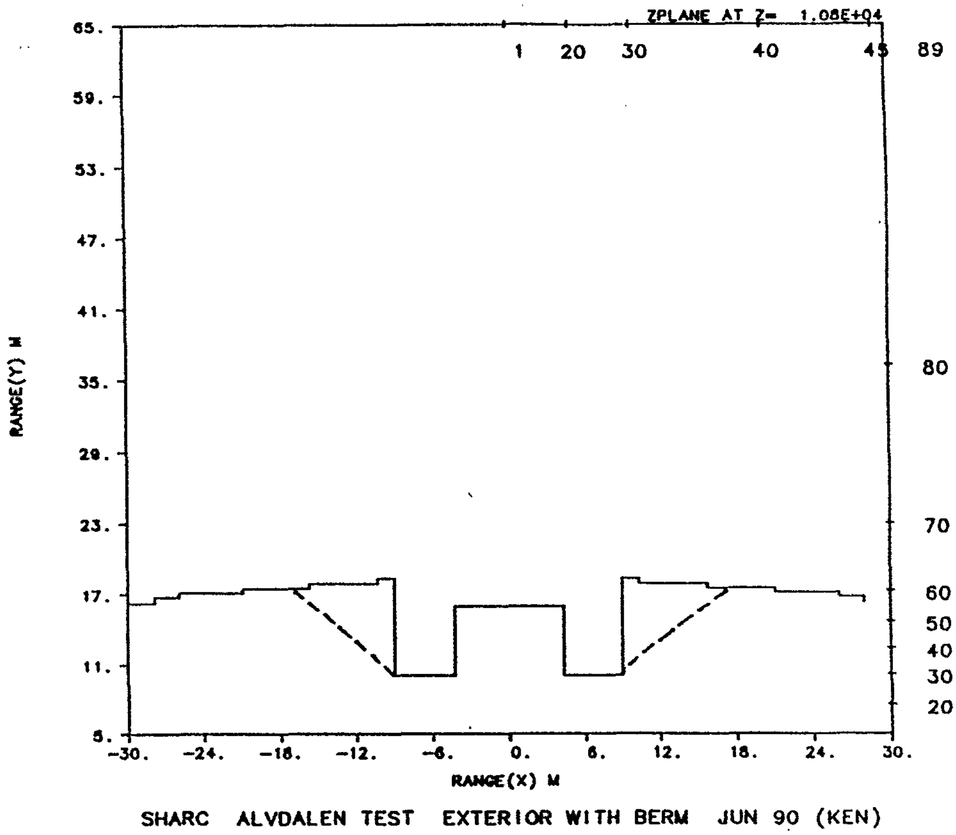


Figure 13. Z-Plane Plot Through Berm and Side Embankments, Showing Uncertainty of Slope

this plane passes through the front part of the berm and through the embankments on each side. These banks were more sloped than was modeled by the calculation, as shown by the dashed lines, and thus there was a significant difference in the space available for the expanding shock wave. We did not model the contours of these features carefully because we did not recognize their importance at the time the calculations were set up. Improvements could be made in this area which would enhance the ability of calculations to produce accurate predictions for test configurations.