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Research on Shells by Means of Model Tests

Recherches sur les voiles au moyen d'essais sur modèles

Modellversuche an Schalen

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During the last two years, an extensive programme of research on shells by means of models has been carried out at the "Instituto de Mecánica Aplicada y Estructuras". The main purpose of this paper is to present a survey of the programme showing the different kinds of models employed, and the most important conclusions reached.

Five shells were tested; four of them were hyperbolic paraboloidal shells of various shapes, the last model was a prismatic shell.

The first model was a hypar shell of considerable curvature, rhomboidal in plan, supported on two opposite corners. The diagonals of the prototype were 27 m. and 19 m. in plan. The supports consisted of two hypar shells

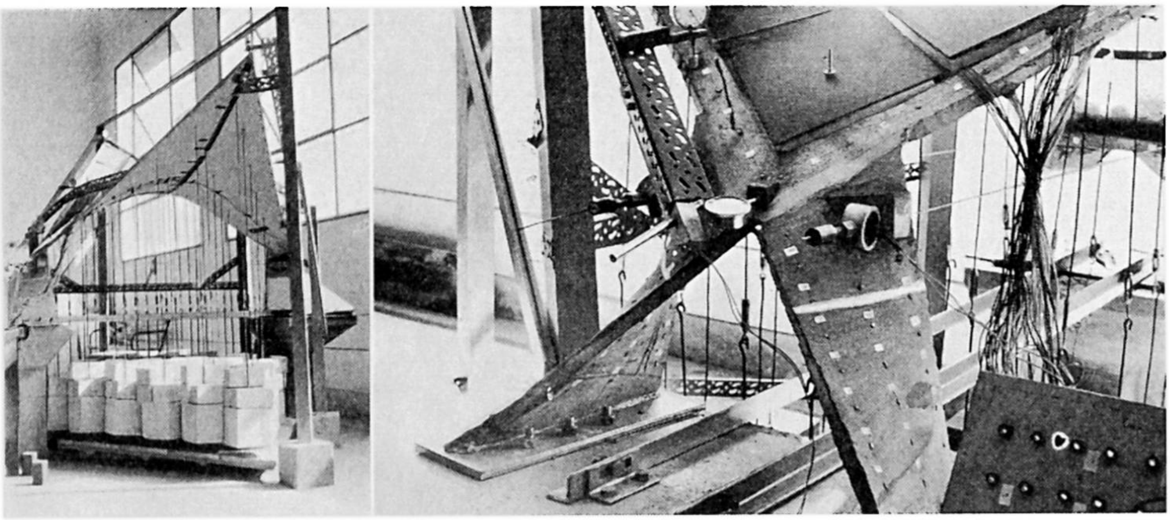

Fig. 1.

specially designed to absorb both the "arch" and the "rolling" effects. Tests were carried out on a $^1/_{10}$ model, made with reinforced mortar. In Fig. 1, a general view of the model prepared for testing is presented. The membrane stresses, bending moments and deflections under various load conditions were recorded. Typical bending moment curves along the diagonals of the free corners, due to uniform load, are presented in Fig. 2. Stresses due to bending moments in this structure did not exceed twice the stresses evaluated by means of the linear membrane theory. In Fig. 3, the distribution of edge forces under uniform load is presented. Actual edge forces are approximately one-half of those estimated by means of the simplified membrane theory.

