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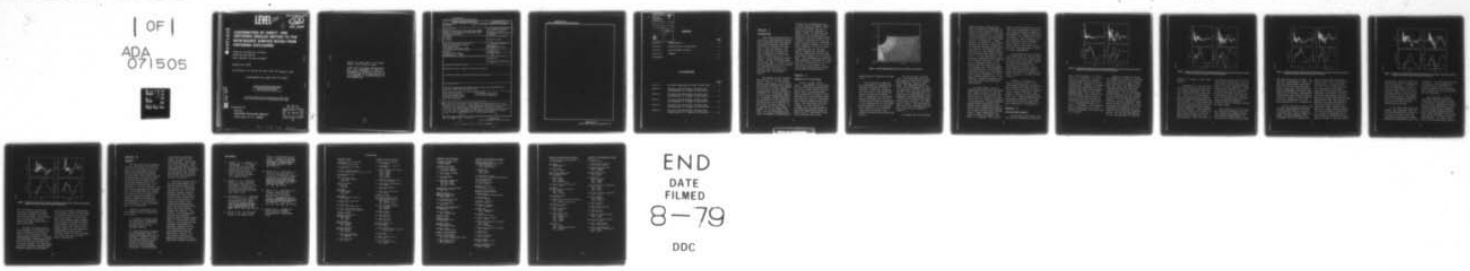

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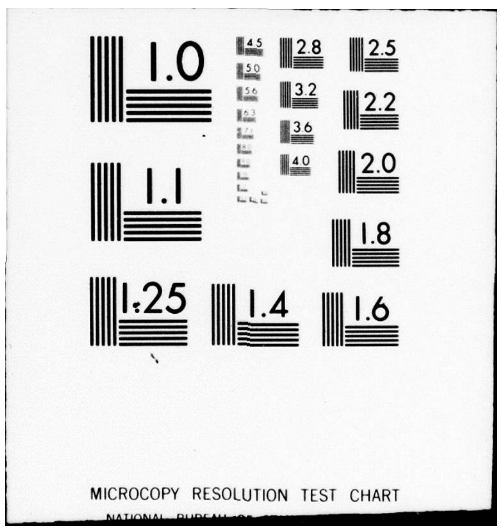
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CONTRIBUTION OF DIRECT- AND CRATERING-INDUCED MOTION TO THE NEAR-SOURCE SURFACE WAVES FROM CRATERING EXPLOSIONS

Physics International Company
2700 Merced Street
San Leandro, California 94577

September 1978

Final Report for Period 18 April 1977—31 August 1978

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

The results of calculation of the cratering and ground motion for a 5-Mt nuclear surface burst over a layered geology are described. This calculation included a full description of the energy source and thus the direct-, cratering- and airblast-induced ground motion. The calculation was performed to a real time of 2.1 seconds, and the ground motion waveforms for scaled ranges as small as 6V1/3 exhibited a distinct Rayleigh wave.

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ILLUSTRATIONS

Section 1

INTRODUCTION

The origin and character of late-time, low-frequency ground motion observed near the source from large surface explosions has been of interest for some time. This motion has often been termed the "ground roll" and is observed at ranges at least as small as 5 to 6 $V^{1/3}$, where V is the explosion crater volume. Recent investigations have shown that, at least for the several explosion events studied, the characteristics of the "ground roll" are those of a Rayleigh wave (References 1 and 2).

The origin of this surface wave motion is not well understood. That is, it is not well established whether this surface wave motion is solely the result of the action of the outward propagating airblast (airblast-induced), or the energy coupled to the ground immediately below the explosion (direct-induced), or the motion of the ground associated with the formation of the crater (crater-induced), or a combination of these mechanisms. It is well known, however, that the propagating airblast is capable of generating a surface wave (References 3-6). A recent study by Murphy (Reference 2) has shown that for at least one specific geology, a desert playa, the Rayleigh wave portion of the surface motion observed from the Pre-Mine Throw IV-Event 6 explosion can be calculated theoretically, assuming only airblast loading of the surface. However, it is not clear in general, and for all geologies, whether the airblast is the only mechanism contributing significant energy to the surface wave. The investigation reported here addresses the question of the relative contribution to the surface wave of the direct- and cratering-induced motion versus the airblast-induced motion.

