DEVELOPMENTS IN PHOTOELASTICITY

COMMEMORATION AT UNIVERSITY COLLEGE, LONDON

A JUBILEE commemorative exhibition of photoelasticity has been held in University College, London. With a lecture delivered on April 15 by Colonel H. T. Jessop, special lecturer in photoelasticity in the College and sometime research assistant to Prof. L. N. G. Filon, it recorded the progress made in this method of stress exploration in the fifty years since its two most formidable protagonists, Profs. Coker and Filon, began their uneasy but extremely profitable partnership ; E. G. Coker was the Kennedy professor of engineering and L. N. G. Filon was the Goldsmid professor of applied mathematics in the College.

In 1909 Prof. Filon had been working for some years on the optical phenomenon of stress-induced birefringence, which had remained a laboratory curiosity since its original discovery by Brewster in 1816. While an undergraduate at University College, he had become interested, too, in the mathematical theory of elasticity as a result of his contact with Karl Pearson.

By 1909 Prof. Coker had also been attracted by the subject and his interest was that of a mathematically uninhibited engineer. He wanted to know the stresses in bodies for the purposes of design studies. He was introduced to photoelasticity by Silvanus Thompson and, in a four-year period of collaboration, these two men proposed a series of stress investigations using celluloid models of structures having engineering significance.

Coker seems to have been the first to realize the practical engineering significance of stress-induced birefringence, and his proposals precede similar work of Mesnager (who used glass) by three years. Coker's use of celluloid models was largely intuitive, and Filon pointed out the many theoretical questions that it begged. This brought the two men together, though no details are available of the first meeting in 1909. They clearly had very different approaches to the subject ; even so, their subsequent collaboration lasted until Coker's retirement twenty-seven years later. Furthermore, the text-book which bears their names has no equal, and is, for those interested in photoelasticity, what Love's treatise has been for elasticians.

The Exhibition of Apparatus

The early exhibits show the differing interests of these two pioneers. Filon's experiments and apparatus illustrate his concern with the optical behaviour of materials, and in particular glass, under simple and calculable states of stress. Coker's apparatus shows how he wanted the practical answers that could be obtained from each experiment, and he seems to have taken it as axiomatic that the elastic stresses—and in particular the maximum values of stress—were the significant quantities. Coker concerned himself with the purely two-dimensional problem of photoelasticity with three unknown quantities at each point. For his purposes, the directions of the principal stresses were obtained from isoclinics in a plane polariscope, the difference between the two principal stresses was deduced from the isochromatics in a circular polariscope, and their sum was found by the measurement of lateral strains. To this limited extent Coker could have claimed that he had completely 'solved' the problem of two-dimensional photoelasticity—indeed, the claim has often been made for him.

Filon seems to have distrusted the lateral strain measurements, although he verified their validity for a state of 'generalized plane stress'. He relied instead on the differential equation of equilibrium to give him the extra information which permitted the principal stresses to be separated. But for Filon's approach, the measurements which could be taken were not sufficiently accurate to justify calculation of their derivatives. This led him to consideration of stress trajectories which gave a curvilinear coordinate system, from which the so-called Lamé–Maxwell equations could be obtained. The errors of calculation were then mainly included in a single estimate of a radius of curvature.

Only a few pieces of Filon's apparatus survived the bombing in the Second World War. His first experiment on a glass beam in bending still exists, but the rest of the original apparatus has been lost. Two of his early experiments on dispersion and a calibration experiment on glass have been reassembled by Colonel Jessop, who was Filon's research assistant when the experiments were performed. Many of Coker's ingenious loading rigs and other pieces of his apparatus still exist. They illustrate his interest in stressed bodies of complex shape which, while they are far removed from mathematical abstraction, are common in engineering practice.

Not only were 'museum pieces' displayed ; the exhibition also gave an idea of the progress of the photoelastic method in recent years. The exhibits of recent origin revealed the amazing degree of confidence which is now placed both in model-making and in subsequent stress exploration. In fact, the method has been applied (both at University College and elsewhere) to structures of a complexity that would have surprised Prof. Coker, even in his most optimistic moments.

Recent Developments

During the Second World War, the laboratories of Profs. Coker and Filon disappeared, one literally (as a result of bombing), the other figuratively as a consequence of the rigours of war-time academic life. The revival of interest in photoelasticity in University College since then owes much to the support and encouragement of Prof. H. J. Collins and to the zeal of Colonel Jessop.

