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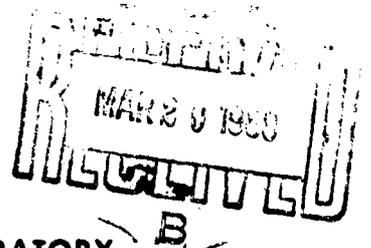


# AN ANNOTATED BIBLIOGRAPHY OF PROTECTIVE STRUCTURES RESEARCH

Mary J. C. Garcia  
Civil Engineering Technical Information Service  
(CETIS)

TECHNICAL REPORT NO. AFWL-TR-67-145

February 1968



AIR FORCE WEAPONS LABORATORY  
Air Force Systems Command  
Kirtland Air Force Base  
New Mexico

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OF PROTECTIVE STRUCTURES RESEARCH

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AIR FORCE WEAPONS LABORATORY  
Air Force Systems Command  
Kirtland Air Force Base  
New Mexico

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FOREWORD

This report was prepared under Program Element 6.16.46.01.H, Project 5710, Subtask PSS3157.

This report was submitted by the author 14 December 1967. Inclusive dates of research were December 1966 to December 1967. This technical report supersedes AFWL-TR-66-160.

The author wishes to acknowledge the previous bibliographies in this area that have been done by Captains Douglas H. Merkle, John E. Scott, Mahlon E. Traylor, Jr., and Lieutenants Richard L. Player, Jr., and Roger A. Gurner. The author has obtained a large amount of material from their reports.

This report has been reviewed and is approved.

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ABSTRACT

(Distribution Limitation Statement No. 2)

Summaries of research reports dealing with nuclear weapons effects on protective structures as well as with the analysis and design of such protective structures are presented. These summaries are from reports published by the Civil Engineering Branch, Development Division, Air Force Weapons Laboratory, and predecessor organizations from July 1951 to December 1967. The bibliography is arranged in four sections. Section I contains edited abstracts of technical memoranda, technical notes, technical reports, and technical documentary reports. (Parts A, B, C, and D.) Section II gives a chronological listing of all undesignated reports and weapons test reports related to protective structures published before July 1958. Section III lists all designated reports by document number including title, publication date, and classification. Section IV gives a listing by contractor.

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SECTION I

Edited abstracts of Technical Memoranda, Technical Notes, Technical Reports,  
and Technical Documentary Reports (Parts A, B, C, and D).

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## INTRODUCTION

This bibliography is a compilation of research reports dealing with nuclear weapons effects on protective structures as well as with the analysis and design of such protective structures. These reports have been published by the Civil Engineering Branch, Development Division, Air Force Weapons Laboratory, and predecessor organizations from July 1951 to December 1967.

A large amount of the information appearing herein has been excerpted from the following reports:

- a. Garcia, Mary J. C., "An Annotated Bibliography of Protective Structures Research," AFWL-TR-66-160.
- b. Gurner, Roger A., Lt, USAF, "An Annotated Bibliography of Protective Structures Research," AFWL-TR-65-141.
- c. Merkle, Douglas K., Capt, USAF, "Project 1080 Research Summary," August 1963, RTD TDR 63-3023 (Revised March 1964).
- d. Scott, John E., Capt, USAF, "A Summary of Recent Reports Produced Under AFSC Project 1080," September 1961, AFSWC TN 61-26.
- e. Traylor, Mahlon E., Jr., Capt, USAF and Player, Richard L., Jr., Lt, USAF, "A Summary of Reports Produced Under ARDC Project 1080," March 1959, AFSWC TN 59-11.

Section I contains edited abstracts of the reports arranged by document number designation as indicated below:

- TM - Technical Memorandum
- TN - Technical Note
- TR - Technical Report
- TDR - Technical Documentary Report

For each report the following information is shown:

- Report Number
- AD (Accession Document) Number--The Defense Documentation Center number assigned to the document, if available.
- Title
- AF Contract Number

Report Contractor

Publication Date

Security Classification--U - UNCLASSIFIED

OUO - OFFICIAL USE ONLY

C - CONFIDENTIAL

S - SECRET

S-FRD - SECRET FORMERLY RESTRICTED DATA

SRD - SECRET RESTRICTED DATA

**Report Summary**

Section II lists, in chronological order, undesignated reports published prior to July 1958, with the following information:

TITLE	DATE	CLASSIFICATION	CONTRACTOR	AVAILABILITY
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Section II also contains a numerical index of Weapons Test Reports related to protective structures published from 1951 to 1959.

Section III lists all designated reports by document numbers.

Section IV lists reports by contractor in the following manner:

Contractor	TM	TN	TR	TDR
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None of the reports listed in this bibliography are available for distribution from the Air Force Weapons Laboratory; however, where an AD number is indicated, copies may be obtained from the Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314.

## BACKGROUND

The Civil Engineering Branch of the Development Division, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, began in 1950 as the Special Studies Office of the Design Branch, Installations Engineering Division, Headquarters Air Material Command (AMC), Wright-Patterson AFB, Ohio. Originally intended to handle civil engineering problems of a difficult or unusual nature throughout AMC, the Special Studies Office also provided engineering support for Air Force participation in nuclear field test operations GREENHOUSE (1951), JANGLE (1951), and UPSHOT KNOTHOLE (1953). Personnel in the group were from both AMC and Air Research and Development Command (ARDC), and a large share of their mission requirements came from the Office of the Chief of Intelligence, USAF. Most of the early reports written for the group deal with target analysis, physical vulnerability, and damage assessment.

As interest in nuclear weapons effects increased, emphasis within the Special Studies Office shifted from damage assessment to developing design criteria for structures intended to withstand nuclear attack. In 1955, the group was transferred entirely to ARDC, under the leadership of Eric H. Wang, and became the Blast Effects Research Group of the Aeronautical Research Laboratory, Wright Air Development Division, Wright-Patterson AFB, Ohio.

In September of the following year, "Nuclear Weapons Effects on Hardened Structures," designated Project 1080, was transferred to the Air Force Special Weapons Center, Kirtland AFB, New Mexico, and the Blast Effects Research Group then became the Structures Division of the Research Directorate, Air Force Special Weapons Center (AFSWC). When the Air Force Weapons Laboratory (AFWL) was formed in May 1963, at Kirtland AFB, it became the Structures Branch, Research Division, AFWL, and in May 1964, it became the Civil Engineering Branch of the Research Division. On 1 February 1965, the Branch was transferred to the Development Division of the Laboratory.

Project 1080, Nuclear Weapons Effects on Hardened Structures, was superseded by Project 5710, Nuclear Weapons Effects Research and Testing, effective 1 April 1964. Under this project there are four subtasks which are the responsibility of the Civil Engineering Branch:

1. Determination of Dynamic Properties of Soils
2. Dynamic Response of Buried Structural Systems and Materials
3. Development of Techniques for Simulation of Nuclear Weapons

**Blast Effects**

4. Effects of Dynamic Response of Structures on Contents

This bibliography will be updated periodically with summaries of research reports generated by both in-house and contractor projects connected with these subtask areas.

**PARTS A, B, C, AND D**

**PART A: TECHNICAL MEMORANDA**

**PART B: TECHNICAL NOTES**

**PART C: TECHNICAL REPORTS**

**PART D: TECHNICAL DOCUMENTARY REPORTS**

SWC-TM-57-2

AD-467 201

PROCEEDINGS OF FIRST SHOCK TUBE SYMPOSIUM, 26-27 FEBRUARY 1957

In-house

February 1957

U

This report presents papers delivered at the first AFSWC Shock Tube Symposium. The purpose of the symposium was to promote exchange of information on progress in shock tube research at numerous shock tube laboratories. The papers presented are listed below:

- (1) The Air Force Shock Tube as a Research Tool
- (2) Design and Performance of the General Electric Six-Inch Shock Tunnel Facility
- (3) The Development of a Shock Tube to Generate Variable Stepped Shock Fronts
- (4) Studies of Transient Air Forces on Two-Dimensional Airfoils
- (5) Studies of Grids in Shock Tubes
- (6) The Development of the Shock Tube Facility for Airfoil Studies
- (7) The Surface Film Thermometer: A Versatile Shock Tube Technique
- (8) Some Observations of Bifurcated Reflected Shock Waves
- (9) Numerical Solution for the Reflection of a Compression Wave from a Rigid Wall
- (10) The Use of the Shock Tube in Hypersonic Research
- (11) Study of Re-entrant Corners

SWC-TM-58-3

AD-211 239

PROCEEDING OF THE SECOND SHOCK TUBE SYMPOSIUM, 5-6 MARCH 1958

In-house

March 1958

U

Papers given at the second AFSWC Shock Tube Symposium are presented in this report. The symposium reviewed modern developments, techniques, operation, and instrumentation of shock tubes. Below is a list of papers presented:

- (1) Shock Tube Wind Tunnel Research at the US Naval Ordnance Laboratory
- (2) Shock Tube Studies of Blast Pressures Behind Frangible Wall Panels
- (3) A Comparison of Shock Tube and Field Test Data on the Pressure Buildup Behind Frangible Walls

- (4) Some Results of a Shock Tube for Biomedical Investigation
- (5) Experimentation with the General Electric Six-Inch Shock Tunnel
- (6) Pressure-Time History in a Chamber Subjected to Shock Wave Filling Through an Orifice
- (7) Determination of the Time History of the Flow Field About Blunt Bodies in a Shock Tube
- (8) Some Experiments with Periodic Shocks
- (9) On the Effect of Attenuation on Gas Dynamic Measurements Made in Shock Tubes
- (10) Generation of Pressure Wave Forms Through the Detonation of Explosive Charges
- (11) Problems in the Use of Piezo-Gages for Shock Tube Instrumentation
- (12) Determination of the Dynamic Response Characteristics of Pressure Measuring Systems Utilizing Shock Tube Testing Techniques
- (13) High Temperature Effects in Shock Structure
- (14) Shock Wave Calculations for High Temperature Gases
- (15) Heat Transfer Measurements on a Hemisphere-Cylinder in the Lockheed Three-Inch Shock Tube
- (16) A Particular Application of a Conventional Shock Tube for the Study of Transient Ignition and Combustion in Subsonic Flow
- (17) One-Dimensional Shock Waves from an Axially Symmetric Electrical Discharge

SWC-TM-59-1

AD-

FOURTEENTH MEETING OF THE PANEL ON BLAST EFFECTS ON  
BUILDINGS AND STRUCTURES, AND PROTECTIVE CONSTRUCTION, VOLUME I

In-House

October 1958

SFRD

The agenda of the fourteenth meeting of the panel on blast effects on buildings and structures are mainly devoted to presentations by contractors working on problems arising from Project 1080, "Nuclear Weapons Effects on Standard and Hardened Structures." The purpose of this meeting of the panel is to give each contractor a good overall picture of the integrated program of Project 1080 and to enable them, as well as the consultants and representatives of the interested government agencies to comment on these efforts. Project 1080 is divided into tasks; presentations will be by task in order to present the work in the same field in consecutive order. A discussion will follow each presentation.

## PROCEEDINGS OF THE THIRD SHOCK TUBE SYMPOSIUM, 10-12 MARCH 1959

In-house  
March 1959

U

This report presents papers delivered at the third Air Force Special Weapons Center Shock Tube Symposium. The purpose of this symposium was to exchange information of the development, techniques, operation, and instrumentation on shock tubes. The papers presented and their authors are listed below:

- (1) Resume of Experiments Conducted in the High-Pressure Shock Tube of the Gas Dynamics Laboratory at NASA--Jim J. Jones, NASA Langley Research Center
- (2) A Probe for Determining Flow Conditions in a Short Duration Hypersonic Stream--A. V. Former, Lockheed Aircraft Corporation
- (3) Flow Phenomena in the Convair Free Jet Shock Tunnel--Karl A. Faymon, Theoretical Aerodynamics Group, Convair
- (4) An Explosive Driven Conical Shock Tube for the Study of Spherical Shock Waves--William S. Filler, US Naval Ordnance Laboratory
- (5) Kinetics of Hydrogen Recombination in a Chemical Shock Tube--C.V. Metzler and W. H. Moberly, North American Aviation, Inc., Rocketdyne Division
- (6) Measurement of  $O_2$  Concentration Behind Shock Waves Using an Ultraviolet Absorption Technique--John S. Evans and Charles J. Schexnayder, NASA Langley Research Center
- (7) Diffusion Effects on Shock Structure in a Plasma--O. W. Greenberg and H. K. Sen, Air Force Cambridge Research Center, and Y. M. Treve Block Associates, Inc.
- (8) Techniques of Pressure Measurement on an Airfoil in a Shock Tube--J. Ray Rustenik
- (9) The Application of Pressure and Force Transducers in Shock Tunnel Aerodynamic Studies--C. J. Harris and E. M. Kaegi, General Electric, Missile and Ordnance Systems Department
- (10) Shock Tube Studies of the Effects of Sharp-Fising, Long-Duration Overpressures on Biological Systems--D. R. Richmond, R. V. Taborelli, F. Shering, M. B. Wetherbe, R. T. Sanchez, V. C. Goldizen, and C. S. White, Lovelace Foundation
- (11) Program for the NCKL Blast Simulator--S. L. Bugg, Naval Civil Engineering Laboratory
- (12) Factors in the Design of Shock Tube Facilities--D. B. Singer, Armour Research Foundation
- (13) The Shock Chamber--A Device for Producing High Strength, Spherically Expanding Shock Waves--Kenneth Kaplan and A. B. Willoughby, Broadview Research Corporation
- (14) A One-Inch Force Cage for Drag Measurements in the Shock Tube--William C. Zuka, US Naval Ordnance Laboratory

- (15) Changes in Drag Caused by Shielding--George A. Coulter, Ballistic Research Laboratories
- (16) A Comparison of Pressure Coefficients Obtained in Wind Tunnels to Shock Tube and Field Tests--Captain Marcus L. Whitfield, Armed Forces Special Weapons Projects
- (17) Interaction of Blast Waves with Wings, Part I. Ten-Foot Diameter Free Jet Shock Tube--Harold B. Pierce, NASA Langley Research Center
- (18) Interaction of the Blast Wave with Wings, Part II. Wave-Table Studies--Donald R. McFarland, NASA Langley Research Center
- (19) Experiments and Theory on Explosive Decompression in the Six-Foot Shock Chamber--T. H. Schiffman and A. H. Wiedermann, Armour Research Foundation
- (20) Theory of Filling Process for Chambers; Shock Tube and Field Tests--A. H. Wiedermann, Armour Research Foundation
- (21) Diaphragm Calibration Techniques in a 2.00-inch Diameter Shock Tube--George H. Tweney, Boeing Airplane Company

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SWC-TN-56-66

AD-358 730

TEST PLAN FOR PROJECT 3.4 OPERATION PILGRIM (PLUMBBOB)

33(616)-2534: Armour Research Foundation

October 1956

S-RD

This report outlines a test plan for Operation PILGRIM Project 3.4, utilizing existing structures at the Nevada Test Site. The test plan includes (1) response of drag-type buildings, (2) tests of concrete panels, (3) air-blast effects on underground structures, (4) interior loading and response of underground structures in the precursor region, (5) blast loading on interior obstacles, (6) blast loading behind failing walls, and (7) miscellaneous items.

Note: This operation later became the full-scale atomic test PLUMBBOB.

SWC-TN-57-18

AD-460 995

STUDY OF SHOCK ABSORBENT DEVICES

33(616)-2534: Armour Research Foundation

May 1957

U

Theoretical analyses carried out in this study show it is possible to eliminate reflections of a plane flat-top blast wave at the partially open end of a shock tube. This is done by placing a grid at the tube end. Area ratio is the principal variable defining reflected signal magnitude, grid geometry and viscosity being of secondary importance. Analysis predicts reflected signal magnitude when a shock wave is incident upon the grid at the shock tube end.

Analysis further illustrates the effectiveness of the grid in both reducing and delaying the reflected signal from the shock tube end whenever a peaked shock wave is incident upon it.

The case of a grid in a constant area channel (shock tube) is also treated and the transmitted and reflected shock wave strengths are presented (for air). Results are presented as a function of incident shock strength and grid area ratio.

SWC-TN-57-27

AD-153 637

THE FEASIBILITY OF GENERATING VARIOUS DESIRED PRESSURE WAVE FORMS IN SHOCK TUBES THROUGH THE SUCCESSIVE DETONATION OF EXPLOSIVE CHARGES

33(616)-2534: Armour Research Foundation

August 1958

U

This report presents an analysis of gas flow relationships behind an explosive-generated shock front advancing in a constant area channel. A density distribution behind the shock front of the form

$\rho = \rho_g \left(\frac{r}{R}\right)^g$  is assumed, where  $\rho$  is gas density at a distance  $r$ , from the explosion source, and  $\rho_g$  is gas density at a shock front distance  $R$ , also measured from the explosion source. The exponent  $g$  is determined from physical considerations. Application of principles of conservation of mass, momentum, and energy, together with an assumed density distribution, leads to a particle velocity distribution, pressure wave form, and shock strength-scaled distance decay curve. Values of flow variables at the shock front are, of course, determined by Rankine-Hugoniot relations.

Analogous flow variable relationships are derived by an approximate method for the situation where several explosive charges are detonated successively. By employing this analysis, charge weights, detonation time delays, and explosion source distances required to generate pressure wave forms of various shapes can be calculated. Calculations are presented for three particular wave forms, including nonpeaked and multiple-peaked cases.

Analysis shows, within the validity of assumptions made, it is possible to generate desired pressure wave forms. This may be accomplished by detonating a series of charges of appropriate size, at the proper times. Analysis also tells the size of charges needed and at what time each is to be detonated, in order to generate predetermined wave forms. Detailed specifications for generating three desired wave forms are presented in the report.

SWC-TN-57-32  
NET-FORCE SENSOR RESEARCH  
33(616)-2457: American Machine and Foundry Company  
April 1958  
U

AD-458 130

The objective of research reported herein was to produce working models of net-force sensors, and to develop the technology of their fabrication and use. A net-force sensor is an instrument which measures net blast force on an object as a function of time. It is used to study blast loading on objects in the path of a blast wave.

On the basis of the research effort, the following conclusions were reached:

- (1) A cantilever beam net-force sensor can be constructed to measure transient force phenomena in a shock tube model. A sensor of this type was constructed with a minimum of preliminary theoretical design analysis, and was used to measure force on a rectangular bar model in the shock tube.
- (2) The SLM pressure gage, used as the sensing element, has outstanding possibilities for use in net-force sensor construction. It permitted construction of a rugged instrument which gave accurate data. The SLM gage has a high degree of sensitivity and a high natural frequency.
- (3) The net-force sensor demonstrated certain inadequacies which have to be corrected before it can be used as a practical instrument. The principal disadvantage was excessive vibration superimposed on force vs. time records. This effect was reduced by stiffening the beam and using a crude filter at

the output. More refined cantilever beam design and filter analysis would be desirable.

Another inadequacy in the sensor is the fact that the SLM gage is not used in an optimum manner. A more refined design, which would balance gage output with cantilever beam stiffness, could substantially increase the sensor natural frequency. This would make the sensor more useful in measuring transient phenomena and possibly reduce vibration problems.

(4) Future designs of net-force sensors should not be limited to the cantilever beam concept. Sensors using multiple load-cell arrangements and supports other than a cantilever beam should be considered.

Note: No further development of this type of net-force sensor was undertaken.

SWC-TN-57-37

AD-153 637

OPERATION OF THE AIR FORCE SHOCK TUBE LABORATORY, GARY, INDIANA

33(616)-2644: Armour Research Foundation

October 1957

U

This report summarizes activities of the Armour Research Foundation in operating the Air Force Shock Tube Laboratory at Gary, Indiana from 1 September 1956 to 30 September 1957. During that year, work was conducted on the following programs:

1-7 Airblast loading on oil storage tanks; mill buildings; block cylinders and domes; building interiors; and successive bents

8 Instrumentation

9 Annular ring shock attenuators in tunnels

10 Response studies on miniature oil storage tanks

11 Tests of the BRL field "Q" gage

12 Explosive aircraft decompression

Work on seven programs was performed entirely during the report period. Two final reports, one technical memorandum, and four preliminary reports were written for the Air Force as part of these programs. On two programs final reports were issued for outside agencies; raw data were turned over to outside agencies on two other programs.

In addition to routine laboratory maintenance, continuous effort was made to increase operating accuracy of instrumentation equipment, and to design and construct better pressure gages. These efforts were reasonably successful. Improvements of the facility included a 9 $\frac{1}{2}$ -foot extension of the 6-foot shock tube, reorientation of the existing 6-foot tube in the opposite direction to accommodate its extended length, installing and equipping an additional building to be used as office space and to house the 4-inch shock tube used for gage calibration, and installing additional equipment in and remodeling the instrument room.

## GEOLOGICAL AND GEOPHYSICAL CONSIDERATIONS FOR ICBM LAUNCHING SITE SELECTION

In-house

December 1957

C

This study discusses desirable and undesirable geologic characteristics of sites for an underground, cylindrical shelter containing an ICBM. Soil and rock properties are investigated regarding their capability to absorb and/or redistribute dynamic energy induced by nuclear explosions.

General recommendations presented in the report are as follows:

1. A ground water table above the elevation of the missile platform is undesirable.
2. The soil condition at ground surface should be firm enough to support construction operations.

Unfavorable geologic conditions can be overcome during the construction phase, but to do so will decrease confidence in the adequacy of the structure, and result in a considerable increase in construction cost. Five geological regimes are recommended in order of preference:

1. Sound, uniform, igneous, metamorphic, or sedimentary rock, 300 feet or thicker, overlain by predominately sand or gravel soils 100 to 200 feet in thickness.
2. Sound, uniform, igneous, metamorphic, or sedimentary rock, 300 feet or thicker outcropping at the site and for an appreciable distance around it.
3. Sound, uniform, igneous, metamorphic, or sedimentary rock, 300 feet or thicker, overlain by more than 200 feet of predominately sand-gravel soils.
4. Deep sedimentary soil, sand-gravel, at least 500 feet in thickness.
5. Deep sedimentary clays, silts, or shales, which are thinly bedded or intermixed and at least 500 feet in thickness.

Highly fractured non-uniform weak rocks of great thickness, water-filled silts or clays, thinly bedded saturated shales, and solution-channeled limestone should all be avoided. In addition, the climate should be semi-arid to arid, to avoid temporary major changes in ground water level.

## INVESTIGATION OF WAVE PROPAGATION IN SEMI-SOLIDS

29(601)-465: Armour Research Foundation

March 1956

U

This research program had two main objectives: (a) further development of experimental methods of dynamic photoelasticity and embedded grids as a means for studying wave propagation phenomena in solids, and (b) development of a method for studying the performance of pressure gages, embedded in a

specimen and subjected to an impact type of loading. The program was a continuation of a previous research program, in which a Fastax camera in conjunction with soft model materials was introduced as a means for studying wave propagation.

During the course of the program, a microflash method was developed for recording photoelastic patterns and grid deformations simultaneously. A soft photoelastic material (Hysol 8705) was selected as the model material and its static and dynamic properties (physical and optical) were completely determined. By using the photoelastic pattern, grid measurements, and material properties, it was possible to determine stress distributions resulting from impact-type loadings. As an indication of the procedure to be used, principal stresses along the vertical diameter of a disk subject to diametral compressive impact loading were determined.

In another phase of the program, the Fastax camera was used to study wave propagation phenomena in large plates subjected to air blast and explosive-type loadings. This series of tests clearly showed a shock tube can be used in conjunction with photoelastic models for air blast studies. Fringe patterns obtained were satisfactory for studying overall wave propagation phenomena. In regions where more detail was required than could be recorded on the 16-mm Fastax film, a microflash unit gave suitable records.

Performance of barium titanate and diaphragm pressure gages embedded in soil or soft rubber specimens and subjected to impact loadings was studied, using impact pendulums. In general the barium titanate gages recorded pressures which compared favorably with independently determined pressures, when the loading rate was high. The diaphragm gages performed better when the loading rates were low.

SWC-TN-58-23

AD-358 334

GROUND MOTION INDUCED BY NUCLEAR EXPLOSIONS--A STUDY OF FUNDAMENTAL PROBLEMS

29(601)-540: Stanford Research Institute

November 1958

C

This report discusses analytical and experimental approaches to studying dynamic soil behavior, particularly the response of soil and rock subjected to nuclear airbursts and loadings which this response will impose on buried structures.

Three general areas of research were investigated: laboratory experiments to determine dynamic properties of soil and rock; scaled HE field experiments; and mathematical theory of two-dimensional wave propagation.

Solution of the nonhomogeneous elastic problem was investigated, and three-dimensional viscoelastic theory is discussed. Feasibility of an electric network analog solution is shown to have considerable promise.

## INITIAL INVESTIGATION OF WAVE PROPAGATION IN LARGE SOIL MODELS

29(601)-796: Armour Research Foundation

December 1958

U

Preliminary shock tube tests were conducted to study pressures recorded by barium titanate pressure sensors located in a moist clay sample with one surface exposed to the pressure pulse of a transient air blast wave. Primacord was used to generate the blast wave.

A cylindrical sample 15-3/4 inches in diameter and 36 inches long, containing 15 gages at various distances from the loaded surface, was subjected to blast overpressures of 6.5, 10.5, 19.0, and 31.4 psi. Good records were obtained from 13 gages on each of four shots. The compression wave exhibits a finite rise-time, increasing with depth up to a depth of roughly one diameter, after which it remains roughly unchanged. Time-of-arrival of the wave front at a given depth was found to be independent of air blast overpressure, while time-of-arrival of initial peak pressure decreases with an increase in overpressure, largely as a result of reflections of the compressional wave from the sides of the sample container.

Results indicate the shock tube is an effective device for loading large soil samples (dimensions of the order of about 1.0 to 5.0 feet) with controllable and reproducible impact loading. Furthermore, overall performance of a barium-titanate pressure gage embedded in moist clay seems to be satisfactory. Further tests should be conducted on samples of this general type in redesigned containers.

## AIR BLAST LOADING ON ARCHES AND DOMES

29(601)-796: Armour Research Foundation

September 1958

U

Tests were conducted on solid arches and domes in the Air Force 6-foot shock tube in Gary, Indiana. Primacord high explosive was used to generate shocks ranging in strengths from about 1.3 to 7.0. This resulted in both subsonic and supersonic flow behind the shock front.

Two arches and four domes were tested. The arches were sections of circular cylinders, with central angles of 120 and 180 degrees, oriented with flow normal to the axis of the cylindrical surface. The domes were sections of spheres, with central angles of 60, 90, 110, and 180 degrees.

Point pressure measurements were obtained at various points on the surface of each structure. Flush-mounted miniature barium titanate pressure sensors were used to obtain individual pressure-time records for each gage position.

Pressure-time curves are presented together with charts giving numerical values of essential quantities. These quantities are normalized pressure-time values for critical points of the diffraction phase, and drag coefficient for the pseudo-steady-state phase. Profiles showing variation of these quantities

with angle of incidence in the vertical plane are presented for the arches. Contour diagrams are utilized to express variation of these quantities over the dome surfaces. Different curves with shock strength as a parameter are shown when necessary.

SWC-TH-59-4

AD-460 997

SHOCK TUBE AIR VELOCITIES

33(616)-2457: American Machine and Foundry Company

November 1958

U

The purpose of this experiment was to measure mass flow velocity behind a shock front in a shock tube, by observing displacement of heated air bubbles created in the flow by spark discharges. The report contains the measurements and following conclusions:

Data show a general trend of increasing velocity behind the shock front. Whether or not the shock front velocity itself changed was not determined. Data also indicate flow velocity is consistently higher than theoretical values. However, because the number of observations was small, and because of a discrepancy in determining the basis for theoretical calculations, comparisons with theory are inconclusive. Direct flow measuring, however, is practical, adaptable to shock tube study, and yields a graphic velocity-time history.

SWC-TH-59-8

AD-211 213

REVIEW OF THE LITERATURE PERTAINING TO THE BEHAVIOR AND DESIGN OF DEEP STRUCTURAL MEMBERS

29(601)-468: University of Illinois

June 1958

U

After a comprehensive literature survey of the field of deep beams, 80 pertinent references were selected for presentation.

Roughly half of these pertain to reinforced concrete deep beam theory. No conclusions were drawn although voluminous data of failure mechanics were obtained for diverse configurations of reinforcement. These data can be used as a guide in organizing future testing.

Another group of references concentrates on moment-shear interaction in medium-thick beams (1:6 ratio), from which web reinforcement information was obtained. Unfortunately, theories used in this group of reports were for an uncracked, idealized material. The big void in this particular phase is the behavior of beams of real materials.

Another group of reports reviews the response of small beams of conventional length-depth ratios to impact loading.

The last group of references are papers on behavior of deep steel members. Considerably more seems to be known about moment-shear-plastic flow interaction in steel. Laboratory check points are needed, however, to verify recent analytical studies.

SWC-TN-59-11

AD-307 301

A SUMMARY OF REPORTS PRODUCED UNDER ARDC PROJECT 1080, PROTECTIVE CONSTRUCTION AND TARGET VULNERABILITY, AND ITS PREDECESSORS

In-house

March 1959

C

The purpose of this report is to summarize the work of AFSWC Structures Division, its predecessors, and contractors in research dealing with nuclear weapons effects on protective structures, in order that other interested agencies may be made cognizant of results obtained, and that closer coordination and cooperation may be effected between them. Some work mentioned was performed under tasks previously terminated.

Individual contracts and pieces of work are grouped under their respective general fields of research, with the exception of reports prepared under Program 3 of Operat. as GREENHOUSE, BUSTER-JANGLE, and UPSHOT-KNOTHOLE, and miscellaneous reports prepared under ad hoc contracts. These latter reports have been grouped in separate chapters.

SWC-TN-59-14

AD-216 716

IMPROVEMENT IN THE CAPABILITIES OF THE AIRFORCE 6-FOOT SHOCK TUBE BY SEVERAL ORDERS OF MAGNITUDE

In-house

May 1959

8-RD

A new way of arranging primacord strands (the shock-producing agent) in the Air Force 6-foot shock tube has increased the capability of the laboratory to produce clean shocks equal to those observed in detonations of nuclear weapons. The old arrangement furnished clean shocks equal to those produced by 1/8-KT explosions up to 70-psi overpressure. The new arrangement gives shocks in the test section equal to those produced by 5-KT detonations up to 100-psi peak pressure with the tube ends closed.

The report shows how to obtain a shock in a similar, but much improved tube, which reproduces the clean blast wave conditions of megaton detonations up to 400-psi peak overpressure.

SWC-EI-60-20

AD-247 991

A GLOSSARY OF GEOPLOGICS: THE SYSTEMATIC STUDY OF EXPLOSION EFFECTS IN THE EARTH

29(601)-1948: Stanford Research Institute

July 1960

U

Growing interest in ground motion, design of underground protective structures, earth moving, and predictions for field experiments requires engineers and scientists to be familiar with the language of geoplomics, its theories and phenomena. This glossary attempts to provide, within a single cover, a reservoir of that special language.

Terms and their definitions have been selected to include not only the dynamic aspect of ground motion (acceleration, velocity, and displacement) but also the permanent effects of that motion (craters, residual strain, and permanent displacement). Also included are terms from related fields, such as seismology, which may not now be in widespread use but which are likely to be used more often as ground motion research increases.

Many words contained herein already have standard meanings in other contexts and are applied to ground motion with their usual meanings intact. Some have a definition in one field and have taken on a different meaning when applied to ground motion; and others, as standard terms in this field, have had their meanings brought up to date. Still others, in the interest of unambiguous communication, are coined to describe heretofore unnamed phenomena.

SWC-TN-60-30  
ATTENUATION OF STRESS WAVES IN BILINEAR MATERIALS  
29(601)-2855: Paul Weidlinger and Associates  
October 1960  
U

AD-603 676

Attenuation of plane stress waves in a bilinear medium, generated by a decaying surface pressure pulse, is studied to obtain an approximate solution when the medium has a stress strain diagram with positive curvature. Wave equations are derived, and beyond a given distance from the surface the intensity of peak stress and peak particle velocity is found to depend on a single parameter. This result is helpful in establishing the physical characteristics of granular soils which control their dynamic behavior under high-intensity nuclear surface blast pressures.

SWC-TN-60-36  
DESIGN AND ANALYSIS OF FOUNDATIONS FOR PROTECTIVE STRUCTURES  
29(601)-2561: Armour Research Foundation  
September 1960  
U

AD-251 478

The behavior of footings subjected to time-dependent forces has been the subject of continuing research. Ultimate bearing capacity under such loading conditions and dynamic behavior beyond ultimate capacity are both of interest. An attempt has been made in this investigation to relate laboratory experiments to theoretical studies.

Two- and three-dimensional experiments were conducted on small footings in the laboratory to observe their behavior and obtain quantitative information. A device was developed for applying dynamic forces to small footings. This relatively simple device made possible application of loads having various rise times, decays, and durations. Force-time and displacement-time records were obtained in forms suitable for analysis, and Fastax movies of footings failing under dynamic loads were also taken.

Behavior of footings subjected to dynamic loads was also studied analytically. The possibility of applying plasticity theory or limit analysis was considered, and other loadings and various failure modes were investigated.

SWC-TN 60-39

AD-248 576

**AN EXPERIMENT ON SOILS LOADED DYNAMICALLY BY A SHOCK TUBE**

In-house

December 1960

U

The Air Force 6-foot shock tube was used to pass air shocks across the upper surface of different soil samples having controlled properties. Gages were buried in the samples or mounted on the sample container supports. The tests were intended to develop into an experimental study of energy transmission in soil samples of different types, first by investigating experimental difficulties common to such tests. The apparatus and procedures are described, and data from a few tests are presented. Compaction observed in samples is described, and certain preliminary results are qualitatively discussed, including shock transmission in sample pores, velocities and attenuation of transmitted waves, and the extent to which differences in sample properties were reflected in various measurements.

SWC-TN-61-6

AD-253 880

**A THEORETICAL STUDY OF STRUCTURE-MEDIUM INTERACTION**

29(601)-2838: National Engineering Science Company

November 1960

U

This report presents results of an analytic study of the interaction of a plane longitudinal stress wave with a thin cylindrical shell, embedded in an infinite elastic medium. In contrast to previous studies of this type, the shell is neither infinitely rigid nor infinitely thin (cavity) but is given finite dimensions (with the assumption of thin shell geometry), finite density and elastic properties differing in general from those of the medium. Both steady-state and impulsive waves are considered. For the steady-state case, a general series solution is presented, for arbitrary properties of medium and shell. A procedure is outlined for obtaining transient (pulse) solutions from steady-state solutions. Application of the Laplace transform method is outlined and certain formal results obtained; for a cylindrical cavity an approximation valid for a slowly varying wave is given explicitly. A method for calculating Fourier-Mellin inversion integrals is outlined and should be of assistance in obtaining numerical solutions to specific transient problems by applying automatic computing techniques.

SWC-TN-61-7

AD-253 057

**BASIC INTERACTION CONSIDERATIONS--DYNAMIC STRESS CONCENTRATIONS AROUND UNLINED OPENINGS**

In-house

February 1961

U

Two recently published theoretical studies discussing two-dimensional interaction in an elastic medium between a plane stress wave and a circular hole are compared to a classic static solution and a newly published experimental solution. These solutions were obtained independently and are in excellent agreement, within their range of applicability. The two theoretical solutions predict an increase over static stress concentration of approximately

9 percent. The experimental study measured an average increase of 11.4 percent. Maximum hoop stresses occur within 4 to 5 transit times and then approach computed static values. Until more experimental and theoretical studies can be applied to real materials, it should be possible to use these extremely simplified solutions as a first approximation when designing unlined cavities in competent rock to withstand stress waves from a nuclear weapon detonation.

SWC-TN-61-14

AD-261 566

DESIGN AND ANALYSIS OF FOUNDATIONS FOR PROTECTIVE STRUCTURES

29(601)-2561: Armour Research Foundation

September 1960

U

The behavior of footings subjected to time-dependent forces has been the subject of continuing research. Approaches to this research have been both theoretical and experimental. This interim report presents experimental results and compares them with theoretical results.

Two- and three-dimensional footings on Ottawa sand were loaded dynamically, using the loading apparatus and instrumentation developed for this program. The two-dimensional experiments permitted observation of footing behavior on loose and dense sand, when subjected to vertical, inclined, and eccentric dynamic loads. The three-dimensional experiments provided force-time and displacement-time records of footing behavior on dense sand for vertical loads.

The experimental results show the theories developed previously on this program to be unsatisfactory. They also indicate the direction to be taken in future theoretical research.

SWC-TN-61-16

AD-261 958

TESTS ON ATLAS BLAST VALVES

29(601)-790: Armour Research Foundation

April 1961

U

This report presents results of performance tests on the 16-inch and 42-inch WS-107A-1 (Atlas) Silo Blast Closure Valves. The tests were intended to simulate actual conditions to which the closures would be subjected during normal operation. The closures were subjected to air blast loading, prolonged cold and hot environments, and repeated use (cycling).

The 16-inch closures reacted satisfactorily to all performance tests except the cold environments. They were subjected to an air blast loading of 120 percent of the anticipated maximum design blast load without failure. The closure temperature was raised to 200°F and held for 72 hours; it operated satisfactorily afterward. The closures were also repeatedly operated through 1,500 cycles without failing. During the cold environment experiments, pressure leaks in the closures' hydraulic system developed at approximately 0°F. These pressure leaks resulted from shrinkage of Teflon seals.

The 42-inch closures failed every test except the hot environment tests. The temperature of the 42-inch closures was raised to 300°F before any failures occurred. Pressure leaks in the hydraulic system occurred when the closures

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SWC-TR-56-46

AD-144 146

TRANSIENT DRAG AND ITS EFFECT ON STRUCTURES

33(616)-2285: American Machine and Foundry Company

November 1956

C

This report presents results of a study of drag forces on typical structural sections not found in the literature. The influence of section parameters, principally corner radius, have also been examined, as have the effect of interference obstacles and inclusion of the item in a structural complex. The flow of gas in the so-called steady state portion of shock tube flow was also examined to some extent.

There is basic information in this report for further test work necessary to solve the ideal wave transient drag loading problem. No definite conclusions are given; however, recommendations for future transient drag work are included.

SWC-TR-56-47

AD-118 359

A METHOD FOR THE ANALYSIS OF FRAMES SUBJECTED TO INELASTIC DEFORMATION INTO THE RANGE OF STRAIN HARDENING.

33(616)-170: University of Illinois

November 1956

U

This report presents a method for determining the static resistance of frame structures composed of elements having individual resistance-deformation characteristics of any monotonically increasing form that can be described graphically. The method is useful in research and is the only one available for analyzing the static behavior of frames in the strain hardening range.

A simplified procedure for analyzing independent frames, using moment distribution with bilinear approximations to the moment-end slope relationships, is presented in the appendix.

SWC-TR-56-48

AD-134 700

AIR BLAST LOADING ON STRUCTURES

33(616)-226: Stanford Research Institute

August 1956

C

The main objective of the Air Force empirical blast study program was to develop a technique for predicting airblast pressure loading on targets exposed to nuclear explosions. This report discusses a series of tests on cubical and cylindrical models subjected to airblast loading from high explosive airburst detonations.

Data are analyzed to study repeatability, effect of shock strength, and effect of cylinder height. Results are compared with data from shock tube

loading tests, and full-scale nuclear tests. They indicate that design of satisfactory net force measuring devices (particularly for model studies) requires better use of materials and transducers than was previously possible.

SWC-TR-57-1

TWO- AND THREE-DIMENSIONAL SHOCK TUBE LOADING STUDIES ON MODELS OF OPERATION KNOTHOLE PROGRAM 3; VOLUME II, APPENDIX 2, COMPARISON OF FIELD AND SHOCK TUBE RECORDS

33(616)-2540: Armour Research Foundation

Volume I -- August 1953 -- S

AD-360 105

Volume II -- August 1956 -- S

AD-360 111

The objective of this program was to obtain a better correlation between blast loading data obtained from Operation KNOTHOLE Program 3, and scaled shock tube models of the test structures. The test structures were solid rectangular parallelepipeds, horizontal cylinders, and vertical cylinders. Volume I compares pressure-time records and related data from Operation KNOTHOLE Program 3 with those from scaled models of the same structures tested in a shock tube. The model testing was done in the Air Force 2-foot-diameter shock tube at Gary, Indiana. Volume II presents graphs comparing field test and shock tube records.

SWC-TR-57-9

AD-302 050

EFFECTS OF TOPOGRAPHY ON SHOCK WAVES IN AIR

33(616)-160: Broadview Research and Development

August 1956

C

This final report does not attempt a complete description of the 4 years of research conducted under this contract, since it has already been published in a series of Interim Reports (enumerated in appendix A of the final report). Instead, the primary aims of this report are (1) to briefly summarize important results, and (2) to suggest methods for employing them. The report covers pressures up to about 30-psi peak incident pressure.

Experimental measurements were made of the variation in shock overpressure near the earth's surface, due to the natural topography. Shock wave overpressures from miniature high explosive charges were recorded as a function of time, using gages imbedded in three-dimensional topographic models.

A procedure for predicting effects of topography on shock waves in air is presented.

SWC-TR-57-21

AD-144 532

SLOW AND RAPID LATERAL LOADING TESTS OF SIMPLY SUPPORTED BEAMS AND BEAM-COLUMNS

33(616)-170: University of Illinois

June 1957

U

The two major purposes of the program described in this report were to determine experimentally the resistance of several beams and beam-columns to inelastic deformations as a function of loading rate; and to correlate these resistances with static and dynamic properties of the materials used.

The results indicate that beyond the static elastic limit, resistance of a mild steel beam or beam-column to rapidly applied lateral displacement exceeds that corresponding to the same lateral displacement applied slowly. Also, the increase in resistance of a beam with increasing rate of lateral deformation can be explained, within reasonable limits not greatly exceeding experimental error, by consideration of experimentally determined dynamic properties of the material used, which include delayed yielding and rate of general yielding for mild steel.

SWC-TR-57-22

AD-144 533

60-KIP CAPACITY SLOW OR RAPID LOADING APPARATUS

33(616)-170: University of Illinois

June 1957

U

To test structures or structural components in the laboratory it was necessary to design and construct a machine to provide the required load and stroke. Operating and loading characteristics of three such machines are described in this report.

The 60-kip pulse loading machines described in this report have been used successfully to test both steel and reinforced concrete beams and to apply lateral loadings to steel columns. They have also been used to study beam-to-column connections and to study simple column base connections. In all tests the specimen either collapsed or was deflected well into the strain hardening range.

A load having any selected value up to 62.8 kips can be applied at a controlled rate in either tension or compression. The duration of the peak load can be varied from as little as 0.008 second to many hours.

## STATIC AND DYNAMIC TESTS OF STEEL FRAME STRUCTURES INTO THE INELASTIC RANGE OF DEFORMATION

33(616)-170: University of Illinois

May 1957

U

The experimental and analytical program conducted at the University of Illinois under Contract AF 33(616)-170 is summarized in this final report. The basic purpose of the program was to obtain basic information concerning the behavior of steel structural frames and elements, subjected to static and dynamic loading resulting in extensive inelastic deformations. Each phase of the project and major conclusions reached are described briefly. Abstracts of each technical report produced are given in one appendix and a tabulated summary of tests performed is presented in another.

The conclusions presented in the report are listed below:

1. Actual resistance of a mild steel structural element to an imposed inelastic deformation increases with rate of deformation and is also dependent upon the duration of load.
2. In most specimens in which local inelastic buckling occurred, it was less pronounced in rapid tests than in slow ones, indicating the effectiveness of beam sections is increased with rapidity of deformation.
3. The presence of an axial load decreases the ability of a member to resist lateral load, but does not appreciably affect the total resistance of a member to an external moment, except in the limited range of deformation immediately following initial yielding.
4. The effect of shear on the moment capacity of an 8 WF 58 section loaded laterally and slowly in the plane of the major axis was found to be negligible, even for a beam having an equivalent cantilever span to depth ratio as low as 2. However, in a region of constant shear but gradient moment, the development of a general shear yielding condition in the web caused deflections considerably greater than those which resulted from concentrated yielding primarily caused by moment.
5. In most of the structural elements and models tested, the initial "elastic" region of the resistance-deflection relationship had a slope less than that derived using elementary theory and assuming ideal support conditions.
6. A static resistance-deflection function for a simple structural element or a relatively simple structure can be determined with good accuracy by using approximate strain-deflection relations, then computing resistance on the basis of known static stress-strain characteristics of the material involved.
7. For research studies requiring good accuracy, an equivalent resistance-deflection function for relatively simple structures subjected to rapid

deformation can be determined in a manner similar to that mentioned above, using dynamic material properties. The equivalent resistance is computed using instantaneous material stresses at critical sections, which are compatible with strains, strain rates, and times involved. The total resistance (which does not include inertia forces) is actually a function of time as well as displacement, and therefore is strictly valid only for the particular case considered, or for others with a very similar loading function and structural configuration.

