# Recent Advances in Solid Mechanics

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Solid mechanics is the oldest field of science and is still advancing rapidly in all areas of technology. The advancement of the methods of analysis of structures of various kinds over the years is indeed quite impressive. The emergence of digital high speed computers with their enormous computing speed and core memory capacity has changed the direction of solid mechanics to a great extent. Sophisticated high speed computers are available to solve large sized problems with complicated aspects. High Performance Computing (HPC) has become a fashion for the scientist involved in modeling of systems. Numerical methods are developed at a great speed in recent years. Many problems including complicated geometry, boundary conditions and non-uniform loading that could not be dreamed of yielding a solution can now be attempted conveniently. Difficult practical problems can be solved with ease with available tools. Plenty of software packages including ANSYS, ABACUS, ALGOR, NASTRAN, PLAXYS, SAP, STAAD Pro are available to solve different problems of industry. A sizeable development is noticed in the area of instrumentation used in experimental mechanics to study the real behavior of structures. Small scale model to full scale tests are being done around the globe to study the behavior of structures. The subject 'Solid Mechanics' has advanced quite far than could be anticipated two decades back. Examples of engineering structures vary from a building or a bridge to a power plant to a ship or aircraft subjected to a varieties of loading. The current trends of development of solid mechanics clearly moves towards emphasis on analyzing and experimenting the failure and damage of structures with preserve of structural integrity [1]. Some of the recent research developments are:

- FRP Composites
- Smart Structures

- Nanotechnology
- Structural health monitoring
- Damage Mechanics
- Mesh free finite element
- Multi-scale modeling
- Earthquake resistant design
- Spectral finite element
- Modal testing

## FRP Composites

Laminated composite structures are increasingly used in aerospace, automobile, marine, nuclear, civil engineering structures and other industrial fields because of the higher value of specific strength, stiffness and its ability to be tailored through the variation of geometrical parameters to obtain an efficient design. The development of advanced composite materials is one of the big technical revolutions after jet engine. The tensile strength of composites is four to six times greater than that of still or aluminum. The strength to weight ratio of FRP is 18 times that of steel and 50 times that of concrete. FRP materials are 30-40% lighter than aluminum structure. Besides military aircrafts like F-35, even the recent Boeing-787, Airbus-350 passenger plane uses 50% of composites in wings, fuselage and other components in comparison to Boeing-777 models. The composite bridge in Oxford, the Avantime passenger car, Kenwood truck the award winning Oracle sail boat are only applications of FRP composites. The F-35 lightening II will be the first mass-produced aircraft to integrate structural nanocomposites in non-load bearing airframe components. Meanwhile, the same carbon nanotube reinforced polymer (CNRP) material is being considered to replace about 100 components made with other composites or metals throughout the F-35's airframe. The first, large-scale commercial applications of composite materials began during World War II in the military sector in the late 1940s and early 1950s. Since then, global use of composite materials has grown rapidly from 158,800 metric tonnes/350 million lb in 1960 to 6.1 million metric tonnes/13.5 billion lb in 2004 — representing 3,800 percent growth in the last 45 years [2]. Efforts are on for the research on renewable biomaterials for better performance to meet the emerging challenge.

## Smart Structures

A smart structure is basically a system which has the capability to learn about the environment, process the information in real time, reduce uncertainty, generate and execute control actions in a safe and reliable manner to accomplice the desired objectives [3]. The prime objectives of the smart structures are its ‘ability to sense, measure, process and diagnose at critical locations any change of selected variables and to command appropriate action to preserve structural integrity and continue to perform intended functions’. The variables are deformation, temperature, pressure, change of state and phase. It may be optical, electrical, magnetic, chemical, or biological. The three basic three elements to be embedded in a structure is sensor, processor and actuator which enable the structure to behave smartly to maintain the integrity of structures. While structures with some degree of smartness have been designed from times immemorial, the current activity and excitement in this field derives its impetus from the level of sophistication achieved in materials science, information technology, measurement science, sensors, actuators, signal processing, nanotechnology, cybernetics, artificial intelligence, and biomimetic [4]. Smart materials are: **Piezoelectric materials** are materials that produce a voltage when stress is applied. Since this effect also applies in the reverse manner, a voltage across the sample will produce stress within the sample. Suitably designed structures made from these materials can therefore be made that bend, expand or contract when a voltage is applied.

