Sandia Corporation

Bibliography

IMPACT PHYSICS

by

Robert Graham

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ABSTRACT

This bibliography consists of a rather complete collection of references and abstracts on the subjects of: (1) plastic wave propagation in bounded solids; (2) behavior of metals under explosive conditions; (3) dynamic photoelasticity; (4) penetration phenomena. Other topics covered in less detail are: (5) behavior of material at high strain rates; (6) lateral impact; (7) impact measurement devices.

General references at the beginning of the bibliography cite articles or books which cover the field of impact. An author index and a chronological listing of articles within a particular topic are included.
PREFACE

The Physical Research Department at Sandia Corporation has encountered many impact problems in its past and current activities. In order to become familiar with past work in this field, a systematic search and study of the literature was undertaken. This bibliography is the result of the literature search and is being published since comparison with other bibliographies shows it to be more complete in certain areas.

The subject of wave propagation is an important consideration in most impact problems but it was decided not to search the literature for articles dealing with wave propagation, as such, since this extensive field is the subject of several recent survey articles and books.1, 2, 3, 6, 7, 8*

The bibliography in its final form deals with wave propagation as it applies to specific areas of interest in impact problems. The references have been assembled into groups according to the main topic of the reference. The major subjects included in the bibliography are:

1. Plastic Wave Propagation in Bounded Solids
2. Behavior of Metals Under Explosive Conditions
3. Dynamic Photoelasticity and Related Topics
4. Penetration Phenomena

All of the references listed under these subjects are articles which are technically related and which normally follow the same general trend of thought in the literature. These subjects are felt to be well developed in the bibliography. That is, the references listed can be considered as representing a high percentage of the total references on this subject. To obtain this extensive coverage a search was made of the indexes of well known applied mechanics and physics publications. The articles listed in these indexes were then obtained and the references in each article were added to the bibliography. This new list of references was searched for more references, this method being continued until the list of references given by the various articles converged.

The subjects listed below are also included in this bibliography but do not necessarily represent extensive coverage of the subject:

5. Behavior of Materials at High-Strain Rates
6. Impact Measurement Devices
7. Lateral Impact-Beams and Plates
8. Miscellaneous

The general references listed at the beginning of the bibliography are a group of articles or books which cover the field of impact rather completely. No attempt has been made to duplicate the bibliographies given in these references.

*Superscripts refer to reference numbers in the bibliography.
To improve the usefulness of the bibliography, a complete author index has been prepared along with a chronological listing of the references within a particular subject. The chronological listing is particularly helpful in giving the proper perspective to the various references.

The abstracts included are either the author's abstracts or short reviews made by this author.

To obtain current information on activities throughout the nation, an extensive trip has been made to the various centers of activity in this field. The observations made on this trip have been very enlightening and have served to give information which would not appear in the literature for some time. A report on this trip will be published in a Sandia Corporation Technical Memorandum.

The author hopes that users of the bibliography will call attention to errors or omissions.

The author would like to express appreciation to A. F. Beck who suggested this work, and Dr. S. E. Whitcomb who made many helpful suggestions.
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STRESS WAVES IN SOLIDS
(165 references).

2  Rinehart J S and Pearson J
BEHAVIOR OF METALS UNDER IMPULSIVE LOADS
The American Society for Metals Cleveland, Ohio, 1954.
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3  Abramson H N, Plass H J and Ripperger E A
STRESS WAVE PROPAGATION IN RODS AND BEAMS
(145 references).

4  Brennan J N
BIBLIOGRAPHY ON SHOCK AND SHOCK EXCITED VIBRATIONS
Vols. I and II
The Pennsylvania State University
Engineering Research Bulletin Nos. 68 and 69.
(1583 references with abstracts).

5  Rice M H, McQueen R G and Walsh J M
COMPRESSION OF SOLIDS BY STRONG SHOCK WAVES
Solid State Physics, Advances in Research and Application Vol. 6

6  Davies R M
STRESS WAVES IN SOLIDS
(Survey article containing 99 references).

7  Davies R M
STRESS WAVES IN SOLIDS
Surveys in Mechanics
Taylor G I Anniversary Volume
Cambridge at the University Press, 1956.
(104 references).

8  Ewing M, Jardetzky W and Press F
ELASTIC WAVES IN LAYERED MEDIA
Andersen J R and Nestler D E
SHOCK WAVE PROPAGATION IN SOLIDS
(A Survey of the Literature)
University of Pennsylvania, Project Frank, Contract NOrd-12772
ASTIA AD 39616.
(298 references annotated).

Goldsmith W, University of California, Berkeley
BIBLIOGRAPHY ON WAVE PROPAGATION IN SOLIDS
Private publication. (938 references).
PLASTIC WAVE PROPAGATION IN BOUNDED SOLIDS
(1000-1099)

Subtopics

Experimental technique; material behavior as deduced from wave propagation characteristics; and graphical wave propagation analysis.
PLASTIC WAVE PROPAGATION IN BOUNDED SOLIDS
(1000-1099)

Bibliography

1001 Taylor G I and Whiffin A C
THE USE OF FLAT-ENDED PROJECTILES FOR DETERMINING
DYNAMIC YIELD STRESS
Proceedings of the Royal Society of London

The deformation of a flat-ended projectile, due to being
fired at high velocity against a steel plate, is used as a
measure of the dynamic yield stress of the projectile.
In Part I the theory of the method is presented. Results
of experimental tests are shown in Part II. Satisfactory
results obtained for velocity of impacts from 400 to 2500
ft/sec.

1002 Johnson J E, Wood D S and Clark D S
DYNAMIC STRESS-STRAIN RELATIONS FOR ANNEALED 2S ALU-
MINUM UNDER COMPRESSIVE IMPACT
Journal of Applied Mechanics, Trans. ASME

This paper presents the results of an experimental study
of the dynamic stress-strain relations for annealed 2S
Aluminum. Methods of obtaining data are presented. The
technique used in analyzing the data involves the use of
plastic and elastic stress-wave propagation.

Impact velocities to a maximum of about 150 fps.

1003 Von Karman T and Duwez P
THE PROPAGATION OF PLASTIC DEFORMATION IN SOLIDS
Journal of Applied Physics

The stress wave caused by longitudinal impact on a cylin-
drical bar is analyzed for the case where impact velocity
is large enough to produce plastic strain. The concept
of a critical velocity is presented. An experimental in-
vestigation is performed which substantiates the theoretical
presentation.
Clark D S and Datwyler G
STRESS-STRAIN RELATIONS UNDER TENSION IMPACT LOADING
Proceedings ASTM

Force elongation curves are obtained for several materials for an impact velocity of 11 ft/sec. It is concluded that yield forces under dynamic conditions are higher than under static conditions.

Clark D S and Duwez P E
DISCUSSION OF THE FORCES ACTING IN TENSION IMPACT TESTS OF METAL
Journal of Applied Mechanics, Trans. ASME

A method is described for measuring the forces acting on a specimen during a tension impact test. Plastic wave propagation theory is used to interpret the results obtained. Impact velocities are determined for maximum of 200 ft/sec. Very good article on interpretation of force-time curves obtained from such tests.

Plass H J
A COMPARISON OF PLASTIC LONGITUDINAL WAVE THEORIES FOR STRAIGHT RODS
University of Texas, Defense Research Lab. N. 327, CF2009.

Lee E H and Tupper S J
ANALYSIS OF PLASTIC DEFORMATION IN A STEEL CYLINDER STRIKING A RIGID TARGET
Journal of Applied Mechanics, Trans. ASME

The G. I. Taylor dynamic compression test (article 1001) is used to determine the entire strain distribution for a test cylinder of nickel-chrome steel. In the interpretation of results, interest is concentrated on the plastic and elastic wave fronts which emanate from the surface of contact. The theory of the propagation of plastic waves is presented. This is a fundamental article in relation to impacts large enough to cause plastic deformation. Impact velocities to about 1500 fps.

Lee E H and Wolf H
PLASTIC-WAVE PROPAGATION EFFECTS IN HIGH SPEED TESTING
Journal of Applied Mechanics, Trans. ASME
1951, Vol. 73, p. 379.

This article discusses how a material test carried out at high speed may be markedly influenced by plastic-wave
propagation effects. The range of speed is determined which permits satisfactory test interpretation without the need for detailed plastic-wave analysis.

Fundamental article on the interpretation of high speed material tests.

1009  Habib E T
A METHOD OF MAKING HIGH-SPEED COMPRESSION TESTS ON SMALL COPPER CYLINDERS
Journal of Applied Mechanics, Trans. ASME
1948, Vol. 70, p. 248

High-speed compression tests are performed on small copper cylinders by subjecting them to the impact of a piston fired from a pneumatic gun. Experimental techniques are discussed and results of the tests are shown as energy absorbed versus deformation. The complication due to plastic strain waves is mentioned.

Velocity of impact 25-200 fps.

1010  White M P and Griffis LeVan
THE PROPAGATION OF PLASTICITY IN UNIAXIAL COMPRESSION
Journal of Applied Mechanics, Trans. ASME
1948, Vol. 70, p. 258.

A theoretical investigation of the mechanism of uniaxial compression impact on elastic-plastic materials is described. It is concluded that four different modes of behavior can occur, depending on the impact velocity.

1011  Sternglass E J and Stuart D A
AN EXPERIMENTAL STUDY OF THE PROPAGATION OF TRANSIENT LONGITUDINAL DEFORMATIONS IN ELASTOPLASTIC MEDIA
Journal of Applied Mechanics, Trans. ASME

An experimental study is presented which is concerned with confirming the theory of the propagation of plastic waves. It is concluded that the velocity of propagation of the wave front is that of the elastic wave which is not in agreement with theory as proposed by Von Karman and Taylor.

1012  Malvern L E
THE PROPAGATION OF LONGITUDINAL WAVES OF PLASTIC DEFORMATION IN A BAR OF MATERIAL EXHIBITING A STRAIN-RATE EFFECT
Journal of Applied Mechanics, Trans. ASME
The theory of propagation of plastic longitudinal waves is extended to include the strain rate effect on the stress-strain curve. See also 1052. Bibliography contains 30 references.

1014 White M P
ON THE IMPACT BEHAVIOR OF A MATERIAL WITH A YIELD POINT
Journal of Applied Mechanics, Trans. ASME
1949, Vol. 71, pp. 39-52

A very complete analysis is made of impact behavior of materials with a yield point. The theory of plastic wave propagation and the combination of plastic and elastic waves is presented very clearly.

1015 White M P and Griffis LeVan
THE PERMANENT STRAIN IN A UNIFORM BAR DUE TO LONGITUDINAL IMPACT
Journal of Applied Mechanics, Trans. ASME

A method is presented for giving the final distribution of strains in a uniform bar subjected to a plastic impact. The wave propagation theories are used in the development. The presentation is very basic from the standpoint of interpretation of impact stresses and strain in cylindrical specimens.

1016 Mann H C
HIGH VELOCITY TENSION IMPACT TESTS
Proceedings ASTM

1017 Duwez P E and Clark D S
AN EXPERIMENTAL STUDY OF THE PROPAGATION OF PLASTIC DEFORMATION UNDER CONDITIONS OF LONGITUDINAL IMPACT
Proceedings ASTM

1018 Von Karman Th
ON THE PROPAGATION OF PLASTIC DEFORMATION IN SOLIDS
NDRC Report No. A-29
OSRD No. 365, 1942.
Von Karman Th, Bohenblust H E and Hyers D H
THE PROPAGATION OF PLASTIC WAVES IN TENSION SPECIMENS
OF FINITE LENGTH
NDRC Report No. A-103
OSRD No. 946, 1942.

Campbell J D
AN INVESTIGATION OF THE PLASTIC BEHAVIOR OF METAL RODS
SUBJECTED TO LONGITUDINAL IMPACT
Journal of Mechanics and Physics of Solids
1953, Vol. 1, pp. 113-123.

A dynamic stress-strain relation is obtained for an
aluminum alloy. An SR-4 type strain gage is mounted
on the specimen. The specimen is in the form of a
long rod. Successively larger impacts are imparted
to the specimen to obtain a stress-strain curve. Im-
 pact is applied to a steel rod then transmitted into the
specimen. The effect of the steel rod is to increase
the applied stress and also separates the flexural and
longitudinal components due to differences in velocity
of propagation.

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GRAPHICAL SOLUTIONS FOR PROBLEMS OF STRAIN PROPAGA-
TION IN TENSION
NDRC Report No. A-131
OSRD No. 1204, 1942.

Von Karman Th and Duwez P E
ON THE PROPAGATION OF PLASTIC STRAINS IN SOLIDS
Presented at the Sixth International Congress for Applied Mechanics,
Paris, France, September 1946.

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WAVE PROPAGATION IN A UNIFORM BAR WHOSE STRESS-STRAIN
CURVE IS CONCAVE UPWARD
NDRC Report No. 152
OSRD No. 1302, 1943.

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PLASTIC WAVES IN COMPRESSION
British Official Report App,
Coordinating Subcommittee No. 57, 1943.

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THE ANALYSIS OF THE PLASTIC DEFORMATION IN A CYLINDER
OF SHOT STEEL STRIKING A RIGID TARGET
Taylor G I
THE PLASTIC WAVE IN A WIRE EXTENDED BY AN IMPACT LOAD

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THE PLASTIC PROPERTIES OF METALS AT HIGH RATES OF
STRAIN
NDRC Report A-41
OSRD 495, April 1942.

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HIGH SPEED COMPRESSION TESTING OF COPPER CYLINDERS AND
SPHERES, II
NDRC Report A-324
OSRD Report 5039, April 1945.

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THE INFLUENCE OF SPECIMEN DIMENSION AND SHAPE ON THE
RESULTS OF TENSILE IMPACT TESTS
NDRC Report A-237
OSRD Report 3028, December 1943.

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HIGH SPEED COMPRESSION TESTS ON COPPER
Journal of Applied Physics

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THE BEHAVIOR OF LONGITUDINAL STRESS WAVES NEAR DIS-
CONTINUITIES IN BARS OF PLASTIC MATERIAL
NDRC Report A-212
OSRD 1799, September 1943.

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THE FORCE PRODUCED BY IMPACT OF A CYLINDRICAL BODY

Duwez P E, Wood D S and Clark D S
THE PROPAGATION OF PLASTIC STRAIN IN TENSION

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ADDENDUM TO VON KARMAN's THEORY OF THE PROPAGATION
OF PLASTIC DEFORMATION IN SOLIDS
NDRC Memo A-41 M
OSRD No. 664, 1942.
Duwez P E, Clark D S, Wood D S and Charyk J V
THE EFFECT OF STOPPED IMPACT AND REFLECTION ON THE
PROPAGATION OF PLASTIC STRAIN IN TENSION
NDRC Report No. A-108
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PROPAGATION OF PLASTIC WAVES IN PRE-STRESSED BARS
Technical Report No. 5, Navy Contract N6-ONR-243
Task Order III
Johns Hopkins University, June 1951.

