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INSTRUMENTATION FOR EARTH STRESSES AND MOTIONS PRODUCED BY EXPLOSIONS

by

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Foreword

This report is based on a paper presented at the New York Academy of Sciences conference on "Prevention of and Protection Against Accidental Explosions of Munitions, Fuels and Other Hazardous Mixtures" on 12 October 1966.

The material presented was obtained as a result of U. S. Army Engineer Waterways Experiment Station (WES) participation for several years in nuclear weapons effects research sponsored by the Defense Atomic Support Agency (DASA) and the Office, Chief of Engineers (OCE), U. S. Army, Washington, D. C.

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Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	25.4	millimeters
feet	30.48	centimeters
pounds	0.45359237	kilograms
tons	907.185	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
feet per second	30.48	centimeters per second

Summary

Instrumentation for measurement of earth stresses and motions caused by explosions is described. Emphasis is on field transducers used in the strong shock region beyond the crater and on gages used in blast-simulation devices in the laboratory. Included in the discussion of stress, strain, and motion sensors is a description of a newly developed dynamic soil stress gage and various other current devices applicable in this field. Problems associated with gage installation and placement are discussed.

Requirements of the electronic signal conditioning and recording equipment are mentioned. These requirements include frequency response and data processing.

INSTRUMENTATION FOR EARTH STRESSES AND MOTIONS

PRODUCED BY EXPLOSIONS

Introduction

Background

1. Research concerned with nuclear weapons effects is conducted by the Waterways Experiment Station (WES) utilizing theoretical, analytical, and experimental methods. The experimental work is carried out by means of small-scale high-explosive tests, special laboratory tests, and full-scale nuclear tests. Investigations are concerned chiefly with the design of protective structures and with underwater explosion effects.

2. Earth stress and motion measurements are made in conjunction with protective structures experimentation and explosion effects tests. Free-field measurements are made to study the behavior of soils under dynamic loads. Measurements are also made to determine loading conditions as well as the response of buried structures to loading.

3. Instruments used to record data are light-beam galvanometer oscillographs, magnetic tape recorders, and cathode-ray oscilloscopes. Frequency modulated (FM) magnetic tape recorders (0-20 kHz bandwidth) are usually supplemented to some extent with oscillographs. Oscilloscopes are often needed to record data from small-scale high-explosive tests or laboratory tests on rock models or rock-simulation materials.

Purpose and scope

4. The purpose of this report is to describe some of the instruments used to measure earth stresses and motions in explosion effects tests. Although many commercial transducers are used, it is often necessary to modify a commercial device or to develop an instrument to meet a particular need. Most of the transducers to be described fall into the latter category.

5. Only transducers will be discussed in detail since, in general, adequate electronic signal conditioning and recording equipment is available from commercial sources. Usually the transducer requirements are the most difficult to meet in explosion effects measurements.

6. Fig. 1 is a schematic illustration of the regimes of interest and the types of structures under consideration. Measurements are required in soil and rock and on structures in regions where stress levels

Fig. 1. Types of protective structures

range from approximately 10 to 100,000 psi.* Peak particle velocities range from approximately 0.1 to 100 ft/sec. Measurements are made both in the field and in laboratory tests in various simulation devices, some of which are described in reference 1.

Description of Transducers

Soil stress gages

7. For design of protective structures, stress measurements are needed in the free field (remote from boundaries) of the material in which the structures are located, and on the surfaces of the structures. The

* A table of factors for converting British units of measurement to metric units is presented on page 19.

ideal gage would have the same deformation modulus and Poisson's ratio as the material in which it is installed. For dynamic measurements the densities of gage and soil should match to avoid inertial errors. Moreover, previous investigators² concluded that a disk-shaped gage should have a diameter-to-thickness ratio greater than 5 to avoid errors caused by stress distribution around the gage. Because of the wide range in soil properties, it is not practical to match the gage compliance to that of the soil; this would require several gages. In addition, a relatively stiff gage is needed to meet the durability and high frequency response requirements of ground shock measurements. A family of soil stress gages, which includes free-field gages and gages for determining loads on buried structures, has been developed at the WES.

