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Fascicolo 8 - Booklet 8

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Meccanica strutturale: alcuni recenti sviluppi con notevoli contributi all'ingegneria e alle tecnologie.

Structural mechanics: some recent developments with meaningful contributions to engineering and technologies

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Indice / Summary

Teaching mechanics in Italy
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Giulio Maier. Short biography

Professor Emeritus of Structural Engineering at the Technical University (Politecnico) of Milan, Italy.

Education

Master in mechanical engineering, University of Trieste; «specialization» (PhD) in aerospace engineering, University of Rome, both *cum laude*.

Academic appointments

At the Technical University (Politecnico) of Milan: Assistant 1959-1963; Associate 1964-1970; Full Professor 1970-2006; Emeritus 2007-present.

Department Head 1975-1978; Continuing Education Chairman 1973-1986; Doctoral School Coordinator 1993-2002. Visiting Scholar at Brown, Cambridge, Mons, Illinois, Minnesota, Tsinghua Universities.

President of the Italian Association of Theoretical and Applied Mechanics (AIMETA), 1986-1990.

Rector, International Centre of Mechanical Sciences, Udine, Italy, 2005-2010.

Research contributions to:

mechanics of elastoplastic structures: shakedown theory, computational methods and extremum properties of solutions; structural design optimization by mathematical programming; constitutive parameter identification by inverse analyses, in particular by Kalman filters; boundary element methods, in particular based on Galerkin symmetric formulations; quasi-brittle fracture mechanics; diagnostic analysis of structures based on non-destructive testing and simulation; mechanics of composites; structural engineering problems, in particular concerning tension structures, offshore pipelines and concrete dams.

Publications

Author or co-author of about 270 scientific publications; co-author or co-editor of 9 monographs and books.

H factor in Scopus, 2012: 27 (2.056 citations), 24 without self-citations.

Editorial board member of 16 international scientific journals. Former Editor of «Meccanica» and Associate Editor of «European Journal of Mechanics A/Solids».

Honors

- Member of: National (Italian) Academy («Lincei»), Rome; National (Italian) Academy of Sciences («dei XL»), Rome; «Istituto Lombardo Accademia di Scienze e Lettere», Milan; «Istituto Veneto di Scienze, Lettere ed Arti», Venice; «Accademia Udinese di Scienze, Lettere e Arti», Udine; «Accademia delle Scienze», Turin.
- Foreign Member of: Polish Academy of Sciences, Warsaw; Hungarian Academy of Sciences, Budapest; Russian Academy of Engineering, Moscow; National Academy of Engineering of the United States, Washington DC; Polish Academy of Sciences and Arts, Krakow; Portuguese Academy of Sciences, Lisbon; Royal Society of South Africa; Honorary Visiting Professor, Tsinghua University, Beijing.
- Fellow of: American Society of Civil Engineers (ASCE); American Society of Mechanical Engineers (ASME); International Association of Computational Mechanics (IACM); American Academy of Mechanics (AAM); Polish Association of Theoretical and Applied Mechanics. «Member At-Large» of the General Assembly of International Union of Theoretical and Applied Mechanics (IUTAM).

Awards

Honorary doctoral degrees from: University of Thessaloniki, Greece; Faculté Polytechnique de Mons, Belgium; State University of Saint Petersburg, Russia; University of Ho Chi Minh City (Saigon), Vietnam; University Medal from University of Colorado, Boulder, USA.

Copernicus Medal from Polish Academy of Sciences. Feltrinelli Prize from Italian National Academy «Lincei»; Warner Koiter Medal 2000, from American Society of Mechanical Engineers (ASME); O.C. Zienkiewicz Medal from Polish Association for Computational Mechanics. Ritz-Galerkin Medal from the European Community of Computational Methods in Applied Sciences (ECCOMAS). Life-Time Achievements Medal at the International Conference on Computational & Experimental Engineering and Sciences (ICCES'11), Nanjing, China; Blaise Pascal Medal in Engineering 2011 from European Academy of Sciences (EAS), Liege, Belgium.

Structural mechanics: some recent developments with meaningful contributions to engineering and technologies

abstract

by Giulio Maier

Since centuries construction activities have promoted interdisciplinary convergence of mechanics as scientific area and architecture as production of human environments. In the second half of the last century mechanics has increased the centrality of its role in the synergistic interactions of diverse cultural areas for the society, and such synergism is still growing at present and, hopefully, will still grow in the future.

Structural mechanics is itself a symbiosis of physics, mathematics, computational and experimental techniques. Its frequent alliance and cooperation with other cultural fields, architecture included, have provided and provide substantial improvements of technologies and developments in a broad sense.

This seminar is intended to present a brief survey of some representative contributions of structural mechanics to solutions of technical, and sometimes also socially and culturally meaningful, problems. The subjects considered and briefly discussed in the seminar are listed in what follows.