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Prikladnaia Matematika i Mekhanika
1945, Vol. 9, pp. 91-100.

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ON THE PROPAGATION OF PLANE ELASTIC-PLASTIC WAVES
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Prikladnaia Matematika i Mekhanika

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THE PROPAGATION OF ELASTIC VISCOS-PLASTIC WAVES
IN BARS (Russian)
Prikladnaia Matematika i Mekhanika

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LONGITUDINAL WAVE TRANSMISSION AND IMPACT

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ANALYSIS OF STRESS-STRAIN-TIME RELATIONS FROM THE
ENGINEERING VIEWPOINT
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April 1949, revised September 1951.

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British Official Report R C 70, 1940.

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A BOUNDARY VALUE PROBLEM IN THE THEORY OF PLASTIC
WAVE PROPAGATION
Quarterly of Applied Mathematics
Brown A F C and Vincent N D G
THE RELATIONSHIP BETWEEN STRESS AND STRAIN IN THE TENSILE IMPACT TEST

DeJuhasz K
GRAPHICAL ANALYSIS OF IMPACT OF BARS STRESSED ABOVE THE ELASTIC RANGE
Journal of the Franklin Institute

This article gives a detailed explanation of the use of graphical solutions to picture and solve problems relating to the impact of bars. A bibliography on impact, consisting of 45 references, is given. Wave propagation is pictured graphically.

Burr A H
LONGITUDINAL AND TORSIONAL IMPACT IN A UNIFORM BAR WITH A RIGID BODY AT ONE END

Riparbelli C
ON THE RELATION AMONG STRESS, STRAIN, AND STRAIN RATE IN COPPER WIRES SUBMITTED TO LONGITUDINAL IMPACT

A series of exploratory tests of tensile impact on copper wires is presented to show that the elastic component of a stress wave moves at a constant velocity regardless of the amount of plastic deformation. Method consists of dropping weight on copper wire. Bright tin spots on wire are photographed with high-speed photography to observe motion of the stress waves.

Alter B E K and Curtis C W
EFFECT OF STRAIN RATE ON THE PROPAGATION OF A PLASTIC PULSE ALONG A LEAD BAR

A very thorough article on the effect of strain rate on the velocity of propagation of a plastic wave in a bar. Tests were carried out to determine how pulses of plastic deformation disperse during propagation along a lead bar. The theory of rate of propagation is reviewed and experimental results are presented. Article contains a list of 20 references.
1050 Wood D S
ON LONGITUDINAL PLANE WAVES OF ELASTIC-PLASTIC STRAIN IN SOLIDS
Journal of Applied Mechanics, Trans. ASME

1051 Taylor G I
THE TESTING OF MATERIALS AT HIGH RATES OF LOADING
Journal of the Institution of Civil Engineers

1052 Malvern L E
PLASTIC WAVE PROPAGATION IN A BAR OF MATERIAL EXHIBITING A STRAIN RATE EFFECT
Quarterly of Applied Mathematics
1951, Vol. 8, pp. 405-411.

1053 Campbell J D and Duby J
THE YIELD BEHAVIOR OF MILD STEEL IN DYNAMIC COMPRESSION
Proceedings Royal Society of London

Experiments are described in which a mild steel specimen is subjected to a compressive impact load. Stress-time curves are obtained and analyzed. Micrographs of specimens after yielding are shown to show the metallurgical mechanism of yielding.

1054 Kolsky H
AN INVESTIGATION OF THE MECHANICAL PROPERTIES OF MATERIALS AT VERY HIGH RATES OF LOADING
Proceedings Physical Society of London

1057 Lee E H
WAVE PROPAGATION IN ANELASTIC MATERIALS, DEFORMATION AND FLOW OF SOLIDS
Colloquium, Madrid, 26-30 September 1955
Berlin, Springer Verlag, 1956
Also Office of Naval Research Contract Nonr-562(10)
NR-064-408, Brown University, Technical Report No. 5
December 1955.

1058 Ogibalov P M and Loginova M A
ON THE DEPENDENCE OF THE STRAINS IN A RAPID DEFORMATION UNDER IMPULSIVE LOADING BEYOND THE YIELD POINT (Russian)
Vestnik, Moskov University No. 5, pp. 39-58, 1948.
Lensky V S
ON THE ELASTOPLASTIC IMPACT OF A ROD AGAINST A RIGID OBSTACLE (Russian)
Prikladnaia Matematika i Mekhanika

Lebedev N F
SECONDARY ELASTOPLASTIC WAVE (Russian)
Prikladnaia Matematika i Mekhanika

Campbell W R
DETERMINATION OF DYNAMIC STRESS-STRAIN CURVES FROM STRAIN WAVES IN LONG BARS
Proceedings Society for Experimental Stress Analysis

An exploratory experimental program is conducted to
determine the feasibility of using a tangent modulus
method to determine dynamic stress-strain curves.
Analytical procedure is outlined and experimental
results are presented. Measurements made with SR-4
type strain gages.

Zener C and Hollomon J H
EFFECT OF STRAIN RATE UPON PLASTIC FLOW OF STEEL
Journal of Applied Physics

Bell J F
THEORETICAL AND EXPERIMENTAL STUDIES OF PLASTIC WAVE PROPAGATION IN LONGITUDINAL RODS SUBJECT TO IMPACT
Johns Hopkins University, Institute for Cooperative Research

A new method employing diffraction gratings of very
short length will be utilized to study propagated plastic
wave fronts of large magnitude. Unloading waves, re-
lected waves from fixed and free ends. Dynamic deter-
mination of Poisson's ratio.

Rubin R J
PROPAGATION OF LONGITUDINAL DEFORMATION WAVES IN A
PRESTRESSED ROD OF MATERIAL EXHIBITING A STRAIN-RATE EFFECT
Journal of Applied Physics

The longitudinal propagation of stresses above the yield
stress in a material exhibiting a strain-rate effect is
studied analytically. Mathematical expressions are deVel-
oped which describe the wave propagation. The system
analyzed is a semi-infinite rod subjected to end impact.
This article is referred to by many investigators and several extensive experiments are being conducted to verify this theory.

**1065**

Campbell J D  
**THE YIELD OF MILD STEEL UNDER IMPACT LOADING**  
Journal of Mechanics and Physics of Solids  

In an extension of work reported in article 1020 the dynamic stress-strain curves of mild steel are obtained. The apparatus is adapted so that the steel rod which transmits the stress to the specimen is larger than the specimen. This increases the stress transmitted into the specimen. The strain gage is attached to the specimen.

**1066**

Campbell J D and Maiden C J  
**THE EFFECT OF IMPACT LOADING ON THE STATIC YIELD STRENGTH OF A MEDIUM CARBON STEEL**  
Journal of Mechanics and Physics of Solids  
1957, Vol. 6, pp. 53-61.

Although the results of this investigation are not of particular interest the experimental technique is interesting. A similar test setup is used as in articles 1020, 1065. Stress magnitude is amplified by transmitting the impact through steel rods of two cross-section changes. This amplifies the stress about two times. Strain gages are attached to the anvil bar.

**1067**

Riparbelli C  
**A PARADOX IN THE THEORY OF IMPACT**  
Journal of the Aeronautical Sciences  

**1068**

Gilhamet J and Goldsmith W (Translators)  
**PROPAGATION OF PLASTIC STRAIN**  
Translation of five articles from Russian and French

1. On Explosions in a Compressible Plastic Medium  
   Altschuler V

2. Concerning a Dynamic Problem of Thermoelasticity  
   Danilovskaya I

3. Elasto-Plastic Waves of Loading  
   Bakhshian R A

4. The Propagation of Cylindrical Waves of Plastic Deformation (Torsional Impact)  
   Rakhmatulin Kh A
5. The Propagation of Spherical Waves in an Elasto-Plastic Medium
Luntz Ya L

University of California, Institute of Engineering Research, July 1953.
# PLASTIC WAVE PROPAGATION

## Chronological Listing

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BEHAVIOR OF METALS UNDER EXPLOSIVE CONDITIONS
(1100-1199)

Subtopics

Equations of states of solids; experimental techniques; free surface velocity determinations; scabbing (analysis and experimental) and fracture.
BEHAVIOR OF METALS UNDER EXPLOSIVE CONDITIONS  
(1100-1199)

Bibliography

1101 Rinehart J S and Pearson J  
ENGRAVEMENT OF TRANSIENT STRESS WAVE PARTICLE VELOCITIES  
Journal of Applied Physics  

A simple and unique technique is described for determining the particle velocity of a material subjected to high-speed loading. The force is applied to a plate that has a pellet attached on the opposite side. The propagation of the wave through the plate and pellet causes the pellet to indent the surface of the plate. Average particle velocity can be determined by measuring the depth of penetration.

1102 Shreffler R G and Deal W E  
FREE SURFACE PROPERTIES OF EXPLOSIVE-DRIVEN METAL PLATES  
Journal of Applied Physics  

A photographic technique for study of metal-free surfaces under acceleration by high explosives is presented. Methods for reducing the data from the photographic record are described. Specific results using brass plates driven by explosives are cited. (Author's abstract)

1103 Allen W A  
FREE SURFACE MOTION INDUCED BY SHOCK WAVES IN STEEL  
Journal of Applied Physics  

Free surface motion is studied by photographing the motion of the image of point light sources on a highly polished steel surface. Plate is forced by the detonation of explosives. Results are analyzed.

For details of experimental technique, see article 1051.
The phenomenon of scabbing is stated to be dependent on the stress distribution within a wave and a critical normal stress that is a characteristic of the material. This paper presents the results of a modified Hopkinson pressure bar experiment in which results of stress versus time and critical velocity were obtained.

Pressure magnitudes of from 150 to 500 kilobars were obtained from metals with high explosives. Free surface velocities were determined by photographing the movement of shock waves in air or argon due to the pressure wave in the material. Results are analyzed and techniques are described.

The transient behavior of a thick circular plate deform- ing under explosive attack has been investigated. An experimental technique, based upon the principle of the optical lever has been used to measure surface oscillations as small as 10μ in amplitude. Measured particle velocities determined by this method indicate the presence of elastic and plastic waves.
One aspect of the part that high intensity stress waves play in the fracturing of metal cylinders subjected to internal explosive loading has been studied. It has been found that tensile type fractures will result from the interference of reflected tensile stress waves whenever the resulting tensile stress exceeds the critical normal fracture stress of the material.

Stress wave velocities have been measured for low-carbon steel, brass, copper, lead and aluminum alloys from the geometry of fracture. These velocities are in reasonable agreement with accepted values for the velocities of dilatational waves in these metals.

Rinehart J S
SCABBING OF METALS UNDER EXPLOSIVE ATTACK, MULTIPLE SCABBING
Journal of Applied Physics

The mechanism of multiple scabbing is explained in terms of stress propagation theory. Experimental results are shown which verify the theory. Particle velocities are determined by the use of pellets in a hole drilled on the back of the plate.

Rinehart J S
SOME EXPERIMENTAL INDICATIONS OF THE STRESSES PRODUCED IN A BODY BY AN EXPLODING CHARGE
Journal of Applied Physics

The effects of detonating explosive charges on the surface of heavy steel plates is discussed. The mechanism of failure is discussed and stress distribution is determined by conducting a hardness survey after the plate is sectioned. Experimental techniques are not discussed.

Pack D C, Evans W M and James H J
THE PROPAGATION OF SHOCK WAVES IN STEEL AND LEAD
Proceedings of the Physical Society, London

An experimental investigation is presented in which transit times for the passage of a shock wave through plates are measured. Wave is instigated by the detonation of explosive. Lead and steel plates are used. Time measured by making and breaking electrical contacts.

Rinehart J S
WORK HARDENING OF MILD STEEL BY EXPLOSIVE ATTACK
Journal of Applied Physics
Wood R W
OPTICAL AND PHYSICAL EFFECTS OF HIGH EXPLOSIVES

The deformation of the copper cap on an explosive
detonator is studied to gain information about the
mechanism of detonation. A spectroscopic investi-
gation of the exploding materials is also made.

Broberg K B
SHOCK WAVES IN ELASTIC AND ELASTIC-PLASTIC MEDIA
Kungl. Fortifikations for valtningen Befästningsbyran

Report gives interesting review of experiments on
the propagation of elastic, plastic and shock waves
produced by impact and by the detonation of explo-
sive charges. The theory of wave propagation is
discussed and the propagation of spherically diver-
gen stress-waves is treated in detail. Tables of
numerical values of dynamic stress-strain results
for metals and other solids are presented and the
fractures produced by the reflection of intense
stress waves at the free boundaries of a specimen,
are described and discussed. The bibliography con-
tains 71 references in the field, most of which are
recent. (Abstract as given in Applied Mechanics
Review).

Broberg K B
STUDIES ON SCABBING OF SOLIDS UNDER EXPLOSIVE ATTACK
Journal of Applied Mechanics, Trans. ASME

The mechanism of the scabbing phenomenon is dis-
cussed both theoretically and experimentally. Exper-
imental method used to determine pressure-time rela-
tion on face of plate where detonation occurs, is a
modified pressure bar. Plane scabbings are obtained
by inserting cylinders in hole in plate.

Kumar S and Davids N
ELASTIC-PLASTIC ANALYSIS OF SCABBING OF MATERIALS
Journal of the Franklin Institute

The graphical method is used to analyze stress prop-
gation. Stress states are analyzed which can cause
scabbing. No experimental work is presented.
Analytic expressions of displacements, velocities and stresses as a function of location and time, as solved with the use of an IBM machine, are presented in pictorial form. Presentation is applicable to spherical divergent waves in homogeneous, isotropic, elastic media of infinite extent under the waves generated by an explosion on one face of the medium. Graphs permit a rapid evaluation of the nature of the disturbance.

Author discusses the plastic deformation and some of the fractures which occur when an explosive charge is detonated in intimate contact with, or a high-velocity fragment strikes a solid body. Several specific examples that have not been heretofore reported are described. Each example is accompanied by a brief description of the other investigations that are most likely to lead to an understanding of what has taken place in each case.

Well-known laws which govern the reflection of elastic waves that strike free surfaces obliquely, are used to deduce particle motion at the free surface of a body.

