CALCULATION OF SOIL MOTION FROM CONTAINED EXPLOSIVE ARRAYS

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SUMMARY

Finite element calculations show that soil motion from contained explosive arrays can be predicted with good accuracy. This theory allows calculation of the complete motion throughout the entire test bed and hence detailed design of soil and soil-structure tests. The theory also allows extrapolation to other soil sites and design of arrays to reproduce specified soil motion.

INTRODUCTION

Contained explosive arrays consist of a series of vertical line sources placed in the soil to form a planar array. The vertical line sources are rubber tubes, which act as bladders, containing steel canisters charged with explosive. The canisters release the explosive gases at a controlled rate into the rubber bladders, which expand to move the soil. The resulting soil stresses are low enough that the test area is placed only a short distance from the array. Experiments with a 10-m-long array of 10 sources and a 24-m-long array of 8 larger sources are reported in Refs. 1 and 2, respectively. Reference 1 also includes a quasi-static theory to calculate the average soil stress (at a short distance from the array) produced by the radial pressures in the individual sources, and the resulting displacement field in the soil with this stress assumed to act on a slit in an infinite solid. The theory was extended in Ref. 2 to include displacement enhancement by means of trenches placed on the far side of the test area. The present paper gives a dynamic theory to predict the complete time histories of motion throughout the test bed.

MATHEMATICAL MODEL

Figure 1 shows the two-dimensional finite element mesh used in the calculations. It is a vertical section through the array, test area, and a region extending far enough that the silent boundaries have no

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effect on the results. The finite length of the array out of the paper is not taken into account by this model, but the finite depth is. The dots labeled 1 through 5 and the associated arrows are the locations and directions of motion that were output for comparison with experimental results.

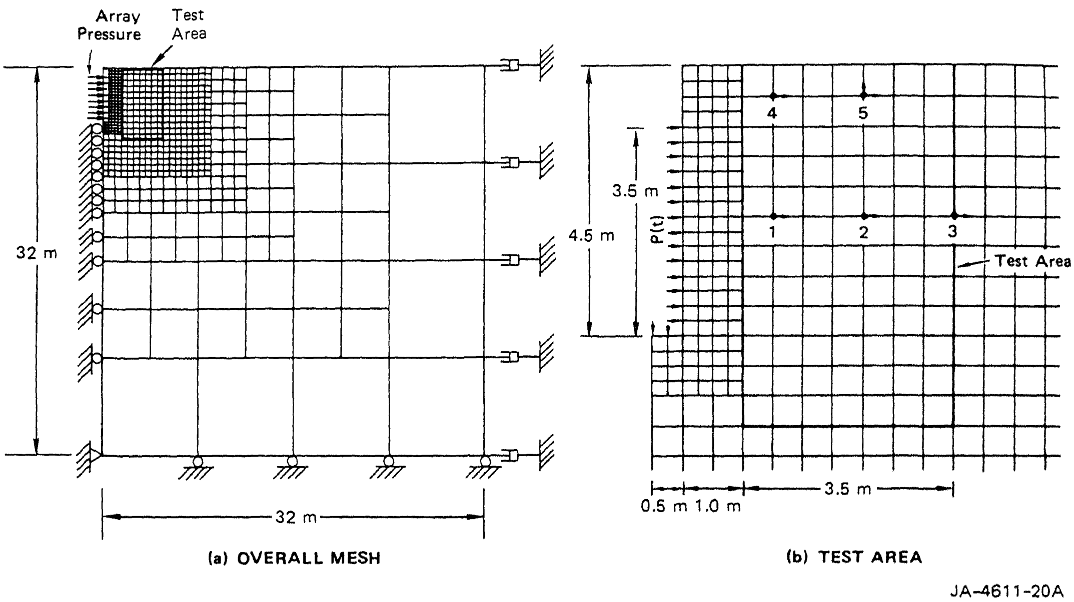
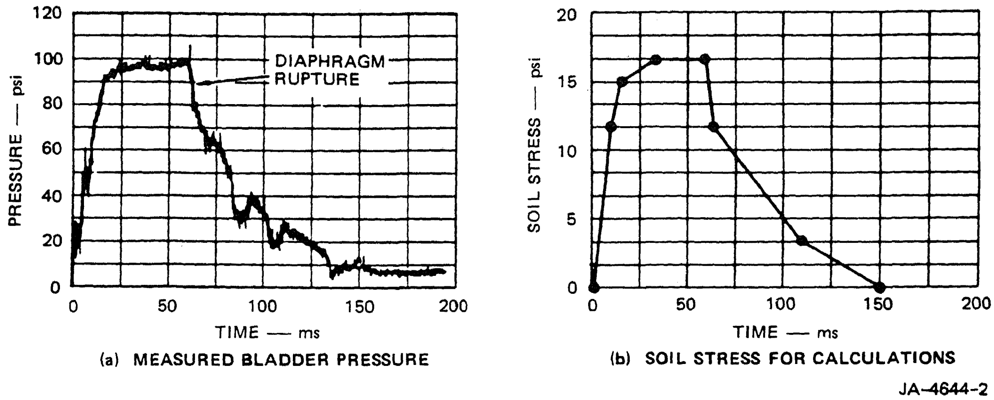


