THE NEXT DECADE OF CIVIL ENGINEERING

Inaugural Lecture of the Professor of Civil Engineering delivered at the College on 22 February 1962

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B.Sc., Ph.D. (London), D.I.C., M.I.C.E.

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BEFORE plunging into the discourse on the subject, I should attempt to give my reasons for choosing the title of this Inaugural Lecture. Alternative courses set by others have usually been concerned with an historical description or a survey of a particular aspect of their work which would be of general interest. It is, however, my impression that one of the functions achieved by an Inaugural Address is to clarify and maybe to justify the existence of a particular field of study and if possible to map in broad terms the direction of its progress. To do this it is clearly necessary to survey the field and the trends operating in it at the present and to attempt an extrapolation into the future. The title does in addition allow the speaker, with relative impunity, to project his ideas as to what may be, in his opinion, desirable for the future of Civil Engineering.

What is Civil Engineering?

At the outset I believe we should concern ourselves with the matter of definitions. What is Civil Engineering and how, if at all, does this activity differ from other kinds of Engineering practised today? The well-known definition of Thomas Tredgold of being 'the art of directing the sources of power in nature for the use and convenience of men' embraces almost every conceivable kind of engineering (with perhaps the exclusion of the type concerned mainly with the destructive activities of war). An alternative suggested recently at a conference on Civil Engineering education (Michigan, 1960) as the kind of Engineering concerned with 'The fulfilment of human needs through the adaptation and control of the land-water-air environments' is perhaps more acceptable.

To the layman, some results of the Civil Engineer's activity are obvious. Bridges, dams, roads, and canals are without dispute Civil Engineering works, but the recognition of his contribution to the solution of problems of water pollution, planning, or transportation is less wide. The scope of his activity may perhaps be best seen from the groups into which the Institution of Civil Engineering is divided. The American Society of Civil Engineers parallels this by a somewhat more elaborate classification. To illustrate the breadth of Civil Engineering activity let us consider the list of the divisions of this society:

TABLE I

Professional Divisions of the American Society of Civil Engineers

Engineering Mechanics	Waterways and Harbours
Structural	Soil Mechanics
Pipeline	Surveying and Mapping
Construction	Air Transport
Hydraulics	City Planning
Power	Highways
Irrigation and Drainage	Sanitary Engineering

With so diverse a field of activity what common denominators other than the general one concerning 'control of land-water-air' environment can be extracted? To me these seem to be two.

In the first place, the Civil Engineer's work precedes the work of other engineers and, perhaps it would not be too bold to say, any other form of organized activity in society. No industry can be started without his prior construction, no power development without his effort. In the great strides now being made to develop the emerging nations of Africa and Asia his contribution is the first one. The Kariba Dam, the proposed development of

the Volta River, or the power plants on the Yang-Tse are his brain children. Of all engineers, he has the greatest contact with and impact on the society he lives in.

Even in that great engineering feat of sending Colonel Glenn into orbit Civil engineers played a not insignificant part. From the design of the capsule to the immense servicing and launching structure their influence was obvious. Perhaps here I could make a little aside in defence of engineers in general. It has become customary to refer to a successful launching as a 'scientific success' and to a fiasco as an 'engineering failure'. Maybe the engineers' publicity agents are at fault here!

The second common denominator of Civil Engineering is that the majority of the works are 'custom made'. Unlike his colleagues in other branches of engineering he is seldom concerned with a repetitive production of articles. Even when he is using standardized components, as sometimes is the case in structures used for highway bridges and buildings, each structure has to be tailored to suit the particular characteristics of location. This 'one of' design entails a heavy burden of responsibility. The Mechanical or even Aeronautical Engineer can test prototypes of their creations. The Civil Engineer designing a dam or bridge costing several million pounds does not have this opportunity. He must be right the first time. Unlike the doctor, the Civil Engineer cannot bury his mistakes and his professional reputation is at stake at all times.

