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Introduction

वागर्थाविव संपृक्तौ वागर्थ प्रतिपत्तये ।
जगतः पितरौ वन्दे पार्वती परमेश्वरौ ॥

Vaagarthaaviva sampruktau vaagartha pratipattaye
Jagatah pitarau vande paarvati paramesvarau

I salute to the parents of this world, in the form of Parvati and Parameswara, who are inseparable just as the word and its meaning are inseparable, in the understanding of the meaning of the word.

—Raghuvamsa 1-1

Applied impact mechanics deals with high magnitude forces developed by sufficiently high impact velocities inducing significant local contact deformation, damage, plasticity and fracture phenomena from an engineering design and analysis viewpoint. Typically, impact events last for few tens of micro-seconds up to few milli-seconds. Conventionally, the notion of shock loading is referred to the relative time period of the load with respect to the natural time period of the structure or the object. Even loads acting for few seconds as in earthquakes and meteor impacts can be classified as shock loading under the gamut of impact problems. However, shock physics also deals with extremely high stresses on the order of 10-100 times the static yield stress generated within 10 nanoseconds. Moderate shock levels on the order of the static yield stress of engineering materials are abundantly evident in vehicular collisions and common modes of structural collapse. Thus an impact is any abrupt change of a force, a position, a velocity, or an acceleration affecting the body under consideration.

The principal concept underlying impact engineering revolves around the idea of critical states involving a triad of factors:

1. Characterization of loads and excitations;
2. Overall structural dynamic response and integrity assessment; and
3. Local material performance assessment.

In the context of above three issues, a critical state is deemed to have been reached in a specific impact encounter when an unfavorable structural response results from an admissible list of measurable loads and detectable local failures of material. There are no well defined critical states in applied impact mechanics. Rather there are infinitely many critical states demanding a probabilistic approach. Probabilistic models have been discussed extensively for predicting earthquake ground motion. The necessary model parameters have to be obtained either through field data or generated experimentally. Paucity of data quantitatively and qualitatively means that impact design problems in general are ill-posed. Seemingly similar impact events can result in vastly different outcomes. However, a statistical analysis of the mean and variance calculated from various outcomes can be helpful for assessing the efficacy of theoretical as well as numerical simulations. In this context, it is important to differentiate the functional aspects from the aesthetic aspects of a structure or a machine.

1.1 GENERAL INTRODUCTION TO ENGINEERING MECHANICS

Impact phenomena demand a comprehensive synthesis of ideas and data garnered from experiments, theory and computation. These three distinguishing features are the hallmark of engineering mechanics. Theoretical and applied mechanics spans a much larger scope including all of classical mechanics developed over centuries of mathematical, metaphysical and philosophical transactions dating back to the times of Archimedes, Aristotle and Euclid during the early Roman period extending to 200 BC. However, major developments after Galileo and Newton pioneered by Gauss, Euler, Bernoulli and Lagrange and others turned mechanics into a formidable mathematical fortress. The real world of solids, liquids and gases were idealized mathematically to conjure elegant solutions to many problems of elasticity, gas and hydrodynamics that inspired generations of applied mathematicians until the advent of quantum concept by Planck. Today, modern mechanics which is synonymous with quantum mechanics has generated a radically new type of mathematics. Though classical analyses continue to inspire applied mathematicians working on general relativity and electromagnetic phenomena, explosive computing power has ushered in a new era of computational mechanics of great significance to engineering mechanics and design.

The advent of quantum concepts propelled by Schrodinger, Heisenberg, Fermi and Dirac signaled a major transition in the course of mechanics and mathematics.

Though Einsteinian general theory of relativity extended the role of classical mathematical analyses, probability and statistics took over modern physics in general and quantum mechanics in particular. These major upheavals that began well over a century are now slowly but steadily penetrating engineering mechanics for designing quantum devices in space technologies based on general relativity. This brief history highlights the challenges and opportunities in engineering mechanics today.

