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3 EXPERIMENTAL STUDY OF THE APPLICATION OF THE PENETROMETER TECHNIQUE TO THE LUNAR SURVEYING STAFF CONCEPT 6

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EXPERIMENTAL STUDY OF THE APPLICATION OF THE PENETROMETER TECHNIQUE TO THE LUNAR SURVEYING STAFF CONCEPT

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SUMMARY

An experimental investigation was performed to study the application of a penetrometer to a proposed concept for a lunar surveying staff. The penetrometer is one suggested subsystem of a hand-held instrument for use by astronauts in surveying the lunar surface. Mockups of the lunar staff were constructed, and impact tests were conducted on target materials having a wide range of hardness or penetrability to evaluate conceptual and alternative penetrometer designs.

Acceleration time histories generated during the impact of penetrometers integral with the staff revealed distinguishing characteristics on penetrable target materials including sands and balsa; however, on firm targets such as lead and concrete, the impact acceleration signatures were distorted by superimposed high-frequency structural responses of the staff. An alternate configuration in which the penetrometer was link-mounted to the side of the staff appeared to eliminate the deficiencies of the integral design. Characteristics of the impact acceleration time histories are shown to provide convenient means for distinguishing between the bearing strength of granular target materials. An increase in target bearing strength is accompanied by an increase in the impact peak acceleration and a decrease in both the total duration of the acceleration pulse and the staff penetration depth.

INTRODUCTION

A field geological exploration system has been proposed (ref. 1) for the collection of photographs, electronically recorded imagery, and data on the physical properties of the lunar surface material during early Apollo missions. The proposed system is designed to aid the astronaut in the selection and collection of desirable data. The fundamental component of the system is a lunar surveying staff which is a highly instrumented version of an ordinary Jacob's staff or geologist's staff used to measure terrestrial stratigraphic sections. The proposed staff is equipped with cameras, tracking and orientation instrumentation, and a physical-properties module to collect and record data on the features and materials of the lunar surface during the astronaut's traverse.

Among the instruments being considered for the physical-properties module is a penetrometer which measures accelerations incurred when the staff is impacted on the lunar surface by the astronaut and which provides information on the hardness, penetrability, and bearing strength of the examined surface areas.

The method of measuring the accelerations of impacting projectiles to obtain data on the physical characteristics of a surface material is not new. The Langley Research Center has been actively engaged in developing the penetrometer technique for remote applications for several years. References 2 and 3 present the results of penetrometer experimental tests on various terrestrial and assumed lunar surface materials and references 4 to 6 discuss the application of penetrometers for investigating properties of lunar and planetary surfaces.

Obtaining penetrometer-type information from an accelerometer housed within a staff introduces problems not previously considered in penetrometer development. The results of an experimental investigation conducted with a full-scale model to study the application of the penetrometer technique to the surveying staff are presented herein. Impact tests with different penetrometer configurations were performed on target materials having a wide range of hardness or penetrability.

SYMBOLS

a_{max}	acceleration, g units unless otherwise indicated ($1g = 9.8$ meters/second^2)
D	penetrometer diameter, centimeters
f	filter cutoff frequency, cycles per second
k	penetration parameter
m	surveying staff mass, kilograms
t_r	rise time to peak acceleration in acceleration time history, milliseconds (1 millisecond = 0.001 second)
t_t	total time for acceleration time history, milliseconds
V	impact velocity, meter/second
y	penetration depth, centimeters

l average particle size, microns ($1\mu = 0.001$ millimeter)

ρ dust density, kilograms/meter^3

APPARATUS AND TEST PROCEDURE

Lunar Surveying Staff

Figure 1 is a sketch of the staff initially conceived to aid the astronauts in the surveying of the lunar surface. The mass distribution estimated for the conceptual system and that for the constructed mockup are also shown. The staff, as proposed, would house a television camera, a stereometric film camera, tracking and orientation subsystems, and a physical-properties module which includes, among other instruments, an accelerometer to provide data on the lunar-surface bearing strength.

The lunar surveying staff mockup, shown in figure 2, was constructed from thin-wall aluminum tubing approximately 5 centimeters in diameter. Ballast was added (see fig. 1) to obtain the 12.96 kilograms of total mass of the conceptual model. However, two additional staff masses were examined in the investigation: a 2.13-kilogram model, which corresponded to a version 1/6 the mass of the concept, and a 4.30-kilogram model, which was chosen as an intermediate version to aid in defining the effect of mass on the impact characteristics. The general appearance and dimensions of the mockup approximated those given for the surveying staff in reference 1. The only working feature of the mockup was the accelerometer-equipped assembly referred to hereinafter as the penetrometer.

Penetrometer

The penetrometer for the lunar surveying staff was considered only for mounting to the base (lower end) of the staff in order to minimize or eliminate possible distortions in the acceleration data due to staff modal frequencies, component responses, and similar interference. The basic penetrometer configuration consisted of a hemispherical nose cap, 5 centimeters in diameter, rigidly coupled to a housing which contained the acceleration sensor and provided space for the signal electronics required in the conceptual model. Photographs of the disassembled and assembled penetrometer are presented in figure 3. The total mass of the assembly, exclusive of the adapter which connected the penetrometer to the staff, was 0.30 kilogram. Two additional penetrometer configurations were equipped with elastomeric materials in an effort to isolate the accelerometer signals of the penetrometer from inputs attributed to the staff and its other components. These configurations are shown in figure 4, which illustrates the alterations to the basic penetrometer configuration. In one configuration (fig. 4(a)) a room-temperature vulcanizing (RTV) rubber material was molded around the accelerometer-mounting stud and in the second version (fig. 4(b)) a neoprene rubber-sleeve insert was placed between the adapter and the staff. In the first altered configuration the nose cap and the accelerometer were isolated from the staff, whereas in the second the entire penetrometer assembly was isolated from the staff. Some damping was provided in both versions by the shearing action of the rubber.

Another penetrometer evolved from further attempts to isolate the impacting system from the staff structure. This penetrometer was link-mounted to the side of the surveying staff as illustrated in figure 5 and consisted of an accelerometer-equipped body having a 5-centimeter-diameter hemispherical nose and a trailing guide rod. The total mass of the impacting body in this configuration was 0.118 kilogram. The base of the staff employing this penetrometer was equipped with a flat plate, as shown in the figure, to provide a convenient support for the staff as it rested on the target surface during penetrometer applications.

Impact Surfaces

The materials used in the impact studies with the lunar surveying staff penetrometer consisted of two grades of sand, one grade of aluminum oxide, and balsa wood (density = 112.1 kg/m^3). Additional targets of rubble, lead, concrete, and basaltic lava were used to demonstrate the workability of the surveying staff penetrometer models but were not used extensively as impact surfaces. Characteristic particle size distribution of the granular materials (sands and aluminum oxide) are given in figure 6 as determined by the sieving technique discussed in reference 7. The average particle size of these materials was as follows: fine sand, 121 microns; coarse sand, 268 microns; and aluminum oxide, 550 microns. The general particle shape of these materials is shown in the photomicrographs of figure 7. The rubble consisted of gravel, which was sized by a screening technique that permitted the particles to pass through a 0.634-centimeter screen but not through a 0.317-centimeter screen.

The granular target materials were also examined for their load-supporting capability (bearing strength). Incremental loads were gently applied to the penetrometer in the link-mounted configuration (fig. 5) and the penetration measured subsequent to each loading. At least three such quasi-static bearing-strength tests were performed on each material, and the curves which fair the composite unit loading-penetration data are presented in figure 8.

All tests upon the granular materials and the rubble were performed in 61-centimeter square test bins filled to at least a depth of 15 centimeters. Before each test these target materials were manually agitated to remove extraneous packing and leveled to provide a smooth impact surface. The same agitation process was repeated before each test.

Instrumentation

A crystal accelerometer was mounted in the base of the penetrometer housing as shown in figures 3(a) and 4(a) with the sensitive axis oriented along the longitudinal axis of the staff to sense the impact accelerations. Likewise, the accelerometer in the link-mounted penetrometer was confined to sense only normal impact accelerations. Signals from the accelerometer in both configurations were routed through an external impedance-matching-cathode follower amplifier and a variable bandpass filter to a memory oscilloscope, where they were displayed as a voltage-time trace on a calibrated screen. High-frequency components which seem to be characteristic of impacts on granular materials were filtered out to facilitate more rapid data reduction. Photographs of the accelerometer traces on the display screen were taken for subsequent analysis.

A signal electronics module was constructed during the course of the investigation to insure that sufficient space had been provided within the designed penetrometer housing. This module, shown in figure 3(a), consisted of an encapsulated accelerometer signal conditioning circuit which would take advantage of the power supply, transmitter, and antenna available in the conceptual staff model (fig. 1).

Test Procedure

The testing technique for the penetrometer configuration designed to be integral with the staff involved impacting the lunar surveying staff onto each of the test target materials from specific heights above the target surface. The free-fall drop heights resulted in velocities which ranged from 1.22 meters/second to 3.75 meters/second and were chosen to correspond to the staff impact velocities expected during operations on the lunar surface. Each test was repeated three or more times. The impact characteristics recorded during and following the tests included the acceleration time histories and the resulting staff-penetration depths.

The testing technique for the link-mounted penetrometer consisted of resting the base of the staff on the target surface, releasing the penetrometer assembly to impact the surface, and recording the impact characteristics.

For one series of tests on the balsa target, lunar gravity was simulated by the gravity-component method as illustrated in figure 9 and discussed in references 8 and 9. The full-mass staff (12.96 kg) was impacted on balsa under the simulated lunar gravity over the test velocity range.

DISCUSSION OF RESULTS

Impact Data

Acceleration time histories recorded during the impact of an accelerometer-equipped body on target surfaces display various characteristics which are related to properties of that surface. Representative samples of time histories obtained from impacts of the lunar staff with the basic penetrometer configuration are reproduced in figure 10 where the measured voltage has been converted to acceleration in earth g units. The pertinent time-history characteristics are noted in figure 10(b) and include the magnitude of the peak acceleration a_{max}, the rise time t_r required to reach that acceleration, the total duration of the pulse t_t, and the overall shape of the pulse. The characteristics derived from the impact acceleration time histories obtained with the basic penetrometer configuration impacting targets which included the granular materials and balsa are presented in figures 11 and 12. The depths to which the impacting staff penetrated the impact surfaces are presented in figure 13. These characteristics are discussed in the paragraphs which follow.

Peak accelerations.- The peak accelerations incurred during impacts on the granular targets and balsa are presented in figure 11 as a function of empirical parameters which contain the impact test variables. Expressions containing these parameters which best fit the data are also included in the figure. The empirical expression shows the influence on the peak acceleration of the test variables, impact velocity V, and the staff mass m. (The penetrometer diameter was held constant at 5 centimeters, the diameter of the staff.) The results show that the peak acceleration varies with $V^{3/4}/m^{1/2}$ in the aluminum oxide, $V/m^{1/2}$ in the coarse sand, $V^{5/4}/m$ in the fine sand, and $V^{5/4}/m^{1/2}$ for impacts on balsa. The differences between these parameters and those of references 2 and 3 for similar target materials are attributed to the differences in the masses and the impact test velocities of the systems.

The peak impact accelerations measured on a balsa target (fig. 11(d)) include acceleration data obtained with the staff in a simulated lunar-gravity field. These data are for the total conceptual model mass (12.96 kilograms) at impact velocities between 0.5 and 3.8 meters/second. Figure 11(d) shows that one empirical expression describes the peak accelerations of the staff impacting on balsa in both the earth and lunar gravitational fields. Hence, as expected, a staff impacting a balsa target at identical velocities on either the earth's or the moon's surface would encounter the same peak acceleration.

Characteristic times.- The characteristic times of the various penetrometer-target combinations are presented in figure 12 as a function of impact velocity. The total pulse times t_t are presented in figure 12(a) and the rise times t_r are presented in figure 12(b). In general, the total pulse times are only slightly affected by impact velocity over the test range. Above approximately 2 meters/second there appears to be little effect due to velocity changes. The results further show that shorter pulse times accompany lighter staff masses, the effect being more pronounced in the granular materials than on the balsa impact surface. In general, the rise times for impacts on the granular materials are only slightly affected by changes in the impact velocity, although figure 12(b) shows that these times appear to reach a minimum between 2.5 and 3 meters/second. The one exception was noted during the impacts of the lighest staff on aluminum oxide, where the rise times showed a pronounced decrease as the velocity was increased from approximately 2 to 4 meters/second. Acceleration time histories for this staff-target combination are reproduced in this figure at selected velocities to illustrate the shift in the location of the peak acceleration from near the pulse terminator at low velocities toward the beginning of the pulse at higher velocities. Figure 12(b) also shows that the magnitudes of the rise times in the granular targets decrease with decreasing staff mass. Changes to either the impact velocity or the staff mass had negligible effects on the rise times associated with the balsa target, which concurs with the findings of reference 2.

Penetration depths.- The depths to which the lunar surveying staff penetrated the granular targets are presented in figure 13. The depths are plotted as a function of a parameter which contains the test variables velocity and mass. The data for each target are faired by the general empirical expression

$$y = km^{1/2}V^{2/3}$$

where k, a penetration parameter, is a function of the target material. This relationship between penetration depth and the staff impact velocity and mass is identical to that developed in references 2 and 3 for impact tests on sand and aluminum-oxide dusts. A comparison of the penetration parameter for the various materials indicates that the aluminum oxide offered the least resistance to dynamic penetration and the fine sand offered the most resistance.

Penetrometer Isolation Considerations

In the study of the performance of the integral surveying staff penetrometer it was found that impacts on surfaces having a hardness in excess of that of balsa, as for example lead and concrete, produced large-amplitude oscillations in the accelerometer response. The distorted response from impacts on these firm targets (figs. 10(e) and 10(f)) was attributed to the excited staff and component modal frequencies which appear to dominate the acceleration signal. The excited frequency observed in the tests with the basic penetrometer was found to be approximately 5000 cps and of the same order of magnitude as the frequency corresponding to the duration of the impact pulse on these materials. The response of a structure to impulsive loads can amplify or distort the basic impulse by different percentages depending upon the type of load and the ratio of the period of the response to that of the impulse. Such distortions are discussed in a number of references, as for example, reference 10, which presents the results of a comparative study of a wide variety of pulse and step-like loads on a simple vibratory system.