The data are expected to be of value in the solution of problems connected with impulsively loaded bodies such as metal-explosive systems. (Excerpt from author's summary).
1121 Pearson J and Rinehart J S
COMPUTATION RELATING TO REFLECTION OF PLANE ELASTIC WAVES STRIKING FREE SURFACES OBLIQUELY
13 August 1952, NOTS TM No. 931.

1122 Allen W
ELASTIC DESCRIPTION OF A HIGH-AMPLITUDE SPHERICAL PULSE IN STEEL
21 April 1953, NOTS TM No. 994.

1123 Huth J H and Cole J D
A THEORETICAL TREATMENT OF SPALLING
Rand R M - 1181.

1124 Evans W M and Taylor G I
DEFORMATION AND FRACTURES PRODUCED BY INTENSE STRESS PULSES IN STEEL

The mechanism of plastic deformation and fracture due to high explosives is investigated by studying the fractures produced. Specimens are sectioned and etched. Metallurgical photomicrographs are made to study the change in crystalline structure. Article is well illustrated with typical fractures.

1125 Kolsky H and Shearman A C
INVESTIGATION OF FRACTURES PRODUCED BY TRANSIENT STRESS WAVES

The mechanism of fracture due to detonation of explosives is studied by observing the fractures of bodies of various shapes. Plastic bodies are used. Large plates, small plates, cylinders, and cones are investigated. Various fractures are well illustrated.

1126 Kochler J S and Seitz F
THE STRESS WAVES PRODUCED IN A PLATE BY A PLANE PRESSURE PULSE
1944, OSRD Report No. 3230.

1127 Rinehart J S and Pearson J
CONICAL SURFACES OF FRACTURE PRODUCED BY ASYMMETRICAL IMPULSIVE LOADING

The conical surface of fracture of an explosively loaded thick wall cylinder is analyzed from the
standpoint of stress wave propagation. It is shown that the angle of failure is a function of the velocity of propagation of the wave. Experimental results are shown which tend to verify the explanation.

Pearson J and Rinehart J S
DEFORMATION AND FRACTURING OF THICK-WALLED STEEL CYLINDERS UNDER EXPLOSIVE ATTACK
Journal of Applied Physics

This article discusses the deformation and fracturing of thick-walled cylinders due to internal explosives. The presentation is primarily focused on describing the mechanism of failure that occurs under these circumstances. Stress wave propagation and behavior of the material are not emphasized in the presentation.

Starr L and Savitt J
SPALLING PRODUCED BY DETONATION OF EXPLOSIVE IN VERY HEAVY WALLED METAL TUBES
Physical Review

Rinehart J S
HARDNESS PLATEAUS AND TWINNING IN EXPLOSIVELY LOADED MILD STEEL
Journal of Applied Physics

Mallory H D
PROPAGATION OF SHOCK WAVES IN ALUMINUM
Journal of Applied Physics

The velocity of shock waves in aluminum and the associated translational motions, produced by metal-metal impact, have been determined by an electrical contact technique. The results obtained have been used to evaluate an equation of state for the metal. (Author's abstract)

Rinehart J S
SOME OBSERVATIONS ON HIGH SPEED IMPACT
U. S. Naval Ordnance Test Station
Technical Memorandum RRB-50
19 October 1949.

Rinehart J S
THE BEHAVIOR OF METAL UNDER HIGH AND RAPIDLY APPLIED STRESSES OF SHORT DURATION
U. S. Naval Ordnance Report No. 1183
27 September 1949.
A number of interesting effects produced as the result of detonating explosive charges in intimate contact with metal plates, rods, and tubes are described. The principal observable effects are (1) fracturing of the metal caused by a tensional stress produced as the result of the reflection of a high compressional stress wave at a free boundary, (2) the fracturing of the metal caused by high stress concentration, and (3) permanent straining of the metal. (Author's abstract)

Scardin H
MEASUREMENTS OF SPHERICAL SHOCK WAVES
Communications on Pure and Applied Shock Mathematics

Although this article is primarily concerned with shock waves produced by explosives in air, it develops the pressure versus time data on explosives. Experimental data is shown which verify the experimental results. Photographs shown from multiple-spark camera, streak camera, condenser-microphone, kerr-cell photography, x-ray-photography.

Walsh J M, Rice M H, McQueen R G and Yarger F L
SHOCK WAVE COMPRESSIONS OF TWENTY-SEVEN METALS
EQUATIONS OF STATE OF METALS
Physical Review

An explosive system is used to drive a strong shock wave into a plate of 24 ST aluminum. This shock wave propagates through the 24 ST aluminum into small test specimens which are in contact with the front surface of the plate. A photographic technique is used to measure velocities associated with the 24 ST aluminum shock wave and with the shock wave in each specimen. Resulting pressure-compression curves are given for 27 metals. Pressure interval 150 to 400 kilobars. Very detailed information on the various metals behavior is given. (Author's abstract)

Bancroft D, Peterson E L and Minshall S
Journal of Applied Physics

This article investigates the propagation of compressive waves generated by high explosive in Armco iron. The pin technique is used to obtain free surface velocities. The presentation is given to investigate whether three stable shocks are propagated. Problem of wave propagation and reflection is well discussed.
Drummond W E
EXPLOSIVE-INDUCED SHOCK WAVES, PART II OBLIQUE SHOCK WAVES
Journal of Applied Physics

The explosive production of oblique shock waves in solids is analyzed in the approximation that third and higher order terms in the shock strength can be neglected, and a procedure is developed for calculating the attenuation of the shocks. Application is made to the problem of determining the equation of state of the burned explosive gas. See also 1139. (Author's abstract)

Drummond W E
EXPLOSIVE INDUCED SHOCK WAVES, PART I, PLANE SHOCK WAVES
Journal of Applied Physics

Deal W E
SHOCK HUGONIOT OF AIR
Journal of Applied Physics

Experiments are described in which an explosive driven plate set up a strong shock in air in contact with the plate. Free surface velocity and air shock velocity are measured by means of a high-speed framing camera which views the plate in profile.

Experimental results are shown for pressures up to 200 bars. A 24 St Dural plate is used.

Allen W A and Goldsmith W
SPALL EFFECTS PRODUCED BY A CYLINDRICAL AND A SPHERICAL CHARGE OF HIGH EXPLOSIVE
Journal of Applied Physics

A letter to the editor discusses the feasibility of using a spherical charge in replacement for a cylindrical charge in determining spall effects on the free surface of a plate.

Becker H
ON SHOCK PROPAGATION IN BRASS
Journal of Applied Physics

Savitt J, Stresau R H and Starr L E
COMPRESSION WAVE VELOCITY EXPERIMENTS WITH COPPER
Journal of Applied Physics
The velocity of compression waves in copper is investigated by detonation of explosives inside cylinders. The angle of failure of the end of the cylinder is taken as proportional to the wave velocity. Theory is explained and results are compared to article 1127.

1144 Mallory H D
ON THE EXISTENCE OF A BINARY REACTION ZONE AT A METAL-EXPLOSIVE BOUNDARY DURING DETONATION
U.S. Naval Ordnance Laboratory 1954
Library of Congress P.B. 122054.

This report is a summary of recent progress made in the interpretation of pin-point data. The pin technique has been used to measure the free surface velocity of aluminum targets struck by a plane detonation wave from crystalline TNT at a loading density of 0.624 g/cc. (Author’s abstract)

1145 Rinehart J S
DEFORMATION OF AN EXPLOSIVELY LOADED ALUMINUM SINGLE CRYSTAL

A hollow cylindrical single crystal of pure aluminum was deformed by detonating an explosive charge that had been placed axially within the crystal. The approximate strain rate achieved was $10^5$ sec$^{-1}$. The object of the test was to relate the pattern of deformation to the stresses set up by the explosive and the crystallographic axes of the crystal. The reaction of the cylinder was markedly different from the reaction which would be exhibited by a similarly shaped cylinder of polycrystalline material. The deformation was non-uniform with both the fracturing and the plastic flow exhibiting a twofold symmetry that could be unambiguously related to the orientation of stress with respect to the crystallographic axes and their associated slip systems. (Author’s abstract)

1146 Goranson R W, Bancroft D, Burton B L, Blechar T, Houston E E, Gittings E F, and Landeen S A
DYNAMIC DETERMINATION OF THE COMPRESSIBILITY OF METALS

Equation of state data for Duralumin in the pressure range from 0.1 to 0.3 megabar have been determined dynamically by measuring shock and free surface velocity electrically in a plate of 24 ST Duralumin that has been stressed by a high explosive detonation. A theory is presented which allows comparison with data obtained by other experimenters, and which yields the relationship
between pressure and compression either at constant entropy or constant temperature. The empirical form chosen for the equation of state ($p = a \mu + b \mu^2$) expresses the pressure as a quadratic function of the compression. Experimental techniques are described in detail. Five points are given for the equation of state of Duralumin in the pressure range from approximately 0.15 megabar to 0.33 megabars. Some data are also presented for cadmium and steel. (Authors' abstract)

Pearson J and Rinehart J S
APPLICATION OF THE ENGRAVEMENT METHOD TO THE STUDY OF PARTICLE VELOCITY DISTRIBUTION IN EXPLOSIVELY LOADED CYLINDERS
Journal of Applied Physics

Application of the engraving method to the study of particle velocity distribution in the wall of a thick-walled metal cylinder internally loaded with an explosive charge is described. Tests were conducted with this method on modified cylinders of annealed low-carbon steel and of brass. Even though each of the modified cylinders broke into a number of fragments, the engravings were well enough preserved to furnish considerable data. Many measurements were obtained from each cylinder by using a large number of pellets of several thicknesses. Particle velocity data were obtained to within 7/16 inch from the metal explosive interface. Temporal particle velocity distribution curves are presented for each of the cylinders. (Author's abstract)

Minshall S
PROPERTIES OF ELASTIC AND PLASTIC WAVES DETERMINED BY PIN CONTACTORS AND CRYSTALS
Journal of Applied Physics

Experimental techniques are described by which one can observe the separation of a shock wave in a metal into an elastic wave and a slower plastic wave. The plastic-wave velocity was about 15 percent less in steel and 10 percent less in tungsten than the elastic-wave velocity, at pressures imparted by Composition B explosive. Elastic-wave velocities were the same, within experimental error, as the measured sound velocities. The pressure in the elastic wave in SAE 1020 steel, deduced from the material and wave velocities, is independent of the plastic-wave pressure within experimental accuracy, and is about 12 kilobars. SAE 1040 steel, however, does not exhibit a single characteristic elastic-wave pressure. The pressure initially is about 6 kilobars and increases to about 12 kilobars before the arrival of the plastic wave. (Author's abstract)
Allen W A, Mapes J M and Mayfield E B
SHOCK WAVES IN AIR PRODUCED BY ELASTIC AND PLASTIC WAVES IN A PLATE
Journal of Applied Physics

Letter to the editor describing shock waves in air produced by free surface velocity of plate. Shadow graphs are shown of these waves. Two shock waves shown for brass but only one wave for copper. Steel and lead also reported. No numerical results presented.

Savitt J
A NOTE ON SHOCK PROPAGATION IN BRASS
Journal of Applied Physics

A theoretical description is given on the propagation of longitudinal waves through a body of large lateral extent. (Plates) Combination of elastic and plastic stresses is investigated.

Murgai M P
APPLICATION OF THE HERTZ THEORY OF IMPACT TO EXPLOSION PHENOMENON
Journal of Chemical Physics

Singh Sampooran
SPATIAL DISTRIBUTION OF FRAGMENTS OF EXPLOSIVELY LOADED THIN-WALLED STEEL CYLINDERS
Proceedings Physical Society

Allen W A and Goldsmith W
ELASTIC DESCRIPTION OF A HIGH-AMPLITUDE SPHERICAL PULSE IN STEEL
Journal of Applied Physics

Extensive calculations have been performed with an electronic calculator to evaluate a problem in elasticity that simulates the effect of a cylindrical charge of high explosive detonated in intimate contact with a steel plate. The general method of calculation has been described in detail. Although elastic theory has been extrapolated into a regime where it is known not to apply, insight of a valuable general nature has been obtained on the nature of the negative component of the pulse. (Author's abstract)
Kumar S and Davids N
BASIC THEORY OF SCABBING-ELASTO-PLASTIC WAVE PROPAGATION

Semi-graphical approaches to the propagation of stress pulses in bars created by impacts is presented. This report consists of two main parts, viz., "Stress Jump Approach" and the "Strain Contour Approach." In the first part, after a brief discussion and development of the theory of plastic wave propagation, solutions of a number of problems with various boundary conditions for rectangular and triangular pulses of both long and short duration, are presented. An idealized stress-strain diagram for 14 ST-4 Aluminum alloy obtained in our laboratory has been used for most of the above cases. In the second part, first the theory of contour propagation in the X-T plane is developed and a set of rules that govern their geometrical patterns are presented. Then solutions are provided for most cases of reflections and interactions of the strain and velocity contours that are considered necessary for solving any given problem. (Authors' abstract)

Dewey J, Breidenbach H I and Gehring J W
SOME OBSERVATIONS OF ELASTIC PROPERTIES OF SOLIDS UNDER EXPLOSIVE LOADING
Ballistic Research Laboratories, Report No. 931.

The strains and shock fronts in a magnesium alloy subjected to a contact detonation have been determined from flash radiographs. From these the stresses and stress-strain ratios for the compressional and shearing strains at the shock fronts have been computed, using finite strain theory. The compressional stress-strain ratio exceeds the infinitesimal and increases rapidly with strain. The shearing stress-strain ratio is considerably lower than the infinitesimal and about that predicted from Murnaghan's second order theory, $\mu - p$. Much less complete observations on plate glass and Catalin 61-893 are reported and reduced. Observations on heavier materials give subsonic shock velocities under very high stresses. In all materials except glass the compression front is markedly curved, indicating a rapid decay of shock strength. (Authors' abstract)

Kumar S and Davids N
MULTIPLE SCABBING IN MATERIALS
Interim Technical Report No. 4, OOR Project TB2-0001 (1253), Pennsylvania State University.