1.2 GENERAL INTRODUCTION TO FRACTURE MECHANICS

Fracture is a natural reaction of solids to relieve stress and *shed* excess energy. Fragility of solids is a constant threat to our survival as we drive over a bridge, go through a tunnel, or live inside a building. Our bones and teeth are just as fragile as the glass and china we use at home. Trees bend in the wind before they break; and, a blast of gunpowder breaks a mountain into a million fragments. Earthquakes shake and break the thin crustal shell on which we live. We *accept* fracture as a way of life and admire solids for what they provide. Fragility is *not* always perceived as a baneful threat because if all solids were unbreakable, we would not be able to break things when we *want* to. Just imagine an unbreakable eggshell that cannot be hatched; or, a hard grain of wheat that cannot be ground. Whether it is for cracking bottles, breaking woods, or chipping rocks for making sculptures, controlling fracture holds the key. Thus, in a way, fracture, like fire and wind, is both a foe and a friend of mankind-friend if controlled, foe otherwise. *Prediction, prevention, control* and *treatment* of fractures represent a big bulk of engineering and medical practice today, bringing together a diverse group of professionals ranging from orthopedics and dentists to crash helmet designers and earthquake experts. This kind of an unprecedented confluence of different professionals has unleashed a spectacular array of products for solving fracture problems. Fracture phenomena in general are just about as wild and unpredictable as fire, wind, rain and thunder. Taming these elements of nature to protect life and property is the principal theme of control; and today, we have buildings that are fire-proof, rain-proof and even earthquake-proof (designed to *rock* but not break).

In spite of all these glorious engineering and medical achievements, strategies for prediction and prevention of fracture are largely unclear. Though a *post mortem* can tell us *how* a thing broke, it is hard to tell *when, where* and *why* fractures strike solids, often without any warning. Fractures unleash even more extraordinary scientific issues like the emission of photons and electrons from fracturing rocks and ceramics. These phenomena classified as *fracto-emission* often accompany *acoustic emission* which is employed widely by engineers for non-destructive evaluation. Another issue of great concern is bone fracture. Natural healing is so good that it is hard to tell where a bone broke in younger people. However, in older adults, particularly women and some rare neonatal cases, healing becomes difficult. Current science is in vigorous pursuit of answers to these questions. Thus, fracture phenomena pose a formidable challenge for modern engineers, doctors and scientists alike.

The main question in fracture research today is: Why are some materials tougher than others? Here, the word *tough* is the antonym for *fragile*. This question has generated a vast academic and industrial literature, cutting across many disciplines in engineering, medicine, physics, chemistry and mathematics. With particular reference to engineering, materials scientists and mechanics experts are interacting more vigorously than ever before to unravel fracture mechanisms and address the *multidimensional totality* of fracture problems. Even if a diverse group of fracture expertise is assembled, bridging different ideas of different people demands extraordinary insight into the nature of matter in the solid state.

Toughness is the key word in the fracture research today. Unlike other properties describing the solid state, toughness is not a single invariant quantity like density, elastic modulus or tensile strength. Understanding the variability of fracture toughness of engineering materials under the different operating conditions is equally critical to the modern engineer. In simple terms, *fracture toughness* denotes the energy required to break a *unit* area of the material. The required energy is drawn from the *elastic strain energy* stored in bodies under stress which is of the order of magnitude more than the energy required to break into two parts. This fact, however, does not mean that the body will break in two *unless* cracks are already present in the body. Even in the case when cracks are present, some materials can tolerate *longer* cracks than others. The situation is somewhat similar to a spark setting off an explosion inside an internal combustion engine. Just as a feeble spark fails to ignite the mixture, a crack smaller than a minimum critical length, fails to propagate inside a stressed body. However, when the material is extremely fragile as a glass, even a tiny crack can begin to propagate and break the material apart. This way, the material property *toughness* enters fracture mechanics. Ways and means of enhancing the toughness of materials is a challenge facing materials science and mechanics. From the materials side, toughness essentially combines strength and ductility. While materials experts examine the microstructural aspects, mechanics experts handle the strain energy pathways to a potentially dangerous crack.