Attempts were made to modify the basic penetrometer to extend its capability for detecting materials harder than balsa. (See fig. 10.) The first modification consisted of isolating the accelerometer and nose cap from the remainder of the staff (fig. 4(a)) by molding a room-temperature vulcanizing rubber compound between the accelerometer mounting stud and the penetrometer housing. Typical impact acceleration time histories for this configuration are presented in figure 14. The figure shows that this modification not only failed to improve the response to impacts on the lead and concrete targets but also introduced distortions in the response to impacts on the weaker, granular materials. Thus, the isolation of the accelerometer and nose cap by means of the techniques and rubber materials used had a detrimental effect on the overall performance of the staff penetrometer.

The second modification to the basic penetrometer resulted in a configuration that isolated the entire penetrometer assembly from the staff but maintained the staff conceptual operating mode. Isolation was accomplished by inserting a neoprene rubber sleeve between the penetrometer housing and the staff proper as shown in figure 4(b). Typical impact acceleration time histories observed with this configuration are presented in figure 15. The accelerometer response to impacts of this configuration with the granular materials is distorted, however, some improvement is shown over the first isolated configuration in that the frequency and damping of the oscillation present at the onset and the conclusion of the impact pulse have been considerably reduced. Furthermore, the response to impacts with the more firm targets (including balsa) fails to provide intelligent information for target discrimination.

The two modified penetrometer configurations which incorporated isolation materials did not extend the range of material hardness for which the integral configuration would yield meaningful data. In view of these results a third configuration illustrated in figure 5 and designated the link-mounted penetrometer was constructed and impact tested. Acceleration time histories recorded during the impact of this configuration with eight different target materials are presented in figure 16. The accelerometer signals of this figure appear satisfactory for all targets examined, both hard and soft. High-frequency hash or pulse distortions are negligible to the extent that the signals required no filtering. Much data already exists on penetrometers of this shape and mass (for example, refs. 2 and 3) which may be applied to the design of such a penetrometer-staff system.

Application of Results

The purpose of equipping the lunar surveying staff with an accelerometer is to permit a field-exploration team to obtain dynamic measurements of lunar-soil parameters. Such measurements of the reaction of the soil to a moving body yield data on certain physical characteristics of the surface such as its hardness, penetrability, and bearing strength. On the basis of these data, the shape and magnitude of the characteristics of the acceleration time histories must be interpreted in terms of the forces applied to the impacting body with minimum contributions from other flexibly mounted structures. Experimental tests conducted with a mockup of the surveying staff indicated that an external link-mounted penetrometer system (fig. 5) provides essentially distortion-free impact data.

Impact tests conducted on several configurations wherein the penetrometer was attached to the base of the staff revealed that the configuration where the penetrometer was not isolated afforded the most useful data. Negligible distortion of the impact signature was attainable on all examined targets having a strength, up to and including, that of balsa wood. However, the impact acceleration time histories recorded with this configuration during impacts on more firm materials such as lead and concrete were highly influenced by frequencies associated with the staff structure. Since it is of less interest to distinguish between the hardness of firm materials than to define certain physical characteristics of loose, granular materials on the lunar surface, the rigidly attached, integral penetrometer would appear to be a useful component of the lunar surveying staff. However, better data could be obtained by link-mounting the penetrometer as shown in figure 5.

The capability of the rigidly attached (basic) integral penetrometer staff configuration to distinguish between granular materials of different bearing strengths is illustrated in figures 17 to 19. For the purposes of these figures, the bearing strength is arbitrarily defined as the static loading per unit area that produces a penetration of 1 penetrometer diameter (5 cm). These bearing-strength values were obtained from figure 8 and are as follows: aluminum oxide – 71.4 kilonewtons/meter^2, coarse sand – 131.6 kilonewtons/meter^2, and fine sand – 228.0 kilonewtons/meter^2. Figure 17 shows the variation of the peak acceleration with the bearing strength of the three granular targets for different impact velocities (fig. 17(a)) and for different configuration masses (fig. 17(b)). The figure shows that, for all test impact velocities, the greater the bearing strength, the higher are the peak accelerations. Further, the data show that the penetrometer sensitivity to changes in the bearing strength becomes more pronounced with systems having less mass. Hence, to distinguish between targets on the basis of peak accelerations alone, requires that consideration be given to the overall mass of the staff with attempts to keep it as light as possible.

Total pulse time as a function of target bearing strength is given in figure 18 for all examined staff masses. The data of this figure is for an impact velocity of 2.44 meters/second; however, data for other velocities exhibit similar trends. These results show that the duration of the impact-acceleration time histories decrease with increasing target bearing strength. Figure 18 further illustrates that an increase in the staff mass increases the total pulse time.

The penetration parameter k, as obtained from figure 13, is plotted as a function of target bearing strength in figure 19. The figure shows that, as expected, the penetration parameter, and hence the penetration depth (for a given mass and impact velocity) decreases with increasing target bearing strength.

CONCLUDING REMARKS

The following remarks are based upon the results of an experimental investigation to determine the usefulness of a penetrometer (as an integral part of a lunar surveying staff) for determining the properties which define the bearing strengths of extraterrestrial surfaces. Impact tests were performed on target materials having a wide range of hardness or penetrability to evaluate different configurations.

In the basic design, the penetrometer is an integral part of the staff rigidly attached to the base. Impact tests conducted with a mockup of this configuration revealed that the system was capable of providing useful information on certain physical characteristics of surfaces having a penetrability or hardness up to and including that of balsa wood. Impacts onto more firm materials such as lead and concrete produced acceleration time histories which were distorted by superimposed high-frequency structural responses of the staff. Attempts to isolate all or portions of the integral penetrometer with elastomeric materials failed to extend the capability of the conceptual design to define characteristics of the firm target materials. A penetrometer link-mounted to the side of the staff appeared to overcome the deficiencies in the integral configuration and performed satisfactorily on all tested target materials.

Empirical expressions containing the staff parameters, mass and velocity, were developed for the peak acceleration and penetration depth of the conceptual staff design during impacts on various particulate target materials and balsa. These expressions and other characteristics of the impact acceleration time histories provide a convenient means for distinguishing between the penetration resistance or bearing strength of target materials. An increase in the bearing strength of the target is accompanied by an increase in the peak impact acceleration and a decrease in both the total duration of the acceleration pulse and the staff penetration depth.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., December 22, 1966,
125-24-03-25-23.

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Lunar-surveying-staff component	Staff-concept mass, kg	Staff-mockup mass, kg
TV camera and transmitter	5.00	8.52
Stereometric film camera	2.20	
Orientation subsystem	.30	
Tracking transponder	.90	
Staff batteries	3.00	2.97
Gamma-ray fluxmeter	0.80	1.17
Susceptibility-conductivity induction balance	.30	
Penetrometer	0.30	0.30
Total	12.80	12.96

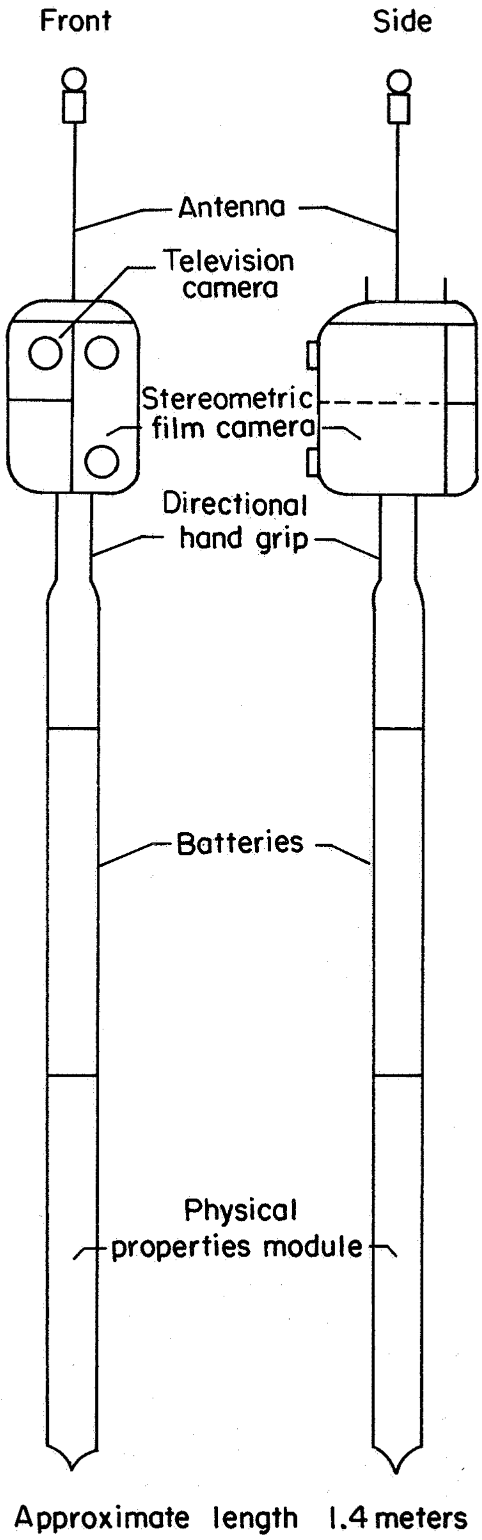

Figure 1.- Lunar surveying staff concept.

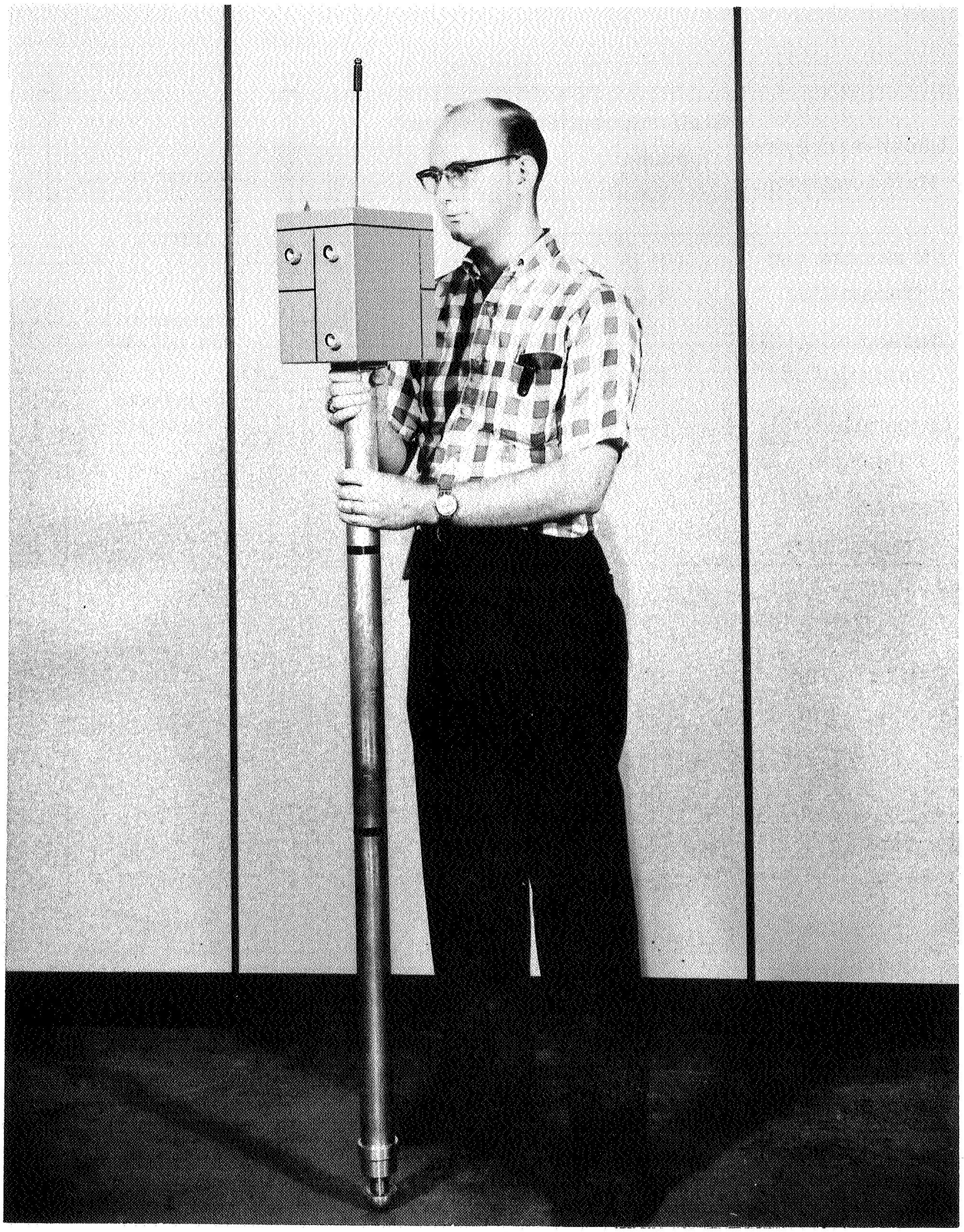

Figure 2.- Mockup of lunar surveying staff.

