SwRI®

Split-Hopkinson Pressure Bar Apparatus

An Historic Mechanical Engineering Landmark

Designated by The American Society of Mechanical Engineers

Designation Ceremony
Southwest Research Institute®
San Antonio, Texas
December 1, 2006

ASME
SETTING THE STANDARD

Introduction

The Southwest Research Institute® Split-Hopkinson Pressure Bar apparatus is a mechanical test instrument used to characterize the dynamic response of materials at high strain rates (typical of impacts and explosions).

The apparatus, based on devices invented by Bertram Hopkinson and Herbert Kolsky, was developed at SwRI in 1962 by Dr. Ulric Lindholm. Initially created to evaluate the behavior of metals under various conditions, the SwRI Split-Hopkinson Pressure Bar has since been applied to a wide range of materials.

Notable applications include determining the dynamic strength of steel in North Sea offshore platforms subjected to impact, defining the compressive strength of ceramics used in advanced armors, evaluating pipeline and nuclear pressure vessel steels, and evaluating the strength of materials on the pressurized hulls of the U.S. Space Station under impact from meteorites or other orbital debris impact.

Today, the SwRI Split-Hopkinson Pressure Bar remains the standard test technique for high strain rate materials characterization.

Dr. Ulric Lindholm with a present-day SwRI Split-Hopkinson Pressure Bar apparatus. In the 1960s, he and coworkers developed a technique that allowed direct generation of the complete dynamic (high-rate) stress-strain curve in a single experiment.

Historical Significance

The design or performance assessment of a component or structure requires accurate knowledge of the elastic and inelastic strength properties of the materials involved. These properties may vary with both temperature and time.

Conventional mechanical test systems have been available for years to obtain strength data under long term conditions (hours to days) or static conditions (minutes) using screw or hydraulic loading systems. The maximum deformation or strain rate of these machines is about 0.1 per second (0.1 s^{-1}). Pendulum impact machines such as Charpy or Izod can produce strain rates of up to about 100 s^{-1}, yielding only energy absorbed to fracture, but not a complete stress-strain curve. During World War II, strength properties associated with shock waves were developed using light-gas gun or explosively driven flyer-plate impact experiments, producing high hydrostatic pressures and strain rates in excess of 10^4 s^{-1}.

The SwRI Split-Hopkinson Pressure Bar developed at SwRI in 1962 was designed to fill the strain rate range from 10^2 s^{-1} to 5.0×10^3 s^{-1}, the time duration of many explosive, ballistic impact, crashes and other accident scenarios of interest for both military and civilian applications.

A technique to measure the shape of a stress pulse in a long elastic bar was first described in 1914 in England by Bertram Hopkinson. In 1949, Herbert Kolsky, also of England, improved on Hopkinson's device, adding displacement gages and oscillographic recording techniques to obtain complete pulse amplitude wave forms in similar elastic bars. Kolsky used a two-bar system, sandwiching a short compression specimen between them. The test specimen, lower in strength than the bars, experienced plastic deformation. Both the stress and strain could be derived. This modification became know as the Split-Hopkinson Pressure Bar. Hopkinson and Kolsky used explosive pellets to generate the stress pulse that propagated along the bar.

In the early 1960s, Ulric Lindholm of SwRI modified the Kolsky technique primarily by altering the bar lengths and the placement of the strain gages, and by using modern strain gage technology to record transient pulse shapes on both bars with electronic circuitry that allowed direct generation of the complete stress-strain curve for a single impact. Additionally, he used a

The SwRI Split-Hopkinson Pressure Bar Apparatus was developed at Southwest Research Institute in 1962.

The SwRI Split-Hopkinson Pressure Bar Apparatus characterizes the dynamic response of materials at high strain rates.

mechanical spring device to launch a striker bar instead of using explosive pellets. The impact of the striker bar against the incident bar generated the stress pulse. The impact speed determines the magnitude of the stress pulse, and the velocity of the striker bar was controlled quite accurately by adjusting the compressed gas pressure. The duration of the stress pulse is controlled by the length of the striker bar.