Separation versus Unity

I have attempted so far to show the common bonds unifying the Civil Engineering profession. These appear more in the motivating forces and similarities of practice than in the engineering sciences on which the practice is based. The disciplines on which the work of the Structural Engineer is based mean that often he is more at home with aircraft designers than with his colleagues engaged in public-health aspects who, in turn, have a common language with Chemical and Biochemical Engineers. It is my feeling that this stratification of the subject may well grow within the next decade as already indicated by the number of specialized associations created within the past years. But, while it is no longer possible for the Civil Engineer to be the 'master of all trades' (as was the happy situation in the last century) the preservation of the name has, I believe, more than an historical significance. He must, of necessity, remain the co-ordinator and planner of the activities of various specialists.

Trends shaping the Profession

What are the trends which will shape the growth of the profession in the next decade? The two factors I would choose to select here are of somewhat different nature. The first is the impact of the digital computer and the second the growth of large organizational units in the profession carrying out simultaneously the processes previously assigned separately to consultants and contractors.

The digital computer with its extraordinary capacity for performing rapidly routine arithmetical operations is already taking over the repetitive computational work often necessary in design. Already a large proportion of Civil Engineering firms in the United States and a smaller, but significant, proportion of those working here possess their own computer and a library of programmes. The meaning of this to the profession is clear. The wastage of professional Engineers carrying out sub-professional work will be largely eliminated. Even at this moment many engineering graduates of universities are being used with shocking inefficiency, though the scarcity of engineers here is considerably greater than in most European or transatlantic countries. For days and some-

times weeks on end they may be engaged on the process politely called 'design' but in reality consisting of routine computations calling for little intelligence or creativity. Such repetitive processes can be performed by the machine with incredible speed. Let me quote some savings which can be achieved, from a recent paper describing the 'design' of standard road bridges. The process requiring normally some 25 man-days was reduced, using a medium-speed, office-size computer, to 21 man-machine hours using a so-called non-integrated programme. With additional time spent on programming the actual design was ultimately reduced to 4 man-machine hours. Similar examples can be obtained in large numbers showing even more dramatic results on time saving but the other advantages are perhaps not quite as obvious. The elimination of human error and the speed with which alternative designs can be investigated once a basic programme has been set up, result already in improved and more economical structures.

The influence of the second factor, i.e. that of the growth of the large consulting-contracting organization, is less predictable. It would appear that the increased incentives of competition will produce a more rapid growth of new designs and construction techniques than hitherto apparent. Be that as it may, this irreversible trend towards larger organizations will lead to a greater demand for highly qualified engineers with specialist knowledge. This factor in conjunction with the reduced need for routine work caused by the utilization of computers will have to be reflected in the approach to the problem of education and training of future engineers.

Future Problems to be solved by Civil Engineers

What lies ahead of Civil Engineers in the way of new problems, undertakings, and fields of activity? At this point I am somewhat perplexed as to the direction this talk should take so as not to slight by omission or bore by inclusion. One way would be to list some of the major engineering projects conceived now, as was done admirably by Willy Ley in his book *Engineers' Dreams*. Some projects described by him such as that of the Channel tunnel are already nearing the stage of realization while others such as the damming of the Mediterranean or the Red Sea for purposes of power generation may never come to fruition. The alternative which I shall follow will be to describe the growth I envisage in certain general areas (with apologies to those omitted).

As the first of these I have chosen the field of transportation. The spectacular growth of new urban and long-distance highways which is in progress throughout the civilized world is but one of the many facets of this which will influence our lives in the next decade. The impressive intersections and city express ways shown in the accompanying figures (1 to 4) are only a sample of the things which will become familiar to all of us in this country.

The transportation and planning engineers are becoming increasingly involved in the general problems of national economy. Their activity only begins with the problem of providing an adequate road system. The economics of alternative methods of transportation, present and future land use values, and optimization of route location, are also being studied actively. Application of new mathematical techniques of systems analysis, operations research, and in particular of linear programming yield promise that the future may well see a more quantitative approach to such problems in place of the political polemic.