- **Shape-memory alloys** and shape memory polymers are materials in which large deformation can be induced and recovered through temperature changes or stress changes (pseudoelasticity). The large deformation results due to martensitic phase change.
- Magnetostrictive materials exhibit change in shape under the influence of magnetic field and also exhibit change in their magnetization under the influence of mechanical stress.
- **Magnetic shape memory alloys** are materials that change their shape in response to a significant change in the magnetic field.
- pH-sensitive polymers are materials that change in volume when the pH of the surrounding medium changes.
- Temperature-responsive polymers are materials which undergo changes upon temperature.

- Halochromic materials are commonly used materials that change their colour as a result of changing acidity. One suggested application is for paints that can change colour to indicate corrosion in the metal underneath them.
- Chromogenic systems change colour in response to electrical, optical or thermal changes. These include electrochromic materials, which change their colour or opacity on the application of a voltage (e.g., liquid crystal displays), thermochromic materials change in colour depending on their temperature, and photochromic materials, which change colour in response to light—for example, light sensitive sunglasses that darken when exposed to bright sunlight.
- Photomechanical materials change shape under exposure to light.
- Self-healing materials have the intrinsic ability to repair damage due to normal usage, thus expanding the material's lifetime
- **Dielectric elastomers** (DEs) are smart material systems which produce large strains (up to 300%) under the influence of an external electric field.
- Magnetocaloric materials are compounds that undergo a reversible change in temperature upon exposure to a changing magnetic field.
- Thermoelectric materials are used to build devices that convert temperature differences into electricity and vice-versa.

## Nano technology

Nanotechnology is a field that is dominated by developments in basic physics and chemistry research [5], where phenomena on atomic and molecular level are used to provide materials and structures that perform tasks that are not possible using the materials in their typical macroscopic form. Nanotechnology covers the design, construction and utilization of functional structures with at least one characteristic dimension measured in nanometers [6]. The field of nanotechnology has developed in major leaps during the past 10 years. Nanoscale science can be divided into three broad areas, e.g. nanostructures, nanofabrication and nano-characterization with typical applications in nano-electronics and life sciences & energy [6]. Nanotechnology can be used for design and construction processes in many areas since nanotechnology generated products have many unique characteristics. These include products that are for: Lighter structure; Stronger structural composites e.g. for bridges etc ; Low maintenance coating ; Improving pipe joining materials and techniques ; Better properties of cementitious materials ; Reducing the thermal transfer rate of fire retardant and insulation ; Increasing the sound absorption of acoustic absorber ; Increasing the reflectivity of glass. There are large numbers of applications of nanotechnology in construction engineering/industry. Research has been conducted to study the hydration process, alkali-silicate reaction (ASR), and fly ash reactivity using nanotechnology [7]. Addition of nanoscale materials into cement could improve its performance. It is found that nano-SiO2 could significantly increase the compressive for concrete, containing large volume flyash, at early age and improve pore size distribution by filling the pores between large fly ash and cement particles at nanoscale. The dispersion/slurry of amorphous nanosilica is used to improve segregation resistance for self-compacting concrete [8]. It has also been reported that adding small amount of carbon nanotube (1%) by weight could increase both compressive and flexural strength. Nano and microelectrical mechanical systems (MEMS) sensors have been developed and used in construction to monitor and/or control the environment condition and the materials/structure performance. One advantage of these sensors is their dimension (10-9m to 10-5m) [9]. These sensors could be embedded into the structure during the construction process. Smart aggregate, a low cost piezoceramic-based multi-functional device, has been applied to monitor early age concrete properties such as moisture, temperature, relative humidity and early age strength development. The sensors can also be used to monitor concrete corrosion and cracking.

