SHELL STRUCTURES AND CLIMATIC INFLUENCES

VOILES MINCES ET EFFETS CLIMATIQUES

Editors

P. G. Glockner
Amin Ghali

v

International Association for Shell Structures

SHELL STRUCTURES AND CLIMATIC INFLUENCES

VOILES MINCES ET EFFETS CLIMATIQUES

Editors

P. G. Glockner

A. Ghali

Professors of Civil Engineering
The University of Calgary, Canada

Proceedings of Symposium held at
The University of Calgary
July 3-6, 1972

EDITORS' PREFACE

The First Canadian IASS Conference, IASS CALGARY, was held at The University of Calgary, Calgary, Alberta, Canada, July 3rd through 6th, 1972. The theme of the conference was "Shell Structures and Climatic Influences". This conference was organized under the auspices of the International Association for Shell Structures, IASS, an international association which, during its twelve years of existence, has organized annual meetings in various countries throughout the world. These conferences have not only contributed to the development of the design and construction techniques of shell, shell-like and spatial structures, but have also served as a meeting place for engineers, architects and contractors from various countries in the "east" and "west", thereby emphasizing and helping to develop cooperation at a truly international level.

Planning for the IASS CALGARY symposium was initiated, in private discussions between the past president of IASS, Professor A. M. Haas, and the chairman of the Conference Committee for IASS CALGARY, during the Weimar IASS Symposium in May 1968. Subsequently, the Executive Council of IASS approved the possibility of a Canadian IASS conference on "Shell Structures and Climatic Influences" at its meeting in Spain on October 6, 1969 and gave final consent to the programme at their meeting in Vienna in September 1970. In view of the international stature of IASS, it was considered to be an honor to be able to host this 1972 IASS Symposium in Canada, to have an opportunity to acquaint visitors from abroad with the beauty and natural resources of our great country, and to be able to contribute to the development of peaceful relations amongst the people of the world. The Conference Committee always felt that Calgary and Western Canada are particularly well suited for such a symposium if one keeps in mind the famous "hospitality of the west", the proximity of the Rocky Mountains and the fact that visitors from Europe have to travel across Canada in order to reach Calgary.

In accordance with the theme of the conference and the basic philosophy of IASS, our information bulletins called for papers dealing with the architectural aspects, the design and analysis aspects, or the constructional aspects of shell, shell-like and spatial structures as they may be affected by climatic influences such as hot and cold weather, sudden temperature fluctuations, wind, waves, precipitational and drainage effects, as well as humidity and moisture effects. Contributions could deal with plates, shells and shell-like structures made of any structural material.

A special feature of IASS CALGARY was the session on Hyperbolic Cooling Towers which was sponsored jointly by IASS CALGARY and the ACI-ASCE Committee 334 on Concrete Shell Design and Construction.

These proceedings contain all full-length technical papers presented at the symposium, together with the keynote addresses delivered by six invited lecturers: Professors Felix Candela, University of Illinois at Chicago Circle; A. G. Davenport, University of Western Ontario; W. D. L. Finn, University of British Columbia; B. C. Gerwick Jr., University of California, Berkeley; P. M. Naghdi, University of California, Berkeley; and J. T. Oden, The University of Alabama in Huntsville. In addition, included are the general reports given by invited General Reporters.

Acceptance of the papers for presentation at the conference was based on at least two opinions expressed by reviewers competent in the particular area of specialization pertinent to the paper. The papers were classified into seven sessions as follows: General Climatic Factors, Membrane Analysis and Inflatables, Wind Effects, Construction, Thermal Effects, Special Topics, and Hyperbolic Cooling Towers. There are a total of 56 technical papers printed in these proceedings, including the six general lectures as well as the reports of the General Reporters. The technical papers were submitted by authors residing in nine countries throughout the world.

The proceedings were reproduced by a photolithographic process. The papers which met format specifications appear in the form they were received by the chairman of the Papers Committee. A few required minor corrections for reproduction and were therefore partially retyped by the editors prior to printing. The complete papers of the invited speakers appear in alphabetical order of the authors at the beginning of the proceedings. The technical papers are arranged in accordance with the sessions in the final program of the symposium. The general reports are printed at the end of the proceedings.