The SwRI Split-Hopkinson Pressure Bar became an integral element of a materials research program that studied and characterized the behavior of metals under various loading conditions. Since then, the device has undergone a number of modifications and improvements, and has been applied to a wide range of other materials including geologic materials, ceramics, polymers and other soft materials.

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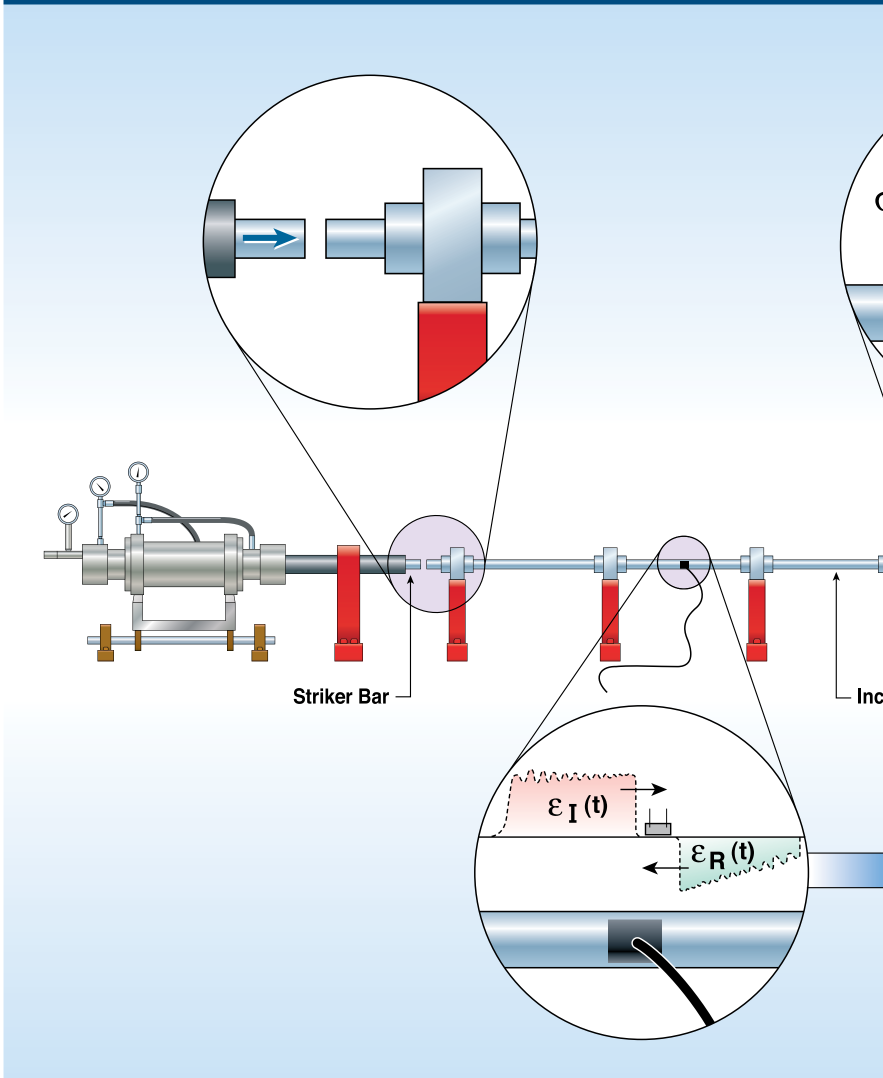
The Split Hopkinson Pressure