Calculation of energy flow to the crack tip is the capital achievement of fracture mechanics which began with Griffith in England in 1920 and was enriched vastly by Irwin in the USA during the second half on the twentieth century. Current trends in fracture mechanics are pointing more towards novel medical and mining applications. For example, fracturing kidney stones and tumours by using shock waves has become a standard medical procedure. Similarly, fracturing shale deep underground for extracting oil and gas called *fracking* is rapidly attracting investments despite criticism. Atomistic modeling of plasticity, creep, damage and fracture mechanics is also being pursued with the help of powerful supercomputers to design novel materials.

Today, engineering fracture mechanics is essentially the application of the pioneering ideas of Griffith and Irwin, through experiments, simulations and field trials. There is a virtual flood of papers and books on fracture problems, making it difficult for beginners and working professionals to appreciate the basis of the subject. But the novice can take comfort from the fact that fracture of solids is far too complex and mysterious, even for the experts, particularly when the cracks propagate at high speeds under impact loads.

In summary, tough materials survive longer than their fragile counterparts. This simple maxim is true not only of inanimate solids but also humans. Fracture is a consequence of the innate strength of solids undermined by cracks that inevitably develop during service due to stress. This unavoidable fate of all solids under stress makes it imperative for engineers in general, and designers in particular, to pay special attention to fracture mechanics.

1.3 IMPACT MECHANICS – Appreciating Impact Problems In Engineering

Impact mechanics is perhaps the most challenging branch of engineering mechanics required for design of high energy devices for civil, military and scientific applications. For example, the high energy hadron collider in CERN Switzerland which featured in the discovery of the Higgs boson requires impact mechanics analysis for designing several hardware. Powerful codes are now easily accessible for solving a variety of applied impact mechanics problems such as LS-Dyna, ANSYS, Abaqus, Dytran, Nastran, IMPACT, PAM-Shock, PAM-CRASH, Radioss, Marc, Lusas, etc. All these modern computational tools notwithstanding engineering mechanics demand a thorough appreciation of experimental facts, field observations and underlying theory, if available. This inseparable trinity of experiment-theory-computation offers unlimited research opportunities in the areas of contact mechanics, wave propagation, plasticity, damage, and fracture mechanics.

This book is an attempt to weave together the essential concepts underlying impact mechanics. Impact phenomenon ubiquitously present in daily life as well as in the entire physical universe, which can turn out to be hazardous or sometimes desirable for the system. Let us briefly discuss the problems and applications of impact in practice.

Tragic and dangerous impact effects on the **Columbia space shuttle disaster** is a well-known example caused by impact damage, in 2003, resulting in the death of all seven crew members. The loss of Columbia was a result of damage sustained during launch when a piece of foam insulation of the size of a small briefcase broke off from the space shuttle's external tank under the aerodynamic forces of launch. The debris struck the leading edge of the left wing, damaging the shuttle's thermal protection system, which shields the vehicle from the intense heat generated from atmospheric compression during re-entry. Although tests had been conducted before the disaster, the size of the chunks was much smaller than that which fell away from the booster rocket and hit the exposed wing.

Road traffic accidents usually involve impact loading, such as when a car hits another car, traffic board, water hydrant or tree; the damage being localized to the impact zone. When vehicles collide, the damage is proportionate to the relative velocity of the vehicles; the damage increases as the square of the relative velocity since it is the impact kinetic energy that manifests as damage. Much design effort is made to improve the impact resistance of cars so as to minimize user injury.

The breakage of vulnerable cladding components of buildings (windows, etc.) from impacts by **windborne debris** was the most common failure mechanism when tropical cyclones and other extreme wind events happen.