The second shell tested was part of a basic research programme for the investigation of the stress distribution, edge perturbations and deflections of a hypar shallow shell. The model, as represented in Fig. 4 (left), was made

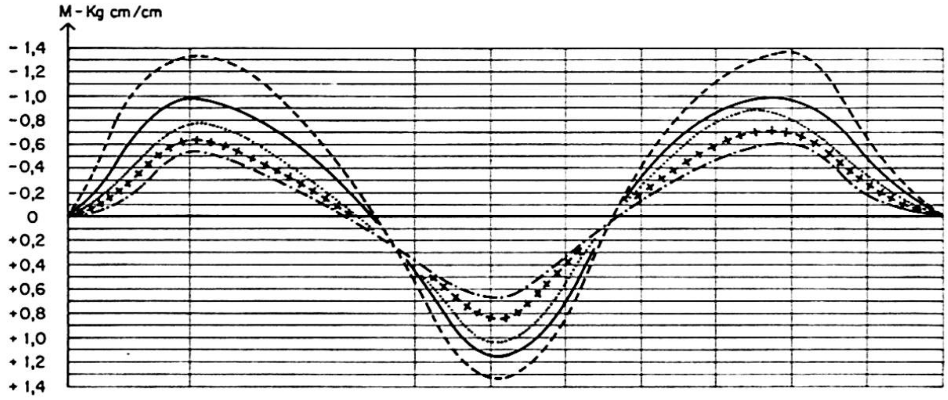

Fig. 2.

—·—·—·— load g = 320 kg m^{-2} ———————— load g = 545 kg m^{-2}
++++++++++ load g = 395 kg m^{-2} ---------- load g = 620 kg m^{-2}
··················· load g = 470 kg m^{-2}

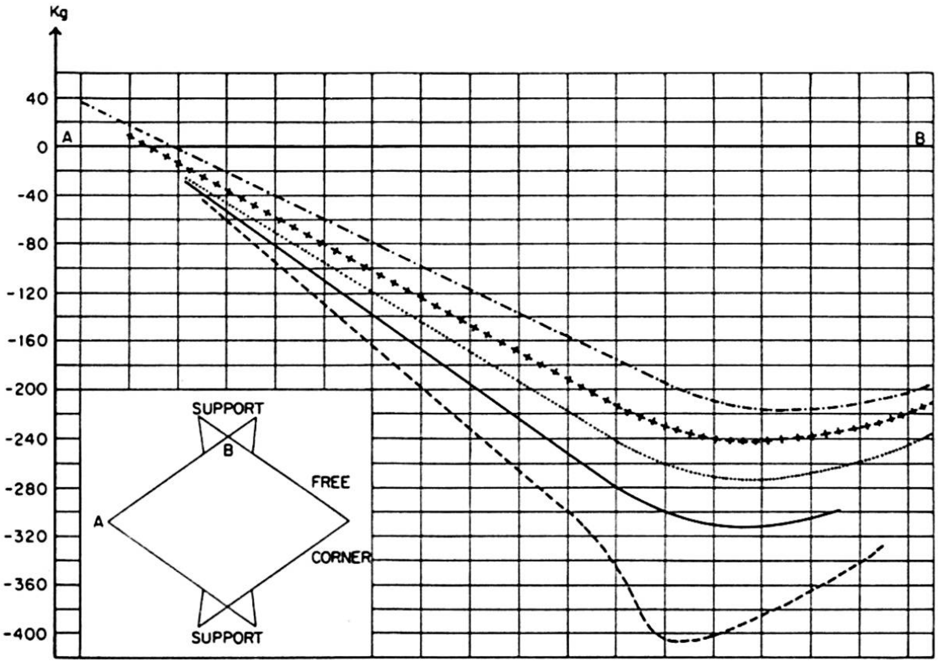

Fig. 3.

—·—·—·— load g = 320 kg m^{-2} ———————— load g = 545 kg m^{-2}
++++++++++ load g = 395 kg m^{-2} ---------- load g = 620 kg m^{-2}
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of reinforced plastic material. Three different boundary conditions were considered in order to compare the influence of edge conditions on the stress distribution and moment perturbations. In Fig. 4 (right) the model arrangement is represented, when free edges were considered. A pneumatic device was used for loading and unloading.

