THE HOMEOSTATIC MODEL AS A TOTAL MODEL

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1 - Introduction

Trough the History of Construction, physical and numerical models have played important and complementary roles in all regarding development of structural engineering and architecture. However, the evolution of both model types shows well differentiated stages: while physical models, which are well known since ancient times, have experienced a relatively slow development, the more recently appeared numerical models have experienced a surprising and explosive development. In fact, the introduction of electronic calculation means has greatly expanded the efficiency and potentiality of Structural Analysis in numerical model processing. At the same time, this great potential of numerical models has opened horizons to creativity in allowing and claiming the conception and generation of new structural types and shapes. It is precisely within this field of Conceptual Design where physical models have an important role to play.

This paper deals with a particular type of physical models: the *homeostatic models*. The homeostatic model appeared as a design tool for the generation of non-conventional shell structure shapes. However, technology advancement has allowed to use this same model as a tool for structural analysis too.

2 - Physical Models

In order to be clear and avoid confusion it is convenient to distinguish from the beginning the different physical model classes we are going to deal with:

a) Scale models: these are used to make a three dimensional representation of a building under construction or already completed.
b) Analysis models: these are used to study structural behaviour of a previously designed structure.
c) Design models: these are used to create, generate and determine the geometry of a building to be built.

No doubt, the scale models were the first to be used by man. Ancient civilizations (the Egyptians among others) used models made to scale as a tool not only to represent their projects but also to study erection and construction procedures [1]. The use of models with the exclusive purpose of analysis corresponds to not so ancient stages in Construction History. An important landmark in the development of this technique was the funicular model constructed by Giovanni Poleni (1685-1761) in order to verify the stability of S. Peter Cathedral dome in Rome [2]. However, only in the present century the analysis model acquires real importance and becomes a valuable tool especially due to the introduction of electrical strain measurement. Curiously enough another funicular model --A.Gaudí's stereo funicular (1852-1926)-- became a new landmark in the development of design models proving its potentiality as a proper tool for the conception, generation and determination of new structure shapes. Later other physical design models were proposed by using other materials instead of Gaudi's thread: soap solution films, elastic membranes, elastic thread nets, plastic materials, etc. [3].

Following we are going to discuss a physical model for multiple purposes: the homeostatic model which was originally conceived as a design model, but which can be used as an analysis model and obviously is also a scale model to make spatial representation of a structure.

3 - The Homeostatic Model

The Homeostatic Model was conceived and materialized for the first time in 1988 [4], with the primary aim of generating new structural shapes, specifically shell roofs. Though later presentations at IASS meetings and publications [5,6,7,8] exempt from the need to give further details, we are going to make a brief description of its principles and the technique for its application.

a) Principles:
Homeostasis is a principle of Biology according to which when any living creature is attacked by an external agent, it reacts intelligently in order to recover its vital functions balance. Something similar occurs with structures. When an external agent (such as load increase, degrading of the mechanical properties of its materials, etc.) attacks a structure, this defends itself intelligently in order to recover its withstanding capabilities. In the homeostatic model technique, heat is used as an external agent to provoke the degradation of its material. The model thus attacked reacts intelligently trying to find the most proper structural shape to continue resisting loads. For example, a small square thermoplastic plate (400x400x2 mm) suspended from its corners and submitted to a uniformly distributed load (approximately 2 gram/cm^2) is heated to over 125 °C. Under such conditions its compression Young's modulus decreases approximately 100 times and therefore it loses its bending strength capabilities and experiences a metamorphosis: intelligently it changes its plate status becoming a membrane thus modifying its initial shape in order to resist the applied load. The model generates its own resisting shape and after being cooled, recovers its original stiffness.

b) Technique:
In order to obtain a homeostatic model of a shell roof, for example, the following procedure is applied:

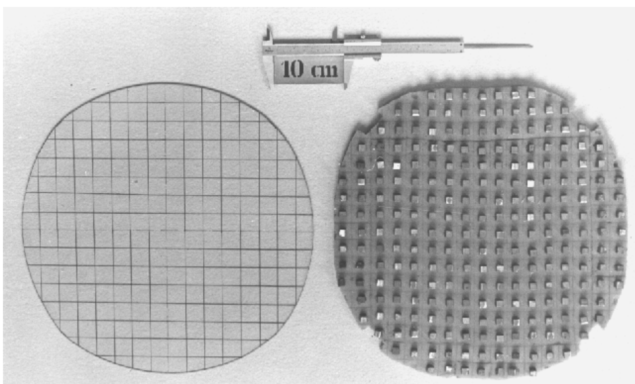

Fig.1 Mother plate and loading carpet

- An acrylic material plate is cut in the shape of the perimeter to be covered (mother plate).
- This plate is suspended from the points or lines where links (boundary conditions) will be applied.
- On the mother plate a loading carpet is applied *(Fig.1* shows mother plate and loading-carpet corresponding to models 103, 104 and 105 shown on Fig. 6, 7, 8).
- Balancing forces are applied at the

points (or lines) corresponding to the above links.
- The assembly (plate, load and balancing forces) is put into an oven to be heated to over 125 °C.