This report discusses first, scabbing and multiple scabbing from a phenomenological point of view, then past experiments on scabbing with critical comments. It then suggests new types of experiments and the use of an
inverse approach which could yield information on pulse shapes and some of the dynamic properties of the material. The relationships among these quantities have been determined graphically. (Authors' abstract)

Davids N and Kumar S
THE BASIC THEORY OF SCABBING IN MATERIALS WITH TWO SOLIDS IN CONTACT, PART I, ELASTIC THEORY

Basic relationships for scab formation in a solid are developed from the point of view of elastic materials. Relationships giving the thickness of scabs are obtained for semi-infinite plates and thin rods on the basis of normally incident pressure pulses of arbitrary form. The effect of a backing medium has been expressed in terms of impedance matching relations between the two media, and these used to determine quantitatively the reduction in stress. Criteria for required thicknesses are developed on the basis of momentum considerations. A preliminary treatment is included for spherically-diverging waves arising from a point explosion in a semi-infinite medium. Some available data are made use of in a discussion for the purpose of evaluating time constants of typical pressure pulses used in the report. (Authors' abstract)

Davids N
STRESS WAVES OF PENETRATION IN PLATES

Scabbing effects in plates may be analyzed theoretically by assuming elastic stress-waves excited periodically at a point-source on its boundary. The usual classical results are inaccurate since, first, the damaging wave is the one penetrating through the plate rather than propagating along it, and second, the dimensions of the plate in practical applications are just of the order of a wavelength. A more precise boundary-value problem is worked out and resulting axial stress-wave distributions for aluminum plates are given. (Author's abstract)

Kumar S
SCABBING IN BARS AND PLATES - FURTHER STUDIES

Scabbing, a fracture phenomenon in materials, due to stress reversal of strong dynamic loads, is first discussed here from a phenomenological point of view. Then an elastic analysis for determining scab lengths both in bars and plates under plane stress and plane strain is presented. As a further refinement, after explaining briefly and applying the basic theory of
elastoplastic wave propagation in solids, a study is made of scabbing possibilities in bars by semi-graphical methods, and also the basis for the elastoplastic analysis of scabbing in plates. Implications of both the elastic and elastoplastic analyses are compared. Idealized stress-strain relations for 14ST-4 Aluminum, obtained in our laboratory, have been used. (Author's abstract)

Duvall G E
PRESSURE-VOLUME RELATIONS IN SOLIDS
American Journal of Physics

An equation of state of the form \( P(V) = f(V) + T g(V) \), which is useful for condensed matter, is proposed for the illustration of thermodynamic principles. Pressure-volume relations for adiabatic and shock compressions are derived with the assumption that specific heat at constant volume is independent of temperature. These derived relations are illustrated for a "Murnaghan" equation of state, and constants of this equation for several metals are tabulated. (Author's abstract)

Duvall G E and Zwolinski B J
ENTROPIC EQUATIONS OF STATE AND THEIR APPLICATION TO SHOCK WAVE PHENOMENON IN SOLIDS
Journal of the Acoustical Society of America

Drummond W E
COMMENTS ON THE CUTTING OF METAL PLATES WITH HIGH EXPLOSIVE CHARGES
Journal of Applied Mechanics, Trans. ASME,
1958, Vol. 80, pp. 184-188.

Kumar S
SCABBING AND PULSE PROPAGATION IN MATERIALS

Davids N and Kumar S
STRESS WAVES AND SCABBING IN MATERIALS
OOR Technical Memorandum 58-1, May 1958 (73 references).

Katz S, Curran D R and Doran D G
HUGONIOT EQUATION OF STATE OF ALUMINUM AND STEEL FROM OBLIQUE SHOCK MEASUREMENT
A new method for determining the Hugoniot equation of state of solids has been developed. This method uses an oblique shock in a wedge-shaped specimen, cut so that the oblique shock is incident at an angle close to normal over the wedge face. The oblique shock is produced by a slab of explosive, lying on top of the wedge and line-initiated, providing essentially a two-dimensional shock. Simultaneous measurement of shock and free-surface velocities down the wedge face provides the data for calculation of the Hugoniot pressure and density over a wide range on a single shot. In aluminum a pressure range exceeding 2:1 may be observed on a single shot. (Authors' Summary)

Al'tshuler L V, Krupnikov K K, Ledenev B N, Zhuchikhin V I and Brazhnik M I
THE DYNAMIC COMPRESSIBILITY AND THE EQUATION OF STATE FOR IRON AT HIGH PRESSURES

The paper describes two methods for measuring the dynamic compressibility of substances. These methods are based on determining the kinematic parameters of shock waves (propagation velocity and the mass velocity of the material behind the wave front). Using these methods in the pressure range from $4 \times 10^5$ to $5 \times 10^6$ atm., the adiabatic curves are obtained for the shock compressibility of iron specimens with various initial densities. The resulting experimental data is used to derive the compressibility curve at absolute zero. The curve is extrapolated to pressures for which the statistical models for an atom are valid. (Authors' abstract) (Abstract in Physics Express, July 1958).

Al'tshuler L V, Krupnikov K K and Brazhnik M I
THE DYNAMIC COMPRESSIBILITY OF METALS AT PRESSURES FROM FOUR HUNDRED THOUSAND TO FOUR MILLION ATMOSPHERES

The paper presents a method for determining pressures and densities under conditions of shock compression. The method is based on measuring the propagation velocities for high-power shock waves. The method was used to measure the dynamic compressibility of copper, zinc, silver, cadmium, tin, gold, lead and bismuth in the pressure range $4 \times 10^5$ to $4 \times 10^6$ atm. The highest degrees of compression (2.26 and 2.28 times) were observed in zinc and bismuth (i.e., for elements with large atomic volumes). The highest absolute density (32.7 g/cm³) was registered for gold. (Abstract in Physics Express, July 1958).
Allen W A, Mapes J M and Mayfield E B
SHOCK WAVES IN AIR PRODUCED BY WAVES IN A PLATE
Journal of Applied Physics

A shadowgraphic technique has been used to measure surface motion of a series of steel plates while they deform under impact caused by 1/2-in. diameter steel cylinders fired into their back surfaces at about 2800 ft/sec. The strength of the air shock produced when an initial longitudinal wave in a plate strikes the free surface of the plate has been inferred from the measured shock wave velocity in the air. The shock strength has been related to particle velocity of the surface of the plate. The results are compared to previous work involving contact explosions of small charges on plates. (Authors' abstract)
BEHAVIOR OF METALS UNDER EXPLOSIVE CONDITIONS

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DYNAMIC PHOTOELASTICITY AND RELATED TOPICS
(2000-2099)
DYNAMIC PHOTOELASTICITY AND RELATED TOPICS
(2000-2099)

Bibliography

2001
Frocht M M
KINEMATOGRAPHY IN PHOTOELASTICITY
Transactions American Society of Mechanical Engineers

Moving pictures are presented showing stress fluctuations in a beam due to impact of a falling weight.
Camera Speed limited to 64 frames/sec.

2002
Foepl L
SLOW MOTION PICTURES OF IMPACT TESTS BY MEANS OF PHOTOELASTICITY
Journal of Applied Mechanics
Transactions American Society of Mechanical Engineers

Moving pictures are presented showing the stress fluctuation in beams due to the impact of a hammer.
Both elastic and plastic conditions are shown. Camera speed maximum of 3020 frames/sec.

2003
Perkins H C
MOVIES OF STRESS WAVES IN PHOTOELASTIC RUBBER
Journal of Applied Mechanics, Trans. ASME

Moving pictures are presented which show stress waves propagating in photoelastic rubber specimens.
Camera speed maximum of 5000 frames/sec.

2004
Frocht M M and Flynn P D
STUDIES IN DYNAMIC PHOTOELASTICITY
Journal of Applied Mechanics, Trans. ASME

Equipment and techniques are described for obtaining dynamic photoelastic stress patterns by means
of streak photography. Dynamic photoelastic stress patterns showing stress-wave propagation are given for a bar struck axially by a rigid mass. 1,500,000 equivalent exposures/sec.

2005 Durelli A J and Riley W E
EXPERIMENTS FOR THE DETERMINATION OF TRANSIENT STRESS AND STRAIN DISTRIBUTION IN TWO-DIMENSIONAL PROBLEMS
Journal of Applied Mechanics, Trans. ASME

A photoelastic material of low modulus of elasticity is developed for use in stress-wave propagation studies. Dynamic and static photoelastic and mechanical properties are investigated and methods are described. Photographs of fringe patterns are shown for circular discs and beams subjected to impact. Camera speed 14,000 frames/sec.

2006 Sutton G W
A PHOTOELASTIC STUDY OF STRAIN WAVES CAUSED BY CAVITATION
Journal of Applied Mechanics, Trans. ASME
Discussion Journal of Applied Mechanics
1958, Vol. 80, pp. 298-299.

Ultra-high-speed photoelastic techniques have been applied to a study of the transient stresses and strains in a photoelastic plastic when subject to cavitation. Cavitation bubbles have been photographed collapsing on the surface of a photoelastic specimen and the resulting strain wave has been photographed. The static and dynamic properties of CR-39 are determined. Camera speed 1,000,000 frames/sec.

2007 Betser A A and Frocht M M
A PHOTOELASTIC STUDY OF MAXIMUM TENSILE STRESSES IN SIMPLY SUPPORTED SHORT BEAMS UNDER CENTRAL TRANSVERSE IMPACT
Journal of Applied Mechanics, Trans. ASME
1957, Vol. 79, p. 509
Discussion Journal of Applied Mechanics
1958, Vol. 80, p. 305.

Photoelastic streak photographs were taken for beams subjected to the impact of a heavy mass. This article is primarily concerned with the interpretation of results of this study. Experimental techniques are not fully discussed.
2008 Frocht M M, Flynn P D and Landsberg D
DYNAMIC PHOTOELASTICITY BY MEANS OF STREAK PHOTOGRAPHY
Proceedings Society for Experimental Stress Analysis

A review of literature on high-speed photography and
dynamic photoelasticity is presented. Equipment and
techniques for streak photography are described in
detail.

2009 Senior D A and Wells A A
A PHOTOELASTIC STUDY OF STRESS WAVES
Philosophical Magazine
1946, Series 7, Vol. 37, pp. 463-469.

This article shows the first photographs of stress-
wave propagation by photoelastic means.

2010 Findley W N
THE FUNDAMENTALS OF PHOTOELASTICITY APPLIED TO DYNAMIC
STRESSES
Ninth Semi-Annual Eastern Photoelasticity Conference, 13 May 1939,
p. 1-11, published by the College of Engineering, Cornell University.

2011 Riparbelli C, Boehler G and Hitch H
PHOTOELASTIC ANALYSIS OF IMPACT STRESS PROPAGATION IN
TWO DIMENSIONS (See also 2028)
Fluid Dynamic Division, American Physical Society, Cornell University
(Unpublished).

2012 Tuzi Z
PHOTOGRAPHIC AND KINEMATOGRAPHIC STUDY OF PHOTO-
ELASTICITY
Scientific Papers of the Institution of Physical and Chemical Research

2013 Frocht M M and Flynn P D
A PHOTOELASTIC STUDY OF DYNAMIC STRESSES IN STRUCTURES
Technical Report to the U. S. Navy Bureau of Docks and Yards,
U. S. Naval Civil Engineering Research and Evaluation Laboratory,
Structures Research Department Port Hueneme, California, Contract
No. -28149, Project Order 10703
30 June 1952.

2014 Tuzi Z and Nisida M
PHOTOELASTIC STUDY OF STRESSES DUE TO IMPACT
Scientific Papers of the Institution of Physical and Chemical Research
April 1936, Vol. 26, No. 566, pp. 277-309; also
2015 Feder J C, Gibbons R A, Gilbert J T and Offenbacker E L
THE STUDY OF THE PROPAGATION OF STRESS WAVES BY PHOTOELASTICITY
Proceedings of The Society for Experimental Stress Analysis

The propagation of stress waves in CR-39 plastic is shown. Propagation is instigated by the impact of a rod and by the explosion of blasting caps in contact with the specimen. Maximum photo speed was 1.25 microsec between frames. Results are analyzed in terms of wave propagation theory.

2016 Betser A A, Flynn P D and Frocht M M
ON THE STRESS-OPTIC LAW UNDER IMPACT LOADINGS

2017 Flynn P D
STUDIES IN DYNAMIC PHOTOELASTICITY

2018 Betser A A
STUDIES IN DYNAMIC PHOTOELASTICITY: FRINGE VALVES AND BEAMS UNDER IMPACT

2019 Clark A B J
STATIC AND DYNAMIC CALIBRATION OF A PHOTOELASTIC MODEL MATERIAL, CR-39

A thorough investigation of the properties of CR-39 is conducted. Dynamic properties are determined by passing a stress wave through the material and using a photocell to record lightness and darkness (i.e. passage of different fringes). Techniques are fully discussed and results are analyzed.

2020 Christie D G
REFLECTION OF ELASTIC WAVES FROM A FREE BOUNDARY
The photoelastic technique is used in studying the problem of reflection of stress waves at a free boundary. Photographs shown are very clear and show the reflection very descriptively. Multiple spark camera was used which could take successive pictures at times ranging from 5 microsec to 50 microsec. Very clear photographs.

2021  
Zandman F  
A PHOTOELASTIC STUDY OF RUPTURE UNDER PURE FLEXURE  
Compt. Rend. Académie des Sciences (Paris)  

2022  
Volterra E  
SOME RESULTS OF THE DYNAMIC TESTING OF MATERIALS  
Riv. Nuovo, Cim.,  

2023  
Schwieger H  
PHOTOELASTIC SHOCK INVESTIGATIONS IN THIN GLASS BARS  
Ann. Phys. (Leipzig)  
1955, Vol. 16, pp. 119-133.

2024  
Schwieger H and Dietz H  
OPTICAL POLARIZATION EXPERIMENTS ON THE ELASTIC IMPACT THEORY OF ST. VENANT AND FLAMANT  
Ann. Phys. (Leipzig)  

2025  
Frocht M M and Betser A A  
A PHOTOELASTIC STUDY OF MAXIMUM TENSILE STRESSES IN SIMPLY SUPPORTED BEAMS UNDER CENTRAL TRANVERSE IMPACT  

2026  
Stanton J S  
A METHOD OF ASSESSING TRANSIENT STRESSES IN PHOTOELASTIC SUBSTANCES  
Review of Scientific Instruments  
1949, Vol. 20, p. 139.

A brief half page note showing a photograph as an indication that photoelasticity can be used to study transient stress phenomena.

2027  
Murray W M  
A PHOTOELASTIC STUDY IN VIBRATION  
Journal of Applied Physics  

A photoelastic study of steady state vibration of a cantilever beam. Moving pictures not taken.
Riparbello C, Hitch H and Boehler G
PHOTOELASTIC STRESS ANALYSIS OF A SHOCK LOADED STRUCTURE
Paper presented at Meeting of the Division of Fluid Dynamics,
American Physical Society, Ithaca, New York, 11-12 September 1951

The analysis of stress propagation in solids of nonconstant
section has occasioned the development of this technique,
of which some of the first results are presented. High veloc-
ity moving pictures (4000 frames per second) were taken in
the polariscope of specimens made out of gelatin. The speci-
mens were struck by a hammer at various velocities between
zero and 30 ft/sec __. Moving pictures of isochromatic
patterns are presented with emphasis on the boundary effects
in plates of various shapes. ____________________________.

