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Laboratório Nacional de Engenharia Civil

MEMÓRIA N.º 820

**A HISTORICAL OVERVIEW OF THE
DEVELOPMENT OF COMPUTATIONAL
MECHANICS IN PORTUGAL DURING
THE SIXTIES AND SEVENTIES**

E. R. DE ARANTES E OLIVEIRA

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A HISTORICAL OVERVIEW OF THE DEVELOPMENT OF COMPUTATIONAL MECHANICS IN PORTUGAL DURING THE SIXTIES AND SEVENTIES

SUMMARY

Ferry Borges was one of the first to recognise, by the late fifties, the importance of the contribution that computers could give to the development of engineering and science. One of his great merits as a pioneer consisted in understanding that computers should not be used as mere calculating machines aimed to execute computing routines which before used to be executed by hand: more adequate mathematical models should be established for taking benefits of the new tools. Such was the basis of an, entirely new research program in Mechanics, a program which would leave a deep mark in the history of computational methods in the country.

SUMÁRIO

No fim da década de cinquenta, Ferry Rorges foi um dos primeiros a reconhecer a importância do papel que os computadores iriam desempenhar no desenvolvimento da engenharia e da ciência. Um dos seus grandes méritos como pioneiro consistiu em entender que eles não deveriam ser usados como simples máquinas de calcular capazes de executar programas de cálculo antes executados à mão, mas que tinha chegado a ocasião de desenvolver novos modelos matemáticos adequados a tirar partido dos novos instrumentos. Tal foi a base de um programa de investigação em Mecânica cujo desenvolvimento deixaria marcas profundas na história dos métodos computacionais em Portugal.

A HISTORICAL OVERVIEW OF THE DEVELOPMENT OF COMPUTATIONAL MECHANICS IN PORTUGAL DURING THE SIXTIES AND SEVENTIES

Tracing the research on computational methods, in Portugal, back to its beginnings, it is fair to recognise that Júlio Ferry Borges was its first promoter. Having understood very early, i. e., by the late fifties, the importance of the contribution that computers could give to the development of engineering and science, he succeeded in deeply interesting in their use his institution, the National Laboratory of Civil Engineering/LNEC, the huge Portuguese public research establishment in the area of civil engineering.

The author joined LNEC in 1960 and started to collaborate with Ferry Borges, assisting him in the development of the method he had conceived [1] for the analysis of the suspension bridge aimed to span the Tagus River in Lisboa which was then being designed by an American firm. The method was enthusiastically adopted by the designers.

In 1962, a NATO ASI was held at LNEC followed by an international symposium on *The Use of Computers in Civil Engineering* [2] which gathered a large number of participants and was one of the first major scientific events in the field.

A second NATO ASI organised by Ferry Borges together with the author was held in 1971, also at LNEC, on *Finite Elements in Continuum Mechanics*. The lectures would later be edited by J. T. Oden and myself [3].

One of the great merits of Ferry Borges' pioneer work consisted in understanding that computers should not be used as mere calculating machines aimed to execute in a very fast and more or less automatic way the computing routines which before used to be performed by hand. Such routines had indeed become obsolete and new computational methods were necessary to take full benefit of the new tools. In addition, more adequate mathematical models should be established whose equations could now be solved by using such tools: an encouragement for research in Mechanics. Such was the basis of an entirely new research program at LNEC – an institution which had been made famous for its expertise in the use of physical models –, a program which would leave a deep mark in the history of computational methods in the country.

Working under Ferry Borges, who was then, at LNEC, the Head of Structural Engineering, the author of the present article was invited to collaborate in the program and was in charge of the more theoretically oriented part of it.

My first entirely personal contribution was a method for plane stress/strain analysis of elastic bodies which was the subject of a thesis submitted to LNEC in 1965. This method, which Ferry Borges called *the integral method*, may well represent the first instance of the techniques which 10 to 15 years later would become popular under the name of *boundary element methods*. The fact that such contribution was practically overlooked when published [4] in the *Journal of Engineering Mechanics* of the ASCE, and only much later happened to be quoted as a pioneer work, may be explained by the understandable success of the *finite element methods (f.e.m.)*.

We were interested of course in the f.e.m. and I myself became particularly interested in its mathematical formulation, including convergence criteria and error estimates. These researches led to the publication in 1968 of an article on the *Theoretical Foundations of the Finite Element Method* [5] in which the use of Functional Analysis made it possible to present the subject in a rigorous and very general frame. It was in such article that general completeness criteria for two-dimensional plane elasticity elements were first stated and demonstrated.