8. Since the effect of delayed yielding is probably important only for short duration impulse loads, and the general yielding resistance of mild steel is relatively insensitive to changes in strain rate within one or two orders of magnitude, suitable accuracy can be obtained in most practical problems (where the dynamic loading function is seldom known with great accuracy) simply by increasing the static inelastic resistance of the structure in accordance with the estimated strain rates at critical locations in the structure.

9. Methods were developed for analyzing indeterminate frame structures deformed inelastically. In these procedures the resisting moments throughout the structure, corresponding to a compatible deflection configuration, are determined. These methods are illustrated by solution of "static" problems. However, with slight change they could be used in a step-by-step solution of problems involving structural response under rapid loading, particularly if a high-speed digital computer were available.

10. The analytical procedures developed under this program were intended for use in research applications. However, they should be useful in planning test programs, evaluating experimental results, and also determining the relative accuracy of simpler methods more suitable for design and routine analysis.

SWC-TR-57-29  
BLAST SHIELDING IN COMPLEXES  
33(616)-3778: Broadview Research Corporation  
August 1958  
U

AD-144 535

This report presents results of an experimental investigation of the shielding effects of city complexes on blast loading of structures both within the complex and in the region surrounding the complex.

Small scale models of idealized city building complexes were exposed to small high explosive charges (simulating weapons of about 140-KT yield) to measure building loading and shock wave characteristics at various points in and around the models.

For the test conditions investigated, it was found that shielding effects of the city complex were limited to the complex and a small adjacent area. At relatively small distances behind the complex the shock waves showed virtually complete recovery. Within the complex, however, significant changes in loading were measured when the spacing between structures was comparable to or less than the structure height.

This study was undertaken because city complexes are considered prime targets of both friendly and enemy forces, and because until this study attention had been focused on blast loading of single structures, with, at most, one shielding structure, with little regard for the influence of additional buildings.

SWC-TR-57-32

AD-157 167

PROCEDURES AND SPECIFICATIONS FOR EXPERIMENTAL DETERMINATION OF LOAD-DEFLECTION CHARACTERISTICS OF FULL-SCALE BUILDINGS

29(601)-467: University of Michigan

April 1958

U

During construction of a new highway or building, it is sometimes necessary to destroy existing buildings. With cooperation of proper authorities these buildings may be made available for full-scale static and dynamic testing. In the event structures and funds do become available, it is desirable that a general guide for planning and executing the tests be available, in the form of specifications and test procedures.

This report outlines procedures for conducting static and dynamic tests on full-scale structures. Buildings considered for testing are of steel or reinforced concrete construction, either single-story industrial structures or 3-5 story commercial structures. The report includes specifications covering selection, inspection, and modification of the test structures; discussions of vibration, shock, pulldown, and story shear tests; and descriptions of loading methods, instrumentation, and recording. Estimated costs for various major test equipment items, for both static and dynamic tests, are tabulated in an appendix.

SWC-TR-57-45

AD-462 212

THE RESPONSE OF TIER BUILDINGS TO BLAST LOADS

29(601)-467: University of Michigan

May 1958

U

This report discusses the development of relatively simple analytical techniques for predicting whether multi-story buildings can withstand blast loads. The scope was confined to steel-frame buildings, and the component of load due to vertical blast pressure was ignored.

In developing the procedures, properties of the structure and the blast load are approximated mathematically. Determining structural response then involves integrating a system of nonlinear differential equations, using a high-speed digital computer. To further simplify the procedure, an equivalent single-degree-of-freedom system is proposed, which is derived from properties of the structure and has a response comparable to that of the multi-degree-of-freedom system. Integrating the equation of motion for this equivalent system is a simple numerical integration problem which can be solved rapidly with a desk calculator.

To correlate the multi-degree-of-freedom and single-degree-of-freedom approaches, a series of buildings representative of modern office buildings is analyzed as both multi-degree and single-degree-of-freedom systems. The results of these analyses are presented in chart form, relating parameters of blast overpressure, weapon yield, building height, and initial impulse.

SWC-TR-58-5

AD-144 531

AN INVESTIGATION OF RIVETED AND BOLTED COLUMN-BASE AND BEAM-TO-COLUMN CONNECTIONS UNDER SLOW AND RAPID LOADING

33(616)-3780: University of Illinois

February 1958

U

This report contains a description of slow and rapid load tests of riveted and bolted column-base and beam-to-column connections, and the test results. Measurements of load, deflection, strain, and acceleration were taken to evaluate the resistance characteristics of the connections.

The small number of specimens and variety of connection types limited the scope of the investigation. The tests clearly indicated that rate of deformation had an effect on connection resistance, because rapidly deformed specimens had a greater resistance at a given deflection than those tested slowly. In these tests the type of fastener, whether rivet or high strength bolt, had little effect on the moment-rotation characteristics of the connections studied. This limited pilot study served only to indicate the general form of the resistance function which could be expected for connections of the type tested.

Also presented is a procedure for evaluating the resistance of a frame having semi-rigid connections, as it deforms into the inelastic range. The method of analysis considers the resistance characteristics of the connection, as well as of the members. The method is of particular use in research, since strain hardening is included.

SWC-TR-58-23

AD-358 739

FEASIBILITY STUDY OF AN ABOVE-GROUND HARDENED HANGAR

In-house

June 1958

8

An initial concept for a practical and economical protective aircraft shelter is presented. The hangar cost is only a fraction of the cost of the aircraft which it shields. Further engineering research is necessary before final design can be undertaken.

SWC-TR-58-28  
PROTECTIVE ARCH STRUCTURES  
29(601)-467: University of Michigan  
March 1958  
8

AD-304 625

Arch structures are proposed to protect aircraft against nuclear attack. Earth covered structures employing arch construction have been designed to protect aircraft from the destructive effects of nuclear weapons. Approximate cost estimates, based on section requirements for major structural components, were obtained for various structures. Approximate methods were used to obtain estimates of the structural requirements. The limited amount of information available on loading in the high overpressure regions, and the complex nature of the structure necessitated introduction of several simplifying assumptions concerning blast loading and response. Details of the designs were not worked out, and many assumptions employed still need further justification.

SWC-TR-58-48  
DESIGN AND DEVELOPMENT OF A NET FORCE SENSOR  
29(601)-431: Atlantic Research Corporation  
October 1958  
U

AD-460 787

The objective of this study was to design and construct a prototype device to measure the aerodynamic forces on a model structure installed through the floor plate of the Air Force 7-inch-diameter shock tube at Gary, Indiana. Design concepts and development status of the device are described in the report.

The study revealed no fundamental technical reasons for abandoning the design approach described in the report, although significant additional development was needed to produce a device having all the desired characteristics. In particular, some means was required to increase transducer load capacity, and a closer impedance match between model and support was needed.

SWC-TR-58-49  
DOORS AND ACCESS OPENINGS TO PROTECTIVE STRUCTURES  
29(601)-467: University of Michigan  
October 1958  
C

AD-358 761

Preliminary investigations of door-system requirements for dome, arch, silo-type, and rectangular protective structures for aircraft are described. Structural analysis, design, door removal systems, door economy, and continuity connections between the main structure and door are considered. Each of these items is only touched upon and much work still remains before definite conclusions can be reached. Proposed future work on the above-mentioned items is outlined.

SWC-TR-59-2

AD-306 645

PROTECTIVE CONSTRUCTION (3 Parts)

33(616)-2522: American Machine and Foundry Company

December 1958

S

This report presents results of an investigation of the design of protective structures, capable of accommodating one or more long-span aircraft, for overpressure levels up to 100 psi. Detailed investigations of dome and arch structures are presented. Blast pressures, thermal and ionizing radiation effects, and relative economy of construction were considered.

Conclusions reached provide guidance in the selection of a structural configuration to protect a specific weapon system at a given pressure level. A summary of the preliminary results of full-scale field tests of domes conducted in Operation PLUMBBOB is included.

SWC-TR-59-3

CROSS-REFERENCED LISTING OF EXPERIMENTAL DATA ON THE BLAST LOADING OF STRUCTURES

33(616)-2534: Armour Research Foundation

May 1958

C

Volume I

AD-329 671

Volume II

AD-329 682

Volume III

AD-329 684

Volume IV

AD 329 683

A bibliography and cross-index file of data dealing with pressure-time blast measurements on model structures is presented. Included are nuclear, high explosive, and shock tube test reports.

Data have been abstracted and filed. For each case treated, values of critical parameters in the following groups are given: (1) blast parameters, (2) model parameters, (3) scale size, (4) instrumentation, (5) test results, (6) agencies involved, and (7) publications available. Each case treated is assigned a case number and filed according to the program from which it was derived. In addition, each case has been assigned an address. The address is a code consisting of letters and numbers and is defined in terms of the model shape and orientation, location of the instrumentation, blast wave parameters such as the wave peakedness, shock strength, and reflection type (Mach, regular, etc.); and type of test (nuclear, high explosive, and shock tube).

The bibliography consists of two main portions, (1) Text, and (2) Catalog. The Catalog is subdivided into three parts, namely: Part 1, Address File; Part 2, Data Sheets; and Part 3, Notes and References. The Text and Parts 1 and 3 of the Catalog is presented in Volumes II, III, and IV, which contain Data Sheets for nuclear, high explosive, and shock tube tests respectively.

Utilizing this system of addresses together with the data sheets, one can determine the existence and whereabouts of certain data, knowing only the

range in the type of variables described above. Furthermore, specific features of the blast wave, model, and instrumentation used can be determined directly from the data sheets.

SWC-TR-59-9

ANALYSIS AND DESIGN OF DOMES, ARCHES AND SHELLS

Volume I -- ELASTIC ANALYSIS OF SPHERICAL DOMES

AD-210 924

Volume II -- ANALYSIS OF CIRCULAR ARCHES

AD-

29(601)-464: University of Illinois

July 1959

U

Part 1 of Volume I presents a numerical procedure for computing the dynamic response of a spherical shell subjected to transient uniform pressure. This procedure employs a discrete mechanism which replaces the continuous shell, having both bending and membrane resistance and large deformation effects. A numerical procedure is developed for obtaining the dynamic response of the mechanism, and a code programmed which performs the analysis on a digital computer. The program flow diagram is presented in a form enabling an experienced programmer to convert the code to any type of computing facility. Using the computer program, the effects of variation of certain parameters were investigated. Significant results and conclusions are presented. Those conclusions which can be stated in a general form are listed below.

1. Maximum axial and bending stresses are linear functions of the ratio of radius to thickness.
2. Maximum displacements and stresses are also linear functions of the ratio of radius to the square of the thickness, before the first maximum; after that time, however, apparent nonlinearity develops.
3. Increasing the semi-angle of opening from  $30^\circ$  to  $45^\circ$  causes no significant effect.
4. Stresses and deflections increase with decreasing ratio of shell period to pulse duration.

Part 2 of Volume I discusses the analysis of a discrete framework approximation to a membrane spherical shell. Equivalent bar areas are derived on the basis of equivalent stiffness under identical loading. The natural modes of the framework are found, and the response of the framework to triangular blast loading is obtained by linear superposition of normal modes. Time histories of displacements are converted to time histories of bar forces, which are then combined to yield stresses in the equivalent shell. A short digital computer program was written to combine modes and compute shell stresses.

Part 3 of Volume I presents a mathematically exact analysis of the free vibration of an elastic membrane spherical dome of arbitrary radius, material, and total opening angle. Expressions involving trigonometric and Legendre functions are derived for displacements and stresses during vibration. A table

of natural frequencies of vibration for various values of shell opening angle is given. Displacement vectors for the first five modes of symmetrical vibration of a hemispherical dome also are tabulated.

Volume II discusses the analysis of arch structures under dynamic loads. A numerical procedure is described for computing the dynamic response of circular arches subjected to transient forces for both the elastic range and the range approaching failure. The problem is analyzed approximately by replacing the continuous arch with a framework consisting of rigid bars and flexible joints.

The scope of this investigation is described briefly in Chapter 1. Characteristics of the substitute framework are described in Chapter 2. In Chapter 3 equations necessary for dynamic response calculations are derived, and an outline is given of the procedure for their solution. Chapter 4 presents results of studies on computing natural frequencies and buckling loads of uniform circular arches. Pertinent equations are formulated, and numerical solutions obtained for arches with fixed dimensions, by considering different numbers of bars in the analogous framework. These solutions are determined to estimate the accuracy of the substitute framework. Included in Chapter 5 for convenience, is a summary of existing formulae for approximate calculation of natural frequencies and buckling loads of uniform, circular arches with hinged or fixed ends.

SWC-TR-59-10

AD-331 396

ON A METHOD OF AMPLIFICATION OF THE DYNAMIC STRENGTH OF STRUCTURES

18(600)-1638: Paul Weidinger, Consulting Engineer

October 1958

S

This report presents a dynamic device capable of significantly increasing the dynamic strength of structures subjected to very high intensity nuclear blasts. Strength amplification is obtained by providing a large movable mass over the structure to be protected. Under blast loading the mass descends and exerts a pressure of predetermined duration and intensity on the structure. This pressure is significantly less than the intensity of the peak blast pressure. The motion of the protecting mass is retarded by forces provided by the blast pressure itself.

Analytical methods are presented governing the mechanical and thermodynamic response of the device. Various applications to shelters are shown and a numerical example of the design of a particular shelter is presented.

SWC-TR-59-16

**SURFACE EFFECTS ON BLAST LOADING**

33(616)-3218: Armour Research Foundation

May 1958

8-ED

Volume II

Volume III

AD-323 560

AD-323 610

This report describes the propagation of a blast wave from a nuclear explosion and the pressures occurring over ideal and real reflecting surfaces. In separate sections, the following subjects are discussed: propagation of a blast wave in free air, thermal radiation of an atomic weapon, reflection process of a blast wave from an ideal surface, influence of mechanical effects on reflection of a blast wave, and effects of atmospheric inhomogeneities on shock wave propagation. The results are summarized in a chapter where schemes for describing blast waves reflected over real surfaces are presented. A number of specific conclusions are also presented.

The IBM Problem M solution for the free air pressure curve accurately represents the hydrodynamic variables at the shock front. The solution can be used as a standard against which test data are compared.

The thermal radiation output of a nuclear weapon is investigated. Many characteristics of the thermal output can be explained theoretically, and it is possible to consider scaling laws for thermal radiation. Thermal radiation does not scale in a simple manner, and variations in thermal pulse shape are to be expected with variations in bomb yield.

The reflection of an air blast wave process from an ideal surface is considered. Height-of-burst curves are extended to higher overpressure regions and larger values of ground range. The reflected wave forms obtained in regions of clean shock propagation are found to have an exponential character, as do free air curves. The reflection process causes the wave to have several piece-wise exponential segments, each with different decay constants. An experimental device was developed to measure Mach stem growth, and results were in agreement with field test measurements.

Height-of-burst curves have been determined for varying amounts of dust loading present in the air. Mechanical effects are not much different from present predictions, even when extremely high values of dust loading are assumed.

Propagation of blast waves in the presence of thermal and mechanical effects have been investigated. Theoretical predictions of thermal shock agree roughly with measured values. Reflected pressures in the main blast wave agree with ideal surface conditions, when mechanical effects which tend to attenuate the peaks are smoothed from the records, except for one region in the precursor propagation. There mechanical effects dominate the pressures. A heavy boundary layer is believed to obscure the meaning of measurements taken near the ground surface.

Variations in atmospheric density can cause appreciable variations in pressure for a blast wave in free air. A theoretical method has been used to compute these inhomogeneous effects, and gives results which agree with experimental data.

A method for predicting wave forms to be expected over real surfaces is summarized. Although it suffers from many inaccuracies, the method does present a reasonably coherent technique. Refinement of the technique may ultimately lead to a realistic method for predicting blast waves in many different situations.

SWC-TR-59-18

AD-462 213

AN INVESTIGATION OF THE BEHAVIOR OF DEEP MEMBERS OF REINFORCED CONCRETE AND STEEL

29(601)-400: University of Illinois

February 1960

U

The purpose of this investigation was to obtain information on the strength and behavior of deep beams of reinforced concrete and steel, subjected to slowly and rapidly applied loading, and to develop means for predicting their behavior.

The report contains the following:

(1) A thorough survey of the literature pertaining to the behavior of deep beams subjected to static and dynamic loads; (2) results of static tests of 23 simply-supported, deep, reinforced concrete beams, 14 under uniform loading and 9 with a single concentrated load at midspan; (3) results of dynamic tests on 2 simply-supported, deep, reinforced concrete beams; and (4) results of one test of a deep, steel beam of I-shape cross section subjected to slowly applied uniform loading. Experimental results are compared with theory.

SWC-TR-59-24

AD-315 611

BLAST SHIELDING IN COMPLEXES, PART II, MEGATON WEAPONS

29(601)-1149: Broadview Research Corporation

July 1959

C

This report presents results of the second part of an experimental investigation of the shielding effects of city complexes on blast loading of structures both within the complex and in the region surrounding the complex. This study extends the previous work, in which kiloton weapons were simulated, to include the effects of megaton weapons.

The approach used was to expose small-scale model city building complexes to small high-explosive charges and to measure building loading and shock wave characteristics at various positions in and around the model.

Shielding effects of the city complex in the region behind the complex were found to extend to greater distances for megaton weapons than for kiloton weapons. Within the city complex significant changes in loading take place

when the spacing between structures is comparable to or less than the structure height. A limited series of tests indicated that these loading changes are due to a relatively small number of structures surrounding the particular structure, rather than to the city complex as a whole. Although no full-scale results are available for comparison, it is felt that these scaled test results can be directly applied to real city complexes.

SWC-TR-59-47  
GROUND SHOCK ISOLATION OF BURIED STRUCTURES  
29(601)-1134: Armour Research Foundation  
August 1959  
C

AD-408 467

This report discusses the problem of alleviating the damaging effects of blast-induced ground shock on underground structures of the type presently contemplated for hardened missile sites. This first year's effort has been directed primarily toward design and implementation of an experimental program utilizing small silo-like structures and several types of shock-isolation devices.

The test structures (rigid aluminum cylinder, 2 inches in diameter and 8 inches long) were placed in a bed of uniform Ottawa sand; the ground disturbance was created by means of a small (0.02-lb) HE charge. Acceleration measurements were obtained at three points within the cylinders. The isolation devices consisted of (1) a wrapping of low-density (2-pcf) flexible polyurethane foam, (2) a simulated pile foundation for the cylinder with an air void between the cylinder and the sand, and (3) a simulated pile foundation for the cylinder with pre-expanded polystyrene beads between the cylinder and the sand.

The experimental technique was developed to the point where a satisfactory level of shot-to-shot reproducibility of effects was attained. Of the isolation devices tested, the polyurethane foam material proved to be the most effective, reducing peak accelerations (of the unisolated cylinder) by a factor of from 5 to 10. The stress level in the sand is estimated to be on the order of 1 psi. Various theoretical considerations relating to both the unisolated and isolated cylinders are discussed.

SWC-TR-59-48  
BLAST EFFECTS ON TUNNEL CONFIGURATIONS  
29(601)-796: Armour Research Foundation  
October 1959  
U

AD-239 640

Pressure measurements were made in tunnel-type models at the Air Force Shock Laboratory at Gary, Indiana. Tunnel overpressures were measured as a function of both geometric and free-stream blast wave parameters.

The tunnels were oriented so that their major axes subtended angles of 0, 45, and 90 degrees with the direction of free-stream blast flow. The tunnels were loaded by free-stream shock strengths in the range of 3 to 15. Pressure-

time records (overpressure as a function of time) were obtained at various positions within the tunnels. The effect of surface roughness on pressure attenuation was investigated utilizing a range of surface roughness factors from 0 to 7 percent. Geometric variations in the tunnel complex included expansion chamber configurations, short 90 degree beads, and entrance restrictions.

Within one and one-half diameters from the tunnel's entrance, the peak overpressure was of the order of 30 to 50 percent of the free-stream overpressure, for 90-degree tunnel orientations. For tunnel orientations of zero degrees, the peak overpressure just inside the tunnel's entrance is greater than the initial free-stream overpressure, but considerably smaller than reflected pressure existing in the vicinity of the tunnel entrance. Overpressure near the entrance of the tunnels varied with both the orientation of the tunnel and the magnitude of free-stream shock strength. Attenuation of pressures farther down the tunnels was a function of distance from the entrance, tunnel orientation, and tunnel geometric complex. Attenuation of pressure in small wall tunnels scaled according to the standard pressure-time scaling laws for the blast wave parameters tested. However, when wall roughness was introduced, pressure and time did not scale, especially for large diameter tunnels. In effect, the influence of wall roughness on attenuation became less pronounced as the absolute tunnel diameter increased.

SWC-TR-59-49

AD-318 329

ANALYTICAL STUDIES, INVESTIGATIONS, AND PRELIMINARY DESIGN OF DOOR AND FOUNDATION SEALS FOR PROTECTIVE STRUCTURES

29(601)-1166: Sandberg-Serrell Corporation

May 1959

C

The purpose of this project was to study problems connected with sealing protective structures against blast pressures, nuclear and thermal radiation, and ground water leakage. Because of severe conditions encountered in nuclear weapon blast, it is reasoned that conventional sealing practices might be inadequate. Particular attention is given to effects of both thermal and nuclear radiation on elastomers which might be used for seal materials.

A few design concepts are included in the report for various door and foundation configurations.

SWC-TR-59-56

AD-234 697

DESIGN AND ANALYSIS OF FOUNDATIONS FOR PROTECTIVE STRUCTURES

2 (601)-1161: Armour Research Foundation

October 1959

C

A combined theoretical and experimental program was conducted to investigate the behavior of foundations under time-dependent loading.

The standard theoretical approaches describing soil failure under foundations are reviewed with respect to time-dependent loading. Equations are developed for failure of soil under spread footings, taking into account inertial effects, pressures on the surface, and time-dependent forces. A method of solution for time-dependent loading on pile foundations is also developed. All the theoretical work employs standard soil parameters, the assumption being that means for selecting the appropriate values for these parameters will be provided by other current or future research.

The experimental work is of two types: (1) static loading of footings to obtain data not normally reported but vital for considering dynamic behavior and (2) limited dynamic loading of footings. The static loading tests supply full information on the load-displacement curves for given footings, establish the properties of the Ottawa sand used in the experimental work, and provide visual descriptions of footing behavior. The dynamic loading tests, in which the loading was achieved by dropping a known weight from a controlled height, supply abundant qualitative but only limited quantitative information. In particular, the observations of dynamic failure as contrasted with the observations of static failure lead to serious questions regarding the assumption that the mode of failure under static loading is descriptive of behavior under rapidly applied (dynamic) loading.

Design recommendations concerning footings for protective structures are made, based on currently available knowledge. Continuing research into this general problem may soon provide better design methods. The limitations of the research conducted are described, and recommendations for future work are outlined.

SWC-TR-59-57

AD-315 882

INVESTIGATION OF SILO LININGS

29(601)-1168: Armour Research Foundation

September 1959

C

Some aspects of the problem of determining the response of vertical underground silo linings to blast-induced loads are considered. These include the response of circular cross sections to radial pressure, effects of differential horizontal displacement, and analysis of the steady state motion of a rigid cylinder in an infinite elastic medium in the presence of a continuous plane wave.

The results show that increasing the wall thickness will decrease radial displacements of the lining but may not reduce the elastic bending stresses.

The investigation of effects of differential horizontal displacement shows that circular cross sections remain circular during deformation and that large longitudinal bending stresses result from relatively small differential displacements.

The analysis of the motion of a rigid cylinder in an elastic medium indicates that the rigid body response to high frequency components of the disturbance in the free field will be greatly attenuated.

SWC-TR-59-58  
A DOOR DESIGN FOR TUNNEL CLOSURE  
29(601)-467: University of Michigan  
October 1959

AD-231 442

U

Some problems confronting the designer of deep underground military installations are discussed in the preface. Placing a door near the entrance of a tunnel leading to the heart of an installation should be considered, especially in the high-pressure regions. A general design is presented for a revolving closure. Such a door could protect the complete interior of an installation against shock effects resulting from a nuclear detonation. The closure will be openable after exposure to blast and would not be adversely affected by debris within the tunnel. Power requirements are relatively small. Cost estimates are presented.

SWC-TR-59-70  
AIR FORCE DESIGN MANUAL: DESIGN OF PROTECTIVE STRUCTURES TO RESIST  
THE BLAST EFFECTS OF NUCLEAR WEAPONS (Superseded by AFSWC-TDR-62-138)  
29(601)-1162: University of Illinois  
December 1959

AD-460 852

C

This is the first draft of the Air Force Design Manual. Its intended use will be for planning and designing structures to resist the effects of nuclear weapons ranging into the Megaton class. Emphasis is primarily on underground construction. The material presented is derived from existing knowledge and theory, so the manual is also a report of the state of the art.

Starting with general considerations of site selection and structural function, various phases of design are considered: free-field phenomena in air and ground, material properties, failure criteria, architectural and mechanical features, radiation effects, surface openings, conversion of free field phenomena to loads on structures, and design and proportioning of structural elements and structures.

The appendixes include treatment of dynamic theory of structures, discussion of a solution for attenuation of stress in earth caused by three-dimensional dispersion, and illustrative design problems.

SWC-TR-59-71

AD-347 447L

GROUND MOTION PRODUCED BY ABOVEGROUND NUCLEAR EXPLOSIONS

29(601)-542: Stanford Research Institute

April 1959

8-RD

This report summarizes free-field ground motion observations made on aboveground nuclear and applicable HE detonations. Prediction methods are presented for estimating variation of maximum values of ground motion parameters with weapon yield and ground range.

The question of scaling cannot be resolved solely by experimental data, and for weapons detonated in Nevada the scatter of data are sufficient to mask the relationships between ground motion and known soil property variation. Geology of Eniwetok Proving Ground is grossly different from that of Nevada, and hence the ground motion at the same overpressure is within an entirely different theoretical and experimental regime than in Nevada. This makes correlation of these ground motion data with soil properties tenuous.

However, theoretical analysis of viscoelastic media and correlation of maximum values of surface particle velocity, strain, and displacement data with elastic theory suggest that transient nuclear ground motion data (with the exception of acceleration) can be treated on the basis of a "nearly elastic" medium in overpressure regions less than approximately 500 psi. A nearly elastic medium is one in which elastic parameters play a major role, while viscous and plastic parameters play minor roles. In contrast, ground motion produced by HE detonations of less than 2,560 pounds (the largest HE ground motion experiment) is strongly influenced by dissipative phenomena, and data suggest two-dimensional phenomena. Until a more complete theoretical description of the phenomena is available, these data do not provide quantitative extrapolations to nuclear detonations.

Ground motion data have been analyzed for 14 United States nuclear experiments at Nevada Test Site, 8 United States experiments at Eniwetok Proving Ground, and 3 United Kingdom experiments at Maralinga, Australia. Correlations are presented for horizontal and vertical acceleration and particle velocity near the ground surface and for the attenuation of acceleration and particle velocity with depth in the superseismic and c/trunning regions. For the superseismic region the vertical surface displacement, stress, and strain are given. Rules of thumb are presented for the attenuation with depth of horizontal velocity and displacement.

SWC-TR-59-72

BEHAVIOR AND DESIGN OF DEEP STRUCTURAL MEMBERS (7 Volumes)

29(601)-468: University of Illinois

April 1961

U

The purpose of this investigation was to obtain information on the strength and behavior of deep beams and slabs of either reinforced concrete or steel under static and high-energy impulsive loadings, and to develop means for predicting this behavior.

PART 1. BEHAVIOR AND DESIGN OF DEEP STRUCTURAL MEMBERS

AD-262 107

Part 1 contains a summary of each of the specific investigations reported in detail in Parts 2-7. The summaries include the object and scope of the test programs and digests of test results, and conclusions for each part.

PART 2. TESTS OF REINFORCED CONCRETE DEEP BEAMS WITH WEB AND COMPRESSION REINFORCEMENT

AD-244 739

Results of tests of seven reinforced concrete deep beams with tensile and web reinforcement and two beams with tensile and compressive reinforcement are described in Part 2. Several patterns of web reinforcement were used. Beams with web reinforcement had a span-depth ratio of about 3.0 and beams with compressive reinforcement had a span-depth ratio of 2.32. All beams were tested under uniform, slowly applied loading. The general behavior of test specimens is described and explanations of observed phenomena are given.

PART 3. TESTS OF REINFORCED CONCRETE DEEP BEAMS

AD-240 853

Tests of eleven reinforced concrete deep beams subjected to slowly applied, uniform loading are described in Part 3. Studies of the strength and behavior of simply supported, reinforced concrete deep beams are made, and procedures for predicting static load-deflection behavior of such members up to flexural failure are presented.

PART 4. DYNAMIC TESTS OF REINFORCED CONCRETE DEEP BEAMS

AD-247 468

Tests of simply supported reinforced concrete deep beams subjected to rapidly applied loads are described in Part 4. Five beams were tested under a triangular-shaped pulse and three beams under a flat-top pulse of "infinite duration." Five beams were tested statically to serve as control beams for beams tested dynamically. Studies of relationships of the sum of measured reactions to deflections, steel strains, and concrete strains are made. Data concerning effect of strain rate on behavior are presented.

PART 5. RESISTANCE AND BEHAVIOR OF REINFORCED CONCRETE BEAMS OF NORMAL PROPORTIONS UNDER RAPID LOADING

AD-240 854

The object of this investigation was to obtain information on the strength and behavior of reinforced concrete beams subjected to rapid loading. To this end, 33 beams of various strengths, 6 by 12 inches in cross section and 9 feet or 12 feet 8 inches in span, were tested under static and dynamic loads. Three percentages of tension reinforcement were employed, using intermediate grade steel. Some beams also had compression and/or shear reinforcement. Concrete strength, beam width and depth, and yield strength of reinforcement were essentially constant.

Eight of the two-point loaded beams were tested statically, requiring from about 2 to 6 minutes each to reach collapse deflection. In the dynamic tests of 25 other beams, loads were applied in from 0.1 to 0.8 times the natural

period of vibration of the beam. Some dynamic loads were of "infinite" duration, while others were terminated at from one-half to three times the beam period. Load levels varied from less than static yield capacity to more than dynamic ultimate capacity.

Analysis of test results consisted of determining dynamic resistance characteristics of test beams. This was accomplished by considering the beam to be a single-degree-of-freedom system and analyzing its behavior on an analog computer. The measured load pulse was fed into the computer along with an arbitrary resistance function for the beam. This resistance function was then changed until its response matched the response measured in the test. Dynamic resistance functions were also determined using measured strain rates, together with available results of dynamic tests of coupons of reinforcing bars. Resistance functions determined with the analog computer are compared with computed functions and static load-deflection characteristics. An analytical procedure for determining dynamic resistance of reinforced concrete beams is proposed, using deflection rate of yield.

The most important conclusions concern a direct relation between dynamic yield level of a reinforced concrete beam and yield strength of tension reinforcement under dynamic loading; the apparently small effect dynamic loading has on collapse deflection of a reinforced concrete beam; and the feasibility of using established formulas, developed in connection with static tests for predicting dynamic resistance provided proper account is taken of an increase in yield strength of reinforcing steel.

PART 6. THE YIELD STRENGTH OF INTERMEDIATE GRADE REINFORCING BARS UNDER RAPID LOADING

AD-240 855

The object of this investigation was to determine the influence of rapid loading on yield strength of deformed reinforcing bars of intermediate grade steel. Thirty-four specimens consisting of 2-foot coupons cut from No. 6, No. 7, and No. 9 bars were tested at room temperature under uniaxial tension. The static yield strengths ranged between 40,500 psi and 48,900 psi. Dynamic yield strength varied from 102 to 149 percent of static yield strength and was related to strain rate during yielding. Load and strain data for each bar tested are presented in graphical and tabular form.

PART 7. PLASTIC BEHAVIOR OF DEEP STEEL BEAMS INCLUDING SHEAR EFFECT

AD-262 108

The static resistance-deformation relationship of steel I or WF beams subjected to a uniform loading resulting in inelastic shear and flexural deformations is investigated. Essentially, three specimens from as-rolled 8 WF 35 beams were tested; the flanges were milled to obtain desired variations in resistance. Plastic shear deformations occurred in all specimens. One specimen deformed primarily in flexure; another specimen deformed from a combination of shear and flexure. Material properties in both tension and torsion were determined from coupon data. Comparing the experimental results from specimen tests and torsional properties of the material, it is determined that a considerable portion of shear resistance is derived from the flanges.

A shear-moment interaction relationship is derived which defines the perfectly plastic condition. This relationship includes consideration of shear distribution in the flange and an effective width of the flange in resisting shear. It is shown that shear capacity is dependent on the shear-moment ratio of the section, although reasonably accurate shear deformations can be computed for specimens of this investigation from a single shear-shear strain relationship which approximates the shear-shear strain relationship for no moment.

SWC-TR-60-1  
DOORS AND ACCESS OPENINGS TO PROTECTIVE STRUCTURES  
29(601)-467: University of Michigan  
March 1960  
C

AD-318 866

The general objective of this study was to develop analytical methods which can ultimately be applied to design of access openings to protective structures. Doors for dome, arch, rectangular, and silo-type structures are considered from an intuitive point of view. Because of mathematical difficulties involved, it is proposed that the continuous structure (both the main shelter and the door) be replaced by an equivalent frame for the analytical investigation. A method for analyzing dynamic elasto-plastic response of the frame is presented.

SWC-TR-60-3  
CONCEPTS OF PRELIMINARY DESIGN OF STRUCTURE PROJECTS FOR  
UNDERGROUND NUCLEAR DETONATIONS; APPENDIX A -- FREE FIELD  
PREDICTIONS; APPENDIX B -- INTERACTION OF BURIED STRUCTURES  
WITH GROUND SHOCK  
29(601)-1169: Armour Research Foundation  
January 1960  
Basic Report -- S  
Appendix A -- S  
Appendix B -- S

AD-462 209

AD-462 210

The basic report describes a structure test program for a contained underground nuclear detonation, designed to obtain data which did not exist at that time and which would give designers additional guidance needed in planning protection in relatively high pressure fields. Four individual tests are proposed, all at the same free-field stress condition, each designed to answer at least one specific question regarding interaction of a buried structure with a ground shock wave. A cost estimate is also given.

Appendix A describes a method for estimating earth motions, stresses, strains, etc., resulting from a contained underground nuclear detonation. This appendix also attempts to delineate factors which are influential in controlling shock or stress waves which propagate outward from the epicenter. It also gives estimates of earth motions in the white and reddish tuffs found at the Nevada Test Site, for an approximate range of stress levels from 400 to 2,000 psi. In addition, a factor is given permitting crude estimates of earth motion to be made in other soil or rock.

Appendix B presents a theory for estimating forces acting on a buried structure subjected to a ground shock wave. This work is intended to be applicable primarily for the type of rock found at the Nevada Test Site, such as white or reddish tuff.

A discussion of free-field variables is given, together with an idealization of the stress wave forms of interest. The basis of soil-structure interaction concept is the assumption of the nature of forces acting on the buried structure. The force acting on the structure is assumed to be composed of two parts. One, the wave force, is due to the sudden motion of surrounding media and the subsequent state of stress in the ground shock wave. The other, the arching force, is due to local deformation or displacement of the structure relative to surrounding media. Motion of the structure is governed by the usual equation of motion; however, in this treatment the forcing term has been split into two independent terms. The wave force term is a function of relative displacement between the structure surface and its corresponding soil position. The response of the buried structure is given for a range of ground shock wave parameters, structure configurations, and structure parameters, and includes some analysis of shock isolation systems.

SWC-TR-60-4

AD-237 255

RESEARCH STUDIES OF STRESS WAVES IN EARTH AND MODEL EARTH MEDIA

29(601)-1167: Armour Research Foundation

October 1959

U

A solution to the problem of stress distribution on the boundary of a circular hole in a large plate during passage of a stress wave of long duration is presented. The solution was experimentally obtained by using a low modulus model material in a combined photoelasticity and grid analysis. The results of the investigation indicate that a biaxial state of stress exists, such that the maximum tensile stress, produced in the free field, was approximately 0.45 times the maximum compressive stress. The study also indicates that the maximum compressive stress on the hole boundary can be computed with a fair degree of accuracy by applying the Kirsch solution for a hole in an infinite plate, using the free field biaxial stress conditions. The maximum tensile stresses on the hole boundary were always found to be smaller than predicted values. No solution was known to have been published in the technical literature for an impact-produced time dependent stress distribution around a discontinuity.

A laboratory program was conducted to study the performance of small diaphragm and barium titanate pressure gages. Barium titanate gages embedded in cylinders of clay and of urethane rubber were subjected to dynamic loadings, while diaphragm gages, embedded in urethane rubber cylinders, were subjected to static and dynamic loadings. The embedded barium titanate gage response was in all instances approximately 40 percent greater than the response for an equivalent air shock loading. The embedded diaphragm gage response to dynamic loadings was approximately 80 percent higher than the response for an equivalent static air pressure loading and about 30 percent higher than the static response of the embedded gage. The percent increase in response depends upon gage type and material properties of the medium in which it is embedded. It was also established in the program that embedded gages respond only to the

normal component of stress acting on their sensitive faces. The closely controlled performance of these gages in materials whose properties are very accurately known is expected to provide many answers to the rather nebulous problem of making underground measurements in soils loaded by nuclear detonations. Some preliminary development of a wafer-thin sensing element which has the same response to static and dynamic loadings when embedded is discussed.

An attempt was made to obtain the stress distribution on the boundary of an embedded rigid obstruction in a large plate during passage of compressive stress waves. A combined photoelasticity and grid analysis was used. The results of the program indicate that maximum shearing stresses can be obtained from photoelasticity data with sufficient degree of accuracy. However, in order to separate principal stresses and determine normal, tangential, and shear components of stress on the boundary of the obstruction, data from a grid analysis are required. The results of the program indicate that the grid method should be further developed to obtain these data.

SWC-TR-60-5

AD- 318 630

PRELIMINARY DESIGN METHODS FOR UNDERGROUND PROTECTIVE STRUCTURES

(Superseded by AFSWC-TDR-62-6)

29(601)-1171: Nathan M. Newmark, Consulting Engineering Service

December 1959

S

The objective of this contract was to determine simplified methods and criteria for design of underground structures subjected to nuclear blast loading.

Available data were investigated, classified and studied. Required analytical studies were made where needed, to supplement presently available data. Design methods and procedures for simplified application of limited available knowledge were developed to the extent that they are suitable for use in preliminary design.

Because of lack of data and knowledge, many areas in this volume were cursorily treated. Recommendations for future study are made.

SWC-TR-60-8

AD-278 170

THEORETICAL STUDY OF GROUND MOTION PRODUCED BY NUCLEAR BLASTS

29(601)-1190: American Machine and Foundry Company

October 1959

U

This study is part of a program aimed at analytically determining free-field ground motions of soils in response to overpressure loadings caused by nuclear weapons. The analysis will ultimately provide designers of underground protective structures with necessary quantitative information on ground motions and pressures as a function of soil properties and weapon yield.

A fair idea of the behavior of soil may be gained from knowledge of less complicated media. It is, therefore, natural that the first need is a thorough understanding of elastic phenomena. Then extensions into visco-elastic phenomena may be made.

As a first approximation to the actual problem, two-dimensional motion of an elastic half-plane under an exponentially decaying normal load traveling at constant velocity along the boundary is determined analytically and results presented graphically. Analytic expressions in integral form are then obtained for three-dimensional axi-symmetric motion of an initially quiescent homogeneous isotropic elastic half-space under an arbitrary axi-symmetric time-dependent normal loading. These expressions are then utilized for the special case of a concentrated normal point load and a uniform concentrated normal ring load suddenly applied and thereafter maintained at a fixed position on the plane boundary. Analytic expressions are also obtained for three-dimensional axi-symmetric motion of a homogeneous isotropic visco-elastic half-space under identical conditions as for the elastic case.

SWC-TR-60-11  
COMPARATIVE PROTECTIVE STRUCTURAL DESIGN  
29(601)-547: Armour Research Foundation  
June 1960  
S

AD-318 970

The objective of this study was to develop cost figures for hardened structures employed in air weapons systems. Design techniques employed in the study were based on best available methods. If these were regarded as incomplete, or insufficiently accurate as compared with design methods used elsewhere in the study, rapid and approximate methods were developed specifically for the program. This study was further directed toward determining minimum cost designs of complete protective structures for ultimate use by Air Force planning agencies in selecting the optimum combination of hardening, mobility, and dispersal for given funding levels. This required an extensive investigation of structural components. The final report contains cost figures in terms of both structural elements (beams, slabs, columns, etc.) and structural enclosures (cubicles, large-enclosures, etc.). In addition, silos, silo doors, arches, and domes are treated in separate appendixes. The study showed that underground structures were far less expensive than surface structures at moderately severe overpressures. At very high pressures, surface structures are regarded as not feasible, while underground structures appeared reasonable from a cost standpoint. Optimum burial depths, which resulted from the design method assumed, were found to exist for higher overpressures. It was found less expensive to build underground protective structures in sand than in clay.

SWC-TR-60-16

ANALYSIS AND DESIGN OF DOMES, ARCHES AND SHELLS

VOLUME I -- ANALYSIS OF SPHERICAL DOMES (2 Parts)

AD-245 290

VOLUME II -- DYNAMIC RESPONSE OF CIRCULAR ARCHES UNDER A  
UNIFORM ALL-AROUND PRESSURE PULSE

AD-245 291

29(501)-464: University of Illinois

October 1960

U

Part 1 of Volume I presents numerical results of an investigation of the dynamic response of an elastic spherical shell to uniform axi-symmetric pressures. A continuous dome has been replaced by a series of elastic members having distributed flexural and membrane stiffnesses. Internal moments, thrusts, and shears for the replacement mechanism have been expressed in terms of tangential and radial displacements of the middle surface. The time-dependent response of the dome to external pressures was investigated by solving these force-displacement relations using an iterative technique similar to physical relaxation.

The response was investigated for two types of edge restraint: (a) rigid support, and (b) moment-free support. Also studied were the effects on response of radius-to-thickness and period-to-pulse duration ratios. Finally, the effect of peak dynamic pressure on axi-symmetrical buckling was investigated. Results and conclusions are summarized in the text.

Part 2 of Volume I discusses a physical mechanism developed to represent shell action for domes dynamically loaded into the inelastic range. A sandwich type of cross section with two thick uniformly reinforced face sheets is introduced to simulate the behavior of a concrete dome.

Physical relaxation is used in computing dome response, and the incremental loading procedure is described in detail. Even for symmetrical pressures, possible combinations of elastic and plastic areas in the dome surface become extremely large. Thus, in an actual numerical calculation, a large amount of bookkeeping is necessary. This bookkeeping problem was solved in a unique fashion for a binary computer and is presented in the chapter devoted to the computer program.

Volume II is concerned with the behavior of arch structures under dynamic loads. Numerical solutions are presented for the elastic response of two-hinged circular arches of constant cross section subjected to a uniform all-around triangular pressure pulse with an initial peak. Parameters investigated include duration of the pressure pulse, magnitude of peak pressure compared to critical buckling pressure, geometric and physical properties of the arch, and initial out-of-roundness of the arch.

The problem is analyzed approximately by replacing the continuous arch by a framework consisting of a series of rigid bars and flexible joints. The actual structure mass is lumped as a series of point masses at the joints. The equations of motion for the analogous framework are solved by a step-by-step method of numerical integrations.

SWC-TR-60-21

AD-329 441

SUMMARY OF INTERIOR BLAST LOADING IN HOLLOW MODEL STRUCTURES

29(601)-796: Armour Research Foundation

July 1960

C

This report summarizes results of a series of four interior loading studies conducted in the Air Force 6-foot Shock Tube. Primacord high explosive was used to generate shocks having overpressures between 5 and 30 psi and durations of about 22 millisecc, at the test section.

A series of hollow models with some exterior surface openings was studied to determine the value of initial and maximum pressure attained inside the models. Barium titanate pressure sensors were used to measure inside pressures on the floor and back wall of the models, as well as on small blocks placed on the floor. The basic model was a 4 x 6 x 12 inch cubicle with openings of either 0, 30, or 100 percent in the front, back, top, or sides. Variations in roof geometry treated include parapet walls and gable roofs, both with and without eaves. A model full-scale field test structure was also treated. These models were tested at angles of incidence of 0°, 145° and + 90°. Most shots were at 0°.