Description

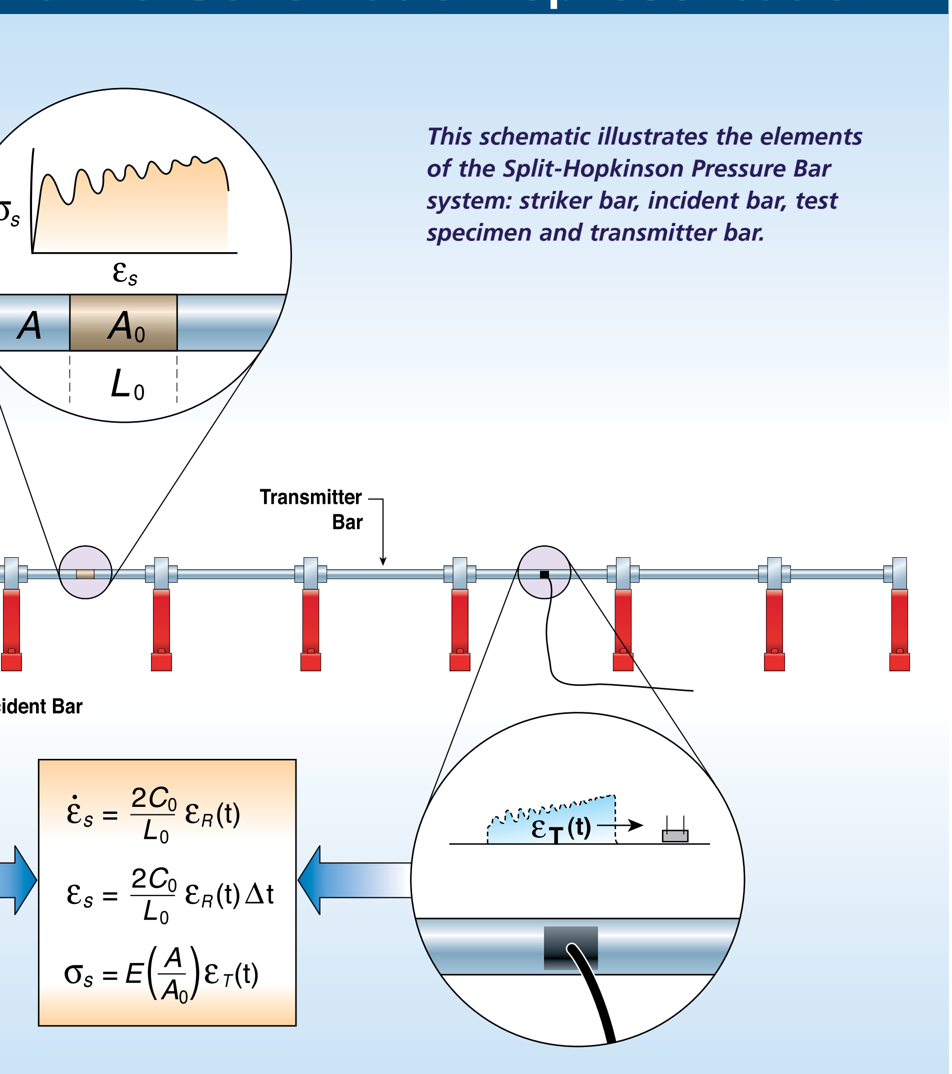
The SwRI Split-Hopkinson Pressure Bar is located in the High-Rate Materials Laboratory at Southwest Research Institute. The laboratory supports the Engineering Dynamics Department, part of SwRI's Mechanical and Materials Engineering Division. The Institute has 11 technical divisions. The laboratory is available for tours. However, because it is an active research laboratory, public access must be coordinated and scheduled in advance.

The Split-Hopkinson Pressure Bar (SHPB) was designed and built by SwRI personnel in 1962. The system comprises half-inch diameter by approximately eight-foot-long incident and transmitter bars machined from 4340 steel, mounted to a free standing 25-foot-long, 4-inch steel I-beam. Launching of the 26-inch-long, half-inch diameter 4340 steel striker bar was accomplished via a torsion spring and shear pin assembly. Impact velocity was measured using a magnetic pickup. Strain gages were mounted to both incident and transmitter bars, and data was recorded using an x-y oscilloscope and Polaroid® camera. Impact velocity, and therefore strain rate, was limited, however, by the yield strength of the 4340 steel bars. Stress pulses created by the impact of the striker on the incident bar must remain below the yield strength of the bars, approximately 160,000 pounds per in.^{2}, thus limiting the impact velocity to 167 feet per second. This system has since been modified for the testing of small threaded tensile specimens. The system now uses a laser diode device for impact velocity measurements and a high-speed digital data acquisition system, and also has a set of 7075-T6 aluminum bars for the tensile testing of lower strength materials. After 40 years of use, the system still remains in routine service for high strain rate tensile testing.

