IMPACT OF WEIGHT FALLING ONTO THE GROUND

Discussion by Mark R. Svinink, Member, ASCE

An interesting analytical approach to analyze the soil-falling weight interaction has revealed the characteristics of the forces transmitted to the ground during a nondestructive testing procedure.

Actually, at the moment of impact, an inelastic collision occurs at the contact area between the falling weight and the ground, and rebounds are usually not observed. For that reason, the discussers conducted in-situ experiments to investigate the effect of plastic soil deformations at the moment of impact under a dropping rigid mass on ground surface oscillations (Svinink 1973; 1976). The falling steel weight had a cylindrical shape with a 20 cm diameter and 100 kg mass. Dropping heights were 2 m and 0.5 m. Impacts were executed by dropping a steel mass on the same spot for various conditions at the contact area between the ground and the mass. First impacts were done onto the ground surface. Then an excavation was dug, having the dimensions of $0.7 \times 0.7 \text{ m}$ in a plan and 0.3 m deep. Impacts were carried out onto the bottom of the excavation, then onto a steel plate with spikes dipped in the soil at the bottom of the excavation, and, after, onto the sand and gravel, which were alternately used to fill the excavation. Accelerations of the falling mass and vibration displacements of the ground surface at 1.5 m, 4.3 m, and 10.8 m from the contact area were measured in the experiments.

At the moment of contact between the falling weight and the soil, the weight itself represented an accelerometer of inertia type, in which a narrow neck with glued strain gauges was an elastic element, and the mass of the falling weight was an inertial mass. At impact, the load had a shock motion with a duration of contact, $t_d$, larger than 0.02 s, determined from trial tests. To choose the accelerometer's natural frequency, it is necessary to take into account the spectrum content of measured impulses (Raevski and Subbotin 1961). The shapes of measured impulses can be considered to be close to a bell or half-sine. For these shapes, the high-frequency spectrum components at frequencies greater than $2/t_d$ in Hz have negligibly small amplitudes. Thus, the accelerometer's natural frequency should be higher than $10(2/t_d)$. In the cases under consideration, this value was equal to 1,000.0 Hz, below the measured accelerometer's natural frequency of 1,250.0 Hz. The period of natural oscillations of the falling mass-accelerometer, 0.0008 s, was smaller than one-tenth of the duration of impacts. Because of that, it was allowable to use the static calibration of the accelerometer (Krylov 1937), which was performed at the hydraulic press. The values of accelerations were determined using the equation (Raevski and Subbotin 1961)

$$a = v/0.5t_d$$ (27)

where $v = \text{velocity at moment of impact}$. The calculated results of (27) matched well with accelerations measured using the static calibration. The amplifier had a working frequency range of 0.0–7,000.0 Hz with a carrying frequency of 35.0 kHz. Signals of the strain gauges were recorded by an MOV-2 (type 1) galvanometer built in an H-102 oscillograph. A

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*August 1994, Vol. 120, No. 8, by Jose M. Roisset, Eduardo Kausel, Vicente Cuellar, Jose L. Monte, and Julian Valerio (Paper 5957)."
galvanometer working frequency ranged from 0.0–1,400.0 Hz. Velocity of a film motion was 1 m/s.

Measured acceleration impulses and their computed spectra are shown in Fig. 17. It can be seen that soil conditions at the contact area influenced the duration of impacts. Acceleration impulses were close to the bell shape for impacts onto the ground surface (impulse 1, 1), bottom of excavation (impulse 1, 2), gravel (impulse 1, 3) and steel plate (impulse 1, 4). The minimum contact time of \( t_0 = 0.025 \text{ s} \) was observed for impact onto the steel plate. In the rest of the three cases, duration of contact did not exceed 0.035 s. For impact onto sand, contact time increased to 0.06 s and the impulse shape was close to a shifted half-sine with its greater steepness in the leading phase. Changing the drop height from 0.3 to 2.0 m did not affect the contact time. The maximum and minimum low-frequency components of 0.62 and 0.50 g/s (\( g = 9.81 \text{ m/s}^2 \)) in Fourier spectrums of the impact forces were found for duration of contact of 0.06 and 0.25 s, respectively.

Applicable measurement system consisted of VAGIK or K-001 seismographs and a H-004 oscillograph with GB galvanometers. The frequency range of this system for velocity and displacement measurements was from 1.0 to 100.0 Hz. For the same values of impacts, records and spectrums of ground vibrations at 1.5, 4.3, and 10.8 m from the center of the contact area are depicted in Fig. 18. Shapes of records measured at each location were actually the same for different conditions at the contact area. The predominant frequency of ground vibrations, approximately 160.0 rad/s, turned out to be independent from conditions at the contact area. In fact, an increase of duration of the bell-shaped impulse from 0.025 to 0.035 s did not practically change the amplitudes of ground vibrations. Thus, at distances of 4.3 and 10.8 m these amplitudes differed by only 5–8% (Fig. 18, records 1–4). Enhancement of low-frequency components of the half-sine shaped acceleration impulses (Fig. 17, spectrum II-5) had weak effect on frequency content of ground vibrations (Fig. 18, records 5). In the proximity of the contact area (\( r = 1.5 \text{ m} \)) an increase of impulse duration to 0.06 s diminished the amplitudes of ground vibrations to 50–70% as compared with other conditions at the contact area. However, moving further from the place of impact, this difference decreased to 20–35% and 10–25% for \( r = 4.3 \) and 10.8 m, respectively. The distances of 4.3 and 10.8 m were 40–100 times greater than the radius of the contact area between the falling weight and the ground. Thus, at the locations in the proximity of the place of impact, amplitudes of ground vibrations were decreased with an increase of impulse duration, but these changes decreased with distance from the contact area.