On February 15, 2013, an **asteroid entered Earth's atmosphere over Russia** with an estimated speed of 18 km/s and exploded above the city of Chelyabinsk. With an estimated initial mass of 11,000 tones, and measuring approximately 17 to 20 meters across, the Chelyabinsk meteor is the largest known object to have entered Earth's atmosphere. The object's air burst occurred at an altitude between 30 and 50 km above the ground, and about 1,500 people were injured, mainly by broken window glass shattered by the shock wave. About 7,200 buildings in six cities across the region were reported damaged due to the explosion's shock wave (sonic boom).

The April 2011 **Fukushima earthquake in Japan** was a potent intraplate aftershock to follow Tohoku earthquake occurred in March 2011. The tremors caused little structural damage but killed people and injured many. The strong shaking cut electricity to about 220,000 households. Impact mechanics is a generic subject encompassing a wide field of applications and activities. The mechanisms of earthquakes also falls under impact mechanics if we consider the energy released from the participating tectonic plates. As per the currently accepted theory of plate tectonics, the entire earth surface is an assemblage of disparate and dissimilar plates in relative motion with respect to each other. The plate boundaries called faults accumulate stress and huge amounts of energy when they remain fused and release the stored energy through waves and tsunamis in land and ocean, respectively. Relating the magnitude and energy of waves during loading and unloading is a fundamental aspect of impact mechanics. Loading waves during indentation and release waves during restitution constitute a major aspect of low velocity impact mechanics.

The waves created by a sudden disturbance in the ocean are known as **Tsunami**. Typical causes are earthquakes and underwater landslides (sometimes tripped by small earthquakes). Tsunami generally travels very fast across the ocean (typically 500 km/h or more). In deep water the tsunami height might not be great but the height can increase dramatically when they reach the shoreline because the wave slows in shallow water and the energy becomes more concentrated. In addition to the inherent increase in the height of the wave from this shoaling effect, the momentum of the wave might cause it to reach a considerable height as it travels up sloping land. It is typical for multiple waves to result from one tsunami-generating event and these could be several hours apart when they reach a distant shore. These waves induce significant fluid-structure interactions and impact the structures and buildings on the seashore.

Although, for a given location on the Earth's surface, the risk of a "direct" hit from an asteroid is slight, researchers realized that an ocean impact had the potential to be much more destructive due to the effects of tsunami. An airburst explosion is a three dimensional event and energy decreases according to the square of the distance but a radiating ocean wave is a two-dimensional phenomenon and, in theory, energy decreases in proportion to distance. Since the early 1990s some advanced computer simulations have been conducted to estimate the effects of asteroid impacts above deep oceans.

There is a strong historical trend to bundle impact parameters together as defined by some of the more typical and problematic engineering scenarios where impact poses a threat. Five examples of such groups commonly found in the literature are termed **crashworthiness**, **dropped tools**, **runway debris**, **bird strike** and **ballistic**.

The subject of impact attracts the interest of scientists and engineers from different areas of knowledge from astrophysics to robotics. The common goal is to develop theories that can predict the behavior of colliding objects. The impact of a solid on the free surface of a fluid is a ubiquitous problem arising in areas as diverse as military projectiles and water-walking lizards. The fundamental phenomenon involves the cavity and/or splash produced by the object as it enters the fluid, often accompanied by bubble entrainment and acoustic noise.

There are a variety of collisions in **sporting activities**. Understanding the characteristics of the collisions between a ball and the player's body (e.g., soccer, volleyball) or between a ball and any equipment (e.g., baseball, tennis, billiards) is important for performance enhancement and injury prevention. In soccer, the most typical and important collision is that of ball impact during kicking. There are several studies that have focused on ball impact during soccer instep or similar full kicking.

There are various applications of impact phenomenon in engineering. A **nail** is pounded with a series of impacts, each by a single hammer blow. These high velocity impacts overcome the static friction between the nail and the substrate. A **pile driver** achieves the same end, although on a much larger scale, the method is being commonly used during civil construction projects to make building and bridge foundations. The weight is dropped, using a quick-release. The weight of the piston compresses the air, heating it to the ignition point of diesel fuel. Diesel fuel is added/injected into the cylinder. The mixture ignites, transferring the energy of the falling weight to the pile head, and driving the weight back up. The rising weight draws in fresh air, and the cycle starts over until the fuel runs out or is stopped by the pile crew.