The graphic outlines the operation of the SHPB. A stress pulse, generated by impact of the striker bar onto the incident bar, travels down the incident bar and into the specimen. Some of this stress pulse is transmitted to the transmitter bar, and some of the pulse is reflected back to the incident bar. Strain gages, mounted to the incident and transmitter bars, record the strains of these two bars. Analysis of these strain-time records permits reconstruction of the stress-strain response (and the strain rate of the response) of the specimen.

Approximately 10 years later, a second SHPB system was designed and built by SwRI personnel for compression testing. As in the previous system, it had half-inch diameter incident, transmitter, and striker bars. However, the incident and transmitter bars were shortened to four feet in length, and the entire system was mounted to a steel reinforced

Bar: a Schematic Representation

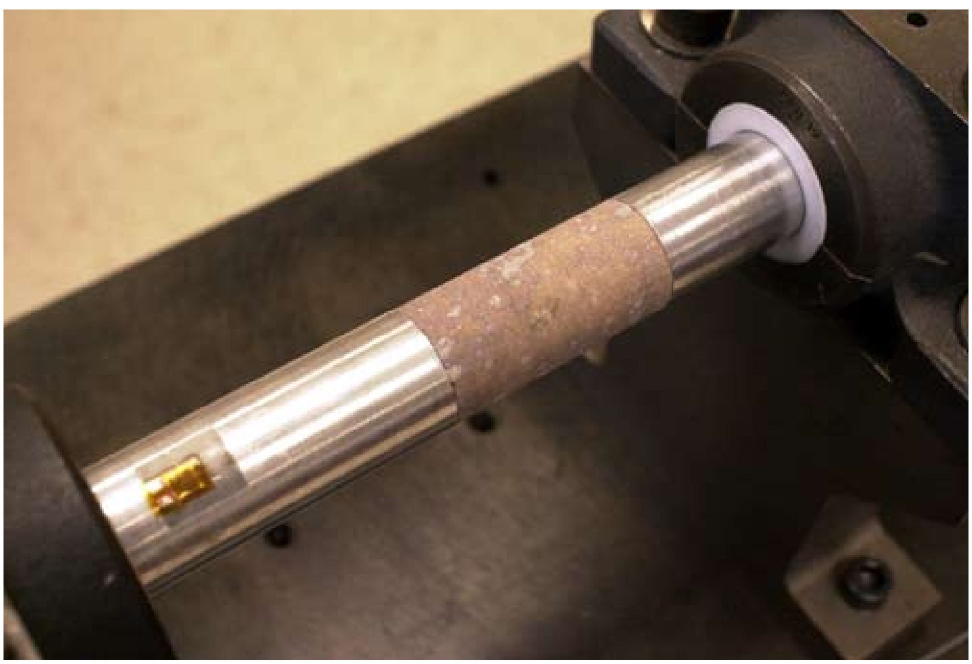


This schematic illustrates the elements of the Split-Hopkinson Pressure Bar system: striker bar, incident bar, test specimen and transmitter bar.

concrete base. Two other modifications of the original are noteworthy. A different type of steel, a high strength maraging steel alloy, was used for the bars. This material, known commercially as Vascomax 350, has a yield strength of nearly twice that of the 4340 steel used previously, permitting substantially higher impact velocities, nearly 333 feet per second, producing significantly higher strain rates in the specimen. Secondly, the addition of a compressed gas breech mechanism to launch the striker bar made operation simpler, and led to more repeatable velocities and the ability to reach impact velocities equivalent to the yield strength of the bar material. Subsequent modifications to the system have included the adaptation of one-inch diameter Vascomax and 7075-T6 aluminum bars for the testing of larger samples, porous samples and composites. Also added were the capabilities for elevated temperature testing and confining pressure tests.

