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"Civil Engineering Research and its Future."†

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Mr. W. L. Campbell observed that an outstanding problem in road and runway construction was the evolution of a design method for what the Americans called "flexible pavements"; the term "pavement" included the whole structure—surface and base or base courses. The road design formulas mentioned by the Author on p. 230, *ante*, were all more or less empirical, and the modification for the heavier loading of runways was presumably extrapolation. That procedure, based on a sound theory, was permissible, though perhaps dangerous: without the theory it was certainly dangerous, as it led to either over- or under-designing.

There were two approaches to the problem, one by fundamental research and the other by empirical methods. The latter provided a means of correlating a mass of data obtained from conditions varying from place to place; the former built up a theory from experiments under controlled conditions. A method was needed for the design of a road or runway structure for given loadings from a knowledge of the essential properties—whatever they might be—of the subgrade, base, and carpet materials. It would be very interesting to know the Author's views how that could best be obtained. Probably the two approaches should be regarded as complementary, with the fundamental side as a centralized research and the empirical side done locally under the guidance of the central authority.

Mr. A. J. H. Clayton wished to support the Author's reference to the need for "functional" research and to suggest that research should go back farther still. There was, for example, a very strong need for research in the basic facts affecting road design. Most of the organized research in Great Britain had been into materials and construction. There was insufficient knowledge about the flow of traffic for which the roads were designed. The behaviour of traffic at intersections of different designs was a matter for research on existing roads and for full-scale experiments. In addition, information was required as to the lengths of the journeys taken by vehicles in different types of areas. Whilst much mathematical research had been done upon the design and setting out of road curves,

† J. Instn Civ. Engrs, vol. 24 (1944–45), p. 211 (May 1945).

very few data were available as to the basic constants to be used and the extent to which precise design of curves was justified.

Mr. Clayton suggested the following outline programme of research :—

(1) Capacity of roads and their intersections.
  (*a*) Variation in density in various circumstances; for example, width, speed, surface.
  (*b*) Effect of standing vehicles and overtaking.
  (*c*) Capacity of roundabouts.
  (*d*) Efficiency of intersections of different types.
  (*e*) Behaviour of vehicles at intersections.

(2) Distribution of traffic over a road system.
  (*a*) Length of journeys.
  (*b*) Distribution of traffic when the shortest route was congested.

(3) Variation of traffic with time.
  Annual
  Seasonal } Variation in different types of locality.
  Hourly

(4) Behaviour of vehicles on curves.

Research on some of the problems had been carried out by the Public Roads Administration in the United States, but the results needed relating to British conditions and there was still much to be done. The subjects for research suggested above were quite independent of the gathering of statistics as to traffic volumes on roads in different parts of the country, carried out by the Ministry of Transport and the local police authorities, or traffic surveys made for special projects. Those were analogous, for example, to the collection of run-off data in connexion with water engineering and did not form part of research.

Research was needed into the causes of road accidents, and the efficiency of various methods adopted to reduce the accident hazard.

Mr. A. W. H. Dean observed that Civil Engineering research in India had hitherto largely been sponsored by the Government, although it worked through semi-official and non-official bodies as far as possible. The two bodies most concerned were :—

(1) The Central Board of Irrigation, an official body consisting of the Chief Engineers of Irrigation in the various Provinces of India, which met annually and maintained a Secretariat with a library and a technical secretary. It performed an extremely valuable function as an " abstraction service," producing a monthly bulletin of abstracts, not only on strictly irrigation engineering, but also on all branches of civil engineering, including airfields and roads.

(2) The Indian Roads Congress, which met annually and was subsidized by the Government and organized under Government

auspices; its membership consisted of engineers working on road construction in the various Provinces, States, municipalities, and districts of India. It had a group of technical sub-committees, one of which was concerned with research on soil stabilized roads, whilst another supervised the work of a small test-track.

On the hydraulics and irrigation side there was one Central Research Station, the Indian Waterways Experimental Station at Poona, which for many years was under the control of Sir Claude Inglis, C.I.E., M. Inst. C.E. It had produced a number of valuable reports. In addition the six provinces of the Punjab, Sind, Bombay, the United Provinces, Bengal, and Madras, all maintained their own separate research stations.

The results of work done at those stations had contributed very largely to the success of the irrigation undertakings throughout India, on which, as was well known, India largely depended for its agricultural prosperity. Examples of research carried out were those into the flow of water in channels and the transport of silt. As a result of those researches it was now possible to design efficient channels which neither scoured nor became blocked by silting. Research on the model scale had also led to the design of sand-excluders which were now constructed at the headworks of canals and sand-ejectors used in canals. Another line of research had been on the hydraulic uplift pressure on structures founded on sand, as a result of which many failures, which would have occurred if the old traditional methods of construction had continued to be followed, had been avoided. Various devices for the economical measure of the flow of water had been designed; in recent years, special attention had been paid to the control of floods.

The Government of India had recently set up a Commission for Irrigation and Waterways and had placed a distinguished Indian engineer, Rai Bahadur A. N. Khosla, in charge. It was expected that under his direction a much enlarged Central Research Station would shortly be constructed, possibly at Delhi.