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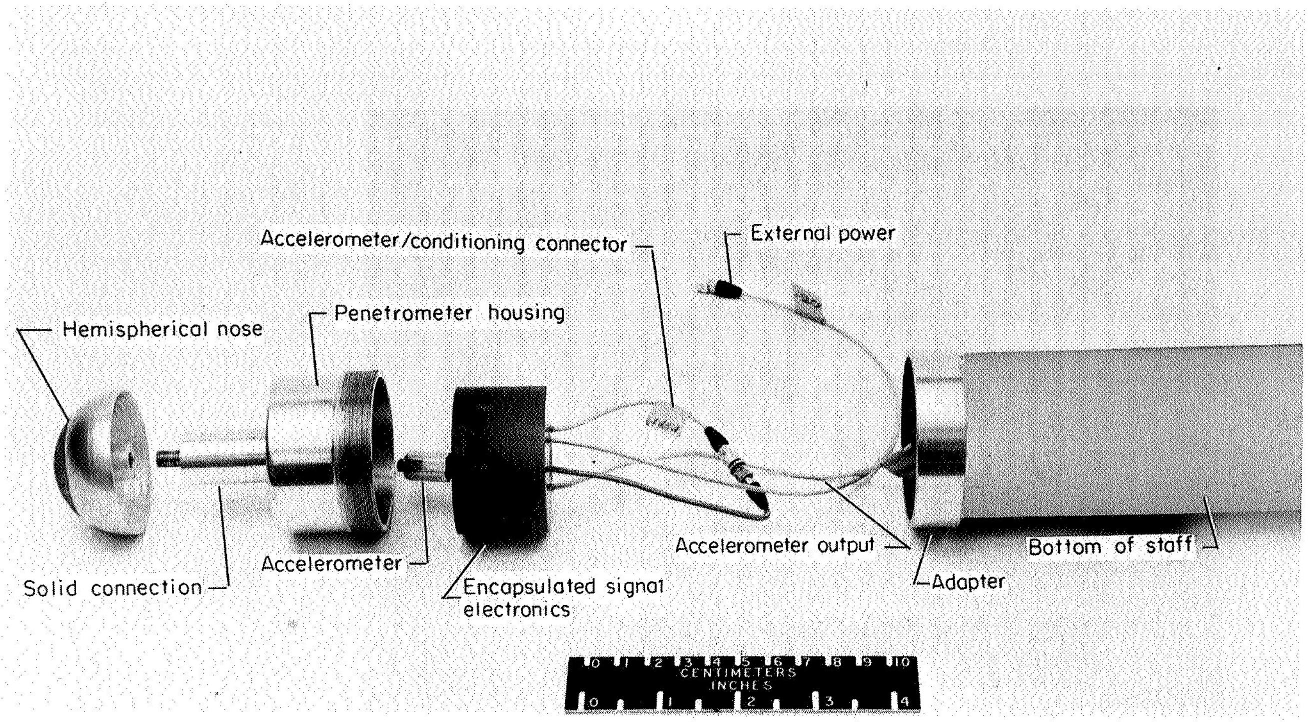
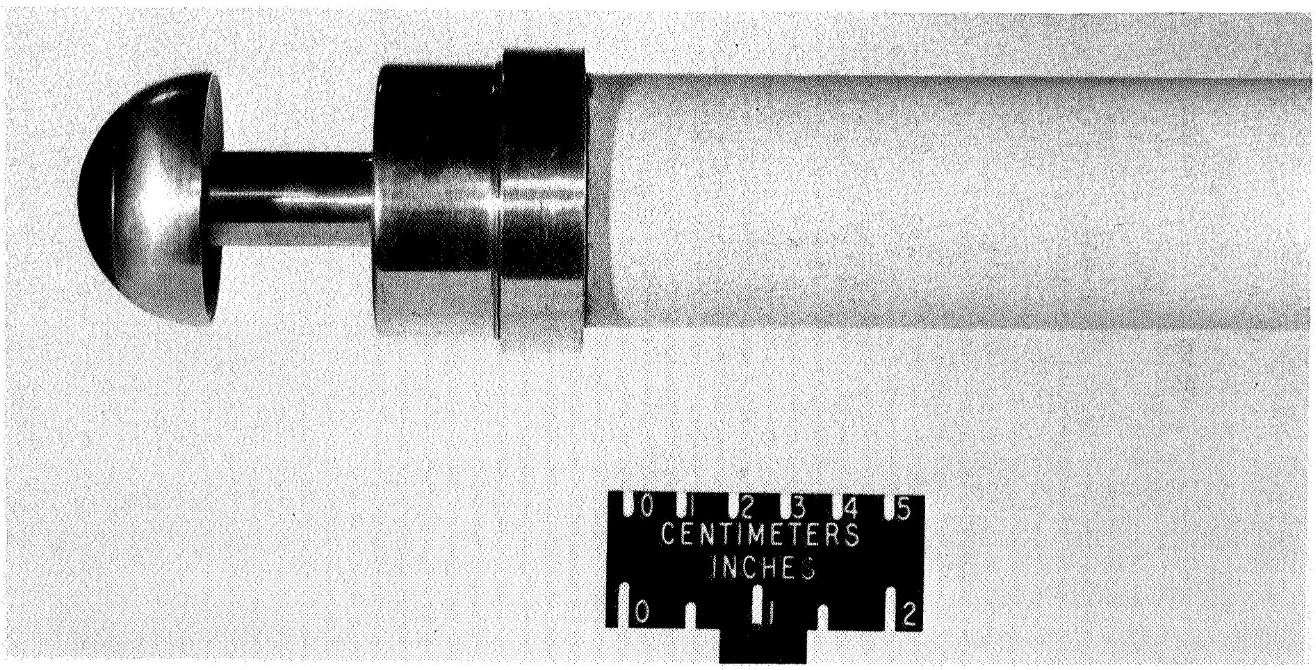
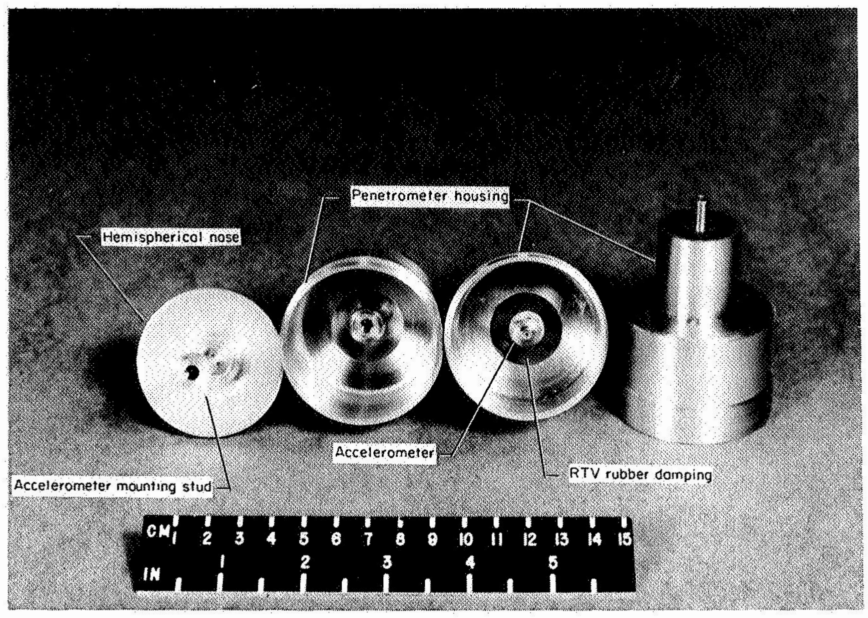


(a) Disassembled. L-66-4016.1

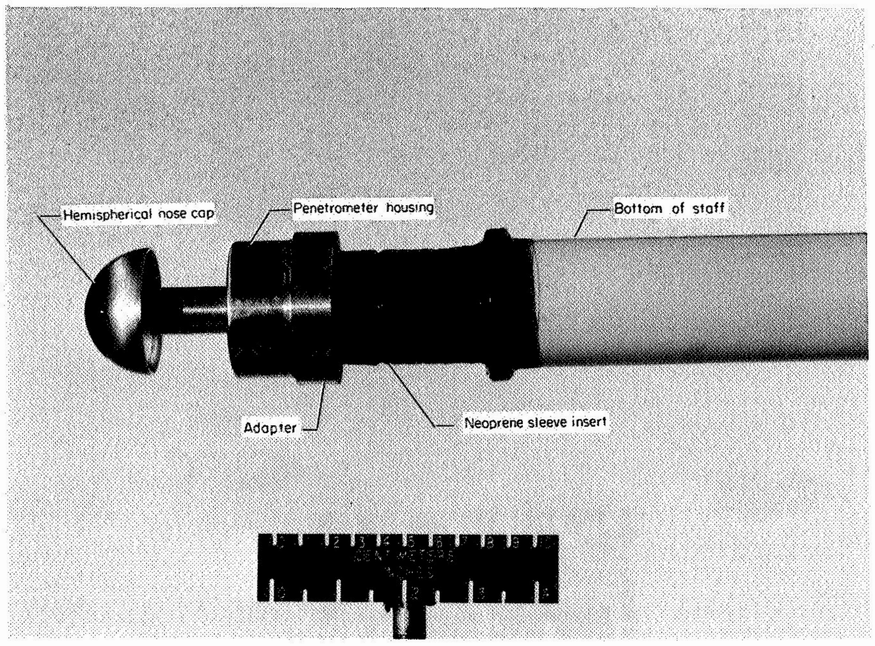


(b) Assembled. L-66-7868.1

Figure 3.- Basic penetrometer configuration for lunar surveying staff.

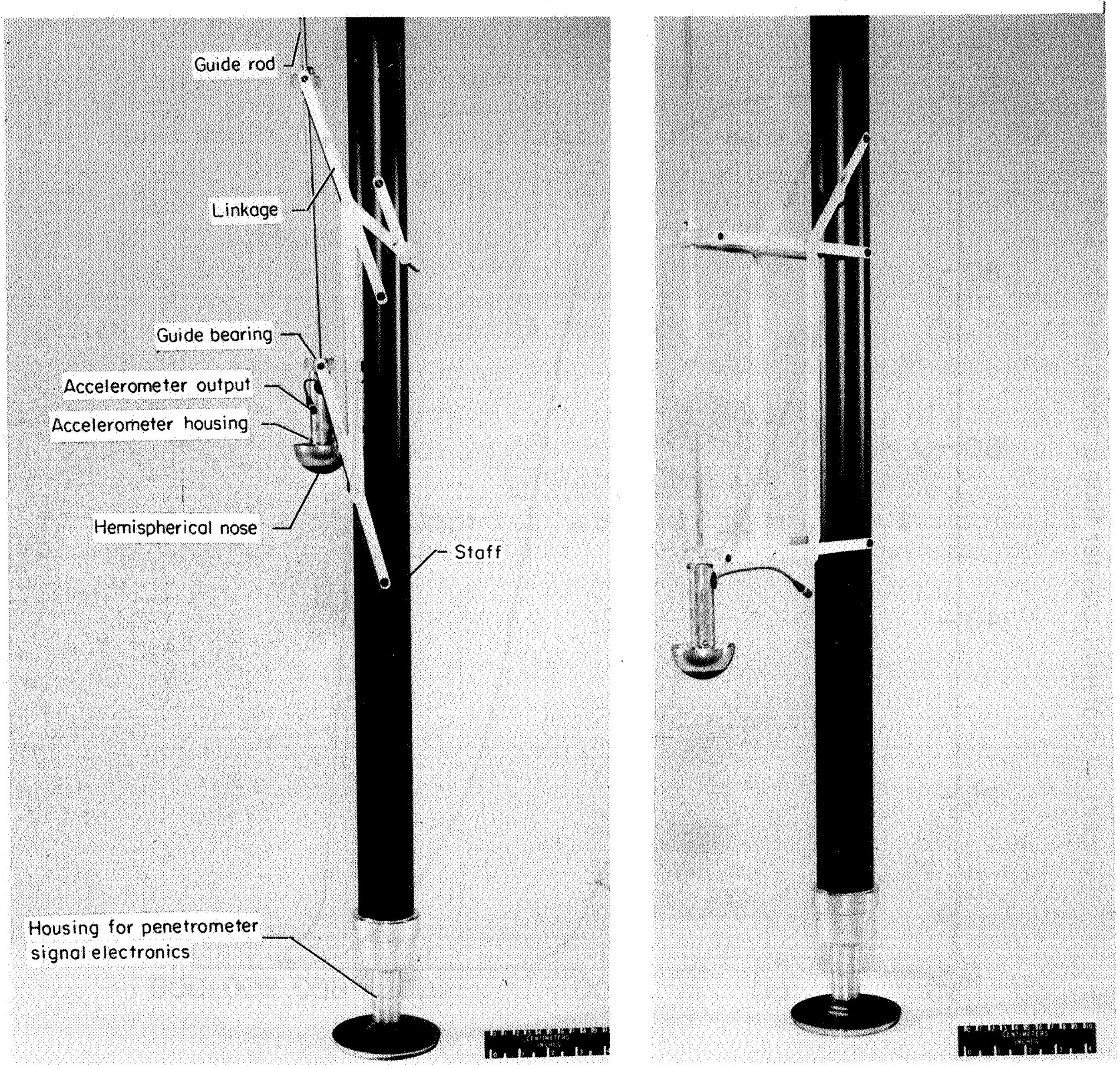


(a) Isolated nose cap and accelerometer. L-65-6977.1



(b) Isolated penetrometer assembly. L-66-4017.1

Figure 4.- Modified penetrometer configurations for lunar surveying staff.



(a) Stored position. L-66-4011.1

(b) Operating position. L-66-4013

Figure 5.- Link-mounted penetrometer configuration for lunar surveying staff.