One of the alternative forms of transportation (fortunately not yet suitable for commuters) is that provided

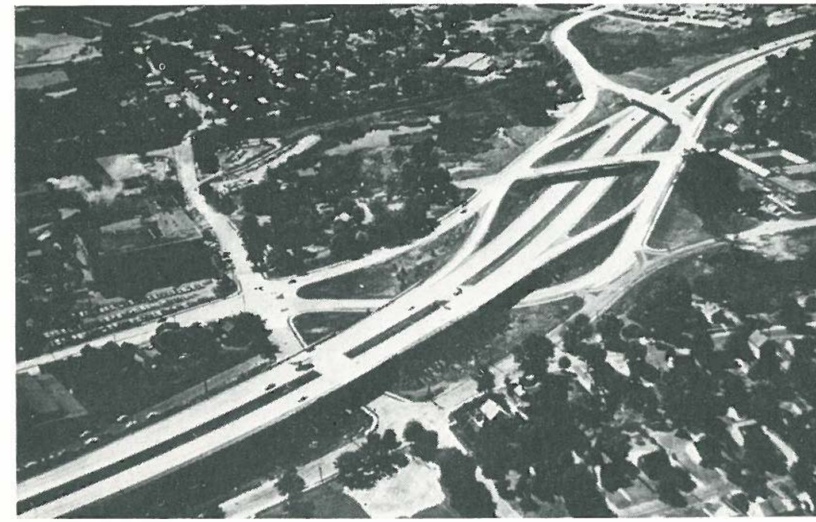

FIG. 1. An interchange on the Connecticut Turnpike (U.S.A.)

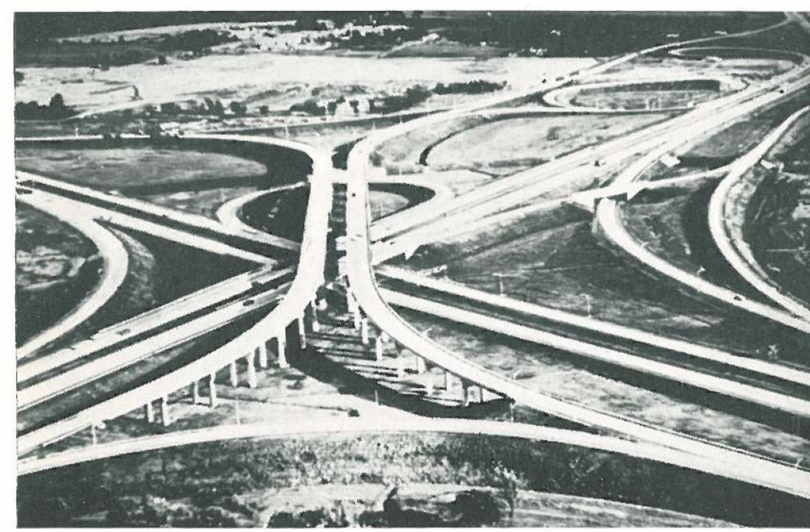

FIG. 2. Tri-level intersection near O'Hare Airfield, Chicago, U.S.A.

FIG. 3. Congress Expressway, Chicago, U.S.A.

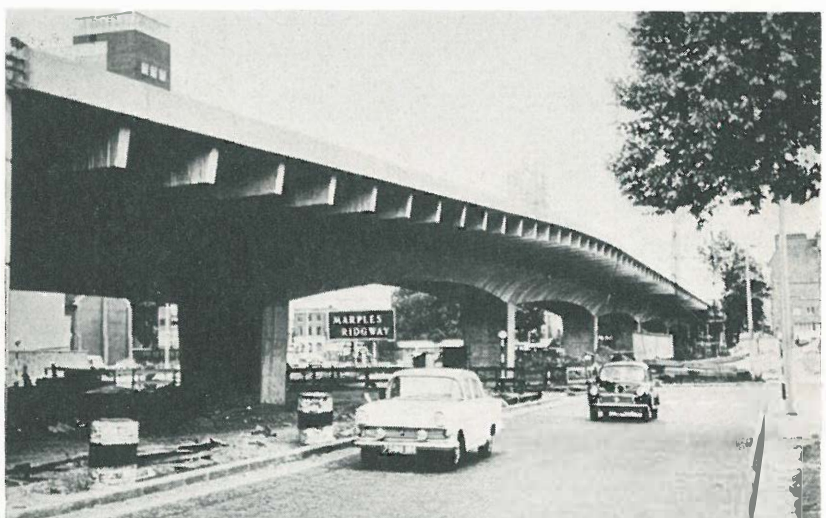

FIG. 4. Hammersmith flyover

by pipelines. Gas, oil, and even coal can be transported through these at relatively small cost. In the United States alone some 1·4 million miles of pipeline are in use (with about half of this mileage carrying oil). In this country a network of 1,200 miles was constructed during the war for aviation fuel, and many more miles since. A national network is in the discussion stage. In both Great Britain and Europe many pipelines for distribution of gas are being actively considered, ultimately linking the African gas sources with the consumers. A considerable growth of this method of transport will undoubtedly occur in the next decade.