Both Coker and Filon appear to have believed that their exploitation of photoelasticity was more or less complete. But here, for once, they were quite wrong, and it is, perhaps, of interest to consider why this is so. The most striking advance has been made in three-dimensional work. This extension has been made possible by several factors. Of these, the development of a really suitable synthetic resin is a logical extension of Coker's step from glass to celluloid. With the appearance of modern epoxy casting resins, and in particular of 'Araldite *B*', practical materials have become available in adequate sizes; they possess good elastic behaviours, negligible creep, and sufficient optical sensitivity to be useful. With these new materials has come the stress-freezing technique—now more than twenty years old; this opens up an almost foolproof method for the analysis of solid models. By subjecting a model to a heating and loading cycle, it can be persuaded to 'remember' its loading system, and to retain an optical pattern which is equivalent to an elastic system of stress. The solid model can then be sectioned without disturbance of the optical effect, and a three-dimensional analysis can be made. The possibility of doing this was noted in Germany in 1935, but was apparently not known to Filon or to Coker (who was, by then, a sick man). A similar effect had been noted in glass at University College by Dr. F. C. Harris, although its implications for three-dimensional work were not recognized.

It is interesting to note that, with this development, one returns to the original difficulties of measurement which faced Coker. However, his primitive methods have been superseded by the techniques due to Tardy or Sénarmont. Sufficiently accurate measurements can now be made with strains in the model which are not more than ten times the strain in the prototype.

The interpretation of the results found from a model in terms of the corresponding full-scale structure in a different elastic material, and the effect of a tenfold increase in magnitude of strain in the model, was discussed in a review of the present state of knowledge. This was given at University College in two lectures on modern aspects of photoelasticity by Mr. C. Snell. He argued that although the position is not entirely clear, there are good theoretical and experimental reasons for transferring the stress pattern without significant change from model to prototype.

The problem of thermal stressing was exemplified in the exhibition, and the experimental difficulties that have yet to be overcome were mentioned. Dynamic stressing was also illustrated, with a demonstration that problems of dynamic elasticity can sometimes be studied by photoelastic means. In particular, periodic excitation can be investigated in this way unless the periodic time is too short for stroboscopic techniques to be adequate.

The use of optically sensitive layers to show the strain patterns in metals beyond the elastic range is probably the most recent development in photoelasticity. This technique was illustrated in two exhibits and is undoubtedly a promising new departure. Perhaps not so promising—but by no means without interest—was some apparatus (of recent origin) for investigating the optical behaviour of a moving fluid.

Photoelasticity in Engineering

These, and many other, exhibits leave no doubt about the future of photoelasticity. It has been put to use time and time again, particularly in the aircraft industry, where the economical use of material is vitally important. Now it seems clear that the methods will be widely employed in design work on nuclear engineering projects.

Historically, our knowledge of the stress–optical effect is of Scottish origin, the earliest investigations having been made by Brewster and, later, Maxwell. But practical stress exploration undoubtedly grew up in University College, London. It is most unlikely that any other institution could arrange, from its own resources, an exhibition covering so wide a range of productive work within photoelasticity—even if the earlier exhibits of purely historical interest are disregarded. This is a direct outcome of the collaboration of Profs. Coker and Filon—an engineer and a mathematician—and of the subsequent efforts of a small group of workers under the leadership of Colonel Jessop and, since his retirement, Mr. Snell.

R. E. D. Bishop

OBITUARIES

Dr. Paul Chabanaud

Dr. Paul Chabanaud, Chevalier de la Légion d'Honneur, well known for his researches on fishes, died on February 27 at the age of eighty-two.

Although he had been from childhood a keen amateur naturalist, Chabanaud began by preparing himself for a career in the law, but he considered this to have been a false start. Soon after the beginning of the First World War he was declared medically unfit for the Armed Forces and became a voluntary assistant to Prof. Roule at the Museum of Natural History in Paris, classifying and preparing exhibits from the collections of reptiles and amphibians.

In September 1919, Chabanaud received the blessing of the professors of the Museum to fulfil his great ambition of a collecting trip to tropical West Africa. Apart from free passage to French Guinea and free rail travel within the territory, the only financial assistance he received was a grant of ten or twelve hundred francs. He spent about eight months in the field, covering about 1,200 km. on foot, and brought back valuable collections of arthropods, reptiles, amphibians and fishes, as well as considerable ethnological material.

It was only on his return from this voyage that Chabanaud sought any remuneration for his scientific work, and in 1920 he was appointed Préparateur à l'École des Hautes Études, working in the Laboratoires des Pêches et Productions Coloniales d'Origine Animale. From this time his main studies were in ichthyology, and it was in this field that in 1936 he obtained his doctorate, with a thesis on the morphology and phylogeny of the flatfishes (Heterosomata). This penetrating study confirmed the groupings recognized by Tate Regan in 1910 and 1929, and demonstrated a better understanding of the details of flatfish structure than had been possessed by any of his predecessors. His interpretation of this classification, however, was unique. He agreed with Tate Regan that *Psettodes* was a little-modified percoid fish, diverging less from the symmetrical form than any other flatfish. But whereas Tate