Openings located in or near the front were found to be most effective in producing high inside pressures, while gable roof models showed slightly lower inside pressures than flat roof models; neither parapet walls nor eaves affect inside loading. There is no effect of overpressure on inside pressure ratios in the 5 to 30 psi pressure range, but impulses on the block although difficult to measure satisfactorily, appear to increase for the block roof and decrease for the net horizontal load on the block, as overpressure increases. For a given opening configuration, inside pressures decrease almost linearly as the angle between openings and flow goes from 0° to 90°, then increases only slightly in the 90° to 180° range. Shock tube loadings compare quite well with those on a very similar 24:1 large-scale model with 18 percent openings in the front and back surfaces, at 7.0 psi.

A series of curves giving values of initial and maximum inside pressure ratios for models with simultaneous openings in the front and back is also presented. These curves are based on data from the Orientation Program.

SWC-TR-60-41

AD-251 140

SHOCK CHAMBER DEVELOPMENT AND EVALUATION

29(601)-546: Broadview Research Corporation

July 1960

U

Development of a test facility, for detonating explosives in reduced pressure ambient conditions to determine blast loadings on models of protective structures from spherically expanding shock waves, is described. The facility consists of a large cylindrical vacuum vessel 10 feet in diameter and 19 feet long, equipped with a model-mounting stand, charge holder, vacuum system, access ports, and quick opening door.

The development program involved tests of reduced ambient pressure scaling in a small (5-foot diameter, 9-foot long) cylindrical vacuum vessel prior to design of the final chamber. Work in the small (pre-design test) chamber also included a study of effects of topography on overpressures in high strength shock waves.

Tests in both the pre-design chamber and the final chamber indicate that Sachs' (reduced ambient pressure) scaling of shock strengths is valid to ambient pressures as low as 0.01 atm and shock strengths as high as 50.

A description of the operation of the shock chamber for simulating detonations both at sea level and at high altitudes is also included.

SWC-TR-60-53  
RESPONSE OF ARCHES UNDER DYNAMIC LOADS  
29(601)-2591: University of Illinois  
August 1960  
U

AD-257 572

This report concerns a study of the response of arches subjected to the influence of transient forces.

A numerical procedure is presented for computing the dynamic response of arches in both elastic and inelastic ranges of deformation. The procedure is applicable to arches having any shape and any distribution of mass and stiffness. The distribution of pressure along the arch and its timewise variation may be arbitrary.

The analysis is simplified by replacing the actual arch, which has an infinite number of degrees of freedom, by a discrete framework consisting of a series of rigid bars, flexible joints, and concentrated point masses. To compute the response in the inelastic range, the arch cross-sectional area is considered to consist of two concentrated flange areas connected by a thin rigid web. The equations of motion of the substitute system are solved by a step-by-step method of numerical integration.

Computer programs are described for analyzing two general classes of problems: (a) circular elastic arches subjected to uniform normal pressure of arbitrary timewise variation, and (b) arches of arbitrary shape subjected to a triangular moving pressure pulse. For the latter case it is possible to evaluate the response in the inelastic range of behavior.

Numerical solutions are presented for a wide range of parameters and effects of various parameters are discussed.

SWC-TR-60-54  
SURFACE EFFECTS ON BLAST LOADING  
29(601)-3218: Armour Research Foundation  
May 1958  
S-RD  
Volume II  
Volume III

AD-323 360  
AD-323 610

This report discusses the propagation of a blast wave from a nuclear explosion and the pressures occurring over ideal and real reflecting surfaces. In separate sections the following subjects are discussed; the propagation of a blast wave in free air, thermal radiation of an atomic weapon, reflection process of a blast wave from an ideal surface, influence of mechanical effects on blast wave reflection, and effects of atmospheric inhomogeneities on shock-wave propagation. Results are summarized in a chapter where schemes for constructing blast waves reflected over real surfaces are presented.

Significant advances in predicting the propagation and reflection of atomic blast waves were achieved. Further work is necessary, however, before the accuracy of predictions is adequate to meet military requirements for predicting target damage.

SWC-TR-60-55  
RESEARCH STUDIES ON FREE FIELD INSTRUMENTATION  
29(601)-1944: United Electrodynamics Company  
December 1960  
U

AD-257 886

This report discusses development of a free field stress gage. The gage was tested under static and dynamic conditions to pressures in excess of 1,000 psi in a pressure tank specially designed and fabricated for this purpose. Test results indicate the gage reads within 10 percent of free field stress somewhat beyond 200 psi. Future gages developed along similar lines should accurately measure free field stresses up to 1,000 psi.

An important side result of this work was the design and fabrication of a dynamic pressure tank used in gage development and evaluation. The tank is capable of producing static and dynamic pressures in excess of 1,000 psi. Rise times (time for pressure to reach 63 percent of its final value) range from 10 to 40 milliseconds, for pressure levels currently used.

SWC-TR-61-5  
CLOSURES FOR HARDENED PROTECTIVE HANGARS  
29(601)-2550: American Machine and Foundry Company  
January 1961  
S-RD

AD-358 682

Methods for designing closures for hardened dome and arch aircraft shelters are described and discussed. Seven closure concepts for earth-covered arch shelters and six closure concepts for concrete dome shelters

are described in detail and compared. Sample calculations are given for predicting the response of closure structures subjected to blast loading at the 100-psi overpressure level. Solutions to important design detail problems, unique to design of hardened closures, are also given.

SWC-TR-61-6

AD-266 248

THEORETICAL STUDY OF GROUND MOTION INDUCED IN NON-HOMOGENEOUS MEDIA BY NUCLEAR EXPLOSIONS (2 Volumes)

29(601)-1948: Stanford Research Institute

December 1960

U

In Part 1, a numerical example is set up to provide a test of the method developed in Part 2 for calculating stresses and displacements in an elastic half space caused by an axially symmetric airblast loading. The compressional and shear wave velocities, relative to the speed of sound in air, are taken as  $1 + z$  and 0.6, respectively, where  $z$  is dimensionless depth. Results are shown for an arbitrary surface loading which has general but not specific characteristics of the airblast from a nuclear surface burst. A complete description of coding procedures and the Algol code are given in the appendixes.

In Part 2, a finite-difference numerical method of determining motions and stresses in an elastic nonhomogeneous half space caused by a time-dependent, axially symmetric, surface loading is presented for cases in which compressional wave velocity varies linearly with depth, while shear wave velocity is constant. The method may also be applied to layered media where the elastic parameters are constant in each layer but differ from layer to layer. The usual smearing of compressional and distortional wave fronts in such methods is avoided by introducing a coordinate system following the front. In this characteristic system, regions of influence may be traced before actual motion is determined.

SWC-TR-61-7

AD-261 935

DEVELOPMENT OF A MINIATURE DYNAMIC PRESSURE GAGE

29(601)-1200: Armour Research Foundation

January 1961

U

This report describes the development of a miniature dynamic pressure gage suitable for shock-tube use, and use in shock flows of relatively short duration.

In the course of the program, several disk-shaped gages, using a single sensor to measure the difference between stagnation and side-on pressure, were fabricated and tested in a shock tube. The completed gages each contained minor modifications of a basic design, and each exhibited a different rise time, noise level, and sensitivity. Subsequently, one gage, namely Q-5, was delivered to the Air Force Shock Tube Lab in December 1960 and satisfactorily passed evaluation and calibration tests in the 4-inch shock tube, in the 5-25 psi region for shock wave durations of 6-7 ms.

The report describes operating principles and design of these gages, and summarizes the development program. It also presents preliminary data on a gage of similar design, which incorporates diaphragms in the disk faces, and data on operating characteristics of the gage delivered to the Air Force.

SWC-TR-61-12

AD-350 848

SUMMARY OF FULL-SCALE FIELD TESTS OF STRUCTURES  
SUBJECTED TO HIGH OVERPRESSURES

In-house

March 1961

S-FRD

This report summarizes test data for blast resistant structures which received at least 20 psi overpressure when exposed to nuclear blast effects in the United States full-scale field tests. General information on blast, structure, and test results have been included where available. The purpose of this report is to provide the reader with a feel for the behavior of structures exposed to nuclear blast; in addition, it is hoped the report may provide an easy reference for those interested in the various nuclear test operations involving structures.

For those desiring more information, references have been included for each structure.

SWC-TR-61-25

AD-262 985

STRESS WAVE PHENOMENA IN SEMI-SOLIDS

29(601)-2564: Armour Research Foundation

June 1961

U

Research conducted under this contract had four principal objectives:

a. First was determination of stress distributions on boundaries of unlined circular, elliptical, and round-cornered square holes in large thin photoelastic plates subjected to a dynamic point load on one edge. The centers of all holes were identically located with respect to the load point. The effect of variation in dynamic shock wavelength was also studied.

b. Second was comparison of stress distributions on boundaries of three unlined circular holes located at constant depth below a dynamic point load applied to the edge of a large thin photoelastic plate, but at varying horizontal distances from the load point.

c. Third was study of the stress distribution on the boundary of a lined circular hole in a large thin photoelastic plate subjected to a dynamic point load on one edge.

d. Fourth was calibration of electrical resistance strain gages embedded in a large thin photoelastic plate subjected to a dynamic point load on one edge.

During the course of the current study use of rubber thread grids for measuring transient internal strains was refined. Later this method was supplemented by introducing the Moire fringe technique for determining transient surface strains.

SWC-TR-61-32

AD-448 434

STATIC EXPERIMENTS FOR THE STUDY OF THE INTERACTION OF BURIED  
STRUCTURES WITH GROUND WAVES

29(601)-2652: Armour Research Foundation

April 1961

U

An experimental program was conducted to evaluate and extend basic assumptions and concepts used in soil-structure interaction theory developed by Armour Research Foundation. These experiments were static, and examined the form of the arching force acting on axially loaded buried cylinders.

Compacted Ottawa sand was used for these experiments. Uniaxial compressive loading characteristics of this soil were almost linear on the loading part of the cycle. However, when unloaded the material exhibits some hysteresis characteristics. Experiments were performed on a number of buried models which varied in length and stiffness. The soil mass was loaded pneumatically to 20 psi. During the loading part of the cycle, the assumed form of the arching force was very good. Hysteresis characteristics of the soil require that some modifications of the concept be made for unloading.

Auxiliary experiments were performed on small samples of soil confined in a steel cylinder and compressed axially. These experiments indicated that side wall friction effects were appreciable. Further experiments with various wall treatments, such as Teflon sheets, indicated a large portion of the frictional effect could be eliminated.

SWC-TR-61-47

THE INVESTIGATION OF DEEP REINFORCED CONCRETE BEAMS UNDER STATIC AND DYNAMIC  
LOADING

VOLUME I -- STRENGTH AND BEHAVIOR IN FLEXURE

AD-268-848

VOLUME II -- STRENGTH AND BEHAVIOR IN SHEAR

AD-268 849

29(601)-2372: University of Illinois

July 1961

U

VOL. I. The object of this investigation was to study the strength and behavior in flexure of a simply supported deep reinforced concrete beam subjected to slowly and rapidly applied loads, as a basis for developing a rational and efficient design procedure. In particular, it was desired to determine behavior in flexure under dynamic load and to compare it with static behavior; to determine the relation of ultimate deflection under dynamic load to ultimate static deflection; to determine increase in flexural strength as a function of strain rate or some other factor; and, if data collected were sufficient, to recommend design procedures for deep reinforced concrete beams.

VOL. II. The object of this investigation was to determine the strength and behavior in shear of reinforced concrete deep beams subjected to static and dynamic loading, to determine whether the dynamic mode of failure is different from the static mode of failure, and to evaluate the effectiveness of web reinforcement.

SWC-TR-61-48

AD-268 466

PRELIMINARY DESIGN STUDY FOR A DYNAMIC SOIL TESTING LABORATORY,  
APPENDIX B -- SMALL SCALE FOOTING STUDIES, A REVIEW OF THE LITERATURE  
29(601)-1947: Massachusetts Institute of Technology  
July 1961

U

A review is made of literature on small-scale testing of footings on soil, particularly of efforts to determine static ultimate bearing capacity. Literature published earlier than 1960 is discussed, while later reports are only listed in the bibliography. The review was performed as part of a preliminary design study for a dynamic soil testing laboratory, and was intended to determine why some past efforts were worthwhile and others were not. The report concludes that the best success is achieved in nonquantitative verification of deformation modes and patterns of behavior, particularly the size, shape, and presence of rupture zones. Good results are obtained from attempts to supplement established theories with empirical correction factors, but attempts to verify quantitative relationships or to establish numerical values have generally failed.

SWC-TR-61-51

AD-263 870

GROUND SHOCK ISOLATION OF BURIED STRUCTURES  
29(601)-2586: Armour Research Foundation  
August 1959

U

This is a continuation of the study of isolation of buried structures from ground shock, reported in AFSWC TR 59-47, Ground Shock Isolation of Buried Structures. Small aluminum cylinders (2 inches in diameter x 8 inches long) were embedded in dry Ottawa sand and subjected primarily to ground shock components of an HE charge. Accelerometers mounted on the cylinders were used to measure motions.

Various devices were then employed on or about the cylinders to alleviate induced motions, which were compared to the unisolated response. These isolation devices consisted of open and closed cell polyester urethane foams and loose and dense sand contained in a stove-pipe. In addition, variations in response with changes in overall bed density were investigated. An analytical study was also conducted to explore certain aspects of response including kinematics of cylinder motion, the structure-soil interaction problem, and isolated cylinder response.

The study demonstrated that accelerations generally increase with increase in bed density, and effectiveness of isolation systems must be measured relative

to characteristics of the overall bed. It is also shown that high frequency components of response are important for cylinders placed close to the charge. The study reinforced previous conclusions regarding validity of testing procedures and effectiveness of soft foam isolation.

SWC-TR-61-55

AD-272 956

ANALYSIS OF THE DYNAMIC RESPONSE OF AN ABOVEGROUND SIMPLY SUPPORTED  
CYLINDRICAL SHELL SUBJECTED TO BLAST LOADING

29(601)-2591: University of Illinois

August 1961

U

The purpose of this study was to determine the elastic response of an aboveground simply supported shell roof subjected to blast loading. The study naturally divides itself into four parts:

1. Review of blast loading phenomena and evaluation of forces which might reasonably be expected to act on the structure;
2. Derivation and discussion of the equations of motion of the shell;
3. Development of a solution to the equations of motion which would be suitable for programming for a digital computer;
4. Preliminary study to establish which parameters are most important, and general effects of these parameters.

SWC-TR-61-58

AD-268 467

PRELIMINARY DESIGN STUDY FOR A DYNAMIC SOIL TESTING LABORATORY,  
(APPENDIXES K, L, M, AND N)

29(601)-1947: Massachusetts Institute of Technology

August 1961

U

Four laboratory experiments performed on small samples of soils are discussed. The experiments were designed to furnish certain information on soil behavior needed for design of a dynamic soil testing laboratory. The four experiments studied friction angles of sands at low confining pressures, side friction in the consolidation test, failure conditions in hollow soil cylinders, and failures in tubes surrounded by soil. Apparatus and procedures used in each case are described, and typical data and results are presented.

SWC-TR-61-60

AD-265 896

DYNAMIC RESPONSE OF THE 6-FOOT DIAMETER SHOCK TUBE TO A CONSTANT  
VELOCITY PRESSURE FRONT

29(601)-2793: University of Michigan

August 1961

U

The problem of determining the dynamic effect of an internal nondecaying pressure front moving with constant velocity parallel to the axis of a circular tube is treated. It was known that the equations for the problem of a beam

resting on an elastic foundation are equivalent to those for a circular tube, after a simple replacement of constant terms. Thereafter, the equivalent beam problem is considered with both infinite and finite lengths. The finite beam is investigated with two types of boundary conditions: both ends simply supported, and both ends fixed. Viscous damping is considered for the infinite beam. The effects of shear and rotatory inertia are neglected in all cases. It is shown that dynamic factors for the infinite and finite beams are nearly identical, and the solution for one circular tube is obtained on the basis of an equivalent infinite beam.

SWC-TR-61-90

AD-276 290

STUDIES OF THE RESPONSE OF ARCHES AND DOMES UNDER DYNAMIC LOADS

29(601)-2591: University of Illinois

October 1961

U

This report, consisting of Parts I, II, and III, is concerned with three aspects of the response of arches and domes under dynamic loads.

In Part I the accuracy of an approximate design method for arches subjected to dynamic loads is evaluated by comparing predictions using this method with exact solutions. Primary emphasis is placed on effects of loads distributed uniformly around the arch.

In Part II the response of circular elastic arches under a moving pressure pulse is investigated by the modal method. Various combinations of natural modes are considered, and the combination of the smallest number of modes which satisfactorily approximates the exact solution is determined. It is concluded that good approximation to the true response can be obtained by considering contributions of the first anti-symmetrical and the first two symmetrical natural modes of vibration.

Part III presents a derivation of an approximate theory for the dynamic response of spherical shells loaded unsymmetrically by time-varying pressures. Nonlinear effects are considered, so the resulting equations reflect buckling tendencies associated with large-deflection behavior.

WL-TR-64-108

AD-614 108

EFFECTS OF BOUNDARY FRICTION ON TRANSMISSION OF STATIC STRESS THROUGH SAND IN CYLINDRICAL TANKS

29(601)-6002: Air Force Shock Tube Facility -- University of New Mexico

March 1965

U

Experiments to determine the effects of boundary friction on the transmission of static vertical stress through standard 20-30 Ottawa sand in 8-inch I.D. tanks are discussed. In these experiments the tank type, tank length, applied overpressure, sand density, and boundary were varied. Theory and tests showed that the percent transmission did not vary significantly with overpressure between 7 and 85 psi, but decreased with the length of the tank. The decrease in transmission with increase in tank length could be approximated by a theoretical equation up to some maximum length. It is concluded that a greased membrane is perhaps the simplest and certainly an adequate means of reducing wall friction.

## EJECTA DISTRIBUTION FROM CRATERING EVENTS IN SOIL AND ROCK

29(601)-6270: The Boeing Company

February 1965

S-2D

Data resulting from 4 nuclear craters and 31 chemical craters were obtained and evaluated to determine ejecta distribution on the ground surface surrounding the crater and to account for the disposition of total ejecta mass, fallback mass, and compaction and distortion mass. Emphasis was on surface craters in rock and soil; however, data for rock craters are sparse. Existing theories on cratering were surveyed to determine if they could be used or modified to explain ejecta observations made on experimental craters. It appears that the Knox-Terhune theory could be modified to predict ejecta distribution for subsurface craters; however, a similar theory for surface shots does not exist.

Analysis of data for a single near-surface nuclear crater indicates that ejecta mass represents 35 percent of true crater mass and 53 percent of apparent crater mass. Fallback mass represents 27 percent of true crater mass, and the compression and distortion mass represents about 37 percent of true crater mass.

For chemical (HE) surface craters, ejecta mass represents about 35 percent of true crater mass and does not exhibit a particular function of yield. Chemical surface craters are characterized by fallback representing about 34 percent of total ejecta mass; and compaction and distortion of the surrounding medium represent about 31 percent of the true crater mass.

As charge weight is increased, the ejecta mass for surface chemical craters is deposited closer to the crater edge. When charges of fixed weight are fired at successively greater burst depths, ejecta mass is deposited at increasing distance from the crater edge until the burst depth for optimum apparent crater is reached.

Ejecta mass distribution was similar for two surface craters of the same chemical weight: one in rock and the other in soil. The ratio of total ejecta mass to apparent crater mass was 1.7 and 0.75 for the rock and soil crater, respectively. The contribution to the crater due to compaction and distortion is negligible for craters in rock.

Scaling laws for surface craters in soil media were developed.

## PREDICTION TECHNIQUES FOR SOIL AND ROCK BEHAVIOR IN THE VERY HIGH OVERPRESSURE REGION

29(601)-5540: Shannon and Wilson, Inc.

May 1965

S

This report extends the current semiempirical method for determining the ground displacements due to air blast effects to the very high overpressure region. As a background for the method, the pertinent behavior characteristics of the soil and rock are discussed and field and laboratory

techniques are outlined. Since the method is based on limited field data and many assumptions, the limitations are fully discussed. Appendixes to this report present a numerical example of the method, techniques for in situ rock testing, and construction considerations for underground protective structures in rock.

WL-TR-64-113

AD-619 969

CLOSE-IN EFFECTS FROM A SURFACE BURST

29(601)-5009: MRD Division - General American Transportation Corporation

June 1964

U

A computer program for the solution of stress wave propagation into a real rock material near the center region from a surface burst of a large-yield nuclear device has been prepared. Preliminary numerical results are shown.

The computer program was prepared from a set of finite difference equations representing the differential equations of motion.

The differential equations of motion are taken in a form which includes large displacements, large strains, large rotations, large velocities, and accelerations.

A constitutive equation relating stresses to displacements, stresses, and temperature was derived. This equation accounts for plasticity, finite strains, and temperature. The equation was developed in two stages:

1. The form of the reversible component was derived in accordance with classical thermodynamics and finite elasticity theory. The Helmholtz free energy used in the derivation of the macroscopic stress strain temperature relationship via the calculus of variations was derived from a microscopic and atomic model of a crystalline material representative of rock.

2. The irreversible component of the macroscopic deformation was derived from the microscopic theory of the motion of crystalline imperfections and their relationship and response to stresses and temperature.

Several illustrative examples of stress strain curves are shown.

WL-TR-64-118

AD- 615 457

STATIC AND DYNAMIC COMPRESSIBILITY OF SUFFIELD EXPERIMENTAL STATION SOILS

29(601)-6352: M. T. Davisson, Foundation Engineer

April 1965

U

Static and dynamic one-dimensional compression tests were performed on each of ten 5-inch undisturbed shelly tube soil samples taken from the site of Operation Snowball at the Suffield Experimental Station. The maximum stresses attained were generally in the 390- to 1,300-psi range. The results of the tests are presented in the form of plots of axial stress versus axial strain, constrained modulus versus axial stress, and radial stress versus axial stress. The dynamic modulus observed for the upper 13 feet of the soil profile has a minimum value of approximately 3,000 psi, and is approximately twice the static value. Between the depths of 13 and 23 feet, moduli values ranging 18,000 to

24,000 psi are applicable at the 100-psi stress level. Below a depth of 23 feet, the estimated water level, the constrained modulus is considered equal to that of water -- 300,000 psi. An air-blast-induced ground motion prediction was made for a range of 250 feet from a 500-ton TNT explosion. A peak transient surface displacement of 4.6 inches was computed for a time of 39 milliseconds after arrival of the shock front at the ground surface. Because of differences between the laboratory and field loading histories, and the strain rate sensitivity of the soil, the computed displacement is probably from 50 to 100 percent of the actual displacement.

WL-TR-64-122

AD-468 736

A STUDY OF STATIC & DYNAMIC RESISTANCE & BEHAVIOR OF STRUCTURAL ELEMENTS

Final Report -- Project M266

29(601)-5372: IIT Research Institute

June 1965

U

In the current phase of a research program designed to study the behavior of a number of simple structural models buried in a soil medium which is subjected to static and dynamic loads, a dynamic loading device was developed for applying air blast loadings to the surface of a bed of soil. This facility was then used to study the behavior of four cylindrical shell models which were buried in a dry cohesionless soil medium of uniformly graded silica sand (Ottawa sand).

In this report, experimental results in the form of longitudinal and hoop membrane force and bending moment distributions at the central transverse plane of each of the cylindrical shell models are presented. Horizontal and vertical diameter changes at the central transverse cross section are also presented along with acceleration-time records of the crown, invert, and springing line. Some conclusions are then drawn regarding the influences of the end closure system, and the rate of loading on the behavior of a cylindrical shell buried in Ottawa Sand and subjected to static and dynamic overpressures.

WL-TR-64-142

AD-614 892

SIMILITUDE OF DYNAMICALLY LOADED BURIED STRUCTURES

29(601)-5359: Iowa State University

April 1965

U

Results of an investigation to determine similarity requirements for dynamically loaded buried structures are presented. Scaling relationships are developed and investigated experimentally. Tests were performed with small-scale structures buried at different depths and dynamically loaded in either a drop-weight loader or a shock tube. Hollow tubes instrumented with strain gages and solid blocks instrumented with accelerometers were used as the model structures. Three soil types were utilized in the test program: dry Ottawa sand, dry sand mixed with mineral oil, and a cohesive (Colo) soil. Complete strain-time and acceleration-time curves were obtained at different depths of burial for a series of geometrically similar models and for a series of hollow cylinders of different stiffnesses. A detailed analysis of the data is presented.

The results of the test program indicate that reliable predictions, based on the scaling relationships presented in the report, can be obtained for

structures buried in dry sand. For more cohesive soils distortion is present and the use of prediction factors is required if the same materials are used in both the model and prototype.

WL-TR-64-143

AD-615 906

ANALYSIS OF FREE FIELD DATA IN A HALF-SPACE UNDER DYNAMIC LOADS

29(601)-5552: MRD Division - General American Transportation Corporation

April 1965

U

Exact analytic formulas are developed for obtaining wavefront stress and stress-gradient values in elastic and viscoelastic half-spaces subject to dynamic surface loading. These exact wavefront stress values are used along with the results of a double-precision computer code in the display of stress profiles for the elastic half-space problem. Viscoelastic and elastic attenuation formulas are derived. Attenuation contours are plotted.

WL-TR-64-155

AD-616 344

THE MECHANICAL AND OPTICAL CHARACTERIZATION OF SOLITHANE 113 AND INVESTIGATION OF PHASE LAG RELATIONSHIPS BETWEEN PRINCIPLE MECHANICAL AND OPTICAL AXES IN PHOTOVISCOELASTIC ANALYSIS

29(601)-5367: Firestone Flight Sciences Laboratory

October 1964

U

A complete mechanical and optical characterization is given for Solithane 113, a urethane rubber compound having high birefringent sensitivity and excellent optical transmission properties. Its viscoelastic transition region is found to span about six decades on logarithmic time, somewhat narrower than other materials of the urethane family.

The time-dependent orientation of the principal mechanical axes and optical axes is investigated for a circular Solithane specimen subjected to a rapidly changing diametric load situation. The results indicate the possibility of large phase lag of the optical axes orientation compared to principal stress axes. The agreement with principal strain axes is generally much closer, but even here the phase angle can be as much as  $45^\circ$ .

WL-TR-64-157

AD-614 481

A STUDY OF THE BEHAVIOR OF SOIL & ROCK SUBJECTED TO HIGH STRESS LEVELS

29(601)-5817: University of Illinois

March 1965

U

An analytical and experimental investigation has been conducted to study the behavior of sand and clay under high stresses. The analytical work developed equations for the stress-strain properties of a medium composed of elastic equi-radii spheres in a face-centered cubic array. Theoretical relationships between the coefficient of earth pressure at rest, the angle of internal friction, and the coefficient of friction between the coefficient of earth pressure at rest, the angle of internal friction, and the coefficient of friction between the spheres were also derived. A special zero-lateral-strain device was developed for one-dimensional compression tests on sand and clay.

The tests were carried to axial stresses of 3300 psi on four sands and 2200 psi on five remolded clays. The tests on sand demonstrated that the grain shape and gradation were as important as relative density in influencing the stress-strain properties. Controlled radial strain tests on the sand, with axial stresses up to 5000 psi, disclosed a failure envelope with a significant decrease in slope under the high pressures. Unloading of the sands and clays caused the coefficient of earth pressure at rest to increase and approach the coefficient of passive earth pressure.

WL-TR-64-163

AD-468 460

BEHAVIOR OF PLAIN CONCRETE UNDER HIGH TRIAXIAL LOADING CONDITIONS

29(601)-6049: University of Colorado

June 1965

U

Concrete mixes with average compressive strengths of 5200 psi, 8100 psi, and 8700 psi were tested under four different conditions of triaxial compressive loading as follows:

- Type I.  $\sigma_1 > (\sigma_2 = \sigma_3)$
- Type II.  $(\sigma_1 = \sigma_2) > \sigma_3$
- Type III.  $\sigma_1 = \sigma_2 = \sigma_3$
- Type IV.  $\sigma_1 = C\sigma_2 = C\sigma_3; C > 1$

$\sigma_1$ ,  $\sigma_2$ , and  $\sigma_3$  are the major, intermediate, and minor principal stresses, respectively. Tests were performed on 6- by 12-inch cylinders. Type I and Type IV tests were run until the axial stress dropped or until 2 inches axial deformation was produced. Results of Type I and Type IV loadings differed little, and the following equations fit the combined results very well:

$$\sigma_1 - f'_c = 4.690 \sigma_3^{0.8330} \quad 0 \leq \sigma_3 < 35 \text{ ksi}$$

$$\sigma_1 - f'_c = 10.570 \sigma_3^{0.6329} \quad 35 < \sigma_3 \leq 75 \text{ ksi}$$

Considerable bulging occurred, and it appeared that the average normal stress at midheight remained nearly constant during bulging and represented an approximate yield stress,  $\sigma_c$ . Equations for this stress are

$$\sigma_c - f'_c = 3.042 \sigma_3^{0.9782} \quad 0 \leq \sigma_3 < 35 \text{ ksi}$$

$$\sigma_c - f'_c = 7.257 \sigma_3^{0.7101} \quad 35 < \sigma_3 \leq 75 \text{ ksi}$$

Type II tests were run until the lateral stress dropped. Results of these tests are given by

$$\sigma_1 - 2.105 f'_c = 4.056 \sigma_3^{0.8510} \quad 0 \leq \sigma_3 \leq 20 \text{ ksi}$$

The difference in Type I-Type IV and Type II results indicates that the intermediate principal stress has an effect. No drop-off of load occurred in Type III tests, but the unconfined compressive strengths were decreased according to the linear expression

$$f'_c'' = f'_c' (1 - 0.005635 \sigma_3) \quad \sigma_3 \leq 86 \text{ ksi}$$

Results obtained are in good agreement with those of previous investigators, but the present tests attained much higher stresses than any previous tests.

WL-TR-64-164  
PROJECT AIR VENT - EJECTA DISTRIBUTION STUDIES  
29(601)-6270: The Boeing Company  
November 1964  
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Ejecta distribution studies were made on 21 high-explosive cratering shots of the 30-shot Air Vent series. Of these, 11 shots with charge weights ranging from 64 to 6000 pounds of TNT were fired at the ground surface, and 10 shots, each 256 pounds, were fired at varying depths beneath the ground.

When burst depth was varied and charge weight held constant, ejecta mass was distributed in a similar way relative to the apparent crater for all charges fired at depths between the ground surface and 4.8 feet. At greater burst depths, ejecta mass was deposited farther from the crater, reaching maximum distances at the burst depth that produced the maximum apparent crater. For surface bursts, ejecta were deposited relatively closer to the crater as energy release was increased.

For surface craters, 35 percent of the true crater mass was represented by ejecta, 40 percent by fallback, and 25 percent by compaction and distortion of the medium surrounding the crater. Ejected material represented about 88 percent of the apparent crater mass. The ratio of ejecta mass to true crater mass increased with burst depth, reaching a maximum of 0.58 at a burst depth of 1.2 feet. The fallback mass was approximately equal to the ejecta mass at a burst depth of about 6.4 feet.

WL-TR-64-175  
GROUND DISPLACEMENT STUDIES, Project 3.7  
29(601)-6378: Shannon & Wilson, Inc.  
November 1964  
U

AD-471 182

Measurements of transient and permanent vertical and permanent horizontal ground movements with depth were made at four locations at the Suffield Experiment Station during Operation Snowball. The four locations were at distances of 245, 280, 310, and 370 feet from ground zero on a true azimuth

of 322°. Specially designed scratch gages were installed inside of couplings joining aluminum Slope Indicator casing at the stations to measure vertical transient movement with depth. Slope Indicator readings were taken at pre-determined intervals post- and pre-shot to determine the alignment of the aluminum casing and to determine permanent horizontal movement.

Surface surveys indicated that the tops of the casing at the two stations closest to ground zero moved toward ground zero, while the remaining two stations moved away from ground zero. Analysis of the data obtained with the Slope Indicator suggests that extensive radial displacements probably occurred below the bottom of the various casings. This is believed to be feasible since the lack of surface debris was small compared to the size of the crater, suggesting that the major portion of the material was displacement downward and laterally. The measured horizontal and vertical movements are therefore generally considered a combination of directly induced and air blast effects. It is impossible to ascertain the amount of horizontal or vertical movement attributable to each.

Data obtained in about the upper 15 feet at Station 3 are believed to be primarily the result of air blast effects. Values of constrained modulus and vertical elastic compression were computed from the data and results compared favorably with those recommended for present day displacement predictions.

Dynamic compression tests performed by the Air Force Shock Tube Facility and the Air Force Weapons Laboratory to evaluate the constrained modulus of elasticity are included in appendixes in this report.

AFWL-TR-65-8

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SHEAR AND BOND STRENGTH OF HIGH STRENGTH REINFORCED CONCRETE BEAMS

UNDER IMPACT LOADS - FIRST PHASE

29(601)-6246: University of Texas

June 1965

U

The Air Force Weapons Laboratory, Kirtland AFB, New Mexico, initiated a comprehensive investigation into the shear and bond capacity of very-high-strength concrete beams subjected to impact forces, the investigation to be conducted by the Structural Mechanics Research Laboratory of the University of Texas. This is the final report on the first phase of that study. The scope of the first phase was broad rather than intensive in any one aspect of behavior. Useful qualitative information from this report will be helpful for designing shear and bond strength into hardened structures, but precise quantitative advice will require intensive study on specific aspects of behavior. The first phase did indicate that further research on particular items should yield specific design criteria.

The University of Texas College of Engineering has obtained new recording equipment for dynamic measurements, and an on-campus drop facility has been constructed. The improved equipment along with testing experience from the first phase of the program will be very beneficial during later phases.

AFWL-TR-65-9

AD-478 706

SIMULATION OF AIR SHOCKS WITH DETONATION WAVES

29(601)-6002: The Eric H. Wang Civil Engineering Research Facility, University of New Mexico, Albuquerque, New Mexico

February 1966

U

Presented theoretically and experimentally are (1) the feasibility of simulating a nuclear blast environment by detonating a gas and (2) determination of the initial conditions of hydrogen-oxygen mixtures to yield blast waves of the same pressure-velocity relationship as that in air shock waves. When the theory was derived by predicting the characteristics of the simulated blast waves, a computer program was written. Experimental data were used to adjust the computed data. The experiments were conducted in a 13-inch-diameter, high-pressure shock tube and yielded four mixtures of hydrogen and oxygen capable of simulating shock waves with overpressures of from 300 to 1,200 psi. It was found that detonation waves may be substituted for air shock waves when the incident loading is important and that applications are generally limited to instances in which only one characteristic of an air shock is simulated.

AFWL-TR-65-11

AD-614 990

SIMULATION OF AIR-BLAST-INDUCED GROUND MOTION (PHASE I)

In-house

April 1965

U

An analytical and experimental program was performed to determine the most promising techniques for simulating the air-blast-induced ground motions from a large-yield nuclear weapon. Two techniques were then selected for further development. One of the selected techniques employs a detonable gas mixture and the other a primacord matrix to generate a traveling wave both of which load the ground. The nuclear air blast overpressure is described, and the simulation produced by either scheme is compared to this environment. Sufficient data are presented to enable the design of simulation experiments which use either technique.

AFWL-TR-65-12

AD-469 553

THE EFFECTS OF SHEAR ON STRESS WAVE PROPAGATION

29(601)-5548: University of Washington, Seattle, Washington

August 1965

U

The propagation of high-intensity stress waves in cylindrical geometries is considered as a means to obtain a measure of the shear stress effects on material behavior. A discontinuity theory is applied to show that when Hugoniot's are used as equations of state, the Hugoniot's must necessarily coincide for all geometric configurations. It is also shown that the simple equations of state of this type may accurately predict particular information that does not depend on the shear properties of the material but that little evidence exists to permit its use in a general fashion for dynamic problems. A criterion is proposed for hydrodynamic behavior, and the parameters controlling this behavior are given. A technique to check the validity of proposed equations of state using flash radiography is also suggested.

AFWL-TR-65-13

AD-465 109

APPLICATION OF RESEARCH TO AIR FORCE CIVIL ENGINEERING VIA  
A SCIENTIFIC AND TECHNICAL INFORMATION SERVICE

In-house  
May 1965  
U

The development of a capability for processing and evaluating scientific and technical information (STINFO) pertaining to Air Force civil engineering is described. During the initial phases of this development considerable attention was given to identifying sources of information and analyzing storage and retrieval systems. The information storage and retrieval system being used for processing civil engineering STINFO is a manual, nonconventional type commonly referred to in the field of documentation as concept coordination. The indexing of the information is accomplished through the use of words or combinations of words to which "roles" have been added to form "term-roles." "Links" are also used in the indexing process as an additional aid for retrieving only relevant information when a search is being conducted. Evaluation of retrieved information in response to an inquiry made to the CE STINFO service is the final step in devising a "best known" answer. This operation is performed by professional engineers engaged in research work who in most cases have advanced degrees and use the combination of experience and education to evaluate information for its applicability to a given problem.

AFWL-TR-65-15

AD-620 334

DEVIATORIC EFFECTS IN HIGH INTENSITY STRESS WAVES  
29(601)-5008: IIT Research Institute Technology Center  
August 1965

U

The governing equations for dynamic cavity expansion are developed for a continuum which can be characterized as a compressible, kinematic hardening, elasto-plastic material. A numerical procedure for integrating these governing equations, utilizing shock-fitting as opposed to artificial viscosity for numerical stability, is outlined. The shock-fitting, as well as the starting procedures is based on a progressive wave solution of an adjunct problem which is asymptotic to the formulated problem.

Continua theory of dynamic cavity expansion, as formulated here, indicates that the hydrostatic component of the stress state decreases much more rapidly than a decreasing cavity pressure as long as the cavity is expanding. The capability of the continua to transmit radial compressive force is due to a rapidly increasing deviatoric stress.

AFWL-TR-65-16

AD-622 445

HIGH COMPRESSIVE STRENGTH CONCRETE, Report 3, Summary Report  
U S Army Engineer Waterways Experiment Station, (29-601)-61-04  
September 1965

U

The information contained herein constitutes the third and final report on high-compressive-strength concrete. The first report consisted of a review of the state of the art. In phase two, approximately 150 mixtures were proportioned

to study the effect of mixture variables on the ultimate strength. In this report are presented the results of the previous two phases, and results of physical and thermal tests of high-strength concrete including creep, shrinkage, thermal properties, heat rise, and stress-strain relations. Procedures for proportioning, mixing, placing, using, testing, and inspecting high-strength concrete and the practical application to structural works are discussed. Recommendations are made for additional work to fully utilize the properties of high-strength concrete.

AFWL-TR-65-20, Volume 1

AD-472 608

DYNAMIC STRESSES IN A THICK ELASTIC CYLINDER SUBJECT TO TRANSIENT PRESSURE LOADINGS - Theoretical Analysis and Discussion of Results  
29(601)-5993: Grumman Aircraft Engineering Corporation, Bethpage, New York  
September 1965

U

The response of a hollow circular cylindrical shell of arbitrary thickness, in either an elastic or a viscoelastic medium, to transient dilatational and shear waves (and their superposition) is presented. The solution is valid within the scope of the linear theory of elasticity or viscoelasticity. The technique for obtaining the solution relies upon (1) the construction of a train of incident pulses from steady-state components, where each pulse represents the time history of the transient stress in the incident wave, and (2) the existence of a physical mechanism that, between pulses, restores the disturbed particles of the cylinder and the surrounding medium to an unstrained state of rest.

The influence on the cylinder response of the following factors is discussed: liner thickness, cylinder-medium impedance mismatch, viscoelasticity in the medium, and incident wave form (step pulse, rectangular, linear rise-exponential decay).

AFWL-TR-65-20, Volume II

AD-472 864

DYNAMIC STRESSES IN A THICK ELASTIC CYLINDER SUBJECT TO TRANSIENT PRESSURE LOADINGS - Discussion of Computer Program  
29(601)-5993: Grumman Aircraft Engineering Corporation, Bethpage, New York  
September 1965

U

The response of a hollow circular cylindrical shell of arbitrary thickness, in either an elastic or a viscoelastic medium, to transient dilatational and shear waves (and their superposition) is presented. The solution is valid within the scope of the linear theory of elasticity or viscoelasticity. The technique for obtaining the solution relies upon (1) the construction of a train of incident pulses from steady-state components, where each pulse represents the time history of the transient stress in the incident wave, and (2) the existence of a physical mechanism that, between pulses, restores the disturbed particles of the cylinder and the surrounding medium to an unstrained state of rest.

The influence on the cylinder response of the following factors is discussed: liner thickness, cylinder-medium impedance mismatch, viscoelasticity in the medium, and incident wave form (step pulse, rectangular, triangular, linear rise-exponential decay).

AFWL-TR-65-26, Volume I  
SIMULATION OF AIR-BLAST-INDUCED GROUND MOTIONS (PHASE II)  
In-house (Auld, H.E., D'Arcy, G.P., and Leigh, G.G.)  
April 1965  
U

AD-613 674

Results from the Phase II, Long-Duration High-Explosive Simulation Technique (LDHEST) experiment are presented. This experiment simulates the air-blast-induced ground motions from a large-yield nuclear weapon over a plan area 96 feet by 150 feet. A specially designed matrix of primacord was utilized to produce the desired explosion in a confined volume of air. An overburden, or mass of material, was placed over the explosion to provide a reaction force to shape the resulting wave pulse and to provide the required long durations. The experiment produced an air pressure pulse which had a peak overpressure of 312 psi, a time to one-half peak pressure of 18.2 msec, and a total duration of 170 msec. The shock front traveled at an average velocity of 5,120 ft/sec. On the basis of these results, recommendations are made for future simulation experiments. The measured earth free-field motions and stresses are compared with theoretical calculations, and the validity of the technique for simulating the desired nuclear environment is established.

AFWL-TR-65-26, Volume II  
SIMULATION OF AIR-BLAST-INDUCED GROUND MOTIONS (PHASE II)  
In-house (Auld, H.E., D'Arcy, G.P., and Leigh, G.G.)  
May 1965  
S

AD-613 674

The principal objectives of this portion of the experiment were to investigate the response of underground structural configurations and hardened communication components to simulated nuclear-air-blast-induced ground motions. The structural configuration investigated consisted of a small scale reinforced concrete silo similar to a typical missile launch facility. The test structure was analyzed in detail and instrumented with accelerometers, strain gages, interface pressure cells, and mechanical scratch gages. The recorded data were analyzed to determine the behavior of the test structure and this behavior was then compared to the predicted response. In general, the predicted and measured responses correlated fairly well, but additional refinement of the analytical procedure appears necessary. Similitude relationships were developed, but the validity of these relations cannot be evaluated until future tests of full-scale structures have been performed. The hardened communication system was made up of cable splice cases and interface connections typical of the LGM30 Hardened Intersite Cable System used at MINUTEMAN installations. A description of the test items and their post-shot condition is included along with a discussion of their survivability.

AFWL-TR-65-29  
STATIC & DYNAMIC BEHAVIOR OF SANDS IN ONE-DIMENSIONAL COMPRESSION  
29(601)-6369: University of Illinois  
December 1965  
U

AD-621 895

Static, rapid, and dynamic one-dimensional compression tests were performed on four different sands at each of three different initial relative densities.

The maximum stresses attained were generally 10,000 psi or higher, except for a low-pressure dynamic test series which attained stresses from 1,000 to 1,500 psi. The results of the tests are presented in the form of plots of axial stress versus axial strain, constrained modulus versus axial stress, and radial stress versus axial stress; grain size distribution curves are also presented for each specimen for both the before- and after-test conditions.

The static data were compared to Hendron's static data on the same four sands; general agreement was noted, although the compressibility was consistently somewhat higher than that observed by Hendron. The radial stresses were also somewhat lower; however, the discrepancies are probably a function of the test devices and the manner of performing the test.

Crushing of the sand grains was very pronounced for the coarse sands, especially the angular sand, and had an overwhelming effect on the stress strain relationship. Consideration of sand grain contact stresses provides a qualitative explanation for the observed behavior. It was noted that at high pressures each sand attained a common void ratio, at a given stress level, regardless of its initial relative density. Beyond this stress level each sand has essentially unique properties. No strain rate effects were observed that are likely to be of significance in the engineering use of this data.

AFWL-TR-65-31

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INTERACTION OF PLANE ELASTIC WAVES WITH A THICK CYLINDRICAL SHELL

29(601)-5007: University of Illinois

June 1965

U

A method is presented for computing stresses in the vicinity of a lined cylindrical cavity in an infinite, elastic, isotropic, homogeneous medium as it is enveloped by a plane stress wave of dilatation traveling in a direction perpendicular to the axis of the cavity. The liner, which may be thick, is considered as a second elastic medium. Both the incident stress and the perturbations in the stress field are represented by Fourier series where the coefficients are functions of radius and time. These coefficients represent two-dimensional traveling-wave solutions and are found by solving sets of coupled integral equations of the Volterra type. A computer program was written to carry out the numerical computations. Hoop stresses in the liner and in the medium at the liner medium interface were computed at various angles around the opening for a plane longitudinal step wave. It was found that the maximum dynamic stresses occur on a diameter which is perpendicular to the direction of wave propagation, and that the dynamic stresses are sensitive to variation of the ratio of thickness of the liner to its radius, and stiffness of the liner relative to that of the medium. Further studies were then made to determine the variation of maximum hoop stresses in the liner and medium with these parameters. The maximum dynamic stresses were compared with the corresponding static values. In addition, the effect of decay and rise time of the incident on the maximum hoop stress was investigated.