FIGURE 1 TEST AREA AND OUTPUT LOCATIONS

Soil density, 1920 kg/m^3, was measured from samples taken at the Camp Parks, CA, test site. Soil Young's modulus, 138 MPa, was calculated from the observed dilatational wave speed and an assumed Poisson's ratio of 0.25. The array input stress indicated in Figure 1 was determined from the measured bladder pressure given in Figure 2(a). The transformation from bladder pressure in the cylindrical sources to a planar soil stress was done by the elastic-perfectly-plastic finite element procedure in Ref. 1. Soil unconfined strength, 200 kPa, and friction angle, 30 degrees, for these calculations were measured on soil samples taken as the array was installed. Soil damping was used in Rayleigh form, with the mass and stiffness matrix damping factors chosen to give 5% of critical damping at the two lowest frequencies of calculated dominant soil motion (7.5 and 18 Hz).

COMPARISON OF MEASURED AND CALCULATED MOTION

Measured acceleration, velocity, and displacement time histories in the horizontal and vertical directions near the surface at the center of



(a) MEASURED BLADDER PRESSURE

(b) SOIL STRESS FOR CALCULATIONS

FIGURE 2 PRESSURE INPUTS IN EXPERIMENT AND CALCULATIONS

the test area are given in Figure 3. Corresponding theoretical results are given in Figure 4 for the baseline soil properties given above. The general form and amplitudes of motion are reasonably reproduced. The peaks in all three quantities are reached at nearly the same times in the theory as in the experiments, and the peak values agree within 30% or less. Also, the dominance of horizontal motion over vertical motion is clearly reproduced by the theory.

However, the fundamental period of soil motion is longer in the theory than in the experiment. This difference is most apparent in the horizontal velocity and displacement histories, which reach their negative peaks later in the theory than in the experiments. The difference is attributed to the use of a two-dimensional mesh, which assumes that the array is infinite in lateral extent. With the finite length, as well as depth of the array, included in a three-dimensional mesh, the stiffness resistance to array pressure would be greater and the soil frequencies would increase.

To explore such an effect, we artificially quadrupled the soil modulus and repeated the calculations. The wave forms of resulting motion, shown in Figure 5, more closely reproduce those in the experiments. However, the amplitudes of motion are approximately half those in the baseline calculation. We conclude that a three-dimensional mesh would definitely improve the accuracy of the calculation but that the baseline two-dimensional calculation gives a quite reasonable approximation to the motion for preliminary design and analysis of experiments.

SOIL MOTION FROM TRIPLE-PULSE SOURCES

Current and future experiments with contained explosives take advantage of another feature of this technique; namely, that because the sources are not damaged by the explosions, several explosions can be

LOCATION 5 (MIDDLE, SHALLOW)