Rather less had so far been done with regard to roads, largely owing to the extreme paucity of available funds. A Road Fund was collected, however, by the Centre; a proportion of the petrol tax being set aside for expenditure on roads, of which a very small proportion was earmarked for Intelligence and Research. Intelligence was of extreme importance. Inaccessibility of information had been the greatest single handicap to the advancement of civil engineering research in India.

For the future, the Indian Roads Congress which, as a technical organization of road engineers, largely corresponded to the American Association of State Highway Officials, had worked out a comprehensive scheme for road research, modelled on the research organization of the United Kingdom and based on information collected in the summer of

1944 by Mr. Dean from the Author, to whom a very great debt was owed. It was expected that research would be carried out on (1) road materials: (2) methods of construction; and (3) working processes, which were suitable for Indian conditions; and that as a result of that research, standard specifications and codes of practice would be prepared. India was, in particular, interested in low cost roads, and in that connexion some work on soil stabilization was at present in hand.

It was regarded as very important that there should not be too great a divorce between engineers working on research and those in charge of construction. A system by which the engineer-in-charge of the experimental construction of stabilized soil roads was also in charge of the main research laboratory for that subject, which had a group of mobile laboratories working at the site of construction, had been organized.

Except for occasional work by individual officers, notably some work by Sir Alexander Brebner on reinforced brickwork about 25 years ago, little structural research work had so far been done in India. A scheme was under consideration for setting up a Building Research Station on a small scale. That also would follow the lines of the Building Research Station in Great Britain, and Mr. Dean had received considerable help from the Director.

A substantial amount of research work was being done by the Forest Research Institute at Dehra Dun under Government auspices, and regular reports were published. The Institute dealt with the preservation of timber and with the utilization of timber, particularly special timbers which had not been traditionally considered suitable for structural purposes, and had recently done some work on the preparation of plywoods and pressed woods.

Mr. C. G. Evans observed that the Paper provided an excellent survey of the fields in which research work could be carried out; but he considered that one aspect, that of research aimed at producing better civil engineering materials, could be amplified a little. The emphasis seemed to have been more on the solution of *ad hoc* problems using present materials. The commonest, steel and concrete, were good materials, but were capable of improvement and possibly replacement with newer materials. Steel was heavy and corroded rapidly, especially in tropical climates; and both of those factors would be of great importance when opening up the tropical land masses, especially if air transport was to play any large part. Concrete was subject to difficulties in compaction after pouring, unless the mix was too wet, when a poor concrete resulted. The addition of small percentages of chemicals had already been shown to produce remarkable results on the pouring, setting, and final strength characteristics of present-day concrete; further experiment could no doubt produce strong concretes requiring only very small quantities of cement and possibly entirely new concretes, using cheaper fillers more readily available in undeveloped countries than good sand and ballast.

There seemed to be a big potential field for structural materials to be complementary to steel. A large proportion of the load on many load-carrying structures of any size was the weight of the structure itself; that was especially true of such structures as the Golden Gate bridge, where a light-weight structural material could reduce the massiveness of the structural members and with it the cost of raw material and erection of the structure. Some of the new aluminium alloys were worth looking into; there were also resin-impregnated glass fibres having great impact strength and light weight, and there were resins such as nylon; both of the latter materials were not attacked by corrosion in tropical climates or by fungi or insects. Great daring was needed to use such materials for the first time in a large structure and a body, subscribed to by everyone interested, could help to spread the financial load of experiments and the benefits of success, as well as co-ordinating the work to reduce overlapping, thus increasing the quantity of work which could be achieved for a given expenditure of effort. At present, light-weight materials were expensive in comparison with steel or concrete and their use, at first, would have to be confined to structures where reduction of maintenance costs or increase in pay load resulting from reduction in structural weight would pay for the added raw material cost.

As the Author had observed, there was a huge problem in collecting information and disseminating it to those requiring it. Equally, there was a huge problem in bringing the research worker into contact with the requirements of the engineer, especially when the latter might be in a distant land and when he frequently was not aware of what might be achieved and, hence, of what he wanted. The value of personal contacts could not be over-emphasized and the arrangement of such contacts should, if possible, form a part of the work of any body set up to organize the collection and dissemination of information and the formulation and finance of research programmes. Exchange of research workers between countries was a practical way in which they could become familiar with each other's problems and, by introducing a new angle of approach, frequently solved a problem which, to those working on it, had appeared insoluble.

Mr. Evans felt that whatever was done in setting up reference libraries, advisory panels, research programmes, and inter-commonwealth and international liaison, The Institution formed a logical and proper focal point for the United Kingdom's part in the work.

Mr. J. T. Evans observed that the Author's advocacy of a National Hydraulic Laboratory to investigate problems connected with rivers, canals, estuaries, and harbours would be supported by engineers in charge of inland waterways, who were faced with many problems depending directly or indirectly on the properties of flowing water. Not only would such a laboratory help in the design of locks, weirs, channels, and banks, but also it could investigate and develop many improved designs and

methods of operation which had been suggested from time to time but never actually tried.

Since many of those problems could be solved only by deliberate experiment or by the more expensive method of practical experience, and since it was widely held that no considerable construction should be carried out on rivers, estuaries, or harbours without previous investigation by models, it was surprising to see what scant facilities there were for research on such matters in Great Britain in comparison with other countries. Whilst there were several large laboratories on the Continent of Europe, and more in America, there was not a single permanent hydraulic laboratory in Great Britain whose main function it was to investigate those problems either in the abstract or in relation to specific problems placed before it by clients.