An impact **wrench** is a device designed to impart torque impacts to bolts to tighten or loosen them. At normal speeds, the forces applied to the bolt would be dispersed, via friction, to the mating threads. However, at impact speeds, the forces act on the bolt to move it before they can be dispersed.

Ballistics deals with the flight behavior and effects of projectiles, especially bullets, gravity bombs, rockets, or the like; the science or art of designing and accelerating projectiles so as to achieve a desired performance. In ballistics, bullets utilize impact forces to puncture surfaces that could otherwise resist substantial forces. A rubber sheet, for example, behaves more like glass at typical bullet speeds. That is, it fractures and does not stretch or vibrate.

Impact is essential for functioning of various **percussion instruments** such as timpani, tubular bells, tabla, drums, etc. A percussion instrument is a musical instrument that is sounded by being struck or scraped by a beater (including attached or enclosed beaters or rattles), or struck, scraped or rubbed by hand, or struck against another similar instrument.

Cryogenic grinding, also known as freezer milling, freezer grinding, and cryomilling, is the act of cooling or chilling a material and then reducing it into a small particle size. Freezer milling is a type of cryogenic milling that uses a solenoid to mill samples. The solenoid moves the grinding media back and forth inside the vial, grinding the sample down to analytical fineness. This type of milling is especially useful in milling temperature sensitive samples.

Cryogrinding is a method of cell disruption employed by molecular life scientists to obtain broken cell material with favorable properties for protein extraction and affinity capture. Once ground, the fine powder consisting of broken can be stored for long periods at –80°C without obvious changes to biochemical properties - making it a very convenient source material in e.g. proteomic studies including affinity capture/mass spectrometry. Recently, food processing industries and pharmaceuticals are interested in synthesizing novel polymorphic molecules for achieving crack-free tablets to resist impact loads.

1.4 HISTORICAL BACKGROUND

Before evolving into a complex, interdisciplinary science, *impact mechanics* and *shock wave theory* were initially regarded as specific branches of physics, attracting only minor attention in scientific community. Following table summarizes the evolution of *impact mechanics* based upon 17th century classical percussion and 18th century aeroballistics.

Table 1.1: Historical evolution of impact mechanics

Year	Name of Scientist	Work
Sixth century B.C.	Pythagoras	Origin of musical sounds and the vibrations of strings
1636	Marin Mersenne	Vibrations of strings, velocity and intensity of sound in air
1638	Galileo Galilee	Vibrations of pendulum, strings and phenomenon of resonance, observations on lunar craters
1678	Robert Hooke	Law of proportionality between stress and strains of elastic bodies; Experimental modeling of lunar craters, bullets, streaks; Explosion like disintegration of ‘Prince Rupert Drops’; Demonstration of optical method for visualizing density variations
1686	Isaac Newton	Speed of water waves and sound in air, motion of visible bodies resting on his three Laws of Motion, Aerodynamic drag for body moving with high speed through a gas, Newton-Busemann pressure law, Corpuscular fluid model, Isothermal theory of sound