EXPERIMENTAL STUDY OF STRESS WAVE INTERACTION IN  
PHOTOVISCOELASTIC PLATES

29(601)-6240: IIT Research Institute Technology Center

January 1966

U

The objective of this investigation is to obtain experimental solutions to viscoelastic stress wave interaction problems pertinent to the design of protective structures. The methods of photoviscoelasticity and experimental viscoelasticity in general were employed. The model material used, plasticized polyvinyl chloride, was characterized mechanically and optically by creep tests at different temperatures using the temperature-time equivalence principles and by sinusoidal oscillation tests. Good agreement was obtained by the two methods of property determination. Photoviscoelastic plates were subjected to falling weight and air shock loadings. In the falling weight loading, stresses were determined on the boundary of a circular hole and at a similarly located point in the free field. It was found that the measured maximum compressive stress on the hole boundary is up to 17 percent higher than that obtained by using the free-field stresses and static stress concentration factors. In the air shock loading, stresses were determined at a free-field point and on the boundaries of a circular hole and a rigid circular inclusion. The maximum compressive stress on the hole boundary is appreciably higher than the "statically" computer stress initially, but approaches it at later times. In the case of the rigid inclusion, differences of up to 25 percent between dynamic and "static" stresses were found.

## THE DEVELOPMENT AND EVALUATION OF A MINATURE VELOCITY GAGE

29(601)-5419, 29(601)-6418: Stanford Research Institute

29(601)-6002: University of New Mexico

March 1967

U

Part I of this report describes the theoretical and experimental development of a compact velocity gage. This gage was developed to measure transient velocities from less than 2 cm/sec to above 600 cm/sec over a frequency range from 1 to 500 cps. It can be used at any inclination and measures the velocity component along one axis only, unaffected by crosswise motion. The gage is nearly a cube of about 5-cm edge length and weighs 375 gm. This gage uses a highly overdamped spring-mass system with its undamped natural frequency at the geometric mean of its frequency range. The relative displacement between mass and instrument case is a direct measure of the velocity of the case. The gage is accurate to within  $\pm 10$  percent if calibrated properly. Part I' describes an evaluation of the Stanford Research Institute (SRI) velocity gage discussed in Part I. This evaluation was made to determine the gage performance in measuring the particle velocity of shock-loaded soils. Results indicate that the SRI gage measures the input velocity to within about 10 percent. Gage response to harmonic motion is flat up to about 700 cps. Gage sensitivity is affected by temperature changes by about 1 percent per fahrenheit degree. The gage shows a tilt signal which, for a horizontal gage, is about 1.5 percent of full scale per degree of tilt. The gage is not affected by loads of up to 1,000 pounds on the case.

It will withstand shocks of approximately 4,000 g along the sensitive axis and 1,000 g along the cross axis. Tests of the SRI gage in soil indicate that its presence disturbed the motion field to the extent that the measured velocities may have been considerably in error. The problem of soil motion measurement requires more work, particularly in the development of a gage or gage package that will follow the soil motion.

AFWL-TR-65-48

AD-469 994

A COMPARISON OF THE DYNAMIC AND STATIC SHEAR STRENGTHS OF  
COHESIONLESS AND COMBINED SOILS

29(601)-5174: University of Notre Dame, Notre Dame, Indiana  
August 1965

U

A direct shear device capable of applying maximum shear stresses to soil specimens in a period of time range from 1 millisecond to 20 minutes has been utilized to test a wide variety of soils.

The cohesionless materials, an Ottawa sand in the loose and dense condition, a powdered Nevada silt, and a dry powder clay, did not exhibit any increase in maximum shear resistance due to an impact-type dynamic shear force application as compared to a static force application. An increase of apparent friction angle from 45 degrees to approximately 60 degrees caused by inertial confinement was observed in a dense Ottawa sand.

Cohesive materials, which included undisturbed and remolded clays and combined soils (mixtures of sand and clay), demonstrated an increase in maximum shear resistance under impact loads described solely by the apparent cohesion intercept of the failure envelope. The friction angle was essentially insensitive to test duration. The ratio of the apparent cohesion for a failure envelope involving failure times of 5 milliseconds to the corresponding intercept for failure times of nearly 1 minute was approximately 2. This ratio appeared to be relatively insensitive to moisture content, dry density, grain size and soil structure (flocculated or dispersed) for degrees of saturation in excess of 85 percent. The apparent cohesion ratio appeared to decrease on the dry side of optimum for compacted soils.

Investigation of different pore fluids indicated that pore fluid viscosity was not primarily responsible for the increases in strength.

The simultaneous dynamic application of normal and shear forces did not alter the apparent cohesion ratio of the clays studied.

A preliminary discussion of repetitive force results on clays is included in the report.

AFWL-TR-65-51  
BEHAVIOR OF ROCKS AND SOILS UNDER HIGH PRESSURE  
29(601)-6411: IIT Research Institute Technology Center  
December 1965  
U

AD-626 378

This report describes a program which was directed toward developing a capability suitable for generating engineering data on the high pressure mechanical properties of geologic materials. To provide the greatest possible contribution, this effort concentrated on three of the most important deficiencies in high-pressure experimental technology: (1) development of a system capable of accepting relatively large samples so that more nearly representative data may be obtained than with the smaller samples used previously, (2) development of a system suitable for monitoring the strains of highly deformable geologic materials, and (3) development of an encapsulating technique for soils.

Each of these objectives was attained to a certain degree. Specimens up to 3 inches in diameter were subjected to fluid pressures of several kilobars. The deformation of soil was measured with a potentiometric slidewire device. An encapsulating technique was developed for soils which was suitable up to about 2 kilobars. Further refinements are necessary, but it appears that the more important of the limitations of past studies have been overcome.

AFWL-TR-65-59  
STEP LOAD MOVING WITH SUPERSEISMIC VELOCITY ON THE SURFACE OF  
A HALF-SPACE OF GRANULAR MATERIAL  
29(601)-6055: Paul Weidlinger, Consulting Engineer, New York, NY  
September 1965  
U

AD-621 363

The two-dimensional steady-state problem of the effect of a step pressure traveling with superseismic velocity on the surface of a half-space is treated for an elastic-plastic material. The plasticity condition selected is suitable for a granular medium where inelastic deformations are due to internal slip subject to Coulomb friction.

The problem is inherently nonlinear and leads to a system of coupled differential equations which are solved by digital computer. Numerical solutions are tabulated as functions of the significant nondimensional parameters, i.e., of the Mach number, Poisson's ratio, and a value  $\alpha$  defining the internal friction.

AFWL-TR-65-67  
STUDY OF WAVEFORM CHARACTERISTICS FOR USE IN THE ANALYSIS OF SHOCK  
ISOLATION SYSTEMS FOR UNDERGROUND PROTECTIVE STRUCTURES  
29(601)-6277: Ralph M. Parsons Company, Los Angeles, California  
January 1967  
U

AD-805 746

A recent review of nuclear ground shock test data revealed oscillatory motions of undetermined origin, but of sufficient magnitude to be of concern in the design of shock isolation systems for underground protective structures.

Response spectra of the oscillations exhibited amplification ratios far exceeding those employed in most groundshock prediction methods, the ratios being functions of the number of oscillations, and the amplitude and period of each cycle. As the source of the oscillations was not identified, there was no rational basis for relating these waveform parameters to such basic site and weapon conditions as yield, range, geologic structure and properties of the medium. In this investigation, two possible sources of the oscillatory motion are examined. First, the propagation of waves in a stratified site are studied and their directions and phase relationships estimated by use of wave front diagrams and time-distance curves. Second, the form and strength of Rayleigh waves in an elastic, homogeneous half-space which result from surface pressure distributions similar to those generated by nuclear bursts were calculated. In both cases, oscillatory phenomena can be predicted and certain features related to the observed oscillations. However, the simple approaches employed in this analysis will not yield realistic wave strengths and thus, the composite waveform at a point in the half-space cannot be determined quantitatively.

AFWL-TR-65-71

AD-628 064

DEVELOPMENT OF EQUIPMENT AND PROCEDURES FOR PRODUCING LARGE  
QUANTITIES OF FOAMED SULPHUR IN THE FIELD

29(601)-6408: Southwest Research Institute, San Antonio, Texas  
January 1966

U

Work performed under this contract represents the first practical development of a process and equipment for producing large quantities of rigid sulphur foam. While the sulphur foam formulations and the resultant properties of the foams have not been fully optimized, this new foam material represents a significant advance in the field of foam technology and has applications that measurably exceed the use intended herein. It was demonstrated that foamed sulphur can indeed be produced on a continuous basis at a remote field site by a process and with equipment that is simple and capable of being scaled up to any size. The foam prepared using the procedures and equipment developed herein has mechanical properties comparable to those produced on a batch basis in the preceding laboratory study--namely a density of  $27 \text{ lb/ft}^3$ , a compressive strength of 130 psi, a constant strain rate deformation to 65-70 percent, and a low water absorption. Since the cost of the raw materials for these sulphur foams is less than 2 cents per pound, a foam with a density of  $27 \text{ lb/ft}^3$  can be produced for only \$0.54 per cubic foot. Conventional foams with similar physical properties that can be produced at a remote field site are the rigid urethane foams. The comparative cost of a urethane foam having a compressive strength of 125 psi is approximately \$3.00 per cubic foot. During the week of 17 January 1965, the feasibility of producing foamed sulphur in the field was demonstrated for the Air Force at Kirtland Air Force Base, Albuquerque, New Mexico, by filling a 30-cubic foot annular space with rigid foamed sulphur.

AFWL-TR-65-75

AD- 618 069

A STUDY OF PARAMETERS AND METHODS INVOLVED IN RELATIVE  
DISPLACEMENT MEASUREMENTS IN SOIL

29(601)-6002: E. H. Wang Civil Engineering Research Facility, University of  
New Mexico, Albuquerque, New Mexico

June 1965

U

A study of the parameters and methods involved in relative displacement measurements in soil was conducted. Static tests were performed to assess the influence and corrective measures necessary to eliminate the erroneous effects of arching, overstress, and lateral deformations of the coupling shaft found in spool gage displacement measurements. Stress wave reflections and gage lengths are discussed with reference to dynamic data collected in dry sand several months prior to this study. The study resulted in the formulation of a set of minimum criteria to be used when the spool gage concept is employed to measure relative displacements in soil. These criteria were applied to the design of a spool gage which was tested and compared with the performance of a magnetic coil displacement gage that is relatively free from mechanical mismatch effects. The results from the two gages tested in a controlled environment were very similar.

AFWL-TR-65-78

AD-484 717

AN EXPERIMENTAL INVESTIGATION OF THE ARCHING PHENOMENON  
OCCURRING OVER A BURIED RECTANGULAR PLATE

29(601)-6388: University of Illinois

June 1966

U

This report presents the results of an experimental investigation of soil-structure interaction and its effect on the pressure transmitted to a horizontally buried flat plate. The primary objective of this effort was to determine the validity and range of applicability of an analytical arching theory developed to predict the pressures developed on a flat plate buried horizontally in a cohesionless soil (Ref. 1).

Static and dynamic tests up to 500 psi peak overpressures were conducted in a 2-foot-diameter cylindrical test tank having an adjustable bottom which permitted variations in depth of burial to plate width ratios from 0.5 to 3.0. The tank bottom housed a long rectangular rigid plate supported by springs which allowed the plate to deflect vertically under load. These springs could be changed to investigate the effect of support stiffness on plate pressure. All tests were conducted on two sands, one with smooth rounded grains (Minnesota sand) and one with angular grains (Wabash sand), at various values of relative density. In all tests, data were recorded for overpressure, plate pressure, and plate deflection.

The results indicate that greater arching develops as the burial depth of a given-size plate is increased. The amount of arching developing over the plate is affected by the relative density as well as the type of soil and stiffness of the plate supports. In general, for a given air pressure more load was transmitted to the buried plate in the dynamic tests than in the comparable static tests.

AFWL-TR-65-82

AD-486 834

OPTIMAL SHOCK ISOLATION SYNTHESIS

29(601)-6487: IIT Research Institute Technology Center

July 1966

U

The objectives of this study were to determine if the response of a single-degree-of-freedom active shock isolation system provides a substantial improvement over that of a conventional single-degree-of-freedom passive shock isolation system, and to determine what control parameters are necessary and desirable in an active shock isolation. The best possible shock system and its performance were compared to an optimized passive system. Four techniques were employed in the analysis of the optimal systems: dynamic programming, linear programming, a simple graphical procedure, and direct integration. The above methods were also used to construct what we have chosen to call a tradeoff limit diagram, which relates, in nondimensional form, the maximum mass acceleration with the rattle-space required for the optimum isolation systems as well as for any other system under consideration. As is demonstrated, this diagram provides the designer with the tool for a rational comparison of the performance of any isolation system with that of the best possible. Thus, from it, the designer can assess the practical utility of trying to improve the performance of any given concept or to search for other designs which would approach or actually duplicate the performance of the best possible system. For the typical shock input wave forms investigated, the superiority of the active system was quite evident. Furthermore, the performance of the optimal active system has been found to be insensitive to the wave shape details of the input. This was not true for the optimal passive system considered.

AFWL-TR-65-92, Volume I

AD-627 096

THE GREAT ALASKA EARTHQUAKE, VOL. I

In-house (W. E. Fisher and D. H. Markle)

November 1965

U

The tremendous Alaska earthquake of March 1964 killed many people and caused property damage in the millions. Nevertheless this quake provided scientists and engineers with an almost unique opportunity to study the effects of so huge a natural phenomenon in a relatively urban and built-up environment. The coastal location of the quake's epicenter created a wide variety of tumbler effects including crevasses or grabens, pressure ridges produced by landslides, and a broad spectrum of structural damage. The bays, inlets, harbors, and the seacoast for many hundreds of miles were inundated by powerful seismic sea waves (tsunamis). Such diverse effects suggested unlimited areas of study and evaluation. This technical report presents a general summary of all the effects catalogued above, and investigates in some detail the strengths and weaknesses of the many types of structures affected by the tumblers. The volume of illustrations which supplement this report shows many details of structural damage, information that could be extremely useful to engineers, architects, contractors, city planners, and others who plan to erect structures on land known to be subject to earthquakes. All maps and illustrations are contained in Volume II of this report.

AFWL-TR-65-92, Volume II  
THE GREAT ALASKA EARTHQUAKE, ILLUSTRATIONS AND MAPS  
In-house (W. E. Fisher and D. H. Merkle)  
November 1965  
U

AD-627 020

Volume II of AFWL-TR-65-92, The Great Alaska Earthquake, consists of the photographs, maps, and drawings which supplement Volume I of this report. Credits for these illustrations are given in the Foreword.

AFWL-TR-65-98  
PRESSURE DISTRIBUTION ON UNDERGROUND STRUCTURAL CYLINDERS  
29(601)-6368: Massachusetts Institute of Technology, Cambridge, Mass.  
April 1966  
U

AD-631 671

The objective of this study was to investigate the magnitude and distribution of radial contact pressures on a horizontally buried structural cylinder under the action of a uniform static overpressure applied on the soil surface. A computational procedure was developed for predicting these contact pressures, and a parallel experimental phase, which constituted the major effort in this study, were conducted. The tests were designed to measure directly the radial pressure on the cylinder interface. The primary variables investigated were cylinder flexibility, cylinder compressibility, depth of sand cover, and magnitude of applied surface pressure. The approach taken in the analytical phase was to analyze an idealized representation of the soil-structure system by a closed mathematical formulation which assumed the soil to behave like a continuous, elastic medium. Simple modifications of the mathematical model were introduced to make it represent more realistically a structural cylinder buried in soil. The final distribution of stresses and displacements was computed in a step-wise linear fashion over the pressure range to account for the nonlinear stress-strain relationship for sand. The experimental and analytical results were compared to each other and to previous semi-empirical recommendations for the design of underground structures. It was concluded that the analytical formulation provides an extremely useful approach to the design of underground structural cylinders in general.

AFWL-TR-65-99  
BEHAVIOR OF FLEXIBLE UNDERGROUND CYLINDERS  
29(601)-6368: Massachusetts Institute of Technology, Cambridge, Mass.  
September 1965  
U

AD-621 145

An investigation was made of the "elastic" behavior and failure condition of underground flexible cylinders with particular attention given to arching, deformation, and buckling. The report presents no new data, rather draws heavily from experimental and theoretical work done in the past several years in an attempt to arrive at a unified picture of the chosen aspects of behavior. Active arching was found to reduce the load acting on tubes buried at depths up to several diameters in stiff soil by an average of 30 percent. On the other hand, passive arching may subject tubes buried in compressible soil to loads somewhat higher than applied on the surface. Spangler's deformation equation

was modified to account for arching, lateral pressures, and variability of the soil modulus with pressure. Values of the modified modulus of passive soil resistance, backcalculated by the new equation from tube deformation data, were successfully related to the constrained modulus of the soil. A comprehensive theory of buckling of underground cylinders is presented. It starts with the previously derived theory for elastic buckling in the circular-symmetric tube-soil configuration and extends it to cover (1) elastic buckling of an underground cylinder, (2) inelastic buckling, (3) the effects of soil stiffness and presence of water, and (4) buckling of corrugated cylinders. It proved possible to correlate the soil modulus  $K_s$  controlling buckling to the constrained modulus  $M$  of the soil. The theory agreed well with the few available data. More comparisons with laboratory and field data are required, in particular to verify the values of  $K_s$  and their relationship to values of  $M$ . Regardless of the exact value of  $K_s$ , however, it was shown that for many practical situations of underground cylinders the controlling mode of failure is buckling rather than compressive yield.

AFWL-TR-65-104

AD-489 079

DEVELOPMENT OF THE UNIVERSITY OF NEW MEXICO SOIL STRESS GAGE

29(601)-6002: The Eric H. Wang Civil Engineering Research Facility,  
University of New Mexico, Albuquerque, New Mexico  
August 1966

U

The University of New Mexico soil stress gage was developed at the Eric H. Wang Civil Engineering Research Facility, is fabricated of aluminum with a modulus of approximately  $10 \times 10^6$  psi, and weighs 2 ounces. The gage was evaluated in a series of tests which included (1) full bridge and potentiometer circuitry; (2) three types of calibration: hydrostatic calibration to 1,500 psi, zero-cover calibration statically in soil, and zero-cover calibration dynamically in soil; and (3) burial in soil containers of two different configurations for static and dynamic testing at various depths from zero cover to 36 inches at centerline and quarter point. The UNM gage was found capable of measuring static and dynamic soil stress in a dense 20-30 Ottawa sand in field and laboratory tests up to 2,000 psi. Static measurements within  $\pm 8$  percent of the applied pressure and dynamic measurements of  $\pm 10$  percent of the applied pressure were obtained.

AFWL-TR-65-115

AD-475 498

DIGITAL CALCULATION OF AXISYMMETRIC ELASTIC-PLASTIC GROUND MOTIONS  
FROM NUCLEAR BURSTS

29(601)-5851: University of Illinois, Urbana, Illinois  
November 1965

U

Numerical solutions are presented to axially symmetric wave propagation problems in elastic and elastic-perfectly plastic solids. Use is made of mathematically consistent lumped parameter models in cylindrical-polar and spherical-polar coordinates to obtain strain relationships and equations of motions; the latter are then integrated by a numerical technique. The material behavior is specified by Hooke's law in the elastic range, the Prandtl-Reuss

stress-strain laws in the plastic range, and Hooke's law in rate form for unloading. Mises' yield criterion determines the point of yielding. Results in the form of graphs are presented for the following problems: (1) directly induced motions and stresses in an elastic-perfectly plastic half-space resulting from a pressure applied to a semispherical cavity at the surface (two different yield levels are considered); (2) motions and stresses in an elastic half-space due to a moving surface pressure wave which simulates the air shock wave emanating from a nuclear burst. A method and limited results are presented for wave propagation in an elastic layered medium. By means of the lumped parameter mathematical model wave, propagation phenomena can be simulated in the elastic as well as the perfectly plastic range of material behavior. However, a finite rise time for input pressures is required since the method is of a central finite difference character. Listings of the computer programs in FORTRAN II are presented.

AFWL-TR-65-116

AD-646 610

ENGINEERING CLASSIFICATION AND INDEX PROPERTIES FOR INTACT ROCK

29(601)-6319: University of Illinois, Urbana, Illinois

December 1966

U

Physical and elastic properties of NX-size rock core from 27 localities were investigated in order to develop an engineering classification system for intact rock, and also to develop index properties related to important physical and engineering characteristics. Thirteen rock types are represented. Laboratory tests were conducted on these rocks as follows: unit weight, Shore scleroscope hardness, Schmidt hammer hardness, abrasion hardness, absorption, sonic-velocity stress-strain under cyclic loading to 5,000 psi, uniaxial stress-strain to failure, and point-load tensile strength. A total of 257 specimens with L/D ratios of 2:1 were tested. Statistical studies were conducted with the IBM 7094 computer to determine correlation and regression relationships for selected pairs of variables. A system of engineering classification is proposed in which rocks are classified on the basis of their strength and modulus properties either obtained directly from laboratory tests, or approximately from index properties recommended herein. Application of the proposed engineering classification system to data obtained by others is shown by individual charts for each of several several different rock types. Five charts are presented for estimating the strength or modulus properties for intact rock from the numerical indices obtained by either the Schmidt hammer, the Shore scleroscope, or the sonic pulse velocity, all used in conjunction with the unit weight of the rock.

AFWL-TR-65-122

AD-479 704

**RESPONSE OF CYLINDRICAL SHELLS ENCOMPASSED WITH ISOLATION MATERIAL  
TO A PLANE PRESSURE PULSE**

29(601)-6112 and 6647: IIT Research Institute

February 1966

U

This research program was conducted to determine changes introduced by an encompassing layer of isolation material (closed cell polyurethane foam) in the response characteristics of a cylindrical shell tunnel model buried in soil and subjected to a plane pressure pulse. During the course of the program the response characteristics of nine different models, each having a steel shell 5 inches in diameter by 42 inches long, were experimentally determined for a 12-inch depth of burial in dense Ottawa sand in the IITRI 4-foot-diameter dynamic soil loader. The pressure pulse applied to the soil surface throughout the program had a rise time of approximately 6 milliseconds and a peak of approximately 560 psi. The model parameters studied include shell stiffness, foam thickness, and foam crushing strength.

The results of the study indicate that the presence of an isolation layer produces large reductions in the shell membrane forces in all instances and large reductions in shell bending moments in those instances (stiff shells) where significant moments are present with no isolation material. If the foam strength is such that a significant amount of crushing occurs, then shell deformations are also substantially reduced. The analytic model developed in conjunction with the experiments permits reasonably accurate predictions of shell response. Of particular interest is the ability of the analysis to predict the overall character of the model deformations and the large accelerations associated with "ringing" of the shell in the elastic foam for cases where a high strength foam exhibits little or no crushing. For low strength foams which exhibit significant crushing, the analysis predicts the oscillatory character of the model deformations and the decay of the shell accelerations with time as observed in the experiments.

AFWL-TR-65-140

AD-625 458

**FRACTURE OF GYPSUM PLASTERS AND CEMENT MORTARS BY  
DYNAMIC LOADING**

29(601)-6420: Melpar, Inc., Falls Church, Virginia

December 1965

U

An experimental study was made of influence of strain magnitude and strain duration on dynamic fracture in uniaxial tension of low-strength gypsum plaster, high-strength gypsum plaster, high early strength portland cement mortar, and ordinary portland cement mortar. Dynamic test specimens were circular cylindrical bars with diameters ranging from 0.9 to 1.2 inches and lengths ranging from 18 to 58 inches. Static test specimens 2 inches long were cut from the long bars. A special loading device, designed and constructed by Melpar, generated a compressive pulse by longitudinal impact of two metal bars and applied the pulse to one end of the dynamic test specimens. The compressive pulse was reflected at the free end of specimens as a tensile pulse and caused fracture in tension at a section near the middle.

Time from zero strain to maximum tensile strain varied from 10 to 35 microseconds, and total duration of tensile strain varied from 20 to 430 microseconds with few exceptions. All materials withstood tensile strains two to three times the static fracture strain for short periods. The straining time required to cause fracture varied with strain magnitude.

AFWL-TR-65-141

AD-473 340

AN ANNOTATED BIBLIOGRAPHY OF PROTECTIVE STRUCTURES RESEARCH

In-house (R. A. Gurner)

September 1965

U

Summaries of research reports dealing with nuclear weapons effects on protective structures as well as with the analysis and design of such protective structures are presented. These summaries are from reports published by the Civil Engineering Branch, Development Division, Air Force Weapons Laboratory, and predecessor organizations from July 1951 to July 1965. The bibliography is arranged in five sections. Section I contains edited abstracts of technical memoranda, technical notes, technical reports, and technical documentary reports. Section II gives a chronological listing of all undesignated reports and weapon test reports related to protective structures published before July 1958. Section III lists all designated reports by document number including title, publication date, and classification. Section IV lists reports by subject area; Section V gives a listing by contractor.

AFWL-TR-65-145

AD-480 048

STRUCTURAL BEHAVIOR OF RING SECTIONS UNDER NONUNIFORM EXTERNAL PRESSURE

29(601)-6496: Mechanics Research, Inc., El Segundo, California  
March 1966

U

The purpose of this research investigation was to develop practical methods of analysis and the resulting structural design recommendations on the behavior of ring sections under a prescribed nonuniform external pressure distribution. This pressure distribution corresponds to that which is assumed to act normal to an isolated tunnel or silo liner. The ring sections are constructed either of materials which exhibit an isotropic, homogeneous elastic-perfectly plastic stress-strain relation, or of reinforced concrete. The "exact" two-dimensional elasticity equilibrium solution in polar coordinates was obtained as a basis for predicting incipient material yielding, and also in establishing the equilibrium displacement vector required in the elastic stability solution. Using these results, a criterion for predicting the primary mode of failure (i.e., buckling or gradual yielding and eventual collapse) is obtained. The method of limit analysis is then applied to determine the collapse load. Post-elastic deformation relations for ring sections subject to this particular mode of failure are derived based upon approximate plasticity methods. Using the gross internal forces generated in the homogeneous case, together with an ultimate reinforced concrete section model (employing the so-called "Whitney" rectangular concrete compressive stress distribution), a nomograph is derived to determine the required reinforced concrete section properties (i.e., thickness and reinforcing steel). In addition, shear and diagonal tension design relations are obtained. Test techniques for the experimental verification of the theoretical findings were also developed.

## INVESTIGATION OF EQUATION OF STATE OF POROUS EARTH MEDIA

Stanford Research Institute, Menlo Park, California

February 1966

U

Earlier experimental work has been extended to evaluate the effect of moisture on the Hugoniot of plays. For engineering applications the Hugoniot of moist plays can be predicted with sufficient accuracy from the Hugoniot of dry plays and water and the assumption of pressure equilibrium.

Isentropic release data were obtained for moist and dry plays. The steep release curve (in the P-V plane) from high pressure implies an irreversible phase change. Some low pressure data in the elastic-plastic region are presented.

A theoretical discussion of various forms of the Mie-Grüneisen equation and the physical basis of asymptotic statistical models is presented.

Shock stability is reviewed. Phase transitions in which  $\Delta V = 0$  are classified according to the signs of the slopes of the coexistence curves. Relative slopes of Hugoniot and isentropes in the mixed phase region are calculated. The results of the theoretical discussion are applied to transitions in bismuth, iron, and quartz. Agreement of values of  $dP/dT$  deduced from shock data and measured directly are good for bismuth and poor for quartz and iron.

Calculations of spherical shock propagation in a hypothetical medium that undergoes a phase change are presented. The calculations show qualitatively some types of pulse shapes that may be expected in a transforming medium.

It is concluded that the proper treatment of phase changes is an outstanding problem in predicting equations of state for earth materials.

## DEVELOPMENT OF CONTROLLED IMPULSE TECHNIQUE FOR IN-SITU

TESTING OF ROCK

29(601)-64-PO-10: U.S. Department of the Interior, Denver, Colorado

February 1966

U

Object of the work is development of equipment and techniques for transmission of nondestructive, repetitive, stable, closely controlled-shape sonic pulses through various types of rock in place. Rock masses tested were granitic gneiss schist, potash rich salt beds, and porphyry-copper ore. The tests measure some physical properties of a rock mass over various periods of time. Sonic pulses are produced by electronically excited, piezoelectric-ceramic transducers housed in transmitter and receiver units. Electronic pulses for transducer excitation are generated by transistorized battery-powered pulse generators. Output from receiver units (or geophones), amplified by transistorized preamplifiers, is led into a portable transistorized oscilloscope triggered by the electronic pulse generator to display the signal. Various models of transmitter and receiver units differing in size, weight, and manner of insertion into boreholes in rock are described. Two models of electronic pulse generators and a receiving unit preamplifier are described. With exception of the oscilloscope, all major equipment components were developed by U.S. Bureau of Mines facilities. Transmission

distances attained varied from 55 feet in strongly hydrothermally altered porphyry copper ore to 1,373 feet in sylvitehalite. Data obtained could be used to compute dynamic moduli of rigidity and elasticity. Under proper conditions, data were obtained that revealed development or presence of permanent rock-structure damage.

AFWL-TR-65-160

AD-801 487

NONLINEAR STATIC ARCHING FOR VERTICALLY BURIED PRISMATIC STRUCTURES  
29(601)-6002: The Eric H. Wang Civil Engineering Research Facility,  
University of New Mexico, Albuquerque, New Mexico  
August 1966

U

This research was both theoretical and experimental in scope. The theoretical section analyzes the method by which static arching problems involving nonlinear, vertically buried, prismatic structures and nonlinear mediums may be handled when, first, a condition of no failure occurs. A theoretical solution is presented which bounds the admissible range of arching factors by assuming, second, a condition of complete failure of the medium. Good experimental agreement was obtained in the no-failure tests, and it was also shown by experiment that the complete-failure theory gave adequate bounds to the arching factor at relatively shallow depths of burial and relatively high overpressures. A third condition, local failure of the medium in the vicinity of the ends of the structure, was shown to be possible in passive tests. This was demonstrated both by quantitative arching data and by photographs from tests in layered sand. It was shown that the no-failure theory gave an upper bound to the arching factor in a problem involving local failure. The problems of the floating structure and the rigidly mounted structure were both studied. All tests were conducted in 20-30 Ottawa sand, predominantly dense, although some tests in loose sand were included. All tests were included. All tests were on right-circular cylinders. Other variables included depth of cover; diameter, height, and stiffness of structure; and overpressure level. It is suggested that the results of this study would be useful in the design and analysis of protective-type structures and soil stress or strain gages.

AFWL-TR-65-161

AD-627 138

EXPERIMENTAL STUDY OF STATIC AND DYNAMIC FRICTION BETWEEN  
SOIL AND TYPICAL CONSTRUCTION MATERIALS  
29(601)-5204: Purdue University, Lafayette, Indiana  
December 1965

U

A report is made of research carried out at Purdue University; to determine, on the basis of laboratory measurements, the coefficient of friction between two sands of different gradation (one with angular and the other with rounded particles) in contact with portland cement mortar, steel, teflon, and graphite. In the static tests, loads were applied at a uniform rate until slip occurred in approximately 5 minutes. Dynamic loads were applied by means of a shock tube, which produced a step-like forcing function; slip usually occurred in approximately 2 milliseconds or less. It was found that the coefficients of friction depend on the relative size, shape, and surface roughness of the sand grains with respect to that of the surface in question; when the sliding surface is "rough" in comparison with the sand particles, the coefficient of friction

approaches the coefficient of internal friction of the sand. Both graphite and teflon serve as friction reducers, compared to the plain surfaces, irrespective of the rate at which slip is initiated. For plain steel or cement mortar, the dynamic coefficient of friction was greater than the static coefficient of friction by about 25 percent, unless the static coefficient was such that sand/sand slip was approached. The angle of shearing resistance of the sand thus provides an upper limit to the coefficient of wall friction at all rates of loading.

AFWL-TR-65-176

AD-482 661

AN INVESTIGATION OF THE DYNAMIC BEHAVIOR OF A PARTIALLY SATURATED SILT WITH APPLICATIONS TO SHOCK-WAVE PROPAGATION

29(601)-6002: The Eric H. Wang Research Facility, University of New Mexico, Albuquerque, New Mexico

May 1966

U

Computations relating to wave propagation through soil are dependent on adequate methods of determining the necessary dynamic soil parameters. To study methods of obtaining these parameters, static and dynamic, one-dimensional compression, triaxial, and rod-vibration tests were performed on silt specimens compacted at moisture contents of 8, 12, and 14 percent. The initial static pressure was varied to simulate an increase in geostatic stress with depth. Pressures of 15, 45, 75, and 100 psi were used as initial static surcharge pressures in the dynamic, one-dimensional tests, and as confining pressures in the triaxial tests. The results are presented in the form of stress-strain and moduli plots with comparisons between the various test methods. Based on experimental results, a model was proposed for representing the stress-strain relationship of soils during locking behavior. This model, together with the equation of momentum and the shock condition, was used to develop the equations governing stress attenuation, shock-front velocity, and shock location in a nonlinear medium. A parametric study of stress attenuation with depth was conducted to illustrate the significance of the method of analysis.

AFWL-TR-65-178

AD-483 472

STRUCTURE-MEDIUM INTERACTION IN A NONELASTIC MEDIUM

29(601)-6680: Science Engineering Associates, San Marino, California

May 1966

U

The interaction of a plane dilatational wave with a circular cylindrical inclusion buried in elastoplastic medium is studied. The cylindrical inclusion is rigid and stationary and of infinite length. The surrounding elastoplastic medium exhibits a bilinear stress-strain relationship concave towards the strain axis. The incident plane dilatational wave travels in a direction perpendicular to the axis of the cylinder and has the form of a step wave. The magnitude of the wave is such that the stresses behind the step correspond to yielding of the medium. This will cause yielding in the medium as the wave is reflected off the cylindrical obstacle, using Kirchhoff's terms of surface and volume integral equations. These equations are solved by means of finite-difference approximations of the integrals. A computer program was written to evaluate the boundary stresses as the incident wave engulfs half of the cylindrical inclusions. Numerical results obtained for wave front stresses show excellent agreement with those obtained using high-frequency wave front analysis.

AFWL-TR-65-180

AD-630 792

A STUDY OF THE PROPAGATION OF STRESS WAVES IN SAND

29(601)--6002: The Eric H. Wang Research Facility, University of New Mexico, Albuquerque, New Mexico  
March 1966

U

The propagation of near-failure, soft-fronted stress waves in 5-foot-long, 1-inch-diameter, unconstrained rods of dry 20-30 Ottawa sand is studied. The input is created by a shock tube, modified to yield soft-fronted, long-duration, air-pressure loadings. Primary data are displacement-time histories from seven stations along the rod, read by light-sensing gages designed for negligible inertia and friction; secondary data are stress-time histories at the input and the rigidly held reaction ends. Static, dynamic, and additional static triaxial data are given. Variables are applied ambient stress and sand density. From findings that the material is strain-rate insensitive and follows Coulomb's failure law at subfailure stresses, the following observations of wave-propagation parameters for above-seismic stresses and a specific material condition have been made: (1) wave and particle velocities depend on the one-half power of ambient stress; (2) all energy densities depend on the first power of ambient stress; and (3) energy partitioning and reflection are independent of ambient stress. Effects of density on wave-propagation parameters for the sand and the variables studied are that (1) all increase with increasing density, (2) some are specifically linear on density, and all can be taken as such for engineering purposes, and (3) waveform parameters are much less sensitive to small errors in density than are static parameters. Also shown: (1) reflections of stress from rigid boundaries can be estimated for nonlinear materials; and (2) correlation between seismic velocity and triaxial strength exists, provided there is a power-function relationship between seismic velocity and ambient stress and the material follows Coulomb's law.

AFWL-TR-65-191

AD-478 879

MULTICHANNEL TIME-OF-ARRIVAL INSTRUMENTATION SYSTEM

In-house (Michael Robinson)

February 1966

U

To fill the Air Force's need for a low-cost-per-channel instrumentation system to accurately measure the propagation of soil stress waves, an experimental 6-channel Time-of-Arrival system was developed by the Research Division of General American Transportation Corporation. Upon delivery of this prototype system to the Air Force Weapons Laboratory, an evaluation program was initiated to determine its feasibility. Because of the success of the prototype system a 100-channel system was constructed by the AFWL. This upgraded system was used successfully in a simulated nuclear test experiment at Kirtland AFB, New Mexico on 15 December 1964.

AFWL-TR-65-201

AD-479 427

PRELIMINARY INVESTIGATION OF STRUCTURAL PROPERTIES OF STABILIZED  
PRESSED EARTH BLOCKS

In-house (R. B. Kent and R. A. Gurner)

March 1966

U

A preliminary investigation was made of the engineering properties of pressed earth blocks manufactured in a manually operated block-making machine. Different admixtures were tested using Type 1 (normal) portland cement, Type 3 (high early strength) portland cement, masonry cement, hydrated lime, SS-KH and RS-KH asphalt emulsions, Cohex, aggregates, and various combinations of these mixtures. Compressive strength and stress-strain characteristics of the blocks were determined. Tests were also conducted on the absorption and moisture content of the different percentages of admixtures. Nine 4-foot by 4-foot wall panels were constructed using the various combinations of additives, and tested with .30-caliber, .50-caliber, and 20-millimeter weapons to evaluate resistance of the blocks to penetration by small arms fire. The results obtained indicate the blocks may be used in any construction where compressive strength and mass density are controlling criteria.

AFWL-TR-65-202

AD-476 431L

DEVELOPMENT AND TEST OF AIRCRAFT PROTECTIVE REVETMENTS

In-house (D. D. Piepenburg)

December 1965

U

The results of testing aircraft protective revetment wall panels are presented. Four revetment walls were constructed from timber, stabilized earth blocks, plain and stabilized sandbags, and cement blocks. These walls were tested with ground-fired conventional weapons including a 30-caliber rifle, a 50-caliber machinegun, and a 20-millimeter cannon. In addition, the walls were tested with statically detonated 81-millimeter and 4.2-inch mortar rounds. All four test walls prevented the perforation by 30-caliber, 50-caliber, and 20-millimeter ammunition. The test walls also prevented the perforation by shrapnel from 81-millimeter mortar rounds detonated at ranges of 20 to zero feet from the face of the walls and from 4.2-inch mortar rounds detonated at ranges greater than zero feet from the walls. Only the timber wall withstood the detonation of a 4.2-inch mortar in contact with the face of the wall.

AFWL-TR-65-204

AD-486 712

THEORY FOR VISCOUS SHOCK ATTENUATION IN DUCTS BASED ON THE KINETIC  
THEORY OF GASES EXPERIMENTALLY VERIFIED TO A SHOCK STRENGTH OF 68  
29(601)-6002: The Eric H. Wang Research Facility, University of  
New Mexico, Albuquerque, New Mexico

July 1966

U

An equation for the viscous attenuation of shock-front pressure in smooth-wall ducts is developed utilizing simple concepts from the kinetic theory of gases. This attenuation equation is presented in four forms to show its dependence on the dimensionless products, shock strength, dynamic pressure ratio, Reynolds number, and Mach number. The equation is used to obtain an expression for the

shear stress imparted to a surface by the passage of a shock front. Tests performed with a high-pressure, combustion-driven shock tube to a shock strength of 68 show very good support for the attenuation equation and the kinetic-theory approach to its derivation. A rough-wall theory, previously developed by the author and experimentally verified at low-shock pressure, is substantiated at high-shock pressure and found to be consistent with the kinetic-theory approach to viscous attenuation. Some of the tests necessitated the use of peaked shock waves which, in addition to viscous attenuation, exhibit attenuation by wave expansion. Therefore, a wave-expansion theory, previously developed by the author, was used and is consequently found to be applicable in the high-shock-pressure as well as the low-shock-pressure range.

AFWL-TR-65-206

AD-478 980

AIRCRAFT CHARACTERISTICS FOR AIRFIELD PAVEMENT DESIGN AND EVALUATION

In-house (R. B. Kent)

March 1966

U

Aircraft characteristics data are presented for use by civil engineers in the layout, design, and evaluation of airfield pavement systems. Aircraft dimensions, pertinent gross weights and performance data, and landing gear configurations are presented in convenient reference tables.

AFWL-TR-65-207

AD-633 887

SOIL STRAIN GAGE INSTRUMENTATION

29(601)-6410: IIT Research Institute

April 1966

U

Soil strain gage instrumentation was developed for the measurement of static and dynamic strains when embedded in soil. The gage is suitable for both laboratory and field application. The strain sensor consists of two mechanically uncoupled flat-coil disks which are embedded in the soil in near parallel and concentric orientation. The remainder of the gage comprises an identical set of coils positioned external to the soil as a standard reference, specially designed electronic driving, amplifying, and recording circuitry, and a precision micrometer coil mount. Soil deformations are determined by the resulting change in spacing of the embedded coil disks sensed as changes in mutual coil inductance. The gage is a reliable precise measuring device which is well suited for the measurement of strain in soil.

AFWL-TR-65-211

AD-484 830

CALCULATION OF UNDERGROUND AND SURFACE EXPLOSIONS

29(601)-6400: Physics International Company, San Leandro, California

June 1966

U

A calculational program is described which has been directed toward prediction of shock strength and ground motion resulting from chemical or nuclear explosions contained in or on the surface of geologic materials. Two-dimensional time-dependent computer codes have been developed that can be applied in the high pressure region near the explosive source where violent distortion develops, as

well as in lower pressure regions where material strength is important. Equations of state have been used that take into account the irreversible compaction of porous materials and also the contribution of internal friction to shear strength. Calculations are reported of TNT explosions at the surface of limestone and buried in a layered soil.

AFWL-TR-65-224

AD-629 607

SIMULATION DEVICES FOR USE IN STUDIES OF PROTECTIVE CONSTRUCTION

In-house (J. A. Mahoney)

February 1966

U

This report contains information on dynamic loading simulation devices that were either designed or could be modified for use in studies of protective construction. The information includes the following items: (1) the type of device, (2) the owner and location, (3) the loading characteristics, (4) the physical description, (5) the driver used, and (6) a short discussion concerning the device and its present use. Pictures and diagrams are also furnished for the majority of the devices.

AFWL-TR-66-4

AD-377 112L

HARDENED COMMUNICATION CABLE SYSTEM COMPONENT TEST PROGRAM

In-house (John F. Flory, R. H. Atkinson)

July 1966

S

A series of five tests was performed on typical hardened communication cable system components using the High Explosive Simulation Technique. The components which were tested are typical of those employed in the Hardened Intersite Cable System used in the Minuteman system. The Type VI Channell splice case, the AMF splice case, and the ATI splice case were tested on typical cable splices. The facility interface damper and the facility interior clamp were also tested. The test preparations and test results are described in detail. Recommendations are made concerning the design and installation of splice cases and other components.

AFWL-TR-66-19

AD-485 510

THEORY AND STRUCTURE OF THE AFTON CODES

29(601)-6683: Nortronics, A Division of Northrop Corporation, Newbury Park, California

June 1966

U

A procedure for writing finite difference analogs of the principles of continuum mechanics is presented. The method leads to analogs of the integral statements of mass and momentum conservation, and the first law of thermodynamics, which are exact under two simple discretization assumptions, and which imply an exactly conservative finite difference equation for the total energy. The method and the equations which follow from it apply to general systems of continuous media, hydrodynamic or otherwise. The finite difference equations form the basis

of a set of computer codes for the calculation of motion described by one and two spatial coordinates. The codes permit the use of arbitrary time-dependent coordinate systems to solve specific problems.

The AFTON I code, which deals with linear, cylindrical, and spherical one-dimensional systems, has been expanded to include general stresses and strains. Some preliminary attempts have been made to define an optimum coordinate mesh to describe continuum motion, and specific problems have been solved by AFTON I using these coordinate systems. For spherically diverging waves in an elastic medium, the solutions obtained have been more accurate than those given by numerical Lagrangian methods with the same number of mesh points, although some shock front erosion is evident, apparently as a result of deficiencies in the coordinate systems employed.