Section 2

DESCRIPTION OF CALCULATION

Orphal, et al. (Reference 1), performed a calculation of the cratering and ground motion for a 5-Mt nuclear surface burst over a layered geology. This calculation included a full description of the energy source and thus the direct-, cratering- and airblast-induced ground motion. The calculation was performed to a real time of 2.1 seconds, and the ground motion waveforms for scaled ranges as small as $6V^{1/3}$ exhibited a distinct Rayleigh wave with a

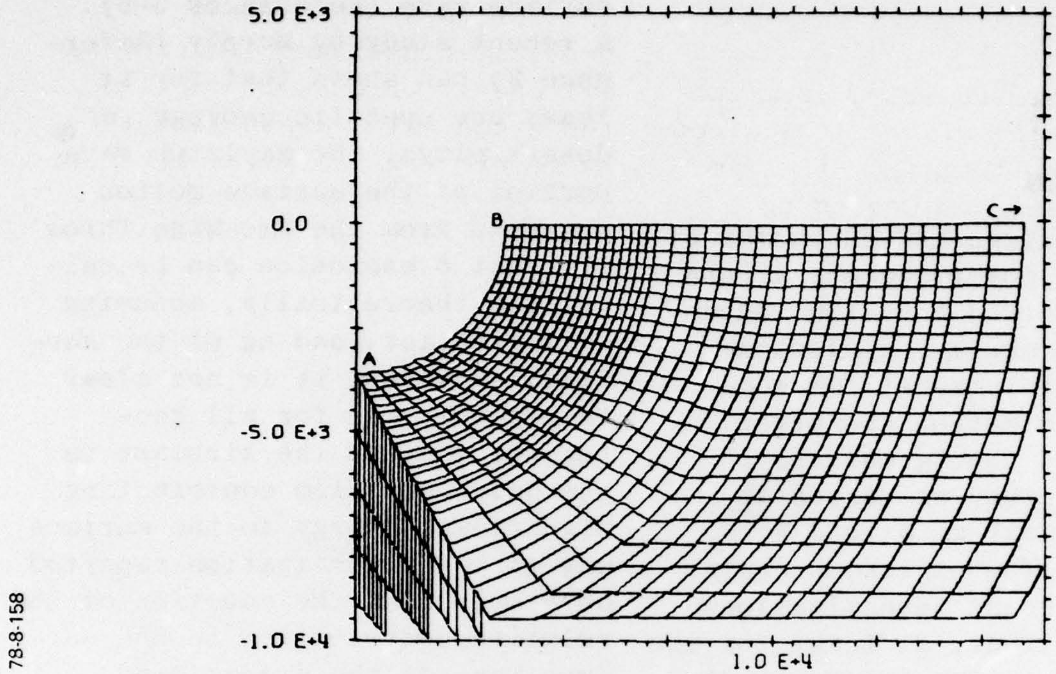

Figure 1 *Original Lagrange grid near ground zero (distances in centimeters).*

characteristic frequency of about 1 Hz.

The calculation reported here consisted of repeating the previous calculation cited in Reference 1 with the exception that the direct- and cratering-induced energy was deleted. Thus a comparison of the ground motion waveforms from the two calculations allows an assessment of the contribution of the propagating airblast to the surface wave relative to the contributions from the direct- and cratering-induced motion near the source.

The calculation of Reference 1 was performed using the ELK computer code and a coupled Euler-Lagrange computational grid. The Lagrange portion of this grid was designed for ease of computation of the developing crater. This Lagrange grid incorporated a hemispherical Euler-Lagrange coupling boundary with a radius of 36 meters and essentially polar zoning in the near-source region. The near-source portion of the Lagrange grid for this calculation is shown in Figure 1.

To ensure that the calculational results reported here would be directly comparable to those results reported from the previous calculation, it was considered important that the same finite-difference zoning be used in both calculations. Consequently, although it was neither optimum nor typical zoning for an airblast-induced ground motion calculation, the computational grid used in the current calculation was also that shown in Figure 1. In the calculation, the airblast loading function applied at the point labeled B in Figure 1 (original radius of 36 meters) was also applied along the boundary AB. The mathematical description of the airblast loading function was that reported by Brode (Reference 7) for a 5-Mt nuclear surface burst. The identical airblast loading function was used in the previous calculation.

As noted above, use of a computational grid with the geometry shown in Figure 1 and the initiation of the airblast loading at R=36 m instead of at the origin were not normal procedures in performing an airblast-induced ground motion calculation but, rather, were compromises made to allow direct comparisons between the current and previous calculations. These compromises did have one positive aspect, however: to "define," for the purpose of this calculation, direct- and cratering-induced energy as all energy originally coupled to the ground at ranges less than 36 meters for a 5-Mt nuclear surface burst. This "definition" was arbitrary and no argument will be made to justify it, other than to note that while it may have been arbitrary, it was at least unambiguous.