I would next like to speak about public-health and water resources engineering. The major tasks here are the preservation of our water resources and creation of new ones. Though in general less spectacular in achievement than the other fields of Civil Engineering, this field is one of growing importance both in highly industrialized countries and in underdeveloped and arid areas in the world. The increasing demand for water in domestic use is bound to increase rapidly with the increasing standard of living in this country (at present the *per capita* consumption is somewhat below one-half of that of the U.S.A.) and the increasing industrial demands are already causing difficulties to be experienced, as apparent from the recent Manchester Corporation's demands for supply from the Ullswater lake. In California, the ground water is already being extracted at a rate exceeding many-fold the natural rate of replacement. To remedy this, ways of utilizing the abundant supplies of seawater are being studied. Already distillation plants are operating successfully in many parts of the world where the relatively high cost can be justified economically. At present this stands somewhere between 3*s*. to 10*s*. per 1,000 gallons compared with the cost of supply from Ullswater to

Manchester of approximately 1*s.* 6*d.* Processes other than distillation, such as osmosis, electrodialysis, freezing, and solvent extraction, are being studied and the next decade will see, without doubt, a considerable expansion of the utilization of this supply.

Finally I would like to turn to the field with which my own interests are intimately concerned. This is the subject of the structure and its foundation. Where do we stand here and what will be the future development? In this, the most classical branch of the profession, it is most difficult to forecast the 'break-throughs'. Most probably these will not take place in a revolutionary manner but rather as a gradual evolution and refinement of the presently discernible trends together with an increased knowledge of the behaviour of the structure and its foundation.

Looking back over the past few years, the rapid development of concrete in both its prestressed and reinforced form has created a revolution in structural and architectural engineering. The development of the surface structure (a structure resisting forces by plane or curved surfaces) and a growing departure from the era of truss or frame type construction is, I believe, the main significant change. This, I am sure, is going to be exploited in the next decade to a much greater extent than today, not only in concrete but in aluminium, plastics, and other materials yet to be developed.

The accompanying figures (5 to 7) show some of the types of structure which are being built at present in concrete. Clearly in some of these the rather flamboyant use of form is governed by aesthetic rather than purely structural features. To illustrate the development of a pure structural form it is interesting to follow the evolution of one type of structure with which my own work has been largely connected. This is the dam—an expensive

