

# Introduction

## A brief note on the scientific contributions of Jacques Heyman (b. 1925)

Jacques Heyman has been one of the main contributors to the development of structural theory in the 20th century. After graduating he joined the famous Cambridge Team directed by J. F. Baker that established the basis for plastic analysis of steel frame structures. Baker had worked for the Steel Structures Research Committee (SSRC) between 1928 and 1936, with the specific task of writing a rational code for elastic analysis of frames. For the first time, and thanks to the generous financial support coming from the British steel industry, real structures were tested. The results were surprising; elastic analysis was not suitable for predicting the actual state of the structure, contradicting what was believed at the time. Baker soon realised the reason: construction and assembling imperfections, residual stresses accumulated during the rolling process, small foundation movements, etc., led to large changes in the internal stresses of the structure. This failure caused him to change the direction of his research. In 1936 Baker traveled to Germany to attend the second IABSE Conference, where he met those researchers from central Europe who, for over two decades, had been studying the elasto-plastic behaviour of steel beams: Kazincy, Maier-Laibnitz, Bleich, Prager, etc. Back in the UK, he continued studying this field at Bristol University; he repeated Maier-Laibnitz's tests and started a program of tests on frames. The Second World War interrupted the work, which would continue at Cambridge once the war was over.

It is in 1946 when Jacques Heyman, who had recently graduated as an engineer (1944), joined Baker's team. He soon took on great responsibilities in the team and in 1949 he obtained his doctorate degree. He then travelled to the United States to work with William Prager. Professor Prager had escaped from Ger-

many in 1939, and in 1941 he had joined a strong Department of Mathematics at Brown University, where one of his key research topics followed on from the research on plasticity. Baker and Prager established an exchange program between Brown and Cambridge, and this collaboration proved to be crucial. Prager had shown how the three different kinds of statements about mechanics of solids (equilibrium and compatibility equations, and material properties), blended in a single equation in classic elastic theory, are combined in a very different fashion in the field of plasticity. This new approach was proved to be fundamental when time came for rigorously formalising plastic theory for steel frames. The standard duration of post-doctoral exchanges was one year. Jacques Heyman stayed at Brown University for three, and when he returned in 1952 he had acquired a fundamental theoretical base. In 1956 he was co-author (with J. F. Baker and M. Horne) of the first book, rigorously covering plastic theory for the analysis of steel frames: *The steel skeleton. Vol. 2: Plastic behaviour and design*. The book summarised all the work carried out by the Cambridge team over the previous decade and, for the first time in a book about analysis, the Fundamental Theorems of Limit Analysis are stated and applied for design purposes.

These fundamental Theorems had been proven in 1936 by the Russian engineer Gvozdev. However, they had only been published, obscurely, in the Proceedings of the Science Academy of Moscow (in Russian), and they were unnoticed by the international scientific community. The Theorems were rediscovered by Prager's team in the early 1950's. The application of the theorems to the analysis of steel frames allowed for the rigorous use of the plastic analysis that had been carried out in the UK since 1948 (when a clause allowing plastic analysis was added to the British code). In a team effort it is difficult to differentiate individual merits, but it is evident that Professor Heyman occupies a central position in the process of elaboration of the plastic theory applied to steel frames. The list of publications published in this book shows that he took part in most of the key aspects of the theory and the analysis practice. Plastic theory was consolidated in the decade between 1960 and 1970. Specialised studies gave way to the publication of manuals that were crucial for the spread of the theory. They were written by the main figures involved in the process: Beedle, Neal, Horn, etc. Heyman, too, published in 1967 (together with Baker) one of the most comprehensive manuals, a model used for many of the later contributions.

Plastic theory was developed for steel structures and, later, it was seen that it could be applied to reinforced concrete structures. Actually, plastic theory can be applied to any kind of structure that exhibits a ductile behaviour and does not have stability problems. This fact that had been foreseen by some engineers since the beginning of the 20th Century, was clearly and rigorously stated by Jacques Heyman. He is the first one to notice that the Fundamental Theorems meant a

new paradigm that could be applied to all structures built with conventional materials. This could perhaps seem evident for reinforced concrete (in fact, Gvozdev's contribution in 1936 was thought for the analysis of limit loads in reinforced concrete structures). The application in the case of materials such as timber was not as clear and, even less so, the application on stone or brick constructions. Jacques Heyman realised that the Theorems could, also, be translated even for heterogeneous materials such as stone or brick.

In 1966 he published his article "The Stone Skeleton" which constituted a milestone in the development of the modern theory of masonry structures. This highly original and lucid article explains how plastic theory is adapted to the field of masonry architecture. Following a hint from Prager, he realised that, if certain properties are given to the material masonry, the Fundamental Theorems can be translated to suit this case of seemingly different structures. In the field of masonry, over 30 other articles and various books have followed his first article of 1966. In these publications he has applied the modern theory to the study of basic structural elements in masonry buildings (vaults, domes, flying buttresses, towers, spires, etc.).

In fact, his interpretations of Gothic theory close the debates about the structural behaviour of gothic vaults and cathedrals, ongoing since the mid-19th century, occupying the minds of academics such as Viollet-le-Duc, Ungewitter, Mohrmann, Abraham, etc. The deep meaning and the practical consequences of Jacques Heyman's discovery has not been yet really understood by many architects and engineers, who still are using sophisticated computer programs trying to obtain the actual state of internal stresses in masonry buildings.

Finally, we must point out that Jacques Heyman is an internationally recognised scholar in the fields of History of Construction and History of Engineering. He has published memoirs about some of the most important contributions within the history of structural theory. In particular, his book published in 1972 about *Coulomb's memoir on statics* has become a model for these kinds of studies. Also it is worth mentioning his work on specific contributions from other illustrious architects and engineers such as Robert Hooke, Pierre Couplet, Christopher Wren, etc. Within the highly specialised field of the History of Structural Theory (the subject of this book), his work is of crucial importance too. In his book *Structural Analysis, a Historical Approach* (1998), he discusses for the first time the history of the theory of structures, also taking into account the contributions in the field of plastic theory. This completes, therefore, previous attempts by Todhunter and Pearson, Timoshenko, Truesdell and Benvenuto, the main contributors amongst many, who only considered the history of elastic analysis and strength of materials. It is not possible to understand the current situation of structural theory without considering plastic theory.

Jacques Heyman impersonates the best qualities of a humanist engineer, with a great tradition in Spain (Saavedra, Torroja, Fernández Ordóñez, etc.). His competence and originality in theoretical studies of great difficulty have not stopped him from maintaining all throughout his life an interest in history of architecture and engineering, in people (Coulomb, Hooke) and in buildings. In a world where specialisation seems to impose an exclusive dedication to narrow fields, he has shown the importance of general theories when it comes to understanding particular phenomena, and the need of historic studies when it comes to assessing the current situation, even when working on technical fields.

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