Models set up temporarily in establishments designed primarily for other purposes were dismantled at the end of the experiment and part of the equipment and staff were dispersed. The absence of any permanent establishment or staff undertaking such work had harmful results. In the first place, it retarded the growth of a connected set of principles, derived from the many experiments already carried out at home and abroad, which would enable engineers to predict more closely the effect of proposed new works, and secondly, it meant that special arrangements had to be made to investigate new problems and therefore the use of models was much less practised in Great Britain than would profitably be the case.

Dr. Rehbock had recorded that the whole cost of the construction of the Karlsruhe Hydraulic Laboratory had been saved many times over by reductions in construction costs resulting from hydraulic investigations carried out there for clients. Similar successes had been reported elsewhere. As for waterways in Great Britain, model experiments on a river navigation in England had led to economies in the design of lock and weir work far exceeding the cost of making and operating the models.

The setting up of such an hydraulic laboratory in Great Britain was long overdue and it was urgently required. One could be established as a department of the National Physical Laboratory, on a similar footing to that of the William Froude Laboratory. A laboratory, corresponding to the principal ones elsewhere would be an expensive undertaking, but valuable work could be done and experience gained in a smaller and comparatively cheap laboratory. Since problems sent by clients for solution would probably not be sufficiently frequent during the first few years to occupy a full-size laboratory it would be advantageous to build a small one first and expand it when required in the light of experience. It had been found that laboratories of that description started with general research problems and then became more and more engaged on specific problems for clients as the value of their work became more widely recognized.

Mr. Reginald Heywood observed that the reference made to the

financial aspect of engineering research invited reflection as to whether some more positive means of encouraging that work could be devised.

The figures given in Table I, although incomplete, showed that the funds spent on research amounted to only 0·1 per cent., or £1 per £1,000, of the total cost of the works in the case of roads and railways. A small percentage levy or tax on works would raise an appreciable sum for the benefit of research; for example, a tax of 0·1 per cent. on the figures quoted would yield an additional £55,000 per annum in respect of road expenditure and £20,000 in respect of railway expenditure.

Mr. Heywood had selected road and railway work by way of illustration, because roads were financed entirely from public funds and railways were of a *quasi*-public nature, and before long their cost also might be defrayed out of public funds.

Apart from the increased revenue thereby made available for engineering research, a considerable impetus would be given towards the establishment of that partnership between the research worker and the practising engineer which the Author had commended.

From time to time most practising engineers were confronted with problems, some small and elusive, which they would gladly refer to a research organization established on the lines suggested.

The Library, with its abstracts and more detailed information available when required, would be a valuable contribution to engineering generally, and would undoubtedly save more than the money contributed towards research.

Administration of the moneys raised should present no difficulty.

The Department of Scientific and Industrial Research, or a Board or Committee constituted on somewhat similar lines, could be entrusted with the distribution of the funds.

The incidence of the tax was a point worth considering. It would be most satisfactory if it were shared by all the partners financially interested in the work, namely, the party or parties financing the works by contract, and the contractor or persons executing the work. That, however, was a matter apart from the principle involved, and would call for further consideration if the proposal became practical politics. It had the merit of extending the liaison already envisaged between the engineer and the research worker, to include that important person, the contractor responsible for the construction of the work.

Mr. Gerald Lacey observed that the Paper was an admirable presentation in broad outline of the problems facing those workers, either physicists or engineers, who were engaged on civil engineering research. He had been employed for many years intermittently on hydraulic research and had found the Paper interesting, stimulating, and valuable.

The Author, referring to the motion of water within granular boundaries subject to movement, had remarked that little had been done to

place the subject on a sound basis or to elucidate the physical laws governing the phenomena associated with such flow. It was clear from that statement that he was not fully aware of the mass of experiments performed on alluvial channels in India during the past decade, and the progress that had been made in introducing the measured diameter of the bed silt grains into alluvial hydraulic equations. It would be more correct to state that evidence was being collected on sound lines, and that when the evidence was complete the physical theory would follow. The reason for the slow progress was the complexity and intractability of the problem.

Very little progress appeared to have been made in England, and for very good reasons. The problem of pipe flow, with the possibility of controlling variables, was admirably adapted to experimentation in laboratories. The problem of flow in natural channels was of an entirely different character and required the closest possible co-operation between the workers in the field and those in the laboratory. That co-operation was defective. The problem could not be solved on traditional, academic lines. It was highly probable that the physical theory would be developed in the field and that the laboratory would ultimately play its part in performing *ad hoc* experiments designed to confirm or modify parts of the physical framework.

Mr. Lacey entirely agreed with Sir Edward Appleton that courage was required, and a great deal of it. The remark of the experimenter in Dr. Johnson's " Rasselas," that if every objection were to be met in advance nothing would ever be attempted, was as true to-day as when it was written. Without that courage engineers in India would have sat with folded hands.