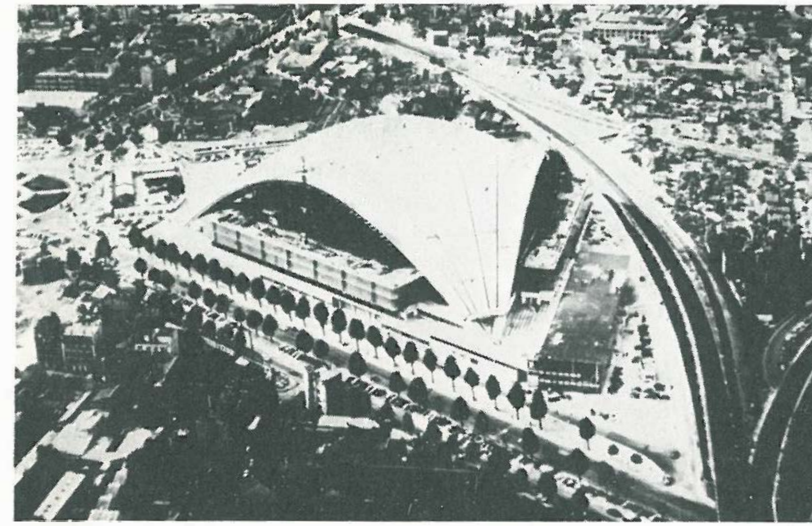

FIG. 5. Exposition Hall, Paris

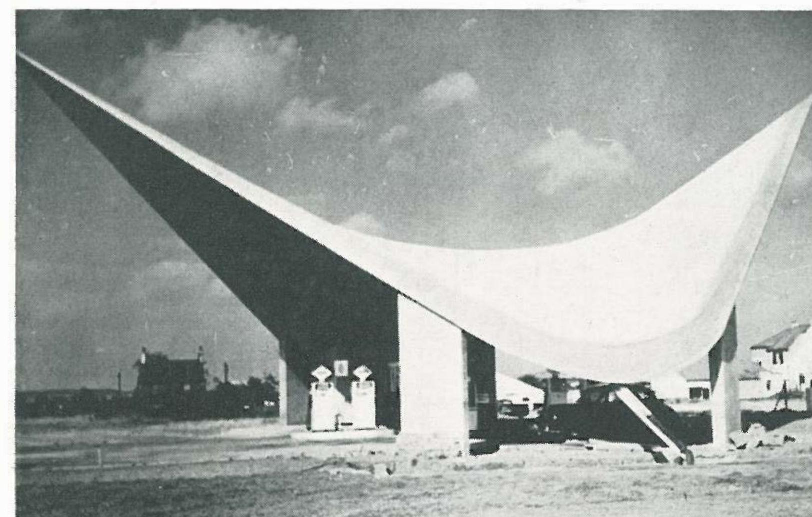

FIG. 6. Petrol Station, Retford Bypass, U.K.

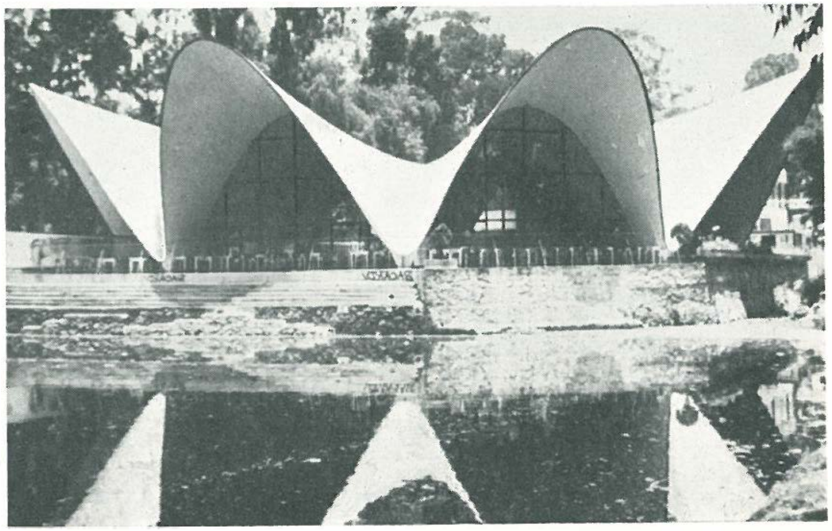

FIG. 7. Restaurant in Mexico (Xochilco)

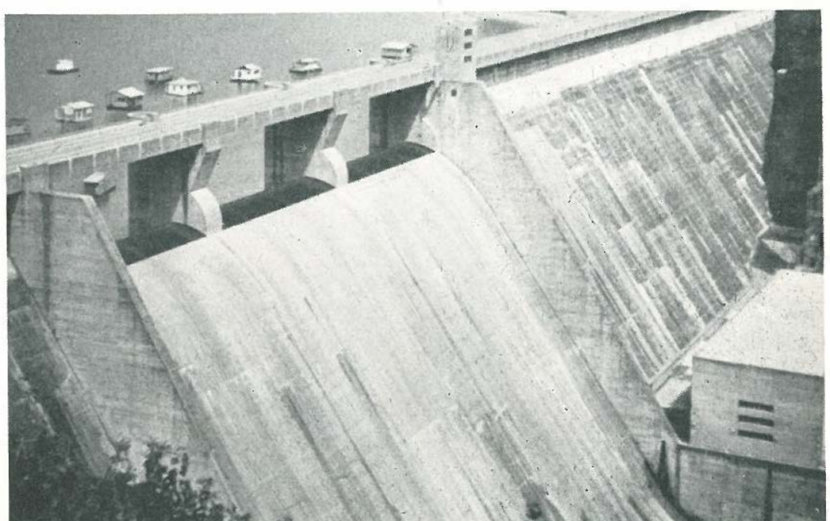

FIG. 8. Norris Dam (gravity dam), Tennessee, U.S.A.

structure in which the shape is governed by purely functional considerations and where continuing study, by effecting even a small relative refinement, may save very appreciable sums of money.