## Structural health monitoring

The process of implementing a damage detection and characterization strategy for engineering structures is referred to as Structural Health Monitoring (SHM). Here, damage is defined as changes to the material and/or geometric properties of a structural system, including changes to the boundary conditions and system connectivity, which adversely affect the system's performance. The SHM process involves the observation of a system over time using periodically sampled dynamic response measurements from an array of sensors, the extraction of damage-sensitive features from these measurements, and the statistical analysis of these features to determine the current state of system health. For long term SHM, the output of this process is periodically updated information regarding the ability of the structure to perform its intended function in light of the inevitable aging and degradation resulting from operational environments.

After extreme events, such as earthquakes or blast loading, SHM is used for rapid condition screening and aims to provide, in near real time, reliable information regarding the integrity of the structure. Non descriptive evaluation (NDE) methods including vibration and soft computing including neural network, fuzzy logic are employed to assess the integrity of the structure, including radio graphics, fibre optics, x-rays acoustic emission and ultrasonic techniques. These traditional NDE methods are not suitable for damage detection of large complex structures and can only give qualitatively an idea of the extent of deterioration of local areas [1].

## Meshless FEM :

Meshfree methods are a particular class of numerical simulation algorithms for the simulation of physical phenomena. Traditional simulation algorithms relied on a grid or a mesh, meshfree methods in contrast use the geometry of the simulated object directly for calculations. Meshfree methods exist for fluid dynamics as well as for solid mechanics. Some methods are able to handle both cases. Recent advances on meshfree methods aim at the development of computational tools for automation in modeling and simulations. This is enabled by the so-called weakened weak (W2) formulation based on the G space theory [10] The W2 formulation offers possibilities for formulate various (uniformly) "soft" models that works well with triangular meshes. Because triangular mesh can be generated automatically, it becomes much easier in re-meshing and hence automation in modeling and simulation. In addition, W2 models can be made soft enough (in uniform fashion) to produce upper bound solutions (for force-driving problems). Together with stiff models (such as the fully compatible FEM models), one can conveniently bound the solution from both sides. This allows easy error estimation for generally complicated problems, as long as a triangular mesh can be generated.

## Multi-scale modeling:

Multiscale modeling is the field of solving physical problems which have important features at multiple scales, particularly multiple spatial and (or) temporal scales. Multiscale modeling, connecting the hierarchy of scales in materials nano-micro-meso-macro is a dominant trend. Embedding a discrete model at one scale e.g., atomistic simulation, simulation of discrete dislocations, simulation of particles or fibers in a matrix, the role of nanopores in concrete into a continuum model at the next higher scale is a challenge where success can yield superior understanding of composites, polycrystals, and porous or cellular materials. In operation research, multiscale modeling addresses challenges for decision makers which come from multiscale phenomena across organizational, temporal and spatial scales. This theory fuses decision theory and multiscale mathematics and is referred to as Multiscale decission making. The Multiscale decission making approach draws upon the analogies between physical systems and complex man-made systems. Spatial multiscale approaches are grouped into two categories: information-passing and concurrent. In the concurrent multiscale methods in space multiple scales are simultaneously resolved, whereas in the information-passing schemes, the fine scale is modeled and its gross response is infused into the continuum scale. The issue of appropriate scale selection is discussed. Among the temporal multiscale application we describe block cycle and temporal homogenization approaches with application to fatigue life prediction of composites. Application of multiscale modeling methods for the determination of structure and properties of advanced macromolecular materials. The purpose of multiscale models is to determine the locally averaged global constitutive behavior of heterogeneous materials taking into account the effect of the microstructure, which may exhibit all kinds of heterogeneity, including evolving cracks. And these micro-structural details, such as fiber volume fraction, fiber orientation, crack density and orientation, and constitutive properties of the individual constituents, certainly have a substantial impact on the overall properties of the materials.