AFWL-TR-66-21

AD-482 053

A GEOMETRICAL METHOD OF STUDYING WAVE PROPAGATION THROUGH REAL  
GEOLOGIC LAYERED MEDIA

In-house (H. F. Cooper and J. J. O'Kobrick)

April 1966

U

The data from contained nuclear and high-explosive experiments in geologic media are used to obtain the peak particle velocity as a function of the cross-sectional area of an infinitesimal tube of rays originating at the source (this area is proportional to the square of the range). It is then assumed that this function is a general relationship of which the spherical geometry is only a special case. Layered media are then studied by geometrically constructing the relationship for the area of the infinitesimal tube of compressional rays transmitted through the interface. For lack of something better, the transmission coefficient at the interface is taken from the theory of elastic wave propagation. The method currently treats only the transmitted compressional wave, but it may be extended to treat other waves produced by the interface. Two parametric studies involving a tuff-granite interface are made to demonstrate the method. A 1-kiloton source is placed at distances between 20 and 200 feet from the interface in the tuff and granite. One interesting result is a knee in the peak-value velocity profiles in the tuff for the source in granite. Thus, the velocities at points off of the vertical passing through the source may be higher than the velocity at the same depth directly under the source. (The FORTRAN listings for the programs developed are given in the appendix.)

AFWL-TR-66-39

AD-489 248

DEVELOPMENT OF AN UNLINKED LONG SPAN STRAIN GAGE

29(601)-6810: IIT Research Institute

September 1966

U

Measuring the relative displacement of widely separated points in soil is becoming increasingly important in determining the effects of overpressure and shock upon the soil. Present capability involves the use of linked gages. This program was concerned with determining the feasibility of developing unlinked gages to measure the displacement. The unlinked concept involves the transfer of energy between the extremes of a vertical hole in the soil. Techniques studied

were electromagnetic, acoustic, and optical. Both a waveguide technique and transmission through soil were investigated on a theoretical basis. Each appears to be capable of performing the desired measurement if certain environmental conditions are met; e.g., deformation of the hole must be restricted for the waveguide technique. The direct energy propagation through soil is limited to ranges less than one-half that desired because of losses in the soil. Of the low and high frequency ultrasonic methods studied, the most promising appeared to be the low frequency transmission. Results from experimental investigations of this system indicate that it can be made to perform adequately on a static basis but the dynamic performance will be limited by environmental noise. A possible technique for reducing this noise level is presented, but field tests will be necessary to prove its capability. It is recommended that the waveguide technique be further developed in the laboratory and the effects of deformations expected in the field be determined.

AFWL-TR-66-47

AD-804 472

DEVELOPMENT AND EVALUATION OF PROTECTIVE REVETMENTS

In-house (D. D. Piepenburg)

November 1966

U

Revetment wall sections construction from soil-cement, steel-sheet piling, corrugated asbestos, and fiberglass were evaluated for their effectiveness in providing protection to parked aircraft and equipment against the effects of conventional weapons. The results of this evaluation program indicate that the soil-cement wall provided protection against small arms ammunition, mortar rounds statically detonated at elevations less than 12 feet and at any range, 3.5-inch High Explosive Antitank (HEAT) rockets, and shrapnel resulting from the detonation of a 750-pound bomb 10 feet from the wall. The steel sheet piling wall provided perforation protection against 30-caliber ball ammunition only, but may result in untrapped ricochets on the front face of the wall. Fifty-caliber and 20-millimeter ammunition and mortar rounds caused perforations in the piling, produced secondary projectiles, untrapped ricochets, and shrapnel on the front face of the wall, and spalled the sheet piling, producing shrapnel and secondary projectiles on the rear face of the wall. The fiberglass wall provided protection against small arms ammunition and mortar rounds statically detonated at elevations less than 11 feet and at any range. The fiberglass wall did not prevent the perforation of the core from a 3.5-inch HEAT rocket. The corrugated asbestos wall provided protection against 30-caliber and 50-caliber ammunition. Twenty-millimeter ammunition and 3.5-inch HEAT rockets did considerable damage to the wall.

INVESTIGATION OF SLASH X-RAY TECHNIQUES IN SOIL DYNAMICS  
AND INTERACTION PROBLEMS

29(601)-6002: The Eric H. Wang Civil Engineering Research Facility,  
University of New Mexico, Albuquerque, New Mexico  
August 1966

U

This research was conducted to assess the utility of flash X-ray techniques in soil dynamics studies. Areas where these techniques should be successful, their limitations, and the type of information to be expected from them are discussed. Static and dynamic tests were conducted on soil samples of various thicknesses and densities, and on buried structures of various dimensions using the Zenith Radio Research Corporation Model 1454 Flash X-Ray System. Initial tests defined the proper techniques to record pictures under optimum conditions of exposure, scatter elimination, and sample size and density. Final tests showed that qualitative information could be collected on certain loose soils and that interaction problems could be designed to yield large deformations. Soil thicknesses of over 5 inches could not be penetrated satisfactorily by the Zenith Flash X-Ray System. However, recent preliminary tests (June 1965) with a 300-kv Field Emission Corporation field-emission X ray were made through 8 inches of soil. It was concluded (1) that direct recording on film instead of using an image intensifier provides better contrast, field of view, and resolution, but problems of intensity and film transportation are great; (2) that more refined techniques and improvements are needed to collect quantitative information; and (3) that the inadequate state of the art in multiple flash X rays at the time of this research limited their utility in soil dynamics. Further investigation is recommended based on recent and significant developments in field-emission X-ray-type systems.

## PIEZORESISTIVE SOIL STRESS GAGES

29(601)-6628: IIT Research Institute  
September 1966

U

A study was conducted to review the characteristics of available piezo-resistive materials and evaluate their suitability as transducers for soil stress gages. The scope was limited to gages for measuring one component of static and dynamic freefield stresses. Three concepts were considered theoretically: (1) piezoresistive strain gage elements mounted on a deflecting diaphragm, (2) solid piezoresistive elements in direct compression, and (3) solid piezo-resistive beam elements subjected to bending. Gages were designed and fabricated to test each of these concepts. The most satisfactory overall results were obtained with the diaphragm gage. Four such gages were delivered to AFWL in fulfillment of the contract requirements. The compression gage has merit, but there remain many fabrication problems to be overcome. Further effort will be required to develop this concept. The beam gage does not appear as practical as the other types. A systematic study of the behavior of diaphragm gages in soil is one of the most important activities that needs to be undertaken.

## PHOTOELASTIC STUDY OF WAVE PROPAGATION

29(601)-6696: IIT Research Institute Technology Center, Chicago, Illinois

October 1966

U

This research program was conducted to study some fundamental aspects of wave propagation in layered media and to obtain information on the dynamic state of stress in the vicinity of a point source explosion. The experimental method selected for the program was dynamic photoelasticity. A Cranz-Schardin multiple spark camera was used to record the dynamic isochromatic fringe patterns associated with the stress waves. Columbia Resin CR-39 was used for most of the models. Small lead azide charges were used to load all models. In the study of the effects of interfaces on stress wave propagation a model with an acoustic impedance mismatch of 6 to 1 was used for most of the work. In this model six different wave types were clearly identified. Three of these waves were headwaves. In the region near the source the predominant waves were the incident  $P_1$  wave and the reflected  $P_1S_1$  waves. In regions away from the source the headwaves dominate since their rate of attenuation is much lower than the rate associated with the incident and reflected shear waves. The results from the models with an explosively loaded cavity indicate that a high intensity shear wave is produced as the cavity fractures. The stress distribution in this wave depends upon the manner in which the fracture forms. For the spherically symmetric model, the fracture is a random process; therefore, a unique solution for the stress distribution cannot be obtained.

## STRESS WAVE PROPAGATION IN CONFINED SOILS

29(601)-6717: IIT Research Institute Technology Center, Chicago, Illinois

October 1966

U

Phenomena involved with the propagation of air-induced stress waves in soil were investigated in experiments on Edgar Plastic Kaolin (EPK) clay and Ottawa sand. The principal soil variables were moisture content and density in the case of clay, and density in the case of sand. The soil specimens were loaded with overpressures in the range of approximately 50 to 300 psi. Two overpressure wave shapes were used, one where peak overpressure had a dwell time of approximately 1 msec and the other where peak overpressure had essentially a zero dwell time. Stress-time and strain-time relationships were measured at various points along the length of the specimens. Peak stress attenuation, strain and strain-rate relationships, propagation velocity, changes in wave shape, and stress-strain relationships are discussed in the light of the data obtained. Experimental data are compared with theoretical predictions of a linear hysteretic model in the case of Ottawa sand, and a constant  $\tan \delta$  viscoelastic model, in the case of the EPK clay. It was found that in both cases the theories could be used to predict the experimental results with proper evaluation of critical attenuation parameters to be input with the theories.

AFWL-TR-66-57

AD-800 185

FEASIBILITY STUDY FOR USING SULPHUR-AGGREGATE MIXTURES AS A  
STRUCTURAL MATERIAL

29(601)-6844: Southwest Research Institute

September 1966

U

This study represents the first systematic approach ever undertaken to determine the technical feasibility of using sulphur combined with various types and sizes of natural and crushed aggregates as a structural material. In this program, the engineering properties of sulphur combined with the various single aggregate gradations were determined. Following this, the engineering properties of mixtures of sulphur and fine and coarse aggregates were determined. High early strengths in the range of 4,000 to 6,500 psi in compression were obtained when using a physically poor aggregate such as limestone. The mixtures were studied for workability, and a mix design was prepared such that, in the future, by referring to this mix design, proportions of materials may be selected at will.

It was demonstrated that sulphur-aggregate concrete can indeed be looked upon as a structural material possessing a variety of outstanding characteristics including simplicity of formulation, ease of preparation, insensitivity to ambient temperature conditions, and high early strengths. In addition to this, these mixtures are low in cost and have the potential of being broken up, remelted, and used again upon completion of their useful life in a given application.

AFWL-TR-66-59

AD-375 983L

AD-375 983L

STATISTICAL DESIGN PROCEDURES FOR SHOCK ISOLATION SYSTEMS

29(601)-6788: Technology Incorporated, Dayton, Ohio

September 1966

Secret-ED

From the analysis of acceleration-time histories of vertical earth motion, a statistical design procedure for shock isolation systems in underground protective structures was evolved. Data yielding the time histories were collected during past atmospheric nuclear tests conducted by the United States at Nevada and Eniwetok. These data proved to lack both stationarity and ergodicity. After statistical properties had been deduced from a specially prepared normalization technique, they were utilized to develop a step-by-step procedure for the design of single degree-of-freedom underground systems.

AFWL-TR-66-63

AD-378 975L

EFFECTS OF SOURCE GEOMETRY ON DIRECT-INDUCED GROUND MOTIONS

In-house (J. J. O'Kobrick)

January 1967

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The feasibility of increasing direct-induced ground motions by changing the geometry of an energy source was studied. If the source can generate shock waves that are more planar than spherical, then ground motion attenuation due to spatial dispersion can be reduced. Experimental and theoretical programs were

conducted to investigate this possibility. The experimental program consisted of three field tests, two using disc-like charges and one using a spherical charge. Each of the charges weighed six pounds and were fabricated from flexible sheet explosives containing PETN. The charges were placed on the surface of a pit filled with Ottawa sand. The sand was instrumented with soil stress, particle velocity, and accelerometer gages, most of which were vertically oriented. Experimental results indicated that the disc-like charges reduced geometric attenuation, but that the ground motions from the spherical charge were higher down to a vertical stress of 110 psi due to greater energy coupling. Theoretical models were developed for a thin circular and a finite spherical energy source. These models could not be used to obtain quantitative results, but did indicate that ground motion attenuation was less for the circular source. A normalization technique was used to correlate the theoretical curves with the experimental data and good correlation was obtained. It is concluded that a disc-like energy source is less effective than a spherical source because a disc-like source can, at best, produce higher vertical ground motions in a very limited region.

AFWL-TR-66-81

AD-816 183

RESPONSE OF CLAY TO SHOCK LOADING

29(601)-6610: Purdue University, Lafayette, Indiana

June 1967

U

Axisymmetric, compressional shock waves with initial rise times and peak stresses less than 0.1 millisecond and at least 1,000 psi, respectively, were propagated through a compacted clay soil by detonating an explosive cord along the axis of the sample. Piezoelectric stress gages and spool-type strain gages embedded within the soil measured stress and strain with time and radial distance. Measurements were made in all three principal directions except that strain measurements could not be obtained in the axial direction. Both the incident and peak stress wave velocities were found to be independent of radial distance. The rate of peak stress attenuation was greater than that which could be attributed to geometric attenuation in an elastic medium. Tensile stresses were both observed and computed in the radial, tangential and axial directions. Measured strains in the radial and tangential directions showed a significant time lag between peak stresses and peak strains.

AFWL-TR-66-83

AD-489 889

GENERATION OF AN ELASTIC WAVE BY QUASI-STATIC ISENTROPIC EXPANSION OF A GAS IN A SPHERICAL CAVITY: COMPARISON BETWEEN FINITE DIFFERENCE PREDICTIONS AND THE EXACT SOLUTION

In-house (H. F. Cooper)

September 1966

U

The exact solution is obtained for the spherical wave generated by the quasi-static expansion of a "gamma law" gas that fills a spherical cavity contained in an elastic medium. The results from several parametric studies involving the particle velocity, the stresses, the "hydrodynamic" pressure, and the stress deviators are presented. Results from a typical Lagrangian finite

difference technique are compared with the exact theory in order to estimate errors that may exist when these techniques are used to calculate numerical solutions for problems that have no exact solution.

AFWL-TR-66-84

AD-800 266

USE OF DISTORTED MODELS IN THE STUDY OF DYNAMICALLY LOADED  
UNDERGROUND STRUCTURES

29(601)-6797: Iowa State University of Science and Technology, Ames, Iowa  
October 1966

U

An experimental investigation on the use of small scale models to predict the dynamic response of underground structures is described. Earlier studies, using dry sand as the soil cover, indicated the feasibility of this approach. However, for naturally occurring cohesive soils, significant distortion between observed model and prototype response was expected. In the present investigation four geometrically similar models were tested in four naturally occurring soils. Two of the soils were classified as silty loam, one as clay, and one as silty clay. The soils varied in clay content from 16 percent to 47 percent and the moisture content was approximately 15 percent. The models used were hollow aluminum cylinders, ranging in diameter from 1 inch to 8 inches. Each cylinder was instrumented with a strain gage and an accelerometer. Dynamic loads were applied with a drop-weight loader, and complete strain-time and acceleration-time curves at several different depths of burial were measured. The results of the test program clearly show that significant distortion is present; accurate predictions cannot be made without accounting for the distortion. A method is developed for the use of distorted models and it is shown to correlate the data satisfactorily.

AFWL-TR-66-95

AD-822 085

SIMULATION OF AIRBLAST-INDUCED GROUND MOTIONS PHASE IIA

In-house (J. L. Bratton and H. R. Pratt)

October 1967

U

The results of the Phase IIA, High-Explosive Simulation Technique (HEST) experiment are presented in the form of reduced data. A comprehensive analysis is not presented, although irregularities in the data are discussed. The experiment simulated airblast loading from a nuclear burst by detonating a contained Primacord matrix over a plan area 88 feet by 100 feet. The peak overpressure was 598 psi, the total impulse 19.25 psi-sec, the total duration was 172 msec, and the shock front velocity was 5640 feet per second. Measurements of free field stress, strain, particle velocity, particle acceleration, time of arrival of the wave front, and long span displacement were made. These data are presented as plots of peak values and time histories.

AFWL-TR-66-86

AD-381 631

STRUCTURAL RESPONSE OF A HARDENED UHF ANTENNA (437B-4)

In-house (R. H. Atkinson) Combined effort with  
University of New Mexico (CERF) (G. Triandafiledis)  
April 1967

S

This report documents an investigation conducted by the Civil Engineering Branch, Air Force Weapons Laboratory, on the overpressure and ground shock loading, dynamic response, and hardness of the 437B-4 hardened UHF antenna. The investigation consisted of a HEST (High-Explosive Simulation Technique) experiment, static strength testing, and theoretical studies. An experimental door closure device and a model air intake structure were also included in the HEST test. The HEST experiment provided an applied overpressure and an input ground motion to an instrumented operational 437B-4 antenna. Free-field instrumentation was provided to measure the input loads to the antenna. Instrumentation of the concrete foundation and various parts of the antenna was provided to measure the resulting dynamic response. In addition, VSWR (voltage standing wave ratio) measurements were conducted before and after the HEST test to determine any change in the operating efficiency of the antenna resulting from the blast and ground shock loading. The static test program investigated the stiffness and failure levels associated with vertical and horizontal motions of the transmitting probe. The analytical studies predicted the structural response under the HEST loading and extended the HEST results to the nuclear loading. Conclusions were drawn regarding the validity of HEST as applied to testing this type of structure and the nature of the antenna response. The survivability of the antenna to the nuclear environment was estimated.

AFWL-TR-66-113

AD-807 447

COMPUTATION BY THE METHOD OF CHARACTERISTICS OF DISTURBANCE

IN AN ELASTIC HALF-SPACE CAUSED BY BLAST-LIKE SURFACE LOADING

29(601)-4283: Stanford Research Institute, Menlo Park, California

January 1967

U

Details of the disturbance in the earth due to blast loading above its surface are important in protective structure design and elsewhere. A method for computing those details in the simple case of an elastic earth will provide qualitative data on earth response and can be extended later to more realistic media. The computation by the method of characteristics developed in this report locates propagating shocks and gives their strengths precisely. It can provide the other details of the disturbance field with arbitrary accuracy through refinement of the finite difference mesh. Since the equations represent a medium without dissipation, their stabilization is a major difficulty. This stability problem has not yet been solved completely so that no numerical results of engineering usefulness are presented. The continuation and completion of the development of the present exact calculation method is recommended so that results of simpler, approximate methods for non-elastic media can be checked.

AFWL-TR-66-118

AD-805 719

SHOCK UNLOADING CHARACTERISTICS OF POROUS GEOLOGICAL MATERIALS

29(601)-6699: IIT Research Institute, Chicago, Illinois

January 1967

U

The shock unloading characteristics of porous geologic materials have been determined for a number of pertinent variables. Experiments have been conducted on dry volcanic tuff for three different values of initial density. These experiments indicate that the unloading characteristics are essentially independent of the initial density and that a rather universal set of unloading curves exist. A series of experiments was conducted on wet samples of volcanic tuff. These experiments indicate that the moisture content is an important parameter and that the energy recovery can vary from approximately 20 percent of the internal energy for dry samples to 100 percent for completely saturated samples. A 50 percent saturated sample yielded a recovery factor of approximately 80 percent. Experiments were conducted on dry sandstone samples and established the existence of a phase transition in the Hugoniot at approximately 220 kilobars. Unloading data were also obtained on dry sandstone at three different stress levels. These unloading curves were similar to those for dry volcanic tuff.

AFWL-TR-66-123

AD-805 664

A GEOMETRIC TECHNIQUE FOR STUDYING SURFACE MOTIONS FROM UNDERGROUND

NUCLEAR EXPLOSIONS IN REAL GEOLOGIC LAYERED MEDIA

In-house (H. F. Cooper and J. B. Seamon)

January 1967

U

A semiempirical technique, utilizing the methods of geometrical optics, is used to examine the effect of geologic layering on the surface peak particle velocity associated with the direct compressional wave produced by underground nuclear explosions. This geometric technique is different from former "ray" techniques in that it accounts for the curvature of the wave front, i.e., the divergence of the rays, as well as the distance that wave travels. Data from contained nuclear explosions in "homogeneous" media are used to determine the relationship between the peak particle velocity and the divergence of the rays. This empirical relationship is then used for layered media, where the divergence of the rays is determined by the methods of geometrical optics, to predict the free-surface peak particle velocity. The required transmission and reflection factors are currently taken from the theory of elastic wave propagation. Several parametric studies and comparisons with data from experiments in layered media are presented. It is found that a number of previously unexplained departures from what was measured and what might intuitively be expected are qualitatively and sometimes quantitatively predicted by this technique. It is emphasized that layering between the source and the free surface (which usually occurs) can have a profound and deceiving effect on the surface motion, and therefore, it should not be neglected in any prediction technique. (The FORTRAN listing of the program developed is given as Appendix C.)

AFWL-TR-66-124

AD-809 275

PROPERTIES OF ROCKS TESTED IN ONE-DIMENSIONAL COMPRESSION

29(601)-6587, University of Utah, Salt Lake, Utah

January 1967

U

An apparatus has been developed and used to obtain static stress-strain data on rock and soil samples in one-dimensional compression. This report describes the design and method of use, and reports test results obtained on several types of rock and sand specimens. A 4-inch diameter specimen with height up to 2 inches is contained in a thin-walled steel cylinder. This cylinder is contained in the main pressure vessel which has a pressure cavity surrounding the specimen. Load is applied through a load cell on top of the specimen by a hydraulic press. An operator maintains a constant zero balance on strain gages bonded to the thin steel cylinder containing the specimen by pumping hydraulic fluid into the pressure cavity, thus nullifying the tendency of the test specimen to expand laterally as it is compressed axially. Axial load and deflection are recorded on an x-y plotter from signals received from the load cell and the deflectometer mounted on the load cell. This apparatus has been successfully used to obtain data on rocks to axial stresses of 75,000 psi and on sand to 30,000 psi. Test data for both rocks and sand are presented in this report.

AFWL-TR-66-134

AD-818 668

CALIBRATION OF A VERTICAL SHOCK TUBE AND ITS ASSOCIATED SOIL BIN

29(601)-6002: University of New Mexico (CERF), Albuquerque, New Mexico

August 1967

U

This report covers the results of experiments performed to calibrate the Civil Engineering Research Facility 2-foot by 40-foot vertical shock tube and its associated soil bin when filled with dense 20-30 Ottawa sand. The objective of the research was to vary the amount of Primacord (PETN) detonated in the shock tube and to measure air shock velocity, incident pressure, reflected pressure versus time, soil wavefront velocity, soil stress versus time, and soil strain versus time. The intent of this research was to accumulate data over the full range of safe, shock-tube-driver charges so that investigators using the same equipment in the future would have a good estimate of what to expect and could plan their tests accordingly. It was anticipated that future investigators using this equipment would include those interested in studies involving dynamic soil-structure interaction, one-dimensional wave propagation, and soil gage evaluation or calibration. The precision of this calibration was limited by the ability to measure shock pressures in air, and stress and strain in dense sand. Since at the time of these experimentations precise measurements of any of these quantities were not feasible, a large quantity of data was averaged to serve as the best possible calibration and also to give some idea of the scatter to be expected from such instrumentation. Displacement versus time records derived from the strain versus time records are included. By differentiation of displacement versus time records, estimates of peak particle velocity were possible. It is concluded that the apparatus can be used in its present configuration only for those soil dynamics studies in which early stress reflections from the bottom of the bin do not present a problem.

AFWL-TR-66-138

AD-807 738

EFFECTS OF CONTAINER BOUNDARIES ON FREE-FIELD BEHAVIOR OF DENSE SAND SUBJECTED TO SHOCK LOADING

29(601)-6002: University of New Mexico (CERF), Albuquerque, New Mexico  
February 1967

U

The effects of wall boundary friction and support conditions on the behavior of dense 20-30 Ottawa sand were studied in a nominal 2-foot-diameter by 4-foot-deep soil test container subjected to shock loading from a 2-foot-diameter by 65-foot vertical shock tube. Thirty static tests (25 stress-transmission and 5 stress-strain) were conducted. Twenty dynamic tests (13 with and 7 without membranes to reduce wall friction) were conducted in which soil stresses and velocities with depth were measured. In 16 tests, a wide flange beam support system was used; in 2 tests a polystyrene foam support was used for the sand; and in 2 tests a concrete support was used for the bin. Shock pressures to nearly 500 psi were used in the dynamic tests. Dynamic tests showed that if the wall boundary friction were eliminated peak-stress attenuations were about 25 percent at the 4-foot depth and generally predictable from theory. When wall friction was not reduced, the attenuation was nearly 80 percent. The stress-time history with depth was radically affected by support conditions. In particular, the WF support boundary reflected both decompression and compression waves; the concrete support, only compression waves; and the foam support, only decompression waves. For the rigid and yielding support conditions, the observed wave-propagation behavior could be reasonably predicted using Heierli's method-of-impulses solution for inelastic wave propagation. It was also shown that a trilinear approximation of the stress-strain load and unload behavior of the sand adequately predicted the observed stress wave velocities for all support conditions. Recommendations for use of the existing system and a proposed new system are outlined.

AFWL-TR-140

AD-824 037

ULTIMATE LOAD-BEHAVIOR CURVES FOR REINFORCED CONCRETE FLEXURAL MEMBERS

29(601)-6002: University of New Mexico (CERF), Albuquerque, New Mexico  
October 1967

U

This report consists of 210 graphs of an equation relating shear stress to the following variables: average concrete stress, maximum concrete stress, concrete cylinder strength, reinforcing ratio, ultimate compressive concrete strain, and reinforcing steel strain. A wide range of variables was used for the solution of the equation to include most cases encountered. The figures will facilitate the determination of steel stress,  $f_s$ , in reinforced concrete beams with only tensile reinforcing at ultimate load.

AFWL-TR-65-146

AD-816 665

WAVE-PROPAGATION STUDIES IN LATERALLY CONFINED COLUMNS OF SAND

29(601)-6002: University of New Mexico (CERF), Albuquerque, New Mexico

June 1967

U

An experimental study of the relationship between pertinent wave-propagation parameters and the one-dimensional stress-strain behavior of two sands was conducted. The stress-strain relation for the sands was characterized by a non-linear strain-hardening behavior. The nature of the stress-strain curve implied that shocks should form or be sustained in the soil. This phenomenon was studied by observing the dynamic and kinematic characteristics generated by a soft-fronted stress pulse applied at one end of a long slender column of laterally confined sand. To develop a method of predicting the kinematics of wave propagation from the stress-strain curve, the observed wave-propagation parameters were related to laboratory stress-strain curves. A unique sample container, loading system, and instrumentation system was developed. The experiments approximated one-dimensional conditions up to reflected stresses of 1,600 psi. The results indicated the shocking-up of the soft-fronted input pulse that could be predicted from the laboratory stress-strain curve. The particle-velocity versus wave-velocity relationships dictated the change in shape of the kinematic pulse and could be predicted using a secant modulus analysis technique. A very high stress versus time gradient (rise times less than 50  $\mu$ sec) was observed to form as the wave propagated through the soil. A 1-msec stable rise time was also observed to form in the particle velocity versus time pulse. The particle velocity versus time lagged behind the stress versus time pulse exhibiting a short-time creep effect. The stress in the soil could be calculated from the mass density, particle velocity, and wave velocity.

AFWL-TR-66-147

AD-381 844L

EVALUATION OF STRUCTURAL RESEARCH MODEL PHASES II AND IIA HEST

29(601)-7076: N. M. Newmark Consulting Engineering Services, Urbana, Illinois

May 1967

S

The free-field data and the structural model loading and response data from the Phase II and Phase IIA HEST tests were studied in an effort to explain theoretically the observed response of the structural research model. Primary emphasis was placed on the Phase IIA results because the loading was more intense and the data were more complete and were available in original form. The principal conclusions that were drawn from this study are the following: (1) The free-field data were qualitatively reasonable when considered collectively, but individually were subject to substantial uncertainty. The velocity data are considered to be the most reliable of the several free-field parameters measured. (2) The measured radial pressures on the upper chamber generally confirmed the loading currently recommended for design of near surface vertical cylinders. (3) Reasonable agreement was obtained between the computed and measured maximum vertical strains in the upper chamber walls in the vicinity of the critical section. Similar agreement between measured and computed strains was not obtained elsewhere on the upper chamber. (4) The depth of the zone of influence of the upper chamber footing pressure appears to be somewhat greater than one footing width as presently recommended. The significance of

soil-wall skin friction as a source of load on a buried vertical cylinder was clearly demonstrated. (6) The surrounding soil effectively restrained the lower tube against significant circumferential flexural deformations.

AFWL-TR-66-154

AD-809 210

A SONIC BOOM STUDY FOR THE STRUCTURAL ENGINEER

In-house (Mr. D. Bailey)

March 1967

U

Sonic booms generate an N-type pressure wave. Equations and tables are presented for the calculation of peak overpressure for the sonic boom generated by aircraft in straight level flight. An equation is also furnished for the calculation of the time duration of the sonic boom pressure wave.

Aircraft maneuvers, ground terrain, and meteorological conditions affect the peak overpressure of the pressure wave. Corrections for these effects can only be roughly estimated.

Dynamic load factors for the pressure waves of sonic booms are presented. These factors may be used to calculate the dynamic deflection and stress caused by a sonic boom. Sample calculations of dynamic deflection and stress for a beam, plate, and roof truss are found in Appendixes III, IV, and V respectively.

AFWL-TR-66-155

AD-811 447

SOIL STABILIZATION FOR CONSTRUCTION OF LOW-STRENGTH  
AUSTERE LANDING STRIPS

In-house (R. R. Vadnais, Jr.) Combined effort with  
University of New Mexico (CERF), Albuquerque, New Mexico  
29(601)-6002

March 1967

U

The Air Force Flight Test Center (AFFTC) at Edwards Air Force Base, California, has a long-standing interest in construction of austere test strips for the purpose of evaluating the performance, landing, and takeoff of certain aircraft (especially the F-111A) under unfavorable foundation conditions. This report presents data on the subsoil conditions at Edwards AFB and the feasibility of preparing and maintaining subsoil conditions with CBR values varying between 3 and 20. Theoretical considerations for the design of austere test strips and use of local material for preparation of the required test beds are also presented.

AFWL-TR-66-160

AD-810 163

AN ANNOTATED BIBLIOGRAPHY OF PROTECTIVE STRUCTURES RESEARCH

In-house (Mrs. Mary J. C. Garcia)

February 1967

U

Summaries of research reports dealing with nuclear weapons effects on protective structures as well as with the analysis and design of such protective structures are presented. These summaries are from reports published by the Civil Engineering Branch, Development Division, Air Force Weapons Laboratory, and predecessor organizations from July 1951 to December 1966. The bibliography is arranged in five sections. Section I contains edited abstracts of technical memoranda, technical notes, technical reports, and technical documentary reports. Section II gives a chronological listing of all undesignated reports and weapons test reports related to protective structures published before July 1958. Section III lists all designated reports by document number including title, publication date, and classification. Section IV lists reports by subject area; Section V gives a listing by contractor.

AFWL-TR-67-7

AD-819 539

EFFECTS OF GROSS INACCURACIES IN STRUCTURE ALIGNMENT AND SOIL RESISTANCE PROPERTIES ON THE RESPONSE OF BURIED STRUCTURES TO NUCLEAR BLAST LOADINGS

29(601)-6776: University of Illinois, Urbana, Illinois

August 1967

U

This report presents the results of an analytical research effort aimed toward defining the degradation of structural integrity that may result when design conditions are not met during the construction of hardened facilities. Parameters of primary concern were: (a) variations in the soil resistance around a buried structure (nonuniform backfill properties); (b) variations in the structural geometry (improperly enforced construction tolerances); (c) variations in structural material properties. A computer program was developed to study the influence of variations in these parameters by representing the structure-soil system by a lumped-parameter model and solving the resulting equations by numerical integration. The program is restricted to planar reinforced concrete structures, with particular emphasis on buried arches and cylindrical structures. The program considers both elastic and inelastic response of the structure under any combination of axial force and bending. It is also capable of representing a variety of multilinear blast pressure pulses that may approach the structure from any direction in the plane of the structure.

MULTIPLE THREAT CRATERING EXPERIMENT, VOLUME I: SUCCESSIVE  
CRATERING IN HARD ROCK

In-house (T. E. O'Brien and J. E. Seknicka) Combined effort with  
Boeing Company (R. H. Carlson and G. D. Jones)

29(601)-6787

April 1967

U

A research program compares successive craters formed by high-explosive charges detonated in basalt along a common vertical axis with single explosions equivalent in yield to the sum of the successive bursts. Studies include craters and ejecta distribution; energy coupling of cratering explosions at and near the ground surface; charge shape effect on craters and related phenomena; and distribution, size, and weight of discrete ejecta missiles. Results indicated that the excavated crater depth may be increased by a fourth half-buried successive shot. This increase is between zero and 25 percent, depending on the technique used. The data were not conclusive.

The apparent crater formed by a hemispherical surface charge exhibits a radius about 90 percent and depth about 85 percent of the dimensions formed by a corresponding spherical, half-buried charge. Excavated craters formed by hemispherical charges are likewise smaller.

Scaling relationships determined for apparent craters formed by half-buried spherical charges were  $R_a = 1.30 W^{0.27}$ ,  $D_a = 0.42 W^{0.28}$ ; for apparent craters formed by hemispherical charges:  $R_a = 0.48 W^{0.37}$ ,  $D_a = 0.06 W^{0.47}$ .

Fifty percent of material ejected from the 4000-pound and 16,000 pound half-buried charge craters were deposited between the crater edge and 1.9 and 1.2 crater radii, respectively.

MULTIPLE THREAT CRATERING EXPERIMENT, VOLUME II: GROUND MOTION  
IN ROCK

In-house (J. H. Gee)

July 1967

U

The Multiple Threat Cratering Experiment (MTCE) was conducted during June-July 1965. The ground motion portion of this experiment was intended to study the particle velocities, strain, accelerations, displacement, and propagation characteristics of a hard rock medium. Forty-eight gages placed in three bore holes were used to measure the ground motion of eleven shots of the MTCE series. Nine of the shots were 4,000-lb spheres with the remaining two being a 16,000-lb sphere and a 16,000-lb hemisphere. The depth of burial ranged from surface tangent to fully buried. Due to problems involving gage calibrations, gage placement and orientation, and electrical transients, only arrival times and some down-hole magnitude measurements provided enough data for comment. The arrival times indicate that the direct transmitted ground shock outran the air blast. Seismic velocities varied by as much as 3500 fps between the north and south sections of the test area. A further difference in velocity was noted to be connected to a 31-foot difference in elevation between the north and south holes. The up-slope velocity for any given area appears to average approximately 450 fps faster than its down-slope equivalent.

AFWL-TR-67-12

AD-822 142

**TONEDOWN TREATMENT OF RUNWAYS--STATE OF THE ART**

F29601-67-0040: Prismo Safety Corporation, Huntington, Pennsylvania

September 1967

U

A preliminary investigation was made of the characteristics of the various materials having possible application as airfield tonedown agents. Literature surveys as well as personal contacts were conducted with both governmental and industrial sources. All pertinent data were collected including such factors as costs, drying times, abrasive characteristics, etc. Special emphasis was directed toward those materials having possible use in Southeast Asia (SEA) environments. A wide range of materials was investigated, ranging from light film stains to thick surface cappings. Cost data indicate that treatments can vary from a few cents to almost one dollar per square foot for initial installation. The results obtained indicate that several materials show possible use as airfield tonedown agents in SEA. Additional testing of these materials is necessary to determine the most suitable materials for various operational requirements.

AFWL-TR-67-15

AD-823 129

**EVALUATION OF A 400-CUBIC-FOOT SOIL BIN LOADED DYNAMICALLY**

**BY A LARGE SHOCK TUBE**

29(601)-6002, University of New Mexico (CERF), Albuquerque, New Mexico

August 1967

U

An engineering evaluation was made of a 400-cubic-foot soil bin loaded dynamically by a 6-foot-diameter, explosive-driven shock tube. The shock tube produced an air shock wave that moved horizontally across the surface of the soil bin containing 20-30 Ottawa sand. An air-induced ground shock wave entered the soil bin at a velocity of 1,075 feet per second, resulting in an incident wave front inclined approximately 21 degrees to the horizontal. Soil stress and strain were measured by instrumentation placed in a grid pattern at depths of 1, 4, and 7 feet. Special attention was given to the uniformity of stress and strain at a given depth, attenuation with depth, reflections, and the effectiveness of a friction-reducing wall membrane. Conclusions were drawn regarding the application of the test device for wave-propagation and interaction studies.

AFWL-TR-67-16

AD-821 823

**AN EXPERIMENTAL INVESTIGATION OF THE DYNAMIC RESPONSE OF MODEL**

**SILO-TYPE STRUCTURES IN COHESIVE SOILS PHAS I, SOIL PROPERTIES**

29(601)-6811: University of Illinois, Urbana, Illinois

October 1967

U

A series of static and dynamic triaxial and one-dimensional compression tests was performed using specimens of Goose Lake clay compacted at a range of water contents from nine percent dry of optimum to three percent wet. This investigation was performed as the first stage of a general investigation of the interaction of cohesive soils and buried silos. The physical properties

of the specimens were studied as functions of water content at compaction, stress level, and loading rate. Triaxial compression tests were performed using confining pressures ranging from 10 psi to 1000 psi and times to failure ranging from 3 milliseconds to 50 minutes. Both the compressive strength and the secant modulus increased significantly as the loading rate increased. Undrained one-dimensional compression tests were performed using rise times of 2 milliseconds and 10 seconds, and peak pressures of approximately 200 psi and 400 psi. The stress-strain characteristics were shown to depend on the water content at compaction and the loading rate.

AFWL-TR-67-21

AD-818 424

EXPONENTIALLY DECAYING PRESSURE PULSE MOVING WITH SUPERSEISMIC VELOCITY ON THE SURFACE OF A HALF SPACE OF GRANULAR MATERIAL

29(601)-7082: Paul Weidlinger, New York, New York

July 1967

U

An approximate solution is given for the effect of an exponentially decaying pressure pulse traveling with superseismic velocity on the surface of a half space. The material of the half space is an elastic-plastic model of a material having internal Coulomb friction. The yield condition selected may be suitable for a granular material. The effect of a step wave for this geometry and medium was treated previously. For that case, the peak pressures do not decrease with increase in depth, while such a decrease is obtained for a decaying surface load. It was the prime purpose of this investigation to determine the magnitude of this attenuation. The approximate solutions obtained are valid for a limited distance behind the wave front, and are tabulated for 11 different sets of parameters pertaining to the material and velocity. The tabulated results show that the peak pressures in the case of the decaying surface load to decrease with depth, but that the decrease is less than one might intuitively expect.

AFWL-TR-67-25

AD-814 165

COMPARISON STUDIES OF FINITE DIFFERENCE RESULTS FOR EXPLOSIONS ON THE SURFACE OF THE GROUND

In-house (H. F. Cooper)

May 1967

U

This report discusses the numerical results from four finite difference codes (AFTON, FLU, OIL, and PIC) for two initial value problems involving the geometry of a surface burst. The problem geometry, constitutive relation, and initial zoning were specified by the author, and hydrodynamic Eulerian calculations were performed by the companies responsible for the development of each code. The results show significant inconsistencies in peak pressure and velocity attenuation curves, pressure and particle velocity spatial profiles, and time of arrival plots. The general conclusion is that the inconsistencies can be traced to the handling of the numerics, primarily rezoning procedures. The degree of the inconsistencies indicate that numerical errors in many current state of the art high pressure Eulerian calculations may be on the order of a factor of 2 or more.

AFWL-TR-67-27, Vol. I

AD-818 301

**NUMERICAL GROUND MOTION STUDIES, VOLUME I: STUDY OF NUMERICAL SOLUTION ERRORS IN ONE- AND TWO-DIMENSIONAL FINITE DIFFERENCE CALCULATIONS OF GROUND MOTION**

29(601)-7143: Applied Theory, Santa Monica, California

July 1967

U

Results are presented here of a study to determine numerical solution errors in two-dimensional hydrodynamic calculations of surface bursts. The changes in solution errors due to variations in mesh point distribution are studied in one and two dimensions; the results of the investigation are applied to improving the solution to a two-dimensional problem. A method is described which allows a grid to expand automatically to contain a moving shock. Methods are presented for achieving several kinds of mesh point distributions based on a geometric progression in the distance between mesh points.

AFWL-TR-67-28

AD-822 144

**AERODYNAMIC EFFECTS ON A STRUCTURE OSCILLATING WITHIN A CONFINED CAVITY**

29(601)-6126: Agabian-Jacobsen Associates, Los Angeles, California

October 1967

U

The influence of aerodynamic forces on shock-isolated structures oscillating inside a confined cavity was investigated by defining aerodynamic terms with analytical and grapho-numerical procedures and incorporating them in the equations of motion of a three-degree-of-freedom system subjected to a transient velocity pulse having vertical and horizontal components. A computer solution was developed for a parametric study of several geometric configurations and frequencies. The results are interpreted in terms of the influence of the aerodynamic forces on response accelerations and rattlespace requirements. In general, this influence is very small for the practical ranges of interest of structures with small aspect ratios having small clearances between cavity and structure. An experimental program is recommended to perform simple tests to verify the estimated effect of aerodynamic forces and to develop a basis for scaling results from a limited number of tests.

AFWL-TR-67-50

AD-820 672

**EVALUATION OF SOIL STRAIN GAGE INSTRUMENTATION**

29(601)-6002: University of New Mexico (CERF), Albuquerque, New Mexico

August 1967

U

A soil strain gage instrumentation system, developed by the Illinois Institute of Technology Research Institute (IITRI) for the Air Force Weapons Laboratory, having the unique feature of no support column between the strain sensing elements was evaluated dynamically in soil loaded with a nominal 100- or 1,000-psi shock-wave pressure pulse. The average dynamic calibration in Ottawa sand at 100 psi was within 10 percent of the average static calibration. To further establish the characteristics of the strain gage, static tests conducted by IITRI were repeated at CERF. The repeatability of measurements is indicated by standard deviations around 25 percent. It was demonstrated that

multigage arrangements are feasible for laboratory and field applications. The beginning of the strain-time traces usually contained a spurious spike, which could not be attributed to actual strain information. The results of a series of tests now indicate that the spiking is probably due to noise generated by the shock in the cable connectors.

AFWL-TR-67-61, Volume II AD-  
SHEAR BEHAVIOR OF DEEP REINFORCED CONCRETE BEAMS, VOLUME II: STATIC TESTS  
29(601)-6002: University of New Mexico (CERF), Albuquerque, New Mexico  
October 1967  
U

Large-scale static tests were performed on deep reinforced concrete beams. Nominal concrete strengths for all tests varied between 2,500 and 4,000 psi, and intermediate-grade ASTM A 15 reinforcing steel was used. All beams were simply supported. Tests consisted of thirteen test beams of three span-depth ratios, 1.66, 2.67, and 3.62, subjected to a uniformly distributed load. Beams contained longitudinal tensile reinforcing with or without web reinforcing. Both horizontal and vertical web reinforcing were used. Behavior was observed as span-depth ratio and web reinforcing were varied. Numerous modes of failure in shear were observed as beam configuration was varied. Modes of failure transitioned from shear to flexure as span-depth ratio increased and amount and orientation of web reinforcing were varied. Test data were correlated with mathematical models derived in this study and from models developed by others. The mathematical models were used to investigate shear behavior for deep beams. Equations were developed which adequately predict the median shear behavior of deep beams with web reinforcing. Test data were also correlated with theories developed by others for flexural moment and deflection behavior. Generally, flexural moment behavior was adequately predictable; deflection predictions, however, were not adequate. Recommendations are made for further research with respect to development of improved design criteria for Air Force defense systems.

AFWL-TR-67-65 AD-822 360  
BEHAVIOR OF SMALL VERTICALLY BURIED CYLINDERS  
29(601)-6002: University of New Mexico (CERF), Albuquerque, New Mexico  
October 1967  
U

Tests to determine the lateral pressures and interface shearing stresses acting on small vertical cylinders buried in dense 20-30 Ottawa sand were carried out in a nominal 2-foot-diameter by 4-foot-deep soil test container. Eighteen static tests were performed on 4-inch-diameter, 2-foot-long aluminum cylinders. The cylinders were buried with their tops flush with the sand surface and supported on either a rigid base or a dense sand base. Three wall thicknesses were chosen so that the cylinder diameter-to-thickness ratios were 24, 48, and 114. Static test results indicated that the lateral pressure coefficient, the ratio of the lateral pressure on the cylinder to the surface pressure, was independent of the cylinder stiffness. The average value ranged from 0.30 to 0.35, increasing slightly with depth and when the support was changed to the dense sand base.

Interface shearing stresses acted downward over the upper two-thirds to three-fourths of the length of the cylinder, their magnitude being controlled by the lateral pressure and the coefficient of friction between the sand and the aluminum. Ten dynamic tests were performed on the cylinders supported on a dense sand base and loaded by a decaying surface pressure pulse. Shock pressures to 1,000 psi were used. Dynamic tests indicated that the lateral pressure and the interface shearing stress behavior are dependent on the length of the cylinder and the ratio of the acoustic velocity of the cylinder material to that of the sand.