The figures 8, 9, 14 illustrate the gradual transition from the simple gravity type of structure (still economical under certain circumstances) to two distinct surface types—that of the buttress design composed of relatively thin vertical slices and that of an arch or shell type of dam used frequently today. The prestressed dam is (Fig. 10) following its own evolutionary path shown here by way of illustration.

In none of these structures has the ultimate word been spoken. Optimization of shape aided by the computer, studies on both models and prototypes of such structures, and development of improved construction techniques will result in more economical and safer structures. The lead in this field, lost by this country in the post-war years, will, I believe, be regained by the research efforts now being made. The need to export our knowledge and skill is adding a vital stimulus to this work.

That much yet remains to be done is illustrated by the two recent failures of dams. The importance of the foundation forming an integral part of the complex cannot be overestimated.

As it is often the weakest link in the chain the foundation requires intimate study. The Malpasset dam above Fréjus in the Riviera was at the time of its completion in 1958 one of the most advanced structures of the shell type (Figs. 11, 13).

Its shell structure, designed by one of the foremost French engineers, was above reproach and yet one day in December 1959 it collapsed, causing some 400 casualties. This followed almost a year after a similar disaster involving approximately the same number of

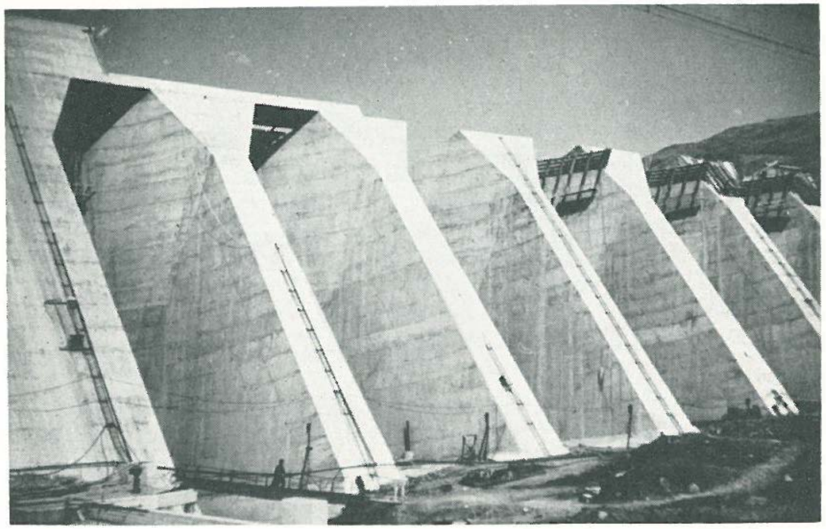

FIG. 9. Glen Shira Dam (buttress dam), Scotland

FIG. 10. Allt na Lairige Dam (prestressed dam), Scotland

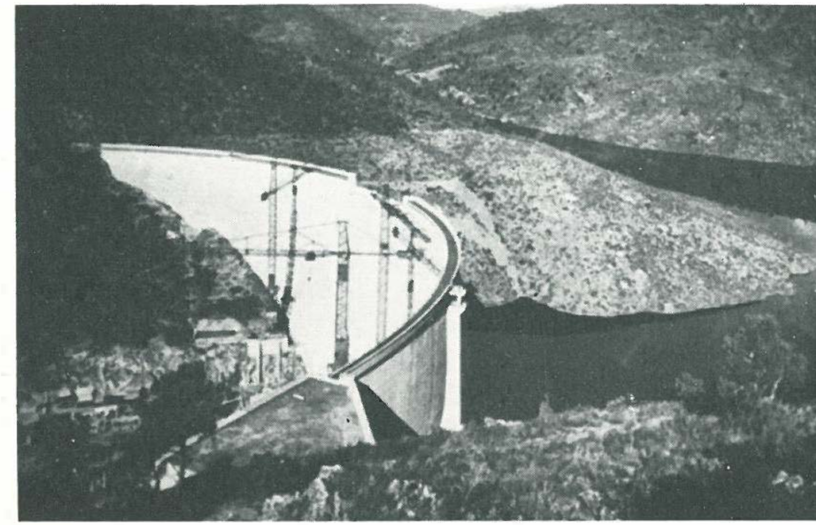

FIG. 11. Malpasset Dam, Fréjus, France

FIG. 12. Vega de Terra Dam, Spain, after failure

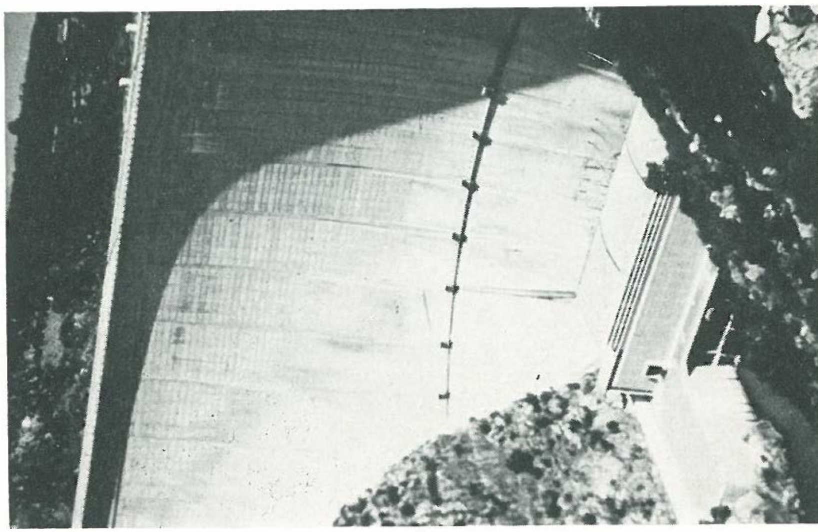

FIG. 14. Cabril Dam (arch-shell dam), Portugal

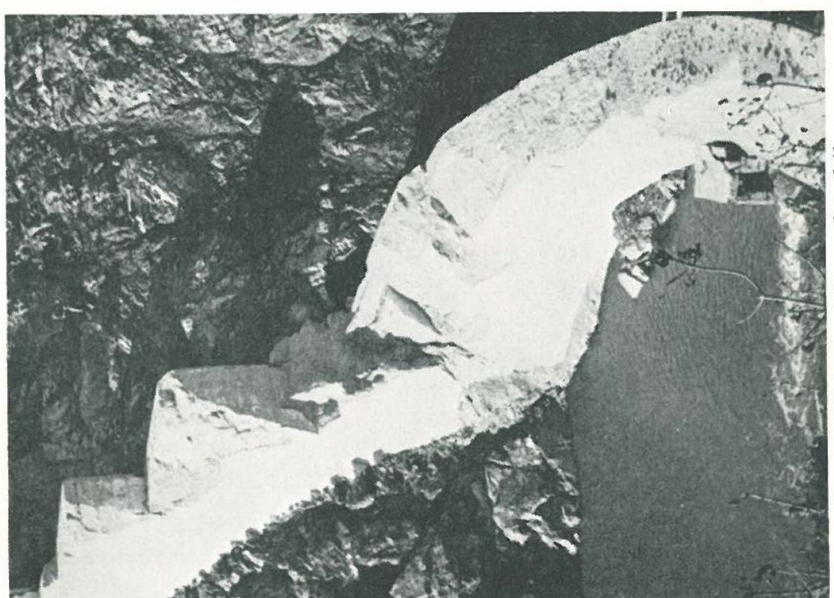

FIG. 13. Malpasset Dam after failure

casualties in Spain (Vega de Terra dam, Fig. 12). Certainly in the first dam the fault was the matter of foundation. In the second the same was, at least possibly, at fault. The failures, combined with others less spectacular, illustrate our reason for a recent interest in a subject termed 'rock mechanics'.