Professor Robert F. Legget observed that civil engineering research, not only in Great Britain but also in the several Dominions and British Colonies, should receive real impetus from the publication and discussion of the Paper, with its logical analysis of a complex and widespread subject. The strangely slow progress of civil engineering research, in comparison with that in other fields of work, had naturally received attention from the Author (p. 214, *ante*). Since civil engineering work involved an extensive use of materials, was it not possible that the relative backwardness of civil engineering research was due to the fact that, although there had been much research into the properties of manufactured materials (generally under other branches of engineering), the principal material of the civil engineer—soil—was not a commercial product, being sold by no large industrial organizations, and that research into its properties had thus had to await the institution of publicly sponsored research laboratories which, in turn, had been occasioned to a large extent by the necessary development of highways for automobile traffic ? Correspondingly, had not the processes adopted by the civil engineer in the use of his materials been usually " left to the contractor " until relatively recently, the application

of scientific analysis and investigation in construction being again a relatively recent development ?

Interesting as such inquiries into the past might be, it was the Author's thesis with regard to the future which demanded attention. Since it was almost two decades since Professor Legget had worked in Great Britain, it would be invidious for him to comment upon the Author's specific suggestions for research work in Great Britain except, perhaps, in one connexion. He could well remember the interest aroused in his graduating class by a research project which was in progress during their final year of study at the University of Liverpool; watching that work gave an inspiration to undergraduates, with regard to the possibilities of work in their own chosen profession, which could not have been obtained in any other way. Therefore, he suggested that every possible use should be made of University facilities in the development of civil engineering research work, since University research work had that double value.

As illustrating one way in which that could be done, mention might be made of the School of Engineering Research of the University of Toronto, with which Professor Legget was associated. Founded in 1917, the School had been the medium through which had been carried out all the research work of the staff of the Faculty of Applied Science and Engineering of the University. The results of that work had been published in more than 170 bulletins, forty of which had been concerned with subjects generally regarded as in the field of the civil engineer. Expansion of the work of the School was anticipated in the near future, in keeping with the general expectation of increased activity in research in Canada, so well expressed in a recent paper by Dr. C. J. MacKenzie, President of the National Research Council of Canada.[1] The Council's organization was itself a centre of very active research; the Council also co-ordinated much research work carried out elsewhere in Canada, such as some of that at the Universities. Corresponding research organizations existed in some of the Provinces, notably the Ontario Research Foundation, but it had to be admitted that, as yet, neither the National nor the Provincial research bodies included a division of civil engineering, or even one concerned with building research—a part of civil engineering in which immediate research appeared to be a most urgent need in view of the vast post-war building and rebuilding projects already in immediate prospect.

The Author's emphasis upon the importance of the dissemination of information regarding research touched a vital topic—one which Mr. H. G. Wells had long been proclaiming with his advocacy of a world encyclopaedia. Would that such a solution were possible! As a step towards that ideal, engineers in North America were fortunate in having available the excellent services of the Engineering Societies' Library in New York.

[1] "Industrial Research in Post-War Canada", *Eng. Journal* (Montreal), vol. 27, 1944, pp. 136–138.

Despite that, however, much unfortunate duplication still occurred, the elimination of which was more than desirable.

Professor Legget wished to endorse strongly the Author's suggestion (p. 237, *ante*) that environment necessarily exercised a marked influence upon all civil engineering work, and therefore upon corresponding research. Although the Author might with propriety have omitted his reference to the Dominions in his fifteenth conclusion, it was a fact that civil engineering problems varied with every locality, if only because all civil engineering work involved work on or in the crust of the earth, the variations of which were boundless. So it was that the challenge of civil engineering research, now that it had at last been recognized, was so stimulating: and so it was that the civil engineer before all others might well use as a guide in his researches those famous words of William Harvey:—"Nature is herself to be addressed; the paths she shows us are to be boldly trodden. . . . Truly in such pursuit it is sweet not merely to toil, but even to grow weary, when the pains of discovering are amply compensated by the pleasures of discovery."

Mr. A. Shaw Maclaren observed that the Paper presented clearly the numerous aspects of civil engineering research. Nearly all civil engineering works which were not merely repetitive entailed research, using the term in a wide sense, as each work presented in a new form problems which required elucidation and solution. To that extent civil engineers might be said to be research-minded, so that the soil in which the tree of civil engineering research had taken root and from which it would draw strength for future growth could perhaps, happily, be regarded as a fertile one. The Paper should perform a service not only to The Institution and to the engineering fraternity, but also to the general community, through its results.

With regard to research for airport engineering, in addition to the valuable work which had been carried out in the Road Research Laboratory and elsewhere, on materials, structural design, and methods of construction, a good deal of work had been done in recent years and months on the functional design of airports from the point of view both of the technique of aviation and of the technique of air transport. Nevertheless, the Minister of Aircraft Production had said, in a more general connexion, that hitherto the tendency had been for the technique of transport to be sacrificed to the technique of aviation: Mr. Maclaren thought that was true of the recent war years, and he agreed with the Author that there was still a substantial field for research in airport engineering, especially from the transport point of view.

He had been particularly interested in the first three items of expenditure listed in Table I, which were entirely transport items. The figures for roads and railways showed in each case an expenditure on research of from 0·1 to 0·15 per cent. of the capital expenditure on works, and he wondered if the somewhat remarkable similarity between the two sets of

figures could be regarded as setting a standard for airports. His view was that because commercial air transport was still very much in the development stage, a greater expenditure could be justified economically in the years immediately to come, although perhaps the figures given for roads and railways indicated the desirable minimum of expenditure on research for airport engineering when more knowledge and experience of the subject had been gained, and information was more widely disseminated.