AFWL-TR-67-69

AD-821 654

HAND SOLUTION OF ONE-DIMENSIONAL INELASTIC WAVE-PROPAGATION PROBLEMS

29(601)-6002: University of New Mexico (CERF), Albuquerque, New Mexico

October 1967

U

A method for obtaining a numerical solution to a wide variety of one-dimensional inelastic wave-propagation problems is discussed. The emphasis is on solutions to problems involving air-induced propagation in soil or rock resulting from a nuclear detonation under superseismic conditions. Emphasis is also placed on hand solutions obtained using a desk calculator and drafting instruments. The method is quite versatile in that it allows any pressure or kinematic condition at a boundary, any nonlinear and hysteretic material stress-strain curves, and any layering of different materials. The principal limitations of the method are that it does not treat viscoelastic material behavior, problems involving more than one-dimensional behavior, and problems in which strains and particle velocities are not relatively small. Two example problems are included: one shows the formation of a shock in a homogeneous medium, and the other shows wave propagation through a layered medium.

AFWL-TR-67-72

AD-822 964

EXPERIMENTAL VERIFICATION OF NEUTRON TRANSPORT CALCULATIONS IN LITHIUM HYDRIDE

F296-1-67-C-0031: General Dynamics Corporation, San Diego, California

November 1967

U

Measurements of the high energy neutron angular flux spectrum in a sphere of natural lithium hydride have been made by the time-of-flight method. Fast neutron spectra were obtained at  $0^\circ$  and a radius of 25.1 cm, and at angles of  $0^\circ$ ,  $19.2^\circ$ ,  $39.2^\circ$ , and  $54.7^\circ$  at the surface, which is a radius of 45.7 cm. Preliminary results were obtained for the intermediate energy spectrum. The work is a continuation of the comparison of accurate, detailed, high resolution measurements, formerly made in  $\text{CH}_2$ , with DTF-IV discrete ordinates and OSR Monte Carlo calculations. The  $\text{CH}_2$  sphere was recalculated with OSR, using an angular resolution corresponding to experiment, and good agreement was obtained. The exponential transform was investigated to reduce variance at a fewer number of neutron histories. The optimum biasing parameter was found for the uncollided flux, but the exponential transform as applied to the  $\text{CH}_2$  sphere problem did not result in large reductions of variance. The lithium hydride sphere was calculated with DTF-IV, using different quadrature sets and cross sections. Agreement with experiment is not as good as for  $\text{CH}_2$ , and further investigations are recommended.

AFWL-TR-67-90

AD-821 550

A FREEZING TECHNIQUE FOR GAGE PLACEMENT

In-house (C. J. Lemont)

October 1967

U

A problem exists when gages are to be placed in drill holes below the water table. Freezing the soil around a proposed instrumentation hole was attempted as a solution to the problem. Laboratory and field tests proved that liquid nitrogen would freeze a zone of soil around the supply tube and that an instrumentation hole, drilled into that zone, would remain water-free long enough to allow instrumentation to be placed and the hole to be backfilled. It was concluded that the freezing technique was a solution to the problem of placing gages below a static water level in the soil.

AFWL-TR-67-102

AD-822 353

HIP-1A DATA REPORT

In-house (C. J. Lemont)

October 1967

U

The HIP-1A test was conducted as a proof test of the design parameters of a HEST overpressure facility. It was intended that, using these parameters, the simulated criteria of peak overpressure, impulse, and detonation frontal velocity would be verified before their use in the design of an overpressure facility for an operational Minuteman vulnerability test. The instrumentation consisted of air pressure, soil stress and acceleration transducers, with primary emphasis on air pressure. The average peak overpressure was 703 psi against a predicted 1000 psi, the average impulse was 34.4 psi-sec compared with a predicted impulse of 40.6 psi-sec, and the average frontal velocity was 8980 fps as compared with a predicted velocity of 8600 fps. The test allowed the redesign of the facility parameters such that the desired overpressure was more closely developed.

AFWL-TR-67-107

AD-823 298

CHEMICAL STABILIZATION OF PLAYA SOILS

29(601)-6002: University of New Mexico (CERF), Albuquerque, New Mexico

November 1967

U

The physical, chemical, and mineralogical parameters of soils from selected playas were investigated to determine effective chemical stabilants. The effect of differing amounts of additives on forming soil-cement in humid conditions was determined at two curing times. The unconfined compressive strengths of the cured soil-cements, compacted at ASTM standard optimum moisture-densities, were determined and correlated with known soil characteristics. The playa soils generally consisted of material, and had an average plasticity index of about 15. The soils generally were predominantly composed of silicate and carbonate minerals. Clay minerals comprised only about 15 percent of the soils by weight. Portland cement proved the only effective soil stabilization agent, which gave sufficient soil-cement strength to most playa soils to resist destruction by the ASTM freeze-thaw test. Fly ash was somewhat deleterious, and lime

and sodium cation additives were very destructive to portland cement-soil mixtures. Kaolinite was beneficial only in specific soil-cements. It is suggested that metallurgical cements, slag cements, and sulfate-resistant portland cement should be tested as additives for playa soil-cements where Type I portland cement proves inadequate.

AFWL-TR-67-110

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INVESTIGATION OF BURIED DOMES, PHASE 1, EVALUATION OF INSTRUMENTATION  
AND PRELIMINARY TESTS

29(601)-6002: University of New Mexico (CERF), Albuquerque, New Mexico  
December 1967

U

An evaluation of a soil stress transducer and its application to the measurement of soil stress distribution on and around a rigid buried dome are presented. The soil stress gage developed for this study was found to respond linearly with less than 4-percent hysteresis in a granular medium. This gage also has a linear response when oriented at various angles to the vertically applied load. It can be located very closely in the soil and adjacent to rigid boundaries without affecting its response. Static tests were performed in which on-structure soil stresses were measured and compared with soil stresses adjacent to the structure, as well as comparable stresses in a soil medium without a structure. The soil pressure distribution on the dome structure indicates that passive arching occurs near the crest of the dome. The total vertical force acting on the dome was measured by load cells beneath the dome and found to be greater than the total vertical force obtained from the vertical component of the normal soil stress as measured by on-structure gages integrated over the dome surface. The reason for this difference in forces was probably due to the size of the structure and tangential loading.

SWC-TDR 61-66

AD-328 826

A METHOD FOR THE PREDICTION OF GROUND SHOCK PHENOMENA IN SOILS

29(601)-2855: Paul Weidinger and Associates

March 1962

S

Determination of free field ground shock parameters is the first step in designing underground protective structures. This report summarizes a theoretical method for predicting stresses, particle velocities, displacements and associated shock response spectra in soil subjected to air-induced ground shock in the 100- to 1,000-psi pressure ranges.

Soil behavior is represented by a compacting medium, i.e., one which exhibits strain hardening and large permanent strains upon unloading. One-dimensional wave equations are derived and a simplified method for making engineering calculations is presented. Good correlation is established between full-scale nuclear weapon ground shock data and theoretical predictions based on the above compacting medium theory.

SWC-TDR-61-93

AD-274 825

GEOLOGIC STRUCTURE STABILITY AND DEEP PROTECTION CONSTRUCTION

29(601)-2821: University of Missouri

November 1961

U

This study concerned problems associated with protective construction in rock, particularly deep protective structures. Information from the experience of mining engineers and past weapons tests is given on rock structure and properties and on theories relating these to stability of underground openings under both static and dynamic loads. Recommendations are made for meeting design problems of underground protective structures and for research to improve design reliability.

SWC-TDR-62-1

AD-278 063

INVESTIGATION OF SILO AND TUNNEL LININGS

29(601)-2596: Armour Research Foundation

March 1962

U

The problem of determining the response of underground cylindrical tunnel and silo linings to blast-induced loading is discussed in this report. The study includes effects on silo linings of differential horizontal soil displacements, vertical skin-friction forces generated by vertical compression of surrounding soil, and axial response of a silo with integral cover to blast-induced cover loading.

A theoretical method for estimating forces acting on a cylindrical structure subjected to airblast-induced ground shock is presented. Radial forces on the cylinder surface are the undisturbed free-field pressure component plus pressures proportional to differential radial velocity and displacement between the

structure and the free-field particles. The effect of virtual mass, foundation modulus, and damping or response was studied by obtaining solutions appropriate for tunnel and silo linings. Static test results for three metal cylindrical tunnel models, buried in dense Ottawa sand, are presented and compared with theoretical predictions.

SWC-TDR-62-2

AD-273 229

STUDY OF THE USE OF MODELS TO SIMULATE DYNAMICALLY LOADED UNDERGROUND STRUCTURES

29(601)-4375: Iowa State University

January 1962

U

This report presents results of an analytical investigation of the use of models to simulate the dynamic response of buried structures.

Proposed scaling laws are used to relate a model structure and soil medium to its corresponding prototype components. As an initial step in verifying the proposed scaling laws, small structures were buried in soil at various depths, and impact loads applied with a falling weight.

SWC-TDR-62-3

AD-274 294

STUDY OF THE USE OF MODELS TO SIMULATE DYNAMICALLY LOADED UNDERGROUND STRUCTURES

29(601)-4374: American Machine and Foundry Company

February 1962

U

This report presents results of an analytical investigation of the use of models to simulate the dynamic response of buried structures.

Proposed scaling laws are used to relate the response of the model structure and soil medium to the response of corresponding prototype components. Material properties are suggested as a guide in choosing possible modeling parameters, and a method is presented for simulating soils. The report represents an initial effort toward solution of the dynamic similitude problem.

SWC-TDR-62-6

AD-330 059

PRELIMINARY DESIGN METHODS FOR UNDERGROUND PROTECTIVE STRUCTURES

29(601)-2837: Nathan M. Newmark, Consulting Engineering Service

June 1962

S

The objective of this study was to revise, modify and amend the report Preliminary Design Methods for Underground Protective Structures, AFSWC TR-60-5, December 1959, prepared under Contract AF 29(601)-1171.

This report reflects the latest knowledge about many aspects of preliminary design procedures for underground protective structures. The section on free-field ground motions is updated, and a number of charts for predicting free-field particle displacements, velocities, and accelerations are presented. The section on surface airblast parameters is completely revised.

The section on design shock response spectra is revised and expanded with the addition of much new material, and contains the latest recommendations for formulating design shock response spectra. New material on dynamic soil-structure interaction is also presented.

Many other changes in the earlier report have been made, including deletion of considerable material (summaries of design significance have been retained) and addition of summaries of numerous smaller studies carried out as a part of the investigation. Recommendations for future studies are presented.

SWC-TDR-62-9

AD-275 037

DESIGN AND ANALYSIS OF FOUNDATIONS FOR PROTECTIVE STRUCTURES

29(601)-2561: Armour Research Foundation

April 1962

U

The behavior of footings subjected to dynamic forces has been the subject of continuing research. Significant contributions have been made through a combination of theoretical and experimental research.

Prior analytic studies have been based on an "engineering approach" which extended standard soil mechanics approaches to include dynamic behavior. This approach is reviewed and comparisons are made with experimental results. To improve theoretical results the influence of soil compressibility was investigated. These studies considered formation of plastic stress waves below the footings, and produced improved correlation with experimental data.

Experimental studies conducted include three-dimensional static and dynamic tests of footings with overpressure on the surrounding soil surface, two-dimensional static and dynamic tests on inclined footings with overpressure on one side (a situation simulating that encountered in footings for arches and/or domes), and three-dimensional static and dynamic tests with improved instrumentation to verify earlier results and provide improved data. The report also contains a presentation on the Dynamic Soil Facility, built by Armour Research Foundation and used for portions of this research.

SWC-TDR-62-10

AD-244 646

STUDY OF BLAST CLOSURE DEVICES

29(601)-4354: American Machine and Foundry Company

February 1962

U

This report describes investigations and analyses accomplished during ANF's study of blast-actuated blast-closure systems. The objective of this study was to survey the state of the art of blast-closure system design, and establish design criteria for formulating development and design procedures and techniques.

The initial effort was devoted to a state-of-the-art survey, after which work was started concurrently on establishing blast-closure system criteria and studying blast attenuation in tunnels affected by 90° bends, orifices, plenums, etc. In addition to defining satisfactory closure systems, a selection of optimum configurations for particular overpressure ranges and installation types was made.

Results of this study indicate only one valve has been designed for the maximum operating pressure specified. Therefore, additional effort should be expended to produce additional blast-closure concepts.

SWC-TDR-62-30

AD-285 053

THEORETICAL STUDY OF STRUCTURE-MEDIUM INTERACTION  
29(601)-2838: National Engineering Science Company  
March 1962  
U

This report presents numerical results from a continuation of a previous study described in AFSWC TN-61-6, concerned with the plane strain problem of interaction of a plane longitudinal stress wave with a hollow cylindrical shell embedded in an infinite elastic medium. The shell is given finite dimensions (with the assumption of thin shell geometry), finite density, and elastic properties differing in general from those of the medium. Tables and/or graphs are given for the following quantities:

1. Steady-state, tangential stress response of a cavity and thin shell to a harmonic stress wave input.
2. Transient displacement response of a rigid cylinder (shell) to a step-function displacement input.
3. Transient tangential stress response of a cavity to a step function stress wave input.
4. Transient displacement and inner tangential stress responses of a thin shell to a step function stress wave input.

A specific result is obtained for the last problem with a shell-thickness-to-cylinder-radius ratio of  $1/20$ , the shell having properties close to those of steel and the medium having elastic properties representative of rock. In this case dynamic increase in the inner tangential stress by a step stress input over the static value was found to be approximately 6 percent.

SWC-TDR-62-43

AD-286 485

THEORETICAL STUDY OF ENERGY DISTRIBUTION IN A HALF-SPACE UNDER DYNAMIC LOADS  
29(601)-2832: General American Transportation Corporation  
July 1962  
U

An analytical procedure is developed for predicting free-field ground motions and stresses for design of underground protective structures. Analytic solutions in integral form are obtained for problems of elastic and viscoelastic half-spaces, each under an axi-symmetric time-dependent normal loading with the essential features of a nuclear burst. A computer code for evaluating these expressions is developed through use of a Fourier-Legendre series and other special analytical techniques. Graphs are presented for one elastic problem.

SWC-TDR-62-44  
RADIOGRAPHIC INSTRUMENTATION STUDY  
29(601)-4154: American Machine and Foundry Company  
April 1962  
U

AD-277 661

Various radiographic techniques are examined and evaluated to determine their feasibility for studying dynamic soil phenomena. Data which can be obtained radiographically from a dynamically loaded soil sample are particle motion and density change as a function of position and time. The primary advantage of a radiographic system is that the condition of the soil sample is not modified by transducers within it, except for small pellets which have no measurable influence on dynamic phenomena.

Two specific radiographic systems, used to observe dynamic phenomena in soil samples subjected to suddenly applied loads, are examined in detail. One of these systems uses a steady X-ray source, and the other uses a flash X-ray machine. Radiographic records from both tests are presented and analyzed.

SWC-TDR-62-47  
STUDY OF STRESS WAVE INTERACTION WITH BURIED STRUCTURES  
29(601)-4312: Armour Research Foundation  
May 1962  
U

AD-283 750

In a series of experimental programs sponsored by AFSWC at Armour Research Foundation, dynamic photoelasticity and moire displacement measuring techniques have been developed for solving two-dimensional dynamic stress problems, and several wave propagation problems have been solved by these methods.

In the research program discussed in this report, an air shock tube facility was developed for applying airblast loadings to the edge of a photoelastic model. This facility was then used to determine stress distributions which develop on boundaries of circular holes and circular inclusions embedded in a plate, when an air shock travels across one edge.

The stress determinations indicate dynamic loadings of the type used in this study produce stress concentrations which exceed static concentrations for equivalent loadings by approximately 10 percent. After the wave front in the plate passes the discontinuity, dynamic stresses approach static stresses asymptotically.

SWC-TDR-62-56  
HIGH-COMPRESSIVE-STRENGTH CONCRETE  
29(601)-6104: Waterways Experiment Station, USA  
August 1962  
U

AD-286 522

This report presents results of a review of published and unpublished data pertaining to high-strength concrete, including consideration of factors affecting strength, high-strength concretes previously made, and applications, economics, and procurement of high-strength concrete. Data reviewed indicate that practical, routine production of portland-cement concrete having a

compressive strength consistently above 10,000 psi after 90 days moist-curing will require careful selection of materials, mixture proportions, and mixing, placing, consolidating, and curing procedures. The most important single factor affecting the practicality of such concrete is achieving a sufficiently low water-cement ratio. Data reviewed indicate high-strength concrete cannot be obtained for mixtures having water-cement ratios higher than 0.45 by weight; and in order to provide adequate workability, it will usually be necessary to use at least seven bags of cement per cubic yard of mixed concrete. Although high-strength concrete may not be economical in conventional reinforced concrete construction, it will afford important economic advantages in underground arch and dome construction.

SWC-TDR-62-64

AD-298 578

GUIDE FOR THE DESIGN OF SHOCK ISOLATION SYSTEMS FOR UNDERGROUND PROTECTIVE STRUCTURES

29(601)-4551: Ralph M. Parsons Company

October 1962

U

This report reviews major considerations relating to design of shock isolation systems for underground protective structures, emphasizing areas where special guidance is needed by facility engineering contractors. Ground motion due to nuclear blast, interaction of ground motion with buried structures, and tolerances of typical facility equipment to shock are described and used to establish input and output requirements for isolation systems. Analytical methods for determining dynamic responses of both linear and nonlinear isolation systems are summarized, and, for several commonly used configurations, these equations are reduced to simple form. Use of the shock response spectrum is suggested as a unified approach to specifying shock attenuation requirements, equipment shock tolerances, and shock test machine selection criteria.

SWC-TDR-62-90

AD-402 753

LABORATORY EXPERIMENTS ON THE RESPONSE OF SOILS TO SHOCK LOADINGS

29(601)-2830: Purdue University

January 1963

U

This report discusses research carried out at Purdue University, the purpose of which was to develop, on the basis of direct measurements, mathematical models suitable for describing propagation of a compression shock wave through soils, principally partly saturated clays. This interim report describes selection of a suitable laboratory test, and design, calibration, and use of gages to measure stress and strain near a point during propagation of a shock wave. Preliminary test results from samples of compacted clay are also included.

SWC-TDR-62-91

AD-402 779

ENERGY ABSORPTION CAPACITY OF GRANULAR MATERIALS IN ONE-DIMENSIONAL COMPRESSION

29(601)-4302: University of Illinois

July 1962

U

Energy-absorbing mechanisms in sand subjected to one-dimensional compression are reported. For pressures below that required to cause grain crushing,

a medium of equal radii elastic spheres in a face-centered cubic array is assumed. Expressions are obtained for the axial stress-strain curve, constrained modulus, coefficient of earth pressure at rest, and relationship between absorbed energy and input energy for one cycle of loading. Energy absorbed because of grain crushing is considered by analyzing statistical relationships between changes in grain size distribution curves and new surface areas created in test samples. An apparatus is described which has the capability of maintaining zero radial strain for a cylindrical sample under increasing axial stress. Lateral stresses developed under these conditions are measured. Preliminary experimental results are presented for one sand, showing variation of the coefficient of earth pressure at rest and stress-strain relationships with initial void ratio, overconsolidation ratio, and strain rate. A correlation of theory and test results is presented.

SWC-TDR-62-126

AD-292 629

SYMPOSIUM ON THE EQUATION OF STATE FOR EARTH MATERIALS

In-house

November 1962

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On 10-11 September 1962 the Structures Division of the AFSWC Research Directorate sponsored a symposium on the equation of state for earth materials. Attendees were personnel under contract to the Structures Division, and personnel interested in this area of research. This document contains abstracts of papers presented at the symposium. The abstracts reflect current theoretical and experimental efforts being undertaken by the Structures Division in the area of equation of state for earth materials.

SWC-TDR-62-138

AD-295 408

AIR FORCE DESIGN MANUAL--PRINCIPLES AND PRACTICES FOR DESIGN OF HARDENED STRUCTURES

29(601)-2390: University of Illinois

December 1962

U

This is the second edition of the Air Force Design Manual, Design of Protective Structures to Resist the Effects of Nuclear Weapons, AFSWC TR-59-70, December 1959 (Conf.). Its intended use is for planning and design of structures to resist effects of nuclear weapons ranging into the megaton class. Emphasis is primarily on underground construction. Material presented is derived from existing knowledge and theory, so the manual is also a report of the state of the art.

Starting with general considerations of site selection and structural function, various phases of design are considered: free-field phenomena in air and ground, material properties, failure criteria, architectural and mechanical features, radiation effects, surface openings, conversion of free-field phenomena to loads on structures, and design and proportioning of structural elements and structures.

SWC-TDR-62-153

AD-405 162

EXPERIMENTS ON THE MEASUREMENT OF THE RESPONSE OF ROCKS TO DYNAMIC LOADS

29(601)-2821: Missouri School of Mines

March 1963

U

The purpose of this study was to develop instrumentation techniques to measure dynamic stress and strain within rock subjected to impulse-loads. These techniques were to be applicable to the determination of rock response to nuclear explosive loadings. Electric resistance strain gages and piezoelectric stress gages were the sensing devices utilized. Transducers were embedded in concrete test cylinders, which were loaded by a plane wave generated by an HE explosive. The sensitivity of the piezoelectric gages utilized was too great for the stress intensities developed, and therefore satisfactory evaluation of the stress measuring technique was not possible. The material presented, summarizing the theoretical aspects of stress and strain measurement at an interior point in a solid, may prove valuable in future embedded gage installations.

SWC-TDR-63-2

AD-405 153

STEP LOAD MOVING WITH LOW SUBSEISMIC VELOCITY ON THE SURFACE OF A HALF-SPACE OF GRANULAR MATERIAL

29(601)-2855: Paul Weidlinger and Associates

April 1963

U

The plane strain problem of a step load moving on the surface of a half-space of granular material is considered. Strength of the material is governed by internal friction and cohesion. As a preliminary step toward a more complete solution, it is assumed that in regions of slip, elastic deformations may be neglected in comparison to those resulting from slip. This assumption limits the application to Mach numbers of less than about 0.20.

Two possible types of material behavior are considered. During slip, one material exhibits dilatancy, while the other does not change in volume. Because elastic deformations are neglected in the slip region, only degenerate results are obtained for the case of dilatancy, i.e., while stresses can be determined, deformations, velocities and accelerations vanish. For the other material, all desired quantities are obtained.

The analysis predicts that if the load exceeds a certain limit, granular particles will be expelled at the surface ahead of the pressure front, and the applied pulse will be preceded by a precursor of expelled grains.

SWC-TDR-63-3

AD-402 707

DEVELOPMENT OF A SMALL SOIL STRAIN GAGE

29(601)-5343: Armour Research Foundation

March 1963

U

This report describes the development of a small strain gage for measuring static and dynamic strains in soil samples. The gage consists of two sets of two coil discs; associated instrumentation includes electronic driving,

amplifying, and recording circuitry. One set of coils is embedded in soil as the strain sensing element; the other is externally positioned to serve as a reference. The principle of operation is that of an air core differential transformer with a null balancing system to permit accurate measurements of small strains.

The gage is a reliable precision measuring device. Results of static and dynamic evaluations prove the coils can be consistently placed in soil specimens within spacing and alignment requirements. Thus, the gage accurately defines the relative position of two points in soil and accurately measures the change in spacing of these points when the specimen is strained.

The gage appears well suited for measuring strain in soil. With further investigation of the distorting effect of the gage on the adjacent strain field, and appropriate modifications to reduce this effect, the gage may be used to reliably measure both static and dynamic strains within a very small gage length.

SWC-TDR-63-5  
CALIBRATION OF A 6-FOOT AND A 2-FOOT DIAMETER SHOCK TUBE  
29(601)-4520: Air Force Shock Tube Facility  
June 1963  
U

AD-405 124

This report discusses the first phase of calibration of the 6-foot and 2-foot diameter shock tubes located at the Air Force Shock Tube Facility, Kirtland Air Force Base, New Mexico. The report is concerned primarily with calibration of the 6-foot shock tube, but some data from the 2-foot shock tube were used in theoretical analyses of the 6-foot shock tube.

The 6-foot shock tube was calibrated using varying specific primacord high explosive charge ratios as the driver to generate air shock strengths ranging from 1.83 to 9.33 (overpressures of 10 psi to 100 psi respectively), at the air test and soil test sections. Overpressures at the air test and soil test section were monitored with pressure transducers mounted flush with the shock tube walls. Pressure transducers were ARF barium titanate and Granath ST-2 gages. For an overpressure of 100 psi at the air test and soil test sections, the average maximum positive phase duration was about 190 milliseconds.

Fundamentals of thermodynamics were applied in a theoretical analysis of the shock tubes. From this analysis it was found more data was needed to completely calibrate the shock tubes.

SWC-TDR-63-6  
STUDY OF THE COLLAPSE OF SMALL SOIL-SURROUNDED TUBES  
29(601)-4927: Massachusetts Institute of Technology  
June 1963  
U

AD-405 123

This report describes a program of experimental and theoretical work concerning failure of structural tubes surrounded by a thin layer of soil, loaded by uniform external radial pressure. Properties and thickness of the soil layer were varied, and the pressure at which the tube failed, as well as

deformations of the tube before and after failure, were observed. Theories based on idealized models of soil-structure interaction were developed. Experimental results were then correlated with these theories to determine which, if any, theories explained the behavior of the samples.

In addition to this work, a new test apparatus was designed and built, in preparation for similar tests with tubes buried under a plane soil surface.

SWC-TDR-63-26

AD-409 456

STUDY FOR DEVELOPMENT OF RECIPROCITY PROCEDURES FOR ANALYZING DATA FROM UNDERGROUND EXPLOSION TESTS

29(601)-5132: Space Technology Laboratories

June 1963

U

The purpose of this study was to explore the theoretical and practical feasibility of using ground motion measurements at the surface from an underground explosion test to determine the response of an underground cavity to a traveling surface pressure pulse. The investigation showed average cavity strain history can be determined by applying a dynamic reciprocity theorem; an IBM 7090 program was then developed to carry out necessary computations. When more general types of cavity response to a given surface pulse are desired, dynamic reciprocity requires, as part of the input information, surface response to loads applied on the cavity.

However, the dynamic reciprocity relationship developed in this investigation is subject to some limitations which restrict its scope. First, when data obtained from underground explosions are used as input, dynamic reciprocity yields only the average radial displacement of the cavity, i.e., volume change. An underground blast cannot furnish data needed to determine the complete history of cavity displacement, because an explosion in a closed cavity is a pressure pulse which has no resultant force. Therefore, measured surface displacements, when used with the dynamic reciprocity relation, yield only mean radial displacement time history, or volume change. Information on rigid body translation and cavity distortion, which is important for adequate design of underground facilities, is not obtained.

SWC-TDR-63-27

AD-405 120

THE USE OF ROCK FILTERS TO ATTENUATE AIR SHOCKS

29(601)-4520: Air Force Shock Tube Laboratory

March 1963

OUO

This report describes tests performed on 2-foot-diameter rock filters for use as shock-attenuating devices in ventilation systems of protective, underground structures. Lengths varying from 1 to 4 feet, made up of 2-inch and 5- to 7-inch cobbles, were tested through an overpressure range of 30 to 100 psi. Pressure readings were taken of incident pressure (input) on the filters, and transmitted pressure (output) through the rock filters. Static pressure drops for steady flow for each filter were also measured through a range of volume-flow rates.

With the aid of theory research data were adapted to small, personnel shelters utilizing a rock filter and plenum volume behind the rock filter.

SWC-TDR-63-43

AD-411 367

A THEORETICAL ANALYSIS OF STRESS WAVE INTERACTION IN A MODEL SCIL

29(601)-5395: National Engineering Science Company

June 1963

U

In this study an attempt was made to formulate and solve by analytic methods a problem of stress wave interaction, using a structure buried in a nonlinear, soil-like medium. After considering the literature on theories of inelastic solids, a model was chosen to represent soil behavior under large compressional transient stresses. This model has a bilinear compressional stress-strain curve in a conventional uniaxial test, with unloading behavior similar to that observed experimentally in metals and certain soils.

The structure chosen was a cylinder of infinite density and rigidity. The stress wave form chosen was a step magnitude just sufficient to cause incipient yielding of the medium. Numerical solutions were obtained which indicate that, after an initial loading jump due to impingement of the stress wave on the front cylinder face, unloading takes place, followed by subsequent reloading. Quantitative estimates of loadings on the front cylinder face during unloading were not obtained.

SWC-TDR-63-45

AD-416 673

RESEARCH STUDIES ON FREE FIELD INSTRUMENTATION

29(601)-1944: United Electro Dynamics, Inc.

June 1963

U

The design of a gage capable of measuring free-field stress, strain, and acceleration is reported. Prototypes based on the design were fabricated and tested in a test tank capable of producing dynamic pressures up to 800 psi and static pressures up to 1,000 psi. The gages were used to investigate the static and dynamic characteristics of the test tank.

Developmental soil gage prototypes and a field system were developed for and used in a nuclear field experiment. A description of this field system and test results are given in Appendix B.

The field system was later refabricated into two systems; one remained at UED, the other was delivered to the Air Force Shock Tube Facility for further evaluation. A description of the Shock Tube System is given in Appendix C.

SWC-TDR-63-47

AD-423 739

EXPERIMENTAL STUDY OF THE EFFECT OF MATERIAL PROPERTIES ON COUPLING OF EXPLOSION ENERGY

29(601)-5360: United Research Services

May 1963

U

An experimental study was made of the influence of material properties on the directly transmitted effects of explosions. Small spherical high-explosive

charges were used to load a series of cylindrical blocks of fine aggregate concrete, either at the surface of a block, within a block, or at the contact surface of two blocks. Measurements were made of the variations in concrete properties, of the total impulse delivered to the block supports, of the permanent deformations and craters, and of the air-blast pressures. It was found that material properties have a major effect on the total impulse transmitted to the material, little effect on the air blast waves, and a very large influence on the sizes and shapes of the craters produced. Although crater dimensions appeared to vary approximately as the cube root of charge weight, both the crater volume and the total impulse varied by at least a factor of two, and scaled crater depth appeared to be approximately independent of burst geometry. The compressibility, as measured by Young's modulus, appeared to have the greatest effect on impulse, while the internal shear strength and other properties reflecting the internal structure of the material had greatest effect on crater dimensions.

SWC-TDR-63-48

AD-

FEASIBILITY STUDY OF METHODS FOR DYNAMIC THREE-DIMENSIONAL PHOTOELASTICITY

29(601)-5362. Armour Research Foundation

June 1963

U

The purpose of this research program was to investigate the feasibility of using photoelasticity and Moire methods to obtain dynamic three-dimensional stress distributions. Photoelasticity methods considered include scattered light techniques, embedded polariscopes, and embedded photoelastic layers in optically insensitive materials. During the course of the program physical and optical properties of a number of model materials were determined, effect of stress Polaroid materials was established, and several preliminary model studies were conducted using impact loadings. As a result of these experiments, the embedded polariscope technique has been selected as the most suitable method for immediate application to dynamic three-dimensional problems. Instrumentation and calibration procedures required for studies of this type are discussed.

SWC-TDR-63-53

AD-411 132

CLOSE-IN EFFECTS FROM NUCLEAR EXPLOSIONS

29(601)-5008: Armour Research Foundation

June 1963

U

This report presents an analytical treatment of close-in effect from surface and subsurface nuclear explosions, including an analysis of several real materials, leading to computation of both nuclear and chemical explosive efficiencies. By comparison of these efficiencies a nuclear-HE equivalence is established for full contained and shallow-buried bursts, from which effects such as cratering may be scaled. Equivalences are dependent on material properties, such as water content, vaporization level, and Hugoniot relations. For all materials treated, equivalences range between 30 and 40 percent for subsurface explosions, and about 2 percent for nominal yield surface bursts. Surface burst equivalence is shown to be largely dependent on weapon volumetric energy release. Methods for predicting free-field flow variable behavior are also presented.

The report also contains an analytical method for predicting surface spall resulting from deep subsurface explosions. Results are dependent on both tensile and shear strengths. In addition, a one-dimensional model describing stress propagation in real materials is presented, utilizing a material description independent of any specific stress field. This analysis shows that dissipation effects in plane waves, which have been attributed to strain rate effect, can equally well be accounted for by deviatoric effects.

RTD-TDR-63-3020

AD-433 965

A STUDY OF THE DESIGN AND ANALYSIS OF FOUNDATIONS

AF 29(601)-5197: IIT Research Institute

January 1964

U

The behavior of foundations for protective structures was studied through a combination of theoretical and experimental research. Particular emphasis was placed on formulating a mathematical model which accurately predicts the gross motion of a dynamically loaded footing. A single-degree-of-freedom model incorporating a linear damping factor was developed and the results obtained from this model were correlated with results from experiments performed under previous contracts.

Other studies reported include three-dimensional static experiments of small model footings on cohesive soils; static experiments on a cohesionless soil where the footing and surrounding soil were subjected to overpressure; formation of the logarithmic spiral failure surface for bearing capacity of continuous foundations; and solution of a dissipation mechanism for dynamic soil behavior.

RTD-TDR-63-3021

AD-415 362

INTERACTION OF PLANE ELASTIC WAVES WITH A CYLINDRICAL CAVITY

AF29(601)-5007: University of Illinois

June 1963

U

A method is presented for computing stresses in the vicinity of a long cylindrical cavity in an infinite, elastic, isotropic, homogenous medium when the cavity is enveloped by a plane stress wave traveling perpendicular to its axis. Hoop stresses at the cavity boundary were computed for a wave of dilatation and a wave of pure shear; stresses in the medium away from the boundary were computed for a wave of dilatation. Initially the stress behind the incident wave front was considered constant. The effect of a stress decay behind the front was then computed using the Duhamel integral for the case of an incident wave of dilatation.

The method of solution involves superposition of the stress field of an incoming plane step wave and a stress field corresponding to waves which diverge from a line source.

RTD-TDR-63-3023  
PROJECT 1080 RESEARCH SUMMARY  
In-house  
February 1964  
U

AD-419 631

This report contains summaries of all research reports dealing with nuclear weapons effects on hardened structures, published under Project 1080 by the AFWL Structures Branch (formerly the AFSWC Structures Division) and predecessor organizations from July 1951 to February 1964. Section I contains edited abstracts of unnumbered reports and technical documentary reports. Section II lists all reports by document number (unnumbered reports are listed chronologically), Section III lists reports by subject area, and Section IV lists reports by contractor.

RTD-TDR-63-3024  
GAGE PLACEMENT STUDY  
AF 29(601)-5412: Armour Research Foundation  
August 1963  
U

AD-419 316

A study has been made of the various factors which affect the behavior of gages in soil. The ultimate objective of the study is to provide guides and recommended procedures for gage placement. Previous field and laboratory experience with stress, strain, and motion measurement in soil has been reviewed and a list of references provided. This was supplemented by an experimental investigation of embedded accelerometers to determine the importance of gage density and placement procedures on gage response.

The most important factors influencing motion measurement appear to be (1) gage density in relation to the soil and (2) placement conditions. Reproducibility of peak acceleration measurements was within +15 percent on the average. For a variation in accelerometer density of 55 percent, a 12 percent difference in peak accelerations was observed for pendulum tests in sand and a 37 percent difference for shock tube tests in clay. Changing the static compaction pressures for placement of gages in clay from 12 psi to 42 psi resulted in a decrease of 22 percent in the peak accelerations recorded.

RTD-TDR-63-3025  
BIBLIOGRAPHY OF EXTRATERRESTRIAL RESEARCH  
In-house  
June 1963  
U

AD-410 518

This bibliography on extraterrestrial research is subdivided into the following categories: Astrobiology; Astronomy and Cosmology; Cratering Phenomena; Extraterrestrial Matter; Materials; Meteoritic Cratering; Moon (Atlases and Photography, Configuration, Experimental Research, Exploration and Basing Concepts, Lunar-Earth Phenomena, Lunar Trajectories, Surface Materials, and Topographical Features); Planets; Power Systems; Space Vehicles and Probes; Tektites; and Vacuum Environmental Simulation. Each category is separately alphabetized and cross-indexed. Where more than one article appears for any one author, they are listed in chronological order.

RTD-TDR-63-3041, Vol I

AD-348 510

EVALUATION OF TUNNEL LINERS IN GRANITE SHOT HARDHAT, OPERATION NOUGAT

AF 29(601)-4993: University of Illinois

February 1964

S

The Hard Hat event was undertaken to investigate the structural systems required to give a high degree of survivability to deep underground structures which are subjected to the effects of a nuclear burst. The basic concept for the design of the structural systems was to provide a structural lining surrounded by a soft packing material to isolate the lining from the rock. The test results are analyzed with particular reference to the structural behavior of the test sections. Two methods of analysis have been used to interpret the measurements. The first method employs displacement-interaction diagrams which incorporate the effects of the strength of the liner, the stiffness of the liner, the yield strength of the packing, and the thickness. The validity of these approaches is evaluated by comparing the observed behavior of the test sections with that indicated in the analysis. Reports on pretest planning and material properties are included in Volumes II, III, and IV.

RTD-TDR-63-3041, Vol II

AD-433 205

EVALUATION OF TUNNEL LINERS IN GRANITE SHOT HARDHAT, OPERATION NOUGAT

AF 29(601)-4993: University of Illinois

February 1964

U

This volume contains a report, with some editorial revision, issued initially in draft form in September 1960 under Contract AF 29(601)-2151. It contains a summary of the studies made to establish the basis for the design of the experiment, and it summarizes the details of the tunnels and linings used in the experiment. This appendix is Phase I of the final report on Contract AF 29(601)-2151.

RTD-TDR-63-3041, Vol III

AD-433 191

EVALUATION OF TUNNEL LINERS IN GRANITE SHOT HARDHAT, OPERATION NOUGAT

AF 29(601)-4993: University of Illinois

February 1964

U

This volume contains the results of tests of various materials considered for use as backpacking in the Hard Hat tests.

Specific trade names and manufacturers are referred to in this volume to define the materials tested more completely. In most instances similar materials are available from other manufacturers. Use of specific trade names herein should be interpreted only as a more complete definition of the characteristics of the materials actually tested. Since no effort was made to obtain random samples of materials, the results presented may not be representative of the materials in general. Further use or publication of the data herein for any purpose without prior approval of the Air Force Weapons Laboratory is not authorized.

## EVALUATION OF TUNNEL LINES IN GRANITE SHOT HARDHAT, OPERATION NOUGAT

29(601)-4993: University of Illinois, Urbana, Illinois

February 1964

U

This volume summarizes work accomplished under Contract AF29(601)-2151. The material herein has not been presented previously. This volume constitutes Phase III of the final report on Contract AF29(601)-2151.

In an effort to document the physical properties of the steel used in the structural tunnel linings for the Hard Hat experiment, tests were made on samples provided by the two contractors who performed the construction. The samples provided by the original lump-sum contractor are identified herein as Group I, and those provided by the contractor who completed the construction are identified as Group II. In all cases, samples were provided from each mill heat from which the actual linings were fabricated.

Segments of lining corresponding to one-half the circumference of the completed lining were supplied as part of the original order for each type of tunnel lining. Since the 10-inch-wide flange-rings were made up of two flange plates welded to a web plate, one 8-inch by 10-inch plate was supplied for each thickness of material used. In addition, one 12-inch length of corrugated tunnel liner plate was provided for each gage used in the Group II materials. This short segment was provided from the material before it was formed to the 36-inch internal radius; that is, the plate was corrugated but was not curved. No such flat piece was provided from the Group I materials.

## EVALUATION OF TUNNEL LINERS IN GRANITE SHOT HARDHAT, OPERATION NOUGAT

## VOLUME V: REMOVAL OF TUNNEL LINERS

29(601)-4993: University of Illinois, Urbana, Illinois

August 1964

U

This report describes the removal of four tunnel liners in the HARD HAT complex to determine the extent and type of damage to the surrounding rock. Although there was considerable crushing of rock at some locations, there was no evidence that classical spalling of rock had occurred.

In contrast to the considerable rock damage observed in the two unlined sections in C-Drift, the rock surface behind the two liners removed in C-Drift appeared to be undamaged.

From tests conducted on recovered samples of polyurethane foam, it was possible to make estimates of the minimum thickness to which the foam had been crushed during dynamic loading.

RTD-TDR-63-3048

AD-424 414

STRESS WAVES IN GRANULAR MATERIAL

29(601)-2855: Paul Weidinger, Consulting Engineer

July 1963

U

The results of research into stress wave propagation in granular media are presented. The purpose of this work is to clarify air-induced ground shock phenomena in soils, leading to reliable analytical methods of prediction, and to provide guidance for experimental verification and research.

This final report summarizes work on one-dimensional wave propagation in bilinear, locking, and compacting materials, and presents the first results of the extension of these researches into two-dimensional wave phenomena in the same nonlinear media.

RTD-TDR-63-3052

AD-603 167

SCATTERING OF TRANSIENT ELASTIC WAVES BY A CIRCULAR CAVITY

29(601)-5395: National Engineering Science Company

January 1964

U

This report presents solutions to two problems of transient wave scattering from a circular cylindrical cavity in an infinite elastic solid. The first problem is that of a cylindrical cavity subjected to a suddenly applied concentrated line load at the interior. The second is that of a traveling transient plane compressional wave impinging on the cavity wall.

Formal solutions are obtained for both problems by employing double Fourier integrals, using a double integral transform (Laplace for time and Fourier for circumferential coordinate angle). The integrals represent circumferential waves, governed by particular branches of the complex frequency equation. In particular the Rayleigh waves on the cavity surface, which correspond to a limiting high frequency (large wave number pair), are evaluated. They are found to be independent of the circumferential coordinate, nondecaying, and periodic in time. Thus they predominate in long time solutions and produce sizable disturbances not previously considered.

RTD-TDR-63-3055

AD-423 417

DEVELOPMENT OF AN APPARATUS FOR THE DYNAMIC DIRECT SHEAR TESTING OF SOILS

29(601)-5174: University of Notre Dame

October 1963

U

The objective of the work reported herein was to design and develop a pneumatic direct shear device which can force soil failures on a chosen plane by either dynamic or static loadings.

Design criteria, design, construction, and operation of the device, as well as the instrumentation used to control, measure, and record the soil loading phenomena are each discussed in detail.

The apparatus can produce separate or synchronous normal and shear loads up to 500 pounds and can accommodate specimens up to 4 inches in diameter and 0.75 inch thick. Time interval for the strain loadings can be varied from 1.0 millisecond to days.

The present facility is operable and an extensive soil testing program is currently being undertaken.

RTD-TDR-63-3059

AD-424 401

TWO-DIMENSIONAL DYNAMIC STRESS ANALYSIS IN A NONELASTIC MATERIAL

29(601)-5109: IIT Research Institute

November 1963

U

This program is one of a series of related programs whose ultimate objective is to provide technical information for the design of underground structures capable of withstanding the extremely high pressures generated by nuclear explosions.

One approach to this problem has been the experimental study of stress-wave propagation and interaction with discontinuities in soil-like media. Soft near-elastic media have been used in the past and methods of dynamic photoelasticity and moiré grids have been developed for the solution of dynamic elastic stress analysis problems. In the present program a viscoelastic medium has been selected to more closely simulate soil characteristics.

The specific objective of this program was to develop materials, methods, and techniques for two-dimensional experimental stress analysis in viscoelastic, polymeric materials. A great number of polymeric photoviscoelastic materials were investigated and one was selected as suitable for the program. This was plasticized Polyvinyl Chloride, a low-modulus, transparent, and birefringent viscoelastic material. Mechanical and optical properties under creep and relaxation conditions were determined. Dynamic Mechanical and optical properties were determined by means of forced sinusoidal oscillations over a wide range of frequencies.

Photoviscoelastic and moiré methods were developed for solving two-dimensional dynamic stress analysis problems and their application is demonstrated for a strut subjected to a falling weight load.

RTD-TDR-63-3060

AD-426 338

A STUDY OF STATIC AND DYNAMIC RESISTANCE AND BEHAVIOR OF STRUCTURAL ELEMENTS

29(601)-5372: IIT Research Institute

January 1964

U

The objective of this research program is to determine the behavior of a number of simple structural elements, embedded in a soil medium and subjected to static and dynamic loads. During the first year of the program, covered by this report, techniques were developed for making the determinations, and

studies were conducted on four cylindrical shell models under static loading. Three models had hemispherical end closures with diameter-thickness ratios,  $(D/t)$ , of 40, 80, and 160. The fourth model had a  $D/t$  ratio of 80 and an end closure system which could not transmit load to the shell. Most of the work used a dry cohesionless soil medium of uniformly graded silica sand (Ottawa sand). The model with hemispherical heads and  $D/t$  ratio of 80 was also studied in a cohesive soil medium of silty clay.

In the main body of the report an analysis is given of the behavior of the central transverse plane of each shell. Conclusions are drawn regarding the influences of model stiffness, soil media, overpressure level, and end-closure system on hoop and longitudinal membrane forces and bending moments in the shells.

RTD-TDR-63-0061

AD-429 039

STUDIES IN AXIALLY SYMMETRIC WAVE PROPAGATION PROBLEMS IN PLASTIC AND HYDRODYNAMIC MEDIA

29(601)-4965: Stanford Research Institute

January 1964

U

This report outlines a finite difference method for computing motions of a general elasto-plastic-hydrodynamic material. The constitutive equations are those proposed by Grigorian and thus include both volume and shear plasticity. The method uses differences of function values at points on characteristic wave front surfaces. The characteristic difference equations have been established and a procedure for computing motions is described, but no solutions have been obtained.