The methods for mathematically modeling mechanical phenomena, *in primis* the finite elements methods, at present provide more and more accurate simulations and reliable quantitative predictions in diverse engineering fields. Such methods are essential tools in all mechanical topics mentioned here in the sequel. A pioneer and research leader in the finite element area has been Olek Zienkiewicz, Doctor Honoris Causa in our Politecnico.

Limit and shakedown analyses in elastoplasticity provide assessments of safety margins with respect to collapse (rather than of responses to service loadings). Pioneering contributions to such developments are due particularly to the Brown University team led by William Prager, to whom our Politecnico conferred a Honorary Doctoral Degree at the celebration of its 100th Anniversary. These subjects belong to an area of applied mechanics useful in recurrent engineering situations, particularly in civil engineering, with remote origin in the architecture history and with strong links with mathematics promoted by economy (namely «mathematical programming», originally developed by economy-oriented mathematicians like

George Dantzig in Stanford and by John Nash, Nobel Prize winner and «Beautiful Mind» in a successful film).

A structural mechanics methodology related to limit analyses, but with more recent origin, is design optimization. It can provide improvement of diverse structural products, including the architectural ones, by means of mathematical-computational procedures as supports, or as alternatives, to technically intuitive, or aesthetical, approaches.

Assessments of damages in structures and in industrial plants and estimates of parameters in material models are obviously based on experiments. Remarkable progresses in such area, progresses both in terms of accuracy and economy, are at present due to a recent and still growing methodology of computational mechanics, namely «inverse analysis». Attention will be paid in the seminar to this subject and to several relevant research results (among those achieved in our Structural Engineering Department) in view of their useful and meaningful consequences in structural diagnoses and in various industrial processes. The following results will be briefly presented by examples: assessments of possible deteriorations in dams, metallic plant components, bridges, offshore and other structures by non-destructive tests; calibration of material constitutive models in a variety of products. The dangerous damages due to creep in many pre-stressed concrete bridges around the world are investigated at present, among other mechanical problems, by Professor Zdenek Bazant, Honorary Doctor in our Politecnico, and collaborators.

Many other topics in structural mechanics would deserve consideration, like the following ones: methods for predictions of responses to dynamical loads such as earthquakes, impacts, explosions; homogenization of composites and multi-scale analyses; probabilistic assessments of safety margins and damages, et alia.

The few items briefly considered in this seminar are hopefully sufficient to corroborate the following remarks or warnings, cited here as conclusions, but formulated years ago by a master in mechanics, Dan Drucker, and, respectively, by a master in architecture, Eduardo Torroja: «design gigantic structures is in large measure based on experience and tests; however the greater the science contents the better the design will be»; «the art of building has a scientific, particularly mathematical, background without which the technician cannot live today».

Teaching mechanics in Italy

by Carlo Cercignani and Giulio Maier

Since teaching mechanics is part of the educational process in technology and sciences, an understanding of this broader context must obviously be the premise to any discussion of our theme. And since at present, the whole university system in Italy displays a number of peculiarities which tend to isolate it even from those of countries with a comparable cultural background, describing it to foreigners is not only fairly difficult, but also somewhat sad and frustrating.

Until recently, the underlying philosophy of technological and scientific education in this country was imbued with those ancient, but yet illustrious ingredients of Illuminism and Positivism, together with the concept of a centralized national State. The merging of these ingredients took place along with the process of political unification of the country, accompanied on the European scene by remarkable concomitant events such as industrialization and the «triumphs» and myths of science and technology in the 19th century. Prototypes for the implementation of that philosophy were institutions like the École Polytechnique and the Middle European (particularly German) universities.

Among the far-reaching implications, the following seem worth mentioning in connection with our subject: emphasis on the theoretical bases rather than on applications; training in abstract thinking more than in problem solving techniques; priority to conferring *formae mentis* and potentialities rather than specific competence, technical information and professional training; «systematic» organization of engineering curricula where the general basic disciplines (mathematica, physics, rational mechanics) formed a massive «propedeusis» in the first two years, while more specific engineering-oriented disciplines (strength of materials, structural mechanics, hydraulics, etc.) were treated only in the subsequent years.

The educational system that resulted could be further qualified as centralized and homogeneous, with relatively small differences in contents and standards of syllabus and courses and in organization for different universities and different branches of engineering and science. It can also be described as rigid and élite, awarding a single degree, the «laurea», and selecting its students not on the basis of an *ad hoc* examination, but on high school standards and on the above mentioned nature of university education and, hence, implicitly also on psychological and social background. The traditional system, as outlined above, matched to a large extent some essential characteristics and requirements of the country as far as scientific and technological education was concerned.