8. Free-field gage. The free-field gage, called the SE gage, is described in detail in reference 2. The gage (fig. 2) is 2 in. in overall diameter and 0.25 in. thick. Two 0.75-in.-diameter, stainless steel diaphragms are each gaged with two solid-state (piezoresistive) strain gages. These diaphragms comprise the surfaces of the gage when assembled. The strain gages are connected in a 4-arm bridge circuit with a half bridge on each diaphragm. An epoxy outer rim is cast onto the steel portion to provide a measure of density matching and to obtain the desired aspect ratio. Other pertinent gage characteristics are tabulated below.

Gage output	0.017 mv/v/psi (0.242 mv/v/kg/cm ²)
Linear range	0 to 1800 psi (0 to 126.55 kg/cm ²)
Design pressure	500 psi (35.15 kg/cm ²)
Max pressure limit	2000 psi (140.61 kg/cm ²)
Linearity	0.4 percent full range
Hysteresis	1.6 percent full range
Temperature range	+30° to +150° F (-1.1° to 65.6° C)
Suggested excitation	10 volts
Max excitation	21 volts
Acceleration sensitivity normal to diaphragm	0.04 psi/g (0.0028 kg/cm ² /g)
Apparent strain sensitivity*	20 to 30 μ in./in./psi (2.8 to 4.3 μ /cm/kg/cm ²)
Thermal sensitivity	1 psi/°F (1.3 kg/cm ² /°C)

* Read with strain indicator at gage-factor dial setting of 2.0.

a. Before assembly showing strain gages

b. Assembled gage with epoxy rim

Fig. 2. SE soil stress gage

9. The diaphragm thickness (0.075 in.) is such that the diaphragm's natural frequency is about 40 kHz, and the modulus of rigidity, based on diaphragm center deflection, is about 4×10^5 psi. Thus the gage is much stiffer than most soils, is rugged, and has high frequency response. Rise time to a step shock in an air-driven shock tube is approximately 6×10^{-6} sec.

10. An inclusion more compliant than the soil will yield and allow the stresses to arch around it; conversely a stiff inclusion, such as the SE gage, will carry more stress than the average free field; thus, the gage tends to overregister. This is tolerated in the SE gage in order to gain the previously mentioned features. The overregistration can be compensated for by proper calibration.

11. Piezoresistive strain gages are inherently more temperature-sensitive than the more conventional foil or wire gages; thus, despite precautions with full bridges, temperature compensation, etc., the SE gages are fairly temperature-sensitive. Fortunately this is not a problem, since the gage ordinarily operates in a stable temperature environment.

12. Perhaps the largest unknown in the measurement is the effect of gage placement. It is virtually impossible to control the density precisely, and to be sure of initial conditions when placing gages in "undisturbed" soil. However, these effects are being studied in carefully controlled laboratory tests and satisfactory placement techniques are being devised.

13. Several SE gages have been fabricated and are being used routinely in the laboratory. They have also been used in five large high-explosive tests at Suffield Experimental Station, Ralston, Alberta, Canada. Fig. 3 shows typical results from a laboratory test in a small blast simulator. The major oscillations on the SE gage traces are characteristic of the test chamber and are not caused by the gages ringing.

14. On-structure gages. Several gages have been developed at the WES for measuring dynamic soil stress on the surface of buried structures. These gages are essentially miniature load cells which employ strain gages to measure strains in end-loaded metal columns. Both aluminum and stainless

Fig. 3. Typical SE gage oscillogram from test in blast simulator

steel have been used with foil and solid-state strain gages as sensors. These gages are very stiff and are designed (including the mount) so that the sensing face remains flush with the structural surface under load. Fig. 4 is a photograph of three typical on-structure gages. Because of their relatively large size and weight, they are not suited

Fig. 4. Three on-structure stress gages

for measurements on thin shell structures. The IF gage is extremely stiff and was designed for use on thick-walled, reinforced concrete structures. Incidentally, this model was used to measure gas pressure transients with peaks of 7000 psi in the firing tubes of the WES blast generator. Excellent records were obtained.

15. Smaller gages have been designed specially for specific applications associated with laboratory measurements on model structures. An

adaptation of model FS was used by the Air Force Weapons Laboratory for soil stress loading of a model silo. Another version is currently in use in the Blast Load Generator facility to measure pressure on a model slab.