Jahn R G
PHOTOELASTIC STRESS ANALYSIS OF A SHOCK LOADED STRUCTURE
Paper presented at Meeting of the Division of Fluid Dynamics,
American Physical Society, Ithaca, New York, 11-12 September 1951
Abstract in Physical Review, 1951, Vol. 84, p. 612
Also Princeton University Department of Physics Technical Report
II-9 Contract NRO61-020, N80Ri-105.

To study the form and intensity of the stress distributions
set up inside an object subjected to a shock wave, a solid
model of photoelastic Bakelite was mounted in the shock
tube and the stress progressions in it analyzed by means
of a conventional circular polariscope. __________(p - q)
patterns were taken at 10 - 20 microsec intervals starting at
the time of impact. ________________________________

Sutton G W
A STUDY OF THE APPLICATION OF PHOTOELASTICITY TO THE
INVESTIGATION OF STRESS WAVES
Ph.D. Thesis, California Institute of Technology, Pasadena,
California, 1955.

A detailed account is given of the determination of the static
and dynamic optical and mechanical properties of CR-39.
The suitability of photoelastic techniques for investigating
stress waves is analyzed very carefully.

Kolsky H
A PHOTOELASTIC INVESTIGATION OF THE HARDNESS OF PLASTIC
AND GLASS
Transactions Society of Glass Technology

Kolsky H and Christie O G
THE FRACTURES PRODUCED IN GLASS AND PLASTICS BY THE
STRESS OF WAVES
Transactions Society of Glass Technology
Post D
A NEW PHOTOELASTIC INTERFEROMETER SUITABLE FOR STATIC AND DYNAMIC MEASUREMENTS
Proceedings Society for Experimental Stress Analysis

Marshall D F
THE DYNAMIC STRESS-OPTIC COEFFICIENT OF PERSPEX
Proceedings Physical Society of London

Pugh E M, Heine-Geldern R V, Foner S and Mutschler E C
GLASS CRACKING CAUSED BY HIGH EXPLOSIVES
Journal of Applied Physics

High-speed photographs have been obtained of the fracture of glass produced by the detonation of a high explosive charge. Using photoelastic methods, the shock waves set up in the glass can also be photographed.

not shown in data obtained.

Wells A A and Post D
DYNAMIC STRESS DISTRIBUTION SURROUNDING A RUNNING CRACK, A PHOTOELASTIC ANALYSIS
Office of Technical Service, P. B. 121987.

Hetenyi M
A STUDY IN PHOTOPLASTICITY

Fried B and Shoup N H
A STUDY IN PHOTOPLASTICITY

Nisida M, Hondo M and Hasunuma T
STUDIES OF PLASTIC DEFORMATION BY THE PHOTOPLASTIC METHOD
Proceedings Sixth Japanese National Congress of Applied Mechanics, University of Kyoto, Japan, October 1956, pp. 137-140.

A proposal is made to use celluloid to represent an elastoplastic material such as a non-strain-hardening metal, and to determine stress and strain patterns in the plastic range by photoelastic techniques. The few simple examples tested indicate that not only can the plastic stress and strain distribution be determined but also the residual stress pattern after unloading can
be found. Although the time for a complete test is relatively long, the method shows considerable promise for at least qualitative studies of elasto-plastic materials in the plastic range.

Bayoumi S E A and Frankl E K
FUNDAMENTAL RELATIONS IN PHOTOPLASTICITY
British Journal of Applied Physics

A fundamental procedure for photoplastic investigations is proposed. This consists of taking two fringe photographs of the same model, one under load, the second immediately after removal of load. The difference between fringe counts at corresponding points gives the stress difference which in elastic problems is derived from a single photograph. (From authors' summary)

THEORY AND APPLICATION OF PHOTOELASTICITY IN THE
ELASTO-PLASTIC REGION (German)
Zeitschrift des Vereines Deutcher Ingenieure, Düsseldorf

Monch E
THE DISPERSION OF DOUBLE REFRACTION AS A MEASURE OF PLASTICITY IN PHOTOELASTIC INVESTIGATIONS (German)
Forschungsarbeiten auf dem Gebiet des Ingenieurwesen, Berlin.

Fried B
SOME OBSERVATIONS ON PHOTOELASTIC MATERIALS STRESSED BEYOND THE ELASTIC LIMIT

Garvin Elsie L
BIBLIOGRAPHY ON HIGH-SPEED PHOTOGRAPHY
Eastman Kodak Company, Rochester, New York, September 1956. (840 references)

BIBLIOGRAPHY ON HIGH-SPEED PHOTOGRAPHY INCLUDING SCHLIEREN AND CATHODE-RAY OSCILLOSCOPE PHOTOGRAPHY
Journal of the Society of Motion Picture and Television Engineers 1953, Vol. 61, pp. 749-757. (210 references)

Edgerton H E and Barstow F E
FURTHER STUDIES OF GLASS FRACTURE WITH HIGH-SPEED PHOTOGRAPHY
Christie D G
AN INVESTIGATION OF CRACKS AND STRESS WAVES IN GLASS
AND PLASTICS BY HIGH-SPEED PHOTOGRAPHY
Transactions of the Society of Glass Technology

Hetenyi M and Kilner D D
AN IMAGE DISSECTOR CAMERA FOR DYNAMIC STUDIES
Presented at the Spring Meeting of the Society for Experimental
Stress Analysis, Los Angeles, California, April 1955.

Schardin H
RESULTS OF KINEMATOGRAPHIC INVESTIGATION OF THE GLASS
FRACTURE PHENOMENON (German)
Glastechnische Berichte, January, March, and December 1950, Vol. 23,

Courtney-Pratt J S
A REVIEW OF THE METHODS OF HIGH-SPEED PHOTOGRAPHY
Reports of the Physical Society on Progress in Physics
1957, Vol. 20, pp. 379-432. (130 references)

Goldsmith W and Norris G W
STRESSES IN CURVED BEAMS DUE TO TRANSVERSE IMPACT
Paper presented at Third U.S. National Congress of Applied
Mechanics, Brown University, June 1958

Frocht M M and Thomson R A
STUDIES IN PHOTOPLASTICITY
Paper presented at Third U.S. National Congress of Applied
Mechanics, Brown University, June 1958

Ellis A T
TECHNIQUES FOR PRESSURE PULSE MEASUREMENT AND
HIGH-SPEED PHOTOGRAPHY IN ULTRASONIC CAVITATION
Hydrodynamics Laboratory, California Institute of Technology

Eisner R L
REVERSIBLE PHOTOELECTRIC FRINGE COUNTING
Review of Scientific Instruments

Simple modifications of a Fizeau interferometer are
shown which give a sense of direction to the passing
fringes, enabling a suitable counting system to operate
reversibly. Very fast counts can be made accurately
using an electronic circuit actuated by four phototubes
sighted on four points in the fringe pattern. An oscillo-
scope display can be used for fractional fringe inter-
polation. (Author's abstract)
DYNAMIC PHOTOELASTICITY AND RELATED TOPICS

Chronological Listing

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</tbody>
</table>
PENETRATION PHENOMENA
(3000-3099)

Subtopics

Hypervelocity impact; ballistic penetration and cratering due to projectile impact.
Bibliography

3001 Zaid M and Paul B
MECHANICS OF HIGH SPEED PROJECTILE PERFORATION
Journal of the Franklin Institute

3002 Paul B and Zaid M
NORMAL PERFORATION OF A THIN PLATE BY TRUNCATED
PROJECTILES
Journal of the Franklin Institute

An analytical investigation is made of the perforation
of a thin plate by truncated projectiles. Solutions are
presented in graphical form. The strength of the plate
is assumed to be negligible, which experimental data
show is accurate for high velocities. Solutions are
primarily concerned with loss of projectile velocity as
it passes through the plate.

3003 Zaid M and Paul B
ARMOR PENETRATION SURVEY
Ordnance
January 1956, pp. 609-611.

3004 Van Valkenburg M E, Clay W G and Huth J H
IMPACT PHENOMENA AT HIGH SPEEDS
Journal of Applied Physics

A study of high speed, metal-to-metal impact in the
velocity range of 1 to 5 mm/μsec using 1/8 inch diam-
eter spherical pellets is described. Ex-
periments relating to the mechanism of cratering and
the perforation of thin targets are presented.

(Authors' abstract)

Projectiles given high velocities by putting a hollow
cone in one face of a cylindrical explosive charge.
3005 Allen W A, Mayfield E B and Morrison H L
DYNAMICS OF A PROJECTILE PENETRATING SAND
Journal of Applied Physics

The results of an experiment are presented for the
case of a nonrotating projectile penetrating randomly-
packed sand. Results are interpreted in terms of
theories of penetration. See also article 3006.

3006 Allen W A, Mayfield E B and Morrison H L
DYNAMICS OF A PROJECTILE PENETRATING SAND, PART II
Journal of Applied Physics

3007 Huth J H, Thompson J S and Van Valkenburg M E
SOME NEW DATA ON HIGH-SPEED IMPACT PHENOMENA
Journal of Applied Mechanics, Trans. ASME

This article presents a summary of some recent experi-
mental work aimed at evaluating the role of various phys-
ical parameters in high-speed impact phenomena. Depth
of cratering in thick targets is the main interest in this
investigation. Impact velocities about 10,000 fps.

3008 Bluhm J I
STRESSES IN PROJECTILES DURING PENETRATION
Proceedings Society for Experimental Stress Analysis

Stresses in a projectile during penetration of a thin plate
are measured by attaching SR-4 type strain gages to a
stationary projectile and firing a plate at the projectile.
Force versus time records are obtained at velocities of
from 400 to 3000 fps.

3009 Craggs J
THE NORMAL PENETRATION OF A THIN ELASTIC-PLASTIC
PLATE BY A RIGHT CIRCULAR CONE
Proceedings Royal Society of Edinburg

3010 Rinehart J S
SOME OBSERVATIONS ON HIGH SPEED IMPACT
Popular Astronomy

This article was presented to a meeting of the Meteoritical
Society. The results of high speed impact tests are sum-
marized as an indication of the craters formed by the im-
pact of meteors. The meteor crater in Arizona is discussed.
This article summarizes the armor penetration work performed during the World War II with shaped charges. The mechanism of penetration by the jet formed by the liner, and the slug formed by the liner is discussed. Mathematical expressions are developed for the formation of the jet and the slug. Photographs are shown of various penetrations.

Gehring J W
OBSERVATIONS ON HIGH SPEED PELLETS AND THEIR IMPACT UPON TARGET PELLETS
B. R. L. Memorandum Report No. 704, 1953 (Unclassified)
Aberdeen Proving Ground, Maryland.

Van Valkenburg M E
MODELING OF HIGH SPEED IMPACT THROUGH THE USE OF PLASTICS
1955, OSR Report No. 1, University of Utah.

Van Valkenburg M E and Hendricks C D
METHOD FOR PRODUCING HIGH- VELOCITY METALLIC AND PLASTIC PELLETS
Journal of Applied Physics

Masket A V
THE MEASUREMENT OF FORCES RESISTING ARMOR PENETRATION
Journal of Applied Physics
1949, Vol. 20, pp. 132-140.

This paper summarizes the experimental and theoretical status of the optical chronograph developed in the course of ballistic research at the Naval Research Laboratory. The instrument together with a simple procedure for analysis of data, is capable of yielding the position velocity and deceleration of a non-plastically deforming small arms projectile during armor penetration.

(U (Author's abstract)

Lindsay J L and Masket A V
ULTRA-SPEED TRANSIENT DYNAMIC ANALYZER FOR MECHANICS AND BALLISTICS
Review of Scientific Instruments
A photoelectronic apparatus has been developed which makes possible the continuous simultaneous measurement of the depth of penetration, the speed, and the deceleration of a nondeforming small-caliber projectile during armor penetration. The basic operating principle of the apparatus is to have the flight path of the projectile pass perpendicularly through a thin parallel light beam of uniform intensity which activates a vacuum type phototube

(Author's abstract)

Decelerations as high as $10^8$ ft/sec$^2 \pm 2\%$.

3017 Beth R A
CONCRETE PENETRATION
1945, OSRD 4856.

3018 Bethe H A
AN ATTEMPT AT A THEORY OF ARMOR PENETRATION
1941, Ordnance Laboratory, Frankford Arsenal.

3019 Rinehart J S and White W C
SHAPES OF CRATERS FORMED IN PLASTER OF PARIS BY ULTRA-SPEED PELLETS
American Journal of Physics

3020 Thompson L T E and Scott E B
A MOMENTUM INTERPRETATION OF PENETRATION DATA
Memorial de l'artillerie Francaise

3021 Pugh E M, Heine-Geldren R V, Foner S and Mutschler E C
KERR CELL PHOTOGRAPHY OF HIGH SPEED PHENOMENA
Journal of Applied Physics

3022 Spells K E
VELOCITIES OF STEEL FRAGMENTS AFTER PERFORATION OF STEEL PLATES
Proceedings Physical Society of London

3023 Pack D C and Evans W M
PENETRATION BY HIGH VELOCITY JETS I, II
Proceedings Physical Society of London
April 1951, Series B, pp. 298-310.
Sonntag G
CRITICAL CONSIDERATIONS OF THE DYNAMIC RESISTANCE OF A PLATE CONSISTING OF SEVERAL LAYERS, STRESSED BY IMPACT (German)
Zeitschrift für Angewandte Mathematik and Mechanik, Berlin

The author considers two cases of impact stress in a plate consisting of several layers. The author investigates the question of whether it is of advantage to divide the plate into several layers in order to reduce the impact force, decrease the deceleration of the point of impact and thereby decrease the shear stress around the impact center.

(Abstract as it appears in Applied Mechanics Review).

Nishiwaki J
RESISTANCE TO THE PENETRATION OF A BULLET THROUGH AN ALUMINUM PLATE
Journal of the Physical Society of Japan, Tokyo
September-October 1951, Vol. 6, pp. 374-378.

Heine-Geldren R V and Pugh E M
THE PHOTOGRAPHY OF HIGH-SPEED METALLIC JETS
Meteoritics
1953, Vol. 1, No. 1, pp. 5-10.