Several new factors, however, of varying importance and relevance have emerged in the last few decades and, more markedly, in the last few years. Besides very general and obvious circumstances (such as the growing impact and role of science and technology in society at large, the expanding request for scientific research in technology, the configuration of new disciplines and interdisciplinary fields), we must mention here some recent events peculiar to Italian society and relevant to our subject. These are: the rush for education as a large-scale social phenomenon, the «homogeneization» of the high schools, the open access to universities, the «liberalization» of curricula. Approximately three times as many students enter university today than did twenty years ago, with no admission examination. They no longer come from the some-what élite and partly exclusive «licei classici» and «licei scientific» alone, but from a broad spectrum of technical high schools as well. All these institutes, mostly State sponsored, are overpopulated. They are much less diversified than in the past, but many are still mainly intended for strictly professional training in specific technical jobs. Last, but not least, these schools bear the consequences of student unrest and teacher frustration. As a result, students entering the university are generally less prepared today than in the past and this is particularly true in scientific disciplines. By virtue of a recent «liberalizing» law, at present university students may choose courses for their curriculum with fewer constraints than in the past.

Finally, as in other countries, the productive structures (industry, professions, administration) continue to increase their demands for a university output of young people with diverse specializations and educational levels, part of them trained to under-take professional activity immediately. Our educational System has yet to make an adequate adjustment to the above variety of drastic changes. The present situation can only be described as a sort of temporary compromise between rigid traditional structures stemming from a past rich in values but lacking in adaptability on one side and, on the other, various partly conflicting trends and attempts to cope with the new conditions and demands arising from the evolution of both technology and society.

Some of the innovations favored for years both inside and out of the academic environment can be regarded as more or less inspired by American models: departments as units of organization instead of the present «Facoltà», «Istituti» and «cattedre»; semesters instead of the academic year for the typical duration of courses; three degrees instead of the traditional single «laurea»; autonomy of individual institutions rather than centralization; «integrated» curricula with basic and application oriented courses given for the same level of study and possibly interrelated and mutually motivated, instead of the past and present «systematic» curricula. Why innovations of this kind have remained wishful thinking for decades, unable to negotiate the constraints of tradition, unimplemented by a long discussed and long awaited organic reform, is a question which puzzles most foreigners and indeed many Italians. Any tentative answer would lead far beyond the scope of this paper.

We have tried so far to outline the changing «scenario» in which the present situation of teaching mechanics in Italy must be inserted. Now, to be specific, let us consider the case of the structural engineering student in Italy today. He enters the university at nineteen, having merely passed his final examinations in any one of the large variety of high schools. His university curriculum is still divided into two cycles of two and then three years. The first cycle is still mainly devoted to basic theoretical subjects, but within the narrow margin permitted by the present laws, some introductory exposure to engineering is provided in some universities. This cycle functions more or less as a selection filter, a painful substitute for an admission examination.

Mechanics is first met in the second year under the name of Rational Mechanics. At this level students have had a first course in Calculus and in Physics and are taking a second in these subjects. Basic principles of Newtonian Mechanics, the Mechanics of Solid Bodies and Lagrange equations are the typical parts of the teaching of Rational Mechanics, which is usually concluded with a few lectures on the basic principles of Continuum Mechanics. Rational Mechanics is taught by lectures whose interests range from mathematical fields such as Functional Analysis and Differential Equations to the more or less traditional fields of Mathematical Physics, such as Continuum Mechanics, Relativistic Field Theories or Transport and Diffusion Phenomena.

The course is divided into a group of main lectures devoted to discussion of basic principles and typical examples and another group of lectures on problem solving, the former to show the logical structure and the experimental foundations of the subject, the latter to allow students to develop reasonable confidence and ability in applying the principles and basic equations of statics and dynamics. Seventy hours are allotted to each of these two sets of lectures which are given concurrently, but sixty-five to sixty hours is a more realistic estimate in practice. (An hour means forty-five minutes in old academic tradition.) Examinations usually comprise both a written and an oral test.

In the third year, courses related to engineering mechanics and practically compulsory for all students in engineering are «Scienza delle Costruzioni», Mechanics Applied to Machines, Structural Elements and Hydraulics, all organized in much the same way as Rational Mechanics. The first of these courses, clearly fundamental for the structural engineering student, present basic topics in Strength of Materials and Structural Mechanics, i.e., kinematic analysis of structures, statics of nonredundant systems, an introduction to linear elasticity from the continuum mechanics point of view, Saint-Venant's beam theory, analysis of redundant beams, trusses and frames, yield criteria, introductory notions of elastic stability.