Well-known difficulties associated with the convergence of the f.e.m. in case of non-conforming plate elements led to the investigation of tests and criteria capable of replacing conformity as a convergence criterion. The last research devoted to such subject, aimed to a justification of Irons' *patch test*, was published in 1976, in an article [6] inserted in the *International Journal of Solids and Structures*.

The estimation of the order of the discretisation error in the *finite difference method* was the subject of another article [7] published, after years of persistent researches, in the *Journal for Numerical Methods in Engineering*. The assessment of the effectiveness of different finite difference approximations was made possible, not as it had been done before, by evaluating the order of the truncation errors associated to such approximations, but, as it was being done for finite elements, by determining the upper bound of the discretisation error. The analysis developed in the paper may be used for any meshless collocation method.

Use was made of the application of error analysis techniques developed for structural problems to the f.e.m. solution of the Navier-Stokes equation, in a paper [8] published in 1975 in the *International Journal for Numerical Methods in Engineering*.

The subject of the optimal decomposition of a body into finite elements became important in the beginning of the seventies. The computational effort associated to the initially used technique, which consisted in minimising the functional with respect to the node co-ordinates, was the reason which made us start to look for optimality topological criteria for finite element networks. In 1971, the so-called *isoenergetic criterion* was found [9] which was numerically confirmed at the University of Waterloo, in Canada, and deserved to be carefully studied by outstanding numerical analysts. Later, the subject lost interest to adaptive approaches. An important conference on *Accuracy Estimates and Adaptive Refinements in Finite Element Computations/ARFEC* was proposed by Jorge Gago [10] and held at LNEC in 1984.

A large part of our interest in convergence was due to the perception of the role that this concept should play in a true Theory of Structures. In such theory, convergence could become indeed a justification, not only for the finite element method, which leads to a discrete model, but for the continuous two-dimensional and one-dimensional models, i. e., the theory of shells and the theory of rods. Such idea of the Theory of Structures represented a contribution, not just for Numerical Analysis, but for Solid Mechanics, within which the Theory of Structures was aimed to represent a new and wellcharacterised scheme. These ideas were the basis for the thesis [11] I submitted in 1966 for becoming a full professor at the School of Engineering/IST of the Technical University of Lisbon.

The fecundity of such concept was demonstrated by solving a classical problem of Solid Mechanics, the justification of the theory of shells, which had sofar been treated as a problem of an exclusively mathematical nature. The situation is not entirely analogous to the one which arises in the finite element theory, since the aim is not proving that a sequence of approximate solutions tends to the exact solution but that a sequence of exact solutions provided by the three-dimensional model lends to the solution provided by the theory of shells, i. e., to the approximate solution, as the shell becomes thinner and thinner. The assumption must be made that the values of the membrane and bending stiffness coefficients keep their values as the thickness tends to zero, condition that can be satisfied only if the shell is a Cosserat's shell [12].

One of the fields in which LNEC was more active was dams engineering. Although LNEC was outstanding in scaled models techniques, the institution realised, during the sixties, that, at least in Structural Engineering, the future belonged to mathematical models and, therefore, to computational methods. Modelling dam-foundation systems resorting to finite elements soon became thus a challenge to LNEC. The first paper on concrete arch-dams modelling using three-dimensional elements [13] was Oliveira Pedro's thesis, finished in 1967.

During the seventies, the department resorted to three and four-sided thin and thick shell elements, first flat and then curved, for modelling dams and other kinds of structures, as well as

joint elements. Three-dimensional elements were specially developed for foundation rock masses. On the other hand, the dam-foundation system was realistically analysed by taking into account the construction sequence. Comparison was made between the results obtained by scaled models and computational methods [14, 15].

The monitorisation of construction works, one of the fields in which LNEC excelled, due to Manuel Rocha's pioneer ideas, was a source of inspiration for the development of structural modelling, as well as the developments occurred in Rock Mechanics, another field mastered by Rocha, the elasto-plastic, visco-elastic and visco-elasto-plastic, isotropic or anisotropic, linear or non-linear behaviour of materials were considered in the study of typical scenarios under either static or dynamic actions. Also actions were modelled, even those of an exceptional nature, like seismic actions.

It would be fully realized later [16], already in the eighties, that progress in structural engineering did not depend anymore on the development of new kinds of finite elements but on the use of those already existing for simulating collapse scenarios. For these scenarios, prototypes and scaled models had been the main source of information, at least from a qualitative point of view. The use of computational methods in such studies could not help to seduce an institution that was at the frontier of structural safety theory, in which Ferry Borges himself had been a pioneer. Ironically enough, it was by that time that a new method, the distinct element method, was being developed which would question the excellence of the finite element paradigm as a discretisation technique.