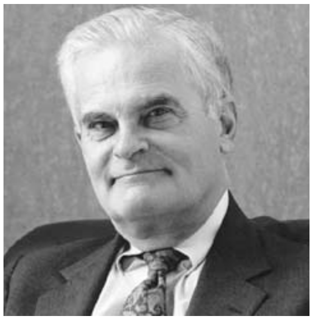
Dr. Ulric Lindholm (left), a pioneer in the development of the Split-Hopkinson Pressure Bar apparatus (shown), with SwRI staff members involved in research on dynamic materials response (from left) Dr. James Lankford, Dr. James Walker, Dr. Kathryn Dannemann and Dr. Charles Anderson. Dr. Lankford recently retired from SwRI.

In recent years a third system, designed and built at SwRI, has been added to the laboratory. This system uses 1½-inch diameter Vascomax incident and transmitter bars six feet in length, and a 1½-inch diameter striker bar. A second compressed gas gun with greater volume and higher operating pressure was designed and fabricated to launch the larger diameter striker bar. A massive steel I-beam — nearly 35 feet in length and 31 inches high — supports the entire system. Use of the larger diameter bars in this system permits the compression testing of large-grained composite materials, e.g., rock. A second set of incident and transmitter bars was also fabricated to permit the testing of large, threaded tensile specimens. Future modifications to this system will occur in our endeavor to continuously improve and broaden our research capabilities.



The Split-Hopkinson Pressure Bar was originally developed for testing metallic materials (top) at high strain rates. The device has since been refined to include testing of other materials such as geologic materials (bottom) and ceramics.

Key Developers



Dr. Ulric S. Lindholm retired from Southwest Research Institute in 1994 as vice president of the Engineering and Materials Sciences Division. During his 34-year career at SwRI, he made significant contributions in the area of dynamic response of materials and structures to transient loads. The author of more than 50 papers in the technical literature, he is especially known for his work on the measurement of strength properties of metals at intermediate- and high-strain rates. This effort included the development of pneumatic, electro-hydraulic, and impact-type materials testing equipment and associated measurement instrumentation. Dr. Lindholm also was involved with the development of generalized constitutive equations for solids, particularly metals, including the coupled effects of combined stress, strain rate and temperature for both monotonic and cyclic loading. He served as technical editor and reviewer for a number of technical journals, and is a Fellow of ASME and the American Association for the Advancement of Science. He holds the following patent relevant to material characterization: A. Nagy, U.S. Lindholm, L.M. Yeakley, U.S. Patent No. 4,026,145, "Hydraulic Grip for Tubular Mechanical Properties Specimen," May 31, 1977.

Mr. Lester M. Yeakley left Southwest Research Institute in 1976 and is now retired. A graduate of The University of Texas at Austin (B.S., physics), he is skilled in applied physics, including applied mechanics and instrumentation. He has spent 40 years in engineering mechanics, materials research and product development. His work has included the development of mechanisms, transducers, instrumentation, actuators and servo controls, which he applied to the research of dynamic material properties at SwRI. Notable among this was the development of instrumentation for the Split Hopkinson Pressure Bar. He also developed controls and specialized instrumentation for facilities such as impact testers,

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Future modifications to this system will occur in our endeavor to continuously improve and broaden our research capabilities.

servo-controlled electro-hydraulic testing machines, a servo-controlled electro-hydraulic two-axis earthquake simulator, tire tests and a model helicopter rotor. Mr. Yeakley is the author of a number of published papers in the fields of engineering mechanics and materials research and holds 29 U.S. patents. The following patents are relevant to material characterization.

L.M. Yeakley, U.S. Patent No. 3,766,831, "Compound Axial Torsional Hydraulic Actuator," October 1973.

A. Nagy, U.S. Lindholm, L.M. Yeakley, U.S. Patent No. 4,026,145, "Hydraulic Grip for Tubular Mechanical Properties Specimen," May 31, 1977.

E.B. Norris and L.M. Yeakley, U.S. Patent No. 4,030,347, "Biaxial Capacitance Strain Transducer," June 21, 1977.