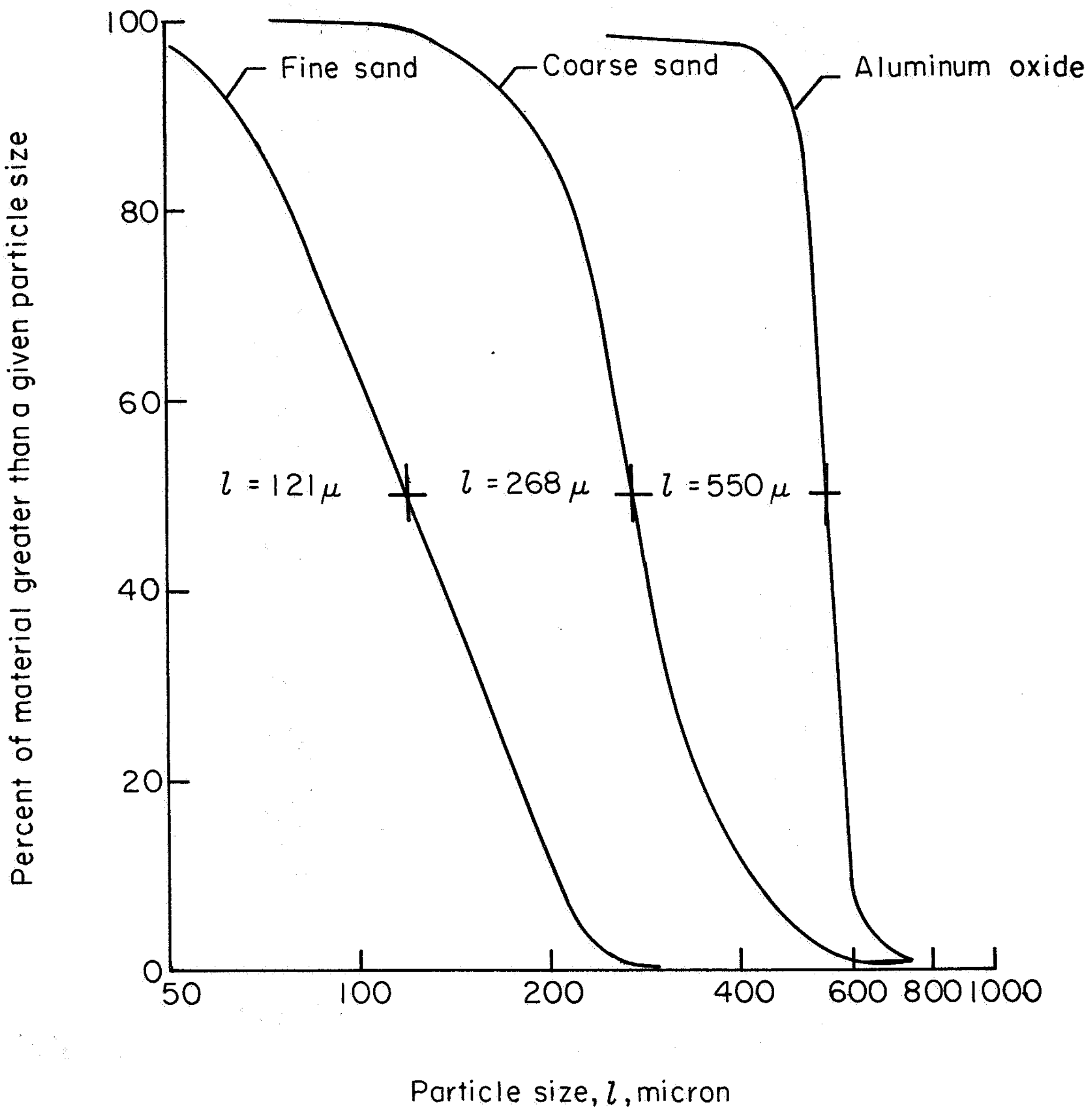
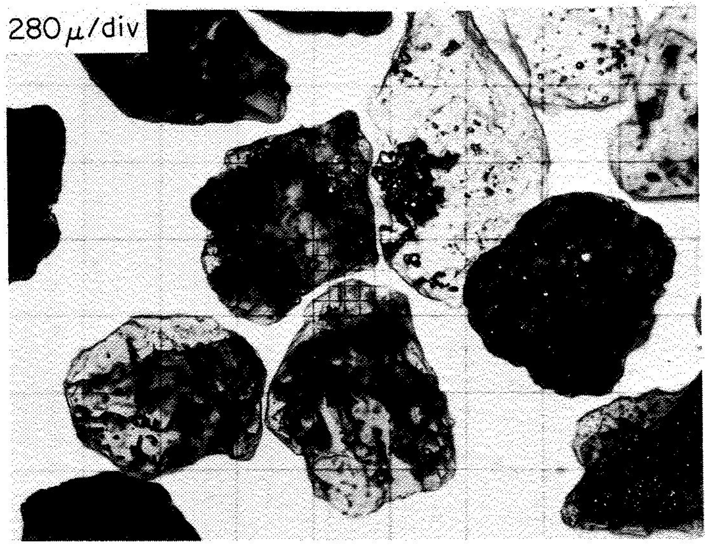
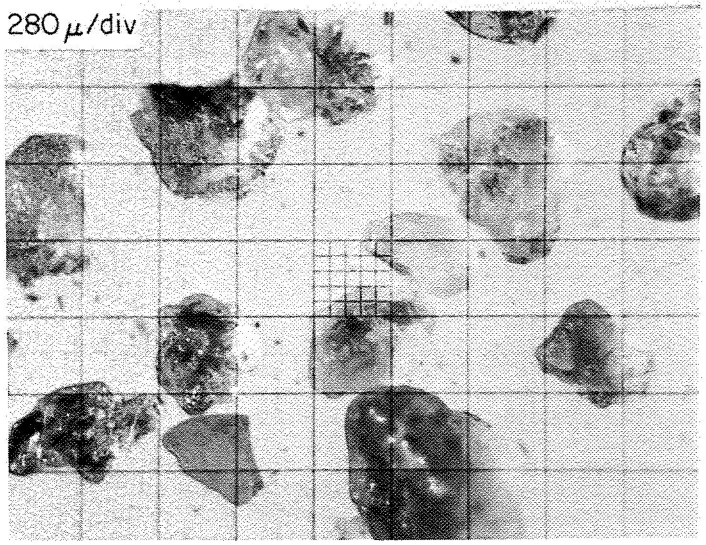


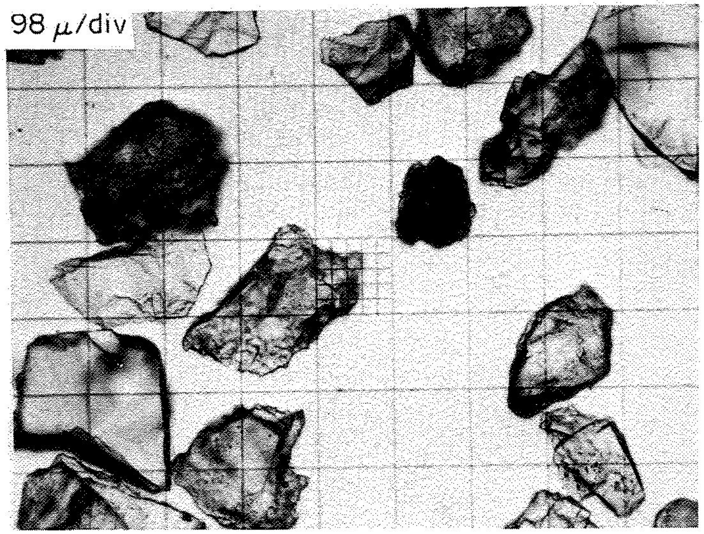
Figure 6.- Grain size distribution of granular target materials.



(a) Aluminum oxide; $l = 550\mu$.



(b) Coarse sand; $l = 268\mu$.



(c) Fine sand; $l = 121\mu$.

Figure 7.- Photomicrographs of granular impact materials.

L-67-921

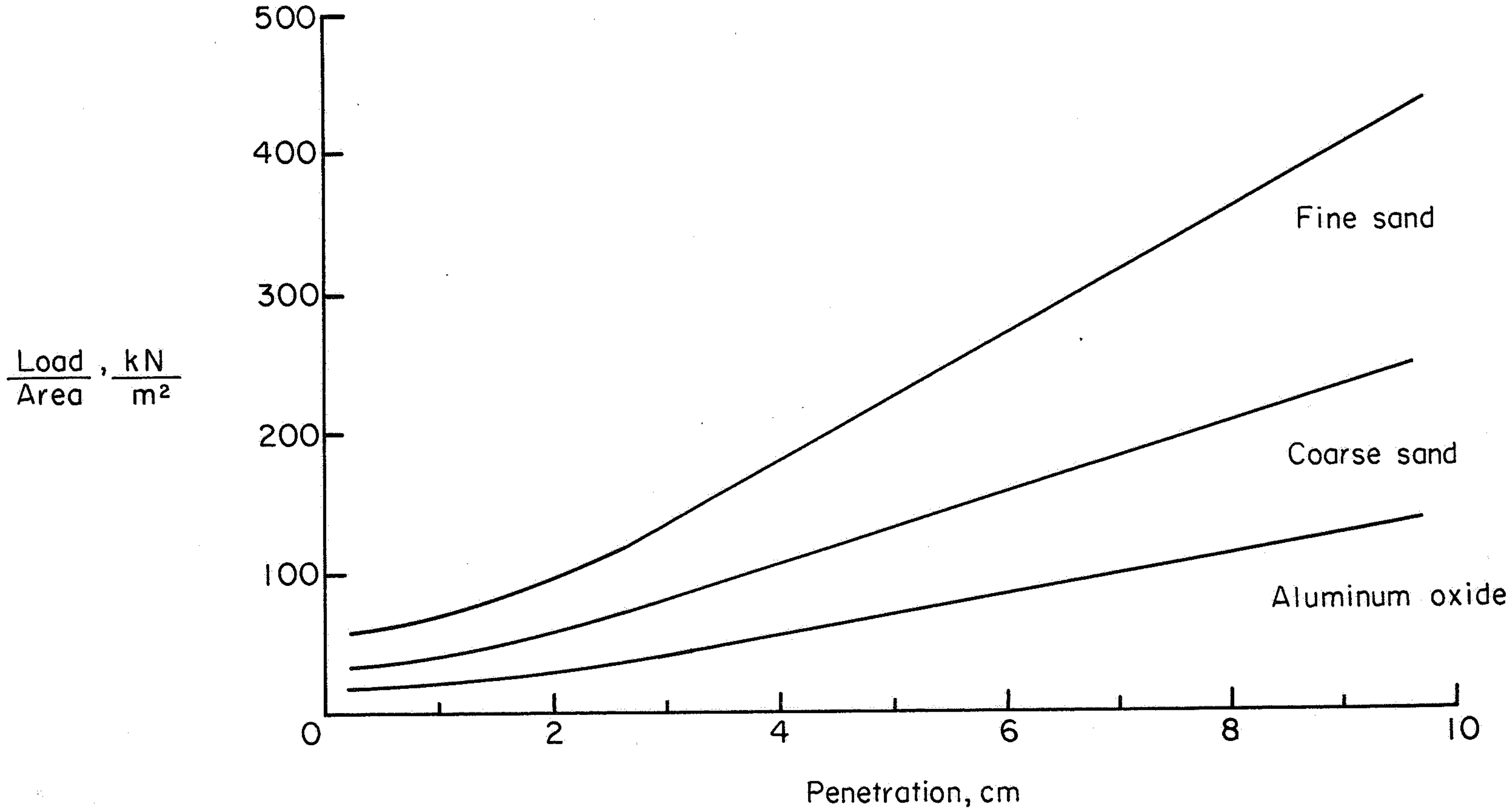


Figure 8.- Summary of bearing-strength tests.