Year	Name of Scientist	Work
1744	Leonard Euler	Equation of vibrations and normal modes of beams at various boundary conditions, Laws of conservation of mass and energy of fluids, Mach number, Continuous and discontinuous function
1747	Jean Le Rond D' Alembert	Equation of motion of string, Laws of conservation of living forces, 1-D wave equation for sound in air
1751	Daniel Bernoulli	Principle of superposition and vibration of strings
1753	Leonard Euler	Analysis of projectile trajectories with aerodynamic drag values, Euler equations of hydrodynamics
1770	Daniel Bernoulli	Wave theory of elastic percussion
1781	Joseph Louis De Lagrange	Analysis of string as a system of discrete mass particles, percussion force of water jet on a plane, Ballistic problems
1802	Ernst F. F. Chladni	Longitudinal and torsional vibrations of beam and rods
1821	Claude Louis Navier	Equilibrium equations and vibration of elastic solids (Navier Stokes equation), Law of motion of continuous media, Dynamic strength of materials
1823	Simeon D. Poisson	Propagation of waves though elastic solids, Vibration of rods, Velocity of sound, Gas laws for adiabatic compression, Discovery of transverse and longitudinal waves, Impulsive friction
1826	Augustine Cauchy	Impact of two cylindrical rods, theory of elasticity
1834	John Scott Russell	Solitary wave of translation (Soliton)
1872	John Hopkinson	Plastic wave propagation in wires
1882	Heinrich R. Hertz	Theory of impact, Hertz law of contact, elastic stress distribution for contact of hard sphere on plate, Hertzian fracture
1883	Saint Venant	Saint Venant's principle, Transverse impact, compressible flow in a duct
1885	Ernst Mach	Blast waves originated from chemical explosions, Laws of impact, V-propagation, Mach funnels, velocity-distance profile of a blast wave, ballistic experiments, sound wave of large excursion, hypersonic boundary layers
1877	Lord Rayleigh	Propagation of surface waves on solid, frequency equation of waves in a plate, Rayleigh wave, earthquakes, Plane shock waves in air
1904	Horace Lamb	Pulse propagation in semi-infinite solid, Lamb waves, a minor tremor, the main shock, early expansion of the gas bubble of an underwater explosion
1914	Bertram Hopkinson	Propagation of elastic pulses in bars, dynamic strength of steel wires, scabbing, Hopkinson effect, experimentation of penetration of metals by bullets and shell, pressure of a blow, Hopkinson law

Year	Name of Scientist	Work
1921	Stephen Timoshenko	Theory of beams for shear deformation
1930	Lloyd Hamilton Donnell	Effect of a non-linear stress strain law on the propagation of stress waves in bar
1932	Theodore Von Karman	1-D finite amplitude plastic wave theory, Wave drag
1949	Rhisiart Davies	Waves in bars, Davies pressure bar

1.5 PERCUSSION, CONCUSSION, COLLISION AND EXPLOSION

The term ***percussion*** designates the action of striking of one moving object against another with significant force. Percussion refers to solid bodies, more rarely to liquids, and to air. The fundamental theory of percussion was based on two spheres of the same material but different masses moving in a straight line and impacting either head-on (central percussion) or at an angle (oblique percussion). The principle of percussion has been widely applied in military technology, civil engineering and medical diagnostics. Real percussion phenomena depend upon the shapes of the impacting bodies, their masses, elastic properties (rigid, perfectly elastic, elastic, or inelastic), and their initial velocities. In purely elastic percussion, no permanent deformation takes place, while inelastic percussion produces permanent deformation. Modern vehicle design attempts to largely absorb the kinetic energy in the case of collision accidents by using materials which deform plastically.

The term ***concussion*** describes the action of violently shaking or agitating, particularly in relation to the shock of impact. In the past it was also used to describe the sudden shaking actions of violent seismic waves or in gunnery. Today the term concussion is primarily used in medicine to designate a period of paralysis of nervous function resulting from an injury to the brain which, produced by a violent blow to the head, causes temporal unconsciousness. Concussions of the brain can affect memory, judgment, reflexes, speech, balance and coordination. A concussion fracture designates one of a system of fractures in individual grains of a shock-metamorphosed rock that is apparently formed by violent contacts in passage of waves.

The term ***collision*** describes a wide range of processes and phenomena ranging from very high, relativistic velocities observed at the molecular, atomic and subatomic levels to very slow velocities seen in earth sciences and vehicle collision. In general physics, collision does not necessarily imply actual contact as in classical mechanics. There are three types of collision based on the direction of body motion: 1. Direct central collision; 2. Side collision; and 3. Oblique central collision. Examples of collisions are solar wind collision with interstellar plasma, collision accretion by gravitational forces during formation of a solar system, galaxy-galaxy collision, earth's plate convergence, and vehicular collision.