Soil strain gages

16. For the past several years, free-field soil strains have been measured largely by a variety of "spool" type gages. A typical gage of this type is described in reference 3. Similar gages have been used by several investigators. These gages consist of telescoping tubes attached to thin, stiff disks, the spacing of which determines the gage length. Relative motion is usually sensed with a linear variable differential transformer (LVDT) or a linear potentiometer. Spool gages ranging in length from a fraction of an inch to several inches long have been used with varying degrees of success. A major problem with spool type gages is minimizing friction and binding between the coupled parts which are constrained to move rectilinearly. Adaptations of this basic method have been used to measure strains or displacements over distances of several feet.⁴

17. A recent innovation by the Illinois Institute of Technology Research Institute (IITRI) overcomes the binding problem by using two uncoupled, disk-shaped coils in an inductive transducer.⁵ A pair of coils are placed parallel to each other in the soil as close as possible to the desired separation (gage length). Soil is placed between the coils in a sandwich fashion. One coil, which is excited with 10 to 50 kHz alternating current, serves as the primary coil; voltage proportional to spacing is induced into the secondary coil. An additional matched pair of coils, which complete a bridge circuit, are mounted on a micrometer stand located at the recording station. By proper calibration and adjustment of the micrometer, the gage length of the buried coils can be determined prior to application of the load.

18. The original gage coils (fig. 5) were about the size of a five cent piece and were designed for use in laboratory soil specimens. Subsequently, larger coils (about 4 in. in diameter) have been developed for

Fig. 5. IITRI decoupled strain gages

field use. Sensitivity is sufficient to permit use of the larger coils at spacings of several inches. An obvious difficulty with the uncoupled coil gage is in placement and possible errors resulting from misalignment or rotation of the disks; however, tests have shown that acceptable accuracy is attainable even when the coils are deliberately misaligned prior to loading.⁵

Rock strain gages

19. Strain histories are often required in connection with structural response and wave propagation studies in rock and simulated-rock materials. Although some improvements have been made recently in the manufacture of strain gages and associated electronic equipment, the techniques for making strain measurements in rock have not changed appreciably in recent years. The methods of Obert and Duvall⁶ are still used effectively. Strain gages are bonded to intact cores in desired orientations on flat, ground surfaces. Waterproofing and maintaining good bond to the rock are the most difficult problems. Brass or copper shims are often used to help overcome these problems.

20. A major factor in the success of these measurements is proper coupling of the gaged core with the surrounding rock. Special grouts are used to match the acoustical impedance and modulus of the rock.

21. The WES has developed satisfactory techniques for installing strain gages in cement grout mixtures. The method, as illustrated by

fig. 6, consists of bonding a foil gage to a copper shim which is folded and soldered into a waterproof envelope. (Gages 6 in. long and manufactured by this technique are now available commercially; short gage lengths are not available in this configuration.) The envelope is coated with

Fig. 6. Preparation of foil strain gages for placement in cement grout

epoxy and sprinkled with dry sand to enhance bonding. This package may be placed directly in the grout mass or cast into a smaller block (as shown in fig. 6) to facilitate handling during placement.

Motion gages

22. Accelerometers and velocity gages are widely used to measure structural motions and particle motions of waves moving through the earth. A wide assortment of accelerometers is available from commercial sources. Selection of the instrument for a given task is usually based on frequency response and signal-to-noise requirements.

23. Generally, fluid-damped, variable reluctance gages are used in

nuclear weapons effects tests where acceleration frequencies are usually less than about 600 Hz. The main advantage of these gages is relatively high output and, because of low impedance, low sensitivity to extraneous noise. Range of these instruments is in the order of 1000 g.

24. Fluid-damped, strain gage type accelerometers are used effectively for acceleration bandwidths to approximately 1500 Hz for field testing with relatively short cables. They are also used extensively in laboratory blast-simulation chambers and for measurements from small-scale explosions in soil. Recent commercial developments in which piezoresistive (semiconductor) strain elements are used have extended the maximum acceleration capability of strain gage type accelerometers from about 1000 g to 2500 g.

25. Piezoelectric accelerometers are required for accelerations with peak amplitudes exceeding about 2500 g and frequency components greater than 1 or 2 kHz. Piezoelectric accelerometers are frequently used for small explosions, especially for explosions in rock. However, they are not ordinarily used in nuclear weapons effects tests, primarily because of problems with noise and long cable effects; also the frequencies of interest do not dictate their use.