That led him to endorse very strongly the point made by the Author that research was of most value to the community when its results were disseminated in the form of information for practical application. He had come across one or two examples of airfields being built overseas where there was a grave risk of the expenditure of money and effort being rendered largely nugatory in future simply because there had been available to the authorities responsible for the construction neither information regarding the trend of requirements, such as the wheel loading of aircraft, nor the latest information regarding the structural design of runways.

The form in which the results of research were published was important. The engineer who had to design and execute works wanted comparative information in " tabloid " form, so that it could be digested rapidly and easily in order to determine in which direction lay the solution of the particular problem with which he was faced. Only after that did he want to know the prescriptions from which the tabloids were prepared, in order that he might satisfy himself that the selected treatment would in fact provide the best available solution.

He particularly welcomed the references to research for civil engineering overseas. Great Britain had given a lead in engineering in the Commonwealth, and he considered that it should endeavour both to maintain that lead technically and to assist the less well endowed members of the family by means of research. That, again, was particularly relevant in airport engineering. An airport in Great Britain and an airport overseas could not be regarded as entirely separate entities. They were both, as it were. stations on the same railway-line and they should, therefore, have features of design and standards of safety and amenity in common.

Mr. T. W. Moran observed that the Author had done well to counter the suggestion that civil engineering research was something apart from practice. One of the most important branches of research—and one of the most neglected—was the study of the behaviour of structures and their foundations in normal conditions of usage and the collection of precise information whenever any defects or failures appeared. Every defect—even one of everyday occurrence—presented an opportunity for analysing the cause and learning something about the design, the materials used, or the soil conditions. Such investigations might contribute little to text-book knowledge, and they frequently entailed no laboratory work, but they were, nevertheless, genuine research of a type that yielded important

and practical results. Furthermore, they could be carried out by almost every civil engineer who was concerned in ordinary maintenance and repair works in the normal course of his duties. Yet the vast majority of such opportunities were lost or the lessons went unrecorded. Far too many maintenance items were examined only very superficially, no proper diagnosis was made, the wrong remedy was applied, and in turn failed, and nothing was learnt.

One crucial difficulty that arose when investigating the cause of a foundation failure was that of collecting facts about the ground and water conditions that were encountered during construction, and even details of the foundations as actually built. Either no records had been kept, or they had proved to be unreliable, or they had been lost. Thus it was impossible to build up a "case history." It would be of considerable value if some one body could be made a clearing house for subsoil information. The Geological Survey was probably the most suitable body for that purpose, but it was doubtful whether more than a small fraction of the available information from construction works ever reached it. Mr. Moran's wartime experience suggested that the converse was also true; far too little use was made of the information in the Geological Survey's records when planning new works.

With regard to research into the civil engineering aspects of aerodrome construction, Mr. Moran suggested that it would be very misleading to think in terms of *runway* research. There were in the main three aspects to be considered.

The first was research into the engineering problems of *pavement design and construction* as touched on by the Author. That might be sub-divided into :—

(*a*) the effect of variation in the amount, intensity, and frequency of applied loads, a subject on which hardly any recorded information was available ;
(*b*) the mechanical analysis of pavement stresses ;
(*c*) the effect of the nature of the sub-soil and its water-content ;
(*d*) the behaviour of various forms of pavement construction in service.

Rather too little attention had been paid to the first and fourth of those items. A great deal could be learned by compiling records of the ground reactions of various types of aircraft, when standing, taxying, taking-off, etc., and by tabulating failures on existing aerodrome pavements. Both theoretical considerations and practical observation in service suggested that runways, taxi-ways, aprons, hard standings, etc., all entailed separate consideration in regard to the live loading to which they were submitted. A field existed there for joint civil and aeronautical engineering research.

Secondly, the *construction of grass airfields* would seem to be worthy

of the closest examination. A grass airfield properly constructed was very low in first cost and had low maintenance costs. Therefore, the grass landing-ground was likely to be an important feature in private civil flying in the future, in places where heavy machines were not catered for, and where the volume of traffic was small.

The essential difference between a grass landing-ground and a paved one was that the field was surfaced by living turf, instead of inanimate concrete. The soil properties required to support a healthy wear-resisting sward were entirely different from those needed when the soil was used as a base for a pavement. That problem was a horticultural rather than an agricultural one, since the aim was not to produce crops seasonally, but to produce and maintain an all-the-year-round hard wearing, well-drained turf.

Hardly any recorded information appeared to be available as a guide to the optimum balance between the mechanical and nutritive properties of soils; the degree of compaction allowable; the selection of seeds and fertilizers; effective seasonal maintenance; and the prevention of over-compaction and panning in course of time. Research in those matters would need to be carried out jointly by civil engineers and horticulturalists.