Considering the very specialized nature of the theme of the symposium, it is gratifying to see the number and quality of papers which were submitted for presentation at the conference and publication in the proceedings. These papers, together with the key-note addresses of invited speakers, contain results of research and experience gained in design, analysis and construction which constitutes an important contribution to the area of shell and spatial structures as they are affected by climatic influences. We feel that IASS CALGARY may rightly take its place among previous IASS Conferences, including those held on this continent, namely the IASS Conferences at San Francisco in 1962 and Mexico City in 1967.

To assist the Conference Committee in planning this symposium, an Advisory Board, consisting of outstanding members of Calgary industry, was organized under the chairmanship of Dr. J. D. Wood, Senior Vice-President, Engineering and Research, ATCO Industries Ltd., Calgary, Alberta.

The importance of hosting an IASS Conference in Canada, and particularly in Western Canada, was recognized by a number of institutions across Canada who generously donated support for the organization of this conference. Particular thanks are due to The University of Calgary, which not only provided outright financial support, but also provided the use of all the physical facilities required in connection with the operation of this symposium. Special recognition must go to the National Research Council of Canada as well as the Department of Industry, Trade and Commerce for providing substantial financial support, thereby making this international meeting possible. Special mention should also go to CP Air for not only providing direct support through a courtesy ticket for one of our speakers, but also for helping us in advertising the symposium and distributing information to possible participants. Finally, recognizing the relatively severe financial climate in Canadian universities, we particularly appreciate the contributions from universities across Canada that gave us financial support. On behalf of the Conference Committee we would like to express our sincere appreciation for the financial support provided by the sponsoring organizations listed on page IV of these proceedings. We would also like to thank the members of the Conference Committee; the chairman and members of the Advisory Board;

Dr. Phillip L. Gould for his help in organizing the special session on Hyperbolic Cooling Towers; all authors, keynote speakers, general reporters and session chairmen, as well as all individuals who have contributed to this symposium. We would also like to thank Federation Internationale de la Precontrainte for helping us publicize our symposium and for their moral support. Finally, we would like to record our sincere appreciation for the efficient secretarial assistance provided by Mrs. E. Lennon throughout the organization period of the symposium.

P. G. Glockner
A. Ghali

Calgary, Canada
July, 1972

SPONSORING ORGANIZATIONS

Bank of Montreal, University Campus
CP Air
Department of Industry, Trade and Commerce
Faculty of Applied Science, University of British Columbia
Laval University
National Research Council of Canada
Portland Cement Association
Province of Alberta
Sir George Williams University
The University of Alberta
The University of Calgary
University of Waterloo

CONFERENCE COMMITTEE

P. G. Glockner	Chairman
A. Ghali	Chairman, Papers Committee
A. Huizer	Chairman, Social Committee
C. Y. Chia	Treasurer

ADVISORY BOARD

G. Adam	J. R. McCaïg
W. Clark	E. Raines
W. de Silva	G. W. Walker
G. W. Govier	W. Wenzel
J. L. Holman	J. D. Wood (Chairman)
D. J. Sampson	H. A. Wyss

OPENING ADDRESS

A. Paduart
President
International Association
for Shell Structures

Mr. Chairman, Mr. Vice-President, Ladies and Gentlemen:

As President of the International Association for Shell and Spatial Structures, I have the honour and the pleasure to address you at this opening Session.

First of all, I want to express my gratitude to the organizers of this Conference, especially to Professor Glockner, who took this excellent initiative and, who during more than two years, worked very hard in order to have everything ready today. And we may already say that he succeeded perfectly.

I must also thank the very numerous sponsoring organizations, thanks to which the preparation of the Conference has been possible.

My compliments are extended to the Conference Committee and to all those who by their care have contributed to the job.

As you know, the IASS holds regularly conferences, symposia, and working sessions in various countries all over the world. In the last years meetings have been organized in Leningrad as well as Mexico, in Tokyo, Kyoto and Honolulu as well as in Madrid.

But this is the first time that our Association has come to Canada, and this gives me the opportunity to stay in this country for the first time also.

The choice of this place is one more statement of the world-wide character of our organization and of our aim of discussing everywhere all the technical and economical problems relating to shells under the most various aspects.