After being cooled, the model thus obtained is a prevailing tensile shape (when suspended) or prevailing compression shape (when it is inverted and placed on the supports).

4 - Design Model

The homeostatic model generated as explained is a design tool. As well as the funicular model can be used to design the shape of a 2D tensile structure (or a compression one, if inverted), the homeostatic model is applied to design the shape of a 3D continuous structure. In fact, it is possible to measure X, Y and Z coordinates of a network of points on the surface of the homeostatic model, with which its geometry is fully determined. Then it is sufficient to expand these coordinates by means of the use of a scale factor in order to obtain the geometry of the structure to be built. This operation can be made rapidly and safely taking advantage of the facilities of a digitizer arm such as the SpaceArm, which is shown in *Fig.2*. All that is necessary is to scan the model surface with the arm probe and to click at each point to obtain its three coordinates. SpaceArm ModSA48 has an accuracy of 0,4 mm, such that by applying a scale factor of 50 it is possible to obtain structure coordinates with an accuracy of 2 cm, which in most of the cases is sufficiently good for the execution of the real work [9]. It is convenient to point out that: a) model surface finish is perfectly smooth and continuous due to nature of the plastic material (acrylic), and b) stability and stiffness of models are good enough as to admit probe scanning. Therefore, the determination of coordinates given by SpaceArm is reliable, precise and consistent.

Fig.2 Digitizing a model by means of the SpaceArm

5 - Analysis Model

It is well known that structure analysis has the aim to study its behaviour under loads with the purpose to evaluate its safety level. By using the homeostatic model, it is possible to reach this objective by two different ways:

a) *Experimental method:*

The acrylic homeostatic model, generated as explained in 3b) allows the application of the experimental technique of strain measurement by means of electrical strain gauges. In general, for the application of this method, the conventional guidelines of this technique are followed [10]; as a result of their own experience the authors point out:

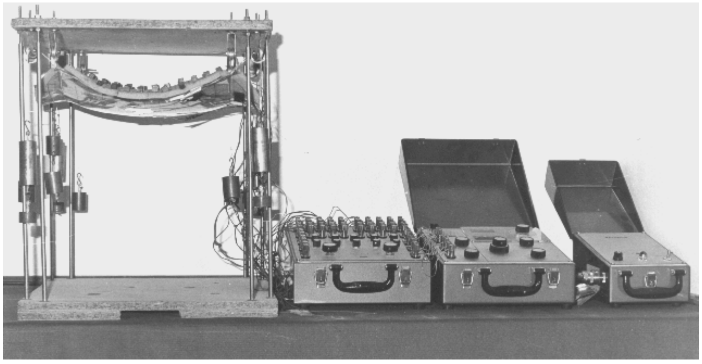

Fig. 3 Model analysis by means of electrical strain gauges

1- It is convenient to make measurements by keeping the model suspended in order to avoid any modification in the distance between supports (suspension points) *(Fig.3)*. When load increments are made, balancing force increments must be made simultaneously.

2- Strain gauges can be adhered directly to the acrylic surface by means of cyanoacrylate adhesive. The interposition of metallic sheet to dissipate heat is not necessary.

3- Loads must be applied during short periods in order to avoid slow-creep.

Experiences made by applying strain gauges on both faces (inner and outer) at different points of the models have shown a membrane (or quasi-membrane) behaviour in most part of the homeostatic model surface.

b) Hybrid method:

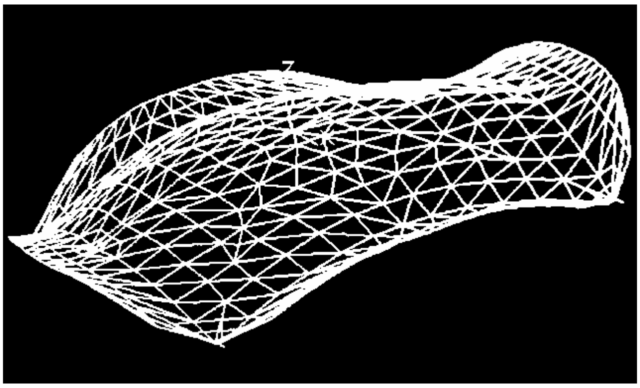

Fig.4 FEA mesh for model 103

By this method two different models are used in two consecutive steps:

1- A physical model, namely the homeostatic model generated as explained and described in 3b).