The third field for airport research, namely, the *functional aspect of airport design*, was possibly the most important of all. Engineering had been described as the application of scientific knowledge to the solution of economic problems; and, bearing in mind the probable high cost of airports designed to receive the heavy long-distance machines of the future, the main problem before the research worker was to ascertain, not how many runways, aprons, etc., should be built, how long, how wide, and how thick they should be, but rather, how few, how short, how narrow, and how thin. The whole matter was extremely complex, and the civil engineering problem could not be dissociated from aeronautical design, from traffic operation, from meteorology, and finally from the practical piloting of the machine. The quantity of information available on that subject from English sources was very small and, to some degree, disjointed and contradictory; yet there was no branch of airport design where research would yield greater dividends.

The Civil Aeronautics Administration of the United States Bureau of Commerce had carried out a good deal of applied research work into the functional planning of airports, and their published reports were of the first importance.

With regard to the economics of airport research work, the cost of a single runway for local airliners using municipal airports was of the order of £100,000, whilst the cost of a normal municipal airport of the future would probably be not less than £1,000,000. For a Transocean airport those costs might be multiplied by 10. An expenditure of £250,000 on airport research might thus be recovered on a few sites.

Whilst Mr. Moran's observations on airports went into greater detail

than the Author could be expected to do in his Paper, they were designed to indicate the gaps in knowledge and the directions in which research was most needed. Mr. Moran wished to acknowledge the valuable assistance which he and his colleagues had received from the Author during the past 3 years in meeting the many problems with which they had had to deal in Ministry of Aircraft Production airfields. The Road Research Laboratory certainly kept its information in accessible form and was most willing to share it with others.

Professor A. J. Sutton Pippard observed that the Universities of Great Britain had a dual responsibility; first, to provide undergraduate and post-graduate education, and secondly, to carry out research. Too often when the first of those obligations had been fulfilled there remained little time or money for the second. Even in Departments which were adequately staffed and in which there was some leisure for research, the lack of financial assistance made experimental work impossible and only that of mathematical character could be done. Since there was an unfortunate tendency in some quarters to assume that only the former was of real importance, it was not surprising that in many cases potentially good workers became disheartened and devoted their leisure to other interests. There was little doubt that the provision of adequate funds would result in an increased output from the Universities—the will was there but the means too often were absent.

In spite of those handicaps, which were scarcely comprehensible to the average worker in an organized research institution, the output of some Universities, at any rate, was not inappreciable. In the Department of Civil Engineering which Professor Pippard knew best—which was only one among many—during the period from October 1933, to the present date, more than sixty publications had appeared under the names of people working in the Department; six of them had been published in the Proceedings of the Royal Society, nineteen in the Journal of The Institution (eight of which had gained awards of premiums), and the remainder in various scientific and technical journals. Many of them had described experimental work in various fields of hydraulics, structures, road construction, etc., and some had been assisted by grants from the Research Committee of The Institution, The Department of Scientific and Industrial Research, and other sources. Those grants alone, however, would not have been sufficient, and only the continuous and very generous help given by the Clothworkers' Company had made it possible to equip the laboratories and provide the assistance necessary to conduct any experimental research.

For half of the period under review the nation had been at war and during that time a substantial number of researches and special investigations had been undertaken by the Department, which at present could not be published. Those would add appreciably to the figures given.

The contribution to actual research by Departments of Civil Engineering

did not, however, give the complete story. An important part of their work was the training of research workers. Much of the work done by students for Higher Degrees was valuable in itself, but the training associated with it was even more important. In the Department to which reference had already been made, and during the same period, thirty-six students had obtained the degree of M.Sc. and fifteen that of Ph.D. Some of those students had joined the staffs of Research Institutions, whilst many had taken up direct engineering work ; in both spheres their training would undoubtedly have considerable influence on research in the future ; but those figures were considerably less than they might have been, since no students had been allowed to take post-graduate training during the war years.

Only one speaker in the discussion had championed the cause of the Universities by reference to work done for the Steel Structures and other Committees in various Universities. In reply, the Author had suggested that the work done on Steel Structures in the University of Bristol was the result of experience gained at the Building Research Station. But in justice to the Universities, it should be said that that was not the whole story, since the man concerned had already done experimental and analytical research in a University before going to the Building Research Station and his appointment with the Steel Structures Committee was partly, at least, due to his record in that respect.

Many research problems could undoubtedly best be undertaken by teams in Research Establishments, but others could be better done in University laboratories, and Professor Pippard and the Author were at least in agreement in the hope that adequate help might be forthcoming to develop the potentialities for research of the Civil Engineering Departments in all the Universities of the country.

In conclusion Professor Pippard pleaded for a liberal view of what constituted Civil Engineering research. It was more than startling to read the statement in the Paper that in 1937 only thirty-seven people in the Universities were engaged on research and higher studies in Civil Engineering, when in the Sessions 1936–37 and 1937–38 there were respectively twenty-four and eighteen post-graduate and research students working in the one Department alone to which reference had already been made. If six members of staff actively engaged in research were added to those, it would appear that the figure quoted was either grossly in error or was based on too narrow a definition of advanced study and research in Civil Engineering. He considered that civil engineers would make a grave mistake if they allowed the historical definition of their responsibilities, as given in the Charter of The Institution, to be forgotten.

Mr. A. R. Thomas observed that he had noted with satisfaction the progressive attitude towards civil engineering research adopted by The Institution and expressed by the Author.