Explosions are extremely rapid phenomena that cause a rapid increase in heat and pressure. The resulting overpressure, propagating as wave of condensation steepens its front, thus turning into a shock wave i.e. it travels at supersonic velocity. In an explosion, a divergent process, the pressure decays with increasing distance from the explosion source. The geometry of the explosion source strongly determines how quickly the blast pressure decreases from the center of the explosion. There are three main types of explosion: 1. Mechanical; 2. Chemical; and 3. Nuclear.

Mechanical explosion

An explosion is not necessarily connected with the exothermic reaction of chemical explosives. In particular, explosions in air have been defined as the release of energy is rapid and concentrated enough to produce a pressure wave that one can hear. This depends on the energy rate, the total energy released, and the source geometry (measured as TNT equivalents). Examples: steam-boiler explosions, bursting membrane in a shock tube, etc.

Chemical explosion

Sudden or extremely rapid conversion of the solid or liquid bulk of an explosive into gas or vapor which is highly expanded by the heat generated during the transformation is called as Chemical explosion. Some of the total energy released is also transformed into endothermic reactions of the explosion products, and into radiation. Example: dust explosions.

Nuclear explosion

The fission energy that is converted into the shock and the blast in a nuclear aerial explosion is reduced to the additional production of initial and residual nuclear radiation. Nuclear explosions result from an instantaneous fusion or fission process that can be many thousands (or millions) of times more powerful than the largest chemical detonations. Nuclear explosions provide access to a realm of high temperature, high-pressure physics not otherwise available on a macroscopic scale on Earth. Such events are accompanied by the emission of electromagnetic radiation over a wide spectral range, such as light, heat, radio waves and gamma rays, generally referred to as *thermal radiation* (Hiroshima and Nagasaki, 1946, Pokhran in 1998).

1.6 SUMMARY

Impact mechanics is a broad application of basic mechanics of solids and materials science to understand and appreciate transient loads producing high strain rates in engineering and scientific applications on the one hand and industrial accidents and explosions on the other. The resulting dynamics is dominated by impact generated waves propagating rapidly inside the colliding bodies as well as on their surface. The action of waves is felt far and wide as in the case of earthquakes, tsunamis and blasts. Predicting the damage potential of these waves generated by the impact processes demands a comprehensive material modeling including plasticity, hydrodynamics and damage formulated by eminent scientists like Rankine, Hugoniot, Mie, Gruneisen, Taylor, Johnson to mention a few.

The next chapter extends the concepts of rigid body mechanics to deformable bodies to highlight the elastic response. Deformability alters the material response in a subtle fashion owing to the action of waves discarded in rigid body mechanics. Elastic and inertial properties manifest in the wave action lead to characteristic wave motion along longitudinal and transverse directions that are discussed in Chapters 3 and 4. Characterization of materials subjected to impacts at different strain rates require exhaustive experimental techniques as discussed in Chapter 5. Modelling the material deformation and its failure under impact as discussed in Chapter 6 are essential to understand and quantify the deformation and failure mechanisms. The impact processes can be numerically simulated using advanced numerical concepts evolved in the form of numerical or computational codes which form the basis of computational impact mechanics provided in Chapter 7 which rely on the concepts developed in Chapters 5 and 6. The study of vehicle collisions and design for crashworthiness are becoming increasingly important mainly considering the safety of occupants and these concepts are discussed in Chapter 8. The ballistic impact played a vital role in development of projectiles and armour protection systems. The theories involved in understanding the mechanics of ballistic impact, different failure mechanisms and ballistic models are detailed in Chapter 9 including the procedures adopted in ballistic tests. A vast bibliography accompanying this introductory chapter highlights the multidisciplinary nature of applied impact mechanics to modern science, engineering, medicine and technology.

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