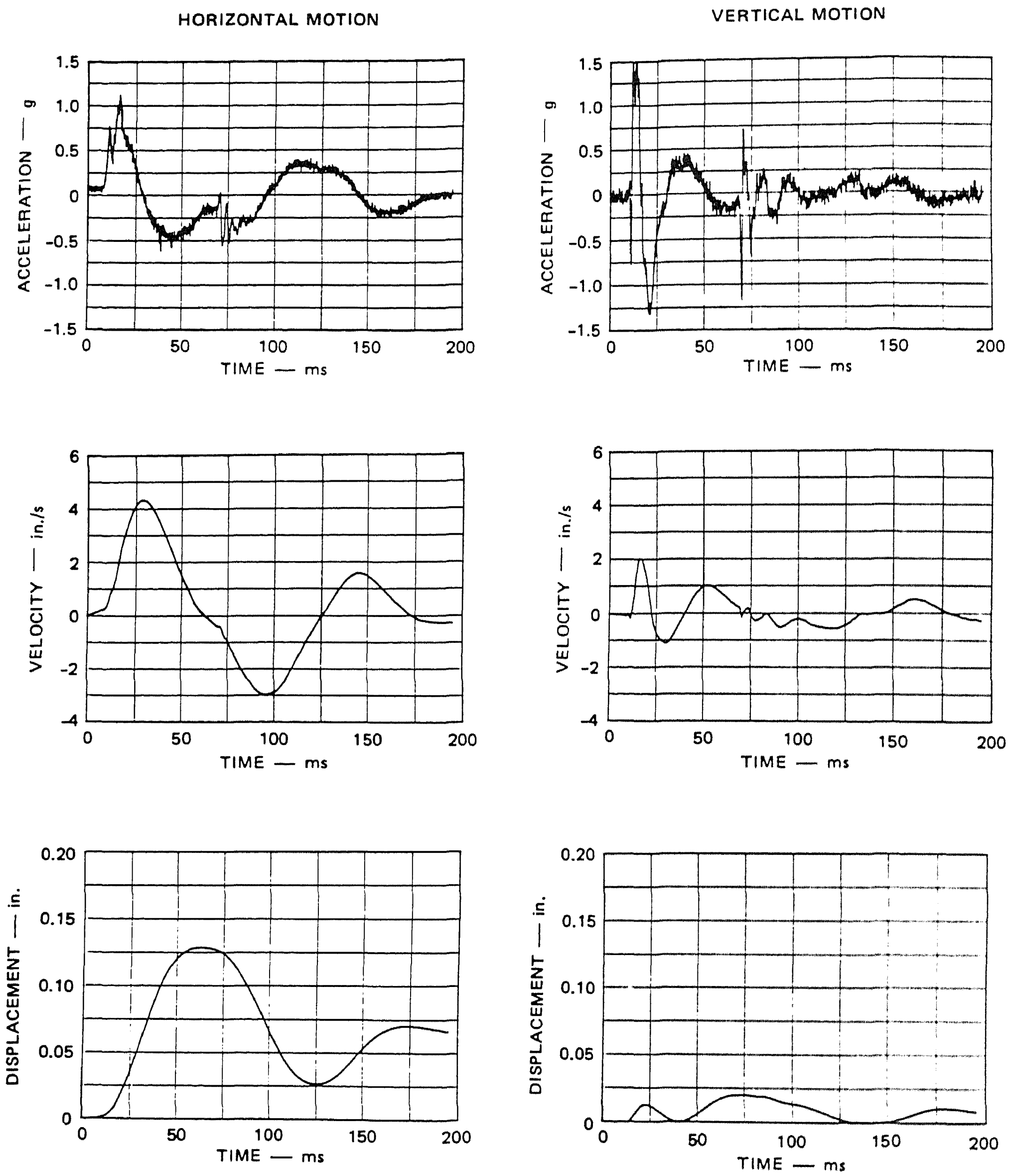


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FIGURE 3 MEASURED SOIL MOTION AT LOCATION 5