He wished to supplement the information given in paragraph (*d*), p. 230, *ante*, by referring briefly to research in India. Starting with a

research division formed under the Bombay Government in 1916 by Mr. (now Sir) Claude Inglis, M. Inst. C.E., the number of government research organizations had increased to seven, two of which—the Indian Waterways Experiment Station, Poona, and the Punjab Irrigation Research Institute were among the largest in the world, both in respect of the amount of work done and the scale to which river and other models were constructed. Their work was co-ordinated and published by the Central Board of Irrigation.

The experience of those stations had shown that numerous problems of practical importance were awaiting solution. For example, the Government of India had been rather hesitant in taking over the hydrodynamic section of the Bombay research division in 1937 to form a central station to serve the whole of India, and did so only on a temporary basis. Once the Station had been formed, however, so many specific problems were referred to it by irrigation, road, railway, and harbour authorities that the station had had to be expanded and had since been placed on a permanent footing. The experience of the Provincial stations had been similar, and one unfortunate result had been that, with so many specific problems in hand, insufficient attention could be devoted to problems of a more general or basic character.

Progress in the latter type of problem had, however, been made, owing largely to the activities of the Research Committee of the Central Board of Irrigation in co-operation with the various stations. That Committee had at present eighteen subjects on its agenda, ranging from rainfall run-off to river behaviour and control, and from soil mechanics to tube wells.

Research in Great Britain on maritime and waterways engineering could, as suggested by the Author, perform two very useful functions. Firstly, it could undertake research of a basic character, for the benefit of Britain and the Commonwealth; such work required specialization and continuity and could usefully be supplemented, but not substituted, by post-graduate research at the Universities. Secondly, it could conduct experimental and advisory work on specific problems for harbour, coast, canal, river, catchment, hydro-electric, and water-supply authorities both in Great Britain and abroad. Mr. Thomas was convinced that the establishment of an experiment station would be fully justified by the number of problems referred to it by authorities prepared to meet the cost of their investigations. The Station, however, should not be entirely dependent on such payments, and separate funds should be allocated for basic research.

The need for an information service, rightly stressed by the Author, had been equally evident in India, and the Information Bureau instituted by the Central Board of Irrigation had been fully justified during its fourteen years' existence. The facilities offered by that Bureau, like those of the Building Research Station and the Road Research Laboratory, were

of service to practical engineers as well as to research workers, but they embraced a wider range of civil engineering subjects. Technical inquiries were dealt with by means of a detailed index (which now contained more than 90,000 cards) arranged on the Universal Decimal Classification system, supplemented by a lending library to which would soon be added a microfilm service. Abstracts of current literature were published monthly.

As pointed out by Dr. Holmstrom, considerable overlap existed in the preparation of abstracts by various bodies. A valuable service could be performed by a central co-ordinating agency in preparing or collecting and distributing abstracts on all subjects connected with engineering. In the same way, classified index cards could be supplied to those who wished to maintain detailed card indexes and the originals or microfilm copies of literature could be supplied on loan. In fact, a wide scope existed for the creation of a central bureau, working in co-operation with other bodies in Great Britain and abroad, to collect, index, and co-ordinate technical information, and there was every prospect of a bureau of that kind becoming financially self-supporting.

Mr. J. G. Thon observed that research in civil engineering had passed the stage when startling new advances could be expected from the solitary scientist. The present stage of research was characterized by detailed investigations in special problems. That type of research required large teams of research workers and well-equipped laboratories.

It was quite obvious that those best suited to undertake those expensive and tedious investigations were government-subsidized Institutions and Universities.

The Author had given a detailed account of the work of the Department of Scientific and Industrial Research and its subsidiaries, and Mr. Thon would like to refer to the role the Universities might play in fostering research and suggest some improvements.

Each year the British Universities granted a number of higher degrees in Engineering. According to information supplied by the Academic Registrar of the University of London in the years 1935–1939, that University alone awarded 108 M.Sc. (Eng.) and sixty-eight Ph.D. (Eng.) degrees. In its curriculum for those degrees the University stipulated original research work for a period of two academic years. A thesis had subsequently to be submitted before a degree could be obtained; but those theses were seldom published, the considerable amount of useful information contained in them was almost inaccessible, and the work was lost sight of.

The catalogues of the Science Museum Library contained a large number of dissertations and bulletins published by various Universities abroad, giving an account of research work carried out by them, yet very few Papers published by a British University could be found.

Mr. Thon suggested that steps should be taken to remedy that anomaly.

A fund should be created which would enable the Universities to publish bulletins containing results of completed investigations.

The benefits of adopting that suggestion would be the following :—

(*a*) A careful selection of subjects for research would result. There would be wide scope for co-operation between the Research Committee of The Institution and the Universities. The Research Committee was best equipped to suggest problems requiring further study.

(*b*) The results of investigations and tests would be made accessible to the practising engineer and consequently the standard of design methods would be raised.

(*c*) Duplication of research work would be avoided.

Finally, the incentive effect the suggestion would have upon the University staffs and students should be mentioned.

The Author, in reply, observed that it was clear from the discussion that civil engineers were conscious of the pressing need for increased research activity, and that any action The Institution might initiate would be welcomed.

Two branches of civil engineering—maritime and waterways (hydraulics) and airports—had received much more attention from the contributors than the others. The reason was clear ; in neither was there a main establishment for research in Great Britain, and in both engineers were severely handicapped by lack of knowledge. It seemed evident that the correction to those deficiencies was an urgent requirement.