The IASS accepted with alacrity the proposal of our Canadian friends to have this Conference on the American Continent and to facilitate its attendance to the specialists of all the States belonging to the New-World.

Canada gives to us a nice example of a young country in economical and demographical expansion, and for those coming from Europe, this is extremely interesting.

We know that Canada is the second largest country of the world and I have learned that it is 330 times the area of Belgium. But the population is only twice that of Belgium.

This shows immediately that the natural wealth of Canada is very important and, indeed, we find here plenty of all that is necessary for human living and industry: agriculture, fishing, forests, coal, petrol, gas, minerals, hydroelectric power, etc.

Since the 17th century, the goldseekers, the trappers and the settlers have been replaced by technicians, engineers and businessmen. The industrialisation is particularly important in the province of Alberta and among others here in Calgary. This city was therefore the most convenient place to have this meeting and I am sure that we will all enjoy very much our stay in this University.

I am glad to see that so many specialists are here together and I hope that the lectures and the discussions will be most fruitful for all of us.

The meetings of our Association are always characterised by a warm and heartful atmosphere, that is to say a very fair "climatic influence". And I think that this cordial climate is for a great part due to the presence of the ladies, which usually are accompanying a great number of members. It is a pleasure for me to salute the present ladies and also to render homage to all the wives who, for one or another reason, could not follow their husbands, but are here in mind.

In our Association, all aspects of shells are taken into consideration, so that this Conference brings together architects, engineers, researchers, mathematicians, contractors and all those concerned with the equipment for shell construction. That is why full attention is given not only to calculation or structural design, but also to architectural concept and execution problems.

The program of this Conference shows that in fact there are two parts:

- on one side, the problems of climatic influences, and
- on the other side, special topics of very great actuality, such as analysis of plates and shells, thermal stresses, vibration and cooling towers.

The climatic influence gives a very big problem. Indeed, if there were no snow, no rain, no wind and no changes of temperature, we could live and work in the open air; we should not need any shell, and our Association would never have been born.

It is the first time that this theme is considered and, at the end of this address, I want to thank Professor Glockner for his so important initiative.

TABLE OF CONTENTS

GENERAL LECTURES

SHELL STRUCTURES AND CLIMATIC INFLUENCES

F. Candela
Professor of Architecture
University of Illinois
at Chicago Circle
Chicago, Illinois, U.S.A.

Abstract

Design of indigenous buildings has evolved through time to sensitively respond to climatic demands, while structures designed by architects, aided by engineers, express the fashions of technologically advanced nations, disregarding climatic imperatives and the state of local industrial development; this conference should reassert the necessity of designing structures honestly adapted to climatic needs rather than emphasizing ameliatory measures.

It may be appropriate in trying to explore climatic influences on the development of shell structures to examine briefly, in a more general context, the bearing of those factors in the evolution of building methods and architectural prototypes throughout the world.

It could be found that only vernacular architecture or, more specifically popular or folk housing, has been able to produce significant examples of construction systems leading to highly differentiated models characteristic of each particular region. These popular architectures do not recognize artificial national boundaries, but are instead spread in broader or narrower territorial limits which share similar geographical conditions, agricultural practices, and living customs. They were developed over the course of ages without benefit of professional architects or engineers, but following an evolutionary pattern very much like those used by nature in its selective process. A truly functional and expressive architecture was thus achieved, rich in tradition, closely adapted to the needs of the people to protect themselves from the rigors of weather, and conditioned by availability of local materials.

Beside this indigenous tradition, contrived by nameless and illiterate builders, another exotic flow of affected and learned architecture was introduced in most countries by the privileged classes in an attempt to follow the fashion of the moment. This became the international style of each epoch, copied by architects to please the whims of the aristocracy and tailored according to the customs of the powerful countries that happened to be temporarily in world ascendancy. Both currents run parallel courses through history with the ephemeral aristocratic styles introducing some new elements into local modes, but not infrequently the indigenous tradition--if it were strong and deeply rooted--influenced the imported fashion giving origin to a well defined variety of the universal mannerism. These vernacular undercurrents are the famous "invariantes castizos"

(which can only be inaccurately translated as "indigenous constants") which the historian Fernando Chueca tried to define as recurrent distinctive features throughout the continuous invasion of foreign styles in the architecture of Spain.