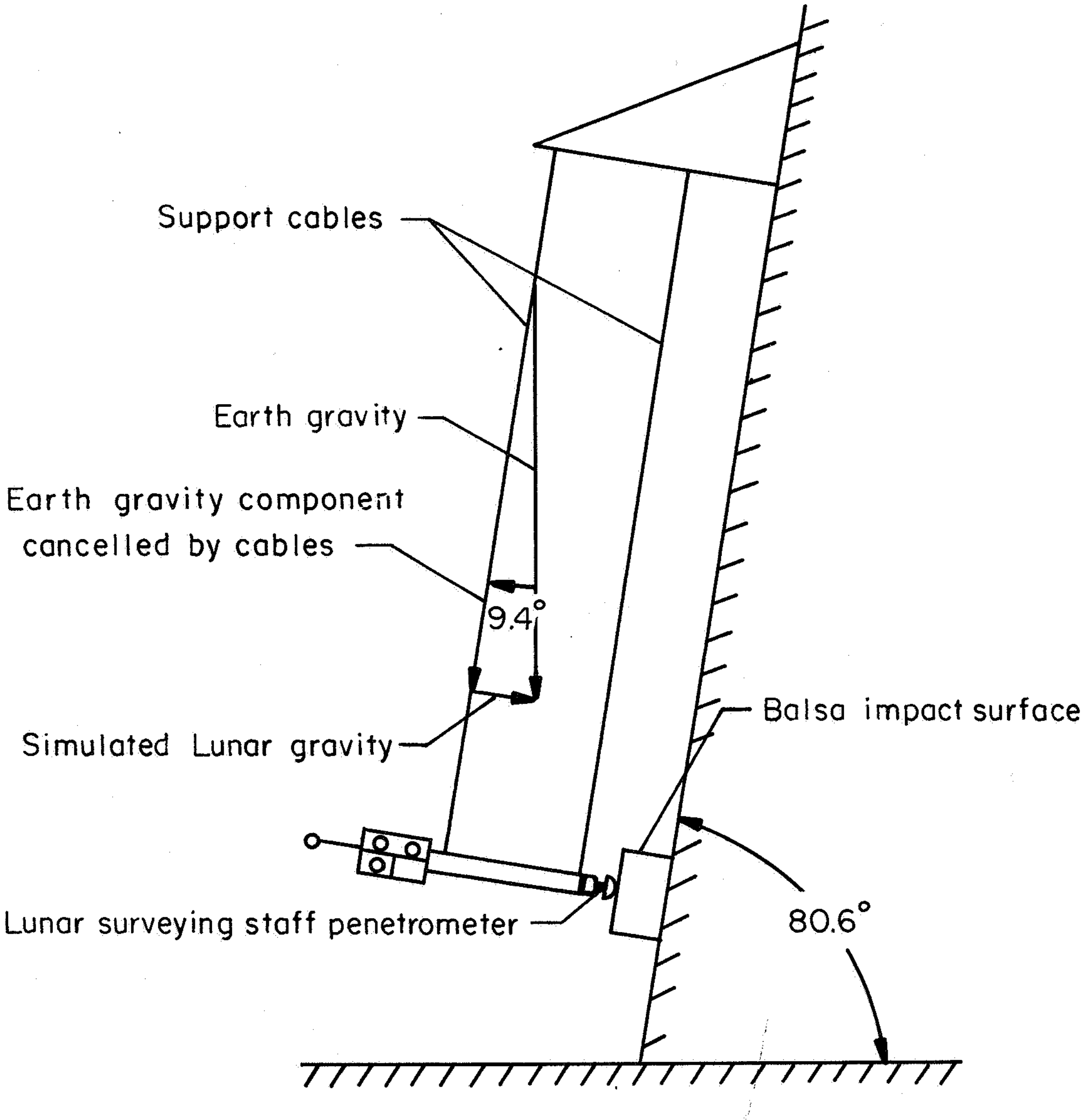
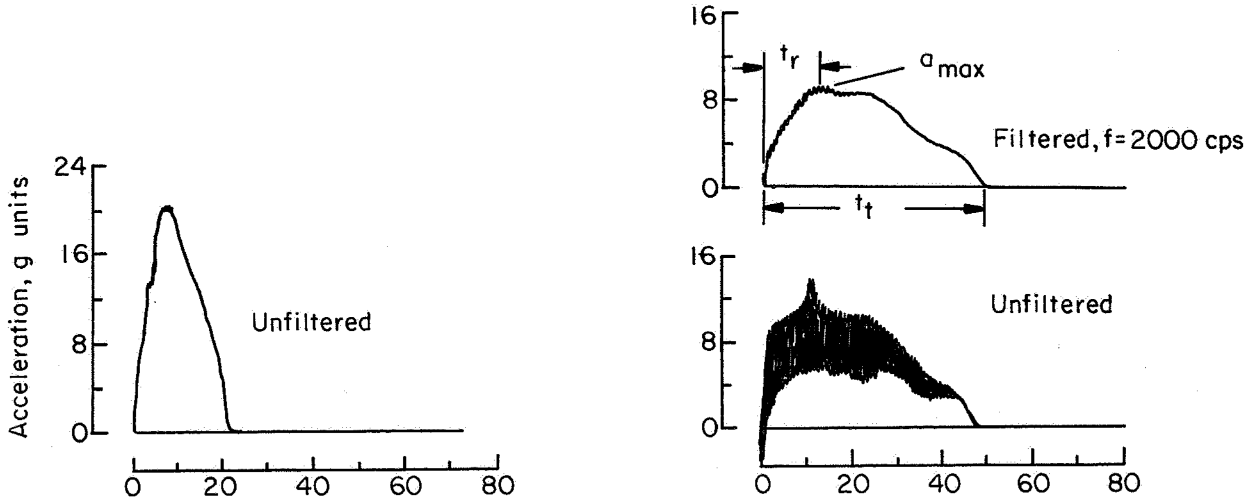
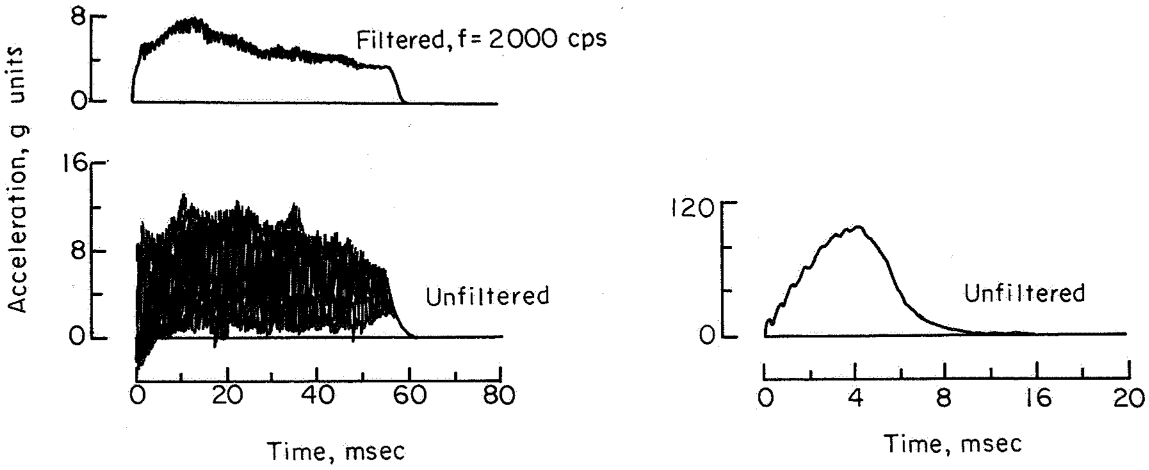


Figure 9.- Gravity-component method of lunar-gravity simulation.



(a) Fine sand. V = 3.75 m/sec.

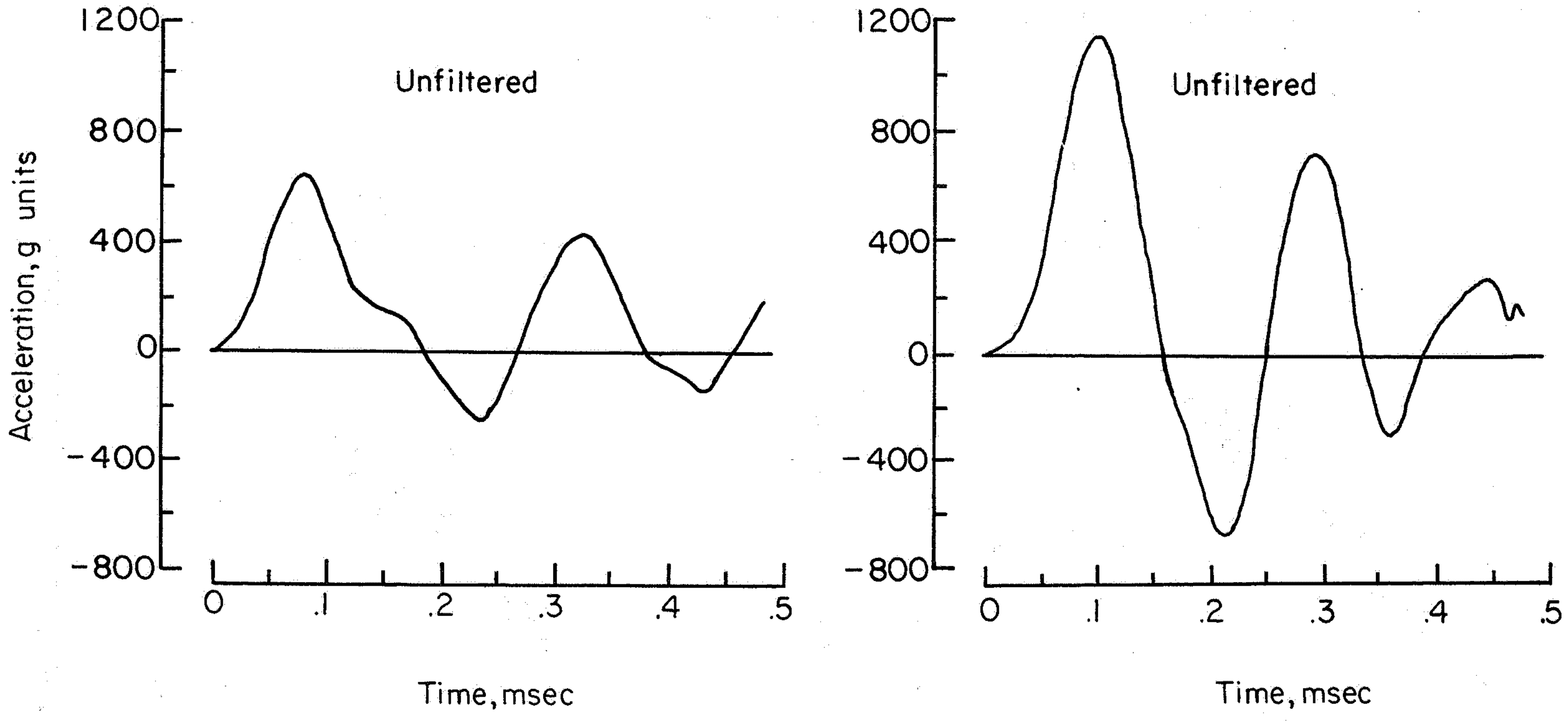
(b) Coarse sand. V = 3.75 m/sec.



(c) Aluminum oxide. V = 3.75 m/sec.

(d) Balsa. V = 3.75 m/sec.

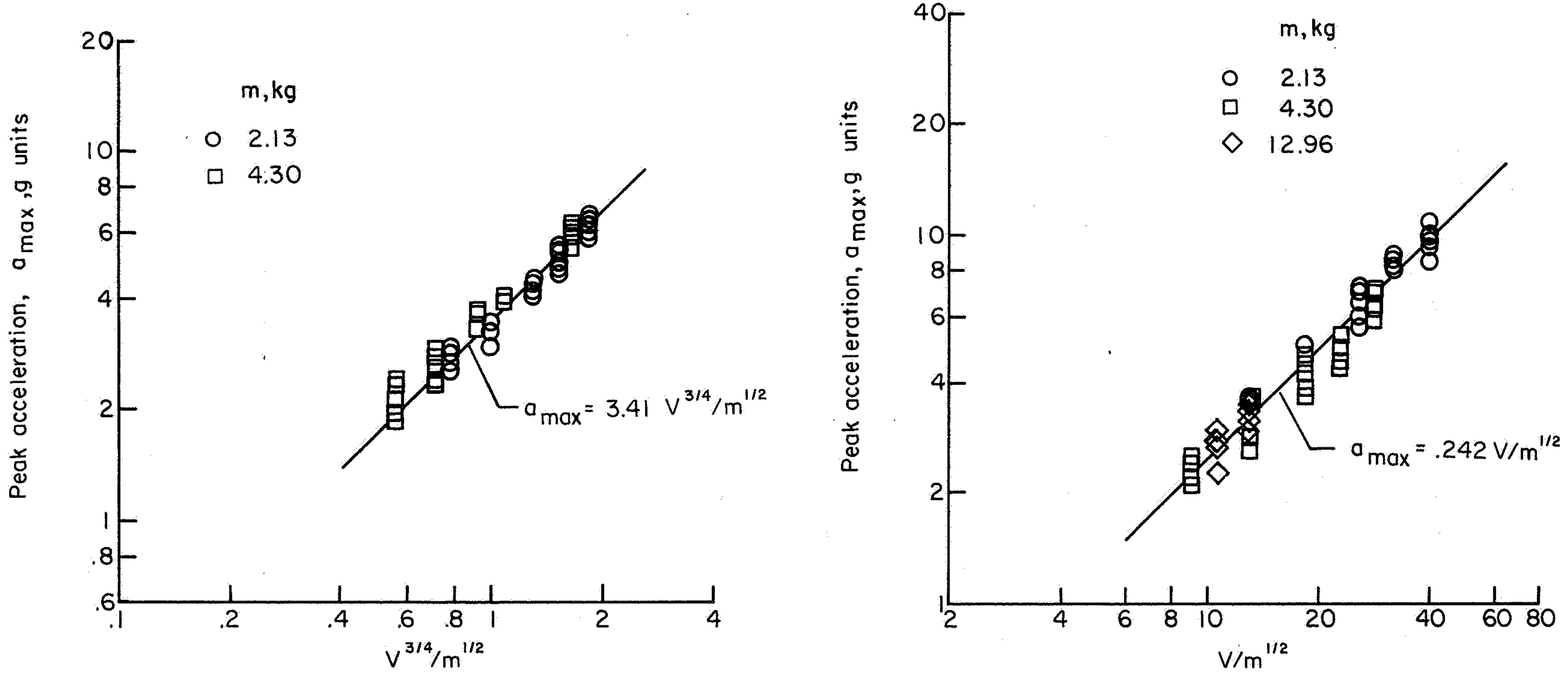
Figure 10.- Typical acceleration time histories for integral lunar surveying staff with basic penetrometer configuration. m = 2.13 kg.



(e) Lead. V = 1.06 m/sec.

(f) Concrete. V = 1.06 m/sec.

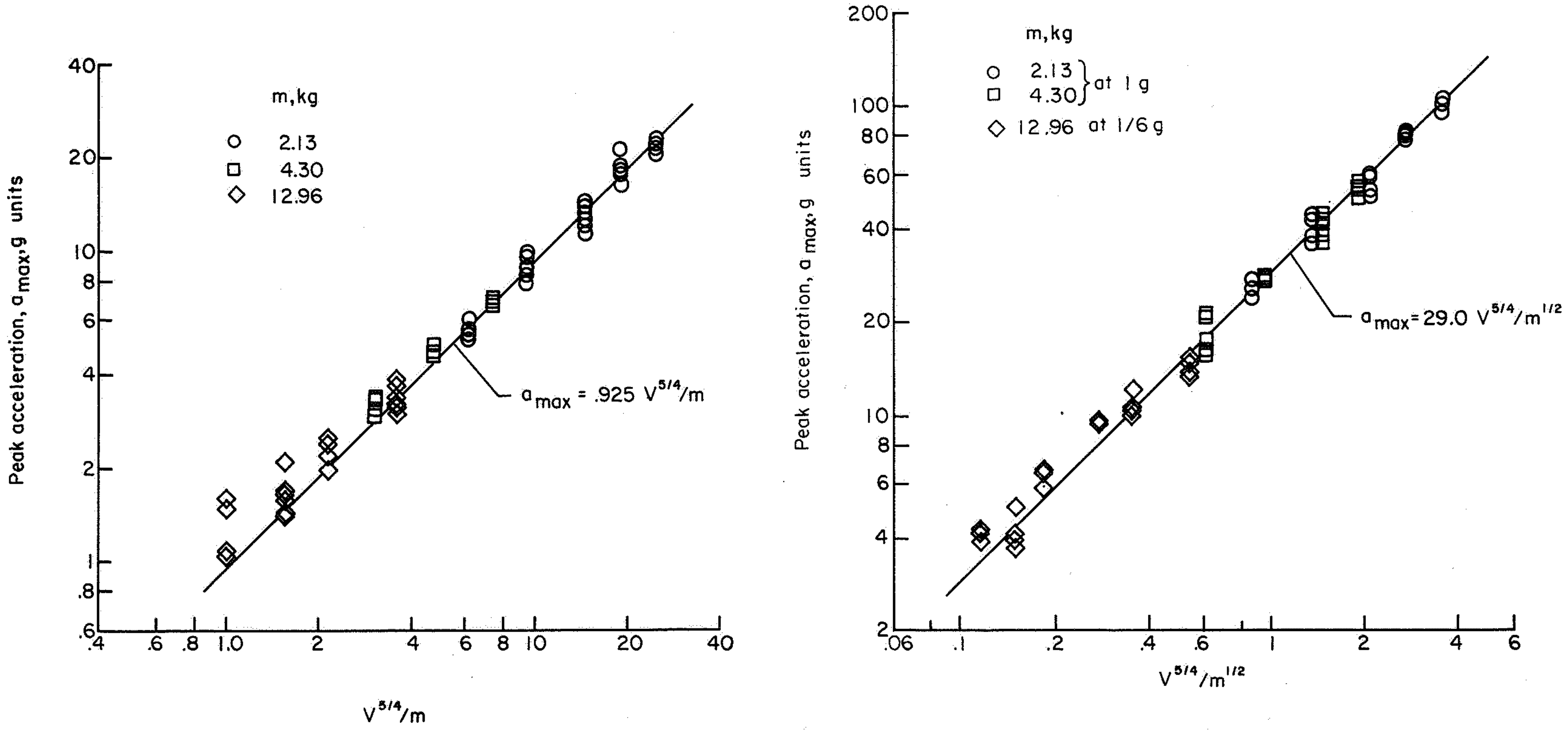
Figure 10.- Concluded.