2- A numerical model whose geometry is generating by digitizing the homeostatic model by means of the SpaceArm. Files obtained in this operation and multiplied by the scale factor are input as data into finite element software (Algor in our case [11]). These data all together with the mechanical constants of the material, edge and load conditions of the real structure are processed by the software. It allows to obtain numerical and graphic results of stresses and displacements of the structure, which are then used to evaluate its safety conditions *(Fig.4)*.

The application of both methods (experimental and hybrid) on the same physical model, allows the possibility of checking them and therefore guarantees a better reliability of the results. The authors made this check with several homeostatic models (among other model 103, *Fig. 6*), and in all cases obtained a good coincidence of results.

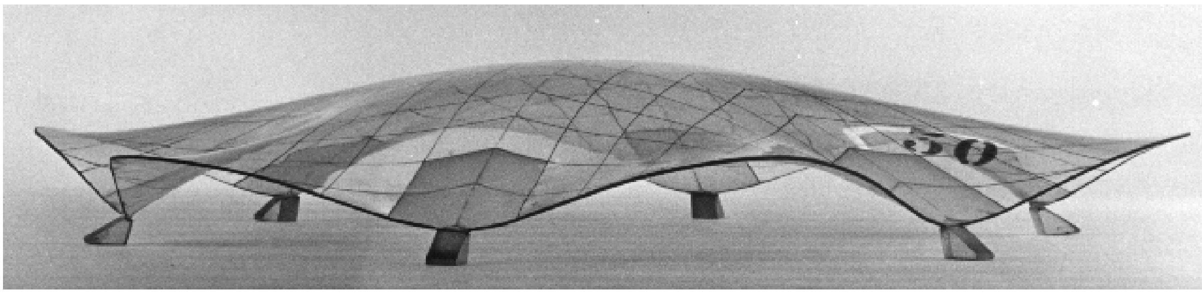

Fig.5 Free form shell roof supported on six points

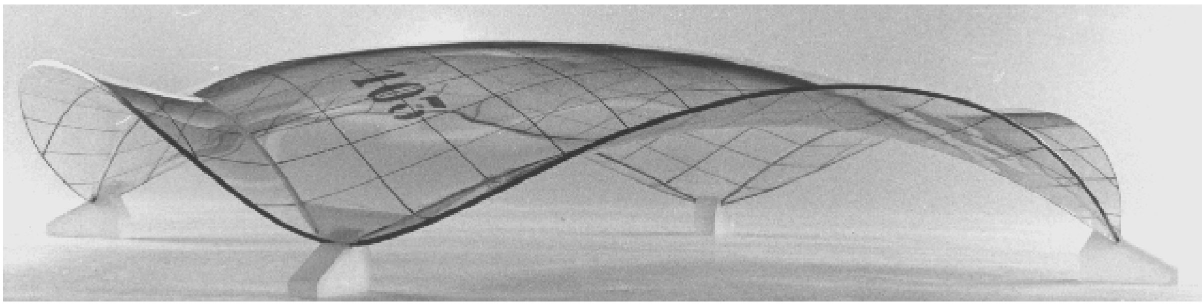

Fig.6 Free form shell roof supported on four lateral arches

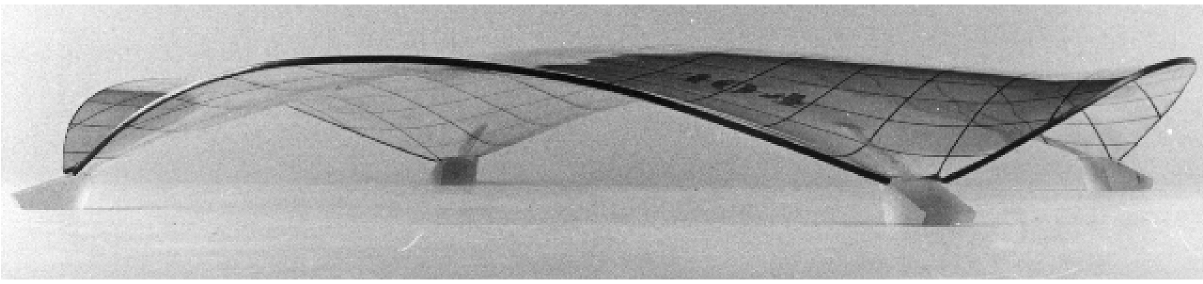

Fig.7 Free form shell roof supported on four points

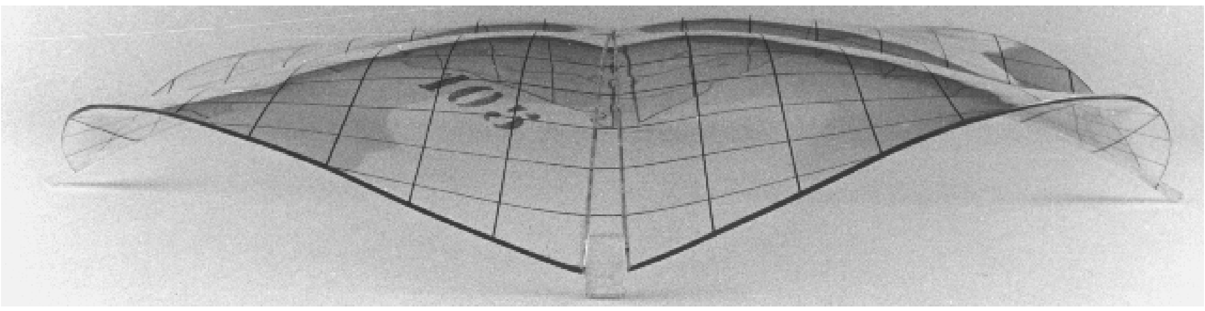

Fig.8 Free form shell roof supported on two diagonal arches

6 - Conclusions

On the basis of the gathered experience the following conclusions were drawn:

a) From the structural design viewpoint:

- Simplicity in structural shape generation. To make a homeostatic model is a straightforward, fast and economical procedure.

- Generation of free forms with free edges is one of the most fertile field for the application of the method *(Fig.5).*