The same pattern that characterized this alluvial process was repeated again recently when the new conceptions brought about by the architectural revolution of the 1920's in Europe did not gain popularity and become universally accepted until the United States had adopted them as of her own and even named the movement the "international style."

But times have changed and local traditions, except in a few isolated and still primitive cultures, are quickly disappearing, unable to resist the unifying impact of massive and instantaneous communications media. They can no longer cause any significant impact on the main body of what are now easily exported fashions, and regional distinctions are becoming hardly noticeable. Glass buildings proliferate all around the world with complete disregard for climatic conditions or state of industrial development as an unconscious, but nevertheless servile, homage to the most powerful nation of the times.

What I want to point out is that climatic influences are not taken into account in the design of modern buildings which follow those universal fashions--not even in the country that originates them. Monumental design mistakes are partially corrected by exorbitantly expensive mechanical devices, disguised now with the recently coined expression of "environmental controls." It seems however that the need for such controls could at least be alleviated by reasonable and proper design, but there appears to be very little interest in curtailing wasteful procedures and customs.

This follows a current trend in our affluent societies which is fostering a tragically vicious circle in the stubborn and vain attempt to correct the disastrous effects of irresponsible abuse of power and technology by further application of more power and more technology, instead of stopping the problem at its source by sensible and insightful planning.

I find both welcome and timely this conference whose expressed aim is to analyze the influence of the climate on the design of at least one special type of structure. But shells are not natural structures whose precedence in traditional building customs might counterbalance the entrenchment of unsound or unsuitable foreign fashions. Restraint must come from the promoters or the expert designers of such structures.

I have been hoping for many years that one of our professional meetings might come forth with a set of recommendations for design, instead of the usual and repetitious flood of analytical papers. We tried very hard to achieve this aim at a meeting in Mexico a few years ago, but our efforts were not very successful.

I wish that on this occasion the word "design" could be applied in its proper context--as related to the conceptual stage of the long process whose

final product is an actual building. For most English-speaking engineers, design means, instead, the analytical procedure by which we attempt to reproduce in a mathematical model what really happens in a structure. Sometimes these mathematical representations are so beautifully complicated that their authors and users fall in love with them, and even tend to believe that the contraptions may be accurate images of the flow of forces and stresses in the actual structure.

I do not ignore the importance of these delightful intellectual games, nor do I deny that their manipulation requires even more skills than those demanded for putting together the original idea. Each one of these operations asks for different types of skills, rarely found in the same person. Although both complement each other, there is no doubt about which comes first. Since we are not dealing with a natural science, before being able to analyze any object, we have to produce it. This process of creation -- no matter how prosaic and common it may be--is what we should call design, instead of continuing with the semantic confusion, already infiltrating itself in other languages, of employing it as a synonym of calculation or, as Nervi says, "comprobation" of a structure.

Design--and structural design, of course--is an intellectual process of synthetic nature, in which is to be found imagination, intuition, and experience, and which demands a certain freedom in the creative agent. It adheres, in short, to the same laws as those of artistic creation in that it can only take place in a single mind, and generally at a single stroke. It follows, therefore, that a structural designer should not only be well versed in the play of forces and general behavior of structures, but also familiar with the available methods of analysis, so that he can avoid the proposal of structures which will behave poorly or are difficult, if not impossible, to analyze. It could be stated as a general principle, supported by experience, that the quality of any structural design is in inverse proportion to the amount of mathematical effort necessary for its detailing and erection.

In light of this principle and for the sake of economy, which should always be one of the most important considerations in any building venture, it can be seen how much more consequential it is to have a good design than a beautiful calculation.

As a result of the artificial and endless subdivisions of the construction industry--a process which seems to be irreversible--the task of designing the structure falls generally upon the architect, even if he is not properly equipped for such an endeavor. The structural consultant rarely has access to this crucial creative stage; his role being reduced in many instances to the impossible job of justifying with numbers somebody else's blunders.

But even timely and friendly collaboration is not the answer to the problem, because training of structural engineers does not involve sufficient emphasis on design qualifications. Both professions and their schools fall short in this most important aspect of their activities, and structural design still lies forgotten in a no man's land.