26. There are several makes of piezoelectric accelerometers on the market. These employ natural piezoelectric materials, such as quartz, and man-made materials such as barium titanate, lead titanate-zirconate, and other ferroelectric materials. Although piezoelectric accelerometers have high natural frequencies, they are usually not damped and will ring or resonate when shock-excited. Electric filters are often used to reduce the ringing from the output signal. These gages are available in fractional gram sizes--a desirable feature when large accelerations are to be measured on relatively lightweight structures. Heavy accelerometers might produce intolerable inertial forces on the test specimen under high-acceleration loading. A minor disadvantage of piezoelectric transducers is their inability to measure reliably at frequencies approaching zero; this is not particularly troublesome in explosion effects measurements.

Velocity gages

27. SRI-SL gage. Although particle velocity can be obtained by

direct (analog) or digital integration of accelerometer signals, it is preferable to measure velocity directly to avoid errors arising from the integration process. Swift, at Stanford Research Institute (SRI), developed a horizontal velocity gage which operated on the principle of an overdamped accelerometer.⁷ An inductive pickup was used to sense the position of a heavily damped pendulum. For damping much greater than critical, the gage output is proportional to velocity over a bandwidth appreciably above and below the undamped natural frequency of the gage. Subsequently, Sandia Laboratory (SL) modified the basic design to effect certain improvements,⁸ one of which permitted the gage to be used for vertical motions. This was done by supporting the pendulum with a weak spring with the pendulum oriented horizontally.

28. In its present form, the SRI-SL velocity gage (fig. 7) weighs about 1.25 lb and is capable of measuring particle velocities ranging from approximately 0.1 to more than 100 ft/sec. Usable bandwidth, which

Fig. 7. Velocity gage sensing element

varies with damping, typically extends from less than 0.1 Hz to more than 200 Hz. These gages have been proven in the field and are being used extensively by several laboratories engaged in explosion effects measurement.

29. Fig. 8a shows records obtained at the 5-ft depth in soil at different ranges between 200 and 560 ft from a 500-ton TNT surface burst;⁹ fig. 8b shows a composite plot of radial particle velocity versus time measured at different ranges λ_R beneath a 2-lb TNT surface burst. The record in fig. 8b shows the attenuation and dispersion of the wave as it moves through the soil.

30. More recently SRI has developed a gage with about half the weight of the previous design.¹⁰ The upper frequency bandwidth has been extended to 500 Hz, and the placement problems should be less because the gage can be used at any inclination. Although the gage has undergone evaluation and calibration in the laboratory, its field performance is unknown at this time.

31. Induction wire gage. The WES is currently using an induction wire technique (used previously by experimenters in hypervelocity impact^{11,12}) to measure particle velocity in soil and rock specimens subjected to impact by a projectile fired from an air-operated gun. Fine wires are installed in the specimen which is then placed in a uniform magnetic field during the impact. Voltage induced in the wire is proportional to magnetic field strength, length of the wire, and velocity of the wire. By placing several wires along the path of the wave, it is possible to measure wave propagation velocity as well as particle velocity. With these values and the initial density of the specimen, the stress-strain relation of the material can be computed. Fig. 9 is a schematic drawing which illustrates the test conditions and fig. 10 shows typical records obtained from the wires.

32. Precise placement of the wires in test specimens is difficult, but satisfactory methods have been developed for soil and rock. Good results have been obtained in tests conducted to date. The method is especially useful in determining material properties at stress levels (for many earth materials) in the transition region from elastic to

Fig. 8. Velocity measurements made with the SRI-SL gage

Fig. 9. Schematic illustration of impact test condition

Fig. 10. Records of velocity from induction wire gage during impact (plexiglas model)

inelastic behavior. This information is useful for predicting wave propagation.

Conclusion

33. Soil stress gages have been described for free-field and on-structure measurements. Under carefully controlled conditions of gage placement and calibration, accuracy of a single stress measurement should be within 20 percent. Use of multiple gages is recommended to improve accuracy in the data.