Experiments with a drop mass of 15.0 t showed that considerable increase of acceleration impulses excited ground vibrations with a low predominant frequency pertaining to the natural frequency of soil medium rather than to the natural frequency of the falling weight-soil system.

**APPENDIX. REFERENCES**


**Discussion by S. Thilakasiri,7 G. Mullins,8 P. Stinnette,9 and M. Gunaratne10**

The authors present a closed-form solution to predict impact stress in soil due to a falling weight using a linear-elastic...
spring and dashpot model. It should be noted that very similar models, such as those proposed by Scott and Pearce (1975) and Qian (1982), have previously been used to predict impact stresses in soil. However, the authors have advanced the mass-spring-dashpot model further by not overlooking the significance of overdamped and critically damped conditions, as opposed to Scott and Pearce (1975) and Qian (1982).

The discussers have also investigated the same problem, both analytically and experimentally. Accordingly, impact tests on soil were designed by the discussers to understand the effects of drop height, drop weight, and impact area on the contact stress. One series of tests in this experiment involved dropping a 2.27 kg, 7.62 cm square drop hammer on compacted sandy soil from various drop heights. Stress measurements, recorded at a sampling rate of 10,000 Hz, were obtained using stress cells embedded in the surface of the hammer at the corners and center. The input parameters required to execute the authors' model, such as the shear wave velocity and Poisson's ratio, were back-calculated from the experimentally observed peak stress and contact time from the first trial of a previous test series on compacted sand. This prevented possible uncertainties in the precise measurement of the shear wave velocity, which is an important parameter in the authors' model. The values of shear wave velocity and Poisson's ratio were determined for the compacted sand tested. These parameters were then utilized to predict the impact stresses and contact times for the subsequent drops.

FIG. 19. Peak Stress versus Drop Height for 2.27 kg Drop Weight

FIG. 20. Stress-Time History for 2.27 kg Drop Weight with 0.61 m Drop Height

The writers, on the other hand, had to formulate a nonlinear spring and dashpot model to explain the experimental observations (Thilakasiri et al. 1994). However, the complexity involved in a more realistic model certainly prohibits a closed-form solution such as that presented by the authors.

Furthermore, in most cases, drop weights permanently deform the ground surface. Nonlinear models such as the one formulated by the writers are needed to predict the permanent ground indentation. This limits the applicability of the authors' model to situations involving a low energy impact on a relatively stiff soil, which is certainly not illustrated by the example provided in the paper where a 125.7 kg weight is dropped from 5 m on a stiff soil. Moreover, the contact stress of 6,000 kPa produced in the authors' example is likely to induce a bearing capacity failure in the soil, thus invariably exceeding the limiting strain levels for elastic behavior.

Generally, elastic total stress techniques are also inadequate for saturated or partially saturated soils where pore pressure generation and dissipation govern the soil behavior under dynamic conditions. Within the limitations described previously, the authors' analytical model does provide an accurate closed-form prediction of the magnitude of peak stress induced by a rigid mass dropped on soil.

APPENDIX. REFERENCES


Closure by Jose M. Roesset,11 Member, ASCE, Eduardo Kausel,12 Member, ASCE, Vicente Cuellar,13 Jose L. Monte,14 and Julian Valero15

The writers wish to thank the discussers for bringing to their attention some earlier works containing additional material relevant to the topic at hand, of which they were not aware. Of these, only the paper by Scott and Pearce (1975) is readily available to us for immediate consultation. We are also indebted to the discussers for presenting some actual test results for drop masses, which they used to highlight aspects where simple models fall short.

We are impressed by Thilakasiri et al.'s excellent agreement.

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of experimental and predicted peak impact stresses shown in Fig. 19. We also concur with them that the variation with time of such stresses, as illustrated in Fig. 20, is sensitive to inelastic phenomena occurring at the point of contact with the soil and to local dynamic effects (i.e., participating mass of soil, wave travel). The most striking features in this figure, however, is the fact that the contact force has a finite rise time, and that the drop mass does not appear to rebound, since the impact stresses creep to zero; also, a quick hand calculation reveals that the area under the experimental curve (the impulse) does indeed match the actual momentum of the drop mass (about 7.85 kg m/s). By contrast, the theoretical curve shown by the discussers has an obvious rebound at the point where the stresses change sign, which is consistent with a hand calculation giving a dimensionless impact velocity $\frac{\text{d}gT}{T}$ of about 35 or greater for the experiment. However, the area under the first portion of this curve is too large for the available momentum; hence, the soil shear modulus used by the discussers to assess the theoretical model is too small (shear wave velocity of about 37 m/s?). A stiffer soil would have given a somewhat shorter period, a more triangularly shaped variation with time of the contact stresses (i.e., similar to Fig. 6 in the original paper), and a better agreement between theoretical and experimental results, except for the rise and contact times.

The writers agree with the discussers that inelastic phenomena and local wave propagation effects are important—or even essential—to explain the finite rise times of contact forces, the lack of rebound in actual tests, or the spectrum of the energy transferred to the ground. The authors conducted, in fact, as a second part of their study, a series of parametric analyses with a nonlinear soil model that also accounted for wave propagation phenomena. We believe, however, that a simple model such as the one presented in the paper, can be invaluable in the planning of an experiment (to estimate orders of magnitude of the expected forces, contact time, required characteristics of the measuring devices, etc.), or to quickly carry out a preliminary interpretation of an actual test.