Rostoker N
THE FORMATION OF CRATER'S BY HIGH SPEED PARTICLES
Meteoritics

This article is a study of the craters formed by high-speed particles (>10,000 ft/sec). The theories of Opik are compared to the theory that has been used for lower velocities (volume of crater proportional to kinetic energy). Experimental results are shown.

Problem is well discussed.

Allen W A, Mapes J M and Wilson W G
AN EFFECT PRODUCED BY OBLIQUE IMPACT OF A CYLINDER ON A THIN TARGET
Letter in Journal of Applied Physics

Letter to the editor describes a phenomenon observed when a circular steel cylinder is fired at ordnance velocities at thin lead targets (0.005 - 0.010 in).

If a critical angle of incidence of the projectile on the target is exceeded the front surface of the cylinder is marked by a series of ridges. Photographs are shown of the phenomenon.
The role that pulverization of the target material may play in absorbing the energy of an impacting missile is discussed. The energy absorbed depends upon the area of the new surfaces formed. Correlation is made to impact of meteorites.

The frictional adhesion between projectile and target during a ballistic penetration has been measured with a torsion-type Hopkinson bar. The apparatus allows measurement of the torsional adhesion of a spinning projectile during target penetration. By assuming the friction resisting rotation to be equal to that resisting axial penetration, the energy loss due to friction was computed. The results show that the torque time pattern during penetration of a "mechanically" clean projectile can be predicted with the assumption of a frictional energy loss just sufficient to keep the sliding surfaces at the melting temperature of the metal. Metallographic analysis of the target metal at the projectile interface gives a further indication of a molten interface. In these tests, sliding friction accounts for about 3 per cent of the striking energy of the projectile common surface contaminants, not necessarily special lubricants, reduce this loss to less than 1 per cent. (Author's abstract)

The problem of armor penetration of thin plates is considered from a quasi-dynamical approach. Equations are derived for the energy dissipation due to plastic deformation and for heating of the projectile target interface. Both the conical and the ogival head are considered in the application of the general equations. (Author's abstract)

de Callatay X
BEHAVIOR OF METALS UNDER IMPACT LOADING AND THE MECHANISM OF CRATERING
University of Utah, Institute for the Study of Rate Processes, October 1956
Library of Congress P.B. 125534.
Wax targets are used to study the condition when impact velocities are greater than the sonic velocity of the target. The penetration was found to vary linearly with the cube root of the pellet velocity up to velocities in excess of twice the sonic velocity of the target material.
The dynamic interaction of steel projectiles striking aluminum alloy plates at normal incidence has been investigated for geometrically simple projectiles. Observations on the penetration craters formed by flat-nose projectiles and certain idealized stress wave considerations lead to a theory of cavity formation. This can be formulated quantitatively as the relationship of the depth of penetration to (1) impact velocity, (2) certain functions of the characteristic impedances of the target and projectile materials, and (3) an empirically determined dynamic elastic limit. This theory agrees with measurements for small projectiles traveling at velocities between 300 and 850 meters/sec. Velocity ranges of dominantly elastic and dominantly plastic target behavior can be identified. (Author's abstract)
Bloxsom D E
ELECTRICALLY DRIVEN SHOCK TUBE
Journal of Applied Physics

HIGH VELOCITY IMPACT CRATERS IN LEAD-TIN ALLOYS
University of Utah Report No. TR-OSR-13
January 1958.
PENETRATION PHENOMENA

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BEHAVIOR OF MATERIALS AT HIGH-STRAIN RATES
(1200-1299)

Subtopic

Time delay for yielding.
BEHAVIOR OF MATERIALS AT HIGH-STRAIN RATES
(1200-1299)

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A MATHEMATICAL INTERPRETATION OF SOME EXPERIMENTS
ON PLASTICS AND RUBBERLIKE MATERIALS
Rheology Congress Proceedings pp. 73-78

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HIGH SPEED TENSILE DATA FOR CELLULOSE ACETATE BUTYRATE
U. S. Redstone Arsenal, July 1956, order from O. T. S.

1203 Maxwell B, Harrington J P and Monica R E
TENSILE IMPACT PROPERTIES OF SOME PLASTICS
Princeton University, order from Library of Congress P.B. 124336.

1204 DYNAMIC SHEAR PROPERTIES OF RUBBER-LIKE POLYMERS
Journal of Applied Mechanics, Trans. ASME
1951, Vol. 73, p. 195.

1205 Volterra E, Eubank R A and Muster D
AN INVESTIGATION OF THE DYNAMIC PROPERTIES OF PLASTICS
AND RUBBER-LIKE MATERIALS
Proceedings Society for Experimental Stress Analysis

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SOME THEORETICAL CONSIDERATIONS ON THE DYNAMIC
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Proceedings Royal Society of London

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SIVE STRESS-STRAIN PROPERTIES OF POLYSTYRENE
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THE MECHANICAL PROPERTIES OF CERTAIN STEELS AS
INDICATED BY AXIAL DYNAMIC LOAD TESTS
Proceedings Society for Experimental Stress Analysis

Stress strain curves are obtained for several steels at
strain rates up to about 30 in/in/sec. Strain measured
by SR-4 type gage on specimen. Stress measured by
dynamometer. Unique loading arrangement used involv-
ing shock table and specimen connected to table. Speci-
men held mass which caused load when table was accel-
erated. Not short time impact.

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STRESS-STRAIN CHARACTERISTICS OF METALS AT HIGH RATES
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British Journal of Applied Physics

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NACA TN No. 868, October 1942.

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Davis E A
THE EFFECT OF THE SPEED OF STRETCHING AND THE RATE OF LOADING ON THE YIELDING OF MILD STEEL

Elam C F
THE INFLUENCE OF RATE OF DEFORMATION ON THE TENSILE TEST WITH SPECIAL REFERENCE TO THE YIELD POINT IN IRON AND STEEL

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THE TENSILE YIELD STRENGTH OF CERTAIN STEELS UNDER SUDDENLY APPLIED LOADS

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EXPERIMENTAL DETERMINATION OF THE YIELD POINT OF MILD STEEL UNDER IMPACT LOADING (German)

Kraft, Sullivan and Tipper
THE EFFECT OF STATIC AND DYNAMIC LOADING AND TEMPERATURE ON THE YIELD STRESS OF IRON AND MILD STEEL IN COMPRESSION

Wood D S and Clark D S
THE INFLUENCE OF TEMPERATURE UPON THE TIME DELAY FOR YIELDING IN ANNEALED MILD STEEL

Parker E R and Smith E A
HIGH SPEED TENSILE IMPACT TESTS ON SINGLE CRYSTAL AND POLYCRYSTALLINE BARS OF COPPER
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THE MECHANICAL PROPERTIES OF SOME METALS AND ALLOYS BROKEN AT ULTRA SPEEDS
Journal, Institute of Metals
1937, Vol. 61, p. 61.

1224 Hawkes G A
TENSION AND TORSION PROPERTIES OF SOME METALS UNDER REPEATED DYNAMIC LOADING
Proceedings Institution of Mechanical Engineers

1225 Author unknown
EXPERIMENTS ON THE EFFECT OF RATE OF TESTING ON THE CRITERION OF FAILURE OF CERTAIN MILD STEELS WHEN SUBJECT TO DYNAMIC TORSION AND STATIC TENSILE STRESSES
Proceedings Institution of Mechanical Engineers

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DYNAMIC ELASTIC MODULI OF IRON ALUMINUM AND FUSED QUARTZ
Journal of Applied Physics

1226a Author unknown
THE BEHAVIOR OF METALS UNDER TENSILE LOADS OF SHORT DURATION
Proceedings Institution of Mechanical Engineers (B)

1227 Calvert N G
EXPERIMENTS ON THE EFFECT OF RATE OF TESTING ON THE CRITERION OF FAILURE OF CERTAIN MILD STEELS
1955, Institution of Mechanical Engineers.

1228 Klinger R F
TENSILE PROPERTIES OF SOME AIRCRAFT STRUCTURAL MATERIALS AT VARIOUS RATES OF LOADING
Proceedings American Society for Testing Materials

1229 Eder F X
MEASUREMENT OF THE DYNAMIC STRENGTH OF PLASTIC MATERIALS (German)
Zeitschrift für Angewandte Physik

Starting from theoretical considerations, the importance of experimental conditions in determining the influence...
of strain rate on the mechanical properties of materials is pointed out. Some interesting and hitherto unpublished experimental results, obtained by the author by means of an electromagnetic apparatus in which copper wires were loaded by a brief, strong current impulse, are briefly discussed. The effects of the propagation of plastic waves at high-test strain rates (with strain hardening) and of the length of test bar on accuracy of measurement, are considered in this paper.

1230

Meyer R H
EFFECT OF SPEED OF TESTING ON THE TENSILE PROPERTIES OF AUSTENITIC STAINLESS STEEL SHEETS
American Society for Testing Materials Bulletin Nos. 158,162
May, December 1949, pp. 57-62 and pp. 53-55.

1231

Author unknown
THE EFFECT OF RATE OF LOADING ON THE BENDING AND COMPRESSION STRESSES OF WOOD (Swedish)

1232

Warnack F V and Pope J A
THE CHANGE IN MECHANICAL PROPERTIES OF MILD STEEL UNDER REPEATED IMPACT

The dynamic properties of various plastics are determined. The experimental method involves placing the specimen on the end of a long bar. Another bar is impacted onto the first bar as in a ballistic pendulum. The movement of the two bars together after impact is recorded photographically by high-speed photography.

1233

Fitzgibbon D P
STRESS-STRAIN CHARACTERISTICS OF MATERIALS AT HIGH STRAIN RATE, PART I
Structural Mechanics Research Lab., The University of Texas.

A photoelectric method for measuring displacements during high-velocity impacts is described. The theory of the system is discussed in detail and a prototype system which was built and tested is described. The performance of the prototype system is evaluated by comparing the results which it gives with results obtained by other methods of measurement. The system was found capable of a resolution of at least .01 inch.

(Author's abstract)
The stress-strain curve of a material for dynamic loads is chosen as the basic dynamic property of the material. The importance of strain-rate and other factors affecting it are discussed and some historical remarks presented. Then the present techniques of dynamic testing are discussed. Some semi-analytic approaches to estimate the theoretical relationships are given. After this some qualitative estimates of the nature of behavior of stress-strain curves are presented. In order to be able to study the general behavior of a material under dynamic loads, the necessity of experiments with controlled strain rates is pointed out and design of some experiments of this kind is given. (Authors' abstract)
IMPACT MEASUREMENT DEVICES
(2100-2199)
IMPACT MEASUREMENT DEVICES
(2100-2199)

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A METHOD OF MEASURING THE PRESSURE PRODUCED IN THE
DETONATION OF HIGH EXPLOSIVES OR BY THE IMPACT OF
Bullets
Transactions Royal Society of London
1914, Vol. 213A.

2102 Davies R M
A CRITICAL STUDY OF THE HOPKINSON PRESSURE BAR
Transactions Royal Society of London

2103 Bell J F
DETERMINATION OF DYNAMIC PLASTIC STRAIN THROUGH
THE USE OF DIFFRACTION GRATINGS
Journal of Applied Physics
1956, Vol. 27, pp. 1109-1113.

A new method is given for measuring dynamic plastic
strain in metals under central impact. Strain-time
curves for initial and reflected wave fronts have been
determined using at gauge length of 1/32 inch. The
measurements are made by observing the behavior
during strain of the diffracted and central images
of an 8300 line reflection grating ruled on the speci-
men surface.

2104 Courtney-Pratt J S
A NEW METHOD FOR THE PHOTOGRAPHIC STUDY OF FAST
TRANSIENT PHENOMENA

2105 Elliott K W T and Wilson D C
AN OPTICAL PROBE FOR ACCURATELY MEASURING DISPLACE-
MENTS OF A REFLECTING SURFACE
Journal of Scientific Instruments

The probe described is capable of accurately measuring
the displacement of a plane reflecting surface along its
normal without making mechanical contact with it. The image of an illuminated grating of special construction is formed on the surface to be observed, and the light reflected from this surface then forms an image of equal size on a second, exactly similar grating. The disposition of the second image relative to the second grating depends upon the position of the probe relative to the plane surface.

Displacements may be measured with a standard deviation of $2.8 \times 10^{-5}$ in. Device is apparently for static deflections but appears to have promise for dynamic conditions.

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2106 Barret P
MEASUREMENT OF SMALL DISPLACEMENTS OF A PLANE SURFACE WITH A SEMI-VIRTUAL SLIT MODULATOR (French)
Journal de Physique et le Radium, Paris
June 1956, Vol. 17, No. 6, p. 29.

This method is suitable for measuring the displacement of a polished or plated surface. A metal plate such as a razor blade is mounted parallel to and about 0.01 mm away from the surface observation of the slit at grazing incidence shows a real and a virtual (reflected) edge. Variations in the magnitude of this "semi-virtual slit" are used to modulate a beam of light falling on a photocell for recording static or dynamic displacements of the surface.

(Author's abstract)

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2107 Kirby P L
APPARATUS FOR THE MEASUREMENT OF TIME OF IMPACT
British Journal of Applied Physics

An apparatus is described for measuring the time of impact of a ball impacting on a plane surface. A direct connection to the ball is not necessary. The plane surface forms one surface of a capacitor. The other capacitor electrode is a ring at about 5 mm above the plane surface. The ball drops through the ring which changes the capacitance. While the ball is in contact with the surface, the capacitance is unchanged and therefore a measure of the time of impact.

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2108 Krafft J M
WEIGH BAR APPARATUS FOR MEASURING FORCES RESISTING BALLISTIC PENETRATION
Review of Scientific Instruments
Dineff J, Carson J A and Charters A C
PISTON-TYPE STRAIN GAGE FOR MEASURING PRESSURES IN
INTERIOR BALLISTICS RESEARCH
Review of Scientific Instruments

Dapigny J, Kieffer J and Vodar B
SHOCK WAVES IN A DENSE MEDIUM. II EXPERIMENTAL
METHODS AND SOME RESULTS OF MEASUREMENTS MADE
BY THE METHOD OF ULTRA RAPID RADIOGRAPHY

Muster D F and Volterra E G
USE OF A ROTATING DRUM CAMERA FOR RECORDING IMPACT
LOADING DEFORMATIONS
Journal of the Society of Motion Picture and Television Engineers

Mintrop H
MEASUREMENTS OF LARGE IMPACT FORCES (German)
Schweizer Archiv für Angewandte Wissenschaft and Technik, Zurich,

Author's method of measurement of impact forces is
based on Hertz classical equations, concerning the
contact between elastic solid bodies. In order to
verify their validity and utility for this purpose, ex-
tensive static and dynamic tests were made, where
the contact areas between spheres and plane solid
surfaces were measured and the corresponding forces
observed and computed. Balls were dropped on plane
surfaces, and new methods, one of them involving the
use of high-speed films, were used to measure the time
of impact and the diameter of the circular contact sur-
face. (Author's abstract)

MacLaren D D, Taylor I J and Beadle L S
A MECHANICAL DEFLECTION GAGE--AN INSTRUMENT FOR
MEASURING DISPLACEMENT UNDER IMPACT
Proceedings Society for Experimental Stress Analysis
Vol. 10, No. 1, pp. 135-142.