The solutions of some relatively simple flow problems in locking solids are also described. The spherical case has been solved in detail, using both analytical and characteristic numerical methods; a special class of solutions for the axially symmetric problem has been obtained, and the characteristic difference procedure for numerical solutions has been formulated.

RTD-TDR-63-3064

AD-425 539

USE OF MODELS TO PREDICT THE BEHAVIOR OF DYNAMICALLY LOADED UNDERGROUND STRUCTURES

29(601)-5359: Iowa State University

January 1964

U

Similitude requirements for predicting the dynamic response of underground structures were investigated, and the validity of proposed model design conditions was checked experimentally. The structures used in the tests were hollow aluminum cylinders instrumented with SR-4 strain gages. Most of the test specimens were circular cylinders having diameters of 4 inches, 2 inches, and 1 inch. Some data are also presented for structures having square cross sections. In all tests the structures were buried in dry Ottawa sand. Three different types of loading devices were used in the test program: a drop-weight loader, a vertical shock tube, and a horizontal shock tube. Peak strain and complete strain-time curves were obtained for various depths of burial, and a detailed analysis of the data is presented. For the series of tests performed with the horizontal shock tube no consistent data were obtained and a discussion of the discrepancies encountered is presented. Several series of tests were completed with the drop-weight loader and the vertical shock tube. The results of these tests indicate that the proposed similitude requirements are satisfactory within the range of parameters investigated.

RTD-TDR-63-3073

AD-425 990

THE CALIBRATION AND INTERPRETATION OF RECORDED SHOCK-TUBE PRESSURE DATA USING  
PIEZOELECTRIC SENSORS

AF 29(601)-6002: Air Force Shock Tube Facility (University of New Mexico)  
November 1963

U

This report is a guide for calibration and analysis of recorded pressure data. Many of the techniques and areas covered are also applicable to other types of gages, e.g., strain, velocity or acceleration. Photographs of typical shock-tube data are used to familiarize the reader with the appearance of a true pressure pulse which has been modulated by the effects of resonance, overshoot, groundloops, inadequate bandwidth, and poor gage isolation.

RTD-TDR-63-3075

AD-427 820

A STUDY OF THE DYNAMIC SOIL-STRUCTURE INTERACTION CHARACTERISTICS OF REAL SOIL  
MEDIA

AF 29(601)-5537: United Research Services  
January 1964

U

This report describes an experimental and theoretical study of the dynamic soil-structure interaction characteristics of real soil media. An extensive list of the more important references obtained from a literature search is included. Basic concepts of passive and active arching phases of soil-structure interaction, including equations representing static behavior, are presented. The experimental program consisted of a study of soil-structure interaction on small, idealized, cylindrical structures buried in a sand medium subjected to dynamic loads. Test data obtained indicate that very large overstresses are produced by passive arching. The data also show that overstress due to interaction is dependent upon depth, stress level, relative density of soil, length-to-span ratio, and the compressibility of the structure. The theoretical program consisted of an investigation of the dynamic response of a simple cubic packing of spheres for waves of low stress levels. Certain boundary value problems, representative of phases of soil-structure interaction, were reduced to a form for numerical evaluation.

RTD-TDR-63-3078

AD-421 559

STATIC AND DYNAMIC BEHAVIOR OF A PLAYA SILT IN ONE-DIMENSIONAL COMPRESSION

AF 29(601)-6107: University of Illinois  
September 1963

U

One-dimensional static compression tests, dynamic and rapid limited radial strain compression tests, and unconsolidated-undrained triaxial tests were performed on specimens from the Nevada Test Site Frenchman Flat playa. Static axial stress-strain properties and radial stresses for zero radial strain are presented for a maximum axial stress of 5,480 psi. Rapid and dynamic axial stress-strain properties and radial stresses for limited lateral strains are presented for maximum axial stresses varying from 3,900 ps<sup>i</sup> to 20,300 psi. Stress-strain relationships and shear strength parameters are presented for the triaxial tests for a maximum stress difference of 380 psi.

RTD-TDR-63-3082  
DYNAMIC MODEL TESTS, NORAD COMBAT OPERATIONS CENTER  
In-house  
June 1964  
U

AD-443 071

A study is presented on the design and test of a model which is dynamically similar to the South Building of the NORAD Combat Operations Center complex. The primary objective of this investigation was to study the behavior of a shock-isolated building module subjected to dynamic loading. The design of a scaled model and its important parameters are presented. Dynamic rigid body response of a building module mounted on coil springs has been analyzed. Theoretical scaling relationships and governing displacement-time histories and acceleration-time histories are derived. Test results and analyses with a comparison of the theoretical predictions are presented. The results show a verification of response predictions; it is concluded that response predictions for the actual facility to similar scaled inputs are valid.

RTD-TDR-63-3085  
ANALYTICAL AND EXPERIMENTAL INVESTIGATIONS OF SILO AND TUNNEL LININGS  
AF 29(601)-5384: IIT Research Institute  
January 1964  
U

AD-450 572

This report presents results of analytical and experimental investigations of the response of silo structures to nuclear blast induced loadings. Radial shell motion, longitudinal silo bending, and longitudinal silo skin friction loading are all discussed.

An analytical method was developed to determine the radial response of a cylindrical shell engulfed by a plane stress wave. The structure was idealized as a system of lumped masses connected by inextensional bars. The surrounding soil was given nonlinear characteristics and the structure was loaded by a traveling stress wave which can be given a step or variable linear rise to peak with a constant value or exponential decay after the peak.

A dynamic method of analysis was formulated to investigate the response of silo linings to a prescribed time-dependent free field displacement function that varies with depth. A lumped parameter system was used to represent the structure. Both bending and shear rigidity were included in the analysis. Loads were assumed to be generated from the rigid body relative displacement and velocity of the structure with respect to the free field.

Two theoretical methods were used to investigate the magnitude of vertical skin friction loading on silos. The first used the "friction-circle" method to determine the vertical load carried by the silo at soil failure. The second method made use of the limiting equilibrium concept as applied to an axisymmetric problem. Numerical results for both investigations are presented in the form of skin friction to overpressure ratios for various silo shapes. An extensive series of experimental silo push-out tests was performed to check the theoretical work.

A well instrumented segmented silo model was used to determine the distribution of the skin friction loads. The location of the neutral axis of bending was determined for a structure in loose and dense sand.

RD-DR-63-3089

AD-424 192

THE BEHAVIOR OF SAND IN ONE-DIMENSIONAL COMPRESSION  
AF 29(601)-5817: University of Illinois  
October 1963

U

The behavior of sand in one-dimensional compression was investigated with both theoretical and experimental studies. Phenomenological aspects of one-dimensional behavior, such as stress-strain characteristics, energy absorption capacity, and coefficient of earth pressure at rest are discussed.

The analytical study deals with stress-strain relations of an idealized granular medium composed of elastic, equi-radii spheres in a face-centered cubic array. A new solution is derived for the array behavior when subjected to a monotonically increasing axial compressive stress for the condition of zero radial strain.

An experimental device is described which is capable of measuring the radial stresses developed in high-pressure, one-dimensional tests. Measurements of both the coefficient of earth pressure at rest and the stress-strain properties are presented for four sands tested to an axial stress of 3,290 psi. Correlations are presented which compare the actual behavior of a rounded, uniform, quartz sand in one-dimensional and triaxial compression with the behavior suggested by the theoretical analysis.

RD-DR-63-3091

AD-433 522

A STUDY OF THE PARAMETERS WHICH AFFECT SCALING OF UNDERGROUND STRUCTURES  
AF 29(601)-5340: MRD Division of General American Transportation Corporation  
January 1964

U

This report contains results of an experimental investigation to determine the effect of variation of parameters involved in dynamic modeling of underground structures subjected to blast overpressures at the surface.

RD-DR-63-3092

AD-434 074

BEHAVIOR OF SIMPLE AND RESTRAINED DEEP REINFORCED CONCRETE BEAMS UNDER STATIC LOADING  
AF 29(601)-4578: University of Illinois  
March 1964

U

The purpose of this investigation is to determine the influence of end restraint on the strength and behavior of reinforced concrete deep members subjected to slowly applied loads as a basis for the development of minimum design considerations. The end restraint was applied in such a manner as to simulate that which would be developed in continuous beams or frames.

Static tests were made on fifteen beams of which five were simply supported and ten were restrained.

The investigation is concentrated on the crushing stage as the last stage for which meaningful concrete strains were available. It is shown that deep beams do have a capacity beyond crushing in terms of deflections, and, sometimes, of moments. This reserve capacity is not now predictable in the same manner as the procedure developed herein to predict the capacity at crushing.

RTD-TDR-63-3096, Vol I

AD-444 624

DESIGN PROCEDURES FOR SHOCK ISOLATION SYSTEMS OF UNDERGROUND PROTECTIVE STRUCTURES

AF 29(601)-4565: General American Transportation Corporation, MRD Division  
June 1964

U

The primary purpose of this report is to provide guidance for designers of shock isolation systems during the initial phases of design. Volume I presents methods for estimating appropriate free field waveforms and the influence of soil-structure interaction upon interior structure motion. Volume III of RTD-TDR-63-3096, prepared by Newmark-Hansen Associates, presents methods for synthesizing peak relative response spectra from the spectra characteristics of pulse of simple shape.

The inherent error in shock isolation design is  $\pm 20$  percent; to reduce this, much more soil test data than is now available will be required. Further, based on purely theoretical arguments, shock isolation per se can be eliminated for much equipment used in hard installations. If isolators are required they should be designed as low-frequency systems that impose one g acceleration on the isolated equipment. Increase of the acceleration to be tolerated by the equipment will, in the great majority of instances, reduce neither the rattle space required nor the isolator cost.

Methods for making the necessary computations are given.

RTD-TDR-63-3096, Vol II

AD-627 597

DESIGN PROCEDURES FOR SHOCK ISOLATION SYSTEMS OF UNDERGROUND PROTECTIVE STRUCTURES

AF 29(601)-6253: General American Transportation Corporation, MRD Division  
September 1964

U

This volume presents methods for estimating appropriate free-field waveforms resulting from directly induced ground shock and the influence of medium-structure interaction upon interior structure motion.

The medium is represented by an acoustic model and the structure by an infinitely long cylinder whose longitudinal axis is horizontal and perpendicular to a ray connecting it with the point of detonation. Both shell and medium parameters are varied to determine their effect on resultant interior motions. The parameters which influence interior motions are ranked in order of physical importance. A method for applying the results of the program to design problems is presented and a sample calculation is included.

RTD-TDR-63-3096, Vol III

AD-444 989

DESIGN PROCEDURES FOR SHOCK ISOLATION SYSTEMS OF UNDERGROUND PROTECTIVE STRUCTURES

AF 29(601)-4565: Newmark, Hansen and Associates

June 1964

U

A discussion is presented of response spectra for single-degree-of-freedom systems subjected to different forms of ground excitation.

In the study of elastic systems, the sensitivity of the response to variations in the detailed characteristics of the input motion is discussed. For each class of forcing function, simple approximate rules are presented for the construction of spectra for complex input functions by compounding the spectra for the "dominant" component pulses of the input function.

In the studies of inelastic systems, primary attention is given to elasto-plastic systems and, in an exploratory way, to bilinear systems of the softening type. Response spectra are presented from which the yield resistance required to limit the maximum deformation of the system to a prescribed multiple of its limiting elastic deformation can be determined directly.

The maximum deformation of an inelastic system is related to that of an elastic system having the same initial slope in its resistance-deformation diagram and, for certain conditions, simple design rules are formulated for the construction of deformation spectra for elasto-plastic systems in terms of the corresponding spectra for the associated elastic systems.

RTD-TDR-63-3096, Vol IV

AD-627 870

DESIGN PROCEDURES FOR SHOCK ISOLATION SYSTEMS OF UNDERGROUND PROTECTIVE STRUCTURES

AF 29(601)-6253: Newmark, Hansen and Associates

January 1965

U

The purpose of this study is to develop simple rules for the designer so that he may be able to predict the maximum responses of two-degree-of-freedom elastic and inelastic systems under various types of ground shock excitation. The true responses of two-degree-of-freedom systems both in the elastic range and in the inelastic range, when subjected to five different forms of ground excitation, are compared to the modal response of the same systems. Simple expressions are given for linear two-degree-of-freedom mass and spring combinations from which modal parameters can be obtained. From these, modal parameters and the response spectra for one-degree-of-freedom systems for various excitations, as presented in Volume III of this series of reports, one can determine bounds and probable values of the response.

A detailed study is reported of a two-degree-of-freedom system subjected to a step velocity pulse at the base, having various combinations of elastic and inelastic response. In addition, a series of solutions of two-degree-of-freedom systems is presented for comparison with various approximate rules for determining bounds to the response in the various springs of the system. Consideration is given to the effect of damping, and to types of excitation other than those considered directly. The results are given in the forms of graphical comparisons and tabulated data, as well as recommendations for use by the designer. Bounds for the response of inelastic systems are given in terms of the corresponding responses of associated elastic systems.

RTD-TDR-63-3096, Vol. V  
DESIGN PROCEDURES FOR SHOCK ISOLATION SYSTEMS OF UNDERGROUND  
PROTECTIVE STRUCTURES  
29(601)-6253: Newmark, Hansen and Associates  
April 1965  
U

AD-627 516

A discussion of maximum response for multi-degree-of-freedom systems is presented in some detail, with some results for ten-degree-of-freedom systems and other systems for which data are available in the literature. Included are tabulated response data computed from step-by-step integration of the equations of motion for five different forms of ground excitation on a number of systems having varying parameters of mass and stiffness distribution. The results are compared with the modal responses for the same systems, and general rules are developed for comparing the true responses with various combinations of the modal response data.

Consideration is given to treatment of a multi-degree-of-freedom system as a continuous shear beam, and some generalizations are drawn from the study which enable a better interpretation of the results of the specific data tabulated in the report. Some suggestions arising from the studies reported in Volume IV are made to take into account the behavior of multi-degree-of-freedom systems in the inelastic range.

RTD-TDR-63-3096, Vol. V, Supplement  
DESIGN PROCEDURES FOR SHOCK ISOLATION SYSTEMS OF UNDERGROUND  
PROTECTIVE STRUCTURES--RESPONSE SPECTRA OF MULTI DEGREE-OF  
FREEDOM ELASTIC SYSTEMS, A COMPUTER PROGRAM FOR THE COMPUTATION  
OF DYNAMIC STRUCTURAL RESPONSE  
29(601) 5253: Newmark, Hansen and Associates  
April 1966  
U

AD-632 805

This supplement contains a description of the computer program developed to study the dynamic response of multi-degree-of-freedom systems subjected to earthquake or blast-type ground motions. A description of the features and a derivation of the equations solved by the computer program are presented. The data input to the computer is defined by using a control card containing or preceding each type of input information. The purpose of each control card and the data is given with an example of some typical problems solved using the program. The final section contains the flow diagrams of the main program and each subroutine.

RTD-TDR-63-3106

AD-613 482

EXPERIMENTAL STUDY OF ARCHING STRESSES ON BURIED VERTICAL TANKS

29(601)-6002: Air Force Shock Tube Facility (University of New Mexico)

December 1964

U

This report describes special features of an apparatus for studying arching around buried structures caused by modulus mismatch between the structure and the surrounding medium. To attain this goal, duplicate tests were performed on cylindrical and disc structures, providing an opportunity to separate the effect of arching from side-wall friction. All tests were static, using 20-30 Dry Ottawa sand at three different densities. The applied overpressure and geometric configuration of the buried structures were varied to provide an opportunity of studying the influence of these parameters on the arching phenomenon.

RTD-TDR-63-3109

AD-433 522

THE INTERACTION BETWEEN A STRUCTURAL TUBE AND THE SURROUNDING SOIL

29(601)-4927: Massachusetts Institute of Technology

January 1964

U

This report describes experimental and theoretical research on the interaction between a structural tube and surrounding soil. The experimental work used an extremely small scale, which allowed a large number of tests at low cost, but also prevented use of sophisticated instrumentation. The specific situations investigated were a flexible tube surrounded by a thick cylinder of soil and loaded by uniform radial pressures, and a flexible tube buried under a horizontal soil surface and loaded by pressures applied at the surface.

For the symmetric soil-tube configuration, the elastic behavior (i.e., arching) and the failure condition were investigated by experiments and theory. The main conclusion was that the primary beneficial effect of the soil around a very flexible tube is prevention of tube deformations associated with low-mode buckling failures. The tube is forced to a high-mode buckling failure at very much higher pressures. Compared to this effect the arching effect is small, even for a relatively compressible tube.

The buried tube tests yielded experimental results in reasonable agreement with those of the symmetric situation. Moreover, similar but larger-scale buried tube tests performed at the Air Force Shock Tube Facility also agreed roughly with the above theory. This leads to the conclusion that the symmetric theory holds approximately for the buried tube situation. However, to establish a more accurate theory, better instrumented and thus larger tests are necessary.

RTD-TDR-63-3114

AD-433 651

HIGH COMPRESSIVE STRENGTH CONCRETE

MIPR AF 29(601)-61-04: Waterways Experiment Station, USA

February 1964

U

This report discusses the laboratory phase of an investigation of ways to obtain high-strength concrete under normal field construction conditions. Results of tests on 6-inch by 12-inch cylinders indicate the following factors will aid in obtaining a 90-day compressive strength exceeding 10,000 psi:

- a. Cement content should be at least nine bags per cubic yard, and water-cement ratio approximately 0.35 by weight.
- b. Both coarse and fine aggregate should be carefully graded.
- c. Pozzolans appear beneficial for replacing a limited amount of cement, and provide some increase in strength.
- d. A water-reducing admixture is required to ensure a workable consistency in concrete.

RTD-TDR-63-3116

AD-602 738

A STUDY OF THE BEHAVIOR OF A CLAY UNDER RAPID AND DYNAMIC LOADING  
IN THE ONE-DIMENSIONAL AND TRIAXIAL TESTS

29(601)-5535: University of Illinois

June 1964

U

The behavior of soil under dynamic loading is an important factor in the soil-structure interaction problem. To study this behavior, a series of dynamic, high-pressure triaxial and one-dimensional compression tests has been conducted. Special testing devices developed for this research are described. In the one-dimensional tests, the peak pressures ranged from 620 psi to 11,300 psi with rise times to the peak pressure of 1.9 milliseconds to 1.625 milliseconds. In the triaxial tests, cell pressures from 100 psi to 1,010 psi were used with times-to-failure varying from 3 milliseconds to 100 seconds. In addition, partial loading triaxial tests were run in which the applied axial stress was 20 percent to 60 percent of the failure stress. The soil used was a compacted silty clay of low plasticity. The test results are presented and the influence of rate of loading and pressure level on compressive strength, ratio of lateral to axial pressures, stress-strain relations, residual strains, and creep under constant load are evaluated.

RTD-TDR-63-3125

AD-438 711

**THEORETICAL STUDY OF ENERGY DISTRIBUTION IN A HALF-SPACE RESULTING FROM DYNAMIC LOADING IN A DEPRESSION AT THE ORIGIN**  
29(601)-5813: MRD Division, General American Transportation Corporation  
March 1964

U

An analysis of the free-field ground motion in the elastic region due to the energy delivered directly to the ground by a nuclear weapon is presented. The problem is approached along two different lines. One of these approaches treats the elastic region as a cratered half-space, where the hemispherical boundary of the crater is subjected to the pressure history exerted by a hydrodynamic region within the crater. The other approach treats the elastic region as a complete half-space, a portion of which has initial motion and pressures corresponding to the state of the hydrodynamic region at some instant when its behavior is becoming more nearly elastic than hydrodynamic.

For the cratered-half-space approach, exact analytical expressions are obtained for the stresses at the wavefront, and numerical results based on these expressions are presented. For the complete-half-space approach, analytical results alone are obtained.

WL-TDR-64-3

AD-451 475

**PORE-AIR PRESSURE STUDY**  
29(601)-6002: Air Force Shock Tube Facility, University of New Mexico  
February 1964

U

This report deals with the propagation of pore-air pressure in samples of soil subjected to an air shock. The soils tested were a uniformly graded pea gravel, a standard 20-30 Ottawa sand, and a well-graded silty sand. The orientation of the shock wave to the soil sample was "head-on" in the first series of tests, and "side-on" in the second series. For the former, the maximum overpressure on the upstream end of the sample was approximately 126 psi; for the latter, the maximum incident pressure was approximately 115 psi.

The effect of wave shape, peak overpressure, permeability, total unit impulse, and positive-phase duration is ascertained. Also, the data are qualitatively reviewed in the light of full-scale field conditions.

WL-TDR-64-4

AD-601 878

**THE MECHANICAL AND OPTICAL CHARACTERIZATION OF HYSOL 8705 WITH APPLICATION TO PHOTOVISCOELASTIC ANALYSIS**  
29(601)-5367: California Institute of Technology  
June 1964

U

The main requirement for practical photoviscoelastic analysis is optical and mechanical characterization of the material. The report describes the interrelation between the stress and strain optic (operational) coefficients and approximate techniques for obtaining satisfactory quantitative results using broad band rather than three- or four-element representation of material properties. The analysis technique is accomplished by material characterization through a Dirichlet, or Prony, series representation of the time-dependent properties, and appropriate operations on their Laplace transforms.

Time-dependent characteristics of a typical low modulus polymer material, Hysol 8705, are determined from constant strain rate tests for a full range of dynamic loading rates by taking advantage of the time-temperature shift phenomenon. The theory of linear viscoelasticity is then used to construct master curve representations for all pertinent properties of Hysol 8705.

A one-dimensional photoviscoelastic experimental program was conducted to generate experimental data for comparison to a corresponding theoretical problem. A comparison is made between the analytically predicted fringe patterns and the experimental results; also, available two-dimensional considerations are examined. The results indicate the feasibility of quantitative photoviscoelasticity with engineering accuracy.

WL-TDR-64-7

AD-438 826

DEVELOPMENT OF A SOIL STRAIN GAGE FOR LABORATORY DYNAMIC TESTS

29(601)-5343: IIT Research Institute Technology Center

April 1964

U

The original effort under this contract enabled development of the "four-coil" soil strain gage for measurements in laboratory samples subjected to static or dynamic loads. This report covers work done under a contract extension for continued gage development and modifications which have resulted in the "coil-plate" gage. The coil-plate gage can be used for applications for which the four-coil gage in its present form is not suitable.

The new coil-plate gage can be operated with the same auxiliary electronics used with the four-coil gage. The gage consists of two bifilarly wound coils and two conducting plates and associated electronic instrumentation. One bifilar coil and plate is embedded in soil as the strain sensing element; the other coil and plate is externally positioned on an adjustable precision mount to serve as a reference. The principle of operation is that of a series-adding transformer having its secondary connected to an open circuit-null balancing system to permit accurate measurements of small strains. Measurements can be made close to boundaries and to materials exhibiting magnetic properties.

WL-TDR-64-8

AD-451 667

STEP LOAD MOVING ON THE SURFACE OF A HALF-SPACE OF A LOCKING  
MATERIAL--SUBSEISMIC CASE

29(601)-6055: Paul Weidlinger

December 1963

U

Considering a locking material prior to compaction as a special case of a nonlinearly hardening elastic material, conditions at a discontinuity--a locking front--are analyzed on the basis of three-dimensional theory. This study leads to the important result that the major compressive principal stress at a locking front must always be normal to the front, even if the front is not plane. Based on this general result, the effect of a uniform step pressure traveling with sub-seismic velocity on the surface of a half-space is obtained for the case of a locking material which after compaction has elastic-Coulomb behavior. Such a material acts linearly elastic if the state of stress does not overcome internal friction, but slip occurs if the stresses reach a critical state defined by Coulomb friction. As a special case the solution applies also for a material which is linearly elastic after compaction. The stress, velocity, and acceleration histories due to the traveling step pressure are discussed and compared to those in the one-dimensional case of a suddenly applied uniform surface pressure.

WL-TDR-64-11

AD-603 483

A PEAK LOAD, SELF-RECORDING ON-STRUCTURE STRESS GAGE

29(601)-6193: United Electrodynamics, Inc.

June 1964

U

A peak-load, self-recording, on-structure stress gage was developed and four developmental prototype units were fabricated. Magnetic tape was used as the recording medium, employing a carrier-erase data-recording technique. The data readout system designed for this project employs a newly developed direct flux reading magnetic tapehead. Theoretical and experimental comparisons are made between the flux head and a conventional head. Test results are presented for these prototype gages.

WL-TDR-64-12

AD-439 382

A THEORETICAL ANALYSIS OF STRESS WAVE INTERACTION IN A MODEL SOIL--  
FURTHER STUDIES

29(601)-5395: National Engineering Company

April 1964

U

Two formal solutions are given to the plane strain problem of the interaction of a stress wave propagated in a "bilinear plastic" medium with an infinitely rigid/infinitely dense cylinder embedded in the medium.

The two solutions are essentially complementary with respect to points of theoretical difficulty and deficiencies in generality. A numerical study of each solution should lead to further development of a completely general method for treating the problem under consideration or similar problems.

WL-TDR-64-13

AD-606 685

THE RESPONSE OF BURIED CYLINDERS TO QUASI-STATIC OVERPRESSURES

29(601)-6002: University of New Mexico

September 1964

U

An experimental investigation was conducted into the response of small buried aluminum cylinders to quasi-static overpressures. The cylinders were buried with their axes horizontal in dense, dry, 20-30 Ottawa sand.

Cylinders of two stiffnesses were tested at depths ranging from zero to two cylinder diameters. Their behavior was evaluated quantitatively by radial displacement gages and tangential strain gages. Data at five overpressure levels up to 140 psi are presented. This maximum value exceeded the theoretical in air primary buckling pressure of the cylinders by factors of 9.4 and 9.9.

Destructive tests were conducted on noninstrumented cylinders of six stiffnesses. This maximum applied overpressure was 160 psi, 470 times the theoretical overpressure in air primary buckling pressure of the most flexible cylinder. The overpressure required to cause collapse of the various cylinders was determined for as many depths of burial as the maximum overpressure would allow.

The destructive tests demonstrate the great resistance to collapse imparted to a cylinder by burial. The nondestructive tests afford a comparison between the behavior of stiff and flexible cylinders as the depth of burial and the overpressure are changed. Two zones of burial, deep and shallow, are defined. These zones depend on the rigidity of the cylinder and the magnitude of the overpressure.

WL-TDR-64-20

AD-608 518

FEASIBILITY STUDY OF SHOCK ISOLATING A VERY LARGE STRUCTURE

In-house

September 1964

U

This report considers the problem of suspending a very large structure within an underground cavity so as to provide adequate shock isolation. The geometry necessary to uncouple the modes of vibration of a simple system is studied, and recommendations are made concerning the relation between base and side springs. Coil-spring suspension systems are investigated and general design equations and charts are presented. Pneumatic suspension is considered. A new type of pneumatic suspension consisting of corrugated metal bellows is proposed and design equations and charts for such a system are presented. Liquid suspension is briefly discussed. Transient waves in various shock isolation systems are studied.

This report concludes that pneumatic suspension systems employing corrugated metal bellows hold much promise and should be further investigated. Shock isolation of a very large structure appears to be feasible using either coil-spring or pneumatic-bellows supports.

WL-TDR-64-27  
PREDICTION CALCULATIONS FOR FREE FIELD GROUND MOTION  
29(601)-5832: Physics International Company  
May 1964  
U

AD-601 513

This report describes a calculation program designed to predict the cratering dimensions and free-field ground motions which result when chemical or nuclear detonations occur with various degrees of confinement. Calculations were made using a two-dimensional plastic-elastic time-dependent code. A vital part of the program involved the derivation of calculational models capable of describing the response of earth media to shock loading.

WL-TDR-64-28  
RESPONSE OF FOAM-ISOLATED TUNNEL LININGS TO TRANSIENT LOADINGS  
29(601)-6022: IIT Research Institute Technology Center  
June 1964  
U

AD-603 539

This research program was conducted to determine the behavior of a foam-isolated tunnel liner in an elastic material during passage of a plane stress wave. The specific objectives of the program included a determination of time-dependent stress fields in the elastic material, time-dependent magnitudes and location of crushing in the isolation material, and time-dependent stresses and motions of the tunnel liner. The results of the program indicate that the stresses in the liner are significantly reduced by the crushing of the foam. The rigid body motions of the liner, however, are not significantly influenced by the presence of the foam.

WL-TDR-64-29  
BIBLIOGRAPHY OF EXTRATERRESTRIAL RESEARCH (2nd Edition)  
In-house  
July 1964  
U

AD-604 105

This bibliography on extraterrestrial research is subdivided into the following categories: I. General (Astrobiology, Astronomy and Cosmology, Materials--Space Environment Effects, Orbital Vehicles and Probes, and Space Environmental Simulation); II Moon (Atlases and Maps, Configurations and Internal Structure, Environment, Experimental Research, Exploration and Basing Concepts, Lunar-Earth Phenomena, Lunar Trajectories and Associated Problems, Surface Materials and Natural Resources, and Topographical Features); III. Planets (Jupiter, Mars, Mercury, Neptune, Pluto, Uranus, Saturn, and Venus); IV. Extraterrestrial Materials (Asteroids and Comets, Meteors, Micrometeorites, Dust, Meteorites, and Tektites); V. Cratering (Laboratory Cratering Phenomena, Meteorite Cratering and Associated Phenomena, and Nuclear and HE Cratering Phenomena); and VI. Bibliographies.

Each category is separately alphabetized and cross indexed. Where more than one article appears for any one author, such are listed in order of publication date.

WL-TDR-64-35  
29(601)-5837: The University of Texas  
July 1964  
U

AD-444 111

The purpose of this study was to extend the basic information on the behavior of concrete beams reinforced with steel plates and loaded both statically and dynamically at their center lines. The test beams had a steel plate either on the bottom serving as tensile reinforcement or on the top serving as compression reinforcement. Steel studs welded to the plate were used to transfer the shear at the concrete-steel interface. Stud behavior was determined from special push-out tests loaded both statically and dynamically. Comparisons of behavior as obtained from beam and push-out tests were made. The principal variables studied were stud diameter, concrete strength, number of studs per shear span, and type of load.

Dynamic loads were obtained by dropping a mass onto a cushioning material resting on the specimen which provided load pulses with two positive slopes. An initial rise time of 3 to 9 milliseconds and a total duration up to 120 milliseconds, and loads up to 80 kips were obtained.

The results of this study indicate that beams loaded dynamically have approximately a 50 percent greater flexural resistance than companion beams loaded statically. The results from dynamic push-out tests and stud capacities vary directly with study diameter and concrete strength. Various recommendations for use in beam design are presented.

WL-TDR-64-47  
STRAIN VARIATION IN A TRIAXIAL SOIL TEST  
29(601)-6004: IIT Research Institute  
September 1964  
U

AD-606 985

An experimental program was carried out to evaluate the strain behavior of a soil sample being tested in a triaxial apparatus. The patterns of deformation were obtained at specific locations within the specimen by embedded strain gage measurements. The investigation was made in both noncohesive and cohesive soil types, and included study of the influence of confining pressure, size of specimen, rate of loading, and presence of the gage on the uniformity of deformation.

It was determined that the specimen strain behavior is quite different between noncohesive and cohesive soil samples, and that significant nonuniformity of deformation takes place even at small strains, well in advance of failure.

WL-TDR-64-51  
EVALUATION AND INTERPRETATION OF EJECTA DATA FROM CRATERING  
EXPLOSIONS  
29(601)-6009: The Boeing Company  
May 1964  
S

AD-350 182

Ejecta distribution data analyzed are for five chemical-explosive and three nuclear-explosive cratering events. The analytical approach is mainly one of

defining ejecta quantity as a function of radial distance, calculating total ejecta mass, and determining its relationship to the apparent crater volume. Applying this approach, recommended ejecta thicknesses for dry soil are given for each of the crater scaling laws included in this study. Estimated ejecta thicknesses for a hard rock medium are included as an appendix to this report. The validity of scaling ejecta mass quantities is indicated for two cratering events differing in yield by over two orders of magnitude and detonated at the same scaled depth. The statistical variation of circumferential ejecta observations is also defined.

Mean ejecta thicknesses for large yields may be approximated for true surface bursts in dry soil using the relationship

$$t = 0.5d [R/D]^{3.9}$$

where  $t$  is thickness,  $d$  is apparent crater depth,  $R$  is apparent crater radius, and  $D$  is distance.

WL-TDR-64-52

AD-606 142

SHOCK UNLOADING CHARACTERISTICS OF CRUSHABLE ROCKS

29(601)-6007: IIT Research Institute

August 1964

U

The unloading characteristics of dry volcanic tuff were observed for two initial shock states. The unloading paths in the stress-particle velocity plane differed substantially from the reflected Hugoniot curve passing through the corresponding initial shock state. Thus the unloading process does not follow the usually assumed Hugoniot unloading path. The net results of this behavior are that (1) the quantity of energy dissipated in the shock process is considerably greater than that normally assumed, and (2) the propagation speeds of the unloading waves are considerably greater than those normally assumed.

For shock stress intensities of approximately 100 and 200 kilobars it was determined that the amount of energy dissipated at the shock front has been underestimated by 20 to 30 percent, and that the remaining useful energy has been overestimated by approximately 50 percent. Furthermore, the unloading wave speed for these cases has been underestimated by approximately 20 to 25 percent.

A correlation was made between Hugoniot data obtained during this program and other Hugoniot data for dry volcanic tuff of various initial densities. It was found that, when presented in terms of absolute density, all of the Hugoniot states above a critical stress level were located on a single Hugoniot curve. This resulting aggregate mineral Hugoniot correlates well with Hugoniot for the basic nonporous constituents of the geologic materials.

WL-TDR-64-53

AD-602 764

A STUDY OF THE FEASIBILITY OF SHOCK ISOLATING VERY LARGE MANNED UNDERGROUND STRUCTURES

29(601)-6053: The Ralph M. Parsons Company

June 1964

U

The feasibility of shock-isolating very large manned underground structures from the intense ground motions generated by a nuclear blast was investigated. The structure under consideration housed personnel living quarters and communications and survival equipment, including large liquid-filled tanks, and was suspended within a concrete-lined underground cavity. Various suspension configurations, isolators, and damping devices were investigated and their performance characteristics compared with the specific requirements of this facility. It is concluded that an inclined, elastic, pendular suspension system incorporating fluid-filled body motions can be used without exceeding acceptable accelerations. Conventional cage structure and liquid storage techniques are found to be acceptable if careful attention is given to their design.

WL-TDR-64-54

AD-613 545

RESPONSE OF DEEP REINFORCED CONCRETE SLABS

29(601)-5385: Southwest Research Institute

February 1964

U

The response of deep reinforced concrete slabs to uniformly distributed dynamic loads as high as 700 psi was measured and compared with the static behavior of companion slabs. Comparisons between theoretical and experimental results were made.

Experience has shown that one of the major difficulties in predicting the static behavior of reinforced concrete slabs results from the varying friction between the slab and bearing plate. The pressure seals and seal devices presented the primary experimental difficulty and made it impossible to yield the strongest slabs.

WL-TDR-64-59

AD-607 623

INVESTIGATION OF EQUATION OF STATE OF POROUS MATERIAL

29(601)-6024: Stanford Research Institute

August 1964

U

Hugoniot data in the pressure range 40 to 500 kbar for porous plays from Area 5 of the Nevada Test Site are obtained by impedance-match methods using both in-contact and flyer-plate explosive arrangements. Two initial densities, 1.55 and 1.95 g/cm<sup>3</sup> (crystal density, 2.66 g/cm<sup>3</sup>), of dry, reconstituted material are examined. The data show regions in which the pressure is multivalued. This behavior is attributed to polymorphic phase transitions in one or more of the constituent minerals.

A simple, closed-form expression for the zero-degree isotherm is presented which converges asymptotically to the behavior of a free-electron gas at extreme pressure. It also contains the principal term representing the pressure-volume behavior predicted by the Thomas-Fermi model. Interpolation terms are added to fit known zero-pressure quantities, viz., initial density, compressibility, and sublimation energy.

In addition an extensive review of the thermodynamics of equations of state is presented.

Results of shock calculations in spherical geometry assuming hydrodynamic behavior of the medium are also presented. These calculations are intended to indicate the sensitivity of shock decay to uncertainties in the equation of state. The varied parameters include porosity, Gruneisen's ratio, and the zero-degree-isotherm. No large influence on shock decay due to these variations is evident.

WL-TDR-64-64

AD-

A STUDY OF THE BEHAVIOR OF THICK CYLINDRICAL SHELLS

29(601)-5836: Louisiana State University

April 1965

U

This report describes three approaches to the problem of predicting stresses and displacements in thick cylindrical shells.

Section I is an analysis of a ring or segment of an infinitely long, thick cylindrical shell based upon the simplifying assumptions of the Winkler curved beam theory. Dynamic loading of thick rings is treated in Chapter 2 of Section I.

Section II consists of a static analysis of the thick-walled circular cylinder (or ring) by the elasticity approach developed by N. I. Muskhelishvili. Shear and radial stresses on the inner boundary, outer boundary, or both boundaries constitute the loading. A rather complete theoretical development is followed by a computer program and instructions for its use.

Section III presents an analysis of static stresses in axially loaded thick-walled cylinders with end caps. This axisymmetric elasticity problem is solved by finite difference techniques and Southwell stress functions. Cylinders with one end closed by either a flat or a hemispherical cap are analyzed and an example worked for each case. Cylinders with both ends capped are analyzed in the final portion of the report.

WL-TDR-64-65

AD-606 571

THREE-DIMENSIONAL PHOTOELASTICITY STUDY OF THICK-WALLED CYLINDRICAL SHELLS

29(601)-5362: IIT Research Institute

August 1964

U

A study was conducted to determine stress distributions in several types of thick-walled cylindrical shells. The stresses were determined by using both the embedded-polariscope and stress-freezing methods for three-dimensional photoelasticity. The study indicates that an approximate analytical solution for stresses in thick-walled cylinders with hemispherical heads is sufficiently accurate for structural design applications. Simple curved-beam theory is also shown to give reasonable stress values for certain structures which take the form of a thick-walled half cylinder. Finally the study indicates that embedded polaroid elements perform satisfactorily under complex states of stress; therefore, the embedded polariscope method represents a completely feasible approach for transient three-dimensional stress determinations.

WL-TDR-64-72

AD-613 351

STUDIES OF FINITE DIFFERENCE TECHNIQUES FOR CONTINUUM MECHANICS

29(601)-5971: Northrop-Ventura Corporation

December 1964

U

Part I: Solutions to hyperbolic equations typically have discontinuous first or second space and time derivatives. This limits the rate of convergence of time-matching numerical procedures for solving hyperbolic problems. (a) With  $N$  zones on a finite one-dimensional region of space, the truncation error tends to zero no faster than  $N^{-3/2}$  for large  $N$ . This limit is reached in simple centered difference schemes; higher order differencing affords no improvement. (b) Truncation error estimates based on Taylor's Series expansions are usually incorrect. (c) The truncation error can be decreased by using higher order differences if the equations are written in characteristic coordinates. In practice the truncation error will probably not vanish more rapidly than  $N^{-2}$ . These conclusions are reached by solving finite difference equations analytically, e.g., the Richtmyer-von Neumann equations are solved with infinitesimal time-step for a pulse in an elastic medium. Supporting numerical results are shown. Part II: Artificial viscosities--particularly linear viscosities--significantly degrade pulses in elastic media. Numerical results are given for various viscosity coefficients. Part III: A procedure is given for uniquely determining finite strain in finite zones of material. In the general case, it must be assumed that zones are tetrahedral and homogeneously strained. Part IV: Finite difference equations, flow charts, and Fortran listings are given for the AFTON code, which solves the one-dimensional linear, cylindrical, and spherical hydrodynamic equations in an arbitrary time-dependent coordinate system. Part V: Difference equations, etc., are given MR2D, a two-region code for calculating general plane-symmetric continuum motion in an arbitrary time-dependent coordinate system.

WL-TDR-64-76

AD-358 704

THE INVESTIGATION OF THE DETONATION--SHOCK TUBE TECHNIQUE

29(601)-6056: General American Transportation Corporation, MRD Division

February 1965

S-RD

The objectives of this research effort were twofold. The first was concerned with the detonation-shock-tube principle. In particular, the propagation of detonation waves through gaseous media and their subsequent interaction with various other gases was investigated. Included in this work were a theoretical and an experimental program to determine the best gas mixtures and optimum tube lengths which would produce detonation waves and shock waves in air simulating the effects of a nuclear explosion.

Sufficient data are presented in the report to permit the establishment of design parameters for a high-capacity shock tube capable of simulating the overpressures and durations of blast waves from high-yield explosions. The overpressure range of interest is from 100 to 10,000 psi.

The second objective dealt with the feasibility of using the detonation shock tube as a means for simulating high-altitude nuclear blast effects on reentry vehicles. Gas dynamic analyses have established that there are concepts incorporating the detonation shock tube that simulate many of the high-altitude nuclear blast effects on reentry vehicles.

WL-TDR-64-91

AD-450 077

A QUASI-STATIC THEORY OF SOIL STRUCTURE INTERACTION

29(601)-4508: University of Illinois

September 1964

U

This study treats the effect of the interaction between underground structures and the surrounding soil in reducing the loads transmitted to the structure, the so-called "arching" phenomenon.

A continuum theory of soils proposed by G. A. Geniev is applied to a quasi-static, plane-strain problem of arching. The basic partial differential equations are shown to form a hyperbolic set and are solved by the method of characteristics. Consistent stress and velocity fields are obtained.

Comparison with available experimental results shows that the Geniev theory underestimates the surface pressure required for failure of an underground structure in relatively dense granular soils. The source of this difficulty is explained and an approximate method of overcoming it is presented.

A simplified extension of a theory taking account of inertia of the soil and unsteady motions is treated in an appendix.