Typical curves for membrane stresses, bending moments and shear forces

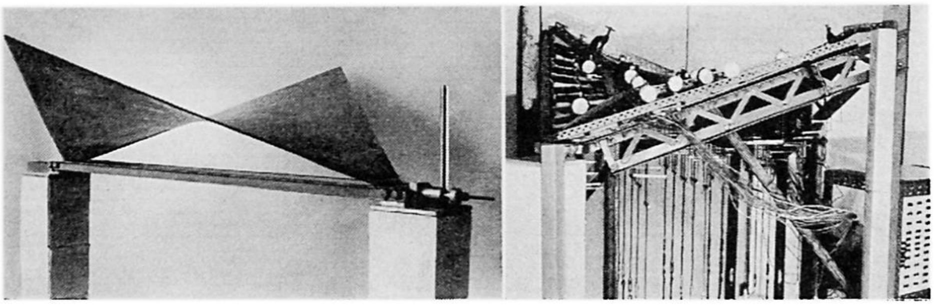

Fig. 4.

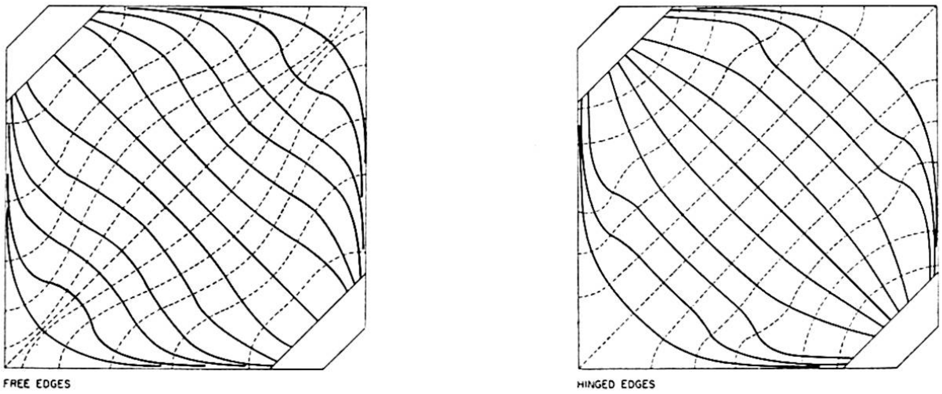

Fig. 5. Isostatics of Membrane Stresses.

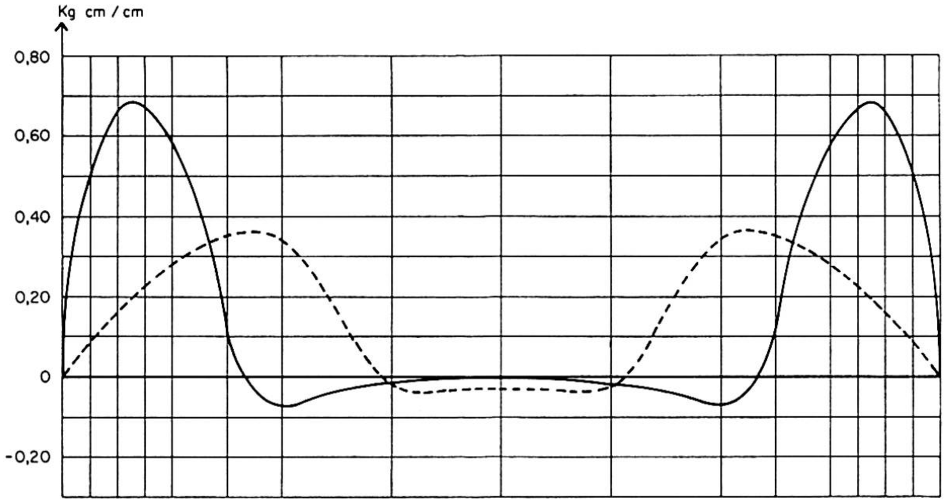

Fig. 6. Bending Moments along the Middle. Straight Generator.