The geology for the present calculation was the same as that used in the previous calculation and consisted of multiple layers of shales and sandstones. A detailed description of the stratigraphy, physical properties, and constitutive models used to describe the geology and earth materials is given in Reference 1.

Finally, to extend the finite-difference grid to the long ranges necessary to achieve the objectives of the calculation, it was necessary to periodically "dezone" the grid, add zones to the end of the current grid, etc. These procedures were performed identically for both calculations and are described more completely in Reference 1.

Section 3

CALCULATIONAL RESULTS

As was noted previously, the full-source calculation of Refer-

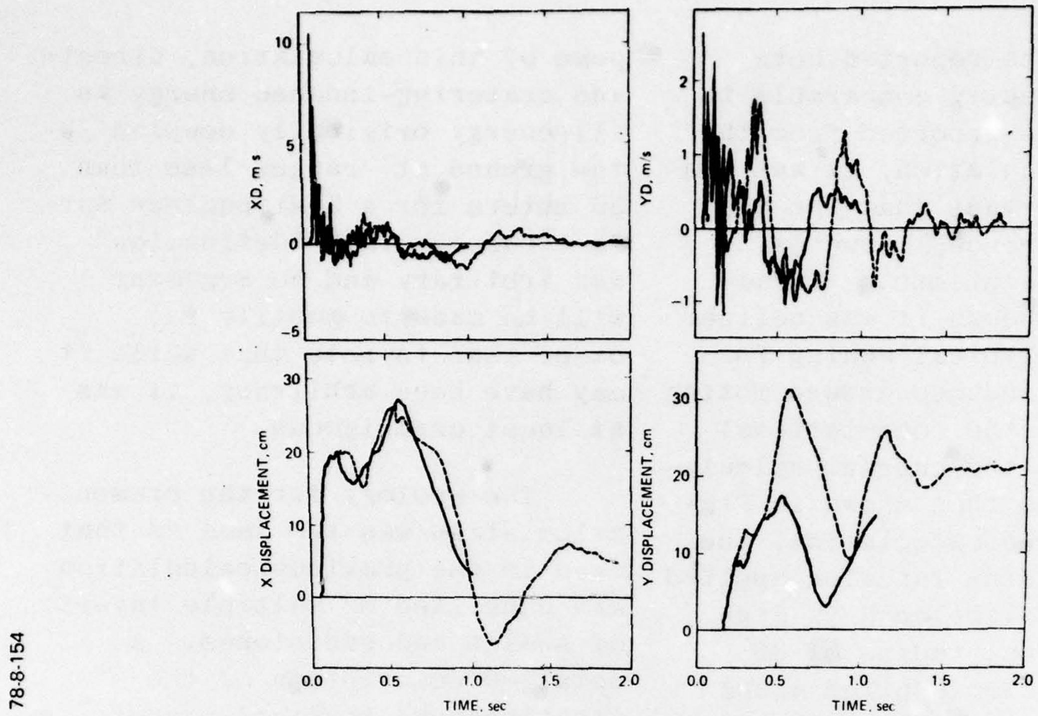

Figure 2 *Vertical (X) and horizontal (Y) velocity and displacement at a range of* 550 *meters (solid line, airblast-only calculation; dashed line, full-source calculation).*

ence 1 was performed to a real time of 2.1 seconds. It was the intent to perform the current, airblast-only calculation to 2.1 seconds also. However, technical difficulties prevented the coupling of the LEEK linear-elastic computational grid to the ELK-Lagrange grid. This had the effect of shortening the time of arrival at the free surface of reflected waves from the bottom of the computational grid to about 1.1 seconds. The airblast-only calculation was only performed, therefore, to a real time of 1 second.