(a) Aluminum oxide.

(b) Coarse sand.

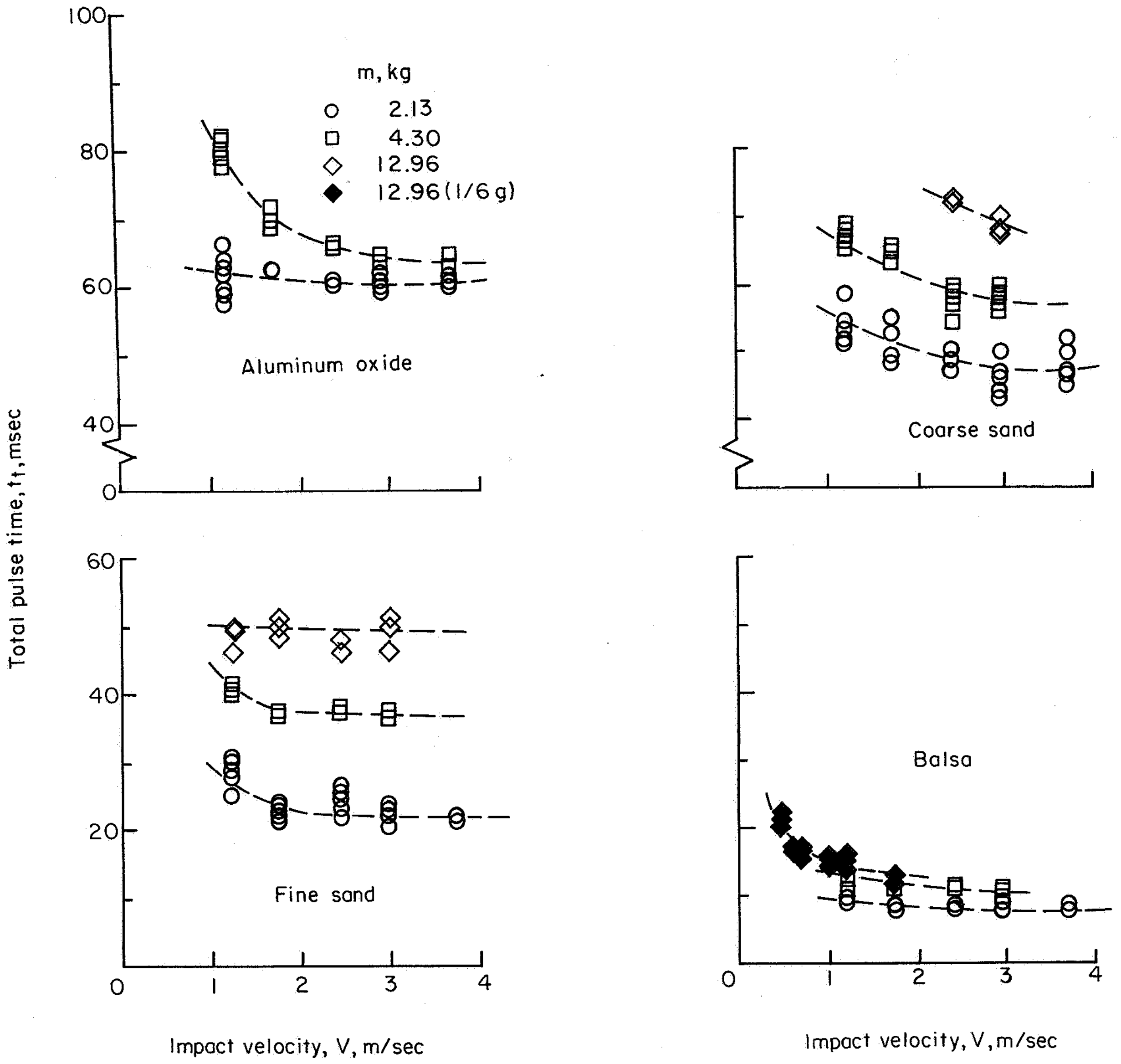
Figure 11.- Summary of peak acceleration data from impact tests using lunar surveying staff with basic penetrometer configuration.



(c) Fine sand.

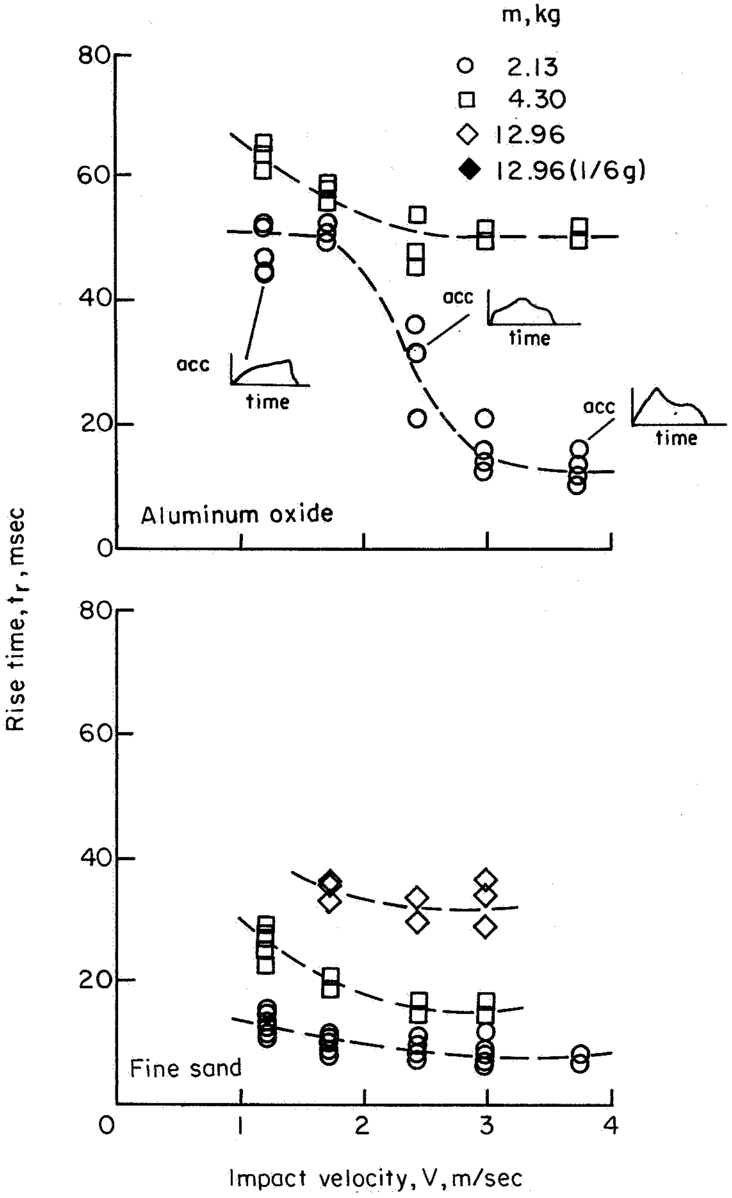
(d) Balsa.

Figure 11.- Concluded.



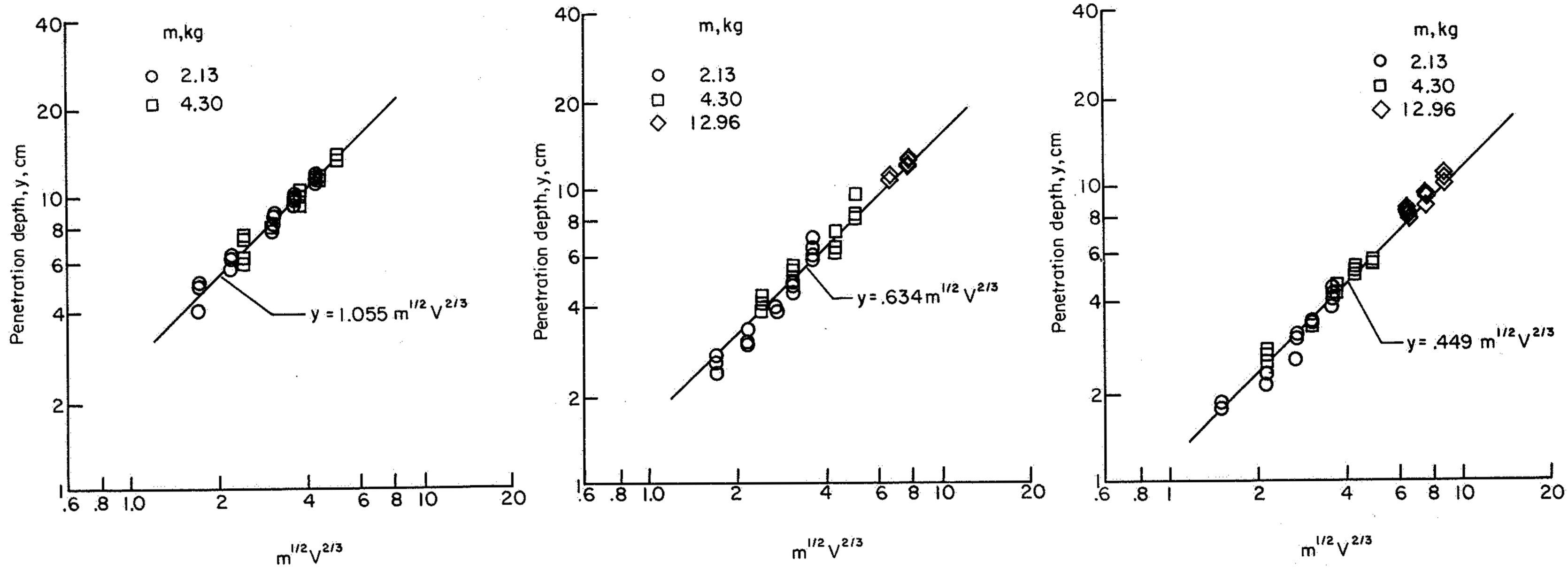
(a) Total pulse times.

Figure 12.- Characteristic times from acceleration time histories recorded during lunar surveying staff basic penetrometer impact tests.



(b) Rise times.

Figure 12.- Concluded.

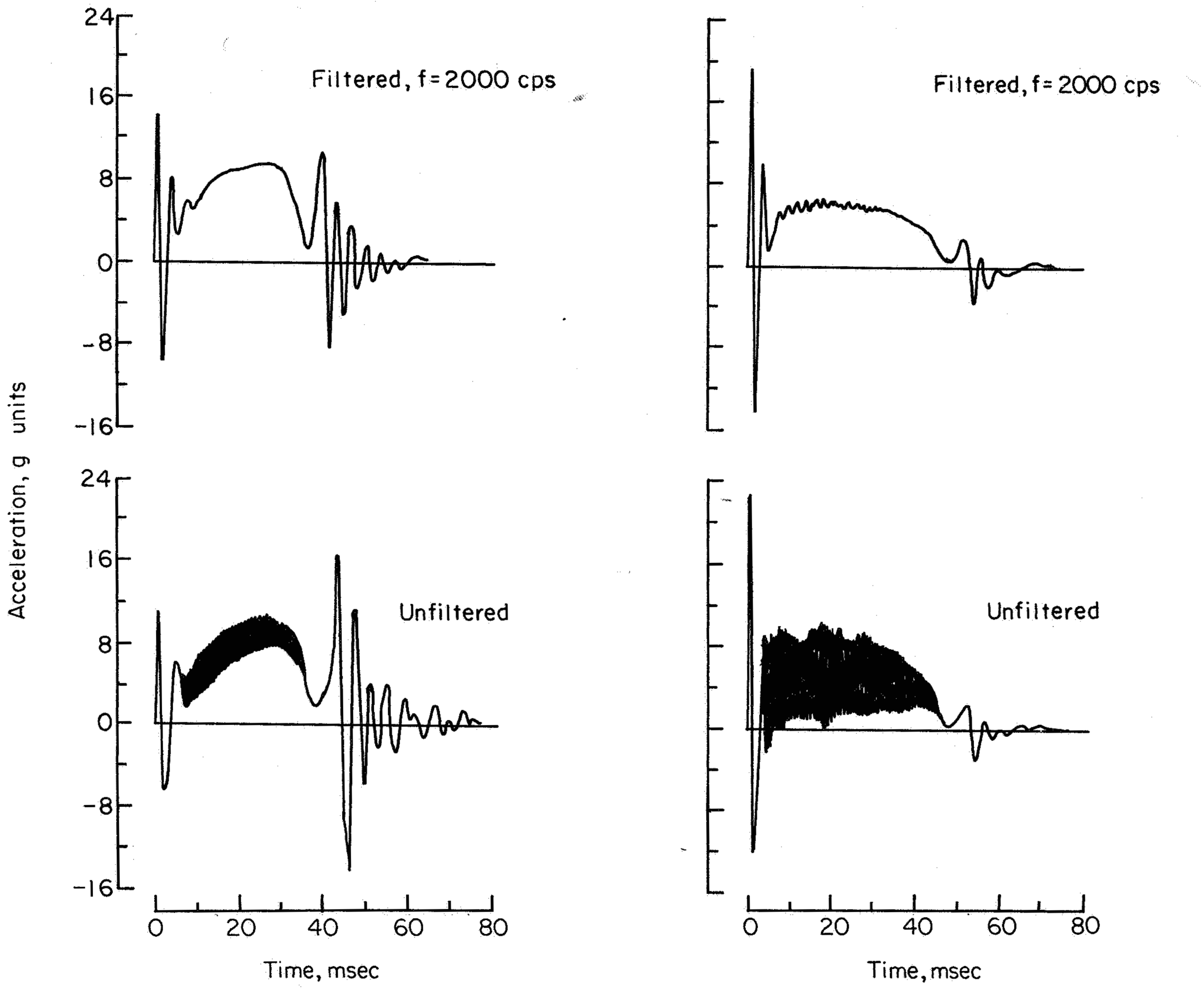


(a) Aluminum oxide.