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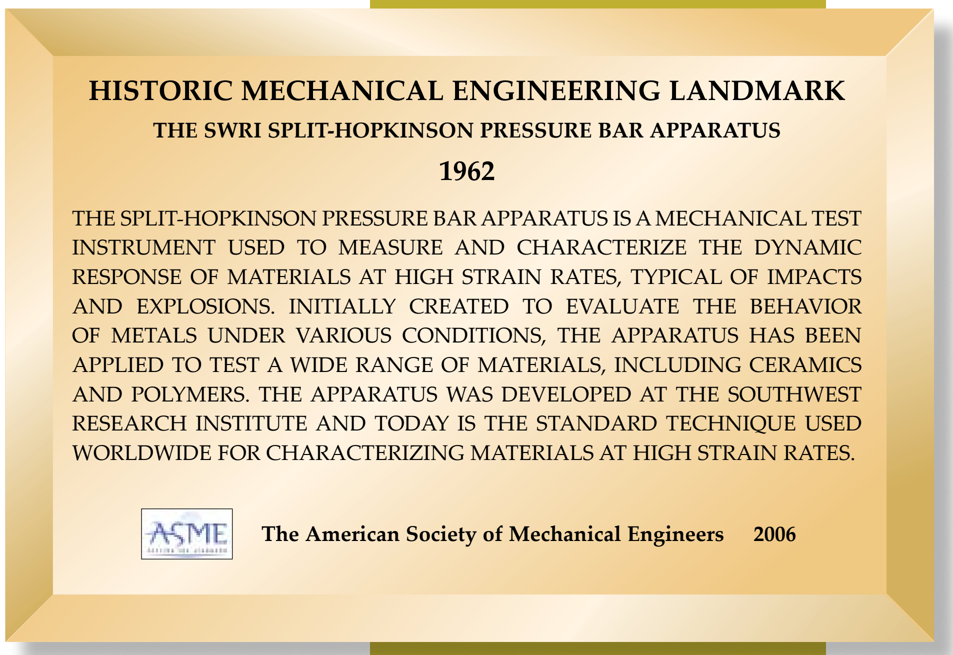
The History and Heritage Program of ASME

The History and Heritage Landmarks Program of ASME (the American Society of Mechanical Engineers) began in 1971. To implement and achieve its goals, ASME formed a History and Heritage Committee initially composed of mechanical engineers, historians of technology and the curator of mechanical engineering at the Smithsonian Institution, Washington, D.C. The History and Heritage Committee provides a public service by examining, noting, recording and acknowledging mechanical engineering achievements of particular significance. This Committee is part of ASME's Center for Public Awareness. For further information, please contact Public Information at ASME, Three Park Avenue, New York, N.Y. 10016-5990, 1-212-591-8614 and ***http://www.asme.org/history***.



Designation

Since the History and Heritage Program began in 1971, 241 landmarks have been designated as historic mechanical engineering landmarks, heritage collections or heritage sites. Each represents a progressive step in the evolution of mechanical engineering and its significance to society in general. Site designations note an event or development of clear historic importance to mechanical engineers. Collections mark the contributions of a number of objects with special significance to the historical development of mechanical engineering.

The Landmarks Program illuminates our technological heritage and encourages the preservation of the physical remains of historically important works. It provides an annotated roster for engineers, students, educators, historians and travelers. It helps establish persistent reminders of where we have been and where we are going along the divergent paths of discovery.

The 120,000-member ASME is a worldwide engineering society focused on technical, educational and research issues. ASME conducts one of the world's largest publishing operations, holds some 30 technical conferences and 200 professional development courses each year, and sets many industrial and manufacturing standards.

Acknowledgments

Southwest Research Institute gratefully acknowledges Dr. Ulric S. Lindholm, Lester M. Yeakley and Andrew Nagy for their tireless research efforts that led to the development of the SwRI Split-Hopkinson Pressure Bar. Southwest Research Institute also appreciates the efforts of Dr. Charles E. Anderson Jr., Dr. James D. Walker and Arthur E. Nicholls for their work in preparing the nomination document and the designation brochure, and for helping plan the designation ceremony.

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About the cover photo . . .

Lester Yeakley (left) and Dr. Ulric Lindholm (second from left) discuss results from a test conducted using the SwRI Split-Hopkinson Pressure Bar (center). The photo was taken in the SwRI High Rate Test Laboratory (circa 1970). With them are co-workers (from left) Andrew Nagy, Bob Tuck and Hans Muhlenhaupt.

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