Figures 2 through 6 display the computed vertical and horizontal ground velocity and displacement histories at ranges of 550, 800, 900, 1220, and 1400 meters from ground zero for both the airblast-only and full-source calculations. All of the ground motion histories are for a depth of 15.2 meters below the ground surface. In the figures, XD is vertical velocity (positive downward) and YD is horizontal velocity (positive outward), with corresponding orientations for the vertical and horizontal displacements. For the geology modeled in the calculations, outrunning

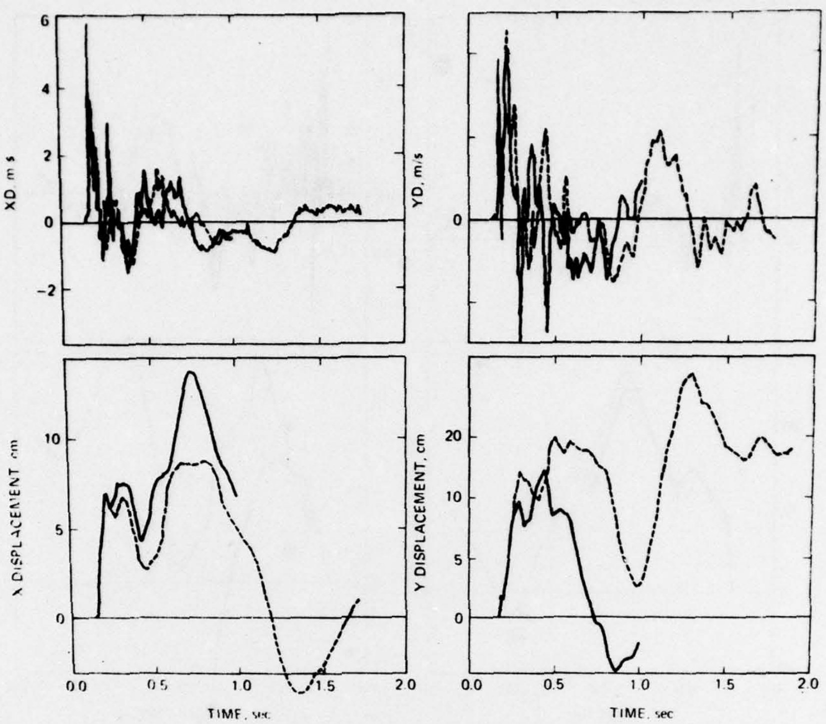

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Figure 3 *Vertical (X) and horizontal (Y) velocity and displacement at a range of 800 meters (solid line, airblast-only calculation; dashed line, full-source calculation).*

begins at a range of about 1200 meters.

Examination of the vertical velocity histories reveals that the overall waveforms from the two calculations were very similar. This is to be expected--since the near-surface vertical ground velocity was dominated by the airblast. At early-times the vertical velocity histories from the two calculations are essentially identical. Peak downward velocity, which is the result of the initial arrival of the airblast, was the same for both calculations. With the onset of the direct-induced motion in the full-source calculation, the results from the two calculations begin to differ somewhat. These differences, however, were relatively minor and the vertical velocity waveforms from the two calculations were very similar, with the airblast-only calculations exhibiting perhaps a slightly higher frequency content at later-times.

The similarity of the vertical velocity waveforms from the two calculations suggests that the vertical displacement histories will be very similar also,

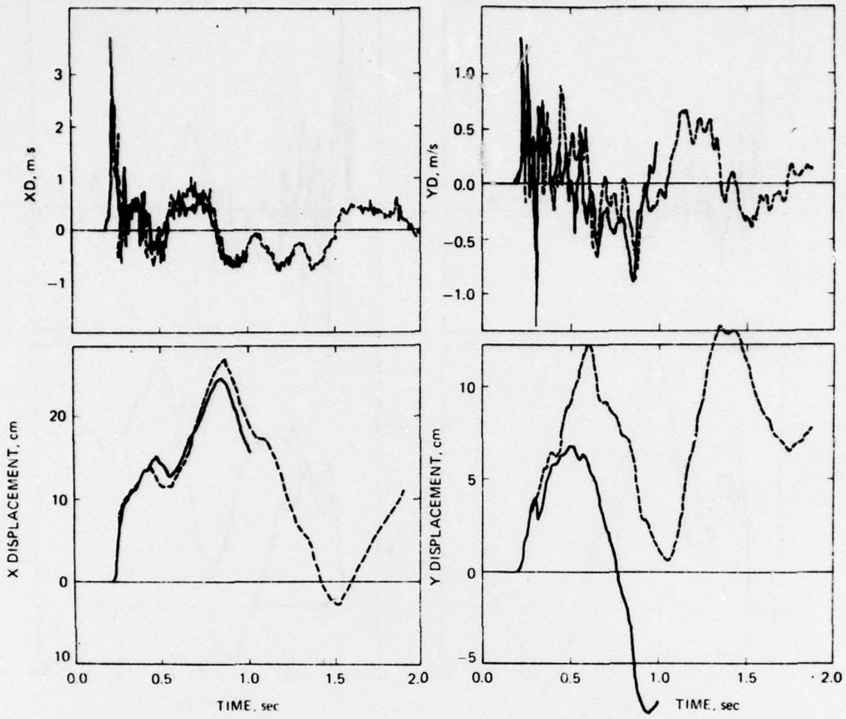

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Figure 4 *Vertical (X) and horizontal (Y) velocity and displacement at a range of 900 meters (solid line, airblast-only calculation; dashed line, full-source calculation).*