**SECTION II**

**Chronological listing of all undesignated reports and Weapons Tests  
Reports related to Protective Structures published before 1958.**

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CHRONOLOGICAL INDEX TO UNDESIGNATED REPORTS

<u>TITLE</u>	<u>DATE</u>	<u>CLASS</u>	<u>CONTRACTOR</u>	<u>AVAILABILITY</u>
Feasibility of a Large Shock Tube	Jul 51	Uncl	Armour Research Foundation	AD-204 049
Damage Evaluation in Connection with Indirect Bomb Damage Assessment Systems	Jun 52	S-RD	Armour Research Foundation	N/A*
A Simple Method for Evaluating Blast Effects on Buildings	Jul 52	Uncl	Armour Research Foundation	AD-38891
Analysis of Gravity Dams Subjected to Underwater Explosions	Jan 53	S-RD	Massachusetts Institute of Technology	AD-360 113
Relative Effectiveness of Surface and Underwater Explosions on Gravity Type Dams	Jan 53	S-RD	Massachusetts Institute of Technology	AD-360 109
Crater Survey	Feb 53	S-RD	In-House	N/A
Water Table Experiments on Transient Shock Wave Diffraction, Part I - Operation, Instrumentation and Preliminary Experiments	Aug 53	Uncl	Massachusetts Institute of Technology	AD-22515
Air Force Pressure Tests	Sep 53	Uncl	New York University	N/A
Static Load Deflection Tests of Beam Columns	Dec 53	Uncl	University of Illinois	AD-23105
Electro Mechanical Pressure Gages for Dynamic Pressure Recording	Dec 53	Uncl	Armour Research Foundation	N/A
Research Investigation and Design of a Large Shock Tube	Dec 53	Uncl	Armour Research Foundation	N/A
Simple Method for Evaluating Blast Effects on Buildings (revised)	Jul 54	Uncl	Armour Research Foundation	AD-38891

\*Not Available

<u>TITLE</u>	<u>DATE</u>	<u>CLASS</u>	<u>CONTRACTOR</u>	<u>AVAILABILITY</u>
Studies of the Influence of Variations of Blast and Structural Parameters on Blast Damage to Structures	Oct 54	Conf	Armour Research Foundation	AD-358 882
Water Table Experiments on Transient Shock Wave Diffraction, Part II -- Experimental Results and Evaluation	Oct 54	Uncl	Massachusetts Institute of Technology	AD-80120
Three-Dimensional Shock Tube	Oct 54	Conf	Armour Research Foundation	N/A
Project Proposals for Operation Dixie	Oct 54	Conf	E. H. Smith & Company	N/A
Forty Channel Test Program for Operation Dixie	Nov 54	Conf	American Machine & Foundry	N/A
Shear Deflection of Wide Flange Steel Beams in the Plastic Range	Dec 54	Uncl	University of Illinois	AD-47270
Application of Tornado Data to Blast Effects Studies	Dec 54	Conf	E. H. Smith & Company	N/A
Air Force Pressure Tests (Supplementary Report)	Jan 55	Uncl	New York University	N/A
A Criterion for Collapse of Buildings Under Blast Loading	Jan 55	Uncl	E. H. Smith & Company	N/A
Transient Drag Tests	Jan 55	Uncl	Armour Research Foundation	N/A
Static and Dynamic Load-Deflection Tests of Steel Structures	Feb 55	Uncl	University of Illinois	AD-59193
Transient Drag and Its Effect on Structures				
Vol I	Feb 55	Uncl	American Machine & Foundry Co.	N/A
Vol II	Feb 55	Uncl	American Machine & Foundry Co.	N/A

<u>TITLE</u>	<u>DATE</u>	<u>CLASS</u>	<u>CONTRACTOR</u>	<u>AVAILABILITY</u>
Experimental Study of Drag Phenomena in Shock Tubes	Feb 55	Conf	American Machine & Foundry	N/A
Operational Implications of the MIT Report, <u>Analysis of Gravity Dams Subjected to Underwater Explosions</u>	Feb 55	S-RD	E. H. Smith & Company	N/A
Project Proposals for Operation Dixie	Feb 55	Uncl	Armour Research Foundation	N/A
Feasibility Study of Dynamic Net Force Sensors	Feb 55	Uncl	Wind Tunnel Instrument Co., Inc.	N/A
Pressure Sensor System for Blast Measurements	Feb 55	Uncl	Rutico, Inc.	AD-80120
Study of the Effect of Orientation on Dynamic Loading and Response of Structures	Mar 55	Conf	Armour Research Foundation	AD-1706
Shock Tube Temperatures	Mar 55	Uncl	Armour Research Foundation	N/A
Notes on the Analysis of Obliquely Loaded Beams in the Inelastic Range	Apr 55	Uncl	University of Illinois	AD-64462
The Response of Model Frames Subjected to Dynamic Lateral Loads	Jun 55	Uncl	University of Illinois	AD-66673
The Response of Beam-Columns Subjected to Dynamic Lateral Loads	Jun 55	Uncl	University of Illinois	AD-66674
Response of Bridges to Atomic Blast	Jan 54	S-RD	Massachusetts Institute of Technology	N/A
Studies of the Influence of Variations of Blast and Structural Parameters on Blast Damage to Structures	Jul 55	Conf	Armour Research Foundation	N/A

<u>TITLE</u>	<u>DATE</u>	<u>CLASS</u>	<u>CONTRACTOR</u>	<u>AVAILABILITY</u>
Criteria for Dynamic Net Force Sensor Selection	Jul 55	Uncl	American Machine & Foundry	N/A
Inelastic Behavior of Mild Steel Beams Subjected to Transverse Impact	Aug 55	Uncl	University of Illinois	AD-69593
A Study of the Resistance of Model Frames to Dynamic Lateral Load	Aug 55	Uncl	University of Illinois	AD-72716
Effect of Long Versus Short Duration Blast Loading on Structures	Aug 55	Uncl	Armour Research Foundation	N/A
Correlations of the Results of Dynamic Tests of Beams and Model Frames	Sep 55	Uncl	University of Illinois	AD-74935
Operation of Six-Foot and Two-Foot Shock Tubes	Oct 55	Conf	Armour Research Foundation	N/A
Structures Improvements on the Six-Foot Tube	Oct 55	Uncl	Armour Research Foundation	N/A
Shielding of Three-Dimensional Blocks	Nov 55	Uncl	Armour Research Foundation	N/A
The Effects of Surface Roughness	Dec 55	Uncl	Armour Research Foundation	AD-93225
Experimental Observations of Regular Reflection Loading on Three-Dimensional Blocks	Jan 56	Uncl	Armour Research Foundation	AD-93226
Diffraction Phenomena in Semi-Solids	Jan 56	Uncl	Armour Research Foundation	AD-90848
Effect of Wall Panel Failure on Shock Parameters	Feb 56	Uncl	Armour Research Foundation	N/A
Technical Comments on PV TM-14 in Connection with Use for Indirect Bomb Damage Assessment	Mar 56	Conf	E. H. Smith & Company	N/A

<u>TITLE</u>	<u>DATE</u>	<u>CLASS</u>	<u>CONTRACTOR</u>	<u>AVAILABILITY</u>
Inspection of Air Force Jangle Structures Included in Operation TEAPOT	Mar 56	S-RD	Armour Research Foundation	N/A
Basic Loading on MIT Multi-Story Structures in the Regular Reflection Region	Mar 56	Uncl	Armour Research Foundation	N/A
Experimental Observations of Interior Pressures in Hollow Models	Mar 56	Uncl	Armour Research Foundation	N/A
Suggestion for a Protective Construction Program	Jun 56	S-RD	E. H. Smith & Company	N/A
Comments on the Applicability of Physical Vulnerability Division Target Analysis Manual PV TM-14 to Indirect Bomb Damage Assessment	Jun 56	Conf	Armour Research Foundation	N/A
Indirect Bomb Damage Assessment	Jul 56	Conf	American Machine & Foundry	N/A
Experimental Observations of Interior Pressures in Hollow Models	Jul 56	Uncl	Armour Research Foundation	N/A
Operation of Six-Foot and Two-Foot Shock Tube	Aug 56	Uncl	Armour Research Foundation	AD-223 162
Improvement of Photographic Techniques	Aug 56	Conf	Chicago Midway Laboratories	N/A
Basic Design of Protective Structures for the Far East Air Force Report Appendix A Appendix B	Sep 56	Uncl C-RD Uncl	American Machine & Foundry	AD-462 211
Snark Base Design Investigation	Sep 56	Conf	American Machine & Foundry	AD-360 115
Review and Criticism of the Armour Research Foundation Report on Drag Loading of Structures in the Precursor Zone	Sep 56	Conf	American Machine & Foundry	AD-360 116

<u>TITLE</u>	<u>DATE</u>	<u>CLASS</u>	<u>CONTRACTOR</u>	<u>AVAILABILITY</u>
Cost Planning Information	Oct 56	Conf	American Machine & Foundry Co.	N/A
Effects of Topography on Shock Waves in Air; Recommendations for Full-Scale Topography Test	1956	Conf	Broadview Research & Development	N/A
High Pressure Tests on Simple Shapes	1956	Conf	Armour Research Foundation	AD-134 797
Blast Effects on Storage Tank Type Structures	1956	Conf	Armour Research Foundation	AD-132 573
Surface Effects on Blast Loading, Vol. I	1956	Conf	Armour Research Foundation	N/A
Surface Effects on Blast Loading, Vol. II -- Thermal Radiation	1956	Conf	Armour Research Foundation	N/A
Surface Effects on Blast Loading, Vol. III -- Peak Pressure Versus Radius, Comparison of Test Data with Theory	1956	Conf	Armour Research Foundation	N/A
A Protective Alert Shelter for the Strategic Air Command	Apr 57	S-RD	Associated Research Foundation	AD 360 112
Underground Shot Study	Apr 57	Conf	E. H. Smith & Co.	N/A
Surface Effects on Blast Loading, Vol. IV Blast Wave Reflection on an Ideal Surface	1957	Conf	Armour Research Foundation	N/A
Surface Effects on Blast Loading, Vol. V -- Spark Gap Experiment: Apparatus	1957	Uncl	Armour Research Foundation	N/A
Architect-Engineers' Handbook for the WS 107A-2 Launcher Installation	Jul 58	Conf	American Machine & Foundry Co.	N/A

WEAPON TEST REPORTS

- WT-29 Scientific Directors Report, U.S. Air Force Structures, Aug 1951 (S-RD), Greenhouse, Program 3.3
- WT-30 Scientific Directors Report. Appendix A - Construction Plans and Specifications; Appendix C - Soils Construction Materials and Methods; Appendix D - Construction Materials and Methods, August 1951 (UNC), Greenhouse, Program 3.3
- WT-82, 83, 84 Scientific Directors Report  
Appendix G - Transient Records  
Appendix H - Reduction of Transient Data from the Air Force Structures, May 1952 (UNC) Operation Greenhouse, Program 3.3
- WT-87, 88 Scientific Directors Report  
Appendix I - Blast Loading & Response of Structures, May 1952, (UNC) Operation Greenhouse
- WT-405, Vols I & II Air Force Structures Program 3.3 of Operation Jangle, Nov 1952 (S-RD)  
Project 3.9 Reinforced Concrete Retaining Walls  
Project 3.10 Two-Story Reinforced Concrete Buildings  
Project 3.11 Airport Runway Sections  
Project 3.20 Masonry Walls & Chimneys  
Project 3.21 Reinforced Concrete Square Cells  
Project 3.22  
and 3.23 Circular Cells and Tunnel Sections  
Project 3.24 Friction Pile Foundations
- WT-721 Project 3.1, Operation Upshot-Knothole, 3.1, Vols I, II, and III (UNC) Apr 1954
- WT-722 Project 3.3 Tests on the Loading of Horizontal Operation Upshot-Knothole Cylindrical Shapes (UNC) Oct 1955
- WT-724 Project 3.5, Tests on the Response of Wall & Roof Panels and the Transmission of Load to Supporting Structure, (UNC) May 1955, Upshot-Knothole 3.5
- WT-725 Project 3.6, Tests on the Loading & Response of Railroad Equipment (C) Sep 1955, Upshot-Knothole 3.6
- WT-736 Project 3.26, Test of the Effects on POL Installations (C) Oct 1955 Upshot-Knothole 3.26
- WT-1124 Study of Drag Loading of Structures in the Precursor Zone (UNC) Sep 1958 Operation Teapot 3.2 Nevada Test Site

- WT-1129                    Effect of Positive Phase Length of Blast on Drag &  
                                 Semidrag Industrial Buildings, Part I, Dec 1958,  
                                 Nevada Test Site, Operation Teapot 3.7 (UNC)
- WT-1325                    Effect of Positive Phase Length of Blast on Drag &  
                                 Semidrag Industrial Buildings, Mar 1958, Operation  
                                 Redwing 3.1, Pacific Proving Grounds (S-FRD)
- WT-1406                    Loading on Buried Simulated Structures at High Incident  
                                 Overpressures, 1959, Operation Plumbbob 1.7,  
                                 Nevada Test Site (UNC)

#### AVAILABILITY OF WEAPON TEST REPORTS

The above listed WT reports can possibly be obtained from DDC, Cameron Station, Alexandria, Va. 22314. If not available through DDC, the Defense Atomic Support Agency, Wash., D.C. 20301 ATTN: Document Library Branch, may be contacted.

### SECTION III

All designated reports by document number including title, publication date and classification.

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<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
TM-57-2	Proceedings of First Shock Tube Symposium, 26-27 February 1957	Feb 1957	Unclas
TM-58-3	Proceedings of the Second Shock Tube Symposium, 5-6 March 1958	Mar 1958	Unclas
TM-59-1	Fourteenth Meeting of the Panel on Blast Effects on Buildings and Structures and Protective Construction, Volume I	Oct 1958	SFRD
TM-59-2	Proceedings of the Third Shock Tube Symposium, 10-12 March 1959	Mar 1959	Unclas
TN-56-66	Test Plan for Project 3.4 Operation PILGRIM (PLUMBBOB)	Oct 1956	SRD
TN-57-18	Study of Shock Absorbent Devices	May 1957	Unclas
TN-57-27	The Feasibility of Generating Various Desired Pressure Wave Forms in Shock Tubes Through the Successive Detonations of Explosive Charges	Aug 1958	Unclas
TN-57-32	Net Force Sensor Research	Apr 1958	Unclas
TN-57-37	Operation of the Air Force Shock Tube Laboratory, Gary, Indiana	Oct 1957	Unclas
TN-58-1	Geological and Geophysical Considerations for ICBM Launching Site Selection	Dec 1957	Conf
TN-58-18	Investigation of Wave Propagation in Semi-Solids	Mar 1958	Unclas
TN-58-23	Ground Motion Induced by Nuclear Explosions--A Study of Fundamental Problems	Nov 1958	Conf
TN-58-25	Initial Investigation of Wave Propagation in Large Soil Models	Dec 1958	Unclas
TN-58-26	Air Blast Loading on Arches and Domes	Sep 1958	Unclas
TN-59-4	Shock Tube Air Velocities	Nov 1958	Unclas

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
TN-59-8	Review of the Literature Pertaining to the Behavior and Design of Deep Structural Members	Jun 1958	Unclas
TN-59-11	A Summary of Reports Produced Under ARDC Project 1080, Protective Construction and Target Vulnerability, and Its Predecessors	Mar 1959	Secret
TN-59-14	Improvement in the Capabilities of the Air Force 6-Foot Shock Tube by Several Orders of Magnitude	May 1959	S-RD
TN-60-20	A Glossary of Geoplosics: The Systematic Study of Explosion Effects in the Earth	Jul 1960	Unclas
TN-60-30	Attenuation of Stress Waves in Bilinear Materials	Oct 1960	Unclas
TN-60-36	Design and Analysis of Foundations for Protective Structures	Sep 1960	Unclas
TN-60-39	An Experiment on Soils Loaded Dynamically by a Shock Tube	Dec 1960	Unclas
TN-61-6	A Theoretical Study of Structure-Medium Interaction	Nov 1960	Unclas
TN-61-7	Basic Interaction Considerations--Dynamic Stress Concentrations Around Unlined Openings	Feb 1961	Unclas
TN-61-14	Design and Analysis of Foundations for Protective Structures	Sep 1960	Unclas
TN-61-16	Tests on Atlas Blast Valves	Apr 1961	Unclas
TN-61-26	Summary of Recent Reports Produced Under AFSC Project 1080: Nuclear Weapons Effects on Hardened Structures	Sep 1961	Unclas
TN-56-46	Transient Drag and Its Effect on Structures	Nov 1956	Conf

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
TR-56-47	A Method for the Analysis of Frames Subjected to Inelastic Deformation into the Range of Strain Hardening	Nov 1956	Unclass
TR-56-48	Air Blast Loading on Structures	Aug 1956	Conf
TR-57-1	Two- and Three-Dimensional Shock Tube Loading Studies on Models of Operation Knothole Program 3		
	Vol I	Aug 1953	Secret
	Vol II	Aug 1956	Secret
TR-57-9	Effects of Topography on Shock Waves in Air	Aug 1956	Conf
TR-57-21	Slow and Rapid Lateral Loading Tests of Simply Supported Beams and Beam-Columns	Jun 1957	Unclass
TR-57-22	60 KIP Capacity Slow or Rapid Loading Apparatus	Jun 1957	Unclass
TR-57-23	Static and Dynamic Tests of Steel Frame Structures into the Inelastic Range of Deformation	May 1957	Unclass
TR-57-29	Blast Shielding in Complexes	Aug 1958	Unclass
TR-57-32	Procedures and Specifications for Experimental Determination of Load-Deflection Characteristics of Full-Scale Buildings	Apr 1958	Unclass
TR-57-45	The Response of Tier Buildings to Blast Loads	May 1958	Unclass
TR-58-5	An Investigation of Riveted and Bolted Column-Base and Beam-to-Column Connections Under Slow and Rapid Loading	Feb 1958	Unclass
TR-58-23	Feasibility Study of an Above-Ground Hardened Hangar	Jun 1958	Secret
TR-58-28	Protective Arch Structures	Mar 1958	Secret
TR-58-48	Design and Development of a Net Force Sensor	Oct 1958	Unclass
TR-58-49	Doors and Access Openings to Protective Structures	Oct 1958	Conf

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
TR-59-2	Protective Construction	Dec 1958	Secret
TR-59-3	Cross-Referenced Listing of Experimental Data on the Blast Loading of Structures (4 Vols)	May 1958	Conf
TR-59-9	Analysis and Design of Domes, Arches and Shells (2 Vols)	Jul 1959	Unclas
TR-59-10	On a Method of Amplification of the Dynamic Strength of Structures	Oct 1958	Secret
TR-59-18	An Investigation of the Behavior of Deep Members of Reinforced Concrete and Steel	Feb 1960	Unclas
TR-59-24	Blast Shielding in Complexes, Part 2--Megaton Weapons	Jul 1959	Conf
TR-59-47	Ground Shock Isolation of Buried Structures	Aug 1959	Conf
TR-59-48	Blast Effects on Tunnel Configurations	Oct 1959	Unclas
TR-59-49	Analytical Studies, Investigations, and Preliminary Design of Door and Foundation Seals for Protective Structures	May 1959	Conf
TR-59-56	Design and Analysis of Foundations for Protective Structures	Oct 1959	Conf
TR-59-57	Investigation of Silo Linings	Sep 1959	Conf
TR-59-58	A Door Design for Tunnel Closure	Oct 1959	Unclas
TR-59-70	Air Force Design Manual: Design of Protective Structures to Resist the Blast Effects of Nuclear Weapons	Dec 1959	Conf
TR-59-71	Ground Motion Produced by Aboveground Nuclear Explosions	Apr 1959	S-RD
TR-59-72	Behavior and Design of Deep Structural Members (7 Vols)	Apr 1961	Unclas
TR-60-1	Doors and Access Openings to Protective Structures	Mar 1960	Conf

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
TR-60-3	Concepts of Preliminary Design of Structure Projects for Underground Nuclear Detonations (2 Appendixes)	Jan 1960	Secret
TR-60-4	Research Studies of Stress Waves in Earth and Model Earth Media	Oct 1959	Unclas
TR-60-5	Preliminary Design Methods for Underground Protective Structures	Dec 1959	Secret
TR-60-8	Theoretical Study of Ground Motion Produced by Nuclear Blasts	Oct 1959	Unclas
TR-60-11	Comparative Protective Structural Design	Jun 1960	Secret
TR-60-16	Analysis and Design of Domes, Arches and Shells (2 Vols)	Oct 1960	Unclas
TR-60-21	Summary of Interior Blast Loading in Hollow Model Structures	Jul 1960	Conf
TR-60-41	Shock Chamber Development and Evaluation	Jul 1960	Unclas
TR-60-53	Response of Arches Under Dynamic Loads	Aug 1960	Unclas
TR-60-54	Surface Effects on Blast Loading	May 1958	S-RD
TR-60-55	Research Studies on Free Field Instrumentation	Dec 1960	Unclas
TR-61-5	Closures for Hardened Protective Hangars	Jan 1961	S-RD
TR-61-6	Theoretical Study of Ground Motion Induced in Non-Homogeneous Media by Nuclear Explosions	Dec 1960	Unclas
TR-61-7	Development of a Miniature Dynamic Pressure Gauge	Jan 1961	Unclas
TR-61-12	Summary of Full-Scale Field Tests of Structures Subjected to High Overpressures	Mar 1961	S-FRD

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
TR-61-25	Stress Wave Phenomena in Semi-Solids	Jun 1961	Unclass
TR-61-32	Static Experiments for the Study of the Interaction of Buried Structures with Ground Waves	Apr 1961	Unclass
TR-61-47	The Investigation of Deep Reinforced Concrete Beams Under Static and Dynamic Loading (2 Vols)	Jul 1961	Unclass
TR-61-48	Preliminary Design Study for a Dynamic Soil Testing Laboratory. Appendix B-- Small Scale Footing Studies, A Review of the Literature	Jul 1961	Unclass
TR-61-51	Ground Shock Isolation of Buried Structures	Aug 1959	Unclass
TR-61-55	Analysis of the Dynamic Response of an Aboveground Simply Supported Cylindrical Shell Subjected to Blast Loading	Aug 1961	Unclass
TR-61-58	Preliminary Design Study for a Dynamic Soil Testing Laboratory. Appendixes K, L, M, and N	Aug 1961	Unclass
TR-61-60	Dynamic Response of the 6-Foot Diameter Shock Tube to a Constant Velocity Pressure Front	Aug 1961	Unclass
TR-61-90	Studies of the Response of Arches and Domes Under Dynamic Loads	Oct 1961	Unclass
WL-TR-64-108	Effects of Boundary Friction on Transmission of Static Stress Through Sand in Cylindrical Tanks	Aug 1964	Unclass
WL-TR-64-111	Ejecta Distribution from Cratering Events in Soil and Rock	Oct 1964	S-RD
WL-TR-64-112	Prediction Techniques for Soil and Rock Behavior in the Very High Overpressure Region	Mar 1965	Secret

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
WL-TR-64-113	Close-In Effects from a Surface Burst	Jun 1964	Unclas
WL-TR-64-118	Static and Dynamic Compressibility of Suffield Experimental Station Soils	Sep 1964	Unclas
WL-TR-64-122	A Study of Static and Dynamic Resistance and Behavior of Structural Elements	Jun 1965	Unclas
WL-TR-64-142	Similitude of Dynamically Loaded Buried Structures	Oct 1964	Unclas
WL-TR-64-143	Analysis of Free-Field Data in a Half-Space Under Dynamic Loads	Feb 1964	Unclas
WL-TR-64-155	The Mechanical and Optical Characterization of Solithane 113 and Investigation of Phase Lag Relationships Between Principle Mechanical and Optical Axes in Photoviscoelastic Analysis	Oct 1964	Unclas
WL-TR-64-157	A Study of the Behavior of Soil and Rock Subjected to High Stress Levels	Mar 1965	Unclas
WL-TR-64-163	Behavior of Plain Concrete Under High Triaxial Loading Conditions	Jun 1965	Unclas
WL-TR-64-164	Project Air Vent--Ejecta Distribution Studies	Nov 1964	Unclas
WL-TR-64-175	Ground Displacement Studies, Project 3.7	Nov 1964	Unclas
AFWL-TR-65-8	Shear and Bond Strength of High Strength Reinforced Concrete Beams Under Impact Loads--First Phase	Jun 1965	Unclas
AFWL-TR-65-9	Simulation of Air Shocks with Detonation Waves	Feb 1966	Unclas
AFWL-TR-65-11	Simulation of Air-Blast Induced Ground Motion (Phase I)	Apr 1965	Unclas
AFWL-TR-65-12	The Effects of Shear on Stress Wave Propagation	Aug 1965	Unclas

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
AFWL-TR-65-13	Application of Research to Air Force Civil Engineering via a Scientific and Technical Information Service	May 1965	Unclas
AFWL-TR-65-15	Deviatoric Effects in High Intensity Stress Waves	Aug 1965	Unclas
AFWL-TR-65-16	High Compressive Strength Concrete Rpt 3, Summary	Feb 1965	Unclas
AFWL-TR-65-20 Vol. 1	Dynamic Stresses in a Thick Elastic Cylinder Subject to Transient Pressure Loadings--Theoretical Analysis and Discussion of Results	Sep 1965	Unclas
AFWL-TR-65-20 Vol. 2	Dynamic Stresses in a Thick Elastic Cylinder Subject to Transient Pressure Loadings--Discussion of Computer Program	Sep 1965	Unclas
AFWL-TR-65-26	Simulation of Air-Blast Induced Ground Motions (Phase II) Vol. I Vol. II	Apr 1965 May 1965	Unclas Secret
AFWL-TR-65-29	Static and Dynamic Behavior of Sands in One-Dimensional Compression	Feb 1965	Unclas
AFWL-TR-65-31	Interaction of Plane Elastic Waves With a Thick Cylindrical Shell	Jun 1965	Unclas
AFWL-TR-65-43	Experimental Study of Stress Wave Interaction in Photoviscoelastic Plates	Jan 1966	Unclas
AFWL-TR-65-46	The Development and Evaluation of a Miniature Velocity Gage	Mar 1967	Unclas
AFWL-TR-65-48	A Comparison of the Dynamic and Static Shear Strengths of Cohesionless and Combined Soils	Aug 1966	Unclas
AFWL-TR-65-51	Behavior of Rocks and Soils Under High Pressure	Dec 1965	Unclas
AFWL-TR-65-59	Step Load Moving with Superseismic Velocity on the Surface of a Half-Space of Granular Material	Sep 1965	Unclas
AFWL-TR-65-67	Study of Waveform Characteristics for Use in the Analysis of Shock Isolation Systems for Underground Protective Structures	Jan 1967	Unclas

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
AFWL-TR-65-71	Development of Equipment and Procedures for Producing Large Quantities of Foamed Sulphur in the Field	Jan 1966	Unclas
AFWL-TR-65-75	A Study of Parameters and Methods Involved in Relative Displacement Measurements in Soil	Jun 1965	Unclas
AFWL-TR-65-78	An Experimental Investigation of the Arching Phenomenon Occurring Over a Buried Rectangular Plate	Jun 1966	Unclas
AFWL-TR-65-82	Optimal Shock Isolation Synthesis	Jul 1966	Unclas
AFWL-TR-65-92	The Great Alaska Earthquake, Vol. I	Nov 1965	Unclas
AFWL-TR-65-92	The Great Alaska Earthquake Vol. II	Nov 1965	Unclas
AFWL-TR-65-98	Pressure Distribution on Underground Structural Cylinders	Apr 1966	Unclas
AFWL-TR-65-99	Behavior of Flexible Underground Cylinders	Sep 1965	Unclas
AFWL-TR-65-104	Development of the University of New Mexico Soil Stress Gage	Aug 1966	Unclas
AFWL-TR-65-115	Digital Calculation of Axisymmetric Elastic-Plastic Ground Motions	Nov 1965	Unclas
AFWL-TR-65-116	Engineering Classification and Index Properties for Intact Rock	Dec 1965	Unclas
AFWL-TR-65-122	Response of Cylindrical Shells Encompassed with Isolation Material to a Plane Pressure Pulse	Feb 1966	Unclas
AFWL-TR-65-140	Fracture of Gypsum Plasters and Cement Mortars by Dynamic Loading	Dec 1965	Unclas
AFWL-TR-65-141	An Annotated Bibliography of Protective Structures Research	Sep 1965	Unclas
AFWL-TR-65-145	Structural Behavior of Ring Sections Under Nonuniform External Pressure	Mar 1966	Unclas
AFWL-TR-65-146	Investigation of Equation of State of Porous Earth Media	Feb 1966	Unclas
AFWL-TR-65-156	Development of Controlled Impulse Technique for In-Situ Testing of Rock	Feb 1966	Unclas

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
AFWL-TR-65-160	Nonlinear Static Arching for Vertically Buried Prismatic Structures	Aug 1966	Unclas
AFWL-TR-65-161	Experimental Study of Static and Dynamic Friction Between Soil and Typical Construction Materials	Dec 1965	Unclas
AFWL-TR-65-176	An Investigation of the Dynamic Behavior of a Partially Saturated Silt With Applications to Shock-Wave Propagation	May 1966	Unclas
AFWL-TR-65-178	Structure-Medium Interaction in a Nonelastic Medium	May 1966	Unclas
AFWL-TR-65-180	A Study of the Propagation of Stress Waves in Sand	Mar 1966	Unclas
AFWL-TR-65-191	Multichannel Time-of-Arrival Instrumentation System	Feb 1966	Unclas
AFWL-TR-65-201	Preliminary Investigation of Structural Properties of Stabilized Pressed Earth Blocks	Mar 1966	Unclas
AFWL-TR-65-202	Development and Test of Aircraft Protective Revetments	Dec 1965	Unclas
AFWL-TR-65-204	Theory for Viscous Shock Attenuation in Ducts Based on the Kinetic Theory of Gases Experimentally Verified to a Shock Strength of 68	Jul 1966	Unclas
AFWL-TR-65-206	Aircraft Characteristics for Airfield Pavement Design and Evaluation	Mar 1966	Unclas
AFWL-TR-65-207	Soil Strain Gage Instrumentation	Apr 1966	Unclas
AFWL-TR-65-211	Calculation of Underground and Surface Explosions	Jun 1966	Unclas
AFWL-TR-65-224	Simulation Devices for Use in Studies of Protective Construction	Feb 1966	Unclas
AFWL-TR-66-4	Hardened Communication Cable System Component Test Program	Jul 1966	Secret
AFWL-TR-66-19	Theory and Structure of the Afton Codes	Jun 1966	Unclas

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
AFWL-TR-66-21	A Geometrical Method of Studying Wave Propagation Through Real Geologic Layered Media	Apr 1966	Unclas
AFWL-TR-66-39	Development of an Unlinked Long Span Strain Gage	Sep 1966	Unclas
AFWL-TR-66-47	Development and Evaluation of Protective Revetments	Nov 66	Unclas
AFWL-TR-66-50	Investigation of Flash X-Ray Techniques in Soil Dynamics and Interaction Problems	Aug 1966	Unclas
AFWL-TR-66-51	Piezoresistive Soil Stress Gage	Sep 1966	Unclas
AFWL-TR-66-54	Photoelastic Study of Wave Propagation Propagation	Oct 1966	Unclas
AFWL-TR-66-56	Stress Wave Propagation in Confined Soils	Oct 1966	Unclas
AFWL-TR-66-57	Feasibility Study for Using Sulphur Aggregate Mixtures as a Structural Material	Sep 1966	Unclas
AFWL-TR-66-59	Statistical Design Procedures for Shock Isolation Systems	Sep 1966	Secret-RD
AFWL-TR-66-63	Effects of Source Geometry on Direct-Induced Ground Motions	Jan 1967	Secret
AFWL-TR-66-81	Response of Clay to Shock Loading	Jun 1967	Unclas
AFWL-TR-66-83	Generation of an Elastic Wave by Quasi-Static Isentropic Expansion of a Gas in a Spherical Cavity; Comparison Between Finite Difference Predictions and the Exact Solutions	Sep 1966	Unclas
AFWL-TR-66-84	Use of Distorted Models in the Study of Dynamically Loaded Underground Structures	Oct 1966	Unclas
AFWL-TR-66-85	Simulation of Airblast-Induced Ground Motions Phase II A	Oct 1967	Unclas
AFWL-TR-66-86	Structural Response of a Hardened UHG Antenna (437B-4)	Apr 1967	Secret

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
AFWL-TR-66-113	Computation by the Method of Characteristics of Disturbance in an Elastic Half-Space Caused by Blast-Like Surface Loading	Jan 1967	Unclas
AFWL-TR-66-118	Shock Unloading Characteristics of Porous Geological Materials	Jan 1967	Unclas
AFWL-TR-66-123	A Geometric Technique for Studying Surface Motions from Underground Nuclear Explosions in Real Geologic Layered Media	Jan 1967	Unclas
AFWL-TR-66-124	Properties of Rocks Tested in One-Dimensional Compression	Jan 1967	Unclas
AFWL-TR-66-134	Calibration of a Vertical Shock Tube and Its Associated Soil Bin	Aug 1967	Unclas
AFWL-TR-66-138	Effects of Container Boundaries on Free-Field Behavior of Dense Sand Subjected to Shock Loading	Feb 1967	Unclas
AFWL-TR-66-140	Ultimate Load-Behavior Curves for Reinforced Concrete Flexural Members	Oct 1967	Unclas
AFWL-TR-66-146	Wave-Propagation Studies in Laterally Confined Columns of Sand	Jun 1967	Unclas
AFWL-TR-66-147	Evaluation of Structural Research Model Phases II and IIA HEST	May 1967	Secret
AFWL-TR-66-154	A Sonic Boom Study for the Structural Engineer	Mar 1967	Unclas
AFWL-TR-66-155	Soil Stabilization for Construction of Low-Strength Austers Landing Strips	Mar 1967	Unclas
AFWL-TR-66-160	An Annotated Bibliography of Protective Structures Research	Feb 1967	Unclas
AFWL-TR-67-7	Effects of Gross Inaccuracies in Structure Alignment and Soil Resistance Properties on the Response of Buried Structures to Nuclear Blast Loadings	Aug 1967	Unclas
AFWL-TR-67-8 Vol. I	Multiple Threat Cratering Experiment Volume I: Successive Cratering in Hard Rock	Apr 1967	Unclas

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
AFWL-TR-67-8 Vol. II	Multiple Threat Cratering Experiment Volume II: Ground Motion in Rock	Jul 1967	Unclas
AFWL-TR-67-12	Tonedown Treatment of Runways-- State of the Art	Sep 1967	Unclas
AFWL-TR-67-15	Evaluation of 400-Cubic-Foot Soil Bin Loaded Dynamically by a Large Shock Tube	Aug 1967	Unclas
AFWL-TR-67-16	An Experimental Investigation of the Dynamic Response of Model Silo-Type Structures in Cohesive Soils Phase I, Soil Properties	Oct 1967	
AFWL-TR-67-21	Exponentially Decaying Pressure Pulse Moving With Superseismic Velocity on the Surface of a Half Space of Granular Material	Jul 1967	Unclas
AFWL-TR-67-25	Comparison Studies of Finite Dif- ference Results for Explosions on the Surface of the Ground	May 1967	Unclas
AFWL-TR-67-27 Vol. I	Numerical Ground Motion Studies, Volume I: Study of Numerical Solu- tion Errors in One- and Two-Dimensional Finite Difference Calculations of Ground Motion	Jul 1967	Unclas
AFWL-TR-67-28	Aerodynamic Effects on a Structure Oscillating Within a Confined Cavity	Oct 1967	Unclas
AFWL-TR-67-50	Evaluation of Soil Strain Gage Instrumentation	Aug 1967	Unclas
AFWL-TR-67-61 Vol. II	Shear Behavior of Deep Reinforced Concrete Beams, Volume II: Static Tests	Oct 1967	Unclas
AFWL-TR-67-65	Behavior of Small Vertically Buried Cylinders	Oct 1967	Unclas
AFWL-TR-67-69	Hand Solution of One-Dimensional Inelastic Wave-Propagation Problems	Oct 1967	Unclas
AFWL-TR-67-72	Experimental Verification of Neutron Transport Calculations in Lithium Hydride	Nov 1967	Unclas
AFWL-TR-67-90	A Freezing Technique for Gage Placement	Oct 1967	Unclas

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
AFWL-TR-67-102	HIP-1A Data Report	Oct 1967	Unclas
AFWL-TR-67-107	Chemical Stabilization of Playa Soils	Nov 1967	Unclas
AFWL-TR-67-110	Investigation of Buried Domes, Phase 1, Evaluation of Instrumen- tation and Preliminary Tests	Dec 1967	Unclas
TDR-61-66	A Method for the Prediction of Ground Shock Phenomena in Soils	Mar 1962	Secret
TDR-61-93	Geologic Structures Stability and Deep Protection Construction	Nov 1961	Unclas
TDR-62-1	Investigation of Silo and Tunnel Linings	Mar 1962	Unclas
TDR-62-2	Study of the Use of Models to Simulate Dynamically Loaded Underground Structures	Jan 1962	Unclas
TDR-62-3	Study of the Use of Models to Simulate Dynamically Loaded Underground Structures	Feb 1962	Unclas
TDR-62-6	Preliminary Design Methods for Underground Protective Structures	Jun 1962	Secret
TDR-62-9	Design and Analysis of Foundations for Protective Structures	Apr 1962	Unclas
TDR-62-10	Study of Blast Closure Devices	Feb 1962	Unclas
TDR-62-30	Theoretical Study of Structure- Medium Interaction	Mar 1962	Unclas
TDR-62-43	Theoretical Study of Energy Distri- bution in a Half-Space Under Dynamic Loads	Jul 1962	Unclas
TDR-62-44	Radiographic Instrumentation Study	Apr 1962	Unclas
TDR-62-47	Study of Stress Wave Interaction With Buried Structures	May 1962	Unclas
TDR-62-56	High-Compressive-Strength Concrete	Aug 1962	Unclas

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
TDR-62-64	Guide for the Design of Shock Isolation Systems for Underground Protective Structures	Oct 1962	Unclas
TDR-62-90	Laboratory Experiments on the Response of Soils to Shock Loadings	Jan 1963	Unclas
TDR-62-91	Energy Absorption Capacity of Granular Materials in One-Dimensional Compression	Jul 1962	Unclas
TDR-62-126	Symposium on the Equation of State for Earth Materials	Nov 1962	Unclas
TDR-62-138	Air Force Design Manual--Principles and Practices for Design of Hardened Structures	Dec 1962	Unclas
TDR-62-153	Experiments on the Measurement of the Response of Rocks to Dynamic Loads	Mar 1963	Unclas
TDR-63-2	Step Load Moving with Low Subseismic Velocity on the Surface of a Half-Space of Granular Material	Apr 1963	Unclas
TDR-63-3	Development of a Small Soil Strain Gage	Mar 1963	Unclas
TDR-63-5	Calibration of a 6-Foot and a 2-Foot Diameter Shock Tube	Jun 1963	Unclas
TDR-63-6	Study of the Collapse of Small Soil-Surrounded Tubes	Jun 1963	Unclas
TDR-63-26	Study for Development of Reciprocity Procedures for Analyzing Data from Underground Explosion Tests	Jun 1963	Unclas
TDR-63-27	The Use of Rock Filters to Attenuate Air Shocks	Mar 1963	OUO
TDR-63-43	A Theoretical Analysis of Stress Wave Interaction in a Model Soil	Jun 1963	Unclas
TDR-63-45	Research Studies on Free Field Instrumentation	Jun 1963	Unclas
TDR-63-47	Experimental Study of the Effect of Material Properties on Coupling of Explosion Energy	May 1963	Unclas

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
TDR-63-48	Feasibility Study of Methods for Dynamic Three-Dimensional Photoelasticity	Jun 1963	Unclas
TDR-63-53	Close-In Effects from Nuclear Explosions	Jun 1963	Unclas
TDR-63-3020	A Study of the Design and Analysis of Foundations	Jan 1964	Unclas
TDR-63-3021	Interaction of Plane Elastic Waves With a Cylindrical Cavity	Jun 1963	Unclas
TDR-63-3023	Project 1080 Research Summary	Aug 1963	Unclas
TDR-63-3024	Gage Placement Study	Aug 1963	Unclas
TDR-63-3025	Bibliography of Extraterrestrial Research	Jun 1963	Unclas
TDR-63-3041	Evaluation of Tunnel Liners in Granite--Shot Hardhat, Operation Nougat Vol. II: Proposed Tests of Lined Tunnels in Granite	Feb 1964	Unclas
	Vol. III: Static Stress-Strain Curves for Various Materials Investigated for Use as Packing	Feb 1964	Unclas
	Vol. IV: Static Tension Tests of Lining Materials and Static Test of 8-Gage Tunnel Liner Plate	Feb 1964	Unclas
	Vol. V: Removal of Tunnel Liners	Aug 1964	Unclas
TDR-63-3048	Stress Waves in Granular Material	Jul 1963	Unclas
TDR-63-3052	Scattering of Transient Elastic Waves by a Circular Cavity	Jan 1964	Unclas
TDR-63-3055	Development of an Apparatus for the Dynamic Direct Shear Testing of Soils	Oct 1963	Unclas
TDR-63-3059	Two-Dimensional Dynamic Stress Analysis in a Nonelastic Material	Nov 1963	Unclas
TDR-63-3060	A Study of Static and Dynamic Resistance and Behavior of Structural Elements	Jan 1964	Unclas
TDR-63-3061	Studies in Axially Symmetric Wave Propagation Problems in Plastic and Hydrodynamic Media	Jan 1964	Unclas

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
TDR-63-3064	Use of Models to Predict the Behavior of Dynamically Loaded Underground Structures	Jan 1964	Unclas
TDR-63-3073	The Calibration and Interpretation of Recorded Shock-Tube Pressure Data Using Piezoelectric Sensors	Nov 1963	Unclas
TDR-63-3075	A Study of the Dynamic Soil-Structure Interaction Characteristics of Real Soil Media	Jan 1964	Unclas
TDR-63-3078	Static and Dynamic Behavior of a Playa Silt in One-Dimensional Compression	Sep 1964	Unclas
TDR-63-3082	Dynamic Model Tests, NORAD Combat Operations Center	Jun 1964	Unclas
TDR-63-3085	Analytical and Experimental Investigations of Silo and Tunnel Linings	Jan 1964	Unclas
TDR-63-3089	The Behavior of Sand in One-Dimensional Compression	Oct 1963	Unclas
TDR-63-3091	A Study of the Parameters Which Affect Scaling of Underground Structures	Jan 1964	Unclas
TDR-63-3092	Behavior of Simple and Restrained Deep Reinforced Concrete Beams Under Static Loading	Mar 1964	Unclas
TDR-63-3096	Design Procedures for Shock Isolation Systems of Underground Protective Structures		
	Vol. I: Structure Interior Motions Due to Air Blast Induced Ground Shock	Jun 1964	Unclas
	Vol. II: Structure Interior Motions Due to Directly Transmitted Ground Shock	Sep 1964	Unclas
	Vol. III: Response Spectra of Single-Degree-of-Freedom Elastic and Inelastic Systems	Jun 1964	Unclas
	Vol. IV: Response of Two-Degree-of-Freedom Elastic and Inelastic Systems	Jan 1965	Unclas
	Vol. V: Response Spectra of Multi-Degree-of-Freedom Elastic Systems	Apr 1965	Unclas
	Vol. V, Suppl.: A Computer Program for the Computation of Dynamic Structural Response	Apr 1966	Unclas

<u>Report No.</u>	<u>Title</u>	<u>Date</u>	<u>Class.</u>
TDR-63-3106	Pilot Study into the Arching Phenomenon	Feb 1964	Unclas
TDR-63-3109	The Interaction Between a Structural Tube and The Surrounding Soil	Jan 1964	Unclas
TDR-63-3114	High Compressive Strength Concrete	Jan 1964	Unclas
TDR-63-3116	A Study of the Behavior of a Clay Under Rapid and Dynamic Loading in the One-Dimensional and Triaxial Tests	Jun 1964	Unclas
TDR-63-3125	Theoretical Study of Energy Distribution in a Half-Space Resulting from Dynamic Loading in a Depression at the Origin	Mar 1964	Unclas
TDR-64-3	Pore-Air Pressure Study	Feb 1964	Unclas
WL-TDR-64-4	The Mechanical and Optical Characterization of Hysol 8705 With Application to Photoviscoelastic Analysis	Jun 1964	Unclas
WL-TDR-64-5	Step Load Moving on the Surface of a Half-Space of a Locking Material Subseismic Case	Dec 1963	Unclas
WL-TDR-64-7	Development of a Soil Strain Gage for Laboratory Dynamic Tests	Apr 1964	Unclas
WL-TDR-64-8	Step Load Moving on the Surface of a Half-Space of a Locking Material Subseismic Case	Feb 1964	Unclas
WL-TDR-64-11	A Peak Load, Self-Recording On-Structure Stress Gage	Jun 1964	Unclas
WL-TDR-64-12	A Theoretical Analysis of Stress Wave Interaction in a Model Soil --Further Studies	Apr 1964	Unclas
WL-TDR-64-13	The Response of Buried Cylinders to Quasi-Static Overpressures	Sep 1964	Unclas
WL-TDR-64-20	Feasibility Study of Shock Isolating a Very Large Structure	Sep 1964	Unclas
WL-TDR-64-27	Prediction Calculations for Free Field Ground Motion	May 1964	Unclas

<u>Report No.</u>		<u>Date</u>	<u>Class.</u>
WL-TDR-64-28	Response of Foam-Isolated Tunnel Linings to Transient Loadings	Jun 1964	Unclas
WL-TDR-64-29	Bibliography of Extraterrestrial Research (2nd Edition)	Jul 1964	Unclas
WL-TDR-64-35	A Study of Dynamically Loaded Composite Members	Jul 1964	Unclas
WL-TDR-64-47	Strain Variation in a Triaxial Soil Test	Sep 1964	Unclas
WL-TDR-64-51	Evaluation and Interpretation of Ejecta Data from Cratering Explosions	May 1964	Secret
WL-TDR-64-52	Shock Unloading Characteristics of Crushable Rocks	Aug 1964	Unclas
WL-TDR-64-53	A Study of the Feasibility of Shock Isolating Very Large Manned Underground Structures	Jun 1964	Unclas
WL-TDR-64-54	Response of Deep Reinforced Concrete Slabs	Feb 1964	Unclas
WL-TDR-64-55	Multi-Channel Time of Arrival Instrumentation	Apr 1964	Unclas
WL-TDR-64-59	Investigation of Equation of State of Porous Material	Aug 1964	Unclas
WL-TDR-64-64	A Study of the Behavior of Thick Cylindrical Shells	Apr 1965	Unclas
WL-TDR-64-65	Three-Dimensional Photoelasticity Study of Thick-Walled Cylindrical Shells	Aug 1964	Unclas
WL-TDR-64-72	Studies of Finite Difference Techniques for Continuum Mechanics	Dec 1964	Unclas
WL-TDR-64-76	The Investigation of the Detonation --Shock Tube Technique	May 1964	S-RD
WL-TDR-64-91	A Quasi-Static Theory of Soil Structure Interaction	Sep 1964	Unclas

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**SECTION IV**

**Listing by Contractor**



Phase II Test Configuration for Project Big Papa.  
Test Conducted 30 August 1967, Utah. (Before)



Phase II Detonation, Project Big Papa, 30 August 1967, Utah.  
(After)

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