In what concerns geotechnical engineering, the first LNEC research project on the analysis of earth dams was launched in 1969 at the Geotechnics Department [17]. In 1973, rock masses were already being analysed. In 1975, the numerical simulation, by finite element techniques, of the collapse of a concrete dam due to a fracture of its foundation was achieved and, by the end of the decade, hydraulic models had been developed for the study of the water percolation in the dam rock foundation.

Researches on computational methods attempted in the Hydraulics Department would have a remarkable development at LNEC, but only in the eighties, i. e., already after the period the present paper is intended to cover.

In the early seventies LNEC established contacts with the International Union of theoretical and Applied Mechanics/IUTAM in order to promote the adhesion of the country to that organisation. As a result of such contacts, the representation of the country was temporarily entrusted to LNEC and LNEC engaged formally in forming a national body which would become the link between the Portuguese Mechanics community and IUTAM. Such body, the Portuguese National Committee for Theoretical and Applied Mechanics, was formed in 1972. The author, already a professor at the IST, was elected as its president. The two vice-presidents, Ribeiro Gomes and Álvares Ribeiro, were professors at the Universities of Coimbra and Oporto, respectively, and Tovar de Lemos, another IST professor, was made secretary-general.

The fact that the four active members of the Committee were affiliated to universities located in the three main scientific centres of the country clearly showed that LNEC was interested in helping the development of Mechanics outside its walls. After 25 years, it became possible to recognise that such strategy was right. For many reasons, most of which have to do with the development of research in Portuguese universities, a large part of the activity in Mechanics and Computational Mechanics now takes place indeed in university departments.

The Portuguese National Committee for Mechanics organised four national congresses for Theoretical and Applied Mechanics, the first of which took place at LNEC by the end of 1974, the second in Coimbra in 1979, the third again at LNEC in 1983 and the fourth in Coimbra in 1987. The first and third were presided by the author, the second and fourth by Prof. Ribeiro Gomes. Such national congresses were intended to promote the national participation in the International Congresses which would immediately follow. Indeed, they took place a little

more than one year before the International Congresses held in 1976 (Delft), 1980 (Toronto), 1984 (Copenhagen) and 1988 (Grenoble). Perhaps due to the National Congresses, and certainly to the natural growth of the Portuguese Mechanics community, the national participation in the International Congresses increased both in size and number of papers.

Meanwhile, the International Association for Computational Methods/IACM was founded and a parallel series of four national conferences on Computational Mechanics have been organised by the Portuguese Computational Mechanics community. A discussion was then initiated by the National Committee for Mechanics on its own future which led to the constitution in 1995 of the Portuguese Association for theoretical, Applied and Computational Mechanics. The national conference which took place last October 1997 in Guimarães was already a joint conference, the 5th of both series. Although the present paper was aimed to be mainly devoted to the development of Computational Mechanics before the eighties, we feel that mention should be made to the EPMESC series of conferences which have been held alternatively in Macau and in Chinese cities and to which Professor Tadahiko Kawai was kind enough to make reference some time ago in the paper [18] he published in this same bulletin.

The first conference of the series was held in Macau in 1985, promoted by Professor Kawai and myself and sponsored by the Government of the territory. I had the honour of chairing an Organising Committee formed by outstanding professors from the Asia Pacific region and also from Europe and the USA (Professor T. H. Pian). The second one was held in Guangzhou in 1987, the third in Macau in 1990, the fourth in Dalian in 1992, the fifth in Macau in 1995 and the sixth in Guangzhou in 1997. The seventh will take place again in Macau in 1999 and again I will chair, as I always had the honour to do whenever the EPMESC conferences were held in Macau. João Bento, a professor at the IST Civil Engineering Department, is the other Portuguese member of the Organising Committee.

The EPMESC conferences (EPMESC used to mean *Education, Practice and Promotion of Computational Methods in Engineering Using Small Computers* and now means *Enhancement and Practice of Computational Methods in Engineering and Science*), which have been important and successful as international conferences (the longest series of conferences in the area held in the Asia Pacific Region), played also a national role, as the Portuguese delegation has been quite a large one since EPMESC II. This is a good reason for mentioning EPMESC project here as a manifestation of the vigor of the Portuguese Computational Mechanics community.

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