- Versatility in structural shape production: variations in value and direction of balancing forces, shape of mother plate perimeter, level of the suspension points, etc., are immediately reflected in the geometry of the structure thus enabling the dialogue between designer and structural shape. *Fig. 6, 7 and 8* show some of the generated shapes obtained from the same mother plate *(Fig.1)*, with and without inner ribs and supported on four points. Completely different shapes are obtained when the perimeter shape of the mother plate is modified. Models shown in *Figures 9 and 10* were generated from a square mother plate having always four supporting points.

- Interaction between shape and forces is direct and its visualisation is immediate, thus guaranteeing the permanent complying with force balance during the search for the best adaptation of shape-space-structure.

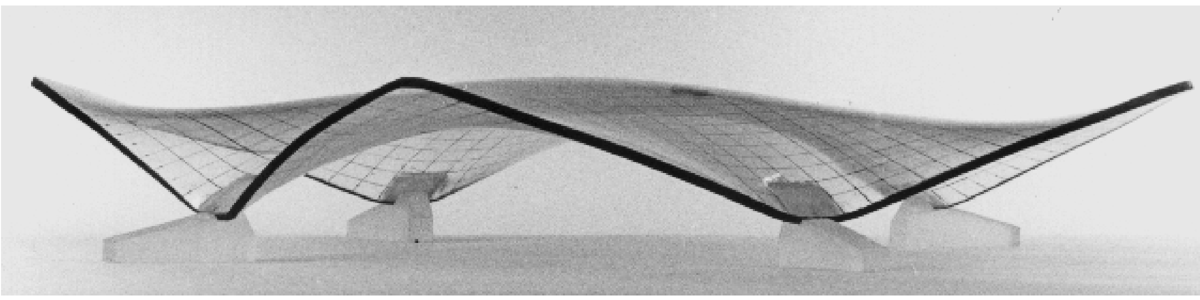

Fig.9 Free form shell roof supported on four middle points of a square plan

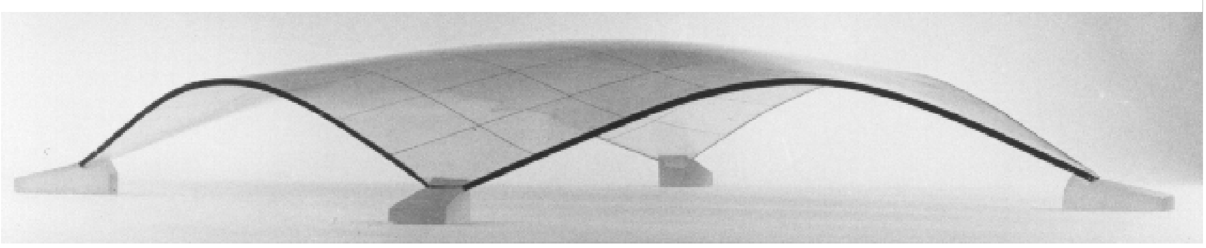

Fig.10 Free form shell roof supported on four corner points of a square plan

As any physical model, it presents obvious advantages from the viewpoint of promoting and exercising creativity as well as from the viewpoint of its application to teaching and research [12].

b) From structural analysis viewpoint:

- Fast and safe generation of a numerical model from the homeostatic model.

- Possibility of a two way (experimental and numerical) thus allowing to check results specially at points located at conflictive areas.

Finally and from a general viewpoint, it is easy to see that its multiplicity of functions (scale model, design model, analysis model) accepted by the homeostatic model allows us to consider this physical model as a total model.

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