34. The decoupled, inductive strain gage developed by IITRI offers considerable promise as a field gage. More field experience is necessary to assess interaction effects in multiple-gage arrays and effects of phase shift problems when cables longer than a few hundred feet are used.

35. Although dynamic strain measurements can be made in in situ rock masses using conventional electrical resistance strain gages, care must be taken to assure proper coupling and impedance matching of the zone of disturbance. Unless some independent means is available for determining the stress state in the rock prior to gage placement, the absolute value of the strain will not be known since the strain gage will measure the change in strain.

36. Within its bandwidth, the SRI-SL pendulum velocity gage is an excellent instrument for use in the field, and in other locations where its relatively large mass is not detrimental. Alignment is somewhat critical, but this is not an insurmountable problem. Because of the high output of this gage, it can be used with very long cables--at least 15,000 ft in length. This is the only known instrument capable of direct measurement of particle velocities much greater than a few feet per second.

37. Commercial accelerometers, including variable inductance, strain gage, and piezoelectric types, are adequate for most ground shock measurements. Short duration, intense acceleration pulses, such as those encountered for small charges in rock, are difficult to measure accurately. Piezoelectric gages are indicated for this application. An electronic analog integrator used with a piezoelectric accelerometer offers good

possibilities as a direct velocity-measuring device for use in rock. The induction wire velocity gage is a simple and effective means of measuring particle velocities on soil and rock specimens in the laboratory.

38. Satisfactory electronic recording and signal conditioning equipment is available on the market. Magnetic tape recorders are favored because of the facility of subsequent data processing, either by digital or analog methods. Moreover, signals on tape can often be optimized during playback by changing amplifier gains and tape speeds.

Literature Cited

1. U. S. Army Engineer Waterways Experiment Station, CE, Description, Proof Test, and Evaluation of Blast Load Generator Facility, by G. E. Albritton. Technical Report No. 1-707, Vicksburg, Miss., December 1965.
2. Ingram, J. K., "The development of a free-field soil stress gage for static and dynamic measurements." Instruments and Apparatus for Soil and Rock Mechanics, ASTM STP 392, American Society for Testing and Materials (1965), pp 20-36.
3. Stagner, J. R., and Obenchain, R., Research Studies on Free Field Instrumentation. Air Force Special Weapons Center, Technical Documentary Report No. AFSWC-TDR-63-45 by United Electrodynamics, Inc., Pasadena, Calif., 1963.
4. Instrumentation Accessories for Seismic Measurements. SC-M-65-330, Sandia Laboratory, Albuquerque Divisions 7244, 7245, and 7246, Albuquerque, N. Mex. (1965), pp 23-36.
5. Truesdale, W. B., and Schwab, R. B., Soil Strain Gage Instrumentation. Air Force Weapons Laboratory, Technical Report No. AFWL-TR-65-207 by IIT Research Institute, Chicago, Ill., 1965.
6. Obert, Leonard, and Duvall, Wilbur I., A Gage and Recording Equipment for Measuring Dynamic Strain in Rock. U. S. Bureau of Mines Report of Investigations No. 4581, 1949.
7. Swift, L. M., Development of an Earth Velocity Gage. Defense Atomic Support Agency, DASA-1191, by the Stanford Research Institute, Menlo Park, Calif., 1960.
8. Chabai, A. J., and others, Close-In Phenomena of Buried Explosions. Defense Atomic Support Agency, DASA-1382, by Sandia Research Corporation, Albuquerque, N. Mex. (also published as Sandia Research Report No. 4907), 1 May 1963.
9. U. S. Army Engineer Waterways Experiment Station, CE, Operation Snow Ball; Project 3.6--Earth Motion Measurements, by D. W. Murrell. Technical Report No. 1-759, Vicksburg, Miss., March 1967.
10. Chilton, E. G., Witherly, T. D., and Driebel, H. W., Miniaturized Velocity Gage. Air Force Special Weapons Center, Technical Report No. AFSWC-TR-65-46 by Stanford Research Institute, Menlo Park, Calif. (In preparation.)
11. Frasier, J. T., Hypervelocity Impact Studies in Wax. Report No. 1124, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., 1961.
12. Ripperger, E. A., and Yeakley, L. M., "Measurement of particle velocities associated with waves propagating in bars." Experimental Mechanics, vol 3, No. 2 (1963), pp 47-56.

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