----------- Experimental ———————— Theoretical were plotted along 5 straight generators for every edge condition. In Fig. 5, typical isostatic patterns are shown. Various perturbation theories were used in order to compare the experimental results. Fig. 6 shows a comparison between perturbation theorie, and the experimental results. A critical discussion of this research work has been published elsewhere [2]. This programme is now being completed with fixture designs which permit the application of edge forces and moments.

The third shell was a $^1/_{20}$ model of an umbrella shell. In Fig. 7 a view of the load model is shown. The height of the column was increased in order to make possible the inspection of the lower face of the shell. The main pur-

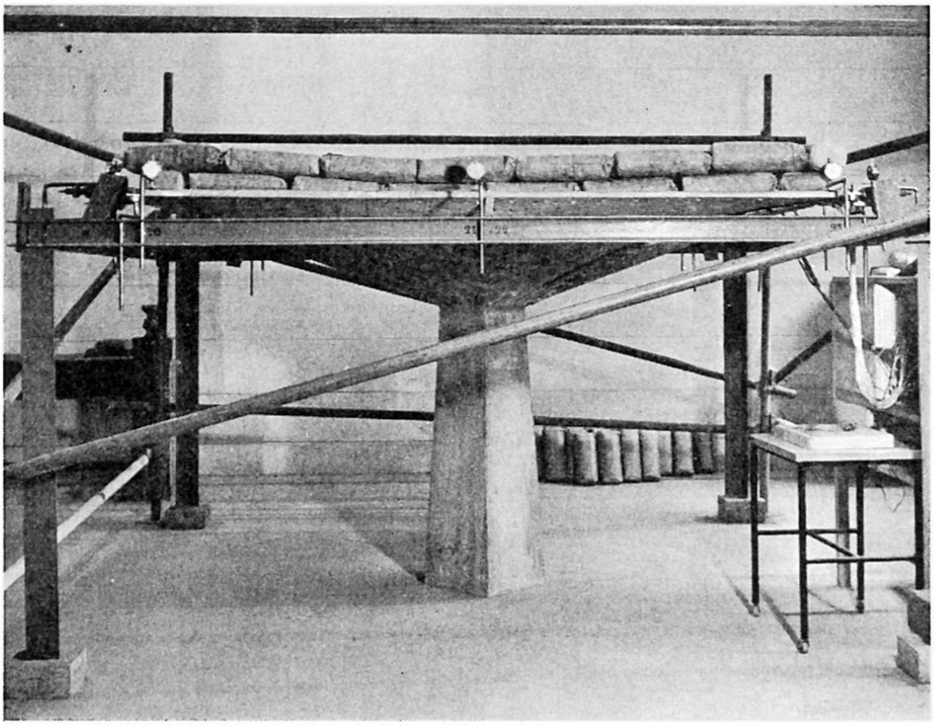

Fig. 7.

pose of this test was to check the general behaviour of the structural design of the umbrella in view of its rather large dimensions. In fact, the umbrella measured — in plan — 50 m. by 50 m. with a thickness of 10 cm. Membrane stresses, bending moments and deflections under design load, were recorded. A complete series of these typical stress distributions has been published elsewhere [3].

Although the stress distribution contributed to an understanding of the behaviour of the structure, a very interesting point was observed at failure. When the load was twice the design load, the umbrella collapsed abruptly, reversing its original shape. The collapse is clearly represented in Fig. 8. This break-through was unexpected, although the collapse occured 75 minutes after the load was applied. Practically no information on this problem was available to those responsible for this programme. Consequently a supplementary investigation was understaken in order to determine the causes of the failure. For this purpose, two models were tested. The first model was a single hypar shell which reproduced exactly one of the four elements constituting the umbrella. This model, made of cement mortar, was mounted on movable supports which were connected by an elastic tie. The purpose of this test was to examine in a single element, the buckling process. An asymmetrical buckling was obtained when the load reached the value at which the umbrella collapsed, Fig. 9 gives a general view of the shell after failure. The buckling process was succesfully interpreted theoretically, with the help of the experimental data obtained. Recently, the stability behaviour of a new umbrella model has been investigated. A full report on the subject will be published shortly.