(b) Coarse sand.

(c) Fine sand.

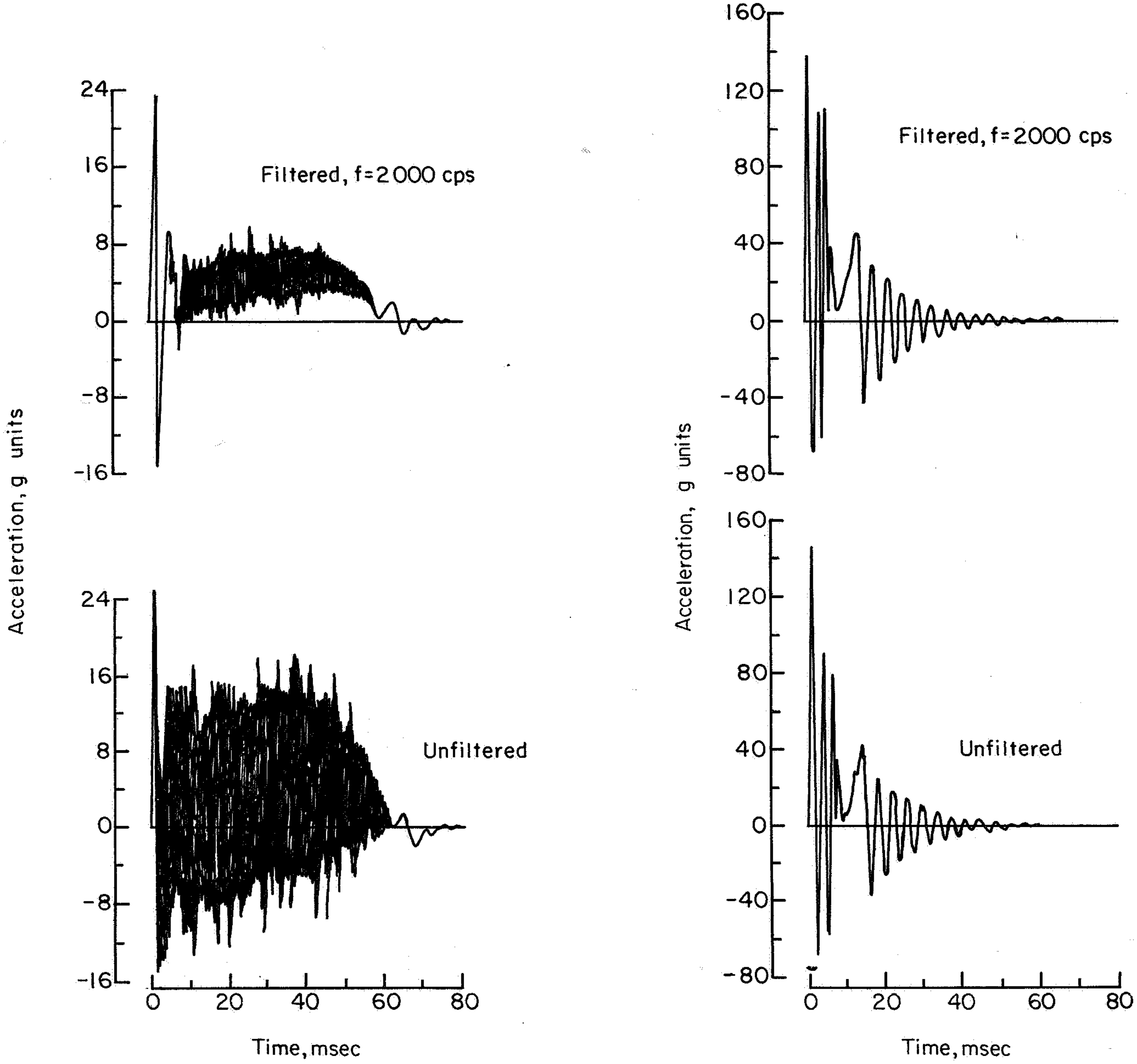
Figure 13.- Summary of penetration depths from impact tests using lunar surveying staff with basic penetrometer configuration.



(a) Fine sand. V = 2.44 m/sec.

(b) Coarse sand. V = 2.44 m/sec.

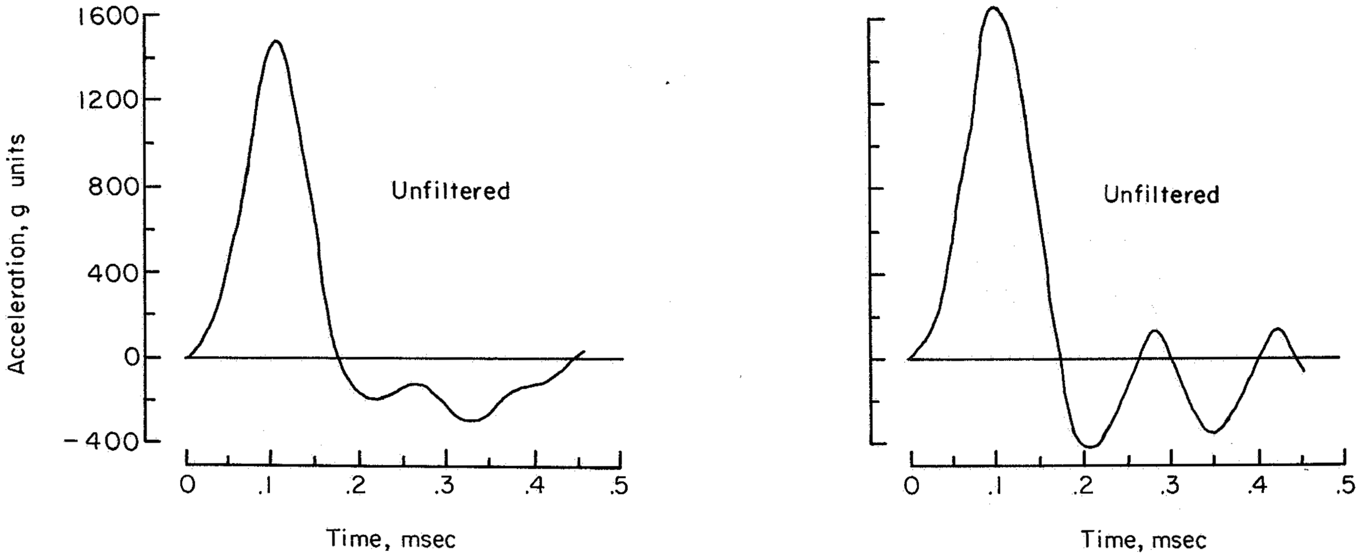
Figure 14.- Typical acceleration time histories recorded during impact on various target materials of lunar surveying staff having a penetrometer with isolated components. (See fig. 4(a).) m = 2.13 kg.



(c) Aluminum oxide. V = 2.44 m/sec.

(d) Balsa. V = 2.44 m/sec.

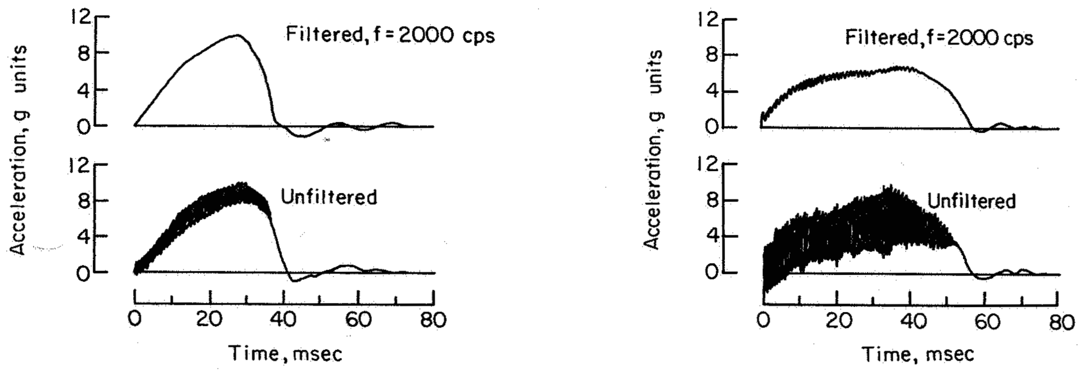
Figure 14.- Continued.



(e) Lead. V = 1.06 m/sec.

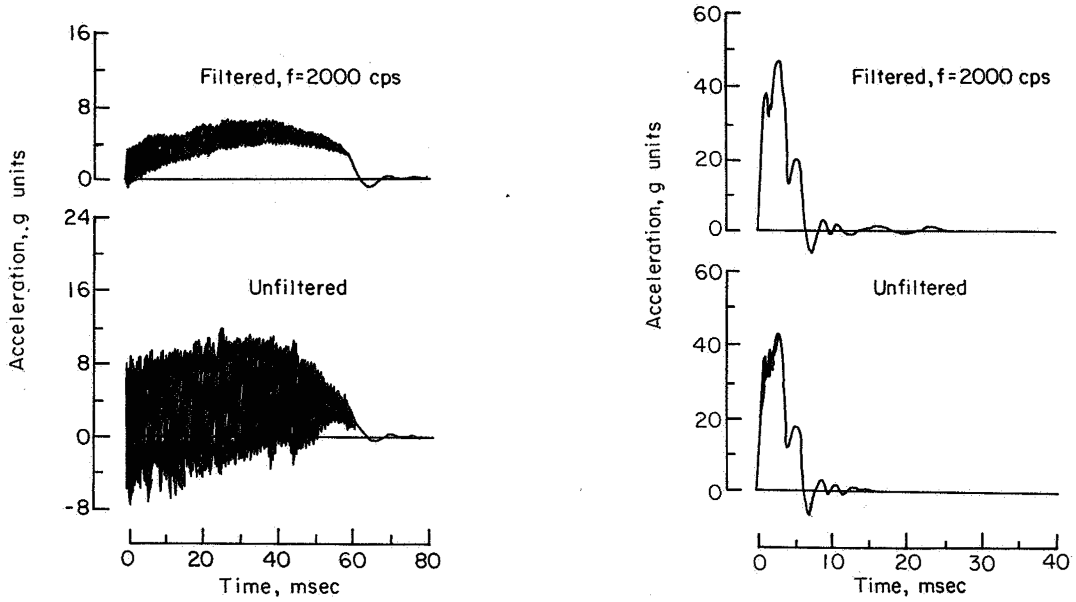
(f) Concrete. V = 1.06 m/sec.

Figure 14.- Concluded.



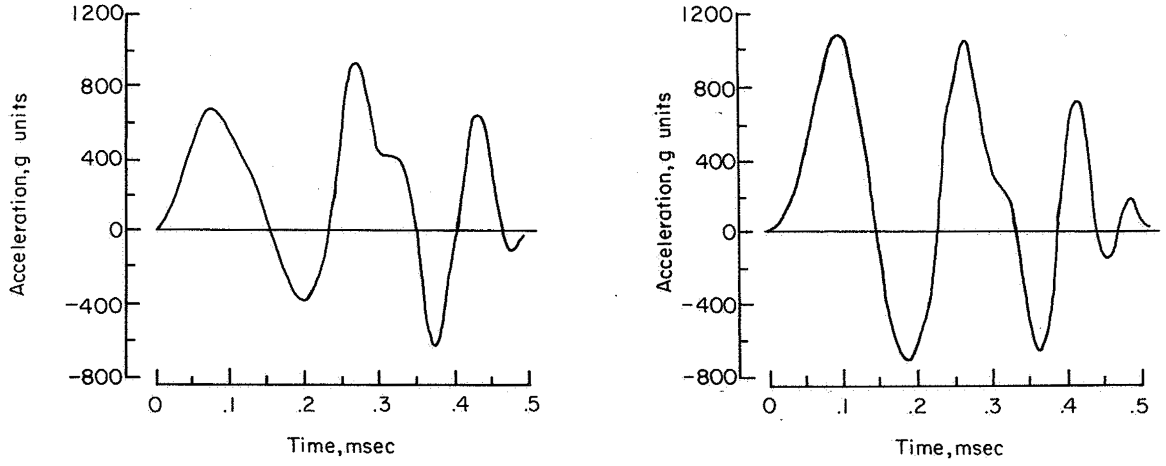
(a) Fine sand. V = 2.44 m/sec.

(b) Coarse sand. V = 2.44 m/sec.



(c) Aluminum oxide. V = 2.44 m/sec.

(d) Balsa. V = 2.44 m/sec.



(e) Lead. V = 1.06 m/sec.

(f) Concrete. V = 1.06 m/sec.

Figure 15.- Typical acceleration time histories recorded during impact on various target materials of lunar surveying staff having isolated penetrometer assembly. (See fig. 4(b).) m = 2.13 kg.