Taylor I J
SOME RECENT DEVELOPMENTS OF THE MECHANICAL DEFLEC-
TION GAGE
Proceedings Society for Experimental Stress Analysis
Vol. 10, No. 1, pp. 142-146.
MacDonald R J, Carlson R L and Lankford W T
APPARATUS FOR DETERMINATION OF STRESS-STRAIN PROPERTIES AT HIGH RATES OF STRAIN

This article describes a machine used for tensile testing up to a strain rate of 190 inches/min. Load measurements are made with a dynamometer made from electric strain gages (SR-4). Head travel is controlled hydraulically. Strain of the specimen is measured with a clip gage extensometer placed between the loading heads.

Hudson D E and Terrell O D
A PRE-LOADED SPRING ACCELEROMETER FOR SHOCK AND IMPACT MEASUREMENTS
Proceedings Society for Experimental Stress Analysis Vol. 9, No. 1, pp. 1-10.

Durelli A J and Dally J W
SOME PROPERTIES OF STRESSCOAT UNDER DYNAMIC LOADING

Fusfeld H I and Feder J C
STUDY OF DEFORMATION AT HIGH STRAIN RATES USING HIGH-SPEED MOTION PICTURES

Fanning R and Bassett W V
MEASUREMENT OF IMPACT STRAINS BY A CARBON STRIP EXTENSOMETER

Caughey T K and Hudson D E
A RESPONSE SPECTRUM ANALYZER FOR TRANSIENT LOADING STUDIES

Vigness I
SOME CHARACTERISTICS OF NAVY "HIGH IMPACT" TYPE SHOCK MACHINES
A response spectrum (shock spectrum) is the response of a series of a single-degree-of-freedom systems of given damping to a shock or vibratory motion, as a function of the frequencies of the simple systems. An oscillographic galvanometer is a single-degree-of-freedom system having a rotational response to an exciting current. If the exciting current is made proportional to the amplitude of the motion, the response of the galvanometer to the current will be proportional to that of a single-degree-of-freedom system to the motion, provided their natural frequencies and damping properties are the same. A commercial galvanometer-type oscillograph has been obtained having twelve undamped galvanometer elements with natural frequencies in the range between 10 and 2500 cps. Damping by electrical means, has been made adjustable between about 3 and 50% of critical. Associated circuitry have been constructed so that electrical playback of recordings of shock and vibratory motions can be conveniently analyzed. Calibration techniques are described and examples are given for analysis of simple and complex shock motions. (Authors' abstract)
2127 Jones J L
N. R. L. SHOCK AND VIBRATION BULLETIN NO. 8
N. R. L. Report No. S-3276
March 1948.

2128 Conrad R W and Vigness I
CALIBRATION OF ACCELEROMETERS BY IMPACT TECHNIQUES
Proceedings Instrument Society of America

2129 Perls T A and Kissinger C W
HIGH G ACCELEROMETER CALIBRATION BY IMPACT METHODS
WITH BALLISTIC PENDULUM AIR GUN, AND INCLINED TROUGH
Paper presented at First International Instrument Congress and
Exposition of Instrument Society of America

2130 Goodier J N, Jahsman W E and Ripperger E A
AN EXPERIMENTAL SURFACE-WAVE METHOD FOR RECORDING
FORCE-TIME CURVES IN ELASTIC IMPACTS
LATERAL IMPACT - BEAMS AND PLATES
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A STUDY OF THE PROPAGATION OF FLEXURAL WAVES IN
ELASTIC BEAMS
Journal of Applied Mechanics, Trans. ASME,
1957, Vol. 79, pp. 431-434
Discussion ASME, Journal of Applied Mechanics

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STRESSES IN BEAMS DURING TRANSVERSE IMPACT
Journal of Applied Mechanics, Trans. ASME

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Transactions American Society of Mechanical Engineers

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IMPACT OF A MASS STRIKING A BEAM
Transactions American Society of Mechanical Engineers
1940, p. A-129.

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IMPACT OF A MASS ON A DAMPED ELASTICALLY SUPPORTED
BEAM
Journal of Applied Mechanics, Trans. ASME

4006 Duwez P E, Clark D S and Bohenblust H F
BEHAVIOR OF LONG BEAMS UNDER IMPACT LOADING
Journal of Applied Mechanics, Trans. ASME
1950, Vol. 72, p. 27.
An experimental investigation designed to study the phenomena incident to the oblique collision of 1/2-inch-diameter steel spheres with mild-steel and annealed drill-rod beams at oblique angles of incidence has been undertaken. Initial ball velocities ranged from 30 ft/sec to 150 ft/sec, beam sizes varied from 1/4 in. x 1/4 in. to 3/4 in. x 3/4 in., angles of incidence were chosen from 85 deg to normal incidence, and simply supported, clamped, and free beams were employed. Information is reported concerning the values of maximum bending stress at various positions along the beam as function of the angle of incidence and as a function of beam size for various angles of incidence. The progressive dispersion of the initial transient has been examined in detail. The effect of end supports, effective beam length, and repetitive shots into the same hole upon stress are described.
Goldsmith W and Cunningham D M
KINEMATIC PHENOMENA OBSERVED DURING THE OBLIQUE
IMPACT OF A SPHERE ON A BEAM
Journal of Applied Mechanics, Trans. ASME

Experimental data relating to the kinetics of oblique impact of a 1/2-inch-diameter steel sphere upon steel beams at initial velocities ranging from 30 to 150 fps are presented. The variation of beam deflection, contact duration, trajectory of the sphere, and contour topography with angle of incidence, beam size, and initial velocity have been determined and the velocity of propagation of several waves has been ascertained.

Symonds P S
DYNAMIC LOAD CHARACTERISTICS IN PLASTIC BENDING OF BEAMS
Journal of Applied Mechanics, Trans. ASME

Eringen A C
TRANSVERSE IMPACT ON BEAMS AND PLATES
Journal of Applied Mechanics, Trans. ASME

Wang A J
PERMANENT DEFLECTION OF A PLASTIC PLATE UNDER BLAST LOADING
Journal of Applied Mechanics, Trans. ASME

Conroy M F
PLASTIC DEFORMATION OF SEMI-INFINITE BEAMS UNDER TRANSVERSE IMPACT LOADING AT THE FREE END
Journal of Applied Mechanics, Trans. ASME

The object of this paper is to consider the plastic deformation of the semi-infinite beams subject to dynamic transverse loading at the free end. The type of loading considered is that of a constant bending moment, together with a transverse force the magnitude of which is inversely proportional to the square root of time. Part 1 of the paper consists of a plastic-rigid analysis of the problem, based on the plastic-rigid analysis of infinite beams under transverse, constant velocity, impact loading developed by the author. Part 2 of the paper consists of an elastic-plastic solution of the problem, based on a theoretical analysis of the plastic deformation of infinite beams subject to transverse, constant-velocity impact loading developed by H. F. Bohnenblust. Specific problems are considered for which the deflection solutions obtained by elastic ideally plastic and rigid ideally plastic analyses are compared. (Author's abstract)
Salvadori M G and Weidlinger P
ON THE DYNAMIC STRENGTH OF RIGID-PLASTIC BEAMS UNDER
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Proceedings American Society of Civil Engineers, Journal of

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RECENT INVESTIGATIONS OF THE STRAIN PRODUCED IN BEAMS
BY LATERAL IMPACT LOADING (German)
Forschungsarbeiten auf dem Gebiet des Ingenieurwesens, Berlin

Seiler J A, Cotler B A and Symonds P S
IMPULSIVE LOADING ON ELASTIC-PLASTIC BEAMS
Journal of Applied Mechanics, Trans. ASME

A simply supported uniform beam of ductile material,
subjected to impulsive loading such that the initial
velocity is a half-sine wave, is considered in this paper.
The elastic and elastic-plastic motions are discussed
under the assumption that plastic flow is confined to one
cross section, and the final deformations are compared
with those computed from an analysis which neglects all
elastic deformations. The purpose of the work is to pro-
vide further information which may help in estimating the
range of validity of the latter ("rigid-plastic") type of
analysis. (Authors' abstract)

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RESPONSE OF AN ELASTIC DISK TO IMPACT AND MOVING LOADS
Quarterly Journal of Mechanics and Applied Mathematics

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IMPACT OF FINITE BEAMS OF DUCTILE MATERIAL
Journal of Mechanics and Physics of Solids

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THE TRANSMISSION OF A SPHERICAL SOUND WAVE THROUGH A
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Brown University, April 1955
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TRANSVERSE WAVES IN BEAMS
Proceedings Society for Experimental Stress Analysis, 1951, Vol. 8, No. 2, pp. 69-82.

Mori D
LATERAL IMPACT ON BARS AND BEAMS

Experimental results are presented for the effect of axial load on the propagation of bending waves in slender beams. Theory is presented and compared to experimental results. Application of method to measurement of tensile load in wires by using results of this work.

Goldsmith W and Cunningham D M
OBLIQUE IMPACT OF SPHERES UPON SIMPLY SUPPORTED STEEL BEAMS

Alverson R C
IMPACT WITH FINITE ACCELERATION TIME ON ELASTIC AND ELASTIC-PLASTIC BEAMS

The purpose of the work described in this paper was to provide information on the elastic and plastic deformation of steel beams subjected to transverse impact. The particular impact problem treated was chosen to correspond to conditions in tests in which a beam initially at rest is struck by a massive hammer, so that a specified change of velocity is imposed at a certain cross section in a small time interval. In the present analysis the initial elastic and subsequent elastic-plastic motions were obtained by methods similar to those used by Bleich and Salvadori (3). As in (3), it is assumed that plastic deformation occurs only at a single stationary plastic hinge (in this case at the struck cross section). Results obtained are compared with those of a "rigid-plastic" solution of the same problem, in which plasticity conditions are correctly taken into account but elastic vibrations are not included.

Dohrenwend C O, Drucker D C and Moore P
TRANSVERSE IMPACT TRANSIENTS
Fischer E G
LATERAL VIBRATION AND STRESS IN A BEAM UNDER SHOCK MACHINE LOADING
Proceedings Society for Experimental Stress Analysis

Locklin/Mills
DYNAMIC RESPONSE OF THIN BEAMS TO AIR BLAST
Ballistic Research Laboratories, Report No. 787.

This paper presents a comparison of the theoretically predicted and observed elastic responses of thin simply supported beams and of cantilever beams to air-blast loading. The theoretical responses are predicted from the linear "small-deflection" beam theory and compared to motions observed with a high-speed motion picture camera. The agreement of observed deflections with predicted ones is adequate for the thicker beams where the deflections were small, but inadequate for the thinner beams where the deflections were large. (Authors' abstract)

Harris J I
LARGE DEFLECTIONS OF NON-UNIFORM ELASTIC BEAMS SUBJECTED TO TRANSIENT LOADS
Ballistic Research Laboratories, APG, Memo Report No. 1105, October 1957.

This report presents a method of solving the non-linear equation for large flexing motions of thin beams subjected to transient loads. The small deflection linearized equation is solved by successive approximation, and this solution is extended to large deflections by a perturbation scheme. The solution shows that the apparent dynamic load on any normal mode is not equal to the applied load. Because no experimental results on non-uniform beams are available, large deflections for a uniform cantilevered beam are predicted from the general solution and compared with experimental results. Agreement between experimental results and the general solution is better than that between experiment and the predictions from the solution of the linearized equations. (Author's abstract)

Baker W E and Allen F J
THE DAMPING OF TRANSVERSE VIBRATIONS OF THIN BEAMS IN AIR
Ballistic Research Laboratories, APG, BRL Report No. 1033 October 1957.

A non-linear partial differential equation describing the free transverse vibration of thin beams in air is formulated. The equation accounts for two types of force on the beam caused by its motion through the air and for the force caused by internal friction of the beam material, in addition to the usual elastic and inertia forces. An approximate solution to the equation is obtained by a perturbation method.
A series of experiments were conducted at large initial vibration amplitude to corroborate the theory, which predicts that "pressure drag" air damping is proportional to amplitude and that "viscous drag" air damping and internal damping are independent of amplitude. The dependence of pressure drag damping on air pressure is also predicted. The experimental results show reasonable agreement with the theory; however, the importance of viscous air drag damping relative to that of internal friction cannot be determined. (Authors' abstract)

4035

Allen F J
AN ELASTIC-PLASTIC THEORY OF THE RESPONSE OF CANTI-LEVERS TO AIR BLAST LOADING
Ballistic Research Laboratories, Memorandum Report No. 886.

An elastic-plastic theory of the response of cantilevers loaded by air blast waves is proposed and the predictions obtained from it are compared to experimental results. The theory is capable of providing estimates for the types of beams considered; it is expected to furnish more precise estimates for certain other beams of practical interest.

A method is developed by means of which a high speed digital computing machine can rapidly and accurately predict dynamic elastic strains, moments, and deflections in certain structures. (Author's abstract)

4036

Allen F J and Rally F
A PLASTIC-RIGID THEORY OF THE RESPONSE OF BEAMS TO AIR BLAST LOADING
Ballistic Research Laboratories, Memorandum Report No. 811.