Messrs. Lacey, Dean, C. G. Evans, J. T. Evans, and Thomas had raised matters relating to maritime and waterways problems, and several of them had given particulars of valuable work now in hand in India. At a time when, following the suggestion made by Mr. Wentworth-Sheilds in his Presidential Address,[1] much thought was being given to the establishment of a research organization in Great Britain, those accounts were specially welcome, for there was no doubt that India's experiences would prove a useful guide.

Mr. Shaw Maclaren's and Mr. T. W. Moran's contributions relating to airport engineering and air transport were authoritative expressions of views in the youngest branch of civil engineering. In airport engineering, research would no doubt find a place more readily than it had in other branches of civil engineering, for the need for it had come at a time when the advantages to be derived from research were more generally appreciated. There seemed little doubt, therefore, that an outlay on research equal to 0·1 per cent. of expenditure on works would, as Mr. Shaw Maclaren had suggested, be found inadequate to satisfy current airport research requirements. Mr. Moran's remarks on grass airfields

[1] J. Instn Civ. Engrs, vol. 23 (1944–45), p. 8 (Nov. 1944).

exemplified the many branches of knowledge touched on in the problems of airport construction.

In reply to Mr. Campbell's questions about the two methods of approach to the problem of pavement design, the Author considered that, although it was important for fundamental inquiry to proceed, the conditions were so complex that interim solutions based on large-scale trials were essential to progress, for construction could not wait for the completion of the basic study.

Several contributors had referred to the need for better information facilities. Clearly there was much room for improvement. Better facilities for collecting and referencing information from engineering experience, to which Mr. Moran had referred, as well as better information services on published research, were essential to efficient progress. The subject justified much thought, for the value of research could be lost through inadequate facilities for making known the results obtained. The suggestions of Mr. C. G. Evans regarding personal contacts and exchanges of workers in different countries, and of Mr. Thon regarding the publication of bulletins containing the results of work described in University theses, indicated steps in the right direction.

When writing the Paper, the Author had been tempted to discuss at length the reasons why research in civil engineering appeared to be so far behind research in other branches of engineering, but limitations of space had prevented such an excursion : nor was it possible in the present brief reply. But the Author felt, with Professor Legget, that the fact that one of the basic materials, soil, was not a commercial product had had an important bearing on the question. Concrete, also, was not a commercial product in the usual sense, and even stone had to be used as it was found in nature.

Professor Legget and Professor Pippard had rightly emphasized the need for associating research with University training, but, as the latter had said, that needed money. It was to be hoped that means would be found. The Author was a little confused by the figures for numbers of research students and workers given by Dr. Holmstrom in his book,[1] and by Professor Pippard and Mr. Thon, but, whatever the correct figures were, it was clear that the total University effort could be profitably increased.

Mr. Clayton's wish to see research on traffic-flow was one that it was hoped would shortly be fulfilled by an expansion of the work of the Road Research Board.

Mr. C. G. Evans had emphasized the civil engineer's need for research aimed at developing new and better materials. The Author particularly welcomed the attention that had been drawn to that matter, for the Paper had hardly done justice to it.

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[1] Holmstrom, J. E., "Records and research in engineering and industrial science" London, 1940 (Chapman and Hall, Ltd.).

In conclusion he wished to thank all those who had taken part in the discussion. In doing so, he ventured to express the hope that the Paper had stimulated the interest of civil engineers in research and had shown the need for improved facilities to help them with their many problems.

Paper No. 5469.

"A Slip in the West Bank of the Eau Brink Cut."†

By ALEC WESTLEY SKEMPTON, M.Sc., Assoc. M. Inst. C.E.

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Mr. W. E. Doran observed that the slip analysed by the Author was typical of a problem which constantly recurred in certain river channels, particularly those which were formed in silty clay deposits and which were subject to the deposition of estuarine silts from tidal action.

The traditional methods of dealing with such slips were by "faggoting," known also as "kidding," and by "stoning." In the first cases the loose slipped material was thrown out down to low-water-level and thorn or willow faggots were laid in courses and secured with stakes driven at an angle through the faggots. The outer face of the work was laid to conform with the slope of the river bank.

In the case of a river bearing an appreciable silt load, such as the Ouse, the silt very soon became deposited in the faggot work and the repair remained effective for some time. In due course, however, further movement took place and the process had to be repeated. On river banks which had been dealt with in that way over many years, the remains of old faggots might be seen extending well beyond the low-water mark. That gradual movement of faggots from the upper slopes to the bottom of the banks had frequently given rise to the impression that the slips were of a superficial character consisting in the progression of the soft "warp" deposits down the slope of the bank. On such a view the function of the faggoting was to exercise a binding action on the warp deposits.

The "stoning" method consisted merely of depositing broken stone or hard chalk lumps on the surface of the bank slope. Neither of those methods was permanently effective. Considerable sums were spent annually in that way and the question arose whether by capital expenditure on appropriate works the relatively heavy annual maintenance costs might not be avoided, or at least reduced considerably.

To decide upon the character and extent of the remedial works it was

† J. Instn Civ. Engrs, vol. 24 (1944–45), p. 267 (May 1945).