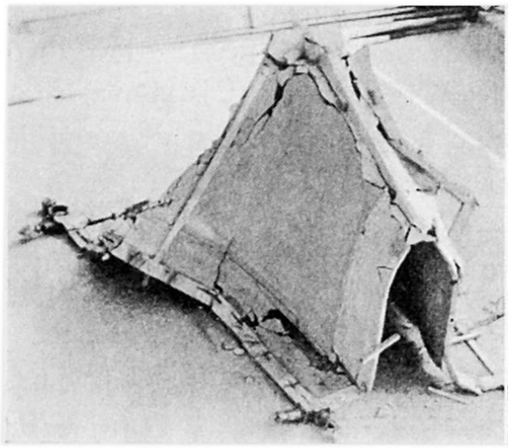

Fig. 8.

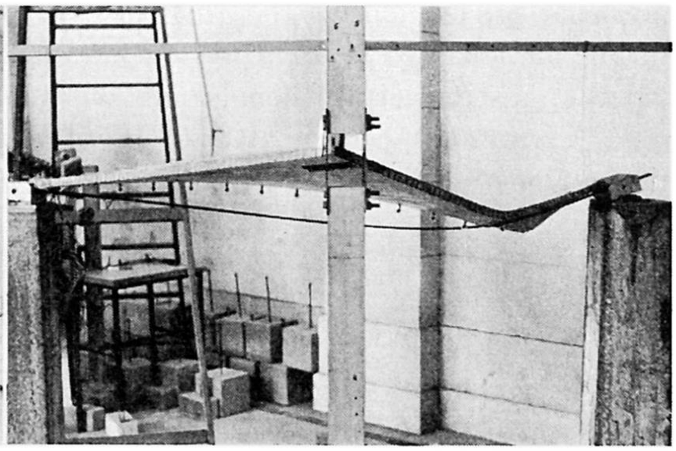

Fig. 9.

The last investigation dealt with an element of a prismatic shell structure. The model was made with Perpex and only information within the elastic range was required. Different loads were applied to the model in order to check experimentally the suitability of various technical theories. It was shown that great accuracy can be obtained by means of the theories for the evaluation of longitudinal and transverse stresses, except for the last plate for which the theories do not generally consider torsional effects.

Finally, some conclusions can be drawn from our experience in this field. It is shown that great advantages can be derived from model tests, not only for predicting the behaviour of actual structures, but also for making improvements on the original design and for obtaining experimental confirmation of the behaviour of structures whose theoretical analysis cannot be carried out rigorously.

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Summary

The aim of this paper is to present a survey of the research programme on shells carried out at the Instituto de Mecánica Aplicada y Estructuras, during the last two years. Tests on models of five shells are briefly described and the most important conclusions obtained are presented. It is shown that great advantages can be derived from model test on shells which enable improvements to be made on the original design.

Résumé

Cette contribution a pour objet de présenter le programme de recherches que l'Instituto de Mecánica Aplicada y Estructuras a réalisé en matière de voiles au cours des deux dernières années. On décrit brièvement les essais qui ont été exécutés sur les modèles de cinq voiles et l'on en expose les principales conclusions. Il est montré que les essais sur modèles de voiles présentent un grand intérêt pour modifier avantageusement le projet initial.

Zusammenfassung

Es wird ein Überblick gegeben über die Modellversuche an Schalen, die in den letzten zwei Jahren am Instituto de Mecánica Aplicada y Estructuras zur Durchführung gelangten. Versuche an fünf Modellen von Schalen sind kurz beschrieben, die wichtigsten Ergebnisse werden angegeben. Es wird gezeigt, daß Modellversuche große Verbesserungen der Ausbildung und Bemessung von Schalen ermöglichen.