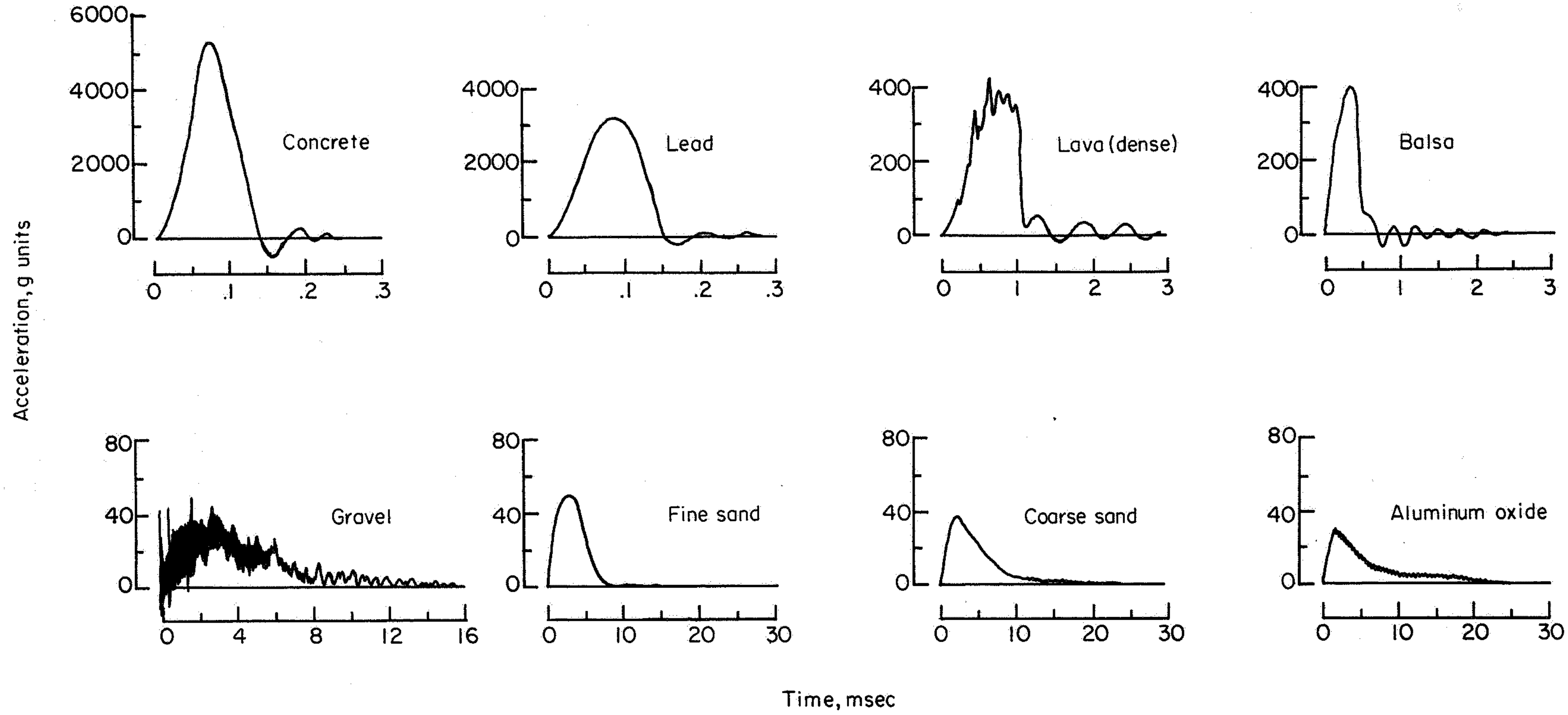
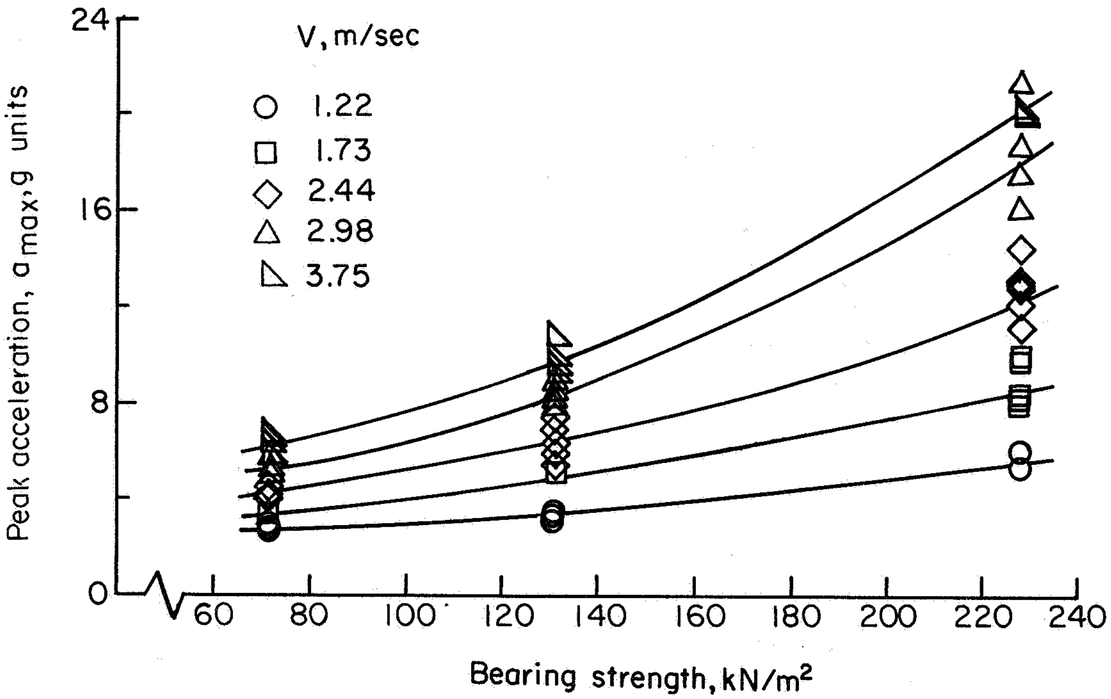
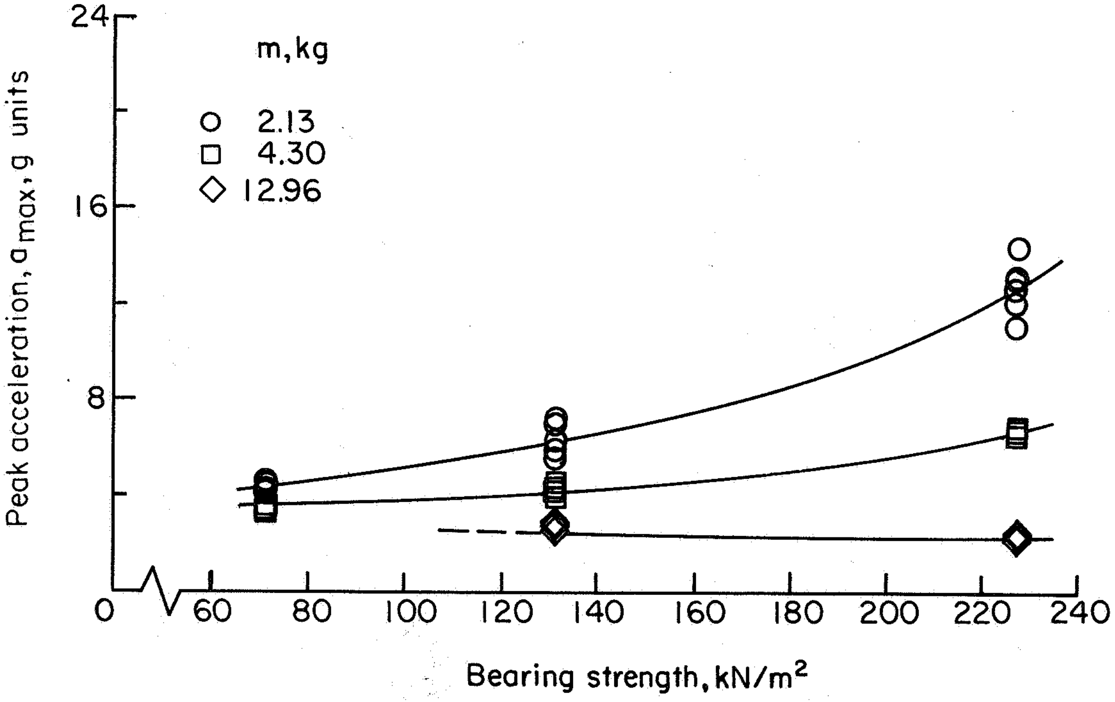


Figure 16.- Typical acceleration time histories recorded during impact of link-mounted lunar surveying staff penetrometer on various target materials. m = 0.118 kg; V = 2.59 m/sec.



(a) Velocity variable. m = 2.13 kg.



(b) Mass variable. V = 2.44 m/sec.

Figure 17.- Variation of peak impact accelerations with target bearing strength.

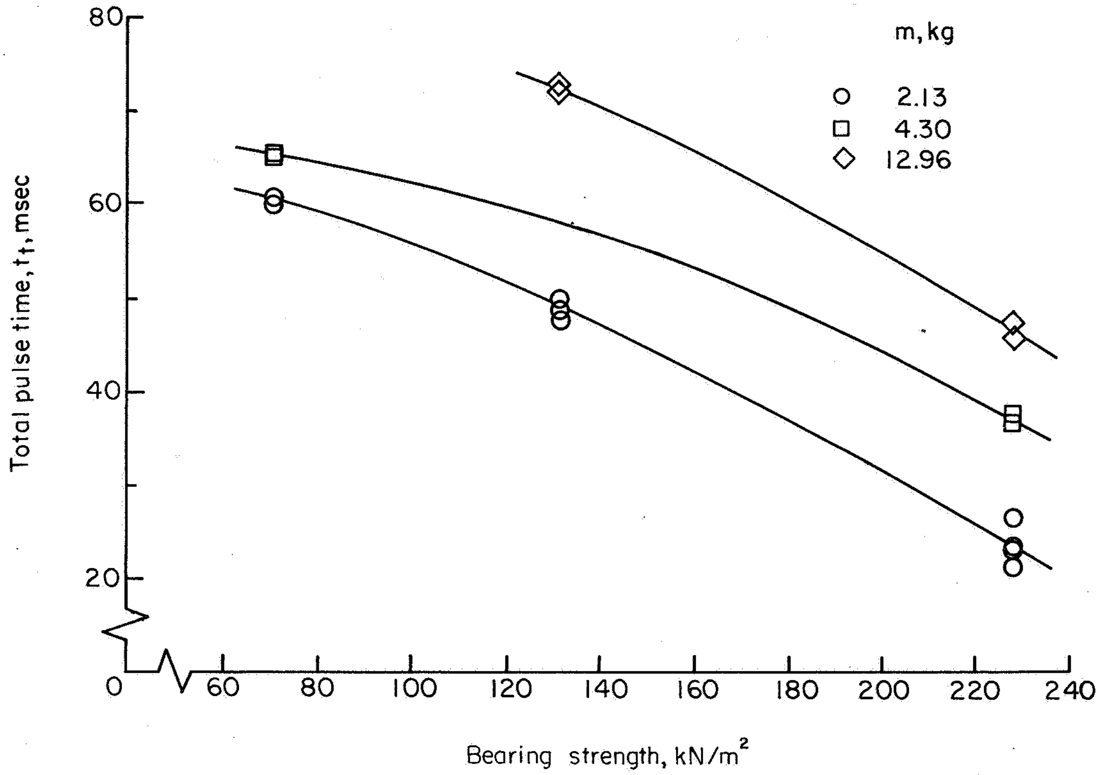


Figure 18.- Variation of pulse time with target bearing strength. V = 2.44 m/sec.

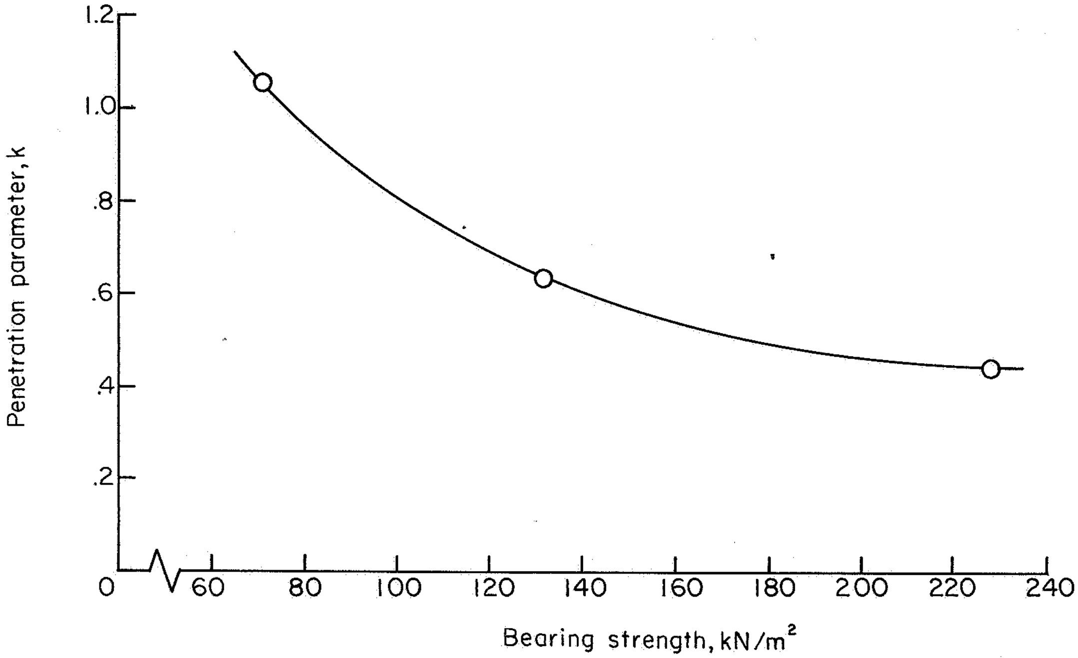


Figure 19.- Variation of penetration parameter with target bearing strength. $k = y/m^{1/2}V^{2/3}$.

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—National Aeronautics and Space Act of 1958

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