In the fourth year, «Tecnica delle Costruzioni» and, in some schools, «Scienza delle Costruzioni II» represent the sequel to the above basic course, the former compulsory, with suitable adjustments, also for students in most of the other branches of engineering. The contents cover topics in classical theory of elastic structures (e.g., frame analysis by moment distribution; plates in stretching and bending; elementary shell theories); limit and elastoplastic analysis of frames; finite element displacement method for elastic analysis; basic notions of reinforced concrete, prestressed and steel structures. At the same time, courses are offered in Structural Stability, Structural Dynamics, Soil Mechanics, Computer Analysis of Structures and, optionally, collateral courses in Mathematical Methods or Numerical Analysis in Engineering. All these courses, however, are available only in those universities where structural engineering curriculum has been organized within the traditional, less specialized civil engineer syllabus.

The fifth year is mainly dedicated to engineering design with courses such as Structural Design, Steel Constructions, Bridges, Foundation Engineering. In some institutions, however, further courses with a substantially mechanical slant are feasible options for this last year, e.g., in our institution, Theory of Plasticity, Rock Mechanics. Of course, besides the above main stream of courses in structural mechanics and design, students are expected to attend a fixed number of optional courses in related areas (e.g., Surveys, Material Technology, Operations Research, Architectural Engineering, Economics, etc.).

After passing the examinations for the courses of the above outlined five year curriculum and a final examination consisting in the discussion of a design theme prepared during the last year, the student is awarded his «laurea» in engineering, and attains the legally protected title of «dott. ing.». This degree is the rough equivalent of a Master's degree in Anglo-Saxon countries; it gives direct access (with the formality of an additional, at present almost token examination) to the engineering profession.

Experience shows that good students are still likely to become successful practicing engineers. Present inadequacies of the educational process and its lack of adjustment, student overpopulation above all, affect primarily the future of poorly motivated students, whom an orientative admission examination would have filtered out in the first place.

Further formal graduate studies for something similar to a Ph.D. degree are not contemplated by the present laws, but will be by the long awaited new laws on university education. In the meantime, so far as future research workers are concerned, the traditional counterpart to the Ph.D. level is study and research in a department in the capacity of junior assistant. As for practicing engineers, Schools of Specialization and Programs for Continuing Education have been developed recently in some universities. The latter consist of short courses on single topics (e.g., Limit-state Design, Structural Optimization, Finite Element Methods).

What has been said with reference to structural engineering holds, *mutatis mutandis*, for other technical fields based on mechanics, such as aeronautical, naval and mechanical engineering. Engineering students are not the only ones exposed to the teaching of mechanics; Rational Mechanics is part of the Mathematics and Physics curricula as well. It should be noted that four years are sufficient for a «Laurea» in Mathematics or Physics. And again, this degree may be compared to a Master's degree in Anglo-Saxon countries. Future mathematicians and physicists are usually taught Rational Mechanics by the same group of teachers as the engineering students, but the choice of topics is usually different: emphasis on Solid Body Mechanics is reduced to a minimum, Continuum Mechanics is usually absent, while a good part of the time is devoted to the Hamilton equations, variational principles and canonical transformations. The course aims at giving an example of applied mathematics to students in mathematics; their colleagues in physics are trained with an eye to their subsequent needs for the study of theoretical physics.

We share the views expressed by G.W. Housner (in *Engineering Mechanics in Engineering*, edited by R.N. Dubey and N.C. Lind, SMD, University of Waterloo, 1977) that «mechanics has a split personality» and that «research workers in mechanics can be classified into two types, according to whether they are more field oriented and mathematically inclined, or more problem oriented and inclined to emphasize thephysics of the situation». Housner mentions Euler, Lagrange, Kirchhoff, Lamb, Biot as examples of the former type; Galilei, Rayleigh, von Karman, Taylor, Mindlin are examples of the latter type. In our opinion, the same classification is applicable to teachers in mechanics. In this country, until recent times, the first, the mathematically inclined approach, has been traditionally the prevailing one, exemplified by Betti, Beltrami, Cremona, Levi-Civita, Signorini, B. Finzi, Colonnetti. Castigliano would have been an example of the second type, had he ever lectured in his brief, intense and troubled life. In the present transitional situation, together with the other previously mentioned trends, the second, problem oriented attitude appears to be gaining impetus and ground in the teaching of mechanics to both future engineers and scientists.

However, the main problems today are not of a philosophical or methodological nature, but usually concern the organizational context at large. A teacher may feel frustrated and hopeless in front of some two hundred students in the lecture hall, should he happen to remember the well-known caveat that the best method of teaching is the one that most nearly approaches the method of investigation, or if he sympathizes with Plato's recommendation that students be directed to learning by what amuses their minds, «so that you may be able to discover with accuracy the peculiar bent of the genius of each».

From the Editor:

This article is the second in the series on the Teaching of Mechanics in various countries. The first, on England by Professor F.A. Leckie, appeared in vol. 3, n. 6, 1976; the next, on the United States, will appear in a forthcoming issue [1978].

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di / of Giulio Maier

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