This report presents a "plastic-rigid" theory of cantilever and simply-supported beams subjected to air blast loading. The equations of motion are derived and the theoretical deformations found. Theoretically predicted permanent deformations are compared to experimentally determined permanent deformations of thin rectangular cross-section metal beams subjected to air blast load. The theory predicts correctly the occurrence of localized regions of plastic deformation, but does not accurately predict the amount of this deformation. However, the results suggest a modification of the theory which is expected to be in better agreement with experiment. (Authors' abstract)
Plass H J
SOME SOLUTIONS OF THE TIMOSHENKO BEAM EQUATION FOR SHORT PULSE-TYPE LOADING
Journal of Applied Mechanics, Trans. ASME

A collection of solutions to the Timoshenko beam equation is presented. Various types of support conditions and impact conditions are included. In every case the impact is assumed to be a pulse in the form of a half-sine wave. The results were found numerically, using the method of characteristics, except for one case, which was done in addition by the Laplace transform method, for check purposes. Agreement with experiment is good except for a pulse of duration comparable to the time required for the bending-type wave to travel a distance of one diameter. Discussion is included of the differences among the various cases studied. (Author's abstract)

Abramson H N
FLEXURAL WAVES IN ELASTIC BEAMS OF CIRCULAR CROSS SECTION
Journal of the Acoustical Society of America

The exact equations of elasticity are employed in an investigation of the flexural vibrations of a solid circular cylinder. Contrary to previous work, it is shown that the phase-velocity-wavelength relation has an infinity of branches, thus overcoming objections, on physical grounds, which have been made to the earlier work. The three lowest branches of this dispersion relation are calculated, and these are used to study the rate of energy transmission in terms of group velocity. (Author's abstract)
MISCELLANEOUS
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PULSE GENERATOR BASED ON HIGH SHOCK DEMAGNETIZATION
OF FERROMAGNETIC MATERIAL
Journal of Applied Physics

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SHOCK SPECTRUM AS A CRITERION OF SEVERITY OF SHOCK
IMPULSES
Journal of the Acoustical Society of America

Shock impulses have not as yet yielded to any practical
method of spectral analysis that would permit convenient
exact calculation of all the peak internal responses of
hardware subject to such accelerations, and also permit
comparison of shock severities by inspection. The shock
spectrum with a few supplementary techniques, provides
adequate insight into the responses of a one degree of
freedom resonator. As an indication of the responses of
a system with several coupled degrees of freedom, a sec-
ond-order shock spectrum is defined. An oscillatory con-
stituent of the spectrum is also defined in such a way as
to be applicable to any order of spectrum. Investigation
of these two concepts leads to the conclusion that if the
first-order shock spectrum technique is to be used as a
basis for comparison of the severity of a laboratory test
shock with that of a service shock, spectra should be
plotted for both positive and negative directions. More-
over, when feasible, such spectra should ordinarily be
plotted as distinct curves for the intervals during and
after the test shock, and the oscillatory constituent for
the interval during the shock should be estimated.
(Authors' abstract)

5003 Conn W M
STUDIES ON THE MECHANISM OF ELECTRICAL WIRE EXPLO-
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Zeitschrift für Angewandte Physik
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LIMITING CONDITIONS FOR JET FORMATION IN HIGH VELOCITY COLLISIONS
Journal of Applied Physics

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Journal of Applied Mechanics, Trans. ASME

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EFFECT OF PULSE SHAPE ON SIMPLE SYSTEMS UNDER IMPULSIVE LOADING
Transactions American Society of Mechanical Engineers

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APPLICATION OF ST. VENANT'S PRINCIPLE IN DYNAMICAL PROBLEMS
Journal of Applied Mechanics, Trans. ASME
1955, Vol. 77, p. 204.

Schmitt A F
A METHOD OF STEPWISE INTEGRATION IN PROBLEMS OF IMPACT BUCKLING
Journal of Applied Mechanics, Trans. ASME

The equations for the dynamic buckling of an axially impacted column are discussed. A method is presented for the calculation of approximate load and deflection variations in problems of high-velocity impact. The method may be extended for cases wherein the stresses exceed the elastic limit. Results of calculations are presented for two cases. In one of these, agreement with a previous exact solution is found to be good.

(Author's abstract)
Yoh-Han Pao
EXTENSION OF THE HERTZ THEORY OF IMPACT TO THE VISCOELASTIC CASE
Journal of Applied Physics

The problem considered is that of two bodies coming into normal contact over smooth curved surfaces. The initial relative velocity and the total kinetic energy involved is low. Contact is, however, confined to such small volumes of the objects involved that very high concentrations of energies are obtained at those places. The rates of application of stress are correspondingly high. The Hertz solution to this type of problem provides a useful approximation in the case of elastic objects.

In the present treatment one of the impinging bodies is of viscoelastic material. Two viscoelastic bodies may also be treated if they are of the same material. The Laplace transform method is used to obtain the viscoelastic expression for the force developed between the two surfaces. This expression is then applied to the impact case. The expression can also be applied to other truly static cases; e.g., contact between gear tooth surfaces.

The results are of technological interest, since it is not possible to say if a plastic is suitable for a certain category of impact applications, unless the rates of straining or stressing obtained in those applications can be estimated. (Author's abstract)

Calvert N G
IMPACT TORSION EXPERIMENTS
Institution of Mechanical Engineers, 1955.

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THE EQUIVALENT STATIC ACCELERATION OF SHOCK MOTIONS
Proceedings Society for Experimental Stress Analysis
1948 Vol. 6, No. 2, pp. 150-158.

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THE DETERMINATION OF STATIC AND DYNAMIC YIELD STRESSES USING A STEEL BALL

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A CONTRIBUTION TO THE THEORY OF ELASTIC WAVES PRODUCED BY SHOCK
Czech Journal of Physics
1953, No. 2, pp. 97-119.
Gerard G and Becker H
COLUMN BEHAVIOR UNDER CONDITIONS OF COMPRESSIVE STRESS WAVE PROPAGATION
Journal of Applied Physics

Krafft J M
ELIMINATION OF THE TRANSIENT STRAIN FLUCTUATIONS WHICH RESULT FROM LONGITUDINAL IMPACT OF BARS
Proceedings Society for Experimental Stress Analysis

The longitudinal impact of cylindrical bars results in a rapid strain fluctuation superimposed upon a constant strain. These transient fluctuations are eliminated by cushioning the impact surfaces with grease or solder. Magnetostriiction is also shown to be partly responsible.

Forkois H M, Conrad R W and Vigness I
PROPERTIES OF BOLTS UNDER SHOCK LOADING
Proceedings Society for Experimental Stress Analysis

Pian T H H and Siddall J N
PREDICTION OF STRESSES IN A STRUCTURE UNDER AN ARBITRARY DYNAMIC LOADING
Proceedings Society for Experimental Stress Analysis

Zener C and Feshback H
A METHOD OF CALCULATING ENERGY LOSSES DURING IMPACT
Journal of Applied Mechanics, Trans. ASME

Ringleb F O
MOTION AND STRESS OF AN ELASTIC CABLE DUE TO IMPACT
Journal of Applied Mechanics, Trans. ASME

Hodge P H
INFLUENCE OF BLAST CHARACTERISTICS ON THE FINAL DEFORMATION OF CIRCULAR CYLINDRICAL SHELLS
Journal of Applied Mechanics, Trans. ASME

Goodier J N and Jahsman W E
PROPAGATION OF A SUDDEN ROTATIONAL DISTURBANCE IN AN ELASTIC PLATE IN PLANE STRESS
Journal of Applied Mechanics, Trans. ASME
Detailed results are found for two plane-stress problems of an elastic plate with a hole from which a symmetrical disturbance is propagated. In the first a uniform shear stress is suddenly applied and maintained at the hole. In the second a uniform (rotary) velocity is suddenly applied and maintained. The subsequent motion is entirely rotary and involves shear stress only. The problems are mathematically analogous to those of symmetrical pressure and radial velocity at the hole, already solved by Kromm, and his analysis is followed. The existence of a similar analogy in the statistical cases is well known. (Author's abstract)

5025 Mindlin R D and Bleich H H
RESPONSE OF AN ELASTIC SHELL TO TRANSVERSE STEP SHOCK WAVE
Journal of Applied Mechanics, Trans. ASME

5026 Tillett J P A
FRACTURE OF GLASS BY SPHERICAL INDENTERS
Proceedings Physical Society

5027 Tillett J P A
A STUDY OF THE IMPACT OF SPHERES ON PLATES
Proceedings Physical Society

5028 Davidson T and Meier J H
IMPACT ON PRISMATICAL BARS
Proceedings Society for Experimental Stress Analysis

5029 Shepler P R
EXPLOSIVE IMPACT TESTS
Proceedings Society for Experimental Stress Analysis

5030 Frankland J M
EFFECTS OF IMPACT ON SIMPLE ELASTIC STRUCTURES
Proceedings Society for Experimental Stress Analysis
1948, Vol. 6, No. 2, pp. 7-27.

5031 Hudson G E
A METHOD OF ESTIMATING EQUIVALENT STATIC LOADS IN SIMPLE ELASTIC STRUCTURES
Proceedings Society for Experimental Stress Analysis
Claflin W M
THE EXPERIMENTAL DETERMINATION OF THE DYNAMIC STRUCTURAL RESPONSE OF AN AIRPLANE TO IMPACT LOADINGS

Welch W P
A PROPOSED NEW SHOCK MEASURING INSTRUMENT

Pederson A H and MacCarthy J G
DETERMINATION OF THE EFFECT OF GROUND IMPACT FORCES IN THE AIRPLANE DROP TEST

Mindlin R D, Stubner F W and Cooper H L
RESPONSE OF DAMPED ELASTIC SYSTEMS TO TRANSIENT DISTURBANCES

Leal O N, Bisplinghoff R L and Pian T H H
STUDIES OF TRANSIENT STRESSES IN AN AIRPLANE MODEL WING DURING DROP TESTS

Nisbet J S and Brennan J N
SOME SECONDARY EFFECTS RELATED TO IMPACT WAVE FORMS

This paper is a theoretical analysis of simple structures under various types of applied impact. The results are presented from the standpoint of a static acceleration which would be required to produce the same maximum response in an undamped single degree of freedom system.

Reference is made to similar work by Frankland

Gerard G and Becker H
COLUMN BEHAVIOR UNDER CONDITIONS OF IMPACT
Meier J H
ON THE DYNAMICS OF ELASTIC BUCKLING
Journal of the Aeronautical Sciences

Hoff N J
THE DYNAMICS OF THE BUCKLING OF ELASTIC COLUMNS
Journal of Applied Mechanics, Trans. ASME
1951, Vol. 73, pp. 68-74.

Kornhauser M
PREDICTION AND EVALUATION OF SENSITIVITY TO TRANSIENT ACCELERATIONS
Journal of Applied Mechanics, Trans. ASME

Orowan E
CONDITION OF HIGH-VELOCITY DUCTILE FRACTURE
Journal of Applied Physics

The Griffith energy criterion, \( dW = -dU \) (\( dW \) = crack propagation work, \( -dU \) = released elastic energy), cannot be applied to essentially ductile fractures. In particular, it does not represent the condition of rapid ductile fracture propelled by the elastic energy of the specimen. The condition of such fractures is
\[
\frac{d^2W}{dx^2} = -\frac{d^2U}{dx^2},
\]
where \( x \) is the plastic extension accompanying the propagation of the crack.
(Author's abstract)

Fung Y C and Barton M V
SOME SHOCK SPECTRA CHARACTERISTICS AND USES
Journal of Applied Mechanics, Trans. ASME
Vol. 80, pp. 365-372.

Flynn P D
ELASTIC RESPONSE OF SIMPLE STRUCTURES TO PULSE LOADING
Ballistic Research Laboratories, Memorandum Report No. 525.

This paper deals with the elastic response of some simple structures subjected to a pulse loading. The structures considered are the mass on a spring, the simply supported beam, the cantilever, the circular membrane, and the clamped circular plate. The loading considered is that of a triangular pulse of pressure uniformly distributed over the area of the structural normal to the direction of motion. The pressure jumps to its peak value instantaneously and falls off linearly with increase in time, reaching
the value zero at the end of the pulse. Initially the structures are at rest and have no displacement.

The case of the simply supported beam is treated in some detail in order to illustrate the method of solution. In the other cases only the conditions necessary to specify the problem and the corresponding solutions for the deflection and strain as functions of the spatial argument and time are given. A numerical example is worked out for the simply supported beam, and the curves of deflection-time and strain-time are given for both during and after the pulse. A method is developed whereby the solutions for the triangular pulse may be modified to give directly the response of the structures to a general pressure-time loading. (Author's abstract)

5045 Baker W E and Allen F J
THE RESPONSE OF ELASTIC SPHERICAL SHELLS TO SPHERICALLY SYMMETRIC INTERNAL BLAST LOADING
Ballistic Research Laboratories, APG, BRLM Report No. 1113, August 1957.

This report presents the results of an analytical study of the reaction of an idealized nuclear reactor containment shell to internal transient loading which could be caused by reactor runaway.

The containment shell is assumed to be an elastic hollow sphere, and the transient loading is assumed spherically symmetric. A general theory of the response, valid for shells of any thickness, is developed. The theory is approximated for thin shells, and compared with experiment. The experiments corroborate the theoretical predictions. (Authors' abstract)

5046 Cunningham D M and Goldsmith W
SHORT-TIME IMPULSES PRODUCED BY LONGITUDINAL IMPACT
Paper presented at Spring Meeting of the Society for Experimental Stress Analysis, held May 14-16, 1958.

A program for the precise measurement of pulses in narrow rectangular bars generated by longitudinal impact of a 1/2-inch diameter steel ball was executed. The pulses were detected by means of resistance wire strain gages of various lengths and sandwiched piezoelectric quartz crystals, and were compared to the measured change of momentum of both ball and bar. An initial impact velocity up to 190 ft/sec always yielded permanent dents in the bar at the contact point with a depth small compared to the ball radius. Rise times of the order of 10 microseconds and peak forces of about 9,500 pounds were produced. No significant difference in the pulse shapes was observed from the records of wire-resistance strain gages and crystals,
but gages are considerably more convenient to use and are more universal in application. The impulses for longitudinal and transverse impact under similar geometric conditions appear to be comparable. (Authors' abstract)

Mason P
HIGH-SPEED FRACTURE IN RUBBER
Journal of Applied Physics

Cinematographic observations have been made of crack propagation under well-defined boundary conditions in rubbers at speeds up to 30 m/sec. The fracture markings showed resemblances to those obtained with metals, plastics, and glass, and could be related directly to the corresponding speed of fracture-propagation. In close analogy with Schardin's observations on glass, a noncrystallizing rubber (GR-S) showed a mode of crack propagation in which the fractured surfaces were visually smooth and the speed was about one quarter of the speed of longitudinal elastic waves. A crystallizing rubber (natural rubber) did not show this mode of propagation under the present test conditions. It is suggested that the modes of solid fracture can be usefully classified in three categories: (i) slow propagation, generally with smooth surfaces, obtained by careful control of the boundary conditions; (ii) propagation at intermediate rates with rough surfaces, involving correspondingly greater energy consumption; and (iii) fast propagation with smooth surfaces, the rate of propagation being limited by the speed of elastic waves in the material in accord with Mott's theory. (Author's abstract)
NOTE: The suffix -d after the reference number signifies that this author contributed to the published discussion.
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