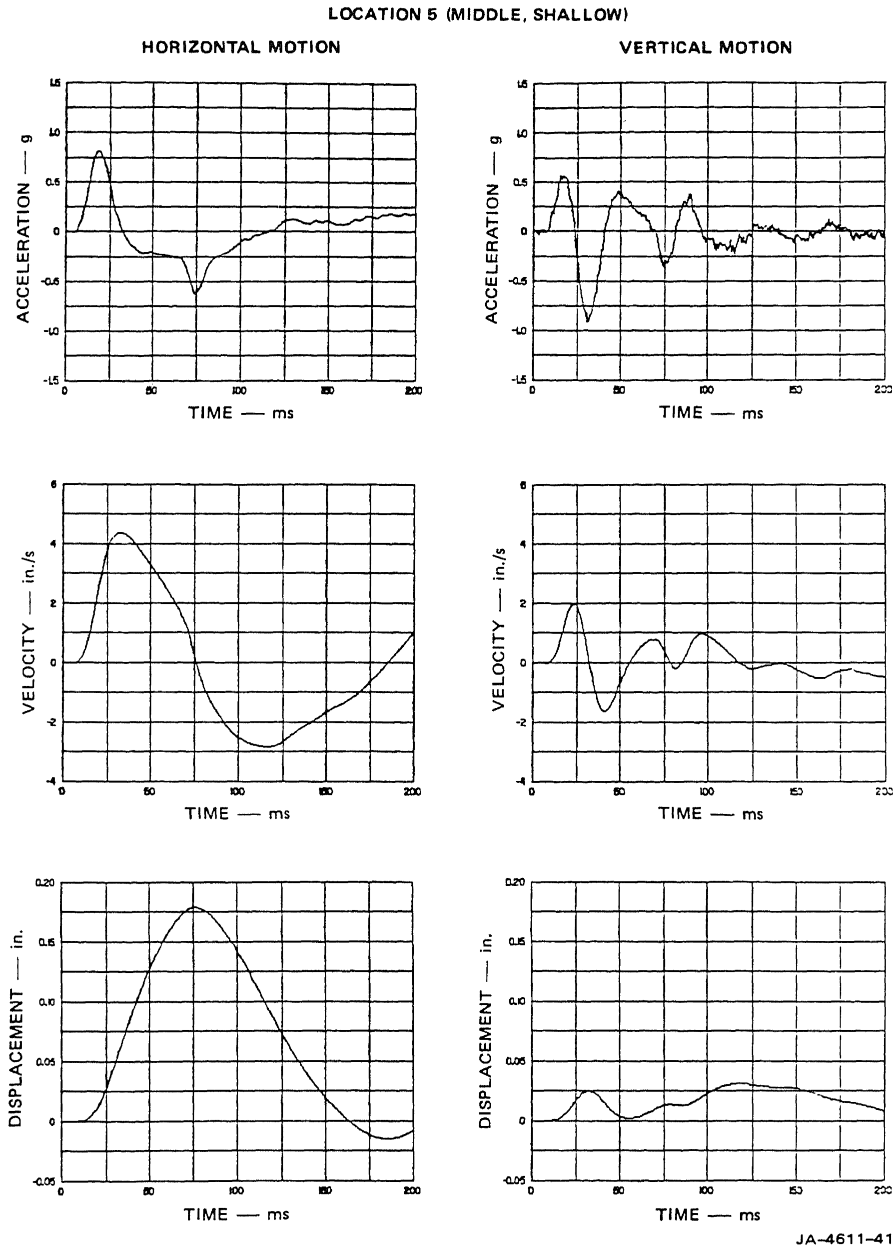


FIGURE 4 BASELINE CALCULATION, LOCATION 5

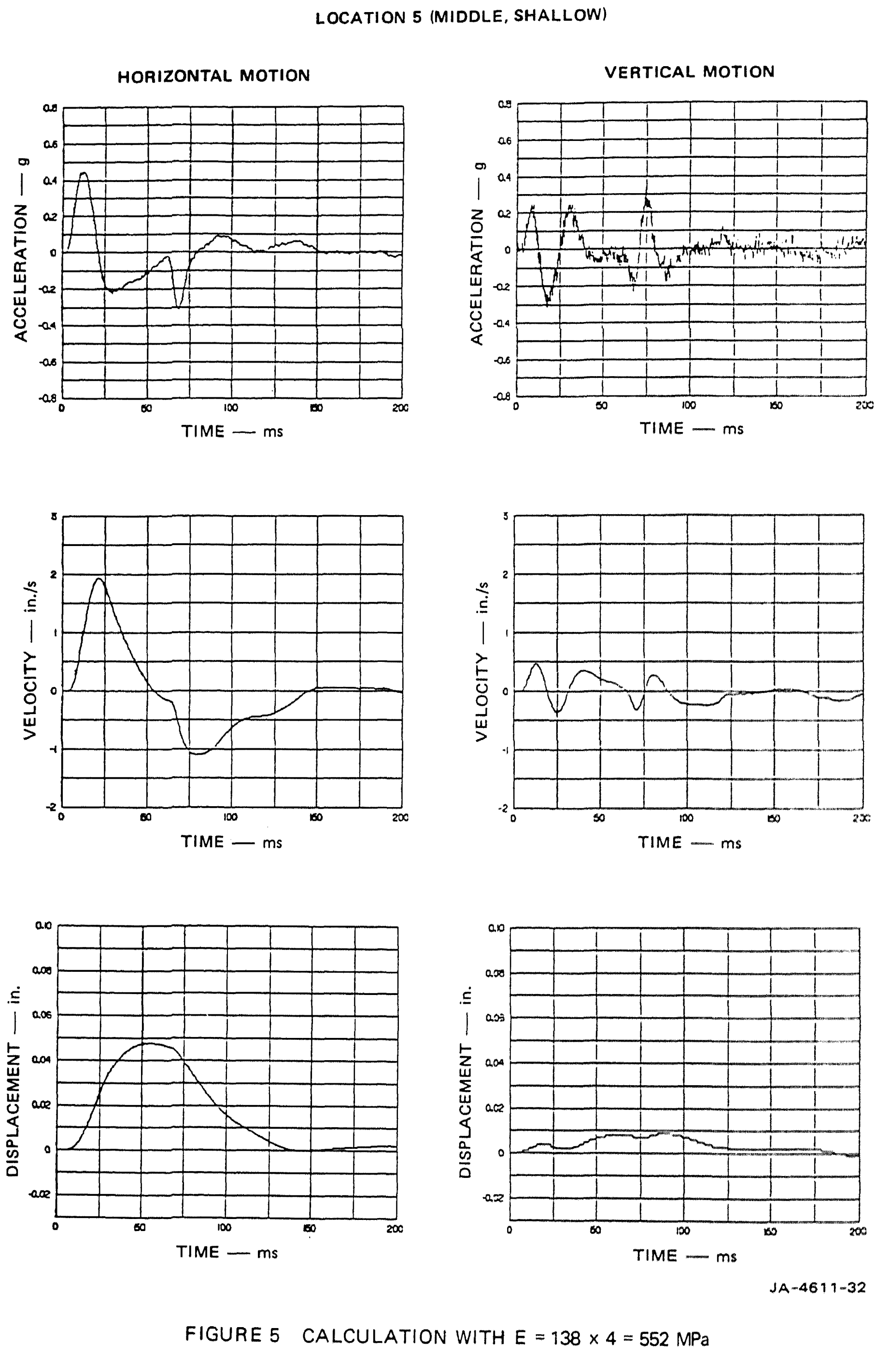
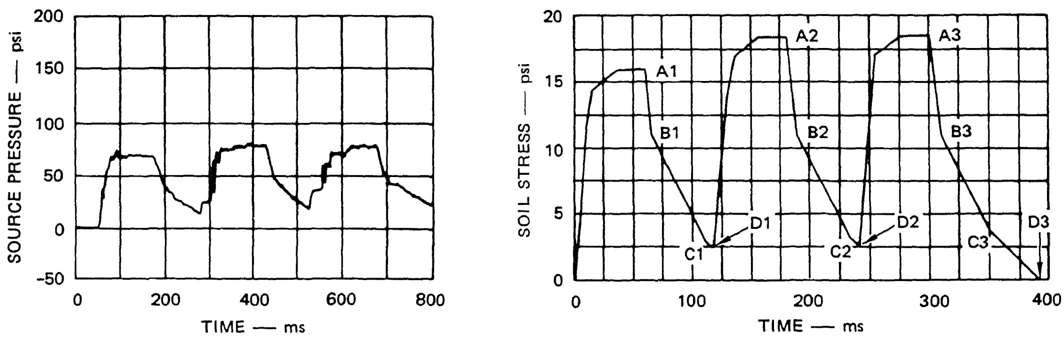


FIGURE 5 CALCULATION WITH E = 138 x 4 = 552 MPa

released in each source to extend the duration of motion. With three or more canisters in each rubber bladder and three or four arrays placed side by side, the total duration of a moderately strong earthquake can be simulated. Calculations of the type just described can be used to predict the motion from these full production arrays and to help in their design.

A bladder pressure-time history from an experiment with a single 0.3-m-diameter by 14-m-long source with a triple canister is given in Figure 6(a). Resulting soil stress for an array calculation is given in Figure 6(b). Durations are scaled down to correspond to the smaller array size in the present calculations, and the soil stress is taken as a reasonable value for routine testing. Resulting motion at the center of the test area is given in Figure 7. Three distinct cycles are produced in acceleration, velocity, and displacement that essentially repeat each other because the pressure pulses were strung together as a repeating sequence. Other calculations with different timings between pulses and later pulses added before the pressure from a previous pulse has dropped to zero show that considerable shaping can be done to the soil motion wave forms.