This science, destined to grow in the next few years, is a new branch of study in Civil Engineering and is receiving additional impetus from other sources. One of these is the Operation 'Plowshare', investigating the peaceful uses of atomic explosions placed underground for creation of 'natural' harbours, mining of minerals, &c. Such projects are perhaps no more fantastic than schemes already accomplished, but at this stage I would like to conclude the matter of crystal gazing and give my attention to the question of the role to be played by the university in preparation for the future.

Education

The university has to be in the *avant-garde* of the professional development and must prepare engineers not for the present needs but for those of ten or twenty years hence, when the current graduates will be reaching the peak of their professional career.

What kind of an engineer do we want to train to play his part effectively in the coming era? Clearly there will be less opportunity for the mediocre with the advent of the computer removing the sinecure held by some of these at present. To become a leader he will have to have on the one hand a broad knowledge of the basic engineering and social sciences and on the other a deeper knowledge of at least some branch of the professional field.

Perhaps his qualifications could be summarized in the words spoken some centuries ago by Vitruvius who says on the subject of training of architects (at that time synonymous with Civil Engineers):

> Wherefore, a man who is to follow the architectural profession manifestly needs to have experience of both kinds. He must have both a natural gift and also readiness to learn. He should be a man of letters, a skilful draughtsman, a mathematician familiar with scientific enquiries, a diligent student of philosophy acquainted with music, not ignorant of medicine, learned in the responses of jurisconsults, familiar with astronomy and astronomical calculations.

Surely one cannot do better than this! How is this to be achieved? Perhaps in the first place by broadening still further some of his undergraduate study—certainly by increasing the amount of postgraduate training which would take him to the frontier of knowledge in a particular area. This tendency is being already followed to some extent at least in the United States where the ratio of postgraduate students to the undergraduate rose from 1 in 20 in 1936 to 1 in 5 in 1960. I believe the comparable figures put us closer to the first ratio. It is certainly necessary to correct this and much could be done by industry in offering suitable rewards to candidates with higher qualifications. This is as much needed as a considerable increase in number and amount of postgraduate studentships available.

In the expanding field of Civil Engineering it is my belief that greater collaboration between the universities and the profession is a necessity. Universities should be in the scientific *avant-garde* and their researches should be readily available to the practitioner. At the same time the universities could well benefit from the technological prowess of the leading practitioners who may well be invited to take up positions similar to 'adjunct professorships' available on the continent of Europe and to a lesser extent in the United States. The feedback of

information and establishment of mutual confidence is a matter of prime importance to both the university and the industry and therefore to the country as a whole. The increase of the small but healthy amount of this collaboration already existing is much to be desired.

A university of the size of Swansea College cannot at the moment, and probably will not in the future, be able to support postgraduate work in all fields of Civil Engineering. We hope, however, to extend active postgraduate work in the areas of solid and fluid mechanics (including structural, soil, and rock mechanics) and if suitable staff becomes available to introduce planning and transportation engineering groups.

There is one further aspect on which I have not yet touched and which is giving me some concern. This is the question of the appearance of the Civil Engineering structure which is so much the part of our everyday life. Often this is magnificent and faultless but on occasion a lack of an aesthetic appreciation of the principles of good design can be observed. Similarly at times in the works of architects an ignorance of the science of the structure can be detected. The reasons for this can, I think, be traced to a comparatively recent divorce of architecture from Civil Engineering. An improvement in this situation could, I believe, be achieved by having architectural schools in close proximity (in the physical as well as the ideological sense) to those of Civil Engineering. Perhaps it is not too much to hope for that in the future such a school could be established here. In any event I strongly believe that an establishment of some competent training for Civil Engineers in principles of good design is of vital necessity.

To conclude I would like to reiterate my belief in the future of the Civil Engineering profession. I have, I hope, shown some of the unifying threads of this branch of Engineering. In the description of the products and activities I have tried to demonstrate the need for research. The growing emphasis on this aspect will not only lead to spectacular new fields but may well result in major revolutions in our everyday existence.

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