and indeed this was the case. At the 550- and 900-meter range, the vertical displacement waveforms from the two calculations were nearly identical, with peak downward displacements differing only about 4 or 5 percent; peak upward displacement was achieved after a time of 1 second at this range so no direct comparison could be made between the two calculations.

On the other hand, while the vertical displacement waveforms at 800 meters from the two calculations had a nearly identical shape, the peak downward displacement for the airblast-only case was more than 50 percent higher than for the full-source calculation: 27.5 cm versus 17.5 cm. This illustrates well the importance of the time-phasing of individual arrivals. Examining the vertical velocity history at 800 meters, one can see that between about 400 ms and 800 ms there were two distinct downward velocity excursions on the time-history for the airblast-only case, whereas there was only a single such excursion for the full-source calculation. This result is probably due to the arrival of refracted direct-induced energy in the full-source

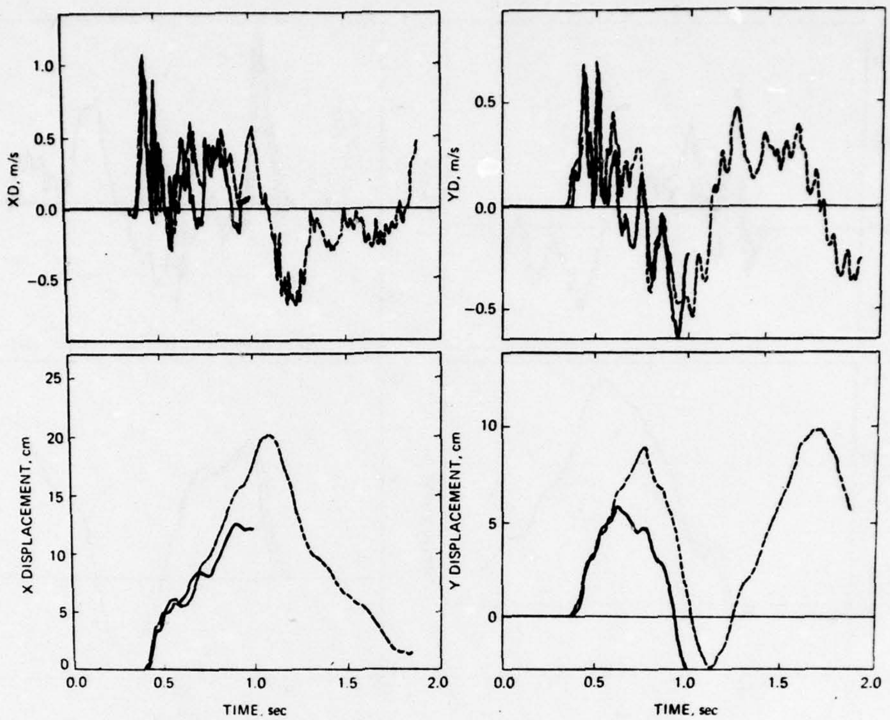

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Figure 5 *Vertical (X) and horizontal (Y) velocity and displacement at a range of* 1220 *meters (solid line, airblast-only calculation; dashed line, full-source calculation).*

calculation, although there are insufficient data to demonstrate this conclusively. A direct-induced compressional wave, refracted along one of the deep geologic layers, returns to the surface with an initial upward and outward motion, retarding some of the downward motion associated with the airblast-induced ground motion.

At the 1220- and 1400-meter ranges, the waveforms from the two calculations were similar to a time of 1-second, with the full-source case having higher downward displacements after 700 to 800 ms. The peak downward displacement at these ranges was achieved after 1-second so a direct comparison of this parameter between the two calculations was not possible.