(a) MEASURED BLADDER PRESSURE, SINGLE SOURCE EXPERIMENT

(b) SOIL STRESS FOR CALCULATION

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FIGURE 6 STRESS-TIME HISTORY FOR TRIPLE-PULSE CALCULATION

CONCLUDING REMARKS

For brevity, only a few selected calculational results to compare with experimental results have been given here, but it is apparent that the complete output from these calculations describe in detail how the direction and magnitude of motion vary throughout the test bed. A three-dimensional mesh promises to give an accurate representation of motion and analysis of soil-structure interaction. Experiments and theory are now under way to provide test cases for both free-field motion and motion with a model building foundation and superstructure.

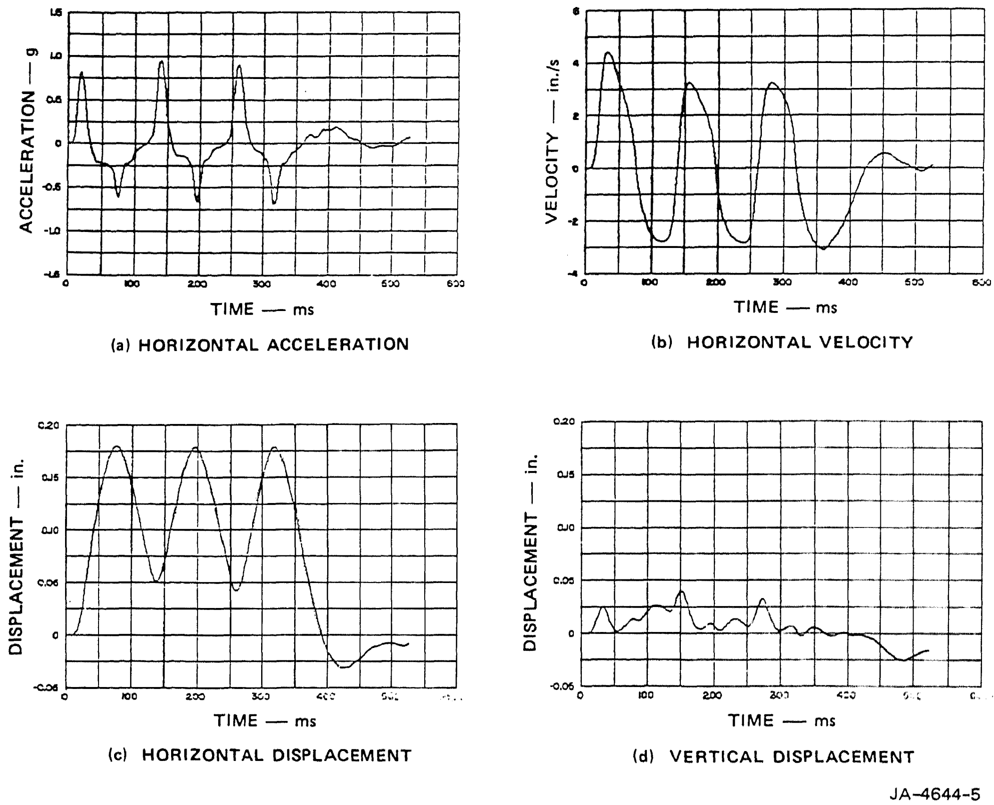

FIGURE 7 MOTION AT LOCATION 5 FROM TRIPLE-PULSE INPUT

REFERENCES

1. Bruce, J.R. and H.E. Lindberg, "Earthquake Simulation Using Contained Explosions," in Proceedings of the Second Specialty Conference on Dynamic Response of Structures: Experimentation, Observation, Prediction and Control, Gary Hart ed., Atlanta, Georgia, ASCE, Jan. 15-16, 1981, pp. 111-125.

2. Bruce, J.R., H.E. Lindberg, and L.E. Schwer, "Soil Motion From Contained Explosions," in Physical Modeling of Soil Dynamics Problems, ASCE National Convention, Preprint 82-063, Las Vegas, Nevada, April 26-30, 1982.