## Earthquake resistant design:

Early stage seismic structural design of buildings has been based on representing the earthquake loading effect in terms of static equivalent forces, which are calculated from elastic response spectra that relate the peak ground acceleration (*PGA*) with the absolute pseudo-acceleration response. From the 1990s onward, increasing emphasis has been put on displacement considerations, leading to the development of displacement-based design procedures. The maximum relative displacement (or displacement ductility) is the structural response parameter most used for evaluating the inelastic performance of structures. However, it is widely recognized that the level of structural damage due to earthquakes does not depend only on maximum displacement, and that the cumulative damage resulting from numerous inelastic cycles must be taken into account. Resorting to the concept of equivalent (reduced) ductility factors, also known as target ductility. Along these lines, Fajfar [11] proposed a methodology in which the ductility of the structure is reduced by a non-dimensional parameter $\gamma$ that represents a normalization of the dissipated hysteretic energy . More recently, Teran-Gilmore and Jirsa [12] used the observed correlation between the plastic energy demand and the strength reduction factor to propose two simple procedures for seismic design against low-cycle fatigue that indirectly control the plastic energy demand through the concept of target ductility.

## Spectral Finite Element Method

Spectral methods are a class of techniques used in applied mathematics and scientific computing to numerically solve certain differential equations often involving the use of the Fast Fourier Transform. The idea is to write the solution of the differential equation as a sum of certain basis functions and then to choose the coefficients in the sum in order to satisfy the differential equation as well as possible. Spectral methods and finite element methods are closely related and built on the same ideas the main difference between them is that spectral methods use basis functions that are nonzero over the whole domain, while finite element methods use basis functions that are nonzero only on small subdomains. In other words, spectral methods take on a global approach while finite element methods use a local approach. Partially for this reason, spectral methods have excellent error properties, with the so-called "exponential convergence" being the fastest possible, when the solution is smooth. However, there are no known three-dimensional single domain spectral shock capturing results. In the finite element community, a method where the degree of the elements is very high or increases as the grid parameter *h decreases* to zero is sometimes called a spectral element method. Spectral methods can be used to solve ordinary differential equations (ODEs), partial differential equations (PDEs) and eigenvalue problems involving differential equations. When applying spectral methods to time-dependent PDEs, the solution is typically written as a sum of basis functions with time-dependent coefficients; substituting this in the PDE yields a system of ODEs in the coefficients which can be solved using any numerical method for ODEs. Eigenvalue problems for ODEs are similarly converted to matrix eigenvalue problems. Spectral methods were developed in 1969 including, but not limited to, Fourier series methods for periodic geometry problems, polynomial spectral methods for finite and unbounded geometry problems, pseudospectral methods for highly nonlinear problems, and spectral iteration methods for fast solution of steady state problems. Spectral methods are computationally less expensive than finite element methods, but become less accurate for problems with complex geometries and discontinuous coefficients.

**Modal testing**

Experimental modal analysis (EMA) still play a key role, because it helps the structural dynamicist to reconcile numerical predictions with experimental investigations. For linear structures, phase resonance testing, also known as force appropriation, has been used for decades, particularly in the aerospace industry (e.g., for ground vibration testing of aircrafts and modal survey of satellites ). It consists in exciting the normal modes of interest one at a time using multi-point sine excitation at the corresponding natural frequency [13]. In the field of vibro-acoustics, development of new combinations of standard composites and highly damped materials of viscoelastic type are currently receiving increasing attention in order to control structural vibrations and find cost efficient designs. For this purpose, numerical models and optimisation techniques are needed to predict the dynamic behaviour of general (anisotropic) composite structures and minimise the amount of experimental testing needed. Another desired feature in development and use of different material models is the possibility and simplicity of extraction of material damping parameters from vibration damping, observed in dynamic testing of assembled structures, such as layered plates and composite structures [14]. The use of modern sophisticated FFT analyser with contact and non contact accelerometers (Scanning Laser vibrometers) paves a long way in this directions. Today, three-dimensional digital image correlation (DIC) techniques have come a long way from their conception in the 1980s. Images taken from a stereo pair of charge coupled device (CCD) cameras can be used to determine surface geometry and displacement in three dimensions of any object whose surface has had a contrasting speckle pattern applied to it. This non-contact full-field technique can take measurements at thousands of points on the surface of an object in a single snapshot.

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