The horizontal velocity histories from the two calculations were very similar in overall waveform. Maximum horizontal velocity occurred shortly after first arrival and was dominated by the airblast-induced motion. Thus, peak horizontal velocities were nearly the same for the two calculations. At later times, while the waveforms were similar,

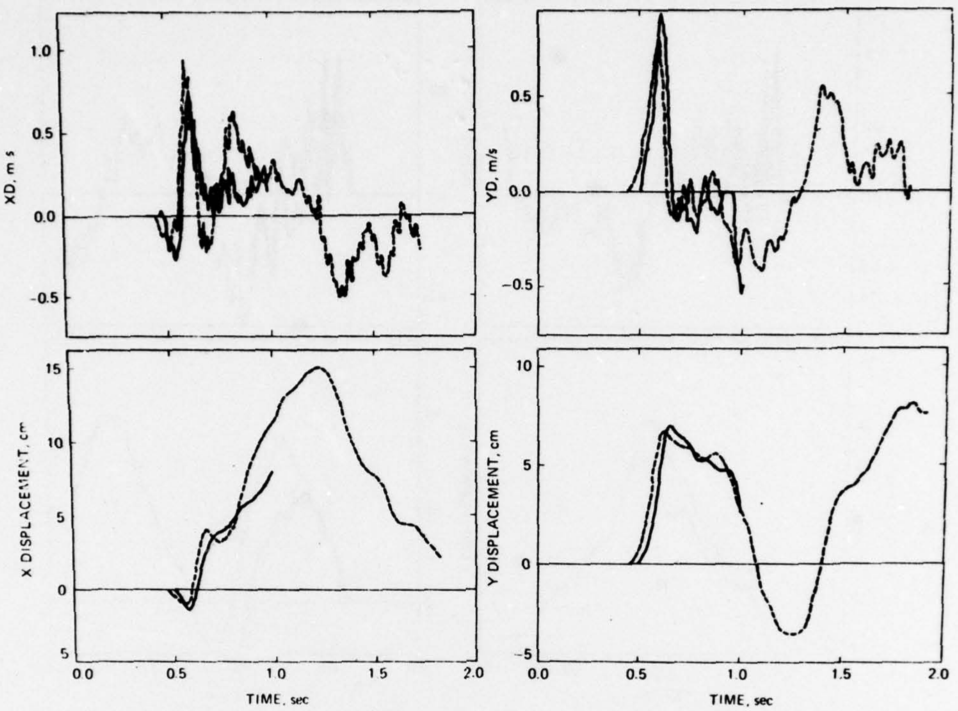

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Figure 6 *Vertical (X) and horizontal (Y) velocity and displacement at a range of* 1400 *meters (solid-line, airblast-only calculation; dashed line, full-source calculation).*

the full-source calculation resulted in generally higher amplitude outward velocities. On the other hand, the airblast-only calculation generally exhibited higher amplitude inward velocities.

The most striking differences between the airblast-only and full-source calculations were in the horizontal ground displacement histories. Although the horizontal displacement waveforms for the two calculations were very similar, the amplitudes generally differed substantially. Maximum outward displacements for the full-source calculation were nearly a factor of two higher than calculated for the airblast-only case. On the other hand, the airblast-only calculation resulted in greater inward displacements than for the full-source case. The overall frequency content of the horizontal displacement histories was slightly higher for the airblast-only case than for the full-source calculation.

Section 4

SUMMARY

The calculation and analyses reported here were initiated as part of an investigation of the origin of near-source surface waves from surface explosions. In particular, effort was focused on evaluating the relative contribution of the direct- and cratering-induced motion to the near-source surface wave, as compared to the contribution from the outward propagating airblast. The two calculations that formed the basis of this analysis involved a specific geology of layered shales and sandstones. Extrapolation of the results of this analysis to other geologies may not be warranted.

Specific conclusions from this analysis may be summarized as follows:

1. Airblast loading alone was sufficient to generate a near source ($R/V^{1/3} \approx 6$) Rayleigh wave for the geology studied.

2. Vertical ground velocity and displacement near the surface was dominated by the airblast. However, direct- and cratering-motion do influence the surface-wave portion of the vertical velocity and displacement histories. This influence is generally relatively minor, at least to the times studied. Peak vertical velocities are controlled by the airblast. However, maximum vertical displacements may be influenced by the direct- and cratering-induced motion, depending on the time phasing of discrete arrivals.

3. Horizontal ground velocity and displacement were significantly affected by the direct- and cratering-induced motion. For this geology, maximum outward displacements were about a factor of two greater for the calculation that includes the direct- and cratering-induced motion than for the calculation in which this near-source energy was omitted. Conversely, the airblast-only calculation exhibited greater inward displacements than the full-source calculation. The horizontal displacement waveforms were generally similar for the two calculations as were the horizontal velocity waveforms. However, the full-source calculation generally exhibited higher amplitude outward velocities.

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