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Editorial. On Refined Theories of Plates and Shells

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Within the 8th European Solid Mechanics Conference held on July 9-12, 2012 in Graz (Austria), the Mini-Symposium "Refined Theories of Plates and Shells" took place. 31 lectures were presented during 5 special sessions, and after the Symposium the authors were invited to write the full-text manuscripts of their contributions and submit them to this special issue of ZAMM. In this double issue we have the honour and pleasure to present to the readers ten selected papers of this meeting on various plate and shell problems.

This is perhaps a proper place and right moment to express some our views on what the field "Refined Theories of Plates and Shells" should mean in the second decade of 21st century. The field belongs to the classical discipline of solid mechanics developed over two hundred years. Many outstanding mechanicians have contributed to the field, probably over one million research papers have been published as well as over one thousand books, conference proceedings and large review articles are available which summarise the main achievements in the field. And yet, each week one can find many new papers and reports on the Internet on various plate and shell problems, each year dozens of new books in the field are published, and specialized international conferences, meetings and workshops as well as separate parts of multidisciplinary congresses are available for shell specialists. The main source of such popularity of this field is that plates and shells are basic structural elements of modern technology and everyday life.

Nowadays, various known models of plates and shells are associated with the names of Kirchhoff, Love, Cosserat, Timoshenko, Reissner, Koiter, Naghdi, Vekua and others. Obviously, some of the models may be considered as refinement of the classical Kirchhoff-Love linear theory of shells. On the other hand, various refined theories of Reissner-type and other are already implemented in commercial FEM software codes and widely used in contemporary engineering practice. Thus, such models can also be treated as the classical ones.

From our point of view, different ways of refinement of plate and shell theories are still required for

- refinement of 2D governing relations for better accuracy and wider versatility;
- application to modelling new materials and phenomena;
- development of new efficient numerical methods.

Let us briefly mention those areas in which some refinements of the existing 2D formulations of plates and shells seem to be desirable.

1. Refinement of classical 2D models

Most of the 2D classical models of plates and shells have been derived for 3D thin bodies using either kinematic and/or static hypotheses or by series expansion of 3D fields in the normal direction with subsequent truncation at some level. Other popular derivation techniques such as asymptotic integration, variational methods, Gamma convergence, 6-field theory for resultants, and others have allowed for some refinements of the classical models and for better understanding their accuracy and applicability. But new more reliable 2D multi-field models are needed for shells with complex microstructure, to describe non-local and/or complex inelastic behaviour in shells such as fracture and damage, for shells with surface and/or residual stresses, for high-frequency vibrations of shells and wave propagation, etc.

However, one should keep in mind that during the past two centuries only small progress has been achieved in better 2D modelling of the shell internal state in the boundary zone of width of the order of a few shell thicknesses, where all the fields are essentially three-dimensional. Without a breakthrough in better 2D modelling of the boundary zone any refinement of existing 2D shell models in the interior domain may not be regarded as satisfactory.

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2. Thin-walled nanostructures

At the nanoscale, carbon thin-walled structures - nanotubes, fullerenes or graphenes - show exceptional mechanical, chemical, optical, electric and electronic properties. This may allow for development of many new important technologies in decades to come. In the 2D modelling of such nanostructures one must deal with several new factors such as atomic structure, interatomic potentials, non-locality of interactions, van der Waals forces, chirality, Cauchy-Born rule, molecular dynamic simulations, etc. Although some classical shell models are known to be adequate for specific representative loading, a more versatile 2D shell theory of thin nanostructures is still under development. Modern composites made of polymer, metal and/or ceramic matrix reinforced by high-strength nanostructures have been in use for some years, but the reliable and versatile plate and shell models made of such composites seem still to be in demand.

3. Irregular and singular shell problems

Real plate and shell structures often contain folds, branches, intersections, stepwise thickness changes, stiffeners, shell-to-beam and/or shell-to-column connections, technological junctions and other design elements such that the shell base surface cannot be treated as a regular geometric surface. In such problems, in order to complete the BVP, appropriate jump conditions at some stationary singular curves and points have to be formulated. Due to various technological constructions of the plate and shell junctions used in engineering and appearing in nature, each type of junction might require some specific modelling.

Time-depending phenomena in shells such as wave propagation, phase transition, strain localization, fracture, etc. also require some 1D jump conditions at singular curves moving relative to the base surface. The singular curves themselves may carry additional thermodynamic fields different from those associated with the adjacent shell. Formulation of the complete sets of relations and analyses of irregular and/or singular BVPs and IBVPs is still in the developing process and has to be continued.

4. Thin-walled structures in biological, biomechanical and medical sciences

Nature presents many examples of living thin-walled structures, such as leaves of trees, blooming flowers, sea shells, the double helix of DNA, cell membranes, wings of insects and birds, etc. A number of bioshells can be found in the human body: eye balls, arteries, the diaphragm, skin or pericardium, etc. Bioshells exhibit a complex bio-chemo-physical, non-linear, inelastic, heterogeneous and anisotropic behaviour that can change with age, diseases, exercises, medical treatment and even gender. Although much has been accomplished in modelling of these complex processes in the last 50 years, yet much remains to be done. Biological membranes of different kind are very important for medicine and pharmacology. Since biological objects may exhibit large deformations and are sensitiv to mechanical, chemical and electrical impacts, the proper mechanical models of such structures are still under consideration. Here one of the main problems is to formulate 2D constitutive equations for biological thin structures appropriate to the specific 2D problem at hand.

5. Direct formulation of plate and shell models

There is another way of construction of 2D theories of plates and shells called a direct approach. Within this approach a shell is modelled as a deformable material surface. All governing equations are formulated here directly as for the 2D material continuum. The direct approach does not require any assumptions usually used for 3D-to-2D dimensional reduction. On the other hand, special efforts are necessary to formulate the 2D constitutive equations and to identify parameters in these equations. An advantage of the direct approach arises when the model is applied to such thin structures whose 2D material properties are significantly different from the bulk, or to thin structures such as nanofilms, cell membranes, etc. which cannot be regarded as real three-dimensional solids.

6. Numerical analysis

The progress in computer assisted numerical technology achieved in the last decades makes it possible to solve various complex engineering and research problems. In FEM computer codes, which are now predominant, the low-order finite elements with C^0 interelement continuity are commonly used. In case of thin-walled structures such elements still bring computational difficulties associated with various types of locking. Numerical methods are required which would avoid such singular behaviour in the thin shell limit. Further progress in high-order C^0 locking-free finite elements, error control and adaptive techniques, automatic model refinement, more efficient and stable iterative solvers, etc. should lead to sensible numerical results for thin-walled structures with a reasonable effort. But an increasing computer capacity already allows one to calculate some responsible thin-walled structures based on 3D solid elements.

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